Road to Nowhere:

United States Nuclear Waste Transportation and Storage Policy

By

Ethan Gelfer

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Preceptors: Allison Kolar and Samantha Steinmetz
Advisor and Second Reader: Professor Robert Rosner

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Abstract: *The production of commercial nuclear power in the United States has resulted in the production of tens of thousands of tons of high-level nuclear waste. The Department of Energy and the Congress had designated Yucca Mountain in Nye County, NV, as a site for a nuclear waste repository for deep permanent geologic storage. However, almost forty years after the initial plan was created, the site has been blocked by Nevada legislators and the public, who disagree that the transportation and storage of nuclear waste is safe. My thesis investigates the efficacy of the US proposed strategy for storing nuclear waste as opposed to other countries' approaches. I then investigate the historic trends in support for Yucca Mountain in a meta-analysis. I finally attempt to identify the determinants of support for the Yucca Mountain project by analyzing survey data. I find that distinct groups of supporters exist for the project, including ages 50+, men, and white respondents. Based on this analysis, I propose several policy recommendations: re-evaluating Yucca Mountain from the community perspective; creating an independent agency for nuclear waste management; designating an interim consolidated storage site for high-level nuclear waste; re-introducing the nuclear power mill fee; considering nuclear fuel reprocessing; educating the public on nuclear waste transportation safety; and focus public engagement campaigns on groups that are historically less likely to support the Yucca Mountain project. Stakeholders should take these recommendations into account when trying to move forward on the essential question of how to deal with the cumulative stockpile of nuclear waste as well as the nuclear waste that is yet to be created by the continuing operation of commercial nuclear reactors.*

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I. Introduction

The University of Chicago, along with a constellation of laboratories and research universities around the United States, contributed to the efforts of the Manhattan Project during the Second World War in triggering the first controlled nuclear fission chain reaction and ultimately building, testing, and deploying the first nuclear weapons against Imperial Japan in August 1945. Throughout the second half of the 20th Century, the proliferation of nuclear energy has been harnessed not just for atomic weaponry but also for peaceful electricity generation purposes. Nuclear fission reactors supply 20% of the electricity to the U.S. grid today.[1] But inherent in the production of nuclear energy is the generation of radioactive byproducts – nuclear waste. The US does not have a clearly defined nuclear waste management program on the federal level, although there is a proposed solution that has existed since the 1980s.

In the United States, there is currently a singular site for the permanent storage of transuranic materials, the Waste Isolation Pilot Plant (WIPP) in Carlsbad, New Mexico. However, there is another site that has been designated for the permanent disposal and storage of high level nuclear waste. Designated as the sole site for a permanent nuclear waste repository by Congress in the Nuclear Waste Policy Act amendments of 1987, the Yucca Mountain Nuclear Waste Repository is a permanent deep storage site designed for the intake of all the nuclear waste generated by the United States through nuclear energy production.

I utilize work from the fields of risk psychology, information theory, scientific analysis, and economic theory to provide an explanation for the lack of consensus on nuclear waste policy. Nuclear waste is an issue that intersects many division points in the population, which is part of

[1] "What Is U.S. Electricity Generation by Energy Source? - FAQ - U.S. Energy Information Administration (EIA)," accessed December 3, 2019, https://www.eia.gov/tools/faqs/faq.php?id=427&t=3.

the reason why it is so divisive. One of the major difficulties in the work of nuclear waste policy is to reconcile experts' opinions with those of the public, which are often radically different and even diametrically opposed. For people involved in the nuclear field, whether engineers or policymakers, the dominant consensus is that the status quo plan for a deep storage repository is not only an improvement over the status quo but likely the best way to minimize risk from high level waste. Public opinion is instead divided, with some support being expressed for the professional view but also entrenched with a fundamental opposition to either shipment of nuclear materials or the prospects of nuclear power whatsoever.

Nuclear waste is fundamentally intertwined with two concepts that are not treated positively by the majority of Americans and Nevadans in particular. The first is nuclear, which I will discuss throughout the thesis. The other is waste, which carries pejorative connotations and contributes to sentiments in Nevada that the Yucca Mountain project amounts to a radioactive waste "dump," with Eastern states that produce the majority of the US nuclear waste looking to slough off their problem of radioactive waste onto Nevada, a state that does not itself produce nuclear power. The terminology of nuclear waste is a major contributor to sentiments about it, but the descriptors that are used have been ossified both in the language of experts and the public.

This thesis will investigate the influential mechanisms of the nuclear waste management chain, providing an explanation for the lack of an operating permanent federal nuclear waste repository, and proposing a potential policy intervention for bypassing political gridlock and implementing a necessary system for managing the tens of thousands of tons of nuclear waste present all around the United States. I employ a three-part methodology to assess the efficacy of the US strategies to deal with nuclear waste; the historical political capital and impetus to construct the Yucca Mountain facility and identify the determinants of support or opposition of the site in

Nevada. First, I look at the comparable projects proposed worldwide and the historical reasons that underpin the original proposition to use Yucca Mountain as a permanent repository for nuclear waste. Second, I examine the historical levels of support for the project and explore the efficacy of previous strategies used to win over the public, specifically looking for whether the Department of Energy and the atomic energy industry has been successful in shifting public opinion in their direction on the repository project. Finally, I conduct a chi-square analysis on crosstab data from public opinion surveys with questions regarding the project. Through this three-pronged approach, I provide a landscape of the challenges facing the nuclear professionals in convincing the public to go along with the project.

I use my analysis to provide policy recommendations to ameliorate the political miasma surrounding the Yucca Mountain site, and attempt to provide a framework to fashion a coherent, popular, and effective strategy for the United States, Department of Energy, Nevada, and the general public to complete the life cycle of nuclear fuel, maximize safety, and fulfill the goals of the DOE to take nuclear waste off the hands of commercial nuclear power companies and provide a permanent disposal solutions. My recommendations come in the form of seven interventions that the US government can engage in, the combination of which may lead to progress in resolving the deadlocked debate over Yucca Mountain that has not changed in basic contour since the 1980s. I recommend first: shifting heavily to a community-based siting approach that re-evaluates the Yucca Mountain locale in light of public acceptance; second: creating a separate organization for the management of nuclear waste independent of the Department of Energy; third: to create an interim consolidated storage site for nuclear waste until a permanent repository can be opened; fourth: reintroduce waste fees on customers whose electricity is derived from nuclear; fifth: consider reprocessing spent fuel from Generation II reactors and push to upgrade the US fleet to

Generation IV reactors as soon as possible; sixth: mount a campaign to educate the public on the safety of high level nuclear waste transportation; and seventh: conduct information sharing campaigns utilizing microtargeting made possible by my analysis that shows particular groups insusceptibility to previous campaigns.

II. Background

Nuclear power is a potent form of energy that can be harnessed for civilian purposes – and has been for decades. Production of electricity through nuclear power generation is achieved by the fission – splitting apart – of highly reactive atoms like uranium by a chain reaction that releases a large amount of energy in the form of heat. This heat boils water, which converts into steam and in turn spins a turbine that generates electricity.[2] Fuel rods have a lifespan of about 18-36 months, after which they still contain about 96% of their original uranium.[3] After this point, they can no longer be used to sustain a chain reaction and produce electricity, thus becoming spent fuel. Along with the fuel rods, many of the byproducts of the production chain of nuclear power are also radioactive.

While not useful for sustaining a nuclear reaction, these materials, which include the fuel rods as well as containers, gloves, and other low-level waste, have decay chains that span centuries or millennia, ensuring that the total amount of radioactive waste products will compound as nuclear energy continues to be utilized, and even if nuclear power generation were to be completely stopped, there would still be thousands of tons of radioactive waste products that will remain dangerous beyond even generational time scales. For example, the radioactive isotope plutonium-

[2] "NUCLEAR 101: How Does a Nuclear Reactor Work?," Energy.gov, accessed February 4, 2020, https://www.energy.gov/ne/articles/nuclear-101-how-does-nuclear-reactor-work.
[3] "Nuclear Fuel Cycle Overview - World Nuclear Association," accessed February 4, 2020, https://www.world-nuclear.org/information-library/nuclear-fuel-cycle/introduction/nuclear-fuel-cycle-overview.aspx.

239 has a half-life of 24,000 years and radioactive materials generated in the process of fission, like cesium-137 and strontium-90, all have half-lives measured in dozens of years.[4] The radiation released by the decay of these particles make them highly dangerous to human exposure, with prolonged radiation exposure leading to cellular destruction, genetic mutation, acute radiation sickness, cancer, and highly increased mortality risk.

Nuclear waste is inextricably tied to nuclear power. For the purposes of this analysis, I focus specifically on the use of nuclear power for civilian electricity generation, as much of the military applications of nuclear power and subsequent handling of nuclear waste remains classified and has a different life cycle chain. There are currently fifty-eight nuclear power plants with ninety-six reactors operating in twenty-nine states in the United States.[5] These power plants, along with thirty commercial reactors that are at different stages of the decommissioning process, have produced over 90,000 tons of nuclear waste that is currently scattered around the country (see Figure 1).[6]

So how do we deal with the danger of radioactive byproducts of an otherwise clean form of energy generation? The history of the handling of radioactive waste is fraught with problematic attempts to dispose of waste into the waters off the coast of New Jersey and suggestions to load waste onto rockets and eject them from Earth's orbit.[7] The life cycle of nuclear fuel does not end when it is removed from the reactor, nor do the other materials that become radioactive in the

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[4] Claus Grupen, *Introduction to Radiation Protection*, Graduate Texts in Physics (Berlin, Heidelberg: Springer Berlin Heidelberg, 2010), https://doi.org/10.1007/978-3-642-02586-0.
[5] "How Many Nuclear Power Plants Are in the United States, and Where Are They Located? - FAQ - U.S. Energy Information Administration (EIA)," accessed February 4, 2020, https://www.eia.gov/tools/faqs/faq.php?id=207&t=3.
[6] "Decommissioning Nuclear Reactors Is a Long-Term and Costly Process - Today in Energy - U.S. Energy Information Administration (EIA)," accessed February 4, 2020, https://www.eia.gov/todayinenergy/detail.php?id=33792."Key Issues: Disposal of High-Level Nuclear Waste," accessed February 4, 2020, https://www.gao.gov/key_issues/disposal_of_highlevel_nuclear_waste/issue_summary.
[7] https://www-pub.iaea.org/MTCD/Publications/PDF/te_1105_prn.pdf,

process of generating nuclear electricity become safe after they are used. There are two primary methods of storing radioactive byproducts of nuclear energy production: temporary and permanent. After fuel rods cool down in spent fuel pools for a number of years, they and the other TRU are placed in more permanent storage containments. The temporary solution is to leave these containers – dry casks – at the site where the radioactive material was produced and actively monitor their status. This method leaves the radioactive material vulnerable to neglect, however, which may contribute to their deterioration if abandoned. The second, more permanent solution is to bury the radioactive waste products in the ground, where they can be indefinitely sealed not only from the elements but not require human intervention to maintain.

As of today, there are no facilities are in operation worldwide that can permanently store "high-level" waste such as spent fuel rods, notwithstanding the current, more unstable, status of nuclear waste. In Finland, one facility is under construction. Another is planned to house Sweden's nuclear waste in Östhammar, the municipality that is home to the Forsmark nuclear power plant that originally detected radioactivity in the air associated with the Chernobyl nuclear accident.[8] But Yucca Mountain has been all but halted and abandoned.

Yucca Mountain was originally scouted as a site for high level waste storage in 1978 by the Department of Energy. While the site was one of ten originally included in a 1985 preliminary report to Congress, in 1987 Congress amended the Nuclear Waste Policy Act directing the DOE to only study Yucca Mountain, partially due to its location in close proximity to the Nevada Test Site, where many nuclear weapons tests had been conducted in the preceding decades. Although a date in 1998 was set as the target for accepting the first shipments at Yucca Mountain, the project

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[8] Deutsche Welle (www.dw.com), "Sweden Plans First Ultimate Storage Site for Nuclear Waste | DW | 22.03.2011," DW.COM, accessed April 24, 2020, https://www.dw.com/en/sweden-plans-first-ultimate-storage-site-for-nuclear-waste/a-14935527.

was continually delayed by legal challenges and concerns regarding transportation. The project was officially recommended by the George W. Bush administration with the signing of House Joint Resolution 87 on July 23, 2002.[9] At that point, the site's first official shipment was slated for 2017, but after the Democratic victory in the U.S. Senate in the midterm elections of 2006, the newly instated Senate Majority Leader Harry Reid (D-NV) vowed to fulfill a long standing campaign promise to his constituents to block the project, saying "Yucca Mountain is dead. It'll never happen."[10] The Department of Energy submitted a license application to open Yucca Mountain in June 2008, reflecting the state of readiness so received spent nuclear fuel that the site had achieved, but the application was never given serious consideration.[11] Subsequently, then-candidate Barack Obama promised to end the project but was pre-empted by Congress, who passed a new budget that allocated no funding to Yucca Mountain.[12]

The Obama administration finally declared the project "'unworkable' in 2011."[13] In 2013, the U.S. District of Columbia Court of Appeals cut off a key source of funding for the project, shutting down the Nuclear Waste Fund, a program where customers whose electricity was derived from nuclear fuel paid a "mill fee" 0.1 cents/kWh.[14] The fund had collected $31 billion at a rate of about $750 million a year, with $8 billion already spent, but without the additional fee, the entire prospect of handling nuclear waste became dependent on Congressional allocations.[15] Worse, by

[9] Statement by the Press Secretary: *President Signs Yucca Mountain Bill*, July 23, 2002.
[10] Michael Byrne, "Yucca Mountain Is Far From Dead," *Vice* (blog), October 18, 2014, https://www.vice.com/en_us/article/vvbybd/yucca-mountain-is-far-from-dead.
[11] "NRC: DOE's License Application for a High-Level Waste Geologic Repository at Yucca Mountain," accessed April 24, 2020, https://www.nrc.gov/waste/hlw-disposal/yucca-lic-app.html.
[12] Michael Byrne, "Yucca Mountain Is Far From Dead," *Vice* (blog), October 18, 2014, https://www.vice.com/en_us/article/vvbybd/yucca-mountain-is-far-from-dead.
[13] Mark Fahey, "How the Department of Energy Became a Major Taxpayer Liability," July 6, 2016, https://www.cnbc.com/2016/07/05/how-the-department-of-energy-became-a-major-taxpayer-liability.html.
[14] "Court Orders Halt to Nuclear Waste Fees - World Nuclear News," accessed April 11, 2020, https://www.world-nuclear-news.org/WR-Court-orders-halt-to-nuclear-waste-fees-2011134.html.
[15] "Court Orders Halt to Nuclear Waste Fees - World Nuclear News."

