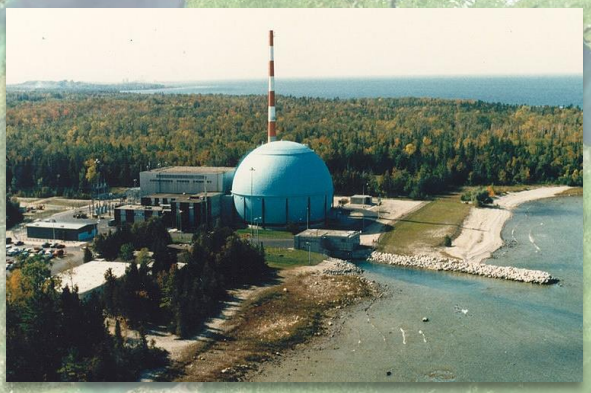
Nuclear Power Decommissioning Practices: Case Studies and Recommendations for the Great Lakes Basin

Final Report
September 19, 2019

Prepared for:
The International Joint Commission's Great Lakes Water Quality Board

Contract Number: 47QRAA18D0074
Order Number: 19AQMM18F4823



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Executive Summary

This report provides an overview of decommissioning practices at nuclear power plants and the associated hazards and environmental risks. It includes a review of the background report prepared for the International Joint Commission's (IJC) Water Quality Board (WQB) titled "Nuclear Power Facilities in the Great Lakes Basin: Background Report" (Graydon et al. 2019); presents findings from interviews with stakeholders knowledgeable about nuclear decommissioning; and documents case studies for seven nuclear power plants in North America and Europe (France and Germany) that have either been decommissioned or are currently undergoing decommissioning. Based on information collected through the interviews, case studies, and other research, the report summarizes key findings and provides recommendations for the WQB's consideration for providing advice to the IJC.

The nuclear power industry is heavily regulated in both the United States and Canada to prevent radioactive releases during operation and decommissioning and, if a release does occur, to minimize the impacts. However, as with any industrial activity, nuclear power plants pose some level of risk. Similarly, there is risk involved in decommissioning a nuclear plant and management of resulting materials and wastes, which are also heavily regulated. Currently there are 14 nuclear power plant sites, with 30 operating reactors, within the Great Lakes Basin and 5 reactors that have been shut down and are being maintained in a state of "safe storage" (SAFSTOR).

Nuclear decommissioning is a complex activity that typically spans a period of several years to decades, including periods of SAFSTOR and active dismantling, and can cost hundreds of millions of dollars or more. It involves dismantling and demolition of equipment and structures, determining the extent of radiological and chemical contamination, cleanup and remediation of the land to pre-determined standards, and management and disposal (or storage) of radioactive and non-radioactive wastes. While risks related to plant operation are eliminated, potential long-term risks remain when spent fuel and other radioactive waste continue to be stored on-site after decommissioning is complete.

This study highlights differences in the decommissioning processes and practices between the United States, Canada, and Europe as well as trends in each country. A common trend is the move away from deferred decommissioning and SAFSTOR, towards immediate dismantling and on-site dry storage of high-level nuclear waste (HLW). On-site dry storage of HLW is typical in the United States and Canada, as neither country has a repository for the permanent storage of HLW. The lack of storage facilities for HLW means that HLW, and associated risks, will remain at multiple locations in the basin. Consolidated interim storage sites are proposed in the United States outside of the basin, and U.S. HLW may be moved to these sites if and when they become available. Movement of the waste to these facilities would remove it from the basin but could introduce new, short-term risks related to waste handling (e.g., repackaging) and transport, in addition to long-term risks wherever the wastes are stored. In Canada, ongoing efforts to site a deep geological repository for permanent HLW storage have narrowed down to five potential sites in Ontario.

In addition to the risks related to decommissioning activities, public outreach and engagement is important for developing and maintaining a positive relationship with Indigenous populations and other stakeholders including the surrounding community. While both U.S. and Canadian processes include opportunities for public comment at different stages, the establishment of citizens advisory panels (although not required) is an effective strategy that has been adopted at several sites.

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Acronyms

AEA	Atomic Energy Act
AMDA	Automated Mobile Decontamination Appliance
ASN	Autorité de Sûreté Nucléaire (French Nuclear Safety Authority)
BfE	Bundesamt für kerntechnische Entsorgungssicherheit (German Office for the Safety of Nuclear Waste Management)
CAD	Canadian Dollars
CANDU	Canadian Deuterium-Uranium
CEAA	Canadian Environmental Assessment Act
CISF	Consolidated Interim Storage Facility
CNEB	Canadian National Energy Board
CNL	Canadian National Laboratories
CNSC	Canadian Nuclear Safety Commission
CORD	Chemical Oxidation Reduction Decontamination
DECON	Decontamination
DOE	Department of Energy
EA	Environmental Assessment
EIA	Energy Information Administration
EPRI	Electric Power Research Institute
ERA	Environmental Risk Assessment
GLWQA	Great Lakes Water Quality Agreement
GTCC	Greater Than Class C
GW	Gigawatt
GWh	Gigawatt-hour
Ha	Hectares
HLW	High level waste
IAEA	International Atomic Energy Agency
IJC	International Joint Commission
ISFSI	Independent Spent Fuel Storage Installation

LIWG	Legacy Issues Work Group
LTE	Long-Term Enclosure
LTP	License Termination Plan
MARSSIM	Multi-Agency Radiation Survey and Site Investigation Manual
MACSTOR	Modular Air-Cooled Storage
MW	Megawatt
MWe	Megawatt-electric
NEPA	National Environmental Policy Act
NGO	Non-Governmental Organization
NLCA	Nuclear Liability and Compensation Act
NRC	Nuclear Regulatory Commission
NWPA	Nuclear Waste Policy Act
NWMO	Nuclear Waste Management Organization
PCB	Poly-Chlorinated Biphenyl
PWR	Pressurized Water Reactor
PSDAR	Post-Shutdown Decommissioning Activities Report
SAFSTOR	Safe Storage
SNF	Spent Nuclear Fuel
TVA	Tennessee Valley Authority
TWh	Terawatt-hour
USD	U.S. Dollars
USEPA	U.S. Environmental Protection Agency
WQB	Water Quality Board
WWMF	Western Waste Management Facility

1. Introduction

The International Joint Commission (IJC or Commission) promotes collaboration between the United States and Canada and provides advice to the governments in their efforts to protect, restore, and enhance the water quality of the Great Lakes and prevent further degradation of the Great Lakes Basin Ecosystem. Under the Great Lakes Water Quality Agreement, the Great Lakes Water Quality Board (WQB) serves the IJC in an advisory capacity. The WQB has identified decommissioning of nuclear power plants as a priority topic in the Great Lakes Basin.

A background report compiling information about applicable nuclear regulations, radioactive waste management, and status of nuclear power facilities in the Great Lakes Basin (Graydon et al. 2019) was prepared for the WQB. This report has been prepared as a follow-up to the background report to identify significant challenges, best practices, and lessons learned associated with the decommissioning of nuclear facilities in North America and Europe. The background report and this report will be used by the Legacy Issues Work Group (LIWG) and the WQB to develop its recommendations to the IJC regarding any additional actions that the United States and Canadian governments could take to eliminate or reduce threats to the Great Lakes from the release of radioactive contaminants as a result of nuclear plant decommissioning.

The contents of this Final Report are as follows:

- Chapter 1 describes the scope of the report and provides background on the GLWQA and the nuclear power industry in Canada and the United States.
- Chapter 2 provides background information on nuclear power plants in the Great Lakes Basin.
- Chapter 3 provides a brief overview of nuclear power plants and reactor types and describes the decommissioning process.
- Chapter 4 summarizes results of interviews with interested parties.
- Chapter 5 presents decommissioning case studies for four North American and three European nuclear facilities.
- Chapter 6 summarizes key findings from the interviews and case studies.
- Chapter 7 discusses application of the findings to the Great Lakes Basin.
- Chapter 8 provides recommendations for the WQB.

1.1 Scope

This report provides an overview of decommissioning practices at nuclear power plants and the associated hazards and environmental risks. The report was developed by Potomac-Hudson Engineering, Inc. and LimnoTech under contract number 19AQMM18F4823. Efforts under this contract include:

- A review of the background report titled “Nuclear Power Facilities in the Great Lakes Basin: Background Report” (Graydon et al. 2019),
- Identification of and interviews with Indigenous communities and other stakeholders with knowledge and interests related to nuclear decommissioning,
- Preparation of case studies for nuclear power plants in North America and Europe that had been completely or substantially decommissioned, and
- Preparation of this report and recommendations.

The background report (Graydon et al. 2019) was reviewed for completeness and accuracy of the information presented on nuclear power plants in the Great Lakes Basin. Information reviewed on nuclear plants included status, closure date, closure plans, closure approval, new plants, waste, and actions taken (decommissioning, monitoring, remediation, public involvement, and regulatory regimes). The review also included an assessment of the adequacy of the research, identification and assessment of data gaps, and identification of any errors, and recommendations were provided for improving the background report including where the report should be expanded or additional information included.

A list of stakeholder groups that would be knowledgeable about, or interested in, issues related to nuclear decommissioning was developed in consultation with WQB workgroup members and IJC staff. The list consisted of industry, regulators, non-governmental organizations (NGOs), Tribes/First Nations/Métis, and other experts including academics, journalists, and authors. Potential interviewees were identified based on publicly available information; and existing contact information provided by the WQB, including NGOs and Tribal contacts. See Chapter 4 for further detail on interviewee selection, the interview process, and interview results.

To identify potential case study sites, nuclear power plants in North America and Europe that had been completely or substantially decommissioned were researched and assessed for environmental impact. Factors considered in the selection of case study sites included the type of reactor technology used, whether the site was in a country with a significant history and experience with nuclear power, and if there were any known environmental issues or challenges with decommissioning. Case study site selection was done in consultation with the WQB workgroup members and IJC staff by prioritizing reactor types similar to those present in the Great Lakes Basin and ensuring that sites with a mix of known decommissioning issues were included. Chapter 5 provides additional information on the case studies.

This report summarizes information collected through the interviews, case studies, and other research, and provides findings and recommendations for the WQB's consideration in providing advice to the IJC.

1.2 Great Lakes Water Quality Agreement

The Great Lakes Water Quality Agreement, first signed by Canada and the United States in 1972 and updated in 1978, 1987, and 2012, commits both countries to "restore and maintain the chemical, physical, and biological integrity of the Waters of the Great Lakes".[1] To achieve this commitment, the respective countries have agreed to take specific, cooperative actions to resolve existing environmental problems and prevent potential issues, "recognizing the inherent natural value of the Great Lakes Basin Ecosystem, and guided by a shared vision of a healthy and prosperous Great Lakes region in which the Waters of the Great Lakes, through sound management, use and enjoyment, will benefit present and future generations of Canadians and Americans."

The IJC plays a key role in the Great Lakes Water Quality Agreement process. By evaluating efforts to restore the Great Lakes ecosystem, engaging the public on their perspectives of Great Lakes health and completing its own research on issues facing the lakes, the IJC assesses the effectiveness of government programs to meet the agreement's goals and objectives. The assessment reports and recommendations

[1] https://www.ijc.org/en/what/glwqa-ijc

help the two countries expand or change approaches to particular challenges, and ensure the agreement evolves to address future environmental issues facing the Great Lakes Basin.

The Great Lakes Water Quality Agreement was revised considerably in 2012 as a result of previous IJC assessment reports and recommendations, and after an extensive consultation and review process led by the IJC. The 2012 agreement includes 9 goals or objectives that the two countries commit to achieving and 10 annexes that outline commitments to specific issues that can affect Great Lakes water quality. The goals of the Agreement are summarized in the text box above.

Great Lakes Water Quality Agreement – Summary of General Objectives

The waters of the Great Lakes should:

i. be a source of safe drinking water
ii. allow for swimming and other recreational use
iii. allow for human consumption of fish and wildlife
iv. be free from harmful quantities of pollutants
v. support healthy and productive habitats
vi. be free from excess nutrients
vii. be free from invasive species
viii. be free from the harmful impact of contaminated groundwater
ix. be free from other substances, materials or conditions that may negatively impact the chemical, physical or biological integrity of the Waters of the Great Lakes

Source: Great Lakes Water Quality Agreement

Under the revised Agreement, the governments of both countries are required to provide progress reports every three years on actions to be taken to restore and protect the Great Lakes Basin. The IJC then conducts extensive research and consults with the public through a variety of opportunities to find out if (and how) Indigenous communities and other stakeholders – including those from NGOs, government agencies, and academia – believe the environment in the Great Lakes Basin is improving or worsening. The IJC combines this input with government assessments to develop its own triennial assessment reports. The first Triennial Assessment of Progress report was released in 2017.

1.2.1 Water Quality Board

The first Great Lakes Water Quality Agreement, signed in 1972, established the WQB and a Research or Science Advisory Board to investigate and report on particular issues of concern to assist in the IJC's assessment of agreement progress. The Agreement also established a Great Lakes Regional Office to support these boards and the IJC for its agreement responsibilities.[2]

The WQB is the principal advisor to the IJC under the Great Lakes Water Quality Agreement.[3] The Board assists the Commission by reviewing and assessing the progress of the governments of Canada and the United States in implementing the Agreement, identifying emerging issues and recommending strategies and approaches for preventing and resolving complex challenges facing the Great Lakes, and providing advice on the role of relevant jurisdictions to implement these strategies and approaches. The Water Quality Board has identified the decommissioning of nuclear power plants located within the Great Lakes Basin as a priority topic.

[2] https://www.ijc.org/en/what/glwqa-ijc
[3] https://www.ijc.org/en/wqb

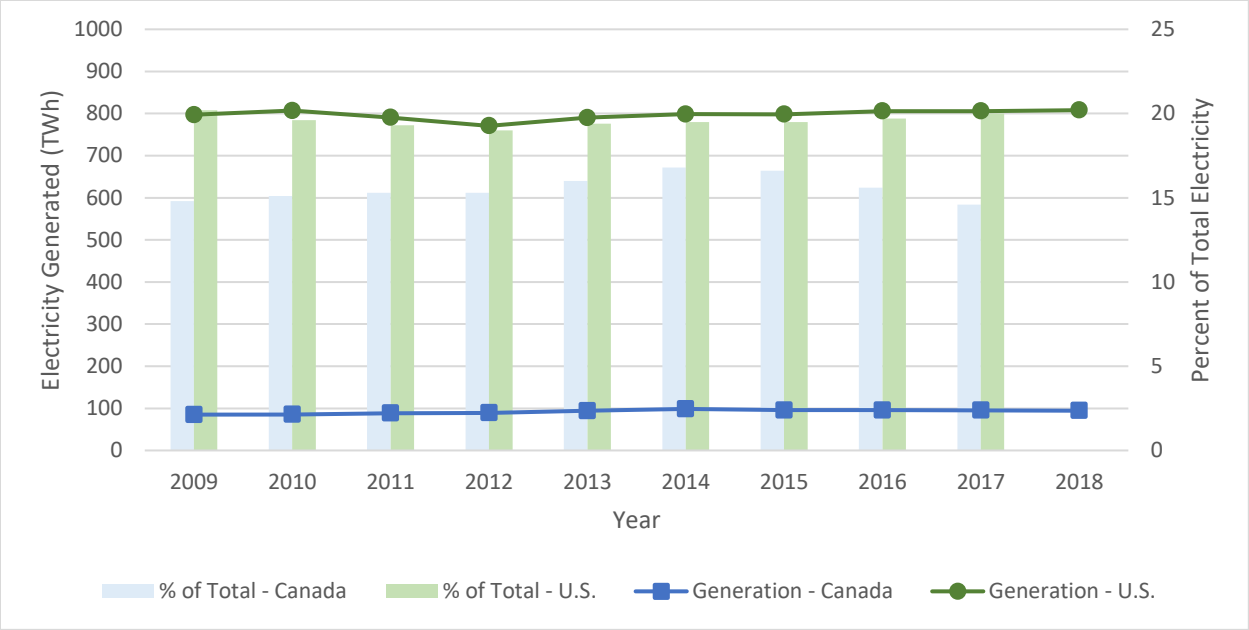
1.3 Trends in Nuclear Power

Within the United States, commercial nuclear power generation started to increase in the 1960s and continued to increase until about the 2000s.[4] Over the past decade, the United States has generated approximately 20 percent of its total electricity from nuclear energy (Figure 1-1 and Table 1-1). However, total nuclear power generation in the United States is expected to decrease to 15 percent by 2025 due to announced plant closures. In addition, economic disadvantages such as the low cost of natural gas fuel and increasing competition from renewable sources are making many U.S. nuclear power plants uneconomical to operate, and utilities are considering early closure of many of these plants. In Canada, approximately 15 percent of total electricity comes from nuclear power plants (Figure 1-1 and Table 1-1). These figures have remained relatively constant over the past decade. The Canadian Energy Regulator (formerly the National Energy Board) estimates that nuclear energy generation in Canada will decrease by about 9 percent by 2040 relative to 2016.[5] Despite the recent and projected decline in nuclear generation, it is worth noting that nuclear power has recently begun receiving renewed attention as a source of carbon-free energy, due to the rising urgency and need to address global climate change.

Although several North America nuclear power plants have closed since 2010, a combination of added capacity through upgrades and shorter refueling and maintenance cycles allowed the remaining nuclear power plants to produce more electricity (EIA 2019). Between 2010 and 2018, only one new nuclear power plant came online in the United States. The Tennessee Valley Authority's (TVA) Watts Bar Unit 2 nuclear power reactor came online in the fall of 2016, providing 1.2 gigawatts (GW) of additional installed capacity. Seven plants with a combined capacity of 5.3 GW have retired since 2013. In Canada, no new reactors have come online in the past decade, although two units at the Bruce A Power Station returned to service in 2013 after having been shut down in the 1990s (CNEB 2019). Quebec's Gentilly-2 nuclear power plant was permanently shut down in 2012.

The age of the nuclear fleet in North America suggests that more plants are likely to be decommissioned in the coming decades, despite the recent trend towards extending operating lifetimes through refurbishment. The majority of North American nuclear reactors are over 40 years old, with some in the United States that are over 60 years old. Currently, 12 reactors in the United States and 6 in Canada are planned to be shut down by 2025.[6]

[4] U.S. Energy Information Administration (EIA). 2019. Today in Energy. https://www.eia.gov/todayinenergy/detail.php?id=38792
[5] National Energy Board (NEB). 2018. Nuclear Energy in Canada. https://www.cer-rec.gc.ca/nrg/sttstc/lctrct/rprt/2018nclrnrg/index-eng.html
[6] EIA 2019; NEB 2018



Source: IAEA PRIS

Figure 1-1. Trends in Nuclear Power Generation in Canada and the United States

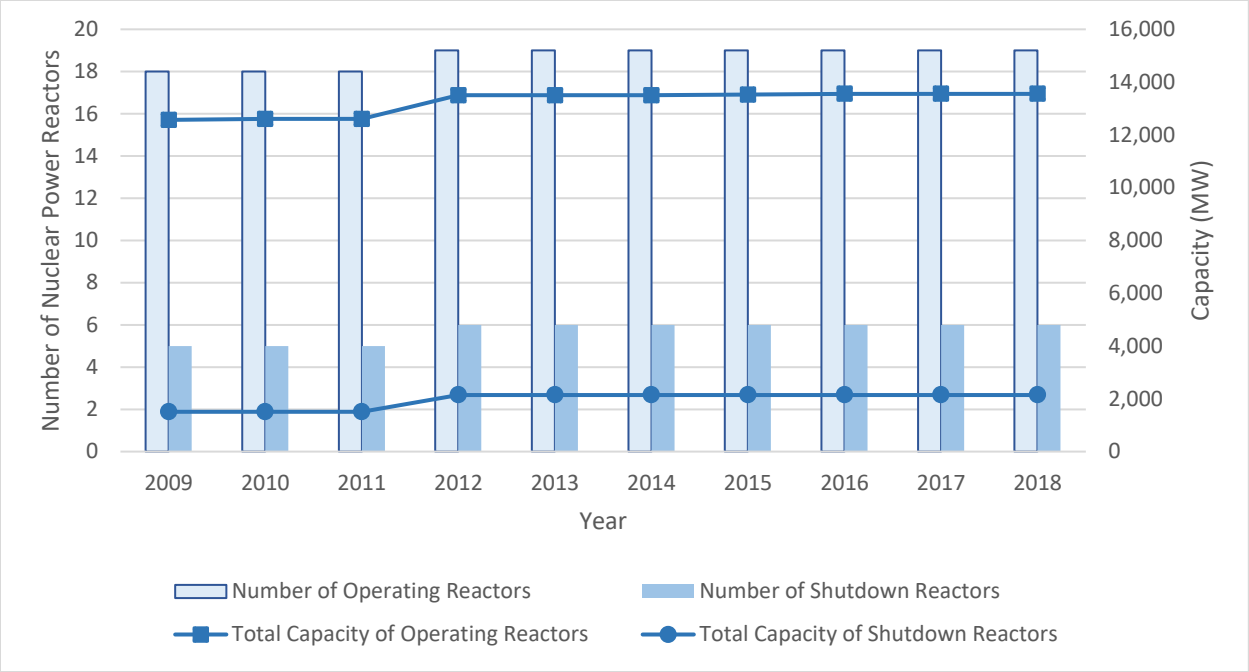
Table 1-1. Nuclear Power Generation in Canada and the United States

Year	Canada		United States	
	Electricity Generated (TWh)	Percent of Total Electricity	Electricity Generated (TWh)	Percent of Total Electricity
2009	85.13	14.8	796.89	20.2
2010	85.5	15.1	807.08	19.6
2011	88.32	15.3	790.44	19.3
2012	89.06	15.3	770.72	19.0
2013	94.29	16.0	790.19	19.4
2014	98.59	16.8	798.62	19.5
2015	95.64	16.6	798.01	19.5
2016	95.65	15.6	805.96	19.7
2017	95.13	14.6	805.65	20.0
2018	94.45	NA	808.03	NA

Source: IAEA PRIS

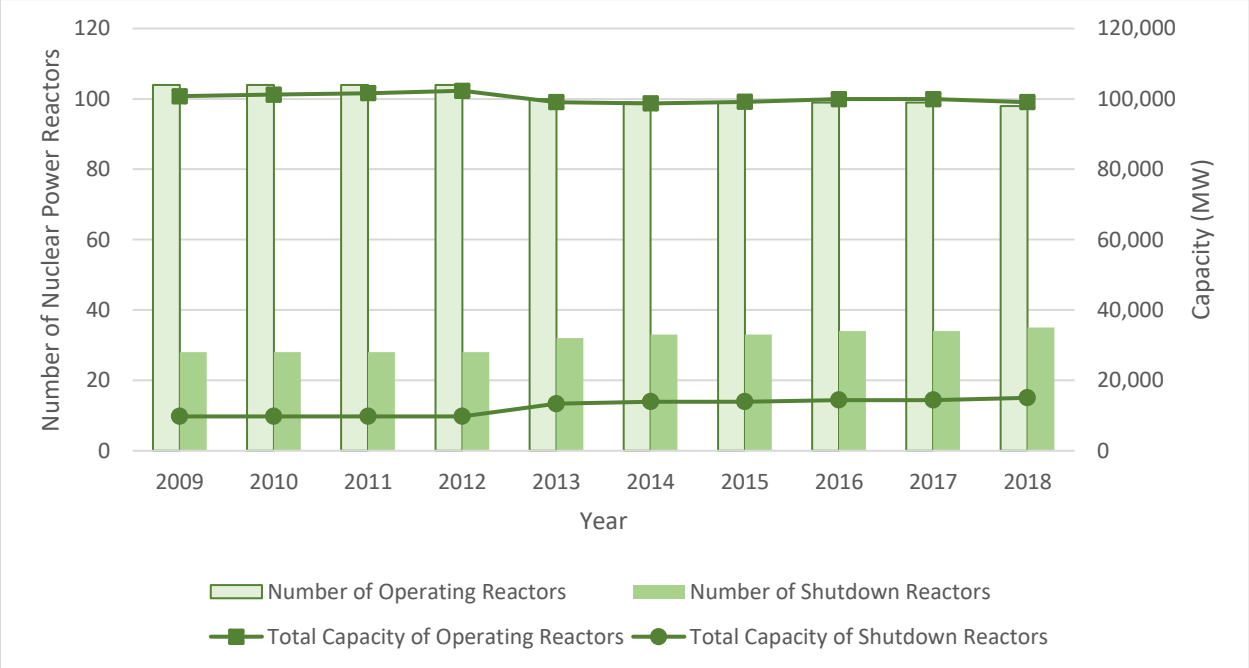
NA = Data Not Available; TWh = terawatt-hour

Figures 1-2 and 1-3 and Table 1-2 show trends in the number and capacity of nuclear reactors in Canada and the United States, including operating nuclear reactors as well as those that have been shut down.



Source: IAEA PRIS
MW = megawatt

Figure 1-2. Canadian Nuclear Power Trends



Source: IAEA PRIS
MW = megawatt

Figure 1-3. U.S. Nuclear Power Trends

Table 1-2. Operating and Shutdown Nuclear Power Reactors in Canada and the United States

Year	Operating Reactors				Shutdown Reactors			
	Canada		USA		Canada		USA	
	Number of reactors	Capacity (MW)	Number of reactors	Capacity (MW)	Number of reactors	Capacity (MW)	Number of reactors	Capacity (MW)
2009	18	12,569	104	100,749	5	1,508	28	9,764
2010	18	12,604	104	101,211	5	1,508	28	9,764
2011	18	12,604	104	101,601	5	1,508	28	9,764
2012	19	13,500	104	102,312	6	2,143	28	9,764
2013	19	13,500	100	99,078	6	2,143	32	13,340
2014	19	13,500	99	98,705	6	2,143	33	13,945
2015	19	13,524	99	99,167	6	2,143	33	13,945
2016	19	13,554	99	99,952	6	2,143	34	14,427
2017	19	13,554	99	99,952	6	2,143	34	14,427
2018	19	13,554	98	99,061	6	2,143	35	15,046

Source: IAEA PRIS
MW = megawatt

2. Nuclear Power Plants in the Great Lakes Region

The WQB prepared a background report compiling information about applicable nuclear regulations, radioactive waste management, and status of the nuclear power facilities in the Great Lakes Basin (Graydon et al. 2019). Key information from the background report is summarized here to provide context for the findings and recommendations discussed later in this report. The first nuclear power station began commercial operation in the Great Lakes Basin in 1963; since then, a total of 38 commercial nuclear reactors have been constructed.

Within the Great Lakes Basin there are numerous facilities involved in the lifecycle of nuclear power generation, including uranium mines and mill tailings sites in Ontario, processing and fuel fabrication facilities, nuclear power plants, and nuclear waste storage sites (Figure 2-1). The background report (Graydon et al. 2019) primarily focuses on commercial nuclear power facilities.

As of 2017, there were 30 operating nuclear reactors located within the Great Lakes Basin at 12 nuclear power plants, and 9 closed reactors (Table 2-1). Of the closed reactors, only one site, Big Rock Point near Charlevoix, Michigan, has been decommissioned and released for unrestricted use, with the exception of the spent fuel dry cask storage area and supporting facilities. Decommissioning activities are currently underway at the Zion Nuclear Power Station in Illinois.

Table 2-1. Nuclear Energy Production in the Great Lakes States and Provinces in 2017

Great Lakes Province / State	Number of Operating Nuclear Stations	Number of Operating Reactors	Nuclear Capacity (MWe)	Electricity Supplied (GWh)	Province / State's Electricity Production (%)
Canadian Provinces[1]					
Ontario	3	18	12,894	89,983	57.5
U.S. States[2]					
Illinois	6	11	11,609	97,253	51.8
Indiana	0	0	0	0	0.0
Michigan	3	4	4,140	32,388	23.8
Minnesota	2	3	1,688	13,904	24.1
New York	4	6	5,343	42,137	34.5
Ohio	2	2	2,150	17,689	10.4
Pennsylvania	5	9	10,040	83,316	41.0
Wisconsin	1	2	1,182	9,654	16.6
Total	23	37	36,152	296,341	-
Great Lakes Total	**26**	**55**	**49,046**	**386,324**	**-**

Sources: [1] *Canada*. International Atomic Energy Agency: Power Reactor Information System. https://pris.iaea.org/PRIS/CountryStatistics/CountryDetails.aspx?current=CA/. Accessed 22 February 2019.
[2] *United States of America*. International Atomic Energy Agency: Power Reactor Information System. https://pris.iaea.org/PRIS/CountryStatistics/CountryDetails.aspx?current=US/. Accessed 22 February 2019.
GWh = gigawatt-hour; MWe = megawatt-electric

Source: Graydon et al. 2019

Figure 2-1. Map of Facilities Involved with the Nuclear Energy Lifecycle in the Great Lakes region

2.1 Regulatory Framework

2.1.1 Canada

In Canada, formal regulation of nuclear activities began in the 1940s with the Atomic Energy Control Board, which was later replaced by the Canadian Nuclear Safety Commission (CNSC) in 2000. Among the many objectives of the CNSC, this independent national nuclear regulatory body conducts environmental assessments under the Impact Assessment Act of 2019 (IAA), implements Canada's bilateral agreement with the International Atomic Energy Agency (IAEA) on nuclear safeguards verification, and strengthens the compensation and civil liability regime for damages resulting from a nuclear accident under the Nuclear Liability and Compensation Act (NLCA) of 2015.

The CNSC also regulates the entire lifecycle of nuclear power plants. This includes decommissioning activities undertaken by a licensee at the end of the useful life of a reactor or after an accident that prevents future operation. The CNSC makes decisions on the licensing of major nuclear facilities through a public hearing process. The one- or two-part public hearings for licensing applications typically take place over a 90-day period. The public hearing gives involved parties, members of the public, and Indigenous groups an opportunity to be heard before the CNSC. Following a public hearing, the CNSC deliberates and makes its decision. CNSC proceedings are accessible via webcast and available for viewing by interested parties. Additionally, the CNSC informs Aboriginal groups of proposed projects, consults with potentially impacted Aboriginal groups, and encourages participation throughout the licensing process.

2.1.2 United States

In the United States, under the Atomic Energy Act of 1954, as amended (AEA), and the Energy Reorganization Act of 1974, Congress established the Nuclear Regulatory Commission (NRC) to regulate the civilian use of radioactive materials in the United States. The regulatory framework of the NRC includes regulations, licensing, guidance to the regulated community, oversight, enforcement, and emergency response. The NRC has rules governing nuclear power plant decommissioning, involving cleanup of radioactively contaminated plant systems and structures, and removal of the radioactive fuel. These requirements are aimed at protecting workers and the public during the entire decommissioning process and protecting the public after the license is terminated.

Many components within the NRC's regulatory framework are meant to be transparent and provide opportunities for public comment and participation in the NRC's regulatory process. For the decommissioning process, public meetings are held after a decommissioning activities report is submitted. Additional public meetings are held after reactor shutdown and when the NRC receives the license termination plan. Also, when NRC holds a meeting with the licensee, members of the public may observe the meeting. For Native American Tribal engagement, the NRC has developed and employs the *2017 Tribal Protocol Manual Guidance for NRC Staff*.[7] The NRC provides advance notification of nuclear waste shipments to affected Tribal governments and conducts outreach and consultation with Tribes on agency actions or decisions that have the potential to affect them.

[7] https://www.nrc.gov/about-nrc/state-tribal/tpm.html

2.2 Inventory of Radioactive Waste at Great Lakes Basin Power Plants

2.2.1 Canada

In 2018, Natural Resources Canada published an inventory of radioactive waste in Canada as of December 31, 2016. Among the four nuclear power stations in the Canadian section of the Great Lakes Basin that store high-level waste (HLW) (Bruce, Darlington, Pickering, and Douglas Point), there were 2,400,287 spent nuclear fuel bundles with an estimated volume of 9,801 m^3 (346,119 ft^3) and containing 47,201 metric tons (52,030 U.S. tons) of uranium. Projected HLW volumes for the four stations in 2019, 2050, and 2100 are 11,084 m^3 (391,428 ft^3), 18,512 m^3 (653,746 ft^3), and 20,085 m^3 (709,296 ft^3), respectively (Table 2-2). No HLW disposal facility currently exists in Canada or in the United States, so spent fuel is stored on-site at operating or closed plants in most cases.

