Hybrid Low-Power Research Reactor with Separable Core Concept

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ABSTRACT

The Korea Atomic Energy Research Institute (KAERI) has designed a low-power research reactor, called the Hybrid Low Power Research Reactor (H-LPRR), to meet the needs not only for a conventional research reactor utilization but also for a critical assembly that can be used for the education of nuclear engineering students at universities.

The core is submerged in a pool and is cooled by natural convection. The use of LEU UO_2 fuels makes the core have a strong negative fuel temperature coefficient and a negative power coefficient. The results of a reactivity insertion accident (RIA) analysis show that the core is inherently safe. The H-LPRR can be operated for more than 20 years without refueling.

The very specific feature of H-LPRR is that the core is horizontally separable into two sub-cores. The central space between sub-cores provides an area that can be used for the experiments in critical or subcritical conditions, such as kinetic parameter measurements, neutron spectrum measurements for a fuel array, and measurements of the neutron detector characteristics.

This hybrid research reactor model will meet the needs in newcomer countries considering a low-power research reactor as the first step toward nuclear research, as well as in countries considering the replacement of existing aged low-power research reactors.

1. Introduction

There are steady demands for a low-power research reactor used for basic research, education, training, and neutron activation analysis (NAA). There are also demands for a critical assembly in which the reactor physics parameters can be measured [1].

KAERI has designed a low-power research reactor, called the Hybrid Low Power Research Reactor (H-LPRR), to meet the needs of not only for a conventional research reactor utilization but also for a critical assembly that can be used for the education of nuclear engineering students at universities.

2. Hybrid Low Power Research Reactor (H-LPRR)

1) Reactor Core

The core of 70 kW in power is submerged in a pool, and is cooled by natural convection. The use of LEU UO_2 fuels makes the core have a strong negative fuel temperature coefficient and a negative power coefficient. Although a graphite block has a positive temperature coefficient, it is too small to effect the power coefficient. The core parameters of H-LPRR are shown in Table 1. The Monte Carlo N-Particle (MCNP6.1) [2] code and continuos neutron cross-section data (ENDF/B-VII.1) were used to calculate the core parameters.

Component	Parameter	Value
Reactor	Type	Open Pool
Core	Thermal Power (kW)	70
	Average thermal neutron flux (#/cm^2.sec)	1 x 10^{12}
	Size of Fuel zone (W x L x H [cm])	32.4 x 32.4 x 32
Fuel[1)]	Type	Rod
	Material	UO_2
	Enrichment	5%
	Clad Material	Zr-4
Coolant	Material	Light Water (H_2O)
	Core cooling	Natural Convection
Moderator	Material	H_2O[2)] / H_2O, Graphite[3)]
Reflector	Material	None[2)] / Graphite[3)]
Absorber	Material	B_4C
	Number	1 CAR, 2 SOR
Reactor Structure	Material	Al 6061T6

Table 1. Core Parameters of H-LPRR

1) The values of the fuel parameters can be modified based on the vendor's conditions

2) Initial core / 3) A graphite block is added for reactivity compensation

Figure 1 shows a core model of H-LPRR. The core consists of 321 fuel rods, 1 control rod, 2 shut-off rods, and a reactor structure. The initial core does not need a graphite reflector owing to its sufficient excess reactivity (about 5mk).