blocking the project, the Department of Energy was in violation of a contract signed with nuclear utilities to begin accepting nuclear waste in 1998, resulting in appeals and awards from the federal Judgement Fund totaling up to $30 billion by 2025.[16] The Blue Ribbon Commission on America's Nuclear Future was appointed to explore other potential sites to use instead of the already constructed repository, since even if the waste would not be stored at Yucca Mountain, a resolution to the *ex-ante* existence of nuclear waste was still necessary.[17] While the Trump Administration has made overtures to restart the process of opening the facility, the federal government's policy regarding Yucca Mountain and nuclear waste handling generally has been scattershot and unclear. On February 6, 2020, President Trump tweeted, "Nevada, I hear you on Yucca Mountain…my Administration is committed to exploring innovative approaches – I'm confident we can get it done!"[18] There have been overtures made that indicate the government wants to make progress on the site, but at the same time, the White House's 2021 budget will continue to allocate no funding for Yucca Mountain.[19]

Since the passage of the Nuclear Waste Policy Act, the state of Nevada has opposed the plan at all levels. Foremost, the state objects to storing highly hazardous materials on its territory particularly given that Nevada does not produce any civilian nuclear power. Citing a compromise deal to create two repository sites, one in the East and one in the West, the Nevada delegation points to the abandonment of the Eastern site and the decision to solely utilize the Yucca Mountain site as an attempt by the nuclear generating Eastern states like New York and Illinois to use Nevada

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[16] Fahey, "How the Department of Energy Became a Major Taxpayer Liability."
[17] "Blue Ribbon Commission on America's Nuclear Future Issues a Final Report," accessed December 3, 2019, https://www.csis.org/analysis/blue-ribbon-commission-americas-nuclear-future-issues-final-report.
[18] "Nuclear Waste Disposal: Why the Case for Deep Boreholes Is ... Full of Holes," *Bulletin of the Atomic Scientists* (blog), March 26, 2020, https://thebulletin.org/2020/03/nuclear-waste-disposal-why-the-case-for-deep-boreholes-is-full-of-holes/.
[19] "Trump Halts Support for Yucca Mountain, Nevada Nuclear Waste Dump," *Reuters*, February 7, 2020, https://www.reuters.com/article/us-usa-trump-nuclearpower-yucca-idUSKBN20101J.

as a “dumping ground” for their radioactive wastes. Nevada’s state legislature has passed a state law banning any shipment of high-level radioactive wastes into the state, governors have vetoed the Yucca Mountain plan consistently for decades, and the Nevada congressional delegation both in the U.S. House and Senate have consistently introduced legislation to reverse the plan and prevent nuclear waste from being stored in Nevada. This kind of action does not presuppose that Nevadans believe there is not a problem. There is broad acknowledgement that nuclear waste presents a policy deadlock that must be solved to guarantee the safety of Americans who may live near unsecured radioactive waste at nuclear power plants that may have been decommissioned decades ago. Nevadans simply oppose the storage of nuclear waste *at Yucca Mountain*. This type of argumentation is the famous NIMBY argument – *not-in-my-back-yard*. Everyone wants something to be done, they just don’t want to be the ones to do it.

Nevadans as well as many Americans are further opposed to the present plan to store nuclear waste at Yucca Mountain because there would need to be tens of thousands of shipments of nuclear waste by the Department of Energy along U.S. highways and railroads (see appendix figure 1 for a depiction of proposed nuclear waste routes as well as the number of casks that are estimated to pass through each state en route to Yucca Mountain). However, the DOE has taken extraordinary steps to ensure that the dry casks that nuclear waste is stored and transported in are safe, including “the 1970s impact and fire testing of spent fuel truck casks at Sandia National Laboratories, the 1980s regulatory and demonstration testing of MAGNOX fuel flasks in the United Kingdom (the CEGB “Operation Smash Hit” test), and the 1980s regulatory drop and fire tests conducted on the TRUPACT II containers used for [TRU shipments to WIPP].”[20] The dry casks are virtually indestructible and have been rated safe under many extreme accident conditions.

[20] Fred Dilger, Robert J. Halstead, and James D. Ballard. “Full-Scale Cask Testing and Public Acceptance of Spent Nuclear Fuel Shipments-12254,” WM 2012 Conference, February 26-March 1, 2012, Phoenix, Arizona, USA.

In 2018, Sandia National Laboratories put the casks through a "nuclear triathlon" where mock waste was transported 500 miles by truck, 10,000 miles by sea, and 4,000 miles by rail to get waste from Spain through Belgium to a testing center in Colorado.[21] And the reality is that thousands of nuclear waste shipments have already occurred over the decades, with the DOE estimating at least 25,400 shipments having already occurred, potentially as many as 44,400.[22] New container designs "go through a series of tests where they're dropped, lit on fire, and submerged in water before the NRC certifies them for use. None of these containers have leaked in over 40 years of transporting nuclear waste."[23]

And yet, the public does not accept these certifications. A University of Maryland Omnibus Survey found four "significant transportation related public perception risks," noting that "2/3 of the respondents felt that property values would be lowered as a result of transportation, approximately 70% of respondents expressed concern for terrorist attacks against shipments, the majority of respondents were unwilling to live near SNF transportation routes, and the majority of respondents always felt that the transportation of SNF was riskier than the transportation of industrial chemicals and volatiles like gasoline."[24] In an interview I conducted with Cara Clarke, VP of Communications for the Vegas Chamber, she expressed virtually the same concerns on behalf of Las Vegas businesses, reflecting the persistent lack of confidence in the safety of transporting nuclear waste.[25]

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[21] Rachel Becker, "Scientists Put a Nuclear Waste Container through a Demanding Trip to See If the Fuel Would Break," The Verge, August 3, 2018, https://www.theverge.com/2018/8/3/17648972/spent-nuclear-radioactive-fuel-transportation-cask-sandia-science-triathlon.

[22] "Enhanced Safety Record Report - Final Public Release," accessed February 4, 2020, https://www.energy.gov/sites/prod/files/2017/03/f34/Enhanced%20safety%20record%20report%20-%20final%20public%20release_0.pdf.

[23] Becker, "Scientists Put a Nuclear Waste Container through a Demanding Trip to See If the Fuel Would Break."

[24] Dilger et al. "Full Scale Cask Testing"

[25] Cara Clarke, Interview with Vegas Chamber by Ethan Gelfer, Phone Call, January 22, 2020.

In lieu of storing waste in a centralized repository, nuclear power plants in the United States have instead been forced to store their radioactive waste in dry cask storage after they have cooled down in the spent fuel pool on site by the reactors. This temporary solution carries two main implications. The first is that the nuclear energy companies remain on the hook for ensuring the safety of a fundamentally more dangerous form of nuclear waste storage, in particular due to its increased susceptibility to natural disasters and weather phenomena. The second implication is that the reactor operators have to maintain the site long past the designated service life of the reactor, indeed, even after the reactors themselves have been decommissioned, the operators still are responsible for the safety of the radioactive waste.

Although the cost of maintaining temporary storage at decommissioned nuclear power plants is covered by the federal judgement compensation fund, which is not subject to appropriation from Congress and can continue disbursing funds regardless of administration position, the cost of decommissioning the plants themselves necessitates a large pool of capital that nuclear utilities must be able to access at the end of the plant's life cycle. Decommissioning a plant requires several difficult and financially burdensome processes as laid out by the Nuclear Regulatory Commission, including the removal of fuel rods from the reactor into storage, taking steps to reduce residual radiation around the site, and removing other contaminants.[26] The nuclear utility continues to be accountable to the NRC for the entirety of the decommissioning project at any nuclear reactor at the end of its life, and until the process is completed, the reactor license is not terminated.[27] For this reason, many nuclear utilities run Nuclear Decommissioning Trusts (NDTs) separately from the federal Nuclear Waste Fund, maintaining a separate fund on their

[26] "NRC: Decommissioning of Nuclear Facilities," accessed April 24, 2020, https://www.nrc.gov/waste/decommissioning.html.
[27] "Decommissioning Nuclear Power Plants," Nuclear Energy Institute, accessed April 24, 2020, https://www.nei.org/resources/fact-sheets/decommissioning-nuclear-power-plants.

balance sheet to ensure that the utility will have appropriate capital to decommission a site at the end of its lifespan. The health of NDTs is essential to the health of the nuclear energy industry, as utilities need to be confident that they will not have to draw down capital from other sources to cover the potentially massive costs of decommissioning nuclear plants. NDTs allocate some funding earlier in the reactor's lifespan that is then invested in a portfolio of market exposures that are expected to appreciate to the value necessary to cover the cost of decommissioning by the time the funds are necessary – a fully funded NDT is equivalent to the net present value of the decommissioning cost. By 2017, NDTs reached an average funded status of 78%, up from 70% in the year before, mostly driven by strong market performance.[28] However, decommissioning costs by 2017 reached 181% of their 2008 levels, as much of the US fleet is aging and even the 20-year license extensions granted to many US reactors by the NRC are expiring in the next few decades.[29] More importantly, new capital contributions have decreased over 40 percent over the same period, from around $560 million total contributions in 2008 to under $300 million by 2017.[30] In a market downturn, the funded status of NDTs will likely decrease, making the nuclear industry even less viable without a permanent solution to the waste problem.

Nuclear waste policy is certainly dependent on nuclear energy policy, but regardless of the status of nuclear energy in the future mix of U.S. electric generation, a policy is still required to manage the previously generated waste. Even if all nuclear power generation was shut down today, nuclear waste from half a century of civilian nuclear power usage would still need siting and permanent storage. However, if a positive permanent solution can be reached on nuclear waste policy, the case for continuing to utilize nuclear power for electricity generation would only be

[28] "Explore Nuclear Decommissioning Funding in Callan's Latest Study," Callan, October 29, 2018, https://www.callan.com/2018-nuclear-decommissioning-funding/.
[29] "Explore Nuclear Decommissioning Funding in Callan's Latest Study."
[30] "Explore Nuclear Decommissioning Funding in Callan's Latest Study."

strengthened. Nuclear power fulfills an important role that cannot be achieved with other renewables: it provides a reliable "baseload" power supply to the electricity grid. While other renewables like wind, solar, and hydropower fluctuate based on times of day or other factors, nuclear power plants provide a consistent, uninterrupted level of electricity to the grid at all times, closely approximating the capabilities of legacy plants like coal and natural gas-fired plants. In a portfolio of a US electricity generation mix, without fundamental changes to the mechanism by which electricity is supplied to the electric grid or currently infeasible advances into battery technology, nuclear power will remain a significant and essential source of electricity.

The research question for my thesis centers on the pathologies of nuclear energy from the perspective of industry insiders, researchers, the U.S. government, and the public at large. Given the *ex-ante* existence of highly radioactive waste, why is there broad opposition to the permanent repository at Yucca Mountain? I will attempt to fashion an answer to this question drawing on a multidisciplinary analysis of the adjacent issues that inform stakeholders' positions on nuclear waste policy writ large and on the question of the Yucca Mountain nuclear waste repository.

III. Literature Review

I rely on a wide breadth of literature for the basis of my thesis. Because I am synthesizing many disciplines, I encompass a spectrum of literature stemming from the fields of risk perception, sociology, political science, and politics as they relate to nuclear policy sentiments and actions.

i. *Psychology of Nuclear Waste Opinions*

One of the clearest voices on the intersection of trust and nuclear waste through the lens of risk perception and risk psychology is Paul Slovic and his co-authors. In a 1991 paper with James

Flynn and Mark Layman, *Perceived Risk., Trust, and the Politics of Nuclear Waste*, Slovic argues that the US Department of Energy and the Nuclear Regulatory Commission have been hampered in their efforts to open and monitor a high-level nuclear waste repository due to intense political opposition driven by negative public sentiments based on perceptions of risk.[31] He argues that the imagery of nuclear power as an apocalyptic weapon and the mishandling of radioactive waste from the national laboratories has contributed to an overall public perception that nuclear waste is inherently dangerous. Slovic and his co-authors conclude ultimately that the quest for a permanent repository (i.e. the Yucca Mountain facility) should be postponed in favor of employing on-site dry cask storage until the political and social issues can be solved.[32] In particular, Slovic argues that there have been a number of developments that have negatively impacted the possibility of solving the problem of nuclear waste storage. First, opposition has increased in the State of Nevada; second, the DoE admitted dissatisfaction with their original assessment of Yucca Mountain and would start over with a better integrated study; and third, the National Research Council's Board on Radioactive Waste Management strongly critiqued that program. The public is furthermore concerned about the possibility of importing nuclear accidents to a new site, including accidents in transportation as well as storage. Nevadans overall were also opposed to the site and displayed an overwhelming distrust for the DOE and the NRC. Finally, Slovic touches on the psychology of nuclear power by highlighting the overwhelming public association of radioactivity and nuclear energy with negative consequences and overall danger.

Slovic updates his demonstration of negative public opinion and association with nuclear energy after the Fukushima disaster in Japan in 2011. He writes of a perception gap of radiation

[31] P. Slovic, J. H. Flynn, and M. Layman, "Perceived Risk, Trust, and the Politics of Nuclear Waste," *Science* 254, no. 5038 (December 13, 1991): 1603, https://doi.org/10.1126/science.254.5038.1603.
[32] Slovic, Flynn, and Layman, "Perceived Risk, Trust, and the Politics of Nuclear Waste."

risk, where the public sees nuclear power and nuclear waste as being high-risk forms of nuclear power and X-rays and naturally occurring radon as lower-risk forms, but nuclear experts see the reverse.[33] He highlights the problems of communication that still exist from experts to the lay public on the comparative risks of different radioactive products. The public's perception of nuclear energies is driven by the framing of the different uses of radioactivity: because X-rays are presented as a medical benefit, the public generally receives it as a more positive and less dangerous radioactive product.

James Flynn develops a structural model to relate public perceptions of risk, trust in risk management, and potential economic impacts of the repository program. He uses the 1989 survey of Nevada residents as the dataset for testing this model and finds that even though the public accepts that the repository will be an economic boon, the economic benefits do not correspond to a positive association with the repository, but instead the acceptance of the site is a matter of trust.[34] Because the perceptions of the experts involved with nuclear energy are opaque and negative, the public does not ascribe an aura of safety to the nuclear waste repository. People also perceived the probability of shipment sabotage as much higher than the calculated risk. The most important determinants of public opposition to the repository in Nevada are shown to be the dual parameters of trust in repository management and the perceived risk heuristic. Nevadans oppose the repository because they do not see the project managers as trustworthy and view the risks associated with opening the repository to be unacceptable.

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[33] Paul Slovic, "The Perception Gap: Radiation and Risk," *Bulletin of the Atomic Scientists* 68, no. 3 (March 2012): 67–75, https://doi.org/10.1177/0096340212444870.

