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Generous Congressional Funding for Nuclear Energy Research Bills for 2021

The Department of Energy's Versatile Test Reactor (VTR) program was included in the Nuclear Energy Innovation Capabilities Act of 2018. The Idaho National Laboratory has focused on leadership for advanced nuclear reactors with director Mark Peters, who will be replaced by John Wagner on December 11. Wagner has been associate lab director since 2017 and has been frequently called upon to provide testimony to Congress and to advise in formulation of policies for nuclear fuel cycles and advanced reactors. [1]

The proposed VTR would test materials in the reactor but not produce electricity. The VTR would be used to test various materials to a high flux of fast neutrons rather than thermal (or slow) neutron flux currently available in the Advanced Test Reactor. Thermal neutrons have been slowed by a moderator such as water.

The Department of Energy has announced that its draft environmental impact statement will be published in mid-December and that the Idaho National Laboratory will be DOE's preferred alternative location for the VTR. [2]

From the Versatile Test Reactor that would be regulated by the Department of Energy to the small modular reactors like NuScale, to the micro reactors to molten-salt reactors and fast reactors, all which would be regulated by the U.S. Nuclear Regulatory Commission, research funding has increased during the last four years while the DOE's overall funding has been steady. [3]

Congressional appropriations of $3.2 billion over the next year years for the Advanced Reactors Demonstration Program (ARDP) are being sought to develop commercially viable advanced reactors, with TerraPower and X-energy receiving initial funding. TerraPower would design a sodium-cooled fast reactor being called Natrium while X-Energy would design a high-temperature gas-cooled reactor. [4] The Natrium reactor being developed by TerraPower with GE Hitachi Nuclear Energy and engineering and construction partner Bechtel. The Natrium would

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[1] Nathan Brown, *The Idaho Falls Post Register*, "Wagner named new INL chief," November 6, 2020.

[2] Nathan Brown, *The Idaho Falls Post Register*, "DOE: INL preferred site for test reactor," November 20, 2020.

[3] Paul Day, *Reuters Events*, "US nuclear plans on track despite partisan divides," November 24, 2020. https://www.reutersevents.com/nuclear/us-nuclear-plans-track-despite-partisan-divides?utm_campaign=NEI%2025NOV20%20%28NEIsmr%29%20Newsletter%20Database&utm_medium=email&utm_source=Eloqua

[4] Paul Day, *Reuters Events*, "US demonstration reactor finalists champion innovative designs," October 20, 2020. https://www.reutersevents.com/nuclear/us-demonstration-reactor-finalists-champion-innovative-designs

use a molten salt storage system and is planned to increase output during peak demand, to work with intermittent wind and solar power installations. Both TerraPower and E-energy's reactors would run on high-assay-low-enriched-uranium (HALEU) which has uranium-235 enrichment of up to 20 percent compared with up to 5 percent for fuel used with the current fleet or reactors.

The Advanced Reactors Demonstration Program was enacted in FY2020 and is a new sub-account within the DOE Nuclear Energy account with $300 million in FY2020 funding. [5]

The enthusiasm for all things nuclear of FY2020 appears poised to continue for FY-2021, despite the lack of progress in obtaining nuclear waste disposal.

Congressional Legislative Efforts for Nuclear Waste Storage and Disposal Appropriations for FY-2020

Despite the ramped-up spending for research for numerous types of nuclear reactors, there has been no funding appropriation for addressing the lack of a way to safety dispose of spent nuclear fuel.

There has been no funding for the Department of Energy's proposed Yucca Mountain nuclear waste disposal facility since 2010. [6] Funding for licensing Yucca Mountain has been requested by the Trump administration in past years but not passed by Congress. The Trump administration did not make a Yucca Mountain funding request for FY-2021. The Department of Energy had submitted its Yucca Mountain license application to the U.S. Nuclear Regulatory Commission in 2008, but withdrawn its license application in 2010, saying Yucca Mountain was unworkable. The NRC reviewed the application favorably, issuing a Safety Evaluation Report in 2015, but did not issue a license to construct the Yucca Mountain repository because DOE had not obtained certain land withdrawal and water rights necessary for construction and operation of the repository. [7]

Spent nuclear fuel generated by commercial nuclear power plants is continuing to build up by about 2000 metric tons each year. Reactor plants that have permanently closed are considered "stranded" fuel sites, with no operating reactor and no spent fuel pool. The spent fuel is then stored in dry storage installations licensed by the NRC. The U.S. Nuclear Regulatory Commission insists that the storage of commercial power plant spent fuel stored in the U.S. is safe. Yet, people living near the permanently-shutdown San Onofre Nuclear Generating Station (SONGS) with dry spent fuel storage on the Pacific Ocean coastline and in a seismically active region aren't so sure that dry spent fuel storage is safe and certainly not for the decades it will

[5] Congressional Research Service, Energy and Water Development: FY2020 Appropriations, Updated January 29, 2020. https://crsreports.congress.gov/product/pdf/R/R45708

[6] Mark Holt, EveryCRSReport.com, Civilian Nuclear Waste Disposal June 9, 2006 – September 14, 2020, RL33461, September 14, 2020. https://www.everycrsreport.com/reports/RL33461.html

[7] U.S. Nuclear Regulatory Commission, webpage "Backgrounder on Licensing Yucca Mountain, https://www.nrc.gov/reading-rm/doc-collections/fact-sheets/yucca-license-review.html

take to attempt to obtain a disposal site. A bill was introduced to encourage moving the dry spent fuel from highly populated regions and from more seismically active regions, see H.R. 2995 in Table 1 below.

To help the SONGS utility understand their options for moving their spent fuel farther from the California coastline, they have hired a consultant, North Wind. A tangled web of possibilities was presented at a public meeting for the San Onofre spent fuel but currently there is no place to move their spent nuclear fuel to. [8]

The utility is also concerned that the full costs of transportation and storage may not be fully reimbursable from the Judgment Fund from the litigation with the Department of Energy's partial breach of contract in failure to start disposing of the spent nuclear fuel from commercial nuclear power plants. Also, it was pointed out that utility customers may not be fully shielded from liability for accidents involving storage of spent nuclear fuel at private storage facilities. Utilities want the Department of Energy to take ownership of the spent nuclear fuel. But the Department of Energy has no place to put it. The Nuclear Waste Policy Act of 1982 and amended in 1987 sought specifically to avoid letting up the pressure on the Department of Energy to obtain permanent, safe disposal of spent nuclear fuel. The DOE was restricted from obtaining interim spent fuel storage unless it had obtained a license for a facility for permanent disposal.

In FY-2020, various funding appropriations for interim storage of spent nuclear fuel have been put forth. Two consolidated interim storage sites, one New Mexico and near it in southwest Texas, are pursuing licenses from the Nuclear Regulatory Commission. [9] [10] [11] Because current regulations limit the Department of Energy's role involving interim storage when no license for a disposal facility has been obtained, some of the bills put forth in Congress are trying to change that.

