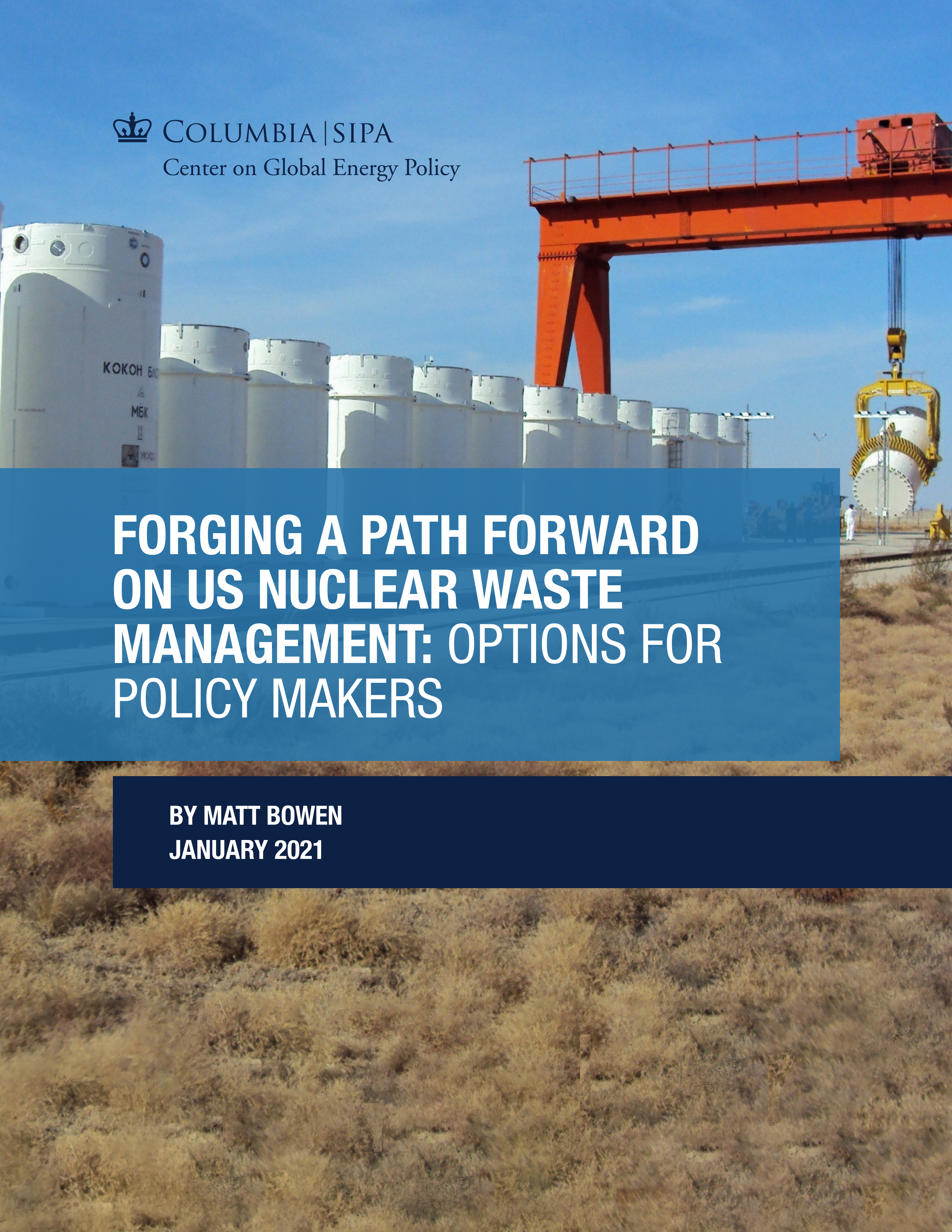

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FORGING A PATH FORWARD ON US NUCLEAR WASTE MANAGEMENT: OPTIONS FOR POLICY MAKERS

BY MATT BOWEN

JANUARY 2021

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ACKNOWLEDGMENTS

Thomas A. Cotton provided beyond-generous assistance during the research and drafting of this report in terms of time, materials, and expertise—the author is indebted to him. The author also thanks the many individuals he interviewed and those who provided feedback on various drafts of the report. Lastly, the author thanks the anonymous reviewers who provided helpful comments and suggestions on the penultimate draft.

This report represents the research and views of the author. It does not necessarily represent the views of the Center on Global Energy Policy.

This work was made possible by support from the Center on Global Energy Policy. More information is available at https://energypolicy.columbia.edu/about/partners.

Front Cover Image Source: NRC/NRC File Photo

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EXECUTIVE SUMMARY

Nuclear power is considered in many countries a critical facet to maintaining reliable access to electricity during a global transition to low-carbon energy sources. One challenge to its potential in the United States, however, is the current standstill regarding a disposal pathway for spent nuclear fuel (SNF) from commercial reactors. This impasse has a negative bearing on nuclear energy's ability to supply more zero-carbon electricity and may cost US taxpayers tens of billions of dollars in government liability for failing to meet contractual obligations to take possession of the waste from utilities.

Despite the scientific community assessing that commercial SNF and other high-level radioactive waste (HLW), such as from defense activities, can be safely isolated in deep underground repositories, US efforts to license and operate one have flatlined. The original plan for siting at least two repositories for such waste was abandoned first by DOE and then by Congress. Yucca Mountain in Nevada was designated in law as the nation's sole potential disposal site by Congress in 1987, fomenting the state's opposition to the project. As a result of that opposition, Congress has not funded the project since 2010.

Still, progress has been made over the last few decades in nuclear waste disposal programs in countries such as Finland, Sweden, and Canada. And the United States has seen the successful opening and operation of the Waste Isolation Pilot Plant in New Mexico to dispose of generally less radioactive but long-lived transuranic nuclear waste from defense activities. Such programs offer insights for how the United States can try to resolve the challenges with commercial nuclear waste disposal and potentially alleviate one obstacle to wider adoption of nuclear energy to decarbonize the US economy.

This report, part of wider work on nuclear energy at Columbia University's Center on Global Energy Policy, explains how the United States reached its current stalemate over nuclear waste disposal. It then examines productive approaches in other countries and a few domestic ones that could guide US policy makers through options for improving the prospects of SNF and HLW disposal going forward, including the following:

- **Create a new organization whose sole mission is nuclear waste management (and whose approach is consent based).** Since the 1970s, reports have noted that a single-purpose organization would have a number of advantages over a program residing within DOE, which has multiple missions and competing priorities. Accordingly, Congress could pass legislation to create a separate nuclear waste management organization that has full access to needed funding and employs a consent-based approach to achieve greater support from state and local communities for the siting of facilities.
- **Improve the funding structure of the US nuclear waste program.** The program was supposed to be self-financing, with owners of nuclear power plants paying into a Nuclear Waste Fund that would cover the costs of management and disposal. However,

due in part to budget laws enacted in the 1980s and 1990s, a lack of access to needed funding has arisen. If the first option of creating a new organization is not achievable in the near-term, Congress could at least improve the waste program's funding structure.

- **Pursue disposal of US defense waste first.** There could be greater public acceptance for the disposal of defense-related waste over commercial waste due to the national security missions involved and patriotic sensibilities. Momentum in one area of waste management could lead to the overall program's advancement, as a successful endeavor for defense waste disposal would inform and encourage commercial waste efforts. Nuclear waste from the defense sector also has some technical characteristics—the inventory being bounded, smaller, cooler, and with less potential for reuse—that may argue for its disposal ahead of power plant SNF.
- **Prepare for a large-scale transportation program.** To date, the transportation of nuclear waste has been very safe. However, there are additional steps the federal government could take to prepare for the eventual larger-scale transportation campaign of SNF to either a consolidated interim storage site or a geologic repository. Such options include amending the Nuclear Waste Policy Act to allow states to recover the full costs of planning and operations for transportation across their borders and ensuring an independent regulator has authority over the transportation regime to strengthen public confidence in the program.
- **Update generic regulatory standards for future geologic repositories.** There are two sets of US regulatory standards for SNF and HLW disposal: one for Yucca Mountain and one for all other sites. The Environmental Protection Agency, Nuclear Regulatory Commission, and DOE could resolve inconsistencies between regulations and ensure that new generic regulations for future disposal facilities are flexible enough to cover novel approaches (e.g., deep boreholes).
- **Negotiate an agreement with Nevada on Yucca Mountain.** The US government could pursue, concurrent with new siting efforts, negotiating an agreement with Nevada to investigate, for example, the disposal of a more limited waste inventory at Yucca Mountain. Nye County, which is where the site is located, sees a disposal facility there as potentially safe and is interested in the associated economic development. Nevada's long-standing concerns regarding the project would have to be addressed to gain broader public support within the state.

INTRODUCTION

The risks associated with a continued accumulation of greenhouse gases in the Earth's atmosphere have focused the world's attention on moving to low-carbon energy options.[1] Of these, nuclear energy was 10% of world electricity generation in 2019 and 19% of US electricity generation.[2] Nuclear power plants emit no carbon dioxide (CO_2), and their power is accessible on demand; therefore they could play a key role in addressing climate change.[3] Partly for these reasons, nuclear energy has received renewed international attention around possible construction of new plants or at least extending the lifetime of existing ones so they are not retired and replaced with CO_2-emitting fossil fuel plants.[4]

But concerns about nuclear energy remain, particularly on what to do with the radioactive waste in the fuel rods used for generating electricity. To date, no country has permanently disposed of commercial spent nuclear fuel (SNF), though some have made greater progress and are closer to a disposal solution than the United States. Finland is the current international leader on this front: it is in the process of constructing what would be the world's first operating geologic repository for commercial SNF.

In the United States, the national program for disposing of nuclear power plants' spent fuel has ceased to make progress.[5] While nuclear energy remains the largest source of low-carbon electricity in the United States (with hydropower and wind energy each generating 7%, and solar plants producing 2% in 2019),[6] the waste management standstill has a negative bearing on nuclear energy's promise. For example, several states have laws prohibiting new nuclear power plants until additional progress is made on managing nuclear waste.[7] The lack of a pathway for waste is also one of the focal points of activist groups opposed to nuclear energy.[8]

This report will explain the origins of nuclear waste—commercial power and beyond—and how the United States arrived at its current stalemate, focusing on key events in the 1980s. Beyond the predicament's negative bearing on nuclear energy as a resource to address climate change, the impasse has created tens of billions of dollars in taxpayer liability in the form of broken contracts between the federal government and utilities. In addition, it has meant that communities hosting decommissioned reactors are unable to fully reclaim all of their land, as licensees must continue to maintain and protect the remaining storage facility.

But a fair amount has changed since the United States first structured its nuclear waste program in 1982 that points to a potential path forward. Other countries have moved ahead with their nuclear waste programs and the United States stands to benefit from those nations' experiences. Another key development has been the opening of the Waste Isolation Pilot Plant (WIPP) in New Mexico in 1999, which has disposed of defense-generated transuranic[9] (TRU) nuclear waste for two decades. This facility offers an opportunity for US state and local officials to visit an operating geologic repository to see for themselves the risks and benefits to hosting such a facility. It also presents proof that the United States is capable of certifying, constructing, and operating a facility deep underground for disposal of long-lived nuclear waste—and, importantly, is able to maintain long-term community support for the program.

Transportation will be a key part of an integrated US nuclear waste management program, including the shipping of commercial SNF to either a consolidated interim storage facility or to a geologic repository. This report focuses on two transportation case studies: defense-generated TRU waste shipments to the WIPP site in New Mexico and the shipment of spent naval reactor fuel to the Idaho National Laboratory (INL). It also examines evidence that commercial SNF has already been safely transported in the United States and around the world. If transporting SNF is done according to the high standards in US regulations governing transportation of radioactive materials, the risks can be lower[10] than those of other hazardous materials shipped around the country on a daily basis. As the report observes, however, various social and institutional challenges to a broader US program for transporting commercial SNF should be addressed prior to initiating a large-scale campaign.

Current US nuclear waste laws and regulations have proved problematic for effectively managing high-level waste (HLW) from defense projects and SNF from commercial and defense activities.[11] This report lays out a concrete set of options—including elements of legislative proposals from recent years—for Congress and the Executive Branch to consider as part of a path forward on managing nuclear waste. Some prominent options include creating a new organization whose sole focus is nuclear waste management (as opposed to housing it within the Department of Energy [DOE], which has many missions); improving the funding structure for the US nuclear waste program; pursuing the disposal of defense-generated nuclear waste first; planning for a large-scale SNF transportation campaign; updating older, generic regulations pertaining to future geologic repositories; and making an effort to negotiate a legally binding agreement with Nevada to address the state's concerns about a potential repository at Yucca Mountain.

II. THE HIGH-LEVEL WASTE AND SPENT NUCLEAR FUEL CHALLENGE

A. Origins: Power Plants, Weapons, Research, Isotope Production, and Naval Reactors

Several entities and efforts create nuclear waste in the United States, including commercial nuclear power plants, the US nuclear weapons program, reactors for research and isotope production, and naval reactors that power US submarines and aircraft carriers. This section provides a brief description of each.

Defense-related activities have generated massive quantities of high-level radioactive waste and about 2,200 metric tons of heavy metal (MTHM[12]) of SNF.[13] During World War II, the Manhattan Project was launched in secret to develop a nuclear weapon, and the project led to the first detonation of a nuclear explosive device in 1945.[14] The United States followed two paths to making material suitable for use in nuclear weapons: the enrichment of uranium in the isotope U-235 and the production of plutonium. The latter involved irradiating uranium fuel in a reactor and chemically processing it to recover plutonium. These operations lasted for decades and produced millions of gallons of radioactive wastes, of which about 90 million gallons of liquid wastes are currently being stored at Hanford, Washington, and Savannah River, South Carolina. The liquid waste inventory is in the process of being solidified for ultimate disposal, including as HLW.[15] DOE estimated in 2016 that cleanup of the former weapon production sites would cost $257 billion and the effort would last for decades.[16]

Following World War II, the United States also pursued development of nuclear reactors to power US Navy vessels. The USS *Nautilus* was the world's first nuclear-powered submarine, commissioned in 1954 before completing its first trip in 1955. About 45 percent of the navy's major combatants are nuclear-powered: 11 aircraft carriers and 68 submarines.[17] There are currently 97 naval reactors in operation, including land-based facilities.[18] Nuclear-powered navy vessels generate about 1 to 2 metric tons of spent nuclear fuel each year, and the navy projects that it will have 65 metric tons of SNF by 2035.[19] Naval spent fuel is currently being stored at the Naval Reactor Facility at the Idaho National Laboratory.

In 1957, the Shippingport Atomic Power Station was connected to the electrical grid in western Pennsylvania as the first US commercial power reactor. Over 100 US power reactors started operations in the subsequent decades, though orders peaked in the 1970s and waned afterward. Originally, it was thought that SNF from commercial power reactors would be reprocessed, though, for a variety of reasons, including proliferation concerns and low uranium prices, initial efforts to deploy commercial reprocessing were abandoned in the United States. As a result, SNF inventories have been accumulating at reactor sites, and power plants began to move their SNF into air-cooled casks as their cooling pools filled up.[20] In 2019, commercial nuclear reactors produced about 19% of the electricity in the United States, and over half of its low-carbon electricity generation. At the end of 2019, the US commercial spent nuclear fuel inventory was 83,831 metric tons—put together it would fit on a single football field at a depth of less than 10 yards—and it is increasing by about 2,000 metric tons each year, making it the largest part of the collective US SNF and HLW inventory.[21] In November of

2020, 94 commercial nuclear reactors were licensed to operate in the United States.[22]

Finally, research and test reactors are used in research, industrial, and medical applications. The US Nuclear Regulatory Commission (NRC) regulates about 31 research and test reactors in the United States, primarily at universities, that have power ratings much lower than commercial reactors.[23] These reactors generate a small but nonnegligible amount of SNF that DOE manages. For example, the High Flux Isotope Reactor at the Oak Ridge National Laboratory in Tennessee began operations in the 1960s and today, among other things, supports fusion energy research and produces californium-252, an isotope used for cancer therapy and detection of pollutants in the environment and explosives in luggage.[24] Reactor-produced radioactive isotopes[25] are used in millions of medical procedures each year in the United States—around 20 million procedures in 2005 alone.[26] The isotope molybdenum-99, produced in reactors in several countries, is widely used for diagnostic imaging.[27]

The United States also operates the Foreign Research Reactor Spent Nuclear Fuel Acceptance Program to accept spent fuel from research reactors in other countries. In support of national security and nonproliferation missions, the program repatriates SNF from reactors that operate on US-origin highly enriched uranium (greater than 20% enrichment in the isotope uranium-235) and returns it to the United States. As of 2012, this inventory of SNF totaled about six metric tons.[28]

All of these activities—the production of plutonium for nuclear weapons, the operation of nuclear-powered naval vessels, the generation of electricity from nuclear power plants, and isotope production from research and test reactors—create nuclear waste that must be properly stored and disposed of. Table 1 shows projected inventories of SNF and HLW over the next several decades, though the amount of commercial SNF will depend upon future reactor operation (e.g., how long nuclear plants operate). Some of the isotopes that make up SNF and HLW have long half-lives (e.g., on the order of millions of years) and thus must be separated from the biosphere for correspondingly long periods of time.

Table 1: Projected amounts of US nuclear waste requiring disposal by DOE

Inventory	Metric tons
Commercial SNF	141,423
DOE-managed HLW from the nuclear weapons program	11,655
DOE-managed SNF from the nuclear weapons program	2,195
DOE-managed commercial SNF	240
DOE-managed commercial HLW	139
DOE-managed navy SNF	65

Note: DOE also manages a small inventory of SNF from its test and experimental reactors, university reactors, government research reactors, fuel from some foreign research reactors, and others. The defense HLW has been converted to metric tons under the assumption that one HLW canister is equal to 0.5 metric tons of heavy metal. DOE has custody of SNF from the Fort St. Vrain and Three Mile Island reactors.

Source: GAO, "Nuclear Waste: Benefits and Costs Should Be Better Understood before DOE Commits to a Separate Repository for Defense Waste," January 2017, table 1.

However, US efforts to dispose of SNF and HLW have foundered. Events in the 1980s—particularly in 1982, 1986, and 1987—help explain the challenges facing the US nuclear waste management program today.

B. The Nuclear Waste Policy Act of 1982: A National Compromise Abandoned

Before DOE was created, the Atomic Energy Commission (AEC) operated from 1946 until it was abolished in 1974. The AEC's original plan was not to dispose of SNF but rather the HLW resulting from the reprocessing of SNF.[29] The AEC did make some unsuccessful attempts to site geologic repositories for HLW disposal,[30] but for the purposes of this report, the actions most relevant for explaining the challenges the United States faces today originated in laws passed in the 1980s and decisions principally made at DOE.

The Nuclear Waste Policy Act of 1982

In 1979, a DOE-led Interagency Review Group on Nuclear Waste Management[31] recommended that repository sites for SNF and HLW disposal be identified in multiple geologies and regions of the country. A series of congressional hearings and draft bills followed, culminating in the passage of the Nuclear Waste Policy Act of 1982 (NWPA).

The NWPA was a careful compromise amid concerns from western states, environmental groups, and industry. In particular, the NWPA required the federal government to identify two sites to potentially host repositories—the first by 1987 and the second by 1990.

To ensure there would in fact be a second repository, a cap of 70,000 MTHM was placed on the first repository until the second one was opened.[32] The intent of having at least two repositories was for geographical equity, to minimize the cost of and impact of transportation, and to prevent one state from having to bear the full burden of the nation's nuclear waste disposal challenge. It was widely anticipated (though the NWPA did not require it) that the first site would be in the West[33] and the second in the East.[34]

The NWPA laid out a timetable for the characterization of potential sites and selection of the first and second repositories. For example, the president was to recommend to Congress the first site by March 31, 1987, and the second site by March 31, 1990. It also authorized DOE to enter into contracts with utilities to take commercial SNF by 1998 in exchange for a fee on nuclear power generation of 0.1 cents/kWh that was to be paid into a new Nuclear Waste Fund (NWF), the intention of which was to shield the American taxpayer from these costs. The secretary of energy was required to perform an annual assessment of the fee and to recommend changes if needed to assure full cost recovery.

Section 8 of the NWPA directed the secretary of energy to arrange for one or both of these repositories to also take defense-generated nuclear waste, unless the president explicitly determined that a separate repository for defense waste was needed. The evaluation was to consider cost efficiency, health and safety, regulation, transportation, public acceptability, and national security. Such a defense-only repository would still be subject to the full NRC licensing requirements, as well as the state/local/tribal participation, consultation, and financial assistance provisions that the NWPA required for a commercial repository.

DOE concluded that it would save on the order of $1.5 billion by comingling defense and commercial waste—otherwise finding no other factors that distinguished the two cases.[35] President Reagan accepted these conclusions and made the requisite determination for codisposal in 1985.

