Spent Power Reactor Fuel: Pre-Disposal Issues

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Why we should be concerned about spent power reactor fuel.

After 60 years (1957-2017), nuclear power reactors in the United States have generated roughly 30 percent of the total global inventory of spent nuclear fuel (SNF) – by far the largest. , There are approximately 80,150 metric tons stored at 125 reactor sites, of which 99 remain operational.

SNF is bound up in more than 244,000 long rectangular assemblies containing tens of millions of fuel rods. The rods, in turn, contain trillions of small, irradiated uranium pellets. 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.

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 for tens-of-thousands of years.

THE AGE OF DECOMMISSIONING – IMPLICATIONS FOR HIGH-LEVEL RADIOACTIVE WASTE (HLRW)

When Reactors Close:

Reactors Close:
- License expires
- NRC orders
- Uneconomic/ Utility decision
- Natural disaster
- Accident/Emergency/ Terrorism

Spent Fuel:
- In pool, 5yrs. normal; 7-10 for hi-burnup
- In dry casks; NRC says safe for ~100 years

Indefinite Storage

Permanent Deep-Geologic Disposal

Industry/Government Response:

Reactors Close:
- Utilities seek bailouts
- Failing bailout, reactors close over course of several years
- Safe-store or Decon (dismantlement)

Spent Fuel:
- In pool, 5yrs. normal; 7-10 for hi-burnup
- In dry casks, no HOSS; NRC says safe for ~100 years

Indefinite Storage
- **HR 3053**: construct one or more **CIS/MRS** facilities "as soon as practicable" (probably not before 2024)
- Candidates: TX; NM; IL; NV
- **Need for "Make Whole"**

Permanent Deep-Geologic Disposal:
- HR 3053 – re-open Yucca Mt., NV
- President's BRC states not likely before 2048, if all goes well; more than 1 site already needed

Environmental/Safe-Energy Alternative:

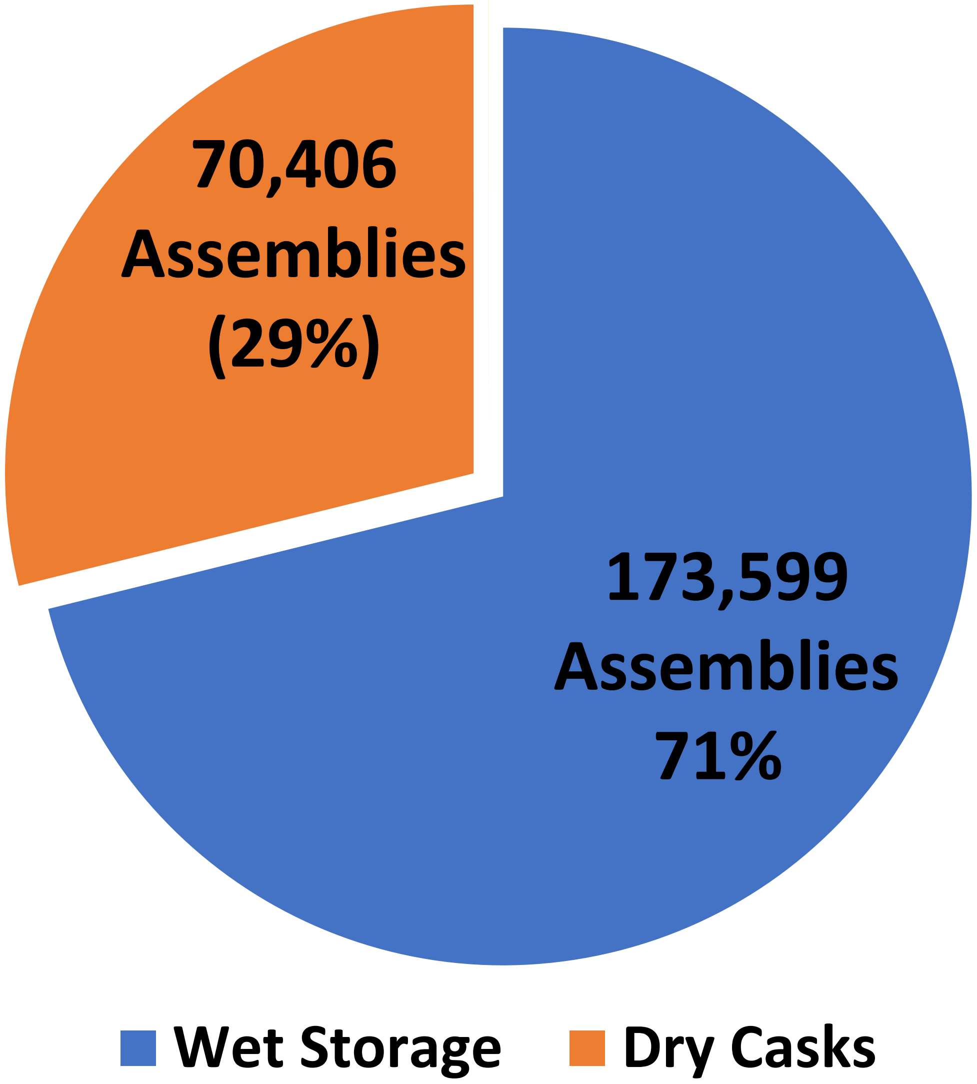
Reactors Close:
- Close reactors
- No bailouts
- **Enact "Just-Transitions" prior to closure**
- Safe-store or Decon (dismantlement)