2.2.2 United States

In the United States, the Department of Energy (DOE) published an inventory of spent nuclear fuel in dry storage at nuclear power facilities on August 22, 2016. Among the 12 active, shut down, or decommissioned nuclear power stations in the U.S. section of the Great Lakes Basin, there were 10,743 spent fuel assemblies stored in 265 casks. At the projected time of final decommissioning for all 12 of the nuclear power facilities in the U.S. section of the Great Lakes Basin, the estimated amount of HLW is 52,190 spent fuel assemblies stored in 1,064 casks and an additional 31 casks storing greater than Class C (GTCC) waste (Table 2-3). The HLW is expected to be stored on-site at each facility's independent spent fuel storage installation (ISFSI), until HLW is moved to a consolidated interim storage facility or is accepted for long-term disposal by the DOE. Disposal at a DOE-operated permanent storage facility will likely not be an option for several decades.

2.3 Operating Nuclear Power Plants in the Great Lakes Basin

Currently, there are a total of 12 operating nuclear power stations in the Great Lakes Basin: 9 in the United States and 3 in Canada. Among those 12 stations, there are 30 nuclear reactors: 12 in the United States and 18 in Canada (Table 2-4). Ten of the Canadian reactors are located on Lake Ontario near Toronto, and 8 are on Lake Huron. The U.S. reactors are on Lake Ontario (4), Lake Erie (3), and Lake Michigan (5).

2.4 Shutdown and Decommissioned Nuclear Power Plants in the Great Lakes Basin

The first reactor in the Great Lakes Basin to be shut down was Enrico Fermi Atomic Power Plant Unit 1 (Fermi-1) in Michigan in 1972, following an accident, and is currently in "safe storage" (SAFSTOR). Since then, another seven reactors have been permanently shut down (Table 2-5). Only one site, Big Rock Point in Michigan, has been decommissioned. In 2007, the NRC approved the release of about 435 acres (176 hectares) at Big Rock Point for unrestricted use, while approximately 107 acres (43 hectares) remain under NRC license for spent fuel storage. Another site, Zion, is currently being dismantled, with decommissioning and restoration activities expected to be completed in 2020.

Table 2-2. High-Level Radioactive Waste Projections at Canadian Reactors in the Great Lakes Basin

Company - Site Name	HLW inventory 2019			HLW inventory 2050			HLW inventory 2100		
	No. of Fuel bundles	Est. Weight (Metric tons)	Est. Weight (U.S. tons)	No. of Fuel bundles	Est. Weight (Metric tons)	Est. Weight (U.S. tons)	No. of Fuel bundles	Est. Weight (Metric tons)	Est. Weight (U.S. tons)
OPG - Bruce A	588,773	11,151,949	12,292,920	1,141,400	21,619,257	23,831,152	1,242,398	23,532,261	25,939,877
OPG - Bruce B	759,571	14,512,364	15,997,143	1,411,201	26,962,406	29,720,965	1,661,142	31,737,779	34,984,913
OPG - Darlington	593,323	11,379,935	12,544,231	1,170,007	22,440,734	24,736,675	1,212,280	23,251,530	25,630,424
OPG - Pickering A	363,885	7,230,395	7,970,146	379,487	7,540,407	8,311,876	379,487	7,540,407	8,311,876
OPG - Pickering B	443,149	8,805,371	9,706,260	503,527	10,005,081	11,028,714	503,527	10,005,081	11,028,714
AECL - Douglas Point	22,256	299,827	330,503	22,256	299,827	330,503	22,256	299,827	330,503
Total HLW	**2,770,957**	**53,379,841**	**58,841,203**	**4,627,878**	**88,867,712**	**97,959,885**	**5,021,090**	**96,366,885**	**106,226,307**

Acronyms: AECL = Atomic Energy of Canada Limited; OPG = Ontario Power Generation

Source: Adapted with permission from Table 6, *Inventory of Radioactive Waste in Canada 2016*. Natural Resources Canada. https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/energy/pdf/uranium-nuclear/17-0467%20Canada%20Radioactive%20Waste%20Report_access_e.pdf.

Table 2-3. High-Level and Greater-than-Class C (GTCC) Waste Inventory in Dry Storage at ISFSIs in the U.S. Section of the Great Lakes Basin

Site Name	HLW Inventory as of August 22, 2016		Projected HLW Inventory at Decommissioning			
	SNF Assemblies	Storage Casks Containing SNF	Reference Year	SNF Assemblies	Storage Casks Containing SNF	Storage Casks Containing GTCC
Big Rock Point[1]	441	7	2006	441	7	1
Davis-Besse Nuclear Plant[2]	72	3	2020	1,529	43	4
Donald C. Cook Nuclear Plant[3]	896	28	2037	6,552	205	6
Enrico Fermi Nuclear Station[4]	408	6	2045	6,528	96	4
FitzPatrick Nuclear Plant[5]	1,428	21	2034	6,314	93	NA
Kewaunee Power Plant[6]	448	14	2017	1,335	38	NA
Nine Mile Point Nuclear Station[5]	1,464	24	2046	14,291	234	NA
Palisades Nuclear Plant[1]	1,096	42	2022	2,082	63	5
Point Beach Nuclear Plant[7]	1,120	39	2033	3,616	85	2
Perry Nuclear Power Plant[2]	952	14	2021	5,393	80	5
R.E. Ginna Nuclear Plant[5]	192	6	2029	1,883	59	NA
Zion Power Station[8]	2,226	61	2014	2,226	61	4
Total	**10,743**	**265**	**-**	**52,190**	**1,064**	**31**

Acronyms: GTCC = Greater-than-Class C waste; HLW = High-Level Radioactive Waste; NA = Not Available; SNF = Spent Nuclear Fuel

Source of HLW Inventory as of August 22, 2016:

Adapted from Table A-1, *Dry Storage Cask Inventory Assessment: Fuel Cycle Research & Development* (FCRD-NFST-2014-000602, Revision 2). Prepared for the U.S. Department of Energy: Nuclear Fuels Storage and Transportation Planning Project by Robert H. Jones Jr (SRNL). 22 August 2016. https://www.energy.gov/ne/downloads/dry-storage-cask-inventory-assessment-revision-2/.

Sources for HLW Projected Inventory at Decommissioning:

[1] *ISFSI Decommissioning Funding Plans* (10 CFR 72.30). Entergy Nuclear Operations, Inc. 17 December 2018. https://adamswebsearch2.nrc.gov/webSearch2/main.jsp?AccessionNumber=ML18351A478

[2] *Triennial ISFSI Decommissioning Funding Plans*. First Energy Nuclear Operating Company. 17 December 2018. https://adamswebsearch2.nrc.gov/webSearch2/main.jsp?AccessionNumber=ML18351A161

[3] *Decommissioning Study of the D.C. Cook Nuclear Power Plant* (Revision 0). Knight Cost Engineering Services, LLC. 21 January 2016. https://adamswebsearch2.nrc.gov/webSearch2/main.jsp?AccessionNumber=ML18341A134

[4] *Fermi 2 ISFSI Decommissioning Funding Plan Update*. DTE Energy. 30 March 2017. https://adamswebsearch2.nrc.gov/webSearch2/main.jsp?AccessionNumber=ML17089A789

[5] *International Joint Commission Request for NRC Assistance in Obtaining Projected HLW Estimates for Nuclear Power Plants Operated by Exelon Generation Company*. U.S. Nuclear Regulatory Commission. 24 January 2019. Accession Number = ML18340A0451.

[6] *Kewaunee Power Station Revision to Post-Shutdown Activities Report*. Dominion Energy Kewaunee, Inc. 25 April 2014. https://adamswebsearch2.nrc.gov/webSearch2/main.jsp?AccessionNumber=ML14118A382

[7] *Decommissioning Funding Status Reports / ISFSI Financial Assurance Update*. Florida Power and Light Company. 30 March 2017. https://adamswebsearch2.nrc.gov/webSearch2/main.jsp?AccessionNumber=ML17093A722

[8] *License Termination Plan, Revision 2*. Zion*Solutions*, LLC. 7 February 2018. https://adamswebsearch2.nrc.gov/webSearch2/main.jsp?AccessionNumber=ML18052A857

Table 2-4. Operating Nuclear Power Stations in the Great Lakes Basin

Site Name	Location	Current Licensee	Operating License - Issued	Operating License - Renewed	Operating License - Expires	Capacity (MWe)	Decommissioning Planning Report	Estimated Decommissioning Cost (in millions)
Bruce Nuclear Generating Stations	Kincardine, ON	-	-	-	-	-	-	2015 CAD
Bruce A: Units 1-4 Bruce B: Units 5-8	-	Bruce Power	1977	01 Oct 2018	31 Sept 2028	6,232	Dec 2016	2,840 (Bruce A) 2,810 (Bruce B)
Western Waste Management Facility	-	OPG	-	01 June 2017	31 May 2027	-	Dec 2016	$111.7 to $118.1
Darlington Nuclear Generating Station	Clarington, ON	OPG	-	-	-	-	-	2015 CAD
4 Reactor Units	-	-	1990	01 Jan 2016	30 Nov 2025	3,512	Dec 2016	$3,360
Darlington Waste Management Facility	-	-	Nov 2007	13 March 2013	30 April 2023	-	Dec 2016	$18.35
Davis-Besse Nuclear Power Station	Oak Harbor, OH	FirstEnergy Solutions Co.	-	-	-	-	-	2017 USD
Unit 1	-	-	22 Apr 1977	08 Dec 2015	22 Apr 2037	894	24 Mar 2017	$467.40
ISFSI	-	-	-	-	-	-	17 Dec 2018	$6.07
Donald C. Cook Nuclear Plant	Bridgman, MI	Indiana Michigan Power Co.	-	-	-	-	-	2015 USD
Unit 1	-	-	25 Oct 1974	30 Aug 2005	25 Oct 2034	1,009	-	-
Unit 2	-	-	23 Dec 1977	30 Aug 2005	23 Dec 2037	1,060	-	$1,634
ISFSI	-	-	-	-	-	-	-	$56.95
Enrico Fermi Nuclear Station	Newport, MI	DTE Electric Co.	-	-	-	-	-	2016 USD
Unit 2	-	-	15 July 1985	15 Dec 2016	20 March 2045	1,141	30 Mar 2017	$1,040
Unit 3 - approved but not constructed	-	-	30 April 2015	-	-	1,600	-	-
ISFSI	-	-	-	-	-	-	30 Mar 2017	$8.60

Table 2-4. Operating Nuclear Power Stations in the Great Lakes Basin

Site Name	Location	Current Licensee	Operating License - Issued	Operating License - Renewed	Operating License - Expires	Capacity (MWe)	Decommissioning Planning Report	Estimated Decommissioning Cost (in millions)
James A. FitzPatrick Nuclear Power Plant	Scriba, NY	Exelon Corp	-	-	-	-	-	2018 USD
Unit 1	-	-	17 Oct 1974	08 Sept 2008	17 Oct 2034	853	10 Dec 2018	$651.14
ISFSI	-	-	-	-	-	-	-	$9.81
Nine Mile Point Nuclear Station	Scriba, NY	Exelon Corp	-	-	-	-	-	2016 USD
Unit 1	-	-	26 Dec 1974	31 Oct 2006	22 Aug 2029	626	-	$595.90
Unit 2	-	-	02 July 1987	31 Oct 2006	31 Oct 2046	1,287	30 March 2017	$666.80
ISFSI	-	-	-	-	-	-	-	$12.70
Palisades Nuclear Power Plant	Perry, OH	Entergy Nuclear Operations, Inc.	-	-	-	-	-	2017 USD
Unit 1	-	-	21 Feb 1971	17 Jan 2007	24 Mar 2031	787	29 March 2018	$466.32
ISFSI	-	-	-	-	-	-	17 Dec 2018	$8.00
Perry Nuclear Power Plant	Perry, OH	FirstEnergy Solutions Co.	-	-	-	-	-	2016 USD
Unit 1	-	-	18 Mar 1986	-	18 Mar 2026	1,240	24 Mar 2017	$651.90
ISFSI	-	-	-	-	-	-	17 Dec 2018	$10.24
Pickering Nuclear Generating Station	Pickering, ON	Ontario Power Generation	-	-	-	-	-	2016 USD
PNGS A: Units 1-4 (Units 2-3 are deactivated)	-	-	1971	01 Sept 2018	31 Aug 2028	3,094	Dec 2016	$5,190
PNGS B: Units 5-8	-	-	-	-	-	-	-	-
Pickering Waste Management Facility	-	-	-	01 April 2018	31 August 2028	-	Dec 2016	$29.82
Point Beach Nuclear Plant	Two Rivers, WI	NextEra Energy Point Beach, LLC	-	-	-	-	-	2016 USD
Unit 1	-	-	05 Oct 1970	22 Dec 2005	05 Oct 2030	595	-	$425.70

Table 2-4. Operating Nuclear Power Stations in the Great Lakes Basin

Site Name	Location	Current Licensee	Operating License - Issued	Operating License - Renewed	Operating License - Expires	Capacity (MWe)	Decommissioning Planning Report	Estimated Decommissioning Cost (in millions)
Unit 2	-	-	08 Mar 1973	22 Dec 2005	08 Mar 2033	597	30 Mar 2017	$425.70
ISFSI	-	-	-	-	-	-	-	$8.10
R.E. Ginna Nuclear Power Plant	Ontario, NY	Exelon Corp	-	-	-	-	-	2016 USD
Unit 1	-	-	19 Sept 1969	19 May 2004	18 Sept 2029	582	30 March 2017	$434.40
ISFSI	-	-	-	-	-	-	-	$6.24

Acronyms: CAD = Canadian dollars; ISFSI = independent spent fuel storage installation; MWe = megawatt-electric; USD = U.S. dollar

Table 2-5. Permanently Shut Down Reactors in the Great Lakes Basin

Site Name	Location	Current Licensee	License Status	Operation Dates	Decommi-ssioning Planning Report	Site Restoration Completion Date	License Termination Plan (LTP)	Annual Radiological Environmental Operating Report
Big Rock Point	Charlevoix, MI	-	-	29 Mar 1963 to 29 Aug 1997	-	-	Revision 3 17 July 2013	-
Greenfield - 435 acres (176 ha)	-	Consumers Energy	Released	-	-	8 Jan 2007	-	N/A
ISFSI - 107 acres (43 ha)	-	Entergy Nuclear Operations	ISFSI	2003 to present	17 Dec 2018	-	-	20 April 2018
Douglas Point Nuclear Generating Station	Kincardine, ON	Canadian Nuclear Laboratories (CNL)	-	-	22 June 2018	-	-	-
Unit 1	-	-	SAFSTOR	26 Sept 1968 to 4 May 1984	-	2059	-	-
Enrico Fermi Atomic Power Plant	Newport, MI	DTE Electric Co.	-	-	30 Mar 2017	-	Revision 4 29 June 2011	-
Unit 1	-	-	SAFSTOR	7 Aug 1966 to 29 Nov 1972	-	2032	-	-
Pickering Nuclear Generating Station	Pickering, ON	Ontario Power Generation	-	-	Dec 2016	2065	-	9 April 2018
Unit 2	-	-	SAFSTOR	30 Dec 1971 to 31 Dec 1997	-	-	-	-
Unit 3	-	-	SAFSTOR	1 June 1972 to 29 Dec 1997	-	-	-	-
Kewaunee Power Station	Carlton, WI	Dominion Energy Kewaunee, Inc	-	-	23 March 2018	4 Dec 2073	-	31 Dec 2017

Table 2-5. Permanently Shut Down Reactors in the Great Lakes Basin

Site Name	Location	Current Licensee	License Status	Operation Dates	Decommi-ssioning Planning Report	Site Restoration Completion Date	License Termination Plan (LTP)	Annual Radiological Environmental Operating Report
Unit 1	-	-	SAFSTOR	16 June 1974 to 7 May 2013	-	-	-	-
ISFSI	-	-	ISFSI	2009 to present	-	-	-	-
Zion Nuclear Power Station	Zion, IL	Zion*Solutions*, LLC				2020	Revision 2 7 Feb 2018	May 2018
Unit 1	-	-	DECON	31 Dec 1973 to 13 Feb 1998	-	-	-	-
Unit 2	-	-	DECON	17 Sept 1974 to 13 Feb 1998	-	-	-	-
ISFSI	-	-	ISFSI	2013 to present	-	-	-	-

Acronyms: DECON = decontamination; ISFSI = independent spent fuel storage installation; SAFSTOR = safe storage

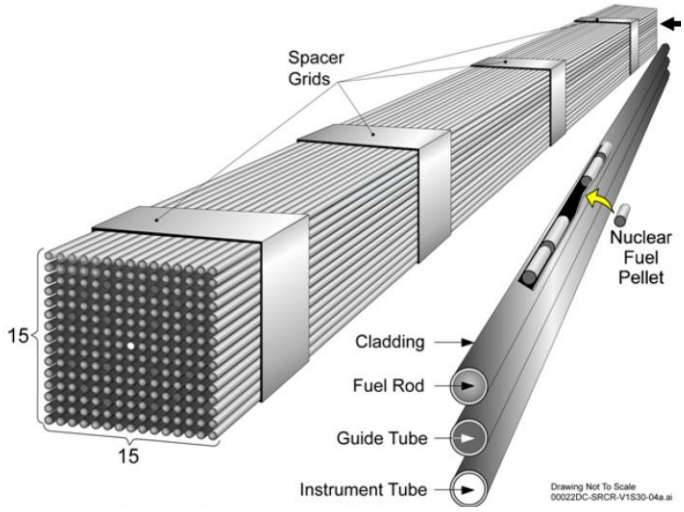
3. Overview of Nuclear Power Plants and Decommissioning Activities

3.1 Nuclear Power Plant Components and Systems

This section provides a brief overview of the major components and systems typically present at nuclear power plants and discusses the major types of nuclear reactors used at nuclear power plants located within the Great Lakes Basin. Every nuclear power plant includes a nuclear reactor, which is where the nuclear fission reactions take place. These reactions generate heat that is used to generate electricity. Even though there are many different types of reactors, there are several components that are common to most types.

3.1.1 Nuclear Reactors

Most nuclear reactors use uranium as fuel. Typically, pellets of uranium oxide (UO_2) are arranged inside metallic tubes to form fuel rods. The rods are then arranged into fuel assemblies, or **fuel bundles** (Figure 3-1), and placed in the reactor core. A 1,000-MW pressurized water reactor may use as many as 51,000 fuel rods with over 18 million uranium fuel pellets.



Source: U.S. Department of Energy

Figure 3-1. Typical nuclear fuel bundle, containing a 15x15 array of fuel rods

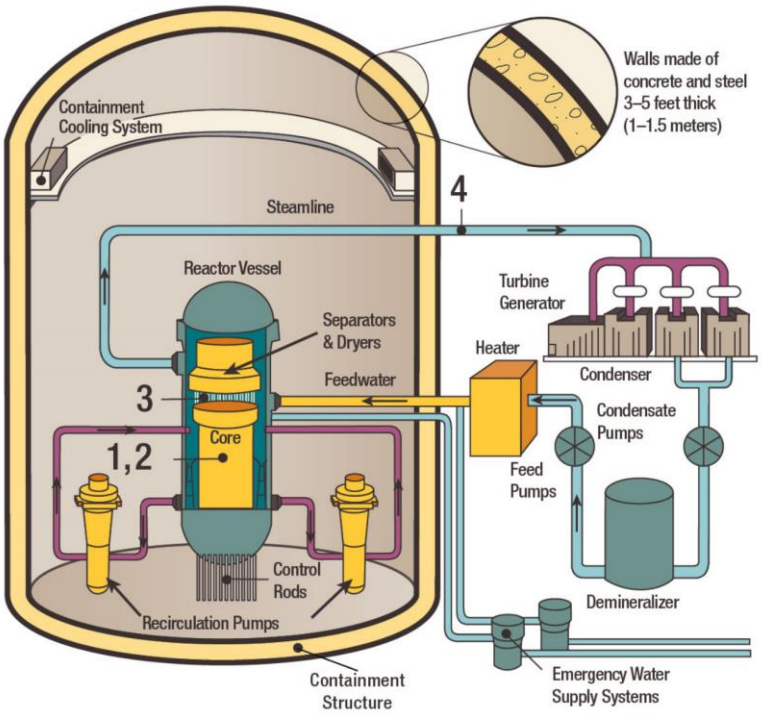
Typically, the reactor core containing the fuel bundles is placed inside a **pressure vessel**. The pressure vessel is typically a large steel vessel filled with a **moderator**, typically water (H_2O) or heavy water (D_2O), which moderates (slows) the neutrons released from nuclear fission and increases the yield of subsequent fission reactions. The moderator also serves as a coolant, absorbing the heat generated from nuclear fission and transferring it out of the reactor. The heat absorbed by the moderator is used to generate steam, which drives a steam turbine and generator to produce electricity.

Most U.S. nuclear power plants use either **pressurized water reactors** or **boiling water reactors**. In a pressurized water reactor, water is used as the moderator and coolant. A primary coolant loop circulates water at high pressure inside the pressure vessel and through the reactor core, and then to a **steam generator**. Inside the steam generator, the hot water heats up water in a secondary coolant loop to form steam, which is then used to drive a steam turbine. Similar to the pressure vessel, steam generators are large pieces of equipment typically made of steel or other metals.

Boiling water reactors use a single coolant loop (Figure 3-2). Hot water is allowed to boil inside the pressure vessel as it flows up through the core. The boiling water turns to steam in the upper part of the pressure vessel. The steam is then dried and pumped to the steam turbine, where it is used to generate electricity. The steam system in a boiling water reactor nuclear power plant, including the turbines and condenser, are part of the primary coolant loop that circulates through the reactor core.

Since the water passing through the core of a reactor is contaminated with traces of radionuclides, the turbines must be shielded, and radiological protection provided to workers.

Canadian nuclear power plants use a reactor design known as the **Canadian deuterium uranium (CANDU) reactor**. CANDU reactors are a type of reactor known as a pressurized heavy water reactor; similar to pressurized water reactors, CANDU reactors use two coolant loops (see Figure 3-3). However, CANDU reactors use heavy water (deuterium oxide) as both moderator and coolant. In addition, instead of a single large pressure vessel, they use a series of pressure tubes. The pressure tubes pass through a large tank known as a calandria that contains the moderator. Each pressure tube holds a series of nuclear fuel bundles placed end-to-end and serves as a passage for coolant to flow through the reactor.



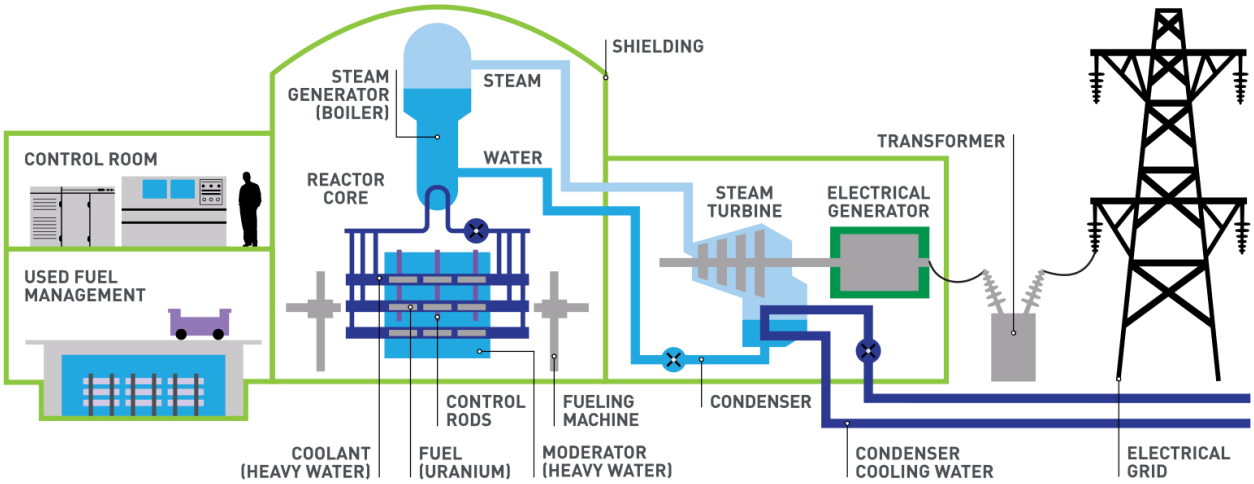
Source: U.S. Nuclear Regulatory Commission

Figure 3-2. Schematic Diagram of a Boiling Water Reactor

The deuterium in the heavy water used in CANDU reactors is readily activated by neutrons released during fission to form tritium, a radioactive isotope of hydrogen. Tritium is a weak source of radiation with a half-life in the human body of approximately 10 days. Radiation exposure is possible from ingestion of tritiated water or tritium-contaminated food. CANDU reactors typically produce several orders of magnitude more tritium than pressurized water reactors or boiling water reactors, which can be a concern both during the plant's operating life and subsequent decommissioning. Tritium is difficult to contain and readily diffuses through most materials, including metals. Tritium can also combine with oxygen to form tritiated water, which is chemically indistinguishable from ordinary water and cannot be separated by filtration or other methods commonly employed to treat radioactive water at nuclear power plants.[8,9] The NRC and CNSC allow operating nuclear power plants to discharge wastewater containing low levels of tritium; these discharges must be included in the plant's routine monitoring and reporting. Decommissioning of sites contaminated with tritium would require mitigation, similar to other sources of radioactivity, to ensure compliance with the facility's decommissioning plan and license termination conditions.

[8] NRC. 2019. Tritium, Radiation Protection Limits, and Drinking Water Standards. https://www.nrc.gov/docs/ML0620/ML062020079.pdf

[9] CNSC. 2012. Tritium Fact Sheet. http://nuclearsafety.gc.ca/eng/resources/fact-sheets/tritium.cfm



Source: Canadian Nuclear Association

Figure 3-3. Schematic diagram of a CANDU nuclear power plant, showing the reactor pressure vessel and ancillary systems

Finally, the reactor pressure vessel (or pressure tubes and calandria, in case of CANDU reactors), along with steam generators (if present), are enclosed within a large reactor **containment structure**. The containment structure around the reactor pressure vessel and associated steam generators (if present) is designed to protect it from outside intrusion and to protect those outside from the effects of radiation. The containment structure typically consists of concrete and steel walls 3-5 feet thick (0.9-1.5 meters).

3.1.2 Ancillary Systems

Ancillary systems at nuclear power plants include monitoring and control systems, steam turbines and electric generators, transformers, cooling towers, and spent fuel storage pools. Depending on the reactor type and the age of the nuclear power plant, some of these ancillary systems can become contaminated with radioactivity and may need to be either decontaminated during decommissioning or disposed of as radioactive waste.

Spent nuclear fuel that is removed from the reactor is placed in the spent fuel pool, typically for a period of five to seven years, until it cools sufficiently to be moved to long-term dry storage. Spent fuel pools are structures similar to large swimming pools that are filled with water to shield plant personnel from radiation. The spent fuel must be properly shielded and separated within the pool to avoid possible creation of a critical nuclear assembly of used fuel. Decommissioning of spent fuel pools is discussed in Section 3.2.4 below.

3.2 Overview of Decommissioning

This section discusses the activities that typically take place during the decommissioning of a nuclear power plant. These activities are subject to regulatory review and approval, as discussed in Graydon et al. (2019), Chapter 3.

3.2.1 Initial Post-Shutdown Activities

The initial decommissioning activities performed after plant shutdown typically include de-fueling the reactor and transferring the fuel into the spent fuel pool, draining of fluids and de-energizing systems, reconfiguring the electrical distribution, ventilation, heating, and fire protection systems, and minor deconstruction activities. Systems temporarily needed for continued operation of the spent fuel pool are reconfigured for operational efficiency and required radiation shielding. Spent fuel is the major source of radioactivity, but other components of the reactor system exhibit radiation due to both contamination and induced radioactivity from the neutron field in the reactor. Typical contaminated components include piping, plumbing, shielding, instruments, and supporting structures made of concrete and metals. The large volume of fluids in the plant are treated using selected water treatment resins that remove radioactive materials. These resins also require adequate disposal consistent with their radiation levels and chemical properties.

3.2.2 Decommissioning Strategies

Nuclear power plants typically use one of three decommissioning strategies, which are discussed below. Note that these are not mutually exclusive and may be used in combination. For example, immediate dismantling may begin on one part of the facility while other areas are allowed to decay in place through a strategy of deferred decommissioning.

Entombment/Decommissioning in Place

Entombment is a decommissioning strategy under which the radioactive portions of a nuclear power plant are encased in concrete or other impervious material and left to decay in place. This would effectively establish a low- and intermediate-level waste repository at the site, and all relevant requirements and controls for the establishment, operation, and closure of radioactive waste repositories would then apply. There are relatively few examples where entombment was selected as the decommissioning method. To date, no nuclear power plant in the United States or Canada has selected entombment as a decommissioning strategy.

Deferred Decommissioning/SAFSTOR

Deferred decommissioning or SAFSTOR refers to a period of time when the plant is maintained in an inoperative but stable condition to allow residual radioactivity in structures and equipment to decay naturally. NRC regulations require decommissioning activities to be completed within 60 years of shutdown, with an extension beyond that considered only when necessary to protect public health and the environment. In the United States, nuclear power plants in SAFSTOR typically plan for decommissioning to be completed within 40 to 60 years following shutdown.

Deferred decommissioning may allow for certain radioactive waste to decay sufficiently to allow disposal as a lower-level waste. Additionally, decommissioning funds would likely continue to grow over time, allowing for a cushion against unforeseen events when decommissioning does eventually take place. However, there are also risks to deferred decommissioning. Liabilities, including unidentified contamination, may continue to grow as well if not detected in time, and facility equipment and systems may deteriorate over time and may no longer be operational. Additionally, decommissioning trust funds are subject to market conditions, and may not yield anticipated returns in the event of a market downturn. Finally, there is a risk of the loss of institutional knowledge if decommissioning activities are delayed for several decades, such that decommissioning personnel may not be familiar with the facility

and potential sources of contamination and risk. This can be mitigated by documenting facility conditions at the time of shutdown, but there is still a risk that records and documents may be lost.

Immediate Dismantling

Under this strategy, the nuclear reactor and ancillary structures and systems would be dismantled and disposed immediately following shutdown. In practice, a nuclear power plant may undergo partial decommissioning followed by a period of SAFSTOR before the site is fully decommissioned and the site license terminated. For U.S. nuclear power plants undergoing immediate dismantling, the time period between reactor shutdown and final license termination typically ranges from 10 to 20 years. As another example, German nuclear power plants are typically decommissioned using a strategy of immediate dismantling, with decommissioning taking from 20 to 25 years. French reactors use a combination of deferred decommissioning and immediate dismantling that takes between 25 and 40 years.

3.2.3 Dismantling and Demolition

Decommissioning involves the dismantling and removal of equipment and structures, whether this is done immediately following shutdown or after a period of SAFSTOR. Typically, decommissioning activities begin outside the reactor vessel, starting with the turbine, electric generator, and other ancillary systems, and gradually move to the nuclear reactor and its fuel elements.

Characterization

The first step in dismantling is to characterize the facility and identify radioactive and non-radioactive structures and components. Potentially, all systems and materials that come in contact with the nuclear fuel, the primary coolant water, and the containment systems are sources of radiation and must be characterized and treated as appropriate for safety and containment.

Decontamination

Decontamination is an approach to reduce the amount of radioactive waste that needs to be disposed in approved LLW facilities, as shown in Table 3-1. Decontamination can help lower costs associated with waste disposal, which may offset the additional cost of completing this step. Decontamination involves removing the contaminated surface layers of structures and components, which are then managed as radioactive waste, while the remaining bulk materials can be managed and disposed of as non-radioactive solid waste. There are a number of decontamination approaches that can be employed, including mechanical and chemical processes.

Table 3-1. Radioactive Waste Volumes from Decommissioning of Two U.S. Nuclear Power Plants

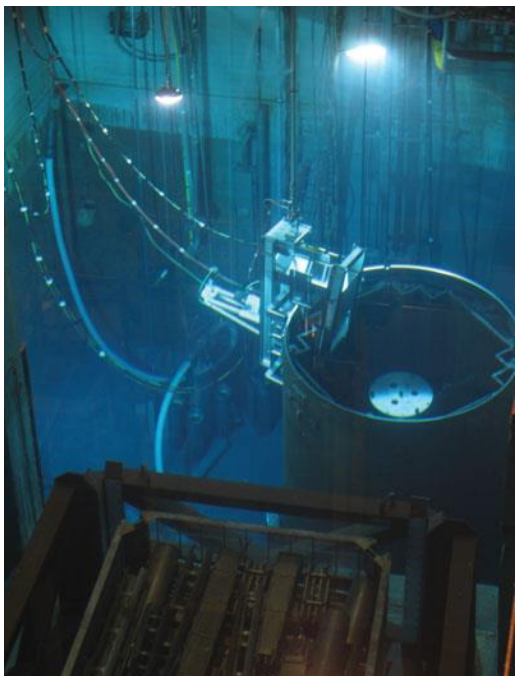
Waste Type (U.S. Classification)	Waste Volumes (m^3)	
	Maine Yankee (860-MWe PWR)	Rancho Seco (913-MWe PWR)
Class A	90,650	17,244
Class B and C	570	93
Greater than Class C	N/A	11
Total	**106,610**	**17,348**
Decommissioning Strategy Employed	*Little decontamination of buildings and equipment*	*Decontamination of buildings; little decontamination of equipment*

Acronyms: N/A = not applicable; m^3 = cubic meters; MWe = megawatt-electric; PWR = pressurized water reactor
Source: Electric Power Research Institute 2014
Note: U.S. low-level waste is separated into multiple categories depending on the nature and extent of radioactivity. Class A waste is the least radioactive while Greater-than-Class C waste is the most radioactive category of low-level waste.