The NWPA originally allowed for monitored retrievable storage (MRS) facilities, known more commonly today as "consolidated interim storage facilities," to be constructed and operated by DOE as part of a waste management system. These facilities would involve above-ground storage of SNF in containers designed to passively cool the fuel and provide shielding from the SNF's radiation. In 1985, DOE recommended that a site in Oak Ridge, Tennessee, be converted into a temporary storage facility.[36] DOE had also considered two other sites in Tennessee for MRS purposes and concluded that an MRS facility in the state "would significantly improve the performance of the nuclear waste management system."[37] DOE identified the Clinch River site in Tennessee as its preferred site for a variety of reasons, including that it was owned by the federal government. In January of 1986, the governor of Tennessee notified the secretary of energy that he opposed the MRS project because he considered it unnecessary and thought it would have a detrimental effect on industrial recruitment, economic expansion, and tourism in the Knoxville–Oak Ridge area.

By law, the secretary of energy was to nominate five sites for the second repository by July 1, 1989. As part of the work building toward nomination, DOE had been investigating granite and crystalline rock in 17 states in the upper Midwest and Atlantic coast. However, when the secretary released preliminary rankings of promising rock formation in seven states in January of 1986, he drew intense opposition from these eastern states. The repository siting process envisioned by the NWPA unraveled soon after that.

The Reagan Administration Suspends Work on a Second Repository

In May of 1986, Secretary of Energy John Herrington announced that DOE had narrowed the candidate sites for the first repository in the West from nine to three: Hanford in Washington, Deaf Smith County in Texas, and Yucca Mountain in Nevada. Secretary Herrington also announced that DOE was deferring indefinitely the search for a second repository. The Congressional Research Service noted[38] that although Herrington's stated reason for putting off a second repository was the lower growth projected for nuclear power, candidates for the first repository saw it as the Reagan administration bowing to political pressure from eastern states and that the decision "unraveled a key regional compromise in NWPA."

The Reagan administration's determination that a second repository was not needed ran contrary to the NWPA: there was no requirement or even authorization for the Executive Branch to determine whether a second repository was needed. In fact, the law was unambiguous that there was to be a second repository, which was part of the grand compromise in 1982.

Members of Congress from eastern states that were under consideration for the second repository expressed enthusiasm and approval for the Reagan administration's decision, while others accused the administration of bowing to political considerations, including midterm elections and Vice President George Bush's potential run for president two years later.[39,40]

The reaction from elected officials representing western states, as well as others, was unsurprisingly quite different than reactions in the East. In a US House of Representatives hearing[41] held two months after the announcement, various members of Congress from the West voiced their displeasure with the Reagan administration's decision. Representative Mo Udall (D-AZ) criticized the administration for repudiating the essential compromise between eastern and western interests that allowed the NWPA to be passed and accused the administration of deferring the second repository round to help with the midterm elections in 1986. Representative John McCain (R-AZ) agreed that the NWPA would not have been passed without the second repository as an integral part of the legislation. Representative Barbara Vucanovich (R-NV) observed that Nevada might have to accept all of the nation's HLW with no assurances that Yucca Mountain was the safest site in the country and a worry that the cap of 70,000 metric tons in the NWPA would simply be lifted at a later time when it became "politically convenient to do so." Representative Beau Boulter (R-TX) noted that people did not believe that the process had been carried out fairly and in accordance with the law and that the indefinite postponement of the second site destroyed the concept of regional balance.

The deferral of the search for a second repository was not a partisan issue—it had both bipartisan support and bipartisan opposition.

The 1987 Amendments to the NWPA

Following the Reagan administration's announcement that it was suspending efforts on a second repository, members of Congress then amended the NWPA to legislatively postpone the siting of the second repository indefinitely.

Governor Bryan of Nevada called the legislation under consideration "little more than a blatant attempt to ram the repository down the throat of an unwilling State, which most informed parties conclude would be Nevada…Nevadans will never accept having a repository forced upon them under such circumstances, and indeed we are astounded that the Congress could even seriously consider such an unprincipled and irresponsible approach…We will fight this unjustifiable Senate Energy Committee legislation with all of our resources, and I will assure those who are supporting that approach that it ultimately will not work and, moreover, ultimately it will be far more costly and time consuming than ever imagined by those proponents of the legislation."[42]

S.1668, the Nuclear Waste Policy Act Amendments Act of 1987, contained most of the provisions that were ultimately included in the legislation passed on December 21, 1987. However, in the negotiations leading to the budget reconciliation conference report that included the bill, the language was revised to focus solely on Yucca Mountain.

The original NWPA had required the final three candidates for the first repository to be characterized[43] before the president made a recommendation to Congress; however, the three sites had not been characterized at the end of 1987, and the president never recommended a site before Congress selected Yucca Mountain. A contributing factor to Congress's actions was that the costs of characterization—as required by the NWPA—had grown to more than $1 billion for each site.[44] In 1981, DOE had estimated costs for site characterization from $60 million to $80 million, but these estimates grew much larger in subsequent estimates in 1984 and 1987.[45]

The legislation that passed in 1987 shattered whatever remained of the original NWPA compromise. The western states felt betrayed by the eastern states—where most of the nuclear power plants resided—and the vote served to harden resolve to oppose the repository project in Nevada, where the law came to be known as the "Screw Nevada" bill.[46]

After the 1987 amendments to the NWPA, Congressman Mo Udall (D-AZ), one of the principal authors of the original NWPA, stated on the floor of the US House of Representatives:

> We created a principled process for finding the safest, most sensible places to bury these dangerous wastes. We were confident that while no State wanted a nuclear waste repository, the States ultimately chosen would accept the outcome because the selection process would have been fair and technically credible.
>
> Today, just 5 years later, this great program is in ruins. To help a few office seekers in the last election, the administration killed the eastern repository program, shattering the delicate regional balance at the heart of the 1982 act. Since then the Western States have felt they are being treated unfairly, and they no longer trust the technical integrity of the Department of Energy's siting decisions.[47]

This is not to say that Congress thought that Yucca Mountain was a bad site in 1987. Years later, Senator Bennett Johnston (D-LA) recalled the increasing costs of site characterization and his effort to call on the Department of Energy to pick one of the three sites and characterize it to "save $2.4 billion." Senator Johnston asserted that in the conference committee, the House wanted to go ahead and name Yucca Mountain—that is to "do it politically, not scientifically"—though he also recalled that the indication he had at the time was that Yucca Mountain might have been picked for scientific reasons anyway.[48] The site was ranked at or near the top of five "well-qualified" sites for several performance metrics, according to a 1986 assessment by DOE.[49]

The law required the NRC to determine whether the site at Yucca Mountain was safe or not, but there was no backup provision in the event that Yucca Mountain was not viable. The absence of a backup plan contributed to a perception by the state of Nevada and other observers that the review process would never be fair given the importance of making the Yucca Mountain repository site work for the US nuclear industry and defense activities and the strong desire of other states not to host the repository.

For example, as directed by Congress in 1992, the US Environmental Protection Agency (EPA) and NRC promulgated regulations specific to Yucca Mountain regarding public health and environmental standards and how to implement those standards (40 CFR Part 197 and 10 CFR Part 63, respectively). These regulations differed substantively from the analogous generic regulations for geologic repositories (40 CFR Part 191 and 10 CFR Part 60) that had first been published before Yucca Mountain was selected. Within Nevada, there arose a perception that the federal government would simply alter design criteria or regulatory standards for Yucca Mountain if problems arose in meeting the existing ones, as the federal government could not afford to have Yucca Mountain fail.[50]

C. The Current Predicament

Many other developments have taken place since the 1987 amendments to the NWPA:

- 1998: the federal government failed to take title to SNF by January 31, as required by the NWPA, and subsequently utilities began to successfully sue the federal government for the costs of managing SNF at reactor sites.[51]
- 2002: the Yucca Mountain site was formally recommended to Congress by President George W. Bush. In response, the governor of Nevada submitted a notice of disapproval to Congress, as outlined in the NWPA, and Congress was then required to vote on a resolution to override Nevada's objection for the project to proceed.[52]
- 2004: a federal court ruled that the EPA radiation standards promulgated for Yucca Mountain were not consistent with the recommendations in a 1995 National Academy of Sciences report, which had been a requirement in federal law.[53]
- 2008: DOE submitted to the NRC the world's first application for a license to construct a geological repository to dispose of SNF and HLW, and EPA revised its radiation standards.[54]
- 2010: the Obama administration announced that it was seeking to withdraw the license application for Yucca Mountain and forming a Blue Ribbon Commission (BRC)[55] to recommend alternatives. The administration did not request money for the project in its subsequent annual budget requests to Congress and dissolved the Office of Civilian Radioactive Waste Management. Several states (including South Carolina and Washington) and parties sued DOE and NRC, contending that DOE had no authority to terminate the Yucca Mountain project.[56]
- 2013: a federal court ruled that the utilities need not pay the NWF fees on account of the federal government's continuing failure on nuclear waste management,[57] and DOE stopped collecting the fee in May of 2014.
- 2013: a federal court ruled that NRC must still evaluate the license application that had been submitted for Yucca Mountain with the money that had been previously appropriated to the NRC for these purposes.[58]
- 2015: the NRC finished a safety evaluation report of DOE's Yucca Mountain application. The NRC staff found that DOE met applicable regulatory requirements, except for requirements regarding ownership of land and water rights.[59]
- 2015: President Obama made a determination that a separate repository for defense waste was required, as section 8 of the NWPA required before proceeding with planning to dispose of defense waste at a non–Yucca Mountain site.[60]

- 2017: DOE issued a draft consent-based siting process in January for both consolidated interim storage and disposal facilities to manage defense and commercial waste.[61]

In 2020, there is still no repository that can dispose of HLW or SNF in the United States. Since 2010, Congress has not appropriated a single dollar for the Yucca Mountain project due to opposition from the Nevada congressional delegation. A life cycle assessment in 2008 for the Yucca Mountain repository estimated that remaining costs included $54.8 billion in construction, operation, and decommissioning costs out to 2133, an additional $19.5 billion for transportation activities, and $8.4 billion for other activities.[62] The Trump administration requested funding for the Yucca Mountain project in its budget requests for FY2018, FY2019, and FY2020, but requested no money for the project in its FY2021 request.

Thus, since 1987, there have been two constants in US nuclear waste policy: commercial SNF can only be disposed of at Yucca Mountain, and the state of Nevada steadfastly opposes the project. Problems from this stalemate have continued to mount. SNF from US aircraft carriers and submarines is discharged annually as the vessels come to shore for refueling or decommissioning. The US government has an agreement in place with the state of Idaho to store it at Idaho National Laboratory, but that agreement includes a clause that if no naval SNF is removed from Idaho by 2035, the federal government will begin to pay a fine,[63] and Idaho has the option to stop further shipments into the state.

The US nuclear weapons complex is no longer operating reactors to produce additional plutonium, and as a result that particular source of defense waste is not increasing. However, there are still thousands of metric tons of HLW from the US nuclear weapons program that sit largely in three states—Idaho, South Carolina, and Washington. Even after all of that waste has been processed at the sites and is ready for final disposal, the federal government will not be able to honor its obligations to those states and local communities without a geologic repository.

Finally, in the realm of nuclear waste from utilities, the US government finds itself in an exceptionally challenging place. Reactor licensees are no longer paying the NWF fee and some of their costs for on-site storage of SNF are reimbursed by the federal government through the US Judgment Fund.[64] Following the federal government's failure to take title to commercial nuclear waste by January 31, 1998, licensees began suing DOE to recover the costs incurred from storing SNF at their reactor sites. Through FY2017, the US government has paid $6.9 billion out of the Judgment Fund for this failure, and DOE has estimated that potential liabilities for repository delays could total as much as $34.1 billion.[65] These legal costs are not paid by DOE, however, which is legally responsible for taking the SNF, and thus DOE's budget is not impacted by this failure.

There is also no safety crisis pushing elected officials to move with alacrity—commercial SNF is being stored safely and securely in pools and dry casks at reactor sites. However, when reactors shut down and are decommissioned, the SNF has nowhere to go (e.g., sites in California, Colorado, Connecticut, Massachusetts, Maine, Michigan, and Oregon[66]). The federal government, through lawsuits and the Judgment Fund, is paying for the storage of SNF at these sites and others (e.g., the security costs associated with guarding the SNF), but the local communities are still prevented from reclaiming all of their land for other purposes.

Thus, the current impasse in US nuclear waste management may potentially impact the US Navy's operations, hamper the ability of the US government to meet its commitments to clean up Cold War nuclear weapons sites, add billions of dollars in costs to US taxpayers, and constrain the potential for nuclear energy to address climate change. These observations alone argue for congressional attention. However, since the US nuclear waste program's direction was last set in the 1980s, there have also been some positive developments in nuclear waste management (in the United States and in other countries) that should be factored into rethinking the US approach, as discussed in the next chapter.

III. THE SCIENTIFIC CONSENSUS ON DEEP GEOLOGIC DISPOSAL

The spent fuel produced by reactors includes isotopes that are radioactive (i.e., "radionuclides"), and the radiation given off by these isotopes is harmful to human health if placed in close proximity to people without proper shielding. Some of these radionuclides are gaseous or water soluble, or they strongly bond to nonnuclear materials and thus can be mobile if they are released from their waste packages. The ultimate concern is human exposure to radiation due to inhaled gaseous and aerosol radionuclides, external radiation exposure due to proximity to contaminated land, or the ingestion of food or water containing radionuclides.

However, for many decades the scientific consensus has been that SNF can be safely disposed of in a manner that protects human health. This chapter briefly reviews the science behind the disposal of SNF in repositories mined out of underground geologic formations and describes the WIPP facility in New Mexico, which is currently disposing of defense-generated TRU waste in an underground salt formation. The chapter reviews three of the foreign geologic repository programs that have been making progress toward disposal, and their consent-based approach to siting using an organization whose sole mission is nuclear waste management. Finally, the chapter discusses some strategic advantages if the United States were to pursue disposal of defense-generated SNF and HLW ahead of commercial SNF disposal.

A. Safely Isolating Nuclear Waste from the Biosphere

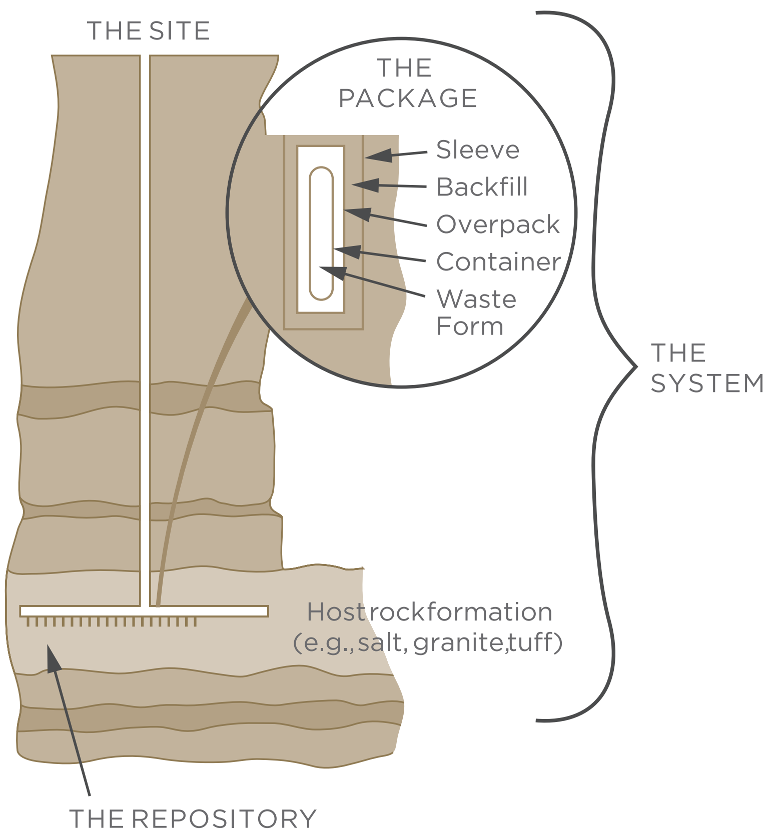
The National Academy of Sciences' National Research Council first endorsed the concept of geologic disposal for HLW in 1957 and in particular found that disposal of such wastes could be done safely and at many different locations in the United States.[67] Geologic disposal has remained the consensus approach in the scientific community.[68] Some underground geologic formations have remained stable for millions to hundreds of millions of years—much longer than the half-lives of some of the most long-lived radionuclides in SNF, such as iodine-129, which has a half-life of 15.7 million years. A mined repository in such geologic formations could potentially provide an appropriate place for the disposal of SNF and HLW, subject to additional analysis of other natural and engineered features (e.g., a specified waste inventory, projected water flow through the site, and waste package construction.)

The plan for HLW and SNF disposal studied by the United States and other countries employs a "defense-in-depth" approach for isolating nuclear waste from the biosphere. This strategy utilizes a combination of engineered barriers and natural barriers to limit radionuclide movement from the repository (figure 1), including[69]

- the waste form (e.g., light water reactor uranium dioxide pellets, which have been partially converted during reactor operation to other heavy elements and fission products; for light water reactor SNF, there is also the metal cladding around the pellets, which is usually a zirconium-alloy metal);[70]

- engineered barriers surrounding the waste form (e.g., metal containers or packages for the SNF/HLW);
- any encompassing buffer (e.g., bentonite clay around the packages) and backfill (e.g., filling the mined tunnels with material before closure); and
- the host rock of the repository site.

Figure 1: Illustration of a potential mined geologic repository with chambers for waste package emplacement



Source: BRC 2012, https://www.energy.gov/sites/prod/files/2013/04/f0/brc_finalreport_jan2012.pdf

The objective of the barriers is to lengthen the travel times of SNF/HLW radionuclides from the repository to the biosphere.[71] The engineered barriers will eventually degrade, at which point the natural barriers will slow radionuclide migration and limit off-site exposures of nearby populations.

Water transport is the principal manner by which radionuclides leave a given repository site and migrate to bodies of water that could be used for drinking or growing food and in that way impact human health. As radionuclides are transported by water from their emplacement locations after package degradation, depending on the specific geology involved, they may also experience reactions (e.g., adsorption reactions with mineral surfaces) along the way, thereby slowing their migration. Modeling of these effects is dependent on the characteristics of particular sites and part of providing evidence that an individual repository will meet regulatory standards for radiation protection.

The relevant standards to protect human health from radionuclide migration from geologic repositories are generally based on limiting radiation dose from the ingestion or inhalation of radioactive materials. The time period for regulating potential off-site dose is long—from 10,000 to as long as 1 million years. People receive doses of radiation from natural backgrounds and man-made sources (e.g., medical procedures) each year (on average 620 millirem),[72] but additional radiation exposure from breathing in dust, drinking water, and eating food contaminated with radioactive materials can lead to an increased chance of cancer in later life. Typically, however, radiation regulatory limits are many times below where health effects can be measured and well below the average yearly radiation dose from natural sources or man-made sources.

By law, the EPA is charged with setting the radiation standards that apply to geologic repositories for SNF and HLW disposal, which it does in 40 CFR Part 191. That standard currently applies to the WIPP site in New Mexico (with additional criteria in Part 194). However, in the Energy Policy Act of 1992, Congress directed EPA to produce regulations specific to Yucca Mountain, which it did in 40 CFR Part 197. Those standards limit the "reasonably maximally exposed individual" to 15 millirem/year for the first 10,000 years following disposal and 100 millirem/year after that. This individual is assumed to drink two liters of water per day from ground water in the "accessible environment above the highest concentration of radionuclides in the plume of contamination."

The heat generated by SNF or HLW at the time of emplacement is another important detail that affects repository design. If the heat generated by nuclear waste in a geologic repository raises the temperature of the nearby host rock significantly, it has the potential to result in adverse impacts to repository performance, including accelerated corrosion and degradation of the waste packages and the SNF/HLW itself, as well as impacts on local geochemistry and groundwater flow. To limit localized temperatures, repositories may reduce the number of waste packages or SNF assemblies in one location and put additional space between the locations of waste packages. In that way, heat considerations can affect the total volume of a repository (e.g., the number and length of tunnels that are mined) for a given amount of SNF and HLW or limit the amount of SNF and HLW that can be disposed if the available repository volume is constrained. As heat considerations can affect the number of waste packages that can be disposed and the volume of tunnels required, they ultimately have cost implications.

The exact isotopic composition of SNF when it is removed from a reactor and the time between when it was removed from reactor operation to when it is emplaced underground determines its rate of heat generation at disposal, as well as the total amount of heat it will ultimately transmit to its environment over the subsequent millennia. Since SNF cools exponentially, longer interim storage of SNF means it will be generating less heat (and radiation) when it is finally transported to and placed in a repository.[73] There are, therefore, some waste management benefits to interim storage of SNF (either at reactor sites or in consolidated interim storage facilities) for a number of decades before final disposal.

