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Flow Groupings and Temperature Calculations for KALIMER-600 Single Enrichment Core

Y. G. Kim, S. G. Hong, Y. I. Kim
Korea Atomic Energy Research Institute
150 Dukjin-dong, Youseong, Daejeon 305-353, Korea,
Phone: 042-868-2966, Fax: 042-861-9605, E-mail: ygkim@kaeri.re.kr

1. Introduction

KALIMER-600 breakeven single enrichment core which uses no blanket has a design improvement with the target of fuel cycle length greater than 18 months and average discharge burnup greater than 80MWd/kg. The core has three zones of single enrichment fuel assemblies without any blanket assemblies. Core thermal hydraulic design and analysis were performed for this core as well as the nuclear design works. This paper describes the core configuration and nuclear design, the core thermal hydraulic characteristics and the calculation results for the KALIMER-600 single enrichment equilibrium core.

2. Core Configuration and Nuclear Design

The design targets of the KALIMER-600 breakeven core have been summarized as follows: peak fast neutron fluence less than $4.0\text{x}10^{23}\text{n/cm}^2$, breeding ratio without blanket assemblies about 1.0, fuel cycle length greater than 18EFPM, average discharge burnup greater than 80MWD/kg, burnup reactivity worth less than 1$, and sodium void reactivity worth less than 8$.

The fuel region has been divided into three enrichment zones in order to control the power peaking factor caused by a single enrichment. Moderator rods, burnable absorbers and neutron streaming tubes are introduced to reduce the power peaking factor. Figure 1 shows the configuration of this core [1].

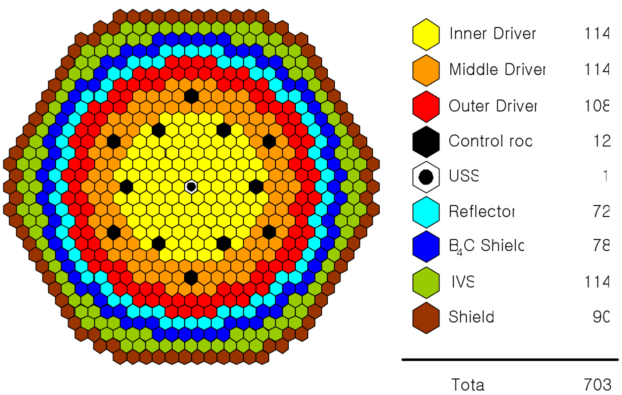

Figure 1. KALIMER-600 single enrichment core

The core has a radial homogeneous configuration which consists of 114 inner core assemblies, 114 middle core assemblies and 108 outer core assemblies. Fuel assemblies have 271 rods in the assembly duct. Inner core assemblies have 4 ZrH_4 rods, 12 B_4C rods and 18 vacancy rods and middle core assemblies have 15 vacancy rods among the 271 rods in the assembly duct. Table 1 shows the basic design data of the KALIMER-600 single enrichment core.

Table 1. Basic design data for the KALIMER-600 single enrichment core

Operating conditions	
Core thermal output (MWth)	1,523.4
Core electric power (MWe)	600.0
Net plant thermal efficiency (%)	39.4
Core inlet/outlet temperature (℃)	390.0/545.0
Total flow rate (kg/s)	7,731.3
Number of core enrichment zones	1
Feed fuel enrichments (w/o%)	14.35
Fuel form	U-TRU-10%Zr
Refueling interval (months)	20
Refueling batches (IC/MC/OC)	4/4/4
Core and fuel design parameters	
Active core height (cm)	100.0
Core diameter (cm)	500.31
Core configuration	Homogeneous
Duct inside flat to flat distance (mm)	167.38
Duct thickness (mm)	3.7
Duct gap (mm)	4.0
Pins per fuel assembly	271
Pins per fuel assembly (IC/MC/OC)	237/256/271
B_4C rods per fuel assembly (IC/MC/OC)	12/0/0
Vacancy rods per fuel assembly (IC/MC/OC)	18/15/0
$ZrH_{1.8}$ rods per fuel assembly (IC/MC/OC)	4/0/0
Pin outer diameter (mm)	8.5
Cladding thickness (mm)	0.53
Gap between wire-wrap and rod (mm)	0.1
Pin P/D ratio	1.176
Average/peak fuel burnup (MWD/kg)	79.0/123.6
Avg/peak linear power (BOEC) (W/cm)	216.2/261.8
Peak fast neutron fluence (E>0.1 MeV) ($\text{x}10^{23}\text{n/cm}^2$)	3.92
Clad material	Mod.HT9

The inlet and outlet temperatures of the KALIMER-600 single enrichment core have been modified to be 390.0℃ and 545.0℃ respectively with the use of Mod.HT9 clads in place of HT9. Because it is expected to have a clad midwall temperature limit of 650℃ for Mod.HT9 clads in place of 635℃ for HT9. The net plant thermal efficiency of this core has been enhanced to be 39.4%.

