Ke

NUCLEAR DECOMMISSIONING: PAYING MORE FOR GREATER, UNCOMPENSATED RISKS

August 8, 2016

Christina Simeone

Kleinman Center for Energy Policy

NUCLEAR DECOMISSIONING: PAYING MORE FOR GREATER, UNCOMPENSATED RISKS

Christina Simeone, August 8, 2016 kleinmanenergy.upenn.edu

EXECUTIVE SUMMARY

Low gas prices, increasing penetration of renewable energy, weak demand, and significant capital expenditure requirements at nuclear power plants are challenging reactor economics and prompting premature retirements, defined as retirement before license expiration. Most public dialogue about these retirements has centered on support or opposition for public policies to keep these plants operating. Justifications for such subsidies typically focus on retention of local jobs, and on how these plants provide reliable baseload power at a low cost. There are also significant concerns about losing zero carbon power, which is critical to meeting national and international climate change goals.

Seemingly absent from the dialogue however is a focus on the imposition of new costs and risks, which are both accelerated upon plant retirement.

Decommissioning is the process of decontaminating the plant site and releasing the plant owner's nuclear operating license. While there are some concerns about plant licensees having access to sufficient funds to pay for the full cost of actual plant decontamination, the bigger issue surrounds the fate of spent nuclear fuel and high-level radioactive waste.

U.S. and international experts agree that permanent geologic (i.e. underground) disposal of highly radioactive spent nuclear fuel is the safest and most secure way to manage this waste, which remains hazardous for thousands of years. The federal government signed contracts with owner/operators (i.e. licensees) of nuclear power plants, committing the government to taking custody of nuclear waste for disposal in a federally-controlled geologic disposal repository, beginning in 1998. Electric utility owner/licensees of nuclear generation paid upfront fees to the government to enable the construction of the geologic repository. These licensee fees were recovered from electricity ratepayers that received the benefits of low-cost nuclear power. These per-kilowatt-hour fees were deposited into a restricted federal fund called the Nuclear Waste Fund (NWF), now valued at $34.3 billion, and these funds can only be used in support of the geologic disposal site. However, the disposal site hasn't been built and there are no plans underway for its construction.

As a result, licensees are forced to temporarily store this spent fuel waste on-site at the plant, most of the time in dedicated facilities. Licensees must expend significant costs to construct, operate, maintain, and secure these facilities located on the same site as the plant. This reality prevents full release of the licensee's land and license, creating ongoing liabilities. Licensees have successfully fought the federal government in court for its failure to accept waste, per contract agreement. As a result, taxpayers have reimbursed about $5.3 billion in licensee costs associated with ongoing on-site storage of high-level radioactive waste. These costs will continue to accumulate until the federal government accepts all of the contracted waste, a figure currently estimated to be between $29 billion and $50 billion.

Public dialogue about nuclear plant retirements should begin to focus on four main themes that result from the facts above:

INCREASED RISKS WITH DISTRIBUTED INTERIM STORAGE – Experts agree that long-term storage of high-level radioactive waste is simply not as safe or secure as permanent geologic disposal. In America, geologic disposal has been pursued, but so far has proven to be politically infeasible. As a result, for decades, nuclear plants have been forced to store waste on site. When a nuclear plant closes, the plant site will be converted to a "temporary" but indefinite waste storage facility. Absent a significant change in political will, America will end up with a collection of distributed interim storage facilities dotting its landscape, potentially in perpetuity. **This distributed interim storage "solution" increases risks, compared to a single geologic disposal site**.

SHIFTING COSTS TO TAXPAYERS WITH NO REFUND TO RATEPAYERS – On-site, interim storage facilities will need to be constructed, secured, maintained and monitored in perpetuity, or until a federal geologic repository and/or reprocessing facility is established. These are new costs, not envisioned when plant licensees signed agreements with the federal government for geologic disposal of waste. Licensees will be forced to build and maintain these interim storage facilities at a significant expense. As a result of licensee's successful litigation against the federal government, **taxpayer funds ranging from $29 billion to $50 billion will be used to reimburse the licensee's interim storage costs**, plus the government's cost of litigation. And these costs will continue to grow by $500 million per year if the government doesn't begin accepting waste in 2025. Many of these taxpayers will be the same ratepayers that paid fees to construct the geologic repository, for which no plans are underway to construct. By law, the $34.3 billion in ratepayer funds accumulated in the NWF can only be used for activities related to the geologic repository. **However, no refund has been offered to these ratepayers, even though they paid for permanent disposal that hasn't materialized, and taxpayers are paying additional (i.e. not transferred from ratepayer funds) costs for interim storage**.

IMPOSING UNCOMPENSATED RISK ON COMMUNITIES – Becoming the indefinite home to tons of highly radioactive nuclear waste upon plant retirement—with all the attendant risks—was certainly not the original expectation for communities that agreed to host nuclear power plants. Furthermore, these communities are home to many of the same electric

SEEMINGLY ABSENT FROM THE DIALOGUE HOWEVER IS A FOCUS ON THE IMPOSITION OF NEW COSTS AND RISKS, WHICH ARE BOTH ACCELERATED UPON PLANT RETIREMENT.

ratepayers who contributed funds to build a geologic disposal repository so this waste would have a safe, secure, and permanent home far from their backyards. Lastly, when a nuclear power plant shuts down, the host community is no longer receiving benefits (i.e. low cost, reliable, carbon-free electricity) from the plant. **The community is receiving no compensation for serving as a nuclear waste storage site, nor is the community being paid a premium for the additional risks associated with such storage activity.** Essentially, these ratepayer/communities have paid to reduce risk, but have in fact received more risk.

LICENSEE'S ABILITY TO PAY FOR DECOMMISSIONING – The U.S. Nuclear Regulatory Commission (NRC) requires licensees to provide upfront financial assurances that funds can and will be available to pay for decommissioning costs. However, there are considerable analysis and data indicating NRC's formula to calculate required minimum decommissioning costs is flawed and understates costs. Licensees are required to provide site-specific decommissioning cost analysis near the time of plant retirement. However, premature retirement accelerates the need for decommissioning funds to be available and reduces the time for these funds to appreciate. **More research is needed to understand if parent companies of current at-risk plants have the ability to pay for actual, site-specific decommissioning costs**. It is unclear who would pay decommissioning costs in the case of licensee/parent company bankruptcy.

It is important to understand that plant licensees did not create the distributed interim storage "solution" that is forcing ratepayers and taxpayers to pay more for increased risks.

The realities of nuclear decommissioning and premature plant retirements may meaningfully impact local politics and should be transparently reviewed as part of contemporary energy policy discourse.

NUCLEAR DECOMISSIONING:
PAYING MORE FOR GREATER, UNCOMPENSATED RISKS

***Christina Simeone, August 8, 2016 kleinmanenergy.upenn.edu

CONTENTS

The author wishes to acknowledge helpful comments from a reviewer of an earlier draft. Any remaining errors are the responsibility of the author alone.

INTRODUCTION

THE ECONOMIC VIABILITY OF SOME EXISTING NUCLEAR POWER PLANTS IS DIMINISHING, CAUSING A WAVE OF PLANNED OR THREATENED RETIREMENTS.

Discussion about these nuclear power plant retirements has centered on the loss of low-cost, zero carbon, baseload power that can help meet reliability and climate change goals. Fear of losing these resources is prompting exploration and promotion of policies to improve plant economics, for example, by establishing state-based zero carbon standards, ratepayer supported power purchase agreements in deregulated states, and competitive market reforms.

Comparatively less attention is being focused on what happens when these nuclear power plants close. The process of decommissioning, which is meant to guide decontamination of the plant site and terminate the owner/operator's license with the U.S. Nuclear Regulatory Commission (NRC), is the focus of this report. The report provides an overview of what happens when a nuclear plant retires, including, identifying decommission options, reviewing the regulatory process of decommissioning, and examining the adequacy of funds to pay for decommissioning costs. The report makes observations related to imposition of new costs and risks, mostly related to treatment of nuclear waste, which should be integrated into contemporary policy discourse about nuclear plant retirements.

