Assessment of Fuel Rod Performance by Consideration of Crud Deposition

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1. Introduction

Deposition of crud on the zirconium alloy fuel rods could result in not only an axial offset anomaly (AOA) with the boron retention in crud deposits, but also the failure of cladding due to excessive corrosion. TMI-1 nuclear power plant (NPP) in US experienced such a failure in 1995[1]. When crud has formed on the surface of fuel rods, it accelerates a cladding corrosion due to its lower thermal conductivity. Crud inhibits heat transfer, increases clad temperature and oxide layer growth rate; finally, it has a possibility to exceed recommended safety design limits of oxide thickness and hydrogen concentration[2]. At the same time, rod performance input values for loss of coolant accident (LOCA) analysis such as a stored energy, internal pressure and oxide thickness will also be affected due to crud deposition.

In this work, corrosion characteristics in steady-state operation and input values for LOCA analysis have been assessed by considering the crud buildup.

2. Analysis Methods

FRAPCON-3 fuel performance evaluation code was utilized to assess the ACE7^{TM} fuel rod (ZIRLO^{TM} cladding) performance in steady-state operation[3]. Two different postulated power histories, but the same discharge burnup (60 MWd/kgU), were adopted to analyze the corrosion characteristics and initial input values for LOCA analysis. Thermal conductivity of the crud varied from 0.8648 to 0.4324 W/m-K for consideration of steam blanketing condition in a crud layer. Crud thickness effects have been analyzed by considering the constant accumulation rate and constant thickness of curd during operation. In case of constant thickness of crud, we also assumed two different cases such that temperature rise through the crud was limited (max.=20F) and not limited.

3. Corrosion Characteristics

3.1 Oxide thickness

Fig.1 shows the oxide layer growth behavior in ZIRLO^{TM} cladding as a function of thermal conductivity, accumulation rate and thickness of the crud. As the accumulation rate increased from 0 to 3.6x10^{-13} m/s, which corresponds to the about 40 μm crud buildup at the EOL, the oxide layer thickness exceeds the recommended safety limit, 100 μm. As the conductivity changed from 0.8648 to 0.4324, the required buildup rate that is needed rate to run over the recommended safety limit was 1.7x10^{-13} m/s. In case of the constant crud thickness, the safety limit was exceeded as the thickness of crud was about 16, 13, 8 μm when the conductivity was 0.8648, 0.69, 0.4324 W/m-K, respectively. However, when temperature rise limitation existed through the crud layer, maximum oxide thickness became saturated about 72 μm above ~10 μm crud thickness, irrespective of conductivity.

3.2 Hydrogen concentration

Hydrogen concentration in the cladding as a function of thermal conductivity, accumulation rate and thickness of the crud showed the same behavior of oxide growth. As the conductivity changed from 0.8648 to 0.4324 W/m-K, the required buildup rate to run over the recommended

