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High Burnup Spent Nuclear Fuel

Nuclear fuel is removed from a reactor every few years when it can no longer economically keep a chain reaction going. This "spent" fuel remains radioactive and must be managed. At first, it goes into a pool onsite for cooling and storage. Some utilities are moving their spent fuel after several years in the pool into NRC-certified dry storage casks. These casks are specially designed to contain the radioactivity and allow hot spent fuel to cool further.

What is burnup?

To understand "burnup," it helps to know more about the uranium that fuels a reactor. Before it is made into fuel, uranium is processed to increase the concentration of atoms that can split in a controlled chain reaction in the reactor. The atoms release energy as they split. This energy produces the heat that is turned into electricity. In general, the higher the concentration of those atoms, the longer the fuel can sustain a chain reaction. And the longer the fuel remains in the reactor, the higher the burnup.

In other words, burnup is a way to measure how much uranium is burned in the reactor. It is the amount of energy produced by the uranium. Burnup is expressed in gigawatt-days per metric ton of uranium (GWd/MTU). Average burnup, around 35 GWd/MTU two decades ago, is over 45 GWd/MTU today. Companies are now able to get more power out of their fuel before replacing it. This means they can operate longer between refueling outages. It also means they use less fuel.

Why does burnup matter?

The burnup level affects the fuel's temperature, radioactivity and physical makeup. It is important to the NRC's review of spent fuel cask designs because each system has limits on temperature and radioactivity. How hot and how radioactive spent fuel is depends on burnup, as well as the fuel's initial makeup and conditions in the core. All these factors must be taken into account in designing and approving dry storage and transport systems for spent fuel.

Nuclear fuel is encased in metal cladding. In the reactor, this cladding reacts with cooling water. The reaction forms oxide on the outside (similar to rust) and releases hydrogen. These processes begin slowly, then start to accelerate as the fuel reaches burnup of 45 GWd/MTU. Anything higher has historically been considered high burnup. But in reality, there is no sharp line between low and high burnup. It is a continuum. That means the difference between fuel burned to 45 GWd/MTU and 46 or 47 GWd/MTU can be very small.

When spent fuel is placed in a dry storage system and the water is removed, the temperature of the fuel temporarily increases, and the makeup of the cladding can change. This change can be more pronounced in high burnup spent fuel, which prompted the NRC to evaluate whether the cladding can become less “ductile,” or less pliable, as it cools. To address the technical concern, the NRC and the U.S. Department of Energy sponsored research programs to evaluate the performance of high burnup spent fuel. This research showed that the cladding remains ductile and the dry storage systems and transportation packages can safely hold the fuel.

Is it safe to store and transport high burnup fuel?

To be certified by the NRC, transportation packages and dry storage systems must meet NRC’s safety requirements. For transportation, these are found in 10 CFR Part 71 and for storage in 10 CFR Part 72. The NRC approves the designs only after a full safety review.

Based on these reviews, the NRC has certified systems for dry storage and transportation of high burnup spent fuel. Because low burnup spent fuel has been around longer and there is more of it, there are more systems for low than for high burnup spent fuel. However, as more data has become available on the performance of high burnup spent fuel, the NRC has certified dry storage and transportation systems for higher burnups for an initial term up to 20 years.

Operating experience since dry storage began in 1986 and short-term tests show that both low and high burnup spent fuel can be stored and transported safely. The NRC has sponsored testing at Oak Ridge National Laboratory on high burnup fuel under stresses greater than the loads expected during normal storage and transport. These tests have shown that high burnup fuel is very strong. However, the NRC wants to continue to obtain valuable information on high burnup spent fuel stored in the U.S., which is why users of dry storage systems will evaluate results from a demonstration program of actual loaded dry storage systems. These results will provide added confirmation of the safety of dry storage and transport of aged high burnup spent fuel.

What confirmatory research is being done?

The primary focus of research today is to get more data to support the continued safety of dry storage systems for high burnup spent fuel beyond the initial 20-year storage term. The research is designed to ensure that the existing data is accurate as the fuel gets older. Results are expected to confirm that the fuel will remain safe for transport even after extended storage.

The Department of Energy is sponsoring two research programs on high burnup spent fuel. The Research Cask Program, run jointly with the nuclear industry and with regulatory oversight by the NRC, is currently underway. In this study, high burnup spent fuel was loaded into a dry storage system fitted with instruments to provide temperature readings and allow sampling of the gas inside. These readings, combined with tests on the fuel assemblies and inspection of the cask’s interior after years of dry storage, will provide more data. The results will enhance our understanding of what happens to high burnup spent fuel in a storage system as it cools over time.

The second study focuses on the characteristics, material properties, and performance of high burnup fuel rods with similar irradiation histories as those loaded in the research cask. These “sister rods” will be tested against the conditions as measured in the research cask as well as against conditions modeled for other dry storage systems that have different thermal profiles and histories. All this work will help system designers, users and regulators better understand how to ensure high burnup spent fuel will remain safe in dry storage over the long term and during eventual transportation to a centralized storage or disposal facility.

How does the NRC make sure it remains safe?

The NRC assures safety by requiring many layers of protection. Dry storage and transportation designs provide several layers and the fuel cladding itself provides added protection. The regulations are designed to ensure the health and safety of the public is maintained during storage or in a transportation accident. The NRC's regulations ensure the system will remain safe even if the cladding did break. The NRC carefully reviews each system application to see if it meets the requirements. As part of this review, the NRC does its own analyses to confirm information in the application.

The NRC also provides oversight before and during loading of dry storage systems to ensure the correct fuel will go into the right systems. Fuel with burnup higher than the NRC certificate allows cannot be loaded. It must remain in pool storage until a cask approved for higher burnup becomes available. The NRC also inspects loaded systems every few years.

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