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The status of AOA and the CRUD deposition in Korean PWR

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1. Introduction

Korean nuclear power plants have experienced several times of AOA (Axial Offset Anomaly). AOA in Korean plants seems to be the consequence of high burn-up and long term cycle of the nuclear fuel as experienced in the foreign plants. The root cause of AOA is not clearly understood until now. Even though plants which have similar operation condition (similar thermo-hydraulic condition, water chemistry and structural materials), the AOA behavior of each plant is different from other plants. To have an understanding of the plant specific behavior of each plant and to have the countermeasures to AOA, the mechanism of CRUD deposition should be clarified.

The purpose of this study is to investigate the AOA status and the CRUD characteristics in Korean power utilities. We surveyed the current AOA occurrence history and collected the Korean CRUD data which are scattered in various sources.

To have some understanding on the key variables of AOA, we built experimental apparatus for CRUD deposition in simulated PWR environment. The status and the investigation plans of our experimental study are introduced in the paper.

2. AOA Status of Korean Power plants

2.1. AOA occurrence in Korean PWR

Korean plants have experienced several times of AOA until February, 2006. In a reactor of Kori site, significant AOA occurred during cycle 9. Ulchin site's reactors also have experienced several AOA recently. 1.17% of the power was reduced due to AOA during cycle 11 in U-b unit.

2.2. Analysis of Crud characteristics in the fuel cladding in Korean PWR

CRUD samples from Several Korean units (mainly from U-b, Y-a) were investigated. Crud samplings were carried out by various methods such as taping, smearing, and scraping of cladding surface. The data of CRUD shown in this paper are the collected results from various scattered sources in Korean institutes.

2.2.1 Presence of CRUD in fuel cladding

The surface morphology of the fuel cladding A of U-b unit along the tube axial direction is shown in Fig. 1.

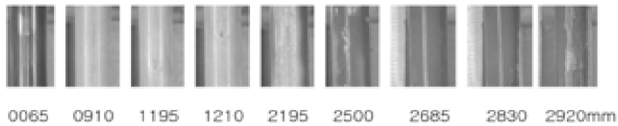

Fig. 1 The surface morphology of the fuel cladding of U-2 unit along the axial direction

The CRUD in the upper part of cladding A of U-b unit is shown in Fig. 2. CRUD is usually deposited in scattered local areas below 3300mm from bottom as shown in (a) of Fig. 2. At above 3300mm ((b) of Fig. 2), CRUD is usually deposited uniformly around the cladding tube surface.

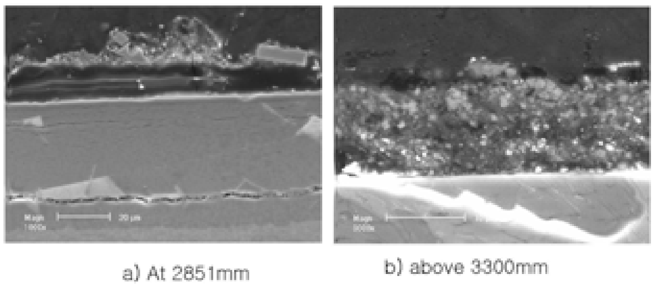

Fig. 2 CRUD in the upper part of fuel cladding

The morphology of two CRUD (from U-b and Y-b) sampled by taping method is shown in Fig. 3. The morphology of the surface crystals is quite different from each other. The CRUD from U-b has many needle-shape crystals mixed with relatively large grains. On the other hand, the CRUD from Y-b has comparatively large sharp edge crystals mixed with small grain particles. The CRUD of Y-b also has needles. But the numbers are very few. We have no information for the phase identification. But based on the various foreign reports [1, 2], the needles seem to be NiO whisker. We need more studies to convince if the morphology difference between the two CRUDs (from U-b and Y-b) is typical or not.

