Radwaste Solutions

Spring 2021

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Ch-ch-changes

The only constant, as the saying goes, is change. That saying, by the way, is attributed to the ancient Greek philosopher Heraclitus. I looked it up. We have seen a fair amount of change lately, from changing administrations to changing routines (thank you, COVID-19) to changing weather. I note that last one because, here in the Midwest, we've experienced a bit of weather whiplash, with one of the top 10 warmest Januarys on record followed by a brutally cold polar vortex in February.

Radwaste Solutions has changed, too, with a new, updated look to match our sister publication, *Nuclear News*. We hope you like the new look. You will still find here the same important and informative content on all things related to radiological decommissioning, remediation, and waste management. That hasn't changed.

And with the start of a new year and a new administration, it is an appropriate time to consider what changes may lie ahead. While the Trump administration, before leaving office, drew up a fiscal year 2022 budget, it is certainly likely that President Biden will submit his own budget sometime this spring. (Budgets are due to Congress the first Monday in February, but are typically delayed several months when a new administration takes office.)

What that budget will look like remains to be seen, but the overarching question is what will be the effect of the continuing health crisis on other budgetary priorities. Given that COVID-19 relief has already contributed more than $3.1 trillion to the federal deficit, and Biden is asking for an additional $1.9 trillion in relief, what will be the president's and Congress's appetite for spending within the Department of Energy and elsewhere? Will the cleanup of the nation's legacy radioactive waste be considered an integral part of the economic recovery, deserving of funding, or will it be seen as a deferrable expense?

And what of the many publicly funded research programs, such as the salt repository testing being done at the Waste Isolation Pilot Plant, as described in the article beginning on page 50. Will these research projects, important as they are to moving forward with the safe management of our nuclear waste, be judged as arcane and inconsequential pursuits?

One thing that is unlikely to change, however, is the public and political aversion to the Yucca Mountain Project. Biden's choice for energy secretary has already confirmed the administration's opposition to the Nevada repository (see Source Points, beginning on page 8, for more). With Yucca Mountain, another aphorism comes to mind: The more things change, the more they stay the same. (Apparently, the French writer Jean-Baptiste Alphonse Karr coined this one. Again, I looked it up.)

But let's go back to our friend Heraclitus. He also, I learned, propounded the doctrine of the unity of opposites, which—and I'm sure I'm oversimplifying here—can be characterized as there being two sides to every coin.

With this in mind, let's look at the two sides of Yucca Mountain. There's Yucca Mountain "the project," which has been denounced by opponents claiming that events such as earthquakes or volcanic eruptions would inevitably release large amounts of radioactive materials. This is Yucca Mountain the myth.

Then there is Yucca Mountain "the geology." As the geologist Dennis O'Leary demonstrates in the article beginning on page 36, even within the long expanse of geological history, Nevada's Great Basin, in which the mountain is located, has seen little change. It is, in essence, a dead landscape. This is Yucca Mountain the reality.

How these two opposites will play out is not yet clear. But I will leave you with another saying, paraphrased from a quote by the bicycle racer Tyler Hamilton (yes, I looked it up): The truth always finds its way out.—*Tim Gregoire, Editor*

Tim Gregoire, editor-in-chief

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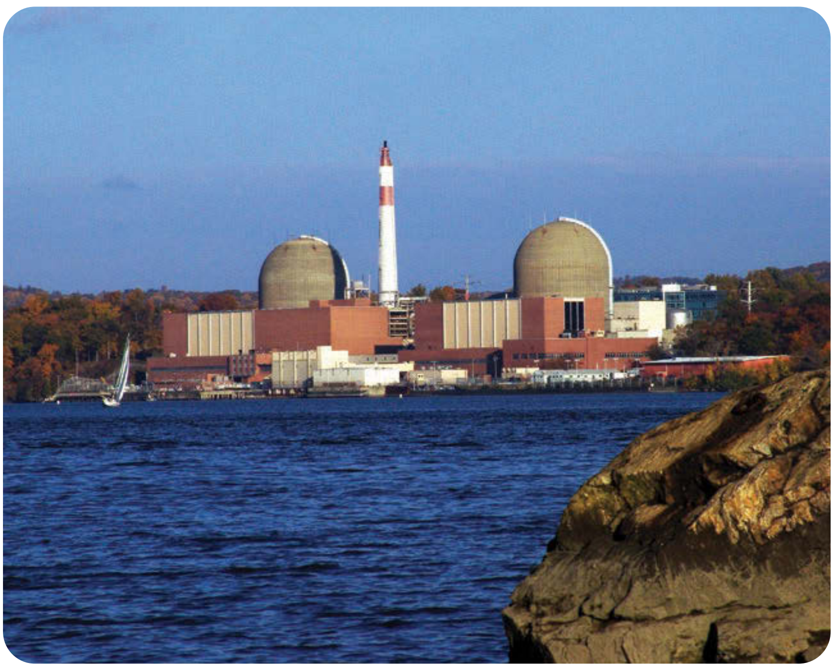
NRC approves license transfers of Indian Point, TMI-2 for decommissioning

The Nuclear Regulatory Commission has approved the transfer of licenses for the Indian Point nuclear power plant in New York and the Three Mile Island Unit 2 power reactor in Pennsylvania for prompt decommissioning. Indian Point will transfer from Entergy to Holtec International, as owner, and Holtec Decommissioning International (HDI), as decommissioning operator, while TMI-2 Solutions, a subsidiary of Utah-based EnergySolutions, will take over TMI-2 from FirstEnergy Companies.



Indian Point's license will transfer to Holtec for decommissioning after the plant shuts down this year. Photo: Entergy

The Indian Point license transfer follows the transfer of the licenses of the Oyster Creek nuclear plant from Exelon and the Pilgrim plant from Entergy to Holtec in mid-2019. As with the Oyster Creek and Pilgrim plants, Holtec and HDI intend to expedite the decommissioning and dismantling of Indian Point.

The NRC order approving Indian Point's license transfer, issued on November 23, 2020, is effective immediately, but the license transfer will not be finalized until after the permanent shutdown of Unit 3 and the completion of the transaction between Entergy and Holtec. At that point, the NRC will amend Indian Point's licenses to reflect the completion of the transfer.

Indian Point's three pressurized water reactors are located in Buchanan, N.Y., approximately 24 miles north of New York City. Units 1 and 2 have been permanently shut down, in 1974 and 2020, respectively, and Unit 3 is scheduled to be shut down in April. The license transfer also includes the plant's independent spent fuel storage installation (ISFSI). According to Holtec, the company is on target to begin transferring spent fuel from Indian Point's spent fuel pools to the ISFSI pad in less than two-and-a-half years after the reactor's shutdown.

The NRC announced the approval of TMI-2's license transfer to TMI-2 Solutions, effective immediately, on December 2, with the license to be

Source Points continues

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amended to reflect the new ownership once the sale of TMI-2 is completed. The New Jersey Board of Public Utilities has approved the sale of the reactor to TMI-2 Solutions, EnergySolutions announced the same day.

Located near Middletown, Pa., TMI-2 experienced a partial meltdown on March 28, 1979. The reactor was placed in a safe and stable storage condition known as post-defueling monitored storage, and its nuclear fuel was moved to a storage facility at Idaho National Laboratory. The license currently authorizes only the possession of by-product and special nuclear materials remaining at the reactor.

To perform the decommissioning work on the TMI-2 project, EnergySolutions and the New Jersey-based construction company Jingoli formed a joint venture called ES/Jingoli Decommissioning LLC.

The NRC commissioners approved the license transfers of Indian Point and TMI-2 while challenges to the transfer applications are still being adjudicated. NRC regulations allow staff to approve a license transfer under the condition that the commissioners may later move to "rescind, modify, or condition the approved transfer based on the outcome of any post-effectiveness hearing on the license transfer application."

New York is currently suing the NRC over the sale of Indian Point to Holtec. The suit challenging the NRC's denial of New York's petition for a hearing regarding the license transfer was filed in the U.S. Court of Appeals for the District of Columbia Circuit on January 22.

Also in January, New York Gov. Andrew Cuomo signed first-in-the-nation legislation giving the communities around Indian Point the ability to collect taxes on the spent nuclear fuel that will be left behind when the power plant shuts down. The law designates spent fuel stored in on-site wet or dry storage as real property that can be assessed.

Source Points continues

DECOMMISSIONING

Holtec applies to decommission Michigan's Palisades

Entergy Corporation and Holtec International jointly submitted in late 2020 an application to the Nuclear Regulatory Commission for approval of the transfer of the licenses for the Palisades nuclear plant, in Covert, Mich., to Holtec, following the plant's permanent shutdown and defueling in the spring of 2022. Holtec intends to decommission the single-unit pressurized water reactor on an accelerated schedule through its subsidiary Holtec Decommissioning International (HDI).

The application, dated December 23, also requests approval of the license transfer of Entergy's decommissioned Big Rock Point facility near Charlevoix, Mich., where only the independent spent fuel storage installation (ISFSI) remains. The acquisition of Palisades and Big Rock Point would expand Holtec's decommissioning fleet to seven reactor units, joining Oyster Creek, Pilgrim, and the three reactors at Indian Point, which the NRC approved for transfer in November 2020.

Holtec aims to complete the dismantling, decontamination, and remediation of Palisades by 2041, more than 40 years sooner than if Entergy had decided to continue its ownership of the facility and had chosen the NRC's 60-year SAFSTOR option for decommissioning, according to the companies. All of the fuel in the plant's spent fuel pool is to be moved into dry cask storage at the Palisades ISFSI within three years of shutdown, with major decommissioning work beginning around 2035.

On February 4, the NRC opened for public comment the Palisades license transfer proceedings, with the opportunity to request a hearing and petition for leave to intervene.

HDI will begin decommissioning the Palisades nuclear plant after it is shut down in 2022. Photo: Entergy

NRC rejects challenge to Pilgrim's license transfer

The Nuclear Regulatory Commission has denied a request by the antinuclear group Pilgrim Watch for a hearing in the transfer of the Pilgrim nuclear power plant's license from Entergy to a subsidiary of Holtec International for decommissioning. The NRC commissioners issued the order denying Pilgrim Watch's petition to intervene and request a hearing on November 12, 2020.

Pilgrim Watch submitted its petition against the transfer of Pilgrim's license from Entergy to Holtec Decommissioning International in February 2019. The NRC staff, however, approved the transfer in August 2019, while the petition was still under review. The transfer approval is subject to the NRC's authority to rescind, modify, or condition the transfer, based on the outcome of any subsequent hearings on the application. Pilgrim, a single-unit, 688-MWe boiling water reactor located in Plymouth, Mass., permanently ceased operations in May 2019.

A separate petition against the license transfer submitted by the state of Massachusetts was withdrawn in June 2020, following a settlement agreement between the state and Holtec.

The Pilgrim nuclear power plant was shut down in May 2019. Photo: Entergy

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Energy Secretary Dan Brouillette speaks during an October 2020 celebration marking the completion of the cleanup of Oak Ridge's East Tennessee Technology Park. Photo: DOE

OAK RIDGE

DOE celebrates realization of Vision 2020 cleanup goal

The completion of the decades-long effort to clean up the former Oak Ridge Gaseous Diffusion Plant was celebrated on October 13, 2020, with then Energy Secretary Dan Brouillette joining U.S. Sen. Lamar Alexander, U.S. Rep. Chuck Fleischmann, Tennessee Gov. Bill Lee, and other state and community leaders at the East Tennessee Technology Park (ETTP), where the uranium enrichment complex once stood.

"We are not only celebrating reaching this achievement, but also how this achievement will impact the future of this region moving forward," Brouillette said. "We turned what was once an expensive government liability that presented risks to the community into an asset that the community can use to usher in new growth for East Tennessee."

The Oak Ridge Office of Environmental Management (OREM) and its cleanup contractor, UCOR, marked the

Source Points continues

realization of Vision 2020, OREM's goal of completing major environmental cleanup of the ETTP by the end of the year. Innovations in the handling, transporting, and disposing of waste made most of the savings to cost and schedule possible, the DOE said.

Decontamination and decommissioning of the plant began in the early 2000s and involved removing more than 500 deteriorated and contaminated buildings that could span the footprint of 225 football fields. As land and buildings were remediated, the site was transitioned into an industrial park, the ETTP, for use by private companies.

Earlier in 2020, the DOE's Office of Environmental Management completed construction on the K-25 History Center. Future plans include the construction of additional facilities to educate visitors about the site's Manhattan Project and Cold War operations. The foundation of the mile-long K-25 Building, once the largest building in the world, is now part of the Manhattan Project National Historical Park. With the accompanying history center, the site's legacy is preserved for future generations.

Experimental reactor prepared for deactivation

Also in October, the Department of Energy announced that the Oak Ridge Office of Environmental Management (OREM) is set to begin cleanup of the Experimental Gas-Cooled Reactor at the Oak Ridge National Laboratory.

OREM and cleanup subcontractor UCOR are in the planning stages to fully deactivate the reactor for eventual demolition. The reactor is one of 16 inactive research reactors and isotope facilities that OREM is addressing and cleaning up at Oak Ridge. The cleanup effort will happen concurrently with other OREM cleanup projects underway at the Y-12 National Security Complex in Oak Ridge.

"We are taking full advantage of the highly skilled workforce that recently completed cleanup at [East Tennessee Technology Park]. Their familiarity with the hazards, the type of facilities, and lessons learned make them ideal for this work and add cost efficiency to our project," said UCOR project manager Susan Reid.

Source Points continues

OREM and cleanup contractor UCOR are set to fully deactivate the Experimental Gas-Cooled Reactor at Oak Ridge for eventual demolition. Photo: DOE



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U-233 downblending restarts following facility upgrades

The processing and downblending of uranium-233 for disposal has resumed at Oak Ridge National Laboratory, following a pause in operations due to the COVID-19 pandemic, the Department of Energy announced in October. Removal and disposition of the U-233 is one of the DOE Office of Environmental Management's highest priorities at the site, as stated in its strategic vision released in early 2020.

A fissile material handler uses a shielded glovebox to dissolve U-233 into a low-level form so that it can be mixed with grout for safe transportation and disposal. Photo: DOE

The project is removing a significant risk by eliminating the inventory of highly enriched fissile material stored in Building 3019, the world's oldest operating nuclear facility, according to the DOE. Employees, known as fissile material handlers, use shielded gloveboxes to dissolve U-233 into a low-level form so that it can be mixed with grout for safe transportation and disposal. The material dates back decades and was originally pursued as a fuel for reactors; however, it did not prove to be a viable option.

The DOE's Oak Ridge Office of Environmental Management and its contractor Isotek worked collaboratively during the operational pause to install upgrades and identify and implement a number of methods to ensure employee safety.

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Crews cleaned and demolished COLEX equipment on the west end of the Alpha-4 building at the Y-12 National Security Complex. Photo: DOE

Y-12 cleanup project recovers, reuses mercury

The Department of Energy's Oak Ridge Office of Environmental Management and its contractor UCOR have found a way to reuse instead of dispose of mercury collected from a cleanup project at Oak Ridge's Y-12 National Security Complex. The DOE is conducting a number of projects to address mercury contamination—the most significant environmental risk is at Y-12, according to the agency.

The work includes the cleanout and removal of equipment at Y-12's Alpha-4, a building that was used initially for uranium separation in 1944 and 1945. Ten years later, the building started being used for lithium separation, a process that required large amounts of mercury and involved column exchange (COLEX) equipment.

Although the COLEX equipment was drained when operations ended at Alpha-4 in the 1960s, recoverable amounts of mercury remained in the aging lines and

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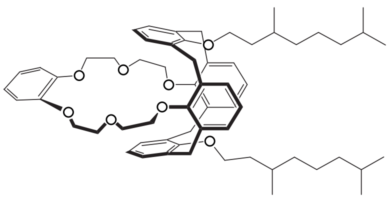


equipment. Cleanup crews have so far retrieved more than 10,000 pounds of mercury, the DOE announced on January 26. The retrieved material was usually sent offsite to be treated for its subsequent storage.

Recently, instead of being sent to interim storage, a batch of nearly 1,200 pounds of mercury was shipped to Oak Ridge National Laboratory after being purified to laboratory-grade quality. It will be used by researchers in an experiment to determine physical properties for liquid metal flow. The data gained from this research will inform models for innovative concepts for material transfer and storage in a variety of fields.

SAVANNAH RIVER SITE

Full operations begin at Salt Waste Processing Facility

The hot commissioning testing phase of operations at the Salt Waste Processing Facility (SWPF) has been completed, signaling the facility's entrance into fully integrated operations with the other liquid waste facilities at the Department of Energy's Savannah River Site in South Carolina.

Radiation shielding, environmental emissions, and product waste acceptance requirements were all tested and validated during the commissioning phase of the SWPF, the DOE announced on January 19. The SWPF will treat the approximately 31 million gallons of remaining salt waste currently stored in underground tanks at SRS.

Parsons Corporation, the contractor that designed and built the first-of-a-kind facility, will operate the SWPF until January 2022. It is anticipated that the facility will process up to 6 million gallons of waste during the first year of operations.

Processing of the radioactive waste began in early October 2020, and by mid-November the SWPF had begun processing undiluted feed from Tank 49 in Savannah River's H Tank Farm. According to the DOE, all hot commissioning testing objectives were met on schedule and without incident. In total, more than 450,000 gallons of decontaminated salt solution have been transferred from the SWPF.

The startup of the SWPF is the last major piece of the liquid waste system at SRS and, according to the DOE, represents a significant leap forward in the department's ability to tackle the largest and one of its most challenging environmental risks—legacy radioactive tank waste. With the SWPF fully operational, it is expected that nearly all of the salt waste inventory at SRS will be processed by 2030.

More on the SWPF can be found in the article beginning on page 58.

An aerial view of the Salt Waste Processing Facility at the Savannah River Site. Photo: DOE

Source Points continues

HANFORD

Evaporator gets upgrades in preparation of DFLAW

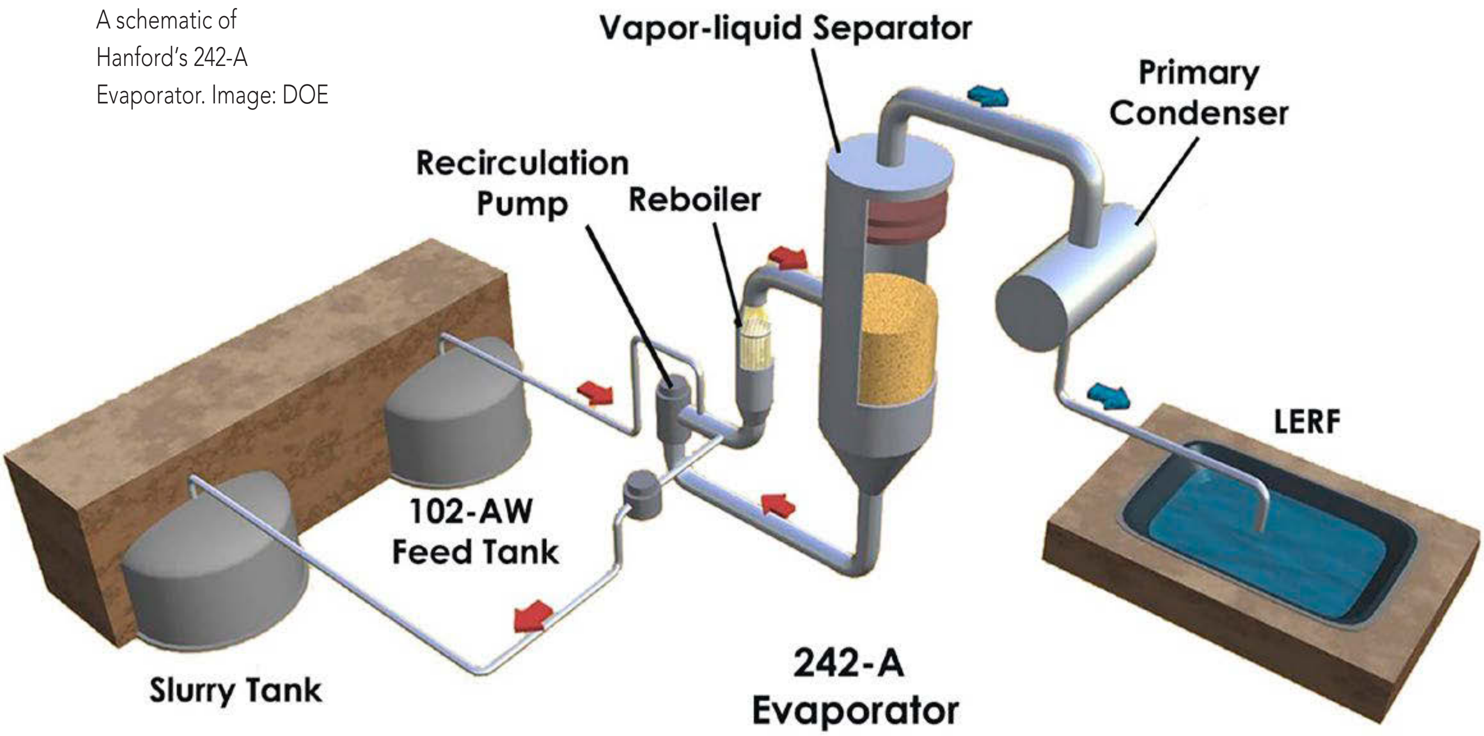
Improvements to Hanford's 242-A Evaporator Facility continue to be made as the Department of Energy prepares to begin its Direct-Feed Low-Activity Waste (DFLAW) approach to treating radioactive liquid waste at the site near Richland, Wash. The DOE announced in early November that its Office of River Protection and contractor Washington River Protection Solutions (WRPS) have completed several major upgrades and repairs at the evaporator, and more are planned.

Used to reduce waste volume by removing liquid from Hanford's underground storage tanks, the 242-A Evaporator is fundamental to the Hanford Site tank waste mission and will play an essential part in the DFLAW treatment approach, according to the DOE.

Recent improvements to the 242-A Evaporator include a new instrument air dryer and a new air receiver tank and piping. Workers also upgraded the facility's monitoring and control system, updating system hardware and software, and improving cybersecurity, the DOE said.

In addition, designs for replacing three waste transfer lines were recently completed by WRPS. Double-walled piping is used to move tank waste from double-shell tanks to the evaporator for reduction and to send the resulting slurry back to a tank.

Other improvements will include a safety system upgrade that will increase the efficiency of equipment testing required prior to an evaporator campaign. All improvements to the 242-A Evaporator, including the installation of the new waste transfer lines, are expected to be completed in fiscal year 2022, according to the Hanford website, hanford.gov. The DOE aims to begin treating waste using DFLAW by the end of 2023. (Turn to page 58 for more on Hanford's liquid waste program.)



A schematic of Hanford's 242-A Evaporator. Image: DOE

Source Points continues

Hanford workers discuss LAW Facility mechanical equipment testing on the two units that make up the "bogie," or cart transport rail system. Photo: DOE

WTP container transport system tested

Startup engineers at the Hanford Site's Waste Treatment and Immobilization Plant (WTP) have been performing mechanical equipment testing on the two units that make up the "bogie," or cart transport rail system, in the lower level of the Low-Activity Waste (LAW) Facility.

During future plant operations, containers will be filled with vitrified radioactive and chemical waste and placed on the bogie transport rail that leads to the facility's finishing line area before the containers are moved to storage. To date, all 94 systems in the LAW Facility have been turned over to startup, and 38 of those have been handed over for commissioning, according to the DOE on January 26.

In the LAW Facility, concentrated low-activity waste will be mixed with silica and other

Source Points continues

glass-forming materials. The mixture will be fed into the facility's two melters and heated to 2,100 °F. The 300-ton melters are approximately 20 feet by 30 feet and 16 feet high, and, when completed, will be the largest waste glass melters in the world, according to the DOE. The glass mixture will then be poured into stainless steel containers, which are 4 feet in diameter, 7 feet tall, and weigh more than 7 tons.

The low-activity waste containers will be stored on the Hanford Site in permitted trenches and covered with soil. (More on Hanford's LAW Facility can be found in the article beginning on page 58.)