B. An Operating Geologic Repository in the United States: The Waste Isolation Pilot Plant

The United States operates the only geologic repository in the world for long-lived radioactive waste disposal. Located in New Mexico, the Waste Isolation Pilot Plant began disposal operations over 20 years ago. WIPP offers a possible model for how a future repository program for SNF and HLW could function.

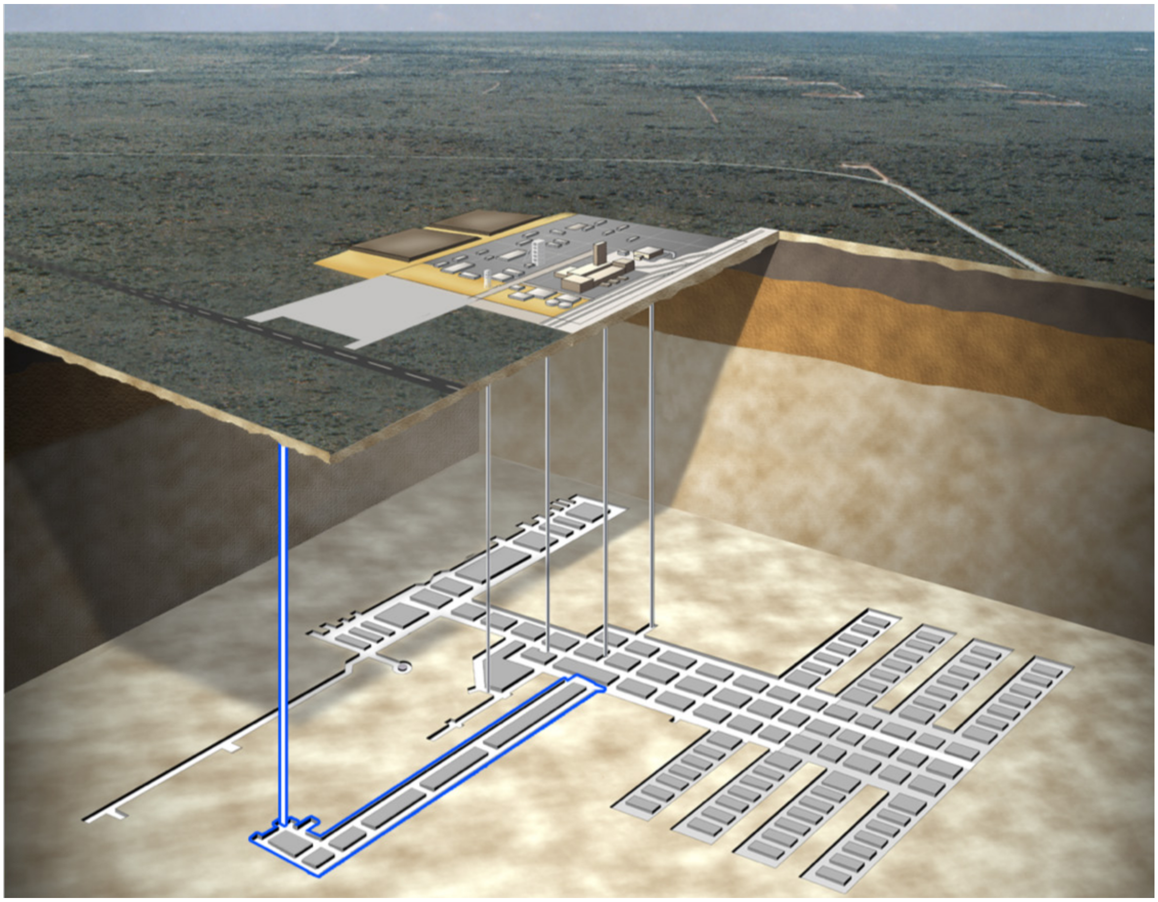
The origins of defense HLW from the US nuclear weapons program began in the 1940s and included a separate and generally less radioactive nuclear waste stream. As part of the operation of nuclear weapons facilities, a large variety of materials (e.g., protective clothing, laboratory equipment, and waste sludges) became contaminated with heavy radioactive elements such as plutonium and americium. These contaminated materials, on account of the long half-lives of some of the elements involved, needed to be disposed of in a geologic repository.

WIPP is about 25 miles east of Carlsbad and has been accepting TRU nuclear waste generated by US defense programs since 1999. The site itself is a network of rooms excavated into a large salt deposit 2,150 feet underground. (See figure 2 for an illustration of WIPP.)

The salt deposit that WIPP is mined into is 250 million years old, and the primary formation containing the WIPP repository is about 2,000 feet thick, beginning 850 feet below the surface.[74] The site presents several appealing features from the perspective of nuclear waste disposal:

- The salt is relatively easy to mine.
- Any fractures are self-healing, on account of salt's plastic quality, which seals off radioactive waste from the environment.
- The existence of the salt deposit indicates a lack of flowing groundwater, which would otherwise have dissolved the formation.
- The large size of the formation would imply "hundreds of thousands to millions of years to dissolve sufficient salt to threaten such a repository."[75]
- The lack of potable groundwater at the site.

Figure 2: WIPP geologic repository illustration



Source: DOE, https://www.lanl.gov/orgs/nmt/nmtdo/AQarchive/02spring/WIPP.html

The facility has two primary regulators: the EPA and the New Mexico Environment Department. Under the Resource Conservation and Recovery Act (RCRA),[76] the EPA authorizes states to implement hazardous waste regulatory programs. The New Mexico Environment Department regulates WIPP through a Hazardous Waste Facility Permit that describes how the repository manages, stores, and disposes of materials that are present in the mixed waste (i.e., containing both radioactive and hazardous waste components).

In the 1970s the federal government began investigations of the salt formations in the area where WIPP is now located for the potential disposal of radioactive waste. Which types of nuclear waste were to be disposed at this potential repository were unclear during the early investigations, and DOE's occasional attempts to potentially include commercial SNF created mistrust and tension with the state.[77] New Mexico got DOE to sign an MOU regarding the site in 1978, creating the Environmental Evaluation Group (EEG), which was an independent scientific body chartered to review technical matters related to WIPP. The EEG would play a valuable role in the ensuing years as a respected independent authority. In one case, as new technical information about the nearby geology emerged, the EEG recommended changes to the repository design and DOE changed its approach.[78]

In December of 1979, Congress passed the WIPP Authorization Act (Public Law 96-164), which limited WIPP's mission to defense waste—ruling out commercial SNF. The WIPP Authorization Act also required that the secretary of energy "consult and cooperate with the appropriate officials of the State of New Mexico, with respect to the public health and safety concerns of such State in regard to such project." There was even a directive that the secretary should seek a written agreement with the appropriate officials of the State of New Mexico by September 30, 1980, laying out the procedures for consultation and cooperation (C&C). DOE and New Mexico entered into negotiations over this agreement, but on September 28, Jeff Bingaman, then the attorney general for New Mexico (later a US senator), said New Mexico would not sign an agreement unless DOE stipulated that it would be legally binding and its implementation subject to judicial review.[79]

A standoff ultimately led Bingaman to sue the federal government (DOE and the US Department of Interior) on May 14, 1981. Eleven days later, the state sought a preliminary injunction to halt construction, but by the following month, DOE and New Mexico had reached a settlement. The stipulated agreement, executed among the State of New Mexico, DOE, and the US Department of the Interior, was filed with the US District Court of the District of New Mexico on July 1, 1981.[80] Among other provisions, the stipulated agreement requires DOE to make a "good faith effort" to work with the State of New Mexico in resolving matters that involve state concerns regarding the WIPP project.

A C&C agreement, signed by New Mexico governor Bruce King and Secretary of Energy James Edwards on July 1, 1981, was included as an appendix to the stipulated agreement. It provided for the timely and open exchange of information about WIPP as well as a mechanism for conflict resolution on matters of public health, safety, and welfare by which the state could challenge DOE in court if it did not address state concerns. The C&C agreement also required the federal government to give advance notice of key events and milestones to the state and prohibited the disposal of defense HLW at WIPP.

A "working agreement" was attached as an appendix to the C&C agreement to serve as a dynamic document setting forth the working details of the C&C process. Included in the working agreement is a listing of key events and milestones relating to development of the WIPP project. The working agreement also provides a detailed description of the information to be included in the "safety analysis report" for WIPP.

These documents were supplemented, revised, modified, and amended over the subsequent decade as part of negotiations between the state and the federal government. They have given the state a significant voice on WIPP's development and have required DOE to respect state views and concerns about the WIPP project.

For example, in 1982, the state and the federal government reached agreement on a supplemental stipulated agreement. The agreement addressed New Mexico's off-site concerns in several areas: (1) state liability, (2) emergency response preparedness, (3) independent transportation / environmental monitoring of the WIPP project activities, and (4) repairing state highways (including assistance to New Mexico in obtaining federal funds to upgrade state highways used for transportation of waste to WIPP).

In the years that followed, DOE failed to adhere to the agreements. To take one instance, DOE did not provide advance notification to New Mexico about the construction of underground structures at WIPP (a "key event"), and in 1983 this led to state threats to invoke the C&C agreement conflict resolution measures. The backlash led to the first modification of the C&C agreement, which was signed in 1984 and included several modifications, such as

- new limitations on the characteristics of the nuclear waste that could be brought to WIPP;
- an agreement that the amount of defense HLW used on an experimental basis at the site would not exceed a specific level of radioactivity per waste canister or a total amount of radioactivity;
- requirements that DOE disclose specified technical characteristics of defense high-level waste canisters;
- a statement that WIPP "is not designed for the permanent disposal of high-level waste, nor has the WIPP site itself been characterized for such permanent disposal"; and
- decontamination and decommissioning responsibilities (assigned to the federal government) along with postclosure institutional controls at the site.

In 1992, Congress passed the Waste Isolation Pilot Plant Land Withdrawal Act of 1992 that limited the mission of WIPP to defense-generated TRU waste and withdrew the land associated with the repository from public use. It required EPA to certify that WIPP was in compliance with the generic repository standards in 40 CFR Part 191 before commencing operations. Furthermore, it gave New Mexico the authority to regulate mixed waste operations at WIPP under RCRA and gave the National Academy of Sciences a formal role in reviewing WIPP-related technical matters. The legislation also authorized economic assistance to the state and put requirements on the WIPP transportation program, including NRC certification of transportation packages and construction of a bypass around Santa Fe.

Under EPA regulations, WIPP must be shown to safely limit the release of radionuclides for 10,000 years. In 1998, EPA certified that WIPP was in compliance with the relevant repository radiation standards, and in 1999 WIPP began receiving TRU waste shipments.

The state granted WIPP a final RCRA facility permit in October 1999, making the facility subject to RCRA operating standards. New Mexico could then take enforcement actions for permit violations at WIPP, should they occur, giving the state leverage in decision-making regarding the repository.

The development of WIPP did not take place along a straight line, nor was it without twists or individual decisions that imperiled its future at times. It does, however, present an alternative development path to the one pursued with Yucca Mountain. The WIPP approach utilized written agreements and involved a vigorous back-and-forth between the federal and state governments that ultimately produced the world's first licensed and operating deep geologic repository for long-lived nuclear waste. The relationship built between the federal government and New Mexico was in fact durable enough that when two accidents at the WIPP site occurred in 2014,[81] the two entities were able to work through them and WIPP returned to operations in 2017.

As discussed in chapter 4, the United States has safely and successfully made over 12,000 shipments of TRU waste from a dozen locations to WIPP for disposal. While TRU waste is generally less radioactive than SNF and HLW, the project as a whole can still be viewed as a model for how a future geologic repository program for commercial SNF could be structured.

C. Progress Made by the Finnish, Swedish, and Canadian Nuclear Waste Programs

As the United States' HLW and SNF disposal program has ceased to make progress, other countries have taken the lead in repository development. Every country with a nuclear power program must manage the SNF once it is removed from reactors, and several have made substantial progress toward a disposal facility.[82] To provide concrete illustrations, three countries' programs are described below: Finland, Sweden, and Canada. Finland can be looked at as the world leader in geologic repository efforts as it is already in the process of constructing a facility, with SNF disposal operations expected to begin in 2023. Sweden is in the process of licensing a repository, while Canada is progressing toward a site selection in 2023. All three countries have pursued an approach that is premised on the concept of obtaining consent from communities that would host the repositories. In the United States, the compromise approach envisioned in the original NWPA of 1982 was that the federal government would select a site, and while a state could submit a notice of disapproval in response to the selection, Congress could then vote on a resolution to override that notice of disapproval, which is exactly what happened in the case of Yucca Mountain.

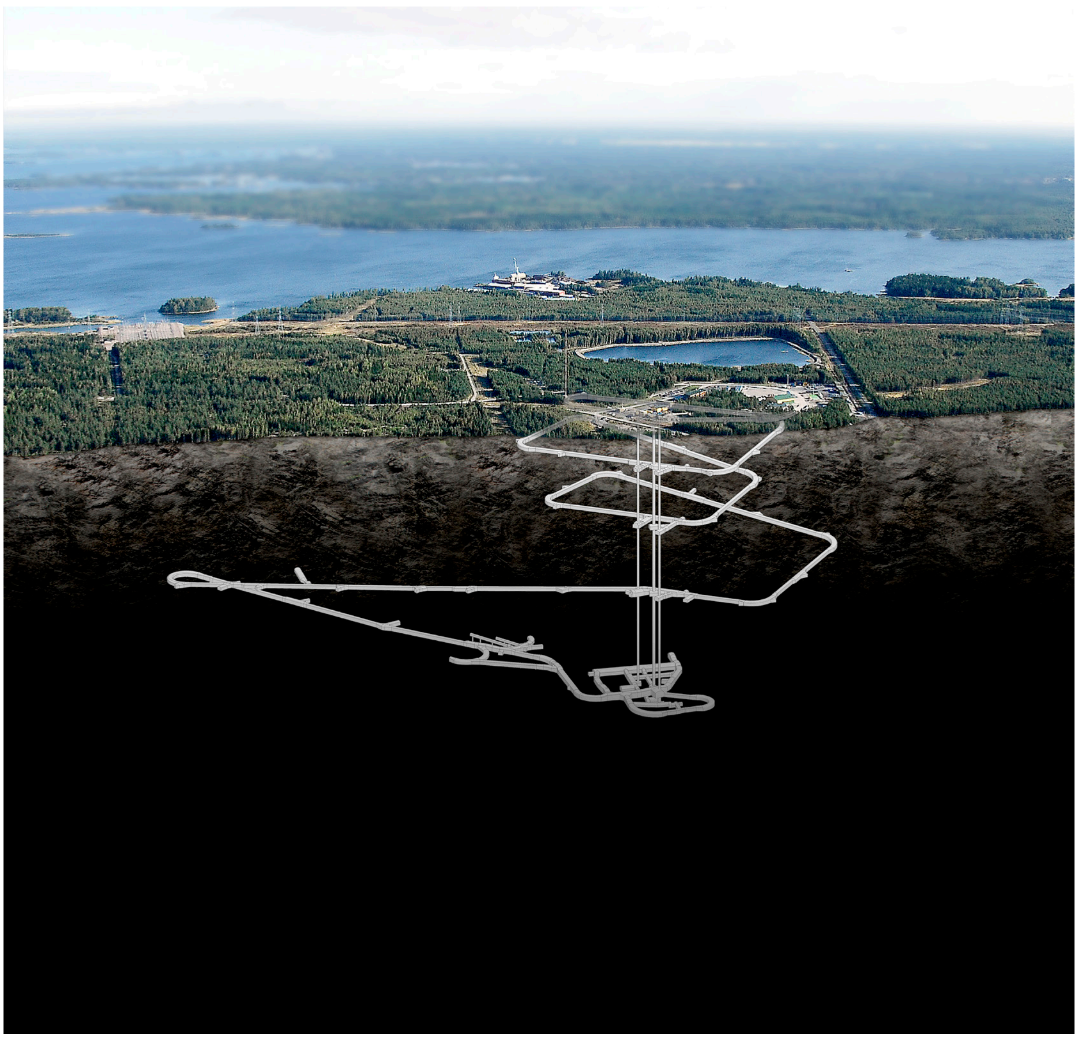
This section is not to suggest that each of these countries' programs have already succeeded—Canada has not yet selected a site, and Finland and Sweden still have additional licensing actions ahead before any SNF can be disposed of, assuming no technical issues prove to be a barrier.[83] The point is that each country has been making progress toward a geologic repository using a single purpose organization that has access to the funds it needs and that each respective entity has employed a staged approach involving both technical evaluations and a back-and-forth with the local communities that would be potentially hosting a repository (including the option for those communities to withdraw from consideration).

Finland has four operating nuclear reactors that supply about 30% of its electricity.[84] A fifth reactor is under construction, and a sixth is planned as part of the Finnish government's effort to phase out coal generation.

The Finnish program to develop a geologic repository began in 1983, and the siting process proceeded in three steps. The first step entailed a countrywide screening of sites, following by a second phase of preliminary investigations. The third phase lasted from 1993 to 2000 and focused on more detailed investigations and environmental impact assessments for four potential sites.

While all four sites were assessed to be technically viable, the local support for SNF disposal in a geologic repository was strongest in two communities. Given that factor and other considerations (e.g., proximity to existing nuclear reactors), the private company responsible for managing SNF (as opposed to the government-led approach in the United States), Posiva Oy, applied to move forward with a repository in one community, Eurajoki. The municipal council there voted in favor (20 to 7) of the repository, and in 2001 Finland's Parliament voted 159 to 3 to proceed. (An illustration of the proposed facility is shown in figure 3.)

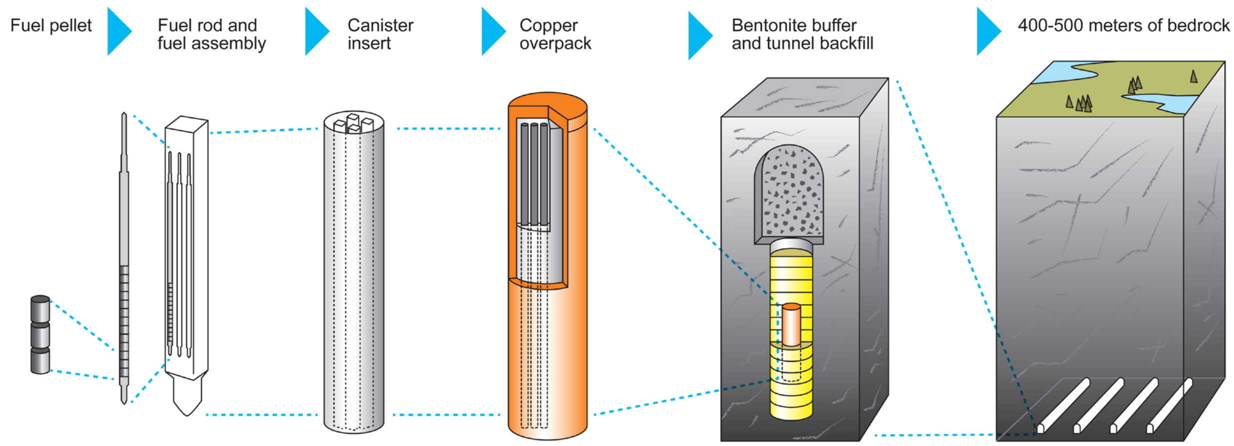
Figure 3: Proposed Finnish repository at Onkalo



Source: Posiva Oy, http://www.posiva.fi/en/media/image_gallery?gfid_2061=92#gallery_2061

Posiva submitted its construction license application to the Ministry of Employment and the Economy in 2013, and the government granted a construction license for the project in 2015. Construction work began on the repository the following year. Posiva is still required to obtain a separate operating license for the facility, with operation expected to begin in 2023.[85]

Figure 4: Barriers to the release of radionuclides from the Finnish repository



Source: Posiva Oy, http://www.posiva.fi/en/media/image_gallery?gfid_2061=92#gallery_2061

The Finnish approach is based on the Swedish KBS-3 concept for nuclear waste disposal, though Finland is actually closer to the start of operations than Sweden.[86] According to the KBS-3 concept, the light water reactor SNF assemblies are loaded into corrosion-resistant canisters made of a cast-iron insert with a copper overpack, which are surrounded by bentonite clay to slow the movement of water and retard the migration of radionuclides. The final barrier is the bedrock surrounding the canisters and bentonite. All of these barriers are shown in figure 4.

Sweden has been generating electricity from nuclear power plants since 1964. Eight nuclear reactors provide about 40% of its electricity.[87]

In 1992, the private company (again, in contrast to the US-government-led approach) in charge of managing SNF, SKB, began a siting process. After inviting interest from municipalities, SKB conducted work with the two local governments that agreed to be considered. However, in both cases, subsequent public referendums rejected the projects.

SKB then studied five potential sites and approached three of the associated communities where nuclear facilities already existed. Two municipal councils consented to more detailed assessments, while the third declined. In 2009, a site was chosen in Forsmark, a village that has an operating nuclear power plant, a disposal facility for shorter-lived nuclear waste, and was judged to have better geologic features. Of potential interest to the US program, the municipality that was not chosen was still rewarded with economic benefits for its participation.

