

# A Feasibility Study for Na Cooled KALIMER-600 Core of a Single Enrichment

Hoon Song, Sang-Ji Kim, Yeong-Il Kim

Korea Atomic Energy Research Institute 150 Dukjin-dong, Yusong-gu, Taejeon 305-353, Korea, [hsong@kaeri.re.kr](mailto:hsong@kaeri.re.kr)

## 1. Introduction

To meet the goals of GENERATION-IV, the KALIMER-600 core of 600 MWe with no blanket assemblies and fuel rods of a single enrichment was designed. To control the power peaking factor caused by a single enrichment, the driver fuel region was classified into three different FA types. Burnable absorbers, neutron streaming tubes and moderator 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 1525.3 MWt. The capacity factor shall be 85 %. The local fuel burnup limit shall be 150 MWD/kg. The peak fast fluence shall be less than  $4.0 \times 10^{23}$  n/cm<sup>2</sup>. The breeding ratio should be near 1.00 and the allowable burnup reactivity swing should be around 1000 pcm. The average discharge burnup shall be more than 80 MWD/kg. The operation cycle length shall be more than 18 months.

### 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 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  $S_N$

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[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

Charged with identical fuel rod with the same enrichment, the power peaking is expected to be high in the core center. To surpass the power peaking factor due to single enrichment, several replacement rods, such as burnable absorbers, moderator tubes, neutron streaming tubes, were introduced to replace some fuel rods in fuel assembly. After extensive trials and errors by varying the number of replacement rods, a final core meeting the design ground rules was selected. 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.

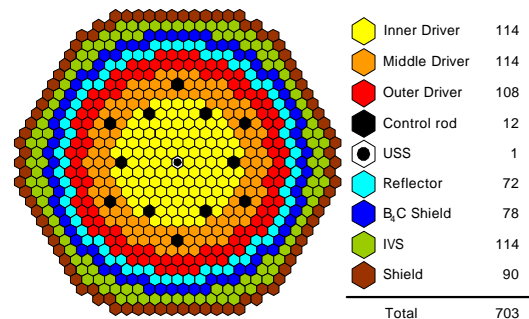


Figure 1. KALIMER-600 Core Layout

### 3.2 Nuclear Performance Analysis

Neutronic results and principal nuclear performance parameters for the equilibrium core were obtained from the equilibrium cycle mode calculations. It is worthwhile to note that top/bottom cutback zones are applied to the burnable absorbers to reduce the fast neutron fluence, which is a limiting design constraint in the design ground rules. The length of cutback is 22 cm from the top of active core and the bottom of active core. One-fourth of the fuel inventory in each core region is replaced during each outage. The reprocessing strategy assumed 0.1% of TRU loss during a heavy metal fuel reprocessing, based on the integral fuel cycle. 5% of the rare-earth (RE) fission products and 99.9% of transuranics were assumed to be recycled while the other fission products are assumed to be gone to waste stream. The assumed reprocessing scheme is the pyro-processing. 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. The fuel assemblies are not shuffled, but remain in their fixed positions for entire cycles. Driver fuel feed enrichment requirements were determined from the flux and burnup calculations to guarantee a hot full power criticality (i.e.,  $k_{eff} = 1.002$ ) at the end of the equilibrium cycle (EOEC).

Table 1. Summary of the Nuclear Performance

|   |           |
|---|-----------|
| Average Breeding Ratio                                      | 1.005     |
| Operation Cycle Length (EFPM)                               | 18        |
| Fuel Reload Batch (batches)                                 | 4         |
| Burnup Reactivity Swing (pcm)                               | 59        |
| Average Discharge Burnup (MWD/kg)                           | 81.7      |
| Peak Discharge Fast Fluence ( $10^{23}$ n/cm <sup>2</sup> ) | 3.92      |
| Peak Fuel Discharge Burnup (MWD/kg)                         | 123.9     |
| Power Peaking Factor(BOEC/EOEC)                             | 1.45/1.46 |

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 59 pcm. 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 average discharge burnup for the driver fuel

was estimated to be 81.7 MWD/kg. The local peak fuel discharge burnup of 123.9 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. The power peaking factors for the driver fuel at BOEC and EOEC are 1.45 and 1.46. 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 1.005 and average discharge burnup of 82 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.

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