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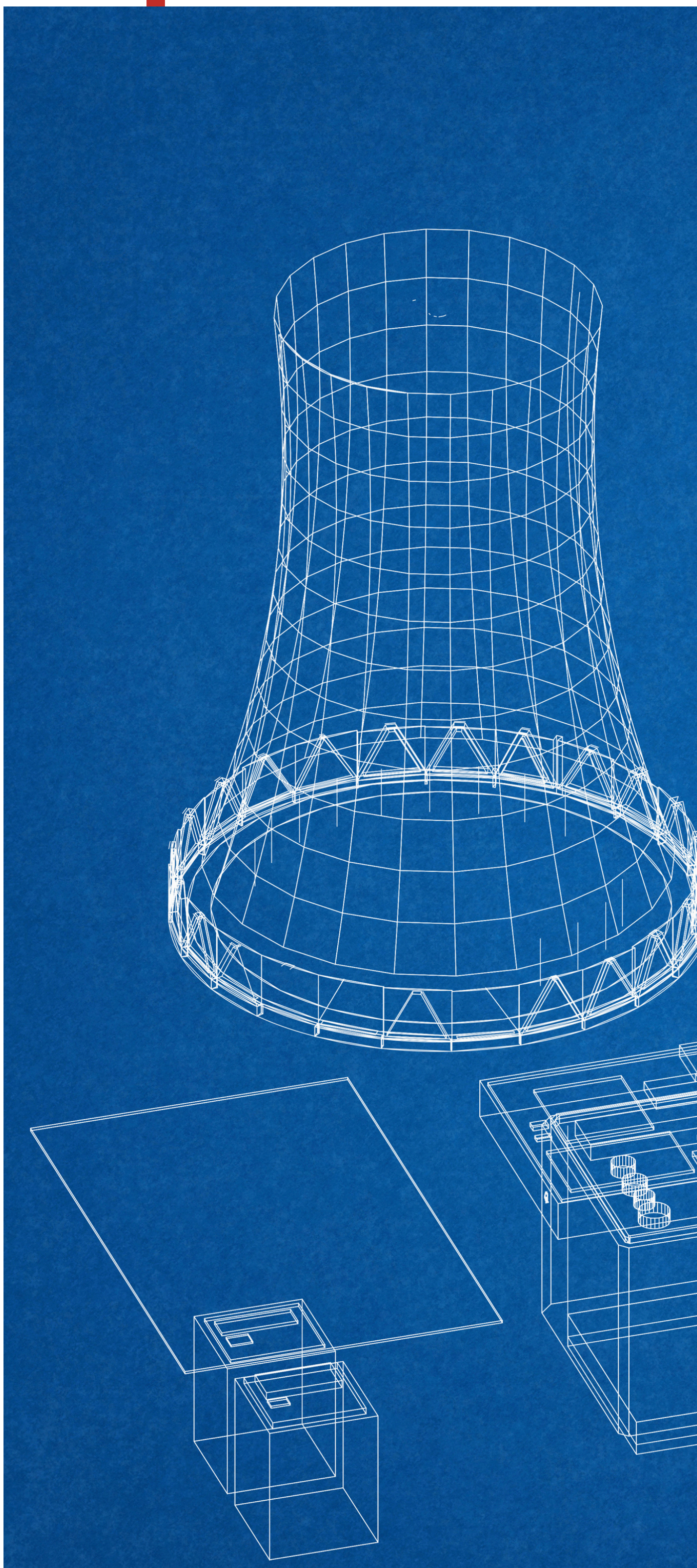

UTAH'S STRATEGIC NUCLEAR ENERGY PATHWAY: SPENT FUEL RECOVERY AND RECYCLING

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Prepared by the Utah Office of Energy Development

Utah's Strategic Nuclear Energy Pathway

Development Considerations: Nuclear Spent Fuel Recovery and Recycling

As the third installment of "Utah's Strategic Nuclear Energy Pathway," a series of documents guiding the state through nuclear development, this document details/analyzes the potential for nuclear spent fuel recovery and recycling to be an asset for Utah in any nuclear operations. This includes a basic review of recovery and recycling technologies, the benefits and risks that come with recycling, and makes recommendations for the legislature.

Introduction

The Utah Office of Energy Development (OED) is charged with the advancement of energy development within the state, in particular, the development of a strategic energy plan that includes **technological innovation and energy efficiency** (code 79-6-401). Technologies recommended for the Strategic Energy Plan will fit within the state energy policy laid out in 79-6-301—new technologies should meet the goals of **adequacy, reliability, dispatchability, affordability, sustainability, security, and cleanliness.** The state has an interest in encouraging innovation in energy resources, promoting energy security, state energy independence and developing the energy workforce.

In supporting the state in meeting these interests, OED is proud to submit a continuation of the Nuclear Pathway series and the first emerging technology consideration for the state: **Nuclear Spent Fuel Recovery and Recycling (NSFRR)**. Represented in academia and industry as spent fuel recycling, we propose the term nuclear spent fuel recovery and recycling to more accurately describe the material and process laid out herein. OED has evaluated this technology for its ability to meet state energy objectives and presents seven considerations:

1. **Feasibility:** Spent fuel recycling is **already feasible** with existing technology. France has been doing **NSFRR for decades** and several U.S. companies are developing their own facilities.

