Conceptual Design of the Second-generation Hybrid-low Power Research Reactor

Kyung-O KIM*, DongHyun KIM, Gyuhong ROH, and Byungchul LEE
Korea Atomic Energy Research Institute, 1045 Daedeok-daero, Yuseong-gu, Daejeon, Korea
**Corresponding Author: k5kim@kaeri.re.kr*

1. Introduction

The IAEA Research Reactor Database (RRDB) has provided information on all the 206 research reactors in the world, which are classified into operational status, age, flux, power, and etc. Particularly, operational and temporary shutdown reactors of 44.3% are included in the range from zero to 100 kW_{th} range, and major types of them are Argonaut (30 kW_{th}), TRIGA (18 kW_{th}), and Miniature Neutron Source Reactor (MNSR, 30 kW_{th}) [1]. Compared to higher power (> 1 MW_{th}) research reactors, the Low Power Research Reactors (LPRRs) have the following functions; (a) Radioisotope (RI) production, (b) studies of reactor characteristics, (c) uses of extracted neutrons, (d) Neutron Activation Analysis (NAA). Considering an important role of research reactor as a fundamental infrastructure for nuclear energy program, many countries including the Republic of South Africa, Saudi Arabia, Kenya, etc., have constructed or planned to build new research reactors prior to the introduction of nuclear power plants.

Recently, Korea Atomic Energy Research Institute (KAERI) has modified the existing model called as Hybrid-Low Power Research Reactor (H-LPRR) [2], and flexibility and cost-effectiveness are the main focus in conceptual design process of the second-generation model. The new reactor model has the "Research Reactor" and "Critical Assembly" modes, and an inherent safety function is increased to prevent the power explosion caused by Reactivity Insertion Accident (RIA). All of design calculations including the fuel burnup behavior are performed using MCNP6.1 code with ENDF/B-VII.0 library [3].

2. Methods and Materials

The second-generation H-LPRR aims to operate for at least 20 years without refueling and to simultaneously provide the functions of research reactor and critical assembly. Furthermore, it can be instantly started up and shut down without considering the xenon dead time, and it can be sequentially operated without the limitation such as the maximum continuous operation time (e.g., MNSR: < 7 hours) [4]. The concept of in-core reactivity compensator is introduced to provide sufficient excess reactivity and to easily approach the core, and the inherent safety function is increased to prevent the damage of nuclear fuel and the power explosion caused by RIA.

The newly designed H-LPRR is an open tank-in-pool type of 50 kW thermal power (see **Figure 1**), which is designed for education and training, producing medical radioisotopes (e.g., ^{32}P, ^{198}Au, ^{99m}Tc, ^{192}Ir, and ^{131}I), and applying the Neutron Activation Analysis (NAA). The reactor core is composed of 20 fuel assemblies and reflector blocks with irradiation holes. Whenever additional excess reactivity is required, vacant region at the center of the core is partially changed to the reactivity compensator to be made with beryllium.

The fuel assembly includes 3×3 UO_2 fuel rod array distributed on a square lattice, and their basic specifications (e.g., enrichment, radius, material, etc.) are same with ones used in OPR-1000, except for the axial length. The reactor core has two kinds of reflectors of beryllium and graphite which are designed to enable replacement with the fuel assemblies. The beryllium is used as an inner reflector, which is surrounded by an outer reflector of the graphite canned with aluminum. The beryllium and graphite reflectors are located on the grid plate to stand by themselves without any support equipment. The reactivity control is performed by four Control Absorber Rods (CARs) filled with natural B_4C, and the reactor core is cooled by natural convection. There are eight irradiation holes on the edge of the core which is classified into two types: IR (for RI production) and NA (for NAA) holes.

In this study, MCNP6 code is used to evaluate the delayed neutron fraction in each group, excess reactivity at the Beginning of Life (BOL), and neutron flux distribution in each irradiation hole. When the reactivity is suddenly inserted as much as excess reactivity in the core, the power trend as a function of time is also analyzed using RELAP5 code [5].