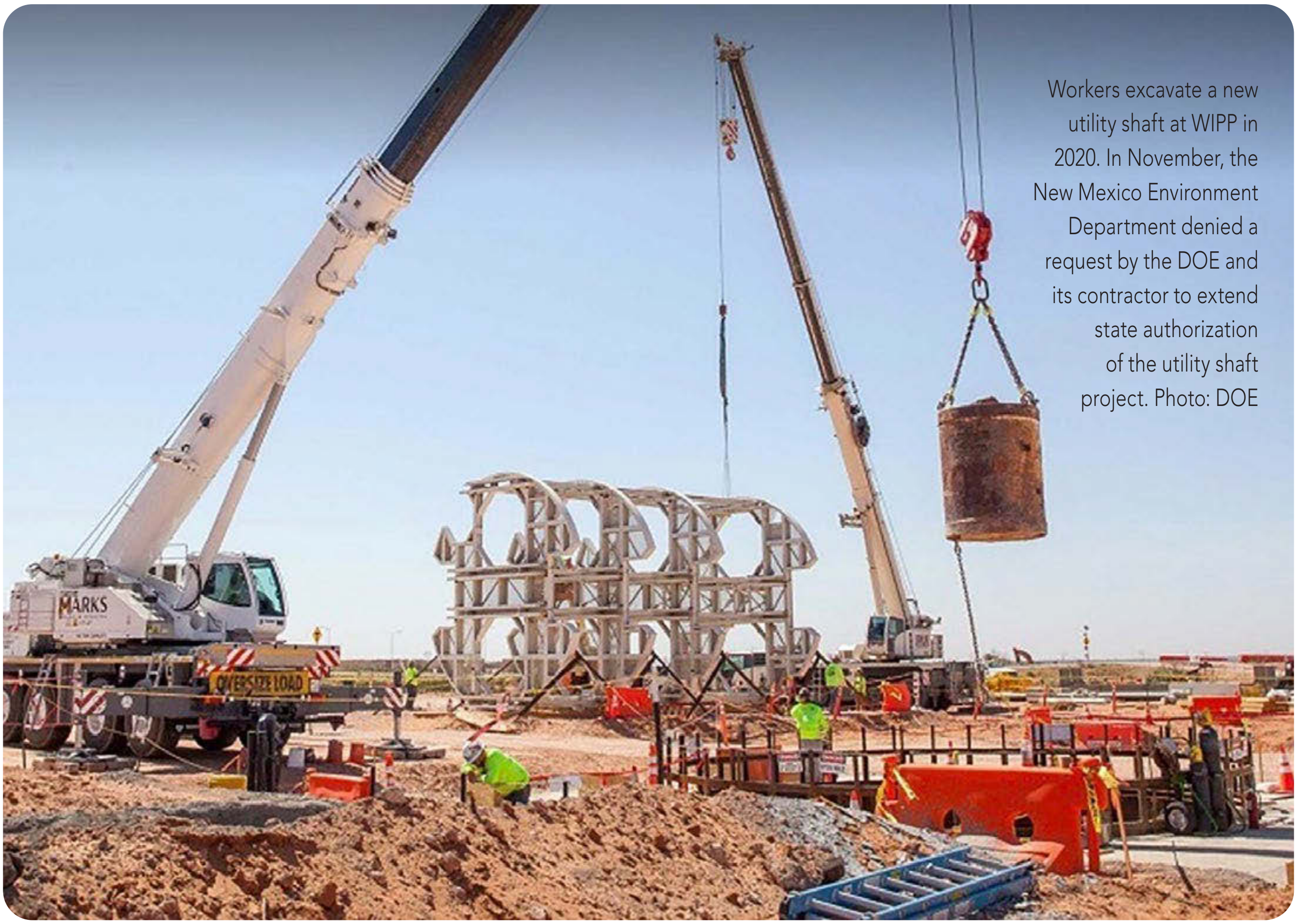
WIPP

Repository risks running out of disposal space, GAO says

A study of the Department of Energy's Waste Isolation Pilot Plant in New Mexico has found that the repository faces long-term issues with ensuring sufficient physical space and statutory capacity to dispose of the federal government's inventory of transuranic (TRU) waste. WIPP is the United States' only repository for the disposal of TRU waste generated by the DOE's nuclear weapons research and production.

The Government Accountability Office study, *Better Planning Needed to Avoid Potential Disruptions at Waste Isolation Pilot Plant* (CAO-21-48), was published on November 19, 2020.

The DOE recently increased the statutory capacity of WIPP by changing the method of calculating waste volume to exclude the air space around some



Workers excavate a new utility shaft at WIPP in 2020. In November, the New Mexico Environment Department denied a request by the DOE and its contractor to extend state authorization of the utility shaft project. Photo: DOE

Source Points continues

waste packages. The DOE also plans to expand the physical space of the repository by excavating new disposal rooms, called panels.

The GAO, however, found that the DOE may run out of room to meet future TRU waste disposal needs at WIPP if significant volumes of waste are added to DOE's inventory or if the permit modification authorizing the revised volume counting method is successfully challenged in court. Most notably, the GAO notes that the National Nuclear Security Administration's plan to produce around 80 plutonium pits per year by 2030 could generate 566 cubic meters of additional TRU waste a year for up to 50 years.

DOE officials informed the GAO that in addition to the TRU waste generated through plutonium pit production, other waste streams are currently under consideration for disposal at WIPP but are not yet part of DOE's TRU waste inventory because they do not meet the criteria for inclusion.

The GAO also found that the DOE does not have assurance that WIPP's planned additional physical space will be constructed before the existing space is full, which would result in a potential interruption to disposal operations.

In addition to the space constraints, the GAO report found that WIPP may not have sufficient staff to address challenges in completing key ventilation projects needed to return the site to full waste disposal operations following the accidental release of radiological contamination in 2014. Currently, the DOE is undertaking two capital asset projects to increase ventilation to the underground—the installation of the Safety Significant Confinement Ventilation System and the construction of a new utility shaft. According to the GAO, the DOE is facing challenges in identifying contractors who are qualified to execute these two projects, as well as in obtaining the necessary regulatory approvals to complete them.

In its report, the GAO recommended that the DOE identify and analyze options to address staffing vacancies, update its schedule for adding physical space at WIPP, and develop a plan for mitigating the impacts that an interruption to WIPP's waste disposal operations would have on the DOE's TRU cleanup program. The DOE agreed with all three recommendations.

LOW-LEVEL WASTE

NRC withdraws LLW rule interpretation

The Nuclear Regulatory Commission has withdrawn a proposed interpretation of its low-level radioactive waste regulations that would have permitted licensees to dispose of waste by transferring it to persons who hold specific NRC exemptions. "The proposal is being withdrawn based on the NRC staff's assessment that the proposed changes may not benefit the regulatory framework for the disposal of low-level radioactive waste," the NRC said in a *Federal Register* notice.

After releasing the proposed rule for public comment on March 6, 2020, the NRC received about 200 individual comment submissions and approximately 15,000 form letter submissions, the vast majority of which were in opposition to the proposed rule.

"We have strongly disputed the argument by various groups who misrepresented the proposal as deregulation of radioactive waste disposal," NRC spokesperson David McIntyre told the *Courthouse News Service* in a December 16 report. "This would not have changed anything, just made an existing case-by-case approval process more efficient."

The proposed rule would have expanded NRC guidance on who is an authorized recipient of radioactive waste, allowing very low-level radioactive waste (VLLW) to be disposed of at approved non-licensed disposal sites. A licensee would be allowed to dispose of VLLW at a hazardous and solid waste facility—if it had been granted an exemption by the NRC to dispose of such waste—without having to seek specific approval from the NRC to transfer the waste.

"The NRC staff assesses that the potential main benefit of the proposed interpretive rule—the potential for fewer regulatory approvals related to disposal at an authorized disposal site—would not outweigh the costs of implementing the proposed interpretive rule, especially given the lack of Agreement State support and a limited number of potential users," the NRC said in the *FR* notice.

Source Points continues

DOE looks to dispose of SRS equipment as LLW

The Department of Energy is considering disposing of contaminated process equipment from its Savannah River Site (SRS) at a commercial low-level waste facility using its recent interpretation of the statutory term "high-level radioactive waste," which classifies waste generated from the reprocessing of spent nuclear fuel based on its radiological content rather than its origin.

In a January 19 *Federal Register* notice, the DOE announced that it intends to prepare a draft environmental assessment on the disposal of contaminated process equipment from SRS at a licensed LLW disposal facility outside of South Carolina. The DOE said that it will analyze commercial disposal options for three specific types of equipment that were contaminated during the on-site treatment of reprocessing waste: Tank 28F salt sampling drill string, glass bubblers, and glass pumps. Currently, there is no disposal pathway for SRS process equipment that has been contaminated with reprocessing waste.

This would be the second time that the DOE has used its revised HLW interpretation to dispose of a waste stream from the South Carolina site in a LLW facility. Last year, the DOE shipped eight gallons of recycled wastewater from the Defense Waste Processing Facility to Waste Control Specialists' (WCS) disposal facility in Texas.

The DOE said that it plans to issue an *FR* notice this year on the availability of the draft environmental assessment. Based on that analysis, the department will either issue a finding of no significant impact or announce its intention to prepare an environmental impact statement.

The DOE has also updated its Manual 435.1–1, *Radioactive Waste Management Manual*, to formally incorporate the department's interpretation of the statutory definition of HLW. Notice of limited change to Manual 435.1–1 was published in the January 19 *FR*. According to the DOE, the objective of the change is to continue to ensure that all DOE radioactive waste, including reprocessing waste, is managed in a manner that protects worker and public health and safety, and the environment.

A December 2020 DOE report to the U.S. Congress shows that the HLW interpretation could save more than $200 billion in treatment and disposal costs while allowing DOE sites to be cleaned up sooner—all still without jeopardizing public health and safety. The report, *Evaluation of Potential Opportunities to Classify Certain Defense Nuclear Waste from Reprocessing as Other than High-Level Radioactive Waste*, identifies potential opportunities for the DOE to reduce risk to public and environment while completing its cleanup mission more efficiently and effectively.

TRANSURANIC WASTE

NNSA to review "dilute and dispose" option for surplus plutonium

The Department of Energy's National Nuclear Security Administration intends to prepare an environmental impact statement (EIS) evaluating alternatives for the safe disposal of 34 metric tons of surplus plutonium through its Surplus Plutonium Disposition Program (SPDP). The NNSA published in the December 16, 2020, *Federal Register* its intent to prepare the EIS, which will examine the agency's preferred alternative, "dilute and dispose," also known as "plutonium downblending," and other identified alternatives for disposing of the material.

Source Points continues

The MOX Fuel Fabrication Facility under construction in 2012. Photo: NNSA

The surplus weapons-grade plutonium was intended to be converted into mixed-oxide (MOX) nuclear fuel at the MOX Fuel Fabrication Facility at the Savannah River Site, but that project was canceled in 2019. Since then, the DOE and the NNSA have pursued the dilute-and-dispose approach to managing the material, in which pit and non-pit metal plutonium would be converted to oxide, blended with an adulterant, and disposed of as transuranic waste at the DOE's Waste Isolation Pilot Plant (WIPP) in New Mexico. According to the NNSA, the dilute-and-dispose approach would require new, modified, or existing capabilities at the Savannah River Site, Los Alamos National Laboratory, the Pantex Plant, and WIPP.

The NNSA had previously decided to use the dilute-and-dispose method to dispose of portions of the 34 tons of surplus plutonium, issuing records of decisions (ROD) in April 2016 and August 2020 to dispose of, respectively, 6 tons and 7.1 tons of non-pit plutonium.

Following the EIS scoping period, the NNSA will prepare a draft EIS for the program, which will be announced to invite further public comment before a final report is prepared. That action will be followed by an ROD officially documenting and explaining the agency's decision. Further information is available at the NNSA National Environmental Policy Act reading room, at energy.gov/nnsa/nnsa-nepa-reading-room.

In comments submitted to the NNSA, the American Nuclear Society urged the agency to reconsider disposing of the surplus plutonium, arguing that a better solution for the material is to convert it to nuclear fuel for advanced reactors.

HIGH-LEVEL WASTE

Columbia University report sets out nuclear waste policy options

A new report out of Columbia University's Center on Global Energy Policy (CGEP) offers a number of recommendations for improving the management of spent nuclear fuel and high-level radioactive waste in the United States. The report, *Forging a Path Forward on U.S. Nuclear Waste Management: Options for Policy Makers*, explains how the United States reached its current stalemate over nuclear waste disposal. It then examines productive approaches in other countries, and a few domestic ones, that could guide policymakers through options for improving the prospects for finding a disposal path for U.S. spent fuel and HLW.

Part of the center's wider work on nuclear energy, the report echoes previous recommendations for U.S. spent fuel and HLW management, such as the use of a consent-based siting process and the formation of an independent waste management organization, both of which were recommended in the Blue Ribbon Commission's 2012 report to the Secretary of Energy and Stanford University's 2018 report, *Reset of U.S. Nuclear Waste Management Strategy and Policy.*

YUCCA MOUNTAIN

Biden appointee confirms opposition to Nevada repository

Jennifer Granholm, President Joe Biden's nominee for energy secretary, told a congressional panel that the administration disapproves of Yucca Mountain as the country's nuclear waste repository, preferring a consent-based strategy as proposed by President Barack Obama's Blue Ribbon Commission on America's Nuclear Future.

"The administration opposes the use of Yucca Mountain for the storage of nuclear waste," Granholm told Sen. Catherine Cortez Masto (D., Nev.), during a confirmation hearing before the Senate Energy and Natural Resources Committee on January 27.

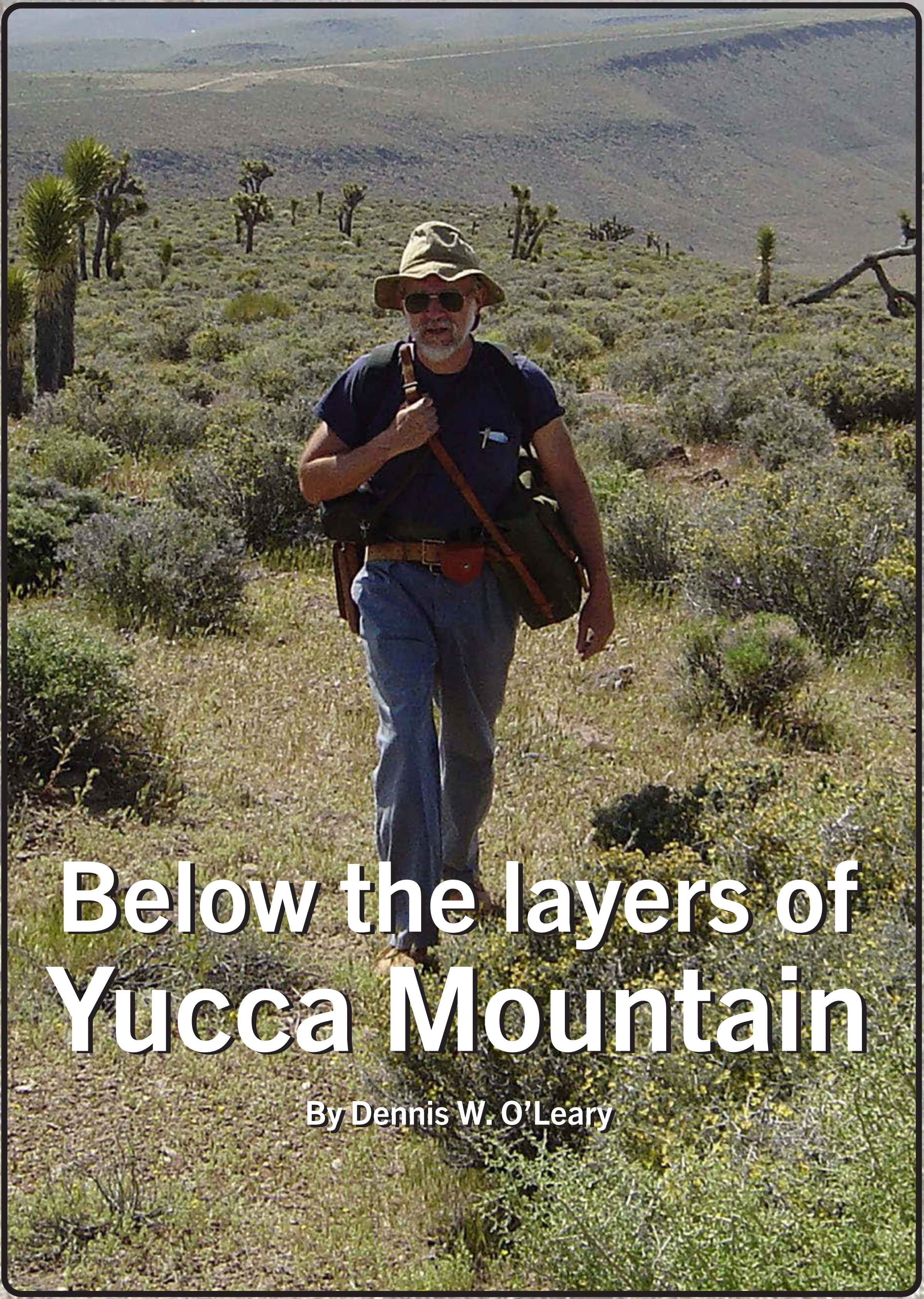
Granholm, a Democrat, served two terms as Michigan governor from 2003 to 2011. According to reports, Granholm was twice considered a candidate for energy secretary under President Obama, but ultimately was not picked.

In response to questions by Sen. Angus King (I., Maine) regarding U.S. spent nuclear fuel, Granholm said, "It is clearly a very sticky situation and we have to maybe look at what the Blue Ribbon Commission did on this, which was to engage with some consensus strategies that will allow us to determine where that waste will go."


Granholm

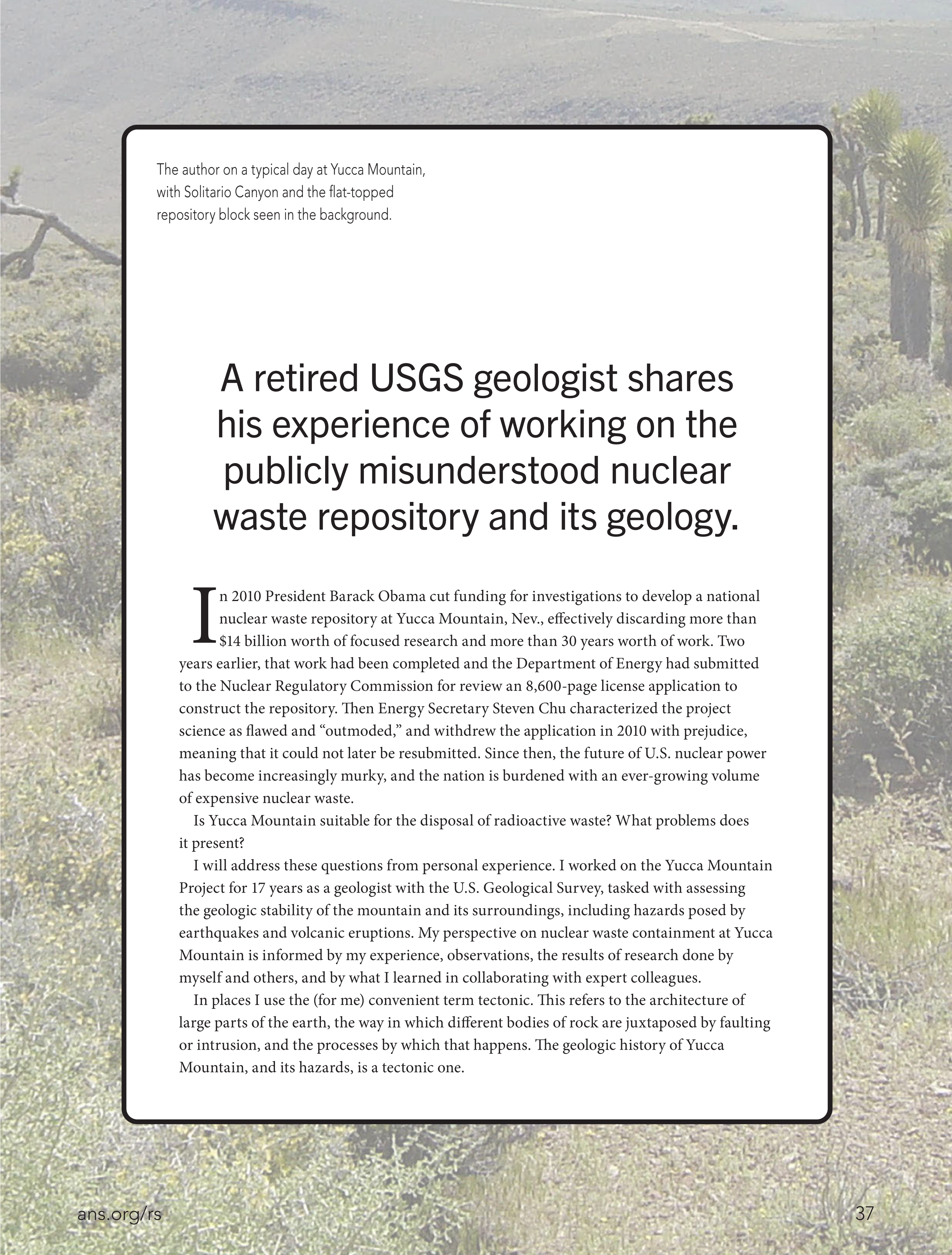
During the hearing, Cortez Masto said that Nevada's entire congressional delegation plans to reintroduce legislation on a consent-based siting process to include Nevada. Asked if she would support such legislation, Granholm said, "Absolutely."

The committee voted 13-4 on February 3 to advance Granholm's nomination to the full Senate. As of this writing, the Senate had not voted on the nomination.



Below the layers of Yucca Mountain

By Dennis W. O'Leary



The author on a typical day at Yucca Mountain, with Solitario Canyon and the flat-topped repository block seen in the background.

A retired USGS geologist shares his experience of working on the publicly misunderstood nuclear waste repository and its geology.

In 2010 President Barack Obama cut funding for investigations to develop a national nuclear waste repository at Yucca Mountain, Nev., effectively discarding more than $14 billion worth of focused research and more than 30 years worth of work. Two years earlier, that work had been completed and the Department of Energy had submitted to the Nuclear Regulatory Commission for review an 8,600-page license application to construct the repository. Then Energy Secretary Steven Chu characterized the project science as flawed and “outmoded,” and withdrew the application in 2010 with prejudice, meaning that it could not later be resubmitted. Since then, the future of U.S. nuclear power has become increasingly murky, and the nation is burdened with an ever-growing volume of expensive nuclear waste.

Is Yucca Mountain suitable for the disposal of radioactive waste? What problems does it present?

I will address these questions from personal experience. I worked on the Yucca Mountain Project for 17 years as a geologist with the U.S. Geological Survey, tasked with assessing the geologic stability of the mountain and its surroundings, including hazards posed by earthquakes and volcanic eruptions. My perspective on nuclear waste containment at Yucca Mountain is informed by my experience, observations, the results of research done by myself and others, and by what I learned in collaborating with expert colleagues.

In places I use the (for me) convenient term tectonic. This refers to the architecture of large parts of the earth, the way in which different bodies of rock are juxtaposed by faulting or intrusion, and the processes by which that happens. The geologic history of Yucca Mountain, and its hazards, is a tectonic one.

Science and quality assurance

Funded through the DOE, work on Yucca Mountain was managed by successive large management and operating contractors. Each transition was hailed as a new beginning of improved efficiency and responsibility; introductory meetings were held, staff released by the previous contractor were rehired and given new marching orders, and new acronyms to signal a revitalized program were learned. Through it all an abiding concern for safety and for quality assurance (QA) remained constant. QA ensured that there was a transparent path of accountability and data quality—no shortcuts or falsifications and no untraceable or shoddy work. An autonomous QA staff continually reviewed protocols and revised technical definitions and work procedures. We were required to carry up-to-date documents in the field, prepare for field audits to ensure we followed the correct procedures, and document retention.

This was science in the regulatory environment. In practice this meant that the cliché about government paperwork was realized to the point where the documentation associated with site work threatened to overwhelm the actual results. Delays were inevitable. Likewise, other agencies expressed concerns about what should be achieved. The original timeline for repository performance was for a 10,000-year outlook. In 2004, an outlook of 1 million years became a court-ordered license requirement.

