NUCLEAR INNOVATION ALLIANCE

From Reactors to Repositories:

Disposal Pathways for Advanced Nuclear Reactor Waste

Summary for Policymakers – December 2024 | *To view the full report, click here*

As the global demand for clean firm energy grows, advanced nuclear energy technologies are gaining significant attention and efforts to deploy them are underway. These advanced reactors offer numerous improvements in safety, efficiency, and operational flexibility largely due to the innovative fuel forms and coolants utilized in their design. New advanced reactor designs, however, will introduce new waste streams that may differ significantly from those generated by conventional reactors, depending on the specific reactor design. With new reactors come new waste forms.

Effective nuclear waste management is essential to the future of advanced nuclear energy and must be grounded in the best available information. Policymakers and stakeholders must therefore understand these new waste forms, their unique characteristics, and the specific management strategies needed for their safe storage and disposal. This report provides clear insights into these topics to enable more informed decision-making, and ultimately help create the conditions for success for advanced nuclear energy so that it can be part of the climate and energy security solution.

Characteristics

The characteristics of advanced reactor wastes will vary greatly. The physical, chemical, and radiological properties of these wastes will depend on the specific reactor technology and company-specific design. *(see chapter 3 of the full report for more details)*

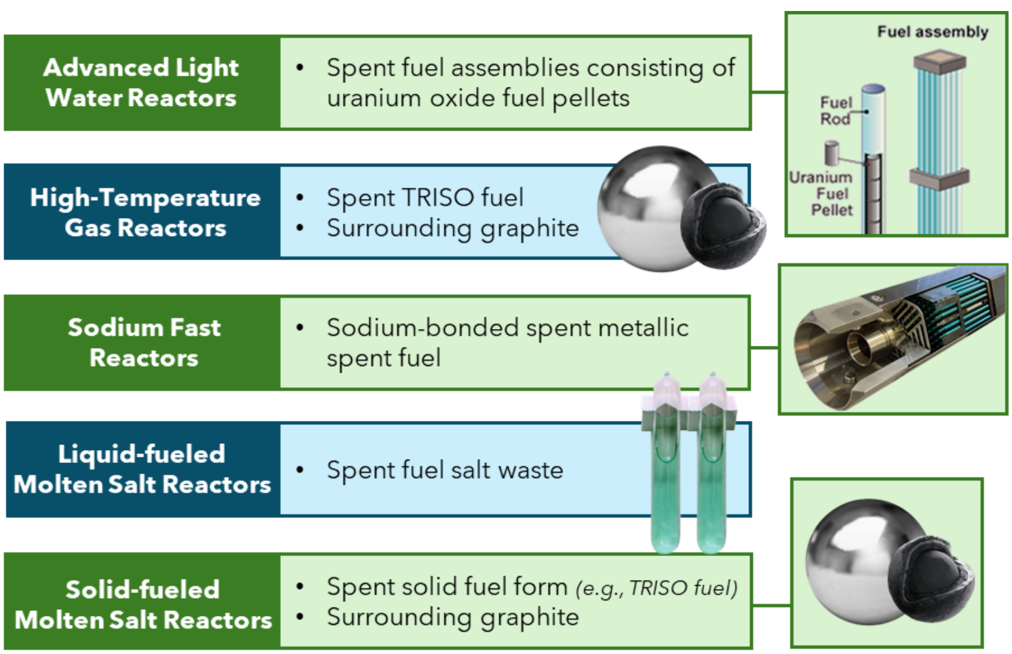

Figure 1: Spent nuclear fuel generated by several advanced reactor technologies

Advanced reactor low-level waste **(LLW) should be relatively easily integrated into existing LLW management and disposal pathways**, except for the most radioactive LLW known as "Greater than Class C" (GTCC) waste. Management and disposal of Spent Nuclear Fuel (SNF) and GTCC waste from both advanced reactors and conventional reactors requires more long-term oversight, planning, and resources for monitoring. These **SNF and GTCC wastes will require more robust interim management and permanent disposal strategies**.

Interim Storage

Onsite interim storage will play a critical role in the management of SNF and GTCC waste generated by advanced reactors because the United States currently lacks a permanent repository. Fortunately, the United States already has significant experience managing the SNF and GTCC waste that will be generated by advanced reactors seeking to be deployed by the end of the decade.

SNF and GTCC waste from Advanced Light Water Reactors (ALWRs) can utilize existing interim storage strategies, given they are nearly identical to those generated by conventional Light Water Reactors. The United States and several other countries have also previously operated a total of five High-Temperature Gas Reactors (HTGRs) and eleven Sodium Fast Reactors (SFRs), which have since ceased operation and undergone varying degrees of decommissioning involving the management of their nuclear waste. Among these reactors, the United States has decommissioned two prismatic block HTGRs and five SFRs. Details regarding each of these reactors can be seen in the table below.

