Cladding Behavior during Dry Cask Handling and Storage

H. Tsai and M. C. Billone

Argonne National Laboratory
Argonne, IL 60439

Because of the limited storage capacity in spent-fuel pools, discharged fuel assemblies are increasingly being relocated into dry casks for interim storage until long-term geological repositories are available. Some of the original licenses issued by the U.S. NRC for 20 years of dry-cask storage of spent fuel up to 45 GWd/MTU burnup are coming up for renewal shortly. As the burnup for fuel assemblies discharged from reactors increases, extending the database for high-burnup fuel cladding becomes pressing for dry-storage cask licensing. High-burnup fuel rods are perceived to be more vulnerable because of their greater water-side corrosion, hydrogen uptake, and radiation damage in the cladding.

Cladding behavior during dry cask handling and storage is being studied with irradiated materials from two pressurized water reactors -- Surry at 36 GWd/MTU burnup and H. B. Robinson at 67 GWd/MTU burnup. The Surry rods are unique in that they had been stored in a dry cask for 15 years and had experienced a range of temperature histories during thermal benchmark tests while in the cask. The Robinson cladding, owing to the high burnup, has a significant oxide corrosion layer (≈100 µm max.) and hydrogen content (≈800 wppm max.)

Extensive characterization was performed on the Surry fuel rods to delineate the effects of thermal benchmark tests (part of which emulated elevated-temperature vacuum drying) and the 15-y storage. Overall conditions of the rods examined were found to be excellent with no evidence of additional fission-gas release, cladding creep, or oxidation. There was no discernible hydride reorientation, i.e., from circumferential to radial, in the cladding. Microhardness of the cladding is comparable to that of reactor-discharged fuel-rod cladding, suggesting negligible annealing during the thermal benchmarks and cask storage.

Thermal creep is the dominant mechanism of cladding deformation under normal storage conditions and is being investigated with defueled cladding segments from Surry and H. B. Robinson rods. In the creep tests, the internal sample pressure is actively maintained constant. Periodically, specimens are depressurized, cooled, and removed from the test chambers for diametral and length measurements. The results to date indicate good creep ductility in excess of ≈4% for both the Surry and Robinson cladding in the 360-400°C and 160-250 MPa hoop stress test regime. No samples have failed during the creep tests. However, during the final shutdown from 400°C, one of the Robinson samples, with a strain of ≈3.5%, ruptured at ≈200°C. This shutdown was unique in that it was conducted intentionally with the sample under pressure (200 MPa hoop stress) in order to study hydride reorientation. The cause of this rupture is under investigation.

As part of the hydride reorientation study, two Surry creep tests (360°C/220 MPa and 380°C/190 MPa) were also shutdown with the specimens under pressure. No rupture occurred in these two samples. Posttest metallographic examination showed redistribution of hydrides in the cladding with some segments of hydrides oriented in the radial direction. As the hydrogen content in these two samples is relatively low, ≈250 wppm, there is no deleterious long-range linkage of the radial hydrides.

Isothermal annealing tests were conducted on Robinson cladding samples to investigate the extent of annealing under conditions relevant to cask handling and storage, particularly during vacuum drying. A corollary objective was to investigate hydride reprecipitation under stress-free conditions. Using microhardness as the figure of merit, the annealing tests show evidence of removal of hardening from radiation damage. The degree of softening correlates well with annealing time and temperature. The hardening recovery may affect subsequent long-term cladding creep behavior. In terms of room-temperature hydride morphology, the annealing tests showed migration of hydrogen from the outer circumference of the cladding to the inner locations. Presumably due to the stress-free test conditions, no radial orientation of the hydrides was noted.

Recognizing the critical nature of hydride reorientation on cladding behavior in cask handling and storage, additional annealing tests are being planned using prepressurized cladding samples.