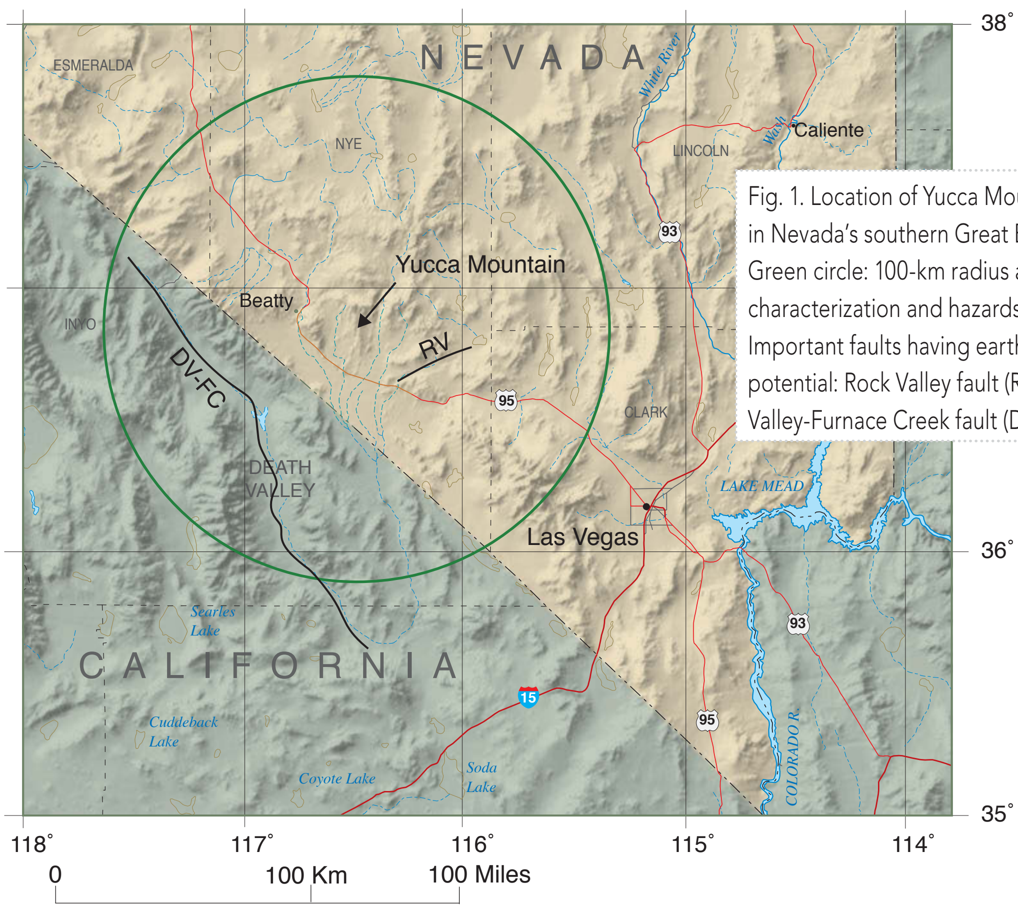


Fig. 1. Location of Yucca Mountain in Nevada's southern Great Basin. Green circle: 100-km radius area of site characterization and hazards study. Important faults having earthquake potential: Rock Valley fault (RV) and Death Valley-Furnace Creek fault (DV-FC).

The 1 million-year time frame was a tough hurdle, as no geologist could confidently predict what might happen that far out. A meaningful prediction had to depend on extrapolating a 15 million-year geologic history constrained, during that time, by the known probability limits of geologic events that might be hazards to the long-term repository performance.

The process of investigation, or site characterization, was accomplished with a very high level of certainty because of QA. If future geological and environmental processes remain in the realm of probability, at least the data concerning that probability, and the means to get that data, had a pedigree for every step of the way; of that we could be certain. And that was the basis on which the DOE license application was created—and dismissed as outmoded by Secretary Chu.

The study of the mountain and its setting entailed the examination of all geological features (e.g., faults) within a 100-kilometer radius of the proposed repository site (see Fig. 1). As many possible natural disasters and problems as could reasonably be anticipated were considered; these were called FEPs, for features, events, and processes. The chief geologic hazards involved, more or less in order of concern, groundwater infiltration, earthquake damage, volcanic intrusion, and erosion of the mountain.

Groundwater

Likely the greatest concern with Yucca Mountain is that water should contact the waste. The compelling geologic reason for a radwaste repository at Yucca Mountain is the deep water table, about 300 meters below the projected repository level (see Fig. 2). Could this water table ever rise to the repository level?

At the very southern end of Yucca Mountain, a short walk off U.S. Highway 95, lies an ancient spring deposit, informally known as the Horsetooth Spring Deposit because of the ice age horse tooth that was found there. This site (see Fig. 3) and several other such ancient springs, seeps, marshes, or ponds in the area represent times when the water table intersected the land surface, a rise of about 120 m above its present elevation. A 120-m rise of the water table beneath Yucca Mountain would still leave the repository 90 m high and dry. Times of high water table occurred during glacial wet periods, about 10,000–15,000 years ago (10-15 kiloannum (ka)), and earlier, between 90–180 ka.

Could infiltration through the mountain over a period of centuries have contributed to the high water table elevation? The geochemical data indicates not. Thorough study and modeling of infiltration shows that the volume and rates of infiltration, both present and past, are very slow. Studies of opaline mineral fillings at the repository level showed no substantial variation in growth rates due to deposition from passage of water over the last 300,000 years; variations in water infiltration over the last three glacial cycles had little effect on deep mineral growth rates.

The more or less uniform and slow infiltration rates at Yucca Mountain depend on the geology of the mountain, which is essentially the remnant of a huge pile of interlayered tuff—siliceous volcanic ash—and lava. The tuff pile above the repository level, at least a few hundred meters thick, includes densely welded tuff, a kind of natural ceramic formed by melting together of countless tiny glass fragments formed during volcanic eruption, and non-welded tuff, an erupted ash too cool to be welded but packed tightly enough to be a strong but porous rock (see Fig. 2). Each of these tuffs has a different kind of unconnected permeability. The welded tuff provides infiltration via its many fractures, but the

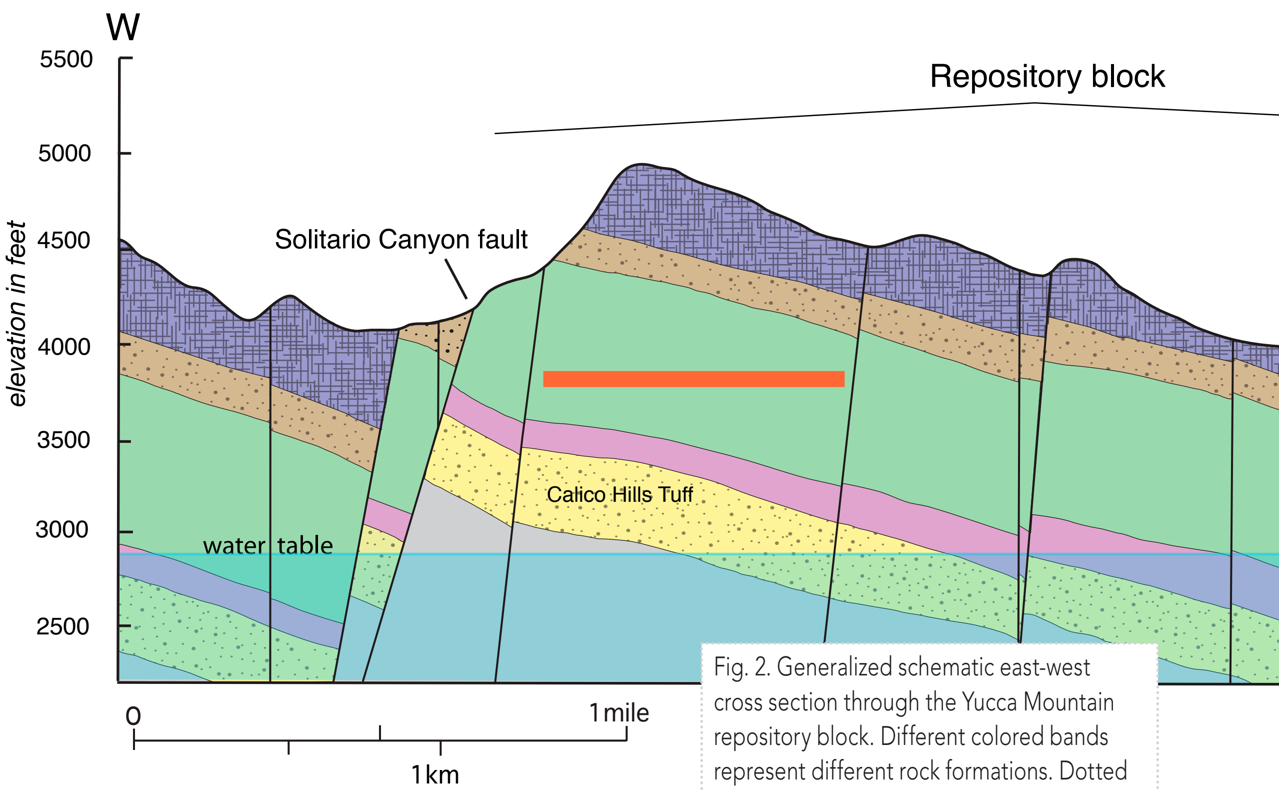
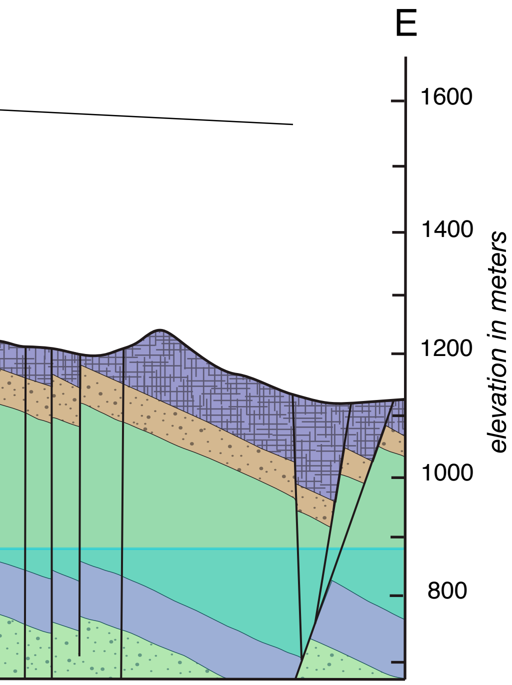


Fig. 2. Generalized schematic east-west cross section through the Yucca Mountain repository block. Different colored bands represent different rock formations. Dotted pattern represents non-welded tuff; crosshatch pattern represents fractured welded tuff. Red rectangle represents the projected repository location in welded Topopah Spring tuff. Pale blue overlay represents water table and groundwater.

porous, non-fractured, non-welded tuff slows infiltration down by virtue of its sponge-like porosity. Hydrologic study indicates that most water needs 5,000 to 10,000 years to get through the non-welded tuff. The repository level is within a thick, densely welded tuff layer.

Not all is slow and steady within Yucca Mountain, however. The mountain is faulted and fractured, a condition that has led to much fear of radioactive waste being flushed through the mountain like a geological sieve. This fear seemed justified following discovery at the repository level of an isotope of chlorine, as well as tritium, created by atomic bomb tests at the Nevada Test Site, which showed that surface water could get to the repository level within about 50 years. Most of the bomb-pulse chlorine samples were found near known faults and in bordering fractured rock. Some faults, at least, clearly provided fast pathways for infiltration (see Fig. 4), and such fast pathways could have been local conduits to a rising water table during glacial pluvial periods.

Although vertical infiltration through the mountain, apart from some local faults, is very slow, a source of lateral inflow during the ice ages is the mountainous terrain at the northern end of Yucca Mountain, where melting snow as well as greater rainfall could have contributed groundwater influx. This inferred source brings into the picture the steep hydraulic gradient near the northern edge of the repository block. Here, over a distance of less than 3 km, the water table rises northward from a depth of about 740 m above sea level to more than 1,000 m above sea level. Increased groundwater flow from north to south across more than a 240-m elevation change could put the northern end of a repository in some jeopardy.



Present-day hydrologic conditions are measurable and well understood, but what about the future? Analyses of climate-influenced isotopic compositions from a calcite core from nearby Devils Hole provided a unique climate change record over the past 425,000 years. Future climate prediction was based partly on extrapolating this record and on a cyclic Earth orbit variation over a 400,000-year period. The present warm, arid climate is expected to end in the next 400-600 years. Net mean infiltration is expected to increase over that time from the present 4.6 millimeters per year to a glacial transition rate of 17.8 mm/yr. Mineral coatings in fractures, however, indicate very little change in deposition rate in the last 8 million years, so low infiltration rates at the deeper levels of the mountain seem uninfluenced by climate.

More recent climate change scenarios for the western United States, based on atmospheric CO_2 concentration, indicate an increasingly dry climate that might override the effect of any orbital cyclicality, and which would continue to decrease infiltration at the mountain. Nevertheless, it is possible that during a radically changed climate, surface water could pass into the repository level mainly through the fast pathway fracture flow and possibly via the steep hydraulic gradient.

Uncertainties about future infiltration engendered numerous revisions to engineering plans during the 1990s. The shape and layout of the repository and the size, construction, and spacing of the waste canisters were repeatedly revisited. A worldwide study of natural analogs indicated that a mined, open cavity could persist over several thousand to hundreds of thousands of years. This fact, plus ground-level access to the repository, led to a basic plan to install the waste by rail in specially designed canisters and to leave the mountain without a permanent seal for at least a century (a "preclosure phase"). In the event of some failure or change of policy, the waste could be removed pursuant to some Plan B.

The waste canisters, made of high-chromium alloy-22, have a modeled undisturbed life of more than 100,000 years. But, exposed to a sustained drip, and especially if damaged by a rock fall, they may last only 12,000 years, exposing an inner stainless steel canister and eventually leaving the waste form (solution-resistant ceramic or metal-oxide pellets) open to leaching and groundwater contamination.

With this prospect in mind, project planners created a License Application Design Study (LADS) in 1999 that resulted in a proposal for a further engineered barrier, a titanium drip shield to be installed over the waste canisters. The drip shield became a kind of public icon for the futility of the Yucca Mountain Project. The shields were to be installed during the closure process, when the last waste canister is emplaced, maybe 300 years out. The drip shield may have been an attempt to normalize a worst-case scenario, or it may represent an engineering belt-and-suspenders mentality (a defense-in-depth barrier).

In the event of water contacting the waste, contaminated water would descend to the Calico Hills Tuff (see Fig. 2), a generally nonwelded tuff largely chemically altered to clay, zeolite minerals, and iron oxides, which all have the capacity to capture and retain at least some metal ions entering via infiltration. The Calico Hills Tuff dips below the water table, so the absorptive effect of the zeolites would occur in groundwater flow over considerable distance. Water moves slowly through the Calico Hills Tuff; impermeable layers in the tuff support perched water that has been in place for 3,500–11,000 years. Experimental work with a high-solubility nuclide, neptunium, indicates travel times of greater than 10,000 years from the repository level to the water table and that a peak dose would arrive at Amargosa Valley well sites, about 35 miles south of the repository site, in about 300,000 years. Well tests indicate that radiation dose to future Amargosa Valley residents would be two-thirds of today's background.

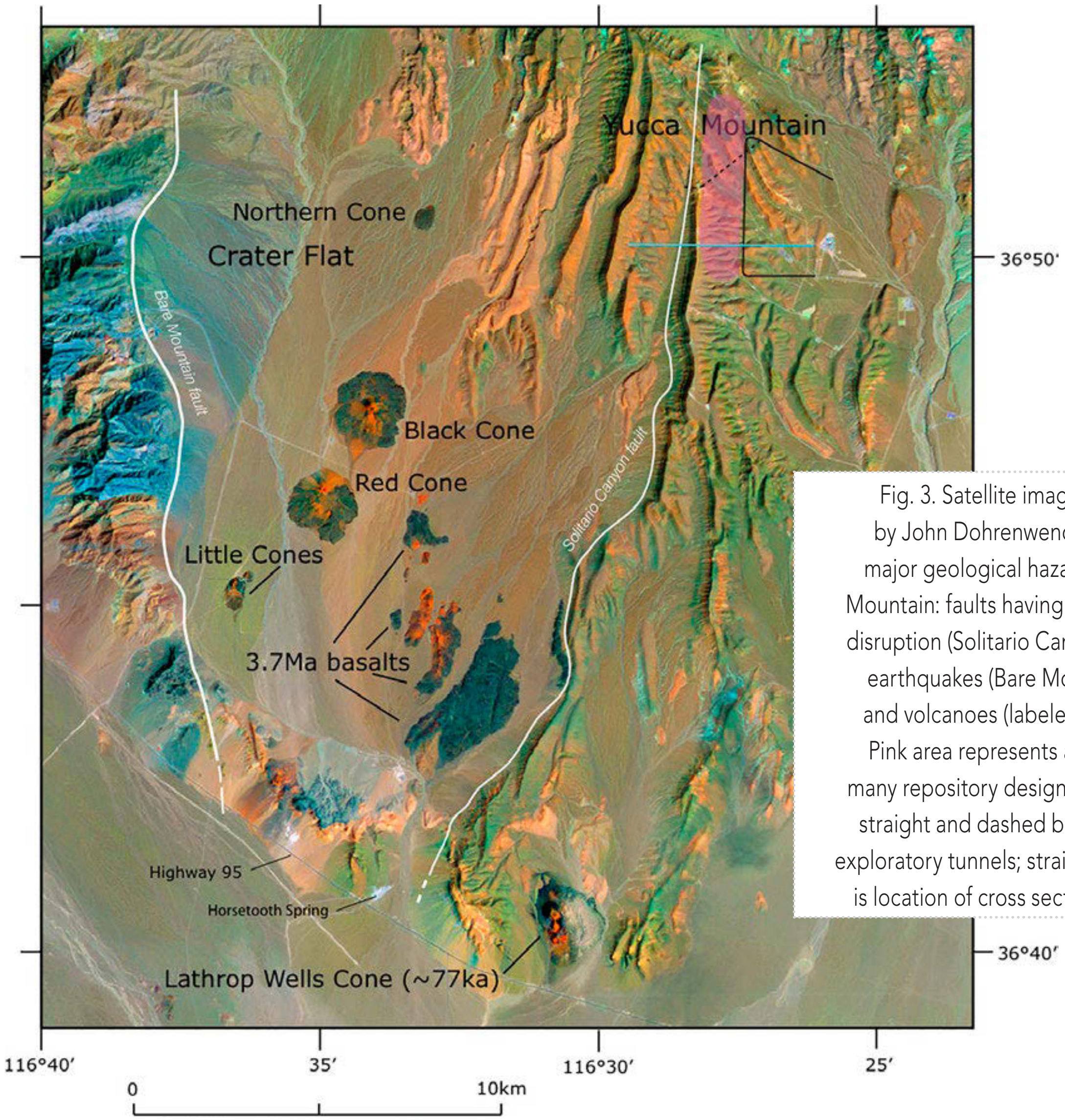
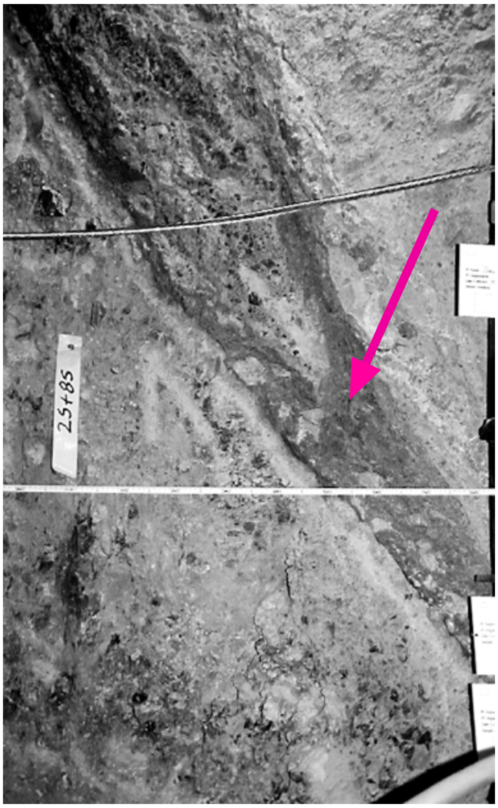


Fig. 3. Satellite image (enhanced by John Dohrenwend) shows two major geological hazards to Yucca Mountain: faults having potential for disruption (Solitario Canyon fault) or earthquakes (Bare Mountain fault) and volcanoes (labeled with ages). Pink area represents a variation of many repository design boundaries; straight and dashed black lines are exploratory tunnels; straight blue line is location of cross section in Fig. 2.



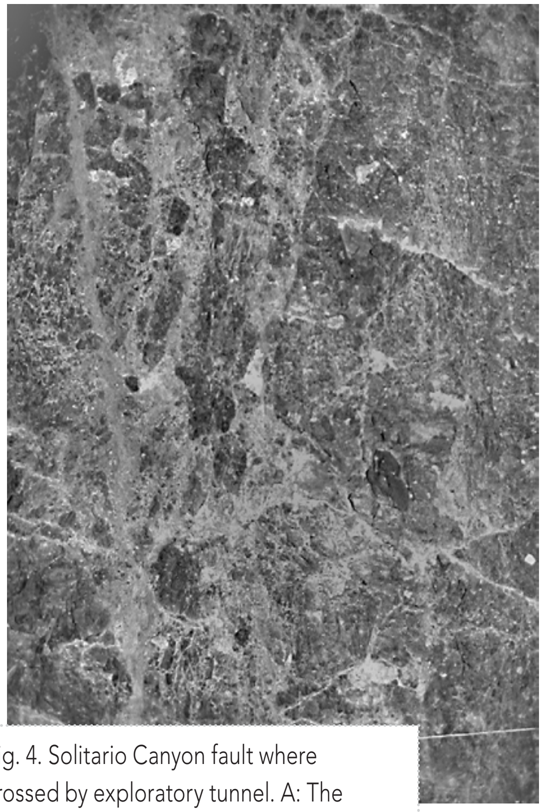


Fig. 4. Solitario Canyon fault where crossed by exploratory tunnel. A: The main fault break (red arrow) is marked by extremely finely ground rock. B: Zone of severely crushed and damaged wall rock bordering the fault break. In the geologic past, this fault has been a conduit for water passing through the mountain.

Earthquakes

Of the hazards facing a Yucca Mountain nuclear waste repository, water infiltration can at least be assessed in the presence of actual water. Ironically, volcanoes and earthquakes are the most vivid fears for the protesting public and the most easily dramatized by pop science writers. The irony is that, unlike rainfall and snow melt, no active volcanism has occurred or is occurring anywhere near the site, and no historical earthquakes have moved faults at or flanking Yucca Mountain.

In fact, only one significant earthquake occurred near Yucca Mountain during site characterization, the 1992 5.6-magnitude Little Skull Mountain earthquake. This quake provided no direct information relevant to Yucca Mountain because it occurred at about a 12-km depth on an unknown, unsuspected fault 15 km from the mountain. The Little Skull Mountain earthquake was a complete surprise; it was a background earthquake, meaning that it was not expressed at the ground surface by an old or new fault. A large collection of seismic aftershock data revealed that the seismic source was a northeast-oriented down-to-the-east normal fault. Although the quake caused considerable damage to local buildings, it had essentially no effect in nearby tunnels.

Yucca Mountain owes its form to a series of down-to-the-west faults. The so-called "repository block" is bounded, east and west, by such faults (see Fig. 3). Starting around 11 million years ago (11 megaannum (Ma)), these faults formed as the stack of tuff layers began to be extended westward into a deepening Crater Flat basin. Because the volcanic pile is only about 2-3 km thick and rests on the eroded limestone rim of Crater

Flat basin, it is very unlikely any of these faults could generate an earthquake. In fact, some of them could be the result of west-directed mass movement. While a handful of very small earthquakes have occurred under Yucca Mountain during site characterization, their relationship to the faults is unknown.

One of the large-displacement faults of Yucca Mountain, the Solitario Canyon fault, is exposed in a tunnel bored at the repository level through the west side of the repository block (see Fig. 4). Severely crushed, bleached, and rusted rock in the fault indicates that water has passed down the fault plane to the repository depth and below. The fault plane is bordered by several meters of crushed bedrock. Given the possibility of future movement on this fault, the simple fix for radwaste emplacement is to keep waste canisters backed off from the zone of rock damage.

Excavation of trenches across the central and southern extent of the fault showed displacement as much as 500 m down to the west. The most recent offset, dated 40-20 ka, is 10-20 centimeters. The average slip rate is 0.01–0.02 mm/yr over 200,000 years, so the Solitario Canyon fault would be expected to have a mean displacement of 12.6 inches per 100,000 years. Near its southern end, the fault forms a fissure as much as 70 cm wide filled with basalt ash correlated with the nearby Lathop Wells cone, so displacement as much as 1.3 m occurred at about 77 ka (see Fig. 3).

