Spent Power Reactor Fuel: Storage and disposal Issues

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After 60 years (1960-2020), U.S. nuclear power reactors have generated the single largest inventory of spent nuclear fuel (SNF) in the world (roughly 20 percent). SNF is bound up in more than 285,900 long rectangular assemblies containing tens of millions of fuel rods. The rods, in turn, contain trillions of irradiated uranium pellets- the size of a fingertip.

After bombardment with neutrons in the reactor core, about 5 to 6 percent of the pellets are converted to a myriad of radioactive elements with half-lives ranging from seconds to millions of years. Standing within a meter of a typical spent nuclear fuel assembly guarantees a lethal radiation dose in minutes.

Pressurized Water Reactor Fuel assembly.

Why we should be concerned about spent power reactor fuel.

The U.S. Government Accountability Office informed the U.S. Congress in April 2017 that “spent nuclear fuel can pose serious risks to humans and the environment ..and is a source of billions of dollars of financial liabilities for the U.S. government. According to the National Research Council and others, if not handled and stored properly, this material can spread contamination and cause long-term health concerns in humans or even death.”

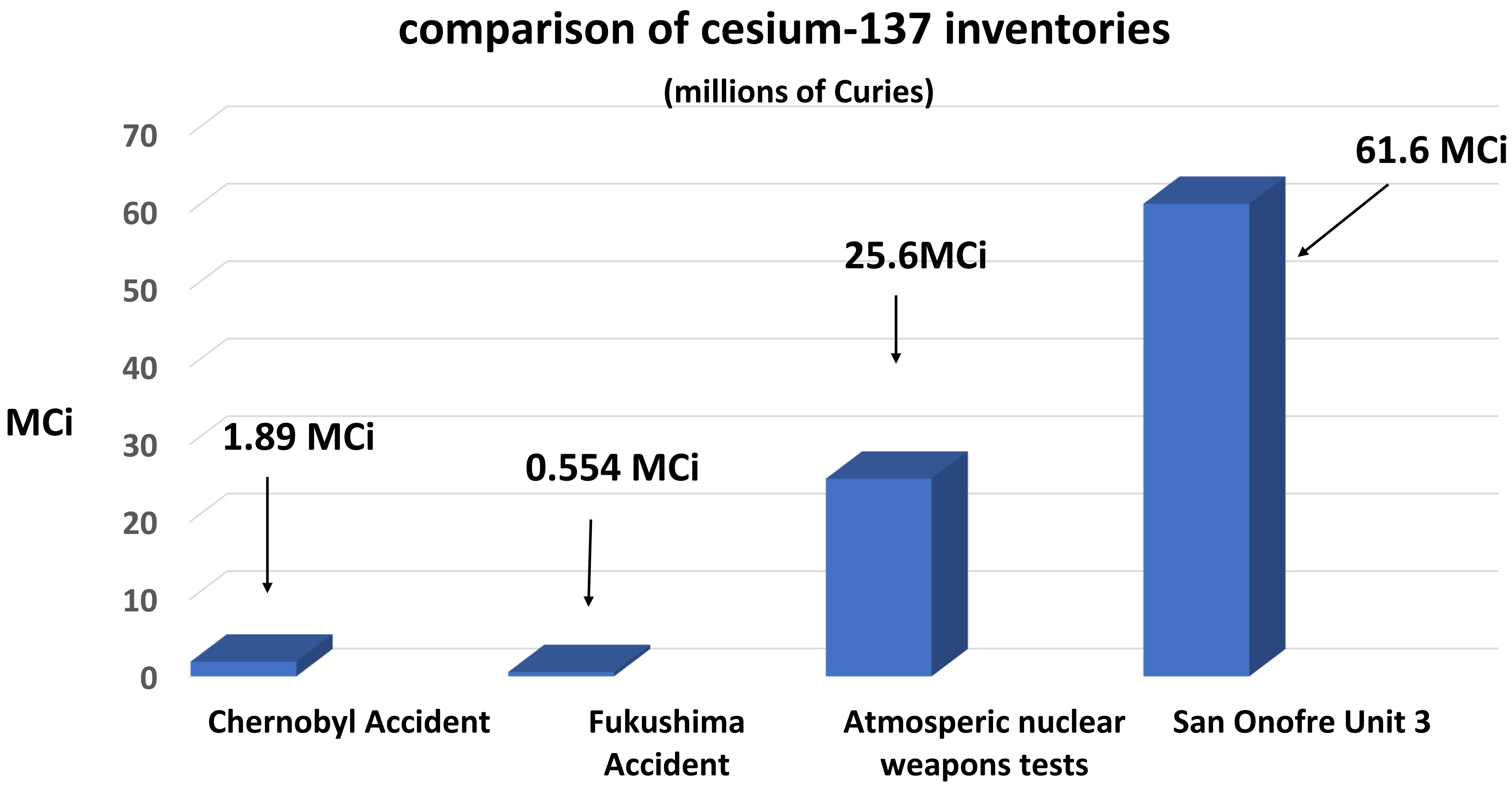
Because of these extraordinary hazards spent nuclear fuel is required under federal law (the Nuclear Waste Policy Act) to be disposed in a geological repository to prevent it from escaping into the human environment up to one million years.