WAVE OF PREMATURE REACTOR RETIREMENTS

Certain segments of the U.S. nuclear power industry are actively seeking government subsidies or market reforms to support economically failing plants. Other struggling nuclear plants have resigned to retirement. Plants that retire prior to the expiration of current NRC operating licenses are considered prematurely retired. Many (but not all) of these struggling facilities are single unit plants operating in deregulated (i.e. competitive generation markets) jurisdictions. These small plants can't take advantage of economies of scale to spread costs over larger revenue streams. For example, after the 2011 Fukushima Dia-ichi Plant meltdown in Japan, the NRC required nuclear plants to make capital investments and take certain actions in response to lessons learned from Japan.[1] Competitive market clearing prices are being pushed down by a combination of increased reliance on low-cost natural gas plants, increased supply of renewable energy, and reduced consumer demand for power. Lower clearing prices reduce revenues to generators, like nuclear power plants, impacting profitability. Even nuclear plants in regulated jurisdictions are not immune from failure.

A 2013 analysis from Platts found that more than one-third (38 reactors) of the U.S. nuclear power fleet's 100 reactors are on the edge of economic viability and could be forced into retirement by an unplanned event, such as an extended repair outage (Dolley 2013). Platts found that 12 of these plants (15 reactors) were especially at risk. An analysis by SNL Energy examined 2015 reports from three rating agencies (Moody's, UBS, and Fitch Ratings) and found that at least 12 nuclear units are "at risk" for early retirement (Engblom and Fawad 2015). The SNL Energy report found that these at risk units represent about 11 percent of all U.S. nuclear power.

Since 2013, five nuclear reactors have retired, all in regulated jurisdictions, representing over 4,000 megawatts (MWs) of summer capacity. Within the past two years, unit licensees have announced or threatened retirement of over 10,000 MWs of summer capacity, mostly in deregulated jurisdictions, with another 4,700 MWs of capacity being identified as "at-risk" by analysts like Platts and SNL. Comparatively, there are only 5,600 MWs of new nuclear currently under construction. A list of these reactors is available in **Appendix A.**

[1] More information on the Fukushima incident and the NRC's response is available at: http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/japan-events.html

SPENT NUCLEAR FUEL AND DECOMMISSIONING OPTIONS

Nuclear power plants use nuclear fission reactions from radioactive fuel to produce heat that generates steam to spin turbines that generate electricity. Use of radioactive fuel creates a host of contamination and waste issues that must be managed during operations and when a nuclear power plant retires. The NRC grants construction and operating licenses for nuclear power plants and also regulates the process of decontamination and safe disposal of radioactive material once a nuclear power plant decides to permanently close. This post-closure "decommissioning" process involves cleanup of radioactively contaminated plant equipment and structures, and the removal of radioactive fuel, with the ultimate goal of reducing on-site radioactivity to levels that permit the release (for restricted or unrestricted use) of the land, and termination of the plant's operating license.

According to the NRC, nuclear power reactors with NRC operating licenses (herein referred to as licensees) can choose one of four decommissioning pathways, but decommissioning must be completed within 60 years of the reactor terminating operations (U.S. Nuclear Regulatory Commission 2015):

DECON – The immediate dismantling of the plant, with equipment and materials contaminated with radiation either decontaminated or removed for disposal/storage. This results in returning radioactivity to levels that allow release of the property and termination of the operating license.

SAFSTOR – A type of deferred decommissioning where the facility is maintained and monitored safely, allowing radioactive materials to decay, and with dismantling and decontamination of the property happening in the future.

ENTOMB – Radioactive contaminants are permanently encased in structurally sound material, on site. The site is maintained and monitored until enough decay has occurred to allow for release of the property. According to the NRC, no licensed facilities have requested the ENTOMB option.

Combination DECON/SAFSTOR – Dismantling and decontaminating portions of the plant, leaving other portions in SAFSTOR. This option may be based on the availability of waste disposal sites.

NRC notes, the combination DECON/SAFSTOR option is likely to be the dominant licensee decommissioning strategy. This is because the federal government 1) prohibited nuclear fuel reprocessing in 1977, and 2) subsequently failed to develop a centralized geologic disposal repository. One of these two options for handling spent nuclear fuel was envisioned by most nuclear plant licensees at the time of original plant development. In the absence of reprocessing or a geologic repository, licensees are forced to store spent fuel on-site, perhaps in perpetuity.

Typically, nuclear power plants refuel every 12-24 months, where about a third of the plant's fuel is removed and replaced with new fuel rods. The removed "spent fuel" is hot, highly radioactive, and must be transferred to on-site pools of water for thermal cooling and decay of certain short-lived radioactive isotopes. These spent fuel pools (SFP) exist at all U.S. operating power plants and require operational controls and maintenance of mechanical and electrical systems (Bagget and Brach 2005). Due to limited space, plant licensees began using high-density storage racks to increase the capacity of SFPs, essentially enabling more fuel to fit in the existing pools (Bagget and Brach 2005). When additional space was needed, NRC permitted the use of "dry cask" storage systems. The dry storage system can be used after the spent fuel has remained in the SFP for a few years (3 to 10 years), allowing it to cool and decay. The cooled spent fuel is placed into a metal cylindrical container, which is then encased in another metal or concrete outer shell. This dry storage system is designed to manage residual heat, contain radiation, and allow the material to decay. As of September 2015, spent fuel in dry storage is occurring in 34 states at more than 59 sites (U.S. Nuclear Regulatory Commission 2015b). At the end of 2009, about 62,600 metric tons of commercial spent fuel had accumulated, with 78 percent being stored in SFPs and 22 percent in dry storage, with total waste accumulation increasing by over 2,000 metric tons per year (U.S. Nuclear Regulatory Commission 2015c).

Dry storage typically takes place at "independent spent fuel storage installations" (ISFSI), permitted by NRC as an interim storage solution. Power plant licensees typically develop ISFSI's on a portion of the land covered under their original license. However, ISFSI's can also be licensed and built separately from a nuclear power plant. For an ISFSI located at a power plant site, the licensee can seek to decommission and release the

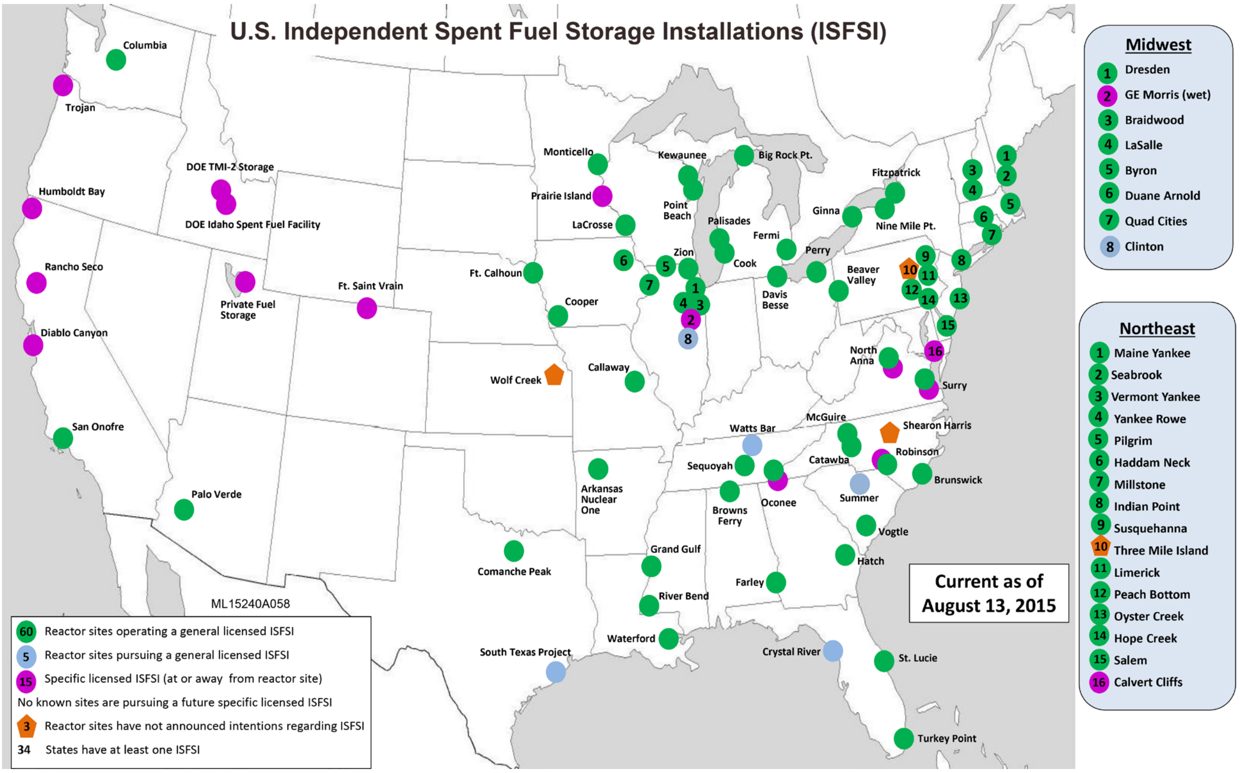

Figure 1: *U.S. Independent Spent Fuel Storage Installations (ISFSI), courtesy of (Nuclear Regulatory Commission 2015e)*

majority of the decontaminated land in its geographic footprint, except for the land containing the ISFSI. The ISFSI must remain under NRC license and regulation, and licensees are responsible for securing, maintaining, and insuring the facilities, and funding the ISFSI's eventual decommissioning.