[34] James Flynn et al., "Trust as a Determinant of Opposition to a High-Level Radioactive Waste Repository: Analysis of a Structural Model," *Risk Analysis* 12, no. 3 (September 1992): 417–29, https://doi.org/10.1111/j.1539-6924.1992.tb00694.x.

The nuclear imagery that Slovic references as part of public associations with nuclear energy is discussed in Spencer Weart's book *Nuclear Fear: A History of Images.* Weart highlights the dual promise of radioactivity and nuclear power, the ultimate source of energy that can be a panacea but also carries a host of terrifying potential consequences. Since the discovery of radiation in the late 19th century, the positives of nuclear energy – a cheap, relatively clean, permanent source of essentially unlimited power - have been quickly supplanted with the negative consequences – destruction, cancer, and waste. And what's more, the fear of nuclear energy overwhelms the positive implications of it, because even if there is a veneer of control, the apocalyptic, deified nature of nuclear energy implies that no human efforts to control it can be fully successful. Weart demonstrates the vastly negative associations that the public has accumulated of nuclear power.[35]

The discovery of nuclear power presented two paths forward: either towards a utopian society that could derive its entire energy needs from the splitting of atoms and could achieve the mythical "white city" that scientists hoped would bring an end to all suffering, or its dystopian antipode – the total destruction of humanity on Earth through the devastating power of the atom.[36] Radiation was a relatively publicized concept throughout the first half of the 20th century and the seemingly magical conversion of one element into another were semiotically related in social and cultural consciousness to *transmutation* – the alchemical, biblical story of the passage from devastation to rebirth. Weart demonstrates that in the first half of the 1900s, images that had been rooted in social consciousness through alchemical transmutation became associated with radiation, those "uncanny rays that brought hideous death or miraculous new life; with mad scientists and

[35] Spencer R. Weart, *Nuclear Fear: A History of Images* (Cambridge, Mass: Harvard University Press, 1988).
[36] Spencer R Weart, *The Rise of Nuclear Fear* (Cambridge, Mass; London: Harvard University Press, 2012).

their ambiguous monsters; with cosmic secrets of death and life; … and with weapons great enough to destroy the world…"[37]

Unfortunately, the world was introduced first to the absolute power of nuclear *weapons* when the United States deployed its atomic bombs against Japan during the closing days of the Second World War. The repercussions of the bomb in social consciousness meant that nuclear power would always be slanted towards the fear of apocalypse: as sociologist and former University of Chicago professor Edward Shils noted, atomic bombs made a bridge across which apocalyptic fantasies, marching from their refuge among fringe groups, invaded all of society.[38] The editorialist Norman Cousins remarked, "The fear of irrational death… has burst out of the sub-conscious and into the conscious, filling the mind with primordial apprehensions."[39] Ultimately, Smith observed that "nuclear energy was conceived in secrecy, born in war, and first revealed to the world in horror. No matter how much proponents try to separate the peaceful from the weapons atom, the connection is firmly embedded in the minds of the public."[40]

This kind of fear and revulsion is clearly demonstrated in the manner in which the public refers to Yucca Mountain as opposed to experts. Expert dialogue about the site refer to it as the "Yucca Mountain High-Level Nuclear Repository," or variations of the same, while the public by and large in Nevada refers to the site as the Department of Energy's "nuke waste dump."[41]

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[37] Weart, *Nuclear Fear*.
[38] Weart, *The Rise of Nuclear Fear*.
[39] Norman Cousins, *Modern Man Is Obsolete* (New York: Viking, 1945).
[40] K.R. Smith, *Energy Environment Monitor* 4, no. 61 (1988).
[41] The Associated Press, "Poll Shows Nevadans' Views on Yucca Mountain Nuke Dump," accessed February 5, 2020, https://www.tahoedailytribune.com/news/poll-shows-nevadans-views-on-yucca-mountain-nuke-dump/.

ii. *Long-Term Safety*

Another problem that is endemic to the nuclear waste question is the difficulty of ensuring that a repository or final disposal site remains undisturbed for tens of thousands of years, until all the nuclear waste contained within has decayed past the point where the radioactive elements would pose a danger to living beings. Part of the search for such assurances is geographic and topographical in nature. In verifying the viability of the Yucca Mountain site for a nuclear repository, the DOE spent billions of dollars on extensive scientific analysis on the geography of the area. Ultimately, Yucca Mountain was chosen because it is relatively remote, in a desert region – making it far from major water sources – and "engineered barriers can be designed to contain waste for thousands of years, and the natural barriers can delay and dilute any radioactive material that migrates from waste packages."[42] The Nuclear Regulatory Commission concluded that the annual probability of a major earthquake that could disturb the nuclear waste at Yucca Mountain was about one in a million.[43]

The other side of keeping the area undisturbed, however, is the human side. Humans are naturally curious and also seek resources, and on the time scales nuclear waste remains active, the successors to current human civilization would also need to be considered. The site would have to communicate a message to beings that may or may not understand radioactivity that under no circumstances should they disturb the site. There are several suggestions on how to approach this issue. One is proposed by Sebastian Musch, who argues for the creation of an Atomic Priesthood to safeguard the knowledge of the dangers associated with nuclear waste through the generations and past the capability to pass down language, signs, and indeed transcending our own cognitive

[42] Senator James M Inhofe, "Yucca Mountain – The Most Studied Real Estate on The Planet," n.d., 25.
[43] "Yucca Mountain Seismic Hazard Analysis," accessed February 4, 2020, https://www.nrc.gov/docs/ML1715/ML17150A114.pdf.

framework.[44] The problem with this idea is that any religion is relatively uncontrollable in the long term, subject to schisms and social change. But Musch highlights that nuclear power is in effect a Faustian bargain that presents both utopian and dystopian outcomes. It is a potentially unlimited source of energy, but the waste that is created requires an active solution and its safeguarding will be a continuous process for millennia. Therefore, nuclear waste constitutes an "eternal commitment, which can only be dealt with if we presume the succession of a perpetual social apparatus."[45] Because the longest-lasting institutions in human history have been institutes of higher learning like universities and religious institutions, they are the natural channel through which the best hope can be found for transmitting the message of safeguarding nuclear waste through generations and geological time scales. But technology as a whole presents a Faustian bargain whereby the advantage humans derive from technology also has the potential to destroy, and although the balance can shift between the two forces, it is never one sided.[46] Since humans, and particularly, for my project, the United States, have undertaken the endeavor of unlocking nuclear power, there is now no option but to handle its consequences. Like Pandora's box, radioactivity cannot be returned to the state it came from. It is on us, rather, as a country and as a people, to solve the associated problems with utilizing this source of electric capability.

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[44] Sebastian Musch, "THE ATOMIC PRIESTHOOD AND NUCLEAR WASTE MANAGEMENT: RELIGION, SCI-FI LITERATURE, AND THE END OF OUR CIVILIZATION: With Sebastian Musch, 'The Atomic Priesthood and Nuclear Waste Management: Religion, Sci-Fi Literature, and the End of Our Civilization'; S. Jonathon," *Zygon*® 51, no. 3 (September 2016): 626–39, https://doi.org/10.1111/zygo.12268.

[45] A. M. Weinberg, "Social Institutions and Nuclear Energy," *Science* 177, no. 4043 (July 7, 1972): 27–34, https://doi.org/10.1126/science.177.4043.27.

[46] Dale S Niederhauser, Joanne K Olson, and Michael P Clough, *The Nature of Technology Implications for Learning and Teaching* (Rotterdam: SensePublishers : Imprint : SensePublishers, 2013), 186, https://doi.org/10.1007/978-94-6209-269-3.

iii. *Divide between Experts and the Public*

Finally, to understand the large gulf between nuclear experts and the lay public and why that gives rise to a differentiation in perceptions on nuclear waste policy including storage, I turn to Hugh Gusterson's ethnography of the Lawrence Livermore National Laboratory in *Nuclear Rites: A Weapons Laboratory at the End of the Cold War*. Gusterson identifies secrecy, regimentation, and classification as a means of delineating the work of the laboratory as separate, worth concealing, and not accessible to the general population. The weapons scientists are differentiated from their non-cleared counterparts by different colored tags that give them varying access to parts of the laboratory, and entitle them to knowing different levels of national secrets.[47] Although Gusterson does not explicitly discuss nuclear waste, this social separation that is engendered through the nuclear research field can be seen as a contributor to the different perceptions of nuclear power and nuclear waste depending on if one is a nuclear scientist or a member of the general population, who are likely to be less informed and come to different conclusions than professionals. As a result, the public may come to oppose a nuclear waste site like Yucca Mountain even in the face of expert approval of it, because their access to information is different.

Trust mediates this relationship: i.e., if the public trusts nuclear experts, they will be more likely to acquiesce to the professional opinion on the situation, but as the previous works I have discussed elucidate, public trust in nuclear experts has seriously deteriorated and as a result the public is not likely to accept on face value what they are told by nuclear experts, but at the same time, because the subject is so technically complicated, the public is not likely to come to the same

[47] Hugh Gusterson, *Nuclear Rites: A Weapons Laboratory at the End of the Cold War* (Berkeley: University of California Press, 1996).

conclusions as nuclear experts even if they do their own investigation of the issue. Previous issues with nuclear power have colored the subject to such a degree that they have become shorthand for a general *a priori* skepticism of the nuclear field that prevents segments of the public from easily accepting a solution like Yucca Mountain, a program whose safety is underpinned by expert consensus. A solution like Yucca Mountain may be perceived as a high risk solution to the nuclear waste problem even with the knowledge of the background to why stakeholders like the Department of Energy and NRC are advocating for the implementation of the nuclear waste repository, because prior beliefs color risk perceptions.

Slovic has demonstrated that much opposition to the nuclear waste repository at Yucca Mountain is derived from distrust of the DOE. Starr argues that "acceptance of any risk is more dependent on public confidence in risk management than on the quantitative estimates of risk."[48] Slovic explains that the loss of confidence in the DOE can be explained by the social psychologically confirmed folk wisdom that trust is lost very quickly and is slowly (if ever) regained. He writes, "A single act of embezzlement is enough to convince us that our bookkeeper is untrustworthy. A subsequent opportunity to embezzle that is not taken would likely do little to reduce the degree of distrust. Indeed, 100 subsequent honest actions would probably do little to restore our trust in this individual."[49] The embezzlement equivalent for the DOE and nuclear waste is the mismanagement of legacy sites like Hanford and the Savannah River Site, locations where the Manhattan Project derived plutonium for the *Fat Man* atomic bomb dropped on Nagasaki, both of which are still highly contaminated with radioactive elements and the cleanup of which consumes a significant portion of the DOE annual budget. The department did not disclose the level of contamination at these sites until the effects became clear; at the Savannah River Site, it

[48] C. Starr, *Risk Analysis* 5, no. 97 (1985).
[49] Slovic, Flynn, and Layman, "Perceived Risk, Trust, and the Politics of Nuclear Waste."

was not until the local population started experiencing highly elevated incidences of cancer that the DOE acknowledged that it had been contaminated.[50]

Lawless develops a model to understand the tradeoffs between risk perceptions and determinations by an organization: $\Delta v \Delta K \approx c \approx \Delta E \Delta t$. Δv represents the uncertainty in the execution of a defensive strategy, ΔK is the uncertainty in the belief or strategy to defend an organization, ΔE is the uncertainty in the energy expended to execute a defensive strategy, and Δt is the uncertainty in the time to execute a defensive strategy.[51] With reference to nuclear waste, Δv would represent the uncertainty in executing the Yucca Mountain project, ΔK is uncertainty in the Department of Energy's strategy to implement the permanent repository solution, Δt represents the uncertainty in the time to conduct the project, and ΔE represents the uncertainty in political capital exerted in defense of the project. The left side of the equation "indicates that the greater the focus brought to bear on a problem, the more the focus will be executed; alternatively, from the right side, the more energy available to attack a problem, the more quickly a solution will be detected."[52] Lawless conducted a pilot study to test this relationship using the DOE's Citizen Advisory Boards (CAB's) to provide advice on cleaning up the contamination at its legacy sites. The experiment tested whether majority rule decisions would be more effective than cooperative-based solutions. The results of a chi-square test found that the majority rule decisions were found to be significantly more practical than the cooperative group ($\chi^2(1) = 4.12$, $p < .05$). In other words, the solutions that were arrived at by an up-or-down vote were found to be significantly more practical than those derived from unlimited community input. The problem with this result, of course, is that the

[50] W F Lawless et al., "The Reduction of Risk Perception: Consensus-Making versus Truth-Seeking," 2006, 16.
[51] Lawless et al.
[52] Lawless et al.

determination approach where the DOE pursues a majority rule solution is exactly what has been used at Yucca Mountain, with disastrous results in terms of state support for the plan in Nevada.

The public perceives different risks as more salient than experts. While the DOE is confident that shipment of nuclear waste to a centralized repository is eminently safer than storing the dry casks at their interim sites by the reactors where the fuel rods were used, the public judges the risks of accident, terrorism, or leaks during transportation of nuclear waste to be greater, perhaps at least partially due to a lack of understanding of the status quo. In an interview I conducted with Cara Clarke, the Vice President of Communications for the Vegas Chamber, she expressed the views of the chamber of commerce that dovetailed with the public perception of nuclear waste. She told me that transportation presented a safety concern, and if the repository were placed at Yucca Mountain, in the Western half of the United States, the route that most nuclear waste would need to traverse would be longer, leading to a greater opportunity for accident and terrorism. She summed up, "Trains can derail, trucks can crash, etc. It's not a question of what if, it's a question of when and to what extent. There needs to be a solution to nuclear waste storage but the longer the route it has to take, the riskier it gets. Finding places adjacent to the waste or states that want it and have the infrastructure as well as the desire to repurpose or store would be preferable."[53] The gap between expert and public opinion is vast, and my thesis provides some indications of the correlates of public opposition. Even if experts do not concur with public concerns about proposed nuclear waste policy, ultimately the public's concerns outweigh expert opinions, since the politics of the project supersede its supposedly objective benefits. If the project is politically infeasible, as it was under the Obama administration, or if not enough political capital is devoted to advocating a defense of the proposed expert solution, as seems to be the case under

[53] Cara Clarke, Interview with Vegas Chamber by Ethan Gelfer.

the current administration, the public's view of the policy will dominate. The status quo will be preserved, and indeed, it is clear that throughout the more than four decades during which the Yucca Mountain permanent repository has been under consideration, the public has exerted more influence over its progress than expert opinion. Until a concurrence is achieved between the Department of Energy's plan, experts, nuclear stakeholders, and the public, the status quo will not change.