What about earthquakes generated by other relatively large faults within the 100-km radius of the repository site? The nearest of these, the Bare Mountain fault (see Fig. 3), is about 20 km long and could produce moderate to large (1.0–1.5 m slip per event) but infrequent (tens of thousands of years) earthquakes. The most recent event was not later than 16 ka.

More widely, the tectonic setting of Yucca Mountain—the Southern Basin and Range—includes a variety of seismogenic faults, the most hazardous of which is the ground-breaking Death Valley-Furnace Creek fault in Death Valley, and the ground-breaking Rock Valley fault zone, projecting toward Yucca Mountain from the east (see Fig. 1). These faults have the capacity to generate 7.2-magnitude or greater earthquakes.

Seismology studies observed that numerous "precarious rocks" are located on the ridges of Yucca Mountain. These rocks were formed in place by gradual, undisturbed erosion during tens of thousands of years. It was straightforward to calculate the amount of seismic ground shaking that would topple these rocks, and on that basis to estimate the size and frequency of earthquakes generated by the largest, most hazardous faults in the region. A large earthquake has not shaken Yucca Mountain for at least the last 24,000 years.

The estimate of earthquake displacements from trench observations is woefully imprecise. How could we assess the risk, the effects, and the probabilities of earthquakes during the time a repository was being filled or in its million-year operation? The answer was probabilistic seismic hazard analysis (PSHA). This method has been used since the 1970s for estimating seismic hazard at nuclear power plants throughout the country.

For Yucca Mountain, the analysis took 18 experts four years to come to a conclusion, which was delivered to project engineers for design guidance. The 18 experts—seismologists and geologists—were given all the known information about all the known faults and the earthquake history within the 100-km-radius study area. The experts were formed into six teams of three each. I was a member of one of those teams.

The teams itemized each fault using a multibranched logic tree, rooted in a tectonic model, which modeled a range of possible magnitudes for a range of earthquakes (basically, seismic source and fault displacement characterization). Each branch represented a fault, each of which had branches showing estimated earthquake magnitudes and associated fault length. Each team also made allowance for earthquakes that could occur, at random, anywhere in a given area without reference to any known fault. This was the "background earthquake" (e.g., the Little Skull Mountain earthquake), generally any earthquake of Magnitude 6 or less. The teams could appeal to any tectonic model that they felt could explain distributed or individual fault movement, or movement on any segment of any fault. This was all a matter of expert judgment.

Each team, after much discussion, met with an elicitor to determine how confident and in agreement each team was about their conclusions. The goal was "to represent the center, body, and range of technical interpretations that the larger informed technical community would have if they were to conduct the study."

The combined elicitation results represented probability estimates by committee: Given an earthquake of given magnitude, what is the likelihood of something worse? The exceedance probabilities of the different earthquake sources were summed up to represent the variety of earthquakes of given magnitude at any time that could affect the repository. This "frequency of exceedance" must be at least 10^{-7} (10^{-8} at repository level) to represent a hazard. Given this information, a group of seven experts then calculated the maximum ground motion that could affect the repository from each earthquake source, and this defined the seismic hazard.

The underground Exploratory Studies Facility at Yucca Mountain. Photo: NRC/DOE.

Volcanism

Probably the most fearsome of the hazard scenarios in the public mind is the eruption of a volcano through the mountain, spewing radioactive waste high into the atmosphere. The scenario derives from four small volcanoes dated at about 1 Ma and located in Crater Flat, on the west side of the mountain. These volcanoes, and nearby fissure eruption flows dated at 3.73 Ma, are aligned more or less parallel to the north-south orientation of the mountain and its faults (see Fig. 3). A most recent, 77 ka cinder cone, the Lathrop Wells cone, presently quarried for aggregate, erupted through the southernmost exposed bedrock of the mountain, close to Highway 95. These volcanoes are close enough and young enough to raise concern over the likelihood of a volcanic intrusion into the repository and/or eruption through the mountain. But how likely is such an event? And how bad could it be?

An analysis of volcanic hazard was carried out using the method used for PSHA, which was not well-suited for the volcanoes of Crater Flat—there are too few volcanoes to establish a recurrence interval, and active or similar volcanoes much farther away in different geologic settings are of questionable relevance as analogs.

Ten experts on volcanism, only one of whom had any familiarity with the volcanic history of the volcanoes in question, were invited to participate. As with the PSHA, the experts were selected to obtain a "diversity of views . . . judged to be representative of the larger informed community." In keeping with this objective, the experts provided impressive knowledge of volcanism in the different places where they had spent a good part of their careers, but had little to contribute concerning the six volcanoes that mattered—the ones in Crater Flat and at the southern end of Yucca Mountain.

At the outset there was considerable disagreement over the subject of analysis, the "volcanic event." With PSHA, an event is universally understood to be an earthquake—the thing that produces destructive ground motion. With volcanism, an event might be a single eruption, or a volcano, a crater formed by successive eruptions, an intrusive dike, a cluster of vents of essentially the same age, etc. Sorting this out was essential, as the definition of hazard hinged on the number and distribution of events in the area.

In looking for presently active analogs for the Crater Flat volcanoes, experts pointed as far afield as Nicaragua and Kamchatka; the assumed levels of any future volcanism near Yucca Mountain were found in environments having no resemblance to Crater Flat, Nev. This brought to mind the old joke about the guy who lost his car keys on a street at night and decided to look for them under a street lamp only because the light was good there. Eventually the whole thing boiled down to statistics—elaborate numerical calculations of probability based on the number of volcanoes and their distance from each other (i.e., clustering).

It was clear that there was no recurrence of volcanism in Crater Flat in the PSHA sense—no theoretical model to even assume an event could occur at the same place twice. Recurrence meant an entirely new volcano at an unpredictable location. Since the magma source for any future volcano was entirely beyond measurement and observation, the experts assumed a random (stochastic) distribution and appealed to statistically defined clusters, such as the Poisson distribution, and let it go at that.

The probabilistic volcanic hazard analysis (PVHA) was completed in 1996, and while new geophysical data published in 2002 and 2004 indicated several more possible buried volcanoes in the area, an updated analysis using the new data and drilling results confirmed the results of the original PVHA; basically, a probability of between 10^{-9}/yr and 10^{-7}/yr for a volcano or an intrusion intersecting the projected repository, which translates to an intrusion or volcano every 10 million to 100 million years, or one chance in 8,000 for a volcano in the next 10,000 years. The agreed-upon median probability level was high enough to require scenario models for magma intrusion into the Yucca Mountain repository and the consequences of eruption-entrained waste entering the accessible environment.

Many of the modeled scenarios were extreme; they could have been taken from the screenplay of a volcano disaster movie. To make matters worse, one of the original PVHA experts later wrote a novel, just for fun, describing a future volcanic eruption through Yucca Mountain that leads to evacuation of Las Vegas and the draining of Lake Mead. Readers assumed, since a geologist had written the book, that it could actually happen. This was not helpful.

In 2003, the Electric Power Research Institute (EPRI) conducted an independent PVHA that did not "rely explicitly on the locations of existing igneous events, but rather on the geologic characteristics of the region that indicate propensity for future igneous activity." The EPRI study took account of the mineral composition of the lava, which indicates a relatively low lava viscosity and relatively low eruptive temperature, in contrast to the unrealistic properties used to support the incredible intrusive scenarios for the repository.

In considering the geologic reality of the volcanic setting rather than considering volcanoes as points on a map, the EPRI analysis got a recurrence probability of 10^{-9}. Furthermore, this probability decreases with time because tectonic deformation, a root cause of igneous intrusion, has been decreasing for the past 11 million years, and that decrease will continue over the next million years.

The 1.0 Ma Crater Flat volcanoes are typical of many Pleistocene basalt volcanoes throughout the Rocky Mountain west—single-episode cinder cones that erupt for a few decades at most, then die forever. The composition of the lava and the structure of the volcanoes indicate that they originated from small batches of magma formed at depths of at least 60 km and having no particular relation to overlying rock structure. The only intrusions in Yucca Mountain are small dikes of about 10 Ma at the northern end of the Solitario Canyon fault and in ridges farther west (see Fig. 5). Two things are important here: The Solitario Canyon fault dikes reveal a remarkably nonviolent intrusion process, and the fault itself forms a barrier to any presumed dike intrusion toward the repository block from any source in Crater Flat.

All this is not to say that a cinder cone could not erupt in Crater Flat. Sunset Crater in Arizona, a large cinder cone—a volcanic event—began eruption in 1064 and continued erupting for decades. Such an eruption might not give much warning as ascent of magma from source depths could occur within weeks to days. A volcano of this type would pose no threat to a repository in Yucca Mountain, but a prolonged eruption of hot cinders might put waste packaging and staging operations at the east side of the mountain out of business for a long time.

Erosion

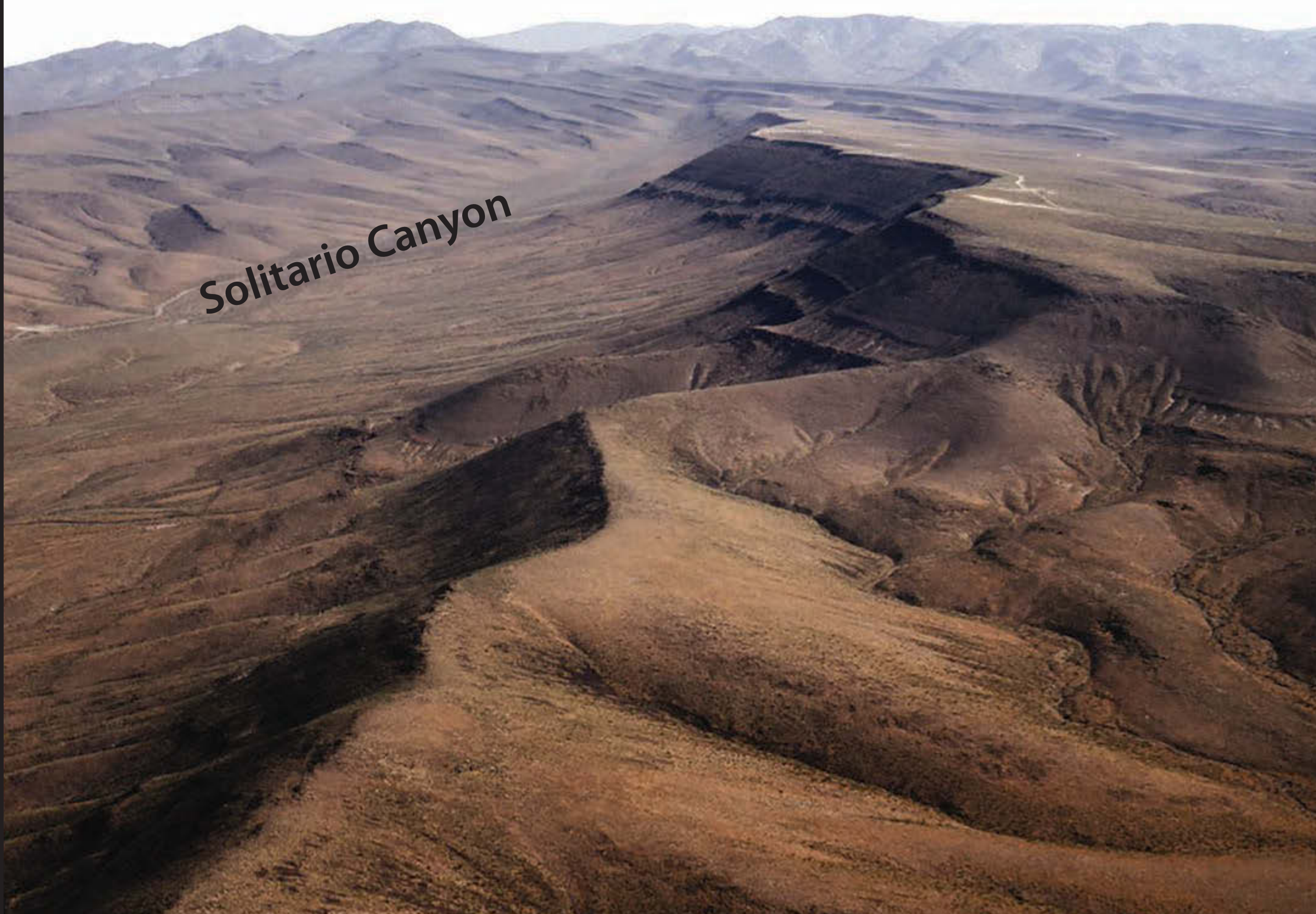
A final geologic hazard of public concern is erosion of the mountain sufficient to expose the radwaste to rain, snow, and everything else. Could erosion of Yucca Mountain uncover the repository?

Because of its block-faulted structure, Yucca Mountain undergoes erosion in two different ways. The east-dipping strata are cut by narrowly converging headward-eroding gullies (see Fig. 5). This erosion has reduced the crest of the repository block in places to a ridge about 40 feet wide. The gullies widen and deepen downslope, but are abruptly terminated by their own alluvial fan deposition at about

3,800 ft elevation. The repository site is also at about 3,800 ft elevation, underground. Because alluvial deposition, less than 2 mi. away, occurs at 3,800 ft, the headward-eroding gullies will never breach the repository. The erosive power of the slope streams will be diminished to nothing as a horizontal gradient is approached and as deposition thickens westward.

Isotope analysis of elements in the cap rock/ ridge crest of Yucca Mountain exposed to cosmic rays that continually hit the planet provided erosion rates of 0.04-0.27 cm every 1,000 years. The average erosion rate for seven bedrock analyses is 1.38 m/million years, about 4 ft of erosional lowering in a million years. To expose the repository, erosion must cut down about 1,000 ft below the crest. Lava exposed at the top of Ammo Ridge, on the west flank of the mountain is significant, as it indicates the ridge tops of the mountain have not been lowered by erosion during the last 9-10 million years, although the gullies and ravines flanking the ridges have been eroded, exposing deeper levels of the intrusion.

Erosion of the west side of the repository block is controlled by the Solitario Canyon fault (see Fig. 5). The streambed of Solitario Canyon lies about 0.5 mi. due west of the repository site and has an elevation of about 4,200 ft, roughly 600 ft above the repository level. Erosion into the repository block will occur only if Solitario Canyon is deepened below 3,500 ft either by displacement of the Solitario Canyon fault or by lowering of Crater Flat basin (vanishingly unlikely). The stream courses on the west flank of Yucca Mountain are graded to alluvial fan deposits, which are at or above the repository level. This "base level" limits the amount of stream incision, since increasing deposition tends to flatten stream gradients. And, as noted above, the Solitario Canyon fault is expected to have a mean displacement of 12.6 in. per 100,000 years.



Conclusions

Such is the story of Yucca Mountain: All for nothing, a casualty of bad publicity, politics, and changed concepts of waste isolation. Perhaps the hazards might be better understood as expressions of a broad, evolving tectonic environment. In this context, the faults and volcanoes that seem to signal hazards to a nuclear waste repository in the future are actually relics of a dying past. There is no earthquake zone passing under Yucca Mountain, no San Andreas faults are going to show up. There is no cauldron of magma brewing under the mountain. Basically, geologically, there is nothing going on at Yucca Mountain—it is all over and done with.

The volcanic ash and lava that forms Yucca Mountain erupted from a large volcanic center (caldera complex) over a period of about 4 million years. The eruptions were exhausted about 11 million years ago, when large parts of the area around Yucca Mountain began to collapse and pull apart. The Solitario Canyon fault marks the boundary west of which many of the volcanic strata have collapsed into the deepening hole of Crater Flat basin. What we call Yucca Mountain is a small, broken fragment of the volcanic pile, lodged on the rim of Crater Flat basin. As the crust cooled after 11 Ma, batches of deep, residual magma erupted as basalt flows through the stretched, subsided crust on either side of the mountain, and later, as small volcanoes in Crater Flat.

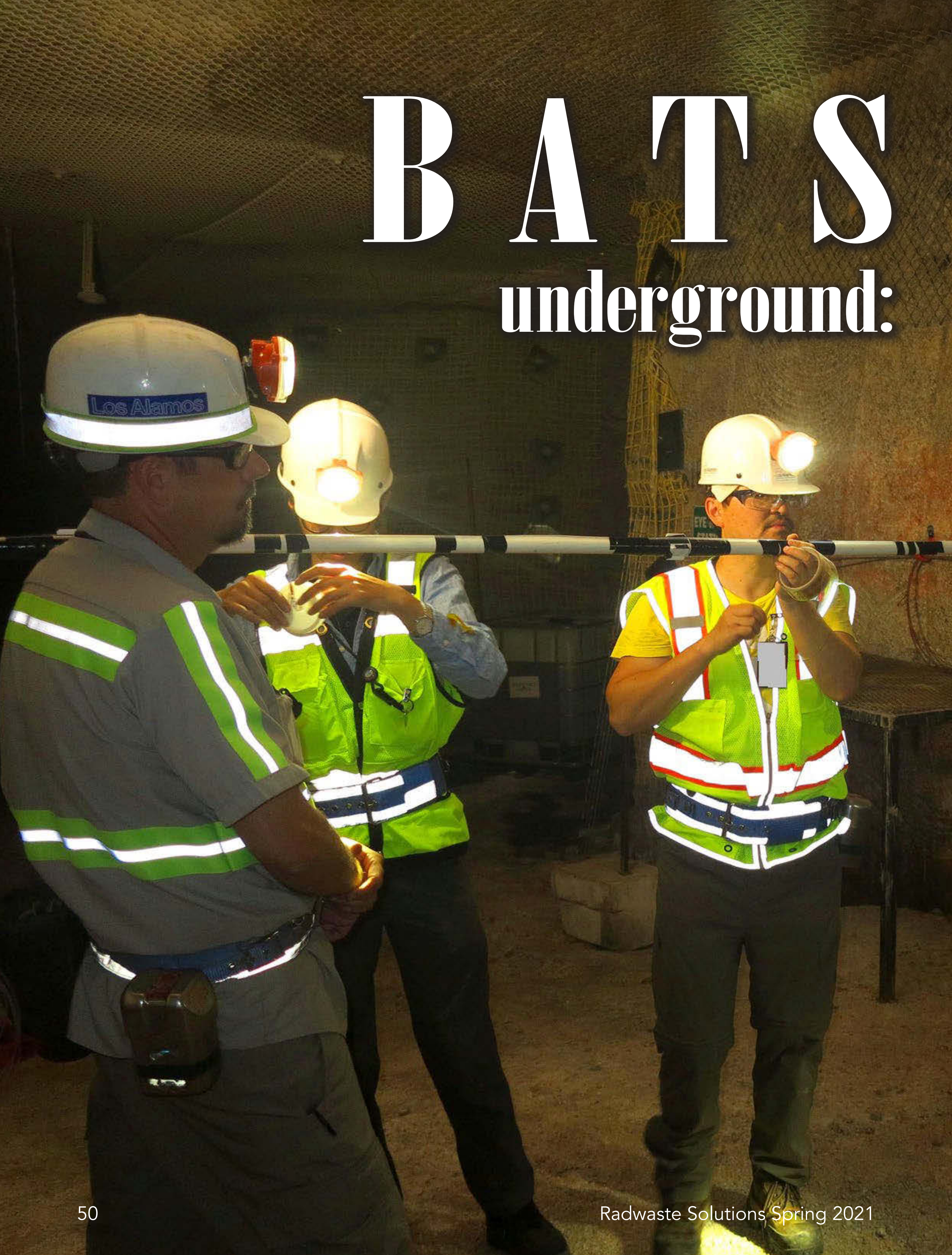
Yucca Mountain, then, is as acceptable a site for radwaste disposal as we are likely to find in the United States, and we are better off than other countries facing the same problem. Yucca Mountain's defects are well-understood and constrained by sound theory and science, none of which is obsolete or outmoded. Professional scientists would not have wasted years of a career on something they knew would be useless or reflect badly on their credibility as scientists. The Yucca Mountain license application deserves review.

Yet, even if the public and political leaders accepted this reality, getting Yucca Mountain anywhere near an operational date will face major problems of construction, transportation, and cost. Likewise, the volume of spent nuclear fuel accumulated in the decade since the project ended exceeds what could safely be stored there. Clearly, at this point we need a second, and probably a third, national waste repository. Whatever choice is made, dealing with our national nuclear waste inventory will be a long and very expensive process. The next generation of taxpayers will pay for one of two things: Either a safe, national disposal program or an expensive aftermath cleanup for what remains of the nuclear power industry—or maybe both.

Fig. 5. View north of the repository block from south end of Yucca Crest. Solitario Canyon becomes smaller to the north as the fault beneath it loses displacement such that gently east-dipping strata are almost continuous with strata of the block to the west.

Dennis O'Leary is a geologist, having served with the U.S. Geological Survey from 1970–2009. He spent 17 years on the Yucca Mountain Project.

BATS underground:



Brine and the long-term safe disposal of high-level waste in salt

Researchers install test equipment into a borehole in the WIPP underground. Photos courtesy of DOE/LANL.

BY KATHARINE COGGESHALL

Can high-level nuclear waste be safely stored in natural salt formations? The Department of Energy's Office of Nuclear Energy (DOE-NE) aims to answer that question with an unequivocal "Yes." To do so, they enlisted the help of three national laboratories and an existing defense waste repository in New Mexico.

"The Waste Isolation Pilot Plant is the final home of transuranic (waste containing elements above uranium in the periodic table) radioactive waste in natural salt 2,150 feet below the surface," said Phil Stauffer, Los Alamos National Laboratory computational earth scientist. "This is non–heat-generating waste accumulated through Cold War defense activities."

The Waste Isolation Pilot Plant (WIPP) is ideal for permanent disposal because the salt rock effectively seals the radioactive waste from the environment. The salt deposit was created 250 million years ago—before dinosaurs walked the earth—and has remained stable. Therefore, it is highly likely to continue to remain stable for the time it will take the radioactive waste being disposed of there to lose most of its radioactivity and be deemed safe.

"Additionally, the chloride in the salt reduces possible nuclear criticality concerns, and rock salt can actually heal its own fractures," explained Kristopher Kuhlman, Sandia National Laboratories earth scientist, "so when we mine access rooms and hallways to emplace waste, the salt effectively and permanently seals it off from the biosphere."

Given these strong benefits, salt disposal appears to be a top contender for all types of nuclear waste, but there is at least one main difference to consider.

The salt rock geology at WIPP currently seals in radioactive waste generating little heat, but this type of rock could also be well-suited for storing more radioactive waste that generates copious heat. That difference—heat generation—calls for research to support a new type of safety assessment that scientifically supports disposal of higher activity nuclear waste in salt. Heat is a key ingredient in chemical reactions and phase transitions, and higher amounts of heat can liberate the small amount of water associated with the salt (about 1–2 percent of the salt by weight). Heat can mobilize the tiny pockets of water trapped inside and in between the salt crystals as well as the water in clay and hydrous minerals. If any open pathways exist, this salt water, or brine, could carry radionuclides off-site, which could impact the surrounding environment and its inhabitants.

In fact, brine has numerous consequences, both good and bad, including neutron absorption and steel container corrosion. Understanding brine availability—the distribution and movement of brine—especially as it relates to heat-generating waste, is a key factor in understanding how to safely dispose of high-activity waste, such as spent nuclear fuel from commercial reactors and high-level waste from defense activities, in natural salt formations.

Therefore, determining where this small amount of brine currently exists and the behavior of where it is going and flowing as heat enters the equation in the near term will aid in understanding brine distribution over longer time periods.

