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Evaluation the Effect of Cr-coated Cladding Surface Roughness on Large Break-Loss of Coolant Accident using MARS-KS 1.5 with Multi-layer Model

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1. Introduction

In the European Parliament, nuclear was conditionally included in Taxonomy, and the condition is the use of Accident Tolerant Fuel (ATF) in existing nuclear power plants and Generation III new builds. One promising ATF candidate is Chromium (Cr)-coated cladding, one of the ATFs, has been widely studied due to the simple principle of adding coating layer. The coating layer is expected to result in difference surface roughness, potentially affecting thermal-hydraulic characteristics in power plants. The NRC recommended in Interim Staff Guidance report that the effect of Cr coating, including changes in roughness, on critical heat flux (CHF) should be considered. The CHF can be influenced by the surface temperature of cladding, flowrate of the coolant, pressure and roughness, etc [1, 2]. Also the other heat transfer characteristics are influenced as discussed in Bae et al. [3].

This study aims to evaluate the effect of surface roughness difference resulting from Cr coating on peak cladding temperature (PCT), pressure drop and core flowrate by analyzing the large-break loss of coolant accident (LBLOCA) for Zion plant. To achieve this, MARS-KS 1.5 code with multi-layer model was used varying the surface roughness of coating layer of cladding [4].

2. Implementation of Multi-layer Model

2.1 Development of multi-layer model for chrome-coated cladding

In MARS-KS, the fuel input modeling just allows the single layer for the cladding input card when using gap conductance model. Therefore, the analyzing of Cr-coated cladding is impossible in the MARS-KS 1.5 code. To analyze the Cr-coated cladding, dividing the cladding into the zircaloy (Zr) layer and Cr layer is necessary. To achieve this issue, the multi-layer model was developed and implemented into the MARS-KS.

The schematic diagram of multi-layer model is showed in Fig. 1. The nuclear fuel consists of the UO_2 pellet, gap, Zr cladding and Cr coating layer. The thickness of the Cr coating was assumed 10 µm. The properties of Cr-coated cladding were provided to the input model.

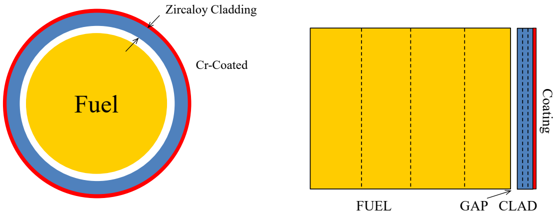

Fig. 1. Schematic diagram of Cr-coated cladding with fuel.

2.1 Validation of Multi-layer Model

Using the MARS-KS with multi-layer model, the steady state of Zion plant was calculated, assuming a thickness of 10µm for the Cr-coated layer. Fig. 2 shows the nodalization of the plant. Table 1 summaries the target value presented by OECD-BEMUSE phase IV [4] for the Zion plant, the calculation results of our previous study. The results are very similar to the target and calculation results of past study.

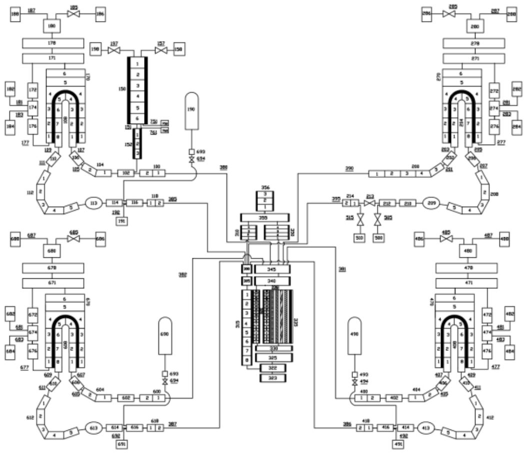

Fig. 2. Zion plant nodalization [2].

