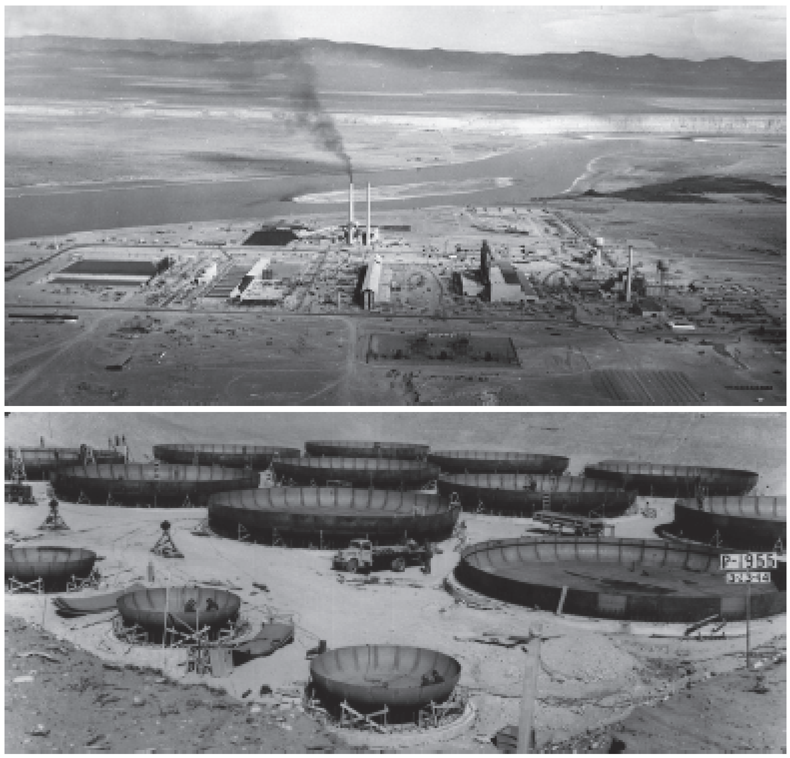
IEEE SPECTRUM

04-28-2020

A Glass Nightmare: Cleaning Up the Cold War's Nuclear Legacy at Hanford

Scientists have spent three decades cleaning up the Hanford Site's 177 giant tanks of radioactive sludge. And they're just getting started

By Maria Gallucci



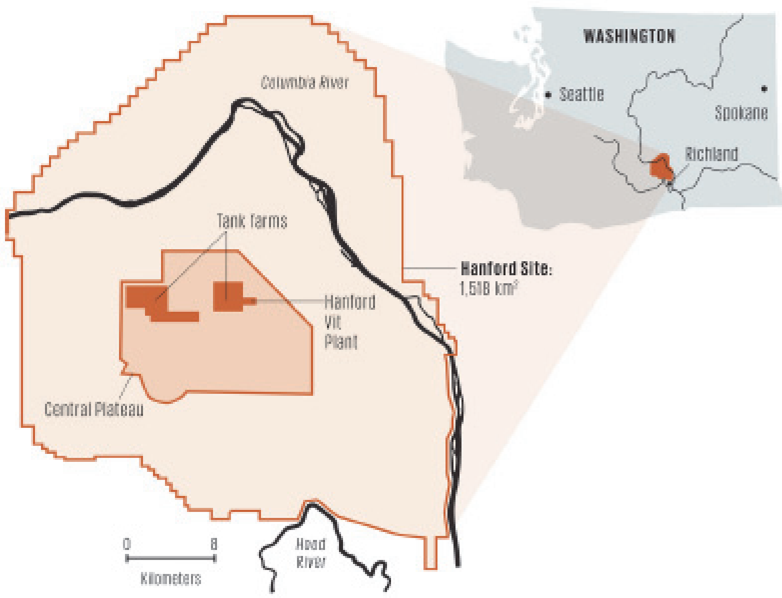
Photos: U.S. Department of Energy

The Hanford Site, in south-central Washington state, produced plutonium for nuclear weapons during World War II and the Cold War. The Hanford Vit Plant is designed to clean up the waste from that nuclear legacy.

It's a place of superlatives. Reporters have called it the most polluted place in the Western Hemisphere. It's also the location of one of the largest construction projects in the world.