Finally, a 2015 analysis by Matthew Nowlin demonstrated that the standard knowledge deficit model does not apply to the Yucca Mountain issue. The knowledge deficit model suggests that the different opinions between experts and the public can be bridged by providing information to the public. However, Nowlin found that "respondents did not update their priors or process information in an unbiased way, but rather that Democrats and Republicans varied in the weight they attached to the information and in their overall support for Yucca Mountain."[54] Although both Democrats and Republicans demonstrated some updated views based on the information they received, the information access was only helpful in reducing a small part of the gap between experts and the lay public. The contribution that I make is to isolate for the demographic predictors of support or opposition for the project, and to identify potential correlates of support.

The overall consensus in the literature is to point to the wide gulf between what experts at the Department of Energy and other agencies say and how they feel about the Yucca Mountain project and the public's aversion to those opinions. The DOE has lost credibility in the eyes of the public, who do not trust the organization to implement sound, safe solutions to the nuclear waste problem. Particularly in Nevada, public opinion is divided on whether the site should be built in their state, but the DOE is not seen as authoritative on the issue. The root of the gridlock on the

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[54] Matthew C. Nowlin, "Partisan, Information, and Public Opinion about Yucca Mountain" (International High Level Radioactive Waste Management, April 12, 2015), https://www.matthewcnowlin.com/files/ans2015.pdf.

Yucca Mountain project, and on a cohesive nuclear waste policy in the United States, is that the public does not see eye to eye with experts. Unfortunately, the solution is not as simple in this case as it might be in other cases, where the knowledge deficit model predicts that sharing more information with the public might bridge the gap between expert and lay opinions. Instead, partially due to the long time horizon of the debate, because of the ossified opinions that have settled in all parties, and because the project invokes such primordial images, the gap in information may be bridged, or in some cases, may already not be so large, but the gulf in opinions remains there.

IV. Methods

I focus on investigating the politics, policy, and psychology of nuclear waste storage, particularly focused on the WIPP and Yucca Mountain designated deep geologic repositories for low- and high-level nuclear waste. I use a mixed-methods approach to interrogate the roots of the issues at stake and deploy multiple strategies to formulate a policy recommendation that may present a long-term solution.

i. *Comparative Analysis of Nuclear Waste Storage Sites*

I first use a historical research method to discuss the landscape of nuclear waste policy. The US has a long history of different approaches to handling waste, and there are differences in how nuclear waste is handled between civilian sources of nuclear waste and military sources. I first discuss the semantic treatment of nuclear fuel as being seen as either spent or used in the United States and other countries like France, respectively. Used fuel semantic treatment implies the possibility of reusing, recycling, or otherwise repurposing fuel that has already provided a supply of radioactive nuclear energy to a reactor, whereas spent fuel treatment implies that there is nothing to salvage, and once used in a reactor, fuel rods need only to be protected from leaking radiation for the duration of their radioactive lifespan. Focusing on civilian power, I compare the Yucca Mountain project timeline and experience with two other nuclear waste storage projects. The first is a high-level nuclear waste repository that is slated to be the first of its kind to actually begin accepting shipments of nuclear waste: the Onkalo nuclear waste facility on the western coast of Finland. The second is a low-level nuclear waste storage facility that has been running since the 1990s: the Waste Isolation Pilot Plant, or WIPP, in Carlsbad, New Mexico. I discuss whether the status quo policy of centralizing all high-level waste in a single repository is an appropriate solution and review the functionality of the site.

The United States has engaged in a relatively opaque method of approaching the nuclear waste problem. Throughout the nuclear age, the Department of Energy and other agencies have generally made use of federal lands and unilateral actions blessed by the President or Congress to take action on nuclear waste transportation and storage. This is particularly the case with military-produced nuclear waste and is partially a legacy of the original generation of waste in the Manhattan Project, where any concerns about long term management were overruled by the military expediency of creating the bomb. I will use this comparative method to see whether the DOE has erred in its treatment of civilian nuclear waste similarly to the military waste in terms of its handling and lack of input from the public. Furthermore, nations like Finland, who do not have a nuclear weapons program, may present a model for how to deal with waste that is purely generated by civilian uses.

ii. *Changing Public Opinion Trends*

The second cut of my research design consists of a trend-based analysis of public opinion surveys on nuclear energy, nuclear waste, and thoughts on the Yucca Mountain facility in particular. In particular, I look to discuss the changes in historical levels of support for the site across different population subsets. I use 2008-2015 county-level data from Churchill County, NV, and 2017 state-level data for Nevada. I supplement the more recent data points with two past public opinion surveys conducted in the 1990s. The first survey, from 1991, conducted by James Flynn et. al., polled a representative sample of 2,500 respondents on a battery of questions regarding their perceptions of the risks and benefits associated with a nuclear waste repository, their support or opposition for the DOE repository program, their trust in the ability of the US Department of Energy to manage the program, and their views on a variety of other issues pertaining to radioactive waste disposal. The second survey, conducted by the Ipsos Public Affairs group in March 2002, polled a representative sample of 1000 respondents on their initial levels of support or opposition for the Yucca Mountain project. The survey continued by presenting respondents with statements that could be made to bolster the arguments for and against the repository, and asked respondents to evaluate whether those standards made them more or less likely to support the repository on a Likert scale.

iii. *Correlates of Support for Yucca Mountain*

For the third cut of my research design, I turn to a quantitative analysis of survey data. I utilize a 2017 public opinion poll from the Mellman Group conducted for the newspaper *The*

Nevada Independent.[55] This survey polled a representative sample of 600 likely voters statewide in Nevada, conducted in January 2017, with a margin of error of +/-4% at a 95% confidence level. Question 14 in the survey asked respondents, "As you may know, there has been renewed discussion about government plans to store nuclear waste at Yucca Mountain in the Nevada desert. I am going to read you what some people are saying about this, and then ask you whether you favor or oppose putting a nuclear storage facility at Yucca Mountain."[56] Respondents were then presented with a positive statement: "Supporters say that the Yucca Mountain program can help develop Nevada's economy and create thousands of new jobs," and a negative statement: "Opponents say that transporting and storing nuclear waste is dangerous, and Nevada shouldn't be our country's nuclear waste dumping ground," in rotation.[57] Respondents were asked to rate their level of support for the Yucca Mountain plan on a Likert scale. The survey results then interacted the responses collected on this question with respondents' demographic data including sex, age, race, and political party affiliation to produce crosstabulations of the results.

A chi-square analysis of a crosstab is a special case of a logistic regression with a dichotomous independent variable as well as dependent variable - $[\widetilde{\chi^2} = \frac{1}{d}\sum_{k=1}^{n}\frac{(O_k - E_k)^2}{E_k}]$. In order to determine the strongest predictors of support or opposition for the Yucca Mountain Repository, I utilized the crosstab information from this survey. I estimated a chi-square statistic for the 1x1 binomial distributions of the categorical variables such as gender and conducted chi-square tests with higher degrees of freedom for variables like age, with more levels of analysis. The limitation of this analysis, however, is my access to raw data.

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[55] "The Independent Poll: Full Results and Crosstabs," accessed February 5, 2020, https://thenevadaindependent.com/article/independent-poll-full-results-crosstabs.
[56] *The Nevada Independent.* The Mellman Group: January 2017, Nevada Statewide Survey. Washington, D.C., accessed February 1-April 24, 2020.
[57] Ibid.

In lieu of individual-level data to conduct logistic regression analysis, I leaned on the Pearson chi-square test of independence to determine if the variation observed in demographic characteristics reported in the crosstabs were significant. I calculated a chi-square statistic for selected variables in the data set and considered whether to reject the null hypothesis at $\alpha = 0.05$, 0.01, and 0.001. Based on the significance levels of the relationship between demographic independent variables like race, gender, and party affiliation, I was able to identify the core metrics by which it is possible to predict whether an individual would be more likely to support or oppose the project. Identifying the groups that are significantly more likely to oppose the project is a key step on the road to progress in developing a functional nuclear waste policy. The Department of Energy, the US government, and the other stakeholders involved in the Yucca Mountain project do not need to expend extra energy and resources on educating a public that has already been convinced. Instead, the arguments that have already been made must be modified with respect to a different audience, an audience that is more recalcitrant and disagrees with the conclusions that stakeholders would like to make regarding Yucca Mountain. My analysis demonstrates possible ways to create groupings of opponents that can be utilized to develop a bespoke argumentative and persuasive approach to win over support from the large segment of the population that as historically opposed the project.

iv. *Limitations*

Nuclear waste storage has been a hotly contested topic for decades, but analyses have not been conducted to determine the correlates of support or opposition outside of the risk psychology and risk perception work done by Paul Slovic, James Flynn, and several others. Most of the public opinion polling that has been done by news companies and the State of Nevada do not make all of their data readily available, so a major limitation of this analysis is that much of the individual level data is difficult to mine, and because there is a dearth of analysis that has been done on this question, the design of the study is fairly limited. I have limited the discussion of the correlates of support to the 2017 study, and in that analysis, I am relying on the crosstabulation information in lieu of a full logistic regression that would be possible only with individual-level data. If that data becomes available, the study will become more robust. Furthermore, the meta-analysis that is currently being conducted is less robust than it could be, since not all the survey questions line up and not all respondents in the different surveys fit similar profiles. It is theoretically possible to track the changes in support, as well as the stability of predictors of support, across the thirty years that the Yucca project has been debated, but with the data I currently have available, accounting for population fixed effects is very difficult due to the high variance between surveys, and therefore impacts the results of my analysis. Again, in this case, access to the Nevada state polling will greatly improve the robustness of my analysis, as this survey has been done since at least 2000 and has consistently asked a similar profile of respondents the same set of questions, thereby providing a potentially perfect dataset for meta-analytic intervention.

Another limitation of my analysis is that the correlates of support or opposition to Yucca Mountain have not been previously investigated. My project fills a gap in the literature by presenting an opportunity for policymakers to consider what groups of people may be more receptive to traditional arguments about Yucca Mountain and which groups need special attention in order to convince them to support the site. However, the lack of other work in the literature makes it more difficult to obtain robust data or design an appropriate model, so my work is limited by the lack of similar studies in the literature that may corroborate my work or provide a framework through which the issue can be analyzed.

V. Analysis

i. *Comparative Analysis of Global Nuclear Waste Policies*

There are two philosophies about the radioactive material in fuel rods that are no longer usable for commercial nuclear reactors. In the United States, the Department of Energy categorizes this radioactive material as *spent* nuclear fuel (SNF), that is, that it is no longer usable in any form. Consequently, US policy regarding SNF is disposal. The main project of the WIPP site as well as the Yucca Mountain site, should it open, is to safely lay the radioactive materials to rest and decay in the safest possible manner, without any interest in the material after it has passed its useful life in the reactor. Around the world, other countries have a different philosophy. Policy in several European countries, Russia, China, and Japan is to reprocess the fuel, which is categorized instead as *used*.[58]

Reprocessing recovers most of the plutonium generated by fission inside the fuel rods as well as much of the less immediately useful uranium, which increases the efficiency of the fuel rods from 4% to as much as 30%.[59] Recovering fissile material in this reprocessing manner creates a type of fuel called mixed-oxide fuel (MOX). MOX fuel is then used in the mix as part of the fuel for traditional light water reactors (LWRs) and water-water reactors (VVER) used in Russia. Advantages of reprocessing are to enhance national energy security and to reduce the amount of material that must be disposed as high-level waste to up to one-fifth of the original tonnage.[60] The United States, among the other countries that do not reprocess used nuclear fuel and instead treat it as spent, considers the economic disadvantage to overwhelm the efficiency and security advantages. While the cost of uranium ore is about $40/kgU, (a value that has remained virtually

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[58] "Processing of Used Nuclear Fuel - World Nuclear Association," accessed February 5, 2020, https://www.world-nuclear.org/information-library/nuclear-fuel-cycle/fuel-recycling/processing-of-used-nuclear-fuel.aspx.
[59] "Processing of Used Nuclear Fuel - World Nuclear Association."
[60] "Processing of Used Nuclear Fuel - World Nuclear Association."

the same today, with a spot price of about $25/lb) the cost of reprocessing today is about $1000/kgU.[61] However, because of the high cost of reclaiming unused plutonium and uranium fissile products from used fuel, reprocessing will not become profitable until the price of uranium exceeds $360/kgU, a price that is not likely to be achieved, even in the long term.[62] The breakeven price point for reprocessing is a function of the relative cost of reprocessing versus acquiring new radioactive fuel and also the yield potential of reprocessed fuel from a used rod. Because the cost of disposal remains about the same for direct disposal and for reprocessed fuel, even with the tonnage savings, the lifetime cost of reprocessing fuel remains prohibitive when compared to direct disposal.[63]

Another form of reprocessing is becoming more feasible, however. With the introduction of fast neutron spectrum reactors as part of the fourth generation of nuclear reactors, the used fuel from LWRs will be almost entirely reusable in the new type of reactor. By reprocessing fuel from its original LWR usage to be reused in fast neutron spectrum reactors, the fuel will be more eminently reusable. The new generation of fast reactors will be 100-300 times as efficient as the traditional LWR, meaning that the volume of waste created after reprocessing in this fourth generation reactor will be on the order of one thousand times smaller than under direct disposal.[64] Furthermore, these fast reactors will be able to burn all the actinides in the fuel mix, reducing both the volume of waste by orders of magnitude and reducing the decay time of the radioactive waste by orders of magnitude as well, from hundreds of thousands of years to just centuries. With US

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[61] Matthew Bunn et al., "THE ECONOMICS OF REPROCESSING vs DIRECT DISPOSAL OF SPENT NUCLEAR FUEL," July 1, 2003, https://doi.org/10.2172/822658.
[62] Matthew Bunn et al.
"Uranium Week: Paddling Fast To Go Nowhere," *FNArena* (blog), February 4, 2020, https://www.fnarena.com/index.php/2020/02/04/uranium-week-paddling-fast-to-go-nowhere/.
[63] Peter R. Orzag, "Costs of Reprocessing Versus Directly Disposing of Spent Nuclear Fuel," *Congressional Budget Office*, 2007, 14.
[64] "4th Generation Nuclear Power — OSS Foundation," Rich document, accessed February 7, 2020, http://www.ossfoundation.us/projects/energy/nuclear.

and multilateral technology advancements in these new reactors, reprocessing can become more feasible as an option over direct disposal. In other words, the problem of nuclear waste is temporally localized to the period when inefficient reactors dominate the civilian nuclear fleet. A shift to Generation IV technology promises to reduce the production of waste materials by several orders of magnitude, dramatically scaling down the rate of production of new nuclear waste. As long as the US fleet can move in the direction of upgrading reactors to these progressive protocols, the status quo problem of nuclear waste will not be significantly further exacerbated by further nuclear energy production. It also recategorizes the debate over nuclear waste storage from a constant necessity to something resembling a one-off, where a policy only really needs to be designed to store the current, comparatively massive quantity of unsecured spent fuel from the inefficient Generation II reactors. Going forward, most of the new waste created can be added to pre-existing repositories, or, if a new repository becomes necessary, the scale of the project will be much smaller, and with the precedent of an original permanent storage repository that is operational, should represent a trivial public policy challenge.