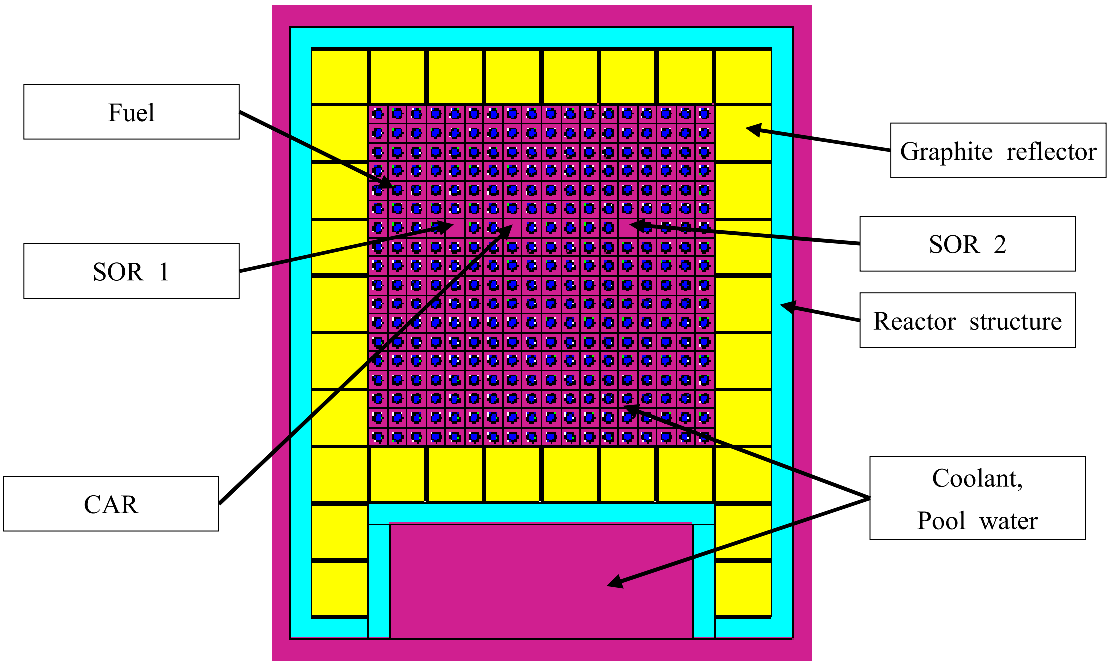

Figure 1. Core Model of H-LPRR

If the core undergoes a sub-critical situation owing to U-235 burn-up and the production of long-lived poisons, a graphite reflector will be added to compensate the loss of reactivity. There are 6 steps for the reactivity compensation. The addition of graphite blocks will provide an excess reactivity (about 3 to 5 mk) for each step. The lifetime of a reactor core is related to the operation time and amount of excess reactivity. The core can be given about 22 mk excess reactivity by the addition of graphite blocks. Thus, H-LPRR can be operated for more than 20 years without refueling, assuming an operation of 40 hours a week and 50 weeks a year at full power.

2) Utilization of H-LPRR

A. Conventional research reactor utilization

H-LPRR will be used for a conventional research reactor such as basic research, education, training, neutron activation analysis (NAA), RI production and Neutron Radiography. H-LPRR has two holes for NAA at the north and east sides of the core. The NAA hole provides a 5 x 10^{11}#/cm^2·sec thermal neutron flux for irradiation of the material. H-LPRR can also produce short lived radio isotope such as ^{41}Ar, ^{198}Au and ^{24}Na.

B. Central experimental zone of H-LPRR

The very specific feature of H-LPRR is that the core is horizontally separable into two sub-cores. The central space between sub-cores provides an area that can be used for experiments under critical or subcritical conditions such as kinetic parameter measurements, neutron spectrum measurements for a fuel array, and the measurements of the neutron detector characteristics. The central experimental zone will accommodate more versatile experimental programs for students.

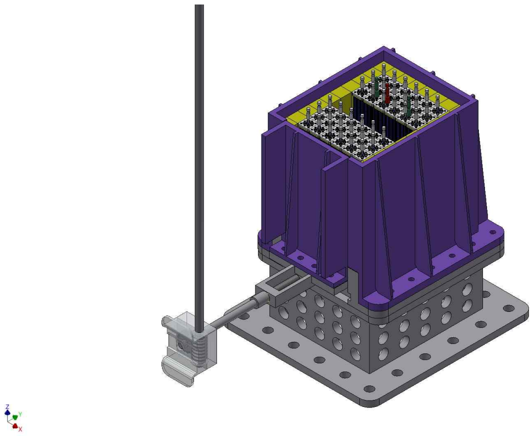

Figure 2. Central space of H-LPRR

The gap of two sub-cores is about 10 cm at maximum. Figure 3 shows an example of using a central experimental zone. The analysis for a typical array of PWR fuel rods with H_2O coolant show that the neutron spectrum at the central experimental zone is very close to an infinite array of fuel rods. The blue line shows the neutron spectrum of an infinite array of test fuels, and the red line shows the neutron spectrum of a finite array fuel in a central experimental zone. Figure 3 shows that the neutron spectra of each array are very close.