At the Hanford Site in south-central Washington state, 177 giant tanks sit below the sandy soil, brimming with the radioactive remnants of 44 years of nuclear-materials production. From World War II through the Cold War, Hanford churned out plutonium for more than 60,000 nuclear weapons, including the atomic bomb that razed Nagasaki, Japan, in August 1945. The sprawling enterprise eventually contaminated the soil and groundwater and left behind 212 million liters of toxic waste—enough to fill 85 Olympic-size swimming pools. Decades after the site stopped producing plutonium, the U.S. government is still grappling with how to clean it all up.

Today the 1,500-square-kilometer site, roughly half the size of Rhode Island, is a quiet expanse of sagebrush and wispy grasses outside Richland, Wash. The underground steel-and-reinforced-concrete tanks are grouped in "farms" beneath a central plateau, while shuttered nuclear reactors stand like sentinels on the periphery. Scientists have identified some 1,800 contaminants inside the tanks, including plutonium, uranium, cesium, aluminum, iodine, and mercury. Watery liquids rest atop goop as thick as peanut butter and salt cakes resembling wet beach sand.



Map: James Provost

The waste is what's left of an intense period in wartime and Cold War innovation. Starting in 1943, Hanford experts pioneered industrial-scale methods for chemically separating plutonium from irradiated uranium, and doing so safely. Their original bismuth-phosphate process yielded hockey-puck-size "buttons" of plutonium, which were then formed into spherical cores and used in the 1945 Trinity atomic bomb test in New Mexico and then the Nagasaki bomb. Over the years, five more processes followed, culminating with plutonium uranium extraction (PUREX), which became the global standard for processing nuclear fuels.

Each of these methods produced its own distinct waste streams, which were stored onsite and then pumped into underground storage tanks. When some of the older single-shell tanks started leaking years later, workers pumped the liquids into newer, sturdier double-shell tanks. Chemical reactions ensued as the different waste products mixed together, leaving each tank filled with its own complex aggregation of liquids, solids, and sludges.

The upshot is that by 1987, when Hanford stopped producing plutonium, the tank farms contained a deadly brew of chemicals, metals, and long-lasting radionuclides. No two of the 177 tanks contain exactly the same concoction, but they all pose a significant public risk. The site borders the Columbia River, which nourishes the region's potato crops and vineyards, serves as a breeding ground for salmon, and provides drinking water for millions of people. So far, the aging, corroding vessels have leaked roughly 4 million liters. Some experts have said it's only a matter of time before more waste seeps through the cracks.

The U.S. Department of Energy (DOE), which controls Hanford, has for decades had a goal of treating and "vitrifying," or glassifying, the tank waste for safer disposal. Vitrification is a time-tested method for immobilizing radioactive waste by turning it into glass blocks. With the waste thus encased, the harmful radionuclides cannot leach into rivers or underground water tables. To enhance the isolation, the most radioactive blocks are put in steel containers, which can then be deposited in a dry and geologically stable underground vault. Vitrification plants have been built and successfully operated in Belgium, France, Germany, Japan, Russia, the United Kingdom, and the United States.

By the Numbers

Hanford's 177 waste tanks hold anywhere from 208,000 liters to 3.8 million liters.

The tanks contain a total of 212 million liters of toxic waste—enough to fill 85 Olympic-size swimming pools.

There are 149 single-shell tanks, built between 1943 and 1964, and 28 larger, double-shell tanks, built from 1968 to 1986.

But Hanford's waste is unique among the world's nuclear leftovers, in both composition and volume. Before they can turn it into glass, workers must first figure out exactly what is inside each tank and then develop glassmaking formulas for each batch.

It is a monumental task, and it's just one facet of one of the biggest engineering projects in the world. The centerpiece of the work is a series of vast facilities called the Waste Treatment and Immobilization Plant, also known as the Hanford Vit Plant, sprawled over some 25 hectares (65 acres). The

DOE currently estimates that it will cost US $16.8 billion to finish the plant, which is being built by Bechtel National and a host of subcontractors. Even as scientists continue to puzzle over Hanford's tank waste, and as contractors flip the lights on in shiny new buildings, concerns about massive cost overruns, contractor lapses, and missed deadlines weigh heavily on the project. Hanford, born and built feverishly in the heat of World War II, now seems to be in a slow, meandering slog toward an unseen finish line.