Outside of the issue of reprocessing and direct disposal, all countries will eventually need to find a permanent resting place for the unusable fuel at the end of its life cycle, regardless of whether it is regarded as spent or used. There is only one nuclear waste repository that is anywhere near completion, the Onkalo nuclear storage facility under construction on the island of Olkiluoto, off the western coast of Finland in the Baltic Sea.[65] The site was chosen to be as inconspicuous and uninteresting to future potential visitors and explorers as possible. The designers specifically "chose a location where the boring bedrock wouldn't interest future prospectors looking for metal, ore, or oil deposits. As the tunnels [in the repository, with caverns for the dry casks] are packed

[65] Story by Andrew Curry, "What Lies Beneath," *The Atlantic*, accessed February 5, 2020, https://www.theatlantic.com/magazine/archive/2017/10/what-lies-beneath/537894/.

full, they will be backfilled with absorbent clay blocks."[66] Once the repository reaches capacity, it will not require any further oversight, management, electricity, or human intervention whatsoever. It will eventually be grown over by forest and completely forgotten.

The two nuclear repository sites in the US demonstrate the importance of choosing a nondescript location. The WIPP site was placed in a salt deposit, a medium that is usually found in areas of low geologic activity (the risk of earthquakes or other movement disturbing the waste would be low). The properties of salt deposits also mean that the repository would essentially self-seal, entombing the waste without much difficulty.[67] The problem with using salt deposits as a location for a repository, of course, is that salt is a valuable mineral and therefore exposes the repository to potential disturbance by future explorers and prospectors. In order to deal with this potential issue, the DOE has turned to the cottage field of nuclear semiotics, developed in the 1980s, that considers solutions to ensure that future living beings that may not understand our language, symbols, or indeed, interpret the world in the same way at all, will be deterred from disturbing the site. Ideas have ranged from "fields of jagged, menacing stone spikes to cats genetically engineered to change color when exposed to radiation."[68] The cat idea is related to a proposition to create an Atomic Priesthood to mimic other religious institutions, the most long-lived institutions in human history, to pass down the information that this site is to remain undisturbed.[69] Nuclear semiotics, a nascent field that operates in time scales and futures beyond the capability of policy to necessarily reach, illustrates the magnitude of the nuclear waste policy debate and speaks to the permanence of a final decision. However, the fact that these discussions

[66] Curry.
[67] "Why Salt Was Selected as a Disposal Medium," US Department of Energy, accessed February 5, 2020, https://www.wipp.energy.gov/fctshts/salt.pdf.
[68] Curry, "What Lies Beneath."
[69] Musch, "THE ATOMIC PRIESTHOOD AND NUCLEAR WASTE MANAGEMENT."

are occurring suggests that if we build it, they will come; that is to say, there are scholars within the Department of Energy and even in the academy who can address the longevity of the nuclear waste problem outside the scope of public policy's ability to influence it. However, the shorter-term solution – actually designing a policy intervention to secure spent nuclear fuel and plan for the future of US nuclear energy consumption – is in the realm of public policy. Indeed, it is the catalyst for the rest of the managerial capabilities of the Department of Energy or any group tasked with protecting nuclear waste to get started; without an actual policy, without the *thing*, nothing can happen. For this reason, policy must come first, and the resolution of the debates over the morality of nuclear waste and its permanence affect the policy even if it ultimately will be relatively temporally constrained.

Of course, disposal in a potentially active area creates many more challenges than it solves, so the selection of Yucca Mountain is premised on similar assessments as the Onkalo facility. The principles were similar on a geographic basis, but the Finnish designers took an extra step that was not conducted at Yucca Mountain. Less scientific than politics and community based, the Onkalo designers "avoided the NIMBY problems that have stalled other projects by gathering consensus from the outset. Nearby communities were granted veto rights during the planning process… [the engineers] spent years organizing town halls, giving tours of mine shafts, and patiently answering questions about the potential risks of a direct meteor strike or future ice age."[70] A similar process was done at the WIPP site, which incurs far less resistance from the local community than Yucca Mountain. The community engagement program that persisted throughout the WIPP and Onkalo processes created a sense that the two facilities were part of the social and geographic fabric of the areas around them, whereas at Yucca Mountain, the site's lack of community input has failed to

[70] Curry, "What Lies Beneath."

create the sense that the repository is part of the social fabric of the area, particularly in the sense of the sense of disconnection that the site has incurred with Las Vegas, which lies less than a hundred miles away from Yucca Mountain. Despite the site's location on the same ground as another nuclear-minded project, the Nevada Test Site, which was the location of a preponderance of the US military's underground nuclear weapons testing throughout the Cold War, Yucca Mountain does not evoke the same sense of community pride as the test site did.[71]

ii. *Trend Analysis*

The history of Yucca Mountain is deeply extended. It was originally designated as a future site of high-level nuclear waste storage under the 1982 Nuclear Waste Policy Act.[72] Since that time, there has been staunch opposition to the site by elected officials in Nevada, including the Congressional delegation, governors, and the Attorneys General since 1982. For the meta-analysis, I use several historical surveys of Nevadans over the last forty years measuring public opinion on the site. The earliest survey that I use is Flynn et al., a 1991 survey of 2500 respondents questioned on their perceptions of the risks and benefits associated with a nuclear waste repository, their support or opposition for the DOE repository program, their trust in the ability of DOE to manage the program, and their views on a variety of other issues pertaining to radioactive-waste disposal.[73] The results were overwhelmingly negative.

[71] Interview with Cara Clarke.
[72] "Nuclear Waste Policy Act of 1987," Pub. L. No. 97–425, 41 U.S.C 10132(b)(2) (1982).
[73] Slovic, Flynn, and Layman, "Perceived Risk, Trust, and the Politics of Nuclear Waste."

Variable: State should stop project

Survey question 46: "The state of Nevada should do all that it can to stop the federal government from locating a high-level nuclear repository in the state."

	Strongly disagree	Somewhat disagree	Neutral	Somewhat agree	Strongly agree	Total
Number	23	17	7	23	221	291
Percent	7.9	5.8	2.4	7.9	75.9	100.0

Figure 1: Flynn et. al. "Trust as a Determinant"

A total of 83.8% of respondents agreed that Nevada should do all it can to prevent the opening of the repository, whereas only 13.7% disagreed.[74]

Survey question 21: "Suppose that the Department of Energy selected the Yucca Mountain site for the nation's first high-level radioactive waste repository, but it wouldn't be located there unless state residents voted in favor of it. If this were the case, would you vote for it, against it, or wouldn't you vote on this issue?"

	Yes	No	Total
Number	42	249	291
Percent	14.4	85.6	100.0

Figure 2: Flynn et. al. "Trust as a Determinant"

If the Yucca Mountain plan for disposing high level nuclear waste was put to a vote in Nevada, the result would be a resounding "no" in 1990.

The next survey was conducted by the Ipsos Public Affairs group in March 2002 (n = 1000). This survey found the public evenly split over the repository, with 47% in favor and 47% opposed. There was an enormous gender gap in this survey, with 58% of men supporting the repository and 56% of women opposing it. Race is another correlate of support, with 50% of white respondents expressing support compared to just 35% of minority respondents. Finally, party affiliation is also associated with support, with Republican respondents much more likely to support (65% support, 29% oppose) the project than Democratic respondents (36% support, 59% oppose) or Independent respondents (29% support, 59% oppose). Finally, Ipsos demonstrates that

[74] Flynn et al., "Trust as a Determinant of Opposition to a High-Level Radioactive Waste Repository."

there are key swing arguments for either side of the issue; after respondents heard arguments for or against the repository their opinions swung in the direction of the argument.[75]

	Much More Likely To Support	Somewhat More Likely To Support	Somewhat More Likely To Oppose	Much More Likely To Oppose	Total Support	Total Oppose
Statements Against the Repository						
Storage of nuclear waste at Yucca Mountain could lead to groundwater contamination	5	9	25	54	14	**69**
Nuclear waste would be transported to Yucca Mountain from storage sites all over the United States, which could mean that nuclear waste would be transported through your state	10	21	29	32	31	**61**
The Yucca Mountain is located just 90 miles from Las Vegas	9	19	24	32	28	**56**
Statements For the Repository						
Scientists say that Yucca Mountain's very dry climate, less than 6 inches of rainfall a year, and its extremely deep water table make Yucca Mountain a good choice for a national storage facility	22	41	16	14	**63**	30
Scientists say the rock will keep the waste sufficiently isolated for thousands of years so that the radioactive material will pose about the same risk or less risk of health effects to the public as that of unmined uranium ore	22	40	19	10	**62**	29
Some people say that it is better to have one central storage facility for nuclear waste rather than storing it in numerous facilities as is currently the case	26	33	18	14	**59**	32

Figure 3: Ipsos, "Yucca Mountain"

The results of the Ipsos survey, conducted twelve years after the Flynn survey, may suggest that there has been movement towards support for the repository, but the results still demonstrate that respondents are wary of nuclear waste and receptive to arguments against the repository. This variance in the result may also be the result of differing study design or question structure, or due to sampling differences as well. Slovic demonstrates the importance of *images* to respondents' opinions on the repository. A total of 3,334 respondents were surveyed in four areas: nationally,

[75] "Yucca Mountain," Ipsos, accessed February 2, 2020, https://www.ipsos.com/en-us/yucca-mountain.

Southern California, Nevada, and 802 residents in Phoenix, and asked to free-associate the concept of a nuclear waste repository.[76] The resulting 10,000 images produced were heavily associated with *negative consequences* and *negative concepts*. These two categories comprised 56% of the total number of images. The respondents did not simply respond negatively to the repository; the images given displayed a hostility and dread with regards to nuclear waste, a revulsion that exceeded simple disagreement. Weart demonstrates that conceptions of nuclear power are linked to the images percolating in our social and cultural consciousness. Atomic energy is heavily associated semiotically with transmutation; both employ the same beliefs and symbols and represent the passage through destruction to rebirth.[77] But instead of representing the potential for life and positivity, Weart links the bombing of Hiroshima and Nagasaki to a kind of 'original sin' for atomic energy, and as Smith observes, "Nuclear energy was conceived in secrecy, born in war, and first revealed to the world in horror. No matter how much proponents try to separate the peaceful from the weapons atom, the connection is firmly embedded in the minds of the public."[78] So nuclear power, and nuclear waste in particular, have a deep rooted negative connotation in the minds of the public that is directly related to fear of the consequences of a nuclear accident or attack.

The next study that I incorporate into my meta-analysis surveyed residents of Churchill County, NV. This study has been running annually since 2009, so there are several years of data for some of the survey questions and the most recent data available is from 2015. The trend towards more support for the repository is evident in this survey.[79]

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[76] Slovic, Flynn, and Layman, "Perceived Risk, Trust, and the Politics of Nuclear Waste."
[77] Weart, *Nuclear Fear*.
[78] K.R. Smith, "Perceptions of Risk Associated with Nuclear Power,". Energy Environment Monitor 4, 61-70 (1988).
[79] Churchill County Community Survey Results December 2015.

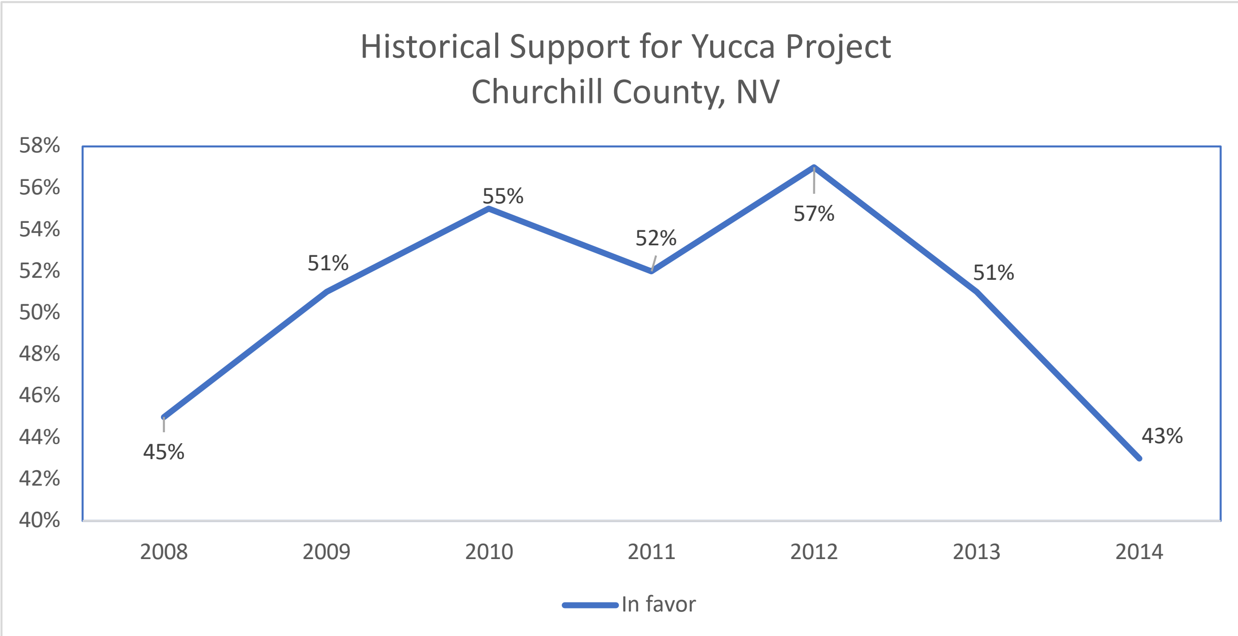

Figure 4: Churchill County Board of County Commissioners, Churchill County Nuclear Waste Project Office, "Churchill County Yucca Mountain Project Community Survey Results," 2015.

