High Burnup Fuel Fact Sheet

High Burnup Fuel is Unstable in Storage and Transport

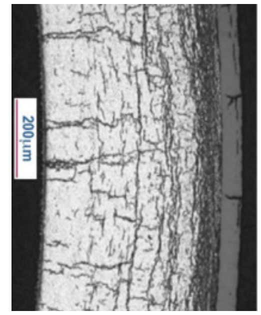

Figure 1 significant radial cracks in fuel cladding

There is both operating experience and experimental evidence that high burnup fuel (HBF) is unstable in storage and transport. HBF can be burned in the reactor twice as long, increasing industry profits, but becomes over twice as thermally hot and over twice as radioactive as lower burnup fuel. This has implications for pool storage, dry storage, repository disposal, transport, and fuel handling.

Operating experience showing higher risk of fuel rod damage from high and medium burnup fuel. Data from commercial fuel rods burned at various levels shows damage risk increases significantly starting about 35 GWd/MTU (GigaWatt days per metric ton of uranium). The NRC changed the definition of high burnup fuel from >35GWd/MTU to >45GWd/MTU in spite of this evidence.

High burnup fuel degrades after dry storage. Experimental and operating data shows that HBF degradation can continue after dry storage (Figure 1). Thin-wall (mostly ½" thick) dry storage canisters (mainly used in the United States) are welded shut, so the condition of the fuel assembly rods (cladding) and uranium fuel pellets, and the fuel baskets is unknown. The NRC has no resolution to these issues, but continues to approve HBF.

Transport of high burnup fuel is not safe. The NRC is still studying whether train vibrations will cause the Zirconium fuel rod cladding to fail. HBF causes fuel cladding to become so brittle it can shatter like glass. The NRC plans to ignore their own transport regulations and allow transport without knowing the condition of the fuel assemblies or fuel baskets.

High burnup fuel results in buildup of oxides and hydrides in cladding, fuel and baskets, increasing risks of explosions and at lower temperatures. The higher the burnup, the more hydrides created, resulting in gases, that if exposed to oxygen or water can trigger explosions. The NRC and utilities do not have a plan to deal with this risk. They assume it is low probability the canisters will have through-wall cracks from environmental or other conditions. They base this on no evidence and numerous false assumptions.

Fuel can go critical in dry storage if exposed to unborated water. The NRC assumes there will be no through wall cracks in the thin-wall canisters and no transport accidents where canisters are breached. The NRC assumes no water from rain, storms, fog, ocean surf, tsunami, snow, lakes, rivers, oceans, or bays will enter the canisters. The borated metal in the fuel assembly baskets is only there to help capture neutrons when loading fuel from pool to storage canisters. The NRC assumptions of no through-wall cracks ignores known risks from moist salt air and other environmental and quality factors that can initiate cracks. The NRC states once cracks start in thin stainless steel canister they can grow through the wall in as little as 16 years. A Diablo Canyon canister has all the conditions for cracking in a 2-year old canister. The Koeberg nuclear plant had a comparable container leak in only 17 years with cracks up to 0.61" long.

1/7/2017

References

High Burnup Nuclear Fuel, Pushing the Safety Envelope, Dr. Marvin Resnikoff, Donna Gilmore, January 2014 https://sanonofresafety.files.wordpress.com/2014/01/hbffactsheet01-09-2014.pdf

> This document contains numerous source links and details about high burnup risks, including transport. Subsequent to this document, two high burnup transport casks were approved. However, even if a high burnup transport cask is approved, the thin-wall canister (holding the fuel) that is inserted into the transport cask needs to be qualified for transport per NRC transport regulation 10 CFR § 71.85. Even partially cracked canisters cannot be transported. And the condition of the high burnup fuel assemblies needs to be evaluated before transport. However, this cannot be done with the thin-wall canisters, since they are welded shut.

NRC Regulation 10 CFR § 71.85 Packaging and Transportation of Radioactive Materials.

> Preliminary determinations. Before the first use of any packaging for the shipment of licensed material — (a) The certificate holder shall ascertain that there are no cracks, pinholes, uncontrolled voids, or other defects that could significantly reduce the effectiveness of the packaging.