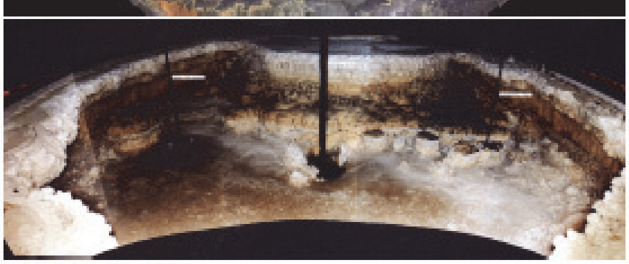
"Hanford is unique," says Will Eaton, who leads the vitrification task force at the DOE's Pacific Northwest National Laboratory (PNNL) in Richland. "There's been lots of work done on the details, to make sure we have the highest likelihood of real, efficient success when we get going. Because it's a long mission." Eaton, who is 53 years old, adds, "My goal is that the plant actually starts up before I retire."

I visited Hanford in July 2019 to get a better understanding of the many challenges facing the beleaguered vitrification project. I met Eaton on a blindingly sunny afternoon on the PNNL campus, which sits in an oasis of green trees amid the desert scrub. Hanford begins directly across the street, stretching out toward the flat ridge of Rattlesnake Mountain.

Eaton held up a clear plexiglass vessel, about 13 centimeters in diameter. In May 2018, his team used containers like this to glassify 11 liters of waste from two of the Hanford tanks. As a safety precaution, the experiment was conducted beneath a radioisotope fume hood. Those vessels contain the largest volume of Hanford waste that's been vitrified so far, after three decades and billions of dollars. Just 211,999,989 more liters to go.

1. The Tanks

For more than 40 years, radioactive waste from plutonium processing was pumped into 177 underground storage tanks on the Hanford Site [above]. Each tank contains a uniquely toxic mix of liquids, solids, and sludges [below, top]; some of the older tanks are leaking [below, bottom]. Researchers have spent decades figuring out how to treat and then safely store the waste. Tank cleanup is expected to take another 60 years and cost as much as US $550 billion.



Photos: U.S. Department of Energy

After I met with Eaton, I set off to visit Hanford. The DOE wasn't letting individual journalists visit the Vit Plant, so I opted for the next best thing: I joined a public tour of the Hanford cleanup site. About a dozen passengers and I rode in an air-conditioned bus through the reservation, most of which resembles arid parkland. Tall bluffs stand off in the distance, carved by ancient rivers. Herds of elk sought shade among spindly trees near an abandoned schoolhouse.

It's an incongruous but resonant sight. In 1943, as part of the Manhattan Project, the U.S. government seized a vast swath of land, including the towns of White Bluffs and Hanford, to build a nuclear manufacturing complex. The government ordered 1,500 homesteaders to leave their farms and towns, and Native American tribes were barred from visiting sacred fishing, hunting, and ceremonial grounds. To the west, members of the Wanapum tribe still live in a community that overlooks Hanford.

As the bus ascends the central plateau, sweeping vistas give way to rumbling forklifts, workers in hard hats, and buildings wrapped in scaffolding. Our tour guide notes that this great-nephew works here as a welder, a member of the 2,800-person construction crew.

The Vit Plant was born out of a comprehensive 1989 cleanup agreement among the DOE, the U.S. Environmental Protection Agency, and the state of Washington's Department of Ecology. Construction began in 2002 and was supposed to wrap up by 2011, at a cost of $4.3 billion. But a series of major unforeseen problems soon cropped up, including dangerous hydrogen accumulation in piping and ancillary vessels, and inadequate ventilation for managing radon and other gases that are produced as the radioactive waste material breaks down. Cost estimates soared, and timelines stretched.

Today, the Vit Plant is a complex of buildings the size of a small town. Its 56 systems require an electric power grid that could light up 2,250 houses; a chilled-water system could supply air-conditioning to 23,500 houses. A 1.3-million-liter storage tank can hold enough diesel fuel to fill the tanks of 19,000 cars at once.