Decontamination is most effective on materials whose surfaces have become contaminated with radioactive residues over time, for example due to leaks, spills, and fugitive emissions. Decontamination is typically not an effective strategy for materials that are directly exposed to neutron radiation, such as components within the reactor pressure vessel. These materials become radioactive over time as a result of neutron penetration and activation, which occurs to some depth within the material and is not limited to the surface. As a result, the bulk material exhibits radioactivity and cannot be effectively decontaminated.

Dismantling and Demolition

Facility structures are demolished and most of the waste is transported to off-site disposal facilities; however, some of the more highly radioactive waste may be stored on-site pending availability of appropriate disposal facilities. Large equipment such as the pressure vessel and steam generators may be segmented prior to transport off-site; however, in some cases these systems may also be transported and disposed of intact, without segmenting. There are a variety of dismantling approaches that can be used such as mechanical dismantling or cutting, thermal cutting, or water jet cutting. Radioactive structures and components may need to be dismantled in enclosed areas to prevent cross-contamination.



Source: ENRESA

Figure 3-4. Underwater segmentation of reactor components at the Jose Cabrera Nuclear Power Plant, Spain.

Remotely operated equipment has also been used in decommissioning hazardous areas of nuclear power plants to minimize the risk of worker exposure, for example in segmenting highly radioactive components of the reactor pressure vessel. An approach that has been used successfully in recent decommissioning activities is to segment radioactive components, such as the reactor pressure vessel and steam generators underwater, using remotely operated equipment. Robotics also represent an innovative approach to inspecting hazardous or inaccessible parts of a nuclear facility, including inside dry storage casks used for storing spent fuel. Robots have been used to survey and handle radioactive waste at the Fukushima Daichi nuclear power plant in Japan.[10]

3.2.4 Radioactive Waste Management

Wastes generated from the decommissioning of nuclear power plants consist of materials with a wide range of radioactivity. The nuclear fuel in the reactor core is the primary source of radioactivity; therefore, materials in close contact with the fuel tend to be more highly radioactive than materials that are relatively isolated from the core. The spent fuel itself is managed as HLW; currently, spent nuclear fuel is being stored on-site at nuclear power plants and will continue to be managed as such until a permanent disposal site or consolidated interim storage facility becomes available.

[10] See, for example, https://www.wired.com/story/fukushima-robot-cleanup/.

As discussed earlier, spent fuel removed from the reactor core is typically placed in a spent fuel pool for a period of several years, and is then moved to a dry cask storage facility located on-site. Dry cask storage consists of fuel rods placed inside metal fuel storage cans, which are then placed inside large containers or casks, typically made out of concrete. These casks may be placed vertically on a concrete pad, vertically inside an underground vault, or horizontally inside an aboveground vault. The casks protect the spent fuel while allowing it to decay and are designed to ensure that sufficient ventilation and cooling is provided to dissipate any generated heat.

Source: Zion Solutions Company

Figure 3-5. Spent nuclear fuel in dry cask storage at the Zion Nuclear Power Plant site.

Next to the spent fuel, the most highly radioactive wastes are typically from components located inside the reactor pressure vessel that are directly exposed to radiation from the spent fuel. Other low-level wastes include the steam generator and piping systems and components. Additionally, low levels of radioactivity may be present at other locations as a result of leaks and other small releases over time; any contaminated materials must be managed as radioactive waste. Table 3-1 shows the volumes of waste (other than spent fuel) generated at two decommissioning sites in the United States and illustrates the effect of decontamination on reducing overall waste volumes.

Currently, disposal options in the United States and Canada are limited by the classification of the waste. HLW (i.e., spent nuclear fuel) and certain other types of waste (e.g., GTCC waste in the United States) do not have any available disposal options. These types of waste must be managed at the generating site in spent fuel pools and dry cask storage, until such time as an appropriate disposal option becomes available.

In the United States, low-level waste may be disposed of at one of four sites licensed by the NRC. These sites are in South Carolina, Texas, Utah, and Washington. However, two of these sites (South Carolina and Washington) only accept waste from certain states. Therefore, depending on its classification (i.e., level of radioactivity), low-level waste from the U.S. portion of the Great Lakes Basin would likely be disposed of at the Utah or Texas sites.

Source: Electric Power Research Institute

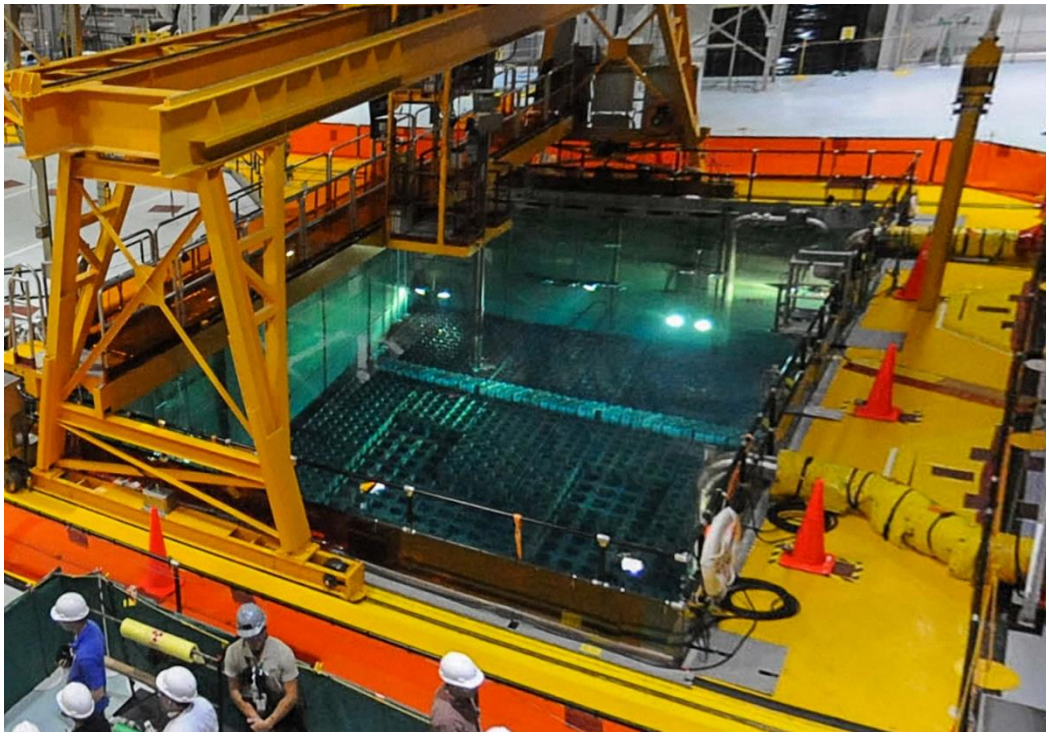
Figure 3-6. Bulk decommissioning waste being prepared for shipment at the Maine Yankee site.

In Canada, there is currently no licensed disposal facility for low- or intermediate-level waste. Therefore, these types of waste must be stored on-site. A deep geological repository for low-level waste has been proposed at the Bruce Nuclear Site near Lake Huron. See Section 4.1.2 of the Background Report (Graydon et al. 2019) for additional details on the proposed low-level waste repository.

Decommissioning Spent Fuel Pools

Spent fuel pools are used to manage spent nuclear fuel following its removal from the reactor. Spent fuel is highly radioactive and must be cooled to ensure that its temperature remains within safe limits until its radioactivity has decayed. This cooling period typically lasts 5 to 10 years but may be longer if dry storage facilities are not available. Water in the spent fuel pool serves as a coolant and also shields power plant personnel from radiation. While a nuclear power plant is in operation, water from the spent fuel pool is typically treated through a resin filtration system prior to discharge, similar to wastewater from other parts of the plant, to lower radioactivity to within permitted levels.

Once a plant has ceased operations, and all spent fuel has cooled sufficiently to allow it to be moved to dry storage, spent fuel pools are typically decommissioned along with the rest of the plant.[11] However, spent fuel pools may be maintained in operation during part of the dismantling stage, to allow radioactive components to be handled, cut, and packaged safely below water. Once the pool is no longer needed, the pool water is characterized and treated to remove any residual radioactivity before discharge. Spent fuel pools typically accumulate sludge from degradation of pool materials and surface corrosion of spent fuel racks, as well as any cutting and dismantling activities that may have taken place in the pool during decommissioning. The sludge must be characterized and managed as radioactive waste if necessary. Once the pool has been drained and cleaned, it can be decontaminated and dismantled similar to other structures at the facility, and backfilled. The degree of decontamination and cleanup depends on the final license termination conditions and whether the site is planned for unrestricted or restricted release.



Source: NRC

Figure 3-7. Spent fuel assemblies in the Unit 2 pool at the Brunswick Nuclear Power Plant.

3.2.5 Remediation and Restoration

Contamination of soil and groundwater at nuclear power plant sites is typically a result of leaks from tanks, process piping, and active waste storage sites. In some cases, chemical contamination (e.g., poly-chlorinated biphenyls [PCBs]) may be present either separately or in combination with radioactive contaminants. The first step in remediation of a site is to determine the history of the site and possible contaminants that may be present and identify the underlying hydrogeology. This is typically followed

[11] IAEA. 2015. Decommissioning of Pools in Nuclear Facilities. https://www-pub.iaea.org/MTCD/Publications/PDF/Pub1697_web.pdf

by site investigations to better characterize the nature and extent of contamination, and development of a conceptual model of the extent of contamination. Depending on the type (i.e., chemical, radiation, or both) and extent of contamination, there are several remediation options that can be employed for soil and groundwater, as discussed below.[12] The effectiveness of these remediation strategies must be verified through monitoring.

One approach to remediate soils is to remove the source of contamination. This can include excavation of the contaminated area and disposal of the bulk material in an appropriate disposal facility. In other cases, contaminants may be separated from the background matrix using methods such as gravity settling, screening, washing, filtration, chemical extraction, or phyto-remediation. As an example, excavation and removal was used at the Connecticut Yankee site to manage of soils contaminated with low-level radioactivity.

The second approach to remediating contaminated soil includes strategies which leave the contamination in place while taking steps to minimize the potential for further spread and exposure. These include capping and installation of subsurface barriers, and immobilization techniques such as cement-based solidification and chemical fixation. Natural attenuation with ongoing monitoring also falls within this category.

Remediation of contaminated groundwater can also be implemented using a range of approaches, depending on the nature of contamination. Physical techniques such as air stripping and carbon adsorption are often used to remove organic compounds, while coagulation and flocculation are effective for treating suspended solids. Chemical and biological treatment methods are also often used to remediate groundwater, along with monitored natural attenuation.

3.2.6 Environmental Monitoring

In the United States, reactors undergoing decommissioning are required by the NRC to monitor air and water releases and any direct radiation, and measure radiation levels in the environment. Operators must collect samples from the air, surface water (such as ponds, streams, and lakes), groundwater, drinking water, milk, fish, and shoreline sediment. Each operator's license specifies monitoring requirements for that site and the environment around the nuclear power plant. These requirements are also discussed in the background report (Graydon et al. 2019, Section 3.2.7).

Operators must also submit annual reports to the NRC in accordance with the terms of their license. These reports specify the quantity of radionuclides released to unrestricted areas in liquid and in gaseous effluents during the previous 12 months, and any other information required to estimate maximum potential annual radiation doses to the public resulting from effluent releases. If quantities of radioactive materials released during the reporting period are significantly above design objectives, the reports must cover this specifically. ISFSIs are required to implement a radiological environmental monitoring program and submit an annual Radiological Environmental Operating Report and an annual ISFSI Radioactive Effluent Release Report. Monitoring reports submitted to the NRC are available via its website, at https://www.nrc.gov/reading-rm/adams.html.

[12] Fellingham, LR. 2012. *Environmental remediation and restoration technologies in nuclear decommissioning projects*. In Laraia, M (Eds), Nuclear Decommissioning: Planning, Execution, and International Experience.

Similarly, the CNSC requires licensees to develop and maintain an environmental protection program addressing all aspects of their facility that have the potential to affect the environment (also see Section 3.1.7 of Graydon et al. 2019). The environmental protection program for a major facility must include:

- An environmental risk assessment (ERA)
- An emissions and effluent monitoring program
- An environmental monitoring programs
- An environmental management system

The CNSC is responsible for ensuring that licensees have effective control measures (e.g., wastewater treatment systems, air pollution control technologies, engineered and administrative barriers, and other techniques) in place to prevent or minimize releases to the environment. The license includes release limits along with regulatory action levels. The effluent monitoring program measures the releases of radiological and hazardous substances in air and water to the environment. The environmental monitoring program is used to measure the concentrations of nuclear and hazardous substances in different environmental media (e.g., air, water, vegetation, foodstuffs, and soil) to demonstrate that abiotic and biotic components of the environment and members of the public are protected. The specifics of this monitoring program are determined by regulatory requirements and the results of the site-specific ERA.

The ERA is reviewed and updated periodically (i.e., five years or earlier) with a corresponding re-evaluation of the associated monitoring programs. Revisions to the ERA are informed by the accumulated site knowledge derived from operational experience, monitoring, special investigations, and the incorporation of advances in other knowledge (e.g., scientific). All these elements are managed within a licensee's environmental management system.

In the context of decommissioning, radiation surveys and site investigation approaches are used to determine the extent of contamination, if any, and the subsequent remedial approach. Within the United States, the Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM) is used to guide these investigations.[13] The MARSSIM discusses the following four types of activities:

- Historical site assessments (HSA), which are intended to gather information about historical use of the site including incidents that may have contributed to contamination.
- Scoping surveys, which include limited measurements to provide site-specific information that guides the design and implementation of more in-depth surveys.
- Characterization surveys, which are detailed assessments used to determine whether remedial action is required. These surveys are typically performed on areas that are identified as potentially contaminated following the HSA and scoping survey.
- Remedial action support surveys, which are intended to serve as a real-time guide to remediation while it is underway, to ensure that remedial goals are met.
- Final status surveys, which are undertaken after any remedial action has been completed to demonstrate that the risk of exposure is within the release criteria established for the site.

[13] https://www.epa.gov/radiation/multi-agency-radiation-survey-and-site-investigation-manual-marssim

REGDOC-2.11.2 includes CNSC requirements for conducting radiological surveys as part of the decommissioning process.[14]

3.2.7 Decommissioning Costs

Decommissioning costs for a commercial nuclear power plant in the United States typically range from around $500 million up to $1 billion dollars.[15] The largest component of these costs is labor; other costs include packaging and disposal of low-level waste, the actual dismantling and demolition of equipment and facilities, and management of spent nuclear fuel on-site. However, some recent cost estimates are higher; for example, Southern California Edison estimates that the decommissioning of the SONGS 2 and 3 reactors could cost a total of approximately $4.2 billion.

Table 3-2 compares the actual cost of decommissioning U.S. nuclear power plants to initial estimates. Note that these estimates include the cost to manage spent nuclear fuel on-site for a period of time. At least in the United States, most nuclear operators are currently being reimbursed for these costs out of the U.S. government's judgement fund, as a result of lawsuits filed against the DOE for its failure to provide a permanent repository for spent fuel as required by the Nuclear Waste Policy Act. Discrepancies between initial estimates and final costs as well as differences in cost between sites are typically related to the extent of contamination, failure to accurately characterize the site and subsequent discoveries of previously unknown contamination, success in keeping wastes segregated, and unforeseen delays and difficulties in completing the decommissioning work such as in segmenting and handling highly radioactive internal components of the reactor pressure vessel.

Table 3-2. Decommissioning Costs of Select U.S. Nuclear Power Plants (in 2007 dollars)

Nuclear Power Plant	Original Estimate in PSDAR (millions of dollars)	Final Decommissioning Costs (millions of dollars)
Maine Yankee	$508	$495
Yankee Rowe	$407	$636
Connecticut Yankee	$427	$931
Big Rock Point	$439	$473
Rancho Seco	$517	$534

Acronyms: PSDAR = Post-Shutdown Decommissioning Activities Report
Source: LaGuardia 2012

3.3 Local Communities and Just Transition

Historically, decisions to close nuclear power plants have been made based on economic factors or following incidents that led to plant shutdowns. However, the impact of plant closures on local communities is often not considered. Many nuclear power plants are located near small communities and often serve as the major economic engine for the area, providing employment to hundreds of local residents, generating tax revenue for local governments, and supporting local businesses. The economic impact of nuclear plant closure on these communities can be significant. Additionally, the closing of a large institution can result in communities feeling as though their identity has been lost.

[14] http://nuclearsafety.gc.ca/eng/acts-and-regulations/consultation/comment/regdoc2-11-2.cfm
[15] LaGuardia, TS and KC Murphy. 2012. *Financing and economics of nuclear facility decommissioning*. In Laraia, M (Eds), Nuclear Decommissioning: Planning, Execution, and International Experience.

As examples, these types of impacts were experienced following the closure of the Yankee Rowe nuclear power plant in Massachusetts in 1992 and again following closure of the Vermont Yankee plant in Vernon, Vermont.[16,17] While it was operational, the Yankee Rowe plant employed approximately 250 people. During the last full year of operation, the plant directly contributed approximately $16.3 million to the local economy in the form of payroll and purchasing from local businesses. Indirect economic contributions from employee spending would increase this number even further. In addition, the company paid local taxes and contributed to local non-profit organizations. Similarly, the Vermont Yankee plant employed over 600 people, contributed over $70 million per year to the local economy through its payroll, and paid over $1 million in taxes to Vernon's government. For a town of 2,200 people, this represented over half of Vernon's budget. The closure of these plants has resulted in significant difficulties for local businesses, governments, and non-profit and charitable organizations. To mitigate these impacts, Vermont Yankee entered into a six-year agreement with the town, under which its tax payments would decrease over time to allow for a transition.

Some communities have taken a proactive approach to planning for the eventual closure of nuclear power plants. For example, in 2015 and 2016, the Town of Plymouth, Massachusetts commissioned a series of reports evaluating the potential impacts of the shutdown of the Pilgrim nuclear power plant.[18] The plant was eventually shut down in 2019. The reports presented the community with an estimate of the activities that would take place following decommissioning and an estimated timeline. They recommended the establishment of a citizen's advisory panel to ensure that the community remained informed about decommissioning activities. Finally, the reports recommended that the community begin evaluating alternative approaches to achieve its desired economic outcomes well in advance of the power plant's closure.

As another example of a planned transition, the State of California passed a bill in 2018 to provide funding to help retain workers at the Diablo Canyon nuclear power plant through 2025, when the plant is scheduled to close.[19] The bill implements a 2016 agreement between the utility company, environmental groups, labor groups, and others that will replace the plant with renewable energy generation, support worker training programs, and provide financial assistance to the local community.

It is likely that a number of different types of efforts will be needed to help communities achieve a just transition following major changes to their economic base. For example, the NRC is currently reviewing allowable uses of decommissioning trust funds.[20] Other industries may also offer lessons for towns and communities that are facing the effect of nuclear power plant closure. For example, many coal mines and coal-fired power plants have closed in recent months and years, leading to a range of negative economic effects for the surrounding communities. Just transition is also a focus area among policymakers and researchers who are concerned about climate change and hope to facilitate a transition away from carbon-intensive energy sources in a way that protects local communities.

[16] Mullin, JR and Z Kotval. 1997. The Closing of the Yankee Rowe Nuclear Power Plant: The Impact on a New England Community. https://scholarworks.umass.edu/larp_faculty_pubs/25/
[17] https://www.wbur.org/earthwhile/2019/04/23/vermont-yankee-vernon-lessons
[18] http://nuclearhostcommunities.com/research/
[19] https://www.nrdc.org/experts/peter-miller/diablo-canyon-legislation-signed-law-governor-brown
[20] https://www.nrc.gov/docs/ML1525/ML15257A282.pdf

4. Interviews

Interviews were conducted with a range of stakeholders to identify potential environmental challenges, best practices, and lessons learned from the decommissioning of nuclear power plants in North America and Europe. This chapter summarizes the interview methodology, including interviewee selection and the interview process, and summarizes the main topics discussed in each of the interviews. Information obtained from interviews is also integrated into other sections of this report, including details that are not reflected in these summaries.

4.1 Interview Methodology

Forty-two individuals from a wide range of stakeholder groups were contacted for interview requests, with a total of 16 individuals ultimately interviewed (Table 4-1). Individuals interviewed included representatives from North American and European decommissioning firms, North American regulators, U.S. and Canadian NGOs knowledgeable about nuclear issues, Tribal, Métis and First Nation members, and independent experts with knowledge of the nuclear industry and issues related to decommissioning and waste management.

Table 4-1. Summary of the Interview Process

Stakeholder Group	Individuals Contacted	Individuals Interviewed
Industry/Consultants	9	4
Regulators	4	4
Non-Governmental Organizations	4	3
Tribes/First Nations/Métis	17	2
Other Experts	7	4
Total	**41**	**17**

Each interview began with an introduction to the IJC, the project purpose, and how the interviews will be used to inform the final report. This was followed by the structured question and answer portion of the interview. While questions were primarily posed, the interviewees were encouraged to ask their own questions about the project and overall process. Before wrapping up, interviewees were thanked for taking the time to participate and willingness to share their knowledge and insights. Interviews typically lasted between 30 minutes and 1 hour.

A set of 10 standard questions were used to facilitate the interviews (Appendix A); in some cases, questions were tailored for specific interviewees. To make the most of the limited amount of time allotted for the interview, interviewees were provided with the questions in advance. Interviewees were given the opportunity to answer all 10 questions but were told that they could omit any questions they were uncomfortable answering or did not have the knowledge to answer. Follow-up questions were also asked to clarify discussion points and to probe ideas brought up during the interview. Interviewees were also told that they could bring up other topics they felt were relevant to nuclear decommissioning.

The process to identify and contact experts within each stakeholder group is described below, along with a brief summary of each interview. Interviewees were told that they would not be identified by name in the report in order to encourage them to speak freely. Some individuals interviewed were amenable to being identified in the report but in order to treat all interviewees consistently, interviewee names or affiliation are not disclosed.

4.2 Interview Summaries

4.2.1 Industry/Consultants

Online searches were performed to identify individuals familiar with these sites and who hold expert and lead positions in decommissioning. Online resources such as reports, conference participant lists, presentation materials, and company websites were helpful in identifying potential interviewees. Interview requests were sent to contacts who were expected to be knowledgeable about selected case study sites (Chapter 5) or other nuclear power plant sites that have either been out of operation for a long time or dismantled. Nine initial email requests were sent out in early March 2019, and follow-up emails were sent a few weeks later. Finding industry professionals willing to provide interviews proved challenging. Three willing participants did respond, representing two from one company in the United States and one in Germany. An interview was also conducted with an individual who works for a nonprofit research institute and has technical experience with decommissioning.

Interviewees 1 and 2: Two California-based employees of a decommissioning contractor

Interviewee Background: The interviewees had expertise in engineering, environmental project management, biology, and permitting related to nuclear power plant operations and decommissioning. Both were actively involved in decommissioning work in Southern California.

Key Highlights:

- Industries have failed to properly educate and disseminate information to the public.
- Inconsistencies with regulations and language used exist among agencies, which has also heightened concerns among the public.
- Many decommissioning-related concerns and permitting challenges are non-radiological, such as chemical waste management.

Interviewee Comments: The importance of industries understanding the environmental component of nuclear decommissioning throughout the project life cycle was discussed. Environmental permitting is the driver to start work and should be considered throughout the entire project. The interviewees discussed the public perception of nuclear power plant decommissioning and how it ties into many challenges. It was also noted that public perception can vary between states and sites and can lead to different levels of public involvement. Work needs to be done to solve the credibility and transparency issue. A potential starting point could be peer-reviewed science. Also, the industry can do a better job of communicating and agencies can have greater accountability, know what their limits and boundaries are, and have a clear chain of command to reduce public frustration with the engagement in the decommissioning process.

Interviewee 3: Technical lead of the decommissioning group within an industry research institute

Interviewee Background: This interviewee has over 20 years of experience, including decommissioning work at Big Rock Point nuclear plant in Michigan in the late 1990s.

Key Highlights:

- Decommissioning problems are more often the result of legacy issues rather than new issues created during decommissioning.
- Disposal pathways exist for all U.S. wastes, except for spent fuel, outside of the Great Lakes.

- Spent fuel is stored on site, but interim consolidated storage facilities are planned to come online in the United States in 2021 or 2022.
- Substantial public concern is concentrated around transport modes and pathways for waste.
- United States and Canadian differences are in the availability of waste disposal sites, reactor design and associated waste differences, and shorter SAFSTOR periods in the United States

Interviewee Comments: In the early days, people did not look for problems during plant operation which resulted in surprises during decommissioning. Political issues arise related to transport of waste. Most transport is by rail. Fuel transport by barge should be avoided, but some barge transport does still occur. Most spent fuel stays on site for now, but interim consolidated storage facilities are planned to come online in 2021 or 2022 in Andrews, Texas (operated by Waste Control Specialists) and near Carlsbad, New Mexico (operated by Holtec).

When comparing the United States and Canada, the interviewee identified a few key differences: (1) waste management in the U.S. is well established except for spent fuel, but that is not the case for Canada where there are not enough facilities for waste disposal, (2) there is more tritium and carbon-14 in CANDU reactors, which is quite different from U.S. reactors, and (3) SAFSTOR (decay in place after shutdown for major reactor components) is planned for all Canadian plants for 30 years, whereas in the United States this is less common. There are disadvantages to SAFSTOR, such as investment fund and cost risk, unknown issues that will get worse with time, and loss of institutional knowledge and plant functionality (e. g., power, ventilation, and overhead cranes). Conversely, better technology could exist in the future, good return on trust fund investments could provide more resources, and components would be less radioactive after longer decay times.

Interviewee 4: German decommissioning expert

Interviewee Background: The interviewee has 28 years of experience and is currently employed by one of the four nuclear power companies in Germany. Over the past 28 years, the interviewee has worked in all aspects of the nuclear business, from engineering to project management and decommissioning. Since 2011 (after the Fukushima Daiichi accident) the interviewee has focused more on decommissioning and worked on projects in the United States, Japan, United Kingdom (U.K.), France, Sweden, and Germany. Now the interviewee works for a German company to help steer their decommissioning portfolio.

Key Highlights:

- Nuclear regulations vary widely with few commonalities between countries.
- The key factor to consider when trying to decrease the hazards of a closing plant is the fuel.
- Older research reactors have more issues related to environmental contamination by radioactive releases than power plants because containment was not understood to be as important in the early years of nuclear research.
- Early planning is critical in determining the timescale and cost of decommissioning.
- Drawn out decommissioning costs much more than more rapid work, and the difference is not always appreciated in advance.

Interviewee Comments: The interviewee believes that Germany is over-regulated, whereas Sweden has a more pragmatic approach which the interviewee believes makes things faster and cheaper, but no less

safe (e.g., removal of larger radioactive components in one piece, rather than segmenting into small pieces and packaging before removal). The Swedish approach is actually safer for workers because there is less direct interaction with radioactive elements. Even within a single country, the laws can be applied in very different ways, such as across the various states in Germany. The interviewee stated that the fuel elements represent 99.99 percent of the hazards, so that once the fuel is removed, the plant is more like a normal industrial site than a nuclear site. The interviewee stated that any discussion on approaches to decommissioning should first be centered on final disposal sites for fuel.

The actual decommissioning process is relatively short (about 10 years) compared to the thousands of years that HLW needs to be managed, and every nation worldwide with nuclear power is struggling with this topic. His company has already concluded the decommissioning of two plants, and the mechanical and engineering aspects are now becoming fairly routine. From these projects, the interviewee identified two key lessons: (1) the effort and expense required to decommission a plant is often underestimated, and (2) plants need to start planning as early as possible because timeframes are long, especially for decommissioning licensing (takes approximately five years in Germany). Even if a plant is shut down, support operations continue, so any postponement of decommissioning can incur enormous costs (millions of dollars per month) with no corresponding benefit. Good project management is critical to deal with the daily changes and dynamic nature of the decommissioning projects, which is a big difference from normal plant operations, which are quite consistent and routine.

4.2.2 Regulators

Federal nuclear regulators in the United States and Canada were contacted by email to request interviews for this study. One of the North American regulators agreed to participate; the other agreed to respond by email but has not yet provided a response. In addition, regulators in France and Germany were contacted since those countries are the focus of case studies in this report and have the greatest experience with decommissioning nuclear power plants that use similar technology as the nuclear power plants located in the Great Lakes Basin, i.e., pressurized water reactors and boiling water reactors. French and German regulators provided email responses to the interview questions.

Interviewee 1: Responsible for decommissioning and waste management at a North American regulator

Interviewee Background: The interviewee is a senior official responsible for decommissioning and waste management at the Canadian Nuclear Safety Commission.

Key Highlights:

- Unanticipated shutdowns (e.g., due to market conditions) can create challenges with respect to planning for decommissioning.
- Operators need to have a public outreach plan in place and need to engage the community well in advance of beginning decommissioning activities.
- Clearance levels for reuse of low-risk materials can potentially be an effective way to manage wastes materials from decommissioning.

Interviewee Comments: No plants have been decommissioned to date in Canada, although some have been shut down. Most facilities have opted for deferred decommissioning (20- to 40-year delay) with on-site fuel storage, until long-term storage at a deep geological repository becomes available. Long-term storage at a deep geological repository is currently planned to be operational around 2045.

Unanticipated shutdowns can create challenges, in that the utility and regulator may not have adequately planned for shutdown and decommissioning. Challenges include operational and human resources issues. Public communication can also be a challenge, especially in case of unplanned shutdown where the operator may not have a communication plan/strategy in place.

Operators are required to have a public communication program, that should be based on community expectations and expectations should be met within reason. Best practice is to seek public input during decommissioning, also required under EA process which may be triggered under certain circumstances. Operators should begin engaging the community well before decommissioning, but that may not be possible in case of unplanned shutdowns. Nuclear plants are required to renew licenses every 10 years, which provides an additional opportunity for public hearings and input.

Related to waste management, clearance and exemption levels are a good practice that allow for low-risk materials to be managed as non-radioactive waste or even recycled. Non-hazardous waste should not be managed with hazardous or radioactive waste. Waste management and decommissioning regulations, currently being updated, will increase opportunities for public input.

The interviewee has no concerns about decommissioning costs, since operators are required to show they have funds available for decommissioning based on their current decommissioning plan. Plants enter a surveillance state after shutdown and are required to have plans and safeguards in place to prevent radiological contamination.

Interviewee 2: Responsible for decommissioning and waste management at German regulatory agency

Interviewee Background: Official responsible for decommissioning of nuclear power plants at the federal Office for the Safety of Nuclear Waste Management (BfE) in Germany.

Key Highlights:

- Immediate dismantling is the preferred method of decommissioning in Germany.
- A new site proposed for low- and intermediate-level waste is currently being developed at the Konrad Mine.
- Spent fuel is currently stored on-site in dry casks.
- Licensing of nuclear power plants and decommissioning activities is done at the provincial level.
- The Federal government is responsible for licensing radioactive waste disposal and interim storage facilities.

Interviewee Comments: Major environmental impacts must be evaluated in the context of decommissioning, among them discharges with air and effluents; land use for new (waste storage) facilities; management of radioactive and conventional waste and residual material including transportation; noise; and radioactive releases due to accidents. Major challenges include retaining competence for decommissioning and waste management and ensuring that sufficient interim storage capacity for decommissioning waste is provided until a repository is available. This is a challenge for the operators as well as for the federal and Länder (provincial) authorities (Germany is a federal state consisting of 16 Länder).

BfE is currently building up competences and participates in the process of drafting a national strategy for sustaining competence in the field of nuclear safety and waste disposal. BfE is the federal regulatory

and supervisory authority for radioactive waste disposal. As the regulatory body, BfE supervises the construction and operation of Konrad repository for low- and intermediate level waste with regard to safety aspects. The operator (Federal company for nuclear waste disposal BGE mbH) has the responsibility for the construction and operation of the disposal facility.

