Thermal Hydraulic Conceptual Design of KALIMER-600 Single Enrichment Core

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1. Introduction

To develop an innovative proliferation-resistant liquid metal reactor core concept in the frame of the national nuclear R&D long-term development program, KALIMER-600 single enrichment core has been designed and analyzed at KAERI. It has three zones of single enrichment driver fuel assemblies without any blanket assemblies. Thermal hydraulic design and analysis were performed of this core as well as the nuclear design works. The main purpose of the thermal hydraulic design is to distribute the core sodium coolant flow into each assembly with the overall goal of equalizing the peak cladding midwall temperatures, thus pin cladding damage accumulation and pin reliability. This paper describes the thermal hydraulic design characteristic and the calculation results of the KALIMER-600 single enrichment equilibrium core.

2. Methods and Results

Thermal hydraulic design of the liquid metal reactor core are consists of flow grouping and coolant/cladding temperature calculation, pressure drop calculation and steady state subchannel analysis. The overall thermal hydraulic design procedures which are expected to be extensively used for basic data production during the KALIMER conceptual design phase are shown in the reference [1].

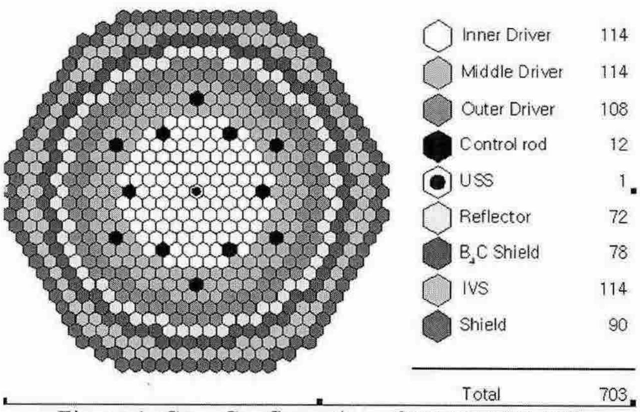

Figure 1. Core Configuration of KALIMER-600 Single Enrichment Core

Figure 1 shows the core configuration of KALIMER-600 single enrichment core. The core consists of 114 inner driver, 114 middle driver and 108 outer driver assemblies [2]. Driver assemblies have 271 rods in the 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.

Table 1. Basic Design Data for the KALIMER-600 Single Enrichment Core

Operating conditions	
Core Thermal Output (MWth)	1,589.3
Core Electric Power (MWe)	600.0
Net Plant Thermal Efficiency (%)	37.8
Core Inlet/Out Temperature (□)	366.2/510.0
Total Flow Rate (kg/s)	8,662
Number of Core Enrichment Zones	1
Feed Fuel Enrichments (w/o%)	14.40
Fuel Form	U-Pu-10%Zr Ternary Alloy
Refueling Interval (months)	22
Refueling Batches (ID/MD/OD)	4/4/4
Core and fuel design parameters	
Active Core Height (cm)	100.0
Core Diameter (cm)	511.62
Core Configuration	Homogeneous
Duct Inside Flat to Flat Distance (mm)	172.36
Pins per Fuel Assembly	271
Pin Outer Diameter	8.8
Pin P/D Ratio	1.170
Average/Peak Fuel Burnup (MWD/kg)	74.8/117.0
Avg/Peak Linear Power for Driver (BOEC) (W/cm)	211.2/248.6
Peak Fast Neutron Fluence (E>0.1 MeV) ($x10^{23}n/cm^2$)	2.04
Cladding Material	HT9

2.1 Flow Grouping

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 fuel, claddings and ducts [1]. Every assembly in the range of about a 5~10% power difference from each other is put in the same group. KALIMER-600 single enrichment core has 11 flow groups, i.e., 2 groups for inner driver, 3 groups for middle driver and 6 groups for outer driver assemblies as shown in Table 2.