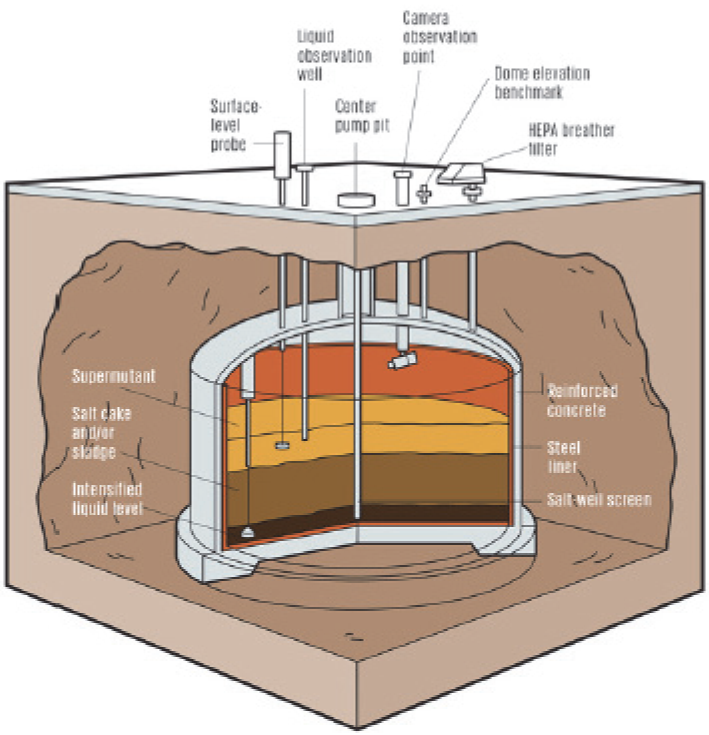


Illustration: James Provost

Some of Hanford's single-shell tanks [above] have leaked 4 million liters of waste into the surrounding soil and groundwater. The single-shell tank design was later replaced with a sturdier, double-shell design.

Even after the Vit Plant is completed, the actual cleanup will take decades more. In its *2019 Hanford Lifecycle Scope, Schedule and Cost Report* [PDF], the DOE estimated that the process of vitrifying and disposing of Hanford's waste could cost as much as $550 billion and last 60 years.

The plan calls for tank waste to flow via underground pipes to a massive pretreatment facility. This facility will eventually rise 12 stories, although during my tour it's still just an outline of metal frames, above which hovers a motionless yellow crane. Inside sealed tanks, pulse-jet mixers, working like turkey basters, will suck up the waste and eject it at high velocity, to keep the whole tank mixed and prevent solid particles from settling.

Ion exchangers will remove highly radioactive isotopes, dividing the waste stream into two groups. High-level radioactive waste makes up only about 10 percent of the total waste by volume but accounts for 90 percent of the radioactivity, Eaton says. The remaining waste is considered low-activity waste, containing very small amounts of radionuclides.

The appropriate streams will flow to separate high-level and low-activity vitrification facilities. In both, technicians will mix the waste with silica and other glass-forming materials and then pour the lot into a ceramic-lined melter. Immersed electrodes will heat the melter's tank to nearly 1,150 °C, turning the mixture into a red-hot goop of molten glass. Low-activity waste will be poured into a container made of stainless steel, where it will cool and harden into a 2.3-meter-tall, 1.2-meter-diameter log. High-level waste will go into longer, skinnier 4.4-meter-tall, 0.6-meter-diameter canisters, also made of stainless steel.

Off-gases, including steam and nitrogen oxides, will exit through a nozzle in the melter's roof, to be collected and treated to remove radioactive isotopes and keep pollutants out of the environment. Up to 1,000 steel-encased logs of low-activity waste will be produced each year and then buried in nearby trenches. The Vit Plant complex also includes an analytical laboratory, which will test some 3,000 glass samples of low-activity waste each year, ensuring that the vitrified waste meets regulatory requirements.

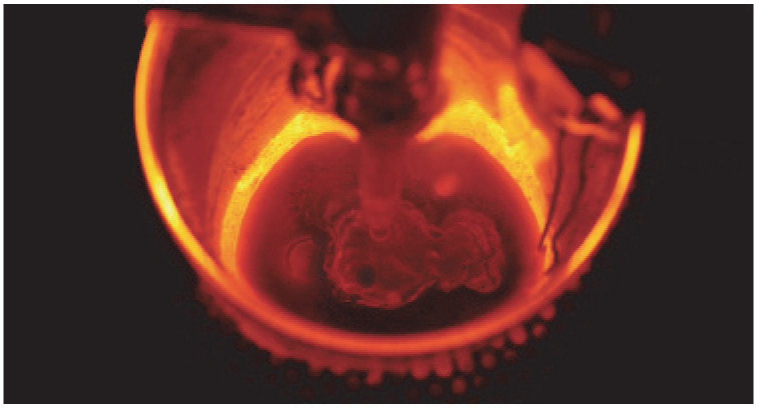
Once completed, the high-level waste plant is slated to produce some 640 canisters per year. The vitrified high-level waste is considered too dangerous to keep on-site, even inside the steel canisters. Instead, that waste will be sent to an as-yet-unidentified offsite location. The original plan called for the high-level waste to be buried in a deep geologic repository such as the proposed and long-delayed Yucca Mountain site in Nevada. Construction on Yucca Mountain began in 1994 but was halted during the Obama administration amid fierce resistance from Nevada politicians, Native American groups, environmentalists, and others. President Trump, who called for the revival of the project early in his administration, recently reversed his stance on the matter. At present, there are no plans to build a deep repository anywhere in the United States.