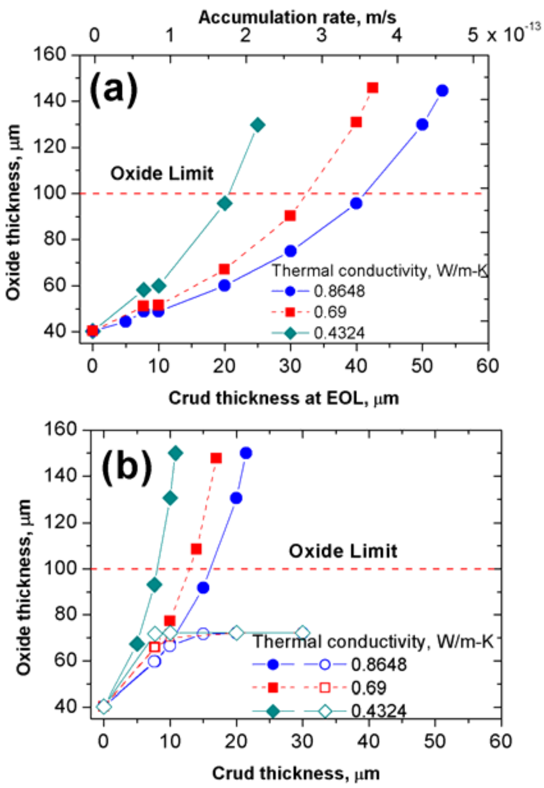

Fig. 1. Oxide layer growth behavior as a function of thickness and thermal conductivity of the crud. Constant accumulation rate (a) and constant thickness of crud (b). (open mark is with temperature rise limitation, closed mark is without limitation.)

safety limit, 600 ppm, was changed from 3.0×10^{-13} to 1.4×10^{-13} m/s, which corresponded to 35, 16 mm crud thickness at EOL, respectively. In case of the constant crud thickness, the safety limit was exceeded as the thickness of crud was about 14, 11, 7 μm when the conductivity was 0.8648, 0.69, 0.4324 W/m-K, respectively

4. Input Parameters for Safety Analysis

Since peak stored energy in the pellets was observed at the center of fuel rod as the burnup reached to 28 MWd/kgU (472days), the changes of input values for LOCA analysis were extracted at that burnup(Fig.2).

Peak stored energy increased about 4 percent when crud thickness increased from 0 to 16 μm with the conductivity of 0.8646 W/m-K. As conductivity decreased to 0.4324 W/m-K, stored energy increased up to ~9 percent compared to original value (262J/g). Oxide thickness also increased from 14 to 24 μm as crud thickness increased up to 16 μm with the same conductivity, 0.8648 W/m-K. However, as the conductivity changed to 0.4324, oxide thickness increased up to 43 μm. Internal pressure also influenced by the conductivity and crud buildup. Without crud deposition on the rod, internal pressure was measured about 8.15 MPa. However, crud thickness increased up to 16 μm, it also increased up to about 8.52 MPa (when the conductivity was 0.8648 W/m-K). Furthermore, as the conductivity changed to 0.4324, internal pressure increased up to 8.9 MPa.

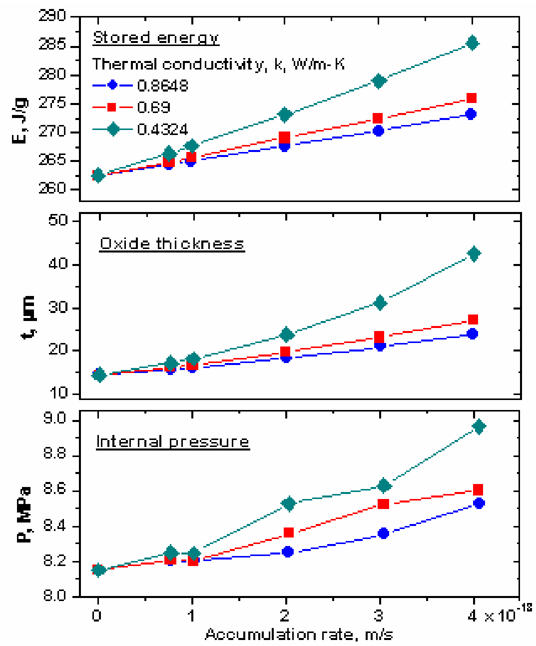

Fig.2. Changes of peak stored energy, oxide thickness and internal pressure as a function of accumulation rate and thermal conductivity of the crud at 28 MWd/kgU burnup(472 days).

5. Summary

Oxide layer thickness and hydrogen accumulation in ZIRLO™ cladding were strongly affected by the thermal conductivity and crud layer thickness. In certain conditions, those exceeded the recommended safety limits related to cladding corrosion.

Fuel rod performance values required to LOCA analysis were also influenced by the crud buildup such that peak stored energy and internal pressure were increased up to several percent depending on the conditions. Based on the results, it might be necessary to take into account of crud buildup for analysis of fuel rod performance in steady-state operation and also in accident condition.

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