Spent Fuel:
- Retain wet pools
- **Use HOSS** onsite with dry casks;
- NRC says safe for ~100 years

Indefinite Storage
- No CIS facilities; onsite storage using HOSS
- **Need for "Make Whole"**
- **Establish independent, science-based *disposal* site search**
- **Strengthen NRC decom regs**

Permanent Deep-Geologic Disposal:
- Find, characterize, license first facility for opening by 2048
- **"Make Whole"** in place until waste moved for disposal

US nuclear power plants are major radioactive waste sites storing concentrations of radioactivity that dwarf those generated by the country's nuclear weapons program.



There are 244,005 spent nuclear fuel assemblies generated as of 2013 .

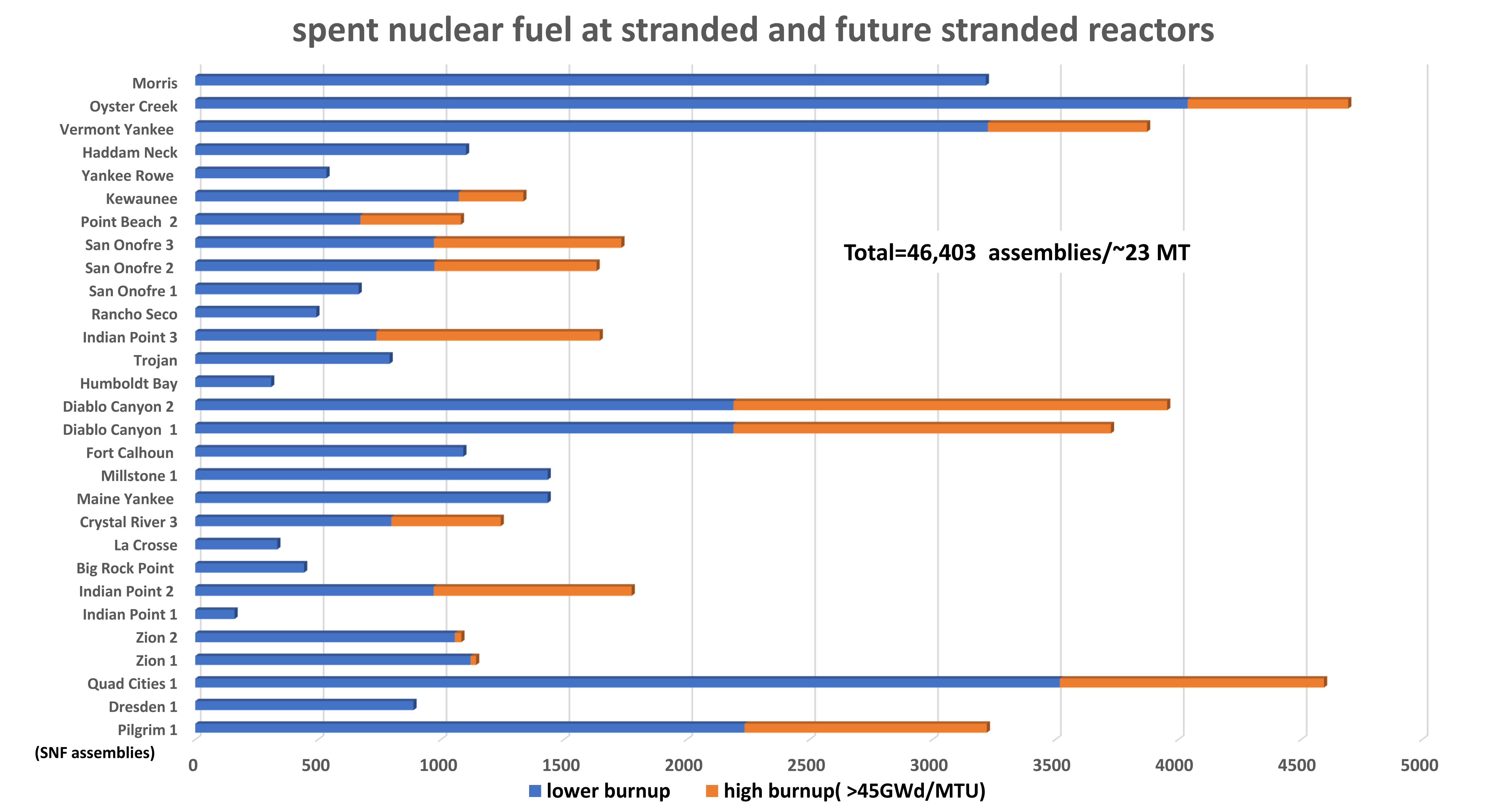
They contain approximately:

