Thermal Hydraulic Study for a Na Cooled KALIMER-600 Core of a Single Enrichment

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1. Introduction

KALIMER-600 breakeven core of a single enrichment which uses no blanket has been designed and analyzed at KAERI. The core has three zones of single enrichment driver fuel assemblies without any blanket assemblies. Thermal hydraulic design and analysis were performed for this core as well as the nuclear design works. This paper describes the core configuration and the thermal hydraulic design characteristic and the calculation results of the KALIMER-600 single enrichment equilibrium core.

2. Core Configuration

The KALIMER-600 breakeven core of a single enrichment is shown in figure 1. To control the power peaking factor caused by a single enrichment, the driver fuel region was divided into three enrichment zones. Burnable absorbers and neutron streaming tubes are introduced to reduce the power peaking factor [1].

The core has a radial homogeneous configuration which consists of 114 inner driver, 114 middle driver and 108 outer driver assemblies. Driver assemblies have 271 rods in the assembly duct. Inner driver assemblies have 12 B_4C rods and 13 vacancy rods, and middle driver assemblies have 19 vacancy rods among the 271 rods in the assembly duct. The basic design data of the KALIMER-600 single enrichment core are given in table 1.

The inlet and outlet temperatures of the KALIMER-600 core of a single enrichment were initially 386.2℃ and 530.0℃, the same values as KALIMER-150 core. But to have more margin in the clad midwall temperature, they were changed to be 366.2℃ and 510.0℃. And to enhance the plant system efficiency, they were modified to be 370.4℃ and 545.0℃ with the use of HT9M in place of HT9. It is expected to have a clad midwall temperature limit of 650℃ for HT9M, in place of 635℃ for HT9. Finally they are now changed to be 390.0℃ and 545.0℃, respectively to have 39.4% of net plant thermal efficiency.

3. Calculation Results

Thermal hydraulic conceptual design of the sodium cooled liquid metal reactor core consists of flow grouping and coolant/clad temperature calculation, pressure drop calculation and steady-state subchannel analysis. The overall procedure which is expected to be extensively used for basic data production during the KALIMER conceptual design phase is explained in the reference [2].

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.

KALIMER-600 breakeven core of a single enrichment has 13 flow groups, i.e., 4 groups for inner driver, 3 groups for middle driver and 6 groups for outer driver assemblies as shown in table 2.

The equalized clad midwall temperature with 2σ uncertainty is calculated to be 650^{o}C, which is the limit value in the clad midwall temperature of HT9M. The coolant flow fraction is as follows: 39.4% for the inner driver, 32.3% for the middle driver, 22.3% for the outer driver fuel assemblies, and 6% of the primary coolant is reserved for the control assemblies, non-fuel assemblies, inter-assembly region and IVS.

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 [3]. This code could provide temperature maps for all pins in all assemblies and thus facilitate code-wide failure probability studies. 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 core pressure drop is calculated to be 0.253MPa with 20% uncertainty. This calculation was done with a rough pressure drop modeling, and it is expected to vary according to the assembly and orifice design.

4. Conclusion

Thermal hydraulic design and analysis of KALIMER-600 breakeven core of a single enrichment without any blanket assemblies were performed. And the thermal hydraulic design characteristic and the calculation results of the equilibrium core were given. The core has 13 flow groups, and the equalized clad midwall temperature with 2σ uncertainty is calculated to be 650^{o}C. The estimated core pressure drop is 0.253Pa with 20% uncertainty. These calculation results will be served for the further nuclear and thermal hydraulic design improvements.

Acknowledgement

This study was supported by the Korean Ministry of Science & Technology through its National Nuclear Technology Program.

REFERENCES

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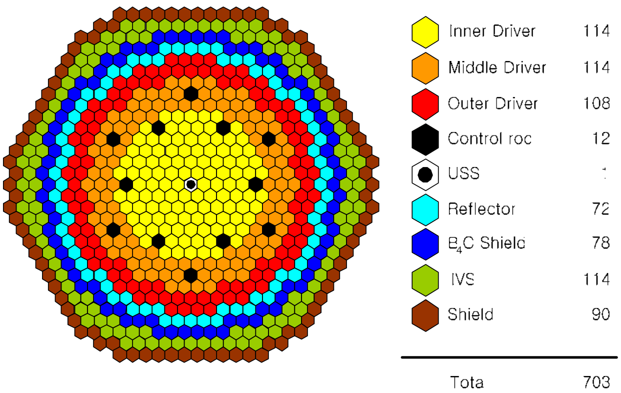

Figure 1. Configuration of the KALIMER-600 breakeven core of a single enrichment

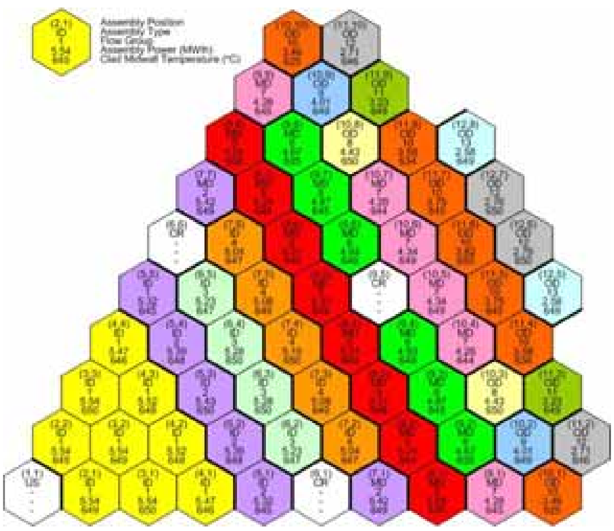

Figure 2. Flow groupings and clad midwall temperatures (2σ) (1/6 Core)

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

Operating conditions	
Core Thermal Output (MWth)	1,523.4
Core Electric Power (MWe)	600.0
Net Plant Thermal Efficiency (%)	39.4
Core Inlet/Out 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-Pu-10%Zr Ternary Alloy
Refueling Interval (months)	20
Refueling Batches (ID/MD/OD)	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
Pins per Fuel Assembly	271
Pin Outer Diameter	8.5
Pin P/D Ratio	1.176
Average/Peak Fuel Burnup (MWD/kg)	79.0/123.6
Avg/Peak Linear Power for Driver (BOEC) (W/cm)	216.2/261.8
Peak Fast Neutron Fluence (E>0.1 MeV) ($x10^{23} n/cm^2$)	3.92
Clad Material	HT9M

Table 2. Flow groupings and flow groupwise temperatures (with 2σ uncertainty)

Flow Group No.	Assy Type	No. of Assy	Assy Flow (kg/s)	Group Flow (kg/s)	Assembly Zone Fraction (%)	Clad Midwall (°C)
1	ID	36	26.4	960.4		650
2	ID	24	25.8	774.0		650
3	ID	24	25.0	600.0		650
4	ID	30	24.1	723.0		650
5	MD	48	25.2	1,058.4	39.4	649
6	MD	36	23.2	835.2		648
7	MD	30	20.2	606.0		649
8	OD	12	20.6	247.2	32.3	650
9	OD	12	18.6	223.2		649
10	OD	36	17.6	633.6		650
11	OD	12	14.8	177.6		649
12	OD	24	12.5	300.0		650
13	OD	12	11.7	140.4	22.3	649

Total primary loop flow including bypass flow : 7,731.3 kg/s
Non-grouped flow fraction : 6.0%
(CR + non-fuel assemblies + inter-assembly region + IVS)