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Studies on the CRUD Deposition on Fuel Cladding Surface Using AOA Water Chemistry Loop

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1. Introduction

Axial offset anomaly (AOA) is caused by the deposition of crud on the fuel cladding of a PWR. When significant levels of crud build up on the cladding, boron can accumulate in the pores of the crud as a concentrated solution or solid phase, and cause the flux depression[1]. 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 on the crud are restricted in the laboratory because the crud is a highly radioactive material. The objective of this study is to develop a test method for simulating the deposition of crud in a nuclear power plant.

2. Tests and Results

2.1. CRUD deposition tests using high temperature wire heating test facility

The cause of AOA is not exactly determined, but it is believed that the occurrence of AOA is 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 phenomena is thought to induce the deposition of impurities on the surface of the cladding [2].

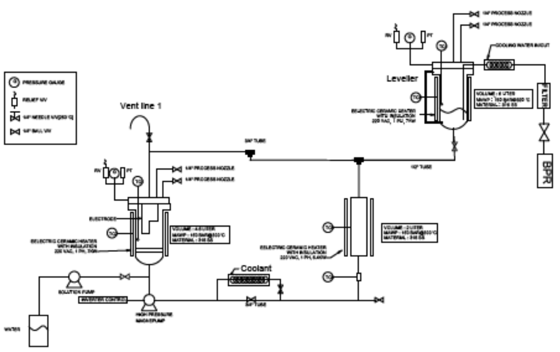


Fig. 1. Schematic layout of high temperature wire heating test facility

To replicate the condition in the primary coolant of a PWR and the typical heat flux of the cladding, was constructed a high temperature wire heating test facility, as shown in Fig.1. There were two electrodes that held the Zircaloy wire specimen and a high current was applied 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, the deposited corrosion products on the specimen surface were analyzed to determine microstructure, chemical composition, deposition rate and porosity of the crud layer.

2.2 . Simulation tests of CRUD deposition using AOA water chemistry loop

A test loop has been designed and made at KAERI to simulate the conditions of AOA, as shown in Fig. 2. The cladding tube was heated by an internal cartridge heater, and the gap between the tube specimen and the heater was filled with MgO paste. The pressure of the loop system was maintained at 96.5 Kg/cm2, which is the equilibrium pressure at 307℃. The temperature at a thermocouple 2 (T/C 2) in Fig. 3 was set to 309℃ during the test, in order to have continuous sub-nucleated boiling on the outside surface of the top portion of the heated length. Three pieces (20 mm each) were cut after each test by a diamond saw in a decane solution, as shown in Fig. 3. The specimen (Ax-3) was near the top of the heated length and the specimen (Ax-1) was near its bottom. The inside the of tube specimens (15 mm in length) for ICP-AES was filled with a resin, and the deposit on the outside of the specimens was removed by an ultrasonification treatment.

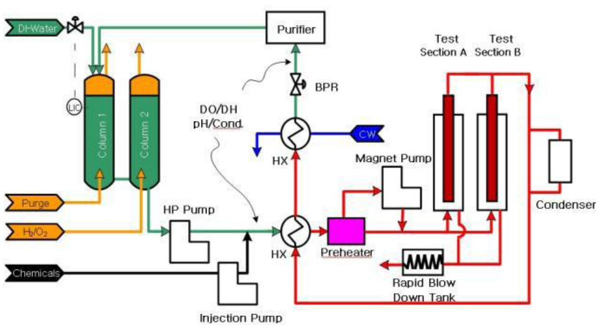


Fig. 2. AOA Test Loop at KAERI

Test conditions have been summarized for A1 ~ A3 in Table 1, and for A4 ~ A7 in Table 2. An external surface was phothgraphed by SEM for the specimen from the location 3 after a 5 day test of A1. Many pores could be observed in the deposit layer as shown in Fig.

4. The pore size is about 0.5μm, and the thickness of deposit is 20 μm. SNB was expected in location 3. However, less amounts of deposit were found on the external surface in location 1, where SNB may not occur. The external surface of the specimen cut from A1-3 was sputtered and analyzed by SIMS, as shown in Fig. 5. The boron could be observed in the deposit, as the deposit was sputtered.