U.S Spent power reactor fuel contains some of the world’s largest concentrations of artificial radioactivity.

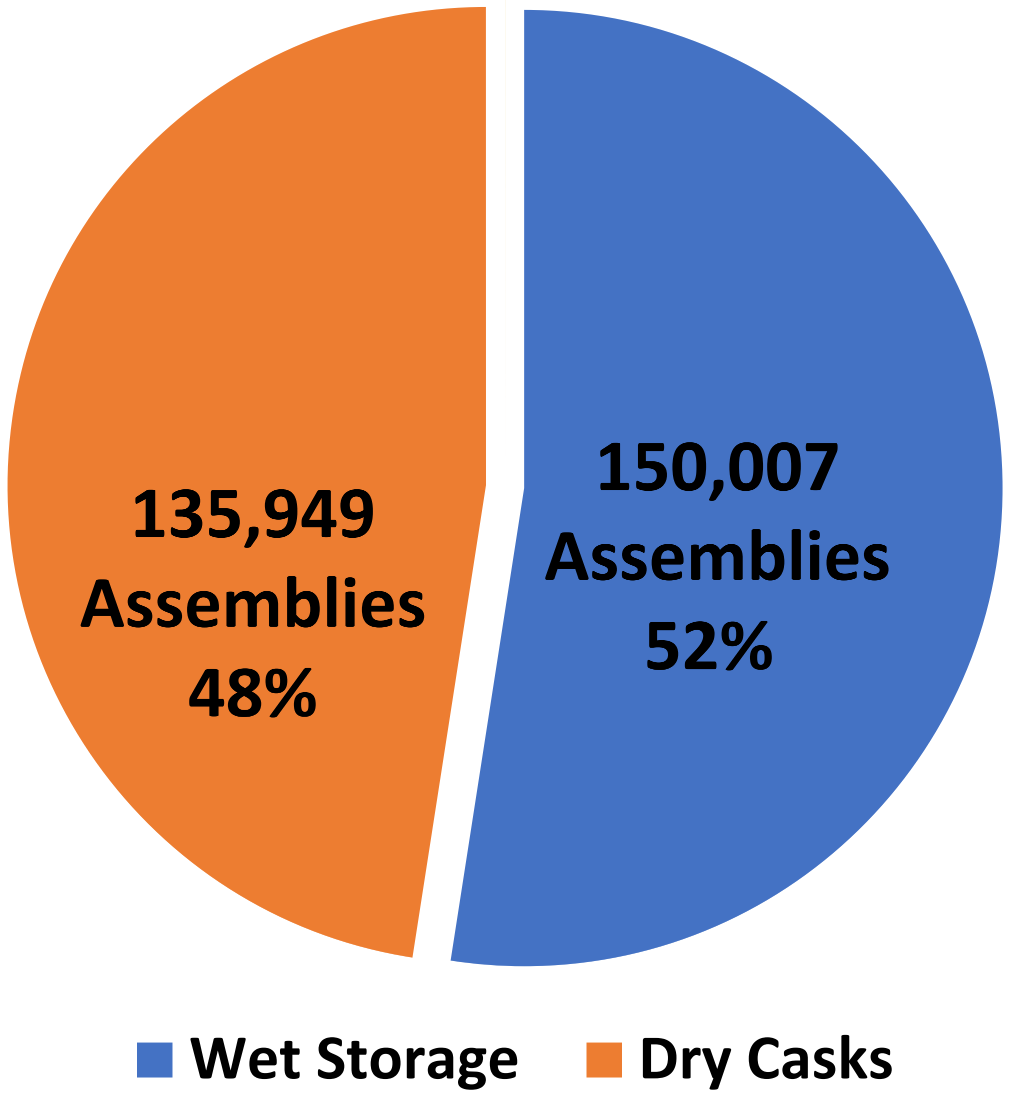
(1) 23 billion curies (8.51E+20 Bq) of long-lived radioactivity (>20 times more than generated by the U.S. nuclear weapons program).