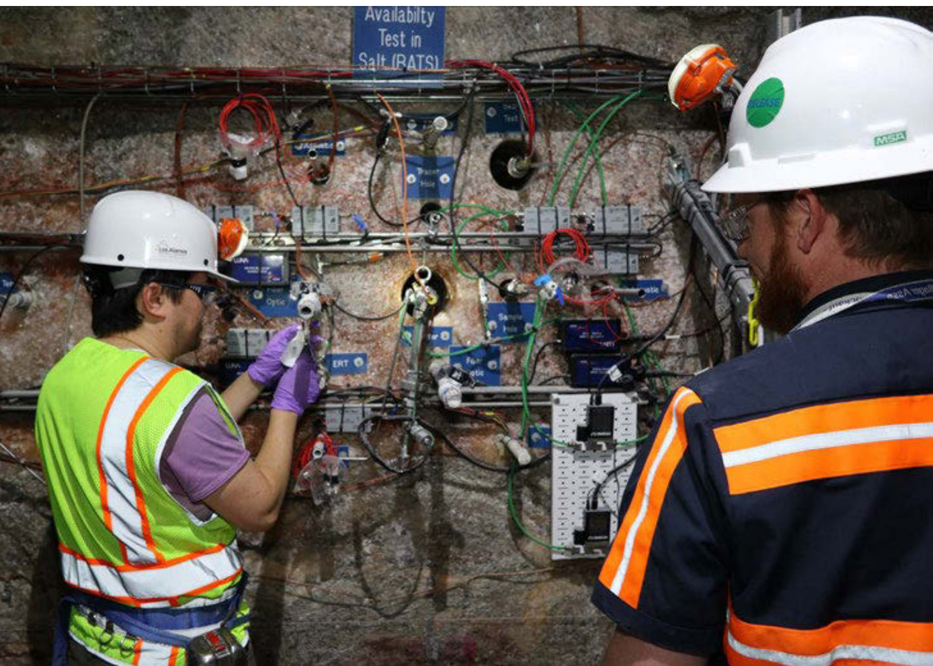
Enter BATS

In 2017, Los Alamos, Sandia, and Lawrence Berkeley national laboratories designed and began implementing the Brine Availability Test in Salt (BATS) project as part of the DOE-NE Spent Fuel and Waste Science and Technology research campaign. The goal of BATS is to better understand and predict brine availability in the damaged area immediately surrounding a salt repository. The damage is created by the very excavation process that creates the rooms used to access the underground. Far away from the excavations, the salt remains undisturbed, whereas near the excavations, damage can change the salt. The damaged salt behaves differently, and BATS is investigating how brine and heat move through and affect the damaged halo surrounding each drift in a salt repository.

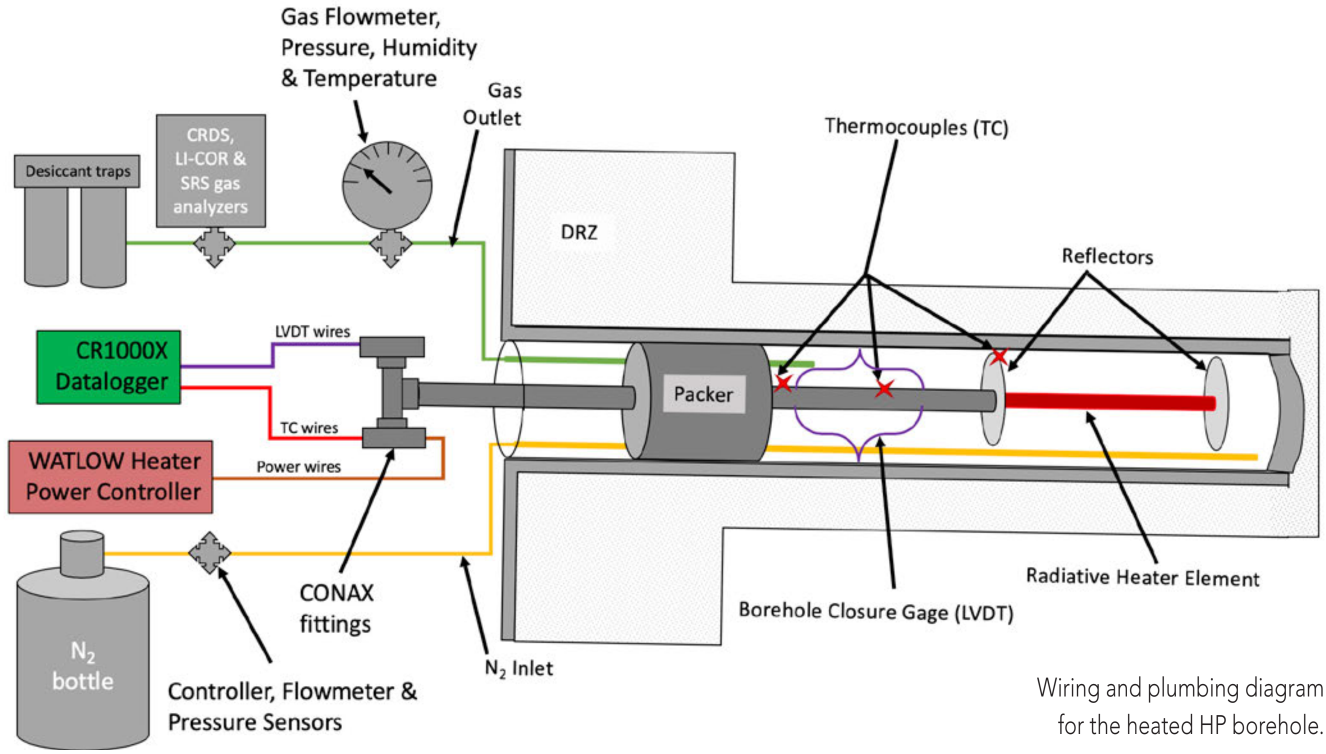
For example, at WIPP, areas for waste storage are mined one at a time, close to when they will be filled with waste. The salt flows (creeps) very slowly, analogous to how tar or honey flow. Typical rooms mined in the underground at WIPP close at about the rate fingernails grow—a few inches per year. This salt creep requires continual maintenance if the mined areas are to remain open.

Additionally, BATS is the first experiment to seek to understand different types of brine. Not all brine is the same, and as a consequence, brine availability differs depending on the water source. The BATS researchers are considering hydrated minerals, water found in clay among the salt, intragranular brine inside salt crystals, and brine between grains as water sources.

"These water sources respond differently to changes in pressure and temperature," Kuhlman said. "So, if you want to know how much brine will flow into an excavation and what timing it has, you need to understand how each of the different types of brine contribute to it."



The first BATS tests were run in existing horizontal boreholes at WIPP, which were previously drilled for other purposes. Horizontal drilling allows for uniform drilling through a salt layer while avoiding non-salt (clay or anhydrite) layers known to exist in rocks above and below.



Wiring and plumbing diagram for the heated HP borehole.

To simulate heat-generating waste in a salt disposal room, the team placed a heater set to 120 °C (250 °F, like a warm oven) inside a small drilled-out hole in the wall. The heater was then surrounded by instruments in other similar boreholes to measure the varied responses of the salt to the additional heat. There are thermal processes (heat moves from hot to cold areas), hydrological processes (water flows downhill), mechanical processes (rooms slowly creep closed and salt expands when heated), and chemical processes (more salt dissolves in hotter water and boiling away the water in the brine precipitates salt). These, and many more complex and coupled processes in the salt, contribute to the observed brine availability.

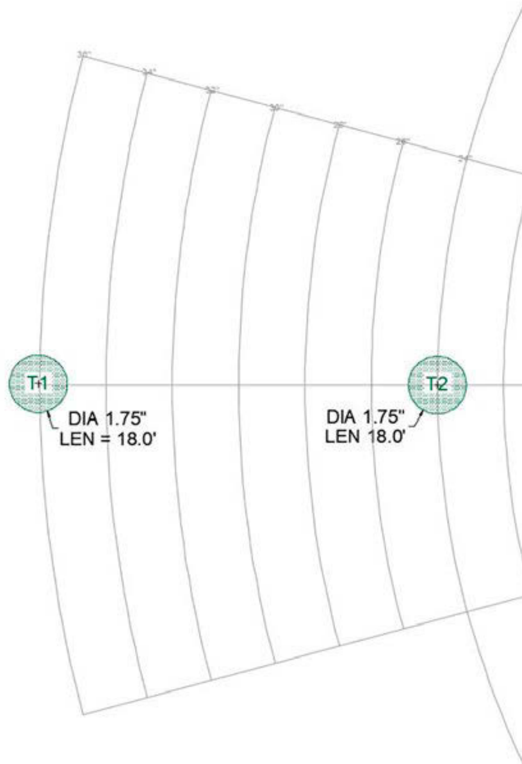
As Kuhlman explained, "To predict the amount of brine that would flow into a future hot repository for radioactive waste, we first work to understand and predict the amount of brine that would flow into a heated borehole as part of BATS."

As a control, a similar array of boreholes was left unheated. A complete technical understanding of all the processes expected to happen in the salt provides confidence in the researchers' ability to predict that the salt will safely and permanently contain the radioactive waste.

There is a great deal of complexity when it comes to predicting and modeling salt systems because the important variables and processes key to controlling the thermal, hydrological, mechanical, and chemical responses are so tightly interconnected. Both the excavation damage and the heat generation impact the balance of the system. Salt is essentially thermally activated; the system changes rapidly in a number of ways—many of which are coupled. For example, high temperatures speed up creep closure, with creep, damage, and healing all changing how the salt responds. BATS is monitoring brine migration to the boreholes, a process very sensitive to these changes in the salt. The salt's properties change depending on whether the heater is on or off, and this is important to understand because the heat generation from radioactive waste will not be uniform in space for a future repository, as some waste is hotter than other waste, and radioactive decay is such that the heat level changes over time.

The coupling and feedback of processes makes simulation challenging, as it must take into account humidity, water distribution, brine composition, salt permeability, and much more. As one variable changes, the others may change in response, which creates a moving target in terms of calculations. The data that the BATS project is collecting will go a long way toward improving our understanding and predictive models of these processes, which will help us forecast the evolution of the near-drift region.

The shakedown



With so many equipment, safety, and environmental variables to consider, the researchers opted to perform an initial shakedown test, also called BATS Phase 1s, which provided foundational learning for BATS. The shakedown began in June 2018 and ran for nearly a year, until May 2019. It marked the first heated borehole salt experiment conducted underground at WIPP in more than 28 years.

"The lessons learned and insights gained in this initial testing were vital to the design and implementation of the larger-scale experiment," Stauffer said.

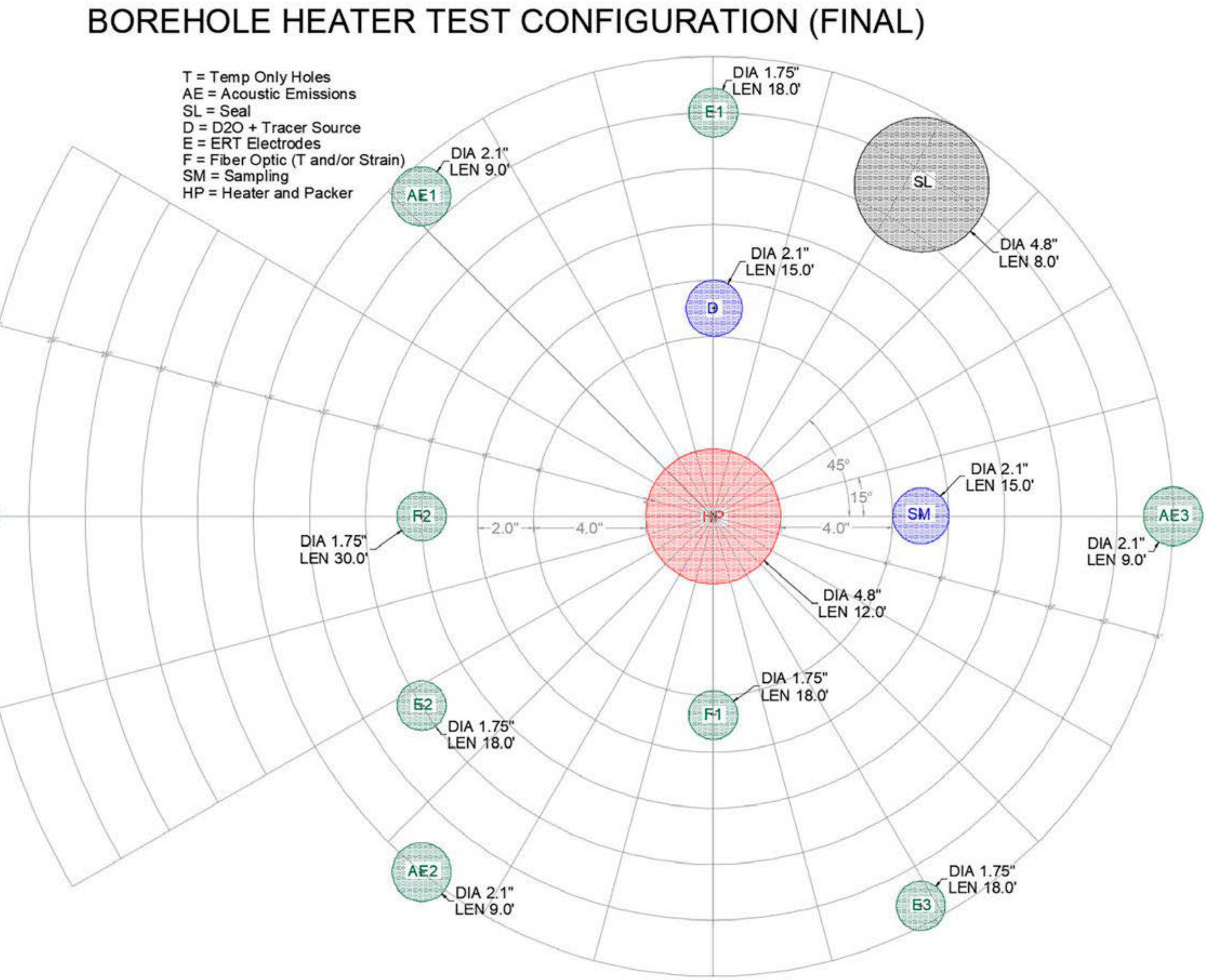
Those foundational lessons included iterating to find an ideal heater design. The original stainless steel block heater the researchers tried did not put enough energy into the system to achieve the targeted 120 °C temperature. Due to the insulating air gap (approximately 1 inch) around the block heater, the temperature at the monitoring boreholes only reached 35 °C. Therefore, the original design was ultimately swapped for a 750-Watt quartz lamp infrared heater, which did in fact deliver the constant temperature desired through radiative energy coupling. The infrared heater was isolated behind an inflatable packer. Dry nitrogen gas flowed through the interval isolated behind the packer, and this gas stream was analyzed for humidity before passing through two desiccant traps, which were weighed to determine the amount of water removed from the borehole. These measurements were compared with those of the gas analyzers.

Establishing the appropriate distribution of liquid pressure and the balance of water and gas (saturation) in the salt around the boreholes are key features needed as part of proper model development.

"There is an iterative loop between the collection of field data and the modeling," Stauffer explained, "and we are always looking for more revealing data sources to help us improve our modeling and understanding."

The shakedown thermal-hydrological model used a 3-D solution mesh containing more than a million nodes, centered upon the central heated borehole. The solution mesh coarsened while moving away from the heater to reduce computational expense where less detail is needed, while keeping artificial boundaries far enough away to reduce their effects on the prediction. The model considered the central borehole as three zones: an air-filled zone, the inflatable packer, and the heater.

This 3-D model was used to predict how the heat and



The borehole layout plan for BATS test array.

brine will equilibrate around the boreholes over a period of years. Additionally, a simpler 2-D radially symmetric model allowed for more rapid investigation of the thermal properties of both the intact salt (far from the boreholes) and damaged salt (near the boreholes). This simpler mesh consisted of only 3,458 nodes and allowed more efficient investigation into processes influencing formation temperature. These and other numerical models will be further constrained (i.e., improved) by data from laboratory measurements of thermal, mechanical, and electrical properties being conducted on salt cores at Sandia National Laboratories.

"We often can't afford to look at all the processes going on in the salt at the same time in the models because it's too complex, so we try to isolate specific processes, which allows for more rapid model-to-data validation," Stauffer said. It is difficult to design an experiment that provides the right data for the modelers, is straightforward for the field team to implement, and will not be overly sensitive to secondary processes or phenomena. While there is always room for improvement, the researchers and the WIPP Test Coordination Office have largely been successful in implementing experiments that provide the needed data.

Working with the Test Coordination Office, the researchers have learned some of the ins and outs of working at WIPP. It can be difficult to bring some equipment underground, sometimes due to physical size constraints (fitting large sections of tubing into the elevator to the underground) and other times due to procedural constraints associated with working at WIPP (an active radioactive waste disposal facility with strict environmental safety and health regulations). Research in the underground at WIPP has taught the BATS team about the effects brine, dark, and salt dust can have while working with sensitive electronics. Guided by the WIPP Test Coordination Office, the BATS team took a cautious and stepwise approach to getting their experiments set up and running in the underground.

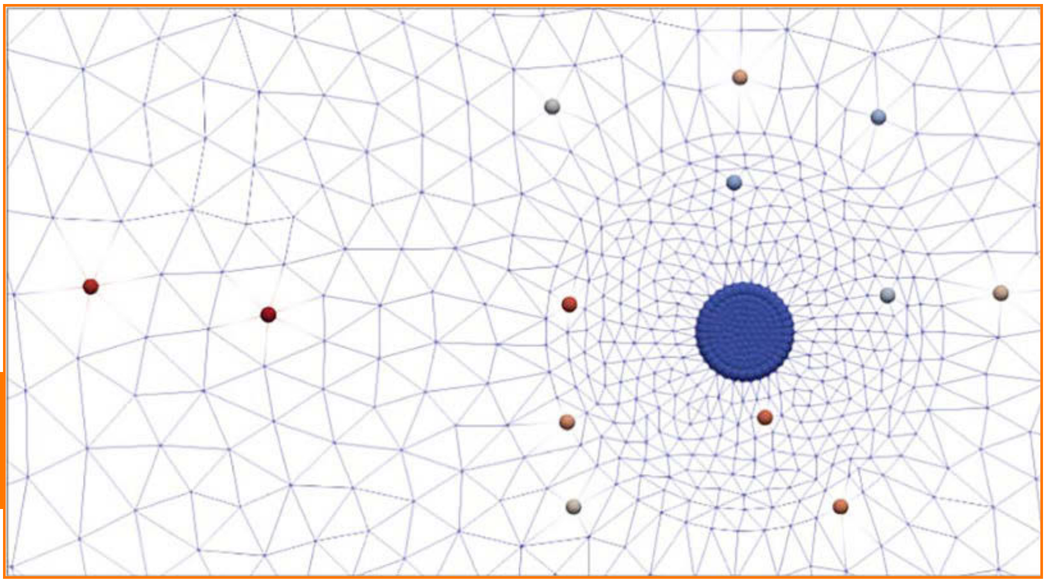
The results of the shakedown were quite positive, with the simulations accurately modeling the observed temperatures. These results were published in *Vadose Zone Journal* (Guiltinan *et al.*, 2020), being featured on the journal's cover. The results along with key lessons learned in experimental techniques and procedural methods were presented to the U.S. Nuclear Waste Technical Review Board in April 2019 and December 2020. Altogether, the shakedown provided the confidence to progress to BATS Phase 1a, the next step in a series of larger-scale experiments that will help the U.S. plan for the future of heat-generating nuclear waste, for which the disposal demand continues to grow.

BATS Phase 1a

Moving beyond experimentation in previously drilled boreholes, the researchers aimed to gather data in newer drilled-for-purpose boreholes. Drilling of the two new arrays was completed in April 2019, with each array consisting of a central borehole for the heater as well as surrounding boreholes for temperature sensors, acoustic emissions, electrical resistivity, and isotopic sampling. The unheated array of boreholes had nearly identical instrumentation to the heated array and was used as a control.

Between January and March 2020, an initial heater test (BATS 1a) in the new borehole arrays was conducted using the established 750W infrared heater from the shakedown. The results of this test were presented at the Waste Management Conference in March 2020 and documented in Kuhlman *et al.* (2020). However, follow-on phases (BATS 1b-1c) in which liquid and gas tracers will be incorporated will be conducted soon but are temporarily on hold due to restrictions associated with the pandemic.

Borehole permeability testing was conducted in June 2019 and in July 2020 by pressurizing the air behind an inflatable packer and while closely monitoring the pressure decay, as the gas flowed into the rock, proportional to the salt's permeability and the relative amount of gas and brine in the salt. Permeability is particularly important in terms of waste disposal safety because it is a measure of the ability of liquids—which could transport radionuclides—to move through the salt. For example, before the rooms creep closed and heal, the fractures within the damaged zone around the drifts are a potential pathway.



A view of the 3-D numerical model mesh showing the heated borehole location (large group of blue dots) and observation boreholes (single dots around it) at WIPP.

Internationally, other groups are also studying the behavior of salt related to radioactive waste disposal and have recently found that typical short-term laboratory experiments illustrating high deformation due to large differential stresses are not always indicative of field conditions (Bérest *et al.*, 2019). Understanding the mechanical processes going on at field-relevant conditions (low differential stress) is actually key for longer time frames, like the ones relevant in a repository. Different small-scale mechanisms lead to the creep observed in the field than during typical tests observed in the lab, making extrapolation from lab data to field applications problematic. This difference implies that creep would actually occur more rapidly in the field than first thought. This new understanding is being used to design more difficult but more relevant laboratory tests, to collect data, improve numerical models, and make better predictions about the behavior of salt.

Thus far, the data collected as part of BATS is aiding better understanding of thermal, chemical, hydrological, and mechanical processes going on in the damaged region surrounding a salt repository. Salt is one of the three media being generically investigated by the DOE-NE Spent Fuel and Waste Science and Technology (SFWST) program (along with granite and shale) because salt is self-healing and essentially impermeable to brine movement far away from excavations. The work being done as part of BATS aids in understanding the complex processes going on near the excavations in the damaged zone, where the ephemeral fractures in the salt allow brine and gas to flow.

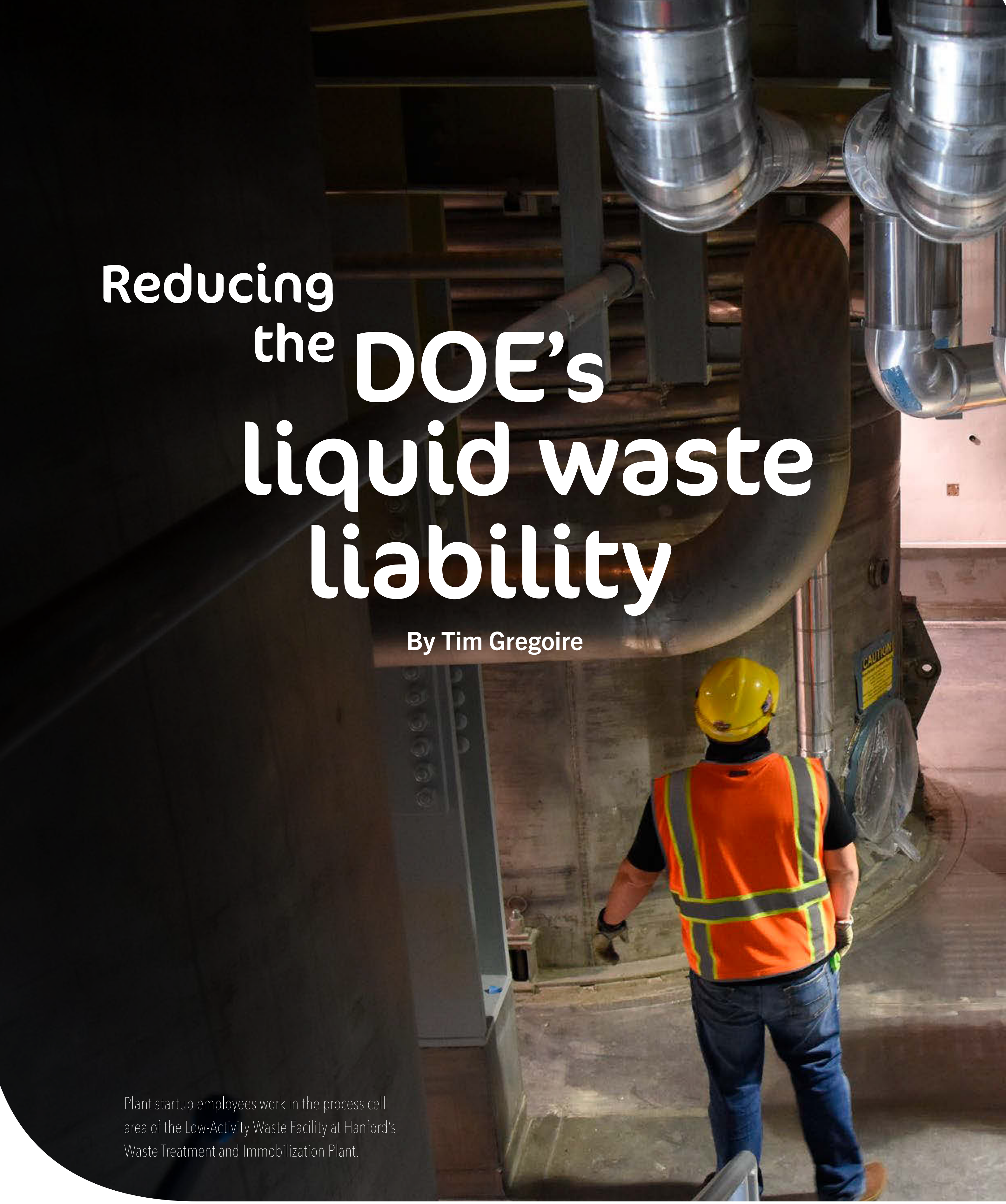
"This work is important because it is what the repository looks like right now," Kuhlman said. "While the rooms in the repository will eventually close up to seal the waste away forever, predicting the behavior in the immediate future provides the initial conditions that allow us to assess the long-term performance of the repository and build confidence in our understanding of the problem."