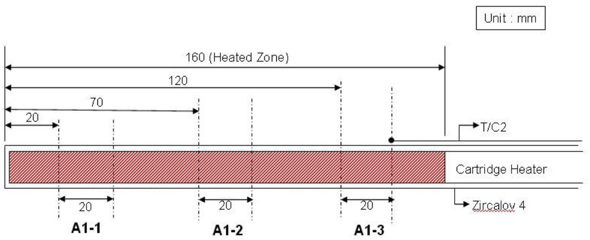


Fig. 3. Location of A1 test specimens for surface analyses

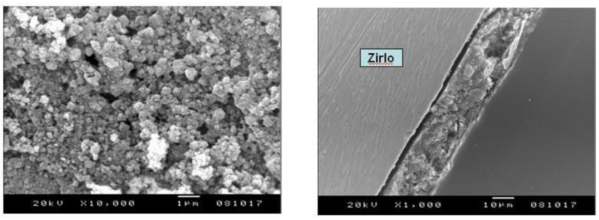
Table 1 Test Conditions for A1, A2 & A3

Test	Material	Solution	pH (RT)	Exposure Time, days	Others
A1	Zirlo	1.5ppm Li, 870ppm B 20ppm Ni as $Ni(NO_3)_2$ 20ppm Fe as $Fe(NO_3)_3$	3.6	5	- Hydrogen : 21cc/Kg H_2O - DO < 5ppb - 96.5 Kg/cm^2 (307℃)
A2		1.5ppm Li, 870ppm B 200ppb Ni as $Ni(NO_3)_2$ 200ppb Fe as $Fe(NO_3)_3$	6.4	5	
A3		1.5ppm Li, 870ppm B 200ppb Ni as $Ni(NO_3)_2$ 200ppb Fe as $Fe(NO_3)_3$	6.4	28	

pH_{RT} (1.5ppm Li + 870ppm B) : 6.46

Table 2 Test Conditions for A4 ~A7

Test	Material	Solution	pH (RT)	Exposure Time, days	Others
A4	Zirlo	1.5ppm Li, 870ppm B 2.0ppm Ni as Ni Acetate 2.0ppm Fe as Fe Acetate	6.3	14	- Hydrogen : 21cc/Kg H_2O - DO < 5ppb - 96.5 Kg/cm^2 (307℃)
A5		3.5ppm Li, 1500ppm B 2.0ppm Ni as Ni Acetate 2.0ppm Fe as Fe Acetate	6.3	14	
A6		5.0ppm Li, 1500ppm B 2.0ppm Ni as Ni Acetate 2.0ppm Fe as Fe Acetate	6.5	14	
A7		2.2ppm Li, 1500ppm B 2.0ppm Ni as Ni Acetate 2.0ppm Fe as Fe Acetate	6.2	14	



a) External Surface b) Cut Surface

Fig. 4. Surface with SNB of A1-3 by SEM after 5 day test

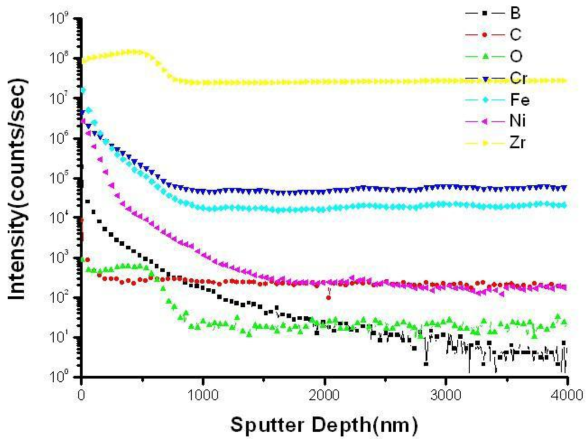


Fig. 5 SIMS analysis on deposit of external surface for A1-3 specimen

3. Conclusions

A test loop has been designed and made at KAERI in order to investigate AOA. An accelerated test showed deposits with 20 μm thickness and pores with about 0.5 μm size on the external surface of the specimen after a short period of test. Some boron was found on the deposits of the external side of the specimen by SIMS.

We was constructed a high temperature wire heating test facility to simulate sub-cooled nucleate boiling on a nuclear fuel surface. By using this facility, the crud deposition mechanism can be studied, and a water chemistry strategy for a nuclear power plant can be developed.

REFERENCES

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[2] P.L. Frattini, J. Blok, S. Chauffriat, J. Sawicki, and J. Riddle, "Axial offset anomaly: coupling PWR primary chemistry with core design", Nuclear Energy, 40, No.2 (2001).