Table I: Steady state results of Zion plant

Parameter	Target	MARS	Multi-layer
Core power[MW]	3250	3250	3250
Cold leg P* [MPa]	15.8	15.8	15.8
Hot leg P*[MPa]	15.5	15.5	15.5
Core outlet T** [K]	603.0	602.6	602.6
Coolant flow rate [kg/s]	17357.0	17107.2	17105.2

* P: Pressure
** T: Temperature

3. Effect of Chromium Coating Roughness

3.1 Effect on Steady state

Table II presents the results of the pressure drop and core outlet flow rate calculations to evaluate the effect of roughness on the steady state of Zion plant. Case 1 is the base case without multi-layer model and Cr coating. The roughness of case 1-0.1 and case 1-10 is 0.1 times and 10 times that of case 1, respectively. In Case 2 series, the thickness of zircaloy cladding was increased by 10 um without multi-layer model, to confirm the effect of geometry by coating. Case 2-0.1 and case 2-10 follow the same methodology as case 1-0.1 and case 1-10, respectively, with the other series applying same methodology. In Case 3 series, the flow rate of the pump was controlled to match that of Case 1, while the performance cures of pump were the same for the other series. Case 4 involves the implementation of a Cr-coated cladding with the multi-layer model.

As the roughness of the cladding increases, the RCS flow decreases by the increased pressure drop. In the case 2 series, the pressure drops increased, and core outlet flow decreased compared to the case 1 series. It is believed that the hydraulic diameter decreases due to the coating layer, thereby increasing the pressure drop and decreasing the flow rate. In the case 3 series, the core outlet flows for 3 and 3-0.1 were the same with the case 1 series. However, the core outlet flow of case 3-10 showed lower flow rate. Due to the increase of roughness, the flow rates of bypass were increased. In the case 4 series, the calculation results shows very similar with case 2 series. It seems that the effects of roughness for pressure drop and flow rate independent with geometry effects due to the coating layer.

Table II: Pressure drop and core outlet flow rate varying roughness of cladding.

Case	Pressure drop through the core [kPa]	Core inlet flow [kg/s]	Sum of reactor inlet flow rate [kg/s]
1	97.0	17107	17383
1-0.1	95.2	17127	17402
1-10	107.1	16991	17278
2	97.5	17103	17380
2-0.1	95.6	17124	17399
2-10	107.7	16985	17277
3	97.0	17107	17383
3-0.1	95.0	17108	17385
3-10	107.3	17021	17380
4	97.5	17105	174380
4-0.1	95.6	17123	17402
4-10	107.7	16984	177398

3.2 Effect on LBLOCA

Table III presents the calculation results of the blowdown PCT and reflood PCT during the LBLOCA of the Zion plant. The calculations were conducted for 400 sec for transient state, with the roughness remaining consistent with Table II. In most of case series, the blowdown PCT increased with the roughness. However in case 3, the same blowdown PCTs were observed for 3 and 3-0.1, which is believed to be due to the increased flow resistance and decrease heat transfer caused by the roughness. In the case of 3 and 3-0.1, the controlled pump flow rate seems to have resulted in the same blowdown PCT. Comparing case 1 and 2 series, the blowdown PCTs of case 2 were lower than case 1 series. As the cladding thickness increased, thermal resistance seemed to increase. In case 2 and 4 series, the blowdown PCTs of case 4 were lower than case 2 series since the thermal conductivity increased due to the Cr coating. However, the reflood PCT did not exhibit a notable trend due to the complexity of the phenomena involved.

Table III: Blowdown and reflood PCT

Case	Blowdown PCT [K]	Reflood PCT [K]
1	1096.4	1176.9
1-0.1	1096.0	1179.0
1-10	1097.0	1164.7
2	1096.5	1172.4
2-0.1	1096.3	1174.1
2-10	1096.9	1176.2
3	1096.4	1176.9
3-0.1	1096.4	1182.0
3-10	1099.5	1167.7
4	1093.6	1175.8
4-0.1	1093.5	1171.5
4-10	1094.1	1175.1

3. Conclusions

The MARS-KS 1.5 code was improved by adopting a multi-layer model for Cr-coated cladding. The steady state calculation for Zion plant showed almost identical results between the multi-layer and default model. Using the multi-layer model, the effect of Cr-coated cladding was analyzed for LBLOCA varying surface roughness of cladding. The results indicated that the blowdown PCT decreased slightly with an increase of the roughness of the Cr coating. The reflood PCT did not show a clear tendency due to the complexity of phenomena involved.

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