In 2014, SKB submitted a license application to the Swedish government to build a spent fuel repository at Forsmark.[88] In January 2018, the Swedish national Land and Environmental Court deferred a decision on the repository pending SKB's submittal of additional information,[89] and a final government decision on construction is still pending. SKB hopes the facility will be ready to receive deliveries in the 2030s.

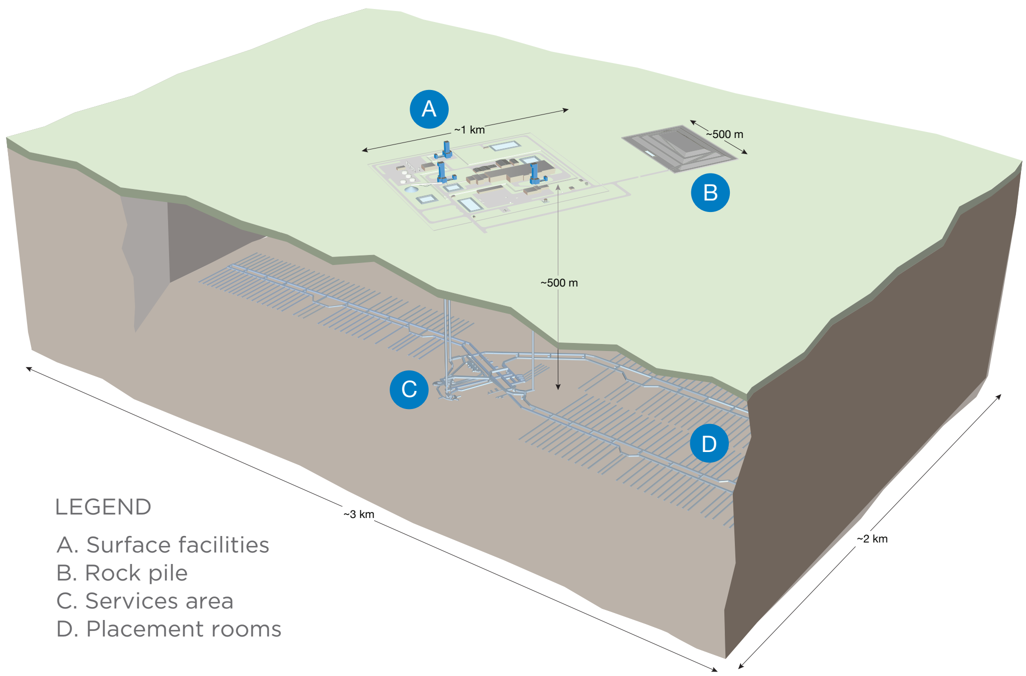
Canada operates 19 nuclear reactors, which provide about 15% of its electricity supply.[90] The Nuclear Waste Management Organization (NWMO) is a not-for-profit, private entity established in 2002 by Canada's nuclear electricity producers as required by Canada's Nuclear Fuel Waste Act. The NWMO's founding members are Ontario Power Generation, New Brunswick Power Corporation, and Hydro-Quebec, and all of these organizations—along with Atomic Energy of Canada Limited—are mandated to fund its operations. The NWMO is charged with developing and implementing a national solution for used fuel.[91]

One relevant and substantial difference between the United States and both Sweden and Finland is that these two countries do not have the equivalent of the US state-level government, which has been a source of opposition to proposed SNF disposal and storage projects even when the local government is supportive. Canada is somewhat more similar to the US situation, as it has provincial-level governments that are in between federal and local governments. A mitigating simplification in Canada's nuclear waste management program, however, is that the large majority of Canadian nuclear power plants are in the province of Ontario, which is also where the repository sites under consideration are located.

Like the United States' program today, Canada's nuclear waste program had to be restructured many years ago. A commission study from the 1990s concluded that the previous Canadian effort did not enjoy public confidence, which contributed to its failure. As a result, the Canadian national government passed legislation that established the NWMO. By virtue of when it was created, the NWMO was able to benefit from the Finnish and Swedish experiences, and it put extensive focus on understanding and incorporating the views of Canadian citizens.

After the NWMO initiated a voluntary siting process in 2010, 22 communities expressed interest in potentially hosting a repository. This number was ultimately narrowed down through multistage technical and socioeconomic and cultural assessments. At the end of 2019, the NWMO announced that it had narrowed down the sites under consideration from five to two. While they had opportunities to do so, neither of these two communities decided to remove themselves from consideration as the site selection process moved forward. NWMO plans to select one site to focus on in 2023. An illustration of what the Canadian repository could look like is shown in figure 5.

Figure 5: The Canadian repository concept



Source: NWMO, "Triennial Report 2017 to 2019," March 2020, 2020 Nuclear Waste Management Organization, https://www.nwmo.ca/~/media/Site/Reports/2020/03/06/19/17/NWMO-Implementation-Plan-202024.ashx?la=en

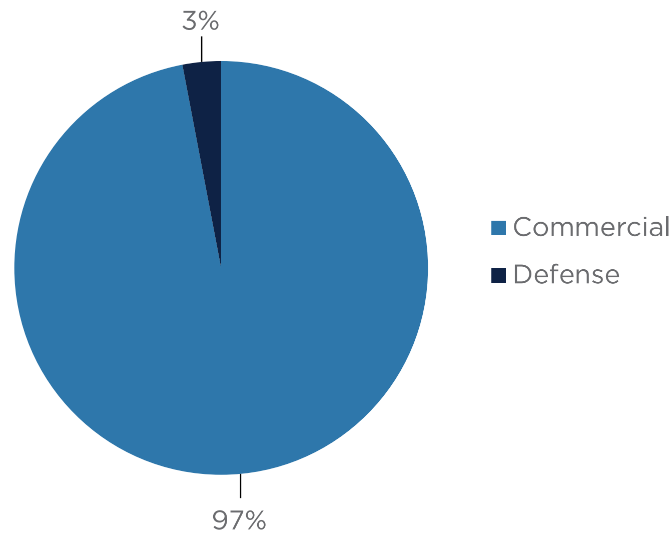
D. Advantages to Pursuing Disposal of US Defense HLW and SNF First

Unlike Finland, Sweden, and Canada, the United States must also dispose of a nuclear waste stream from defense-related activities that is distinct from commercial SNF generation. As discussed earlier in this report, the production of nuclear weapons and the operation of the navy's aircraft carriers and submarines have produced SNF and HLW. This section suggests that pursuing disposal of defense waste before commercial SNF presents some advantages as part of a comprehensive US nuclear waste strategy.

The TRU waste being disposed of at the WIPP site was generated by the US nuclear weapons program. The construction of nuclear weapons during the Cold War was in the context of the threat of Soviet aggression, and a hypothesis that has been suggested is that US citizens (e.g., in New Mexico) recognized that they themselves benefited from these national security missions that produced the associated TRU waste and also that they were helping to serve a national security mission by disposing of it.[92] This could be contrasted with commercial waste disposal, where a state is being asked to accept the risk associated with disposing of the waste without having enjoyed the benefits associated with its generation (e.g., jobs at a power plant outside its borders). That might be especially true if the waste is from a nuclear power plant on the other side of the country, as it is harder to see how the potential repository host state would have benefited from the economic development, power supply, or reduced air pollution that came with the waste (climate benefits aside).[93]

If that hypothesis is correct, then pursuing disposal of defense SNF and HLW first might have an added advantage of potentially greater public acceptance.

Figure 6: Approximate percentages of radioactivity in US SNF and HLW

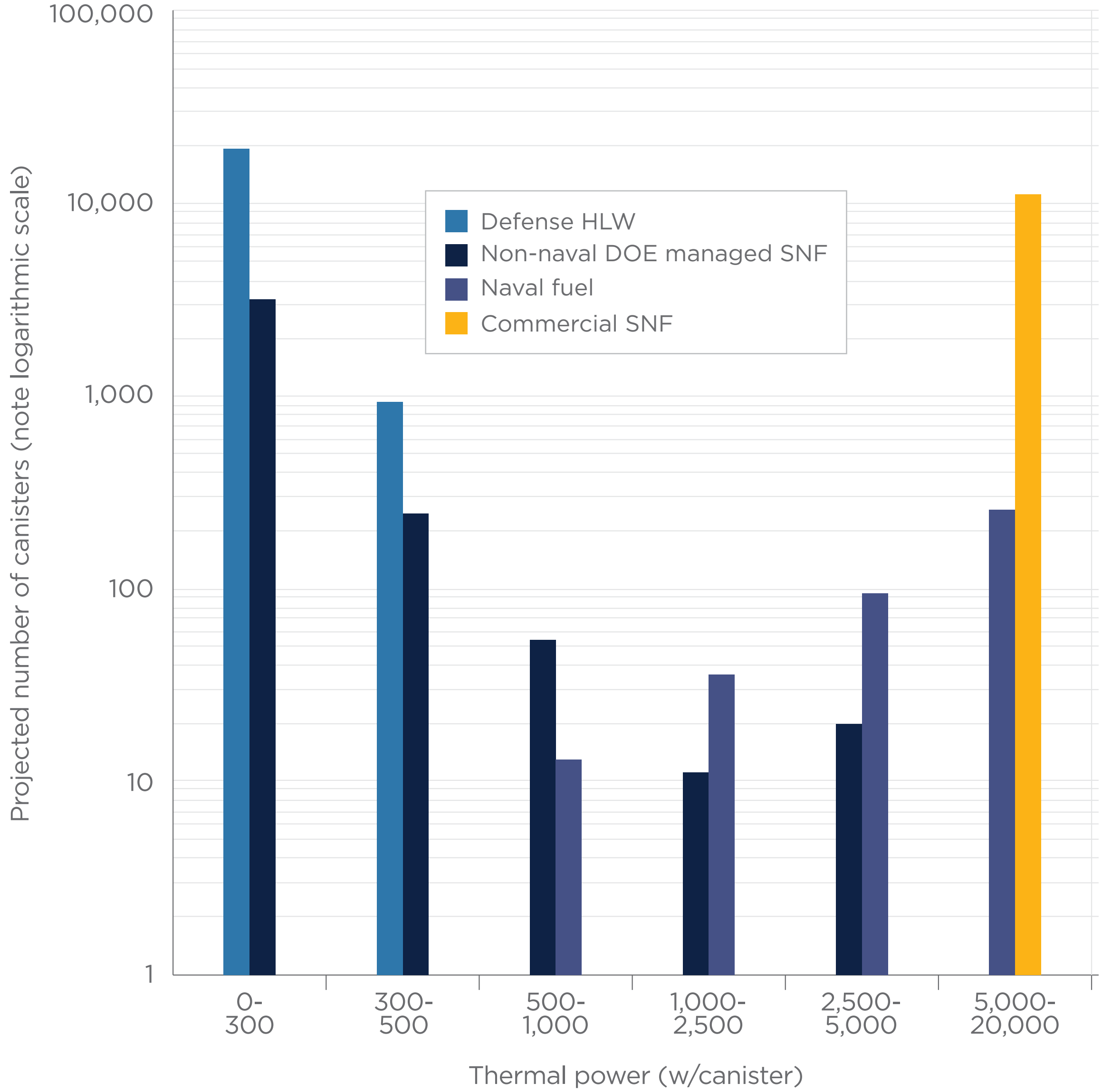


Source: Figure 2 of the US Nuclear Waste Technical Review Board report, "Evaluation of Technical Issues Associated with the Development of a Separate Repository for U.S. Department of Energy-Managed High-Level Radioactive Waste and Spent Nuclear Fuel," June 2015

In addition, the technical characteristics of defense waste make it a good candidate for demonstrating the safe transportation and disposal of SNF and HLW. To begin with, as figure 6 shows, there is a much smaller amount of radioactivity in the defense waste inventory as compared to the commercial waste inventory. Also, as figure 7 illustrates, overall, defense waste canisters are cooler than commercial ones. Finally, the plutonium and enriched uranium have already been removed from the defense program's HLW, so the potential value in being able to retrieve that inventory in the future for reuse is low.[94] This last point could help to enable new approaches to defense HLW such as deep borehole disposal.[95]

Smaller quantities of waste and waste that is less radioactive are two characteristics that by themselves generally tend to reduce transportation risks and make it easier to meet the associated public health protection regulations for disposal in a geologic repository.[96] Cooler waste, for example, would change the heat considerations for a repository design and might enable closer spacing of the waste packages, and thus a smaller repository volume, which could mean less tunneling and associated cost. It could also potentially simplify aspects of repository design and operations, including greater flexibility in the use of backfill (where the tunnels are filled in with materials before closure).[97]

Figure 7: Defense and civil waste binned by number of canisters and thermal power



Source: DOE, "Assessment of Disposal Options for DOE-Managed High-Level Radioactive Waste and Spent Nuclear Fuel," October 2014, Page 13, https://www.energy.gov/sites/prod/files/2014/10/f18/DOE_Options_Assessment.pdf

If the United States were successful in achieving disposal of defense-generated SNF and HLW, it might assist future repository initiatives for commercial SNF. Local and state officials from other locations could visit the repository to understand the safety considerations (as they can at WIPP for TRU waste disposal and international repository projects for commercial SNF like Onkalo in Finland) and see firsthand how such a facility is designed, constructed, and operated to help inform their consideration of hosting a repository for commercial SNF. It would also give the United States additional design, licensing, and operational experience with a repository for HLW and SNF.

One potential concern about disposing of defense waste first is that it could be a more costly approach than disposing of commercial and defense waste at the same time. It would do nothing to defray the ongoing costs of commercial SNF storage, for example. The defense community may also worry about paying greater costs for proceeding first. However, given that the United States currently has no geologic repository for HLW or SNF licensed, much less in operation, these concerns may be misplaced. If defense waste does enjoy greater public acceptance, it could lead to earlier disposal of defense waste and reduce the total costs of storage at DOE sites. And this progress could ultimately benefit a disposal program for commercial SNF. In any case, DOE could conduct a full system analysis of possible scenarios and associated life cycle cost implications to inform the discussion.

The original decision in 1985 to comingle defense and commercial waste was based on fairly small perceived differences between the two options and under different circumstances. The BRC staff noted in a paper[98] that the 1985 evaluation showed a $1.5 billion cost advantage to comingling and "not significant offsetting disadvantages." But the BRC staff also noted that several developments occurred after the 1985 evaluation, which could alter the assumptions that were part of that conclusion, including ceasing the operation of production reactors at Hanford in 1987 that had been part of the US nuclear weapons program (thus, bounding that particular waste inventory), the successful opening of WIPP in 1998, and commitments by the US government to defense waste cleanup (e.g., the Batt agreement in 1995).

Achieving disposal of defense waste safely and with the consent of the state and local community would be a large step forward in the tortured history of US SNF and HLW management. It could help to pave the way for future commercial SNF repositories by providing the United States experience with the large-scale operations associated with a repository for highly radioactive waste. In addition, while defense waste was being disposed of, commercial waste would continue to cool in interim storage—reducing somewhat the challenges associated with its future transportation and disposal. On the other hand, this would then preclude the option to mix the commercial and defense waste streams for a potentially more efficient use of the mined repository volume.

As part of a phased, adaptive, consent-based approach,[99] it is also possible that a community and state that accepts defense-generated waste in an initial phase might consent to some commercial SNF at a later time. The French nuclear waste repository design, for example, has different zones in its underground tunnels for civil and military waste, and there is no reason in principle why the United States could not have separate zones for civil and defense waste at the same site. A community could initially agree to disposal of defense waste using a set of tunnels in one zone, and then later—pending consent—agree to a different set of tunnels and emplacement chambers in a separate zone for commercial SNF. For states that worry over whether accepting defense waste may eventually lead to them being forced to accept commercial waste at a later time, a legally binding agreement (such as the federal government's agreement with New Mexico) blocking this scenario may provide the necessary assurance that their consent will in fact be required for disposal of any commercial waste.

IV. TRANSPORTATION OF NUCLEAR WASTE

According to the NRC, about 3 million packages of radioactive materials are shipped every year in the United States—by truck, train, plane, or ship. It is the joint responsibility of the NRC and the US Department of Transportation to regulate the safety of these shipments.[100] Almost all of these shipments are nuclear materials that are far less radioactive than commercial SNF. This chapter looks in greater detail at that transportation of three categories of nuclear materials: defense-generated TRU waste, spent naval reactor fuel, and commercial SNF.

The number of commercial SNF shipments in the United States is somewhat limited (past transfers have mostly been between nuclear power plants and for research purposes), but in Europe, and in particular France, there has been extensive transportation of SNF from nuclear power plants over many decades. The evidence to date suggests that transporting commercial SNF has been a safe enterprise: tens of thousands of SNF shipments around the world have been conducted safely.

This chapter uses the US experience with shipping defense-generated TRU waste to WIPP as a model for how a large-scale SNF transportation campaign to a disposal site could work. In addition, the transportation of spent naval reactor fuel to the Idaho National Laboratory for interim storage is briefly reviewed. Finally, the chapter discusses societal and institutional challenges associated with a scaled-up transportation program for US commercial SNF that should be addressed before such an initiative (associated with either a consolidated interim storage facility or a disposal site) is undertaken.

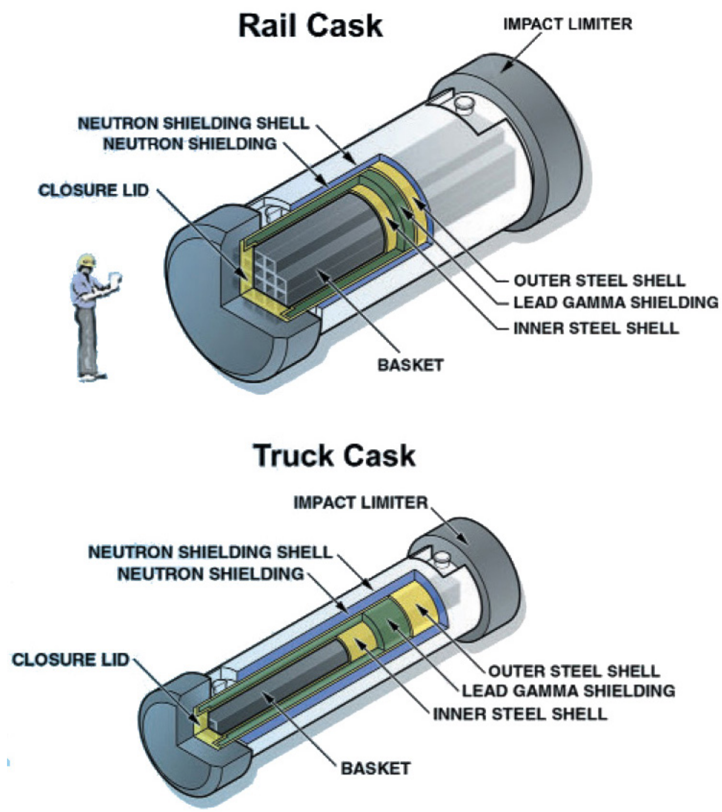
A. US and Global Experience with Commercial Spent Nuclear Fuel Shipments

The NRC has rigorous regulations pertaining to physical requirements for SNF transportation packages, as well as regulations governing the safety and security of transportation operations. Not only are these requirements the basis for estimates that the transportation of SNF can be safer than the transportation of other hazardous materials; the historical experience with SNF transportation in the United States and elsewhere has proved to be safe.

