

## Effect of corrosion products on Crud Deposit on the surface of fuel cladding by wire heating method

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### 1. Introduction

Corrosion products are recognized as one of the major sources of occupational radiation exposure for nuclear power plant workers.[1]. Also, deposited corrosion products (crud) on the surface of fuel cladding result in an axial offset anomaly (AOA).[2]. Numerous studies have been conducted on the primary water chemistry to reduce the amount of crud in the primary circuit to avoid radioactivity build-up and unexpected power transition in the plant. However, experiments with crud are restricted in the laboratory, because the crud is a highly radioactive material. The objective of this study is to develop the test method for simulating the deposition of corrosion products in a nuclear power plant.

### 2. Tests and Results

#### 2.1 Preliminary simulation of sub-cooled nucleate boiling at 1 atm.

Fig.1 shows a wire heating apparatus, which was designed to perform a crud deposition test. This experimental apparatus was composed of a water bath manufactured by quartz, a hot plate installed to maintain the temperature within the water bath, a DC power supply (HP6681A, 0 ~ 8 V, 0 ~ 580 A) for electric power application, and copper electrodes coated with gold. Ferrous ions ( $\text{Fe}^{2+}$ ) and nickel ions ( $\text{Ni}^{2+}$ ) in the Li/B ( $\text{LiOH}/\text{H}_3\text{BO}_3$ ) solution as a test solution were chosen as the corrosion products to be tested. The sources of the  $\text{Fe}^{2+}$  and  $\text{Ni}^{2+}$  ions were ferrous acetate and nickel acetate, respectively. In this system, the wire connected with an electrode was manufactured (L = 130 mm, W = 3 mm, T = 0.7 mm) with a Zirlo tube, one of fuel cladding materials.

The crud deposition tests were performed by the following procedures. First, the electrode was connected with a wire, placed in a water bath, and filled up with a test solution. When the temperature of the test solution in the water bath was increased from 95 °C up to 100 °C, 2.5 V were applied to this system using DC power supply. After that, heat occurred in the wire, local boiling was produced by the temperature differences between the wire and the test solution, and gas bubbles were finally formed from the local boiling sites. We controlled Li/B concentrations to understand the effects of pH in the test solution for crud deposition. Fe/Ni concentrations were also controlled to understand

the effects of corrosion products on crud induction.

The detailed experimental conditions of the deposition tests performed in this study are summarized in Table 1. Energy Dispersive X-ray (EDX) and Secondary Ion Mass Spectroscopy (SIMS) analysis were also applied to examine the precise composition of the oxide layer.

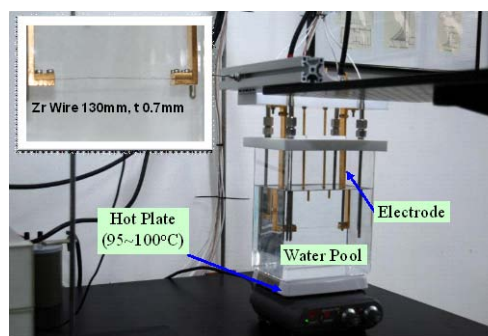


Fig. 1. Wire heating apparatus to simulate sub-cooled nucleate boiling

Table 1 : wire heating test conditions

Time [hr]	Voltage [V]	Chemical conditions			
		B [ppm]	Li [ppm]	Ni [ppm]	Fe [ppm]
144	2.5	1200	2.2	10	20
144	2.5	1200	2.2	20	40
144	2.5	350	3.5	40	80
144	2.5	1200	2.2	40	80
72	2.5	1200	2.2	10	20
72	2.5	350	2.2	10	20
72	2.5	1200	2.2	20	40
72	2.5	350	3.5	10	20

SEM and EDX analysis was performed to analyze the deposits of the corrosion product and their compositions using the wire sample separated from the electrode following crud deposition experiments. Deposits were formed at specific sites all over the Zr wire surfaces, which were consistent with boiling sites where the bubble was generated. It appears iron oxide deposition by decreasing the local solubility of the iron oxide near the vapor bubbles.[3].

