Swelling, Creep and Embrittlement of D9 Stainless Steel Cladding and Duct in four FFTF Driver Fuel Assemblies after High Neutron Exposure

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D9 is an improved titanium-modified variant of AISI 316 developed in the US LMR program. This report focuses on consequences of swelling and irradiation creep on diameter, length changes and embrittlement of 20%cold-worked D9 cladding used in four mixed-oxide-fueled subassemblies irradiated in FFTF to 16.3 to 25.3 x 10^{22} n/cm^2 (E>0.1MeV) or 73-115 dpa. There were significant differences in temperature and lesser differences in dpa rate in the four 217-pin assemblies, allowing observation of response across a wide range of operating conditions. Additionally, two heats of D9 were used for cladding that had very minor differences in phosphorus, but with significant impact on swelling.

Published compilations of some of these data were presented only as a function of neutron fluence, giving the impression that swelling is a chaotic and variable process, requiring large uncertainty bands for predictive correlations. It is shown that in a well-defined and controlled production heat of cladding tubes, swelling for a given set of irradiation conditions is remarkably reproducible, and that "scatter" arises from reproducible effects of temperature and dpa rate on the duration of the transient regime preceding the onset of steady-state swelling. It is also shown that the successful application of a predictive swelling equation requires that the dose be expressed in dpa rather than in fast neutron fluence to reflect differences in neutron flux-spectra between FFTF and the harder-spectrum EBR-II.

Two assemblies receive particular attention. D9-2 operated at lower temperatures compared to D9-4, leading to different swelling behaviour. The cladding reached swelling values of 21-28% in D9-4 and 37-38% in D9-2, with much of the in-core portion of the pins having attained the terminal swelling rate of ~1%/dpa. The well-known "creep disappearance" phenomenon was observed to develop at moderate swelling levels. While no pin failures were observed during in-reactor operation, failure arising from severe void-induced embrittlement occurred in several D9-2 fuel pins and the duct during post-irradiation handling. Compared to data sets derived from the smaller EBR-II fast reactor, it is shown that the temperature dependence of void swelling in the much larger FFTF is rather invariant over a large range of temperatures.