Improvement of Axial Shape Index Prediction of STREAM/RAST-K by Considering the Moderator Temperature History

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1. Introduction

STREAM2D/RAST-K two-step code has been developed in UNIST CORE lab and its capability of PWR analysis has been verified and validated [1]. And 3D neutron transport code STREAM3D also has been developed, which can perform the direct whole core analysis [2]. However, even though STREAM2D and STREAM3D use the same cross-section from PSM resonance treatment method [3], there was a mismatch of the axial shape index (ASI) from STREAM3D and RAST-K. The objective of this work was to identify the reason of the inconsistency and improve the accuracy of STREAM2D/RAST-K two-step analysis as direct whole core analysis of STREAM3D without any tuning technique.

In case of the PWR-based cores with high thermal power, the axial moderator temperature has a gradually increasing axial temperature profile while the moderator flows upward from bottom to top of the core. And this moderator temperature distribution affects the local depletion behavior of the core axially.

In this work, STREAM2D/RAST-K cross-section model was modified to predict axial depletion behavior more accurately. Commercial PWR, APR-1400 analysis was performed by STREAM2D/RAST-K and compared with STREAM3D. Implemented method can improve not only the accuracy of commercial PWR analysis, but also other PWR designs having similar axial moderator temperature profile such as PWR-based SMR analysis.

2. Method and Results

In this section, current using cross-section model, feedback method of STREAM2D/RAST-K and the limitations are described. Improved method and the verification of the implemented code are presented.

2.1. Cross-section Model of STREAM2D/RAST-K

As a lattice code of two-step method, STREAM2D generates few group constants and cross-section set based on a single history at reference state. From the base calculation for the reference state, STREAM2D performs branch calculations for the various state points and saves the deviation of cross-section from the base state. The state points for the branch calculations are parameterized by fuel temperature, moderator temperature, boron concentration and position of control rod. RAST-K feedback the base cross-section by the node-wise burnup and compensates the deviation of cross-section by the state of node.

Fig. 1 shows the thermal group microscopic fission cross-section of U-235. Black solid line and red dotted line represent the base cross-section and compensated cross-section at the given, and blue dotted line represents the base cross-section generated at given state. As shown in Fig. 1, current using compensated cross-section has mismatch with the cross-section generated with the exact depletion history at given state. Due to the different depletion history, the composition of the fuel will be changed, but current using compensation method cannot predict the composition change.

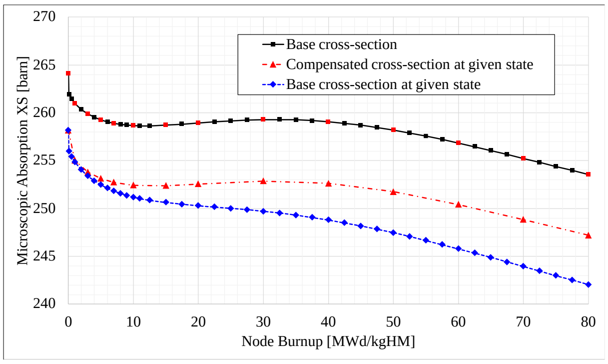

Fig. 1. Thermal group microscopic fission cross-section of U-235 against burnup

2.2. History Following Cross-section Feedback

To predict more accurate axial power distribution by reflecting on the different depletion histories, additional cross-section sets were required. Since the additional cross-section sets should represent the upper/lower region of core, maximum and minimum moderator temperature of core (with a small margin to avoid the extrapolation) were chosen for the base states.

The cross-section reflecting on the depletion behavior in given condition can be interpolated between the cross-sections generated with different depletion histories. A new history index variable was defined as Eq. (1), which represents the node-wise depletion history.

$$T_{mod}^{Hist}(k) = \frac{\sum_{i=1}^{k}(T_{mod,i} \cdot \Delta BU_i)}{\sum_{i=1}^{k} \Delta BU_i} \quad (1)$$

where k is the index of current burnup step, $T_{mod,i}$ is the node-wise moderator temperature at i-th burnup step,

ΔBU_i is the node-wise increased burnup at i-th burnup step. The above history index variable can be also treated as the node-wise burnup weighted average moderator temperature. As shown in Fig. 2, feedback of cross-section of fuel node depleted between base state 1 and 2 can be interpolated using the history index variable in Eq. (1).