2. **Environmental:** NSFRR **reduces the necessary storage space by 90%** and cuts the necessary storage duration from **thousands to hundreds of years**. Recycling also decreases the need for raw fuel materials.

3. **Economic:** NSFRR is a technical field that can employ **thousands of skilled workers for millions of dollars in local revenue**. Reducing storage space alone could avoid 80 billion dollars of cost nationally while **boosting the state economy by 1 billion dollars**. Spent fuel contains **scarce resources used in almost every industry** that can be recovered through NSFRR. Locally, **Huntsman Cancer Institute** is dependent on extremely limited medical isotopes, a supply issue that local NSFRR can help ease.

4. **Energy Security:** Recycling **reduces the need for foreign imports of nuclear fuel**, strengthening reactor supply chains. It also offers a route for permanently decreasing plutonium stockpiles, turning national security concerns into productive energy.

5. **Efficiency:** Through saving raw materials and reducing the long-term waste that needs to be stored, **NSFRR multiplies the effectiveness of other nuclear technologies**. Every gram of mined material goes further and has less environmental impact, letting more be done with the same supply.

6. **Low Risk:** The risks of recycling are primarily political in nature, **all technical risks can and already are being navigated safely** around the world. However, a communication and **public education and engagement strategy will be necessary** to assuage public concerns.

7. **Regulation:** There is a regulatory gap with respect to federal policy and spent fuel recycling. While short-term workarounds exist, **the Nuclear Regulatory Commission (NRC) should be pressed into creating streamlined and standardized rules** for recycling facilities. Utah has the opportunity to capitalize on this regulatory gap.

Given the multitude of benefits NSFRR can provide, this technology can act as a powerful multiplier for any future Utah nuclear pursuits and aligns with state energy policy goals. The rest of this document will expand upon the potential of spent fuel recycling, the foreseeable risks and provide recommendations for the legislature's consideration.

History of Nuclear Spent Fuel Recycling Sentiment

While NSFRR is often presented as an emerging technology, it has been around since the inception of nuclear energy. Initially, recycling was researched in tandem with nuclear power production in the mid-1900s. In fact, several U.S. NSFRR facilities were planned before the technology was discouraged by Ford, later banned by Carter, unbanned by Reagan, discouraged by Bush and Clinton and subsequently abandoned federally until 2022 [1-2]. Outside the U.S., NSFRR development continued, most notably in France, where it is a key component of their current energy strategy.

The U.S. was the original creator and innovator of NSFRR before it was abandoned politically. Currently, many other countries, such as South Korea, Russia, Japan and China are in the process of establishing or cultivating NSFRR [3-4]. France, as the most established NSFRR user in the world, can serve as an ideal benchmark for the state as the U.S makes up ground. Indeed, the early U.S. regulatory bodies around NSFRR were markedly hostile, and that sentiment has cascaded all the way to current nuclear policy [5-7]. **The sentiment around NSFRR is shifting as concerns around energy supply, demand and the environment are intersecting. In recent years, the federal government has officially acknowledged the need for NSFRR, as evidenced in the following statements:**

> For America to further harness the safe, reliable clean energy produced at nuclear facilities across the country, the Biden-Harris Administration and DOE recognize the importance of developing practical uses for America's used nuclear fuel. Recycling nuclear waste for clean energy generation can significantly reduce the amount of spent fuel at nuclear sites, and increase economic stability for the communities leading this important work.
>
> –U.S. Energy Secretary Jennifer Granholm, October 21, 2022 [8].
>
> We are on the precipice of the next frontier of nuclear energy here in the United States. Recently, the House overwhelmingly passed the Atomic Energy Advancement Act to advance a durable, bipartisan policy that will expand nuclear energy… …Responsible and effective Spent Nuclear Fuel management is a critical part of this equation. It can help foster nuclear expansion in the United States.
>
> – House Energy and Commerce Energy, Climate, and Grid Security Subcommittee Chair Jeff Duncan, April 10, 2024 [9].
>
> This is a big deal, it's the first time that we're seeing recycling and reprocessing as a funding item. That says a lot. That is a reflection of how much the nuclear policy landscape in a bipartisan way has changed.
>
> – Chief executive of fuel-recycling startup Curio Edward McGinnis, March 7, 2024 [10].

These statements indicate that the era of stagnation in NSFRR is at an end, and Utah should and can be primed to take advantage of this change, even leading the nation forward. While political quagmire may have delayed the production of recycling facilities, academic institutions and labs across the U.S. have continued to research nuclear energy, advanced reactors and the nuclear fuel cycle – all aimed at improving efficiencies and creating safeguards for the nuclear energy cycle. The fruits of decades of research are ripe, and with the tonal shift at the federal level, private companies are setting the groundwork to pursue NSFRR. With good state policy, Utah can attract these companies, further developing research and technologies, and bring mass benefit to the state and the entire nation.

What is Nuclear Spent Fuel Recovery?

