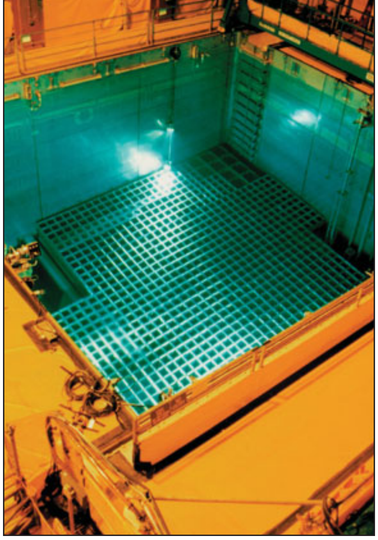

With the volume of nuclear waste building up in pools at power plants, the US needs to come up with a new disposal strategy.

United States launches new direction to manage nuclear waste

By **Prachi Patel**
Feature Editor **Rod Ewing***

The first nuclear power plant in the United States opened in 1958, and ground was broken for each of the country's 104 commercial nuclear reactors by 1974. In all these years, the United States has not decided what to do with the radioactive waste from its nuclear power plants and its nuclear weapons programs.

Approximately 70,000 metric tons of spent fuel sits at power plants, either in swimming pool-like structures or in metal or concrete casks. This waste has nearly 40 billion Curies of radioactivity, hundreds of times the amount released from Chernobyl. The number will likely double by 2040, according to a recent US Government Accountability Office report. The United States also has about 2.5 billion Curies' worth of radioactive waste leftover from its nuclear weapons program. Most of this waste is in slurry form in slurry form in underground tanks at two sites, one at Richland, Washington, and the other at Savannah River, South Carolina.

This waste will remain highly radioactive for tens of thousands of years. The Nuclear Regulatory Commission (NRC) states that storing spent fuel in casks is safe for up to 100 years. Yet, leakage poses a threat to the environment. Besides, storing the waste is expensive for utilities.

The need for permanent disposal is evident. Underground storage is thought to be the best option, and such a geologic repository was being actively developed at Yucca Mountain in Nevada, but the political decision on licensing the repository is in a stalemate.

The problem with radioactive waste disposal is that, aside from scientific and technical challenges, social and political issues dominate the discussion. Experts consider the technological issues surmountable. But disposal is a divisive and controversial sociopolitical issue. The Department of Energy (DOE) is "now reviewing a range of disposal concepts, in a sense stepping back to where we were in the early 1980s, before the program was focused on Yucca Mountain," said Peter Swift, a geoscientist at Sandia National Laboratories. There could be a silver lining to the political impasse: a chance to factor into the country's waste disposal strategy three decades of advances in materials and geological sciences, and computer modeling.

The United States has spent 20 years and nearly $15 billion trying to develop a repository at Yucca Mountain. The process started with the 1982 Nuclear Waste Policy Act, which charged the DOE with identifying and investigating three potential sites, and recommending one to the president. In 1987, Congress chose Yucca Mountain as the only site for evaluation as a potential repository, a move that was not popular with environmentalists and Nevada residents.

In 2002, the DOE recommended the site to the president, and Congress confirmed the choice. "It's said to be the most studied piece of real estate in the world," said Daniel Metlay of the Nuclear Waste Review Board. Six years later, the DOE submitted a license application to the NRC to construct the repository. But the next year, the state's senior senator, Harry Reid, a long-time opponent of the Yucca Mountain project, became Senate majority leader. In 2010, the Obama administration decided to terminate funding and shut down the entire project.

The DOE and NRC now face lawsuits from utilities and states that are storing spent fuel and defense waste. Given the issue's magnitude, the administration set up a Blue Ribbon Commission tasked with devising a plan for waste disposal. The commission's final report, released in January 2012, advocated immediately starting work on a geological repository.

This past January, in response to the commission's recommendations, the administration endorsed a plan including: a pilot interim storage facility estimated to begin operation in 2021 with Congressional approval; a larger interim facility that would accept waste by 2025; and finally a geological repository operating by 2048. The report also endorses a consent-based approach that gives communities a say in hosting a storage site.

Other countries have successfully employed this approach, although none has an operating repository yet. Sweden and Finland chose communities with access to suitable geological features and have given them the final say on hosting the facility. Officials explained potential issues, openly discussed concerns, and offered reassurance, compensation, and even medical treatment. In both countries, communities with nuclear power reactors have taken on the challenge. Britain and Canada are pursuing a similar process.

The international scientific community agrees that storing

*The information presented in this article does not reflect the views or judgments of the US Nuclear Waste Technical Review Board, which Rod Ewing chairs.

Rod Ewing, University of Michigan
Prachi Patel, prachi@lekh.org

https://doi.org/10.1557/mrs.2013.63 Published online by Cambridge University Press

nuclear waste hundreds of meters below ground in a repository is the most viable, cost-effective option. The concept sounds straightforward: put the fuel in the right waste form, enclose it in multilayer containers, and put it in underground boreholes in suitable geology.

