A COLD WAR LEGACY UNDER GLASS

After decades of delays, the most challenging nuclear-waste clean-up project in the United States is gaining ground.

BY JEFF TOLLEFSON

There's a building boom at the Hanford Site, a once-secret complex on the windswept plains of southeastern Washington state. Construction crews are working to finish a 27-metre-tall concrete structure there by June. If all goes well, the facility will finally enable the US Department of Energy (DOE) to begin treating the toxic, radioactive waste that accumulated at the site for more than 40 years, starting during the Second World War.

Decades after the site stopped producing plutonium for nuclear weapons, the legacy of Hanford's activities is still causing trouble. Just this year, a tunnel holding railway carriages full of radioactive material collapsed. Separately, at least a dozen employees who were tearing down a contaminated building reportedly tested positive for plutonium inhalation. But the site's biggest challenge lies underground, in 177 carbon-steel tanks. Together, these buried containers hold more than 200 million litres of highly hazardous liquids and peanut-buttery sludge — enough to fill 80 Olympic-size swimming pools. More than one-third of the tanks have leaked, contaminating groundwater with radioactive and chemical waste.

In a 1989 legal agreement with the state of Washington and the US Environmental Protection Agency, the DOE committed to immobilizing the most dangerous waste in sturdy glass logs through a process called vitrification. Several years later, the agency agreed to vitrify other tank waste as well. All told, the process is expected to generate tens of thousands of logs, each weighing multiple tonnes. Those containing high-level waste would be shipped to a permanent storage facility; the rest could be stored on site. But the effort has been plagued by cost overruns, delays and safety concerns. Although the DOE has spent roughly US$20 billion on the tank problem since 1997, no waste has been vitrified.

Four years ago, the agency hit reset. Rather than making a single vitrification plant, it split the project in two. One plant — the building now under construction — would begin vitrifying the less-hazardous, 'low-activity' liquid in the tanks. A bigger, more-complex plant to process the high-level sludge would follow once researchers resolved some thorny safety questions.

On both fronts, there have been signs of progress. This year, the DOE reported that it had resolved crucial questions related to treating the high-level waste. And a laboratory needed for real-time analysis of the low-level waste is nearing completion. If work continues as planned, the site could crank out its first glass logs as early as 2022.

Hanford's critics, accustomed to missed deadlines and management scandals, remain sceptical. But even officials with the state of Washington, which has battled the DOE in court for nearly three decades over clean-up goals and deadlines, are hopeful that efforts are now on track. "There's reason for optimism," says Suzanne Dahl, who oversees tank activities for the Washington Department of Ecology.

Scientists have been studying vitrification since the 1950s, and a number of countries have used the process to stabilize nuclear waste, including France, India, Russia and the United Kingdom. The United States vitrifies waste at the DOE's Savannah River Site in South Carolina. But the size and complexity of the problem is on a different scale at Hanford.

Established as part of the Manhattan Project during the Second World War, the Hanford Site delivered the plutonium that went into the first nuclear-weapon test and the bomb that was dropped on Nagasaki, Japan, in 1945. It went on to produce the bulk of the plutonium for the US nuclear arsenal. "Hanford is the whole history of nuclear development," says Ian Pegg, a physicist at the Catholic University of America in Washington DC, who works with the DOE on vitrification experiments.

TOXIC BREWS

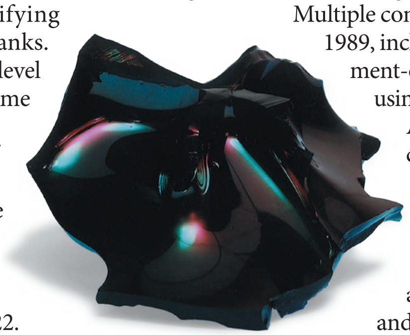
The ever-shifting suite of technologies used at the site produced uniquely toxic brews that include radioactive caesium, strontium, americium and residual plutonium; salts; heavy metals; and myriad industrial chemicals. The containers also hold other surprises. People "threw everything imaginable into those tanks", says Albert Kruger, a glass scientist with the DOE in Richland, Washington. His list includes contaminated gloves, planks of wood, rocks and tape measures.

Once such detritus is removed, vitrification calls for the waste to be combined with ingredients that include silica and boron, then heated to nearly 1,150 °C. The molten mixture is next cooled in stainless-steel canisters to create large cylinders of borosilicate glass — the same material used in oven-safe glassware.

The process is complicated by that fact that each tank contains a cocktail of chemicals and radionuclides that cannot be fully characterized until the waste is extracted. Some of those substances can weaken glass. Others, such as iodine, can't be readily trapped and must be removed. Hanford scientists will have to tailor glass recipes for each batch of waste — a bit like blending different vintages to produce a fine cognac. "Nobody will test the nose, and nobody will take a taste test, but it's an equivalent mechanism," Kruger says.