Currently 25 nuclear power plants are undergoing decommissioning and for 3 plants, decommissioning is finished. Only one plant is in safe enclosure (SAFSTOR). The decommissioning strategy of immediate dismantling is the preferred and proven strategy. Most decommissioning projects use on site storage facilities for radioactive waste. Public involvement is an element of the licensing procedure for decommissioning. In Germany, licensing and supervision of decommissioning is the duty of the Länder. The Länder authorities are responsible for public involvement within the licensing procedure.

BfE is a federal authority with the following main tasks: the regulation of the site selection procedure for a repository especially for HLW including responsibility for public participation within the site selection process; nuclear licenses for interim storage facilities and transports of nuclear fuel; procedures under mining, water, and nuclear law relating to radioactive waste disposal; issues related to the safety of nuclear waste management; and task-related research in these areas. The BfE section Decommissioning of Nuclear Facilities provides technical support for the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) in questions of decommissioning and provides basic information regarding this topic. BfE is not in charge of cost and financing of decommissioning projects. The operators, whether private or public, have to cover the costs for the decommissioning of their nuclear facilities. The private operators of NPPs estimate these costs and accumulate funds during operation. Germany envisages that the spent fuel will be stored at the sites of the nuclear power plants (dry storage facilities).

Interviewee 3: Official at a French regulatory agency

Interviewee Background: Official at the ASN (French agency for nuclear safety) responsible for decommissioning issues.

Key Highlights:

- Older nuclear power plants are more challenging to decommission because often information is lacking on the types and extent of contamination (both radioactive and non-radioactive).
- France is currently considering establishing clearance levels for very low-level radioactive wastes.
- Radioactive wastes are classified according to the level and duration of radioactivity; low-level short-lived wastes are disposed of in a surface facility, but low-level long lived and high-level wastes are stored on-site until a disposal facility becomes available.

Interviewee Comments: Major environmental challenges are related to radioactive waste management. Decommissioning leads to a significant increase in waste production and disposal is not always available. Another environmental concern is related to decommissioning operations which still represent a risk for the environment. For example, they can trigger a fire leading to radioactive releases.

First generation power plants are sometimes difficult to decommission because of lack of information on the conception of the installation or of past events in the installation. As a result, the operators sometimes discover unexpected contaminations or asbestos in some part of the installation. Because of

these challenges decommissioning projects are often delayed. For all kinds of reactors, evacuating the fuel is an important milestone and faces sometimes difficulties because of fuel packages or waste storage facility availability. ASN asks the licensees to characterize the installation as soon as possible to have a better view of the initial state of the installation before starting to decommission.

The French National Plan for the Management of Radioactive Materials and Waste (so-called PNGMDR) is currently subject to a national debate. One of the topics is related to clearance levels for very low-level waste. Depending on the issue of the debate, the regulation related to waste management might change. One of the outcomes could be that licensees have the possibility in the future to release some of their very low-level waste.

Ten NPPs are undergoing decommissioning in France. Six graphite reactors (Saint-Laurent A1&A2, Chinon A1, A2 & A3, Bugey-1), one heavy water reactor (Brennilis), one pressurized water reactor (Chooz-A), and two fast reactors (Superphénix and Phénix). The six graphite reactors are particularly challenging for the licensee to decommission because there is poor learning from experience and the installations were not built to be easily decommissioned. Some common difficulties are linked with the knowledge of the installation. The licensee often doesn't know what is contaminated (soil and structure), for what reason, with what radionuclide. For the fast reactors, sodium management is a challenge for safety.

For getting the authorization to decommission its installation, the licensee has to submit a decommissioning file, which is subject to a public enquiry. During decommissioning, when ASN takes a resolution, the public is consulted. The licensee also has to report on its activity to the CLI, the local information commission, composed of elected representatives, associations, workers trade unions etc. Low-level short-lived waste are sent to the Centre de stockage de l'Aube (CSA) disposal. Low-level long-lived and high-level waste don't have a disposal yet, so they are packed and stored safely until disposals are available.

Interviewee 4: Official at the U.S. Nuclear Regulatory Commission

Interviewee Background: Official at the NRC responsible for decommissioning of nuclear power plants.

Key Highlights:

- Environmental risks from a plant undergoing decommissioning are significantly lower than operating plants, primarily because the risk of accidents is greatly diminished. The major risk of accidents at shutdown plants is associated with spent fuel storage in pools.
- The NRC has a rulemaking in progress that would make the transition from operations to decommissioning more efficient from a licensing standpoint.
- The NRC is currently evaluating applications for two consolidated interim storage facilities, and (as of June 2019) expects to complete its review by the end of calendar year 2021.
- While the NRC does not require the creation of citizen's advisory panels for decommissioning projects, this is a best practice that is encouraged and supported.

Interviewee Comments: [Note: The following is a summary; the NRC's full response is included in Appendix B.] Under the NRC's regulatory framework, decommissioning is the process by which the licensee reduces the site's residual radioactivity to the approved regulatory level by removing or otherwise mitigating on-site radiological contamination (see definition of the term "Decommission" in

the NRC regulation, 10 CFR 50.2, "Definitions"). Thus, the presence of non-radioactive contaminants on the site (e.g., PCBs, asbestos, lead-based paint), and the remediation or mitigation of such non-radiological hazards, are beyond the scope of the NRC's regulatory authority. Based upon the NRC's operational experience, all NRC power reactor licensees that have completed decommissioning have successfully demonstrated meeting the regulatory requirements.

Once the licensee has demonstrated that it has met all requirements, the NRC will terminate the operating license. Upon license termination, the NRC will no longer have regulatory authority over the former licensed site. The former NRC licensee or any new site owner, however, will remain subject to all other Federal (e.g., the Clean Water Act), state, and local laws and regulations, including any applicable environmental protection, human health and safety, and land use and zoning regulations.

The systems and processes required to safely maintain a decommissioning plant are much simpler than those required to run an operating plant. Therefore, when a nuclear power plant permanently ceases operations and the licensee permanently defuels the reactor, the risk to the public and the environment from an accident drops significantly because the accident sequences that dominated the operating plant risk are no longer applicable. The primary remaining source of risk to the public and the environment is associated with potential accidents that involve the spent fuel stored in the spent fuel pool. Moreover, the predominant design-basis accident for a defueled reactor is a fuel handling accident.

The NRC has a rulemaking in progress that would make the transition from operations to decommissioning more efficient from a licensing standpoint. In many cases, these new regulations would formalize steps to transition power reactors from operating status to decommissioning, without needing to use the current process of exemptions and license amendments. The NRC staff also recommended clarifying requirements regarding topics such as spent fuel management and environmental reporting requirements.

The NRC is currently evaluating two applications for consolidated interim storage facilities (CISFs). As of June 2019, the NRC expects to complete the CISF safety and environmental reviews by the end of calendar year 2021. The NRC also has a rulemaking in progress in the low-level waste area; however, any potential changes should have minimal impact on reactor decommissioning waste volumes.

The NRC is required to hold two public meetings in the vicinity of each decommissioning power reactor. The first meeting is held at the beginning of the decommissioning process to obtain comments on the licensee's PSDAR. The second meeting is held toward the end of the decommissioning process to obtain comments on the licensee's License Termination Plan, which is submitted at least two years before license termination. At some plants, the State or utility may sponsor a Community Advisory Board or Citizens Engagement Panel to provide a forum for local residents to provide input to the licensee and become familiar with the planned decommissioning activities. The NRC staff will also typically attend public forums during the decommissioning process.

4.2.3 Non-Governmental Organizations

The WQB provided contacts of NGOs involved in community engagement and activism around nuclear issues. Additional NGOs were identified based on online research and in consultation with the WQB. Individuals at four NGOs were contacted for interviews, and three agreed to be interviewed for this study.

Interviewee 1: Activist with a U.S. public-interest watchdog group involved in a range of nuclear issues

Interviewee Background: The interviewee has been active since 1991 in tracking the nuclear industry in the United States and has participated in NRC public meetings from the point of view of affected communities. The interviewee has been involved from the public's side in decommissioning projects including Yankee Rowe in Massachusetts and Big Rock Point in Michigan.

Key Highlights:

- Decommissioning is typically treated as a cleanup of one site, but not much attention is paid to the effects of transferring radioactive waste to other locations, including transport and disposal of wastes that were unknowingly radioactive.
- U.S. regulations do not allow sufficient opportunities for public involvement in decommissioning.
- Decommissioning by sale of sites to third-party contractors is a concern from the point of view of accountability and transparency.

Interviewee Comments: Long-term waste management needs to be a part of the overall conversation around decommissioning. There is no requirement to complete a National Environmental Policy Act (NEPA) analysis and often the utility companies are free to choose the extent to which the public is involved. State-sponsored citizen advisory panels are coming up at a few locations that may be one way around this issue. Another issue is the lack of funds to clean up sites and how cleanup standards are defined. Worker and public safety are also concerns – there have been cases where radioactive waste was transferred off-site into the community through contaminated equipment and clothing. The interviewee was also concerned about the safety of managing HLW in spent fuel pools. Decommissioning should be viewed as an opportunity to sample and analyze structures and equipment to understand aging, which could help to inform future licensing decisions. The interviewee believes that with very few new nuclear plants under construction, the future of the U.S. nuclear power industry is largely tied to license extensions for existing plants.

Interviewee 2: Activist with a Canadian NGO involved in a wide range of nuclear issues

Interviewee Background: The interviewee has been involved as an activist with nuclear issues for over 40 years.

Key Highlights:

- There are concerns with a broader range of radioactive contamination sites than power plants, including proposals for the waste repository near Lake Huron and use of small modular reactors.
- Regulators are not sufficiently independent from the industry to provide effective oversight.

Interviewee Comments: The interviewee noted that besides decommissioning of nuclear power plants, a major concern is the management of waste and siting of waste disposal facilities, including a proposal to develop an underground repository near Lake Huron for low- and intermediate-level wastes. The interviewee also noted that legacy sites in the Great Lakes region including West Valley are a significant concern. In addition, two Canadian reactors (Whiteshell and Rolphton) are being considered for decommissioning via entombment, which is a concern for long-term safety. Typically, all reactor components inside the containment become highly radioactive waste, including parts of the primary

cooling system. Fission products have relatively short half-lives, but activation products are much longer lasting.

The interviewee believes that Canadian regulators have created a policy vacuum and that clearer standards are needed, especially around decommissioning. The interviewee also believes regulators are not independent enough from the industry to provide effective oversight. Two key principles for long-term waste disposal are retrievability of waste in case of any problems, and ongoing monitoring. Decommissioning proposals should be put on hold until questions surrounding waste disposal are resolved through consultations with First Nations and the public.

The interviewee noted that reactors are typically sited near waterbodies and are not suitable for long-term waste storage. An emerging concern is related to small modular reactors and how they would be decommissioned. Refurbishment of nuclear reactors can also generate significant quantities of radioactive waste depending on the extent to which reactor components are removed and replaced. Lack of segregation of different types of waste can lead to much higher volumes of radioactive waste during decommissioning and refurbishment.

Interviewee 3: Activist with a U.S. public-interest watchdog group involved with nuclear issues

Interviewee Background: The interviewee has worked on nuclear issues since the 1970s. The focus of a lot of the interviewee's work has been on the West Valley Demonstration Project site in New York, where a spent fuel reprocessing facility operated in the late 1960s and early 1970s.

Key Highlights:

- The NRC's prescribed method for determining sufficiency of cleanup (modeled exposure risk versus residual radioactivity) is opaque and difficult to evaluate.
- There is a lack of meaningful public involvement in decommissioning and remediation decisions.
- The decommissioning process is not designed to asses and deal with off-site contamination caused during plant operations.

Interviewee Comments: The West Valley site remains a legacy site with significant contamination and wastes stored on-site to this day. One of the interviewee's concerns is that the NRC's site license termination rule requires contamination cleanup to be based on a modeled dose to the public, which does not have a direct relationship with the amount of radioactivity left on-site. Modeling methodology is based on the MARSSIM manual.

The public is often treated as a spectator with little input into key decisions that are made during discussions between industry and regulators, also more effort needs to be made to translate technical documents and issues into a layperson's terms. Waste management remains a concern, with no approved destinations for HLW. The interviewee would like the IJC to maintain a focus on legacy nuclear sites like West Valley, in addition to looking at future decommissioning. The waste at West Valley resulted from reprocessing of spent nuclear fuel from reactor sites including Big Rock Point.

Other concerns are related to management of low-level waste and ensuring that it does not result in contamination at eventual disposal sites. Radioactivity deposited off-site during operations is also not considered during decommissioning. The interviewee expressed concerns about the sufficiency of

decommissioning trust funds, and the implications of selling decommissioning sites to third-party firms and who would retain the liability in these cases.

4.2.4 Tribes/First Nations/Métis

For First Nation, Métis, and Tribal contacts, names were initially received from the IJC. Interviewees also provided names of additional contacts for potential interviews. Additional research was required to find some email addresses before requests could be sent. Interview request emails were sent to a total of 17 Tribal and First Nation contacts from late February through mid-March. Two interviews resulted from these communications.

Interviewee 1: Environmental transboundary Indigenous leader with the Shinnecock Indian Nation

Interviewee Background: The interviewee is a member of a Tribe located historically on Long Island, New York. The interviewee is now involved in transboundary issues of First Nations in the Great Lakes. The interviewee strives to be a strong advocate for the protection of Indigenous waters through enhanced interjurisdictional coordination and meaningful consultation on water issues. The interviewee has helped protect the interests of Tribes by promoting the value of traditional ecological knowledge.

Key Highlights:

- The interviewee stated that nuclear facilities [not just power plants] have resulted in systemic issues such as degraded health resulting from exposure in soil, water, and fish over decades.
- Not involving First Nations in the process of planning for nuclear power plant decommissioning allows for the same trauma to be perpetuated and repeated as during initial siting of facilities on native lands without consultation.
- Mental health considerations need to be brought into the conversation as well, given that contamination interferes with the connection of Indigenous people to their land and water, which causes long-lasting traumatic effects on people and communities.

Interviewee Comments: The interviewee emphasized the long-term systemic environmental injustices related to nuclear plants and supporting facilities that Indigenous people have faced, and how those issues continue to negatively affect the Tribal and First Nation populations in the Great Lakes. For example, the creation of nuclear plants was done without the consent of the Indigenous people, and many plants are disproportionately placed in close proximity to Indigenous populations (based on anecdotal evidence). The interviewee stated that although consent is now more often being sought regarding environmental decisions, including those related to nuclear power operations, the engagement is still often superficial. Because the Tribes and First Nations are not provided the support and resources to understand technical reports that they are given by agencies, an inappropriate burden is placed on them and they are not able to make informed decisions about various options.

Additionally, Indigenous people are often not brought into the conversation until after a decision has already been made by the NRC or CNSC. The interviewee believes that the entire process needs to be restructured so that all First Nations (given that each Indigenous nation has different priorities) are involved at the beginning of the process, or at least have the option to be involved. Instead of simply having an observer status, Indigenous groups need to feel like they can participate equally.

In terms of cost-benefit, it is often believed that Indigenous nations will not enter into discussions that require them to place values on rivers and lakes. First Nations, however, do perform their own cost-

benefit analyses, but their approaches and value structures do not necessarily align with other cost-benefit approaches. If there is no acknowledgement of First Nation cost-benefit approaches, then no common ground can be reached. The interviewee noted that clear statements in the final project report identifying data gaps are very important so that they can include that information and cite that source when writing proposals for related grants to fill data gaps.

Interviewee 2: Grass roots environmental organizer with the Sault St. Marie First Nation

Interviewee Background: The interviewee's background related to the decommissioning of nuclear power plants started about three years ago. The interviewee participated in the April 2018 joint Union of Ontario Indians (Anishinabek Nation, 40 First Nations) and Iroquois Caucus (12 Tribes and First Nations) nuclear presentations at the United Nations in New York.

Key Highlights:

- The interviewee emphasized the importance of listening to the Indigenous voice and understanding the natural law laid out by the Indigenous nations.
- The public needs to be better informed about the risks to their health.
- The public also needs to be given a say about the use of nuclear technology.
- The goal should not be just to protect human health, but the natural environment as well.
- One way to respect their cultural values would be to include women who are elders in public decision-making panels, since women have a cultural role as the primary caretakers of water.

Interviewee Comments: The interviewee has worked with many groups related to nuclear issues, including teaming with the Iroquois Caucus, a group that has unified to oppose to the transportation of highly radioactive liquid waste from Chalk River Laboratories in Ontario to South Carolina, and the abandonment of nuclear waste from Chalk River in a mound situated beside the Ottawa River. The interviewee expressed major concerns about the continued use of nuclear power in Canada and the United States, despite the rest of the world being more focused on decommissioning.

The interviewee noted that it is particularly sad that these plants are not even run by Canadian companies and feels that foreign groups are using Canadian and Indigenous land as testing grounds for their nuclear technology. The interviewee believes that instead of investing in new reactors, more funds and technology should be devoted to safely shutting down plants [note: proposals in 2006 for up to eight new reactors in Ontario have been withdrawn or tabled]. Companies should be held accountable to spend money on studies to learn how to safely transport wastes and for continuous monitoring of wastes and think about things from a long-term radioactive waste management standpoint instead of simply choosing the cheapest approach. In order to advance the understanding and management of nuclear decommissioning, the Indigenous worldview should be incorporated in all aspects of the discussion, such as research and proceedings.

4.2.5 Other Experts

Other potential experts were identified based on online resources such as reports, conference participant lists, presentation materials, and publications. The WQB also provided contact information for additional experts in the field. Seven individuals were contacted by email for interviews, and four agreed to participate in the study.

Interviewee 1: Academic researcher with extensive experience in nuclear waste management

Interviewee Background: The interviewee has a background in nuclear fuel and waste management, especially in the back end including disposal. No direct experience with on-site decommissioning activities, other than management of radioactive wastes. The interviewee has authored several publications on the effects of radiation, corrosion of spent fuel, geologic storage, and interim storage.

Key Highlights:

- A consensus-based approach to siting a spent-fuel repository is likely the best way forward.
- Fuel handling and storage at ISFSIs is currently a major source of risk.
- Additional scientific study is needed to better understand long-term risks associated with nuclear waste management.

Interviewee Comments: The major concern related to decommissioning is the safe management of radioactive waste, including spent fuel and other highly radioactive materials. Spent fuel is currently scattered across multiple sites in the United States There is not a good understanding of how the fuel and its containers change over time. There are proposals to bring consolidated interim storage facilities into operation in the United States There are examples internationally of geological repositories that had to be cleaned up after operational challenges, e.g., the Konrad mine in Germany. Finland is the only country that is close to licensing a deep geological repository for its spent nuclear fuel. Sweden may be less than one year away, and France is likely a few years away as well from licensing a repository. Canada is following a consensus-based process for siting a repository for HLW that is proceeding according to schedule, however efforts to site an intermediate/low level waste repository have run into roadblocks.

Fuel handling is a major risk during decommissioning including moving fuel from pools to dry storage, e.g., a recent near-miss incident at San Onofre Nuclear Generating Station (SONGS) in 2018, where a container of spent fuel was improperly placed in an underground vault and remained suspended approximately 18 feet (5.5 meters) above the floor for over an hour, until the error was discovered and the container was correctly placed. There needs to be a culture that values safety, and knowledgeable people who understand risks.

Yucca Mountain is not a good site for long-term waste storage from a geologic perspective, leaving aside the political questions surrounding site selection. The public and politicians need a better understanding of the risks associated with different options for managing nuclear waste. More scientific study is needed to understand risks not just in the short term but also hundreds of years into the future.

Interviewee 2: Former official at the U.S. Department of Energy involved with overseeing waste management

Interviewee Background: The interviewee was responsible for overseeing U.S. Department of Energy programs to manage nuclear waste from nuclear weapons development at sites including Hanford, WA and Savannah River, SC.

Key Highlights:

- There are no operating deep geological repositories for spent fuel worldwide.
- There are legal issues in opening a CISF, especially with regards to who will pay for fuel storage.

- Fuel at ISFSIs may need to be repackaged before it can be transported to CISFs.
- DOE transports nuclear fuel and waste on a regular basis and has extensively studied the risks involved.
- Transport-related risks are a key concern with respect to CISFs.

Interviewee Comments: Production plants aimed at producing plutonium for nuclear weapons are different from nuclear power plants in that they do not have all the ancillary systems (e.g., steam generators, turbines), but still need a cooling system and other maintenance facilities. The DOE has access to disposal facilities for low-level wastes at Barnwell in South Carolina, Nevada National Security Site in Nevada, and the Waste Isolation Pilot Plant site in New Mexico. Barnwell has an operating facility to vitrify liquid radioactive waste which is then stored in a concrete vault.

Internationally, 31 countries have spent fuel, but no country has found an effective way to deal with large amounts of spent fuel. Finland is the closest to having an operating repository, but they have waste from a single nuclear power plant and the repository has been sited at the former nuclear plant facility. The United States has over 40 percent of spent fuel globally, from more than 100 reactors and needs to find a way forward to approve a geological repository. However, spent fuel will likely be stored at surface facilities for 40+ years.

CISF is a more viable option in the near term but some legal questions remain related to funding – per the NWPA, DOE cannot fund a CISF from the judgement fund until Yucca Mountain is also approved and funded. There also may be a need for spent fuel pools at ISFSIs to transfer fuel from storage to transport casks. Opposition to CISFs is focused on the risks of transporting nuclear fuel which will have to be transported twice – initially from the ISFSI to CISF, then from the CISF to the repository. DOE transports nuclear fuel and has done extensive work on transport casks and risks associated with transportation.

Interviewee 3: Former employee and Commissioner at a U.S. state public utility commission

Interviewee Background: The interviewee worked for over 20 years at a state public utility commission. The interviewee was also involved in the commission's subcommittee on nuclear waste disposal and spent 5 years as a Commissioner.

Key Highlights:

- Decommissioning and nuclear waste funds should not be used for purposes other than those for which they were originally intended.
- Decommissioning efforts appear to be sufficiently funded at least in the United States
- Finding a skilled workforce for nuclear power plants will be a challenge in the future.

Interviewee Comments: Utility ratepayers have been paying 0.1¢/kilowatt hour into a fund that is meant to pay for the development of a deep geological repository. The interviewee believes the fund should have as much as 50 billion dollars. In addition, state public utility commissions have a fiduciary responsibility to ensure that ratepayer money is used only for the purposes for which it was originally earmarked. State commissions were initially concerned that decommissioning funds would be insufficient but after gaining experience at some sites, have concluded that most decommissioning funds were over-funded. The availability of waste disposal sites is a significant issue. The interviewee believes that waste management is the most significant issue related to decommissioning. Also, a

strong safety culture is necessary at the decommissioning firm. Lastly, the interviewee stated that workforce availability is likely to be a challenge for the nuclear industry moving forward.

Interviewee 4: Academic, former Chair of the U.S. Nuclear Regulatory Commission

Interviewee Background: The interviewee is a former Chair of the NRC and has extensive academic research experience focused on environmental policy and international security issues associated with nuclear energy including nuclear waste disposal.

Key Highlights:

- Decommissioning involves operational risks (e.g., fuel handling, storage, cask aging) and institutional risks (e.g., bankruptcy, lack of oversight).
- CISFs may lower overall risk especially if they are located regionally but the question of title to the spent fuel still needs to be resolved.
- Public engagement is a challenge but decommissioning advisory panels have shown that they can improve interactions with stakeholders.

Interviewee Comments: The United States has limited experience with decommissioning to date. However, decommissioning is one area where the nuclear industry is likely to see significant growth over the coming years and decades. There are three major firms involved in decommissioning in the United States The first company designed the casks for SONGs and was cited by the NRC for changing cask design without prior approval. This firm, under a joint venture with a Canadian engineering firm, wants to take over decommissioning for several nuclear power plants including Palisades, Pilgrim, Oyster Creek, and Nine Mile Point. The firm is also proposing to build a CISF near the Waste Isolation Pilot Plant facility in New Mexico. A second firm owns and operates an LLW site in Andrews, TX and hopes to build a CISF there; an affiliated firm has taken over decommissioning of the VT Yankee plant. The third company is decommissioning Zion, Lacrosse, and SONGS.

NRC regulations rely on industry and may not sufficiently account for risks of decommissioning, especially long term HLW storage. A draft revised decommissioning rule is expected to be issued shortly. Long term on-site storage involves institutional risks, e.g., bankruptcy, lack of oversight. Operational risk includes fuel handling and storage capability. Aging management of casks is important. Casks used for dry spent fuel storage have different thermal ratings, and the casks used at some sites are not appropriate for transport. Fuel will likely have to be repackaged, which creates additional risk from handling. If spent fuel pools are no longer available, may need to use a hot cell i.e., an enclosed chamber that provides protection from radiation.

Risks and benefits of CISF are not clear, but it makes sense to consolidate fuel instead of having it scattered all over the country. May need regional CSF locations. Another question to be resolved is ownership/title to the waste once it is at a CISF. Will the nuclear company retain title? If so, there may not be an incentive to move fuel to the CISF. This is one reason why CISF operators are trying to buy up decommissioning sites. For example, the Yankee company retains title to the Maine, Vermont, and Rowe spent fuel and cannot legally dissolve, even though it has no business reason to exist since the generating stations have all been shut down. Who is liable if the company files for bankruptcy? Public outreach and involvement are a challenge, however decommissioning advisory panels have worked well in some cases. Final cleanup is typically done to USEPA and state standards.

5. Decommissioning Case Studies

Seven case studies were developed to identify potential environmental challenges, best practices, and lessons learned from the decommissioning of nuclear power plants in North America and Europe. The scope of this report was to examine decommissioning practices and experience at nuclear power plants outside the Great Lakes Basin; therefore, the case studies did not include sites within the Great Lakes Basin that have either been decommissioned (e.g., Big Rock Point) or are currently undergoing decommissioning (e.g., Zion). The case studies are described in the following sections.

5.1 Case Study Lessons learned

Significant decommissioning environmental problems and solutions from non-Great Lakes facilities can be informative for Great Lakes planning. Common reasons for plant closure include accidents, economics, aging components, and public opposition. High-profile accidents at operating plants in other locations also tend to increase pressure to close plants, as has been seen in France and Germany following the 2011 Fukushima Daiichi incident in Japan. A common economic driver is decreasing costs of other forms of energy, such as natural gas and renewal energy technologies, which has made nuclear energy noncompetitive in some locations. In most cases, the primary environmental problems that impact decommissioning are related to legacy issues generated while plants were operating such as undetected leakage and releases on the site or off, improper handling of radioactive waste at plants or disposal sites, or chemical contamination. These types of issues can all be dealt with during decommissioning, but they tend to raise costs and increase the time needed to complete decommissioning. Some issues persist after reactor components and support facilities have been demolished and removed, and require monitoring for years to decades.

Some of the major issues related to decommissioning include the following:

- The primary risk is related to spent fuel handling, transport, and disposal. Dealing with permanent waste disposal remains a critical issue for decommissioning in all countries, although Finland is closest to opening a deep geological repository.
- Given the absence of disposal facilities, interim practices such as creation of dry storage facilities at plants prior to shutdown accelerates the shutdown timeline.
- Once spent fuel is out of wet storage, it is usually possible to decontaminate, dismantle, and demolish existing plant components within 5 to 10 years.
- Using experienced decommissioning contractors rather than retraining existing plant employees seems to be the most effective way to move decommissioning forward effectively.
- Building strong community ties and open communication during plant operation fosters trust that becomes critical after shutdown, where public approval of decisions is often required.

5.2 North American Case Studies

5.2.1 Canada

As of 2015, Canada was operating 19 government-owned commercial nuclear power reactors with a total capacity of 13.5 GW, constituting 17 percent of the country's total electric power generation. One of the operating reactors is located in New Brunswick; the rest are all located in Ontario on the shores of Lake Huron or Lake Ontario. Nuclear power accounts for 61 percent of Ontario’s electricity. All Canadian reactors are of a similar Canadian design known as CANDU. Canada has no permanent HLW repository, although five Ontario sites are currently being considered, with three in the Great Lakes Basin--South

Bruce and Huron-Kinloss near Lake Huron, and Manitouwadge north of Lake Superior—and two to the north or west of the Basin. Ontario Power Generation has submitted an application to CNSC for site preparation and licensing of a Deep Geologic Repository for low-level and intermediate-level waste at the Bruce site on Lake Huron, which is pending approval. For more information, refer to Graydon et al. (2019).

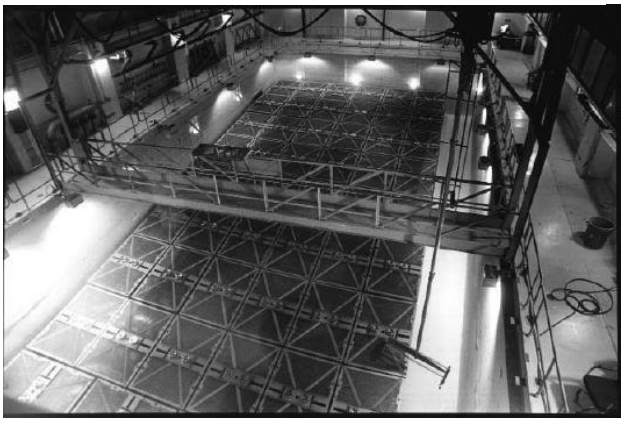
Gentilly-1 and -2 Reactors, Bécancour, Quebec

Gentilly-2 is a 635-MW pressurized heavy-water reactor located on the lower St. Lawrence River in Quebec that began operation in 1982 and was shut down in 2012 at the end of its operational life.[21,22] The Gentilly-1 CANDU reactor was a prototype precursor to Gentilly-2 at the same site, with a design capacity of 250 MW, which only operated for 180 days between 1972 and 1978 and never produced commercial power. Gentilly-1 decommissioning began in 1984; it is now considered a Waste Management Facility (see Figure 5-1). No major accidents or releases of radioactive materials were reported during operation of either reactor or after shutdown, although low levels of tritium were released under permit during operation. This type of reactor uses natural uranium fuel, and heavy water (deuterium oxide, D_2O) to cool the fuel and moderate neutron fluxes.

Source: Canadian Coalition for Nuclear Responsibility

Figure 5-1 Spent Fuel Casks at Gentilly-1

Gentilly-2 was issued a decommissioning permit by CNSC in 2016 and was expected to achieve final site restoration 50 years later, after 40 years of dormancy with pool storage and then dry cask storage of spent fuel, spent fuel transfer, and 5 years of dismantling (see Figures 5-2, 5-3 and 5-4). Some groups have expressed the desire for more accelerated dismantling of both reactors rather than the ongoing dormancy. Prior to shutdown, Gentilly-2 was Quebec's only operating nuclear power plant. The estimated closure and decommissioning cost is approximately $1.8 billion CAN, without including eventual HLW disposal costs. The closure of the plant resulted in the loss of about 800 jobs and resulted in strong opposition from the local business community and labor unions, but environmental groups and the majority of the general public in the region supported

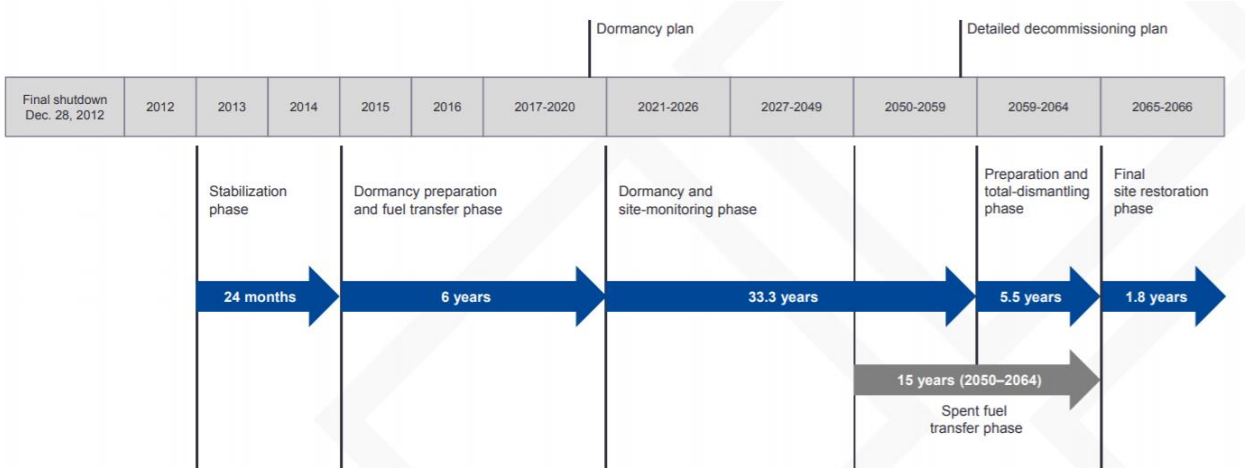


Source: Canadian Coalition for Nuclear Responsibility

Figure 5-2. Spent Fuel Pool at Gentilly-2

[21] http://www.hydroquebec.com/decommissioning-gentilly-2/
[22] https://nuclearsafety.gc.ca/eng/reactors/power-plants/nuclear-facilities/gentilly-2-nuclear-generating-station/index.cfm

closure. The plant never operated at a profit, and the nearby heavy water generation facility (LaPrade) was never used, although it cost $400 million CAN to build.



