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What do new nuclear reactors mean for waste?

New designs mean new strategies for managing spent fuel.

By Casey Crownhart

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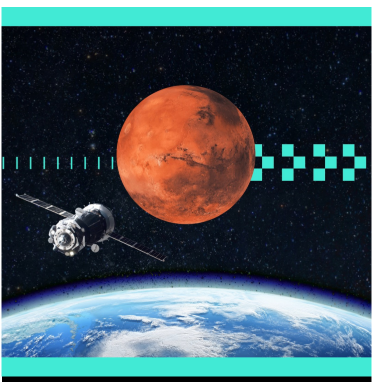
The way the world currently deals with nuclear waste is as creative as it is varied: Drown it in water pools, encase it in steel, bury it hundreds of meters underground.

These methods are how the nuclear industry safely manages the 10,000 metric tons of spent fuel waste that reactors produce as they churn out 10% of the world's electricity every year. But as new nuclear designs emerge, they could introduce new wrinkles for nuclear waste management.

Most operating reactors at nuclear power plants today follow a similar basic blueprint: They're fueled with low-enriched uranium and cooled with water, and they're mostly gigantic, sited at central power plants. But a large menu of new reactor designs that could come online in the next few years will likely require tweaks to ensure that existing systems can handle their waste.



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"There's no one answer about whether this panoply of new reactors and fuel types are going to make waste management any easier," says Edwin Lyman, director of nuclear power safety at the Union of Concerned Scientists.

A nuclear disposal playbook

Nuclear waste can be roughly split into two categories: low-level waste, like contaminated protection equipment from hospitals and research centers, and high-level waste, which requires more careful handling.

The vast majority by volume is low-level waste. This material can be stored onsite and often, once its radioactivity has decayed enough, largely handled like regular trash (with some additional precautions). High-level waste, on the other hand, is much more radioactive and often quite hot. This second category consists largely of spent fuel, a combination of materials including uranium-235, which is the fissile portion of nuclear fuel—the part that can sustain the chain reaction required for nuclear power plants to work. The material also contains fission products—the sometimes radioactive by-products of the splitting atoms that release energy.

Many experts agree that the best long-term solution for spent fuel and other high-level nuclear waste is a geologic repository—essentially, a very deep, very carefully managed hole in the ground. Finland is the furthest along with plans to build one, and its site on the southwest coast of the country should be operational this year.

The US designated a site for a geological repository in the 1980s, but political conflict has stalled progress. So today, used fuel in the US is stored onsite at operational and shuttered nuclear power plants. Once it's removed from a reactor, it's typically placed into wet storage, essentially submerged in pools of water to cool down. The material can then be put in protective cement and steel containers called dry casks, a stage known as dry storage.

Experts say the industry won't need to entirely rewrite this playbook for the new reactor designs.

"The way we're going to manage spent fuel is going to be largely the same," says Erik Cothron, manager of research and strategy at the Nuclear Innovation Alliance, a nonprofit think tank focused on the nuclear industry. "I don't stay up late at night worried about how we're going to manage spent fuel."

But new designs and materials could require some engineering solutions. And there's a huge range of reactor designs, meaning there's an equally wide range of potential waste types to handle.

Unusual waste

Some new nuclear reactors will look quite similar to operating models, so their spent fuel will be managed in much the same way that it is today. But others use novel materials as coolants and fuels.

"Unusual materials will create unusual waste," says Syed Bahauddin Alam, an assistant professor of nuclear, plasma, and radiological engineering at the University of Illinois Urbana-Champaign.

Some advanced designs could increase the volume of material that needs to be handled as high-level waste. Take reactors that use TRISO (tri-structural isotropic) fuel, for example. TRISO contains a uranium kernel surrounded by several layers of protective material and then embedded in graphite shells. The graphite that encases TRISO will likely be lumped

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together with the rest of the spent fuel, making the waste much bulkier than current fuel.

Today, separating those layers would be difficult and expensive, according to a 2024 report from the Nuclear Innovation Alliance. That means the entire package would be lumped together as high-level waste.

The company X-energy is designing high-temperature gas-cooled reactors that use TRISO fuel. It has already submitted plans for dealing with spent fuel to the Nuclear Regulatory Commission, which oversees reactors in the US. The fuel's form could actually help with waste management: The protective shells used in TRISO eliminate X-energy's need for wet storage, allowing for dry storage from day one, according to the company.

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Liquid-fueled molten-salt reactors, another new type, could increase waste volume too. In these designs, fuel and coolant are not kept separate as in most reactors; instead, the fuel is dissolved directly into a molten salt that's used as the coolant. That means the entire vat of molten salt would need to be handled as high-level waste.

On the other hand, some other reactor designs could produce a smaller volume of spent fuel, but that isn't necessarily a smaller problem. Fast reactors, for example, achieve a higher burn-up, consuming more of the fissile material and extracting more energy from their fuel. That means spent fuel from these reactors typically has a higher concentration of fission products and emits more heat. And that heat could be the killer factor for designing waste solutions.

Spent fuel needs to be kept relatively cool, so it doesn't melt and release hazardous by-products. Too much heat in a repository could also damage the surrounding rock. "Heat is what really drives how much you can put inside a repository," says Paul Dickman, a former Department of Energy and NRC official.

Some spent fuel could require chemical processing prior to disposal, says Allison MacFarlane, director of the school of public policy and global affairs at the University of British Columbia and a former chair of the NRC. That could add complication and cost.

In fast reactors cooled by sodium metal, for example, the coolant can get into the fuel and fuse to its casing. Separation could be tricky, and sodium is highly reactive with water, so the spent fuel will require specialized treatment.

TerraPower's Natrium reactor, a sodium fast reactor that received a construction permit from the NRC in early March, is designed to safely manage this challenge, says Jeffrey Miller, senior vice president for business development at TerraPower. The company has a plan to blow nitrogen over the material before it's put into wet storage pools, removing the sodium.

Location, location, location

Regardless of what materials are used, even just changing the size of reactors and where they're sited could introduce complications for waste management.

Some new reactors are essentially smaller versions of the large reactors used today. These small modular reactors and microreactors may produce waste that can be handled in the same way as waste from today's conventional reactors. But for places like the US, where waste is stored onsite, it would be impractical to have a ton of small sites that each hosts its own waste.

Some companies are looking at sending their microreactors, and the waste material they produce, back to a single location, potentially the same one where reactors are manufactured.

Companies should be required to think carefully about waste and design in management protocols, and they should be held responsible for the waste they produce, UBC's MacFarlane says.

She also notes that so far, planning for waste has relied on research and modeling, and the reality will become clear only once the reactors are actually operational. As she puts it: "These reactors don't exist yet, so we don't really know a whole lot, in great gory detail, about the waste they're going to produce."

by Casey Crownhart

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