

High Burnup Spent Fuel

Nuclear fuel rods are ceramic pellets of uranium oxide (UO_2), about the size of a finger joint, stacked and sealed inside a long metal tube (cladding) about as big around as a Sharpie pen. The space between the pellets and cladding is filled with helium.

“Spent fuel” refers to fuel used in a commercial nuclear reactor that has been removed because it can no longer economically sustain a nuclear reaction. Burnup refers to the uranium consumed in the nuclear reaction. It is expressed in gigawatt-days per metric ton of uranium (GWd/MTU)—a measure of how long a fuel rod is in the core and the power level it reaches. “High burnup fuel” is in the reactor core for longer than “low burnup fuel.”

In a reactor core, nuclear fuel undergoes physical and chemical changes. The UO_2 fissions—splits apart and releases energy—producing fission gas and fission products. The pellets swell, crack and release a small amount of fission gas inside the rod. The cladding also reacts with the reactor cooling water. This reaction forms an oxide layer on the outside (similar to rust) and produces hydrogen. About 15% of the hydrogen enters into the cladding metal. These processes occur slowly at first, then start to accelerate at about the time the fuel reaches burnup of 45 GWd/MTU. At this burnup level, the fuel is about 75% through its currently useful life.

The maximum burnup that NRC has allowed increased as technology advanced our ability to understand the changes the fuel undergoes in the reactor core. Our understanding of those changes is key to our ability to make safety decisions. Average fuel burn-ups have increased from around 35 GWd/MTU two decades ago, to over 45 GWd/MTU today. Anything over 45 GWd/MTU is considered high burnup.

Available information indicates that both low and high burnup spent fuel can be stored and transported safely. This information comes from operational experience with storage systems and short term tests. Considerable data is available on the properties of low burnup spent fuel and more confirmatory data is being obtained daily on high burnup fuel. That data is instrumental in enabling the NRC to make licensing decisions to allow spent fuel storage in specific dry cask designs.

As utilities began discharging high burnup spent fuel, dry storage cask designers amended their designs to account for physical differences in the spent fuel. The NRC approved several spent fuel storage amendments based on research data sufficient to show that high burnup fuel could be stored safely. Additional high burnup storage amendments are under review. The NRC fully expects data from current testing will become available to confirm that high burnup spent fuel will behave as expected and remain in a safe condition even in a transportation accident.

What happens to high burnup spent fuel removed from the core?

Like all spent fuel removed from a reactor, high burnup spent fuel is placed in a pool onsite for cooling and storage. Many utilities have begun moving their spent fuel from pools into dry storage casks. This process requires all water to be removed from inside the cask to prevent degradation. The high temperatures that can be reached during drying and the high pressure in the fuel rods affect the hydrogen in the cladding of high burnup spent fuel. This effect on hydrogen—known as “hydride reorientation”—may cause the cladding to become more brittle when it cools. Understanding the impact of that process more fully is an important focus of ongoing research. This information is a key to the NRC’s ability to decide whether a proposed transport cask and its contents will perform safely in an accident. The NRC assures safety through “defense-in-depth,” which requires multiple layers of protection. The fuel cladding is the first layer, but spent fuel casks themselves provide several additional layers of protection.

Is high burnup fuel hotter than other spent fuel?

Higher burnup fuel comes out of the reactor hotter and more radioactive than lower burnup fuel. How much hotter and more radioactive depends on the difference in burnup, the initial makeup of the fuel, and the environment inside the reactor. In general, compared to 35 GWd/MTU, 45 GWd/MTU fuel is 35% hotter and 33% more radioactive. Fuel burned to 55 GWd/MTU is 78% hotter and 72% more radioactive.

The burnup is important to the review of dry spent fuel storage system designs because higher burnup fuel must be cooled longer than lower burnup fuel before it can be placed into dry storage. How much longer depends on the difference in burnup, the specific spent fuel storage system design and the how the fuel assemblies are arranged in the storage cask.

How much high burnup fuel is stored at nuclear reactors?

The NRC does not collect inventory information related to fuel burnup and NRC security policies would not permit the agency to release such information. Reactor licensees and the Nuclear Energy Institute do maintain inventory information. Some reactor licensees are allowed under their license to possess, operate, and store high burnup fuel. ***Is it safe to store and transport high burnup fuel?***

There are many storage system designs that have been approved for the long-term storage of high burnup fuel. A number of transportation packages have also been approved to transport high burnup fuel. The Certificates of Compliance for all approved storage and transportation system designs are publically available in NRC’s online [documents database](#). The NRC does not approve a spent fuel transportation package or storage system until it completes a full safety review and verifies the design meets the requirements for transportation in 10 CFR Part 71 or for storage in 10 CFR Part 72.

The NRC also performs a series of inspections at the site before and during loading of spent fuel to ensure that the correct fuel is loaded into the appropriate storage systems. If fuel burnup levels are higher than the certificate of compliance allows, that fuel cannot be loaded. In those cases, the fuel would remain in pool storage until a dry storage system allowing higher burnup becomes available. Cask designers are continually doing research and development and submit changes in design, including to allow higher burnups, for NRC review.

What confirmatory testing is being done?

Cladding behavior – In late 2012 the NRC completed an experimental program at the Argonne National Laboratory (ANL) to determine at what temperature cladding goes from ductile (able to bend) to brittle condition. That program found different types of cladding become brittle at different temperatures. Cask designers will therefore need to address the cladding type and its temperature to show high burnup fuel can stay intact during a transport accident. The ANL research concluded hydride reorientation was an issue that NRC must follow. The Department of Energy (DOE) is supporting additional testing at ANL to obtain information to allow the NRC to decide if a particular system meets all safety regulations.

Vibration fatigue – The NRC is developing a tool to determine whether fatigue—or structural damage from vibration—could affect high burnup fuel cladding during routine transport. This tool is based on existing research. DOE is continuing that work to improve the quality of the data.

Realistic temperature modeling – Temperature is the principal factor in how high burnup fuel cladding behaves. For this reason, the NRC recommends keeping cladding below 400 degrees Celsius. To simplify analyses and provide a margin of safety, many computer models assume temperatures are higher than they really are. But those calculations cannot determine when a rod will become brittle. A realistic model will be used to determine the percentage of rods that could become brittle, and in those rods, how much cladding material actually may become brittle.

DOE demonstration of fuel behavior – Existing data allowed the NRC to set maximum temperatures for the initial storage period (either 20 or 40 years, depending on the specific cask). For the NRC to approve longer storage terms (for renewals of licenses or certificates of compliance), cask users will need to provide data to confirm the predictions that the high burnup fuel can continue to be stored safely. DOE and industry are conducting a long-term demonstration program to provide this confirmation. The NRC is closely monitoring this program to make sure the information it provides is valid and useful.

International and national interactions – Developing a better understanding of cladding behavior in high burnup fuel is not only important in the United States. Work is also underway internationally, including by the International Atomic Energy Agency, foreign nuclear regulators, the Electric Power Research Institute and others. NRC staff maintains contact with these organizations, reviews their reports and attends their meetings to assess new information as it is developed. That information is also considered in the NRC's review of high burnup cask designs for storage and transport.