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A Study for Prediction Accuracy Improvement of Axial Offset Anomaly Risk

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1. Introduction

During operation of the nuclear reactor, corrosion products from the stainless steel and steam generator tube dissolved in the reactor coolant can be deposited in the form of the crud (Chalk River Unidentified Deposits, CRUD) on the surface of the fuel cladding where the temperature is high and boiling occurs. Boiling occurs at the upper part of the fuel where the coolant enthalpy has increased sufficiently, so that the crud is predominantly deposited there. As the thickness of the crud is increases, the heat transfer from the cladding to the coolant decreases, increasing the cladding surface temperature and causing the coolant dry out. At this time, boron in the coolant is accumulated in the crud pores. This boron causes deformation of axial power distribution. As this result, the difference between the AO (Axial Offset, WH type) or ASI (Axial shape index, CE type) measurements and the design values is more than 3 percent is called Axial Offset Anomaly (AOA)[1].

As the environment in which the crud is deposited is well established, for example, extending of the reactor operating cycle length, replacement of old steam generators and zinc injection for reduction of occupational radiation exposure, the significance of the AOA risk assessment emerged[2]. If the AOA risk is predicted to increase, measures that can reduce the risk such as core design change or ultrasonic fuel cleaning (UFC) are needed. However, if the AOA risk assessment results do not accurate, the safety margins may be lowered due to the failure to take appropriate action. This paper describes the development of a new methodology to improve the accuracy of AOA risk assessment and its effects.

2. Methodologies

2.1 Existing Methodology

Fig. 1 is an existing methodology of AOA risk assessment. The core average axial and radial power distributions in accordance with time steps are carried over from the nuclear design code (ANC) to the sub-channel thermal hydraulic analysis code (VIPRE)[3]. VIPRE passes thermal hydraulic data, such as pressure, temperature, heat flux and coolant density, to BOA (Boron-induced Offset Anomaly) that is water chemistry analysis code developed by Electric Power Research Institute. BOA code calculates the crud source term, subcooled nucleate boiling, crud precipitation mass and thickness. Finally, this code produces the mass of boron deposited in crud to predict the degree of AO deviation. The amount of boron deposition according to the degree of AO deviation was predetermined by conducting neutronics code simulation.

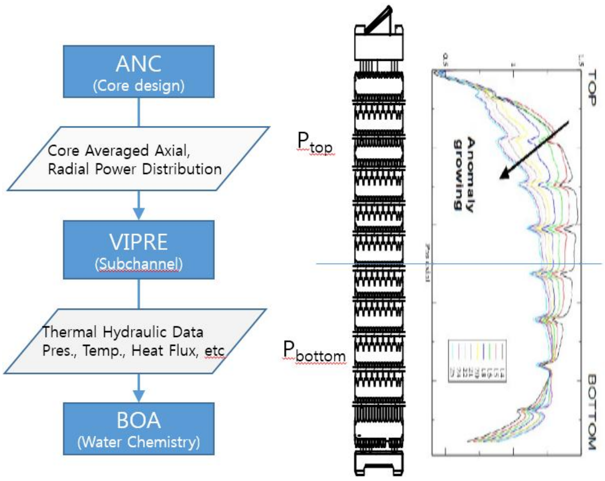

Fig. 1 Flow Chart of Existing Methodology

It can be predicted that the anomaly will grow if the boron deposition mass increases. However, this prediction assumes a steady-state power distribution. So if the distribution is different from the design value, it cannot be predicted properly. Like this, the one-way procedure has several disadvantages. First, cannot apply changes of the power distribution and burnup distribution. For example, the power and burnup at boron deposited region are reduced while they are increased in the other region, but it does not reflect to the distributions. Second, the prediction is possible only in case that the power distribution is shift downward because boron precipitation appears only in the upper part of the fuel (second ~ third grid span from top of the fuel). To overcome these disadvantages, a new methodology was developed.

2.2 New Methodology

The difference from the previous methodology is that the boron mass as a result of BOA is applied to the nuclear design code and the BOA recalculates to reflect the change of the power distribution. If the boron deposition is converged by iteration, the AO from the nuclear design code is also converged. This methodology can reflect change of the power and burnup distribution. It is also possible to predict the power shift upward. Fig.2 is calculation flow chart of the new methodology.

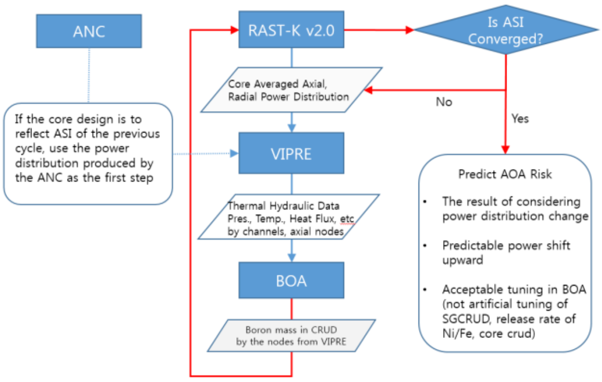

Fig. 2 Flow Chard of New Methodology

The RAST-K, used as the nuclear design code, has the following features.