While an in-depth description of the nuclear power cycle is outside the scope of this document, some basic knowledge is useful to understand why NSFRR is such a compelling technology. In all utility-scale nuclear energy produced today, the power-generating mechanism is the splitting of atoms – fission – which releases vast amounts of energy as well as certain byproducts. The heat from this process is what creates the energy, generally through a steam and turbine system as seen in the U.S. light water reactor nuclear fleet. Fission reduces the fuel material in the system, converting it into other elements and basic particles. When the fission process slows down the fuel is replaced, and the now spent fuel is stored to cool and be disposed of. Generating energy through fission is a straightforward process, but a key concept is that very little of the fuel gets converted into other elements, and well over 90% of the original potential energy remains [11-13]. The spent fuel may be labeled waste and discarded, but this is analogous to throwing away your burger after a single bite.

NSFRR is simply taking spent fuel and processing it for a new use (Figure 1). There are a wide variety of methods with varying complexity**,** but they all center around separating usable fissile material – most commonly uranium and plutonium – from unusable materials [14-15].

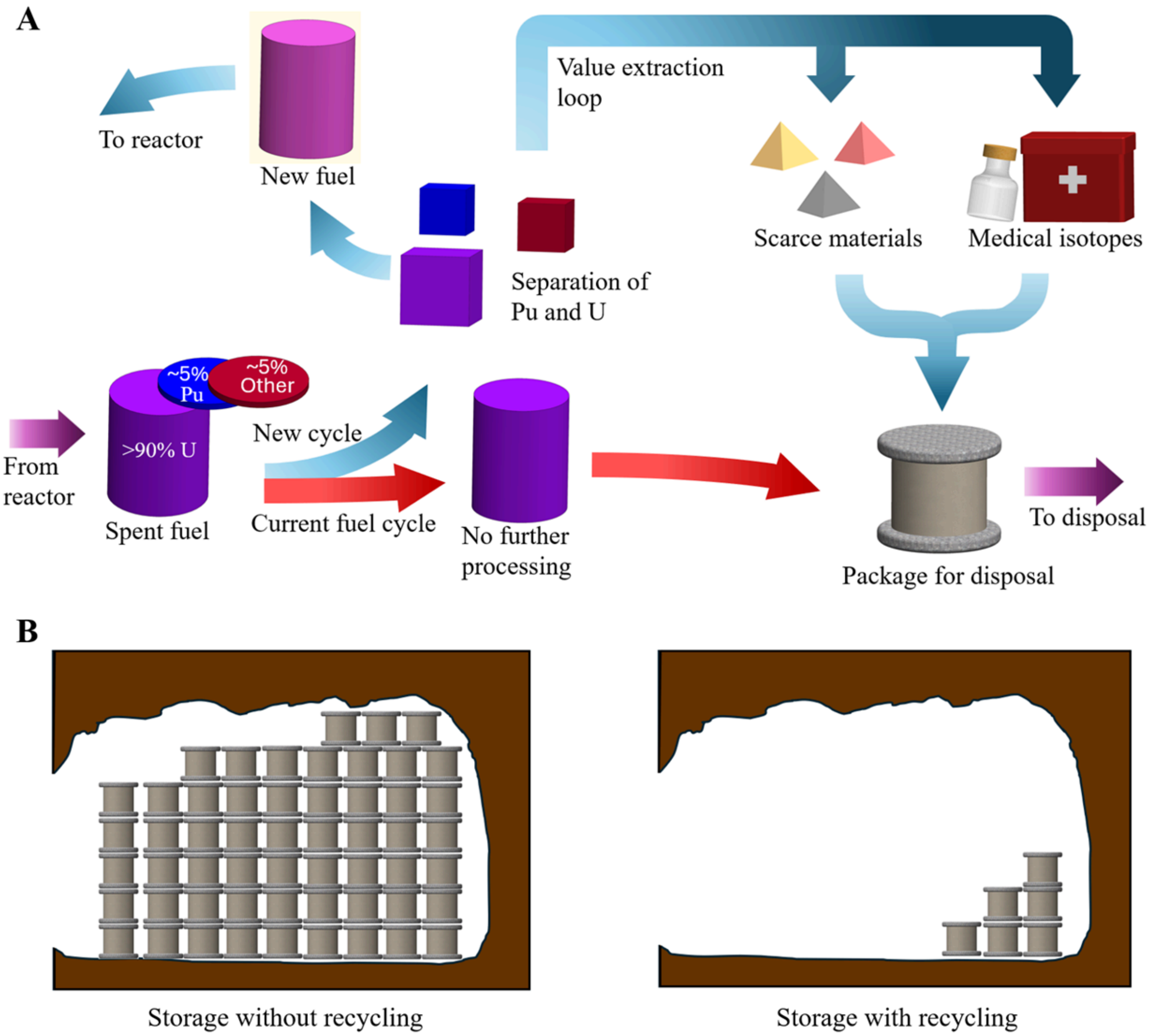

Figure 1. Nuclear fuel cycle with and without spent fuel recovery. A) The nuclear fuel cycle and potential added value from recycling. B) Long-term storage with and without recycling.