Aside from spent fuel, there are other types of radioactive wastes to manage during a power plant decommissioning process. The U.S. NRC classifies waste in four categories (A, B, C, and GTCC) related to increasing levels of radioactivity and corresponding protection requirements. Classes A, B, and C have increasing levels of radioactivity, but are still considered low-level. These low-level radioactive wastes are suitable for near surface disposal, which is available at a very limited number of disposal sites.[2] Class GTCC (Greater Than Class C) waste (e.g. spent fuel rods) is not acceptable for near ground level disposal and requires disposal in a geologic repository.[3] However, NRC has allowed interim storage of GTCC waste to be stored at ISFSI facilities. As you can see from the data in Table 2, the bulk of waste generated at a nuclear power plant is low level. As discussed above, the smaller volumes of GTCC level waste (i.e. spent fuel rods) would be managed through interim storage, such as an ISFSI.

It is important to understand the difference between storage and disposal of nuclear waste, specifically related to spent nuclear fuel. Storage is an interim step, before disposal, in the nuclear waste management process where the waste is kept in isolation with active human control and maintenance. Disposal is meant to be the final step in nuclear waste management, where waste is kept in isolation that does not require active human control or maintenance. Disposal relies on passive natural and man-made barriers to provide isolation and does not easily allow for human access.

Waste Type	Maine Yankee 860 MWe	Rancho Seco 913 MWe
Class A	90,650 m^3	17,244 m^3
Class B & C	570 m^3	93 m^3
GTCC	n/a	11 m^3
Total	**106,610 m^3**	**17,348 m^3**

Table 2: *Decommissioning Radioactive Waste Volumes for U.S. Power Plants*

[2] For example, the EnergySolutions site in Clive, Utah can accept only class A waste and the Waste Control Specialists facility in Andrews, Texas can accept Class A – C wastes from states, provided approval from the state of Texas.

[3] 10 CFR Part 61.55(a)(2)(iv) states, "Waste that is not generally acceptable for near-surface disposal is waste for which form and disposal methods must be different, and in general more stringent, than those specified for Class C waste. In the absence of specific requirements in this part, such waste must be disposed of in a geologic repository as defined in part 60 or 63 of this chapter unless proposals for disposal of such waste in a disposal site licensed pursuant to this part are approved by the Commission."

THE SAFETY AND SUSTAINABILITY OF LONG-TERM RADIOACTIVE WASTE STORAGE

A POSITION PAPER FROM THE INTERNATIONAL ATOMIC ENERGY ASSOCIATION

In 2003, the International Atomic Energy Agency (IAEA) issued a position paper from international experts exploring the safety and sustainability of long-term high level radioactive waste storage (International Atomic Energy Agency 2003). The paper was published in response to the growing trend of indefinite, on-site, surface-level waste storage emerging as a result of difficulties in developing underground, geologic disposal sites.

The IAEA paper found that while short-term storage is a necessary phase in nuclear waste management, perpetual storage of high-level radioactive waste that remains hazardous for thousands of years is neither feasible nor acceptable. Instead, the report reiterated support for geologic disposal of waste, where the waste is placed in containment containers and isolated from humans in the environment by placing it deep underground. Below are some of the issues considered in the IAEA's paper:

SAFETY - Active surveillance and maintenance is required to ensure the safety of radioactive waste storage, whereas geologic disposal offers long-term safety without surveillance and maintenance.

MAINTENANCE - Although maintenance is easier on land surface than it is underground, it is not possible to assure that the institutions responsible for maintenance will remain viable or in control over the thousands of years the waste remains hazardous. In addition, geologic storage provides a natural radioactivity barrier, reducing or eliminating the need for maintenance.

RETRIEVAL - Retrieval of material is easier on land surface; however, geologic disposal can be developed in stages to allow retain ability to retrieve materials.

SECURITY - Putting waste underground increases the security of the materials.

COSTS - Disposal has a large capital cost, whereas storage has a significant operating cost. Long term financing for storage is highly dependent on interest rates and inflation, which are hard to predict over the indefinite timeframe required for these storage facilities.

COMMUNITY ATTITUDES - Storage facilities are perceived to be temporary and tend to excite less public opposition than permanent disposal facilities.

TRANSFER OF INFORMATION - Long-term storage of radioactive waste requires the retention and transfer of information—for example inventories, maintenance activities, safety procedure—to future generations. There are uncertainties about how to accomplish such retention and transfer, for example, choice of language, vulnerabilities of different media (electronic, paper, analog), and ability to maintain knowledge base.

IAEA's publication can be found at: http://www-pub.iaea.org/MTCD/publications/PDF/LTS-RW_web.pdf

DECOMMISSIONING PROCESS

As of July 5, 2016, the NRC references 19 power reactor sites undergoing decommissioning (U.S. Nuclear Regulatory Commission 2016). A list of these facilities is available in Appendix B and is expected to grow, as discussed at the beginning of this paper. There are five general stages to the decommissioning process, summarized below (U.S. Nuclear Regulatory Commission 2015).

Initial Notification – Once the decision has been made to permanently cease operations at a nuclear power plant, the plant's licensee must notify NRC in writing within 30 days. The licensee must also notify NRC in writing when the fuel has been removed from the reactor.

Post-Shutdown Decommissioning Activities Report (PSDAR) – Within two years of ceasing operations, the licensee must submit a PSDAR to the NRC and the affected state(s). The PSDAR includes a schedule and description of planned decommissioning activities, an estimate of expected costs, and a discussion of the rational supporting any conclusion that environmental impacts from site specific decommissioning activities have already been addressed in previous environmental analyses (i.e. Environmental Impact Statements). Submission of a license amendment for approval is required for any decommissioning activities that would result in additional environmental impacts.

Note: The NRC does not approve the PSDAR. Licensees may begin decommissioning activities 90 days after NRC's receipt of the PSDAR as long as such activities do not inhibit the ability to release the site for unrestricted use, cause unforeseen environmental impacts, or jeopardize the adequacy of decommissioning funds (U.S. Nuclear Regulatory Commission 2015d). NRC publishes PSDARs in the federal register for public comment, and hosts a public meeting near the impacted facility.

License Termination Plan (LTP) – Each licensee must submit an application to terminate its license that is accompanied by a LTP, which must be submitted at least two years before the proposed license termination date. The LTP must include site characterization, identification of remaining dismantlement activities, plans for site remediation, plans for the final radiological survey, a description of any restricted end uses for the site, an update on remaining site-specific decommissioning costs, a supplement to the environmental report including any new information or changes, and other factors. The LTP is then published in the Federal Register for public comment and NRC holds a public meeting in the area of the facility to discuss the LTP. The LTP is approved by NRC through a license amendment.

Implementation of the LTP – The licensee or other responsible party must complete decommissioning per the details of the LTP within 60 years of the date of permanent cessation of operations. However, NRC can extend this date when necessary to protect public health and safety based on criteria including, lack of available waste disposal capacity, and other site-specific factors.