Source: http://www.hydroquebec.com/data/production/pdf/schedule-decommissioning-plan.pdf

Figure 5-3. Gentilly-2 Decommissioning Schedule, including Dormancy and Dismantling

Source: www-ns.iaea.org/downloads/rw/conferences/spentfuel2010/sessions/session-eight-a/session-8a-canada.pdf

Figure 5-4. Large Modular Air-Cooled Storage (MACSTOR) units for spent fuel at Gentilly-2

5.2.2 United States

The United States currently generates the most nuclear power of any country in the world. Nuclear power plants in the United States generate approximately 20 percent of the country's electricity, with nuclear power production approximately steady since 1990. Production is expected to decline sharply over the next few decades as existing reactors reach the ends of their operational lifetimes; only two reactors are currently under construction at a single plant in Georgia. There are currently 98 reactors operating in 30 states in the United States, with 12 of these reactors in the Great Lakes Basin. There is

currently no approved HLW disposal site in the United States, although the proposed site at Yucca Mountain in Nevada is being revisited as an option (see Graydon et al. 2019 for more details); interim storage sites in Texas and New Mexico are also being considered. The only fully decommissioned nuclear plant in the Great Lakes Basin is the 72-MW Big Rock Point plant in Michigan on Lake Michigan, which operated from 1962 to 1997. This site was released for unrestricted use in 2007 ("restricted use" release would include certain post-release conditions), after being returned to greenfield status, except for a dry cask storage area for spent fuel that is set back from the lakeshore in the woods.[23] Access is still controlled by the site owner. A sale of the site to Holtec International was announced in 2018.[24] The total cost of decommissioning was $473 million USD. The following summaries are adapted from material obtained from interviews and sources including the World Nuclear Association.[25]

San Onofre Nuclear Generating Station (SONGS), near San Clemente, California

The SONGS plant, located on the Pacific coast in Southern California, operated three reactors: Unit 1 (436-MW pressurized water reactor) from 1968 to 1992, Unit 2 (1070-MW pressurized water reactor) from 1983 to 2012, and Unit 3 (also 1070-MW pressurized water reactor) from 1984 to 2012. During operation, the plant generated approximately 20 percent of Southern California's electrical power. Decade-long steam generator upgrades costing $671 million USD were completed in 2011 to Unit 2 and Unit 3. However, it was reported that design flaws in these upgrades led to ongoing risks of radiation releases to the atmosphere, which led to reactor shutdown in 2012 and premature closure in 2013[26]. The smaller Unit 1 was put into a dormant SAFSTOR state in 1992, but regulatory changes resulted in accelerated decontamination and dismantling activities from 2000 through approximately 2008. The offshore cooling water intake and discharge pipes were abandoned in place and released for general use in 2010, and final closure of the Unit 1 site is anticipated for 2030.[27]

Source: https://danapointer.com/san-onofre-nuclear-plant-cannot-fix-damaged-canisters-of-toxic-waste/

Figure 5-5. Square Tops of Spent Fuel Storage Silos at SONGS Visible in the Foreground

In 2014, decommissioning of Unit 2 and Unit 3 was estimated to take 20 years and to cost $4.4 billion USD. Low-level waste would be disposed in Texas and Utah, and HLW would be stored on the site,

[23] Graydon et al, 2019; Tompkins, B., 2006. Big Rock Point: from Groundbreaking to Greenfield. Nuclear News, 49(12), pp.36-43.

[24] https://www.petoskeynews.com/featured-pnr/big-deal-at-big-rock/article_e17a18af-67da-528e-8746-7a716ffdd2bc.html

[25] http://www.world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-wastes/decommissioning-nuclear-facilities.aspx

[26] https://www.ocregister.com/2013/06/08/san-onofre-nuclear-plant-to-shut-permanently-edison-says/

[27] https://www.nrc.gov/info-finder/decommissioning/power-reactor/san-onofre-unit-1.html

including in part of the area formerly occupied by Unit 1. In 2016, the California Public Utilities Commission approved establishment of a $4.41 billion USD trust fund for decommissioning costs. A joint venture of AECOM and EnergySolutions was selected as the decommissioning general contractor by the plant owner. In 2017, plans for movement of HLW casks to another undetermined inland site was announced instead of long-term on-site storage. This change was in response to a lawsuit by environmental groups. Transfer of spent fuel from wet storage to on-site dry cask storage (see Figure 5-5) is ongoing. Complete decommissioning and site release are expected to be complete by 2050.

Connecticut Yankee, Haddam Neck, Connecticut

This 619-MW pressurized water reactor shut down in 1996 for economic reasons after operating for 29 years. Decommissioning using the decontamination and dismantlement approach took place from 1998 through 2006 [28], generating approximately 350 million pounds (158,757 metric tons) of waste including over 30,000 cubic yards (22,937 m^3) of soil and rock contaminated with PCBs and other chemicals, and/or radionuclides. In 2007, the NRC approved Connecticut Yankee Atomic Power Company's request to release the majority of the site for unrestricted use, except for the small ISFSI[29] (see Figure 5-6), which remains under NRC licensing. The 544-acre (220-hectare) Connecticut Yankee greenfield site continues to be owned by a consortium of electric utilities who maintain its ISFSI and associated site security. The site is surrounded by conservation land and there is an active association seeking to transition ownership of the non-ISFSI portion of the site to a conservation entity as well. The group is known as the Connecticut Yankee Conservation Project[30].

Source: http://www.connyankee.com/html/about_cy.html

Figure 5-6. Connecticut Yankee Spent Fuel Storage Area

Radioactive strontium-90, cesium-137, and tritium were detected in site groundwater in 2001, and monitoring continued until 2015, when termination of the groundwater monitoring program was finalized by the Connecticut Department of Energy and Environmental Protection after potential exposure risk from groundwater was determined to be below safety thresholds[31]. While a $400 million USD decommissioning fund had been established for Connecticut Yankee, this did not cover the

[28] https://manafort.com/wp-content/uploads/2018/01/MBI-Marketing-Sheet-2017_CT-Yankee.pdf
[29] http://www.meredithangwin.com/yankee_decommissioning.pdf
[30] http://cycp-hn.org/current-ownership/
[31] AMEC, 2014. "Groundwater Monitoring Plan for Compliance with CTDEEP RSRs", RCRA Corrective Action Program; Connecticut Yankee Atomic Power Company; Haddam Neck Plant; Haddam, Connecticut; January 2014; http://connyankee.com/_pdf/DEP_CY_Corrective_Action_Completion_Fact%20Sheet.docx

eventual total cleanup cost of $1.2 billion. Radioactive strontium contamination in both the soil and groundwater caused the higher costs, which were ultimately covered by ratepayers. A detailed report on the decommissioning is available from the Electric Power Research Institute (EPRI).[32]

Maine Yankee, Wiscasset, Maine

Maine Yankee was a 860-MW pressurized water reactor plant located on a rocky estuary on the coast of Maine, which came online in 1972 and shut down in 1996, partially due to opposition stemming from safety and environmental concerns.[33] It was decommissioned over the ensuing years at a cost of approximately $500 million USD, with the reactor pressure vessel shipped by barge to Barnwell, South Carolina for disposal in 2003, and the containment structure demolished in 2004. Total wastes removed were approximately 460 million pounds (208,652 metric tons), with most transportation by rail. The site was released for public use in 2005, except for the dry cask storage area for spent fuel. Conservation and educational activities are planned for 200 donated acres (81 hectares), and 400 additional acres (162 hectares) are slated for commercial redevelopment.

The decommissioning Community Advisory Panel report contains informative details on the community input approach and that was implemented over 50 public meetings and other activities.[34] The report includes individual reflections by each member that express mixed perspectives on the process and the outcome. During decommissioning, one unexpected issue that was encountered was radioactive contamination of shallow sediment in the plant's forebay, where once-through cooling water was

Source: http://www.maineyankee.com/public/cap%20final.pdf

Figure 5-7. Maine Yankee Forebay Prior to Remediation

[32] https://www.epri.com/#/pages/product/1013511/?lang=en-US
[33] http://www.maineyankee.com/overview/default.htm
[34] http://www.maineyankee.com/public/cap%20final.pdf

Source: http://www.maineyankee.com/public/pdfs/epri/my%20epri%20report-2005.pdfl

Figure 5-8. Maine Yankee Forebay and Reactor Containment Prior to Demolition

discharged (see Figures 5-7 and 5-8). This area was mitigated and restored to a marsh habitat. Determination of appropriate site background radioactivity, required to assess adequacy of cleanup, was complicated by variable natural radioactivity of bedrock in the area. A detailed decommissioning report is available from EPRI.[35]

5.3 European Case Studies

5.3.1 Germany

Germany began generating nuclear power commercially in 1969, with a peak of generation in the early 2000s at around 25 percent of total energy generation. Following the Fukushima Daiichi nuclear accident in Japan in 2011, the government of Germany committed to closing all 17 reactors at its nuclear power plants by 2022 and shifting to renewable energy sources. Nuclear power production has now fallen to about 12 percent of total energy generation in Germany. Siemens withdrew from nuclear energy generation in 2011; four companies remain in Germany: E.ON,

Source: View gallery, German Federal Office for Radiation Protection. https://e360.yale.edu/features/soaring_cost_german_nuclear_shutdown

Figure 5-9. Barrels of radioactive waste in the Asse II storage cavern in 1975.

[35] http://www.maineyankee.com/public/pdfs/epri/my%20epri%20report-2005.pdf

Vattenfall, RWE, and EnBW. They have collectively set aside $45 billion USD for decommissioning Germany's nuclear plants, but at least $26.4 billion USD more is expected to be needed to cover waste storage costs.[36]

One problem remaining for Germany, as with the United States and Canada, is the issue of nuclear waste disposal, especially for HLW. Spent fuel was reprocessed in France and the U.K. until 2005, but it is now consolidated at interim storage facilities, primarily at Gorleben, in anticipation of eventual final disposal at a nearby deep repository in a salt dome formation. Problems with the 125,000 barrels of low-level and medium-level radioactive waste disposed in 13 chambers at the Asse II salt mine in Germany, including potential for radioactive contamination of unexpected brine seepage and structural failure of some mine passages, have heightened public concern about the planned Gorleben disposal site. Plans for removing and relocating the Asse mine wastes are in development, but no relocation is expected to begin until at least 2033.[37]

Stade Nuclear Power Plant (also known as Kernkraftwerk Stade or KKS), Germany

The 672-MW Stade pressurized water reactor operated from 1972 to 2003 in northern Germany and is currently undergoing decommissioning after shutting down for economic reasons, with fuel cells removed in 2005. The decontamination approach used was Chemical Oxidation Reduction Decontamination (CORD) applied by Automated Mobile Decontamination Appliance (AMDA) to minimize decontamination wastes generated and to minimize exposure of workers to radioactivity. Corrosion products were captured on ion exchange resin. The decommissioning process shifted to Phase 2 (dismantling) in 2006. Four radioactive steam generators (165 metric tons; 182 U.S. tons) were shipped to Sweden and melted down, allowing much of the steel to be recycled, with radioactive slag and casting wastes returned to Germany for storage and disposal. In 2010, the highly radioactive reactor pressure vessel and its attachments were segmented (Phase 3) using remote controlled cutting equipment such that the resulting pieces would fit into shielded waste containers of approximately one m^3 (1.3 cubic yards) in volume[38]. The decommissioning process is still underway, with completion expected in 2022. No environmental issues that could persist after completion of decommissioning have been identified at the site.

Source: Loeb et al., 2011, Figure 4, http://archive.wmsym.org/2011/papers/11100.pdf

Figure 5-10. Remotely controlled equipment cutting the Stade reactor pressure vessel in situ

[36] https://e360.yale.edu/features/soaring_cost_german_nuclear_shutdown
[37] https://e360.yale.edu/features/soaring_cost_german_nuclear_shutdown
[38] http://archive.wmsym.org/2011/papers/11100.pdf

Gundremmingen-A Nuclear Power Plant Reactor (also known as KRB A), Germany

This boiling water reactor located between Munich and Stuttgart began operation in 1966 as Germany's first commercial reactor and had an output of 237 MW. The first fatal accident at a German nuclear power plant occurred at Gundremmingen-A in 1975 due to a steam release that killed two workers. A subsequent major accident resulted in a complete loss of the reactor in 1977. Two other units (B and C) were under construction at the time and came online at the site in 1984; Unit B shut down in 2017, and Unit C is scheduled for shutdown by 2021. The accident at Unit A was triggered by an electrical short in high voltage transmission lines followed by an emergency shutdown, flooding of the reactor building due to errors, and release of radioactive water and gases to the environment.

Decommissioning of the Unit A reactor's turbine house began in 1983 (4,500 metric tons [4,950 U.S. tons] of radioactive waste) and expanded to primary water systems in 1990 (700 metric tons [770 U.S. tons] of waste). Dismantling of the reactor pressure vessel, its internal components, and the biological shield began in 1992, generating 1,300 metric tons (1,430 U.S. tons) of waste. Over 90 percent of the waste from the reactor has been recycled. Dismantling operations at this plant pioneered several innovative techniques including ice sawing and plasma arc cutting, as well as development and testing of cutting methods and equipment on reactor mockups prior to deployment at the actual reactor facilities. The Gundremmingen plant includes an on-site interim storage facility for spent fuel that can house up to 192 dry CASTOR casks. The site remains in operation at present. No information on any ongoing environmental issues related to Unit A decommissioning were identified.

The KRB-A reactor was decommissioned over a period of about 40 years, and the reactor powerhouse was converted into a technology center. The remaining units at the site are undergoing decommissioning (Unit B, shut down at the end of 2017), or preparing for shutdown (Unit C, 2021). As of mid-2018, only 10 nuclear reactors globally had been decommissioned to greenfield status, including 6 in the United States, 3 in Germany, and 1 in Japan (note that not all were commercial power reactors).[39]

5.3.2 France

The French nuclear plant operator, EDF, is controlled by the French state and operates almost 60 reactors at 19 sites. In 2018, France produced over 70 percent of its total electricity from nuclear sources. A 2015 law requires EDF to reduce nuclear power capacity from 75 percent to 50 percent of the country's power generation by 2025. This is resulting in a substantial increase in the rate of nuclear power plant decommissioning in the country, particularly given an earlier policy shift in favor of aggressive dismantling rather than extended enclosure of closed reactors in place. France has historically managed spent nuclear fuel by reprocessing at La Hague facility, including handling of such waste from other countries, and vitrifying remaining waste. Eventual disposal of vitrified HLW is currently planned at a facility known as the Industrial Centre for Geological Storage (Cigéo), which is currently only an experimental laboratory.[40] Construction is scheduled to begin in 2022, with pilot phase operation beginning in 2025.

[39] https://www.worldnuclearreport.org/IMG/pdf/20180902wnisr2018-hr.pdf
[40] https://www.andra.fr/download/andra-international-en/document/editions/504va.pdf

Chooz-A Nuclear Reactor, France

The Chooz-A pressurized water reactor, which is located in underground chambers on a "panhandle" of France that extends into Belgium, had a net power output of 300 MW while it operated from 1967 to 1991. The reactor and support facilities were located in two adjacent underground caverns to provide natural shielding. A decommissioning permit was obtained in 2007, with completion expected by 2022.[41] A policy change in 2011 from long-term enclosure (LTE) to immediate dismantling accelerated the decommissioning plans and reduced the enclosure period from 50 years to only a few years. The Chooz-A decommissioning experience is precedent setting for France, as it represents the first full dismantling of a pressurized water reactor in the country. The four Chooz-A steam generators, primary loops, and pressurizer were removed intact and disposed of at the very low-level radioactive waste site, CIRES (Centre Industriel de Regroupement, d'Entreposage et de Stockage), near the low-level and intermediate-level Aube waste repository in France. Underwater segmentation of reactor vessel internal components began in 2017, with reactor vessel segmentation, containerization, and removal to follow. Dismantling is still underway, but no long-term environmental impacts at the site from the reactor decommissioning are anticipated.

Source: https://www.mammoet.com/cases/Chooz-A/

Figure 5-11. Removing the steam generator from the Chooz-A nuclear power plant.

[41] https://www.neimagazine.com/features/featureexcavating-chooz-a

6. Findings

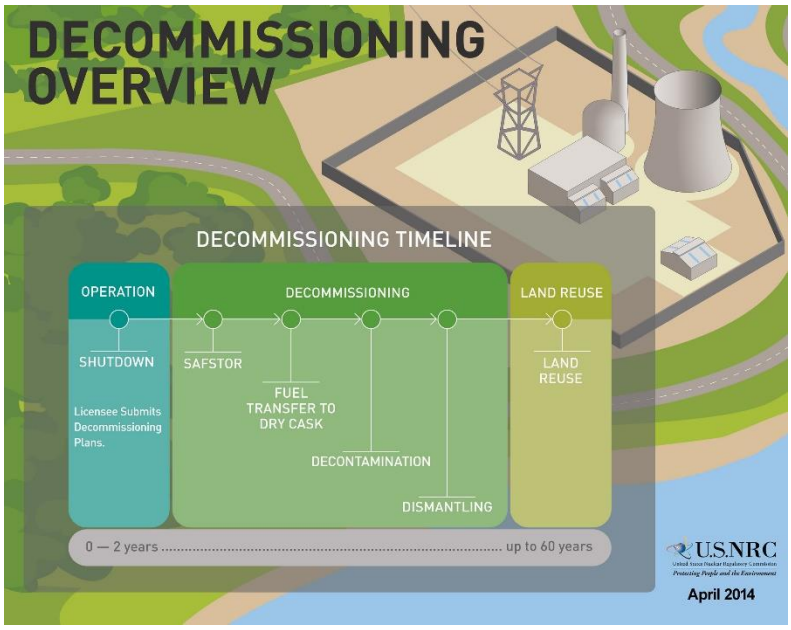
This study compiled information on the various methods and regulatory regimes that are employed for the United States, Canada, and two European countries. Information and perspectives were also collected from a variety of stakeholder including individuals from industry, regulators, NGOs, Tribes/First Nations/Métis, and other experts including academics, journalists, and authors. Additionally, seven case studies were prepared on nuclear plants in the United States, Canada, France, and Germany. Key findings related to this research are addressed below.

6.1 Regulatory Frameworks for Decommissioning

The following sections describe the regulatory requirements for the decommissioning of nuclear power plants in the United States, Canada, Germany, and France. In general, requirements are very similar across countries and requiring the submission of a detailed plan to regulatory authority before decommissioning activities can begin. Plant operators are required to engage with the public before and during the process, and the site must meet radiological release criteria before the license can be terminated. Plant operators are also required to provide financial assurance of funds available to complete decommissioning; however, the specific amounts may vary across countries. Additionally, some countries such as Germany have planned to set aside public funds to support decommissioning-related activities.

6.1.1 North America

Regulation of nuclear power plants in the United States and Canada, including decommissioning and radioactive waste management, is discussed in detail in the background report (Graydon et al. 2019). Some key aspects of the two countries' regulatory regimes are presented below.



Source: U.S. Nuclear Regulatory Commission

Figure 6-1. Example timeline for decommissioning

In the United States, the NRC is responsible for licensing and monitoring operations of nuclear power plants, decommissioning activities, and radioactive waste disposal. The NRC typically grants operating licenses to nuclear power plants for an initial period of 40 years, with license extensions possible in 20-year increments. The NRC requires licensees to submit a Post-Shutdown Decommissioning Activities Report (PSDAR) within two years of plant shutdown, followed by a License Termination Plan (LTP). The PSDAR and LTP are both made available for public review and comment by the NRC.[42] The NRC monitors decommissioning

[42] https://www.nrc.gov/waste/decommissioning/process.html

activities and requires licensees to submit radiological monitoring reports as required by the terms of their license, typically on an annual basis. Final license termination is contingent upon the site meeting the terms of the LTP. Typically, unrestricted release of the site requires that radiation exposure to a member of the public be no greater than 0.25 milli-Sieverts (mSv) per year. Power plant operators are required to establish a decommissioning fund, to guarantee that sufficient funds will be available at the time of decommissioning. Required funds are estimated according to a formula developed by the NRC. The NRC plans to publish a proposed rule later in 2019, on requirements for nuclear power plants transitioning to shutdown and decommissioning.

In Canada, the Canadian Nuclear Safety Commission (CNSC), grants operating licenses and license extensions typically in 10-year increments. The CNSC also requires licensees to submit a decommissioning plan as part of the initial license application. Power plant operators can place nuclear reactors into a state of SAFSTOR without submitting a decommissioning license application. However, a decommissioning license application is required prior to beginning any decommissioning activities. Depending on the nature of decommissioning activities, an environmental assessment (EA) may be required; additionally, public hearings are held as part of the application process. Annual radiological monitoring reports are required to be submitted by licensees as part of the decommissioning license conditions. The decommissioning plan and license specify final cleanup standards for the site; in general, however, unrestricted release requires that radiation exposure to the public be no greater than 1 mSv per year. As of July 2019, the CNSC is in the process of updating its decommissioning and waste management regulatory framework.

6.1.2 Europe

The study looked at the regulatory framework governing decommissioning activities in Germany and France. These two countries historically had among the highest percentages of total electricity generation from nuclear power. Additionally, both countries have significant experience in decommissioning reactors that are similar to those in the Great Lakes Basin.

In Germany, the oversight of decommissioning activities rests primarily with provincial authorities, which are responsible for licensing nuclear power plants and supervision of decommissioning activities. A decommissioning application is required to be submitted before any decommissioning-related activities can begin.[43] The application must include a description of the facility and the proposed decommissioning procedures, and information on monitoring, safety, and potential environmental impacts. In addition, an environmental impact assessment is required for decommissioning of any "stational nuclear fission facility" that exceeds 1kW continuous thermal load. Licensees are required to provide financial assurance for legally specified amounts, depending on the quantity of spent fuel present on-site and other factors. In addition, the German government has set aside $1.17 billion (U.S.) (1.6 billion CAD) to help cover the costs of decommissioning since current policy is to shut down all of the country's nuclear power plants by 2022.[44]

Public involvement is a key element of the licensing procedure for decommissioning, and provincial authorities are responsible for ensuring that public involvement takes place as part of the licensing process. The Radiation Protection Act limits public exposure to radiation from nuclear facilities and

[43] https://www.bfe.bund.de/EN/ns/decommissioning/decommissioning/decommissioning_node.html
[44] https://www.neimagazine.com/features/featuredecommissioning-in-europe-7217338/

other industrial sources to 1 mSv per year. Specific release criteria would depend on the intended future uses of the site (i.e., unrestricted or restricted release) and are specified in the facility license.

In France, nuclear power plant operations and decommissioning are regulated primarily at the federal level by the Agency for Nuclear Security (ASN). To get authorization to begin decommissioning, licensees must submit a decommissioning plan at least three years prior to the planned shutdown date, which is subject to a public hearing process.[45] In addition, licensees must submit a decommissioning application at least one year prior to the shutdown date. During decommissioning, when ASN makes a decision, the public is consulted. Licensees also must report their decommissioning activity to the CLI, the local information commission, composed of elected representatives, associations, workers trade unions, and other stakeholders.

In France, the costs of nuclear decommissioning are planned to be met through a fund established by the country's nuclear power plant operator, EDF, which has proposed to set aside €23 billion (approximately 25 billion USD/33 billion CAD) for this purpose. However, there are concerns that this will not be sufficient to cover decommissioning costs, based on past experience and estimates developed by other countries such as Germany and the U.K.[46] For example, Germany estimates that decommissioning will cost approximately €1.4 billion (approximately 1.5 billion USD/2 billion CAD) per gigawatt, while the U.K. estimates the cost will be €2.7 billion (approximately 3 billion USD/4 billion CAD) per gigawatt. In comparison, EDF estimates that decommissioning French nuclear power plants will cost €300 million (approximately 330 million USD/440 million CAD) per gigawatt.

6.2 Decommissioning Practice

The first step towards decommissioning, once the reactor has been shut down, is to transfer all nuclear fuel into the spent fuel pool. After the spent fuel has been cooled over a period of several years, it can then be transferred to dry cask storage (see Section 3.2.4). Once spent fuel has been removed from reactors and put in dry storage, radiation-related risks from decommissioning activities are substantially reduced. The primary sequence of reactor decommissioning is normally decontamination and removal of steam generators, followed by reactor internal components, then reactor vessels, and finally containment structures. Whether large components can be removed intact or require segmentation prior to removal is determined by the regulations of the jurisdiction, the requirements of the decommissioning permit, and available waste transportation and disposal options. While radioactive risks are a major concern with nuclear plant decommissioning, non-

Source: Zion Solutions

Figure 6-2. Large reactor components being removed during decommissioning of the Zion site

[45] http://www.oecd-nea.org/law/legislation/france.html
[46] https://energypost.eu/how-much-will-it-really-cost-to-decommission-the-aging-french-nuclear-fleet/

radioactive issues including environmental contamination from compounds such as PCBs, hydrocarbons, and metals are also present.

While some general demolition-related risks (e.g., working with heavy equipment, explosives, and falling debris) are common to all sites, the approach to reactor disassembly ultimately determines the level of risk to workers at each site. Much of the work in the areas of highest residual radiation can be done with remote-controlled cutting devices, sometimes operating underwater or in inert atmospheres. Environmental releases, while extremely unlikely, could occur from radioactive gas, fugitive dust, or contact cooling water pathways. Therefore, it is important that special care be taken to contain these components in vessels, pools, and pipes prior to removal. On-site decontamination can be carried out using chemical etching, sand blasting, or other means, which reduces the volume of radioactive waste ultimately needing to be disposed. However, these activities may also increase the risk of potential of releases in the short-term.

Prior to the site being released, the final step is typically to remediate any remaining radiological and non-radiological contamination on site. Radiological contamination must be mitigated to ensure that any residual exposure to the general public does not exceed established limits, once the license is terminated and the site released for subsequent re-use.

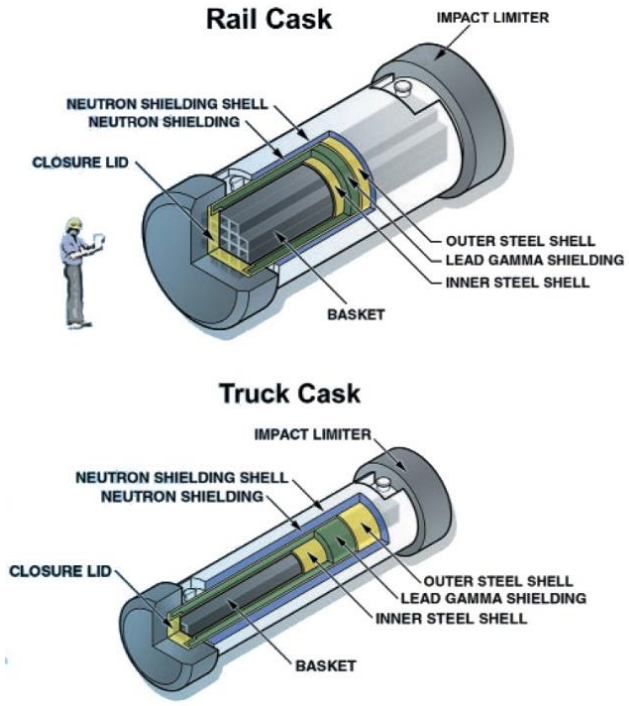
Decommissioning practices and experience vary between the United States, Canada, and Europe. In the United States, the use of SAFTOR has been common practice; however, immediate dismantling and on-site dry storage of spent fuel is becoming more common. In addition, in the United States, there is increasing interest using third parties for decommissioning and closure of shutdown nuclear power plants. There are a number of open questions with this approach that need to be explored related to site ownership, licensing, management and transport of radioactive wastes, and long-term liability. Many of the oldest reactors in the Great Lakes Basin, built in the 1960s and 1970s, have already been shut down and one is completely decommissioned. Most of the others are in SAFSTOR status with radioactive components and spent fuel left on-site to allow radionuclides to partially decay. In Canada, no commercial nuclear power plants have been dismantled, and shutdown plants are currently in SAFSTOR (deferred decommissioning) with spent fuel stored on-site in pools or dry storage. As discussed above, this approach is losing favor for a variety of reasons, and more plants are either transitioning out of SAFSTOR early or never entering a SAFSTOR phase. An advantage of immediate dismantling is that institutional knowledge as well as plant infrastructure can be leveraged, which may not be the case if activities are deferred.

In Germany and France, the preference is to dismantle the facility after shutdown, usually following a waiting period of around 5 years. Currently 25 nuclear power plants are undergoing decommissioning in Germany, and 3 nuclear power plants have been completely decommissioned and released. Only one nuclear power plant is in a SAFSTOR state. The preferred decommissioning strategy is immediate dismantling and most decommissioning projects store radioactive waste on-site. In France, 10 nuclear power plants are undergoing decommissioning, including six graphite reactors, one heavy water reactor, one pressurized water reactor, and two fast reactors. Challenges include the lack of design information, especially for older facilities, and the fact that older plants were not designed to be easily decommissioned. Due to lack of institutional knowledge, decommissioning licensees often are unaware of the nature and extent of contamination.

6.3 Radioactive Waste Management and Disposal

6.3.1 North America

In the United States, the NRC is responsible for licensing disposal facilities for radioactive waste. Currently, there are four facilities that are licensed to receive certain types of low-level waste; however, there is no licensed disposal site for wastes that are more highly radioactive, including spent nuclear fuel and certain irradiated reactor components. These wastes are currently being stored on-site at nuclear power plants, either in spent fuel pools or in dry cask storage, until such time as a disposal facility becomes available. The Nuclear Waste Policy Act (NWPA) charged DOE with developing a permanent repository for spent nuclear fuel at Yucca Mountain in Nevada; however, efforts to site a repository at Yucca Mountain have been stalled for several years.



Source: U.S. Nuclear Regulatory Commission

Figure 6-3. Casks used for transporting nuclear waste

The need for on-site storage in the United States may soon be alleviated with the potential opening of interim storage facilities in Texas and New Mexico. While this would reduce long-term risks in the Great Lakes Basin, transfer of HLW to these facilities could result in shorter-term HLW transportation-related risks. In addition, spent fuel at some sites may need to be repackaged prior to transportation, which would require the use of specialized equipment and facilities (e.g., hot cells) to handle the fuel especially if spent fuel pools have been closed and decommissioned. Even with the opening of an interim storage facility, however, it is important to note that there may be incentives for power plant operators to retain the spent fuel on-site, rather than transfer it to an interim off-site facility. Power plant operators are currently being compensated by the United States government for expenses related to spent fuel management, due to the DOE's failure to meet its obligation to develop a permanent repository for spent nuclear fuel. It is not clear who would retain title to the spent fuel if it was transferred to an interim storage facility, and whether the government would continue to compensate expenses related to spent fuel storage and management at interim storage facilities.

In Canada, the CNSC licenses facilities for radioactive waste disposal. Currently, there are no approved facilities for disposal of low-level, intermediate-level, or high-level waste. Therefore, nuclear power plants are currently stockpiling their radioactive waste on-site. There is a proposal to site a geological repository for low- and intermediate-level waste at the Bruce Power site near Lake Huron. Additionally, the Nuclear Waste Management Organization, an industry group established by nuclear power plant operators and set up under federal legislation, is working on a consensus-based siting process for a deep geological repository for spent nuclear fuel. The site selection process has been narrowed down to five

sites in Ontario, of which three are located within the Great Lakes Basin including two sites close to Lake Huron and one north of Lake Superior.

Canadian waste management regulations allow wastes that have very low levels of radioactivity to be managed as non-radioactive waste, including recycling or disposal in a solid waste management facility. In order to be cleared, the waste must result in a radiation dose to the general public of no more than 0.01 mSv. The NRC is also considering changes to the management framework for very low-level waste in order to increase the availability of disposal options and reduce costs for the large volumes of waste that are anticipated to be generated from decommissioning of nuclear power plants.