In France**,** the specific process used is plutonium-uranium redox extractions (PUREX), which separates the uranium and plutonium with an aqueous solution. The extracted material can be mixed back into natural (not yet enriched) uranium to produce mixed-oxide (MOX) fuel, which is ready for use in modern reactors [16]. Future NSFRR processes and advanced nuclear reactors will be able to utilize spent fuel even more, with potential benefits to a multitude of sectors that are worth individual exploration.

Primary Benefits

While nuclear recycling is still an ongoing research topic with room for future growth, there are some key benefits that can be extracted from the current body of literature. **Three categories of benefit are worth exploring: the economic potential, the environmental benefits and increasing energy security. Environmentally**, NSFRR can reduce the total volume of nuclear waste, its toxicity and the amount of uranium mining. **Economically,** NSFRR is a treasure trove of untapped potential, with uses for current and future fuels, the skilled labor force needed to process NSFRR and acting as an unconventional mine for critical scarce materials. And within **energy security**, NSFRR promotes energy independence, reduces the need for imports and provides a route for reducing plutonium stockpiles.

Waste Volume and Radioactivity Reduction

One of the largest advantages of NSFRR is its ability to substantially reduce the volume of radioactive material that needs to be stored. By nature of reusing the spent fuel, which contains up to 96% uranium, all that extra radioactive mass is avoided [17-19]. **In France, NSFRR leads to a reduction in waste volume of 80%, with room for further reduction as more advanced techniques come along (Figure 1b)** [20-21].

During recycling, plutonium and other highly radioactive components are removed, drastically reducing the heat and radioactivity of the remaining material [22]. **This is impactful enough to reduce long-term storage needs from thousands of years to hundreds, a much easier design constraint for planners** [23-24].

Together, the volume and radioactivity reduction lead to a significantly reduced footprint for any material that does need to be stored long-term. A reduced footprint makes management and safekeeping easier, reduces transportation requirements and extends the usefulness of existing and planned storage facilities. Leveraging NSFRR makes every other form of nuclear utilization go much further by saving materials and with far less environmental impact by reducing waste. Considering the amount of money being spent on storing the 85000+ tons of U.S. spent fuel — 6 billion a year on weapons waste, 40 billion in taxes to date for existing spent fuel, with at least an additional 40 billion over the coming years**—there is a phenomenal opportunity for Utah to capture that value through working with current storage sites and the federal government on reducing those costs through recycling and recovery** [25]. At Sellafield in the U.K., recycling fuel for other countries provided around 10 billion dollars over several decades [26]. In the U.S., the costs for spent fuel storage are placed onto the ratepayers, but NSFRR can funnel that money to the state while reducing future costs. Many states have spent hundreds of millions and will continue to do so; **NSFRR could reduce this fiscal burden, and Utah could become a national hub in this effort** [27].

Environmentally Friendly

Reducing the footprint of stored nuclear waste is an obvious environmental benefit, but NSFRR can benefit the environment in several other ways. Nuclear energy is, in general, an extremely clean energy. It produces no emissions while generating energy, and while waste must be handled carefully, it takes up a very small area, especially compared to other clean technologies. This leads to a total lifecycle emissions unmatched among baseload generators, in line with the impact of renewables like solar and wind, with the added benefit of consuming vastly fewer resources and land area [28-29]. **What emissions nuclear energy produces are generally along the infrastructure and supply chain, including the backend of waste storage and the initial mining of fuel materials at the frontend** [30]. The environmental benefit on the back end of waste management has been covered, but the impact of NSFRR on mining is worth further exploration.

We again have our real-world example in France, where about 17% of their nuclear energy is sourced from recycled waste [31]. From MOX fuel alone, they predict this figure may rise to 30% with future recycling techniques [32]. Taken to its extreme, NSFRR can be done repeatedly to fully close the nuclear fuel cycle with advanced reactors, **recycling spent fuel until minuscule waste material remains** [33]. The reuse of nuclear fuel makes every gram of extracted raw material go further, reducing the need for new uranium mines. Although exact figures depend on the specific nuclear fuel cycle, **reductions in mining and milling waste from a single recycling step have reached up to 30%; within France**, **NSFRR is already saving 20% of their uranium** [34-35].

Promotes Energy Independence

Recycling nuclear material reduces the need for mining. This reduction in mining is crucial beyond its environmental effects; it also heavily impacts energy security and the need for imports. **The stockpile of energy in spent nuclear fuel is remarkable, with existing U.S. stockpiles containing enough uranium to power the entire country for decades, even centuries, to come** [36-37]. In terms of a steady and reliable energy storage device, spent nuclear fuel provides unmatched security. This has been demonstrated in France, where nuclear energy and NSFRR elevate its energy independence above the majority of the other European Union countries [38]. Comparisons to Germany are particularly relevant, with the post-Fukushima, non-nuclear Germany substantially more dependent on external energy supplies compared to their nuclear neighbor [39-40]. This independence shows in the average cost to consumers, with the average German household paying almost double what the average French household pays for electricity [41]. Still, for all that France does well with nuclear energy, there is a crucial chink in their energy independence armor in that they have no domestic uranium mining. Their supply chains include a range of sources, including from geopolitical rival Russia [42-43]. **Without mining, NSFRR is the only domestic source of uranium France can develop**, and they do plan to leverage NSFRR even further in the coming years through expanded recycling [44]. Combining NSFRR with Utah's natural uranium, the state has the potential to leverage the entire nuclear fuel life cycle, enhancing security and meeting future demands.