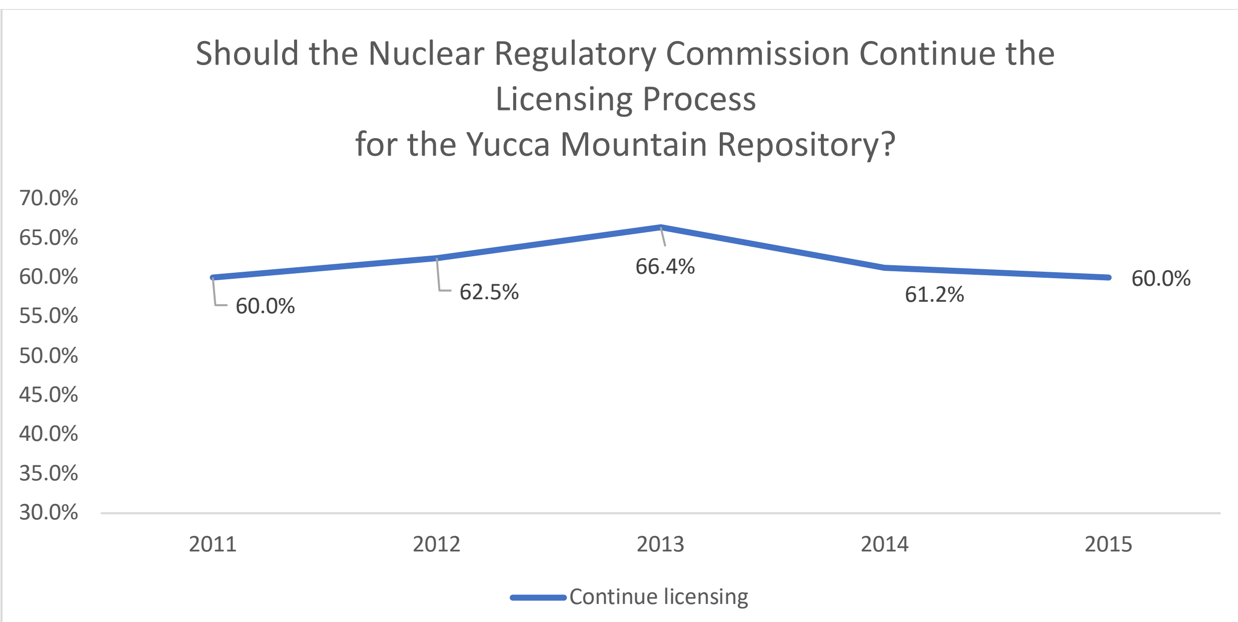

Figure 5: Churchill County, "Yucca Mountain Community Survey Results"

The results from this survey and from the past years of survey data are somewhat heartening, as they demonstrate a further move in support for the repository. The higher levels of support between 2010 and 2012 correspond with a greater focus on Yucca Mountain as the Obama administration moved to cancel the project. This trend may provide support for the information sharing theory; as more discussion on the Yucca Mountain project may lead more people to support it, and as it fades from the top of the political agenda, support also falls.

The most recent study I utilize in my meta-analysis is a 2017 survey from the Mellman Group.[80] The crosstabs from the survey results demonstrate correlates of support for the repository.

		PARTY REG			IDEOLOGY			PARTY ID/IDEOLOGY					GENDER		AGE					GENDER/AGE			
	TOTAL	DEM REG	REP REG	NPA/ OTH REG	LIB	MOD	CONS	LIB DEM	MOD/ CONS DEM	MOD INDEP	LIB/ MOD GOP	CONS GOP	MALE	FE- MALE	18-39	40-59	60+	<50	50+	YOUNG WOMEN	YOUNG MEN	OLDER WOMEN	OLDER MEN
TOTAL	600	240	240	120	194	178	228	143	67	84	55	165	296	304	159	201	240	246	354	117	129	188	166
	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
FAVOR, STRONGLY	140	35	83	23	31	36	74	19	7	19	16	54	94	47	36	50	54	50	90	16	34	30	60
	23.4	14.4	34.6	19.0	15.9	20.0	32.4	13.1	10.5	22.3	28.5	32.5	31.7	15.4	22.5	25.1	22.6	20.5	25.4	14.0	26.3	16.2	35.9
FAVOR, NOT SO STRONGLY	60	23	20	16	18	14	27	14	8	3	8	19	36	24	12	23	25	22	38	7	15	17	21
	10.0	9.7	8.5	13.4	9.3	8.1	12.0	9.7	12.4	3.2	13.9	11.7	12.3	7.7	7.5	11.4	10.4	9.0	10.7	5.9	11.7	8.8	12.7
OPPOSE, NOT SO STRONGLY	44	16	19	9	13	17	14	10	9	5	4	13	27	17	16	15	13	22	22	9	14	9	13
	7.4	6.8	8.0	7.2	6.8	9.4	6.3	7.0	13.3	5.7	8.0	8.1	9.1	5.7	9.8	7.6	5.6	9.1	6.2	7.5	10.5	4.6	8.0
OPPOSE, STRONGLY	304	148	99	57	114	93	97	89	35	50	23	69	115	189	77	92	135	117	187	65	52	124	64
	50.7	61.8	41.3	47.1	59.0	52.2	42.4	62.2	52.4	59.9	41.3	42.0	39.0	62.0	48.1	45.8	56.4	47.5	52.9	55.9	39.9	65.8	38.2
(NET)-FAVOR	200	58	103	39	49	50	101	32	15	21	23	73	130	70	48	73	79	72	128	23	49	47	81
-----------	33.4	24.1	43.1	32.5	25.3	28.0	44.4	22.8	22.9	25.5	42.3	44.2	44.0	23.1	30.1	36.4	33.0	29.5	36.1	20.0	38.0	25.0	48.6
(NET)-OPPOSE	348	165	118	65	127	110	111	99	44	55	27	83	142	206	92	107	149	139	209	74	65	132	77
------------	58.0	68.6	49.3	54.3	65.8	61.6	48.7	69.2	65.7	65.6	49.3	50.2	48.1	67.7	57.9	53.4	62.0	56.6	59.1	63.4	50.4	70.4	46.3
DK	51	18	18	16	17	18	16	11	8	7	5	9	24	28	19	20	12	34	17	19	15	9	9
	8.6	7.3	7.5	13.2	9.0	10.4	6.9	8.0	11.4	8.9	8.4	5.6	8.0	9.2	12.0	10.1	5.0	14.0	4.9	16.6	11.5	4.6	5.2

Figure 6: The Nevada Independent. The Mellman Group: January 2017, Nevada Statewide Survey. Washington, D.C., accessed February 1-April 24, 2020.

Republicans remain far more likely to support the repository than Democrats, with liberals and moderates heavily opposing the repository and conservatives largely split. The gender gap is also evident, as male respondents were split (44% favor, 48.1% oppose) whereas female respondents were strongly opposed (23.1% favor, 67.7% oppose).

[80] "The Independent Poll."

		ACA REPEAL				CLARK CO STADIUM TAX		DEATH PENALTY		YUCCA NUCLEAR STORAGE		MINIMUM WAGE		STATE CAPITAL		PARTY ID		
	TOTAL	REPEAL IMMEDIATELY, REPLACE LATER	REPEAL ONCE REPLACEMENT ANNOUNCED	TOTAL REPEAL	DON'T REPEAL	FAVOR	OPPOSE	KEEP	ABOLISH	FAVOR	OPPOSE	INCREASE MIN WAGE	KEEP AT CURRENT LEVEL	KEEP IN CARSON CITY	MOVE TO LAS VEGAS	TOTAL DEM	INDEP/ OTHER	TOTAL GOP
TOTAL	600	141	143	294	267	229	327	396	160	200	348	416	165	423	124	209	171	220
	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
FAVOR, STRONGLY	140	44	45	91	39	60	67	117	16	140	-	73	62	114	20	26	46	69
	23.4	31.2	31.3	31.1	14.6	26.0	20.5	29.7	9.8	70.1		17.5	37.5	26.9	15.8	12.2	26.8	31.5
FAVOR, NOT SO STRONGLY	60	12	17	33	24	28	30	42	13	60	-	38	21	43	14	22	11	27
	10.0	8.8	12.1	11.1	8.8	12.1	9.2	10.6	8.2	29.9		9.2	13.1	10.2	11.2	10.6	6.3	12.3
OPPOSE, NOT SO STRONGLY	44	5	14	20	22	16	24	26	13	-	44	31	12	33	7	19	8	18
	7.4	3.8	9.9	7.0	8.1	6.9	7.3	6.6	8.4		12.7	7.5	7.5	7.8	5.8	9.0	4.4	8.1
OPPOSE, STRONGLY	304	65	59	125	158	107	179	180	99	-	304	237	56	197	73	124	88	92
	50.7	45.7	41.0	42.6	59.2	46.6	54.6	45.5	61.7		87.3	56.9	34.3	46.7	58.9	59.0	51.7	41.9
(NET)-FAVOR	200	56	62	124	62	87	97	159	29	200	-	111	83	157	34	48	56	96
	33.4	40.0	43.3	42.2	23.4	38.1	29.7	40.3	18.0	100.0		26.8	50.6	37.1	27.1	22.8	33.1	43.7
(NET)-OPPOSE	348	70	73	146	179	123	203	206	112	-	348	268	69	230	80	143	96	110
	58.0	49.5	50.9	49.6	67.3	53.5	61.9	52.1	70.1		100.0	64.4	41.8	54.4	64.7	68.1	56.1	50.0
DK	51	15	8	24	25	19	27	30	19	-	-	37	12	36	10	19	19	14
	8.6	10.5	5.8	8.2	9.3	8.4	8.3	7.6	11.9			8.9	7.6	8.5	8.3	9.1	10.9	6.3

Figure 7: The Nevada Independent. The Mellman Group: January 2017, Nevada Statewide Survey. Washington, D.C., accessed February 1-April 24, 2020.

Table 17-1		Trump Job		Sandoval Job		Heller Job		Masto Job		Laxalt Job		NV Public School Quality				2015 School Law			Ed. Savings Accounts		
Yucca Support	Total	DT Pos	DT Neg	BS Pos	BS Neg	DH Pos	DH Neg	CCM Pos	CCM Neg	AL Pos	AL Neg	Gotten Better	Stayed same	Gotten worse	DK	Right Direc	Wrong Direc	DK	Agree sup	Agree opp	DK
Total	600	191	245	293	234	174	238	179	203	239	153	50	217	229	104	357	155	88	259	272	70
	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Favor, Strongly	140	61	35	81	47	62	47	24	60	48	36	10	53	53	25	71	47	23	77	47	16
	23.4%	32.1%	14.4%	27.7%	20.0%	35.9%	19.9%	13.4%	29.4%	34.4%	23.4%	20.7%	24.3%	23.0%	23.9%	19.8%	30.2%	26.2%	30.0%	17.2%	23.3%
Favor, not so strongly	61	21	21	31	24	18	22	20	18	13	15	5	24	23	8	42	10	8	29	28	3
	10.0%	11.1%	8.7%	10.6%	10.5%	10.4%	9.2%	10.9%	8.7%	9.1%	10.1%	10.5%	11.2%	9.9%	7.3%	11.6%	6.5%	9.3%	11.2%	10.3%	4.3%
Oppose, not so strongly	44	11	20	21	18	12	16	13	15	9	6	3	15	12	14	26	11	8	13	23	8
	7.4%	5.6%	8.1%	7.2%	7.6%	6.8%	6.9%	7.3%	7.5%	6.6%	3.8%	5.3%	6.9%	5.4%	13.8%	7.2%	6.9%	9.0%	4.9%	1.3%	11.9%
Oppose, strongly	304	82	147	141	126	73	131	104	97	63	77	27	108	121	48	191	76	37	122	154	28
	50.7%	43.0%	60.2%	48.3%	53.9%	42.1%	55.1%	57.8%	48.0%	45.3%	50.4%	53.2%	49.5%	53.0%	46.8%	53.5%	48.9%	42.3%	47.0%	56.8%	40.1%
Net - favor	200	82	57	112	71	80	69	44	77	60	51	16	77	75	32	112	57	31	106	75	19
	33.4%	43.2%	23.1%	38.3%	30.5%	46.2%	29.0%	24.3%	38.2%	43.4%	33.5%	31.2%	35.5%	32.8%	31.2%	31.4%	36.7%	35.4%	41.1%	27.5%	27.6%
Net - oppose	348	93	167	162	144	85	148	117	113	72	83	29	123	134	63	217	87	45	134	178	36
	58.0%	48.7%	68.3%	55.5%	61.5%	49.0%	62.0%	65.1%	55.4%	51.9%	54.2%	58.5%	56.4%	58.4%	60.5%	60.7%	55.8%	51.3%	51.9%	65.4%	52.0%
DK	51	16	21	18	19	8	21	19	13	6	19	5	18	20	9	28	12	12	18	19	14
	8.6%	8.1%	8.5%	6.3%	8.0%	4.8%	8.9%	10.6%	6.4%	4.6%	12.3%	10.3%	8.1%	8.8%	8.3%	7.9%	7.5%	13.3%	7.0%	7.1%	20.3%

Figure 8: The Nevada Independent. The Mellman Group: January 2017, Nevada Statewide Survey. Washington, D.C., accessed February 1-April 24, 2020.

On net, the results of this survey demonstrate an opposition to the site (33% net oppose, 58% net favor). When comparing the earliest survey from 1991 to this 2017 survey, there are some indications that public opinion is moving somewhat in the direction of support. Whereas 75% of respondents in Flynn strongly agreed with the sentiment that the state of Nevada should do all it can to oppose the plan to store nuclear waste at Yucca Mountain, by 2017 the opposition had dropped by 17 percentage points to 58%. The conclusion of my meta-analysis is that while progress is frustratingly slow, there is some long-term movement towards support for the site. This result may reflect a slight closing of the information deficit gap between the Nevada public and experts on nuclear policy.

iii. *Correlates of Support for Yucca Mountain*

In order to try to isolate the determinants of support or opposition of the Yucca Mountain site, I used the crosstabulation data from the Mellman Group 2017 survey to conduct a Pearson chi-square test that demonstrated whether the independent variables predict an individual's opinion on the Yucca Mountain project. My hypothesis was that gender, party, and race play a significant role in determining opinions, so I conducted three chi-square tests to test for their relationship.

The first test I conducted was to determine whether the divide in support between Democrats, Republicans, and independent/not registered voters was significant. The three independent variables I tested were party affiliations, and the dependent variable was support for the Yucca Mountain site.

Party ID							
	Dem	Rep	Ind	Marginals			
(net) Favor	58	103	39	200		n	548
(net) Oppose	165	118	65	348		df	2
Marginals	223	221	104			crit 0.05	5.991
						crit 0.01	9.21
						crit 0.001	13.816

Figure 9: Chi-Square Analysis of Party ID and support for Yucca Mountain

From the crosstab itself, it is clear that there is a difference in the ratio: Republicans are relatively split on the issue, while three times as many Democrats oppose the site as support it. But the significance of the party affiliation predictor can be assessed through the chi-square analysis ($\chi^2(1)$

= 39.63, p < 0.001). The relationship between party registration and support for the site is statistically significant at the 0.001 level, indicating strong explanatory power of the independent variables. This result demonstrates the significance of the divide between different parties on the metric of support for the site- as the other surveys used in my meta-analysis also find a wide gulf between Republicans and Democrats on support for the site. One possible explanation for this significant difference in support is that Republicans have more positive sentiments on nuclear energy broadly speaking than Democrats.[81]

I next looked at the explanatory power of gender. I tested whether the gender of the respondent could predict their opinions on the site.