The White House Administration requested funding for Yucca Mountain as well as interim storage. [12] The House passed a bill that included funding for interim storage. Representative Simpson from Idaho added an amendment to fund Yucca Mountain licensing. The Senate included proposed funding for DOE to contract for spent fuel management, including the use of private consolidated interim spent fuel storage. There was language added to authorize DOE to

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[8] San Onofre Nuclear Generating Station (SONGS), 11/20/20, North Wind slide presentation https://www.songscommunity.com/_gallery/get_file/?file_id=5faf01792cfac225d3c64352&ir=1&file_ext=.pdf

[9] Tami Thatcher comment submittal for Environmental Defense Institute for the NRC's draft Environmental Impact Statement for the Holtec Consolidated Interim Storage Facility Project, Docket NRC-2018-0052, September 2020 at http://www.environmental-defense-institute.org/publications/CommentNRCdEISHoltecT.pdf

[10] David B. McCoy, Citizen Action New Mexico, comment submittal for the NRC's draft Environmental Impact Statement for the Holtec Consolidated Interim Storage Facility Project, Docket NRC-2018-0052, September 2020 at http://www.environmental-defense-institute.org/publications/CommentNRCdEISHoltecM.pdf

[11] Environmental Defense Institute comments by Tami Thatcher on the Interim Storage Partners proposed Consolidated Interim Storage at the Waste Control Specialists site in Andrews County, Texas at http://environmental-defense-institute.org/publications/CommentNRC2018Texas.pdf

[12] Congressional Research Service, Energy and Water Development: FY2020 Appropriations, Updated January 29, 2020. https://crsreports.congress.gov/product/pdf/R/R45708

develop pilot federal consolidated interim storage for spent fuel. But despite numerous attempts to grease the way toward interim storage at an NRC-licensed facility, so far, no funding appropriations for Yucca Mountain licensing or interim storage have been included in the FY-2020 funding measure. An online briefing "What Congress Needs to Know About Pending Nuclear Waste Legislation" was held November 13, 2020 by he Environmental and Energy Study Institute, with guest speakers Robert Alvarez, Institute for Policy Studies; Don Hancock, Southwest Research and Information Center; and Diane D'Arrigo, Nuclear Information and Resource Service to explain hazards associated with spent nuclear fuel and history pertaining to the Nuclear Waste Policy Act. [13]

Next year, the legislative efforts are bound to continue.

Current legislation that is pending in the lame duck session of Congress is summarized in Table 1 but so far, none of the legislation has been passed into law.

Table 1. Description of various legislation introduced in the 116th Congress.

Legislation Introduced in the 116th Congress	Description	Status
Nuclear Waste Administration Act of 2019 (S. 1234)	This bill would establish a new organization, an independent agency, called the Nuclear Waste Administration to provide for nuclear waste disposal and additional storage facilities. Its purports to provide a consensual process for siting nuclear waste facilities. It seeks to ensure that persons responsible for generating the waste pay for the disposal. It transfers functions from the Department of Energy, including those related to construction and operation of a repository. It prescribes siting guidelines for nuclear waste storage facilities and repositories. It confers upon the new agency the responsibility for transporting nuclear waste.	Introduced
Nuclear Waste Policy Act Amendments of 2019 (H.R. 2699, S 2917)	The bill would amend the Nuclear Waste Policy Act of 1982 and is for other purposes. It modifies previous laws regarding Monitored Retrievable Storage. It would now allow the Department of Energy to enter into agreements with non-Federal entities to store DOE-owned civilian waste and store it at an interim storage facility that is neither monitored nor retrievable, as long as the DOE secretary declares that a final repository decision is imminent! Seriously. This bill also changes the limit on Yucca Mountain from 70,000 metric tons to 110,000 MT and paves the road for disposal at Yucca Mountain.	Introduced

[13] Environmental and Energy Study Institute (EESI) briefing at https://www.eesi.org/briefings/view/111320nuclear#RSVP

Legislation Introduced in the 116th Congress	Description	Status
Clean Economy Jobs and Innovation Act (H.R. 4447)	This sprawling, multifaceted and complex bill spans many areas, from solar and wind energy, dam safety, to nuclear energy. In Title IV, Nuclear Energy, the bill includes Advanced Nuclear Fuel Availability, and the Nuclear Energy Leadership Act, Defending Against Rosatom Exports, and Fusion Energy Research. The Nuclear Energy Leadership Act would amend the Energy Policy Act of 2005. It would define the term "advanced nuclear reactor." The bill gives funds for research to sustain light water reactors and support developing technologies, including the versatile fast neutron source and nuclear hybrid systems. It includes "Fuel Cycle Research, Development, Demonstration, and Commercial Application" and this include dry cask storage, consolidated interim storge, deep geological storage and disposal, including mined repository, and other technologies.	Passed House
Department of Defense Appropriations Act of FY 2021 (or Multi-agency Appropriations Act for FY 2021) (H.R. 7617)	Sprawling bill with $100 million for integrated hydrogen-nuclear demonstrations; $66 million for construction of the Sample Preparation Laboratory; $61,700,000 for INL's Materials and Fuels Complex Plant health Investments; $125 million for Advanced Test Reactor Recapitialization. Various funding for Hanford, Savannah River, WIPP, INL, Y12, Oak Ridge, Los Alamos and Lawrence Livermore.	Passed House
Nuclear Waste Informed Consent Act (H.R. 1544, S. 649)	The bill prohibits the Department of Energy from using the Nuclear Waste Fund for certain expenditures involving repositories for disposing of spent nuclear fuel or high-level waste. DOE may not use the fund to pay for planning, construction or operation of a repository unless DOE has entered into an agreement with the state in which the repository is located and with affected local governments and Indian tribes.	Introduced
Spent Fuel Prioritization Act of 2019 (H.R. 2995)	A bill to amend the Nuclear Waste Policy Act of 1982 to prioritize the acceptance of high-level radioactive waste or spent nuclear fuel from certain civilian nuclear power reactors and for other purposes. The bill would have the Department of Energy give priority to stranded fuel sites where the reactor is decommissioned, having the largest population and having the	Introduced

Legislation Introduced in the 116th Congress	Description	Status
	highest seismic risk.	
Dry Cask Storage Act of 2019 (S. 2854)	A bill to amend the Nuclear Waste Policy Act of 1982 to provide for the expansion of emergency planning zones and the development of plans for dry cask storage of SNF, and for other purposes. The bill would have utilities expedite transfer of SNF cooled long enough to move from pools to dry storage in order to reduce spent fuel pool risk. The bill would also expand the emergency planning zone to 50 miles radius unless the fuel pool is emptied.	Introduced
The American Nuclear Infrastructure Act of 2020 (S. 4897)	The bill would require the Nuclear Regulatory Commission to review the permitting process for nuclear reactors, create new incentives for developing certain types of reactor projects and keep reactors that might otherwise shut down open as part of a "carbon emissions avoidance program." It would bar the use of fuel from Russia or China while letting Japanese or South Korean entities or ones from a North Atlantic Treaty Organization member state get a license for a nuclear facility in the United States if the NRC approves. And amount other provisions, it would create a national strategic uranium reserve and require the NRC and U.S. Department of Energy to work on the development of high-assay low-enriched uranium, with is used in smaller advanced reactors. U.S. Senator from Idaho, Mike Crapo was quoted in The Idaho Falls Post Register, "The advancement of clean, reliable nuclear energy is paramount to maintaining the United States' eminence in nuclear power, research and innovation. Building on our other work in this space, the American Nuclear Infrastructure Act will further facilitate our country's nuclear competitiveness through enhanced collaboration with allied nations, nuclear energy workforce development and improved review processes to help deploy advanced nuclear technologies. The bill, in conjunction with our other work, will help ensure research at the Idaho National Laboratory continues to contribute to and empower the long-term viability of our diverse domestic energy portfolio." [14]	draft

[14] Nathan Brown, *The Idaho Falls Post Register*, "Crapo, other senators introduce nuke bill," November 18, 2020.