Relevant DOE-NE reports from the SFWST program can be found on the online project hubs: sfwd.lanl.gov for Los Alamos and sandia.gov/salt for Sandia. Significant international collaborations are part of this research as well. Sandia has been involved in international collaborations on salt repository research with Germany for over 10 years. Additional international partners (the United Kingdom and the Netherlands) and U.S. laboratories (Los Alamos and Lawrence Berkeley) are also getting involved in this valuable international exchange of information. The more that interested research partners join in on the research effort, the better becomes our overall understanding of disposal options in salt.

Katharine Coggeshall is a science writer at Los Alamos National Laboratory.

Reducing the DOE's liquid waste liability

By Tim Gregoire



Plant startup employees work in the process cell area of the Low-Activity Waste Facility at Hanford's Waste Treatment and Immobilization Plant.

In 2020, the DOE announced real progress made in the management of liquid radioactive waste at its sites at Savannah River, Idaho, and Hanford.

During the annual National Cleanup Workshop, held virtually in September of last year due to the COVID-19 health crisis, William “Ike” White, senior advisor to the under secretary for science in the Department of Energy’s Office of Environmental Management, said that despite the pandemic, 2020 was an inflection year for the DOE and his office.

“The accomplishments we have this year are keeping us on track to realize transformational progress over the decade ahead,” White said. “It is a decade in which we will achieve cleanup work at some sites and finish significant work scope at others.”

Most notably, White continued, the progress the Office of Environmental Management (EM) has made will enable the DOE to begin work on its largest environmental liability, its inventory of liquid tank waste. “Tank waste represents about 60 percent of the total environmental liability for EM and it takes up about 40 percent of our budget annually,” he said, adding that a ramp-up in tank waste activities will significantly accelerate the timeline for the processing of waste.

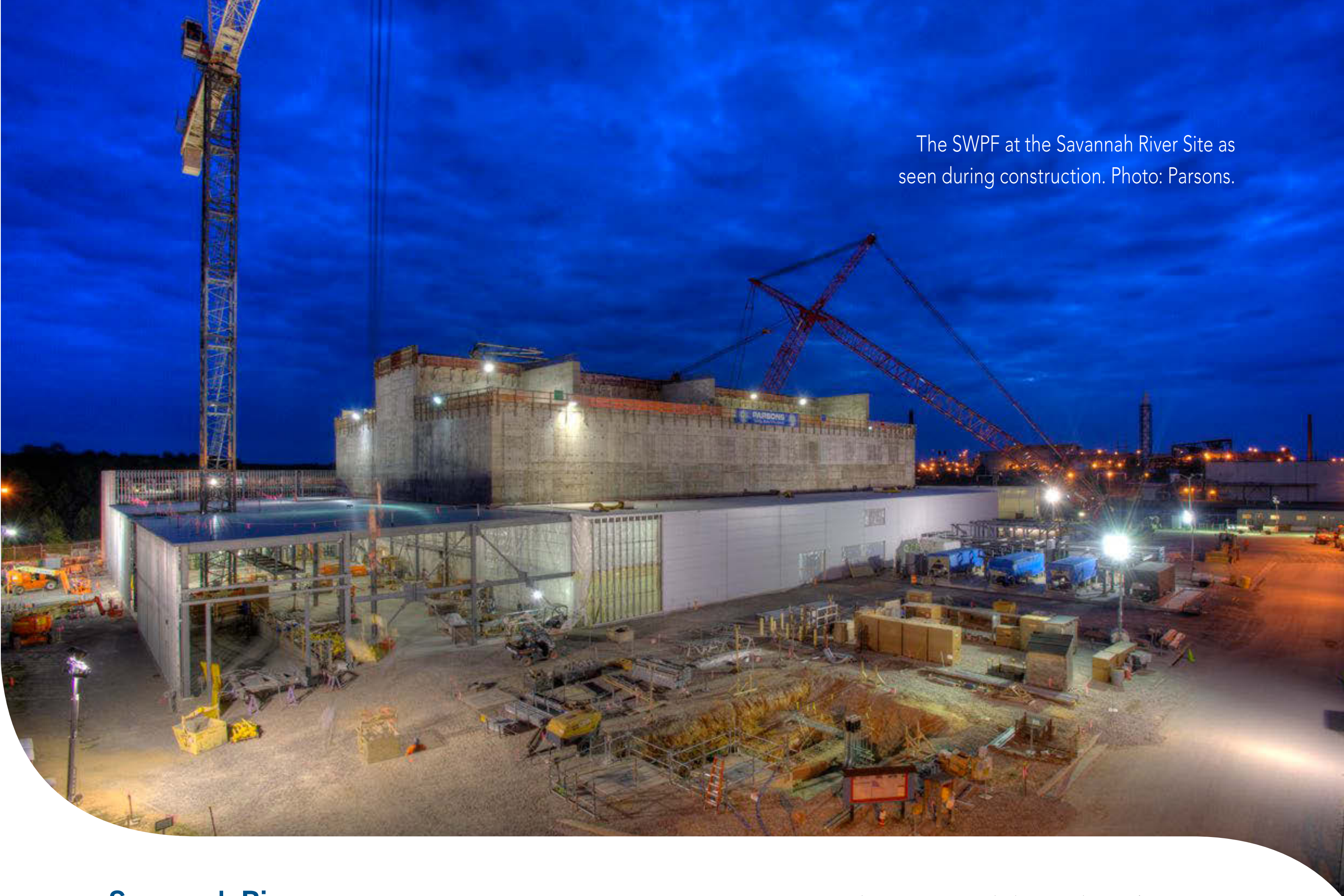
The DOE has nearly 90 million gallons of liquid chemical and radioactive waste stored in underground tanks at three of its sites: the Savannah River Site in South Carolina (31 million gallons); the cleanup site at Idaho National Laboratory (about 900,000 gallons); and the Hanford Site in Washington (about 56 million gallons). Much of the waste is the result of processing plutonium for weapons production, and the goal at all three DOE sites is to stabilize the liquid waste by converting it to a solid form ready for permanent disposal. At Hanford and Savannah River, the liquid waste will be melted into a glass-like form through vitrification, while Idaho's waste will be converted into a granular solid through a process of steam reforming.

While the processes of vitrification and steam reforming are well-understood and straightforward, in practicality it is a complex process with many challenges, including designing glass/solid formulations best suited to the complex chemical compositions of the different waste streams. The design and construction of glass melters and waste reformers capable of safely processing large amounts of liquid waste also pose a number of engineering challenges. Facing such difficulties, the DOE's efforts to treat its liquid waste have faced a number of setbacks, particularly at Hanford and Idaho, where technical issues in the design and construction of processing facilities have caused deadlines to be missed and budgets to be surpassed.

As White noted, however, progress has been made at all three sites. In August of last year, the DOE approved the authorization to operate the Salt Waste Processing Facility at the Savannah River Site, with "hot" commissioning starting in October. At Idaho, the Integrated Waste Treatment Unit is expected to begin processing sodium-bearing waste this summer. While at Hanford, the DOE is on track to begin treating low-level radioactive waste by its 2023 deadline using its Direct-Feed Low-Activity Waste approach.

"Collectively, these capabilities at Savannah River, Hanford, and Idaho represent a fundamental shift for EM as we pivot from long-running construction projects into the actual treatment of waste," White said.

A large-capacity processing vessel is lifted into the SWPF during construction in 2012. Photos courtesy of the DOE.



The SWPF at the Savannah River Site as seen during construction. Photo: Parsons.

Savannah River

Seen as the cornerstone of the DOE's radioactive waste processing strategy at the department's Savannah River Site (SRS), the Salt Waste Processing Facility (SWPF) is the last major piece of the liquid waste system at the South Carolina site. SWPF will treat the majority of Savannah River's salt waste inventory by separating the highly radioactive waste from the less radioactive salt solution.

The remediation of radioactive waste begins by transferring the waste from Savannah River's H Tank Farm to SWPF, where it undergoes a two-step separation process. The first step removes strontium and actinides, such as uranium and plutonium, from the waste. The second step, known as Caustic Side Solvent Extraction, is designed to remove radioactive cesium.

After the initial separation process is completed, the concentrated high-activity waste will be sent to the nearby Defense Waste Processing Facility, where it will be vitrified and stored for eventual disposal. The decontaminated salt solution will be mixed with cement-like grout at the nearby Saltstone Facility for disposal on site. Removing salt waste, which fills more than 90 percent of tank space in the SRS tank farms, is a major step toward emptying and closing the site's remaining 43 high-level waste tanks.

In 2002, the DOE selected Parsons Corporation to design, build, commission, and operate SWPF with the goal of processing the 31 million gallons of salt waste stored in underground tanks at SRS. Parsons finished building SWPF in April 2016, eight months ahead of schedule and more than $65 million under the target cost of the contract for construction activities. Under its contract with the DOE, Parsons will operate the SWPF for one year, until January 2022.

As noted, the DOE approved Critical Decision-4 for SWPF in August 2020, which authorized radioactive (hot) operations to begin at the facility. Hot commissioning of SWPF officially began on October 5, 2020, with the transfer of the first batch of radioactive waste to the facility. That first batch of approximately 4,000 gallons of waste took about two weeks to process as the facility went through a series of surveillances and sampling inspections to ensure all aspects of the process worked as designed. By the end of the first month of operation, during the facility's hot commissioning testing phase, SWPF had processed nearly 86,000 gallons of waste, according to the DOE.

A cell within the IWTU where canisters are filled with solidified waste.

On January 19, the DOE announced that SWPF had completed its hot commissioning testing phase, signaling the facility's entrance into fully integrated operations with the other SRS liquid waste facilities. At that point, more than 320,000 gallons of radioactive liquid waste from the site's H Tank Farm had been processed by SWPF.

According to the DOE, all SWPF hot commissioning testing objectives were met, on schedule and without incident, including validating facility processing capacity at an instantaneous rate that exceeded the 7.3 million gallons per year required by contract. It is anticipated that SWPF will process up to 6 million gallons of waste during its first year of operations and that nearly all of Savannah River's salt waste inventory will be processed by 2030.

"The start of operations enables DOE to now close waste tanks at an unprecedented rate," said Mike Budney, DOE manager for the Savannah River Operations Office, following the completion of hot commissioning testing.

Idaho

While construction of the Integrated Waste Treatment Unit (IWTU) was completed in 2012, several equipment and chemistry issues have kept the facility from beginning treatment of Idaho's 900,000 gallons of liquid radioactive waste. The sodium-bearing waste, stored in three underground tanks at the Idaho Nuclear Technology and Engineering Center, was generated during later phases of spent nuclear fuel reprocessing, which ended in 1992. Located near the research center, the IWTU uses a steam-reforming technology that will convert the liquid to a solid, granular material, which will be packaged in stainless steel canisters and stored in concrete vaults at the site until a permanent disposal facility becomes available.

Delays at the IWTU put the DOE in breach of a 1995 settlement agreement between the federal government and the state of Idaho that set deadlines for waste disposal. That led Idaho Attorney General Lawrence Wasden to block shipments of research quantities of spent nuclear fuel to Idaho National Laboratory (INL) in 2016. Wasden and Gov. Brad Little later signed a deal with the DOE allowing shipments of research fuel, but the IWTU still needs to begin processing waste before INL can receive the fuel.

In 2016, the DOE awarded the Idaho Cleanup Project contract to Fluor Idaho, which has been making modifications to the IWTU to resolve the fluidization, chemical, and equipment issues that have hampered the startup of the facility. In spring 2020, the DOE and Fluor Idaho resolved the last of those problems when it concluded testing of new ceramic filters used in the IWTU's off-gas system.

Startup of the IWTU at the DOE's Idaho cleanup site was to begin late last year but was delayed due to COVID-19. Inset: Stainless steel canisters are stored at the IWTU in anticipation of hot operations.

Previous process gas filters used at IWTU were constructed of a metal matrix. During several demonstration runs of the facility, the metal filters became plugged, reducing their efficiency. A 1,262-hour pilot plant demonstration, concluded last year at Hazen Research, an industrial laboratory in Golden, Colo., showed that ceramic filters were effective at removing fine solids without clogging.

During the most recent outage (Outage J) of the IWTU, the new ceramic filters were installed in the unit's off-gas system. Also during Outage J, wet and dry decontamination technologies that will enable crews to replace equipment during waste treatment operations were installed, along with robotics used to decontaminate stainless steel canisters prior to being placed in concrete vaults.

"Long-term testing has concluded on the ceramic filters—they are still going through the outage, but I'm confident we have addressed the technical challenges that have prevented startup for the past few years, and we hope to get it up and running within the next few months," White said in September.

In January, Fluor Idaho said that the effects of COVID-19 have caused the schedule for completing Outage J to slip at least five to six months, which will delay the start of hot operations. At the time, modifications to the IWTU were nearly complete in advance of a 50-day confirmatory run planned for this year. Following a successful confirmatory run, the IWTU will go through a series of readiness assessments prior to starting radiological operations, Fluor said, adding that the project "will continue with a methodical approach to perform field work within protective guidelines."

The slip in the schedule caused by COVID-19 caused the DOE to miss one of its stated priorities for 2020. Startup of the IWTU was listed under Priority #1 of the department's mission priorities scorecard for the year.

A team conducts walk downs of systems in the WTP's Effluent Management Facility, which will treat effluent generated from the vitrification of Hanford's liquid waste.

Hanford

At the heart of Hanford's liquid waste program is the Waste Treatment and Immobilization Plant (WTP), also known as the Vit Plant, a complex of buildings that has been under construction for nearly 20 years and, according to a May 2020 report by the Government Accountability Office, costing more than $11 billion to date, with numerous technical challenges, cost overruns, and schedule delays.

The WTP was to separate Hanford's approximately 56 million gallons of chemical and radioactive tank waste into high- and low-activity waste streams, which would be sent to different WTP facilities simultaneously for vitrification. When technical issues—ranging from the mixture of waste prior to treatment to the potential erosion of piping—halted construction of the WTP's pretreatment facility in 2012, the DOE switched to a sequenced strategy that would allow low-activity waste to be processed before the completion of the pretreatment facility. The approach, known as Direct-Feed Low-Activity Waste (DFLAW), would allow the DOE to meet its commitment to the state of Washington to begin treating tank waste by 2023.

A system of interdependent projects and infrastructure improvements, DFLAW begins with the Tank-Side Cesium Removal System, a pretreatment system that will filter out suspended solids and remove radioactive cesium to produce low-activity waste feed from tank waste liquid. The waste will then be sent to the WTP's Low-Activity Waste (LAW) Facility, where the waste is vitrified and placed into stainless steel containers. The size of one-and-a-half football fields, the LAW Facility houses two large melters that will mix tank waste and glass-forming materials at 2,100 °F. Secondary liquid waste generated by the LAW Facility will be treated at the Effluent Management Facility, which was the final major construction effort to support DFLAW.

In December, workers with Hanford contractor Bechtel National completed construction of the last of 94 systems in the LAW Facility. And in January, the DOE marked the conclusion of construction activities at the WTP, with all engineering, procurement, and construction being completed on the plant's 17 facilities that will be used in the DFLAW approach, including the LAW Facility, the Effluent Management Facility, the Analytical Laboratory, and 14 support structures. With construction completed, the WTP facilities have now been moved to the startup testing and commissioning phases to prepare for operations.

In marking the construction milestone, DOE Hanford Manager Brian Vance said, "As the plant moves to full commissioning, other Hanford contractors continue to drive to prepare for round-the-clock operations by completing projects and infrastructure improvements that must operate for the plant to be successful. We are moving deliberately and safely toward treating tank waste and meeting our commitment to continue to protect our workforce, the people of this region, and our environment."

As they are completed, the LAW Facility systems are turned over to a startup testing team to ensure they work properly prior to commissioning. As of late December, more than a third of the 94 LAW Facility systems have been tested and handed over to plant management for commissioning.

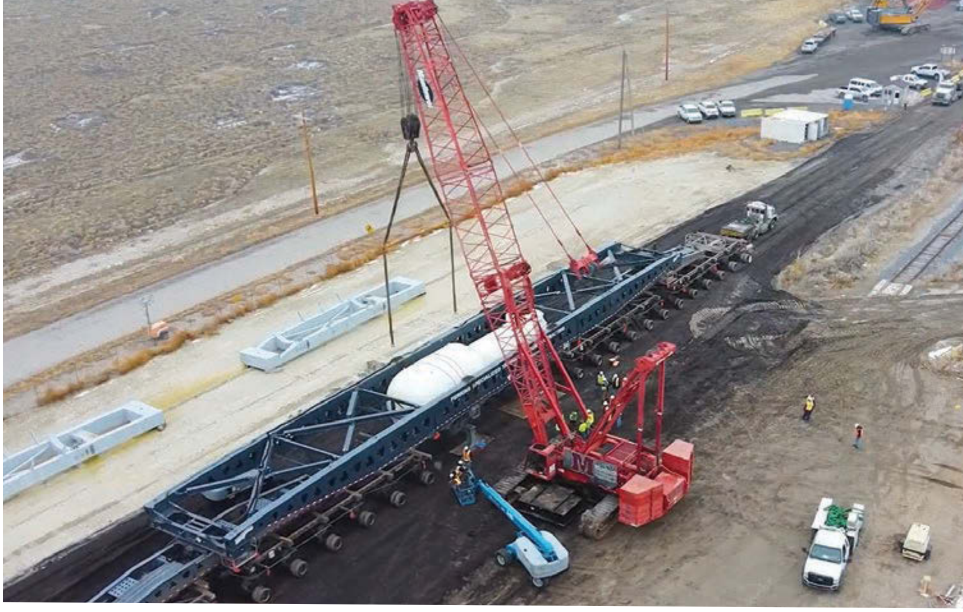
This includes the testing of transfer lines that will move condensate from the LAW Facility to a nearby retention facility. Bechtel National, in collaboration with Washington River Protection Solutions, completed the testing of the transfer lines late last year.

Earlier in 2020, Hanford staff finished startup testing at WTP's Analytical Laboratory, which will analyze up to 3,000 samples of waste each year to make sure it meets disposal requirements.

The DOE said in January that while the full impacts of the COVID-19 pandemic are unknowable, the department is committed to completing commissioning of DFLAW before the December 2023 deadline imposed by the DOE's consent decree with the state of Washington. A force majeure modification to the decree's deadlines, approved by a federal court in December, does provide legal accommodation for the realities imposed by the pandemic. Yet the DOE maintains that the modification does not reflect an actual change to its schedule.

"The start of tank waste treatment at Hanford is an existential victory that has been decades in the making," White said. "It marks the beginning for us of real progress in getting to the single largest environmental liability of any U.S. government agency."

The first set of 20 containers manufactured by Petersen of Utah were delivered to the WTP in October 2020.



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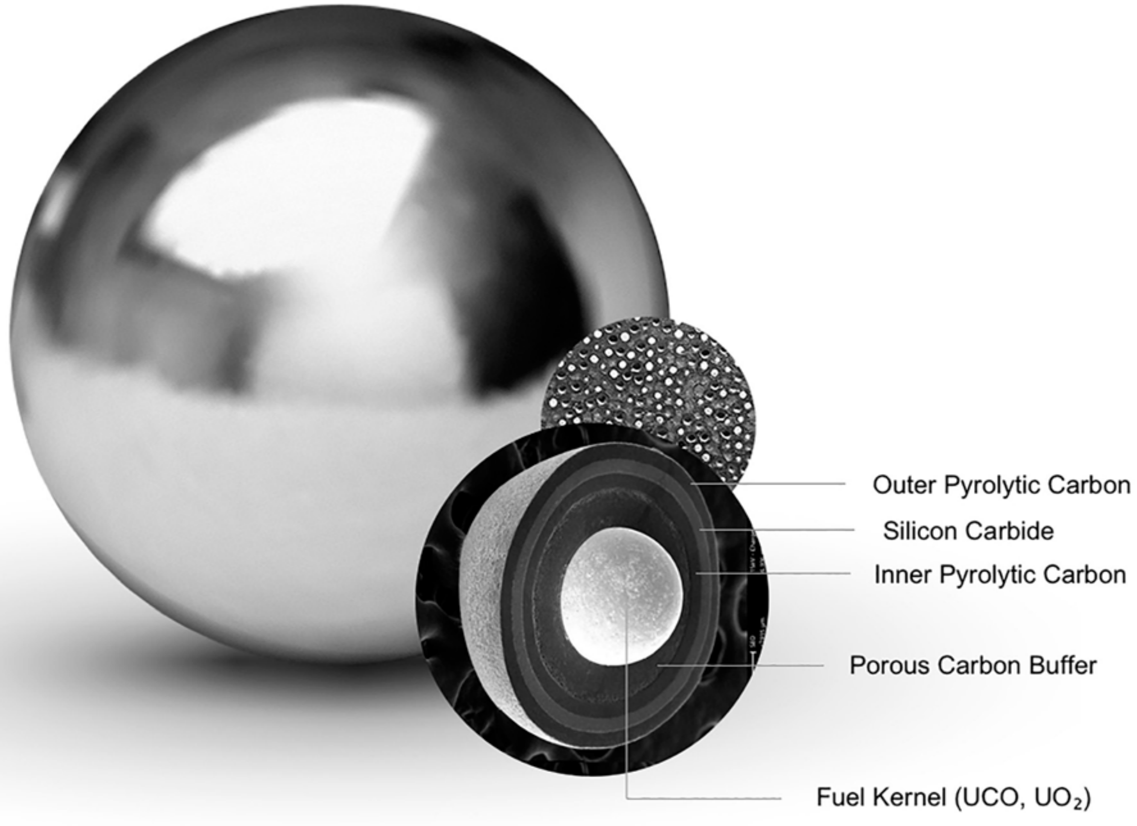
Packaging TRISO:

A storage and transportation strategy for fluoride-salt-cooled high-temperature reactors spent fuel



An illustration of X-Energy's TRISO-X fuel. Image: X-Energy

By Lorenzo Vergari and Massimiliano Fratoni

Spent nuclear fuel from a pebble bed fluoride-salt-cooled high-temperature reactor (FHR) presents a different set of handling and transportation challenges than light water reactor spent fuel. First, FHR cores contain a large number of fuel elements (10^5-10^6), against the 200 fuel assemblies of a typical pressurized water reactor or 700-800 fuel assemblies of a boiling water reactor. Second, in storage conditions FHR fuel pebbles can sustain a much higher temperature than that allowed for LWR fuel rods, with allowable peaks above 700 °C. On the other hand, FHRs are cooled by molten fluorides, which freeze at relatively high temperatures (e.g., 459 °C for FLiBe, used in the Mark-1 FHR [1]), so that retrieval and handling of pebbles trapped in a solidified medium may prove complicated. Third, graphite takes up tritium generated by neutron irradiation of lithium in the molten fluoride [2]. Tritium uptake in and desorption from graphite are temperature-dependent processes, and without any treatment of the used fuel for the removal of tritium, there is a potential to release a fraction of tritium in temperature transients during fuel handling, transportation, and storage [3].

Best practices for the management of the FHR spent fuel need to be devised. In this article, we will outline a potential strategy for the handling of FHR fuel from discharge until transportation off the reactor site.

Pebble bed storage system

Once spent fuel is discharged from any reactor core, proper handling and storage are needed to ensure containment of radioactive materials, subcriticality, decay heat removal, and radiation shielding. In the case of FHR spent fuel, containment relies on the robustness of TRi-structural ISOtropic (TRISO) fuel particles over very long time periods [4]. Here we will focus, instead, on subcriticality and cooling.

Wet storage

Typically, LWR spent fuel requires a period of wet storage in pools before transitioning to dry storage. Spent fuel pebbles may be cooled in pools and/or in dry-storage containers. Salt residuals will be present on their surface and may be removed before being transferred to the wet or dry storage facility or after an initial period of cooling.

Each design option has its advantages and challenges. In a wet storage strategy, using a liquid coolant may enhance heat removal and shield radiation effectively, allowing large stackings of pebbles, but would introduce new material to eventually dispose of. Sealed containers cooled with air or inert gases reduce the risk for contamination and fission product release but have poorer heat transfer performances.