Reduces Plutonium Inventory

The ability of NSFRR to increase security extends beyond energy independence. It is particularly useful for its ability to reduce or entirely consume plutonium stockpiles. This was the prevailing NSFRR method the U.S. was pursuing in its efforts to reduce nuclear weapon proliferation. In agreements with Russia, the U.S. was planning to eliminate at least 34 metric tons of its weapons-grade plutonium stockpile through its separation and subsequent use as MOX fuel [45-46]. However, the planned recycling facility was suspended in 2009, and the plutonium stockpiles remain largely unchanged, with other plans proposed but still in stasis [47-48]. The other proven alternative for plutonium is permanent internment, which leads to its own challenges and fails to capture any of the material's value [49-50]. Despite federal inconsistency in plutonium management, **NSFRR remains a viable option for reducing civilian and military plutonium stockpiles, turning national security concerns into productive energy** [51-52].

Creates Fuel for Current and Future Reactors

As mentioned previously, current light water reactors can get fuel from NSFRR in the form of MOX. France has been doing so for decades, and the process is well-explored [53-54]. **MOX promotes energy security and efficiency and would be an immediately viable product for a NSFRR facility to produce.** The more interesting use will be in the future as advanced systems such as fast reactors and small modular reactors come online.

One of the most pressing issues facing advanced reactors will be the fuel supply; they generally require higher enrichments or different fuel compositions entirely than existing nuclear reactors. America currently has a limited supply due to past research at the national labs, and the only commercial supplier of higher-enrichment fuel is the Russia-owned Tenex [55]. With several advanced reactors nearing completion, the U.S. will not have domestic advanced reactor fuel production capabilities if there is not a similar growth in fuel production facilities [56]. This challenge is something NSFRR can help solve [57]. **The resulting products of NSFRR can be directly used as a fuel by forming different MOX combinations, can provide rare fissile materials for advanced reactors like thorium salt reactors or can be used as precursors to other fuel production techniques** [58-61]. NSFRR could even be co-sited with a reactor, creating fuel on-site from reactor byproducts while reducing the environmental footprint. As more nuclear reactors are deployed, NSFRR can scale as a fuel provider right alongside them.

Harvesting Scarce Materials

The added value of NSFRR extends far beyond providing just fuel. Nuclear reactors produce a tremendous range of different elements as they generate electricity, about half the periodic table, in fact. While the production of these elements is also why reactions slow down and the fuel must be removed, many of these materials are stable. Some of these elements are incredibly rare and valuable, and are in concentrations that would be staggering if found in nature [62-63]. **Extracting other rare materials while the plutonium and uranium are already being recovered would add immediate value to the process** [64]. These various rare materials have been estimated at over $500,000 per ton of separated material, and would find use in sectors from vehicles to energy storage to chemical processes [65-67]. The demand for many of these materials is growing exponentially, and spent nuclear fuel has the potential to act as an unconventional mine, providing large portions (>10%) of the world's supply of certain critical materials [68-69]. Efficient NSFRR processes could be leveraged to generate these materials from already existing waste that is awaiting disposal and can be utilized with future waste production.

Produce Medical Isotopes

The last prominent value that NSFRR can extract from spent fuel is by aiding the medical field. Radioactive materials can be found throughout medicine; they get used in the production of devices and sensors, can be part of diagnostics and imaging, sterilize equipment and are used in radiotherapy treatments [70-72]. **Utah itself has a vested interest in many of these materials through the Huntsman Cancer Institute**, one of the most prominent cancer treatment facilities in the nation [73]. The supply for these medically useful isotopes is extremely limited, requiring scarce materials and advanced equipment like a reactor to create the desired product. Indeed, the supply for some of these isotopes is so limited that a single unexpected reactor outage threatens the supply of the whole world [74-76].

NSFRR can provide longer-lived isotopes and sources of materials that shorter-lived isotopes are created from [77-78]. Prominent nuclear startup TerraPower is already doing this by taking spent-uranium-derived thorium-229 and turning it into the medically useful actinium-225 [79-80]. **As medical isotope demand increases through research and rising treatments, NSFRR can provide a valuable source of materials that are independent of reactor function, firming the medical supply chain and increasing availability** [81-83].

Promote Jobs and Private Industry

Given the importance and demand for many of the products that can be derived from NSFRR, private interest has been spiking in these facilities [84-85]. Advanced reactor developers are considering NSFRR for their own uses, medical providers are looking into producing crucial isotopes, and the federal government is providing funding for expanded development [86-89]. Local universities and labs, such as the San Rafael Energy Lab, can partner with industry, driving research and development into the state. **Given the nascent state of commercial NSFRR in the U.S., labs, universities, and even states that house private industries will be uniquely suited to grow along with the technology.** The value that these facilities can bring is immense; the La Hague NSFRR site in France supports 5,000 employees [90]. This is nearly as large as Utah's Northrop Grumman presence, which boasts a similarly high-skill, high-pay technical workforce as NSFRR would attract [91]. The U.K.'s multi-function Sellafield location employs over 10,000 people, something co-siting a NSFRR with other nuclear facilities would enable domestically [92]. For a national comparison, the closest analogy to a NSFRR site is the Waste Isolation Pilot Plant, where 1,000 permanent employees exist [93]. **Nuclear recycling startup Curio predicts a recycling facility having some 3,000 employees and a value at over 400 million dollars a year in tax revenue, with the entire facility bringing in 1.5 billion dollars [94]. A state environment open to NSFRR could bring this growing private industry to Utah, capturing value while providing thousands of high-skill, high-pay job opportunities and making Utah the center of American NSFRR development.**