US SNF Transportation Packages and Associated Regulations

In order to meet NRC transportation regulations, package construction involves multiple layers of steel, metals, and other materials to provide structural strength and shielding from gamma and neutron radiation (see figure 8). The packages may be designed for transportation by truck or by rail. Truck packages, in general, carry fewer fuel assemblies than rail packages and are thus correspondingly smaller and lighter.[101] Truck packages may weigh 25 metric tons and carry 0.5 to 2 metric tons of SNF. Rail packages, by contrast, may weigh 150 metric tons and carry 10 to 18 metric tons of SNF.[102]

Figure 8: Rail and truck transportation casks for SNF



Source: NRC, https://www.flickr.com/photos/nrcgov/48127898181/

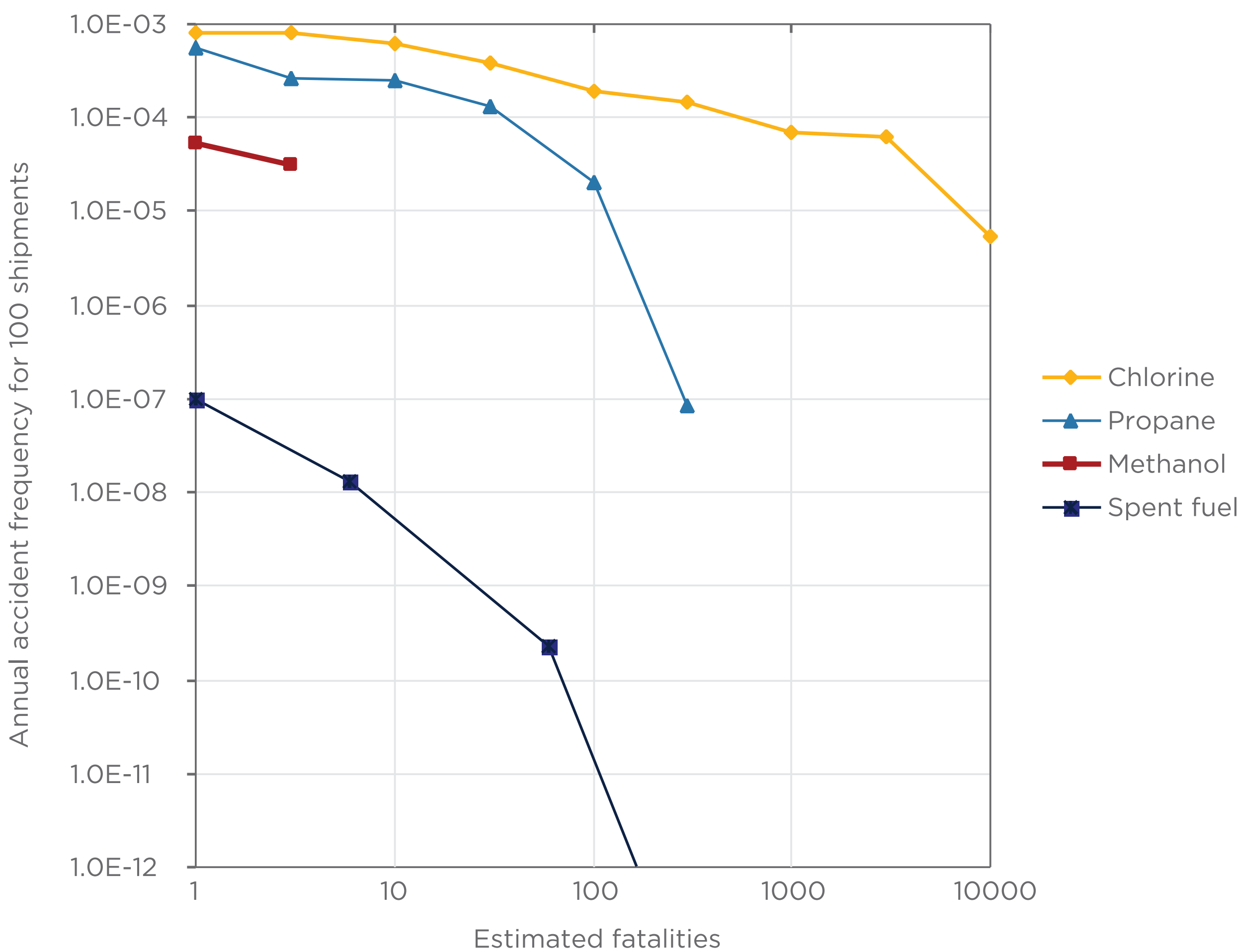
NRC regulations[103] require that "type B" containers—that is, designed to transport relatively large quantities of radioactive materials (e.g., SNF, HLW, and TRU waste)—must be able to survive four tests: impact (a 9 meter drop onto an "unyielding" surface), puncture (dropping the cask on a spike from a height of 1 meter), immersion in fully engulfing fire (for 30 minutes at an average temperature of 800°C), and submersion (in 15 meters of water). The NRC permits compliance with these requirements to be demonstrated using a variety of methods: quantitative analysis, tests of scale-model and full-scale packages or package components, and comparisons with existing approved package designs. In other words, full-scale testing of all transportation casks is not required.

In the event of a severe transportation accident (e.g., a truck collision or train derailment) involving the transportation of a SNF package, the cask serves as one barrier to the release of radioactive material. Inside the cask, the metal tubes surrounding the SNF pellets serve as an additional barrier.

Comparison of Transportation Risks

In 2006, the US National Academies published a report, *Going the Distance*, on the transportation of SNF in the United States. The report concluded that the robust construction of SNF transportation packages, in combination with "rigorous regulatory requirements," ensure that significant releases of radioactive material "are very unlikely except possibly in extreme accidents." The authoring committee examined accidents associated with rail transport and comparative risk with the transport of three other kinds of hazardous materials: a flammable liquid (methanol), a flammable gas (propane), and a toxic gas (chlorine). The comparison is shown in figure 9.

Figure 9: Expected fatalities from hypothesized accidents during transport of hazardous materials and SNF



Source: Transportation Research Board and National Research Council, 2006, Going the Distance?: The Safe Transport of Spent Nuclear Fuel and High-Level Radioactive Waste in the United States, https://doi.org/10.17226/11538. Reproduced with permission of the National Academy of Sciences, courtesy of the National Academies Press, Washington, DC.

The analysis indicates that chlorine gas has the highest accident frequencies and fatalities of the four cases, as it is highly toxic and can be fatal if inhaled. It can be dispersed widely by wind and have adverse consequences even at low concentrations. However, chlorine is one of the most commonly manufactured chemicals in the United States and is used for bleaching purposes, pesticides, and water purification in both drinking water and pool water.[104]

The consequences of explosions or fires from accidents involving propane or methanol transportation are expected to be more localized, and the expected risks are lower. Propane is used as a fuel (e.g., in place of natural gas) for space heating and water heating in homes, backup electricity generators, forklifts, and other purposes. It is also used as a feedstock in the petrochemical industry to produce products such as plastics and glues.[105] Methanol can also be used as a fuel, and as a result of new facilities coming online, the United States is projected to have the capacity for producing 9.4 million metric tons per year by the end of 2020.[106]

The National Academies Committee projected much lower risks for the transportation of SNF by rail compared with the transportation of other hazardous materials by rail because of its robust packaging. The committee further noted that these findings might actually overestimate the risks, though it observed the public does not necessarily look at risks the same way that experts do, and expert assertions about risk may not be convincing to the public.[107]

The NAS report also found that there are operational and safety advantages to shipping older spent fuel first. Many of the radioactive isotopes that are produced in a reactor have half-lives of days, minutes, seconds, or even less. These isotopes have all disappeared by the time SNF has been removed from cooling pools for either dry cask storage at the same site or for transportation to another site. Some radioisotopes in SNF have half-lives on the order of years, and these elements are nearly nonexistent after SNF has been aged for several decades. This is the basis for recommendations that older SNF be shipped first, which has been recommended by Nevada and others.[108]

Global Experience with Transporting Commercial SNF

Worldwide experience with transporting SNF provides a good experiential knowledge base. A 2016 Oak Ridge National Laboratory (ORNL) report estimated that at least 25,400 shipments of SNF had been made worldwide (and likely more than 44,400) and that all of these had been undertaken without injury or loss of life.[109]

In general, there have been few transportation accidents worldwide in the history of shipping SNF, and none has had significant radiological consequences. The safety record is due in part to the robust regulatory requirements for shipping SNF, including the cask requirements, as well as the high level of skill required of the people involved in package design, manufacture, and transportation.[110]

France has had more SNF and HLW shipped within its borders and to it than any other country in continental Europe. A 2001 paper estimated that 5,760 casks of SNF from within the country, broader Europe, and Japan had been transported to the La Hague facility for reprocessing.[111] There were several minor accidents involving SNF casks in continental Europe in the 1980s and 1990s,[112] but none led to a release of radioactive material.

B. Shipping Transuranic Waste to the Waste Isolation Pilot Plant in New Mexico

Over the last 20 years, the US government has transported TRU nuclear waste from DOE sites by truck over public roads, as shown in figure 10.

Drivers and carriers for WIPP shipments must meet stringent requirements and are subject to penalties if they deviate from specific procedures. DOE has worked with states to train thousands of emergency responders on plans specific to WIPP shipments. The shipment protocols and routes have been developed through cooperative efforts between states, tribal governments, and DOE. State officials are notified of shipments to WIPP before they enter the state, and those shipments are subject to inspections at state ports of entry.

Figure 10: Transportation routes from DOE sites to WIPP

Source: DOE, https://www.wipp.energy.gov/NewsandInfo_images/WIPP_Route_Map_2012_lrg.jpg

The safety record for WIPP shipments has been exemplary. The Western Governors' Association observed in 2016 that the more than 11,800 shipments from 12 DOE sites to WIPP involved very few, minor accidents and no radioactive materials release.[113]

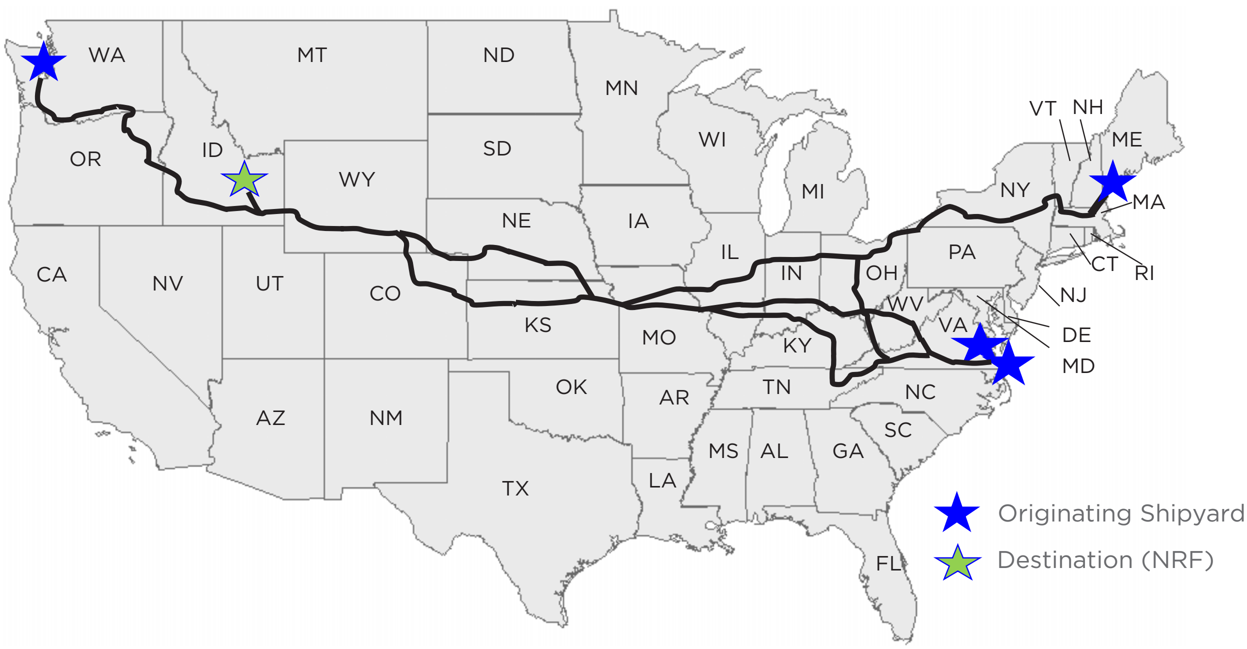
As of August 2020, over 12,700 shipments of TRU waste have been successfully and safely shipped to WIPP,[114] and this experience can serve as a template for future transportation of

SNF to geologic repositories, though there are technical and logistical differences.

C. Transporting Spent Naval Reactor Fuel to the Idaho National Laboratory

The US Navy has shipped over 870 packages with naval SNF to the Idaho National Laboratory since 1957 (see figure 11 for typical shipping routes today). Unlike the WIPP program, which uses public highways, the navy transports its SNF to Idaho by private railroads. All of the naval fuel shipments have been accomplished without the release of radioactive material. In addition to the robust nature of the shipping containers, naval SNF itself has extremely rugged features due to operational needs (e.g., combat situations and protecting the health of crew on aircraft carriers and submarines).[115]

Figure 11: Typical shipping routes for US Navy SNF



Source: DOE, https://www.nrc.gov/public-involve/conference-symposia/dsfm/2015/dsfm-2015-barry-miles.pdf

As with the WIPP program, all activities have detailed emergency response plans in place and a sound exercise program to demonstrate that personnel are well prepared. Also similar to WIPP, exercises have been run with multiple state and tribal authorities to go over response scenarios to accidents involving the transportation of spent naval reactor fuel.

Today, the management of nuclear waste into and out of the state of Idaho takes place under the Batt agreement. Signed in 1995, this legal document can be looked at as an example of a functioning consent agreement between a state and the federal government for a consolidated interim storage facility (see box 4-1).

Box 4-1: The Batt Agreement

The Batt agreement—so-named for the Idaho governor, Philip Batt, who signed it in 1995—is the legal document that has governed transportation of spent naval fuel to INL for storage. As signed, it contained a number of provisions regarding other nuclear waste at INL, though the discussion below focuses mostly on the naval reactor fuel provisions. The agreement can be looked at as an example of a consent agreement between the federal government and a state for a consolidated interim storage facility, including provisions regarding the transportation of nuclear waste to and from the facility. The agreement has a number of measures that limit, for example, the number of shipments of navy spent fuel per year and the total (in metric tons of heavy metal) of spent navy fuel that can be shipped to INL through 2035.

The agreement originally stated that the navy would remove all naval spent fuel from Idaho by January 1, 2035, and that the sole remedy for the navy's failure to meet any of the deadlines or requirements set forth in the agreement would be the suspension of naval spent fuel shipments to INL. If spent navy fuel is not removed by January 1, 2035, there was also a payment obligation of $60,000 for each day that the requirement has not been met. The agreement stated that the spent navy fuel at INL should be among the first SNF shipped to a permanent repository or interim storage facility.

There were other provisions, including the following:

- DOE was required to ship all TRU waste at INL out of the state no later than December 31, 2018.
- No additional SNF from the Fort St. Vrain nuclear power plant in Colorado (which ceased operation in 1989) was allowed to come to INL unless a permanent repository was opened.
- No commercial spent nuclear fuel could be shipped to INL, except for the Fort St. Vrain fuel under the conditions above.
- Construction of various waste handling facilities was to take place.
- Environmental remediation work was to be carried out at the Naval Reactors Facility.

The agreement has served as the foundation for continued negotiations between Idaho and the federal government, and the two entities have successfully negotiated additional provisions several times on nuclear waste management issues.[116] While DOE has met most milestones[117] in the 1995 agreement, all TRU waste was not removed from Idaho by the end of 2018. The state of Idaho did negotiate an agreement with DOE in 2019 that at least 55% of the TRU waste headed to WIPP would come from Idaho National Laboratory until all TRU waste had been removed from the state.[118]

D. Social and Institutional Challenges with a Large-Scale SNF Transportation Program

Observing that SNF has been transported safely in the past does not by itself guarantee that future performance will be the same. In particular, a campaign to move SNF from reactor sites to either an interim storage site or a repository would potentially involve many times the rate of shipments per year, casks per year, and metric tons of SNF per year.[119] The mode of transportation would also be important: truck shipments would be more numerous and take place on public roadways, whereas rail shipments would be less numerous and take place on private rights-of-way.

Technical risk may not be the biggest barrier to public acceptance of a large-scale spent fuel transportation effort. Both the National Academies' *Going the Distance* report from 2006 and the 2012 BRC report recommended that efforts be made to reduce the social risks involved, including potential impacts along transportation routes on property values, tourism, anxiety, and other matters. NAS recommended that transportation implementers take early and proactive steps to help manage social risks by increasing public trust and confidence in transportation programs. The academies observed, among other findings, that the public generally perceived nuclear-related activities to carry higher risks that nonnuclear activities, that these risks are perceived as part of a broader context of social experiences and risk management processes, and that trust and confidence can play important roles in modulating these risks.

The 2012 BRC report noted that several of the 2006 NAS recommendations (e.g., full-scale cask testing) regarding social risks had not been acted upon[120] and observed that vigilance and independent regulation, such as by the NRC, will be required to maintain high safety standards in a scaled-up transportation program for commercial SNF. The manufacturers of transportation packages, for example, will need to continue to produce casks of the highest quality, and regulators and shippers will have to sustain similarly high levels of performance. Ensuring that a strong, independent regulator such as the NRC has authority over the transportation regime would help to achieve these ends, as well as the goal of public confidence in the program by not giving it any special treatment.

V. LIMITATIONS OF CURRENT LAW

As a result of the 1987 amendments to the NWPA and other laws mentioned in chapter 2, the United States is severely constrained in what it can do to make progress on management and disposal of HLW and SNF. A few examples of limitations are discussed in this chapter: the US SNF management program does not have ready access to the Nuclear Waste Fund (NWF), there are potential legal challenges to the federal government contracting with private entities for consolidated interim storage projects, commercial SNF cannot legally be disposed of anywhere except for Yucca Mountain (and even site-specific activities are prohibited everywhere else), and support to states for SNF transportation-related activities is too limited.

Lack of access to the Nuclear Waste Fund. The US nuclear waste program was designed as a "polluter pays" structure where the nuclear power plant owners pay a fee (initially set at 0.1 cents/kWh, to be reviewed by DOE annually and adjusted as needed prospectively to recover the full costs of the waste program) to dispose of the SNF. For that reason, the program was different than other programs at DOE, which are funded out of general revenues (e.g., taxes). The intent was that the waste program be self-contained and not cost the taxpayer any money.[121]

Congressional documents make clear that the NWF was supposed to be a "trust fund" that would provide a predictable source of funding for the waste program and protect it from the uncertainty and policy changes inherent to the federal budget process.[122] While the final version of the NWPA still required congressional appropriations to fund the program, the language "appeared intended to encourage multi-year or lump sum appropriations."[123]

However, a series of budget-related laws passed by Congress—in particular, the Balanced Budget and Emergency Deficit Control Act of 1985 and the Budget Enforcement Act of 1990, as well as subsequent amendments to those laws—and their implementation have prevented the waste program from having access to the payments made by nuclear power plant owners. In effect, regardless of what the nuclear power plant owners paid into the NWF in a given year, the waste program received whatever Congress decided to appropriate from the NWF that year, which was invariably smaller and sometimes much smaller or even zero. In addition, the waste program is usually included under a budget cap that other programs at DOE (and elsewhere in the federal government) are under as well. This means that when the president submits a budget request, in order to increase funding for the waste program, other programs must be decreased in order to stay under that budget cap. Similarly, congressional appropriators must also take from other programs in order to increase funding for the waste program. This has meant that the waste program is in perpetual competition with other programs for money, despite the original intention by Congress for the waste program to be self-financed using utility payments into the NWF, whereas the other federal programs under the same cap are in large part funded by general revenues (i.e., taxes).

As commercial generators have paid over $21 billion to date and interest has accumulated, the lack of appropriations has meant that the NWF balance has swelled to over $40 billion (and annual interest was projected to be over $1.6 billion in 2020).[124] Nuclear power plant owners—and thus, ratepayers—have paid an extraordinary amount of money into a federal fund that has not been accessible to the waste program it was intended to fund. This limited access to waste funds has been a contributing reason for DOE's failure to license and operate a repository for commercial SNF disposal.

Potential legal challenges to DOE contracting with private companies to implement consolidated interim storage projects. In the original NWPA, DOE was allowed to pursue consolidated interim storage sites—called monitored retrievable storage (MRS)—and DOE conducted a search for suitable sites. It ultimately identified three options in Tennessee and selected a site on the Clinch River in the Roane County portion of Oak Ridge. The governor of Tennessee opposed the facility, however, and the state sued DOE over the project.

As part of the 1987 amendments to the NWPA, the Tennessee site selection was "annulled and revoked," and authority for a new DOE-directed MRS siting process was added. However, the ability to site and develop an MRS facility was closely linked to the repository development process. For example, section 148 of the NWPA prevents the construction of an MRS facility until the NRC has issued a license for the construction of a repository and imposes a limit of 10,000 MTHM of SNF and HLW at an MRS facility until a repository under the NWPA begins operation. Finally, no more than 15,000 MTHM of SNF can be at the MRS facility at any time.

Depending on the legal interpretation of section 135(h) of the NWPA, DOE would also appear to be prevented from contracting with private entities to do consolidated interim storage projects, like the ones that have been proposed in Texas, New Mexico, and Utah.[125] For this reason, recently proposed legislation includes amendments to delete that section to remove any legal uncertainty surrounding the issue.[126]

As has been observed in other reports,[127] consolidating SNF in dry casks at interim storage facilities would provide multiple benefits, including

- allowing local communities with shutdown nuclear plants to reclaim all of their land, eliminate security-related site costs; and complete site decommissioning (terminating their existing NRC licenses related to SNF also would reduce DOE's costs for maintaining many separate storage facilities);
- helping the federal government begin meeting its commitments to take ownership of SNF, reducing current costs to US taxpayers out of the US Judgment Fund; and
- providing time for additional cooling of SNF while preserving disposition options for the future.

However, current law constrains this option and the waste management benefits it would entail. The law was written this way to avoid having an MRS site become a de facto repository, and it is possible that without any progress toward geologic repositories, states may be less willing to host a consolidated interim storage facility. One disadvantage to moving SNF to a storage facility (private or federal) not collocated with a repository is that it would also require additional costs and time for two separate transportation campaigns.