Complete Decommissioning – Upon completion of decommissioning activities, the licensee must submit a Final Status Survey Report (FSSR) that details the radiological conditions of the site and requests that NRC either 1) terminate the 10 CFR Part 50 operating license, or 2) reduce the geographic boundary of the license to contain only the area that is storing nuclear waste (e.g. the ISFSI). The NRC will approve the FSSR and license termination request depending on adherence to the LTP and radiological demonstration that the site is suitable for release.

Note: There are also power plant decommissioning sites where a separate license (10 CFR Part 72) for the ISFSI is provided, allowing the 10 CFR Part 50 license to be terminated after completion of reactor decommissioning.

Figure 2: *Location of Power Reactor Sites Undergoing Decommissioning image courtesy of (U.S. Nuclear Regulatory Commission 2016)*

ADEQUACY OF DECOMISSIONING AND WASTE DISPOSAL FUNDS

The approach to funding decommissioning of nuclear power plants and spent fuel waste disposal eventually formed in two paths. First, licensees must provide financial assurances that they can pay the cost of plant decontamination and decommissioning. Methods available include prepayment in a trust fund, a surety, insurance or parent company guarantee, and/or an external sinking fund (e.g. to accumulate ratepayer funds in a dedicated account). Second, utility owners of nuclear generation would deposit ratepayer fees into the Nuclear Waste Fund, to support development of a national geologic repository for disposal of spent fuel. This approach was, in part, meant to ensure that the polluter and benefactors (power plant/ratepayers) could cover all costs for nuclear power clean up, with no budgetary impact on taxpayers and the federal government. More information on these two approaches is included below.

Individual Decommissioning Financial Assurance - Before power generation operations begin, a nuclear power plant licensee is required to establish financial assurances (e.g. trust fund, guarantee or sinking fund) to ensure sufficient funds will be available to pay for decommissioning of the facility. NRC regulations establish a minimum decommissioning amount through a formula based on 1986 dollars. Licensees must recalculate to current dollars annually and report every two years to NRC about the status of their decommissioning funds. The NRC maintains that while each unit is different, the average reactor decommissioning cost is between $300 million to $400 million (U.S. Nuclear Regulatory Commission 2015). Approximately 70 percent of licensees are authorized to accumulate decommissioning funds over the operating life of their plant and the remaining licensees must provide assurances through other methods, for example through prepayment, surety, and/or guarantee (U.S. Nuclear Regulatory Commission 2015).

Nuclear Waste Fund – Authorized in 1982 by the Nuclear Waste Policy Act (NWPA), a per kilowatt hour fee (originally set at one tenth a cent per KWh) was established to be remitted to the fund by utility owners of nuclear generation with these cost being recovered from applicable electricity ratepayers. Proceeds were deposited into the Nuclear Waste Fund (NWF) that was established to cover the costs of developing a geologic repository for permanent disposal of spent nuclear fuel. The U.S. Department of Energy (DOE) agreed to take title of spent fuel in exchange for deposit of ratepayer fees into the NWF, through Standard Contracts. During the 1980s, DOE entered into 76 Standard Contracts covering 118 reactors that committed the government to accept waste for disposal beginning in January 1998 (U.S. Department of Energy 2012, 24). The NWPA also stated NRC could not issue new licenses or renew current licenses without a Standard Contract in place.

For state and local policymakers, the upcoming wave of nuclear reactor retirements should raise questions about the adequacy of existing funds and management strategies to safely and effectively complete decommissioning and waste disposal. There are essentially two issues to be explored at the state and local level: 1) are financial assurances for plant decommissioning activities adequate to cover actual costs, and 2) in absence of a federal repository for nuclear waste disposal, how will spent nuclear fuel and high level waste be safely managed and are there sufficient funds to do so?

FINANCIAL ASSURANCES FOR PLANT DECOMMISSIONING

Multiple reports over time have called into question the adequacy of decommissioning cost estimates for which licensees must financially assure. For example:

- In 2007, Daniel Williams of the U.S. Government Accountability Office (GAO) examined 222 individual decommissioning trust funds, and 99 utility owners covering 122 nuclear reactors spanning the years 1998, 2000, 2001, and 2004 (Williams 2007). He performed 20,000 iterations of Monte Carlo analysis to incorporate risk (i.e. uncertainty of underlying assumptions) into his simulation model to determine funding adequacy. He found decommissioning adequacy percentages of trust funds tend to be highly variable. Although a sizable majority of trust funds are above benchmark levels, he found that 35 percent of the trust funds are below benchmark—a funding shortfall he believed should concern regulators and policymakers.

- In 2011, the NRC commissioned an analysis of the decommissioning formula from the Pacific Northwest National Laboratory (PNNL) (Short, et al. 2012). PNNL's comprehensive analysis studied the various cost categories comprising the decommissioning formula and recommended an update to the formula, which was overall underestimating decommissioning costs. For example, PNNL compared actual decommissioning costs at four reactors (Haddam Neck, Maine Yankee, Trojan and Rancho Seco) to the NRC's minimum formula costs and found for all but Trojan, the formula costs were insufficient. In the case of Haddam Neck, the formula cost of $414 million was less than half of the actual $918 million cost.
- A 2012 report from the GAO found that NRC's formula may not reliably estimate adequate decommissioning costs (U.S. Government Accountability Office 2012). GAO compared NRC's decommissioning formula with site-specific decommissioning estimates for 12 reactors. For five of the reactors, NRC's formula captured 57 to 76 percent of the site-specific costs. For the seven remaining reactors, NRC's formula captured 84 to 103 percent of the site-specific decommissioning costs.
- A 2016 audit report by the NRC's Office of the Inspector General found, among other things, that NRC's minimum decommissioning cost estimate formula relied on studies conducted from 1978-1980 and needs to be re-evaluated as it may not provide a realistic estimate of decommissioning costs (Office of the Inspector General U.S. NRC 2016). The audit report references information from a licensee stating the actual, site-specific cost to decommission the plant was $2.2 billion; while the NRC formula calculated only $600 million (Office of the Inspector General U.S. NRC 2016, 10). The report also found that NRC staff do not typically identify funding shortfalls during the biennial funding reviews.

In 2013, though referencing the information in the GAO report and the PNNL analysis, NRC staff did not recommend revising the minimum decommissioning cost formula (Leeds 2013). NRC staff's justification for not updating the formula was based on:

1. The formula provides a reasonable assurance that the bulk of funds will be provided
2. A site-specific decommissioning cost estimate (SCCE) is required about five years before permanent cessation of operations (or two years after a premature shutdown) which then becomes the minimum acceptable amount to which the licensee must certify
3. The biennial review process allows for funding adequacy review
4. If needed, the NRC has statutory authority to work with Federal Energy Regulatory Commission (FERC) or the licensee's state Public Utility Commission (PUC) to accelerate decommissioning fund accumulation (Leeds 2013).

When a plant retires prematurely, the timeframe for decommissioning fund availability changes compared to financial forecasts. Exelon has three plants either announced or at risk for premature retirement, including the Quad Cities, Clinton and R.E. Ginna plants. According to Exelon's 10-K filing with the SEC, the decommissioning trust funds may not meet NRC's minimum requirements, because premature shutdown accelerates the time to decommissioning and reduces the amount of time the funds in trust can appreciate (Exelon Corporation 2016). As a result, Exelon may be required to provide parent companies guarantees of $315 million (Clinton), $260 million (Ginna) and $65 million (Quad Cities) just to meet minimums (Exelon Corporation 2016, 88). These costs would not factor in any additional decommissioning costs above the minimum that may be identified in the SCCE or realized through actual decommissioning activities. These figures may or may not burden Exelon's considerable balance sheet. Further research is needed to assess the ability for parent companies of at-risk generation to guarantee decommissioning costs.

A GENERAL HISTORY

OF GEOLOGIC DISPOSAL AND YUCCA MOUNTAIN

The Atomic Energy Act of 1946 allowed for federal ownership and use of nuclear material for military and non-military purposes, and was later amended to allow for private sector development of nuclear power production. In 1955, the U.S. Atomic Energy Commission requested the National Academy of Sciences consider disposal options for high-level radioactive wastes, leading to the ground-breaking 1957 National Research Council report, The Disposal of Radioactive Wastes on Land. The report found geologic formations were a good potential option to provide the environmental isolation and water intrusion barrier needed to prevent radioactive exposure.