NRC SAFETY EVALUATION REPORT, Docket No. 71-9302, Areva Model No. NUHOMS®-MP197HB Package, Certificate of Compliance No. 9302, Revision No. 7, April 23, 2014
http://pbadupws.nrc.gov/docs/ML1411/ML14114A132.pdf
Link to full set of documents for this approval:
https://www.nrc.gov/docs/ML1411/ML14114A049.html

> In April 2014 the NRC approved an Areva high burnup fuel transport cask, in spite of having no evidence the fuel can be safely transported. The NRC made the HBF section of their Safety Evaluation Report "proprietary", providing no information to the public as to how they justified this. Therefore, public and independent review is not possible. For something that has for years been an unsolved problem. This refusal to share the data justifying this major safety change in NRC's position is unacceptable.
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> According to the NRC Safety Evaluation Report, Revision No. 7 (ML14114A132) the 24PT4-DSC [Dry Storage Canister] still needs to be approved for high burnup fuel transport. The NUHOMS 32PTH2 [32-fuel assembly canister] is not approved for use in the MP197HB (page 2). Minimum cooling time for the 24PT4-DSC high burnup fuel is 15 years (page 3).
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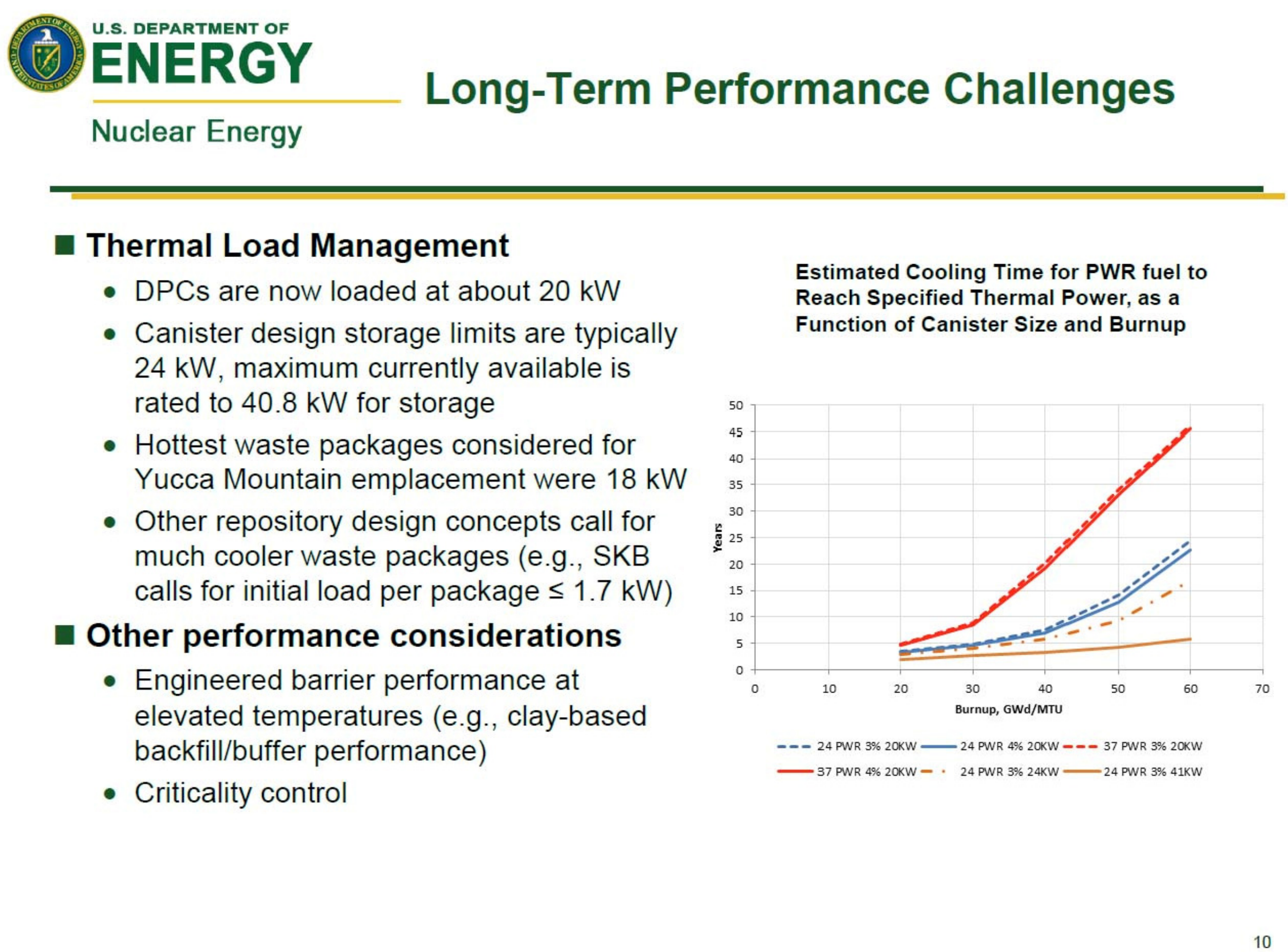
> Loaded transport weight of MP197HB transport casks is 152 tons (137.71 metric tons, 303,600 pounds), exceeding current rail transport standards (page 2, Table 1).