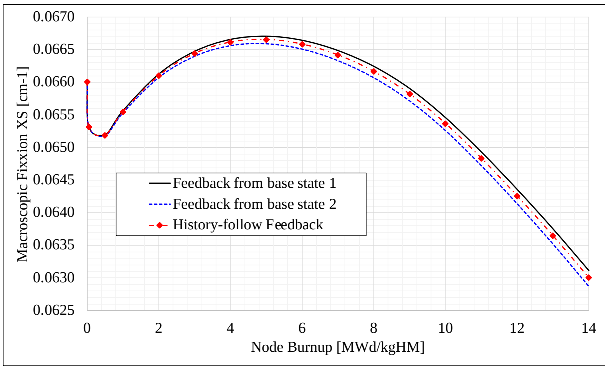

Fig. 2. History-follow cross-section feedback

By using the improved cross-section feedback method, it was possible to track the axial depletion history and expect more accurate analysis. Especially, the accuracy increase of ASI prediction was expected. ASI can be calculated as following Eq. (2).

$$ASI(-) = \frac{P_{bot}-P_{top}}{P_{bot}+P_{top}} \qquad (2)$$

2.3. Commercial PWR Core Analysis

To verify the modified cross-section feedback method, commercial PWR core analysis was performed with STREAM2D/RAST-K using current cross-section feedback method and modified cross-section feedback method. The reference results were generated with the direct whole core analysis code STREAM3D. Comparable variables were critical boron concentration (CBC) and ASI. Table 1 summarizes the design parameters of compared model.

Table 1. Design parameters of model

Parameter	Value
Reactor Type	APR-1400
Thermal Power [MWth]	3983
Number of FA	241
Fuel Active Height [cm]	381
Core Pressure [bar]	155.11
Inlet Coolant Temp. [K]	290.6

Fig. 3 and Fig. 4 show CBC of APR-1400 calculated using current cross-section feedback method and modified method. The black solid line with circular mark represents the reference data generated by STREAM3D. The dotted blue/red line with triangular/rectangular mark represent the RAST-K prediction using current using cross-section method and modified method. Even if the cross-section feedback method was modified, difference of CBC prediction between current method and modified method were less than 3 ppm at every burnup step. Since the depletion history affected oppositely for upper/lower region of core, the effect on CBC which controls the core level reactivity was balanced.