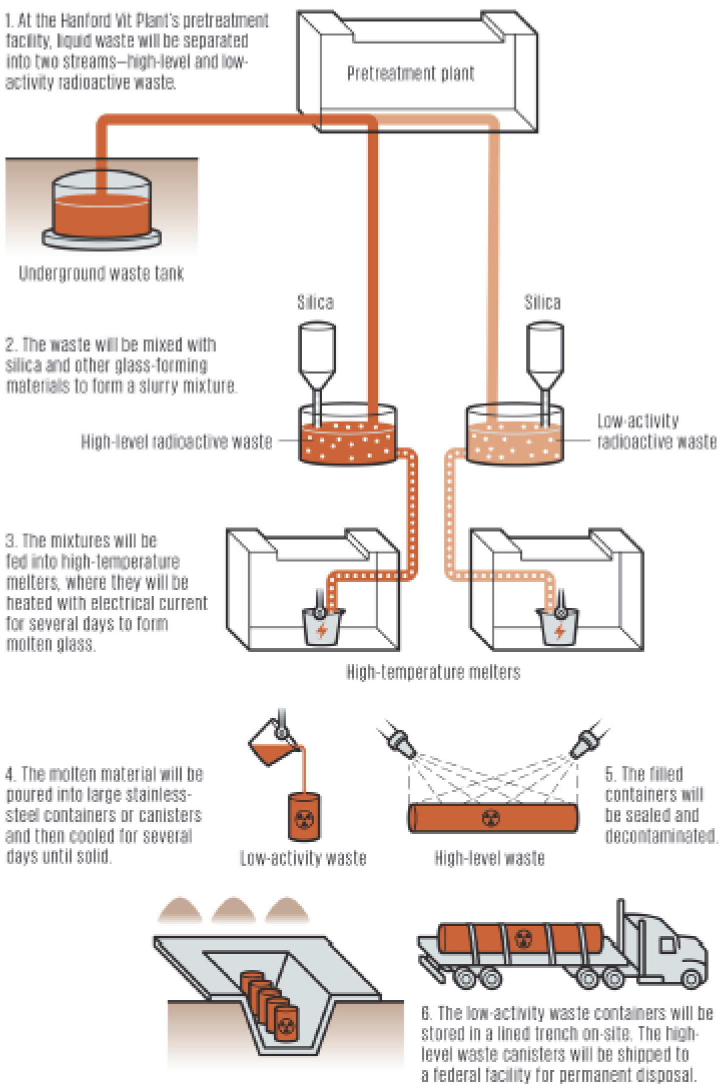
Meanwhile, Hanford cleanup experts are figuring out ways to dramatically reduce the number of vitrified logs they'll need to produce and store. When workers began building the Vit Plant 18 years ago, for instance, researchers were designing glasses that contained no more than 10 percent waste, the rest being materials necessary for glass forming. By modeling different formulas, a team at PNNL found they could double the waste portion to 20 percent, in part by finding ways to accommodate more aluminum, chromium, and other chemicals. That could halve the number of glass logs that Hanford has to produce and store.

2. Vitrification

Treating Hanford's radioactive waste involves "vitrifying" it into glass blocks for safer disposal. Other sites around the world have used vitrification to successfully immobilize their nuclear waste. But Hanford's waste is so complex and varied that scientists need to devise a unique vitrification "recipe" for each batch of waste. Eventually, stainless-steel-encased vitrified logs of low-activity waste will be buried on the Hanford Site. High-level vitrified waste will be transported to an as-yet-undetermined site.

Photo: Pacific Northwest National Laboratory/Science Source; Illustration: James Provost





As the tour bus winds its way through the Hanford Site, empty dirt patches mark the footprints of demolished buildings from the plutonium-production period. Their scraps are now interred in a massive landfill, which holds more than 16 million metric tons of low-level radioactive, hazardous, and mixed wastes. A Hanford employee on the bus points to black pipes snaking along the road; these carry contaminated groundwater away from the Columbia River and toward a central treatment plant, we're told.