Fig.2 shows the deposits of corrosion products in the wire in different pH solutions using different concentration of boron. Different deposited form in the various pH conditions was observed and shown in the

photos of the corrosion product. Higher amounts of deposited corrosion products were measured with lower pH conditions.

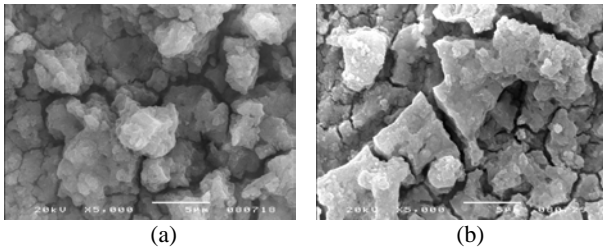


Fig. 2. Typical oxide morphology (a) at 1200ppm B, 2.2 ppm Li and (b) 350 ppm B, 2.2 ppm Li

As shown in Fig. 3, SEM photos and EDX analysis show the cross section of the wire to understand the thickness of the deposited corrosion products. SEM photos show the deposited oxide layer of approximately 2 to 6  $\mu\text{m}$ .

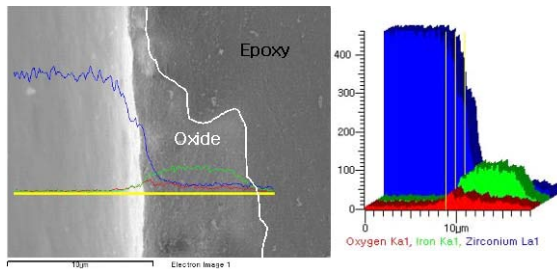


Fig. 3. depth profile of typical elements

## 2.2 . Simulation of sub-cooled nucleate boiling on the surface of nuclear fuel cladding (ongoing process)

The cause of AOA is not exactly determined, but it is believed that the occurrence of AOA is considered due to the deposition of impurities in the coolant on the surface of the fuel cladding. Sub-cooled nucleate boiling occurs at the cladding surface in the central areas of core, and this SNB phenomenon is considered to better enable the deposition of impurities on the surface of the cladding.[4].

To replicate the condition in the primary coolant of a PWR and the typical heat flux of the cladding, we have manufactured the high temperature wire heating test facility as shown in Fig.4. There are two electrodes that hold the Zircaloy wire specimen and apply high current to maintain the surface heat flux on the wire surface. Test parameters are heat flux, temperature, pH, Fe/Ni chemical composition, and the flow rate. After the test, we analyzed the deposited corrosion products on the specimen surface to determine microstructure, chemical composition, deposition rate and porosity of the crud layer.

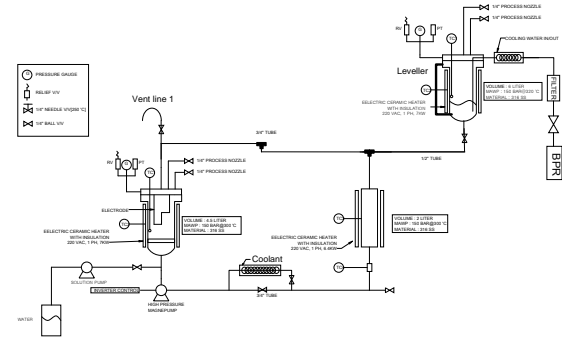


Fig. 4. Schematic layout of high temperature wire heating test facility

## 3. Conclusions

The effect of sub-cooled boiling on the deposition of corrosion product on the heat transfer surface was evaluated by using a wire heating apparatus. We could observe the chimney structure, which is evidence of sub-cooled boiling. The amount of deposition changed with water chemistry conditions such as pH, soluble ion concentration.

We are developing a high temperature wire heating test facility to simulate sub-cooled nucleate boiling on a nuclear fuel surface. By using this facility, we will be able to determine the crud deposition mechanism and develop the modified primary water chemistry condition of a nuclear power plant.

## REFERENCES

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