Opportunities to Optimize Small Modular Reactor (SMR) Used Nuclear Fuel Management in the United States

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Rod McCullum
Nuclear Energy Institute

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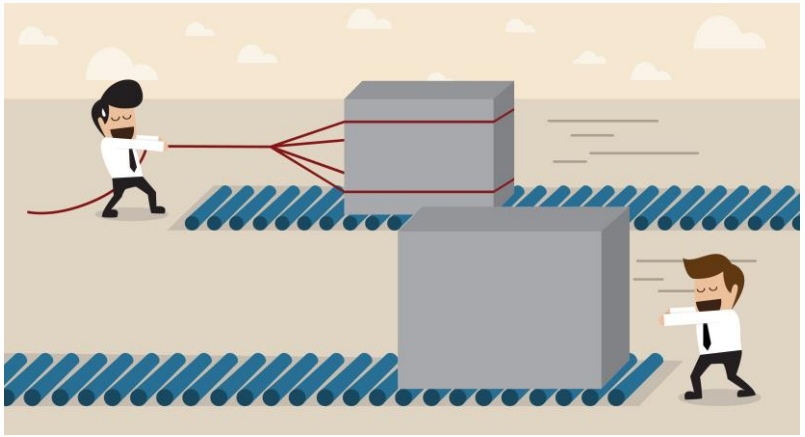
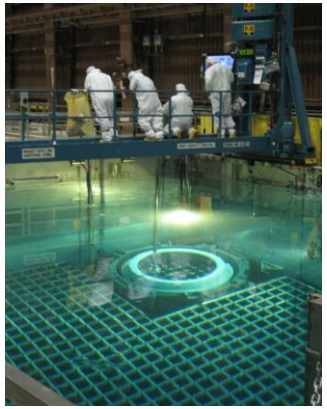
New Momentum

- The biggest impediment to used fuel solutions is a lack of used fuel problems



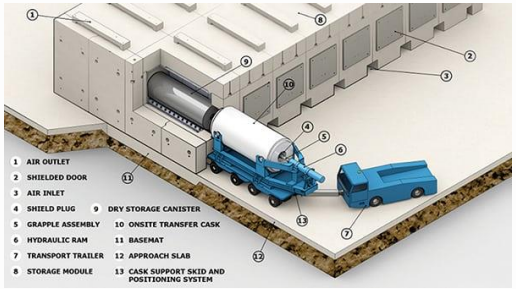
- Interest in decarbonization and reliability is likely to create new used fuel management opportunities

Successful used fuel management in US has been driven by a culture of innovation

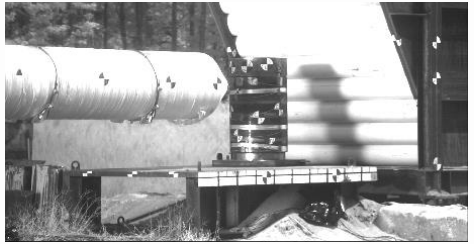


BUSINESS

Coastal Panel Votes 10-0 to Allow Storage of Spent Nuclear Fuel at San Onofre



Holtec Missile Test – 8/29/13, Aberdeen MD
600 MPH impact – no breach of containment



Innovators

What Innovation Has Created

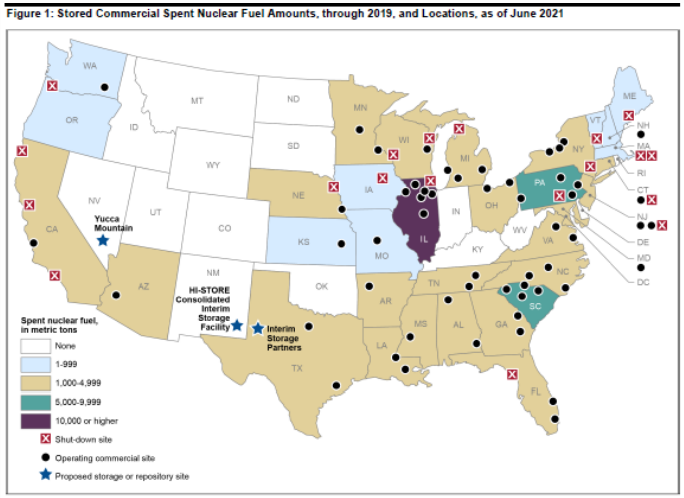
All the used nuclear fuel generated, if stacked, would only cover one football field ~12 yards high