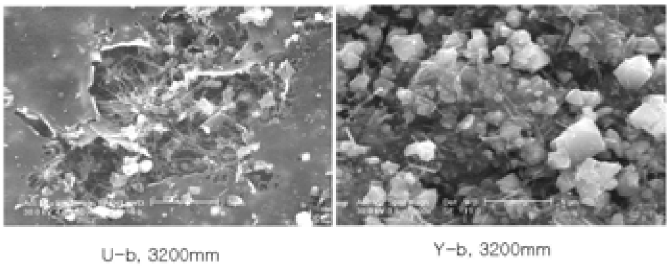

Fig. 3 CRUD morphology sampled by taping method from the cladding of two Korean units (U-b, Y-b units)

2.2.2 Composition of CRUD

The composition of the CRUD is basically Fe, Ni and O as shown in Fig. 4. The composition along the line scan direction for the fuel cladding (A of U-a) is shown in Fig. 4. CRUD layer is divided into three layers (inner, middle and outer layer) based on the O/Fe ratio in Fig. 4. The O/Fe ratio of the middle layer (4~11µm) in Fig. 4 is about 1.5~2.0. The Ni/Fe ratio of the middle layer is about 0.5. It is quite reasonable to conclude that the middle layer is mainly $NiFe_2O_4$ (Ni:Fe:O=0.5:1.0:2.0). Toward outer layer, the Ni/Fe ratio and the O/Fe ratio increase. It seems that the outer layer is composed with other oxide phases besides $NiFe_2O_4$.

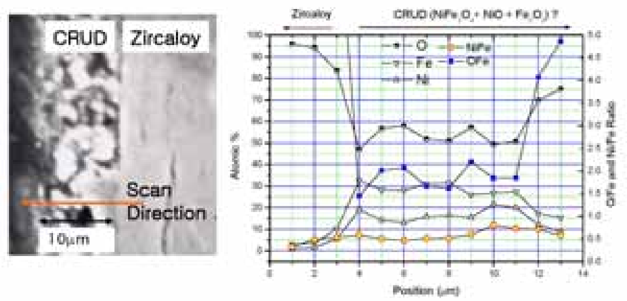

Fig. 4 Composition and Ni/Fe, O/Fe ratio of the CRUD on the fuel cladding A of Y-a unit along the thickness.

The relative high Ni/Fe ratio of the CRUD may be related with the AOA history in the cycle of the unit. Actually, it was reported by Doncel et al [3] that nickel concentration in CRUD has a decisive influence to the B deposition in CRUD. Ni rich CRUD is unfavorable for the prevention of AOA. The high B deposition in Ni rich CRUD maybe due to the easiness of B hideout in the shallow crevice (or small interconnected pore) structure made by nano size NiO needles

2.2.3 Deposited phase and Boron in CRUD [4]

Main chemical phase in the CRUD of Y-a unit seems to be $NiFe_2O_4$ with Nickel Oxide (NiO) considering the composition data colleted. Interesting thing is that $ZnFe_2O_4$ phase was found in Y-a CRUD (though Zn was not injected in the unit). Y-a unit have less experience of AOA. Zn impregnation in the CRUD of Y unit may be related with the less occurrence of AOA in Y-a.

3. Crud Simulation Experiment

3.1. CRUD simulation experiment in high temperature

We built a CRUD simulation apparatus to investigate the effects of water chemistry on the CRUD deposition on the fuel cladding. The apparatus is composed with a high pressure loop and CRUD deposition section as shown in Fig. 5. We will focus our study on water chemistry effects, such as pH and dissolved H_2, on the behavior of CRUD and B deposition.

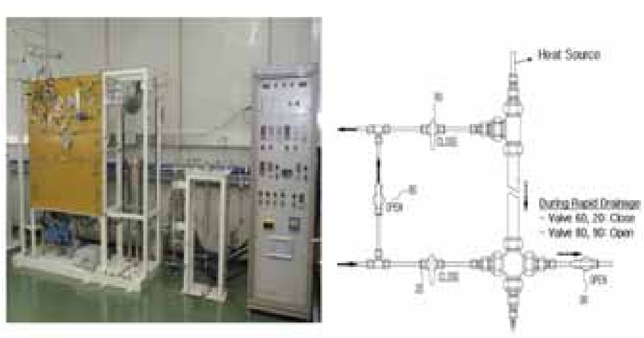

Fig. 5 CRUD simulatin apparatus

4. Summary

The status of AOA and the characteristics of the CRUD deposited in Korean nuclear power plants were reviewed in this paper. AOA occurred in some Korean plants and (it seems) that the risk of AOA in Korean power plant increases as the fuel burn-up and the fuel cycle length increases. Several units in Korea have CRUD (thickness: ~10um) in the upper part of fuel rod. We develop a CRUD simulating apparatus to investigate water chemistry effect on the CRUD and B deposition. The research will be applied to develop the preventive water chemical measures to the AOA in PWR.

5. References

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