Table notes: Source congress.gov accessed November 26, 2020. After a bill is introduced, the status of the bill is posted on congress.gov. The status is updated when a bill passes either the House or Senate and when the bill becomes law.

The "Nuclear Waste Fund" fee is no longer being collected from commercial nuclear power utilities — because the Department of Energy has no spent fuel disposal program

The Department of Energy stated it had collected $28.2 billion from commercial nuclear utilities for the "Nuclear Waste Fund." The U.S. Court of Appeals agreed to end DOE's collection of fees because DOE did not have waste disposal program for spent nuclear fuel and also because the DOE's latest fee assessment covered an enormous range of possible costs, from somewhere between $25 billion and $2 trillion dollars, so there was no way to determine the adequacy of the fees paid. [15]

The court found that the DOE's 2011 plan to somehow find a spent nuclear fuel disposal facility by 2048 was "pie in the sky." [16]

Under the 1982 Nuclear Waste Policy Act, DOE was to have a disposal facility by 1998. And nuclear utility customers would pay one-tenth of a cent for every kilowatt hour of nuclear-generated electricity in to the Nuclear Waste Fund. The collection of the fee ended on what is being called "zero day," May 16, 2014. [17]

The Department of Energy has stated it would begin disposal of commercial spent nuclear fuel in 1998, then 2010, to 2017 to 2020 and now 2048. [18] We know that these dates prior to 2048 have all been empty promises. The U.S. Nuclear Regulatory Commission made its "Waste Confidence Rule" in 1984 stating that the NRC was confident that the spent nuclear fuel would be safely disposed of. The "waste confidence" title has simply been changed to "continued storage." The NRC is pretty sure that spent nuclear fuel will continue to be stored. [19] And the NRC is the agency that continued to grant licenses to nuclear reactors despite no method for disposing of the spent nuclear fuel on the reasoning that they were confident that the spent fuel would be safely disposed of, eventually. The NRC is also the agency that was put in charge of determining the adequacy of the Department of Energy's disposal plans, which DOE submitted to the NRC in 2008.

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[15] Steven Dolley, Elaine Hiruo, and Annie Siebert, *S&P Global Platts*, "Federal court orders suspension of US DOE nuclear waste fund fee," November 19, 2013. https://www.spglobal.com/platts/en/market-insights/latest-news/electric-power/111913-federal-court-orders-suspension-of-us-doe-nuclear-waste-fund-fee

[16] Ibid.

[17] World Nuclear News, Zero day for US nuclear waste fee, May 16, 2014. https://www.world-nuclear-news.org/Articles/Zero-day-for-US-nuclear-waste-fee

[18] Brandi Buchman, *Courthouse News Service*, "Entergy Says Feds Are 50 Years Behind on Nuclear Waste," July 2, 2017. https://www.courthousenews.com/entergy-says-feds-50-years-behind-nuclear-waste/

[19] U. S. Nuclear Regulatory Commission, webpage. https://www.nrc.gov/waste/spent-fuel-storage/wcd.html

Yucca Mountain, it's not the uncertainty — it's the pervasive lack of scientific integrity

The safe disposal of spent nuclear fuel was supposed to mean that the radiological waste would be isolated from the Earth's air, water and soil — the biosphere. The first attempts to create regulations on the limits that the dump site could release to the biosphere were limited to concerns for the first 10,000 years. The Department of Energy eagerly embraced modeling that delayed the releases until after 10,000 years. Part of this was claiming that the waste containers did not corrode for 10,000 years. By arguing that the containers stayed intact for 10,000 years, they also argued, mostly with hand waving, that criticality events involving the spent nuclear fuel were too unlikely to worry about.

The regulations for the proposed Yucca Mountain repository involve standards created by the U.S. Environmental Protection Agency as well as the NRC. When the court ruled that the recommendation of the National Academy of Sciences had been stipulated as needing to be followed, the EPA modified its regulation to limit an individual's exposure from Yucca Mountain trickle out contamination from water that infiltrates the repository from 15 mrem/yr for the first 10,000 years to a two-tier regulatory scheme that allowed more contamination exposure to individuals after 10,000 years.

In the EPA's initial draft of the two-tier scheme, **the limit for exposure after 10,000 years was an obscene 350 mrem/yr,** [20] which the nuclear industry doesn't even like to talk about now. After public backlash, the EPA backed it down from 350 mrem/yr to 100 mrem/yr after 10,000 years. Why didn't the EPA just apply the same 15 mrem/yr dose that the EPA considered safe for the entire duration that the waste was toxic? It appears that the Department of Energy's modeling which had accepted escalating radiation releases after 10,000 years, did not think that estimated doses could be kept below 15 mrem/yr after 10,000 years. It appears to me that the EPA was under the influence of the Department of Energy when its two-tier radiation standard was issued.

The 2007 Draft Yucca Mountain Environmental Impact Statement read as follows:

> "To obtain NRC authorization to construct the Yucca Mountain repository, DOE must demonstrate that the proposed repository meets the regulatory individual radiation protection standards set by EPA and NRC. Under the existing standards, estimated repository performance will be compared to a mean annual dose of 15 millirem for the first 10,000 years after closure. Under the proposed standards, estimated repository performance will be compared to a median annual dose of 350 millirem for the post-10,000-year period."

[20] U.S. Department of Energy, *Draft Supplemental Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada*, DOE/EIS-0250F-S1D, October 2007. https://www.energy.gov/sites/prod/files/EIS-0250-S1-DEIS-Summary-2007_0.pdf

Table 2. History of EPA radiation standards.