Used fuel inventory*

- Approximately 88,000 MTU
- Increases 2 - 2.4k MTU annually

ISFSI** storage

- 168,922 assemblies
- 47,500 MTU (50%)
- 3,767 casks/modules loaded
- 75 Operating dry storage ISFSIs
- 21 sites where reactor operations have ceased



Long-term commitment

- First Casks Loaded in 1986
- Licenses being extended to 60 years
- Licenses extensions approved at 32 sites
- Licenses renewable for additional 40 yr. periods
- NRC determined casks safe for “at least” 100 yrs

All of the pools and casks in which this fuel is stored could be comfortably arranged inside a single big box store distribution warehouse

*As of June 2022

** ISFSI = Independent Spent Fuel Storage Installation

A New Incentive for Innovation

- Existing US reactors are reimbursed for their used fuel storage costs by the federal government in accordance with contracts signed in 1983
- Future reactor owners will have to carry all used fuel storage costs for life of plant + under amended standard contract
- Cost-competitive US electricity marketplace will drive further innovation

Date of Audit Report	Amount Paid from Taxpayer Funded Judgment Fund		DOE's Estimate* of Liability Including Amount Paid
	Cumulative	Annual	
9/30/2021	$ 9.0 Billion	$400 Million	$ 39.9 Billion
9/30/2020	$ 8.6 Billion	$600 Million	$ 39.2 Billion
9/30/2019	$ 8.0 Billion	$600 Million	$ 36.5 Billion
9/30/2018	$ 7.4 Billion	$500 Million	$ 35.5 Billion
9/30/2017	$ 6.9 Billion	$800 Million	$ 34.1 Billion
9/30/2016	$ 6.1 Billion	$800 Million	$ 30.8 Billion
9/30/2015	$ 5.3 Billion	$800 Million	$ 29.0 Billion
9/30/2014	$ 4.5 Billion	$800 Million	$ 27.1 Billion
9/30/2013	$ 3.7 Billion	$900 Million	$ 25.1 Billion
9/30/2012	$ 2.6 Billion	$1.0 Billion	$ 22.3 Billion
9/30/2011	$ 1.6 Billion	-	$ 20.7 Billion

Innovation Challenge – Light Water SMRs

The used fuel management marketplace for SMRs initially might not look much different that the marketplace of today. Three US light water reactor SMR suppliers (Holtec, Nuscale, and GEH) all plan to use low enriched uranium similar to what is in the cores of the current fleet. For these cases innovation is simply a matter of accommodating new configurations and perhaps higher burnups

Innovation Challenge – non-LWR SMRs

Many of the designs not using light water as coolant will be using High-Assay-Low-Enriched-Uranium (HALEU) fuel [6]. Spent fuel discharges from these plants should be met with a storage innovation curve already in progress as a number of the reactors in the existing fleet are also planning to use variants of HALEU (often referred to LEU+) and will already be ordering storage systems before they will be needed by the SMRs. Fast reactors, such as Oklo, are mostly planning to use metal fuels for which there are already well-established transportation and storage technologies in use for discharges from DOE's metal fuelled research reactors.