(1) 23 billion curies (8.51E+20 Bq) of long-lived radioactivity (>30 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

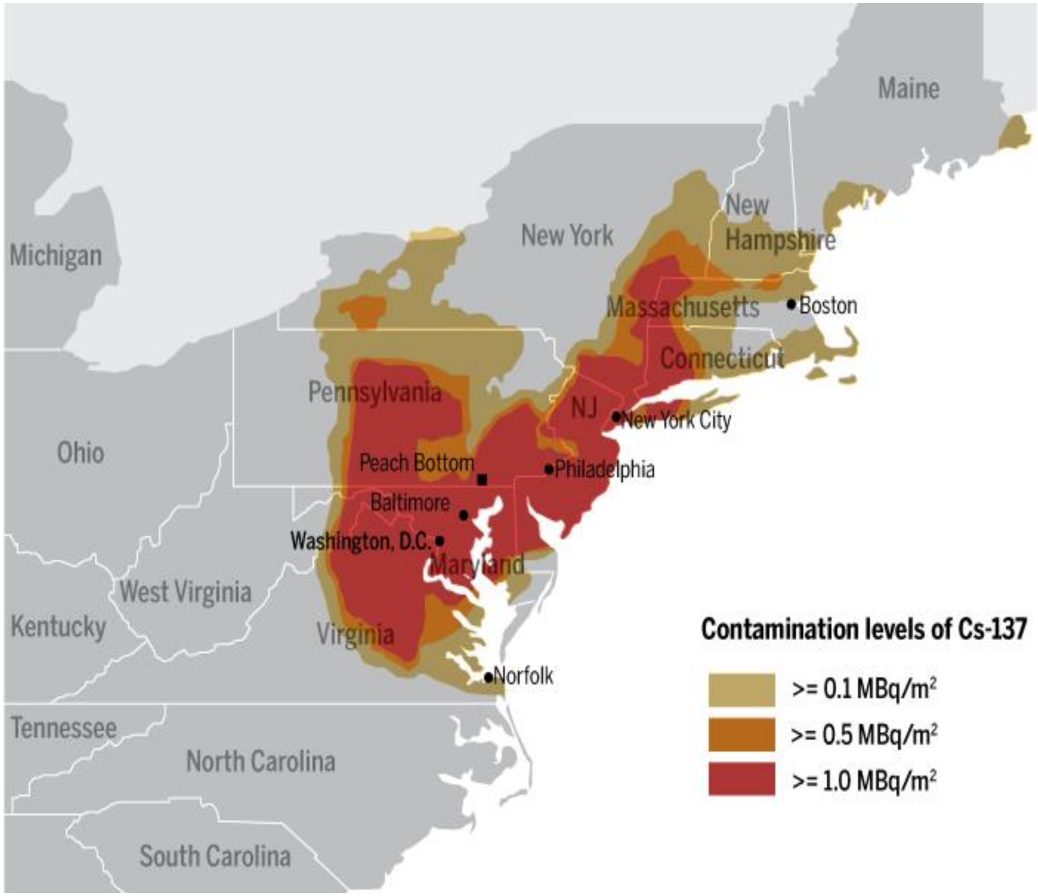
(3) About 700 metric tons of plutonium (about 3 times more than used for weapons throughout the world).