DOE's severely limited ability to consider repository sites other than Yucca Mountain. The framers of the NWPA intended there to be two repositories—one in the West and one in the East—and established a program and schedule for finding sites for both. However, the 1987 amendments postponed the siting of a second repository indefinitely, terminated ongoing research into crystalline rock sites (e.g., geologies in the east), and merely required a report on the need for a second repository by 2010. That report was published in 2008 and assessed that while Yucca Mountain could likely dispose of several times the 70,000 MTHM limit from the NWPA, the country would need another repository if this capacity allowance was not raised.[128] In the same report, the secretary of energy recommended that, consistent with legislation proposed in 2007 by the Bush administration, the statutory capacity limit of 70,000 MTHM be removed, which would defer the urgency in evaluating issues associated with a second repository.

As the 1987 amendments directed DOE to solely focus on Yucca Mountain, DOE is not legally allowed to conduct site-specific activities with respect to a second repository without express approval by Congress. Thus, DOE cannot work with private companies at non–Yucca Mountain sites if that work is directed at potential development of a repository rather than generic development of a new disposal technology—even with the consent of a host state and local communities.

Insufficient support to states for SNF transportation activities. The language in section 180(c) of the NWPA, and DOE's interpretation of it, does not allow states to be adequately reimbursed for the costs incurred as part of SNF transportation. DOE only allows reimbursement to states from the NWF for "training" related to SNF. However, there are other costs that states incur—e.g., the cost of inspecting SNF packages—that do not fall under DOE's interpretation of "training."[129] Language in section 16 of the WIPP Land Withdrawal Act, by contrast, is more flexible and allows states to recover their costs related to transport of TRU waste shipments to WIPP.

Options for addressing these limitations are discussed in the next chapter.

VI. ACTIONS FOR POLICY MAKERS TO CONSIDER

Though there is a paralysis in the pursuit of a disposal path for US SNF and HLW, it is not necessarily going to compel a fix by itself. Commercial SNF is safe and secure where it is, and utilities have little incentive to drive action as they are no longer paying the NWF fee and almost all of the costs that they are incurring for interim storage at reactor sites are being paid for by the US taxpayer out of the US Judgment Fund. Further, those payments out of the Judgment Fund do not have negative repercussions for DOE, which would otherwise drive greater urgency at DOE on the waste disposal program.

But a variety of factors, such as the continued use of zero-carbon nuclear power to further climate goals, weigh on the urgency to forge a path forward on improving the management of SNF and HLW in the United States. Based on the findings of this report, several possibilities for how the federal government could make progress on this issue of national importance are provided here.

Option 1: Create a New Organization Whose Sole Mission Is Nuclear Waste Management (and Whose Approach Is Consent Based)

Congress could create a new organization whose sole mission is to manage nuclear waste and one that has full access to past and future payments from nuclear power plant owners. This is not a new idea. The concept was suggested as early as 1977,[130] and it appeared prominently in a 1982 Office of Technology Assessment report,[131] which noted the structural challenges of having the waste program at DOE and recommended a separate organization be given responsibility. The same 1982 report found that the greatest obstacle to the waste management program was the "severe erosion of public confidence in the Federal Government that past problems have created." The report noted that the federal government's credibility was questioned as to whether it would stick to any waste policy through changes of administration, whether it had the institutional capacity to carry out a technically complex and politically sensitive program over a period of decades, and whether it could be trusted to "respond adequately to the concerns of States and others who will be affected by the waste management program." These concerns appear relevant nearly 40 years later, which argues for a new approach.

A public corporation chartered by Congress was also the preferred alternative to DOE management in a 1984 report to the secretary of energy.[132] More recently, four reports, from MIT (2011), the BRC (2012), the Bipartisan Policy Center (2016), and Stanford–George Washington Universities (2018), all recommended that a new organization be created that was dedicated solely to nuclear waste management.[133] There was general alignment in these four reports that such an organization should operate on a phased, adaptive, consent-based approach and should immediately begin efforts to identify sites for consolidated interim storage facilities and geologic repositories.

Part of the reason the current federal structure for nuclear waste management is not working is that—fair or not—DOE is not trusted by states or tribes. This is in part because of DOE's actions in the 1980s but also inherited distrust from its predecessor, the Atomic Energy Commission. Another problem with trying to sustain a multidecade repository program is that DOE's leadership and policy direction are subject to presidential elections and political appointments. An additional issue is that the waste program, which never got above $600 million in annual funding, resides within a ~$38 billion/year cabinet-level agency with many competing priorities. An organization separated from all of the other work at DOE and with full access to past and future NWF fee payments would by itself be a large step forward for the US waste program.

In looking for a better approach, the United States can benefit from the experiences of other countries, such as Finland, which is the farthest along of any country in its disposal program and is now constructing a repository. Finland also has a single purpose organization for nuclear waste management that has access to the funding it needs to succeed.

The Canadian program is also making good progress and at the end of 2020 is down to two potential sites under consideration for a repository. The Canadian NWMO provides a closer-to-home example of an organization that is solely focused on nuclear waste management and operates on a phased, adaptive, consent-based approach. The utility-owned NWMO's activities are paid for by the Canadian utilities, and the organization does not have to go through a budgeting process every year comparable to the US waste program's structure. The NWMO's siting work has proceeded in phases—e.g., with sequentially more intensive site characterization activities for the locations under consideration in each subsequent phase—and has advanced sites to successive phases with the consent of the potential host communities. That is, communities were able to withdraw themselves from consideration at each step. As additional technical information is learned about each site, and feedback from the public is gathered and negotiations with units of government continue, the NWMO has had the flexibility to adapt as needed, including the adjustment of planning milestones and the narrowing of sites under consideration. A mitigating simplification in the Canadian case is that all of the potential repository sites are in the same province, as are the large majority of Canadian nuclear power plants.

While there are no guarantees that a consent-based approach will succeed, the example of WIPP provides some evidence that it can work in the United States. This report concludes that the balance of evidence suggests the United States should try a consent-based approach. Previous studies, such as the 2012 BRC report, reached the same conclusion: a consent-based approach appears to be more promising than another forced siting process, though with no guarantee of success. This can either be looked at as the right approach for a democracy or a practical acknowledgment that states have a variety of different avenues to oppose facilities and programs that they do not want within their borders.[134]

The final report of the BRC in 2012 did not make a recommendation as to what specific form "consent" should look like, and this report concurs that the form of consent may very well differ substantially from one case to another. Correspondingly, codifying what consent means in law could lead to problems in the future. As the BRC suggested, states may want to negotiate legally binding agreements between themselves and the federal government to "have confidence that they can protect the interests of their citizens." Idaho, for example, entered into such an agreement with DOE and the US Navy in 1995 for interim storage of nuclear waste. A state may also want some kind of regulatory authority over a repository facility, just as New Mexico has RCRA authority over the WIPP facility. This authority comes from the Land Withdrawal Act (Public Law 102-579) that Congress passed in 1992, and similar legislation could be contemplated for states that would like similar power over a geologic repository facility. These are just two examples of working with states on a consent basis, with different arrangements in each case; this argues for leaving the law flexible enough to adapt to the specific circumstances associated with particular potential sites.

Interim storage is going to be needed for decades while new geologic repositories are in the process of being characterized. Chapter 5 discussed some of the benefits that consolidated interim storage projects offer to the nation in terms of waste management, but current law presents potential legal challenges to DOE entering into contracts with private companies (e.g., the consolidated interim storage projects in Texas, New Mexico, and Utah). Congress should ensure that the new organization is able to pursue consolidated interim storage projects and enable the organization to use fee payments from nuclear plant owners to support those projects.

S.1234 from the 116th Congress provides a good starting point for these legislative discussions. It would establish an independent agency to manage US commercial SNF, rather than have DOE carry out this function. The new entity would be headed by an administrator selected by the president and subject to Senate confirmation.

The bill would create a new working capital fund in the US Treasury, and fees paid into it by utilities would be available to the agency without further appropriation. However, access to the existing balance in the NWF would still be subject to appropriations and overall constraints on discretionary spending. While making future fee receipts directly available would not completely solve the funding problem, it would be a substantial advance in US nuclear waste management by enabling the new federal entity to carry out its work and giving states and utilities greater confidence that the agency will be able to deliver what it promises. The new agency would be able to use the fee payments for both geologic repository and consolidated interim storage projects.

S.1234 directs the new organization to build a pilot storage facility to hold spent fuel from decommissioned nuclear plants and emergency shipments from operating plants. It also establishes siting processes for both storage facilities and repositories. If the secretary determines that separate waste facilities are necessary or appropriate for defense waste, the administrator may site them in accordance with the process described in the bill.[135]

Option 2: Improve the Funding Structure of the US Nuclear Waste Program

Sustained and consistent funding is needed to support a successful multidecade repository program that involves site characterization, licensing, construction, operation, and closure. Creating a new organization (option 1) with access to past and future NWF fee payments by utilities would fix the current problem of the waste program lacking access to needed funds.

Even giving a new organization access to future payments, as S.1234 from the 116th Congress does, would be a substantial improvement. However, the creation of a new organization may take years for Congress to reach agreement on, and during that time Congress could pursue avenues to at least partially improve the funding structure for the US waste program.

There have been past legislative efforts to connect the receipt of payments to the NWF with funding of waste program activities.[136] In 2001 DOE also published a report that discussed several possible ways to improve the budgetary system, including reclassifying NWF spending as mandatory.[137] It is suggested here that policymakers consider at least two specific policy formulations:

1. *Reclassify the annual NWF fee from its current mandatory receipt to discretionary offsetting collection.*

   The payments by utilities into the NWF could be collected specifically to offset discretionary spending on the waste program. In other words, DOE could modify how it collects NWF payments from utilities, and appropriations language could better connect the fee collections with spending on the waste program. Money appropriated for the waste program that was offset by these fees would not use up any of the budget cap space of the agency the program lives under, removing it from competition with other budget priorities.

   In a similar manner, HR.2699 (passed by the House as HR.3053 in the 115th Congress), incorporates a mechanism whereby after the NWF fee is resumed, the total amount of NWF fees collected on an annual basis would be limited to 90 percent of appropriations, and the receipts would be reclassified to offset these appropriations. The collection would thus offset most of the annual appropriations for the nuclear waste program—largely freeing it from direct competition with other programs for budgetary space.

2. *Create a separate budget spending category for waste management.*

   Within congressional budget caps, there are some programs that are at least partially self-financed and some of these programs have a separate budget line to recognize this and prevent them being in competition with other programs (e.g., Social Security and the Postal Service). Creating a separate budget spending category for nuclear waste management, as it is supposed to be a self-financed program, would recognize that the waste program is fulfilling statutory and contractual obligations of the federal government. The failure of these contractual obligations to utilities costs billions of dollars paid out of the Judgment Fund. Congressional budget committees could, for example, include in budget resolutions a line specifically for the waste program that recognizes the self-financing nature of the program, and any budget priority tradeoffs (i.e., decreasing the nuclear waste program funding to increase another program's funding or the reverse) would have to be made at the top level of the budget process by OMB and the budget committees. The federal government could then decide what fraction of the total discretionary cap (on the order of $650B) should be spent to honor a clear contractual obligation of the federal government and stop the drain on

> the unappropriated Judgment Fund.
>
> As former Under Secretary of Energy Robert Card told a congressional committee in 2004, the contractual arrangement of a payment for service justifies “special consideration” for the nuclear waste program in the budget process.[138]

A 2011 paper for the BRC included discussion of a potential option to administratively reclassify the NWF receipts as “offsetting collections” and thus be implemented without the need for new law.[139] If the budget scorekeepers—OMB, CBO, and the House and Senate Budget Committees—were to agree, the congressional appropriations committees could continue to set the annual spending levels for the waste program, but those appropriations would be offset by the fee payments so that the program would score “net zero” for budget purposes and thus not have to compete with other programs under the budget cap. However, given that this action has been available for many years and has not been acted upon, this may be a de facto response from the budget scorekeepers that they would prefer Congress make this change legislatively.

There are other ways that Congress and/or budget scorekeepers could improve the funding of the waste program so that it functions closer to how it was originally intended.[140] Of concern, the payments to the NWF were stopped in 2013 by a federal court, and utilities will be loath to restart the fees if they have no confidence that the payments will actually be used for their intended purpose. Utilities had been paying nearly $750 million into the NWF each year, and in some of the same years there were no appropriations for Yucca Mountain or any other repository or consolidated interim storage effort. Fixing the budgetary structural problems of the US waste program is thus keenly important for states and local communities to have the confidence that the federal government will spend the money necessary to honor its obligations.

Since the utilities are not currently paying a fee into the NWF, this obviates the funding fixes discussed in the BRC paper and in legislation such as S.1234 and HR.2699. These approaches are based on the presumption that the federal government is collecting annual fees that can be directly accessed to fund the waste program, which is not the case. But even with access to annual waste fees when they are resumed in the future, anticipated program expenditures will ultimately require a way for the US nuclear waste program to access the corpus of the NWF.

Option 3: Pursue Disposal of US Defense Waste First

The original NWPA had the flexibility to allow one of the two repositories to be dedicated to defense waste disposal, with the other devoted to commercial waste disposal, or either could dispose of a mixture of defense and commercial waste.[141] New repository sites for defense waste can also be pursued under section 8 of the NWPA, but to dispose of commercial SNF at the same site at a later time, the law would have to be amended. A US waste strategy could include pursuing disposal of defense waste at a repository site first, with the possibility of the same site disposing of nondefense waste during a later phase, pending consent and potentially any needed changes to the law.

There are several other reasons why it may make sense to pursue disposal of defense waste before commercial SNF:

- Potentially greater public acceptance due to the national security missions involved
- A smaller and cooler waste inventory
- Less of an argument for the waste to be retrievable for potential reprocessing, as the plutonium has already been removed from defense HLW
- As the defense complex is no longer running production reactors or reprocessing facilities, the inventory is relatively bounded

Defense waste disposal is also not paid for by nuclear power plant operators (and thus not paid out of the NWF) but instead out of defense spending, which is under a different budget cap. Disposal of spent naval reactor fuel could help US naval operations by fulfilling the federal government's commitment to Idaho to remove naval reactor SNF from the state by 2035 (or at least some progress toward opening a repository for defense waste would help with the federal government's ongoing negotiations with Idaho). Disposal of defense HLW would also help fulfill commitments to Idaho, South Carolina, and Washington for federal cleanup of sites involved in nuclear weapons activities during the Cold War.

The engagement of the secretary of defense or the secretary of the navy with states could be particularly helpful. The secretary of defense holds a position of great respect and consequence in the United States, and his or her advocacy would be helpful toward obtaining public acceptance for disposal of defense waste by explaining how, particularly for spent naval reactor fuel, it would serve national security missions.

As implied above, there might be a benefit to future commercial SNF disposal efforts from first demonstrating disposal of defense waste. It would provide a proof of principle for HLW and SNF disposal—just as WIPP has done for TRU waste disposal—including a test of the NRC licensing process. In addition, an operational repository for HLW and SNF would provide the United States with additional design, construction, and operational experience with geologic repositories and allow for visits in the future from state and local officials who might be considering hosting a commercial SNF repository.

Under a truly phased, adaptive, consent-based strategy, there could still be the flexibility and capability to dispose of defense waste and commercial waste in the same repository—e.g., in a separate underground zone—if consent is given by the host community during a later phase.

Option 4: Take Steps to Prepare for a Large-Scale Transportation Program

To date, the annual rates of US transportation of commercial SNF have been relatively small compared with what a future effort to ship SNF to either consolidated interim storage or a geologic repository might entail. Rather than wait until either is imminent, the US government could pursue near-term efforts to prepare for the eventual larger-scale transport of SNF and HLW to consolidated interim storage and disposal facilities. This overarching recommendation was made by the BRC in 2012, along with several individual transportation-related recommendations that have not been acted upon.

In particular, BRC recommended that the NWPA be amended to give the body responsible for waste management similar broad authority as DOE had when supporting large-scale transportation to WIPP. The specific problem that the BRC recommendation would address is language in section 180(c) of the NWPA that is too restrictive and does not allow states to recover the full costs for the planning and operations related to commercial SNF transportation through their borders, even though the law says costs related to disposal of HLW and SNF should be paid by those generating the waste (i.e., not the states it may travel through).

More recently, the Western Interstate Energy Board's (WIEB's) High-Level Radioactive Waste Committee, comprised of nuclear waste transportation experts from 10 western states' energy, public safety, and environmental agencies, issued a series of policy papers in 2018 toward developing a safe and publicly acceptable system for transporting SNF and HLW. In particular, the WIEB committee issued recommendations on social risks, full-scale cask testing, origin site transportation coordination, and funding for state and local development and implementation of a transportation system. The WIEB has particular expertise in nuclear waste transportation given the thousands of TRU shipments to WIPP, which is located in one of the WIEB member states, New Mexico.

DOE could review these proposals to consider endorsing and implementing the committee's various recommendations as part of addressing the institutional and social risks involved with a scaled-up transportation program to a waste site. More generally, DOE could identify a process for consideration of and response to the transportation-related recommendations of independent groups including the National Academies, the BRC, and the Western Governors' Association. DOE could then either take action or, where it does not have the needed legislative authority, submit a proposal to Congress.

Option 5: Update Generic Regulatory Standards for Future Geologic Repositories

The United States has two sets of federal regulatory standards for SNF and HLW disposal—one for Yucca Mountain and one for all other sites—and the substantive differences between the two, such as periods of coverage and release/exposure limits, have been problematic. Resolving some of the inconsistencies between these regulations and ensuring that the generic regulations are flexible enough to cover different approaches (e.g., boreholes) is important for future nuclear waste disposal projects. The update should also be done before multiple sites are examined to help with public confidence that regulatory standards are not being lowered in individual cases to enable sites to qualify that otherwise would not be deemed safe.

For example, EPA's generic protection standard for WIPP covers 10,000 years after closure of the repository, whereas the Agency's Yucca Mountain-specific standard extends to 1 million years. Other nations have pursued time periods of compliance in between these two time frames.[142] It has also been suggested that new approaches could rely on quantitative analyses for shorter periods of time[143] (e.g., up to several thousand years) and rely on more qualitative factors for longer periods of time. Another difference is that the generic standard relies on radionuclide release limits, whereas the Yucca Mountain standard uses individual dose limits.

The NRC promulgated generic regulations for high-level waste disposal at 10 CFR Part 60 in 1983; DOE's site selection guidelines at 10 CFR Part 960 were first promulgated in 1984; and EPA's 40 CFR Part 191 regulations for generally applicable environmental standards for high-level waste disposal were promulgated in 1985. However, US and international thinking on standards for geologic repositories has evolved in the intervening decades.[144] EPA, NRC, and DOE could update their respective regulations—or Congress could direct them to do so—as part of preparations for future repository siting efforts.

Option 6: Negotiate an Agreement with Nevada on Yucca Mountain

The phased, adaptive, consent-based approach to siting new repositories should begin as soon as possible. However, setting up a new organization (as in option 1) may take years, and beginning early site characterization will take additional time. Furthermore, it will take many years for new sites to reach a phase where they have the same level of investigation and technical characterization as Yucca Mountain. An option that the federal government could pursue, concurrent with efforts to begin new siting efforts, is to try to negotiate an agreement with Nevada to investigate the disposal of a limited waste inventory at Yucca Mountain.

Given the long, bitter history over Yucca Mountain, a negotiated solution between the federal government and Nevada regarding the site will be difficult. The state legislature is firmly opposed to the repository concept that was proposed in the 2008 license application[145] to the NRC. While there is no guarantee the state and the federal government can negotiate a smaller repository program that is acceptable to both sides, it also does not appear that these types of discussions have been tried in the past. Addressing the state's technical concerns and ending the federal government's attempt to "jam it all down Nevada's throat" could be a necessary precondition.

One initial step that Congress could take is to recognize that the main thrust of the 1987 amendments to the NWPA—jettisoning the second repository process and prematurely ending the selection process for the first repository—was wrong and to begin undoing the damage they created by removing those aspects of the NWPA. In particular, Congress could eliminate the restriction of provisions in the NWPA to Nevada and Yucca Mountain that came from the 1987 "Screw Nevada" bill. It would also help if Congress explicitly acknowledged that the 1987 amendments effectively abandoned the 1982 compromise and short-circuited the siting process in a way that went against the intentions of the NWPA authors and that that decision made the US waste program completely dependent on the fate of a single site with attendant risks. The amendments in 1987 not only violated the siting equity agreements, they eliminated all of the redundancies in the 1982 program that gave some basis for confidence that a repository would be available at some site within a reasonable time. At least part of Nevada's initial response to the 1987 amendment was based on the disrespect it showed toward the state.[146] Undoing the 1987 amendments to the NWPA would also correct a terrible precedent: Congress should not be the body that does repository site selection.

