Abstract

The QUENCH-10 experiment has been performed in the frame of the EC co-sponsored project LACOMERA, on proposal of AEKI, Budapest, Hungary, to provide information on safety margins in spent fuel storage. The test conduct comprised the phases heat-up, pre-oxidation in steam, intermediate cooling, air ingress, transient heat-up, and water quenching. After brief recapitulation of previously reported information, the results of the comprehensive metallographic post-test evaluation of the QUENCH-10 bundle and of the scale thickness distribution are given and discussed on basis of the observed degradation phenomena.

With reference to the oxidation of the two corner rods, removed at the end of pre-oxidation and air exposure, respectively, the final bundle state at several cross sections is quantified. The measured scale thickness distribution for the components indicates rather flat lateral profiles with considerable local scatter, and pronounced axial profiles. Complete cladding conversion of first rods at 800 mm elevation, fast external oxidation of molten cladding matrix and internal oxygen transfer from the pellets, noticed above, and massive fragmentation and rubble relocation characterize the oxidation extent within the hot zone.

The given condensed mechanistic interpretation of the complex oxidation phenomena separates strictly localized effects of the air exposure from widely distributed ones: Initiation and progression of local rod cladding and shroud damage starts from point and line defects of scale growth (scratches, weld seam), and involves breakaway-similar morphologies and local zirconium nitride phase formation together with mechanical consequences. The often resulting axially elongated wedge-shaped through-wall cracks, which were promoted by air ingress, are most important for the cladding fragmentation and rubble formation within the hot zone. The more widely distributed interaction of nitrogen should have depended on the condition of oxygen consumption in the late phase of air exposure. Below the hot zone the layer of ZrN phase was totally re-converted to fragile oxide during the quench phase. Within the hot zone ZrN penetrated deeper into the scale with scalloped growth front. During the quench phase, re-conversion to oxide and nitrogen release were incomplete here, so that the observed cells of ZrN could survive. A comprehensive scanning electron microscopy (SEM) study has confirmed the experimental observations. Nevertheless, continued efforts are required for the final interpretation of the mechanisms related to air ingress, especially under deviating conditions and as basis for the development of reasonably simplified mechanistic models.