The Risks

While NSFRR has many benefits, at the end of the day, it deals with spent fuel. Nuclear materials are extremely hazardous and must be handled carefully with respect for and an understanding of their nature. However, this is no different than any number of hazardous materials that are handled every day with minimal controversy and without incidents. **Our conversations with nuclear academics, waste regulators, industry professionals, and radioactive material end-users, have revealed no exceptional risks in spent fuel recycling and recovery.** NSFRR poses no greater risks than any other nuclear technologies or processes, which have exceptional safety ratings proven through decades of operation [95]. Nevertheless, the risks that are present must be carefully managed, the most prevalent of which are the storage of radioactive materials pre- and post-recycling, potential proliferation, public opinion, and federal regulation.

Long-term Waste Storage

NSFRR is no different from other nuclear technologies and will result in the production of radioactive waste. While this waste may be less than otherwise would need to be handled due to the volume reduction, **NSFRR does not remove the challenge of on-site and eventual long-term storage of radioactive materials.** A NSFRR facility will need to have storage for pre-processed spent fuel until ready for use, storage for the immediate products of recycling and a procedure for intermittent storage of remaining waste. Eventually, there would need to be a plan for the transfer of waste to the planned federal permanent repository. This storage does not need to be exceptional for NSFRR; the standard cooling pools and dry casks are more than sufficient for safe storage [96-98]. The licensing procedure for these tools exists under NRC regulation 10 CFR, Part 50 and 72, and planned storage would be able to follow set regulatory and licensing processes with little issue (see our companion document Development Considerations: Synchronizing Regulatory Frameworks) [99-101]. The state would need to consider supporting infrastructure and transportation to/from any storage locations, potentially leveraging the Department of Energy's (DOE) newest railcar for maximal reliability [102-103]. While the storage and transportation of spent fuel are common nuclear fears, the track record of existing spent fuel management shows these fears to be unfounded. There has not been a single radiological incident during the shipping of more than 2,500 spent fuel packages over the country's entire nuclear history, and this record is matched worldwide, with few to no incidents anywhere on the globe [104-106]. The issues with storage that have been prominently displayed in the media are, generally, due to federal negligence in handling and securing weapons waste and the use of WWII-era storage containers [107]. New storage is markedly safer, and a new NSFRR facility would be able to leverage these technological advances [108-109].

While intermittent on/off-site storage would be straightforward to manage in as many locations as required, it may greatly benefit Utah to create a single storage location for all of the state's nuclear waste. This is especially topical considering the federal government's lack of movement on a spent fuel repository; plans have been in motion for nearly 50 years, and yet there is no deliverable in sight [110]. Were Utah to expand into nuclear power generation, NSFRR, actively pursue nuclear research, mine materials and create isotopes, a single repository would provide a multitude of benefits, such as increased security and safety, greater ease of regulation, decreased operating costs and standardized waste transportation within the state [111]. The storage could be co-located with any NSFRR facility, decreasing the total footprint and increasing efficiency. Such storage would likely be an underground cavern, as geological repositories allow stable and secure storage for thousands of years [112]. Utah has an advantage in its salt caverns, already planned for use with facilities like the Delta advanced hydrogen plant [113-114]. Local salt caverns would be an ideal location for centralized nuclear material storage and are worth considering in their own Nuclear Pathways document analyzing centralized nuclear storage within the state [115-116].

Proliferation

Preventing the proliferation of nuclear weapons and technology has been a long-standing U.S. doctrine. Non-proliferation was the original justification for shuttering NSFRR in the states and is part of the conversation around any nuclear technology [117]. Certainly, there is an inherent risk to building nuclear facilities of any fashion, and NSFRR is no exception—it is difficult to crash your car without first getting behind the wheel. However, nuclear energy is one of the cleanest and safest of all energy sources, even accounting for disasters [118]. While the risks should be carefully considered, the safety record of the entire nuclear industry suggests that proliferation concerns with NSFRR are unfounded [119].

Fears of nuclear terrorism have existed for decades, but as of today, no threat has ever materialized. Worldwide, between 1993-2023 there were only a reported 4,243 incidents involving radioactive materials out of regulatory control. The vast majority of these were non-hazardous, with only 69 incidents involving weaponizable elements, and of those, the majority involved only grams of material [120]. **The history of nuclear terrorism and smuggling is clear: Stolen nuclear material has not led to a single attack on a populace anywhere in the world. There has never been a dirty bomb detonated, and this is despite nuclear energy growing rapidly worldwide—**set to break production records in 2025 with over 170 more reactors on the way [121-123].