In the 1950's commercial nuclear power reactors began to develop, along with the assumption that waste would be reprocessed. However, by 1977, the United States decided against supporting civilian reprocessing of waste owing to concerns about increasing nuclear weapons availability and risks. In 1982, Congress passed the Nuclear Waste Policy Act (NWPA) that made the federal government responsible for disposal of commercial high-level radioactive waste and spend nuclear fuel. The government was to select three potential sites for further study and characterization, establish two geologic disposal repositories in different geographic locations, and begin accepting waste in 1998. There was also a provision to allow for development of federal interim storage facilities to host waste prior to disposal. Commercial nuclear power generators were expected to pay for the costs of the repositories through a tax on the electricity produced from the plants.

In 1987, the NWPA was amended to require only Yucca Mountain in Nevada to be characterized and gave Congress the ability to override state objection to a Presidential approval of the site. The 1992 Congressional Energy Policy Act (CEPA) required development of safety and environmental protection regulations, licensing criteria, and other requirements for the site. In 2002, at the recommendation of DOE, President Bush approved the Yucca Mountain site as the target location for the geologic repository. Nevada issued a notice of disapproval that was overridden by Congress later that year. This prompted the state of Nevada, along with environmental groups, to pursue litigation opposing the facility, which resulted in project delays. However, in 2008, the U.S. Department of Energy submitted its license application to the Nuclear Regulatory Commission for development of the site.

In 2009, President Obama's proposed fiscal year 2010 budget drastically reduced funding for the Yucca Mountain project, stating the administration would be devising a new strategy for nuclear waste disposal, and the DOE announced plans to terminate the project. At the time, Nevada Senator Harry Reid vehemently opposed the project and held the influential title of Senate Majority Leader. In 2010, President Obama announced the creation of the Blue Ribbon Commission on America's Nuclear Future that delivered a report on alternatives to Yucca Mountain in 2012. According to a 2011 report from the Government Accountability Office, the DOE decision to terminate the Yucca Mountain project was made for policy reasons, and not for safety or technical reasons (U.S. Government Accountability Office 2011). In 2011, the NRC suspended the license application proceeding. However, a subsequent court decision enabled the NRC to complete publication of certain technical and environmental reviews, including a safety evaluation report and environmental impact assessment, in 2015 and 2016, respectively.

Currently, there are no plans to build a geologic repository for permanent waste disposal.

MANAGEMENT OF HIGH LEVEL NUCLEAR WASTE AND SPENT FUEL

The federal government missed its January 1998 deadline to begin accepting high-level waste and spent nuclear fuel (i.e. GTCC waste) for disposal in a centralized geologic repository. As a result, the per-KWh fee deposited into the NWF (which generally amounted to $750 million per year) was suspended in May 2014 due to a court order (Cawley 2015). From 1983 to the end of fiscal year 2015 the fund amassed $41.9 billion ($21.6 in industry fees recovered from ratepayers and $20.3 from intra-governmental transfers of interest credited to the fund) and spent $7.6 billion related to Yucca Mountain analysis, leaving a FY 2015 balance of $34.3 billion (Cawley 2015). In 2008, U.S. DOE estimated the cost to license, construct, operate and close (i.e. full life-cycle costs) Yucca Mountain at $96.2 billion. (U.S. Department of Energy 2008) This cost estimate was for a facility with the capacity to store 122,000 metric tons of waste, while the NWPA limited this repository to 70,000 metric tons. Only 102,000 metric tons or 80 percent of this waste was commercial in nature with the remainder originating from military defense activities, leaving the utility-ratepayer cost share to be approximately $77.4 billion and the federal government share being $18.8 billion. (U.S. Department of Energy 2008) In 2013, prior to the fee being suspended, DOE determined that the 1/10th of a cent per KWh fee did not need to be raised or lowered, as it was generating funds that were neither insufficient nor excessive to recover the costs associated with the geologic repository and other requirements of the NWPA. (U.S. Department of Energy 2013) This indicated that although only a portion of the $77.4 billion in life cycle costs were collected from commercial licensees, the fees would deliver adequate resources over time.

Because the geologic repository has not been realized, nuclear plant licensees have been forced to invest in interim, on-site storage facilities, including expansion of SFPs and development of ISFSIs. The licensees filed breach of contract lawsuits against the federal government (i.e. DOE) for financial damages caused by DOE's failure to begin accepting spent fuel waste per the Standard Contract. DOE essentially claimed it was not obligated to accept and dispose of this waste in absence of an operational repository. In 1996, the D.C. Circuit Court in *Indiana Michigan Power Company v. Department of Energy* found DOE in partial breach of the Standard Contracts.[4] This meant DOE—via federal taxpayers—must pay damages incurred by licensees as a result of the breach. The damage payments are taken from the U.S. Department of Justice Judgement Fund, a taxpayer supported fund established to pay court judgements and settlements resulting from legal actions against the federal government.

In 2002, the D.C. Circuit Court in *Alabama Power Co. v. United States Department of Energy* determined that damage payments from the partial breach of contract could not be extracted from the ratepayer supported NWF.[5] Basically, expenditures from the NWF are restricted only for purposes defined by the NWPA, which generally relate to characterization, construction and operation of the federal storage or disposal facilities, related research, administrative costs, waste transportation and retrieval costs, and local government assistance.[6] This means the $34.3 billion balance in the NWF is basically in a lock box and can't be used for any other purpose than development of a federal repository. In fact, one of the only benefits to taxpayers this fund was providing is that fees deposited into the fund (until 2014) were being treated as tax revenues that for federal accounting purposes helped to balance the budget (U.S. Department of Energy 2012, 73).

Owing to the nature of the partial breach, licensees can only file to recoup damages actually incurred as of the date of filing. This means new lawsuits for recovery of damages must be re-filed every six years, because of to the statute of limitations (U.S. Department of Energy 2012, 79). As a result, additional and ongoing litigation is expected to continue until the government has accepted enough waste to "catch up" with its obligations, or until negotiated settlements with all contract holders can be finalized to allow damages to be paid without additional litigation.

Liabilities from just a portion of these partial breach lawsuits and settlements totaled $5.3 billion in awarded damages as of 2015, with more cases pending (Cawley 2015). Assuming the federal government begins accepting high-level radioactive waste into its repository within 10 years, the federal government's total liability for partial breach damages is estimated to be approximately $29 billion, including the $5.3 billion already paid (Cawley 2015). Nuclear utilities estimate total damages to range as high as $50 billion (Garvey 2009). The cost of any additional

[4] *Indiana Michigan Power Company vs Department of Energy, 88 F. 3d 1272 (D.C. Cir. 1996)*

[5] *Alabama Power Co. v. United States Department of Energy, 307 F.3d 1300 (11th Cir. 2002)*