During Hanford's plutonium-production heyday, workers discharged some 1.7 trillion liters of waste liquids into soil disposal sites, which developed into vast underground plumes of toxic chemicals, including the carcinogens hexavalent chromium and carbon tetrachloride [PDF], that infiltrated aquifers. Today six underground pump-and-treat systems hydraulically push contaminants toward the 200 West Groundwater Treatment Plant, a cavernous space filled with silver tubes and tall gray bioreactors. The plant's operator, CH2M Hill (now part of Jacobs Engineering Group), says it treats some 7.6 billion liters of groundwater every year. In September 2019, workers removed the last of the highly radioactive sludge that was being stored in underwater containers near the river.

Our tour complete, the bus heads back down the dusty plateau, past taco trucks and wisecracking signs: "Got Sludge? Yes We Do!"

The construction is "essentially complete, "the DOE says, on the Vit Plant's low-activity vitrification facility, analytical laboratory, and most of the smaller support buildings. But work on the pretreatment facility has been "deferred," as Hanford experts try to resolve technical questions regarding the separation and processing of waste and the design life of the facility's equipment. In late 2016, officials also decided to halt construction on the high-level vitrification facility so they could focus on treating the low-activity waste.

To make progress on the low-activity waste, the DOE's latest strategy calls for bypassing the pretreatment facility. Instead, the liquid waste will be pumped into a smaller system, near the tanks where the waste is being stored. This system will filter out large solids and remove radioactive cesium, which has a relatively short half-life but emits high amounts of tissue-damaging gamma radiation and is thus considered the most immediately dangerous of the radionuclides in the waste. The liquid will then flow directly to the low-activity waste vitrification plant to be glassified. An effluent-management facility will handle the liquid waste produced by the glass melters and off-gas treatment system.

The DOE's Office of River Protection, which oversees the tank cleanup mission, says it is on track to start processing low-activity waste this way as soon as 2022. As part of the preparations, in May 2019, Hanford workers began installing two towering, 145-metricton vessels that will hold effluent.

Last August, officials from the DOE and Bechtel National celebrated the opening of a 1,860-square-meter annex to the low-activity waste facility. The building houses the control room and operations center, where workers will perform startup and testing activities.

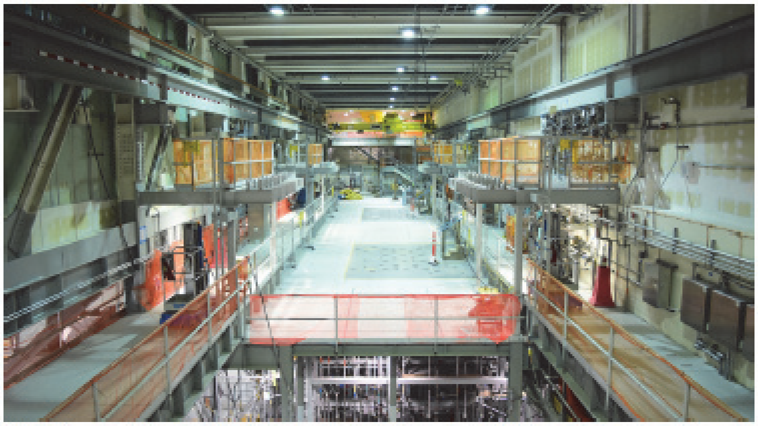
At the ribbon-cutting ceremony, the Vit Plant's project director, Valerie McCain, said, "We are getting closer to making low-activity-waste glass."

It's anybody's guess when Hanford will start vitrifying the high-level waste. The DOE says the technical issues that stalled construction have mostly been resolved but that it "cannot project with certainty" when the pretreatment and high-level waste vitrification facilities will be completed and put into service. The answer depends on many variables, including federal funding, the efficiency of contractors, and the pace of technological advances. In September, the department warned regulators in the state of Washington that it is at "serious" risk of missing deadlines to start treating high-level waste by 2033 and have the plant fully operational by 2036. The deadlines are specified in legal agreements among the DOE, the state of Washington, and other interested parties.

