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Improvement of Axial Power Distribution Control through Increase Overlap of Lead Bank in APR1400 Nuclear Power Plants using HIPER16 Fuel

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1. Introduction

The APR1400 plants encounter issues due to their restricted ASI operational range in the low power region. Consequently, they may face problems to impose constraints on the rate of power increase for a defined period during reactor restart after unplanned shutdown.

The Technical Specification stipulates that the ASI (Axial Shape Index), which monitors axial power distribution in APR1400 nuclear power plants, must be maintained within a limit range of ±0.27 for power level exceeding 20%. Furthermore, the PDIL (Power Dependent Insertion Limits) delineated in the Technical Specifications. To ensure the validity of safety analysis results, operation must adhere to the Technical Specifications' ASI limits, PDIL, and pre-defined overlaps (40%).

The increase overlap is proposed to solve the upper-shifted axial power distribution control problem due to the situation where it is difficult to control ASI such as power reduction, power perturbations caused by RPCS (Reactor Power Cutback System) operation, unexpected shutdown & restart, end of cycle power reduction operation for cycle end, and deliberated power reductions to comply with Technical Specifications. [1].

2. Overview of Increase Overlap

For optimal control of axial power distribution in APR1400 nuclear power plants using increase overlap, it is proposed to modify to the operational range of the control rod assemblies as follows.

- If all the following conditions are met, the distance between the control rod insertion positions for control rod assembly group 4 and 5, as described in the Technical Specifications, may be shortened.
  - Control rod assembly group 4 and 5 must not insert beyond their Power Dependent Insertion Limits (PDIL).
  - Control rod assembly group 4 is located between 60 inches and 150 inches in the core.
  - Control rod assembly group 5 is located at least 10 inches lower than the position of control rod assembly group 4.

The overview of increase overlap is shown in Figure 2-1.

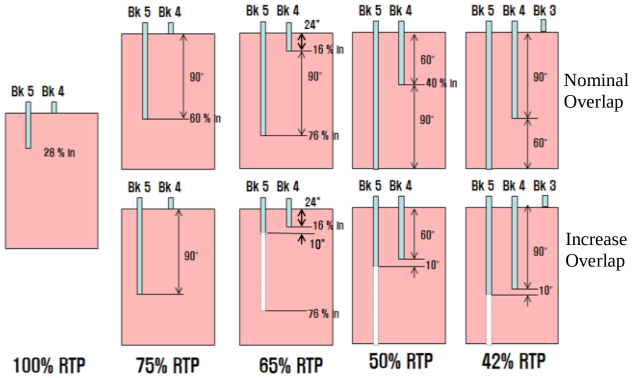


Figure 2-1 Overview of Increase Overlap

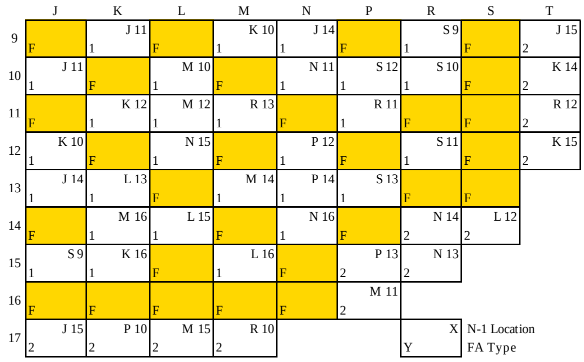
3. Core Design

The design of core was implemented using KARMA(Kernel Analyzer by Ray-tracing Method for fuel Assembly) code and ASTRA (Advanced Static and Transient Reactor Analyzer) code. The KARMA code is used for calculating 2-demensional cross-section, while the ASTRA code is utilized for 3-demensional core calculations [2][3].

To evaluate the increase overlap of the control rod assembly group 4 and group 5, an equilibrium cycle of an APR1400 core using HIPER16 fuel has been selected. The total of 97 fresh fuel assemblies were loaded in the selected core model, including a low enriched fuel assembly in the core center. The key parameter for fuel is listed in Table 3-1 [4]. The loading pattern is shown in Figure 3-1.

Table 3-1 Key Parameters for Fuel

Parameter	Design Value
Fuel Type	HIPER16 (16x16)
High Enriched U-235 (w/o)	4.65
Low Enriched U-235 (w/o)	4.10
Low Enriched U-235 for Center Fuel (w/o)	2.20
Burnable Poison	Gadoinia
Burnable Poison Enrichment (w/o)	6 or 8



Note) F: Fresh, 1: Once Burned, 2: Twice Burned

Figure 3-1 Core Loading Pattern

4. Control Strategy for Shutdown Operation

The increase overlap was implemented to control axial power distribution during end-of-cycle shutdown operation.

The comparison of nominal shutdown operation and shutdown operation adapting increase overlap of lead bank is shown in Figure 4-1. The below assumptions were used in simulation for shutdown operation.

- The nominal shutdown operation has 3%/hr power reduction rate
- The shutdown operation adapting increase overlap of lead bank has 10%/hr power reduction rate
- ASI Limits
  - > 20% Power Level : ± 0.27
  - < 20% Power Level : ± 0.57

Figure 4-1 shows the application of increase overlap of lead bank for quickly shutting down the reactor by controlling axial power distribution during end-of-cycle reactor shutdown operation for power reduction. It can be confirmed that by employing increase overlap of lead bank, the reactor can be quickly and stably shutdown while maintaining the ASI within the operation range.

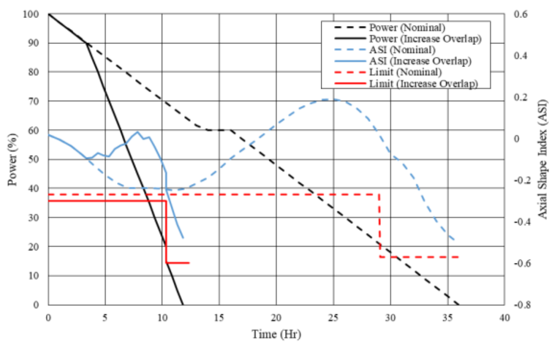


Figure 4-1 Comparison of Shutdown Operations at End-of-Cycle

5. Conclusions

The Technical Specifications for APR1400 nuclear power plants restrict the operation range of the ASI within ±0.27 at the power above 20% power. In specific scenarios, this can make it challenging to control the upper-biased axial power distribution effectively. To optimize the control of upper-biased axial power distribution in such specific scenarios, the simulation of increase overlap of lead bank was conducted.

The reduction in distance between the control rod insertion positions of control rod assembly group 4 and group 5, resulting from the application of increase overlap, facilitate the control of upper-biased axial power distribution at end-of-cycle and enables smoother execution of power reduction for reactor shutdown.

Acknowledgements

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REFERENCES

[1] D. H. Park et al., “Improvement of Axial Shape Index Control during Reactor Power Transient for APR1400,” Korea Society for Energy Engineering kosee Conference 2023.10 (2023), p265-265.

[2] K. S. Kim et al., “Transport Lattice Code KARMA 1.1,” Transactions of Korea Nuclear Society Autumn Meeting (2009).

[3] T. Y. Han et al., “Verification of ASTRA Code with PWR MOX/UO2 Transient Benchmark Problem,” Transactions of Korea Nuclear Society Autumn Meeting (2010).

[4] S. Y. Jeon et al., “Design Characteristics Of HIPER16™ Fuel Assembly For OPR1000 And APR1400,” International congress on advances in nuclear power plants 2023.04 (2013), p1234-1240.