Standards	History	Citation	Apply to	Key Provisions
Generic radiation protection standards	Original 1985 Vacated 1987 Revised 1993	40 CFR 191	WIPP, potential non-NWPA repositories, monitored retrievable storage facilities, private interim storage	1993 standards: exposure limits to any individual, 0 – 10,000 years: 15 mrem/yr *
Yucca-specific standards, draft	Initial two-tier draft, 2007	40 CFR 197	Yucca Mountain	2007 draft standards: exposure limits to “reasonably maximally exposed individual,” 0-10,000 years: 15 mrem/yr; 10,000 – 1,000,000 years: 350 mrem/yr **
Yucca-specific standards	Original 2001 Vacated 2004 Revised 2008	40 CFR 197	Yucca Mountain	2008 standards: exposure limits to “reasonably maximally exposed individual,” 0-10,000 years: 15 mrem/yr; 10,000 – 1,000,000 years: 100 mrem/yr **

Table notes: Some information in the table is based on Richard Burleson Stewart and Hane Bloom Stewart, *Fuel Cycle to Nowhere – U.S. Law and Policy on Nuclear Waste*, Vanderbilt University Press, 2011. But *Fuel Cycle to Nowhere* did not discuss the proposed 350 mrem/yr EPA individual dose limit.

*The exposure limits apply to all individuals outside the controlled area, defined as an area no more than 100 km^2 extending no more than 5 km from the site (40 CFR 191.12. Annual exposure to any individual is limited to 25 mrem (40 CFR 191.03.

** Typically, the EPA defines the controlled area around a toxic waste site as no more than 300 km^2 extending no more than 5 km from the site. For Yucca Mountain, the distance in the direction of groundwater flow was extended to 18 km. Human intrusion limits not included in the table.

The annual dose of 100 mrem/yr commencing to a child, embryo or fetus and continuing over a lifetime would assure a significantly higher rate of cancer and disease. The annual dose rate from the ingestion of radionuclides, of 350 mrem/yr would be a health catastrophe. That EPA’s regulation allows the 95th percentile doses to be as high as the sky and for years on end shows that the EPA’s regulation had little concern for life on the planet Earth. (See our August 2020 newsletter and other articles on the Environmental Defense Institute website to better understand the harm of radiation exposure.)

The Department of Energy's modeling of the trickle out of radionuclides from the disposal of spent nuclear fuel at Yucca Mountain made it problematic to achieve 15 mrem/yr to an individual living 18 km downgradient of Yucca Mountain. But as water seeps into the porous volcanic "tuff" of the mountain and the waste containers inevitability corrode, the radionuclides trickle out, moving with groundwater. The degree of "sorption" of radionuclides to the soil along the way has been modeled based on contrived laboratory tests and often over zealously is modeled to sorb to the soil rather than reach the person drinking water 18 km from the disposal site.

The water infiltration model was thought by one prominent geologist, Lynn W. Gelhar, to underpredict the groundwater flow and the estimated annual radiological dose, as he explained in Chapter 14 of the book *Uncertainty Underground*. [21]

But something would happen to drastically lower the Department of Energy's trickle out radiation doses between 2007 and 2008 when the DOE submitted its license application for Yucca Mountain to the NRC. I had trouble understanding how the predicted doses dropped to less than a mrem/yr for post-10,000-year time frame. Both the earlier and later submittals had assumed perfect titanium drip shield performance, despite the implausibility of ever installing them in the repository. I finally found the answer in a letter on the State of Nevada's website for Yucca Mountain. [22]

An independent review of DOE's calculations had been contracted by the DOE but withheld from the State of Nevada. The review's conclusion was that the Department of Energy's modeling of water infiltration to the disposed of waste **did not provide a credible representation of water infiltration at Yucca Mountain**. In other words, because the periodic spikes in water infiltration had raised the estimated radiation dose, the water infiltration spikes were simply removed from the modeling in order to drive the estimated radiation exposures down. The contamination trickle-out problem that had previously estimated 95th percentile radiation doses above 1000 mrem/yr (yes, one thousand mrem/yr) and would struggle to meet the 100 mrem/yr median requirement by EPA regulations now had contrived the modeling to slash the estimated radiation dose to a person living 15 km (or 11 miles) downgradient to less than 1 mrem/yr.

[21] Edited by Allison M. Macfarlane and Rodney C. Ewing, *Uncertainty Underground – Yucca Mountain and the Nation's High-Level Nuclear Waste*, The MIT Press, 2006. ISBN 0-262-13462-4. Chapter 14 by Lynn W. Gelhar, *Containment Transport in the Saturated Zone at Yucca Mountain*. He concludes that the DOE calculations "could easily be three orders of magnitude larger than the DOE predicts (see figure 14.3). Figure 14.3 shows radiation dose versus time with the dose peaking after 10,000 years from closure. The DOE prediction was from 2001, DOE/RW-0539. Gelhar also points out the looseness of the EPA's standard "that probabilistic results be interpreted by applying the numerical standards to a "reasonable expectation" prescribed to be the mean is troubling." Figure 14.3 shows DOE's model yielded 95th percentile doses above 1000 mrem/yr after 100,000 years.

[22] Senate Hearing 109-523, Yucca Mountain Repository Project, May 16, 2006. https://www.govinfo.gov/content/pkg/CHRG-109shrg29473/html/CHRG-109shrg29473.htm

The DOE's problem of meeting the regulatory standards for Yucca Mountain was easily solved by the use of technically unsupportable assumptions, which naturally the NRC had no problem with. The NRC would tell the media and the Government Accountability Office that there were no technical reasons to object to the repository at Yucca Mountain and that the Yucca Mountain repository would be "safe."

The State of Nevada, however, had noted that in addition to the contrived modeling of the trickle out from Yucca Mountain, that other essential aspects of the license application for Yucca Mountain were technically unsupported and lacked design details or even the identification of applicable codes and standards. The Department of Energy has no technical basis to support the claims in its 2008 Yucca Mountain License Application about corrosion resistance of the metal waste packaging and drip shield and had not corrected the situation even after strong urging from the U.S. Nuclear Waste Technical Review Board. [23] [24]

There are numerous versions of the Yucca Mountain documents, but here's the Department of Energy's 2007 draft EIS which stated:

"The Proposed Action analyzed in this Repository SEIS is for DOE to construct, operate, monitor, and eventually close a geologic repository at Yucca Mountain for the disposal of 70,000 metric tons of heavy metal (MTHM) of spent nuclear fuel and high-level radioactive waste."

"Under the current repository design, the area required to accommodate 70,000 MTHM totals about 6 square kilometers (1,500 acres), with approximately 66 kilometers (41 miles) of emplacement drifts [tunnels in the repository]. About 11,000 waste packages and their emplacement pallets would be placed in these drifts. DOE would use tunnel boring machines to excavate the drifts."

"The waste packages would consist of two concentric cylinders. The inner cylinder would be made of Stainless Steel Type 316, and the outer cylinder would be made of corrosion-resistant, nickel-based Alloy 22. Emplacement pallets would be fabricated from Alloy 22 plates and stainless steel."