Multiple contractors have worked on the Hanford project since 1989, including British Nuclear Fuels Limited, a UK-government-owned company that exported the technology it was using at the Sellafield nuclear-decommissioning complex. After price estimates rose, in 2000 the DOE hired construction and engineering giant Bechtel of San Francisco, California, as the primary contractor.

At that time, the Hanford plant was expected to cost $4.3 billion and to begin making logs in 2007. But as engineers began working through the safety and technical details, the project ballooned in price and complexity. By 2012, senior officials — including a former DOE employee and two contractors who later filed



A sample of vitrified glass.

US DOE/OFFICE OF RIVER PROTECTION

Waste from decades of nuclear-weapons production is buried at the Hanford Site in Washington state.

KAREN KASMAUSKI/NGC

whistle-blower complaints after being fired — were raising concerns. One was that hydrogen, which is generated when heat and radiation split water molecules, would build up in tanks and pipes, creating a risk of explosion. Another was that mixing vessels meant to keep heavy particles moving would not be powerful enough. Over time, enough residual plutonium could settle out to create a dangerous chain reaction.

Then-DOE secretary Steven Chu assembled an expert panel to investigate. Ultimately, Bechtel was ordered to first construct a plant that would vitrify only liquid waste. The liquid represents 90% of the waste volume but just 10% of its radioactivity, and requires less processing than the high-level waste: it can be skimmed off, stripped of highly radioactive caesium and then sent directly to vitrification. "It makes sense," says David Kosson, a chemical engineer at Vanderbilt University in Nashville, Tennessee, who was on Chu's expert panel. If you have got to pick one place to start, he says, "the low-activity waste is not a bad choice".

LINGERING QUESTIONS

The high-level-waste facilities remain on hold, but the DOE and its contractors have spent years investigating the technical issues using computer models and prototypes. In February, the agency announced it had resolved issues related to hydrogen build-up and uncontrolled reactions. Scientists familiar with the effort says tests of a newly designed mixing vessel are nearing completion, apparently without any major hitches. The vessel is equipped with six 'pulse jet mixers' that pull waste in and out like turkey basters, to keep solids from settling.

Researchers are also making progress on the glass recipes. Kruger and external scientists have shown that certain compositions can accommodate more waste than previously estimated, and so potentially save on costs. The number of glass logs produced in the high-level waste facility could drop from 18,000 to as few as 7,000, Kruger says. The low-level plant may need to make just 70,000 logs or so, instead of 145,000.

But questions remain. A 2015 DOE report documented more than 500 vulnerabilities that could affect low-level plant operations — including some in the electrical and mechanical systems that would be used to handle radioactive materials. Tom Carpenter, executive director of the watchdog group Hanford Challenge, hopes the plant will work as advertised. But he is concerned that the DOE, its contractors and even the state of Washington are too eager to bring the facility online. "Everyone is desperate to show progress," he says. "I get that, but you can't paper over the safety issues." Senior DOE officials at Hanford declined to be interviewed for this story; a Bechtel spokesperson said the company has addressed the vast majority of concerns raised in the report and has submitted its responses to the DOE for verification.

Not everyone is convinced that vitrification is the way to go. The DOE is bound by legal agreements and nuclear-waste regulations to pursue the process, but from a technical standpoint there are better options, says Jim Conca, a consultant and former director of an independent research centre that supports the Waste Isolation Pilot Plant (WIPP) outside Carlsbad, New Mexico, the nation's only operating deep geological repository.

Hanford's high-level wastes are currently slated for disposal at Yucca Mountain, a long-stalled geological repository in Nevada. Water infiltration is a concern there, so the waste must be encased in glass to help ensure that it remains stable over thousands of years. But Conca says that the tank sludge is safe enough to simply be dried out and sent to WIPP — if regulations could be changed to allow it. Similarly, low-activity waste could be mixed with grout to create concrete-like material, which would be cheaper and, many believe, just as safe. "Does all of that waste technically need to be vitrified for environmental safety? Probably not," says Kosson. But in the end, Kosson believes that the DOE will press forward with the plan.

Chu remains confident that vitrification can work, but says the DOE should be receptive to new science and shift course as needed. More generally, he says, the country has a long way to go in resolving questions about how — and where — it will dispose of all its nuclear waste. "This is a significant problem, and there has to be a lot of good science in figuring out a better path forward," he says. "Always keep your mind open."

The price tag on Hanford's vitrification facilities now stands at $16.8 billion. Assuming that the latest timetable holds, the plant for high-level waste will open for business in the early 2030s, and operations will continue for decades. In the meantime, dangerous waste will remain underground, out of sight but not out of mind. ■

Jeff Tollefson *writes for* Nature *from New York City.*