In the proposed strategy, it is assumed that fuel is removed from the reactor and loaded into a pool, where it is cooled with a naturally circulating molten fluoride salt. Water cooling is not a viable option for FHR pebbles, and molten salts are a logical alternative. Fluoride salts have good heat transfer properties, are chemically compatible with graphite, and are dense enough to provide effective radiation shielding. In our analysis, we use molten FLiNaK as the cooling medium for the wet storage system. Helium is used as the inert gas covering the molten salt pool.

As soon as the decay power and the dose rates fall below acceptable thresholds, the fuel is extracted from the pool, cleaned of salt residuals, and loaded into dual-purpose casks for storage and transportation. A minimum pool storage time is set at one year based on Nuclear Regulatory Commission regulations, assuming that such requirement will remain unchanged for FHR spent fuel.

Subcriticality requires the multiplication factor k_{eff} to remain below 0.95 at 95 percent confidence during normal operations and accident sequences. We propose a simplified design, with pebbles enclosed within a cubical gridded stainless steel container to be located at the bottom of the pool. It will be assumed that fuel pebbles will be randomly packed in the container with a 60 percent volumetric packing fraction. The actual design of the containers will depend on multiple considerations such as handling of the container and pebbles transfer in and out of it.

Nevertheless, the assumptions made here are expected to provide a conservative framework in regard to criticality (it is excluded that pebbles would be stacked in an ordinate packing with higher density than the random packing). In our simulation, we verify that the fuel maintains subcritical condition during normal operations and in accident sequences that may cause leaking of the salt and/or water flooding.

Fuel cooling might be implemented through natural circulation or forced convection. Since natural circulation implies lower operational costs, and has the safety features of a passive mechanism, it is the preferred cooling mechanism during pool storage. Whereas for LWRs the prerogative is to keep the spent fuel cladding temperature below a given limit (typically 400 °C), intact TRISO particles can withstand temperatures up to 1,600 °C with practically no damage or fission product release [5]. In our simplified design, we assume that a helium heater is employed to make up for heat losses through the walls and to maintain the temperature above the salt melting point (454 °C).

Dry storage and transportation system

After being extracted from the pool, pebbles need to be washed in order to remove any salt residuals. After cleaning, the pebbles might be transferred in canisters. In order to comply with regulations on both dry storage and transportation, the spent fuel must remain subcritical in normal conditions and in case of water ingress. Under exclusive-use shipment, the overpack temperature limit is 85 °C in normal operations.

With several types of canisters and overpacks licensed by the NRC, adopting designs similar to those used for LWR may streamline the regulatory process. The differences in shape between FHR pebbles and LWR elements, nevertheless, are marked. It is therefore unlikely that a current canister could be used for FHR fuel with only minor adjustments.

Current canister designs include internal gridded baskets made of aluminum and boron carbide to reduce k_{eff}. We propose to replace the grid with boron-doped graphite spheres to be dispersed among the pebbles. The spheres, of smaller size than fuel pebbles, would allow for a homogeneous neutron absorption and would limit the space available for water in a flooding accident. Unlike canisters, overpacks might be based on current designs, with small adaptations for compatibility with the new canisters. To this purpose, simulations are performed with an overpack design based on a licensed model (Holtec HI-STAR 100). The modeled canister and overpack are represented in Fig. 1.

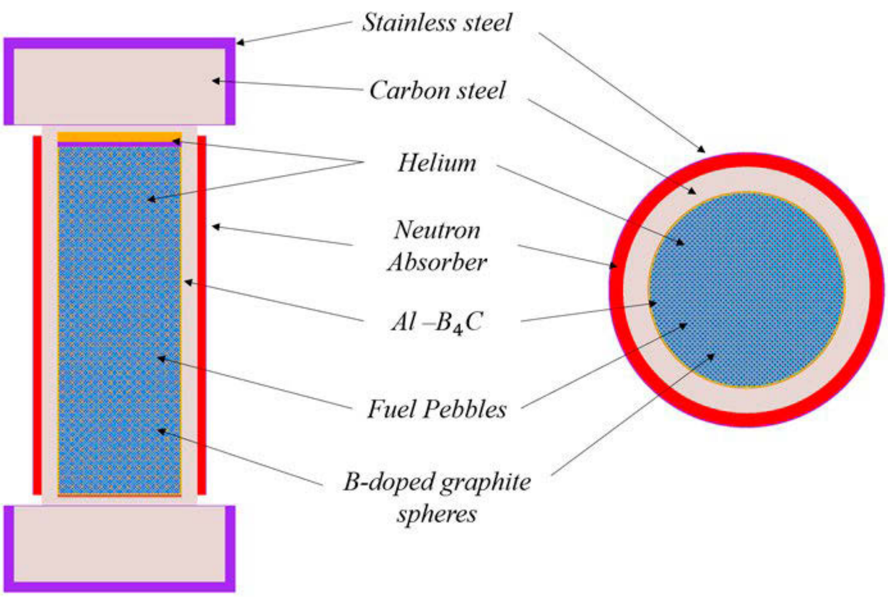


Fig. 1. SCALE modeled HI-STAR 100-based canister and overpack geometries.

Methodology

The spent fuel composition as a function of time was calculated with the ORIGEN computer code using collapsed group constants previously calculated with a KENO (a Monte Carlo code in the SCALE suite) transport sequence based on the FHR equilibrium composition reported by [6]. In the depletion calculation, the irradiation time was set at 1.4 years, and the power density was set at 22.7 W/cm^3.

Criticality simulations were performed using the KENO-VI transport solver. In all criticality simulations, the fuel was assumed to be fresh, and no credit was taken for fuel burnup. It was also assumed that all fuel pebbles were uniformly enriched (19.9 percent). For added conservativity, the simulations for wet storage were performed considering a double number of pebbles.

For the wet storage phase, a conduction-convection model was developed (Eq. 1-4) [7]. Distributed pressure losses were modeled through the semi-empirical Ergun correlation for pebble beds [8], and concentrated pressure losses were assumed at the bends and upon the cross-sectional changes. A flat temperature profile across transverse sections and Boussinesq approximation were assumed in the computation.

$$\frac{1}{r^2}\frac{\partial}{\partial r}r^2\frac{\partial T}{\partial r} = -\frac{\sigma}{k_p} \tag{1}$$

$$\left[\frac{fz}{D_h(0.40A)^2} + \frac{f(2l+2z_{pool}+z)}{D_h A^2} + \frac{\xi}{A^2}\right]\frac{\dot{m}^2}{2p} = \rho g\beta(z+l)(T_f(z) - T_{in}) \tag{2}$$

$$T_f(z) = T_{in} + \frac{0.60A\sigma z}{c_p\dot{m}} \tag{3}$$

$$Nu = 2 + 1.1Re^{0.6}Pr^{1/3} \tag{4}$$

Where, r is the pebble radius, T is the pebble temperature, σ is the power density in the pebble, and k_p is thermal conductivity; f is the friction factor and ξ the coefficient for concentrated pressure drops; z is the height of the fuel pebble stack, z_{pool} is the distance from the stack to the pool surface, and $2l$ is the length of all the other segments of the fluid loop; D_h and A are the hydraulic diameter and the cross sectional area for the fluid flow; m is the mass flow rate, ρ the density, β the thermal compressibility, and c_p the specific heat; $T_f(z)$ and T_{in} are the fluid temperatures at the outlet and at the inlet of the pebble stack; *Nu, Re, Pr* are the dimensionless Nusselt, Reynolds, and Prandtl numbers.

For the dry storage/transportation phase, heat conduction was modeled within the tank, and natural convection and thermal radiation were assumed on its outside. It was assumed that power is dissipated only radially and that the temperature is axially uniform (Eq. 5-8).

$$\frac{1}{r}\frac{\partial}{\partial r}r\frac{\partial T_c}{\partial r} = -\frac{\sigma(r)}{k_c} \tag{5}$$

$$-k_c\left.\frac{\partial T_c}{\partial r}\right|_R = h(T_s - T_\infty) \tag{6}$$

$$Nu = 0.6 + \left[\frac{\mathrm{Pr}(T_s-T_\infty)g\beta(2R)^3}{\nu^2}\right]^{1/6} \cdot \frac{0.387}{\left[\left(\frac{0.559}{Pr}\right)^{\frac{9}{16}}+1\right]^{\frac{8}{27}}} \tag{7}$$

$$h = \frac{2NuR}{k_{air}} + \sigma_b\epsilon(T_s^2 + T_\infty^2)(T_s + T_\infty) - \frac{J_s\epsilon}{T_s-T_\infty} \tag{8}$$

Where, in addition to the previously introduced quantities, R is the cask radius, h is the heat transfer coefficient, and k_c and k_{air} are the cask and air thermal conductivity; T_c is the cask temperature, T_s the temperature at its surface, and T_∞ is the air temperature; ν is air kinematic viscosity, σ_b is the Stefan-Boltzmann constant, J_s is the solar constant, and ϵ the emissivity.

Results

Wet storage

To compute the critical mass of fresh fuel pebbles in FLiNaK, and in case of air and water ingress, pebbles are arranged in an infinitely reflected sphere with a packing fraction of 60 percent in FLiNaK, air, or water. Criticality is never reached when storing pebbles in FLiNaK, regardless of their number. The number of pebbles necessary to achieve a k_{eff} of 0.95 is 387,150, in the case of storage in air, and 7,044 pebbles in water (Fig. 2).

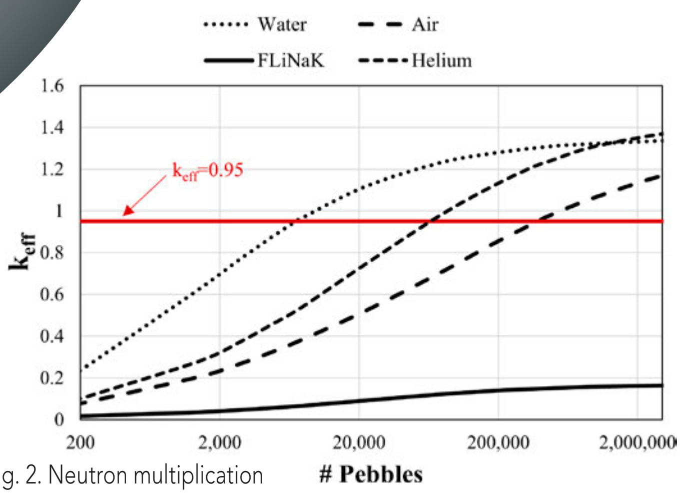


Fig. 2. Neutron multiplication coefficients of an infinitely reflected sphere of fresh pebbles in FLiNaK, water, and air.

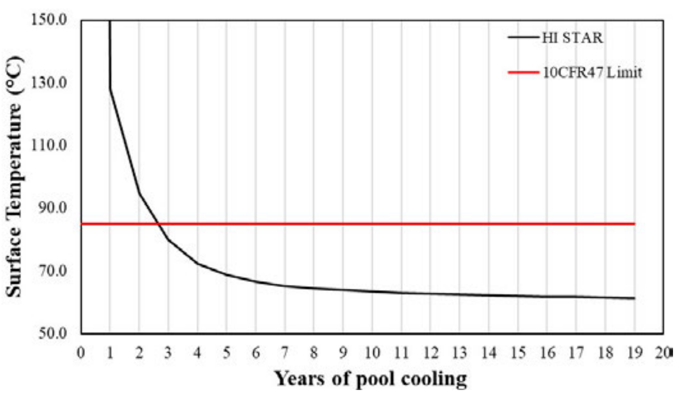
The analysis confirms that criticality does not pose concerns in case of storage in FLiNaK, but that accident scenarios with salt leakage and/or water flood may lead to critical assemblies. As a result, pebbles will need to be separated in multiple containers, possibly using absorbing materials. Distributing the pebbles in containers (72.8 cm × 72.8 cm × 68.25 cm) gridded with a 1-cm-thick Al + B_4C cruciform grid allows them to maintain a subcritical condition in the event of water ingress. The number of containers required varies from 66 (in case of a 1-year storage) to 457 (10-year storage).

Natural circulation with FLiNaK allows heat to be removed effectively, with minimal increases in salt temperatures in the pool (Table I).

TABLE I. Heat-transfer parameters with natural circulations in wet storage for different durations.

Wet Storage Duration	Year	$\dot{m}$ (kg s^{-1})	h (W m^{-2} K^{-1})	$Tf(z)$ (°C)v	Max T (°C)
1 Year	0	2,799	4,731	515.4	534.2
1 Year	1	311	1,308	504.1	504.2
4 Years	0	10,886	5,552	512.7	530.8
4 Years	4	700	1,116	504.0	504.1
10 Years	0	27,889	5,872	511.9	529.8
10 Years	10	1,397	1,021	504.0	504.0

Fig. 3. HI-STAR 100 surface temperature compared to limit surface temperature mandated by the NRC (85 °C).



Dry storage and transportation

With the proposed overpack and canister design, the spent fuel is highly subcritical both in normal conditions (k_{eff} = 0.4593) and in case of water flooding (k_{eff} = 0.7356).

Fig. 3 shows the surface temperature as a function of time of cooling in the pools. One year of cooling is not sufficient to reduce the surface temperature below the 85 °C limit. Hence, a minimum of three years in the spent fuel pool will be required before the fuel can be moved to the dry storage/transportation cask.

The strategy

After performing criticality safety and heat transfer simulations for spent nuclear fuel stored in a FLiNaK pool, it emerges that the most demanding constraints to the design of the wet storage system are set by criticality concerns. Adopting a conservative approach, where no credit for reactor burnup is taken and the quantity of fuel in storage are augmented by a safety factor, a subcritical layout can be achieved by distributing the fuel in several containers, with absorbing material grids within each case. With this layout, the pools are capable of hosting large amounts of spent fuel, allowing for long-term cooling. In a salt pool, the fuel can be successfully cooled at all times relying on natural circulation, with limited temperature excursions.

Limits on the surface temperature of casks for dry storage and transportation require spent fuel pebbles to be stored in the pool for a minimum of three years. Radiation shielding calculations are needed to confirm that the dose at the surface of the overpack is within acceptable limits. The following strategy is, therefore, proposed for handling spent fuel pebbles from FHRs:

1. Nuclear fuel discharged from the reactor core might be moved to FLiNaK pools for its initial cooling.
2. In the pools, the fuel might be arranged in multiple adjacent containers. Each container should be designed to remain subcritical in normal operation and in accident scenarios, upon FLiNaK leakage or water flooding, if the latter cannot be prevented by design.
3. Al + B_4C grids are proposed in order to control criticality through neutron absorbing elements.
4. Helium is proposed as an inert gas in the pool building, and all fuel loading and unloading actions should be managed remotely.
5. The fuel might be withdrawn from the pool after three years of cooling (shielding calculations are needed to confirm that the dose is sufficiently low).
7. The pebbles will be washed to remove salt residuals on the surface and then loaded into dual-purpose (transportation/dry storage) casks.
8. Although currently existing overpack designs could be retained, canisters will need to be redesigned because of geometric dissimilarity of FHR and LWR fuel.
9. Subcriticality of the fuel in the canister can be achieved by introducing a distributed absorbing element, such as boron-doped graphite spheres dispersed among the pebbles.

Before these strategic suggestions can be put into effect, more detailed investigations will be needed. The next steps in such an assessment should be radiation-shielding calculations and detailed thermal-hydraulic simulations. The feasibility of the strategy should also be tested on chemical and mechanical grounds.

Interesting questions, in this area, include the release of tritium in the pool and in the containers, the containment of radioactive products, the handling of fuel across the diverse phases, and the procedure to clean the pebbles.

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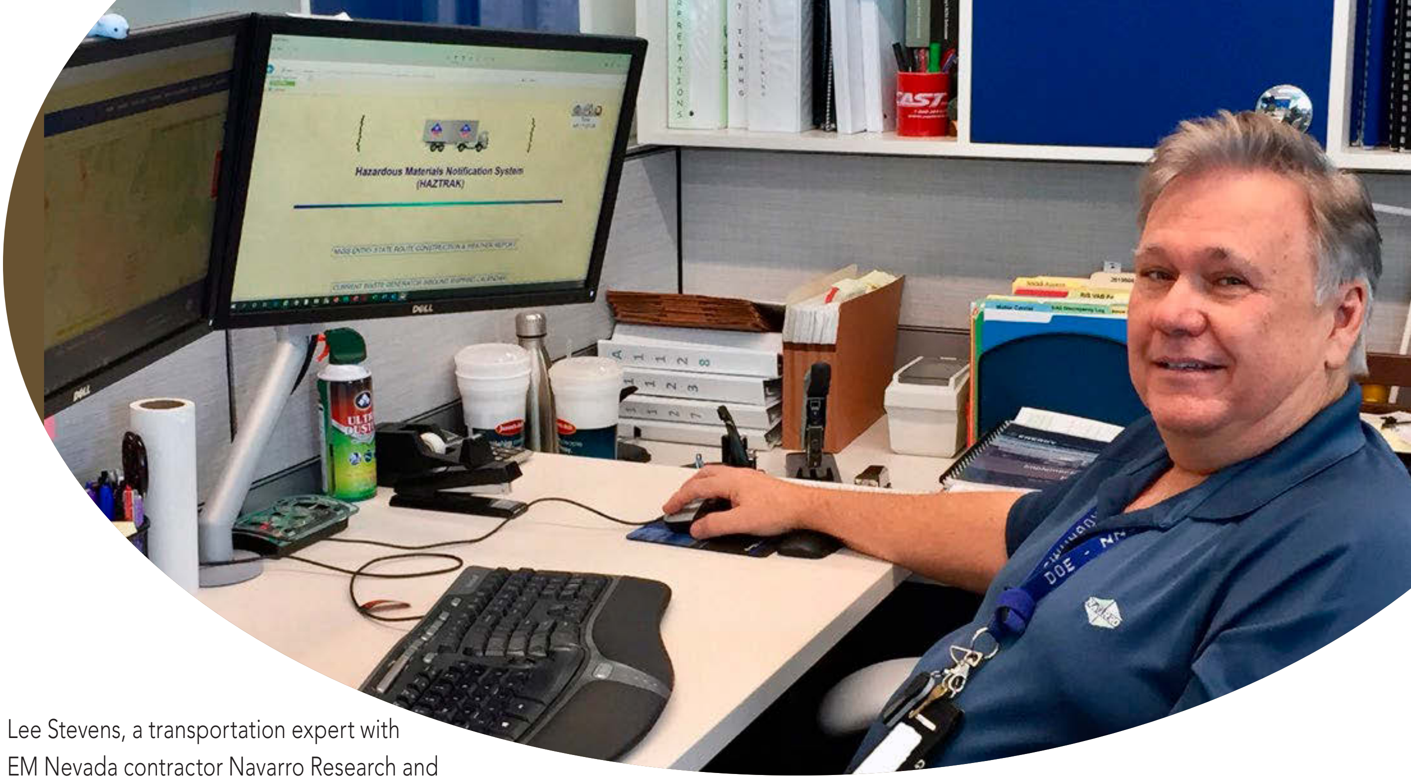
NEVADA BOUND:

How DOE route monitoring ensures waste shipment safety

A truck transports a cargo container of LLW en route to a NNSS disposal cell. Photos courtesy of the DOE/EM Nevada.



Lee Stevens, a transportation expert with EM Nevada contractor Navarro Research and Engineering, monitors LLW shipments to NNSS.

Early on the morning of June 24, 2020, a 5.8-magnitude earthquake shook California's Central Valley. With its epicenter near Lone Pine, Calif., the quake sent truck-size boulders tumbling down Mount Whitney and was reportedly felt from Sacramento to Los Angeles, as well into neighboring Nevada as far as Las Vegas.

The quake did not go unnoticed by the Department of Energy and its Environmental Management (EM) Nevada Program, which promptly began sending notifications to waste generators shipping low- and mixed low-level radioactive waste to the Nevada National Security Site (NNSS) in southeastern Nye County, Nev., about 65 miles northwest of Las Vegas.

According to the DOE, swift reaction to ever-changing road conditions in the region is a routine occurrence that demonstrates the EM Nevada Program's commitment to the safe transportation of waste for the protection of the public, workers, and the environment.

Following the earthquake, Lee Stevens, a transportation expert with Navarro Research and Engineering, the lead environmental program services contractor for EM Nevada, immediately relayed key information concerning regional road conditions and closures to waste generators with shipments en route to the NNSS. According to the DOE, Stevens' quick thinking and proactive communication helped ensure the safety of drivers and their loads, minimized rerouting or shipping delays, and facilitated continuous situational awareness for DOE staff supporting NNSS waste management operations.

"EM Nevada is doing great work to keep waste generators across the DOE complex aware of road and weather conditions on routes to the NNSS," EM Nevada Program Manager Rob Boehlecke said not long after the earthquake. "Lee's rapid response on June 24 not only helped to ensure the safety of drivers and their cargo, but also demonstrated that EM Nevada is ready, willing, and able to respond decisively to a more significant event if the need arises."

EM Nevada uses the NNSS-based Hazardous Materials Notification System (HAZTRAK) to monitor and manage such shipments. Updated four times daily, HAZTRAK is a database providing information on non-classified shipments of radioactive waste originating from or destined to the NNSS. Applicable information from HAZTRAK is also accessible to intergovernmental partners and the general public on the NNSS website, at nnss.gov/pages/programs/RWM/HAZTRAK.html.

EM Nevada also recently worked with personnel from the Nevada Department of Transportation (NDOT) to publish guidance that ensures NDOT route approvals are consistent with agreements between the DOE and Nevada stakeholders.

Continued

Safety compliance

Since 1999, more than 31,000 radioactive and classified waste shipments have been safely transported to the NNSS. Generators of this waste are responsible for ensuring that it is safely packaged and transported in compliance with U.S. Department of Transportation regulations, NNSS waste acceptance criteria, and other applicable federal, state, and local regulations and requirements. This includes packaging waste to comply with safety standards for minimizing public exposure during transport.

Compliance is assessed during numerous radiation surveys conducted pre- and post-shipment, and according to the DOE, studies documenting these assessments have concluded there are no health impacts in communities through which waste travels en route to the NNSS. There are also rigorous training and reporting requirements for carriers and their drivers that provide additional safety measures during transportation of waste, the DOE said.

The DOE also maintains that timely and transparent communications are paramount to the EM Nevada Program. Coordination with intergovernmental and public stakeholders occurs during regularly scheduled meetings where routine updates are provided. Through these stakeholder interactions, the EM Nevada Program worked with Nevada DOT to publish a routing considerations reference that communicates off-limits routes that should be avoided, such as the red-shaded areas of the map seen below. This key communication link helps to prevent the inadvertent identification of routes in state-issued overweight and/or over-dimensional permits that are required for some waste shipments, according to the DOE.

Source: DOE/EM Nevada

Of the more than 31,000 shipments of waste to the NNSS, just 18 have been involved in an "event" during transportation (for the DOE, an event can be as simple as a discrepancy in paperwork or as serious as a road accident). Regardless, none of those reported incidents resulted in contamination. Even with such a great safety record, the DOE said that it is vigilant in supporting emergency response capabilities in communities near waste shipment routes.

Two of these initiatives are the Emergency Preparedness Working Group Grant (EPWG) and the Transportation Emergency Preparedness Program (TEPP). The EPWG, which is administered by the Nevada Division of Emergency Management, provides funding to enhance emergency response capabilities in Nevada counties through which waste shipments are transported to the NNSS. A $0.50 fee for every cubic foot of waste disposed of at the Nevada site funds the EPWG. The TEPP, meanwhile, conducts training across the U.S. (including Nevada) on radiological hazardous material response. Under the program, training has been provided to more than 1,680 emergency responders representing 40 different Nevada communities.

Selecting routes

In addition to DOT regulations that require carriers to select routes that minimize radiological risk, the NNSS waste acceptance criteria require waste shipments traveling to the NNSS to avoid the O'Callaghan-Tillman Memorial Bridge and central Las Vegas (as specified below). When selecting routes, the EM Nevada Program advises generators to:

- Avoid heavily populated/congested areas in the state of Nevada (including the Las Vegas Beltway, I-215, and I-15/US-95 interchange).
- Direct carrier drivers to complete the mandatory driver questionnaire for identifying routes taken and locations where stops occur (fueling and DOT-required rest breaks for drivers, including overnight stops).

During selection of routes, carriers and generators, with assistance from the EM Nevada Program, also consider weather conditions and construction activities. Should weather, construction, or other law enforcement activities require the unexpected rerouting of shipments, drivers are required to make notifications in accordance with the NNSS waste acceptance criteria.