"As now proposed, the newly designed surface and subsurface facilities would allow DOE to operate the repository following a primarily canistered approach in which **most commercial spent nuclear fuel would be packaged at the reactor sites in transportation, aging, and disposal (TAD) canisters. Any commercial spent nuclear fuel arriving at the repository in packages other than TAD canisters would be repackaged by DOE at the repository into TAD canisters.** DOE would construct the surface and subsurface facilities over a period of several years (referred to as phased construction) to accommodate an increase in spent nuclear

[23] State of Nevada to Chairman of the Nuclear Waste Technical Review Board, October 8, 2008. http://www.state.nv.us/nucwaste/news2008/pdf/nv08108nwtrb.pdf

[24] See the State of Nevada website, including the "Key Technical Issues" webpage at http://www.state.nv.us/nucwaste/technic.htm

fuel and high-level radioactive waste receipt rates as repository operational capability reaches its design capacity.” [25]

The TAD canister was not designed, even as of 2008, not available for utilities to use and its performance characteristics not properly considered, wrote Nevada Senator Harry Reid and four other members of Congress. [26] And although the TAD was integral to the Yucca Mountain design, in 2006, DOE did not expect the TAD to be ready for another six years. [27]

The allowed temperature increase of Yucca Mountain by the placement of spent fuel has been subject to flux. Some have argued that the heat would reduce corrosion and others arguing that too much increased heat would undermine the geologic barriers. [28] The forced ventilation cooling of the repository for decades has been included as an assumption, but subject to change.

The safety case for meeting regulatory standards for Yucca Mountain on waste trickle out into groundwater was solved by contriving a complex model to limit water infiltration rates. The safety case for criticality control involved describing the probability of criticality as “low” and assuming various engineered barriers would not corrode for thousands of years, as well.

Assuming waste containers don’t corrode for thousands of years, assuming the installation and perfect performance of titanium drip shields, and assuming low and steady water infiltration that has no technical basis as bounding the water infiltration at Yucca Mountain — it was easy. And it was easy and all too natural for the U.S. Nuclear Regulatory Commission to fail to find any problems with the safety case for Yucca Mountain.

Devil in the details of the Standard Contract with the Department of Energy under the NWPA

The failure of the Department of Energy to secure a solution for the disposal of spent nuclear fuel has resulted in some commercial nuclear utilities having to result to rather torturous litigation in order to get the DOE to pay some of the utilities’ expenses for continued storage of the spent nuclear fuel. The 1982 Nuclear Waste Policy Act allowed the Department of Energy to enter into contracts with commercial nuclear utilities, with the Department of Energy promising to take ownership of the spent nuclear fuel.

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[25] U.S. Department of Energy, *Draft Supplemental Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada*, DOE/EIS-0250F-S1D, October 2007. https://www.energy.gov/sites/prod/files/EIS-0250-S1-DEIS-Summary-2007_0.pdf

[26] Letter from five members of Congress to Dr. Jane Summerson and Mr. Lee Bishop, Department of Energy, January 10, 2008. http://www.state.nv.us/nucwaste/news2008/pdf/DelCmts_YMSEIS_01.10.08.pdf

[27] Letter from five members of Congress to Dr. Jane Summerson and Mr. Lee Bishop, Department of Energy, January 10, 2008. http://www.state.nv.us/nucwaste/news2008/pdf/DelCmts_YMSEIS_01.10.08.pdf

[28] Edited by Allison M. Macfarlane and Rodney C. Ewing, *Uncertainty Underground – Yucca Mountain and the Nation’s High-Level Nuclear Waste*, The MIT Press, 2006. ISBN 0-262-13462-4.

In 2014, it was estimated by contractors for the Department of Energy that by 2035, half of the commercial spent fuel inventory in the US would be stored in approximately 5,000 dual-purpose-canisters. And if no nuclear power reactors were built, but existing reactors continued to run as projected, the spent nuclear fuel inventory was projected to be approximately 139,000 metric tons heavy metal (MTHM) by 2055, or 10,000 canisters in 2055. [29]

But as the utilities sought to be paid for continuing costs of caring for spent nuclear fuel after the 1998 date the DOE was to have a repository for the spent fuel, many would have to fight in court. The Department of Energy fought strenuously to avoid compensating the utilities, saying that the problem was "due to an unavoidable delay." Years of litigation ultimately found that the Department of Energy did need to pay for some of the costs of continuing spent fuel storage and settlements with utilities. [30] But the settlements for partial breach of contract only cover the time up to the date of the court filing. So additional settlements must continue to be requested as time moves on but the spent fuel doesn't.

Commercial power utilities with stranded fuel, that shutdown their nuclear reactors, also wanted to shutdown the spent fuel pools. Other utilities simply ran out of space in their spent fuel pools. The only answer was to put the spent fuel into dry storage casks or canisters.

There are various dry storage systems licensed by the U.S. Nuclear Regulatory Commission. And most of the fuel is in thin-walled stainless steel canisters rather than bolted-lid containers. For many of the canisters, thin means so thin-walled that the Department of Energy is loath to mention just how thin: about 0.5 to 0.5625 inches of wall-thickness of the canister containing about 10 metric tons of spent nuclear fuel. [31]

The dry storage systems used by the utilities were never designed for disposal of the spent nuclear fuel at Yucca Mountain or any other disposal facility. Some of the containers can't be transported, [32] but those that can, are referred to a dual-storage-canisters, meaning they can be stored in place and also transported.

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[29] E. Hardin et al., Spent Fuel and Waste Disposition, Prepared for U.S. Department of Energy, Office of Used Nuclear Fuel Disposition, *Investigations of Dual-Purpose Canister Direct Disposal Feasibility (FY14)*, FCRD-UFD-2014-000069 Rev. 1, October 2014. https://www.energy.gov/sites/prod/files/2014/10/f19/7FCRDUFD2014000069R1%20DPC%20DirectDispFeasibility.pdf

[30] EveryCRSReport.com, Contract Liability Arising from the Nuclear Waste Policy Act (NWPA) of 1982, R40996, February 1, 2012. https://www.everycrsreport.com/reports/R40996.html

[31] E. Hardin et al., Fuel Cycle Research and Development, Prepared for U.S. Department of Energy Used Fuel Disposition Campaign, *Assumptions for Evaluating Feasibility of Direct Geologic Disposal of Existing Dual-Purpose Canisters*, FCRD-UFD-2012-000352, Rev. 1, November 2013. (SAND2013-9780P), https://www.osti.gov/servlets/purl/1673713 See Appendix A.