6.3.2 Europe

Until 2005, spent fuel from German nuclear power plants was reprocessed in France and the U.K. but is now stored on-site or consolidated at interim storage facilities in anticipation of eventual final disposal at a deep repository, which has yet to be developed. The German federal Office for the Safety of Nuclear Waste Management (BfE) is primarily responsible for the regulation of radioactive wastes. Its duties include managing the site selection procedure for a repository for low-, intermediate-, and high-level radioactive wastes, including public participation in the site selection process; nuclear licenses for interim storage facilities and transport of nuclear fuel; procedures under mining, water and nuclear law relating to radioactive waste disposal; issues related to the safety of nuclear waste management; and task-related research in these areas. As the regulatory body, BfE is also supervising the construction and operation of a repository for low- and intermediate-level waste at the former Konrad mine site. The Konrad site operator is the Federal Company for Nuclear Waste Disposal, BGE mbH, who is responsible for constructing and operating the disposal facility. There have been reported problems with degradation of low- and intermediate-level radioactive waste disposed in the Asse salt mine, a former waste disposal site. Plans for removing and relocating the Asse mine wastes are in development, but no relocation is expected to begin until at least 2033.

France has historically managed spent nuclear fuel by reprocessing at La Hague facility, including nuclear waste from other countries, and vitrifying the remaining waste. The vitrified waste is planned to be disposed of at a facility whose construction is scheduled to begin in 2022, with pilot phase operation beginning in 2025. Low-level short-lived radioactive waste is sent to the Centre de stockage de l'Aube (CSA) disposal facility. There is currently no approved site for the disposal of low-level long-lived and high-level wastes, which are packaged and stored on-site pending availability of a permanent disposal facility HLW that has been produced during reprocessing in France of German spent fuel is periodically shipped back to Germany by rail for storage and eventual disposal. Some of these rail shipments have been disrupted by protests.[47]

Similar to Canada, German waste management regulations also allow very low levels waste to be recycled or disposed in a solid waste management facility. The French National Plan for the Management of Radioactive Materials and Waste is currently being revised. One of the focus areas for this revision is related to clearance levels for very low-level waste. Depending on the outcome, licensees could have the ability to release very low-level waste to recycling facilities or for disposal at solid waste disposal sites.

[47] https://www.upi.com/Energy-News/2010/11/08/Nuclear-waste-shipment-marred-by-protests/10551289237225/

6.4 Public Engagement

Early engagement is essential to building a working relationship with local communities and other organizations. Decommissioning citizen advisory panels, whether established by power plant operators or by states and provinces, can help nuclear plant operators and decommissioning licensees engage meaningfully with communities. Examples of advisory panels include Vermont Yankee, Maine Yankee, SONGS and Diablo Canyon power plants. In some cases, these advisory panels may need to overcome existing distrust and other challenges.

The NGOS and Indigenous groups interviewed for this study stated that the nuclear power industry has historically not prioritized open communication and engagement with local communities. This has led in many cases to an atmosphere of distrust and a contentious relationship between nuclear power plant operators and the surrounding community. Additionally, Indigenous communities have not always been consulted on their concerns and priorities.

The issue of economic impacts related to the shutdown of nuclear power plants on local communities, including layoffs that may impact hundreds of employees, the loss of a major revenue base for local governments, and the loss of charitable donations from power plant operators to local service groups that could help with transitions, was also raised as an important concern. These impacts need to be considered carefully. Collaboration between plants and government agencies that can help communities effectively plan for employment losses is critical.

6.5 Key Issues Affecting Future Risk in the Great Lakes Basin

The most significant long-term risk factor for the Great Lakes Basin related to decommissioning is the continued storage of HLW at independent storage installations at power plant sites within the basin. Currently no permanent HLW disposal sites or consolidated interim storage facilities exist in either the United States or Canada. Therefore, spent fuel will continue to be managed at plant sites or related independent storage installation (licensed separately in the United States). In the United States, low-level and intermediate-level wastes can be removed and shipped to licensed long-term storage facilities. However, management of these waste streams in Canada is more challenging because disposal site options are limited.

As previously stated, the potential opening of interim storage facilities in Texas and New Mexico may alleviate the need for on-site storage for the U.S. portion of the Great Lakes Basin. However, transfer of HLW to these facilities (if it occurs) could result in a temporary increase in risks related to the handling and repackaging of waste in preparation for shipment. In addition to spent fuel storage, residual contamination (below regulatory thresholds) may remain on-site after decommissioning and site remediation is complete.

The following chapter provides a discussion of activities during decommissioning that could pose a risk to the Great Lakes Basin, including the potential releases of radioactive materials or other contaminants, pathways by which contaminants could spread through the natural environment, and specific contaminant transport mechanisms unique to each of the great lakes

7. Potential Impacts to the Great Lakes Basin

Both the United States and Canada have well-established processes for decommissioning, which have been generally effective in minimizing risk. The policy, technical, and public involvement aspects of the regulatory frameworks have evolved in response to both nations' experiences over previous decades.

Source: NOAA

Figure 7-1. Looking east over the Great Lakes

No major accidents that have released large quantities of long-lived radionuclides are known to have occurred at Great Lakes nuclear plants, although permitted and accidental tritium releases have occurred.[48] Even though the uncontrolled release of radionuclides to the environment is an unlikely event, the potential impacts of a release could be significant, long-lasting, and extremely concerning to stakeholders and the public. As long as radioactive material or contamination remains at a site or in the surrounding area, there is the potential for environmental and human exposure.

Accordingly, this study identifies activities during decommissioning that could release radioactive materials or other contaminants, pathways by which a release could spread through the natural environment, and specific contaminant transport mechanisms unique to each of the Great Lakes. On-site or off-site legacy contamination may potentially be present at the sites, even if it has not previously been identified, and may be subject to continuing or enhanced transport and impacts on the environment due to disturbance related to decommissioning activities. Alternatively, surveys associated with decommissioning may identify legacy contamination that was not previously known, and which can subsequently be addressed.

7.1 Decommissioning Risk Factors

Of the 38 nuclear reactors (at 16 commercial generating stations on 14 sites) that have existed in the Great Lakes Basin over time, only 21 nuclear reactors (at 8 generating stations on 7 sites) will be operating beyond 2024 (see Graydon et al 2019). Two more reactors at two sites in Ohio may be operated beyond 2021 if their current deactivation orders are successfully rescinded. Only one reactor in the Great Lakes Basin, at Big Rock Point in Michigan, has been decommissioned, while decommissioning of two reactors at the Zion nuclear power plant is nearing completion; HLW continues

[48] *Inventory of Radionuclides for the Great Lakes*, IJC Report, 1997: https://legacyfiles.ijc.org/publications/C131.pdf

to be stored at these sites (see Graydon et al 2019). The remaining five reactors that are permanently shut down at present will need to be decommissioned in the coming years, along with the other 30 reactors that will shut down in the future. Given the increasing preference for immediate dismantling following reactor shutdown, it is likely that decommissioning activities will continue to increase in the Great Lakes Basin into the foreseeable future. Until temporary or permanent off-site facilities are available, HLW will remain at on-site ISFSIs.

7.1.1 Plant Dismantlement and On-Site Waste Storage

Apart from HLW disposal, the engineering aspects of plant decommissioning are now routine, based on extensive experience in the United States and elsewhere. Since both the United States and Canada operate pressurized water reactors, the primary sequence of decommissioning would be similar, normally consisting of decontamination and removal of steam generators, followed by reactor internal components, then reactor vessels, and finally containment structures.

Large components may be removed intact, or in some cases may require segmentation prior to removal. If required, on-site decontamination may be performed by chemical etching, sand blasting, or other means. Much of the work in the areas of highest residual radiation can be done with remote-controlled cutting devices, sometimes operating underwater or in sealed areas. Environmental releases, while extremely unlikely, could occur from radioactive gas, fugitive dust, or contact cooling water pathways. Non-radioactive hazards associated with nuclear plants are also a common concern, including environmental contamination from compounds such as PCBs, hydrocarbons, and metals.

Among the most common impacts that have been identified during previous decommissioning projects are soil and groundwater contamination below and around reactor containment buildings and spent fuel storage pools, and sediment contamination in cooling water discharge areas. Once spent fuel has been removed from reactors and wet storage pools, risks related to potential contamination sources drop substantially. However, HLW is currently stored at nuclear power plant sites, which does pose an ongoing risk in the event of loss of containment.

Long-term monitoring is required at decommissioned sites where very low levels of radioactivity remain in soil, sediment, or groundwater. Based on the activity, decay rate of radionuclides, and potential exposure pathways, these sites may require monitoring and access restrictions for 10 years or more after other decommissioning activities are complete. Once former plant sites are safe for public access or redevelopment, all or part of the property can be released.

7.1.2 Waste Transportation

Within the next few years, it is foreseeable that U.S. HLW in dry casks could be moved by rail (Figure 7-1) and/or highway from U.S. Great Lakes nuclear plants to interim storage facilities in Texas and/or New Mexico, until a permanent disposal facility at Yucca Mountain, Nevada, or elsewhere becomes operational. However, it is important to note that the casks used for dry storage at the power plant sites or interim storage facilities may not be suitable for transport. Under these circumstances, the HLW spent fuel may need to be repackaged into transportation casks which would involve additional on-site handling prior to shipment.

Low-level waste from U.S. sites in the Great Lakes has been shipped to western and southern sites in the past, and this will likely continue. HLW shipments will likely move south and west along routes that have not yet been determined, but which will require at least part of the trip to pass along Great Lakes shorelines or across Great Lakes waters.

Source: http://www.virginiaplaces.org/waste/transportnukewaste.html

Figure 7-2. Railroad Shipping Container used by the U.S. Navy to Transport High-Level Waste

Because of the proximity of the nuclear power plant sites to the lakeshore, it is conceivable that wastes may be transported by barge or ship, including movement of spent fuel casks, contaminated concrete and steel, and large contaminated components such as steam generators. Barge transportation has been used for transportation of large reactor components at some closed sites outside the Great Lakes (e.g., Maine Yankee). However, this practice may be inadvisable in the Great Lakes region due to strong stakeholder opposition, and risks to ecosystems and drinking water in the event of an accident. For example, in 2010 Bruce Power announced that the Bruce Nuclear Generating Station on Lake Huron planned to ship 16 decommissioned and slightly radioactive steam generators via the St. Lawrence Seaway to Sweden for processing and recycling. This generated significant controversy with First Nations and others, and the plan was eventually abandoned.[49]

Both Canada and the United States have conducted numerous studies on the survivability of radioactive waste shipping containers involved loading/transfer accidents (e.g., drops and rollovers), transportation accidents (e.g., collisions, derailments, submersion, and fires/explosions), and intentional destructive acts. Both the design standards for shipping containers and shipping regulations take these scenarios into account and serve to minimize the potential for release if an incident occurred during transportation. However, while the likelihood of an incident causing a release from shipping containers may be small, there is still a risk that a brief or prolonged release to the environment could occur as a result of a transportation-related incident. Loss of one or more containers during over-water shipping could present substantial environmental threats and safe recovery challenges.

7.1.3 Intermediate Storage and Permanent Disposal

Eventual disposal of radioactive waste of all levels is being addressed differently by the United States and Canada. Because almost all of the nuclear plants in Canada are located in Ontario on Lake Huron and Lake Ontario, there is an expectation that the waste generated in Ontario will stay in Ontario, whether in repositories to be built within the basin or at sites to the north. However, no such facilities exist or are nearing licensing in Canada, although candidate sites for permanent disposal of HLW are being reviewed, some of which lie within the Great Lakes Basin. A deep geological repository has been

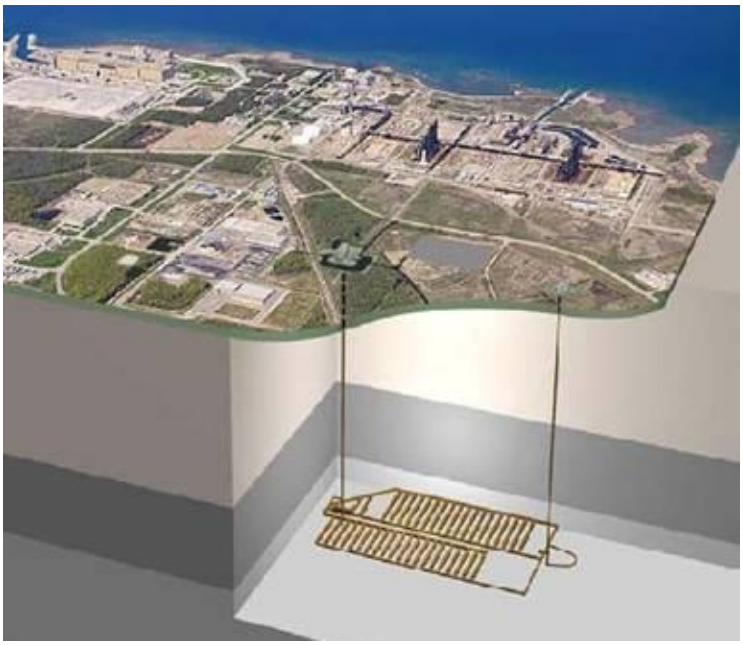
[49] See, for example, July 11, 2010 article in *The Star*: https://www.thestar.com/news/ontario/2010/07/11/critics_slam_proposal_to_ship_nuclear_waste_through_lake_ontario.html

proposed for low-level and intermediate-level waste at the Bruce Nuclear Site located near Lake Huron (Figure 7-23).

By contrast, U.S. nuclear power plants are scattered across the country, leading to a different set of expectations about waste disposal. Current low-level waste disposal sites (note that the United States does not recognize the category of intermediate-level waste) are generally in the arid west or southwest (Texas, Washington, and Utah), with the exception being a site in South Carolina. High-level interim storage or permanent disposal sites have been proposed, but not yet approved, in Nevada, Texas, and New Mexico. Thus, wastes are more likely to be moved out of the basin at some point, and centralized interim storage or permanent storage sites in the United States would not likely pose a risk to Great Lake Basin resources.

Designs for centralized intermediate storage and permanent disposal facilities use a combination of redundant controls to prevent the release of radionuclides into the environment, including container standards, natural (e.g., deep geologic placement) and engineered (e.g., drip shields, spill containment and liners, and surface shields) barriers, and operational procedures. Permanent disposal facilities may be designed to contain wastes with long-lived radionuclides for up to one million years.

Centralized storage and permanent repositories of HLW would remove related risk from the power plant sites and change the risk profile for the Great Lakes Basin. As described, in the United States storage and repository sites would likely be outside of the basin. However, in Canada, there is the possibility that the repository would be in the basin. While risks can be minimized through robust designs and an array of controls, there would still be some level of risk that storage and disposal facilities could fail through either internal or external causes. This is especially true when considering the extremely long timeframes over which exposure to some of these wastes will continue to pose a serious risk to humans and the environment in the event of loss of containment. Internal risks could result from operational failures related to human or design errors. Externally triggered risks (especially to permanent disposal facilities) could result from natural phenomena such as: seismic events causing facility collapse; groundwater or surface water intrusion; corrosion of waste containers and shields; and even inadvertent human intrusion into disposal facilities due to loss of institution knowledge and controls in the distant future.



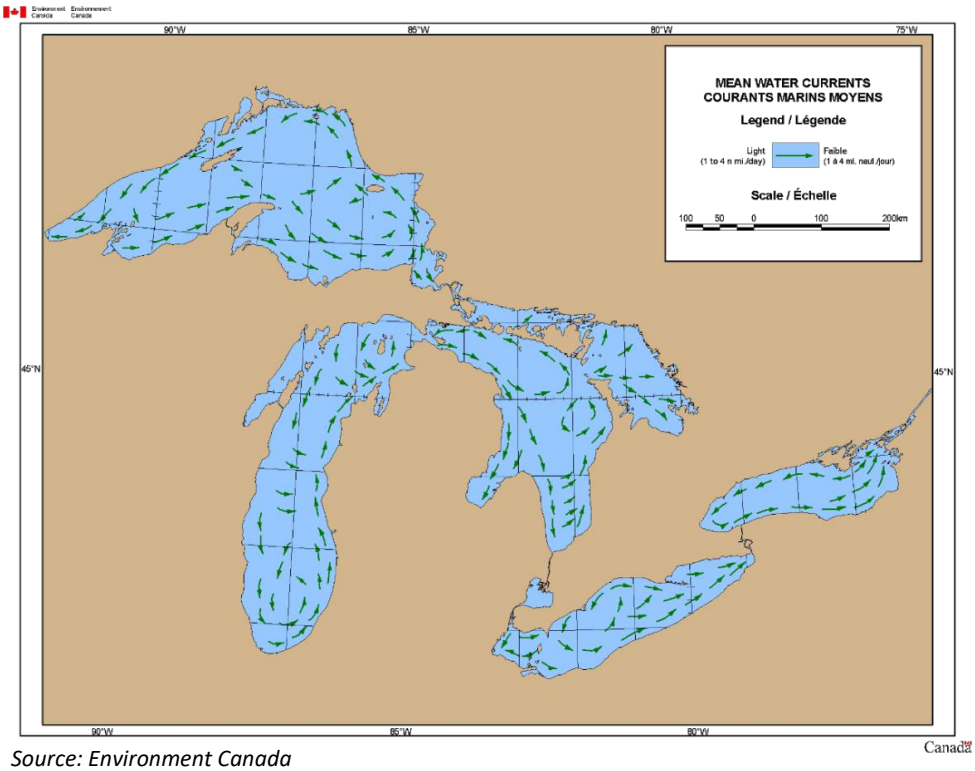
Source: Canadian Nuclear Safety Commission

Figure 7-3. Proposed Deep Geological Repository for Low-Level and Intermediate-Level Waste at the Bruce Nuclear SitePlant in Kincardine, Ontario, Canada

7.2 Basin-Wide Environmental Release Processes

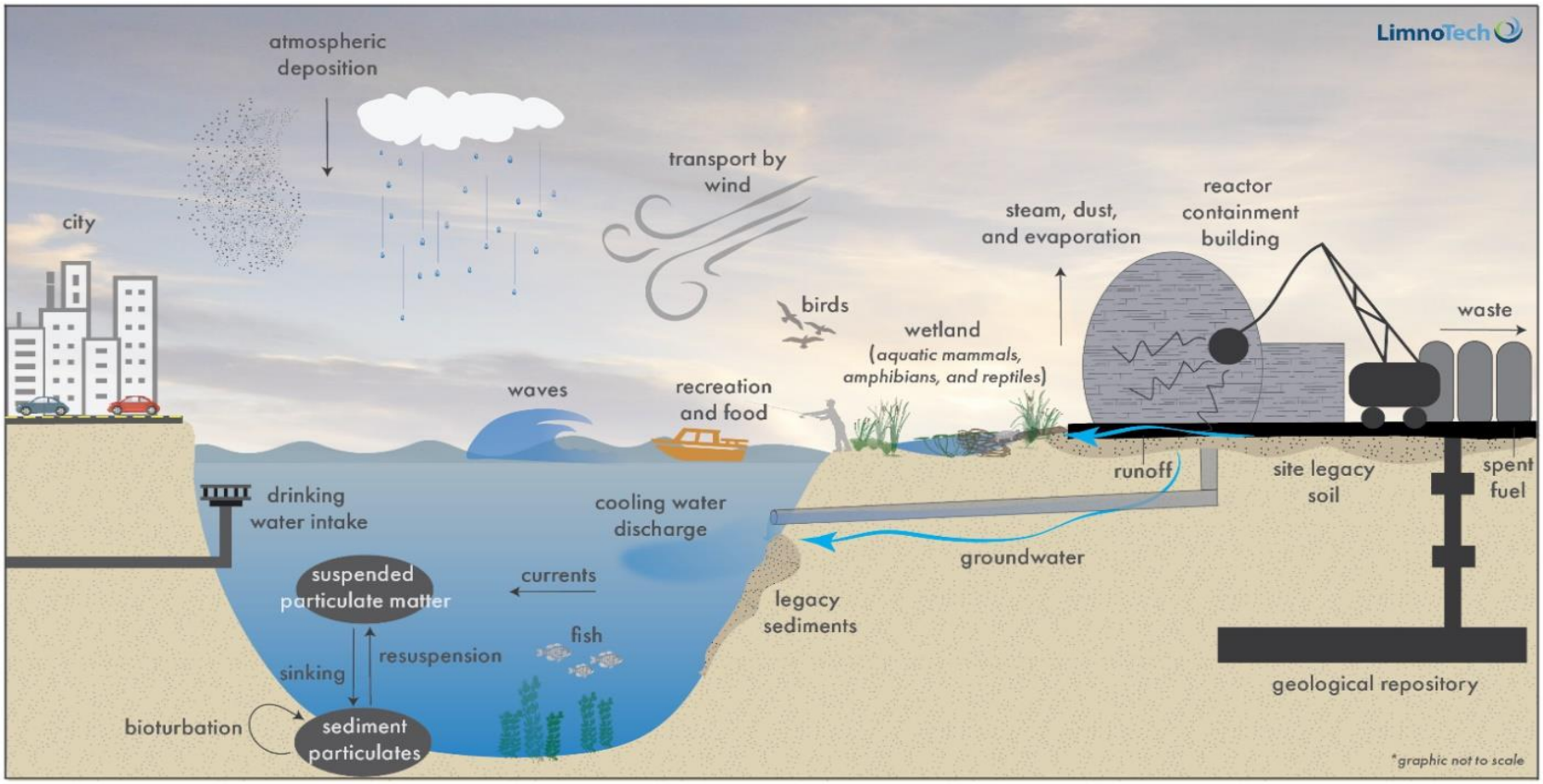
The prior section described potential risk factors related to the decommissioning process including handling, transport, and storage of radiological wastes. This section provides a discussion of how those risks, primarily to potential for release to the environment, relate to the Great Lakes Basin. Figure 7-5 is a conceptual diagram showing pathways of contaminant transport from potential releases associated with nuclear power plant decommissioning in the Great Lakes, and the natural and human resources that could be impacted in the event of a release.

Because the Great Lakes plants are all located on the lakeshore, surficial contamination or discharge of contaminated water (e.g., accidental loss of cooling water) could affect the lakes. As was observed at the Maine Yankee plant, cooling water outlets can also be sources of contamination to sediments near plants. The transport and dispersion of a contaminant release would largely be influenced by lake conditions and flow patterns. The lakes are currently at or near record high levels, which makes shoreline sites vulnerable to flooding and erosion from storm waves, seiches, and meteotsunamis (large storm-generated waves); future climate change could raise lake levels even higher, further exacerbating these threats. Circulation patterns are usually counterclockwise in Lake Huron, Lake Michigan, and Lake Superior, and stronger in winter than in summer, although ice decreases current strength. Lake Erie and Lake Ontario each have two circulation cells or gyres, which are typically counterclockwise in winter. Summer circulation remains predominantly counterclockwise in Lake Ontario, but clockwise in central Lake Erie and counterclockwise in the eastern part of the lake. The western parts of Erie and Ontario are impacted by inflow from the Detroit River and Niagara River, respectively, which tend to push flow from west to east.



Source: Environment Canada

Figure 7-4. Average water currents in the Great Lakes



Note: No geological waste repository currently exists in the Great Lakes region, but one has been proposed at the Bruce site in Ontario for low-level and intermediate level nuclear waste. Five sites in Ontario are being considered for a high-level waste repository. Also note that the repository geometry shown on the figure is schematic and not to scale; the actual proposed setback from the lake for the Bruce site is about 1 kilometer (0.6 miles) and the depth is 680 meters (2,231 feet), or approximately three times the maximum depth of Lake Huron (https://www.opgdgr.com/), and the site elevation is approximately 10 meters (33 feet) above the maximum historical lake level.

Figure 7-5. Pathways of potential contaminant transport and environmental receptors.

Groundwater transport can be also be a pathway for migration of contaminants to the lakes or other surface water on sites (streams, ponds, wetlands). Groundwater infiltration into drained spent fuel pools or other sumps has also resulted in complications during decommissioning at some sites (e.g., Connecticut Yankee). All Canadian plants sit either directly on limestone bedrock or on shallow glacial and lakebed sediments above such rock. Solution cavities and fractures in such rock can transport groundwater quickly to surface water. Many U.S. reactors are similarly situated, although some are built on sand within dune environments, or other permeable sediments. If present, groundwater and any associated contaminants can move rapidly through such sediments to surface water. Potential legacy groundwater contamination with radionuclides, both on-site and off-site, should be considered in planning for decommissioning surveys.

Contaminants can also become airborne through dust suspension by wind, surface water evaporation, steam venting, or catastrophic releases due to events such as fires or explosions. Airborne contaminants and radionuclides can travel significant distances across open or frozen lakes by wind and may be redeposited to the surface later through precipitation or dry deposition.

7.3 Lake-by-Lake Analysis

Nuclear power plants are present adjacent to all of the Great Lakes except for Lake Superior. Because of the particular geographic and engineering situation at each plant, it is appropriate to consider how decommissioning may impact each of the individual lakes and sites in order to better consider factors that may be more important at some sites than at others. Among these factors are geology and hydrogeology, lake level history and climate change, downwind habitats, dominant lake currents, common ice patterns, shoreline and nearshore habitat, plant engineering and shoreline modifications, operational history, demolition design considerations, and logistics of waste transportation and disposal.

The 16 sites of current or former nuclear power plants in the Great Lakes Basin are shown in Figure 7-5. The sites include 38 current or former reactors. Sites are shown as blue dots, with the number of reactors present at the site shown in parentheses (#) after the name if there is or was more than one reactor at the site. The operating status of reactors and associated quantities of HLW are shown in summary tables earlier in this report. Railroads and major highways are also shown to give a sense of potential waste transportation routes on land relative to power plant locations. Waste transportation by water could be in either upstream or downstream directions through the lakes, connecting channels, locks, and canals.

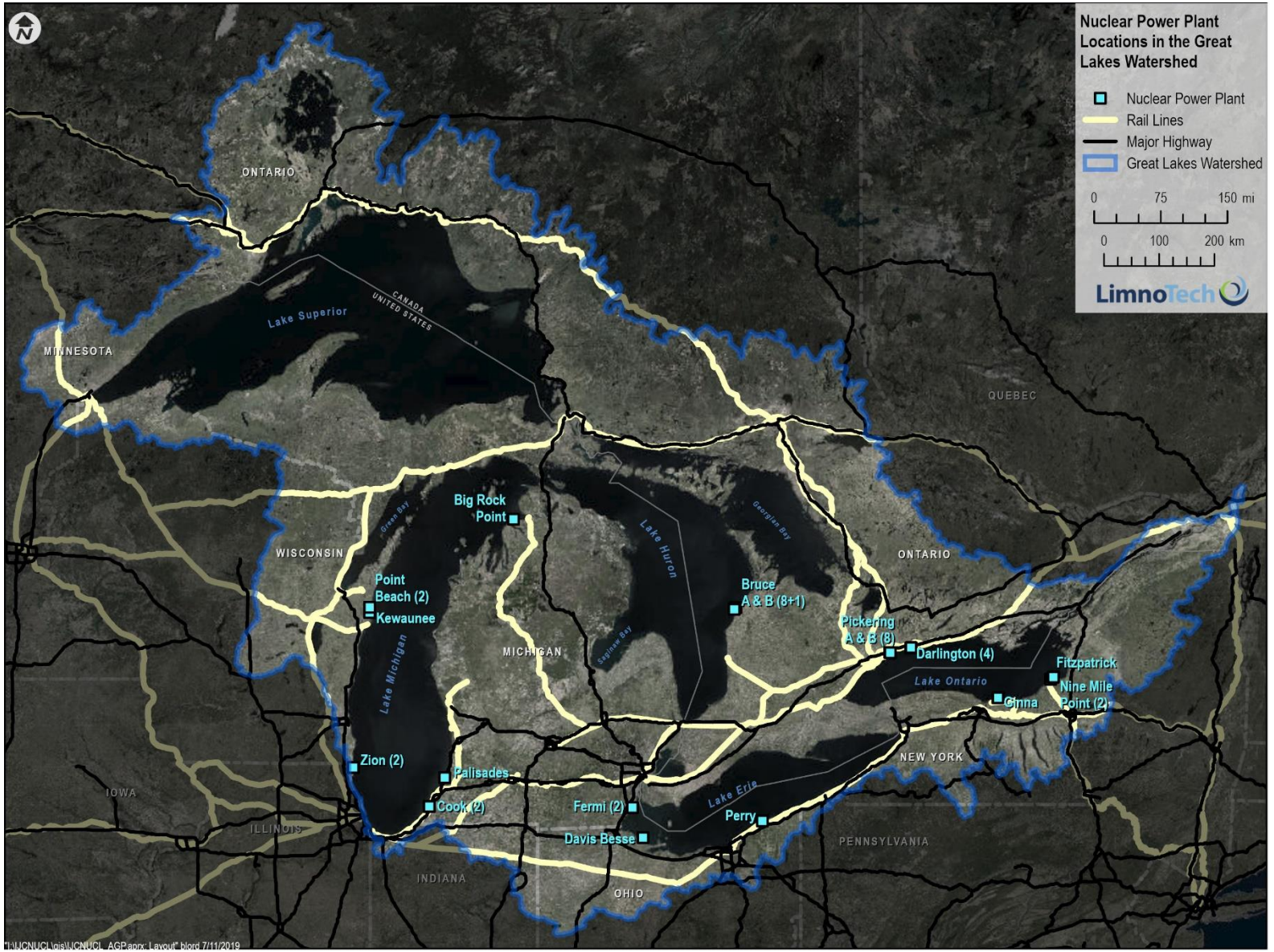


Figure 7-6. Locations of the 16 current or former nuclear generating stations in the Great Lakes Basin. Note that two are co-located.

A summary of potential ecological and human vulnerability associated with nuclear power plant decommissioning and waste transportation is presented in Table 7-1. Note that other known or potential sources of radionuclide releases are present in the basin, such as uranium mines and research reactors, but these are beyond the scope of this study. Likewise, there are nuclear power plants that are present in the airshed of the basin, particularly to the west and southwest of Chicago, that have the potential to release radionuclides to atmospheric pathways during phases of decommissioning that could impact the Great Lakes, particularly Lake Michigan, which are also not considered here. Finally, radioactive wastes generated at nuclear power plants and other sites outside the basin could be transported through the basin in the future by truck, rail, or ship, which creates the potential for transportation accidents involving such wastes to impact the Great Lakes. Future creation of disposal sites within the basin also would present the potential for transportation of wastes generated elsewhere to be brought into the basin.

Table 7-1. Areas of potential ecological and human vulnerability from nuclear power plant decommissioning

Area of Vulnerability	Potential Source(s) of Radionuclide Release	Vulnerable Ecological/Human Resources
Duluth-Superior Harbor	Waste transfer accident from ship to rail	St. Louis River estuary, western arm of Lake Superior, drinking water (lake intakes), shipping
St. Marys River	Vessel waste shipment accident in river channel or Soo Locks	Wetlands, colonial water birds, lake trout spawning, sturgeon, shipping, access to hydropower plant and water level regulation, border crossing, Tribal and First Nations fisheries
Straits of Mackinac	Vessel waste shipment accident in Straits, or truck waste shipment accident on bridge	Lake trout spawning, whitefish, coastal wetlands, drinking water, shipping, bridge transportation, Mackinac Island tourism, Tribal fisheries
Western Lake Michigan	Release from Kewaunee or Point Beach plant sites	Spawning habitat, dunes, beaches, drinking water
Southwestern Lake Michigan	Release from Zion plant site, rail waste shipment or Chicago Ship Canal waste shipment accident	Coastal wetlands, dunes, beaches, drinking water, shipping
Southeast Lake Michigan	Release from Palisades or Cook plant sites	Coastal dunes, beaches, transportation corridor
Northeastern Lake Michigan	Release from Big Rock Point ISFSI or during transfer for shipment	Little Traverse Bay spawning habitat, lake trout, Tribal fisheries; limited transportation infrastructure
Northern Georgian Bay	Nearshore rail or highway waste shipment accident	Coastal wetlands, spawning habitat
Eastern Lake Huron	Release from Bruce Nuclear Site or from potential deep geological repository	Spawning habitat, First Nation fisheries; limited transportation infrastructure

Table 7-1. Areas of potential ecological and human vulnerability from nuclear power plant decommissioning

Area of Vulnerability	Potential Source(s) of Radionuclide Release	Vulnerable Ecological/Human Resources
Huron-Erie Corridor	Vessel waste shipment accident in St. Clair River or Detroit River	Sturgeon, St. Clair Delta wetlands, waterfowl, First Nations fisheries, drinking water, shipping, border crossings
Western Lake Erie	Release from Fermi or Davis-Besse sites	Walleye and perch fisheries, migratory birds, coastal wetlands, drinking water, beaches
Central Lake Erie	Release from Perry site, or rail accident along southern shore	Drinking water and walleye
Welland Canal	Release from vessel waste shipping accident in locks or canal	Drinking water, shipping, tourism
Northwestern Lake Ontario	Release from Pickering or Darlington sites; waste transport accident	Drinking water, beaches
Southeast Lake Ontario	Release from Ginna, Fitzpatrick, or Nine Mile Point sites	Wetlands, beaches, St. Lawrence River habitats
St. Lawrence River	Vessel waste shipment accident in river channel or locks	Sturgeon, shoreline wetlands, drinking water, border crossings

7.3.1 Lake Michigan

There are nine current or former reactors located at six generating stations located along the Lake Michigan shore. These plants, listed counterclockwise around the shore, are Point Beach (WI), Kewaunee (WI), Zion (IL), Cook (MI), Palisades (MI), and Big Rock Point (MI). The Kewaunee and Zion plants are closed, and Palisades is scheduled for closure in 2022; Big Rock Point is closed and decommissioned, leaving only Point Beach and Cook expected to operate beyond 2022.