(2) About 9.2 billion curies (3.4E+20Bq) of cesium-137(350 times more than released by all atmospheric nuclear weapons tests); and

(3) About 700 metric tons of plutonium (about 3 times more than used for weapons throughout the world).



Sources: NCRP -154, WNA 2016, DOE-GC 859 (2013), DOE EIS-0250, Appendix A, Table A-9.



As of the end of 2018, about 82,358 metric tons of spent nuclear fuel is stored at 119 sites.

Currently, there are 95 operating nuclear power reactors in 29 states, which generate about 2,200 metric tons of SNF each year. There are 38 closed nuclear power reactors in the United States at 30 sites in various stages of decommissioning.

About 48% of U.S. power reactor spent fuel is stored in > 3,200 storage casks, of which 600 are at permanently closes sites.

Sources: DOE (2019), NWTRB (2016)

35 States with Commercial SNF from Nuclear Power Reactors

4 States with Research Reactors Only

Approximate Amounts in Metric Tons Heavy Metal (Estimated 12/31/18)

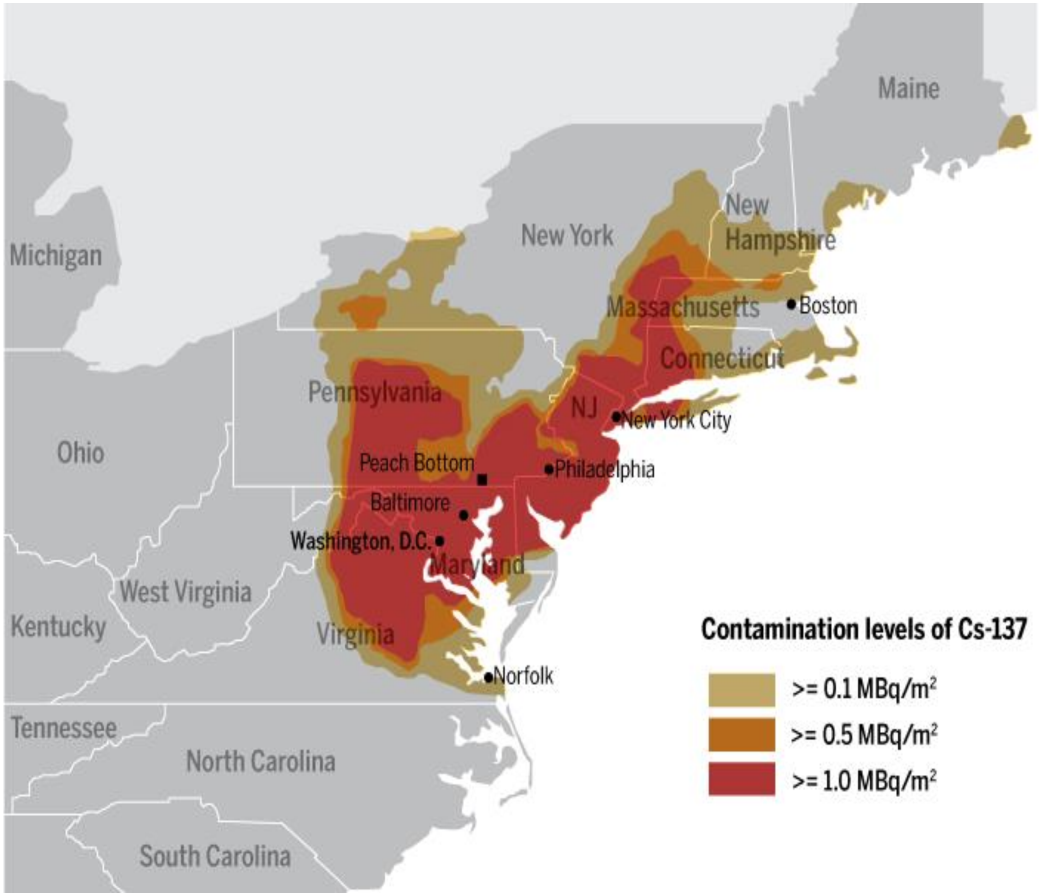
SNF at DOE-Managed, NRC Regulated Facilities (CO, ID)

Research reactors only (IN, NM, RI, UT)

Note: Quantities of SNF from research and defense programs and additional commercial-origin SNF stored under DOE authority are not included.

Heat from the radioactive decay in spent nuclear fuel is also a principal safety concern. A few hours after a full reactor core is offloaded, it can initially give off enough heat from radioactive decay to match the energy capacity of a steel mill furnace. This is hot enough to melt and ignite the fuel's reactive zirconium cladding and destabilize a geological disposal site it is placed in. By 100 years, decay heat and radioactivity drop substantially but still remains dangerous.