[32] E. Hardin et al., Fuel Cycle Research and Development, Prepared for U.S. Department of Energy Used Fuel Disposition Campaign, *Assumptions for Evaluating Feasibility of Direct Geologic Disposal of Existing Dual-Purpose Canisters*, FCRD-UFD-2012-000352, Rev. 1, November 2013. (SAND2013-9780P), https://www.osti.gov/servlets/purl/1673713 p. 24: Storage-only canister systems include the MSB (24-PWR, Energy Solutions) and the NUHOMS-24PS, -24PH, -24PHB< -24PHBL, -52B and -07P (Transnuclear). These canisters currently exist at the Idaho National Laboratory, and at the Calvert Cliffs, Surry, Oconee, Arkansas Nuclear One, Palisades, Davis-Besse, Point Beach, Susquehanna, and H.B. Robinson nuclear power plants. These

Various presentations and reports for the Department of Energy display a disclaimer stating "This is a technical presentation that does not take into account the contractual limitations under the Standard Contract. Under the provisions of the Standard Contract, DOE does not consider spent fuel in canisters to be an acceptable waste form, absent a mutually agreed to contract modification." [33]

According to a decommissioning document submitted to the NRC regarding one utility's canistered spent fuel, "the government's [DOE's] stated positions with respect to such acceptance [of spent fuel in canisters], including assertions in legal proceedings, have been inconsistent." And as recently as 2008, the Department of Energy continued to give empty promises to the U.S. nuclear power electrical generating utilities of promised dates for opening Yucca Mountain by 2020. [34]

In 2009, the Department of Energy Secretary Steven Chu stated that Yucca Mountain was no longer an option. [35] In 2010, President Obama created the Blue-Ribbon Commission on America's Nuclear Future and the commission issued its report in 2012. [36] The BRC's strategy included "**prompt efforts** to develop one or more geologic disposal facilities" and "p**rompt efforts** to develop one or more consolidated interim storage facilities." [37]

Originally the Department of Energy had envisioned and had partially designed a "transport, aging, and disposal" container called the "TAD." It was to be highly corrosion resistant. The license application by the DOE for Yucca Mountain assumes that spent nuclear fuel is placed into TADs and that the TADs don't corrode for 10,000 years. (Other containers, like the multi-purpose canister, were assumed for Department of Energy high-level waste and spent fuel.) Inside Yucca Mountain, the commercial spent fuel was to be protected by the TAD, the neutron absorber in the TAD, additional metal waste package coverings, and the titanium drip shield protects the container of spent nuclear fuel. And in all this fanciful imagining, the likelihood of criticality is deemed to be "low." [38] And the trickle out of radionuclides from the dissolving

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are sealed canisters, not to be confused with non-canistered cask systems (storage-only or storage-transportation) which have bolted closures.

[33] E.L. Hardin and D.J. Clayton, Sandia National Laboratories, R.L. Howard, J.M Scaglione, E. Pierce and K. Banerjee, Oak Ridge National Laboratory, M.D. Voegele, Complex Systems Group, LLC, H.R. Greenberg, J. Wen and T.A. Buscheck, Lawrence Livermore National Laboratory, J.T. Carter and T. Severynse, Savannah River National Laboratory, W. M. Nutt, Argonne National Laboratory, Prepared for: U.S. Department of Energy, Office of Used Nuclear Fuel Disposition, *Preliminary Report on Dual-Purpose Canister Disposal Alternatives (FY13)*, FCRD-UFD-2013-000171, Revision 1, December 2013. https://www.energy.gov/sites/prod/files/2013/12/f5/PrelimRptDPCDisposalAlternativesR1.pdf

[34] Dominion Energy Kewaunne, Inc., Kewaunee Power Station Post-Shutdown Decommissioning Activities Report, February 26, 2013. https://www.nrc.gov/docs/ML1306/ML13063A248.pdf

[35] U.S. Department of Energy, "Strategy for the Management and Disposal of Used Nuclear Fuel and High-Level Radioactive Waste," January 26, 2013.

[36] Blue Ribbon Commission on America's Nuclear Future, "Report to the Secretary of Energy," January 2012.

[37] Dominion Energy Kewaunne, Inc., Kewaunee Power Station Post-Shutdown Decommissioning Activities Report, February 26, 2013. https://www.nrc.gov/docs/ML1306/ML13063A248.pdf

[38] Scientific Analysis/Calculation Administration Change Notice, ANL-DO0-NU-000001, Screening Analysis of Criticality Features, Events, and Processes for License Application, Yucca Mountain Project, 2008. https://www.nrc.gov/docs/ML0907/ML090720250.pdf

containers and the fuel they hold is deemed to be so slow that water downgradient from the Yucca Mountain disposal site doesn't cause more than a 1 mrem/yr radiation dose.

Just a few problems with unloading the welded, thin-walled canisters and putting that spent nuclear fuel in a TAD. First of all, no design for a TAD was ever completed or licensed. Second of all, despite NRC regulations requiring the canisters they licensed to allow the spent fuel to be retrievable, it isn't.

The NRC licensed the dry storage canisters in use at many commercial nuclear power plants in the U.S. The NRC codified the requirement in its regulations, including 10 CFR 72.122(1), which states

> *Storage systems must be designed to allow ready retrieval of spent fuel, high level radioactive waste, and reactor-related GTCC [greater-than-class C] waste for further processing or disposal.* [39]

The canisters used in the US were approved by the NRC but were never actually designed for ready retrieval of spent fuel. So little attention was paid to corrosion issues that degradation including the neutron absorber material in the canisters as well as spent fuel pool racks has occurred and in just a few years. The majority of currently loaded spent nuclear fuel canisters in the US used boron carbide with aluminum, known as Boral. Despite optimism by repository researchers for this type of neutron absorber to last for thousands of years, [40] degradation has already been occurring. [41]

The U.S. Nuclear Waste Technical Review Board (NWTRB) recommended the "design and demonstration of dry-transfer fuel systems for removing fuel from casks and canisters following extended dry storage." [42]

It would seem that the NRC may have started to recognize the difficultly involved with grinding open a welded canister, perhaps with a degraded neutron absorber so the criticality was more likely, and somehow deftly preventing the fuel from being exposed to oxygen, while using the shielding of the water in the spent fuel pool, with fuel of the temperature above boiling, and all with virtually no way to inspect the status of the fuel or the neutron absorber in the canister,

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[39] B. B. Bevard et al., Oak Ridge National Laboratory, *BWR Spent Nuclear Fuel Integrity Research and Development Survey for UKABWR Spent Fuel Interim Storage*, ORNL/TM-2015/696, October 2015. https://info.ornl.gov/sites/publications/files/Pub60236.pdf (discusses U.S. NRC regulations and the issue of spent fuel retrievability from canisters in the U.S.)

[40] E. Hardin et al., Spent Fuel and Waste Disposition, Prepared for U.S. Department of Energy, Office of Used Nuclear Fuel Disposition, *Investigations of Dual-Purpose Canister Direct Disposal Feasibility (FY14)*, FCRD-UFD-2014-000069 Rev. 1, October 2014. See page 4-1. https://www.energy.gov/sites/prod/files/2014/10/f19/7FCRDUFD2014000069R1%20DPC%20DirectDispFeasibility.pdf

[41] U.S. Nuclear Regulatory Commission, Generic Issue 196. https://adamswebsearch2.nrc.gov/webSearch2/main.jsp?AccessionNumber=ML042670379

[42] U.S. Nuclear Waste Technical Review Board, *Evaluation of the Technical Basis for Extended Dry Storage and Transportation of Used Nuclear Fuel*. Arlington, Virginia, 2010. pp. 14 and 125, (at www.nwtrb.gov) as cited in https://info.ornl.gov/sites/publications/files/Pub60236.pdf

while assuring that the fuel remained subcritical and was not further damaged during the transfer of fuel.