OKLO Current projects and collaborators

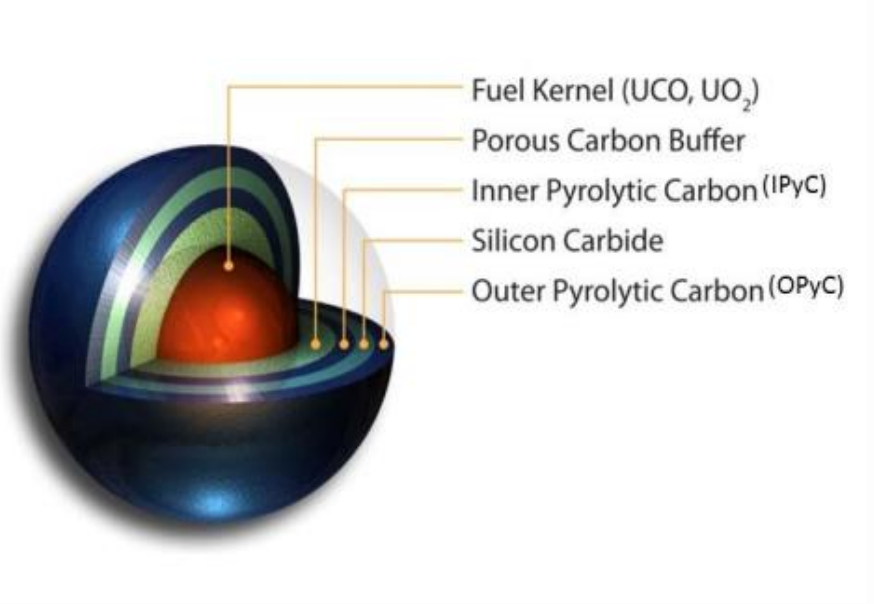
DOE Technology Commercialization Fund
- $2M over 2 years
- Commercializing advanced process sensors

DOE ARPA-E OPEN 2021
- $4.5M over 3 years
- Developing advanced safeguards sensors

DOE ARPA-E ONWARDS
- $5M over 3 years
- Industrializing electrorefining process
- Developing disposal plans, and licensing strategy

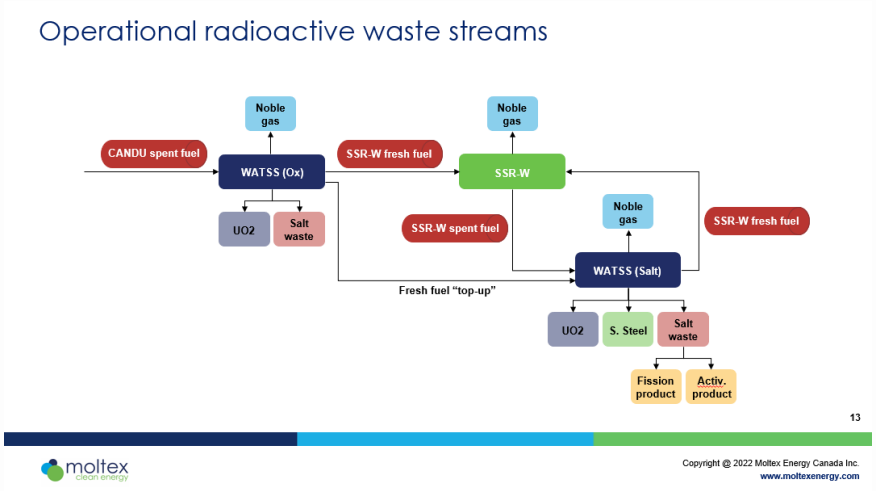
Innovation Challenge – TRISO Fueled SMRs

High Temperature Gas Reactors are planning to use TRISO fuels that, while characterized by higher enrichment and burnups, also provide a particularly robust multi-barrier containment including a stable silicon carbide layer that will last for more than a million years and graphite that does not degrade even in water [8] that should be amenable to a wide range of storage (as well as disposal) approaches



