SEGFSM Topical Meeting on LOCA Issues
Argonne National Laboratory, May 25-26, 2004.

Thermal Shock Resistance of Irradiated PWR Claddings

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ABSTRACT

Zircaloy cladding is oxidized and embrittled under loss-of-coolant accident (LOCA) conditions. The cladding may degrade by thermal shock on reflooding, if the cladding is severely oxidized and embrittled, and affect coolable geometry of the reactor core. The maximum cladding temperature (1200ºC) and oxidation (15%) are defined in ECCS acceptance criteria in order to avoid "significant cladding embrittlement" and maintain coolable geometry. Therefore, to confirm the safety of the reactor in a LOCA, it is most important to evaluate cladding embrittlement under LOCA conditions.

JAERI conducts "integral thermal shock tests" to evaluate fracture conditions of oxidized cladding under simulated LOCA conditions. We consider that the coolable geometry of a core can be maintained if the fuel rods maintain the geometry during a LOCA. So that, obtained conditions for fracture on quenching should be connected with those for "significant cladding embrittlement." Two PWR fuel rods, irradiated to 39 and 44GWd/t (rod average) at Takahama unit-3 reactor, are currently subjected to the tests*. The cladding material is low-Sn Zircaloy-4 and initial oxide layer thickness ranged 18 to 25μm. Ten tests are planned for these fuel rods and three tests have been conducted. Fuel pellets were removed from 190mm-long segments, and alumina dummy pellets were loaded in the defueled claddings. Zircaloy end-plugs were welded at the both ends of the claddings and the fabricated test rods were pressurized to 5MPa with Ar gas. In the tests, the rods were heated up at a rate of 10K/s in the steam flow and isothermally oxidized at temperatures ranging from 1157 to 1192ºC. The test rods were quenched axially restraining, though the maximum restraint load was limited to about 540 N.

One cladding oxidized at 1180ºC to about 30% ECR during the isothermal oxidation failed during quench. Since the failure boundary of non-irradiated claddings containing similar hydrogen concentrations lies at about 28%ECR, the failure of the irradiated cladding agrees with the failure criteria for non-irradiated claddings. Two claddings oxidized at 1192 and 1157ºC to about 16 and 18%ECR, respectively, survived the quench. This indicates that failure boundary is not reduced so significantly by irradiation to the examined burnup level.

Besides the integral thermal shock tests, experimental and analytical efforts are made to establish methodology to predict cladding fracture on quenching. Recent results from the efforts are also reported.

* The test with the irradiated PWR fuel cladding has been performed in the cooperative research program between Japanese PWR utilities and JAERI.