Much about spent fuel degradation with exposure to oxygen and the pyrophoric behavior of uranium and zirconium has been learned by the Department of Energy, the hard way. [43] [44]

For some idea of how uranium behaves, consider that uranium in a 30-gallon inner drum inside a barrel, disposed of at the Idaho National Laboratory from the Rocky Flats weapons plant, upon excavation, ignited and material was forceable expelled, hitting the cab of the excavator. Oxygen introduced to the inner drum caused **rapid oxidation that released hydrogen from uranium hydride** and resulted in a fire and some self-propelled movement of material. [45]

A study updated in 2019 by the Department of Energy confirms that the NRC had no documented evaluation of the consequences of spent nuclear fuel canister failure. The NRC has prepared the draft Environmental Impact Statement for the proposed Holtec consolidated interim storage facility in New Mexico without having any documented basis for the consequences of an expected event, leakage of a spent nuclear fuel canister. [46]

Instead of using thin-walled welded canisters that cannot be adequately inspected or repaired, the Swiss required the use of bolted thick-walled casks. They store them in a building, away from ocean salt spray air, for example. They have a hot cell for repackaging a cask if needed. Read more at SanOnofreSafety.org. [47]

The NRC's response has typically been to admit there's a problem while not actually admitting there's a problem. With regard to the inability to retrieve spent nuclear fuel from NRC-licensed canisters, the NRC solution seemed to be to remove the regulation or provide guidance that gives gibberish saying there's no need to inspect canister internals, unless, of course, there's

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[43] Primer on Spontaneous Heating and Pyrophoricity, DOE-HDBK-1081-2014, 2014 https://www.standards.doe.gov/standards-documents/1000/1081-BHdbk-2014/@@images/file

[44] Brett Carlsen et al., *Damaged Spent Nuclear Fuel at U.S. DOE Facilities, Experience and Lessons Learned*, INL/EXT-05-00760, November 2005. At https://inldigitallibrary.inl.gov/sites/sti/sti/3396549.pdf See Appendix A for an experience in 1980 when transporting spent fuel. A previously unknown phenomena occurred which was oxygen scavenging from the air by exposure of fuel at the points of cladding failure, which enlarged the existing cladding breaks. From this experience, it was learned that the transported fuel required use of an inert gas such as helium in spent fuel shipments. Further experience is described when the high temperature fuel was submerged back into the pool, resulting in overpressure, in steam and spalling of fuel material from the fuel rods, fuel debris and contamination of the pool.

[45] Kevin Daniels et al., Idaho Cleanup Project, CH2M-WG Idaho, LLC, "Independent Investigation Report of the November 2005 Drum Fire at the Idaho National Laboratory Site," RPT-190, March 2006. https://ar.icp.doe.gov/images/pdf/200605/2006051600209TUA.pdf

[46] U.S. Department of Energy, Spent Fuel and Waste Science and Technology, Gap Analysis to Guide DOE R&D in Supporting Extended Storage and Transportation of Spent Nuclear Fuel: An FY2019 Assessment, SAND2019-15479R, December 23, 2019. https://www.osti.gov/servlets/purl/1592862

[47] SanOnofreSafety.org webpage "Swiss Solution – Swiss nuclear waste storage systems exceed US safety standards" at https://sanonofresafety.org/swiss/

a safety issue. [48]And forget about opening a welded canister, it would lead to elevated worker radiation exposures. The full extent of the inability to open a spent fuel canister of higher enriched fuel with a potentially degraded neutron absorber in the canister internals isn't really fessed up to.

But the Department of Energy has now for some years investigated the direct disposal of these canisters, rather than remove the fuel from the canisters and repackage them into the more corrosion resistant TAD as stated in Yucca Mountain's license application to the NRC. [49]

The Department of Energy's research during that last decade has been examining the behavior of different geologic mediums including clay-rich (argillaceous) media including shales, hard rock (crystalline or granite), or salt but not much research any more for volcanic "tuff" as found at Yucca Mountain.

The last 10 years of repository research shows that the criticality issues are a problem, especially for "direct disposal" of spent nuclear fuel canisters

When the Yucca Mountain spent nuclear fuel (and high-level waste) repository was first envisioned back in the 1980s, the enrichment of commercial nuclear power plant nuclear fuel was about 2 percent or less. And highly enriched fuels used by the Department of Energy were reprocessed at the Idaho National Laboratory's Idaho Chemical Processing Plant, now the Idaho Nuclear Engineering and Technology Center (INTEC). Spent fuel reprocessing at the INL ended by 1992, complicating the safety case for any disposal facility that disposes of high enriched fuels used by the Department of Energy or the Navy.

The disposal of higher enriched fuels now used by the commercial nuclear utilities, up to five percent enriched, creates a significantly higher vulnerability to having unintended criticality, in the short term, for storage and transportation, and in the short-term and long-term, for the waste disposal. And while the longer the fuel was operated in a nuclear reactor increases the fuel's burnup and contributes to the breakdown of the fuel matrix and cladding, fuel that was not used in a reactor as long, with the higher enrichment yet low burnup, retains an even higher vulnerability to reaching criticality, should the fuel be moderated with water due to a transportation accident or water ingress in a disposal facility.

[48] Federal Register, Fuel Retrievability in Spent Fuel Storage Applications, A Notice by the Nuclear Regulatory Commission on June 8, 2016. https://www.federalregister.gov/documents/2016/06/08/2016-13569/fuel-retrievability-in-spent-fuel-storage-applications

[49] Energy Workshops, *2018 SFWST Annual Working Group Meeting, Las Vegas, Nevada May 22 to May 24*, 2018. https://energyworkshops.sandia.gov/nuclear/2018-sfwst-rd-team-meeting/ See presentation #05 on direct disposal of spent nuclear fuel, https://energyworkshops.sandia.gov/wp-content/uploads/2018/05/05-Direct-Disposal-of-Spent-Nuclear-Fuel-in-Dual-Purpose-Canisters-RD-Path-Forward-SAND2018-5437-PE.pdf

In order for the light-water reactor (thermal neutron) fuel to go critical, it needs a moderator — water is the moderator for the type of light-water reactor fuel used in commercial nuclear reactors in the U.S.

The so-called "moderator exclusion" assumption that the NRC has resorted to with its now prevalent high burnup fuels means that the NRC had to assume, and to a degree **very unlike** that of the commercial reactors with 2 percent or less enriched fuel, that a moderator such as water would not flood the higher enriched, so-called "high burn-up" spent nuclear fuel. If the moderator was not assumed to be excluded, in many cases, depending on a number of variables, the array of high-burnup spent nuclear fuel would be able to reach criticality. Reaching criticality would create heat and more fission products and possibly influence nearby spent fuel and the performance of the deep geologic repository.

The regulations provide some inappropriate leeway regarding criticality and groundwater protection after 10,000 years giving the Department of Energy room to wiggle regarding criticalities (and their fallout) that occur after 10,000 years. Groundwater protection after 10,000 years is limited to only those events deemed more likely than an annual probability of 1.0E-4/yr. But there are thousands of years to be exposed to a potential criticality event.

