Nuclear Design of a Na Cooled KALIMER-600 Core of a Single Enrichment

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1. Introduction

With the goal of adopting single enriched fuel rods, it was possible to design a core that does not have any blanket assemblies at all and also achieve a single enrichment. To control the power peaking factor caused by a single enrichment, the driver fuel region was classified into three enrichment zones. Burnable absorbers and neutron steaming tubes are introduced to reduce the power peaking factor. After extensive trials and errors by varying the number of replacement tubes, a final core, meeting the design ground rules, was selected.

2. Core Design Approach

2.1 Nuclear Design Basis and Ground Rules

Core design requirements embracing core design criteria and restraints for metal fuel were made based on the metal fuel database currently available. The following requirements guided the nuclear design basis and ground rules: The reactor power shall be 1500 MWt. The capacity factor shall be 85 %. The peak linear power shall be less than 440 W/cm (13.5 kW/ft). The local fuel burnup limit shall be 150 MWD/kg. The peak fast fluence shall be less than 4.0 x 10^{23} n/cm^2. The breeding ratio should be near 1.00 and the allowable burnup reactivity swing should be around 1000 pcm.

2.2 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 K-CORE System is an interactive, integrated modular program. The K-CORE System is under development as a standard analysis system at KAERI for the core design and performance analysis. 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[2] and TWODANT[3] 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 SN 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[4] and REBUS-3[5] codes. Various reactivity feedback effects and neutron kinetics parameters were calculated by utilizing the codes.

3. Core Performance Analysis

3.1 Core Description

The breakeven core configuration is shown in Fig. 1. The core configuration utilizes a radially homogenous core configuration that is divided into 3 zones. The core layout consists of 114 inner driver fuel assemblies, 114 middle driver fuel assemblies, 108 outer driver fuel assemblies, 12 control rods, 1 ultimate shutdown system(USS) assembly self-actuated by a curie point electromagnet, 72 reflector assemblies, 168 shield assemblies, and 114 in-vessel storages(IVSs). 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 511.62 cm. The core structural material is HT9, with low irradiation swelling characteristics which permits an adequate nuclear performance.

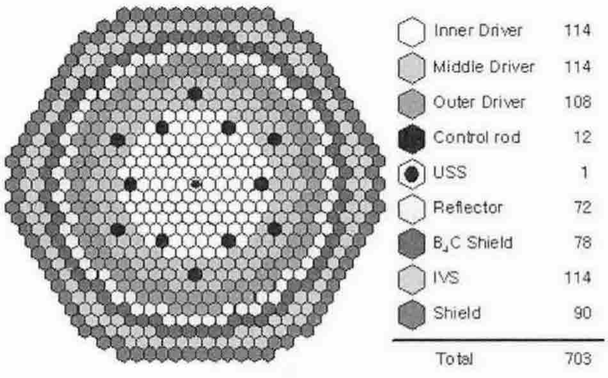

Figure 1. KALIMER-600 Core Layout

3.2 Nuclear Performance Analysis

Neutronic results and principal nuclear performance parameters for the equilibrium core were obtained from the equilibrium cycle mode calculations. One-fourth of the driver fuels are refueled at each outage. The reprocessing strategy assumed 0.1% of TRU loss during a heavy metal fuel reprocessing, based on the integral fuel cycle. For the fission product removal, it was assumed that 5% of the rare-earth (RE) fission products were recycled, whereas all the other fission products were moved to the waste stream. The IVSs were loaded with the spent fuels discharged from the driver fuel for a one cycle cooling according to the fuel management scheme before their eventual removal from the reactor. Driver fuel feed enrichment requirements were determined from the flux and burnup calculations to guarantee a hot full power criticality (i.e., keff = 1.002) at the beginning of the equilibrium cycle (BOEC).

Table 1. Summary of the Nuclear Performance

Average Breeding Ratio	1.007
Refueling Intervals (months)	22
Burnup Reactivity Swing (pcm)	-98
Average Fuel Assembly Burnup (MWD/kg)	74.8
Peak Discharge Fast Fluence (10^{23} n/cm^2)	3.70
Peak Fuel Discharge Burnup (MWD/kg)	117.0
Power Peaking Factor(BOEC/EOEC)	1.42/1.43
Charged Fissile Pu(kg/cycle)	979
Sodium Void Effect(EOEC, $)	7.2
Total Beta-effective(BOEC)	0.00356

The nuclear performance parameters for the equilibrium core are summarized in Table 1. The burnup reactivity swing, i.e., reactivity loss per refueling cycle due to metallic fuel burnup is -98 pcm and it corresponds to -0.3 $. The burnup reactivity swing is determined by the core neutronic performance and it directly affects the performance and manipulation of the control system. Hence the low burnup reactivity loss leads to reduced control system manipulations as well as to a decrease in the reactivity addition available to a potential control rod-ejection accident. The batch-averaged assembly burnup for the driver fuel was estimated to be 74.8 MWD/kg. The local peak fuel discharge burnup of 117.0 MWD/kg at an eventual removal from the reactor after a one cycle cooling in the IVS location meets the design criteria for the peak burnup limit of 150 MWD/kg. Global reactivity feedbacks resulting from the Doppler effect, uniform radial expansion, and various sodium voidings in the equilibrium core were calculated using a series of neutron flux solution calculations for the trigonal-z geometry representation.

4. Conclusion

The selected KALIMER-600 breakeven core has an average breeding ratio of 1.007 and a maximum discharge burnup of 117 MWD/kg. The neutronic performance analysis based on the equilibrium cycle calculations shows that the KALIMER-600 breakeven core is satisfactorily designed to achieve the design goal of a breeding ratio under the design criteria.

Acknowledgments

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