If the water in a reactor spent fuel pool is drained by and earthquake or an act of malice, decay heat can cause a catastrophic fire that could release enough radioactive material to contaminate an area twice the size of New Jersey. On average, radioactivity from such an accident, if it would occur at the Limmerick nuclear station in Pennsylvania, could force approximately 8 million people to relocate and result in $2 trillion in damages.



Source: Science&Global Security (2016)

The dangers of spent fuel fires can be greatly reduced by ending high density pool storage and expanded dry casks storage.

High Burnup Spent Nuclear Fuel Problems

US commercial nuclear power plants use uranium fuel that has had the percentage of its key fissionable isotope—uranium 235—increased, or enriched, from what is found in most natural uranium ore deposits. In the early decades of commercial operation, the level of enrichment allowed US nuclear power plants to operate for approximately 12 months between refueling. In recent years, however, US utilities have begun using what is called high-burnup fuel. This fuel generally contains a higher percentage of uranium 235, allowing reactor operators to effectively double the amount of time the fuel can be used, reducing the frequency of costly refueling outages.

High-burnup waste reduces the fuel cladding thickness and a hydrogen-based rust forms on the zirconium metal used for the cladding, which can cause the cladding to become brittle and fail. High burnup fuel temperatures make the used fuel more vulnerable to damage from handling .

High-Burnup SNF remains thermally hot for longer periods – lengthening at reactor storage possibly into the next century.

U.S. Government liabilities

Reactor operators have filed 40 lawsuits seeking compensation for storage expenses from the U.S. government's failure to open a disposal site on the January 31, 1998 date stipulated in the Nuclear Waste Policy Act.