Gender							
	Male	Female	Marginals				
(net) Favor	130	70	200			n	548
(net) Oppose	142	206	348			df	1
Marginals	272	276	548			crit 0.05	3.841
						crit 0.01	6.635
						crit 0.001	10.828

Figure 10: Chi-Square analysis of respondent gender and support for Yucca Mountain

Applying the Pearson chi-square statistic to the gender independent variable, the result is ($\chi^2(2)$ = 29.74, p < 0.001). This result indicates that the gender of the respondent is strongly predictive of their support or opposition of the site. Gender is broadly also a main divider between support and opposition of nuclear energy, presenting the largest gap in support between men and women. Women are far more likely to oppose nuclear energy, and therefore, the Yucca Mountain project, while men are more split on both energy and the project.[82]

[81] David Roberts, "Americans Love Clean Energy. Do They Care If It Includes Nuclear?," Vox, April 23, 2019, https://www.vox.com/energy-and-environment/2019/4/23/18507297/nuclear-energy-renewables-voters-poll.
[82] Roberts.

I then looked to the age statistic and investigated the explanatory power of age as an independent variable to predict support of the Yucca Mountain site.

Age							
	<50	50+	Marginals				
(net) Favor	72	128	200			n	483
(net) Oppose	209	74	283			df	1
Marginals	281	202	483			crit 0.05	3.841
						crit 0.01	6.635
						crit 0.001	10.828

Figure 11: Chi-Square analysis of respondent age and support for Yucca Mountain

The results of the Pearson chi-square analysis on the age independent variable yielded a result of ($\chi^2(3) = 69$, $p < 0.001$). Age presented one of the starkest dividers in levels of support, with almost inverse rates of support among people under 50 and people over 50. The significance of age as a predictor is difficult to reconcile with nuclear energy. Nuclear energy is one of the strongest potentials for clean energy in the portfolio of possible renewables, presenting an opportunity to source carbon-free energy at levels not currently possible with solar and wind power, and carrying the distinct advantage of allowing the electrical grid to function in the same manner as the status quo, without the need for large batteries or storage capabilities to prevent rolling blackouts. Although nuclear energy is a potent force for mitigating climate change, it is largely rejected by a younger generation of Americans, who may be sobered by the accident at the Fukushima Daiichi nuclear plant in Japan in 2011 and who largely prefer an emphasis on solar, wind, and hydroelectric power generation sources as the most preferable alternative to coal, oil, and natural gas fossil fuels. In the short term, such preferences are clear. The forced early closing of the Indian Point Nuclear Generating Station in New York and willingness to accommodate increased natural gas consumption to compensate until enough wind and solar power can be scaled up to meet the previous generation capability demonstrates the strong aversion to nuclear power. Indian Point certainly suffers from some unique issues, such as concerns about its proximity to New York City, its location near a fault line, and concerns about radioactive leaks into the Hudson River, but the impetus for closing the site has been motivated by a general anti-nuclear power sentiment. The pattern of reactor closings throughout the country echo similar concerns. Age is not generally an independent variable along which nuclear energy is considered, and particularly not considered with regards to nuclear waste. This lack of study combined with the significance of age as an explanatory variable suggests that an avenue of research could be opened into investigating methods of convincing younger people to support the Yucca Mountain site.

iv. *Discussion*

The research questions I set out to answer were threefold. First, I wanted to see if nuclear waste storage requires the deployment of a site like Yucca Mountain to safely store nuclear waste, and if there were permanent solutions that other countries had implemented. Second, given the extended timeframe of the debate and its near-frozen status, I wanted to see if public opinion was dynamic in its support or if it had stayed constant. Finally, I set out to identify the determinants of support and opposition to the site to see if it could reveal potential interventions that could be conducted in order to successfully bridge the gap between the public and experts and ultimately reach a point where the public would be supportive of a final conclusion of the debate.

On the first question, I demonstrated that there is a difference in philosophy in the US and other countries on whether nuclear fuel that can no longer be used in a reactor is used or spent, and whether it should be reprocessed or directly, permanently disposed of. Furthermore, while the Yucca Mountain project has been plagued by a lack of public support and complaints of opacity on the issue, the Onkalo nuclear repository is on track to be opened with broad public support due to their careful community engagement throughout the entire process of planning and building the site.

On the second question, I found that over thirty years there has been some movement towards public support of the Yucca Mountain project in Nevada, but overall it has remained negative, with a majority of Nevadans opposing the plan to store nuclear waste at Yucca Mountain. Representative of this sentiment is the Vegas Chamber and its VP of Communications, whom I interviewed to get her thoughts on the issue. Despite the provision of information, despite attempts at community engagement, the Department of Energy has failed to successfully bridge the gap between expert and public opinion, creating the potent conditions for a stalemate on the issue that has persisted for decades. There is also a distinction on a county-level, with higher levels of support recorded in Churchill County, which has a generally older population and includes some of the military sites that have been used for nuclear testing.

On the third question, I investigated the significance of certain demographic factors on predicting support for Yucca Mountain. I found that party affiliation, gender, and age were all statistically significant ($p < 0.001$) explanatory variables for support of Yucca Mountain. While party affiliation and gender have been identified as variables that demonstrate different levels of support, I show that this distinction is statistically significant and introduce age as a potential factor in contributing to opposition to the site.

I have extended the literature on nuclear waste by demonstrating the correlates of support, by conducting a meta-analysis of the historical levels of support for the site and investigating other solutions that are being implemented globally. Let us now turn to some policy recommendations that follow from these results.

VI. Recommendations

Based on the results of my investigation, there are several policy recommendations that may serve to alleviate the gridlock between the experts, politicians, and the lay public. As the Blue Ribbon Commission on America's Nuclear Future noted, there must be a multi-element strategy implemented in order to "establish a truly integrated nuclear waste management system, create the institutional leadership and wherewithal to get the job done, and to ensure that the United States remains at the forefront of technology developments and international responses to evolving nuclear safety, non-proliferation, and security concerns."[83]

i. *Engage the community and re-evaluate Yucca for high level waste storage*

My first recommendation is that the DOE and US government should incorporate community input into its plans for a nuclear waste repository. The issue with beginning consent-based siting now, however, is that the issue has been in the water supply for so long that opinions have already been ossified and information flow has already largely occurred, with the DOE losing control of the narrative. As Nowlin demonstrates, the knowledge deficit model does not apply well to the nuclear waste issue, but the divide between experts and the public is only exacerbated by the loss of trust that has already been incurred towards the DOE and nuclear waste managers around the country. There is some promise to information sharing; however, as my meta-analysis shows a slight uptick in support as the time frame increases. Therefore, my recommendation dovetails with the BRC on the metric of consent-based siting but suggests that that US government should incorporate considerations for another site into its plan for storing nuclear waste.

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[83] "Blue Ribbon Commission on America's Nuclear Future Issues a Final Report."

Another site is readily available: the WIPP site for transuranic waste. Although it is currently rated for storing the low-level TRU, the DOE is already looking into reclassifying some high-level waste as TRU and diverting it to be stored at WIPP instead.[84] I suggest that the community support for WIPP is stronger than Yucca Mountain, and with the continued blessing of the local community, WIPP can be utilized in lieu of Yucca Mountain to ameliorate the soaring levels of currently designated unsecured high-level waste. Unsecured nuclear waste – the spent nuclear fuel that has spent the appropriate time in cooling pools and has been transferred to dry cask storage but cannot be placed in a permanent repository until a facility like Yucca Mountain opens – would not necessarily be much less safe if it were stored at WIPP. And without the Yucca Mountain or another permanent high-level storage option, storage at WIPP would likely represent an improvement in safety over the status quo. If siting of a true high-level repository proves impossible at Yucca Mountain or elsewhere, I suggest that WIPP could serve as the singular repository for all nuclear waste.

ii. *Create an independent agency for nuclear waste management*

I next recommend that an entirely separate organization be created to manage nuclear waste; a bureaucratic structure that does not include the Department of Energy. The BRC included a similar step in its recommendations. However, the justification for this recommendation is made stronger by my analysis, which shows that the loss of trust in the DOE may be unsalvageable. Even if the public may support nuclear energy, the Department of Energy has been so vilified throughout the process, its numerous failures so public, and its lack of transparency so acute, that it serves as

[84] Adrian C. Hedden, "DOE Proposes Reclassifying High-Level Nuclear Waste, Could Send More to WIPP," Carlsbad Current Argus, accessed February 6, 2020, https://www.currentargus.com/story/news/local/2018/11/02/doe-reclassifying-nuclear-waste/1831914002/.

an albatross on the entire project, whose main goal is to safely site and store nuclear waste. There is a potential concern that a new agency may lack the legitimacy to enforce decisions compared to the DOE and that creating an agency may incur its own political costs. However, I suggest the benefits of an independent agency outweigh the potential costs, as under this system a nuclear waste management agency can devote its full attention to managing nuclear waste rather than operating within the broader nuclear energy ecosystem and the agency would be able to command more community engagement and generate less tainted organizational objectives.

My recommendation to create a separate organization for nuclear waste management goes further than the BRC recommendation, however. In their report, they suggest that "the existing roles of the US Environmental Protection Agency in establishing standards and the Nuclear Regulatory Commission in licensing and regulating waste management facilities be preserved."[85] However, because the bureaucratic entanglement between the DOE and the regulatory agencies is so strong, the distrust of DOE can spill over into the other agencies. An entirely new agency, that could be comprised of experts as well as members of the public, enhanced with authority given it by the President and Congress, could present an entirely independent, untainted commission that could effectively start from scratch in generating, debating, and implementing a cohesive solution to storing nuclear waste.

The independent agency should be set up without oversight from the EPA, which is seen as politicized, but this manner of setup creates another issue: a self-regulating agency that commits errors or is seen to be untrustworthy will incur the same problems as the DOE, which is also a self-regulating agency. To that end, I recommend that this independent agency be led by officials whose term limits span across presidential administrations, and the officials should be held accountable

[85] "Blue Ribbon Commission on America's Nuclear Future Issues a Final Report."

to the public through required community engagement events. I also recommend that this agency be stood up as a federally owned corporation in a similar vein to organizations like AmeriCorps, Amtrak, and the Export-Import Bank. This is for two reasons. The first is that a federally owned corporation does not require appropriation from the general revenue by Congress to operate, and therefore can further ensure its independence. The second reason is that this agency and its operations can be funded by revenue raised from the nuclear electricity customers that are actually benefitting from the reactors, rather than the general public.

There may be some concern regarding the conception of independent agencies, given the muddy relationship many agencies have with the executive branch, but specifically due to a recent increase in concern about the actual independence at many agencies. Under the current administration, several agencies - including the Food and Drug Administration, the Federal Reserve, and the Federal Communications Commission, and others - have come under political scrutiny after perceived interventions in their regulatory practices by the federal government. An independent nuclear waste management agency that functions outside the purview of the executive branch under the Department of Energy could suffer the same reputational damage.

However, I suggest that operating nuclear waste management in a manner that is at least nominally independent from the whims of the executive and financially separated from the politics of Congress provides an opportunity to allay concerns from both public groups and nuclear policy experts. First, the public would have an opportunity to interact with and exert influence over an independent agency at the level of community meetings more effectively than under the current scheme, which constitutes nuclear waste management as a top-down bureaucratic hierarchy where policy regarding nuclear waste depends on policy priorities and objectives of higher-level bureaucrats as well as the President.

Second, constituting the responsibility of managing nuclear waste under an independent agency, particularly one where the appointed head of the agency is an experienced manager with specific knowledge of the nuclear field, would assuage experts that the decisions made by such an agency would be informed principally by scientific conclusions supported by both the academic field and the nuclear industry in conversation with the public that would be directly affected by agency decisions. This structure would be most likely to reduce risk of radioactive contamination or leakage associated with the site and present the best opportunity for decisions' scientific value not to be watered down by the political necessities and expediency that come from political and financial concerns.

iii. *Designate an interim consolidated storage site until Yucca Mountain opens*

My third recommendation is to create an interim consolidated storage site for nuclear waste that is currently held at the nuclear generating stations where it was used. Nuclear waste that has been moved into dry casks currently remains at the location of even decommissioned or nonfunctioning nuclear reactors, like the San Onofre Nuclear Power Station in San Diego, California. Storing nuclear waste at the site of their generation is problematic because it engenders safety concerns from two sources. The first is national nuclear energy security. The dry casks stored onsite at decommissioned or nonfunctional nuclear reactors are more vulnerable to theft and terrorism than if they were centralized and permanently disposed of. The second is that onsite storage exposes dry casks to potential natural disasters, which could harm the structural integrity of the casks if they were severe enough. While the risk of these impacts is low, many opponents of the Yucca Mountain site express worries about accidents or crime against the nuclear waste as reasons to oppose the site. The risk of disaster at dozens or hundreds of sites is exponentially greater, if still small, than the risk to a consolidated storage location.

However, the risk to the nuclear waste from both sources is minimized by permanently storing it in a deep storage repository. In lieu of being able to store the nuclear waste at Yucca Mountain, at the minimum, centralizing the waste in a location that is not disaster prone would minimize the risks. For example, San Onofre is on the Pacific coast, making it more vulnerable to seismic activity than a location in the heartland that is temperate, relatively free of severe weather, and geologically inert. Similarly, the Indian Point Nuclear Generating Station in New York is located in close proximity to major population centers, including New York City. It is scheduled for decommissioning in 2021, and when it goes offline, the waste from its electricity generation will currently remain onsite. One of the main reasons it is scheduled for closing is due to an increase in opposition to nuclear energy in New York State. However, if plans do not change, the nuclear waste from its generating activities will remain onsite, maintaining the same status quo of locating radioactive materials close to the tens of millions of people living in the New York metropolitan area, except without the advantage of generating electricity. Transporting the waste to a centralized facility, even if it is not permanent, at Yucca Mountain or elsewhere, would represent a lower risk solution than the status quo, despite the risk of radioactive release being low once the nuclear waste is placed in dry casks.

iv. *Reintroduce the nuclear power mill fee*

My fourth recommendation is to reintroduce the "mill fee" on customers of nuclear power, modified from the original iteration to be calibrated to generate enough revenue to consolidate and eventually permanently store the waste that is created from nuclear electricity generating activities.

From 1982 until 2017, there was a "mill fee" charged to customers who used electricity generated by nuclear reactors. This fee, which was assessed at 0.1 cent/kWh (1mill/kWh), had lifetime contributions of over $30 billion. An independent agency set up as a federally owned corporation could use funds generated from a similar fee as revenue for nuclear waste storage and transportation activities. The mill fee was removed because of lawsuits brought by nuclear utilities against the federal government for breaking its promise to remove the nuclear waste. Reintroducing a fee structure similar to the mill fee would ensure that an agency responsible for the management of nuclear waste remains funded at the levels necessary to continue carrying out operations. Those funds could be used to create a centralized storage facility that is not permanent but would set the nuclear waste on a path to deep permanent storage. If the agency is able to recover the funds collected by the original mill fee that was part of the general revenue, it could spend the balance of funds on finishing the Yucca Mountain project.