2.2 Coolant and Fuel Temperature Calculation

The equalized cladding midwall temperature with 2σ uncertainty is calculated to be about 593°C as shown in Table 2. This value is below the limit value of 635°C in the cladding midwall temperature of HT9. The coolant flow fraction is as follows: 95.1% for the driver assemblies, 0.5% for the control assemblies, 2.0% for the inter-assembly and non-fuel assemblies and 2.4% for IVS.

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	72	29.0	2,088		593
2	ID	42	28.0	1,176	37.7	592
3	MD	48	28.5	1,368		590
4	MD	36	26.0	936		589
5	MD	30	23.0	690	34.5	587
6	OD	12	23.0	276		590
7	OD	12	21.0	252		587
8	OD	36	20.0	720		585
9	OD	12	17.0	204	22.9	582
10	OD	24	15.0	360		573
11	OD	12	14.0	168		572

Total primary loop flow including bypass flow : 8,662 kg/s
Total bypass flow fraction: 4.4 %

2.3 Assembly and Core Pressure Drop Calculation

The core pressure drop is calculated as 0.27MPa with 20% uncertainty, of which 0.150MPa is in the bundle part of the assembly. This calculation was done with a rough pressure drop modeling, and it is expected to vary according to the assembly and orifice design.

2.4 Steady State Subchannel Analysis

Core wide coolant and fuel temperature profiles are efficiently calculated using the simplified energy equation mixing model and the subchannel analysis method. The SLTHEN is a modified version of the SUPERENERGY2 code, which is a multi-assembly, steady-state subchannel analysis code based on the simplified energy equation mixing model [3]. And the detailed subchannel analysis has been performed with MATRA-LMR, which is developed from MATRA and COBRA-IV-I. These codes could provide temperature maps for all pins in all assemblies and thus facilitate code-wide failure probability studies. They will be extensively used during the conceptual and basic design phases. Figure 2 shows one of the results of the KALIMER-600 single enrichment core calculations in the 1/6 core model.

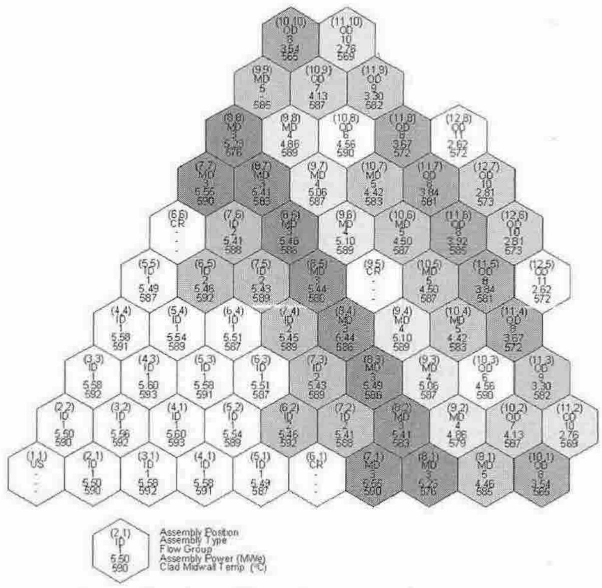

Figure 2. Flow Groupings and Clad Midwall Temperatures (2σ) (1/6 Core)

3. Conclusion

Thermal hydraulic design and analysis of KALIMER-600 single enrichment core were performed. This core has three zones of single enrichment driver fuel assemblies without any blanket assemblies. And the thermal hydraulic design characteristic and the calculation results of the equilibrium core were given. The core has 11 flow groups, i.e., 2 groups for inner driver, 3 groups for middle driver and 6 groups for outer driver assemblies. The equalized cladding midwall temperature with 2σ uncertainty is calculated to be about 593°C. This value is below the limit value of 635°C in the cladding midwall temperature of HT9. The estimated core pressure drop is 0.27MPa with 20% uncertainty. These calculation results will be served for the further improvements of this design, including the elevation of the core outlet temperature 510°C to 545°C.

Acknowledgement

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