The average currents along the lake shore tend to flow to the south with upwelling common on the western shore, and to the north on the eastern shore. Large or sustained releases of radionuclides, particularly of those with long half-lives, could impact ecological and human resources that are located some distance from plants and for many years into the future.

The Lake Michigan sites are located on either glacial materials (sand, gravel till), dune sand, or carbonate bedrock (primarily limestone). Releases of radionuclides at any of these sites have the potential to cause contamination to move into site soils, groundwater, and

Source: NOAA

Figure 7-7. Lake Michigan

surface water, or to be transported by wind in the atmosphere and to be deposited on water or on land. Shoreline and nearshore habitats that could be impacted by historical or decommissioning-related radionuclide releases include coastal wetlands, fish that spawn near shore or in tributaries (walleye, lake whitefish), and fish-eating birds. Human exposure could be by contact with water or sediments at beaches or while boating, ingestion of contaminated fish or drinking water, or inhalation of particulates.

The residence time of lake water is approximately 60 years, so any long-lived radionuclides that remained in lake water after a release would take decades to move through the Lake Michigan system into Lake Huron. Recent high lake levels have resulted in extensive shoreline and dune erosion. Recent research has documented the relatively high frequency of storm-generated meteotsunamis in central and southern Lake Michigan, including a large event in Ludington, Michigan in 2018 that damaged marinas and shoreline structures.[50,51] Meteotsunamis would be most likely to affect the Palisades and Cook sites.

Releases from Wisconsin sites could be transported across the lake by wind or ice, or transported by dominant currents to the south, potentially impacting beaches and drinking water intakes in the lake. Releases from the Zion site in Illinois would behave similarly. The recommended mode for HLW shipments from the Kewaunee plant is via heavy-haul truck followed by transfer to rail.[52] The potential exists in this area for waste shipping accidents associated with rail corridors near the shore in Wisconsin and along the southern shore, at the major rail switching yards in Chicago, and vessel accidents in the Chicago Area Waterways associated with any over-water transport. Releases to sediment or water from Cook and Palisades sites in Michigan would likely be transported north along the shore. There are no major drinking water intakes along pathways that are likely to be impacted by releases from these two sites.

The Big Rock Point (BRP) site along the south shore of Little Traverse Bay on Lake Michigan has been decommissioned, with only spent fuel casks remaining. Concerns at this site would mostly relate to eventual transportation of the spent fuel from the site, and the reduced options presented by its remote location. No major highways or railways provide access to the site, and transportation by water presents land-side and over-water challenges discussed previously. A recent study examined potential transportation modes and routes and recommended the option of “loading canisters into a transportation cask at the BRP facility with subsequent truck transport of the material to a rail spur”.[53]

7.3.2 Lake Huron

The Bruce Nuclear Generating Station and the Douglas Point Generating Station are located on the Bruce Nuclear Site on the eastern shore of Lake Huron in Kincardine, Ontario; no nuclear power plants are located on the U.S. side of the lake. The Bruce Nuclear Generating Station contains eight operating nuclear reactors and the Douglas Point Nuclear Generating Station has one nuclear reactor, which

[50] https://www.nature.com/articles/srep37832;
[51] https://news.umich.edu/scientists-launch-pilot-project-to-warn-of-potentially-dangerous-meteotsunami-waves-in-great-lakes/
[52] https://www.energy.gov/sites/prod/files/2018/07/f53/AREVA%20Kewaunee%20De-Inventory%20Report%20%28Rev.%201%29.pdf
[53] https://www.energy.gov/sites/prod/files/2018/07/f53/BRP%20Deinventory%20Report%20Rev.%202_FINAL_PUBLIC.pdf

operated from 1968 until it was permanently shut down in 1984. With a capacity of 6,430 MW, Bruce Nuclear Generating Station is the second largest nuclear power plant in the world by net capacity, generates approximately 30 percent of Ontario's electricity, and employs approximately 4,000 people directly and thousands more as contractors.[54] The relatively isolated low-relief site is situated on limestone and dolostone bedrock, and contains multiple cooling water tunnels and channels, as well as many shoreline modifications.

Source: NOAA

Figure 7-8. Lake Huron

Since the early 1970s, the low- and intermediate-level radioactive waste produced as a result of the operation of Ontario Power Generation's nuclear sites (Bruce, Darlington, and Pickering) has been stored centrally at OPG's Western Waste Management Facility (WWMF) located on the Bruce Nuclear Site in the Municipality of Kincardine, Bruce County, Ontario. Spent nuclear fuel (from Bruce only) is also stored in hundreds of casks at the WWMF in the Western Used Fuel Dry Storage Facility.[55] OPG has submitted license applications to the CNSC to construct and operate a deep geological repository on the Bruce Nuclear Site, which would only accept low- and intermediate-level waste from OPG-owned or operated nuclear generating stations in Ontario (see Graydon et al 2019). OPG proposed to construct the deep geological repository approximately 1 kilometer (0.6 mile) from the shore of Lake Huron, near the existing WWMF. The deep geological repository would be constructed in Ordovician limestone at a depth of approximately 680 meters (2,230 feet). This plan has met with opposition from Canadian and U.S. groups, notably including the Saugeen Ojibway Nation, which has historical territorial claims to the site. The nearby towns of South Bruce and Huron-Kinloss are on a short list of five municipalities that are currently being considered as sites for a permanent geological repository for HLW as well. A selection is scheduled to be made by 2023. If such a repository is located near the Bruce Nuclear Site, it will receive HLW from sites within and outside the basin. The three other remaining candidate sites are in northern Ontario.

Any atmospheric releases of radionuclides associated with decommissioning or waste handling and storage would likely travel inland. Releases to the lake as contaminated water or sediments would likely travel along the shore to the north with the dominant currents. The water residence time in Lake Huron is approximately 20 years. Biological impacts would be on spawning fish and potentially on First Nations fisheries. Lake Huron freezes consistently in the winter, but ice generally does not move away from the eastern shore due to prevailing winds from the west. Cities to the south and west, including Sarnia, Flint, and Detroit, draw most of their drinking water from Lake Huron, but radionuclide transport in water or air is less likely in this direction from the Bruce Nuclear Site. Shipping of radioactive waste by water could impact drinking water in the event of an accident, particularly given the high volume of ship traffic and strong currents in the Huron-Erie Corridor. Collingwood Harbor in Georgian Bay is a deep harbor

[54] https://www.power-technology.com/features/feature-largest-nuclear-power-plants-world/
[55] https://www.opg.com/document/wwmf-brochure-pdf/

that would likely receive large components or bulk cargo associated with decommissioning at the Bruce Nuclear Site, if the decision were made to transport waste materials by water.

7.3.3 Lake Erie

There are three operating nuclear power plants located on the U.S. side of Lake Erie: Fermi (MI), Davis-Besse (OH), and Perry (OH). The Ohio plants, which had been scheduled to shut down their reactors in the next few years, well before their license expirations, may reverse course as a result of new state legislation. In July 2019, the Ohio legislature authorized an annual $150 million USD operating subsidy through 2027 to keep the plants open longer and delay the loss of approximately 1,400 jobs.[56] The Fermi site in Michigan includes two reactors (one shut down), and the others include one each. The Fermi site, located between Detroit, Michigan and Windsor, Ontario to the north and Toledo, Ohio to the south, is surrounded by coastal wetlands. The Davis-Besse site, located east of Toledo, is also surrounded by wetlands. These sites are located along important seasonal north-south migration routes for birds that follow the shoreline of Lake Erie to avoid crossing the lake.

Source: NOAA

Figure 7-9. Lake Erie

Currents generally flow south and east from Fermi, and east from Davis-Besse. Their low site elevations relative to lake levels make them vulnerable to high water and seiches, which are common in the lake. Meteotsunamis do not generally impact the western basin of Lake Erie. Lake Erie is shallow and has a short water residence time of approximately two years.

Airborne releases from either Fermi or Davis-Besse sites would likely move east. Migratory birds in the nearby wetlands could be impacted in spring or fall. Releases to water or sediment could impact drinking water intakes, with the greatest concern being the Toledo intake to the east of the city. Dominant currents would be more likely to carry released radionuclides from Fermi to the intake than from Davis-Besse. Lake Erie typically freezes early and melts early, but transport of released radionuclides on ice may be possible and would typically be to the east from the release point.

Western Lake Erie and its tributaries support a major recreational, charter, and commercial walleye and yellow perch fishery that could be impacted by releases from either plant. Sediment resuspension is common in the shallow western basin of the lake, so contaminated sediment could be easily remobilized, but also diluted. Remobilized contamination could enter the lower food web, especially via filter feeders and other benthos, and potentially bioaccumulate up the food web. Davis-Besse was slated for closure in 2020, but that decision may be reversed, as described above; a closure date for Fermi has not been announced. Davis-Besse has experienced several significant accidents during its operating life, including a tornado in 1998 that knocked out access to external power.

The Perry site is perched above the lake on a wooded rural site between Cleveland, Ohio and Erie, Pennsylvania in an area of shoreline with low bluffs, narrow beaches, and few wetlands. Dominant

[56] https://www.cleveland.com/open/2019/07/nuclear-bailout-bill-passes-ohio-legislature.html

winds and currents are to the east, away from Cleveland's drinking water intakes, although water currents tend to shift to the west in summer. A steam line leak that impacted site groundwater with tritium was discovered in 2014, but the contamination did not appear to be migrating off-site at that time. The site is in the northeastern Ohio seismic zone, which has had moderately frequent small earthquakes up to magnitude 4.8; an earthquake of magnitude 4.0 occurred offshore in June 2019. The low-level seismicity is not known to have previously compromised the integrity of site structures. The single reactor at the Perry site was slated for closure in 2021, although this decision may be reversed based on recent developments described above. Eventual transport of HLW from the Perry and Davis-Besse sites would likely be by rail along lines that run close to the Lake Erie shore. Concerns about lost employment and tax revenue from the closure of the plants have led to legislative actions intended to extend their operating lives.

7.3.4 Lake Ontario

Lake Ontario is the only Great Lake with nuclear power plants located on both Canadian and U.S. shorelines. Two nuclear power plant sites located in each country, with multiple reactors at each of the sites except for the Ginna plant in New York. Pickering and Darlington in Ontario have 8 and 4 reactors, respectively, and there are 3 reactors at the joint Fitzpatrick/Nine Mile Point plant site in New York, so the Lake Ontario total is 16 reactors—the most of any Great Lake. Two reactors at the Pickering site are not operating. The current record high water levels in Lake Ontario, surpassing 2017 records, may present challenges to nuclear power plants along its shores, depending on design assumptions about lake level range. High flow through the lake decreases the residence time of water below the typical time of approximately six years.

Source: NOAA

Figure 7-10. Lake Ontario

The two nuclear sites on the north shore of Lake Ontario (Darlington and Pickering) are both located downwind and east of Toronto, although the currents along the shore tend to flow toward the west in the direction of Toronto's drinking water intake. Sometimes a small clockwise-circulating gyre forms in the western end of the lake in summer, reversing flow along the shore. Low and intermediate-level waste from these two plants is shipped by truck to the WWMF at the Bruce Nuclear Site on Lake Huron, but spent fuel is stored at each site. Tritiated heavy water is trucked from Bruce and Pickering to the Darlington Tritium Removal Facility.[57]

The Canadian Lake Ontario sites are located in relatively developed areas, compared with most of the other Great Lakes plants. They collectively supply about 30 percent of Ontario's electric power, or almost 60 percent when combined with the Bruce plant. Both Lake Ontario sites have been impacted by fouling of intakes for once-through cooling water by abundant macroalgae that grows in the area during the summer. Eventual transportation of HLW to a planned repository to the northwest will present the choice of either transportation by truck or rail through Toronto. Transportation by water would be

[57] https://www.opg.com/document/wwmf-brochure-pdf/

through the Welland Canal locks, across Lake Erie, and up the Detroit River and St. Clair River to a transfer point on Lake Huron, or through the St. Marys River and the Soo Locks to Lake Superior, depending on the selected location of the eventual high-level deep geological repository .[58] Disposal of HLW outside of Canada is not anticipated.

On the U.S. side, the Ginna plant, located east of Rochester, New York, is the second oldest operating nuclear plant in the United States It is currently licensed through 2029 and began operating in 1970. Lake currents generally flow east and would transport contamination toward the St. Lawrence River in the event of an air or water release associated with decommissioning. Political action has been required to help keep the plant operating, as its generating costs are not competitive with natural gas power plant costs.

The site of the Fitzpatrick and Nine Mile Point plants is located east of Oswego, New York between Syracuse to the south, and Kingston, Ontario, to the north. Currents near the east end of the lake flow east and north toward the St. Lawrence River outlet. The area is generally sparsely populated except for Oswego, which has a population of less than 17,500. In the event of eventual closure, the 1,700 jobs at the plant and associated tax revenue would be hard to replace in the rural area. The shoreline at the site consists of low bluffs, which make it less vulnerable to high lake levels than other areas. Eventual HLW transportation from the site would likely be by ship or rail.

[58] https://www.nwmo.ca/~/media/Site/Files/PDFs/2015/11/09/12/54/660_6-6StatusofTransportationSystemsforHigh-levelRadioactiveWasteManagementHLRWM.ashx?la=en

8. Recommendations

This section focuses on recommendations for the WQB to consider when providing advice and recommendations to the IJC regarding the challenges posed by the eventual decommissioning of the nuclear power plants located within the Great Lakes Basin. The recommendations below are focused on the Great Lakes Basin, to ensure that any future actions with respect to the decommissioning of nuclear power plants are carried out in a way that minimizes risks and potential impacts. Many of these actions would properly be executed by the governments and regulatory agencies, rather than the WQB or IJC itself. Other reports have also provided policy recommendations aimed at identifying solutions to the challenge of spent nuclear fuel disposal. See, for example, the 2012 report by the Blue Ribbon Commission on America's Nuclear Future and the 2018 report titled "Reset of America's Nuclear Waste Management Strategy and Policy".[59,60]

8.1 Policy Development

- Continue to actively monitor the process of siting a deep geological repository for spent nuclear fuel in Canada, as some of the proposed sites lie within the Great Lakes Basin. Consider providing input into the process to support siting and design of HLW disposal facilities that will minimize environmental and human risk in the Great Lakes. Note this recommendation does not necessarily mean supporting siting outside the Great Lakes Basin.
- Continue to monitor proposals to establish consolidated interim storage facilities for spent nuclear fuel in the United States, and the possibility that spent nuclear fuel may be packaged and transported from nuclear power plants in the Great Lakes Basin to these facilities in the relatively near future. Regardless of the storage or disposal site chosen, encourage that local and Indigenous communities be consulted early in the planning process for routing of future HLW shipments from or through the basin.
- Facilitate coordination of binational policies on decommissioning and waste transport and disposal.
- Promote development of an accessible binational database of lessons learned from decommissioning of nuclear power plants within the Great Lakes Basin to support effective management. The database could include examples of known contamination or releases (both radioactive and non-radioactive contaminants), the root cause or sources for contaminant release, and best practices for prevention and remediation. The NRC maintains a lessons-learned database, but it does not appear to have been updated for several years. State and provincial environmental agencies in Michigan and Ontario may be appropriate hosts of such a Great Lakes database.
- Advocate for the establishment of Citizen Advisory Panels as part of the decommissioning process to enhance public involvement, and provide guidance on the structure and functioning of such panels, potentially including binational and Indigenous representation. These panels should be established early in the decommissioning process for individual plants or groups of plants to improve community understanding and relationships.

[59] Blue Ribbon Commission on America's Nuclear Future: Report to the Secretary of Energy. 2012. https://www.energy.gov/sites/prod/files/2013/04/f0/brc_finalreport_jan2012.pdf
[60] Reset of America's Nuclear Waste Management Strategy and Policy. 2018. https://fsi-live.s3.us-west-1.amazonaws.com/s3fs-public/reset_report_2018_final.pdf

8.2 Outreach and Engagement

- Consider convening a binational and Indigenous planning group to discuss safe transport of HLW from Great Lakes nuclear plants to disposal sites, especially including consideration of rail and barge transport.
- Consider working with regulatory agencies from both countries (including provinces and states) to adapt existing materials to Great Lakes situations and audiences, given that community outreach on this topic is an ongoing challenge. The fact that almost all Canadian nuclear power plants are on the Great Lakes places special responsibility on Ontario and the Government of Canada to show leadership in the binational conversation about decommissioning.
- Identify decommissioning liaisons with the appropriate regulatory bodies from each country (CNSC and NRC, as well as states and provinces) so that they can remain informed of current developments. Additionally, consider designating an IJC staff person to track this issue on an ongoing basis.
- Through outreach and advocacy, encourage and promote the consideration of Indigenous world views in all phases of the decommissioning process, including research and the format of public proceedings. An example would be seating female elders, as cultural stewards of water, on panels and authoritative bodies in public consultations.
- Coordinate with nuclear power communities and local governments and economic associations to encourage planning for potential economic impacts associated with closure of nuclear power plants. Substantial economic impacts can occur to local communities as a result of nuclear power plant shutdown, including layoffs that may impact hundreds of employees and the loss of a major revenue base for local governments and charitable organizations.

8.3 Further Research

8.3.1 Decommissioning and Waste Management

- Consider following up on the Graydon et al. (2019) report and this report by conducting or supporting site-specific vulnerability assessments for nuclear power plants and surrounding areas in the Great Lakes Basin. Such studies would be conducted where current vulnerability assessments associated with NRC and CNSC permit requirements and other investigations may not exist or may not adequately address lake and coastal ecosystem threats. Such assessments could take into account the following factors:
    - Estimated operating life and current decommissioning plan
    - Likely duration of spent nuclear fuel storage on-site
    - Need to repackage spent fuel prior to transport, and potential transportation routes
    - Proximity of potential contamination sources or release pathways to sensitive receptors
    - Potential for external accident or release risks related to intentional sabotage, extreme weather events, or natural or man-made disasters.
- While the decision on the choice of decommissioning strategy (i.e., SAFSTOR versus immediate dismantling) is often made based on economic and regulatory factors, the WQB should explore further whether one or the other approach would be likely to be more protective of the environment and human health, and under what circumstances, especially within the Great Lakes environment. Safe storage allows the most radioactive components of plants and fuel to partially decay prior to decommissioning, reducing associated risks. Immediate dismantling takes advantage of existing plant infrastructure and institutional memory of staff to transform

operating components into segmented and contained wastes in just a few years, albeit with higher levels of radioactivity in some components than after prolonged SAFSTOR.

8.3.2 Other Topics

- In 1997, the IJC commissioned a report titled "Inventory of Radionuclides for the Great Lakes." The report developed estimates of the quantities of various natural and synthetic radionuclides in the Great Lakes watershed. The WQB or IJC should consider updating that study, to assess the extent to which operation and decommissioning of nuclear power plants in the intervening period may have contributed to the presence of radionuclides in the Great Lakes environment.
- Investigate the potential for climate change to exacerbate the risks associated with decommissioning of nuclear power plants and long-term storage of spent nuclear fuel near waterbodies, or transport mechanisms, within the Great Lakes Basin.
- Consider evaluating the risks associated with radioactive waste storage and management at military sources (such as weapons and naval vessel power plants), uranium mining, and legacy sites such as uranium processing and spent fuel reprocessing facilities, which may pose greater risks than nuclear power plants. This was a concern expressed by several interviewees.

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Appendix A - Interview Questions

1. What is your background and experience related to the nuclear power industry and specifically, decommissioning of nuclear power plants in the U. S., Canada, and Europe?

2. What is the regulatory environment with respect to decommissioning of nuclear power plants, including federal and state programs?
    a. In the U. S.?
    b. In Canada?
    c. In Europe?

3. What differences exist among the U. S., Canada, and Europe in their technologies and approaches to decommissioning?

4. What are the important concerns and current environmental issues and policy discussions related to nuclear decommissioning?

5. What examples of best practices and challenges/lessons learned can you provide for past or current decommissioning projects? Are you aware of any publicly available documentation on these case studies (reports, presentations, papers, etc.)?

6. What research is being conducted by your organization related to nuclear decommissioning (or by others that you are aware of or involved in)? Is it publicly available?

7. What are the primary data repositories for information related to nuclear decommissioning?

8. What are the primary forums for environmental information exchange related to nuclear decommissioning?

9. What, according to you, should be priorities in advancing the understanding and management of nuclear decommissioning to protect human health and the environment; e. g., regulatory changes, investments, research?

10. Who else should we be speaking to about this topic?

Appendix B – U.S. Nuclear Regulatory Commission's Response to Interview Questions

Question: From the NRC's perspective, what are the major stages during decommissioning of nuclear power plants and what are the biggest environmental risks?

Response:

NRC Reactor Decommissioning Process

Under the NRC's regulatory framework, decommissioning is the process by which the licensee reduces the site's residual radioactivity to the approved regulatory level by removing or otherwise mitigating on-site radiological contamination (see definition of the term "Decommission" in the NRC regulation, 10 CFR 50.2, "Definitions"). Thus, the presence of non-radioactive contaminants on the site (e.g., PCBs, asbestos, lead-based paint), and the remediation or mitigation of such non-radiological hazards, are beyond the scope of the NRC's regulatory authority. Similarly, the licensee's decision to either dismantle and demolish the facility's buildings and structures or to leave some or all of them standing is not within the NRC's purview.

Reactor decommissioning is governed by the NRC's regulations, 10 CFR 50.82, "Termination of license," for power reactors licensed under 10 CFR Part 50 and 10 CFR 52.110, "Termination of license," for power reactors licensed under 10 CFR Part 52. The decommissioning process usually lasts many years, possibly decades, and under the applicable NRC regulations, can take up to sixty years (10 CFR 50.82(a)(3) or 10 CFR 52.110(c)). At the end of the decommissioning process, the licensee will seek to terminate its operating license. The NRC's regulatory objective is that the licensee must meet all applicable NRC public and occupational radiological safety requirements throughout the decommissioning process and that at the completion of that process, the licensee is able to demonstrate that it has reduced the level of on-site residual radioactivity to an acceptable regulatory level (see the NRC's regulations in Subpart E, 10 CFR Part 20; the 10 CFR Part 20 regulations are the NRC's primary radiation protection regulations). Based upon the NRC's operational experience, all NRC power reactor licensees that have completed decommissioning have successfully demonstrated meeting the regulatory requirements of the Subpart E regulation, 10 CFR 20.1402, "Radiological criteria for unrestricted use," which states

> A site will be considered acceptable for unrestricted use if the residual radioactivity that is distinguishable from background radiation results in a [total effective dose equivalent] to an average member of the critical group that does not exceed 25 mrem (0.25 mSv) per year, including that from groundwater sources of drinking water, and the residual radioactivity has been reduced to levels that are as low as reasonably achievable (ALARA). Determination of the levels which are ALARA must take into account consideration of any detriments, such as deaths from transportation accidents, expected to potentially result from decontamination and waste disposal.

Once the licensee has demonstrated that it has met the 10 CFR 20.1402 requirements or those of another Subpart E regulation, then the NRC will terminate the operating license. Upon license termination, the NRC will no longer have regulatory authority over the former licensed site. The former NRC licensee or any new site owner, however, will remain subject to all other Federal (e.g., the Clean Water Act), state, and local laws and regulations, including any applicable environmental protection, human health and safety, and land use and zoning regulations.

We note that the "Performance Work Statement" that was provided to the NRC staff states that reactor facilities may be "abandoned." The buildings and the structures of a decommissioning nuclear reactor power plant, however, are never "abandoned" while under NRC regulatory oversight, although an individual building or structure may be demolished or otherwise dismantled, or it may remain standing and unused. Following the termination of the NRC license, a building or structure would not be abandoned unless such abandonment is allowed under the applicable state or local law or regulation. Moreover, following the termination of the NRC license, there is no longer a radiological concern with respect to any buildings and structures remaining on the site as the residual radioactivity would have been reduced to the appropriate regulatory level in accordance with 10 CFR 20.1402 or other Subpart E regulation.

A prerequisite to decommissioning is the licensee's submission of two certifications to the NRC, the first certifying that the licensee has determined to permanently cease reactor operations, and the second, that all fuel has been permanently removed from the reactor vessel (10 CFR 50.82(a)(1)(i)-(ii) or 52.110(a)(1)-(2)). Additionally, the licensee must submit a post-shutdown decommissioning activities report (PSDAR); the PSDAR describes the planned decommissioning activities along with a schedule for their accomplishment, provides the reasons for concluding that the environmental impacts associated with site-specific decommissioning activities will be bounded by appropriate previously issued environmental impact statements, and provides site-specific decommissioning cost estimates (10 CFR 50.82(a)(4)(i) or 10 CFR 52.110(d)(1)). The licensee must submit the PSDAR to the NRC prior to or within two years following permanent cessation of reactor operations (10 CFR 50.82(a)(4)(i) or 10 CFR 52.110(d)(1)). The licensee may only commence "major decommissioning activities" 90 days after the submission of the certifications and the PSDAR (10 CFR 50.82(a)(5) or 10 CFR 52.110(e)). "Major decommissioning activities" are defined as "any activity that results in permanent removal of major radioactive components, permanently modifies the structure of the containment, or results in dismantling components for shipment containing greater than class C waste in accordance with § 61.55 of this chapter" (10 CFR 50.2).

After the 90-day period identified above, the licensee may commence major decommissioning activities. The licensee does not need prior NRC approval to conduct major decommissioning activities, provided that the licensee's activities remain within a certain defined scope, as prescribed by 10 CFR 50.59, "Changes, tests and experiments." During the decommissioning process, the NRC maintains comprehensive regulatory oversight over the plant. The licensee remains subject to the terms and conditions of its license and to the NRC's regulations, and as such, remains subject to NRC inspection and enforcement. As described in the NRC's Inspection Manual Chapter (IMC) 2561, "Decommissioning Power Reactor Inspection Program" (ADAMS Accession No. ML17348A400), the NRC staff will engage in regular on-site inspections that emphasize radiological controls and management, procedure compliance, spent fuel pool operation, and the safety review program. Many activities that occur during decommissioning are routine and occur frequently in operating plants. These include decontamination

of surfaces and components, surveys for radioactive contamination, waste packaging and disposal, and other activities. During active decommissioning periods, NRC inspectors may be at the facility 2 or 3 weeks of the month to observe ongoing activities. During a long-term storage period, inspectors would be present to conduct inspections at least once a year in accordance with the decommissioning reactor inspection program outlined in IMC 2561.

The NRC has also issued several regulatory guidance documents for nuclear power plant decommissioning, including Regulatory Guide (RG) 1.184, "Decommissioning of Nuclear Power Reactors," Revision 1 (October 2013; ADAMS Accession No. ML13144A840); RG 1.185, "Standard Format and Content for Post-Shutdown Decommissioning Activities Report," Revision 1 (June 2013; ADAMS Accession No. ML13140A038); and RG 4.21, "Minimization of Contamination and Radioactive Waste Generation: Life-Cycle Planning" (June 2008; ADAMS Accession No. ML080500187). The guidance is directed toward NRC licensees and provides acceptable procedures and methodologies to meet the applicable NRC regulatory requirements during decommissioning. Although compliance with guidance is not required, licensees have an incentive to follow the procedures and methodologies set forth in the guidance documents as NRC practice is to presume that compliance with the guidance means that the licensee is in compliance with the applicable NRC regulation upon which the guidance is based (e.g., 10 CFR 50.82 and 10 CFR 20.1402).

The final phase of the decommissioning process is license termination. The licensee is required to submit a license termination plan at least two years before the expected date of license termination (10 CFR 50.82(a)(9) or 10 CFR 52.110(i)). Upon the NRC's approval of the license termination plan, the licensee will take those steps to demonstrate that it has reduced the level of residual radioactivity to the regulatory level for license termination (see the NRC's regulations in Subpart E, 10 CFR Part 20). Once the NRC staff has confirmed that the licensee has met the regulatory standard, typically through a final site confirmatory survey, the NRC will terminate the power reactor operating license; the NRC may only terminate the license in part if the licensee has an independent spent fuel storage installation (ISFSI) under a 10 CFR 72.210 general license (see the "Environmental Considerations/ISFSI" paragraph below).

Environmental Considerations

The systems and processes required to safely maintain a decommissioning plant are much simpler than those required to run an operating plant. For example, unlike an operating plant, a decommissioning plant will not draw in large quantities of cooling water, which after being run through the plant systems and processed as needed, are then released back into the environment. The gaseous and liquid radioactive effluents of a decommissioning plant, to the extent that there are any, will also be far more limited than those of an operating plant.

Therefore, when a nuclear power plant permanently ceases operations and the licensee permanently defuels the reactor, the risk to the public and the environment from an accident drops significantly because the accident sequences that dominated the operating plant risk are no longer applicable. The primary remaining source of risk to the public and the environment is associated with potential accidents that involve the spent fuel stored in the spent fuel pool. Moreover, the predominant design-basis accident for a defueled reactor is a fuel handling accident. As part of its PSDAR, the licensee is required to consider the potential environmental impacts associated with the planned site-specific decommissioning activities. In almost all cases, the potential environmental impacts will be bounded by the previously issued NEPA environmental assessments or environmental impact statements associated

with the licensing of the facility, as well as the NRC's generic environmental impact statement on decommissioning of nuclear power plants ("Final Generic Environmental Impact Statement on Decommissioning of Nuclear Facilities," NUREG-0586 (1988), as supplemented and updated by the "Generic Environmental Impact Statement on Decommissioning of Nuclear Facilities," NUREG-0586, Supplement 1 (2002)). If a licensee decommissioning activity would result in a significant environmental impact that has not been previously analyzed, then the licensee is prohibited from conducting that activity or the licensee must submit to the NRC a license amendment request or an exemption request. The NRC would then analyze the proposed decommissioning activity and prepare the necessary site-specific environmental analysis.

In short, nuclear power plants undergoing decommissioning present *much lower* environmental and radiological safety risks than operating nuclear power plants, primarily because nuclear fission is no longer occurring in the reactor vessel and all nuclear fuel assemblies have been permanently removed from the reactor vessel and placed into the facility's spent fuel pool. After several years in the spent fuel pool, spent fuel assemblies are typically removed from the pool and placed into "dry" storage in an ISFSI located on the site.

Environmental Considerations/ISFSI

An ISFSI consists of a large concrete structure to safely store the spent fuel and typically occupies a very small portion of the licensed site. The spent fuel assemblies are contained in the storage casks that are placed on or within the concrete structure of the ISFSI; the casks can consist of one or more cask designs, all of which must have been approved by the NRC. The storage casks are passive systems and they are designed for one purpose—to safely store spent fuel for long periods of time. In addition to the concrete structure and storage casks, an ISFSI is typically fenced or otherwise secured as NRC regulations require the ISFSI to be located in a restricted access area. Once in "dry" or ISFSI storage, the risk of any adverse environmental impact is remote given both the robustness and the passive nature of the storage casks. In many cases, the reactor license is terminated in all aspects following decommissioning and the licensee's demonstration of compliance with 10 CFR 20.1402 or other Subpart E regulation except for the ISFSI, which remains under active NRC regulatory oversight until the spent fuel is removed from the site and the ISFSI itself is decommissioned (the applicable NRC ISFSI regulations are at 10 CFR Part 72). In this regard, the "footprint" of the licensed site will be reduced to the boundaries of the ISFSI. To date, no ISFSI has been decommissioned.