Sources: DOE GC 859 data (2013), NWTRB (2016)


spent nuclear fuel at stranded and future stranded reactors
Morris
Oyster Creek
Vermont Yankee
Haddam Neck
Yankee Rowe
Kewaunee
Point Beach 2
San Onofre 3
San Onofre 2
San Onofre 1
Rancho Seco
Indian Point 3
Trojan
Humboldt Bay
Diablo Canyon 2
Diablo Canyon 1
Fort Calhoun
Millstone 1
Maine Yankee
Crystal River 3
La Crosse
Big Rock Point
Indian Point 2
Indian Point 1
Zion 2
Zion 1
Quad Cities 1
Dresden 1
Pilgrim 1
(SNF assemblies)
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
Total=46,403 assemblies/~23 MT
lower burnup
high burnup(>45GWd/MTU)

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)

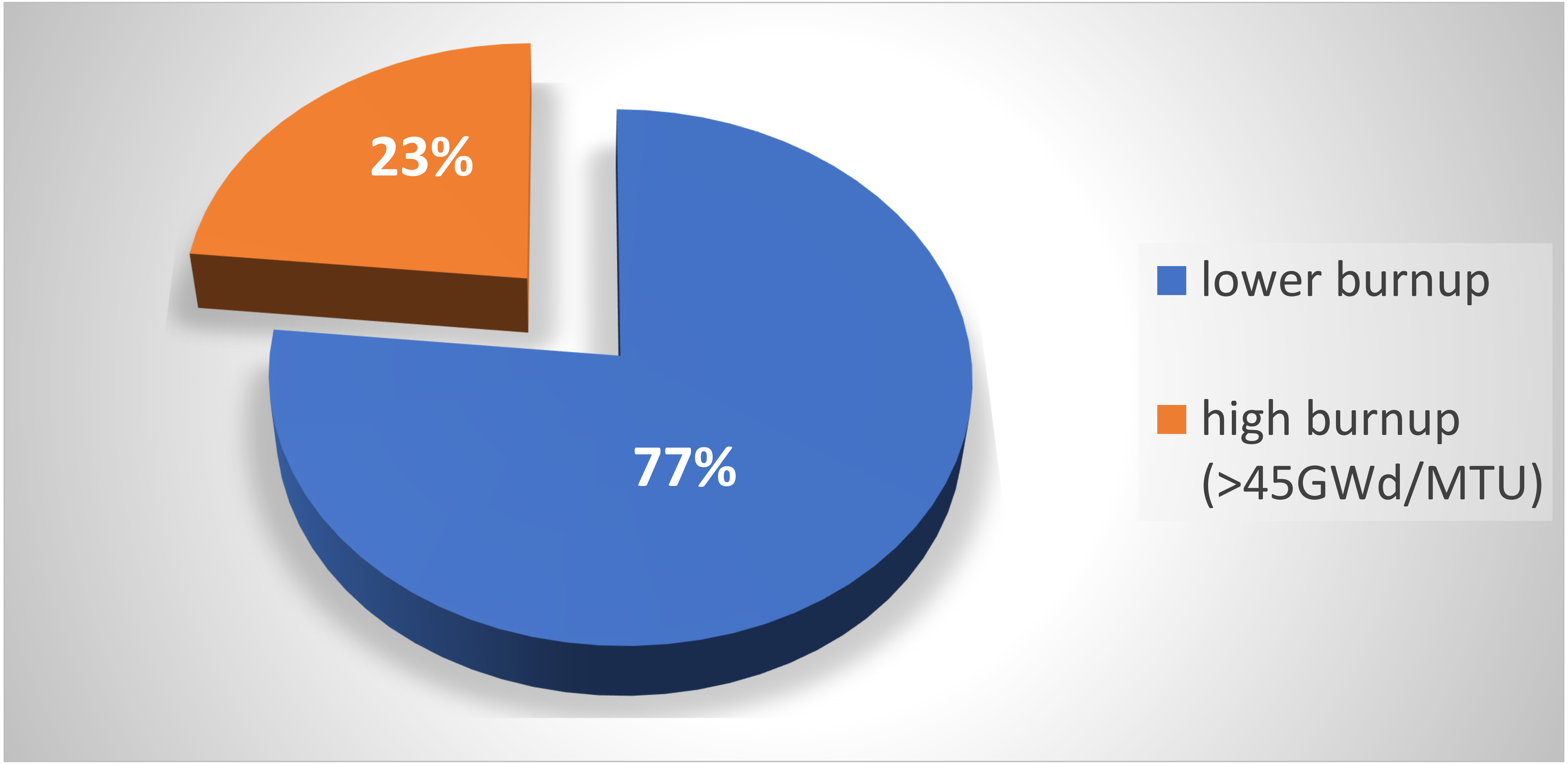
<u>The dangers of spent fuel fires can be greatly reduced by ending high density pool storage and expanded dry casks storage.</u>

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 .

