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The Determination of the Pin Power Distribution in the KALIMER-600 Core

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1. Introduction

A pin power distribution in an assembly is very important for estimation of hot spot or local power spikes. From the safety viewpoints, it is important to guarantee those values do not exceed the design limit. Recently designed 600 MWe KALIMER-600 core[1] has no blanket assemblies and fuel assemblies with a single enrichment. The driver fuel region was classified into three different fuel assembly(FA) types. Burnable absorbers, neutron streaming tubes and moderator rods are introduced to reduce the power peaking factor to control power distribution caused by a single enrichment. It is expected to have a larger power gradient in the KALIMER core than in an ordinary core in which the reactor core has differently enriched zones to control power distribution.

In the method for power reconstruction which is adapted for our calculation, detailed pinwise power distributions can be determined by superposing detailed inner assembly form functions on a smoother intra-nodal shape function. An assembly form function is derived from single assembly calculations, and intra-nodal power shapes are derived from nodal solutions obtained using nodal fluxes and surface currents. Through investigating the influence of various replacement rods, we tried to the calculation of the form function by varying the number and different kinds of non fuel rods and find the guide line for future core design.

2. Core Design Approach

2.1 Nuclear Design and Analysis Methodology

The nuclear evaluation process was initiated by the generation of regionwise microscopic cross sections, based upon the self-shielding f-factor approach. Composition-dependent, regionwise microscopic cross sections were generated by utilizing the effective cross section generation module composed of the TRANSX and TWODANT codes. Cell homogenization over each region was performed to obtain the cross section data for a homogenized mixture. The neutron spectra for collapsing the cross section data to fewer group libraries was obtained from the S_N approximation flux solution calculations for a two-dimensional reactor model as desired. Fuel cycle calculations were carried out with the neutron flux and burnup calculation module consisting of the DIF3D[2] and REBUS-3[3] codes. In addition to the diffusion code as the standard calculation method, the MCNP code calculations based on the Monte Carlo theory were performed to compare the diffusion calculation.

3. Core Performance Analysis

3.1 Core Description

The hexagonal driver fuel assembly consists of 271 fuel rods within a duct wrapper. The rod outer diameter is 0.85cm and the wire wrap diameter is 0.14mm. The duct wall thickness is 3.7mm and the gap distance between ducts is 4mm. These design values give the assembly pitch of 17.878cm. Figure 1 shows the selected core configuration. The core configuration is a radially homogeneous one that incorporates annular rings with a single enrichment. The active core consists of three driver fuel regions (i.e., inner, middle, outer core regions) and three annular core regions have 114, 114, and 108 fuel assemblies, respectively. To suppress the power peaking factor, 12 B_4C absorber rods, 4 moderator rods and 18 neutron steaming tubes are introduced in the inner core and 15 neutron streaming tubes are only applied to the middle core without B_4C absorber rods. In the outer core, no B_4C absorber rod and neutron streaming tube(dummy rod) are introduced.

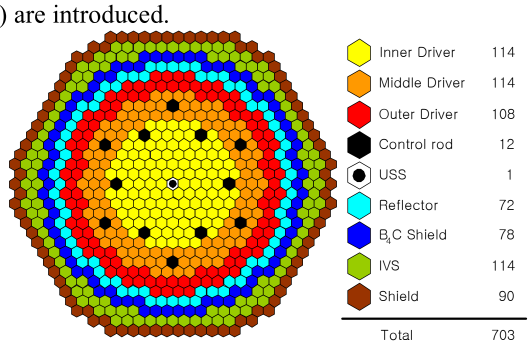

Figure 1. KALIMER-600 Core Layout

Table 1 shows the description of the cases considered for analyses. The cases are considered to investigate the effect of the number of rods and kinds of non fuel rods. The case-2 and the case-3 is the assembly used in the inner core and the middle core of the K-600 core. The case-1 is selected for the comparison of the case-2 to get the effect for the moderator rods. The case-4 is selected for the effect of B_4C rods and the case-5 is selected for the effect of the dummy rods. Finally the case-6 is selected for the effect of adding of the moderator(ZrH_2) rods.

Table 1. Cases considered for analyses

No. of rods	B_4C	dummy	ZrH_2	fuel
Case-1	12	18	0	241
Case-2	12	18	4	237
Case-3		15		256
Case-4	18			253
Case-5		54		217
Case-6		48	6	217

3.3 Pin Power Reconstruction

The current KALIMER-600 breakeven core is designed to use a single enrichment fuel concept to increase the proliferation resistance. A special fuel assembly design for controlling the high power peaking factor due to a single fuel enrichment is required. The power fluctuation near non fuel rods is expected in the concept using the non fuel rods for power control. To consider its heterogeneity, the concept of form function is introduced and investigated its influence of the non fuel rods which are inserted inside fuel assemblies.

The process for determination of pin power is summarized in the following. The nodal hexagonal option of the DIF3D/REBUS-3 code system was used for node average information. Homogenous intranodal distributions of power are efficiently computed using polynomial shapes constrained to satisfy the nodal information. Powers of individual fuel pins in a heterogeneous assembly are determined using these homogenous intranodal power distributions and the form functions obtained from the single-assembly lattice calculations.

Table 2 gives the results for the assembly calculation. The preliminary calculations show that the power ratio vary according to the variation of the pattern of the replacement rod position. Therefore, to get a minimum power ratio the non fuel rods should be located as uniformly as possible. The DIF3D calculation was done with homogenous model as the basic calculation method. The Monte Carlo calculation code MCNP was used with homogenous model and heterogenous mode for comparison with the diffusion results. As seen from Table 2, the relative pin power ratios of cases with moderator rods are more than 10 times larger than those of cases with non fuel rods. It can be understood that the softened neutron spectrum due to ZrH_2 rods enhances the probability of fission reaction. It seems that the non fuel rods do not increase the peripheral power. The number of moderator rods does not seem to relate to power increase. The transport effect appears to be large in all of the cases but the relative pin power ratio in non fuel case, small. The moderator case shows a large pin power ratio. So, in case of using moderator rods the transport code seems to be required to generate the form function.

Table 2. Relative pin power ratio

Peak Pin %	DIF3D Homo	MCNP Homo	MCNP Hetero
Case-1	0.3	0.6	0.7
Case-2	2.2	6.6	6.7
Case-3	0.02	0.5	0.3
Case-4	0.2	0.6	0.4
Case-5	0.04	0.18	0.2
Case-6	1.4	4.9	4.7

4. Conclusion

The pinwise power distribution in the assembly using single enrichment fuel with non fuel rods is determined combining homogeneous intranodal power distribution with form functions obtained from the single-assembly lattice calculations.

The calculation results show that in case of inserting moderator rods the maximum pin power difference is approximately 7% and in case of other non fuel rods, the maximum pin power difference is less than 1%. From these results, if moderator rods are not used in fuel assembly, it is allowable to calculate the pin power distribution without the production of form function with the assumption of uncertainty 1%. However, if moderator rods are used, the form function should be prepared through the transport calculations.

Acknowledgments

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