Holtec Response to NRC First Request for Additional Information (RAI) for HI-STORM UMAX Canister Storage System (TAC No. L24664), January 30, 2013 (ML13032A008)
https://www.nrc.gov/docs/ML1303/ML13032A008.pdf

> Holtec admitted to the NRC that if fresh (unborated) water enters the canister a criticality can occur. The NRC and Holtec are assuming that will never happen.

Research and Development Activities Related to the Direct Disposal of Dual Purpose Canisters, William Boyle, U.S. Department of Energy, U.S. Nuclear Waste Technical Review Board (NWTRB0, Spring Board Meeting, April 16, 2013
http://www.nwtrb.gov/docs/default-source/meetings/2013/april/boyle.pdf

> Maximum heat load for transport of 24PT4 DSC (24 PWR fuel assembly canister) is 24kW, for a 37-fuel assembly canister, 22kW (page 14). This point is significant because it will take 20 to 45 years for canisters to cool long enough to be transportable per DOT Transport safety regulations. DOE slide 10 below shows how many years it will take canisters to cool to those lower temperatures. This chart is for disposal temperatures, but also is useful for transport cooling periods.

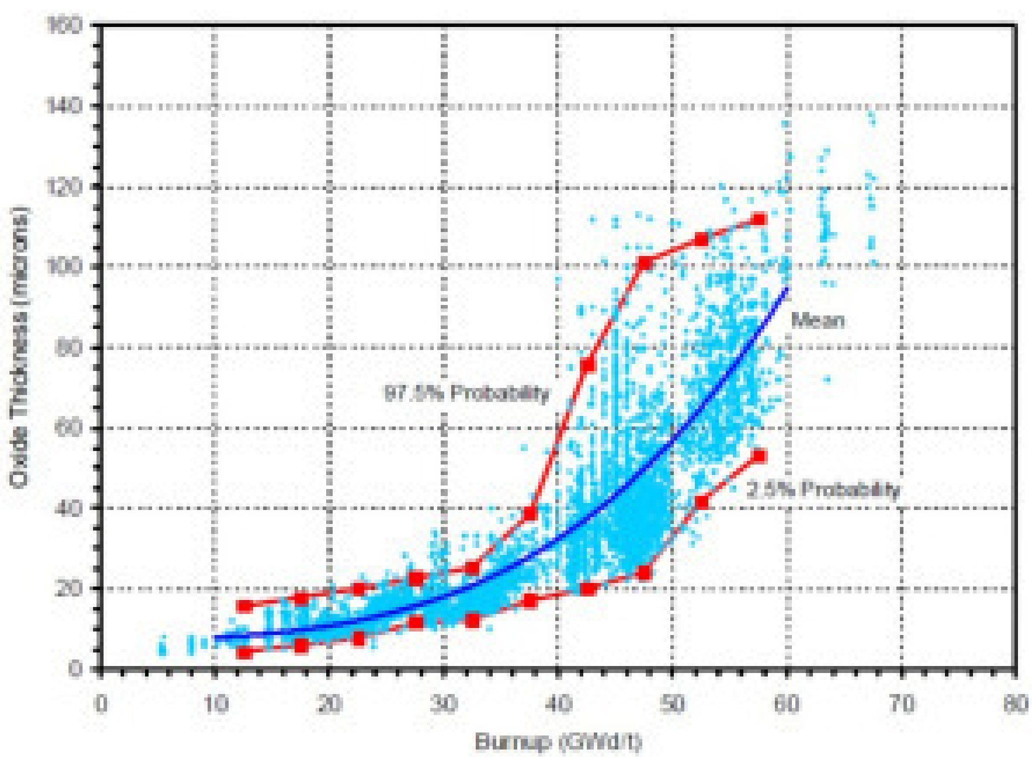


Evaluation of the Technical Basis for Extended Dry Storage and Transportation of Used Nuclear Fuel, Nuclear Waste Technical Review Board (NWTRB), Douglas Rigby, December 2010, PP 55 and 56 http://www.nwtrb.gov/docs/default-source/reports/eds-final.pdf?sfvrsn=8

There is operating data available on high burnup fuel. The NRC and nuclear industry avoids sharing this information.