The EM Nevada Program can suspend generator shipments if waste is not transported in compliance with the identified requirements and guidelines.

Containers of LLW are offloaded to the NNSS Area 5 Radioactive Waste Management Complex.

THE U.S. DEPARTMENT OF ENERGY (DOE) PACKAGING CERTIFICATION PROGRAM (PCP) AND ARGONNE NATIONAL LABORATORY INVITE YOU TO

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LEARN ABOUT INDUSTRY-NATIONAL LABORATORY PARTNERSHIP

RAMM for Critical Facilities — a joint project between Argonne and Embedded Planet, Inc. (EPI) — received one of the 2019 Technology Commercialization Fund (TCF) awards, which are managed by DOE's Office of Technology Transitions (OTT). Multiple RAMM systems have been installed at Argonne's radiological and accelerator facilities for application testing and evaluation.

TO LEARN MORE

For a description of ARG-US remote monitoring systems, see https://rampac.energy.gov/home/tracking-and-monitoring

For a descriptions of current course schedule and locations, see https://rampac.energy.gov/home/education/packaging-university

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DOE PACKAGING CERTIFICATION PROGRAM

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Embedded Planet

WM Symposia:

The best presentations/papers of 2020

Hosted by Waste Management Symposia, the annual Waste Management Conference is widely regarded as the premier international conference for the management of radioactive material and related topics. First held in Tucson, Ariz., in 1974, the WM Conference was relocated to the newly completed Phoenix Convention Center in 2008, where it has been held since. This year, due to the COVID-19 health crisis, WM Symposia made the decision to move to a fully online conference, marking the first year in its 47-year history that the WM Conference has been held virtually.

Each year, the two best oral presentations/papers from the previous year's conference are recognized, and despite its virtual nature, the 2021 WM Conference will continue this tradition. Honoring the highest quality presentations, the American Nuclear Society and the American Society of Mechanical Engineers each present an award for best presentation/paper. The following are the abstracts for 2020's best ANS and ASME papers. The full papers are available to 2021 WM Conference participants through the WM Symposia website, at wmsym.org.

Former WM Symposia Managing Director Jan Carlin addresses the audience of the 2020 WM Conference honors and awards luncheon. Photos courtesy of WM Symposia/Gordon Murray, Flash PhotoVideo.

Continued

ANS
AWARD WINNER

When Every Drum Is a Win: Tackling a Thirty-Five Thousand Drum Legacy

By Thomas P. Smith, Clarence G. Lee, Lori L. Southern, and Rebecca E. M. Peters (Cameco Corporation)

Abstract

Cameco Corporation's Port Hope Conversion Facility was previously owned by the federal Crown Corporation Eldorado Nuclear, which held a significant inventory of legacy waste material at the time Cameco was formed in 1988. As a result, Cameco was granted an allocation of 150,000 cubic meters of space in the Long-Term Waste Management Facility (LTWMF) located in the municipality of Port Hope, which opened to the receipt of Cameco material in June 2018.

Cameco is currently undertaking a major site cleanup and renewal of its Port Hope Conversion Facility, known as the Vision in Motion project. Over its operating history, Eldorado accumulated an inventory of over 35,000 drums of accumulated waste that was primarily stored at two off-site warehouse locations. In 2017 and 2018, the project focused on repackaging two well-characterized legacy wastes (magnesium fluoride slag and depleted uranium titanium oxide) from one of the two off-site locations. At the conclusion of this work, approximately 15,000 drums of these wastes had been repackaged and disposed of at the LTWMF. There remained approximately 1,000 drums from this location that either could not be repackaged safely or were different waste types and required further verification and/or processing. The buildings at this location were scheduled for demolition in early 2019, which triggered the development of a process for triaging legacy drums in August 2018. This allowed for the preparation and shipment of approximately half of these drums to the LTWMF by March 2019, with the remainder moved to the second off-site warehouse location in February 2019 for further characterization, which is ongoing.

This paper will discuss key lessons learned as the drummed legacy waste disposal inventory has been reduced to approximately half of the initial inventory. This includes the development of an alternative packaging process; prioritization of characterization activities and selection of techniques where minimal inventory information is available; determination of next step(s) for each drum as it is assessed; key safety considerations; and how to make inroads into an overwhelming task while under public and regulatory scrutiny.

In a relatively short period of time, significant progress has been made to organize and gather information about the legacy waste, update the inventory records, and determine the most appropriate pathways (i.e., LTWMF disposal, disposal at another appropriate facility, and site storage until future processing and/or disposal). Since 2017, the volume of the decades-old legacy waste inventory has decreased significantly. With the majority of the known materials safely disposed of at the LTWMF, every drum removed from the endless rows of 20,000 pyramidal-stacked waste drums with limited history that is safely characterized, prepared, and shipped is considered a win.

Waste drum processing and repackaging at Cameco's Port Hope Conversion Facility, from the WM2020 ANS best paper/presentation.

A Preliminary Radiological Risk Assessment Model for Disposition of Remote-Handled Transuranic Wastes at Los Alamos National Laboratory Area G

ASME SETTING THE STANDARD

AWARD WINNER

By John Tauxe, Doug Anderson, Aaron Bandler, Paul Black, Hayley Brittingham, Kelly Crowell, Paul Duffy, Aharon Fleury, Leslie Gains-Germain, Terry Jennings, Amy Jordan, Robert Lee, Dan Levitt, Patti Meeks, Gregg Occhiogrosso, Ralph Perona, Amy Rice, Randall Ryti, and Chris Schaupp (Neptune and Company)

Abstract

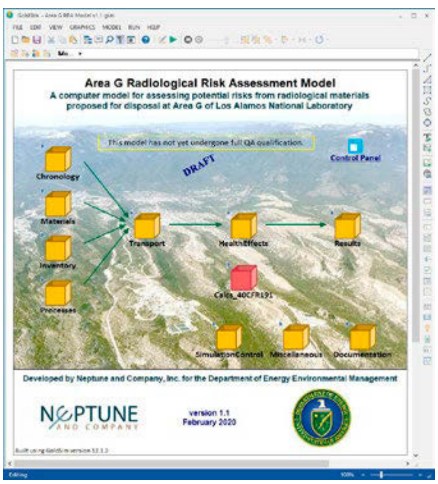
The U.S. Department of Energy operates a low-level radioactive waste disposal site at Material Disposal Area G in Los Alamos, N.M. Area G has been the primary LLW disposal site for Los Alamos National Laboratory (LANL) since the 1960s. In addition to LLW, Area G is host to a variety of other wastes, the disposition of which must be determined before closure of the site. A probabilistic radiological risk assessment (RRA) for Area G is used in order to support decision-making regarding some wastes that are not addressed in the extant Area G Performance Assessment (PA) and Composite Analysis (CA).

Between 1979 and 1987, 33 special shafts were bored into the Bandelier Tuff at Area G. This volcanic tuff is present across Pajarito Plateau on the eastern slopes of the Jemez Mountains and varies widely in its consistency, from weakly indurated non-welded layers to welded layers that uphold the mesa cliffs of the plateau. These mesas are home to LANL, Area G, and the town-sites of Los Alamos and White Rock, with residences about 1,400 meters from Area G. The 33 shafts were lined with steel casing and contain remote-handled transuranic wastes (TRU) resulting from experiments and analysis performed in special glove boxes at the Chemistry and Metallurgy Research facility at LANL. Some of these wastes originated as used nuclear fuel.

The purpose of the Area G RRA is to evaluate the potential future risk to humans and the environment from the remote-handled TRU in the 33 shafts in the context of the risk associated with the surrounding wastes at Area G. The analysis is responsive to expectations outlined in DOE Order 458.1, *Radiation Protection of the Public and the Environment*, and is informed by the manual and guidance accompanying DOE Order 435.1, *Radioactive Waste Management*. Because the waste meets the definition of TRU, the regulatory context necessarily takes into consideration the regulation governing the disposal of TRU from the U.S. Environmental Protection Agency: 40 CFR 191, *Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes*.

Given the broader regulatory context for the RRA, the analysis is subject to different assumptions from those made in the existing DOE Order 435.1 PA and CA, such as allowing for future occupation of the site. The analysis begins with a comprehensive evaluation of features, events, processes, and exposure scenarios (FEPS) for Area G and the wastes it contains. These FEPSs are screened to eliminate from further consideration those of extremely low probability and/or consequence, and a conceptual site model (CSM) is subsequently developed. The scope and structure of the Area G RRA model is informed by this CSM, and the Area G RRA model is developed using the GoldSim systems analysis modeling platform.

This paper presents the initial version of a defensible, transparent, and reasonably realistic model, which is based on the state of knowledge of the wastes, the site, and the FEPSs that govern contaminant transport from wastes into the environment and subsequent exposures to humans and other biota. Probabilistic model input distributions represent uncertainties inherent in the real and modeled systems. The results of the Area G RRA model inform decisions regarding the disposition of the remote-handled TRU in the 33 shafts.



Top level of the Area G RRA model, from the WM2020 ASME best paper/presentation.

Index to Advertisers

If your company is performing or seeking work related to the generation, handling, treatment, cleanup, transportation, storage or disposal of radioactive waste, *Radwaste Solutions* was created for you! For more than 25 years, this specialty magazine has been providing expanded coverage of decommissioning and environmental cleanup of the DOE EM Sites, as well as worldwide waste management activities.

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Business Developments

UniTech Services Group was awarded a basic ordering agreement by the Department of Energy's Office of Environmental Management, enabling the company to conduct nationwide low-level and mixed low-level radioactive waste receiving, handling, and treatment services at Environmental Management cleanup sites. Following the December 3 announcement of the ordering agreement, UniTech officially launched decommissioning support services to current and future nuclear reactor decommissioning sites in the United States. Waste received by UniTech will be processed at the company's Oak Ridge Service Center in Oak Ridge, Tenn.

Nuclear waste storage and disposal company **Deep Isolation** announced on November 18, 2020, that it closed its $20-million Series A raise, led by nuclear industry leader **NAC International**. The companies said the agreement represents a significant industry milestone for the disposal of nuclear waste. Under the terms of the deal, NAC will take a seat on Deep Isolation's board of directors.

Orano announced on January 15 that it recently completed a consolidation and implementation process at its flagship facility in Kernersville, N.C., resulting in the enhanced manufacturing of its NUHOMS canisters for the dry storage of used nuclear fuel. In 2018, Orano's decision to in-source all of its heavy manufacturing led to the establishment of its new TN Fabrication facility in Kernersville. During 2019-2020, Orano consolidated all NUHOMS canister fabrication for U.S. customers to this single site, while maintaining its global supply chain for surge resources, and upgraded the domestic production processes.

Stork, part of **Fluor Corporation**'s Diversified Services segment, has been awarded a framework agreement for inspection quality assurance services by Sellafield Ltd. for its nuclear site in the United Kingdom, Fluor announced in November 2020. Over the next three years, Stork will provide independent third-party inspection and quality assurance services for Sellafield. These services will ensure compliance with regulatory and legal obligations regarding the quality standards of products and services, on-site and off-site, including local and international supply chains. Stork's U.K. office in Aberdeen will lead the work, with support from its Southport office.

Continued

Contracts

Battelle Savannah River Alliance (BRSA) has been selected by the U.S. Department of Energy to manage Savannah River National Laboratory. The contract includes a five-year base with five one-year options. The estimated value of the contract is $3.8 billion over the course of 10 years if all options are exercised. BSRA, which is led by and wholly owned by Battelle, includes five universities from the region—Clemson University, the Georgia Institute of Technology, South Carolina State University, the University of Georgia, and the University of South Carolina—as well as small business partners Longenecker & Associates and TechSource.

Contractor to U.S. federal and allied governments **Amentum** announced in October 2020 that the Department of Energy's Savannah River Operations Office extended the liquid waste operations contract with **Savannah River Remediation**, a team of companies led by Amentum with partners **Bechtel National**, **Jacobs**, and **BWX Technologies**. The extension runs for 12 months, October 1, 2020, to September 30, 2021, with three additional four-month options possible. The estimated value of the contract extension is approximately $630 million, based on the 2020 fiscal year budget.

Amentum also announced in October that the DOE's Carlsbad Field Office has exercised a one-year option on its contract with **Nuclear Waste Partnership** (an Amentum-led entity with partner **BWX Technologies** and major subcontractor **Orano**) for management and operations of the DOE's Waste Isolation Pilot Plant near Carlsbad, N.M. The current option runs through September 30, 2021, with a value of just over $296 million, bringing the total contract value to over $2.7 billion. The one-year option contains two additional six-month options.

French nuclear service company **Altrad** announced in late October 2020 that it had been awarded a four-year contract by **Magnox Ltd.** to support decommissioning work at six sites in Great Britain. Magnox is handling waste management, defueling, decommissioning, and asset management at 12 nuclear sites. The $32.5-million contract with Altrad began in mid-October. The sites involved include Chapelcross, Dungeness A, Hinkley Point A, Hunterson A, Trawsfynnydd, and Wylfa.

The **Dounreay Decommissioning Framework Alliance**, led by **Cavendish Nuclear** and supported by **KDC Contractors** and **BAM Nuttall**, has been awarded a contract for the design of a new waste repackaging facility at the Dounreay nuclear site in Scotland, Cavendish announced on January 13. The program of work is expected to run until early 2022 and forms part of Dounreay Site Restoration Ltd.'s decommissioning services framework. The contract is for the concept and design of a new waste repackaging processing facility, which will support delivery of the site's waste strategy and decommissioning program.

Responsive Non-Destructive Testing, part of Responsive Ltd., announced on October 19, 2020, that it has won a framework contract with LLW Repository Ltd., which operates the Low Level Waste Repository (LLWR) in Cumbria, England. The 12-month framework agreement, issued for tender in August 2020, covers all of LLWR's quality inspection and testing support and will lead to Responsive NDT's increasing the size of its 18-member team, according to the company.

Constable

Fluor Corporation has appointed **David E. Constable**, a member of its board of directors, as its chief executive officer. Constable succeeds **Carlos Hernandez**, who retired as CEO at the end of 2020. Constable held various leadership roles at Fluor from 1982 to 2011. From 2011 to 2016, Constable served as CEO of Sasol Ltd.

Clarke

SNC-Lavalin Group, based in Toronto, Ontario, has appointed **Dale Clarke** president of infrastructure services. Clarke joined SNC-Lavalin in 1996 and has served in several senior and executive roles, most recently as executive vice president of infrastructure services.

Richardson

Retired Adm. **John M. Richardson** has been appointed to the BWX Technologies board of directors. Richardson served as the chief of naval operations for the U.S. Navy from 2015 to 2019 and as director of the Naval Nuclear Propulsion Program from 2012 to 2015. As chief of naval operations, he was responsible for the management of a $160 billion budget covering 600,000 sailors and civilians, more than 70 installations, 290 warships, and more than 2,000 aircraft worldwide. During his 37 years of service in the U.S. Navy, he also served on four nuclear submarines, including commanding the USS *Honolulu*.

Roberts

Glenn Roberts has been named director of health physics and engineering by UniTech Services Group, assuming responsibility for regulatory compliance and corporate oversight while managing the company's radiation safety and quality control programs. The position was previously held by Mike Fuller, who retired at the end of 2019. Roberts brings 32 total years of experience to his new role, including working closely with Fuller in the department since 1996. Prior to joining UniTech as a health physicist in that year, Roberts spent time with Roy F. Weston, Inc., the Nuclear Regulatory Commission, and the state of Delaware.

Wagner

John C. Wagner has been named director of Idaho National Laboratory. Wagner joined INL in 2016 after nearly 17 years with Oak Ridge National Laboratory and has served as associate laboratory director for nuclear science and technology since 2017. He succeeds **Mark Peters**, who is now executive vice president for laboratory operations at Battelle.

Bookless

William Bookless has been named acting administrator of the National Nuclear Security Administration and undersecretary of energy for nuclear security. Bookless, who had served as NNSA principal deputy administrator, replaces **Lisa E. Gordon-Hagerty**, who resigned from the position she had held since February 15, 2018. Bookless spent more than three decades as a senior physicist at Lawrence Livermore National Laboratory prior to joining the NNSA.


Connery

Joyce Connery has been appointed chair of the Defense Nuclear Facilities Safety Board (DNFSB) by President Biden. Connery has been a member of the board since August 2015. She was reconfirmed by the Senate to serve on the DNFSB on July 2, 2020, for a term expiring on October 18, 2024. Connery previously held the chairmanship from August 2015 until January 2017.


Veil

The Nuclear Regulatory Commission has named **Andrea D. Veil** acting director of its Office of Nuclear Reactor Regulation (NRR). She replaces **Ho Nieh**, who left the position in January. Veil joined the agency as an intern in 1992, holding increasingly responsible positions in various offices. In 2019, she was appointed the NRR deputy office director, and later that year, she was appointed deputy office director for engineering at NNR, her most recent position.

DESD/RRSD 2021

2021 Winter Meeting Embedded Topical

October 31 – November 4, 2021 | Washington, DC

CALL FOR PAPERS

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IMPORTANT DUE DATES (NO ABSTRACT SUBMISSION IS NEEDED)

JUNE → SUBMISSION OF SUMMARIES: **Monday, June 28, 2021**

AUGUST → AUTHOR NOTIFICATION OF ACCEPTANCE: **Monday, August 2, 2021**

AUGUST → FINAL PAPERS: **Monday, August 23, 2021**

DESCRIPTION OF EMBEDDED TOPICAL

This embedded topical meeting is a joint venture between the Decommissioning and Environmental Services Division (DESD) and Robotics and Remote Systems Division (RRSD). Authors are invited to participate in this event to exchange ideas and knowledge and to submit papers covering advances in DESD and RRSD topics listed in this announcement.

GUIDELINES FOR SUBMISSIONS

Authors are required to follow the "Guidelines for Transactions Summary Preparation" provided on the ANS website at ans.org/pubs/transactions/. Summaries must be submitted electronically in Adobe Acrobat (PDF) format via the ANS Electronic Paper Submission and Review (EPSR) system at https://epsr.ans.org/. Summaries not based on the ANS Template will be rejected.

Please submit summaries describing work that is NEW, SIGNIFICANT, and RELEVANT to the nuclear industry to epsr.ans.org/. Papers should be one to four pages. ANS will publish all accepted summaries in the Transactions. Papers will incur a $25 per page publication fee. Accepted papers are presented orally at the meeting, and presenters are expected to register for the meeting. If the meeting is oversubscribed, an opportunity for providing a poster paper may be provided.

SUBMIT A SUMMARY

epsr.ans.org/meeting/?m=339

PROGRAM SPECIALIST

Janet Davis
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jdavis@ans.org

DESD/RRSD 2021

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October 31 – November 4, 2021 | Washington, DC

TOPICS

HIGH-QUALITY PAPERS (4-PAGE MAXIMUM) ARE SOLICITED FOR THE FOLLOWING TOPICS

ROBOTICS AND REMOTE SYSTEM DIVISION

1. ROBOTICS AND REMOTE SYSTEMS
   - 1a. Robotics and Remote Systems for Surveillance in Hazardous Environments, including tanks, H-canyon, contamination monitoring
   - 1b. Nuclear Materials Handling – radiography, conveyance, glovebox robotics
   - 1c. Nuclear Plant Maintenance and Operations
   - 1d. Robotics and Remote Systems for Nuclear Waste and Spent Fuel Handling
   - 1e. Robotics and Remote Systems in Commercial Power – SMR refueling, spent fuel management
   - 1f. Dry Cask Storage Monitoring (some overlap with surveillance)
   - 1g. Radiation Damage and Hardening

2. SPECIAL TOPICS:
   - 2a. Artificial Intelligence in Robotics and Remote Systems
   - 2b. Telerobotics
   - 2c. Robotics Operating System (ROS)
   - 2d. Nuclear Emergency Response

DECOMMISSIONING AND ENVIRONMENTAL SERVICES DIVISION

3. ENVIRONMENTAL
   - 3a. Emerging (Non-Radiological) Compounds
   - 3b. Sampling Methods/Techniques
   - 3c. Groundwater Modeling and Investigations
   - 3d. Integrating Site Closure (non-Rad) and License Termination (Rad) during Decommissioning
   - 3e. Nuclear Innovation: Clean Energy Future (NICE Future): Progress on Key Activities for Advancing Policy and Technology
   - 3f. Energy-Water Nexus: Nuclear Technology's Potential to Provide Clean Water with Clean Energy
   - 3g. The Path Towards a Low-Carbon Sustainable Energy Supply System
   - 3h. Meeting Targets for Reduction of CO2 Emission without Causing Economic Damage
   - 3i. Regulatory Framework for the Resumption of Operation for Decommissioning Power Reactors

4. DECOMMISSIONING (PLANNING, EXECUTION AND LESSONS LEARNED)
   - 4a. International Decommissioning
   - 4b. U.S. Decommissioning (both DOE and Commercial)
   - 4c. Innovative Technologies
   - 4d. Regulatory Framework for Decommissioning

RRSD/DESD COMBINED SESSIONS

5. COMBINED TOPICS
   - 5a. Robotics and Remote Systems for Decommissioning and Waste Disposal
   - 5b. Robotics and Remote Systems for Environmental Remediation and Monitoring

Paper acceptance will be based upon originality of the work, strictly implemented methods or models, quality of results, conclusions supported by data, proper citing of references, use of correct grammar and spelling, and adherence to ANS formatting requirements.

Calendar

March

Mar. 8–12—**WM Symposia 2021**, virtual meeting. wmsym.org

Mar. 16–18—**EURAD 1st Annual Event**, virtual meeting. ejp-eurad.eu/events/eurad-1st-annual-event

Mar. 24–25—**Nuclear Engineering for Safety, Control and Security**, virtual meeting. events2.theiet.org/nuclear/about.cfm

April

Apr. 8–10—**ANS Student Conference**, virtual meeting. ans.org/meetings/student2021

Apr. 20–21—**Nuclear Decommissioning and Waste Management 2021**, virtual meeting. virtual.prosperoevents.com/nuclear-decommissioning-and-waste-management

June

June 6–9—**40th Annual CNS Conference/45th Annual CNS/CNA Student Conference**, virtual meeting. cns-snc.ca/events/annual/

June 7–9—**European Cooperative Group on Corrosion Monitoring of Nuclear Materials (ECG-COMON) Annual Meeting 2021**, Villigen, Switzerland. ecg-comon.org/meetings/ecgcomon-meeting-2021

June 9–11—**NUWCEM 2021: International Symposium on Cement-Based Materials for Nuclear Wastes**, Avignon, France. sfen-nuwcem2021.org
Meeting has been rescheduled to September 15–17, 2021

June 13–16—**2021 ANS Annual Meeting**, Providence, R.I. ans.org/meetings

July

July 5–8—**The Society for Radiological Protection Annual Conference**, Bournemouth, U.K. srp-uk.org/events/2021AnnualConference

August

Aug. 3–5—**13th Annual Nuclear Deterrence Summit**, Alexandria, Va. exchangemonitor.com/events/nuclear-deterrence-summit/

Aug. 4–6—**28th International Conference on Nuclear Engineering (ICONE 28)**, virtual meeting. event.asme.org/ICONE

Aug. 8–11—**Utility Working Conference and Vendor Technology Expo**, Marco Island, Fla. ans.org/meetings/view-351/

Aug. 23–Sep. 3—**International School of Nuclear Law (ISNL)**, Montpellier, France. oecd-nea.org/law/isnl

Aug. 25–27—**KONTEC 2021**, Dresden, Germany. kontec-symposium.com/

Aug. 29–Sep. 3—**2021 International Topical Meeting on Probabilistic Safety Assessment and Analysis (PSA 2021)**, Columbus, Ohio. psa.ans.org/2021

September

Sept. 8–10—**World Nuclear Association Symposium 2021**, London, United Kingdom. wna-symposium.org/

Sept. 12–16—**14th International Conference on Radiation Shielding and 21st Topical Meeting of the Radiation Protection and Shielding Division (ICRS 14/RPSD-2021)**, Seattle, Wash. ans.org/meetings/icrs14rpsd21/

Sept. 13–15—**International Conference on Decommissioning Challenges: Industrial Reality, Lessons Learned and Prospects**, Avignon, France. sfen-dem2021.org/

Sept. 15–17—**NEWCEM 2021: International Symposium on Cement-Based Materials for Nuclear Wastes**, Avignon, France. sfen-nuwcem2021.org/

Sept. 20–21—**Decommissioning Strategy Forum**, Summerlin, Nev. www.exchangemonitor.com

Sept. 22–24—**Radwaste Summit**, Summerlin, Nev. www.exchangemonitor.com


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