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Improved Design for Battery Reactor Vessel Assembly

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1. Introduction

The Battery Omnibus Reactor Integral System (BORIS) is being developed as a multipurpose integral fast reactor at the Seoul National University (SNU). Its main goal is to satisfy various energy demands, to maintain inherent safety by incorporating liquid-metal coolant lead (Pb) for natural circulation heat transport, and to improve power conversion efficiency by utilizing Modular Optimized Brayton Integral System (MOBIS) using supercritical carbon dioxide (SCO_2) as a working fluid. This paper focuses on improving geometry of primary part of the reactor considering thermal limits and manufacturing difficulties. Momentum Integral Numerical Analysis (MINA) code is used to calculate steady-state flow and coolant temperature distribution in the reactor vessel assembly (RVA). Thermodynamic information on the heat exchanger is adopted from the calculation result of the Optimized Supercritical Cycle Analysis (OSCA) code. Preliminary calculation results are presented and their characteristics are discussed.

2. Design Considerations

2.1 Neutronic Consideration

Fuel composition data of (U, Pu)N from University Research Consortium (URC) project between Massachusetts Institute of Technology (MIT) and Idaho National Engineering and Environmental Laboratory (INEEL) are used as a reference, since they provide a detailed fuel composition for long-life core in terms of their weight fractions [1]. The one-group fission term and one-group cross section is obtained by utilizing ENDF/B-VII.0 library and flux spectrum data from literature [2, 3]. One-group results are shown in Fig. 1.

In addition to this, assuming of 20 years of operation, limiting value of neutron flux is deduced from the literature to be 6.025x1014 n/cm^2-s [3].

2.2 Thermohydraulic Consideration

The thermal constraints for the core and structural materials are found from literature survey. The most conservative values are used in the analysis. For fuel material the high porosity begins to form if the centerline temperature exceeds 1673K. Also, the same literature reported that gas release, swelling, and dissociation did not occur with linear power density up to 1.3x10^5 W/m [4].

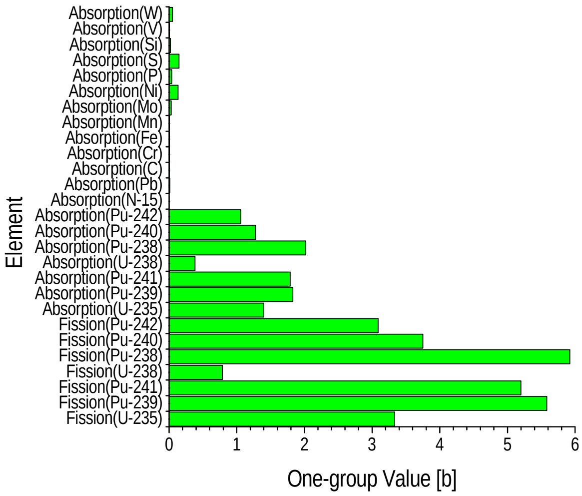

Fig. 1. Calculated one-group fission term and absorption cross section.

For HT9, which is a cladding material, steady state maximum temperature is found to be 873.15K due to the creep strength [5].

For liquid lead as a coolant for reactor systems, its operable range is mainly determined by its boiling temperature. From the literature, 2006K was selected to be the upper limit [6].

From thermodynamic analysis using the OSCA code, the thermal power of the BORIS is set equal to 23.5 MW with its cycle efficiency held at 43.58% [7].

2.3 Geometric Consideration

The fuel rods are assumed to be in a triangular array. The logic proposed by Fraas and Ozisik [8] is utilized to find the number of fuel rods and heat exchanger tubes given the circular or annulus region.

The fuel rod maximum smeared density is kept at 80% to minimize the fuel-clad mechanical interaction [9].

3. Design Objective

3.1 Economic Competitiveness

To simplify the problem, only direct cost of fuel is taken into account utilizing a modified form of the relation proposed by Driscoll and Hejzlar [10].

According to the study, higher values are preferred in terms of thermodynamic efficiency, specific power, fuel residence time and plant capacity factor.

3.2 Stability Consideration

In this study, amount of stability of the system is estimated by its decay ratio or damping ratio evaluated from applying perturbed initial conditions [11]. The system is more stable when its decay ratio is closer to 0.

4. Calculation Methods

4.1 Neutronics

A simple one-group diffusion equation is solved to determine the minimum critical reactor geometry in this study.

4.2 Thermohydraulics

Based upon the core geometry, the RVA is designed by solving the momentum integral model resorting to the finite volume method [12].

5. Conclusions

The optimization procedure is currently under development and interim results from which design modifications are restricted on core region are provided in Table I.

We can observe that by adding neutronic considerations, the cost effectiveness is greatly improved, and this is mainly due to the facts that although overall thermodynamic efficiency is somewhat reduced, huge reduction in the amount of heavy metal in the core resulted in improved specific power. In addition to this, we can also observe the slight improvement in the thermohydraulic stability of the reactor in terms of decay ratio.

Acknowledgments

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Table I: Comparison on Reactor Specifications

Parameters	Preliminary	Interim
Thermal/ electric power [MW]	~22.2/ 10	~23.5/ 10
Cycle efficiency [%]	45	43.58
Core diameter [m]	0.9828	0.9505
Active core height [m]	0.80	0.88
Pitch-to-diameter	1.1	1.34
Number of Fuel Rods	757	817
Fuel pin diameter [m]	0.028	0.023
Mass flow rate [kg/s]	1276.32	1335.36
Temperature difference [K]	120.0	117.1
Thermal center difference [m]	2.45	2.41
C_{ir}/C_{dr}	9.594e6	3.516e7
Decay ratio	0.9974	0.9968

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