Meanwhile, the DOE is also studying alternative methods for treating some of the waste, including filling the tanks with a concrete-like grout, to in effect immobilize the waste in place. Officials had considered such a strategy earlier in the cleanup mission, but they ultimately ruled that vitrification was the safest, surest path for treatment.

3. Work in Progress

The US $16.8 billion Hanford Vit Plant [below, top] is designed to separate and process the Hanford Site's 212 million liters of radioactive tank waste. Under construction since 2002, it has yet to begin treating waste. Melters [below, middle left] will heat low-activity waste, silica, and other glass-forming materials to nearly 1,150 °C. The low-activity waste vitrification facility [below, bottom] will handle about 90 percent of Hanford's tank waste. Low-activity waste contains very small amounts of radionuclides. Vitrified high-level waste will be stored in stainless-steel canisters [below, middle right].



Photos, from top: Bechtel National (3); bottom: Washington Department of Ecology

Regulators as well as activists say they are frustrated to be revisiting the glass-versus-grout debate, particularly given how much work is still left on the Vit Plant. "It can be hard on folks to feel like they're beating their heads against a wall and not actually accomplishing the stuff they set out to accomplish," says Alex Smith, the nuclear waste program manager for Washington state's Department of Ecology.

Adding to the sense of inertia is the somber fact that most people working on Hanford cleanup today won't be alive to see the end results. A person in her 40s now would be a centenarian in 2078, the year the DOE expects to conclude its cleanup work.

"It's easy to say, 'Well, what do you care? You're not going to be here when the consequences of this decision hit,' " Smith adds. "It's really a challenge for our workforce, for the DOE workforce, and for people who have been working at Hanford for a long time."

To keep people aware of the Hanford mission, Smith's department is increasing community outreach, through social media and school talks. She says public awareness is key to ensuring lawmakers continue to fund the cleanup—even if most U.S. taxpayers have never even heard of it. The waste may be buried in Washington state, but it's the product of federal actions meant to safeguard the entire country, through nuclear weapons production.

"We feel that this is a national cleanup," agrees Susan Leckband, who chairs the Hanford Advisory Board. The board offers policy advice to the DOE and regulators, and it includes local experts, current and former Hanford workers, representatives from neighboring Oregon, and members of three tribal governments: Nez Perce Tribe, Yakama Nation, and the Confederated Tribes of the Umatilla Indian Reservation.

Leckband acknowledges that people outside of Washington state don't necessarily share the board's perspective. "They have their own problems," she says. "I get that. There are not unlimited funds." She worries about a growing push for "faster and less expensive" solutions to the cleanup mission, rather than a "better and more permanent" approach.

John Vienna, a materials scientist at Pacific Northwest National Laboratory, hands me a shiny rectangular glass slab. The rusty red and orange stripes are iron, he says, of which there's an abundance in Hanford's high-level waste. Vienna's team analyzes myriad materials to observe how they behave in glass. Inside the lab, cross-sections of metal canisters reveal glasslike obsidian, made from simulants of high-level tank waste. Chunks as green as emeralds contain low-activity waste simulants.

Vienna explains that the contaminants don't sit inside the glass, like beer swishing in a bottle. Rather, they become part of the "bottle" itself, atomically bound in place until the glass dissolves—which won't be for "upwards of a million years," he says. By then, the troubling radionuclides will all have decayed to relatively benign levels.

The two waste types are challenging to treat for different reasons. High-level waste contains higher levels of the "cold chemicals," such as aluminum, that were used in the more inefficient stages of plutonium production and that don't dissolve easily in glass. Low-activity waste is mostly made of sodium salts, which can make glass less durable. Glass formulations must account for these distinct complications.

Photos: Maria Gallucci
John Vienna [above, top] is a researcher at Pacific Northwest National Laboratory, in Richland, Wash. He's holding a nonradioactive mixture of water and chemicals that simulate Hanford's high-level waste. In the bottom photo are samples of some of those chemicals.

Scientists at PNNL's sprawling campus have worked on waste vitrification for more than half a century. In the 1970s, for example, the lab developed the technology for the ceramic melters at the heart of Hanford's high-level waste and low-activity waste facilities. Other U.S. locations as well as sites in Japan and Europe have used the technology to glassify their nuclear waste. Glassification began in 1996 at the DOE's Savannah River Site in South Carolina, the United States' other plutonium-production site, where some 133 million liters of radioactive liquid waste were stored. To date, a little over half of the waste has been processed. At the West Valley Demonstration Project, near Buffalo, N.Y., the DOE vitrified all 2.3 million liters of waste before demolishing the facility.