Over time, the criticality risk doesn't go away. For pressurized water reactor (PWR) fuel arranged as it would be in a canister known as a 32-PWR, having initial 4 percent enrichment (and operated in a reactor to 40 GW-d/MT burnup), k-effective versus time was determined. The higher the k-effective value, the higher the reactivity. A k-effective value at or above 1.0 (or above about 0.98 for margin) when flooded with water can go critical.

While the criticality risk of the fuel is high in the first 100 hours after shutdown and remains at its highest during the first year, the reactivity, or k-effective, declines during the first 100 years. However, after about 100 years, the k-effective climbs steadily, peaking at about 25,000 years after its use in a reactor before starting to decline again. [50]

When water floods the spent fuel, perhaps held in a partially breached canister, then the degree that criticality is possible depends on the enrichment of the spent fuel, the status of various neutron-absorbing fission products built up by operation in a reactor, the status of any neutron absorbing materials designed to reduce the potential for criticality (such as the Boral) when the fuel was loaded into the canister in the spent fuel pool, the status of the basket within the canister, the loading arrangement position of the fuel within the canister, and perhaps other variables. The reduced reactivity from "burnup credit" that accounts for the neutron-absorbing fission products and actinides built up in the fuel, does not apply to fresh fuel or damaged fuel.

[50] Energy Workshops, *2018 SFWST Annual Working Group Meeting, Las Vegas, Nevada May 22 to May 24*, 2018. https://energyworkshops.sandia.gov/nuclear/2018-sfwst-rd-team-meeting/ See presentation #05 on direct disposal of spent nuclear fuel, page 4 the figure of K-effective versus time, and see page 10 for regulations that dismiss fallout effects on groundwater for criticality events after 10,000 years if less than 1.0E-4 annual probability at https://energyworkshops.sandia.gov/wp-content/uploads/2018/05/05-Direct-Disposal-of-Spent-Nuclear-Fuel-in-Dual-Purpose-Canisters-RD-Path-Forward-SAND2018-5437-PE.pdf

Once a canister of spent fuel has been breached, and water is allowed entry into the canister, criticality can occur for a significant and growing number of spent nuclear fuel canisters destined for a repository. The criticality risk is increased significantly by the use of so-called "high burnup" fuels now used at commercial nuclear power plants. The NRC's recent NUREG-2224 [51] of some belated research about the high burnup fuels it had authorized, takes a very short-sighted view of the consequences of canister leakage, neither addressing the ongoing degradation of the fuel due to oxygen ingress to the canister over time nor the criticality risk. The lack of radiological consequence analysis for a leaking canister containing high-burnup fuel had become problematic for the NRC, which had allowed the use of high-burnup fuel without properly assessing the impact on storage and transport. NUREG-2224 manages to assert that the radiological release consequences for a canister containing high-burnup fuel is low, while failing to address the effect of oxygen exposure on the uranium and zirconium over time.

Some of the lower burnup spent fuel used before the 1990s won't go critical, but the fuels used since the 1990s in the industry, known as high burnup fuels, definitely can go critical if non-borated water enters the canister. With degradation of the neutron absorbing materials in the canister, criticality may be possible even with borated water. The neutron-absorbing properties of the chloride in salt brine have been found beneficial but not sufficient to prevent criticalities in some canisters. [52]

The Department of Energy perhaps was perhaps surprised to learn that a significant portion of the spent fuel canisters that it would desire to dispose of directly, in the canisters that the fuel is presently loaded in, could pose a significant criticality risk and beyond 10,000 years. The criticality safety case for Yucca Mountain had speculated that the risk of criticality was "low."

But the fact is that every spent nuclear fuel container will eventually corrode and allow water ingress. That may occur before the canisters are placed in a repository. The 20-year license for the canisters granted by the NRC for the canisters had assumed it would become the Department of Energy's problem, so they didn't worry about the age-related canister problems.

It has been projected that for past and expected nuclear reactor operation in the U.S., by 2055 there will be roughly 10,000 canisters (or 140,000 metric tons heavy metal) of spent nuclear fuel needing disposal, and a significant portion of them would be capable of going critical if water ingress occurs. [53]

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[51] U.S. Nuclear Regulatory Commission, Office of Nuclear Material Safety and Safeguard, *Dry Storage and Transportation of High Burnup Spent Nuclear Fuel*, NUREG-2224, November 2020. https://adamswebsearch2.nrc.gov/webSearch2/main.jsp?AccessionNumber=ML20191A321

[52] E. Hardin et al., Spent Fuel and Waste Disposition, Prepared for U.S. Department of Energy, Office of Used Nuclear Fuel Disposition, *Investigations of Dual-Purpose Canister Direct Disposal Feasibility (FY14)*, FCRD-UFD-2014-000069 Rev. 1, October 2014. https://www.energy.gov/sites/prod/files/2014/10/f19/7FCRDUFD2014000069R1%20DPC%20DirectDispFeasibility.pdf

[53] Alsaed Abdelhalim, Enviro Nuclear Services, LLC, Spent Fuel and Waste Disposition, *Review of Criticality Evaluations for Direct Disposal of DPCs and Recommendations*, SFWD-SFWST-2018-000***, SAND2018-4415R, April 20, 2018. https://prod-ng.sandia.gov/techlib-noauth/access-control.cgi/2018/184415r.pdf

For repository designs, recently the Department of Energy has, therefore, turned to trying to find strategies of putting filler materials into the canisters that would preclude entry of water into the canister.

The Department of Energy is also focusing on trying to say that multiple criticalities in a waste repository won't add that much harm to a disposal repository's already estimated harm. They want to argue that the criticality doesn't harm the repository and doesn't lead to significantly higher radiological releases than it already expects. There is plenty of reason to be concerned about the DOE's drive to find the answers it wants.

In the last decade, there's been a lot of focus in the Department of Energy's spent fuel disposal research on disposal in a salt medium. [54] [55] And given the proposed placement of two consolidated interim storage facilities within 30 miles of the salt mine disposal at the Waste Isolation Pilot Plant (WIPP) in New Mexico, it certainly seems to me that new legislation to grease the opening of one or two consolidated interim storage facilities near WIPP will accomplish for New Mexico what the 1987 NWPA amendments known as the "screw Nevada bill" did to Nevada.

Articles by Tami Thatcher for December 2020.

[54] Henrik Lijenfeldt et al., Spent Fuel and Waste Science and Technology, *Summary of Investigations on Technical Feasibility of Direct Disposal of Dual Purpose Canisters*, SFWD-SFWST-2017-000045, September 2017. https://info.ornl.gov/sites/publications/Files/Pub102524.pdf

[55] Energy Workshops, *2018 SFWST Annual Working Group Meeting, Las Vegas, Nevada May 22 to May 24*, 2018. https://energyworkshops.sandia.gov/nuclear/2018-sfwst-rd-team-meeting/ See presentation number 68 and others.