The globe's excellent track record of no nuclear terrorism is not down to good luck. For one, in order to break into a nuclear facility, specifically, a spent fuel storage facility, and take the spent fuel would be technically difficult, costly, and almost certainly lethal to the thieves. Spent fuel is heavy, stored in secure facilities, and once removed from its containment, would immediately deliver a lethal dose of radiation to the would-be-thieves [124-125]. Second, the waste itself would make for a very poor bomb, even the pure plutonium separated from spent fuel in a process like PUREX, and building the simplest of nuclear weapons is far from trivial [126-127]. A coordinated group capable of stealing and then actually utilizing spent fuel is highly unlikely to need to steal the materials in the first place. Given the state of sensing and surveillance technologies, the rise of a nefarious group capable of carrying off and then using the material without being detected is nonsensical. Additionally, proliferation safeguards are being researched and incorporated into every facet of the nuclear power cycle, NSFRR included [128-132]. **Imagined fears aside, NSFRR offers a concrete method for reducing material stockpiles and provides a route for non-proliferation rather than proliferation.**

Public Opinion

While long-term storage and proliferation can be managed, public opinion is a different type of challenge. The public has outsized fears about the impact of nuclear technology, generally arising from a lack of information and familiarity. The coverage of nuclear energy in the news is usually negative. Terms like the "nuclear option" are common phrases in the lexicon, and most depictions of nuclear in entertainment are either monster- or disaster-related. Combined with a lack of information on the benefits of nuclear technologies, it is no surprise that the perceived risk these technologies pose is not reflected in real-world data.

Still, public sentiment should not be underestimated or ignored. It was public pressure combined with politics that directly led to Yucca Mountain being canceled, and more recently a planned storage facility was canceled in New Mexico and is now buried in a legal battle [133-136]. The Fukushima disaster aftermath directly led to Germany accelerating the closing of its reactors, and here at home, Three Mile Island disrupted the pursuit of nuclear energy in the U.S. for years [137-140]. **Robust public acceptance is a critical component for any nuclear technology and would be one of the most effective areas for the state to focus on with NSFRR.**

On the surface, public support for nuclear technologies is generally positive, as of 2023, 57% of Americans support expanding nuclear power, and people view spent fuel recycling positively as well [141]. Even a location like Three Mile Island is being considered for restart, and public support appears to be increasing each year [142-143]. However, nuclear strongly suffers from a not-in-my-backyard mentality, and support for new local nuclear power plants is much lower [144]. The facts of nuclear technologies will stand on their own if people are given the chance to learn, and evidence shows that public sentiment is highly correlated with public knowledge; the more educated people feel about nuclear, the more supportive they are [145-147].

Once facilities are built, familiarity grows and citizens rapidly come to accept nuclear energy. People who live near nuclear power plants report markedly greater support than average for nuclear technologies; they also generally support rebuilding these assets to keep them functioning [148-149]. **A targeted and well-thought-out public education and engagement campaign would ensure that when the time comes for a nuclear facility to be built, Utahns are supportive rather than antagonistic.**

Regulation

The final primary concern with NSFRR is the regulation surrounding it, or rather the lack thereof. While spent fuel is handled directly by the federal government and reactors can be licensed commercially, there is no such code for NSFRR. The NRC began the regulatory process in 2013, however, they stopped in 2021, stating no foreseeable short-term needs [150]. The NRC states that any plans for a NSFRR facility would be able to work around existing regulation 10 CFR, Part 50 “Domestic Licensing of Production and Utilization Facilities,” since a NSFRR is a type of production facility [151]. Given that private industry is charging forward on NSFRR, with several companies actively seeking to build pilot NSFRR plants at this very moment, **the decision to shelve NSFRR regulation should be revisited by the NRC.**

Beyond NSFRR processes, a recycling facility will need to work closely with the federal government on the spent fuel supply. Since the federal government is ultimately responsible for all spent fuel in the U.S., any NSFRR supply lines will need to follow federal processes and regulations. This parallels the last main regulatory concern, the transportation of the spent fuel and eventual waste through various states. Many states have their own restrictions and notification procedures on nuclear material in addition to the federal restrictions on the transportation of radioactive materials; these will have to be navigated to make sure transportation goes smoothly. Safety of the spent fuel during transportation is a logical concern, but the industry has a sterling record with not a single reported radiological incident during transportation of spent fuel in the country's entire history [152]. The DOE is also continuing to advance transportation safety, and has just completed certification of the Atlas railcar, which was specifically crafted for the transportation of spent fuel [153]. Any NSFRR facility will need to adhere closely to state and federal transportation rules to ensure minimal disruption, but spent fuel transportation and regulation can and is being done safely throughout the country.

