Hydriding Effects in HBU Cladding

R E Einziger, Ph.D.
US Nuclear Regulatory Commission
And
M C Billone
Argonne National Laboratory

The Division of Spent Fuel Storage and Transportation Interim Staff Guidance (ISG) – 1 Rev 3 (Cladding Considerations for the Transportation and Storage of Spent Fuel) establishes maximum cladding temperatures for the storage and transportation of low burn-up spent fuel (<45 GWd/MTU). While the limit may be applied to the storage of high burn-up fuel, transportation of fuels stored at or above this temperature would be considered on a case by case basis due to additional technical concerns about the potential effects of hydride reorientation on the cladding's mechanical properties and subsequent behavior. Hydride reorientation might compromise the ability of the cladding to support all regulatory requirements. The US Nuclear Regulatory Commission, in cooperation with the Electric Power Research Institute, and the US Department of Energy established a program at the Argonne National Laboratory to generate data that could be used by each program sponsor to independently determine the ramifications of reorientation on cladding behavior.

The Argonne program:1) subjects samples to a reorientation treatment that has both decreasing temperature and stress bounding that what might be seen during vacuum drying for dry storage, and 2) after hydride reorientation subjects the cladding samples to limited displacement tests at typical transportation temperatures to determine the cladding residual ductility. From these data, a three axis map of hydrogen content, peak stress, and displacement test temperature was developed. There are data conditions where ductility is preserved, and other regions where cladding cracks dominate. This map can be compared to potential stresses and hydride levels in a variety of spent fuel types to determine potentially adverse behavior during transport.

To date, most tests have been conducted on unirradiated, pre-hydrided Zircaloy-4, -2, and Zirlo with a maximum stress at 400°C of 190 MPa, between 200 – 1000 wppm H_2, and displacement test temperatures of room temperature and 150°C. These tests were followed with similar tests on irradiated Zirlo cladding from Pressurized Water Reactor spent fuel with burn-up ~65 GWd/MTU.

Initial testing on irradiated cladding indicated that due to the difference in initial morphology of the hydrides the behavior of irradiated cladding could not be directly deduced from the unirradiated cladding test map. The peak stress to produce brittle cladding was less for irradiated cladding. In the range of 200 to 700 wppm H_2 it did not appear that the effect of the hydride reorientation increased with an increased H_2 level, since most of the hydrogen remained in the outer rim of the irradiated cladding. It appears that the irradiated cladding with reoriented hydrides will go through a ductile to brittle transition as the transport temperature is dropped below about 140ºC. This may have ramifications for extended storage.