Spent nuclear fuel at stranded and future stranded reactors



Source DOE GC 859 data (2013)

Interim Spent Nuclear Fuel Consolidated Storage

The DOE' s proposed schedule for establishing a pilot interim storage site has slipped. By the time a centralized interim storage site may be available, there could be a "wave" of reactor shutdowns that could clog transport and impact the schedule for a centralized storage operation. Among the uncertainties identified by DOE include:

- Transportation infrastructures at or near reactor sites are variable and changing;
- Each spent nuclear fuel canister system has unique challenges. For instance, some dry casks that are licensed for storage only and not for transport.
- Constraint on decay heat from spent nuclear fuel can impact the timing of shipping.
- The pickup and transportation order of spent fuel has yet to be determined. It has been assumed that the oldest would have priority, leaving sites with fresher and thermally hotter fuel that may be "trapped" at sites for several years to cool down.
- Packaging of transport containers could have a major impact. As many as 11, 800 disposal canisters may have to be reopened.

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- **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.**

- **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”**

DOE's Estimated Costs for Consolidated Storage of "Stranded" Spent Nuclear Fuel

($ thousands)

Reactor	Assemblies	Metric Tons	40 years present value	80 years present value	40 years escalated Value	80 years escalated value
Big Rock Point	442	58.05	$9,125	$9,823	$17,054	$31,249
Haddam Neck	1019	412.49	$64,344	$69,797	$121,182	$222,045
Humboldt Bay	390	28.4	$4,430	$4,806	$8,343	$15,288
La Crosse	333	37.07	$5,783	$6,273	$10,891	$19,955
Maine Yankee	1,434	542.29	$84,591	$91,761	$159,315	$291,917
Ranch Seco	493	228.38	$35,625	$38,644	$67,094	$122,939
Trojan	790	358.85	$55,976	$60,721	$105,424	$193,171
Yankee Rowe	533	127.13	$19,831	$21,512	$37,349	$68,435
Zion 1	1,143	523.95	$81,730	$88,658	$153,927	$282,045
Zion 2	1083	459.49	$71,675	$77,750	$134,990	$247,346
Crystal River	1319	611.98	$95,462	$103,553	$179,789	$329,432
Kewaunee	1335	513.33	$80,074	$86,861	$150,807	$276,328
Oyster Creek	4,660	823.43	$128,446	$139,333	$241,909	$443,257
San Onofre 1	395	146.21	$22,807	$24,740	$42,954	$78,706
San Onofre 2	1,834	759.74	$118,511	$128,551	$223,198	$408,972
San Onofre 3	1,734	716.23	$111,724	$121,194	$210,41	$385,550
Vermont Yankee	4,031	731.84	$114,159	$123,835	$215,001	$393,953
TOTAL	**22968**	**7078.9**	**$1,104,293**	**$1,197,812**	**$1,869,227**	**$3,810,588**

Annual cost inflation =1.9%
Discount Rate=3.4%

Sources: DOE-FCRD-NFST-2013-000263, Rev. 1, (2014),
DOE Generic Design Alternatives for. Dry Storage of Spent Nuclear Fuel , Appendix A-6 (2015)

Spent Nuclear Fuel Repackaging

The current generation of dry casks was intended for short-term on site 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 in this study 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, assuming it will operate until 2043, and could involve cutting open 120 dry casks and repacking approximately 8,160 spent fuel assemblies into casks suitable for disposal. The additional costs 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

Uncertainties

Indian Point 2, LLC's (Entergy) post-closure spent fuel management plan states:

"This report should not be taken as any indication that the licensee knows how the DOE will eventually perform its obligations, or has any specific expectation concerning that performance ***(Emphasis added)."***

Entergy report regarding the decommissioning funding plan for Indian Point's Independent Spent Fuel Storage Facility to NRC December 17, 2015, P. 27 https://www.nrc.gov/docs/ML1535/ML15351A524.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.

First and foremost, to protect public safety, high density pool storage of spent nuclear fuel should end.

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 in regard to nuclear waste storage—leaps that are setting the stage for large, unfunded radioactive waste “balloon mortgage” payments in the future.