As of FY 2019, $8 billion in settlements have been made with an estimated total liability to the USG of $36,5 billion.

Source : ***U.S. Department of Energy, Agency Financial Report for FY 2019. https://www.energy.gov/sites/prod/files/2019/11/f68/fy-2019-doe-agency-financial-report.pdf***

Current Reactor
Operator Liabilities

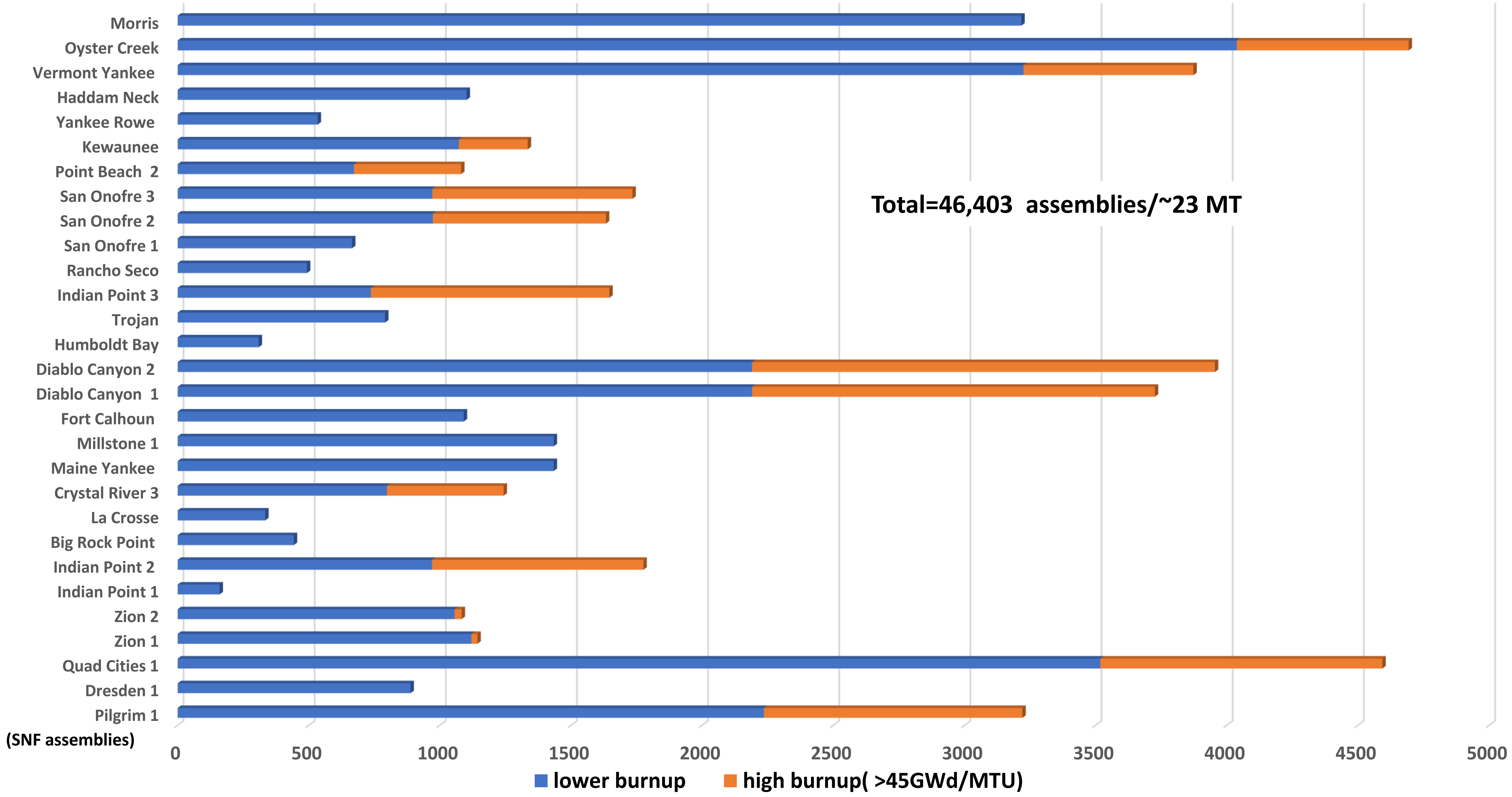
- **Under the Nuclear Waste Policy Act, which sets forth the process for disposal of high-level radioactive wastes, the U.S. Government cannot accept title to spent nuclear fuel until it is received at an open repository site. This process is paid by the collection of a user fee from nuclear power generators to be no more the one mill per kilowatt-hour. Payments were stopped by a Federal Court in January 2014. The Nuclear Waste Fund balance as of 2019 is approximately $40.9 billion. Congress has not approved resumption of fund collection for the Yucca Mt site.**