1) Developed by KHNP to analysis core depletion and transient,
2) Verified through the comparing with ANC and measured values,
3) Simulate boron deposition and boron depletion,
4) ASI adaptation function to enhance core design accuracy of the following cycle,
5) Simplified Self-model for crud and boron deposition without BOA code

The most important feature of using the RAST-K for the new methodology is that it can simulate the boron deposition layer. And he ANC cannot add boron at the outside of the cladding, and KHNP cannot improve the code through source code modification, so the RAST-K code is used.

2.3 Comparative Evaluation

For the specific cycle of the OPR-1000 nuclear power plant, the results of the existing methodology and the new methodology were compared. Comparing the axial power distribution at middle of cycle in Fig. 3, it is shown that the power of the upper part of the core has decreased due to boron deposition.

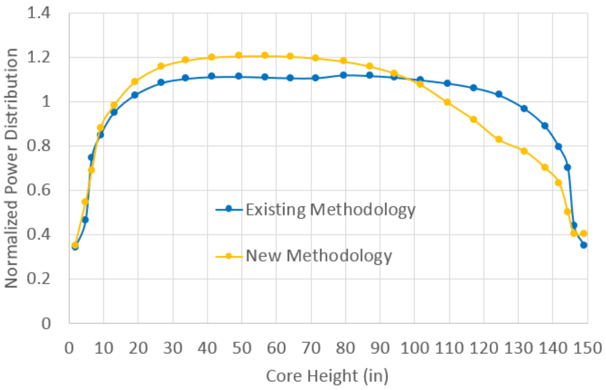

Fig. 3 Axial Power Distribution

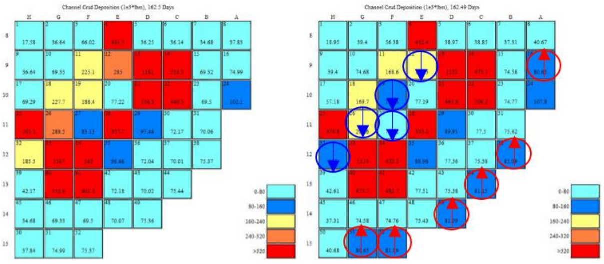

Fig. 4 Crud precipitation mass for each fuel assembly (Left: Existing, Right: New)

Fig.4 shows the amount of crud precipitation for each fuel assembly. The power of boron-deposited high duty fuel assemblies is reduced and the power of the other fuel is increased relatively. So crud mass is changed as shown on the right in Fig.4. Because of these effects, the variation of the axial and radial power distribution changes the amount of precipitation of crud and boron, and eventually the AOA risk changes.

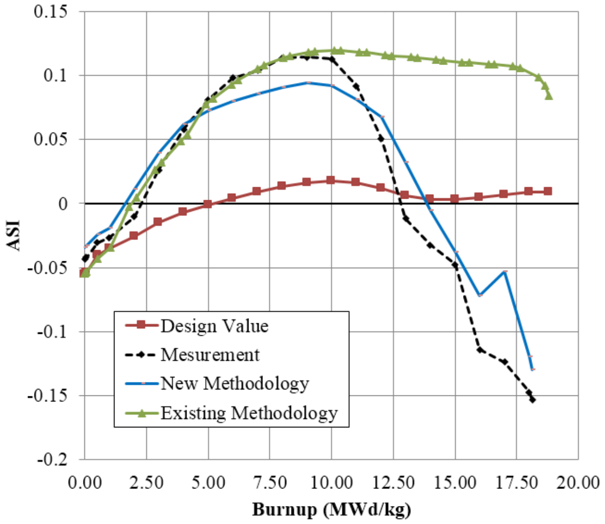

Fig. 5 OPR-1000 ASI benchmark results

Fig. 5 is the results of benchmarking measured ASI data. A positive value indicates that the power at lower part of the core is larger than lower part, and a negative value is the opposite. The ASI evaluated by the new methodology was found to follow the measured value better than the value evaluated by the existing methodology. It is well simulated that the power distribution is shifted toward the upper part of the core after middle of the cycle as much burnup of lower part occurs at the beginning of the cycle.

3. Conclusions

Currently, the degree of AOA risk for all domestic power plants is assessed by the existing methodology. In particular, the crud formation and precipitation characteristics are modeled very detailedly and accurately in BOA code through many experimentation and experience. Therefore, most of the assessment results can be predicted similarly to the measurements. The cycle in which AOA can occur prevents it by performing ultrasonic or chemical cleaning during the overhaul period or by increasing letdown flow rate during operation. However, if severe AOA occurs and the power distribution differ significantly from the design value, accuracy of the prediction may be reduced. If AOA risk is expected to increase, the new methodology can improve accuracy of AOA risk prediction by reflecting changes in the distributions due to boron deposition in crud, and secure safety margins by preparing appropriate measures.

REFERENCES

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