Reconstruction of Pin Power for KALIMER-600 Core of a Single Enrichment

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1. Introduction

The KALIMER-600 core of 600 MWe with no blanket assemblies and fuel rods of a single enrichment was designed. The driver fuel region was classified into three different FA types. Burnable absorbers, neutron streaming tubes and moderator rods are introduced to reduce the power peaking factor to control the power peaking factor caused by a single enrichment, but this core is expected to have larger power gradients than the ordinary core in which the reactor core have a different enriched zones to control power distribution. Therefore, it is expected to have a lot of heterogeneous power shape fluctuation inside a driver assembly. So to investigate the influence of these replacement rods for power distribution inside an assembly, we have attempted the calculation of power reconstruction for this core. The methods used to recover detailed pinwise information from coarse reactor representations, usually referred to as reconstruction methods, have reached a high level of development for light water reactors(LWRs) and liquid metal reactors. These reconstruction methods have become standard analysis tools because they extend the usefulness of computationally efficient nodal schemes and eliminate the need to perform full-core fine mesh computations. All these intuitively assume that the detailed flux shape in an assembly can be approximated by superposing detailed inner assembly form functions on a smoother intra-nodal shape function. The assembly form function is derived from the single assembly calculations, and the intra-nodal power shapes are derived from the nodal solution consisting of nodal fluxes and surface currents.

2. Core Design Approach

2.1 Nuclear Design and Analysis Methodology

All the nuclear designs and evaluations were performed with the nuclear calculation module packages in the K-CORE System[1]. The evaluation procedure for the nuclear design and analysis consists of three parts: a neutronics cross section generation, a flux solution and the burnup calculation, and reactivity calculation. 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. Various reactivity feedback effects and neutron kinetics parameters were calculated by utilizing the codes.

3. Core Performance Analysis

3.1 Core Description

The reference core is designed based on the fuel rod/assembly designs of KALIMER-150. The active core height is 100cm. 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 rod outer diameter is increased from that of KALIMER-150 (i.e., 0.75mm) in order to increase the breeding ratio. 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. The upper gas plenum to fuel ratio is set to 1.75 to accommodate the fission gas pressure buildup. 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. There are 12 control assemblies, 1 ultimate shutdown system (USS) assembly, 72 reflector assemblies, 168 shield assemblies and 114 in-vessel storage (IVS) assemblies. The center assembly is the USS control assembly. The active core height is 100.0 cm and the radial equivalent core diameter (including control rods) is 500.31 cm. The core structural material is HT9M. 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 are introduced.

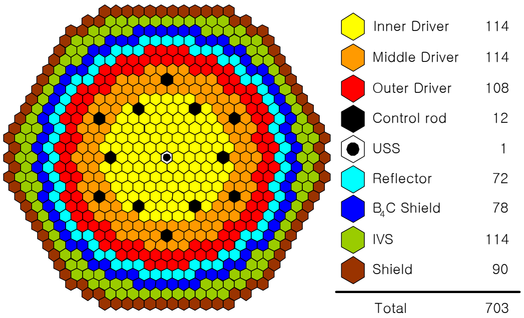

Figure 1. KALIMER-600 Core Layout

3.2 Nuclear Performance Analysis

Neutronic results and principal nuclear performance parameters for the equilibrium core were obtained from the equilibrium cycle mode calculations. The burnup reactivity swing, i.e., reactivity loss per refueling cycle due to metallic fuel burnup is 59 pcm. The average discharge burnup for the driver fuel was estimated to be 81.7 MWD/kg. The power peaking factors for the driver fuel at BOEC and EOEC are 1.45 and 1.46.

3.3 Pin Power Reconstruction

The preliminary calculation tried to perform for the assembly in the third row at BOEC. First, the nodal hexagonal option of the DIF3D/REBUS-3 code system was used for node average information. Second, the homogenous intranodal distributions of power are efficiently computed using polynomial shapes constrained to satisfy the nodal information. The powers of individual fuel pins in a heterogeneous assembly are determined using these homogenous intranodal power distribution and the form functions obtained from the single-assembly lattice calculations. The results of intra-nodal power shape derived from the nodal solution show that maximum power ratio, pin power divided by average pin power in the assembly, is below 1% so that the influence of heterogeneous effect in the assembly concerning the intra nodal power can be negligible, but the results of the single assembly calculation show the different phenomena as it is expected because of a lot of heterogeneous effect. Figure 2 gives the results for the assembly calculation in the third row. As for the assembly calculation, the power ratio varied according to the variation of the pattern of the replacement rod position. As seen from the results of Figure 2, which is the one of pattern investigated, the maximum power ratio is 1.243 and minimum one is 1.106, that means the value in near central position is 12% larger than one in peripheral position but the ratio can be depressed to the level of 4% in the case that the moderator rods are located in the peripheral position.

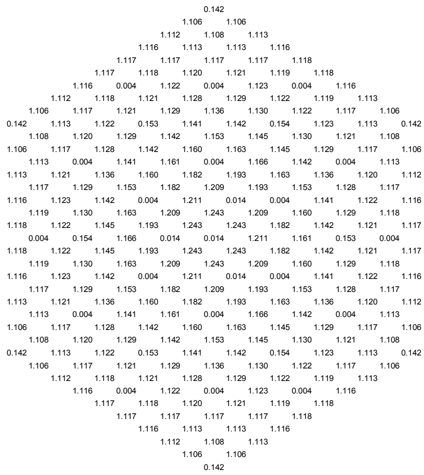

Figure 2. Relative Pin Power Ratio

4. Conclusion

The selected KALIMER-600 breakeven core has an average breeding ratio of 1.005 and average discharge burnup of 82 MWD/kg. The power of individual fuel pins in a heterogeneous assembly is determined using homogeneous intranodal power distribution and the form functions obtained from the single-assembly lattice calculations. The preliminary results show that the maximum power ratio is 1.243 but it is confirmed that this value can be reduce according to the variation of position of non fuel rods and therefore it is expected to need a repeated future calculation for the low level of power peaking as possible in the assembly.

Acknowledgments

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