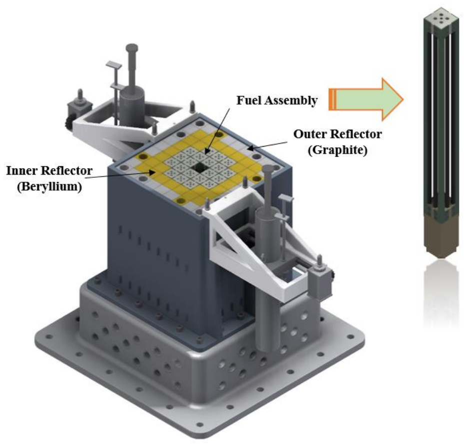

Figure 1. Conceptual Design of Second-generation H-LPRR

3. Results and Discussions

At the BOL, excess reactivity of the newly designed H-LPRR is evaluated to be 4.13 mk, and the delayed neutron fraction in each group is presented in **Table 1**. Based on these results, it is expected that there is no rapid increase in reactor power (i.e., no prompt jump) because excess reactivity is considerably less than the effective delayed neutron fraction (β_{eff}). In order to investigate the neutron flux distribution in the irradiation holes, they are axially segmented into 10 regions, and calculated results are shown in **Figure 2**. As shown in figure, the maximum neutron flux in IR and NA holes are 8.87×10^{11} n/cm^2-sec and 4.56×10^{11} n/cm^2-sec, respectively, and it is almost same level with the performance of MNSR irradiation holes.

Table 1. Delayed Neutron Fraction in Each Group

Precursor Group	Delayed Neutron Fraction [β_i]
1	2.100E-04
2	1.120E-03
3	1.180E-03
4	3.280E-03
5	1.050E-03
6	3.200E-04
Total or β_{eff}	7.160E-03

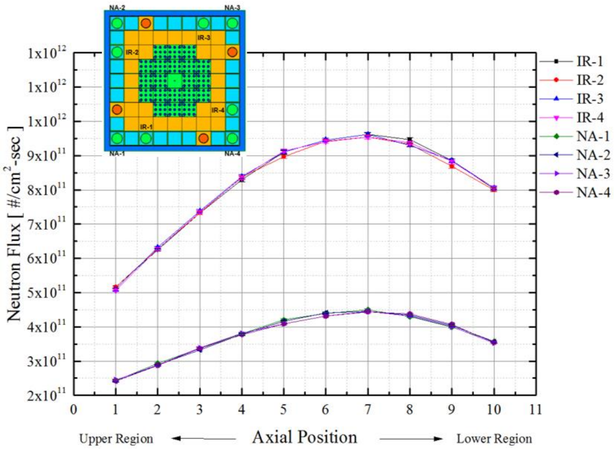

Figure 2. Neutron Flux Distribution in Each Irradiation Hole

When the reactivity is suddenly inserted as much as excess reactivity, the time-dependent power change is represented in **Figure 3**. As shown in figure, the reactor power is exponentially increased up to about 650 kW at an accident moment and after that time, the power excursion is self-limited by the reactivity feedbacks from fuel and coolant temperatures. During the transient period, fuel integrity is assured in terms of critical heat flux and fuel temperature.

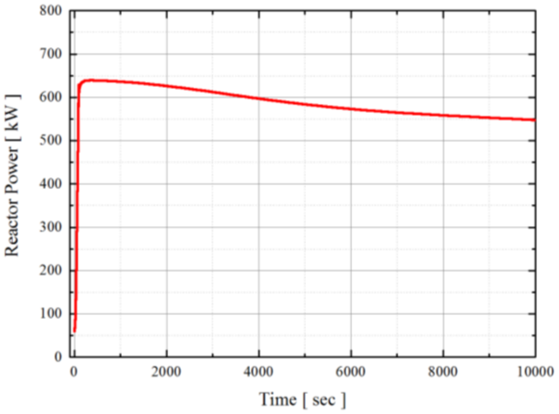

Figure 3. Results of Safety Analysis for RIA

4. Conclusion

KAERI has performed the conceptual design of the second-generation H-LPRR which can be used as a “Research Reactor” and “Critical Assembly” as well. In the design, excess reactivity of the core is restricted to prevent the rapid increase in reactor power by RIA, and the fuel assembly and reflectors are designed to enable replacement with each other. The neutronics calculation and safety analysis are progressed by using MCNP6.1 with ENDF/B-VII.0 library and RELAP5 codes. As a result, excess reactivity and β_{eff} at the BOL are evaluated to be 4.13 mk and 7.16 mk, respectively, and the reactor power does not increase more than 650 kW in spite of RIA as much as the core excess reactivity. Consequently, it is concluded that the newly designed H-LPRR has sufficient inherent safety against RIA and good performance in terms of nuclear design.

ACKNOWLEDGEMENTS

This work has been conducted as a part of the Development of Research Reactor Technology project sponsored by Ministry of Science and ICT of the Korean government.

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