- **Costs for a consolidated interim storage site <u>are not</u> born by the U.S. government, <u>unless title is transferred by amending the Nuclear Waste Policy Act.</u>**

- **Efforts are underway to have the DOE assume title of spent Nuclear Fuel for a “pilot” storage site for “stranded” wastes.**

- **The U.S. Government Accountability Office reported in 2014: “per DOE, under provisions of the standard contract, the agency does not consider spent nuclear fuel in canisters to be an acceptable form for waste it will receive. This may require utilities to remove the spent nuclear fuel already packaged in dry storage canisters”**

spent nuclear fuel at stranded and future stranded reactors



Spent Nuclear Fuel Repackaging

The current generation of dry casks was intended for short-term onsite storage, and not for direct disposal in a geological repository. NRC has licensed 51 different designs for dry cask storage, 13 which are for storage only. None of the dry casks storing spent nuclear fuel are licensed for disposal.

By the time, DOE expects to open a repository in 2048, the number of large dry casks currently deployed is expected to increase from 1,900 to 12,000. Repackaging for disposal may require approximately 80,000 ”small” canisters.

Existing large canisters can place a major burden on a geological repository –such as: handling, emplacement and post closure of cumbersome packages with higher heat loads, radioactivity and fissile materials.

Repackaging expenses rely of the transportability of the canisters, but more importantly on the compatibility of the canister with heat loading requirement for disposal. In terms of geologic disposal, decay heat, over thousands of years, can cause waste containers to corrode, negatively impact the geological stability of the disposal site and enhance the migration of the wastes. Peak temperatures in the repository of 100 degrees C (212F) can extend beyond 300 years after centuries of decay and active ventilation.

Robert H. Jones Jr., Dry Storage Cask Inventory Assessment, U.S Department of Energy, Nuclear Fuel Storage and Transportation Planning Project, FCRD-NFST-2014-000602, Rev. 1, August 2015, P. 55. http://energy.gov/sites/prod/files/2016/10/f33/FCRD-NFST-2014-000602,%20Dry%20Cask%20Assessment,%20Rev%201.pdf
R. Wigeland, T.Taiwo, M. Todosow, W. Halsey, J. Gehin, Options Study – Phase II, Department of Energy, Idaho National Laboratory, INL/EXT-10-20439, September 2010.

Repackaging Costs

The costs of repackaging at centralized storage site are large. The estimates are based on a small (9 assemblies), medium (32 assemblies) and large (44 assemblies) standardized transportation and disposal canister (STAD) for a boiling water reactor. When applied to the Columbia Generating Station, in Washington - it could involve cutting open 120 dry casks and repacking approximately 8,160 spent fuel assemblies into casks suitable for disposal. The additional costs for this single reactor range from $272 million to $915 million. A decision on the type of geologic repository will determine the size of the repackaged canisters.