[6] *42 U.S.C. § 10222(d)*

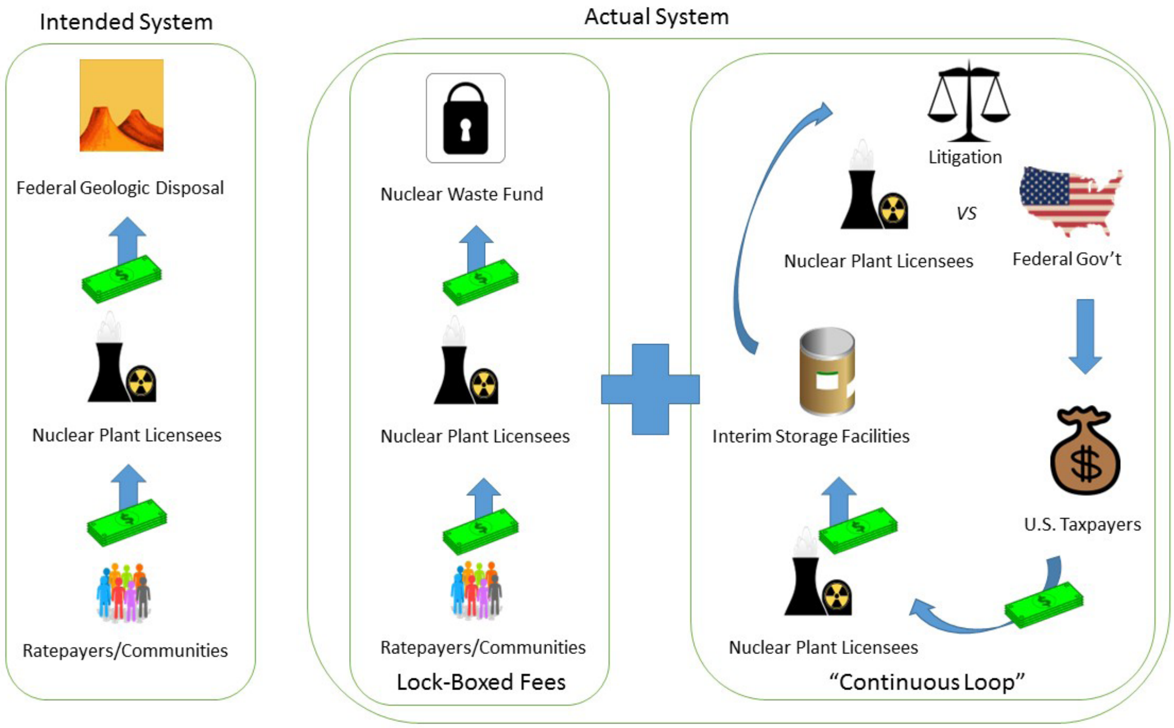

Figure 3: *Graphic Portrayal of Intended versus Actual System of Waste Storage and Funding*

delays is estimated to be $500 million per year (U.S. Department of Energy 2012, 80). Even if DOE begins accepting waste within the next 10 years, the Department will face a backlog that will take 20 years to catch up on, all the while liabilities continue to mount (Cawley 2015). In addition, as of 2009, there were $150 million in U.S. Department of Justice litigation expenses (paid by taxpayers) to support the federal government's litigation efforts (Garvey 2009). Lastly, GAO recognizes that the cost of these damages paid, which are largely related to transferring waste from wet to dry storage, are costs that licensees would not have incurred if DOE began accepting waste for disposal. (U.S. Government Accountability Office 2014) These are in fact new and additional costs, borne by taxpayers.

It is important to note that the amount of nuclear waste that has already been generated currently exceeds the statutory limit on the volume of waste that can be disposed of in the federal repository authorized by the NWPA (Cawley 2015). Therefore, even if the geologic repository is built and filled with existing nuclear waste, DOE may still be subject to liabilities from current licensees for failure to accept waste that is still being generated from existing power plants. However, a change in federal law could eliminate this concern.

NRC developed its first Waste Confidence Rule (WCR) in 1984 for licensing purposes, to provide reasonable assurances that waste would be disposed of safely. The 1984 WCR expected geologic disposal would be available sometime around 2007 to 2009 and that waste could be safely stored until disposal capacity became available (U.S. Department of Energy 2012). In 1989, the NRC updated the WCR, finding that on-site storage of nuclear waste was safe for up to 30 years beyond the licensed lifecycle of a nuclear plant, and that geologic disposal would be available within the first quarter of the 21st century. In 1999, NRC confirmed its previous WCR findings. By 2010, the NRC updated the WCR to state that spent nuclear fuel could be safely stored on site for up to 60 years beyond the licensed lifecycle of the plant, and that geologic disposal would be available when needed. This background is provided to suggest that in the absence of reprocessing or repository capabilities, NRC envisions waste to be stored on site for up to 60 years after a plant is shut down. States and environmental organizations have opposed NRC's WCR findings and subsequent rules allowing for indefinite on-site storage of nuclear waste, with success being generally limited—for example, remanding NRC rules and requiring the agency to perform additional studies.[7]

[7] *For example, see New York v. NRC, 681 F.3d (DC Cir 2012)*

PAYING MORE FOR INCREASED AND UNCOMPENSATED RISK

As nuclear power plants begin to close, there should be (at least) four issues emerging, beyond the current focus of losing jobs, carbon free power, and reliable baseload generation. These issues include increased risks associated with indefinite storage of nuclear waste, shifting new costs onto taxpayers with no refund for ratepayers, failure to compensate host communities for increased risks associated with interim waste storage, and to a lesser extent, adequacy of licensee funds for decommissioning activities.

Increased Risks with Indefinite Distributed Interim Storage. National and international experts agree that long-term storage of high-level radioactive waste is simply not as safe or secure as permanent geologic disposal. In America to date, geologic disposal has been pursued, but proven to be politically infeasible. In fact, no nation has successfully built a permanent repository for spent nuclear fuel and high-level radioactive waste (U.S. Government Accountability Office 2011, 34). As a result, for decades, nuclear plants in the U.S. have been forced to store this waste on site. When a nuclear plant closes, the plant site will be converted to a "temporary" ISFSI waste storage facility, which barring significant political developments on reprocessing or a repository, may end up hosting the waste in perpetuity. Instead of one federally controlled, geologic disposal facility for radioactive waste, the United States will end up with a collection of distributed interim storage facilities dotting its landscape.

With no plans for a federal repository on the horizon, it is unclear how long these facilities will be required to operate and be maintained, though the NRC believes the waste can remain on site for up to 60 years after reactor shutdown. This uncertainty raises questions about costs and ability to adequately maintain safe, secure facilities for the thousands of years that the waste will present health hazards. Compared to geologic disposal, interim storage presents greater risks.

Shifting Costs to Taxpayers, No Refund to Ratepayers. ISFSI facilities will need to be constructed, secured, maintained and monitored in perpetuity, or until a reprocessing capacity or a geologic repository is established. The cost to design, license, and construct a dry storage facility, and applicable safety and security systems is estimated to be between $5.5 million and $42 million (U.S. Government Accountability Office 2014). The cost to operate an ISFSI at a retired reactor site is estimated to range from $4.5 million to $8 million per year, compared to the incremental $1 million cost of operating the ISFSI when the reactor is still running (U.S. Department of Energy 2012, 35). Licensees have been forced to invest in building and maintaining the ISFSIs, as a result of the federal government's failure to accept waste for disposal. Recovery of licensee costs for converting from wet to dry storage, including construction, operation, and maintenance of the ISFSI facilities is being recovered from federal taxpayers, due to licensee's successful litigation against the federal government.

So, taxpayers—many of whom are the same ratepayers that paid fees into the NWF to fund development of the geologic repository—are having to pick up the tab for distributed, interim spent fuel storage, plus litigation costs premiums. This tab is expected to cost at least $29 billion and potentially up to $50 billion, assuming the federal government begins accepting waste by 2025. These liabilities will continue to grow by $500 million per year until the government begins accepting waste.

But what about those electricity ratepayers that already paid a per KWh fee to support development of a permanent nuclear waste disposal site? $7.6 billion of these ratepayer fees were spent to study the Yucca Mountain Nevada site, but nothing was built. $34.3 billion in fees remain to support facility development, but there are no plans to build the facility. Distribution of the $34.3 billion in funds is restricted by statute and can only be used for activities related to the geologic repository, so it remains in a virtual lock box. Essentially, ratepayer communities hosting nuclear plants paid to have nuclear waste removed from their backyards, but taxpayers are funding the cost of keeping the waste in the community.

These communities of ratepayers are still receiving the service of nuclear waste storage. However, the storage service they are receiving is inferior to what was agreed upon because it has greater risks (i.e. disposal versus storage) and these risks remain in the community. If licensee costs for interim storage were being recovered from the NWF, then ratepayers would simply be receiving fewer benefits (or greater risks) than they agreed to accept. However, fees deposited into the NWF are restricted, meaning they can only be spent on activities related to the geologic repository. Therefore, taxpayers have been paying for licensee's interim storage cost. Essentially, many Americans have been billed twice (once for geologic disposal, once for interim storage) to receive greater risks from distributed interim storage. Through litigation, licensees have recovered their costs from taxpayers associated with building and maintaining interim storage capacity. However, no refund of the ratepayer fees in the NWF has been offered to these communities for failure to build a geologic disposal site as promised. Of course, there is the potential for ratepayers to eventually receive the benefits they paid for, through development of the geologic repository and removal of waste from their communities, but there are currently no plans to do so.