However, characterizing a repository site can be complicated. Numerous factors are involved, from waste materials to types of host rock, many of which change over time. Plus, researchers need to estimate how well the repository will isolate radioactive waste for hundreds of thousands of years. For 37 years, the Materials Research Society's symposium entitled "Scientific Basis for Nuclear Waste Management," has addressed the challenge of safe, long-term nuclear waste disposal.

For a typical level of burn-up, spent nuclear power reactor fuel is 96% uranium oxide, mostly U-238 with some remaining U-235. The rest is a complex mixture of radioactive isotopes of elements such as strontium, cesium, plutonium, and curium. The radioactivity of used fuel changes as the radionucleotides decay, said Peter Burns, director of the Energy Frontier Research Center at the University of Notre Dame. The radioactivity of cesium-137 and strontium-90, for instance, falls by half in around 30 years. Others persist for much longer: the half-life of plutonium-239 is 24,400 years, while that of neptunium-137 is over two million years.

Host rock choice is important since it acts as a natural barrier between nuclear waste and the environment. Salt formations, clay deposits, granite, and volcanic tuff are all potential candidates. "Uranium dioxide is pretty stable unless there is oxidation," Burns said. "So the key is not being open to air." A repository should also have low water intrusion, since contaminated groundwater is the easiest way for radioactivity to leach into the environment.

Assessing the viability of the site involves above- and below-ground tests to study geology; groundwater flow in the area; the chemical composition of the groundwater; how easily water can reach the site; and how permeable the host rock is to water.

Specially designed containers offer a second safety barrier from water. The Yucca Mountain design called for encasing spent fuel rods in nickel-steel containers covered by titanium drip shields. In the Swedish fuel disposal concept, fuel rods are enclosed in a copper canister with a cast iron insert and packed in bentonite clay. Choosing the type of container involves balancing cost with structural strength and corrosion resistance. It is important to study whether local groundwater can corrode the containers, the rate of corrosion, and the effect of corrosion products. Researchers are also studying the pore structure of bentonite and examining the viability of various other borehole sealants.

John Vienna, who studies nuclear waste forms at Pacific Northwest National Laboratory, said that expensive nickel-steel containers might be unnecessary if waste is first converted into a more stable engineered form. The DOE is converting highly radioactive liquid waste from the defense program into glass. The process involves adding silica and boron oxide to the waste, heating it to 1150°C, and pouring the liquid into steel canisters, where it cools to form glass. "The waste is chemically bound inside the glass, which should be stable for a hundred thousand to a million years," Vienna said. Engineered ceramics are more durable than glass, he said, but "glass has been chosen worldwide because it is practical for treating very large volumes of waste with variable composition."

Vienna explained that spent uranium oxide fuel from power reactors could be converted to more durable forms. "But if you're going to go to that extent, you might as well reprocess the fuel."

Several countries, including France and Russia, reprocess used fuel. Reprocessing involves extracting uranium and plutonium that can be reused in a reactor. The resulting waste is treated by splitting it into different components, such as high-level liquid waste that can be immobilized in a glass. Reprocessing would cut the volume of nuclear waste needing disposal by 10%, according to Vienna. It would not, however, eliminate the need for a geologic repository. The United States reprocessed for a brief six years until 1972, pulling back amid rising concerns of nuclear weapons proliferation.

In addition to countless materials and geological studies, choosing a repository site involves complex computer modeling. That is because US regulators require a repository's safety estimate for one million years, while scientists typically understand materials behavior over decades-long lifetimes. So researchers use computer models to project a repository's performance over a longer timescale.

Regulators expect a quantitative estimate of the amount and rate of radiation that can escape from the repository, said Sandia's Swift. To calculate that, researchers build separate computational models to describe physical, chemical, and geological processes such as the rate at which each metal in the system corrodes; temperature of the host rock; and how water percolates down from the land surface. "In many models, the natural system is approximated," he said. "Limited, incomplete data is unavoidable and is a big source of uncertainty and so we use a range of inputs."

The models predict how the parameters change over long periods of time. For instance, said Swift, "if a certain metal corrodes at a certain rate in this environment, we assume it will corrode at the same rate over hundreds of thousands of years." Finally, the models are coupled together to create a simplified model of the entire system.

Over the years, with computing advances and better understanding of processes and materials, repository modeling has improved incrementally, Swift said. However, the fundamental principles underlying geological nuclear waste disposal have stayed the same. Other nations have also spent decades testing and modeling the safety of various geological sites. "Their safety assessments prove there are good reasons to believe that excellent long-term isolation could be achieved in many settings," he said.

The evidence is piling up. Experts believe that solutions to the problem of nuclear waste disposal have been or can be found. Whether political obstacles can be overcome and public trust gained remains to be seen. □

https://doi.org/10.1557/mrs.2013.63 Published online by Cambridge University Press