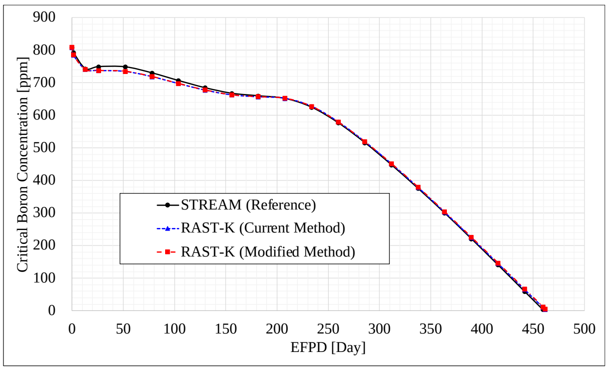

Fig. 3. Critical boron concentration of APR-1400, Initial core

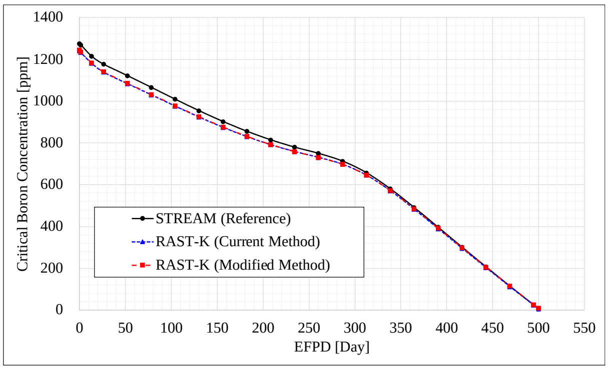

Fig. 4. Critical boron concentration of APR-1400, Cycle 3

Fig. 5 and Fig. 6 show ASI of APR-1400 calculated using current cross-section feedback method and modified method. In case of current using cross-section feedback method, all nodes feedback cross-section from the multi-group constants set generated by a single base state, which means all nodes follow the same depletion history. So, the axial power distribution gradient due to the depletion effect would be underestimated. As shown in Fig. 5 and Fig. 6, ASI predicted by RAST-K using current cross-section feedback method has relatively gentle gradient compared to the reference data. In contrast, ASI predicted by RAST-K using the modified method has gradient as steep as the reference data.

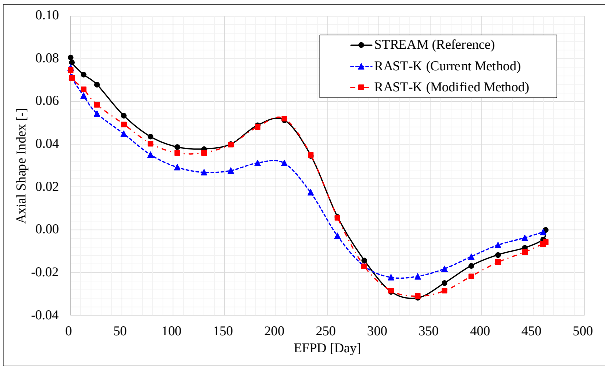

Fig. 5. Axial shape index of APR-1400, Initial Core

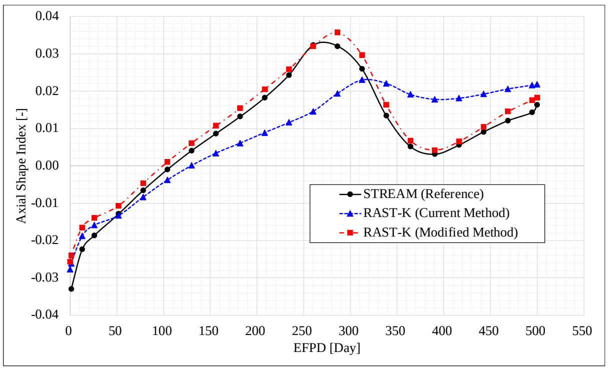

Fig. 6. Axial shape index of APR-1400, Cycle 3

As shown in Table 2, by the adoption of history following cross-section feedback method, due to the increased size of handling dataset and complexed calculations, cross-section feedback time became 84.1% longer and total simulation time became 48.6% longer. This increase of simulation time can become significant for the repetitive executions. The reduction of simulation time by optimization of task should be done.

Table 2. Simulation time of RAST-K

(Unit: sec)

Parameter	Current Method	Modified Method
Total Simulation	916.6	1362.1
Initialization	89.8	165.4
Cross-section Feedback	298.1	623.8
TH Feedback	38.0	39.4
Depletion	243.9	255.0

3. Conclusions

Even though STREAM2D and STREAM3D use the same cross-section from PSM resonance treatment method, the inconsistency of axial power prediction between RAST-K and STREAM3D appeared. To improve the axial power prediction of RAST-K as STREAM3D, moderator temperature history following cross-section feedback method was implemented in RAST-K. By the adoption of history following cross-section feedback method, the axial nodes could reflect the depletion behavior at higher/lower moderator temperature condition. Power feedback for the lower and upper region of the reactor core became more accurate, and eventually ASI prediction by STREAM2D/RAST-K was improved. At the same time, the increase of simulation time was significant that study of simulation time reduction would be the priority.

ACKNOWLEDGEMENTS

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