Compared to Hanford, those sites had less waste, and it was far more uniform in composition. For West Valley, scientists spent years developing one general formula that could be used to treat all of the waste, says Vienna, who worked on that project and several others. Given the sheer volume and complexity of Hanford's 212 million liters of tank waste, experts have to take a different approach.

Researchers at PNNL are creating computational models based on the behavior of actual tank waste, chemically similar simulants, and lab tests. Inside clear cabinets, they study how glass samples are affected by extremely high and low temperatures and by water, so that they can verify the glass will dissolve slowly enough to outlive the radioactive hazard. To understand the effects of time, they've examined the structures of ancient glasses, including a 2- to 4-million-year-old piece of Icelandic basalt glass and a 1,800-year-old bowl handle recovered from a shipwreck in the Adriatic Sea. The idea is that when the Vit Plant becomes operational, experts will be able to refine the glass compositions on the fly, right up until the mixtures hit the melter. Vienna's group is responsible for the modeling that will enable Hanford to double the amount of waste per glass log, for instance.

"Part of what our group does is understand how we can push the limits," says Charmayne Lonergan, a PNNL materials scientist. "As you start doing that, you start cutting back on the number of years that processing all the waste may take. You start cutting back on costs, time, labor, facilities, and resources."

Meanwhile, the clock is ticking, and an air of uncertainty still surrounds the Vit Plant. The DOE is moving to reclassify some of the nation's nuclear waste as less dangerous, which could allow it to sidestep vitrification for some of Hanford's tank waste.

Policy changes designed to accelerate cleanup have to be weighed against the safety and well-being of people who won't be born for tens of thousands of years.

In particular, the department said in June 2019 that it was changing the way it interpreted the definition of "high-level radioactive waste" at Hanford, Savannah River, and the Idaho National Laboratory. Traditionally, any by-products that result from processing highly radioactive nuclear fuels have been considered high level and must be buried in deep geological repositories. All of Hanford's waste (before pretreatment) falls into this category. The department wants to instead categorize waste based not on how it was produced but on its chemical composition.

Under the revised definition, waste from fuel processing could be considered "low-level radioactive waste" if it doesn't exceed certain radioactive concentration limits. The limit for cesium-137, for instance, is 4,600 curies (or 1.7×10^{14} bequerels) per cubic meter.

Under the new interpretation, low-level waste wouldn't necessarily have to move through Hanford's pretreatment and vitrification facilities. Some of it could potentially be turned into a groutlike form and trucked to a private waste repository in Texas. In other cases, Hanford workers could pour grout directly into tanks, as was done with seven underground vessels at Savannah River.

Federal officials and other proponents of this strategy say these steps could dramatically cut the time and cost required to treat Hanford's tank waste. PNNL and five other DOE national laboratories have voiced "strong support" for the technical merits of the new interpretation.

Paul M. Dabbar, the DOE's Under Secretary for Science, told reporters that the department will "analyze each waste stream and manage it in accordance with Nuclear Regulatory Commission standards, with the goal of getting the lower-level waste out of these states without sacrificing public safety." He said that each tank considered for classification as low-level waste would require an environmental study, under the National Environmental Policy Act.

But critics, including Washington governor Jay Inslee and the state's Department of Ecology, say that reclassifying Hanford's waste will jeopardize environmental safety and give the DOE unilateral control over the cleanup mission. In a letter to the DOE, leaders of the Yakama Nation expressed their concern that the changes would lead to more contamination at the site and "a lower standard of clean-up."

This latest controversy highlights the constant calculations that officials, regulators, activists, and citizens must make in confronting Hanford's toxic legacy. Policy changes designed to accelerate cleanup have to be weighed against the safety and well-being of people who won't be born for tens of thousands of years. Waste treatment methods are viewed through the prism of limited, and often dwindling, congressional funding. Scientific results don't exist in a vacuum—they are interpreted according to political motives, public opinions, and business interests.

Leckband, the Hanford Advisory Board chair, says it's important to take the long view. "Our mantra is, we want the best cleanup possible—for the public, the people who are paying for it, the people who will be drinking the water, breathing the air, and eating the vegetables in the entire Pacific Northwest as well as the country," Leckband says. "It needs to be done not just for us, but also for future generations."

This article appears in the May 2020 print issue as "What to Do With 177 Giant Tanks of Radioactive Sludge."