A key advantage of reintroducing the mill fee will be to further bolster the prospects of independence for a nuclear waste management agency and will boost the chances of progress even if the responsibility for handling nuclear waste remains located in the Department of Energy. Segregating funds for the management of nuclear waste from being subject to appropriation from the general revenue by Congress in the yearly budget will ensure the possibility of the nuclear waste management project's operating in perpetuity, collecting funding from a nuclear industry whose capital costs can be brought down by effectively managing nuclear waste and whose utilities and ratepaying customers can then contribute a relatively marginal added cost to nuclear energy tor the benefit of full safe life cycle management of the fuel. Furthermore, the mill fee prevents the emergence of a negative externality on taxpayers who do not derive their electricity from nuclear power and ought not be charged for the financial burden of managing the nuclear waste problem. The mill fee can close the financial gaps in providing for nuclear waste management and provide support for a nuclear industry that needs more than federal subsidies to break even and continue to provide a source of carbon-free electricity that, without massive improvements in battery storage capacity or a fundamental redesign of the electric grid, cannot be reasonably replaced by any other form of renewable energy.

Without a fee structure for customers who benefit from nuclear energy to fund the costs of managing nuclear waste, the future holds an unfunded mandate for the DOE or any independent agency that takes over nuclear waste management. Any actions to continue the management of the nuclear waste will need to be funded through Congressional appropriations, which may be hard to come by especially if the nuclear waste debate continues to be as contentious as it is today. With a separate revenue stream that ensures that the general taxpayers are not assuming the burden of nuclear energy consumers, the introduction of the fee will ensure that nuclear waste management can be funded at the levels it needs to be. A final question regarding the fee is whether to reintroduce the mill fee without any modifications. I recommend conducting a financial review of the projected costs, including inflation, of nuclear waste management under three scenarios: status quo, interim consolidated facility, and permanent repository at Yucca Mountain. The fee should also be dynamic to reflect the changing needs of nuclear waste management: if the repository is opened, the fee should change in value to reflect the different costs that will be incurred in disposing nuclear waste as opposed to the status quo.

v. *Consider reprocessing spent fuel to close the fuel cycle*

My fifth recommendation is to consider reprocessing in the policy toolbox. While reprocessing remains prohibitively expensive to direct disposal, the United States is a leader in nuclear technologies. A multilateral effort between the US and other nations that are interested in reprocessing could bring down its costs to a more manageable level. Furthermore, the actual cost of direct disposal in the status quo is ballooning due to the lack of a permanent storage facility that could facilitate direct disposal, so the breakeven cost of reprocessing as compared to the status quo is lower than other studies have expected. The main advantage of reprocessing would be to reduce the total tonnage of high-level waste to be stored. Although the currently dominant reprocessing process to recover plutonium and create MOX fuel is cost-prohibitive and ultimately does not result in large volume savings, the Generation IV fast neutron spectrum reactors present a potential reprocessing solution that can reduce the amount of waste generated by orders of magnitude. By burning more of the radioactive elements in the process of generating electricity, fast reactors will also reduce the amount of time necessary for the spent fuel to no longer be radioactive by orders of magnitude, from hundreds of thousands of years to centuries. This volume and radioactivity reduction will be helpful because after reprocessing, the US will only have to deal with as little as one-one thousandth of the volume of high-level waste as it would under direct disposal. These significant volume savings mean that if Yucca Mountain is opened, it will be able to accept waste for millennia before it is full. The reduction in volume and radioactivity also means that it will be more feasible to store the waste at a site other than Yucca Mountain, whether a completely new site for deep permanent high level storage or an upgraded WIPP facility. Ultimately, reprocessing would make it more feasible for WIPP, an already proven and relatively popular disposal site, to serve as a singular site for storing all nuclear waste, as I discussed in my first recommendation.

vi. *Conduct a public education campaign on nuclear waste transportation*

My sixth recommendation is to mount a campaign to educate the public on the relative safety of nuclear waste transportation. One of the major sticking points against storing nuclear waste at Yucca Mountain, external to concerns about the site itself, is that the nuclear waste will need to be transported across multiple state lines along federal highways or commercial railroads to deliver it to its final destination. For example, in my interview with Ms. Clarke, many of her concerns were reflective of a fear that nuclear waste could be harmed by accident or intentional tampering. However, as demonstrated in my literature review, the dry casks are eminently safe from most kinds of damage, and throughout the history of all tens of thousands of shipments of high-level nuclear waste, there has never been a release of radioactive materials. If the concerns about transportation can be overcome, the acrimony of the debate over storage will be ameliorated.

To that end, I recommend that the Department of Energy, or an independent commission, take steps to engage in information sharing between experts and the public. Transportation is an understudied aspect of the nuclear waste life cycle, and it is ripe for reconciliation between expert and public opinion. Even if the knowledge deficit model does not necessarily apply to nuclear waste writ large, it may be useful for addressing the transportation question. Videos of the tests conducted on dry casks are readily available on YouTube, and they demonstrate the rigor with which they are certified to be transported. Furthermore, there seems to be a lack of general public awareness surrounding the current status of nuclear waste transportation. The Department of Energy already conducts the same kind of transportation that would be necessary for shipments to Yucca Mountain for military nuclear waste and has done so for decades without incident. Globally, shipments occur frequently without much opposition. Transportation of nuclear waste appears to be an issue that currently serves as a wedge between expert and public opinion, but also provides a potentially great opportunity for reconciliation. If the public can come to an agreement on the safety of transporting nuclear waste, it can serve as a launching pad for a more general discussion of nuclear waste that is more genuine, honest, and incorporates expert and public opinion.

vii. *Focus on swaying the opinion of groups that historically oppose Yucca Mountain*

My seventh and final recommendation is to conduct information sharing campaigns targeted at groups that are currently more heavily opposed to nuclear waste siting at Yucca Mountain. My analysis demonstrates that support of nuclear waste is not equivalent among all individuals. Rates of support are higher among certain groups divided by party, gender, and age: conversely, rates of opposition are significantly higher as well. In particular, Democrats, women, and people under age 50 are particularly strong loci of opposition to the Yucca Mountain project. Their receptivity to support the site is different from the general American or Nevadan public and therefore, an information and education campaign that is targeted specifically at the groups that have higher rates of opposition may be helpful in moving the needle of public opinion more strongly in the direction of support. There is hope for this strategy, as my meta-analysis shows that over time, support for siting permanent nuclear waste storage at Yucca Mountain has increased.

Bringing in detractors is crucial for bridging the divide between supporters and opponents of the Yucca Mountain project. Whether anti-nuclear or anti-Yucca Mountain, the opinions of those who oppose the siting of the nuclear waste repository need to be heard to change the gridlocked status quo. The DOE and nuclear waste experts can lay out the problem clearly and directly to detractors and try to garner their thoughts on a solution. Nuclear waste is a relatively unique problem because a large amount of high level waste has already been created and has nowhere to go. Almost any option would be preferable to the status quo, as the waste that has been moved to dry cask storage onsite at the commercial reactors that produced it is only certified for sixty years. After that point, a new facility will need to be constructed at the site of every reactor to repackage the waste into new dry casks, a process that will be particularly difficult at decommissioned reactors. This process will need to be repeated every sixty years until a permanent solution is implemented. Laying out this problem as a present issue with an untenable status quo will potentially lead to more productive conversations between the proponents and opponents of the Yucca Mountain project.

If the engagement between the Department of Energy and the public is targeted at groups that are more opposed to the site as opposed to the general public, arguments can be modified and tailored to the specific audience. Advertising is one way to accomplish this. Another method dovetails with my first recommendation to engage the community in a more meaningful manner. The DOE can hold community events for people who are particularly concerned about the site and can conduct public tours of the site as well as information sessions that are targeted at women, Democrats, and people under age 50 in order to gather more support for the site.

These seven recommendations are parts of a whole strategy that will be necessary to move the needle of public support towards support of the site. Without public support, the gridlock that currently prevents any progress on permanently siting high-level waste cannot be overcome. And yet it must be, if only because of the cumulative amount of nuclear waste that has already accumulated and is currently unsecured. My recommendations outline an action plan for the Department of Energy or a new independent agency or commission to reinvigorate the debate over the site and mobilize public support for a plan to deal with the nuclear waste in the United States.

VII. Conclusion

In this thesis, I have investigated the landscape of the nuclear waste debate in the United States. I have looked at nuclear waste transportation and storage policies in the United States and abroad and investigated the causes of support or opposition. I have particularly focused on the controversy over the Yucca Mountain Nuclear Waste Repository, a site that was designated by the US Congress as the sole site for high-level nuclear waste storage in the 1980s but whose implementation has been blocked by the Nevada congressional delegation and state representatives since.

I used a three-part methodology to unpack and analyze the Yucca Mountain controversy. I first used a comparative approach to look at the manner in which other countries have approached the nuclear waste problem, specifically focusing on the Onkalo nuclear repository in Finland, which is likely the most promising first site to actually accept nuclear waste, and the WIPP site for low level waste storage in the US. I discussed the differences in political and social approach that was undertaken by the Department of Energy as opposed to the designers in Finland.

I then looked at support for Yucca Mountain over time, conducting a trend analysis of the dynamism of political public opinion on the site. I found that support for constructing the Yucca Mountain facility has grown somewhat over the years, which suggests that with an even longer time frame, the status quo may eventually reach a tipping point where the opposition may dissolve, and the repository may be opened. But the amount of time that this would require is prohibitive, given the cumulative amount of nuclear waste that has already been produced, and the increase in the nuclear waste tonnage that is sure to continue for at minimum, the near term, and if nuclear energy is embraced as a fully viable alternative electricity source, will grow at a much higher rate.

Finally, I dug into the individual level data in a 2017 survey of public opinion in Nevada to try to identify determinates of support for the Yucca Mountain project. I identified three independent variables of individual profiles that have a statistically significant predictive effect on that individual's support or opposition to the project. The results of this analysis suggested that Republicans, men, and people over 50 are most likely to support the plant, while Democrats, women, and people under age 50 are significantly more likely to oppose the project.

I used the results of my analysis to create a suite of seven recommendations for the government and the public to reconcile expert and public opinion. First, I suggest moving towards community consent and input in siting. Second, I propose creating an independent agency specifically designed to handle nuclear waste that is run by a mix of experts and the public. Third, I suggest centralizing nuclear waste in an interim site while the problems are sorted out. Fourth, I recommend reintroducing a fee structure for customers who benefit from nuclear energy to help defray the costs of managing the nuclear waste instead of relying on general tax revenue. Fifth, I recommend considering reprocessing versus direct disposal in the US policy toolbox. Sixth, I argue that transportation is an understudied aspect of nuclear waste disposal and offers a potentially less acrimonious avenue for restarting the debate over nuclear waste management. Seventh, and finally, I recommend taking the determinants of support for Yucca Mountain seriously in targeting argumentation and community engagement to communities that are more opposed to the site, rather than those where the public is already more supportive. This recommendation also allows for tailoring the argumentation to different peoples' susceptibilities and may be helpful in bridging the gap between experts and the public.

Further research based on my thesis should focus on the correlates of support for the site. Identifying more stalwart opponents may help to identify which arguments should be used to try to convince others of the need to create a permanent storage facility and may provide a light at the end of the forty year long tunnel between the origination of the project and the present day.

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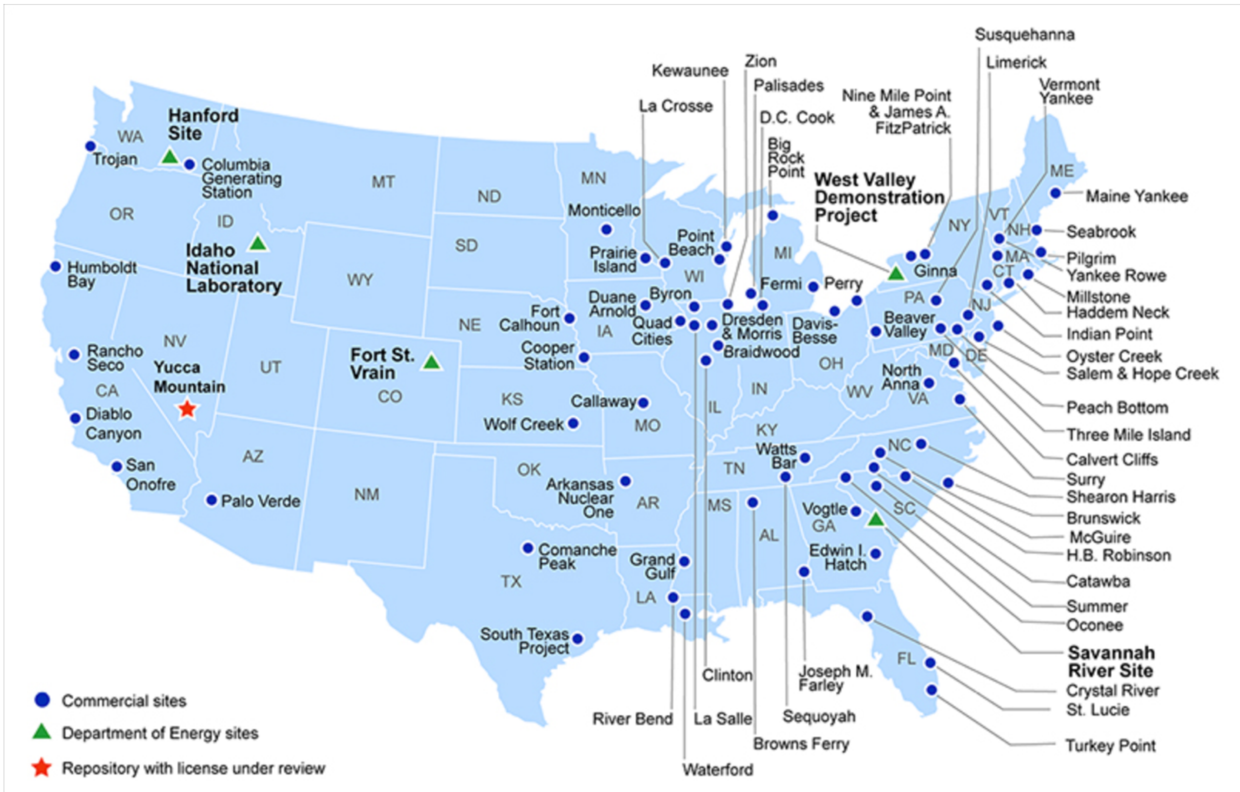
IX. Appendix

Figure 12: Nuclear Waste Site, United States



Source: Department of Energy. | GAO-17-174

Figure 13: DOE Transportation Routes for Nuclear Waste