Conclusion

In promulgating 10 CFR 50.82, the NRC found that "the activities performed by the licensee during decommissioning do not have a significant potential to impact public health and safety and [therefore] require considerably less oversight by the NRC than during power operations" (61 FR 39278, 39279, "Decommissioning of Nuclear Power Reactors," (July 29, 1996)). The NRC determined that any environmental impacts were expected to be "minor" and that "[a]ny site impact should be bounded by the impacts evaluated by previous applicable" generic and site-specific environmental impact statements (61 FR at 39283). The NRC's operational experience to date has confirmed these findings.

Question: What does the NRC consider to be the major challenges related to current practice of decommissioning nuclear power plants? If possible, please provide examples of decommissioning sites that have experienced some of these challenges.

Response:

As described in the response to the first question above, decommissioning reactors present much lower safety and environmental risks than operating reactors. As such, reactor decommissioning does not present "major challenges," particularly when compared to the potential challenges associated with operating reactors. Once spent fuel is transferred from the spent fuel pool to the on-site ISFSI, any remaining decommissioning issues are typically associated with radiological decommissioning activities (e.g., the removal and proper disposal of reactor components, the removal or remediation of contaminated soil, the remediation of radioactive building surfaces, and the demolition of buildings and structures). The NRC staff notes that amongst the various reactor decommissioning activities, the dismantlement and removal of large reactor components, such as the reactor vessel, can be a complex activity. Any radioactive or environmental risk, however, is readily controlled and manageable with the appropriate planning and this level of planning is ensured by the NRC's regulations (including the requirement to submit to the NRC a PSDAR) and the NRC's oversight processes.

Question: What are some best practices related to decommissioning? Again, please provide examples if possible.

Response:

In October 2016, the NRC issued the Power Reactor Transition from Operations to Decommissioning Lessons Learned Report (ADAMS Accession No. ML16085A029), which documented the NRC staff's lessons learned and best practices associated with the permanent shutdowns of five reactors during the period from 2013-2014. The NRC also maintains a Decommissioning Lessons Learned section on the NRC public website at www.nrc.gov/waste/decommissioning.

Additionally, the Electric Power Research Institute has issued several reports outlining best practices related to reactor decommissioning topics, such as large component removal and decommissioning technologies. Many of these lessons learned reports were developed throughout the decommissioning of several power reactors in the United States (e.g., Maine Yankee, Connecticut Yankee, Shoreham, Trojan).

Question: What are the NRC's regulatory priorities going forward, specifically related to decommissioning and nuclear waste management? Are there specific aspects of decommissioning and waste management that the agency is currently focusing on?

Response:

The NRC has a rulemaking in progress that would make the transition from operations to decommissioning more efficient from a licensing standpoint. In many cases, these new regulations would formalize steps to transition power reactors from operating status to decommissioning, without needing to use the current process of exemptions and license amendments. The NRC staff also recommended clarifying requirements regarding topics such as spent fuel management and environmental reporting requirements.

Question: Are there other ongoing policy discussions or initiatives related to nuclear decommissioning or nuclear waste management that the NRC is involve[d] in, or aware of? If yes, please describe.

Response:

The NRC is currently evaluating two applications for consolidated interim storage facilities (CISFs), which are proposed for the interim storage of spent fuel. The two applications are from Interim Storage Partners in Texas and Holtec International in New Mexico. As of June 2019, the NRC expects to complete the CISF safety and environmental reviews by the end of calendar year 2021. The NRC also has a rulemaking in progress in the low-level waste area; however, any potential changes should have minimal impact on reactor decommissioning waste volumes.

Question: During the decommissioning process, what opportunities exist for members of the public and other interested stakeholders to get involved, both to learn about the project and to provide their input?

Response:

The NRC is required to hold two public meetings in the vicinity of each decommissioning power reactor. The first meeting is held at the beginning of the decommissioning process to obtain comments on the licensee's PSDAR (10 CFR 50.82(a)(4)(ii) or 10 CFR 52.110(d)(2)). The second meeting is held toward the end of the decommissioning process to obtain comments on the licensee's License Termination Plan, which is submitted at least two years before license termination (10 CFR 50.82(a)(9) or 10 CFR 52.110(i)). Further, upon the receipt of the license termination plan or if the licensee proposes alternate criteria for license termination (i.e., other than meeting the requirements of 10 CFR 20.1402, which are set forth in the response to the first question, above), the NRC shall publish a notice in the *Federal Register* as well as publish a notice in a forum, such as a local newspaper "that is readily accessible to individuals in the vicinity of the site, and solicit comments from affected parties" (10 CFR 20.1405).

At some plants, the State or utility may sponsor a Community Advisory Board or Citizens Engagement Panel to provide a forum for local residents to provide input to the licensee and become familiar with the planned decommissioning activities. The NRC staff will also typically attend public forums, such as meetings conducted by local community advisory boards, during the decommissioning process.

Question: How does the NRC interface with states during decommissioning of nuclear power plants? What role do state agencies (and state-level regulations) play in decommissioning, if any?

Response:

Upon the receipt of the license termination plan or if the licensee proposes alternate criteria for license termination (i.e., other than meeting the requirements of 10 CFR 20.1402, which are set forth in the response to the first question, above), the NRC shall notify and solicit comments from state, local, and Tribal governments (10 CFR 20.1405). In addition, state agencies can implement more stringent requirements than the NRC in areas where the NRC does not have regulatory authority, such as non-radiological site remediation issues. The NRC also requires licensees to provide advance notification to State governments regarding shipments of spent fuel and other specific types of waste shipments.

Question: Does the NRC have any concerns related to the cost and financing of decommissioning projects? If yes, please describe any steps being taken to address these concerns.

Response:

The NRC has a comprehensive regulatory framework that provides oversight of a licensee's decommissioning funding during operations and while in decommissioning until its licenses are terminated. NRC regulations at 10 CFR 50.75 establish requirements for providing decommissioning funding assurance. Specifically, the requirements address, among other things, the amount of decommissioning funding to be provided, the methods to be used for assuring sufficient funding, and the provisions contained in trust agreements for safeguarding decommissioning funds. NRC regulations require licensees to provide a minimum decommissioning fund using the formula defined in 10 CFR 50.75(c), and licensees must adjust this rate annually during operations. Licensees may also perform site-specific decommissioning cost estimates that could result in amounts that are higher than the generic-formula amounts specified in 10 CFR 50.75(c). During operations, licensees must biennially submit decommissioning funding status reports to the NRC by March 31.

NRC regulations at 10 CFR 50.82(a) and 10 CFR 52.110(h) provide additional decommissioning funding assurance requirements for reactors in decommissioning. At or about 5 years prior to the projected end of operations, a licensee must submit a preliminary decommissioning cost estimate that includes an up-to-date assessment of the major factors that could affect the cost to decommission. Prior to or within 2 years following permanent cessation of operations, a licensee must submit a Post-Shutdown Decommissioning Activities Report (PSDAR) along with a site-specific decommissioning cost estimate. After submitting its site-specific decommissioning costs estimate, a licensee must submit annual decommissioning funding status reports to the NRC by March 31 of each year until license termination. These reports must include the amount spent on decommissioning, the remaining balance of decommissioning funds, an updated estimate of the cost to complete decommissioning, and, if the sum of the balance of any remaining decommissioning funds, plus earnings on such funds calculated at not greater than a 2 percent real rate of return, does not cover the estimated cost to complete decommissioning, additional financial assurance to cover the estimated cost of completion.

Question: Are there other experts on decommissioning that you could recommend we contact, in government, industry, academia, NGOs or other organizations? If yes, please provide their contact information.

Response:

As mentioned above, the Electric Power Research Institute has published a number of “lessons learned” documents related to reactor decommissioning. In addition, we suggest that you contact the NRC’s Canadian counterpart, the Canadian Nuclear Safety Commission, and the Nuclear Energy Institute, which is the leading domestic U.S. nuclear industry association.

Nuclear Power Decommissioning Practices:

Case Studies and Recommendations for the Great Lakes Basin

Prepared for the Water Quality Board of the International Joint Commission

PHE

LimnoTech

Overview

- Study Scope, Drivers and Key Findings
- What is Decommissioning?
- Study Approach
- Findings and Implications for the Great Lakes
- Recommendations

Study Scope

- Goal: Identify major risks and recommendations related to decommissioning of nuclear power facilities in Great Lakes Basin.
- Scope:
  - Decommissioning related environmental risks
  - Case studies of facilities outside of GLB
  - Interviews of stakeholder groups
- Outside of scope – risks from:
  - Operating nuclear power plants
  - Other nuclear sites such as uranium mines, fuel processing, military/legacy sites, waste management facilities

Major Drivers

- Many nuclear power plants are reaching the end of their useful life
- Aging nuclear fleet in the Great Lakes Basin
  - 12 operating nuclear power plants with 30 reactors
  - 6 shutdown reactors
  - 2 undergoing decommissioning
  - 1 decommissioned
- Market forces could accelerate shutdowns
- Ongoing concerns and stakeholder attention
  - On-site waste storage
  - Long-term disposal of waste in the Basin

Nuclear Power in the Great Lakes Basin

LEGEND ONLY FACILITIES SPECIFICALLY RELATED TO NUCLEAR POWER GENERATION ARE ON THIS MAP

- Uranium Mining and Mill Tailings
- Operating Nuclear Power Reactors*
- Closed Nuclear Power Reactors*
- Nuclear Fuel Waste
- Low-and/or Intermediate-Level Radioactive Waste (L&ILRW) Sites**
- Uranium Processing & Fuel Fabrication
- Deep Geological Repository (DGR)
- Incinerator

* Number in brackets ( ) indicates the number of reactors **These wastes are also stored at all nuclear power reactor sites

- Original production by Irene Koch, 1990-91, Nuclear Awareness Project.
- Updated by Anna Tilman (annatilman@sympatico.ca) and John Jackson (jjackson@web.ca), May 1, 2013.
- Funded by the Citizens' Clearinghouse on Waste Management and Great Lakes United.

Key Findings

- The primary concern is the potential for a release of radioactive substances into the environment:
  - Much greater during plant operations (more complex)
  - Significantly reduced once spent fuel placed in dry storage
- Decommissioning risks:
  - Long-term storage/presence of spent nuclear fuel and wastes
  - On-site spent fuel/waste handling and transfer operations
  - Eventual Off-site transportation of wastes
    - Large quantities of waste in basin (> 50,000 metric tons est.)
    - Modes, methods, and routes of transport
- Decommissioning process:
  - Opportunity for improved engagement with Tribes, public, & stakeholders
  - Uncertainties with trend to transfer process to 3rd parties

What is Decommissioning?

- The process used to safely close a facility
- U.S. Nuclear Regulatory Commission

  10 CFR 50.2: *Decommission* means to remove a facility or site safely from service and reduce residual radioactivity to a level that permits—

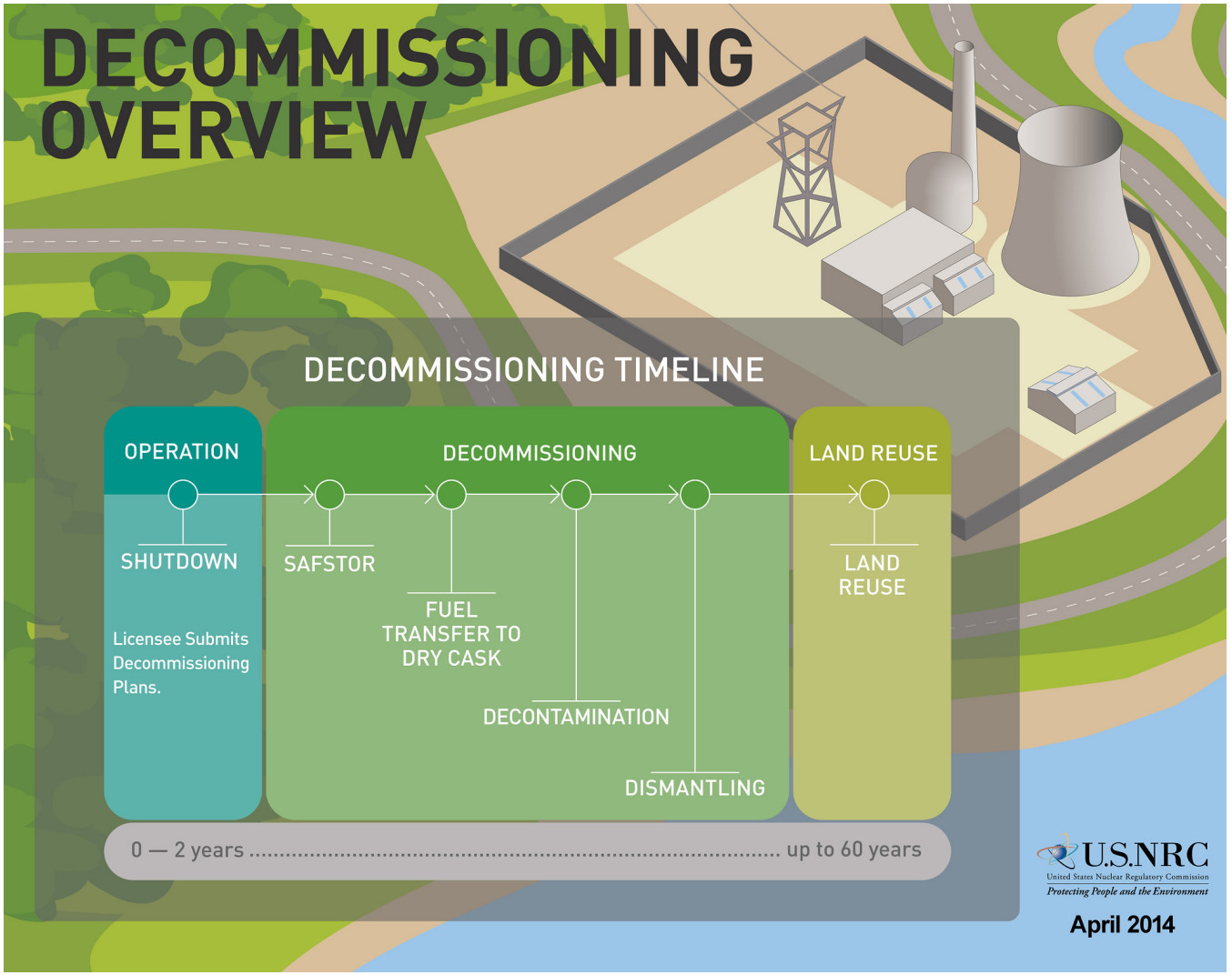
  (1) Release of the property for unrestricted use and termination of the license; or

  (2) Release of the property under restricted conditions and termination of the license

- Canadian Nuclear Safety Commission

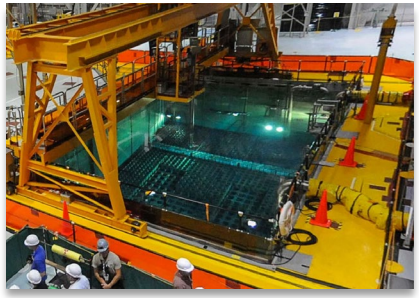
  REGDOC 3-6: Those actions taken to retire a licensed facility permanently from service and render it to a predetermined end-state condition

Decommissioning Overview



Typical Decommissioning Steps

- Shutdown (pre-decommissioning)
  - Major systems turned off
  - Fuel moved from reactor to pool
- Major Activities
  - Planning and facility assessment
  - Decontamination
  - Dismantling and Demolition (Immediate or Deferred)
  - Waste Management
  - Site Characterization and Remediation
  - Monitoring
  - License Termination



Study Approach

- Review WQB Background Report
  - “Nuclear Power Facilities in the Great Lakes Basin: Background Report”
- Conduct Research
  - Decommissioning process, practices, and concerns
  - Evaluate differences in regulations in North America and Europe
- Interview Interested Stakeholders and Identify
  - Concerns
  - Emerging trends, and
  - Future issues and challenges
- Prepare case studies
  - Outside Great Lakes Basin (seven facilities)
  - Identify challenges, successes, and lessons learned

Interviews

- Stakeholders (41 contacted, 17 interviewed)
  - Industry and consultants (4)
  - Regulators (4)
  - NGOs (3)
  - Tribes/First Nations/Métis (2)
  - Other Experts (academics and government) (4)
- Interview Approach
  - Open ended, based on standard questionnaire
  - Anonymity to promote candid responses
  - Key findings and summaries

Case Studies

North America

Canada

- Gentilly 1 and 2 (QC)

United States

- SONGS 1, 2 and 3 (CA)
- Maine Yankee
- Connecticut Yankee

Europe

Germany

- Stade
- Gundremmingen-A

France

- Chooz-A

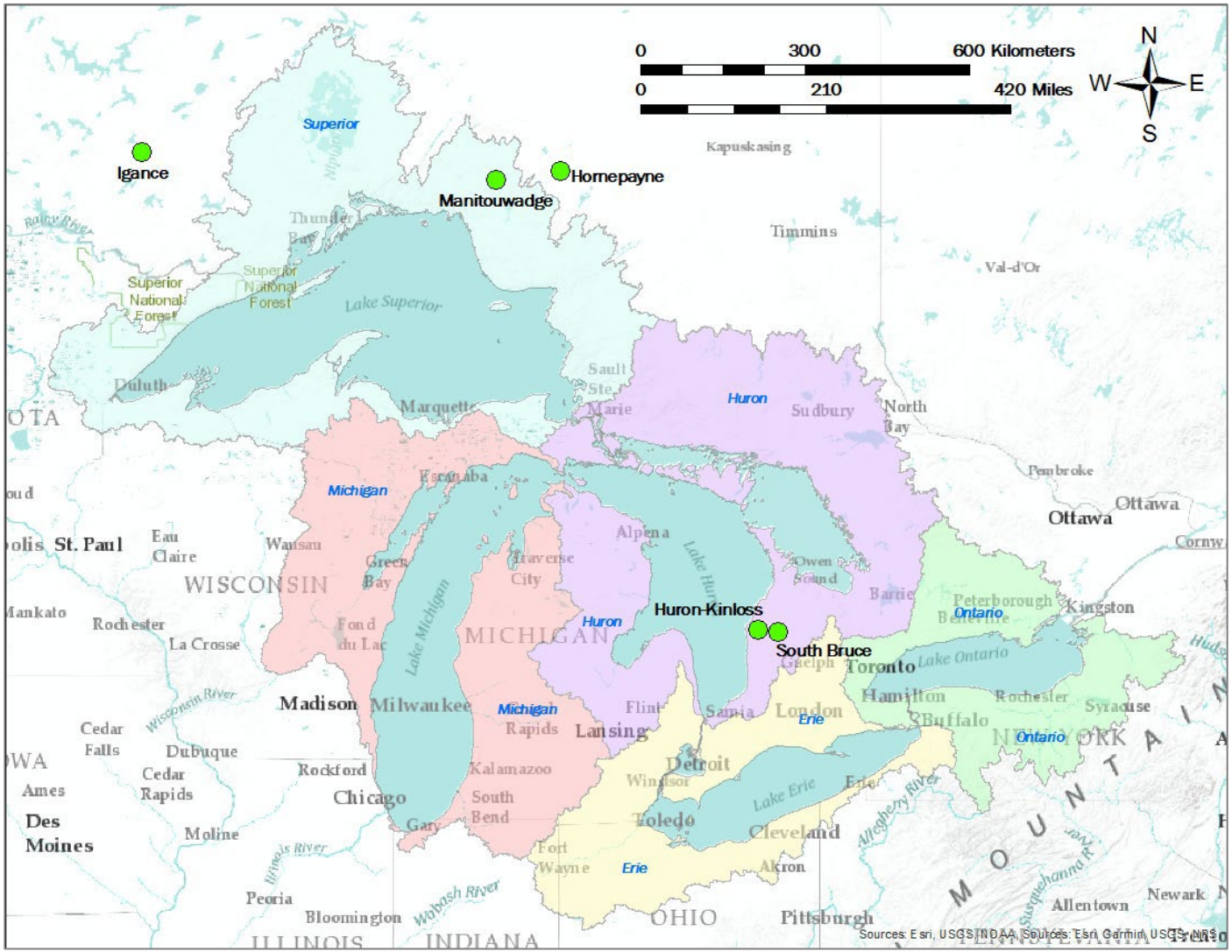
Case Studies (contd.)

Name	Reactor Type	Capacity	Operating Dates	Decommissioning Strategy and Status
North America				
Gentilly-1 and 2	Pressurized heavy water (CANDU)	250 MW (1) 635 MW (2)	1972-1978 (1) 1982-2012 (2)	Both reactors are in a dormant state, with Unit 1 fuel in casks, Unit 2 fuel in pool. Decommissioning completion by 2066.
SONGS 1, 2, and 3	Pressurized water reactor	370 MW (1) 1,070 MW (2, 3)	1968-1992 (1) 1983-2012 (2) 1982-2012 (3)	Unit 1 partially decommissioned. Fuel transfer to casks underway for Units 2 and 3. Completion anticipated by 2030.
Connecticut Yankee	Pressurized water reactor	619 MW	1967-1996	Decommissioned; site released in 2007. Radioactivity in soil and groundwater required additional cleanup and cost.
Maine Yankee	Pressurized water reactor	860 MW	1972-1996	Decommissioned, site released in 2005; cooling water discharge led to forebay contamination. Spent fuel stored onsite.
Europe				
Stade	Pressurized water reactor	672 MW	1972-2003	Dismantling started in 2006, anticipated completion 2022.
Gundremmin-gen-A	Boiling water reactor	237 MW	1967-1977	Dismantling started in 1983, anticipated completion by 2023.
Chooz-A	Pressurized water reactor	300 MW	1967-1991	Permit in 2007, dismantling started 2011, anticipated completion by 2022.

Findings - Waste Management

- High-level waste (spent nuclear fuel)
  - Lack of permanent storage presents a challenge:
    - US: Yucca Mountain appears to be at standstill
    - US: Two Consolidated Interim Storage Facilities (CISF) proposed (Texas and New Mexico)
    - Canada: site selection underway at 5 candidate sites (3 located in Great Lakes Basin)
  - Spent fuel waste is typically stored onsite in dry casks
  - Future Handling/transportation may temporarily increase risk, but remove or reduce long-term risks
- Intermediate and low-level waste
  - Classified based on radioactivity and half-life
  - Four disposal facilities in U.S., none in Canada (interim storage at Bruce Power site, with proposed DGR)
  - Some countries allow “clearance” levels

HLW Repository Siting in Canada



Decommissioning Practices

- Immediate dismantling the preferred approach
  - Europe tends to favor immediate dismantling
  - Deferred approach sometimes used (especially if multiple reactors on a single site)
- Decommissioning license transfer to 3rd parties is an emerging trend
  - Examples – Zion (underway), VT Yankee (upcoming)
  - From utility perspective, a more efficient approach
  - Concerns among public/stakeholders
  - No experience with license transfers in Europe

Example – Big Rock Point

- Big Rock Point
  - 67 MW boiling water reactor
  - Operated 1962-1997
  - Immediate dismantling
  - Fuel transfer to ISFSI complete in 2003
  - Decommissioning completed 2006
  - Except ISFSI, site released for unrestricted use
- Site ownership
  - ISFSI owned by Entergy
  - Rest owned by Consumers Energy
- May be worth more detailed study for lessons learned

Regulations and Funding

- Regulations and Oversight
  - U.S. and Canada – federal regulation and oversight
  - France also has central regulation
  - Germany – federal laws enforced by provinces
- Funding of decommissioning
  - Typically operator's responsibility
  - Concern in France about sufficiency of funds
  - UK, Germany setting aside public funds
- Liability for offsite contamination
  - Operator must have insurance for accidents
  - Unclear for smaller "routine" or ongoing releases

Other Issues

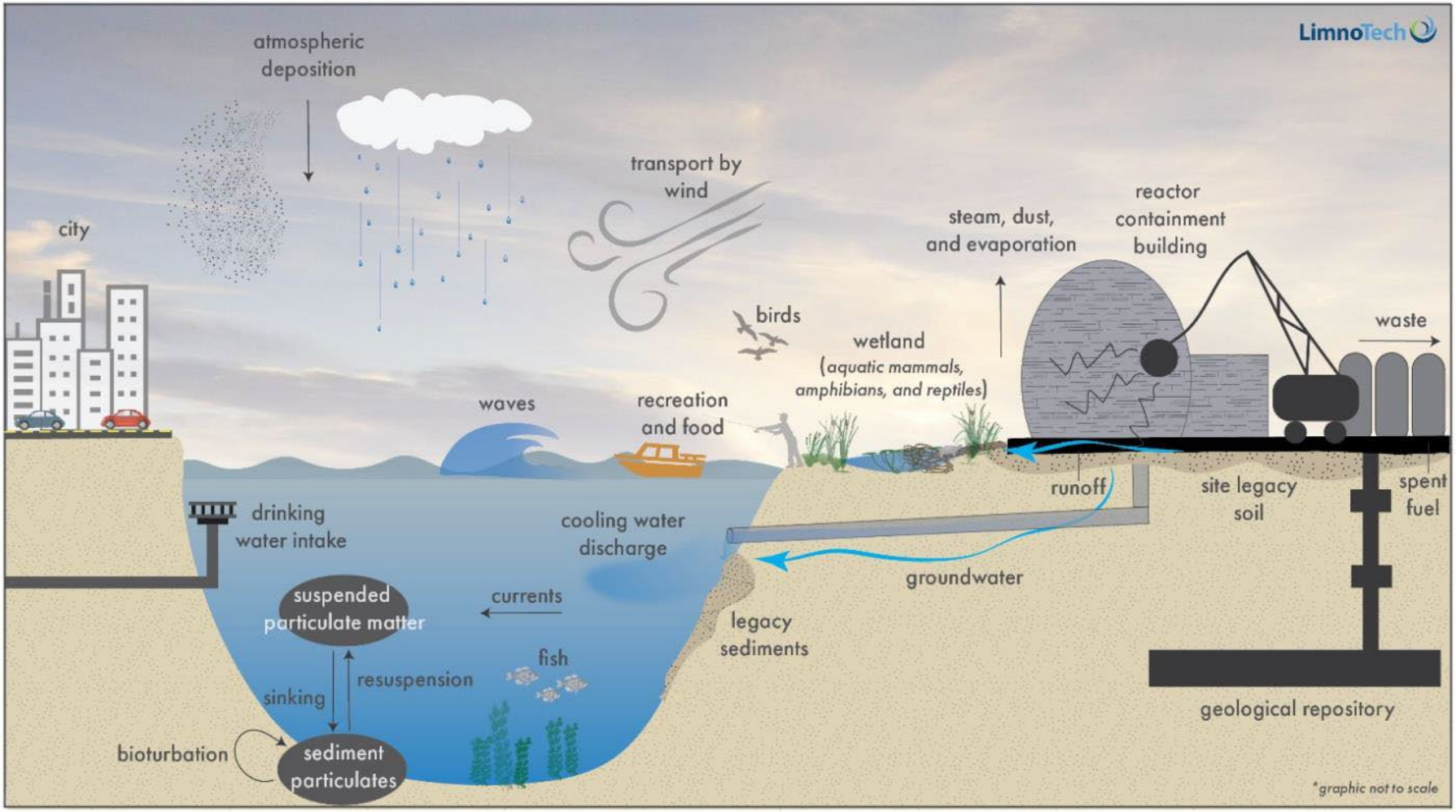
- Challenges related to stakeholder engagement
  - Tribes/First Nations/Métis engaged on nuclear issues
  - Regulatory requirements vs best practice (e.g., citizen advisory panels)
  - Concerns along potential HLW transportation corridors
- Economic impacts of nuclear plant shutdown
  - Lost jobs and tax revenue can be concern for local community
  - Impacts especially severe in rural communities
  - Communities and plant operators need to plan for transition well before shutdown

Implications for the Great Lakes

- Key Concerns:
  - Onsite storage of HLW
  - Onsite contamination (groundwater, soil, sediments)
  - Offsite transport of HLW/LLW

Source	Superior	Michigan	Huron	Erie	Ontario
Reactors	**0**	**9**	**9**	**4**	**16**
- Operating	0	5	8	3	14
- Shutdown	0	1	1	1	2
- Decommissioning	0	2	0	0	0
- ISFSI Only	0	1	0	0	0
HLW Repository	Proposed	-	Proposed	-	-
LLW Repository	-	-	Interim/ Proposed	-	-

Potential Exposure Pathways



Implications for the Great Lakes

- Lake Superior:
  - No nuclear power plants
  - Potential high-level repository site in Ontario (Manitouwadge area)
- Lake Michigan:
  - Nine U.S. reactors at 6 sites, most closed or closing
  - One decommissioned except for ISFSI (Big Rock Point)
  - Prevailing wind transport over lake/ice from western sites, over land from eastern sites
- Lake Huron:
  - Nine Canadian reactors at Bruce site, 1 closed
  - Potential low/intermediate and high-level waste disposal sites at or near plant
  - Wind transport over land
- Lake Erie:
  - Four U.S. reactors at 3 sites, 1 closed
  - Two plants operating under state subsidies (Ohio)
  - Wind transport over lake/ice from MI (Fermi), along shore from OH sites
- Lake Ontario:
  - Twelve Canadian reactors at 2 sites near Toronto
  - Four U.S. reactors at 2 sites
  - Wind transport along shore from both

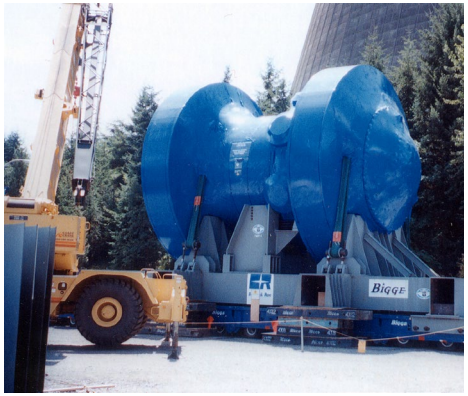
Recommendations

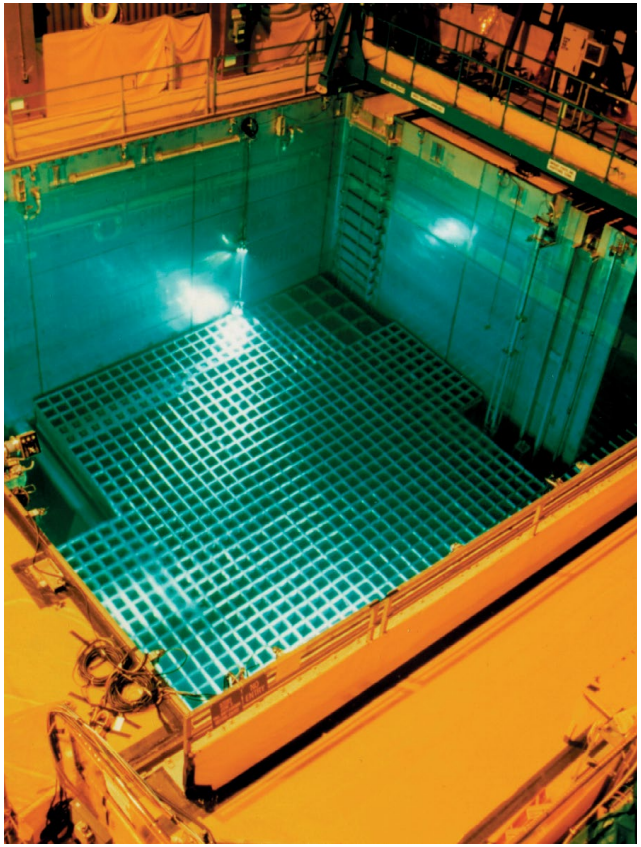
- Continue to monitor issues and trends related to decommissioning
  - Siting geological repositories in Canada
  - Interim storage facilities in the U.S.
  - Decommissioning license transfers to 3rd parties
- Facilitate coordination of binational policies
  - Decommissioning (including offsite contamination)
  - Waste transport
  - Waste disposal
- Promote development of a publicly-accessible binational database
  - Decommissioning lessons learned
  - Best practices

Recommendations

- Advocate for use of Citizen Advisory Panels
  - Promote consideration of Indigenous views during decommissioning
- Encourage planning for transition
  - Coordinate with nuclear power plant operators
  - Communities, local governments, and business groups
- Conduct additional research
  - Update 1997 IJC Report “Inventory of Radionuclides for the Great Lakes” and subsequent “Report on Bioaccumulation of Elements to Accompany the Inventory of Radionuclides in the Great Lakes Basin”
  - Conduct vulnerability assessments at site specific, or community level, concerns for lake and coastal ecosystem threats and vulnerable resources related to decommissioning and post decommissioning activities
  - Risks of deferred or immediate decommissioning within Great Lakes Basin
  - Develop lessons learned and best practices related to Big Rock Point

Thank You!





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