Reactor Type	Reactor	Country	Power, (MW_{th})	Years of Operation
HTGR Prismatic Block	Peach Bottom	United States	115	1966–1974
	Fort Saint Vrain	United States	842	1976–1989
	Dragon	England	21.5	1964–1975
HTGR Pebble Bed	THTR	Germany	750	1985–1991
	AVR	Germany	46	1967–1988
SFR	EBR-1	United States	1.4	1950–1964
	SRE	United States	20	1957–1964
	Fermi 1	United States	200	1963–1975
	EBR-2	United States	62.5	1965–1994
	FFTF	United States	400	1980– 2003
	Rapsodie	France	40	1967–1983
	Phénix	France	590	1973–2010
	Superphénix	France	3000	1986– 1997
	Monju	Japan	714	1995–2010
	BN-350	Soviet Union	~850	1973–1999
	PFR	United Kingdom	500	1974–1994

Source: Idaho National Lab

Table 1: List of decommissioned HTGRs and SFRs

The majority of the SNF generated by these U.S. reactors is currently safely stored at the Idaho National Laboratory (INL).

Advanced reactor developers also already have robust plans for onsite interim storage. Interim storage strategies proposed by both TerraPower and X-energy for their Natrium and Xe-100 reactors, respectively, give insights into the kinds of methods that will be used to manage advanced reactor spent nuclear fuel. Both companies have developed designs for interim storage facilities that have been submitted to the Nuclear Regulatory Commission, demonstrating their plans to safely manage and store SNF until a permanent disposal solution is available.

In summary, **interim storage strategies are robust and the United States is well-prepared to ensure safe and effective management of advanced reactor SNF and GTCC waste until permanent disposal solutions become available.** *(see chapter 4 of the full report for more details)*

Permanent Disposal

Permanent disposal pathways for advanced reactor wastes are still being explored. The United States currently has no permanent disposal capability for GTCC waste or SNF generated by either advanced or conventional nuclear reactors. Currently, most of this waste is stored onsite at the nuclear power plant where it was generated.

DOE has identified several approaches that could be used for GTCC permanent disposal including the use of above-grade vaults, enhanced near-surface trenches, intermediate depth boreholes, and a deep geologic repository at the Waste Isolation Pilot Plant (WIPP). DOE also evaluated several sites to host a GTCC waste disposal facility and identified the LLW disposal facility in Texas and the WIPP as preferred candidates. In May 2024, the NRC issued a proposed rule that would authorize the near-surface disposal of certain GTCC waste which is a major step towards constructing a GTCC disposal facility. However, **political opposition toward constructing a GTCC waste disposal facility remains a key barrier**, particularly from the governors of Texas and New Mexico.[1]

SNF from advanced reactors, like the SNF from conventional reactors, contains long-lived radioactive isotopes that require isolation in a deep geological repository to ensure public health and safety. The safety performance of a geological repository is dominated by engineered and geological barriers, rather than the characteristics of the waste. Therefore, conventional and **advanced reactor waste streams are expected to have little to no impact on the long-term safety performance of geological repositories, provided they are properly processed and packaged prior to disposal**. Some advanced reactor waste streams may need to be processed prior to permanent disposal to reduce the waste's overall volume, render it chemically inert, or stabilize it to ensure long-term safety in a geological repository. Other advanced reactor waste streams may be directly disposed of (i.e., direct disposal) without any major processing steps. The specific disposal pathway, and processing methods that may be needed depend on the waste form in question.

SNF from ALWRs, HTGRs, and solid-fueled molten salt reactors (MSRs) could be directly disposed of, but SNF from SFRs and liquid-fueled MSRs may require processing before disposal, as shown in the table below. **Certain challenges must be overcome to ensure these processing methods**

[1] Bowen et al. (2024). "Revisiting GTCC and GTCC-Like Nuclear Waste Disposal in the United States".

can be used at scale due to the complexity and maturity of these methods, **but their solutions are known to be technically feasible.** *(see chapter 5 of the full report for more details)*

	ALWRs	HTGRs	SFRs	Solid-fueled MSRs	Liquid-fueled MSRs
SNF Waste Form:	UO_2 fuel pellets	TRISO pebbles or prismatic blocks	Sodium-bonded spent metallic fuel	TRISO pebbles or prismatic blocks	Spent fuel salt
Stable SNF Waste Form?[1]	Yes	Yes	No	Yes	No
Disposal Pathway	Direct Disposal	Direct Disposal	Direct Disposal or Processing[2]	Direct Disposal	Direct Disposal or Processing[2]
Processing Method	n/a	n/a[3]	Varies	n/a[3]	Varies
Processing Method Maturity	n/a	n/a[3]	Lab scale demonstrations	n/a[3]	Has not been demonstrated

1. Chemical stability prior to any potential processing
2. Dependent on the design and waste acceptance criteria of the final repository, and laws and regulations that govern. For example, the Resource Conservation and Recovery Act would not currently allow for the direct disposal of sodium bonded spent metallic fuel.
3. Incineration and mechanical separation processes have been proposed but are not generally considered preferable to direct storage

Table 2: Advanced Reactor Permanent Disposal Pathways and Processing Methods

In summary, this paper addresses key knowledge gaps regarding nuclear waste management, specifically in the context of advanced reactor technologies. It seeks to answer critical questions like: What will waste from advanced reactors look like? How will it differ from waste generated by existing light water reactors? How prepared are we to manage advanced reactor waste streams? And what areas require further investigation?

A comprehensive understanding of the answers to these questions is crucial to making informed decisions around advanced reactors and advanced reactor wastes. This more detailed understanding should give policymakers, and stakeholders who help inform policymakers, the knowledge they need to help create the conditions for success for advanced nuclear energy so that it can be part of a climate and energy security solution.

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