Plotting more than 4,400 measurements from commercial fuel-rods taken from reactors around the world, Figure 20 shows the maximum outer-surface oxide-layer thickness data in low-Sn Zircaloy-4 cladding plotted as a function of burnup. Taking these oxide thickness measurements, the maximum wall thickness average (MWTA) hydrogen content can be calculated using a hydrogen evolution model. Figure 21 plots the wall-average hydrogen content in low-Sn Zircaloy-4 cladding as a function of burnup from both measured and model-calculated data. For a discharge burnup in the range of 60-65 GWd/MTU, the maximum oxide thickness is 100 µm and the average hydrogen concentration is 800 ppm, which corresponds to a metal loss of 70 µm using conservative assumptions. Source: Spent Fuel Transportation Applications – Assessment of Cladding Performance: A Synthesis Report, EPRI-TR-1015048, December 2007.

Chart 20 below shows burnup starting at about 35 GWd/MTU have a dramatic increase in oxide build up, resulting in higher risks for cladding damage and hydrogen buildup. See also Chart 21 in above document for the hydride chart.



Damaged Spent Nuclear Fuel at U.S. DOE, Facilities, Experience and Lessons Learned, INL/EXT-05-00760, Brett Carlsen, Denzel Fillmore, Roger McCormack, Robert Sindelar, Timothy Spieker, Eric Woolstenhulme, November 2005, Page 4 & 5
https://inldigitallibrary.inl.gov/sites/sti/sti/3396549.pdf

Damage to the uranium fuel pellets occurs with high burnup fuel.

The uranium metal SNF [Spend Nuclear Fuel] within the DOE inventory contains many elements whose cladding was breached during reactor discharge, subsequent handling, or storage. Initial cladding failures varied from minor cracks to severed fuel elements. The reaction of exposed uranium metal with water produces uranium dioxide and hydrogen. This reaction is not a result of chemical impurity of the basin water. It is a chemical reaction of the water with the uranium metal. Uranium hydride forms from the available hydrogen, particularly where there is a limited amount of oxygen (see Reference 3). The lower densities of the uranium oxide and uranium hydride products relative to the uranium metal **cause swelling of the material within the cladding and subsequent additional cladding damage**. Additional water reaction then occurs with the newly exposed uranium metal. **Each cycle of fuel-water reaction results in fission product releases and contamination of water in the canister or the storage pool**. Examples of uranium metal SNF element damage after extended water storage are shown in Figure 3. In extreme cases, the uranium metal has also been known to completely oxidize and form a mud-like mixture with the water.

The generation of high surface area uranium metal SNF fragments and uranium hydride necessitates additional measures during SNF drying, dry storage, and transportation because of the **pyrophoric nature of these materials when exposed to air**. As a result, degraded uranium metal fuels are stored and transported in inerted canisters after removal from the basin and drying. Radiolysis of water within the SNF-water corrosion products must also be addressed for long-term storage because of the **ability of the resultant gases to overpressurize containers, embrittle welds on containers, and reach flammable concentrations**.

Impact of High Burnup Uranium Oxide and Mixed Uranium– Plutonium Oxide Water Reactor Fuel on Spent Fuel Management, International Atomic Energy Agency, IAEA No. NF-T-3.8, 2011, Page 36 http://www-pub.iaea.org/MTCD/Publications/PDF/Pub1490_web.pdf

Damage to the uranium fuel pellets occurs at the rim with burnup > 33 GWd/t U.

The grain size changes within high burnup fuel as you proceed from the central portion to the outer rim of the fuel. The major portion of high burnup fuel will have a grain size similar to (unchanged from) the as-fabricated grain size of approximately 10 µm typical of commercial fuel. The central portion of the fuel may have some grain growth (up to a factor of 2).(Note: If rod powers were high early in life, i.e. at burnups <20 GW·d/t U, but this will be ignored because it is difficult to estimate the amount of fuel with significant grain growth.)

The rim portion of high burnup fuel will have much higher burnups than the pellet average and forms restructured fine sub-grains at pellet average burnups > 40 GW·d/t U. The sub-grain sizes are generally between 0.1 µm to 0.3 µm [39.49–51]. As the burnup of the rim increases the original as-fabricated grain boundaries begins to disappear as the sub-grain structure becomes dominant. **This restructured rim is not present in the older fuel where rod or bundle burnups did not exceed 33 GW·d/t U.**

Comments to Docket ID NRC-2015-0241 Draft SFM-Interim Staff Guidance (ISG)-2, Revision 2, Fuel Retrievability in Spent Fuel Storage Applications, D. Gilmore, November 20, 2015 https://sanonofresafety.files.wordpress.com/2013/06/retrievabilityisg2rev2commentsdocketnrc-2015-0241dgilmore2015-11-20.pdf

The NRC removed their requirement for fuel assembly retrievability from the canisters. These comments to the NRC addresses why that is an unacceptable change, in addition to not being in compliance with the Nuclear Waste Policy Act of 1982 (NWPA). Numerous technical references included in this document.