3. Flow Groups and Clad Midwall Temperatures

Sodium coolant flow has to be supplied to the assemblies based on the peak pin linear heat generation rate for their whole lifetime to ensure the structural integrity of the fuels, clads and ducts [2].

KALIMER-600 breakeven single enrichment core has 9 flow groups, i.e., 2 for inner core, 3 for middle core and 4 groups for outer core assemblies as shown in table 2. In addition to those flow groups there are 2 groups reserved: 1 for the control rod assemblies and 1 for the USS.

Table 2. Flow groups and clad midwall temperatures

Flow Group No.	Assy Type	No. of Assy	Assy Flow (kg/s)	Group Flow (kg/s)	Assembly Zone Fraction (%)	Clad Midwall (2σ) (°C)
1	IC	60	25.3	1,518.0	37.0	650
2	IC	54	24.9	1,344.6		650
3	MC	6	24.9	149.4	33.7	650
4	MC	66	23.9	1,577.4		649
5	MC	42	21.0	882.0		650
6	OC	24	19.4	465.6	21.5	649
7	OC	36	16.7	601.2		648
8	OC	12	14.0	168.0		649
9	OC	36	11.8	424.84		650

Total primary loop flow including bypass flow : 7,731.3 kg/s
Non-grouped flow fraction : 7.8%
(CR + non-fuel assemblies + inter-assembly region + IVS)

The equalized clad midwall temperature with 2σ uncertainty is estimated to be 650°C, which does not exceed the limit value in the clad midwall temperature of Mod.HT9 clad. The coolant flow fraction is as follows: 37.0% for the inner core, 33.7% for the middle core, 21.5% for the outer core fuel assemblies, and 7.8% of the primary coolant is reserved for the control assemblies, non-fuel assemblies, inter-assembly region and IVS. With the flow grouping optimization there will be a possibility to reduce the equalized clad midwall temperatures.

Core wide coolant and fuel temperature profiles are efficiently calculated using the code of the simplified energy equation mixing model and the subchannel analysis method. And the detailed subchannel analysis has been performed with MATRA-LMR. Figure 2 shows one of the calculation results on the 1/6 core configuration map.

The bundle pressure drop in the peal power assembly is estimated to be 0.163MPa with 20% uncertainty from the rough pressure drop modeling.

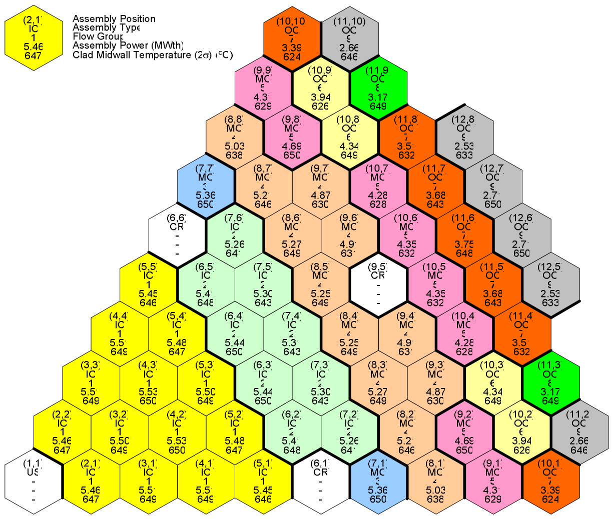

Figure 2. Flow groups and clad midwall temperatures (2σ) (1/6 Core)

4. Conclusion and Further Studies

Flow groupings and temperature calculations for KALIMER-600 breakeven single enrichment core without any blanket assemblies were performed. And the thermal hydraulic design characteristics and the calculation results of the equilibrium core were given. The core has 9 flow groups for the fuel assemblies, and the equalized clad midwall temperature with 2σ uncertainty is estimated to be 650°C. The estimated core pressure drop is 0.163MPa with 20% uncertainty. These calculation results will be served for the further nuclear and core thermal hydraulic design improvements. And the inter-assembly flow analysis will be performed to obtain the temperatures of assembly duct walls with the use of the tools which is under development.

Acknowledgement

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REFERENCES

[1] S. G. Hong et al., Core Design and Nuclear Analysis for a Na Cooled KALIMER-600 Core of a Single Enrichment, Internal Report, KAERI, 2005.
[2] Y. G. Kim et al., Thermal Hydraulic Analysis of the KALIMER-600 Single Enrichment Core, ICAPP'05, Seoul, Korea, 2005.