Recommendation and Future Prospects

To summarize, NSFRR is a technology with many benefits in critical areas. Crucially, NSFRR could take existing/future nuclear technologies further, reducing the footprint for the same material cost. The challenges in implementing NSFRR are large but manageable with the proper planning. Were the legislature to pursue NSFRR, the following areas would offer the greatest immediate impact and lay the foundation for future development (**Figure 2**):

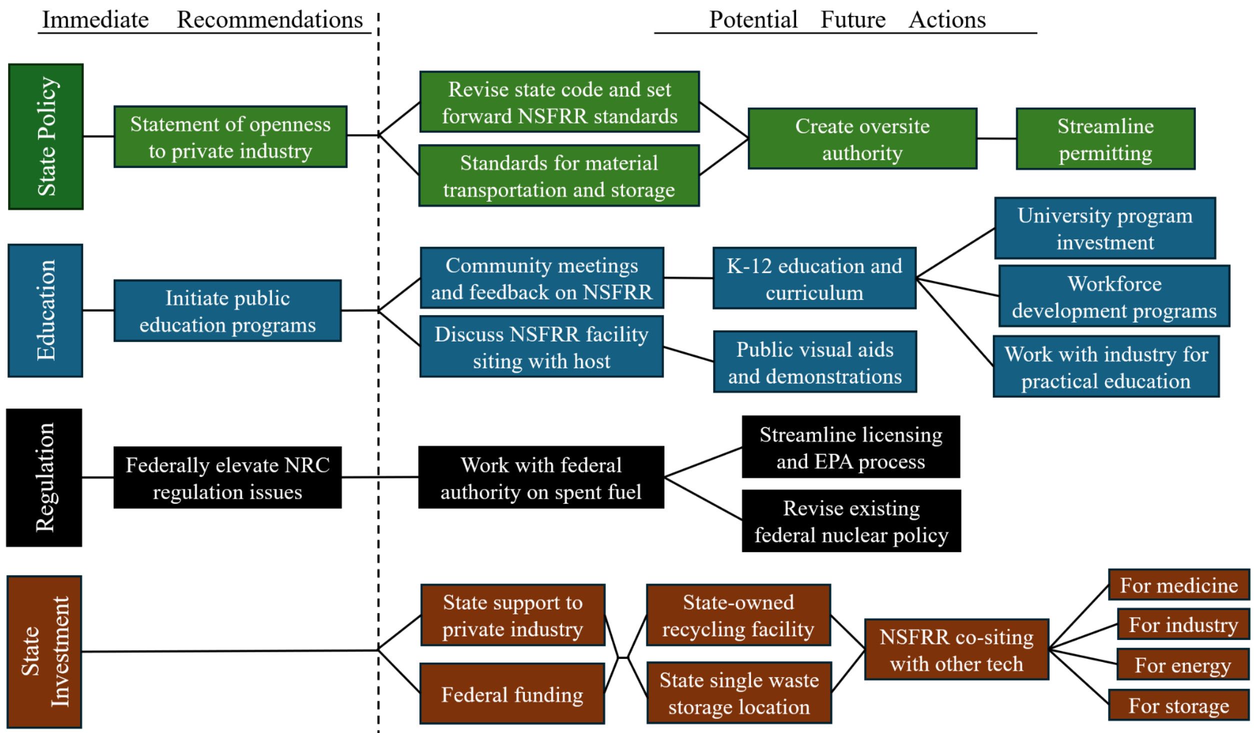

Figure 2. Potential plan for Utah's involvement in NSFRR. Suggested actions do not encompass the entirety of future options, the state may pursue any of these it deems prudent or take different steps.

Several actions can be taken immediately with little investment from the state. Firstly, a statement of support for private industry can be distributed. Private companies in the U.S. are actively seeking locations to build pilot NSFRR facilities at this very moment, and Utah can assure them that they are welcome here. The state can elevate NRC regulatory issues, pressing the NRC to create streamlined spent fuel recycling regulations in a timely manner. Finally, the state should begin a public education campaign. Educating the public on nuclear technologies is absolutely necessary and will create public support for nuclear technologies beyond NSFRR.

The state code should be analyzed, as suggested in our companion document Development Considerations: Synchronizing Regulatory Frameworks, and the legislature should set forward state standards for NSFRR operations and material handling. NSFRR would likely need some form of oversight authority created and NRC licensing, and at the very least, a state permitting and reporting process should be developed.

Involvement at the federal level can be expanded, including pressing for the revision of existing nuclear policy, such as streamlining the permitting processes, where nuclear technologies get wrapped up for years and years at great cost. If a NSFRR facility is established, it would also be prudent to look at spent fuel policy and long-term storage; these are issues intrinsically connected to nuclear spent fuel recovery.

The state's involvement with education can expand far beyond just public information campaigns. An education campaign should target all facets of society, focusing on creating actual expertise. For truly robust acceptance, children should learn about nuclear energy and radiation as a matter of course, routes should exist for technical workers to train in the field, and higher-education programs should be expanded. Private NSFRR industry can be directly involved in this process, providing hands-on experience and expertise. Long-term education plans combined with awareness campaigns will create a stronghold of nuclear knowledge within the state. Given the current lack of a developed nuclear workforce and the importance of education, this topic is worth its own exploration in a future Nuclear Pathways document.

Finally, Utah may wish to monetarily invest in NSFRR. This could go beyond allowing private companies to build within the state; for example, grants and incentives could be created and managed through OED and the San Rafael Energy Lab. In addition, there is much federal funding around advanced nuclear technologies that could be leveraged to support Utah's energy goals. The state may wish to own its own reactors, centralized storage and recycling facilities, or pair NSFRR with other technologies to multiply its effectiveness.

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