Innovation Challenge – Molten Salt Fueled SMRs

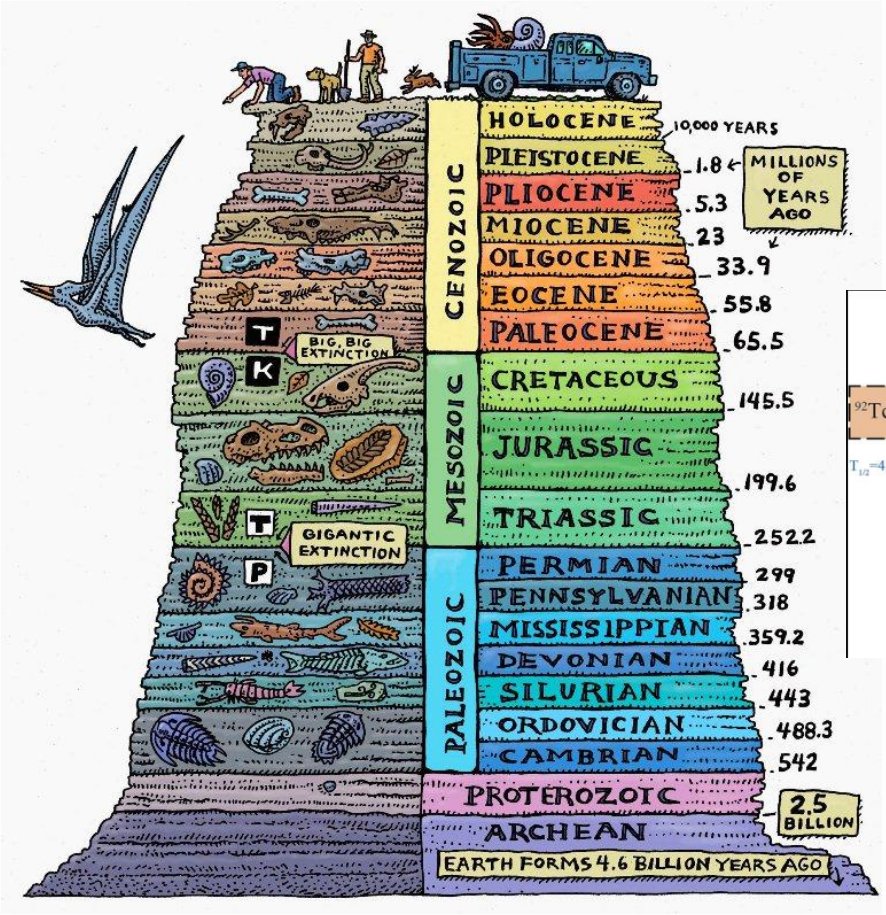
Molten salt reactors pose a unique set of materials related storage and disposal challenges. However, a significant amount of work has already been devoted to waste form and salt treatment options and scientists have expressed confidence that technical solutions are available

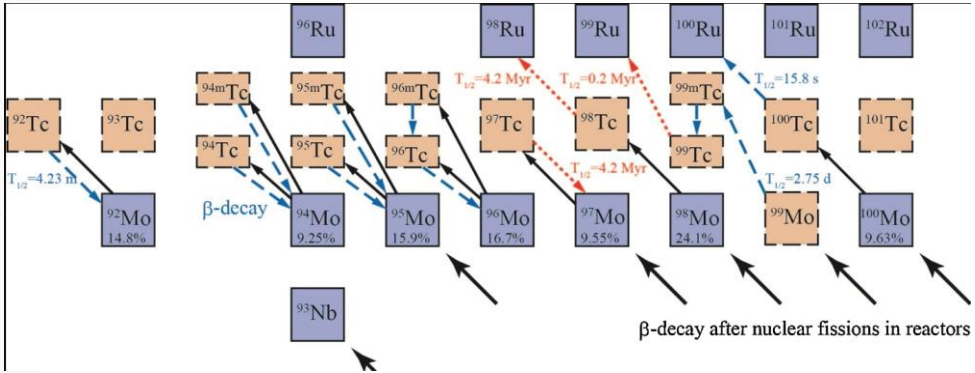


Optimizing the value of nuclear feedstock

- Future reactors may economically recycle used nuclear fuel to extract even more energy from uranium already mined

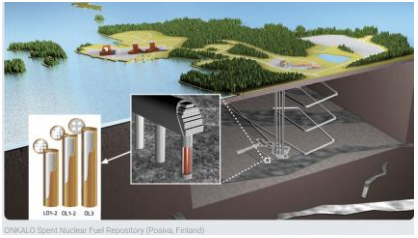
- Initial new reactor startups will be on new fuel
- Between 6 and 9 advanced reactor suppliers may be able to power their machines with used fuel
- Most envisioned recycling strategies would not separate out pure plutonium