Used Nuclear Fuel Storage and Transportation Data Gap Prioritization, Christine Stockman, Sandia Lab (SNL), Brady Hanson (PNNL), Abdelhalim Alsaed (Enviro Nuclear Services), International High-Level Radioactive Waste Management Conference, (IHLRWMC), April 28 – May 2, 2013 Slide 25-30, https://www.osti.gov/scitech/servlets/purl/1078639

High burnup fuel and/or extended storage degrade various parts of the storage system. Much of this is referred to as Data Gaps (things they don't have sufficient information on). This includes degradation mechanisms for the fuel, cladding, fuel baskets, neutron shields and poisons, containers (both thin-wall welded canisters and thick-wall bolted casks), and the concrete overpacks (required for thin-wall welded canisters).

ACRS Recommendations for Improvements to the NRC Staff's Technical Study of Spent Fuel Pool Accident Risk at Decommissioning Nuclear Power Plants, ACRSR-1885, Dana A. Powers, ACRS Chairman, April 13, 2000, (ML003704532), p. 3
https://www.nrc.gov/docs/ML0037/ML003704532.pdf

Many metal hydrides are spontaneously combustible in air. Spontaneous combustion of zirconium-hydrides would render moot the issue of "ignition" temperature that is the focus of the [NRC] staff analysis of air interactions with exposed cladding. The staff has neglected the issue of hydrides and suggested that uncertainties in the critical decay heat times and the critical temperatures can be found by sensitivity analyses. Sensitivity analyses with models lacking essential physics and chemistry would be of little use in determining the real uncertainties.

Explosive Characteristics of Titanium, Zirconium, Thorium, Uranium and their Hydrides, U.S. Dept. of the Interior, Bureau of Mines, Irving Hartmann, John Nagy, Murray Jacobsom, December 1951 https://sanonofresafety.files.wordpress.com/2014/12/4410914explosivezirconiumdivofmines.pdf

Even 5% oxygen in helium, can cause zirconium powder to ignite. Any mechanical or chemical process that reduces the [zirconium] cladding to turnings, chips, granules, or powders can generate a pyrophoricity or flammability hazard. Zirconium powder is so highly flammable it is used in fireworks.

Comments to NRC proposed rule for regulatory improvements for decommissioning power reactors, Docket NRC-2015-0070, Sierra Club, March 2016
https://www.nrc.gov/docs/ML1608/ML16082A004.pdf

The NRC claims nothing can go wrong in dry storage. These comments contain references and examples showing why this assumption is false.

Dry Cask Inventory by State as of June 30, 2013
https://sanonofresafety.files.wordpress.com/2015/10/d32-caskinventorybystate2017-05-18.pdf

DOE inventory of U.S. dry storage thin-wall canisters and thick-wall casks, sorted by state, with year of first loading.

U.S. Nuclear Power Reactor Damaged Spent Fuel Assemblies, June 2013
https://sanonofresafety.files.wordpress.com/2011/11/totaldamagedfuelassemblies2013june30.pdf

DOE inventory of damaged fuel assemblies. Excludes damage fuel assemblies after dry storage, since fuel assemblies are not inspected after dry storage.

Letter to DOE from NWTRB, U.S. Nuclear Waste Technical Review Board Comments on Post Irradiation Examination Plan for High Burnup Demonstration Project Sister Rods, June 3, 2016
http://www.nwtrb.gov/docs/default-source/correspondence/rce060316.pdf?sfvrsn=17

The purpose of the DOE High Burnup Demonstration Project is to "confirm" high burnup fuel is safe. However, it will not prove this. This letter to the DOE brings into questions numerous parts of the plan. For example, Item 6 of the letter:

6. **Low Temperatures in the HDRP Cask** – the Board is concerned that the maximum cladding temperature in the HDRP predicted by modeling is substantially below what was originally anticipated. One study now estimates the maximum cladding temperature will be below 280°C. This calls into question the usefulness of the HDRP to determine the effects of hydride reorientation during storage of HBF, which might experience temperatures as high as 400°C. … If the maximum cladding temperature cannot be raised, DOE should re-evaluate the utility of the HDRP as planned and consider delaying the project until the issues associated with maximum temperature can be resolved.

Additional references at SanOnofreSafety.org
https://sanonofresafety.org/nuclear-waste/
https://sanonofresafety.org/holtec-hi-storm-umax-nuclear-waste-dry-storage-system/

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