Imposing Uncompensated Risks onto Communities. Retired power plant sites will be converted into ISFSI facilities that will indefinitely store radioactive spent fuel. This certainly was not the original expectation for communities that agreed to host nuclear power plants. The fact that many communities will become default nuclear waste storage sites—along with the attendant risks—is something residents and policy makers may not currently appreciate as a result of nuclear plant retirements. No compensation has been provided to these communities for the additional risks associated with hosting long-term storage of radioactive waste. In addition, when a nuclear power plant shuts down, the host community is no longer receiving benefits of low cost, carbon-free electricity from the plant.

These communities are the same electric ratepayers that contributed billions of dollars into the NWF to build a geologic disposal repository. Their expectation was that the waste would leave the community in exchange for these fees. They have not agreed to indefinitely host nuclear waste. As such, more risk is being imposed on these ratepayer communities than they initially agreed to, and they are not being compensated for these additional risks.

Inadequate Funds for Decommissioning. The NRC requires licensees to provide upfront financial assurances that decommissioning costs will be available. However, there are considerable analyses, data, and concerns indicating NRC's formula for calculating required minimum decommissioning costs understates actual costs. Licensees are required to provide site-specific decommissioning cost analyses near the time of plant retirement. However, premature retirement accelerates the need for decommissioning funds to be available and reduces the time for these funds to appreciate. More research is needed to understand if parent companies of current at-risk units have the ability to pay for actual, site-specific decommissioning costs. Lastly, it is unclear who would pay decommissioning costs in the case of licensee/parent company default or bankruptcy.

CONCLUSION

A wave of premature nuclear power plant retirements is crashing along the shores of America's energy systems. Most public dialogue about these retirements has centered on support or opposition for public policies to keep the plants operating. Absent from the retirement dialogue is a focus on the broader impacts of nuclear plant closures, namely decommissioning and the fate of nuclear waste.

Closure of a nuclear plant requires site decontamination through the decommissioning process. There are **concerns about the adequacy of plant licensee funds to pay for the full cost of decommissioning, especially when a plant prematurely retires**. However, these concerns are not as significant as the costs and risks associated with managing the spent fuel and high-level nuclear waste generated at these plants.

Communities hosting nuclear power plants expected nuclear wastes to be removed from their communities for reprocessing or permanent disposal in a federally-secured, geologic repository. Because of the federal government's failure to develop the repository and remove the waste, these host communities will **become the indefinite home to radioactive waste storage sites upon plant retirement. These storage sites, which will be distributed throughout the U.S., are less safe and less secure, compared to permanent geologic disposal.**

Ratepayers benefitting from nuclear power paid per KWh fees to fund development of a permanent geologic disposal repository. These fees were deposited into the NWF, which is currently valued at over $34.3 billion. However, a repository has not been built, so with nowhere for the waste to go, plant licensees have been forced to invest in building and maintaining on-site interim storage facilities. Plant licensees have successfully sued the federal government for its failure to take custody of the waste, **requiring U.S. taxpayers to reimburse licensees for their interim waste storage investments**. It is estimated that **taxpayer liabilities for these costs could range from $29 to $50 billion** if the government begins taking custody of the waste in 2025. This cost increases by $500 million each year this custody date slips.

Meanwhile, **no refund has been provided to the ratepayers** for the fees deposited into the NWF, because by law the fees can only be spent on activities related to the geologic repository.

These communities **did not agree to host these storage sites** and they are **not receiving compensation for the additional risks associated with waste storage.**

These issues are not created by plant licensees, **they are created by the federal government**. Licensees are negatively impacted by the federal government's failure to develop the geologic disposal site. Plant licensees cannot fully release their properties or licenses, and instead must construct, operate, and maintain these on-site, interim storage facilities. Furthermore, lack of a permanent solution for nuclear waste raises questions about future viability of the nuclear power industry.

Essentially, Americans (i.e. ratepayers and taxpayers) are paying more (once for unrealized geologic disposal, once for interim storage) for less safe, less secure distributed waste storage; and communities hosting nuclear plants are not being compensated for having these risks thrust upon them.

It is crucial that stakeholders and policy makers integrate these facts into contemporary discourse of nuclear plant retirements to understand and remedy the immediate impacts on plant licensees, host communities, and the tax-paying public.

BIBLIOGRAPHY

Bagget, Steven, and E. William Brach. 2005. "Regulators Experiences in licensing and inspection of dry cask storage facilities." IAEA International conference on the operational safety performance in nuclear installations, contributed papers. Vienna, Austria: IAEA-CN--133. p. 81-84.

Cawley, Kim. 2015. The Federal Government's Responsibilities and Liabilities Under the Nuclear Waste Policy Act. Testimony before U.S. House of Representatives, Subcommittee on Environment and the Economy, Committee on Energy and Commerce, Congressional Budget Office, Washington, DC: CBO. https://www.cbo.gov/sites/default/files/114th-congress-2015-2016/reports/51035-NuclearWaste_Testimony.pdf.

Dolley, Steven. 2013. "Thirty-eight US nuclear units at risk of retirement: analyst." Platts. July 17. Accessed June 29, 2016. http://www.platts.com/latest-news/electric-power/washington/thirty-eight-us-nuclear-units-at-risk-of-retirement-21294563.

Engblom, Andrew, and Hira Fawad. 2015. "As Pilgrim falls, 11% of nuclear generation at risk of early closure." SNL Data Dispatch. October 16. Accessed June 28, 2016. https://www.snl.com/InteractiveX/Article.aspx?cdid=A-34103057-13109.

Exelon Corporation. 2016. Form 10-K for FY 2015. Washington, DC: U.S. SEC.

Garvey, Todd. 2009. The Yucca Mountain Litigation: Breach of Contract Under the Nuclear Waste Policy Act of 1982. R40996, Washington, DC: Congressional Research Service.

International Atomic Energy Agency. 2003. The Long Term Storage of Radioactive Waste: Safety and Sustainability. A position paper of international experts. Vienna, Austria: IAEA.

Leeds, Eric J. 2013. Staff findings on the table of minimum amounts required to demonstrate decommissioning funding assurance. SECY-13-0066, U.S. NRC, Washington, DC: U.S. NRC. http://www.nrc.gov/reading-rm/doc-collections/commission/secys/2013/2013-0066scy.pdf.

McGrath, Richard, and Richard Reid. 2014. "Waste management for decommissioning of nuclear power plants: An EPRI Decommissioning Progam Report." Symposium on Recylcing of Metals Arising from Operation and Decommissioining of Nuclear Facilities. Nykoping, Sweden: IAEA.

Office of the Inspector General U.S. NRC. 2016. Audit of NRC's Decommissioning Funds Program. OIG-16-A-16, Washington, DC: U.S. NRC. http://www.nrc.gov/docs/ML1616/ML16160A208.pdf.

Short, S.M., M.C. Bierschbach, R.F. Layton, and B.E. Greenfield. 2012. Assessment of the adequacy of the 10 CFR 50.75(c) minimum decommissioning fund formula. Washington, DC: U.S. NRC.

U.S. Department of Energy. 2008. Analysis of the Total System Life Cycle Cost of the Civilian Radioactive Waste Management Program, FY 2007. DOE/RW-0591, Washington, DC: U.S. DOE. http://www.yuccamountain.org/pdf/ocrwm_tslc-2008.pdf.

U.S. Department of Energy. 2012. Blue Ribbon Commission on America's Nuclear Future Report to the Secretary of Energy. Washington, DC: U.S. DOE.

U.S. Department of Energy. 2013. U.S. DOE Nuclear Waste Fund Adequacy Assessment Report. Washington, DC: U.S. DOE. http://energy.gov/sites/prod/files/January%2016%202013%20Secretarial%20Determination%20of%20the%20Adequacy%20of%20the%20Nuclear%20Waste%20Fund%20Fee.pdf.

BIBLIOGRAPHY CONT.

U.S. Government Accountability Office. 2011. Effects of a Termination of the Yucca Mountain Repository Program and Lessons Learned. GAO-11-229, Washington, DC: U.S. GAO, 11. http://www.gao.gov/assets/320/317627.pdf.

U.S. Government Accountability Office. 2012. NRC's Oversight of Nuclear Power Reactors' Decommissioning Funds Could Be Further Strengthened. GAO-12-258, Washington, DC: U.S. GAO. http://www.gao.gov/assets/590/589923.pdf.