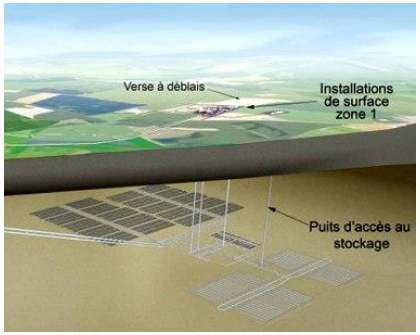




Global Context

- Nations making progress on spent nuclear fuel disposal
  - Finland – repository licensed and under construction
  - Sweden – repository approved for constructing
  - France – site identified, in public consultation toward pilot phase
  - Canada – List of 22 candidate sites narrowed down to 2, geologic investigations under way
  - Switzerland – recently selected a repository site
- All of these are following some version of a consent-based adaptive/phased process
- France, Sweden, and Switzerland all have deployed CIS
  - Swedish Gov't recently approved expansion of CIS

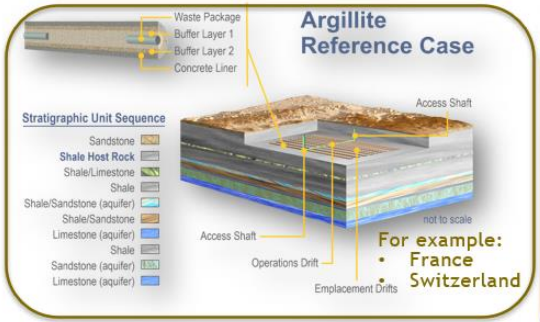


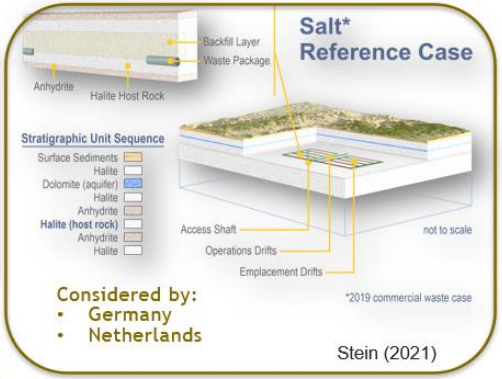


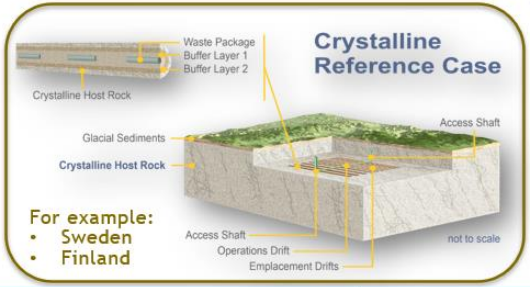
Ongoing US Repository R&D

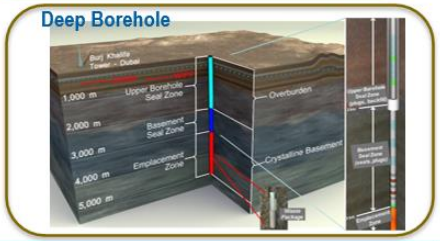
Disposal Research Overview

- Provide a sound technical basis for multiple viable disposal options in the US
- Increase confidence in the robustness of generic disposal concepts
- Develop the science and engineering tools needed to support disposal concept implementation
- Utilize international experience and develop U.S. program capabilities