In the event that discussions over an agreement begin, Nevada would likely want to negotiate legally enforceable provisions regarding transportation routes, the repository design, and the specific waste inventories that would be involved (e.g., types, amounts, locations) to address its stated concerns. The state will—rightfully—be suspicious of any attempt to negotiate even a limited repository program at Yucca Mountain, worrying that a second "Screw Nevada" bill may take place at a later time and the federal government will again try to force the state to take all of the nation's HLW and commercial SNF.

Nevada's congressional delegation has proposed the Nuclear Waste Informed Consent Act (NWICA),[147] which would give any potential repository host state (including Nevada) a form of consent before appropriations are drawn from the NWF for the construction of a repository. The bill could be read as a willingness to complete the licensing of Yucca Mountain—where the state has lodged over 200 contentions that are awaiting disposition with the Atomic Safety and Licensing Board—if the state has a consent provision at the end of that process. However, even passing the NWICA into law and continuing with the licensing of Yucca Mountain would carry some risk for Nevada: a future Congress could amend the federal law carrying the NWICA consent standard and either alter it or eliminate it entirely. The specific approach to consent in the NWICA, which effectively gives multiple entities within a repository host state absolute vetoes over the project, is also a much higher bar than organizations such as the National Governors Association suggested as the part of the deliberations leading up to the 1982 NWPA, and other states may not want this approach to be applied to other states or to themselves.[148]

A site-specific approach that could give Nevada stronger protections could be along the lines of a court-enforceable agreement similar to the "Batt agreement" in Idaho, discussed in chapter 4. Such an agreement could incorporate elements of the NWICA as desired by Nevada and by its nature prevent a future Congress from invalidating it, as well as preclude a future administration from altering it to match policy or political whims. The Batt agreement—between the state of Idaho, DOE, and the US Navy—set parameters for nuclear waste management at INL and could serve as a template structure for an agreement between Nevada and DOE (and if naval SNF is part the investigations, possibly the US Navy).

The "consultation and cooperation" agreement between DOE and the State of New Mexico for the WIPP repository, discussed in chapter 3, is another possible template for negotiations on a phased, adaptive path to potential licensing and operation. It is also possible that the state of Nevada might want regulatory authority over Yucca Mountain in a similar manner to the power that the State of New Mexico has through the WIPP Land Withdrawal Act (namely, RCRA authority). If desired by the state, passing legislation giving Nevada similar authority to regulate the site could also be part of a broader compromise.

It would also need to be absolutely clear as part of any negotiations that additional repositories will be required beyond Yucca Mountain. Even if Nevada is willing to accept some nuclear waste at the site, it will almost certainly not accept all of it. The principle of having more than one repository for the nation's HLW and SNF inventory—at the heart of the 1982 NWPA compromise—is still appropriate and the right approach today. In the end, a negotiated solution may not be possible because of the decades of contentious history, but it is worth trying—a licensed, operating repository negotiated through agreements for even a limited HLW and/or SNF inventory could still serve local, state, and national interests. It could also increase the confidence of states considering consolidated interim storage facilities that the

United States is capable of developing repositories, and such interim sites will not wind up as permanent ones.

The local community that would host a repository at Yucca Mountain—Nye County—sees a project there as potentially safe[149] and is interested in the economic development involved with its construction and operation, as the WIPP project provided to Carlsbad in New Mexico. In 2019, a majority of the counties in Nevada indicated that they would like to see the NRC licensing of Yucca Mountain completed;[150] however, a majority of citizens in Nevada are against the proposed project.[151] The state of Nevada's specific concerns regarding social and institutional risks, transportation routes, repository design details, and other considerations (such as being singled out in the NWPA) would almost certainly have to be addressed as part of any discussions to gain broader public acceptance for a negotiated agreement.

VII. CONCLUSIONS

Objectively, the United States currently has no discernible disposal program for HLW and SNF. There have been no appropriations from the NWF for Yucca Mountain—the only site that has been approved under current law (i.e., the NWPA) for disposal of commercial SNF—since 2010. The FY 2020 appropriations bill funded waste management efforts at $60 million for generic research—effectively a smaller amount than was appropriated to DOE for waste management in 1976.[152] As the country with the largest nuclear reactor fleet in the world, the United States ought to have a robust nuclear waste disposal program. Several other observations are worthy of attention:

- In the absence of congressional action, payments out of the Judgment Fund to utilities storing spent nuclear fuel on-site will cost taxpayers tens of billions of dollars over the coming years. This will not hurt the agency responsible for commercial nuclear waste management (DOE), but communities with shutdown nuclear plants will be unable to reclaim all of their land.
- The cleanup of Cold War nuclear weapons sites in Idaho, South Carolina, and Washington is projected to be a decades-long effort costing hundreds of billions of dollars. However, even if all of the processing and remediation efforts at the sites were completed in 10 or 20 years, the defense SNF and HLW waste packages would have nowhere to go.
- The US Navy will continue to rely on nuclear reactors to power its aircraft carriers and submarines, as there is no viable alternative energy source, and as a result spent naval reactor fuel will steadily accumulate at INL. The 2035 deadline for removal of naval SNF from Idaho in the legally enforceable Batt agreement, however, poses financial and operational risks to the US Navy.
- For the foreseeable future, the United States will continue to use research reactors and isotope production facilities. These activities will continue to produce a comparatively very small stream of SNF and HLW that will nevertheless require a disposal pathway.

All of the options presented in chapter 6 could, largely independent of one another, help the United States make progress on management of SNF and HLW. DOE can take some of these actions on its own under existing legal authorities, such as pursuing a repository for defense waste first. Other actions may need agreement between the budget scorekeepers—the White House Office of Management and Budget, the Congressional Budget Office, and congressional budget committees—such as improving the budget structure for the waste program. But ultimately, Congress will have to amend existing laws in order for the US SNF and HLW management program to succeed. Given the federal government's statutory and contractual obligations for timely disposition of SNF and HLW, mounting liabilities for failure to meet those obligations, and the critical role of nuclear energy in meeting climate goals, Congress in particular should not simply leave the US SNF and HLW disposal program at a standstill.

NOTES

1. See documents associated with the recent Paris Agreement: https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement and http://www.b-t.energy/.
2. Data from 2020 *BP Statistical Review of World Energy*.
3. Staffan A. Qvist and Barry W. Brook (2015) "Potential for Worldwide Displacement of Fossil-Fuel Electricity by Nuclear Energy in Three Decades Based on Extrapolation of Regional Deployment Data," *PLoS ONE* 10, no. 5 (2015): e0124074, https://doi.org/10.1371/journal.pone.0124074.
4. IEA, "Steep Decline in Nuclear Power Would Threaten Energy Security and Climate Goals," May 28, 2019, https://www.iea.org/newsroom/news/2019/may/steep-decline-in-nuclear-power-would-threaten-energy-security-and-climate-goals.html.
5. This report is hardly the first to note this. For example, a 2018 publication from Stanford University and George Washington University, "Reset of America's Nuclear Waste Management: Strategy and Policy," makes many of the same high-level observations and some similar recommendations. This report draws on many of the observations and recommendations from previous reports (cited later) as well as the Stanford University–George Washington University report, which is available at https://cisac.fsi.stanford.edu/research/projects/reset-nuclear-waste-policy.
6. EIA, "Electricity Explained: Electricity in the United States," last updated March 2020, https://www.eia.gov/energyexplained/electricity/electricity-in-the-us.php.
7. The National Conference of State Legislatures has produced a list of states and restrictions on new nuclear power plant construction: http://www.ncsl.org/research/environment-and-natural-resources/states-restrictions-on-new-nuclear-power-facility.aspx.
8. National Research Council, *Disposition of High-Level Waste and Spent Nuclear Fuel: The Continuing Societal and Technical Challenges* (Washington, DC: The National Academies Press, 2001). From page 1: "Tactical opposition by groups opposed to nuclear power has been a factor in the slow progress toward arriving at societal agreement on acceptable approaches to radioactive waste management…some opposition groups have made it a policy to refuse constructive participation in seeking solutions until or unless a prior commitment to close down nuclear power is made."
9. "*Transuranic*" means an element having an atomic number greater than uranium (92).
10. See pages 174–78 of Transportation Research Board and National Research Council's *Going the Distance? The Safe Transport of Spent Nuclear Fuel and High-Level Radioactive Waste in the United States* (2006).
11. In this report, fuel that has been irradiated in a reactor and has not been reprocessed will

be referred to as “spent nuclear fuel,” and the highly radioactive waste resulting from the reprocessing of spent nuclear fuel will be referred to as “high-level radioactive waste” (or “high-level waste”). This convention follows definitions from the Nuclear Waste Policy Act of 1982, as amended.

12. MTHM is a measure of the mass of nuclear fuel and refers to elements with atomic numbers greater than 89. Other parts of SNF, such as the cladding or other structural materials, are not used to calculate the MTHM value.

13. GAO, “Benefits and Costs Should Be Better Understood before DOE Commits to a Separate Repository for Defense Waste,” 2017, https://www.gao.gov/assets/690/682385.pdf.

14. Congressional Research Service, “The Manhattan Project, the Apollo Program, and Federal Energy Technology R&D Programs: A Comparative Analysis,” June 30, 2009, https://fas.org/sgp/crs/misc/RL34645.pdf.

15. Government Accountability Office, “Nuclear Waste: Opportunities Exist to Reduce Risks and Costs by Evaluating Different Waste Treatment Approaches at Hanford,” May 2017.

16. Id., 1.

17. US Department of Energy FY 2020 Congressional Budget Request, p. 9, https://www.energy.gov/sites/prod/files/2019/04/f62/doe-fy2020-budget-volume-1.pdf.

18. Id., 591.

19. Blue Ribbon Commission on America’s Nuclear Future (2012), 18.

20. See, for example, the NRC’s website on dry cask storage: https://www.nrc.gov/reading-rm/doc-collections/fact-sheets/dry-cask-storage.html.

21. Congressional Research Service, “Nuclear Energy: Overview of Congressional Issues,” updated July 16, 2020.

22. US Nuclear Regulatory Commission, “Power Reactors,” https://www.nrc.gov/reactors/power.html.

23. US Nuclear Regulatory Commission, “Operating Reactors,” https://www.nrc.gov/reactors/operating.html.

24. Oak Ridge National Laboratory, “History of the High Flux Isotope Reactor,” https://neutrons.ornl.gov/hfir-history.

25. Most fission-based medical isotopes used in the United States are imported, so the country of origin has the responsibility to deal with the remaining radionuclides resulting from their production.

26. Dominique Delbeke and George Segall, “Status of and Trends in Nuclear Medicine in the United States,” *Journal of Nuclear Medicine* 52, supp. 2: 24S–28S, doi: 10.2967/jnumed.110.085688.

27. National Academies, "Opportunities and Approaches for Supply of Molybdenum-99 and Associated Medical Isotopes to Global Markets," Proceedings of a Symposium, 2018, https://www.nap.edu/catalog/24909/opportunities-and-approaches-for-supplying-molybdenum-99-and-associated-medical-isotopes-to-global-markets.

28. Blue Ribbon Commission on America's Nuclear Future (2012), 16.

29. National Research Council, *Disposition of High-Level Waste and Spent Nuclear Fuel: The Continuing Societal and Technical Challenges* (Washington, DC: The National Academies Press, 2001). From page 10: "In the 1950s and 1960s, it was widely assumed that essentially all spent nuclear fuel (SNF) would be reprocessed to recover uranium and plutonium. Today, the United States and some other nations have established national policies not to reprocess SNF, but rather to dispose of it directly."

30. See, for example, Samuel Walker's "The Road to Yucca Mountain" for a history of AEC HLW disposal efforts.

31. Interagency Review Group, *Report to the President by the Interagency Review Group on Nuclear Waste Management*, TID-29442 (Washington, DC: US Department of Energy, 1979).

32. For example, the joint report accompanying one nuclear waste bill around the same time—S.1662, which was introduced as the National Nuclear Waste Policy Act of 1981—stated: "In addition, the Committee amendment provides a detailed schedule of milestones for the construction of at least one additional repository, and imposes maximum capacity limits on the first repository until a second repository is in operation. Repositories are required to be located on a regional basis to minimize the cost and impact of transportation. These provisions are intended to guarantee that no single State or region of the country will bear the full burden of civilian nuclear waste disposal."

33. As a technical note, some of the locations under consideration for the first repository site were in Louisiana and Mississippi, neither of which are particularly "West." However, as other quotes in this report and other publications show, the characterization of the first repository as being "western" and the second as "eastern" was widely used, including by the authors of the NWPA, such as Representative Mo Udall.

34. Richard Stewart, "Solving the U.S. Nuclear Waste Dilemma," *Environmental Law Reporter* 40, no. 8 (August 2010), https://elr.info/sites/default/files/articles/40.10783.pdf (hereafter referred to as "Stewart, 2010").

35. See the BRC staff draft to the members of the Ad Hoc Subcommittee on Commingling of Defense and Commercial Waste regarding "Background Paper on Commingling of Defense and Commercial Waste."

36. Thomas O'Toole, "Clinch River Site Urged for Storing Atomic Waste," *Washington Post*, April 26, 1985. https://www.washingtonpost.com/archive/politics/1985/04/26/clinch-river-site-urged-for-storing-atomic-waste/fd498bd7-a8e6-43e2-998d-5dd54d26ce5a/?utm_term=.07450d56ee70.

37. Government Accountability Office, "Monitored Retrievable Storage of Spent Nuclear Fuel," May 1986, https://www.gao.gov/assets/90/87143.pdf.

38. Congressional Research Service, "Nuclear Waste Disposal: Alternatives to Yucca Mountain," February 6, 2009, 20.

39. *Washington Post*, "Nuclear Waste Won't Be Dumped in East," May 29, 1986.

40. Robert D. Hershey Jr., Special to the *New York Times*, "U.S. Suspends Plan for Nuclear Dump in East or Midwest," May 29, 1986, https://www.nytimes.com/1986/05/29/us/us-suspends-plan-for-nuclear-dump-in-east-or-midwest.html.

41. US House of Representatives Committee on the Interior and Insular Affairs, Subcommittee on Energy and the Environment, Implementation of the Nuclear Waste Policy Act (Site Selection Program), July 31, 1986. Relevant excerpts: Representative Mo Udall (D-AZ), "By deferring the next round, the administration unilaterally repudiated the major element, an essential compromise between eastern and western interests that allowed the waste bill to become law. But evidently the pressure for action on a Senate seat overwhelmed the administration's ability to think clearly and to protect the act…Nobody is going to win this kind of political game playing. Everybody loses"; Representative John McCain (R-AZ), "We did need a national law, and that law said there would be a second round and it is an integral part of that legislation. I don't believe that legislation would have been passed if there had been the perception or belief that somehow that aspect of the law would be abrogated by this or any other administration"; Representative Barbara Vucanovich (R-NV), "Nevada, unfortunately, has been given a clear message that it may well have to accept all of the Nation's high level waste for the indefinite future, and that it should be prepared to accept it with no assurances that DOE must prove that Nevada is the safest site in the Nation…Under these circumstances, Nevada has no confidence in the present volume cap or that the cap won't just be lifted when it becomes politically convenient to do so"; Representative Beau Boulter (R-TX), "The problem we are facing is that they don't believe that the process has been carried out fairly in accordance with the law. They just simply mistrust the whole process, and I share that feeling very strongly, Mr. Chairman… It really is, because we have had the indefinite postponement of the second site, which destroys the concept of region balance."

42. September 18, 1987, House Interior Committee hearing on H.R.2888 and H.R.2967.

43. Site characterization activities are undertaken to establish geologic conditions, including making use of borings, surface excavations, excavations of exploratory shafts, and other activities to evaluate the suitability of a candidate site for the location of a repository. So, for example, exploratory shafts to do site characterization work had not been sunk at the three sites identified as candidates for the first repository previous to Congress amending the NWPA in 1987 to select Yucca Mountain.

44. Stewart, 2010: "Senator Bennett Johnston of Louisiana, the powerful Chairman of the Senate Energy Committee, was concerned that escalating costs and intensified opposition from potential host states would scuttle the entire program unless Congress moved swiftly

to designate the repository site."

45. GAO, "Nuclear Waste: Information on Cost Growth in Site Characterization Cost Estimates," 1987, 1: "DOE's earliest estimates of site characterization costs, made in 1981, were from $60 million to $80 million per site, or from $180 million to $240 million for three sites. Since then, DOE's cost estimates for characterizing three sites have increased dramatically, to $2.2 billion in 1984, and to $4.8 billion in its latest preliminary estimates."

46. The genesis for this nickname appears to come from Representative James Bilbray from Nevada. Bilbray remembers being told by another member of the House, "I hope you understand what is going on here. There are three sites under review—Texas, Nevada and Washington. And the speaker [of the House, Jim Wright] is a Texan and the majority leader [Tom Foley] is a Washingtonian…It is not going to Washington. And it is not going to Texas." Bilbray told a story of leaving a meeting with Majority Leader Tom Foley and Speaker Jim Wright where he was told that Yucca Mountain was it, and telling a friend that "Nevada had just been screwed." See page 33 of the "Report and Recommendations of the Nevada Commission on Nuclear Projects," http://www.state.nv.us/nucwaste/pdf/2019.11.04%20Draft%20Commission.pdf.

47. Representative Morris Udall, House Debate, Congressional Record, vol. 133, pt. 26 (December 21, 1987), 37068.

48. Congressional Record—Senate, October 31, 1995, p. S16388. "I then introduced legislation to call on the Department of Energy to pick one of the three sites and characterize it to save $2.4 billion. My version did not pass because when it got to the conference committee with the House they said go ahead and name Yucca Mountain—do it politically, not scientifically. They had the votes…I must say in all fairness Nevada probably would have been scientifically picked at least. That was the indication I got at the time. But I think Nevada had a proper cause to complain because it was, in fact, a political decision rather than a scientific decision, although that might well have been the place where it would have been picked."

49. DOE, "A Multiattribute Utility Analysis of Sites Nominated for Characterization for the First Radioactive-Waste Repository—a Decision-Aiding Methodology," May 1986, https://www.osti.gov/servlets/purl/5362489.

50. See chapter 2 of "*Uncertainty Underground*" (2006), edited by Allison MacFarlane and Rodney Ewing.

51. Congressional Research Service, "Civilian Nuclear Waste Disposal," October 7, 2008, 3–5.

52. Id., 6–7.

53. Nuclear Energy Institute v. Environmental Protection Agency, US Court of Appeals for the District of Columbia Circuit, No. 01-1258, July 9, 2004.

54. Congressional Research Service, "EPA's Final Health and Safety Standard for Yucca Mountain," October 6, 2008.

55. The Blue Ribbon Commission on America's Nuclear Future released its report to the secretary of energy in January 2012: https://www.energy.gov/sites/prod/files/2013/04/f0/brc_finalreport_jan2012.pdf.

56. GAO, "Yucca Mountain: Information on Alternative Uses of the Site and Related Challenges," September 2011, 24.

57. Congressional Research Service, "Civilian Nuclear Waste Disposal," September 6, 2018, 6.

58. Id., 8–9.

59. US Nuclear Regulatory Commission, "Safety Evaluation Report Related to Disposal of High-Level Radioactive Wastes in a Geologic Repository at Yucca Mountain, Nevada: Proposed Conditions on the Construction Authorization and Probably Subjects of License Specifications (NUREG-1949, Volume 5)," https://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr1949/v5/.

60. Archived whitehouse.gov website from President Obama's time in office, "Presidential Memorandum—Disposal of Defense High-Level Radioactive Waste in a Separate Repository," https://obamawhitehouse.archives.gov/the-press-office/2015/03/24/presidential-memorandum-disposal-defense-high-level-radioactive-waste-se.

61. US Department of Energy, "Draft Consent-Based Siting Process for Consolidated Storage and Disposal Facilities for Spent Nuclear Fuel and High-Level Radioactive Waste," January 12, 2017.

62. DOE, "Analysis of the Total System Life Cycle Cost of the Civilian Radioactive Waste Management Program, Fiscal Year 2007," DOE/RW-0591, July 2008.

63. For more information on the 1995 agreement, see https://www.deq.idaho.gov/inl-oversight/oversight-agreements/1995-settlement-agreement/; the agreement between the state of Idaho, the US Navy, and the US Department of Energy could be looked at as an example of written consent for consolidated interim storage of SNF.

64. The US Judgment Fund receives a permanent, indefinite appropriation from the US Treasury and exists to pay court judgments and compromise settlements of lawsuits against the federal government: https://www.fiscal.treasury.gov/judgment-fund/faqs.html.

65. Congressional Research Service, "Civilian Nuclear Waste Disposal," September 6, 2018.

66. US Nuclear Regulatory Commission, "Backgrounder on Decommissioning Nuclear Power Plants." https://www.nrc.gov/reading-rm/doc-collections/fact-sheets/decommissioning.html.