U.S. Government Accountability Office. 2014. Spent Nuclear Fuel Management: Outreach Needed to Help Gain Public Acceptance for Federal Activities that Address Liability. GAO-15-141, Washington, DC: U.S. GAO. http://www.gao.gov/assets/670/666454.pdf.

U.S. Nuclear Regulatory Commission. 2015. "Backgrounder on Decommissioning Nuclear Power Plants." NRC.gov. May 14. Accessed June 2016. http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/decommissioning.html.

—. 2015b. Backgrounder on Dry Cask Storage of Spent Nuclear Fuel. October 5. Accessed July 1, 2016. http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/dry-cask-storage.html.

—. 2015c. Spent Fuel Staorage in Pools and Dry Casks Key Points and Questions and Answers. April 13. Accessed July 1, 2016. http://www.nrc.gov/waste/spent-fuel-storage/faqs.html.

—. 2015d. Status of the Decommissioining Program: 2015 Annual Report. SECY-15-0151, Washington, DC: U.S. NRC.

—. 2015e. U.S. Independent Spent Fuel Storage Installations. Washington, DC: NRC. http://www.nrc.gov/docs/ML1524/ML15240A058.pdf.

—. 2016. Locations of Power Reactor Sites Undergoing Decommissioining. April 12. Accessed July 1, 2016. http://www.nrc.gov/info-finder/decommissioning/power-reactor/.

Williams, Daniel G. 2007. "U.S. nuclear plant decommissioning funding adequacy - by individual funds, utilities, reactors and industry-wide - assessed by Monte Carlo and baseline trends methods: 1998, 2000, 2001, and 2004." Energy Economics 29 (5): 1050-1100. http://www.sciencedirect.com/science/article/pii/S0140988306000375.

APPENDIX A

Nuclear reactors planning or at risk for retirement, along with recently retired and new units

STATUS	PLANT NAME	OWNER	SUMMER CAPACITY (MW)	IN SERVICE DATE	STATE	COM-PETITIVE MARKET (Y/N)	DATE OF CLOSURE
ANNOUNCED OR THREATENED FOR RETIREMENT	Clinton	Exelon	1065	1987	Illinois	Y	June 2017
	Diablo Canyon Unit 1	PG&E	1122	1985	California	N	2024
	Diablo Canyon Unit 2	PG&E	1118	1986	California	N	2025
	Fort Calhoun Station	Omaha Public Power District	478	1973	Nebraska	N	December 2016
	James A. FitzPatrick	Entergy	852	1976	New York	Y	2016-2017
	Nine Mile Unit 1	Exelon	636	1969	New York	Y	no date provided
	Nine Mile Unit 2	Exelon	1301	1987	New York	Y	no date provided
	Oyster Creek	Exelon	610	1969	New Jersey	Y	December 2019
	Pilgrim Station	Entergy	677	1972	Massachusetts	Y	June 2019
	Quad Cities 1 & 2	Exelon	1819	1972	Illinois	Y	June 2018
	R.E. Ginna	Exelon	582	1970	New York	Y	no date provided
			10,260				
ADDITIONAL POTENTIALLY AT-RISK PLANTS	Byron Unit 1	Exelon	1164	1985	Illinois	Y	-
	Byron Unit 2	Exelon	1136	1987	Illinois	Y	-
	Davis-Besse	First Energy	894	1977	Ohio	Y	-
	Palisades	Entergy	789	1972	Michigan	Y	-
	Three Mile Island	Exelon	802	1974	Pennsylvania	Y	-
			4,785				
RETIRED	Vermont Yankee	Entergy	612	1972	Vermont	N	December 2014
	San Onofre Units 2	Southern California Edison Co.	1070	1983	California	N	June 2013
	San Onofre Unit 3	Southern California Edison Co.	1080	1984	California	N	June 2013
	Crystal River Unit 3	Duke Energy Corp	860	1977	Florida	N	February 2013
	Kewaunee	Dominion Resources	556	1974	Wisconsin	N	May 2013
			4,178				
NEW PLANTS	V.C. Summer 2	South Carolina Gas & Electric	1117	2019	South Carolina	N	-
	V.C. Summer 3	South Carolina Gas & Electric	1117	2020	South Carolina	N	-
	Vogtle Unit 4	Georgia Power/ Southern Company	1117	2020	Georgia	N	-
	Vogtle Units 3	Georgia Power/ Southern Company	1117	2019	Georgia	N	-
	Watts Bar Unit 2	Tennessee Valley Authority	1150	2016	Tennesseee	N	-
			5,618				

APPENDIX B

Power and Early Demonstration Reactors Undergoing Decommissioning (U.S. Nuclear Regulatory Commission 2015d)

	Reactor	Location	PSDAR* Submitted	LTP Submitted	LTP Approved	Completion of Decomm.**
1	Crystal River Unit 3	Crystal River, FL	12/13	TBD	TBD	2073
2	Dresden Unit 1	Morris, IL	6/98	TBD	TBD	2036
3	Fermi Unit 1	Newport, MI	4/98	2011***	TBD	2032
4	GE-EVESR	Pleasanton, CA	TBD	TBD	TBD	2019
5	GE-Vallecitos Boiling Water Reactor	Pleasanton, CA	7/66	TBD	TBD	2019
6	Humboldt Bay	Eureka, CA	2/98	2013	TBD	2016
7	Indian Point Unit 1	Buchanan, NY	1/96	TBD	TBD	2026
8	Kewaunee	Kewaunee, WI	5/13	TBD	TBD	2073
9	La Crosse	La Crosse, WI	5/91	TBD	TBD	2020
10	Millstone Unit 1	Waterford, CT	6/99	TBD	TBD	2056
11	Nuclear Ship Savannah	Baltimore, MD	12/08	TBD	TBD	2031
12	Peach Bottom Unit 1	Delta, PA	6/98	TBD	TBD	2034
13	San Onofre Unit 1	San Clemente, CA	12/98	TBD	TBD	2030
14	San Onofre Unit 2	San Clemente, CA	9/14	TBD	TBD	2030
15	San Onofre Unit 3	San Clemente, CA	9/14	TBD	TBD	2030
16	Three Mile Island Unit 2	Harrisburg, PA	6/13	TBD	TBD	2053
17	Vermont Yankee	Vernon, VT	12/14	TBD	TBD	2073
18	Zion Unit 1	Zion, IL	2/00	12/14	TBD	2020
19	Zion Unit 2	Zion, IL	2/00	12/14	TBD	2020

GE General Electric
TBD to be determined
EVESR ESADA (Empire State Atomic Development Associates) Vallecitos Experimental Superheat Reactor

* PSDAR or DP equivalent. Prior to August 28, 1996, the effective date of Final Rule "Decommissioning of Nuclear Power Reactors" (61 FR 39278; July 29, 1996), licensees submitted DPs (or equivalent).

** For decommissioning reactors with no ISFSI or an ISFSI licensed under 10 CFR Part 72, completion of decommissioning will result in the termination of the 10 CFR Part 50 license. For reactors with an ISFSI licensed under the provisions of 10 CFR Part 50, completion of decommissioning will result in reducing the 10 CFR Part 50 license boundary to the footprint of the ISFSI.

*** Licensing action put on hold at licensee's request.

APPENDIX C

Decommissioned Power Reactors with ISFSIs
(U.S. Nuclear Regulatory Commission 2015d)

	Reactor	Onsite Fuel Status	Cask Vendor	Model
1	Big Rock Point	10 CFR 50 ISFSI	Energy Solutions, Inc.	Fuel Solutions W74
2	Connecticut Yankee	10 CFR 50 ISFSI	NAC International, Inc.	NAC-MPC
3	Fort St. Vrain (DOE site)	10 CFR 72 ISFSI	Foster Wheeler Energy Applications, Inc.	Modular Vault Dry Store
4	Maine Yankee	10 CFR 50 ISFSI	NAC International, Inc.	NAC-UMS
5	Rancho Seco	10 CFR 72 ISFSI	Transnuclear, Inc.	NUHOMS-24P
6	Trojan	10 CFR 72 ISFSI	BNFL Transtor/Holtec International	HI-STORM 100
7	Yankee Rowe	10 CFR 50 ISFSI	NAC International, Inc.	NAC-MPC