Based on the Energy Department's strategic plan to open a repository by the year 2048, the per assembly cost would be approximately $33,400 (large STAD) to $112,000 (small STAD) in 2015 dollars. The estimated cost of managing low-level radioactive waste from removing spent fuel to new canisters is estimated by the DOE at $9,500 per assembly and could be more than the cost to load the assembly in any canister.

U.S. Department of Energy, Office of Nuclear Energy, Task Order 21: Operational Requirements for Standardized Dry Fuel Canister Systems Updated Final Report, June 19, 2015.
http://energy.gov/sites/prod/files/2016/10/f33/energysolutions-task-order-21-updated-final-report-61915_1.pdf

Pre-disposal costs for the Columbia Generating Station (CGS) 2017 dollars

Dry Cask Procurement (a)	$960,521 per cask
Dry Cask Loading (a)	$277,000 per cask
Storage Pads (b)	$5,660,000 each
Planning and Preparations (c)	$23,727,000
Dormancy w/Wet Fuel Storage (c)	$149,000,000
Annual ISFSI M&O (d)	$1,850,000
Consolidated SNF Storage Opens in 2026 (100,000 Mt) (e)	$74,000 -$223,000 per metric ton
Large Standardized Aging and Disposal(STAD) Canister (44 assemblies) (f) (g)	$33,690 per assembly
Medium Standardized Aging and Disposal (STAD) Canister (32 assemblies) (f) (g)	$30,737 per assembly
Small Standardized Aging and Disposal (STAD) Canister (9 assemblies) (f) (g)	$51,994 per assembly

Total cost for consolidated interim storage and repackaging for the CGS ranges from $384 Million to $1.25 billion.

(a) The United States Court of Federal Claims, No 0410C, Energy Northwest v the United States, February 26, 2010. http://www.uscfc.uscourts.gov/sites/default/files/opinions/DAMICH.ENERGY022610.pdf

(b) United States Government Accountability Office, Outreach Needed to Help Gain Public Acceptance for Federal Activities That Address Liability, GAO-15-141, October 2014. http://www.gao.gov/assets/670/666454.pdf

(c) Entergy Corporation, Post Shutdown Decommissioning Activities Report, Vermont Yankee Nuclear Power Station, December 19, 2014. https://www.nrc.gov/docs/ML1435/ML14357A110.pdf

(d) Energy Northwest, 2015 Annual Report. https://www.energy-northwest.com/whoweare/finance/Documents/2015%20Energy%20Northwest%20Annual%20Report.pdf

(e) U.S. Department of Energy, Office of Nuclear Energy, Task Order 11: Development of Consolidated Fuel Storage Facility Concepts Report, February 12, 2013. https://curie.ornl.gov/system/files/documents/not%20yet%20assigned/AREVA%20-%20TO11%20-%20FINAL%20REPORT_0.pdf

(f) DOE: Task Order 21: Operational Requirements for Standardized Dry Fuel Canister Systems, (2015) Tables 7-5 and 7-6.

(g) DOE: J. Jarrell, Standardized Transportation, Aging, and Disposal (STAD) Canister Design, presentation to the Nuclear Waste Technical Review Board June 24, 2015. http://www.nwtrb.gov/meetings/2015/june/jarrell.pdf

Conclusion

The basic approach undertaken in this country for the storage and disposal of spent nuclear fuel needs to be fundamentally revamped to address vulnerabilities of spent fuel storage in pools, high burnup SNF, and dry cask integrity risks.

Instead of waiting for problems to arise, the NRC and the Energy Department need to develop a transparent and comprehensive road map identifying the key elements of—and especially the unknowns associated with—interim storage, transportation, repackaging, and final disposal of all nuclear fuel, including the high-burnup variety.

Otherwise, the United States will remain dependent on leaps of faith relative to nuclear waste storage—leaps that are setting the stage for large, unfunded radioactive waste "balloon mortgage" payments in the future.