67. National Academy of Sciences, National Research Council, *The Disposal of Radioactive Wastes on Land: Report* (Washington, DC: The National Academies Press, 1957), https://doi.org/10.17226/18527. From page 3: "The Committee is convinced that radioactive waste can be disposed of safely in a variety of ways and at a large number of sites in the United States."

68. National Research Council, *Disposition of High-Level Waste and Spent Nuclear Fuel: The Continuing Societal and Technical Challenges* (Washington, DC: The National Academies Press, 2001), https://doi.org/10.17226/10119. From page 1: "There has been, for decades, a worldwide consensus in the nuclear technical community for disposal through geological isolation of high-level waste (HLW), including spent nuclear fuel (SNF)."

69. This list and much of this subchapter is informed by M. J. Apted and J. Ahn, "Repository 101: Multiple-Barrier Geological Repository Design and Isolation Strategies for Safe Disposal of Radioactive Materials," in *Geological Repository Systems for Safe Disposal of Spent Nuclear Fuels and Radioactive Waste*, eds. M. Apted and J. Ahn (Duxford, UK: Woodhead Publishing, 2017), 3–26.

70. In 2020, all of the operating power reactors in the United States are light water reactors, and SNF from light water reactors is by far the largest part of the US nuclear waste inventory in terms of cumulative radioactivity.

71. These elements also form barriers to human intrusion of a repository, which is a separate but important concern.

72. The EPA estimates that on average a US citizen receives 620 millirem of radiation dosage each year, where approximately half of that dosage comes from natural sources (e.g., radon and thoron, cosmic radiation, radioactive elements in the human body, radiation from foods consumed, etc.) and man-made sources, such as medical procedures (e.g., X-rays and hospital diagnostics and treatment using nuclear medicine). See https://www.epa.gov/radiation/radiation-sources-and-doses.

73. The primary generators of heat from SNF after the first decade following removal from a reactor are initially two fission products—cesium-137 and strontium-90—both of which have half-lives of around 30 years. Depending upon the SNF composition at the time it is removed from reactor operation, perhaps 40 to 60 years later americium-241 (with a half-life of 432 years) eventually overtakes these two isotopes as the leading contributor to heat generation from SNF. It is unlikely that a waste management system would see substantial advantages in cooling SNF for a period of time approaching americium-241's half-life given the implied hundreds of years of storage costs. See the appendix to chapter 5 of MIT's 2011 report "*The Future of the Nuclear Fuel Cycle*."

74. US Department of Energy, "Geologic Disposal Safety Case," https://wipp.energy.gov/geologic-disposal-safety-case.asp.

75. See the appendix to chapter 5 in MIT's 2011 report "*The Future of the Nuclear Fuel Cycle*."

76. RCRA gives EPA the authority to control hazardous waste from cradle to grave. For more information, see EPA's website: https://www.epa.gov/laws-regulations/summary-resource-conservation-and-recovery-act.

77. R. Stewart and J. Stewart, "Fuel Cycle to Nowhere," 2011, 164: "The federal government's maneuvering to include SNF in plans for WIPP soured many in New Mexico on the WIPP project, inspiring the state legislature to come very close to passing a constitution

amendment that would ban storage of any radioactive waste brought into the state. New Mexico had no nuclear power plants, and the state was strongly opposed to hosting other states' nuclear power wastes. Because of its role in the development of the atomic bomb and the ongoing presence of government nuclear facilities, including Sandia, in New Mexico, the state was less averse to hosting defense wastes."

78. Stewart and Stewart, 2011. Page 173 discusses the discovery of an underground brine pocket and the aftermath: "After discovery of the brine pocket, DOE decided, upon EEG's recommendation, to build the repository in a location extending south from the central shaft instead of north as originally planned."

79. Stewart and Stewart, 2011, 171.

80. All of the relevant documents and agreements discussed here are, as of May 2020, found at the WIPP website: https://wipp.energy.gov/Library/Information_Repository_A/Class_3_Permit_Modifications/TID%20References/U.S.%20DOE.%201981a..pdf.

81. First, a truck caught fire while underground in the repository; workers were evacuated, and a portion of WIPP was shut down. Six workers were treated for smoke inhalation. A second, entirely separate, accident was noticed when an underground air monitor within the WIPP tunnels detected airborne radioactivity. The source was traced to a compromised drum of TRU waste that had been emplaced in WIPP in late 2013. The accident was caused when a drum containing the TRU waste ruptured after its contents underwent an energetic chemical reaction. EPA ultimately concluded that the radiation releases did not pose a public health concern. The New Mexico State University's Carlsbad Environmental Monitoring & Research Center similarly found that no negative radiation-related health effects among local workers or the public should be expected. The state of New Mexico and DOE reached a settlement of $74 million related to the state's claims against the DOE and its contractors regarding these incidents. Recovery from the accidents added large costs to the WIPP project, stopped disposal operations at the facility for years, and resulted in more limited operations when it reopened.

82. See, for example, the review of eight countries' nuclear waste programs compiled by Sweden in 2019: https://www.karnavfallsradet.se/en/report-20191-overview-of-eight-countries-status-april-2019.

83. For example, independent, nongovernmental groups in Sweden, such as MKG, have raised concerns over possible early corrosion of the copper canisters involved with the Swedish approach to disposal (http://www.mkg.se/en/mkg-and-member-organisations-send-a-statement-to-the-government-on-skbs-complementary-copper). As of October 2020, the Swedish government is still evaluating additional information on the copper canisters provided by SKB.

84. World Nuclear Association, "Nuclear Power in Finland," https://www.world-nuclear.org/information-library/country-profiles/countries-a-f/finland.aspx.

85. World Nuclear News, "Posiva Plugs Repository Demonstration Tunnel," May 9, 2019, http://

world-nuclear-news.org/Articles/Posiva-plugs-repository-demonstration-tunnel.

86. The Finnish company Posiva has posted a video explaining the operation of Onkalo: https://www.youtube.com/watch?v=A9vWhoT_45s.

87. World Nuclear Association, "Nuclear Power in Sweden," updated March 2020, http://www.world-nuclear.org/information-library/country-profiles/countries-o-s/sweden.aspx.

88. SKB, "Our Task," https://www.skb.com/about-skb/our-task/.

89. MKG, a Swedish nongovernmental environmental organization established to work on nuclear waste issues, published an English translation of the court's opinion at http://www.mkg.se/uploads/Summary_opinion_Swedish_Environmental_Court_regarding_proposed_final_repository_spent_nuclear_fuel_Forsmark_Jan_23_2018_(unofficial_translation_MKG).pdf.

90. World Nuclear Association, "Nuclear Power in Canada," https://www.world-nuclear.org/information-library/country-profiles/countries-a-f/canada-nuclear-power.aspx.

91. Nuclear Waste Management Organization, "Who We Are," https://www.nwmo.ca/en/ABOUT-US/Who-We-Are.

92. See BRC final report or transcript of BRC panel discussion in Washington, DC, on October 20, 2011.

93. DOE, "Assessment of Disposal Options for DOE-Managed High-Level Radioactive Waste and Spent Nuclear Fuel," October 2014, 25: "Available information indicates that a repository limited to DOE-managed HLW and SNF not of commercial origin could be more likely to gain public acceptance than a repository that includes commercial waste, all other factors being equal. In the case of WIPP, the restriction of the facility to transuranic waste of defense origin was an essential condition to the public and state acceptance of the repository (Downey 1985; Stewart and Stewart 2011). In contrast to a repository for commercial SNF, siting a repository for DOE-managed HLW and SNF may be viewed as a national responsibility whereby all states have a share in the benefits and responsibilities."

94. The situation is different for navy SNF, which contains highly enriched uranium and thus involves nonproliferation and criticality considerations.

95. P. V. Brady, B. W. Arnold, G. A. Freeze, P. N. Swift, S. J. Bauer, J. L. Kanney, R. P. Rechard, and J. S. Stein, *Deep Borehole Disposal of High-Level Radioactive Waste*, SAND2009-4401 (Albuquerque, NM: Sandia National Laboratories, 2009).

96. US Nuclear Waste Technical Review Board, "Evaluation of Technical Issues Associated with the Development of a Separate Repository for US Department of Energy-Managed High-Level Radioactive Waste and Spent Nuclear Fuel," June 2015, 7: "In a mined geologic repository where DOE-managed and commercial HLW and SNF are commingled, the total radionuclide release from the repository would be dominated by the release from commercial SNF."

97. DOE, 2014, 17.

98. BRC Staff Draft—Background Paper on Commingling of Defense and Commercial Waste. Transmitted to Members of the Ad Hoc Subcommittee on Commingling of Defense and Commercial Waste, November 17, 2011.

99. National Research Council committees in the past have recommended a staged (or phased), adaptive approaches to geologic disposal programs. For example, a 2001 report, *Disposition of High-Level Waste and Spent Nuclear Fuel*, observed (page 5): "For both scientific and societal reasons, national programs should proceed in a phased or stepwise manner, support by dialogue and analysis." A 2003 report, *"One Step at a Time: The Staged Development of Geologic Repositories for High-Level Waste"*, states (page 2) that adaptive staging "emphasizes continuous learning, both technical and societal, includes scientific and managerial re-evaluations and reaction to new knowledge, is responsive to stakeholder input, and is designed to continually improve the project while retaining the option of reversibility." "Consent-based" is discussed in chapter 6, but at a minimum in the United States a project would likely need to include support from the local government without active opposition from the state government.

100. US Nuclear Regulatory Commission, "Materials Transportation," https://www.nrc.gov/materials/transportation.html.

101. There is the possibility of heavy-haul truck transport with larger casks being moved on highways with low-speed overweight trucks.

102. See page 58 of the 2006 National Academies report "*Going the Distance*" (NAS 2006).

103. The tests are defined in 10 CFR Part 71.73.

104. Centers for Disease Control and Prevention. "Facts about Chlorine," https://emergency.cdc.gov/agent/chlorine/basics/facts.asp.

105. US Energy Information Administration, "Hydrocarbon Gas Liquids Explained," https://www.eia.gov/energyexplained/index.php?page=hgls_uses.

106. Energy Information Administration, "New Methanol Plants Expected to Increase Industrial Natural Gas Use through 2020," February 21, 2019, https://www.eia.gov/todayinenergy/detail.php?id=38412.

107. Transportation Research Board and National Research Council, *Going the Distance? The Safe Transport of Spent Nuclear Fuel and High-Level Radioactive Waste in the United States* (2006), pp. 138 and 149–61.

108. See page 54 of the 2019 Nevada Commission of the Report and Recommendations of the Nevada Commission on Nuclear Projects: "At the direction of the Nevada Legislature, the Agency in 1988 prepared a comprehensive report on transportation issues, known as the ACR 8 Report. Growing out of the ACR 8 Report, the Agency developed ten major safety and security recommendations: 1 Ship oldest SNF first (to reduce overall radiological hazards from fission products)…" This recommendation is also found in the 2006 National Academies' *"Going the Distance"* report and BRC 2012.

109. ORNL, "A Historical Review of the Safe Transport of Spent Nuclear Fuel," 2016, v. As page 35 discusses, there have been incidents where transportation casks have been, for example, placed in a spent fuel pool and as a result contaminated with cesium-137, but those types of contamination incidents were not the result of any kind of failure of the transportation cask.

110. US Nuclear Regulatory Commission, "Transportation of Spent Nuclear Fuel." According to the NRC, thousands of shipments of commercial SNF have been transported throughout the United States "without causing any radiological releases to the environment or harm to the public" over the past 40 years, https://www.nrc.gov/waste/spent-fuel-transp.html.

111. ORNL, 2016, 41. R. Pope, X. Bernard-Bruls, and M. T. M. Brittinger, "A World-Wide Assessment of the Transport of Irradiated Nuclear Fuel and High Level Waste," *Proceedings of the International Symposium on Packaging and Transportation of Radioactive Materials*, Institute of Nuclear Materials Management, Chicago, IL, USA (2001).

112. ORNL, 2016, 41.

113. Western Governors' Association, "WIPP Transportation Fact Sheet," http://westgov.org/images/editor/WIPP_Fact_Sheet_September_2016.pdf.

114. US Department of Energy, "Shipment & Disposal Information," https://www.wipp.energy.gov/shipment-information.asp."

115. US Navy and National Nuclear Security Administration, "United States Naval Nuclear Propulsion Program: Operating Navan Nuclear Propulsion Plants and Shipping (Rail) Naval Spent Fuel Safety for Over 60 Years," September 2017, https://www.energy.gov/sites/prod/files/migrated/nnsa/2018/01/f46/united_states_naval_nuclear_propulsion_program_operating_naval_nuclear_propulsion_plants_and_shipping_rail_naval_spent_fuel_safely_for_over_sixty_years.pdf.

116. The state of Idaho hosts these additional agreements at https://www.deq.idaho.gov/inl-oversight/oversight-agreements/.

117. See page 9 of the Leadership in Nuclear Energy Commission full report from January 2013. Available on the Idaho government's website: https://line.idaho.gov/wp-content/uploads/sites/12/2016/07/LINE-Full-Report-1.pdf.

118. Adrian Hedden, "Department of Energy: Half of Nuclear Waste Shipments to WIPP Come from Idaho National Lab," *Carlsbad Current-Argus*, November 18, 2019, https://www.currentargus.com/story/news/local/2019/11/18/doe-more-than-half-wipp-shipments-come-idaho-national-lab/4205541002/.

119. See page 56 of the "*Report and Recommendations of the Nevada Commission on Nuclear Projects*," November 2019, http://www.state.nv.us/nucwaste/pdf/2019.11.04%20Draft%20Commission.pdf.

120. BRC, 2012, 150.

121. Of note, the 1982 NWPA called for the program to submit a budget to the Office of Management and Budget on a triennial basis, not an annual one. This also recognized the special long-duration nature of the waste disposal program and the need for sustained, consistent funding.

122. See the BRC-commissioned paper by Joseph S. Hezir, "Budget and Financial Management Improvements to the Nuclear Waste Fund," May 2011, 10.

123. Ibid.

124. DOE, *Nuclear Waste Fund Annual Financial Report Summary FY2019 and Cumulative*, https://www.energy.gov/sites/prod/files/2019/12/f69/FY19%20-%20NWF%20Annual%20Financial%20Report%20Summary.pdf.

125. The facility in Utah was licensed but ultimately terminated on account of opposition from within the state. More information on the Texas and New Mexico projects is available at https://www.nrc.gov/waste/spent-fuel-storage/cis.html.

126. The committee report for HR.3053 in the 115th Congress explains that deleting section 135(h) "makes a conforming change to align with the authority under Title I of the legislation, which provides DOE authority to enter into an MRS agreement to store SNF with a non-Federal entity."

127. See pages xii–xiii of the 2012 BRC report.

128. DOE, "The Report to the President and the Congress by the Secretary of Energy on the Need for a Second Repository," December 2008.

129. Testimony of Kelly Horn, Co-Chairman of the Midwestern Radioactive Materials Transportation Committee, to the US House Energy and Commerce Committee, Subcommittee on Environment and the Economy, Thursday, October 1, 2015.

130. The idea appears in a 1977 book by Mason Willrich and Richard K. Lester, "*Radioactive Waste: Management and Regulation*."

131. Office of Technology Assessment, "Managing Commercial High-Level Radioactive Waste: Summary Report," OTA-O-172, April 1982. OTA found that "the establishment of a single-purpose waste management organization, independent of other Federal nuclear programs, is needed to avoid the competition for manpower and policy-level attention that has adversely affected the waste management program in the past, to ensure that the staff's primary incentive is the safe and timely accomplishment of the goals of the waste management policy, and to insulate the program from future reorganizations of Federal energy programs."

132. Advisory Panel on Alternative Means for Financing and Managing Radioactive Waste Management Facilities, "Managing Nuclear Waste—a Better Idea," 1984.

133. MIT, "The Future of the Nuclear Fuel Cycle," 2011; BRC, 2012; Bipartisan Policy Center, "Moving Forward with Consent-Based Siting for Nuclear Waste Facilities:

Recommendations of the BPC Nuclear Waste Council," September 2016; Stanford University and George Washington University, "Reset of America's Nuclear Waste Management: Strategy and Policy," October 15, 2018.

134. See page 185 of Luther Carter's "Nuclear Imperatives and Public Trust." The author describes a conversation with former deputy secretary of energy John O'Leary regarding concessions to states on nuclear waste wherein O'Leary told him that the concessions "amounted simply to a recognition that a repository cannot be built over determined host-state opposition" and quotes O'Leary as saying, "When you think of all the things a determined state can do, it's no contest" citing the regulatory authority a state has with respect to its lands, highways, employment codes, and the like.

135. https://www.energy.senate.gov/public/index.cfm/2019/4/bipartisan-senate-coalition-reintroduces.

136. US Department of Energy, "Alternative Means of Financing and Managing the Civilian Radioactive Waste Management Program," DOE/RW-0546, August 2001. See figure 3 for a summary of past efforts. Page 13: "Several legislative proposals were introduced to restructure the NWF receipts as an offsetting collection user fee, consistent with the structure of most new Government user fees enacted since the [Budget Enforcement Act]."

137. Ibid., figure 4.

138. Statement of Under Secretary of Energy Robert H. Card, before the Sub-committee on Energy and Air Quality, US House Committee on Energy and Commerce, March 25, 2004.

139. Hezir, 2011, 22–26.

140. There are, of course, other ideas. As the BRC-commissioned paper by Joseph Hezir discusses, there are other legislative options including designating the NWF as a trust fund in law or taking the fund "off-budget."

141. This point seems to have been made in a BRC staff draft memo on comingling defense and commercial waste. As of August 2020, the paper is available at https://cybercemetery.unt.edu/archive/brc/20120620231824/http://brc.gov/sites/default/files/documents/defense_waste_policy_issue_paper_final.pdf.

142. Page 90 of the 2012 BRC report.

143. *Reset of America's Nuclear Waste Management: Strategy and Policy*, Stanford University Center for International Security and Cooperation, George Washington University Elliot School of International Affairs. October 15, 2018, 9.

144. See pages 89–95 of the 2012 BRC report for greater discussion.

145. The recent Nevada Commission on Nuclear Projects report states that a 2017 Nevada state legislature vote on Assembly Joint Resolution 10, expressing opposition to a repository for SNF and HLW at Yucca Mountain passed by a vote of 32 yeas, 6 nays, and 4 excused: http://www.state.nv.us/nucwaste/pdf/2019.11.04%20Draft%20Commission.pdf.

146. For example, on page 424 of Luther Carter's 1987 book "*Nuclear Imperatives and Public Trust*," he discusses how many Nevadans cited "lack of fairness" when discussing Yucca Mountain and the feeling that any time a site is needed for an activity no other state would tolerate, a place in Nevada will be chosen. After the DOE announced that the search for a second site would be suspended and Yucca Mountain was one of three finalists to the be the first and, seemingly, only repository, Carter quotes the *Las Vegas Review Journal* as saying: "If those underground atomic shots that ripple the upper floors of high-rise buildings in Las Vegas don't scare the tourists, then, sure as heck, a waste site isn't likely to keep the folks away…What is at issue is the lack of fairness to Nevada, the disregard in Washington for the wishes of the people and the tendency of the technocrats and political forces in Washington to exploit Nevada's relative lack of national political power."

147. The legislation would prohibit the secretary of energy from making an expenditure from the NWF for costs associated with transportation, treating, or packaging SNF or HLW to be disposed of in a repository or stored at an MRS site unless written, legally binding agreements were in place with the governor of the state hosting the site, associated groups of local governments, and affected Indian tribes. Any expenditures from the NWF for costs associated with designing, constructing, and operating geologic repositories and MRS sites would need the same forms of consent. The legislation does not prohibit any funds from the NWF from being used at early milestones of site characterization or even the licensing of a geologic repository in the absence of these written agreements. Instead, the consent is applied just before repository construction. This approach would give a state the maximum amount of knowledge about a repository site before consenting to construction of a facility for commercial SNF disposal.

148. A discussion of these debates, previous to the NWPA of 1982, can be found on pages 177–84 in the Office of Technology Assessment report "*Managing the Nation's Commercial High-Level Radioactive Waste*," OTA-0-171, March 1985.

149. Testimony of Commissioner Dan Schinhofen, Vice-Chairman of the Nye County, Nevada Board of County Commissioners to the House Energy and Commerce Committee, July 7, 2016, https://docs.house.gov/meetings/IF/IF18/20160707/105164/HHRG-114-IF18-Wstate-SchinhofenD-20160707.pdf.

150. Nye County hosts this letter at http://www.nyecounty.net/CivicAlerts.aspx?AID=824&ARC=1487.

151. Yvonne Gonzalez, "Yucca Mountain Panel Shows Divide between State, Rural Counties," *Las Vegas Sun*, September 7, 2017, https://lasvegassun.com/news/2017/sep/07/yucca-mountain-panel-shows-divide-between-state-ru/.

152. US Congress Office of Technology Assessment, Managing the Nation's Commercial High-Level Radioactive Waste, OTA-O-171, March 1985, appendix A.

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