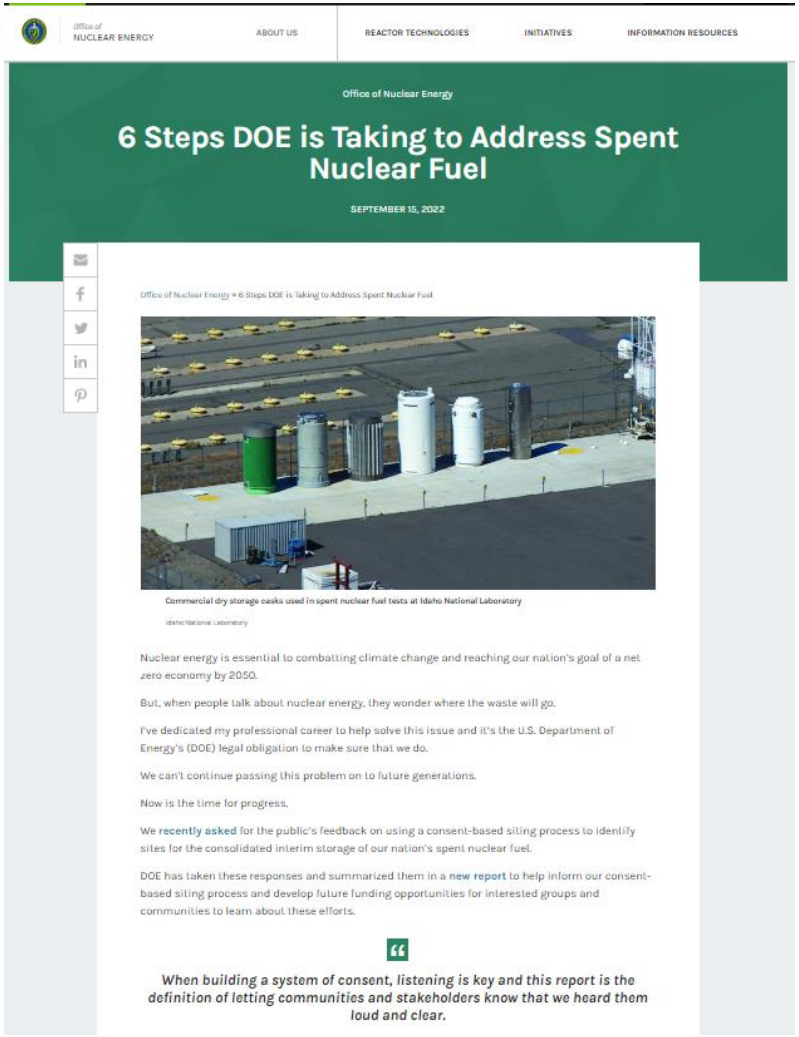








Reconfiguring the US Federal Used Fuel Management Program



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Office of Nuclear Energy

6 Steps DOE is Taking to Address Spent Nuclear Fuel

SEPTEMBER 15, 2022

Office of Nuclear Energy » 6 Steps DOE is Taking to Address Spent Nuclear Fuel

Commercial dry storage casks used in spent nuclear fuel tests at Idaho National Laboratory

Idaho National Laboratory

Nuclear energy is essential to combatting climate change and reaching our nation's goal of a net zero economy by 2050.

But, when people talk about nuclear energy, they wonder where the waste will go.

I've dedicated my professional career to help solve this issue and it's the U.S. Department of Energy's (DOE) legal obligation to make sure that we do.

We can't continue passing this problem on to future generations.

Now is the time for progress.

We recently asked for the public's feedback on using a consent-based siting process to identify sites for the consolidated interim storage of our nation's spent nuclear fuel.

DOE has taken these responses and summarized them in a new report to help inform our consent-based siting process and develop future funding opportunities for interested groups and communities to learn about these efforts.

When building a system of consent, listening is key and this report is the definition of letting communities and stakeholders know that we heard them loud and clear.

Assembling the US SMR used fuel management infrastructure are under way

UPWARDS is a $3.6 Million, 3-year project sponsored by the US office of Advanced Research Projects Agency-Energy (ARPA-E) that will support advanced reactor development and spurs innovation by establishing a universal canister design and waste form acceptance criteria for the disposal of advanced reactor waste streams by bringing together a team with broad competencies in waste form characterization, canister design and development, and geologic disposal performance modelling.