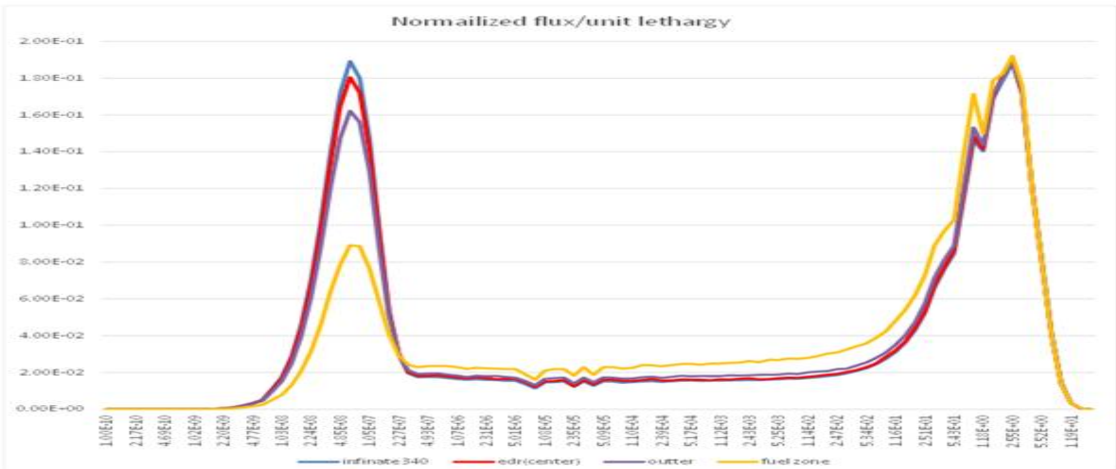

Figure 3. Neutron spectra of each array

3. Safety of the H-LPRR

The priority in the design is given to safety because H-LPRR can be used for the education of nuclear engineering students at universities. The reactor core is submerged in a pool (2m x 2m x 5m [W x L x H]) and is cooled by natural convection. There are some safety parameters and reactivity insertion accident (RIA) analysis of the core. MCNP6.1, McCARD [3] and continuous neutron energy cross-section data (ENDF/B-VII.1) were used for the calculation.

1) Temperature coefficient

Table 2 shows temperature coefficients of core elements. In all cases, the standard deviation of the k-infinity is less than 5 pcm. A strong negative fuel and coolant temperature coefficients lead to the core to be inherently safe.

Core element	temperature coefficient (mk/℃)	temperature range (℃)
Fuel	-0.014	20 ~ 100
Coolant	-0.17	20 ~ 100
Reflector	+0.0026	20 ~ 100

Table 2. Temperature coefficient of core element

2) RIA analysis of the H-LPRR

The transient during RIA is analyzed by the RELAP5/MOD3.3 [4]. Reactor shutdown by reactor protection system is not considered to demonstrate the behavior of reactor power change by temperature feedback effects. The result of RIA analysis shows that the core is inherently safe. Several parameters including initial core power and total inserted reactivity are assumed as Table 3 for transient analysis. Figure 4 shows that power would be converged on the safe level [5].

Parameters	Value
Power	70 kw
Total inserted reactivity	5 mk
Coolant temperature	25 ℃

Table 3. Initial data for RIA

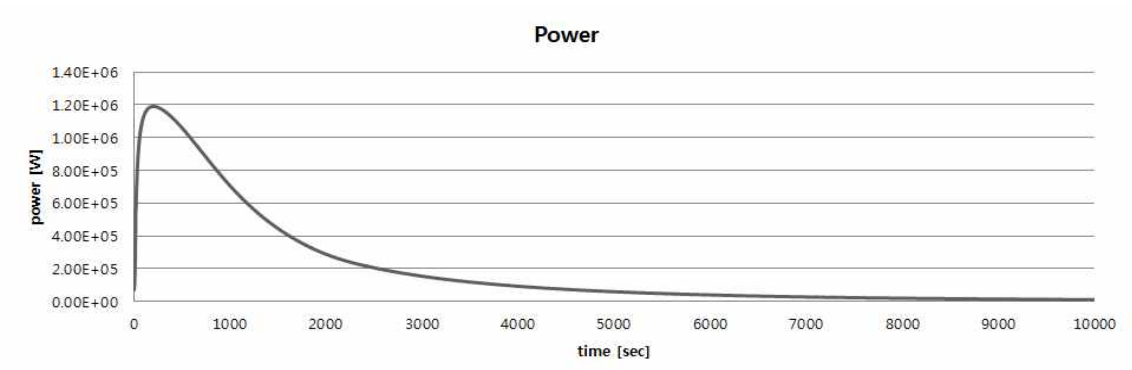

Figure 4. Power level of core after RIA

4. Conclusion

KAERI has designed an H-LPRR to meet the needs of not only for a conventional research reactors but also for a critical assembly. H-LPRR will be used in basic research, education, training, neutron activation analysis (NAA), RI production and Neutron Radiography. The central experimental zone of H-LPRR will provide more versatile experimental programs for students. H-LPRR was also designed such that the core has a strong negative temperature coefficient, and inherent safety.

H-LPRR will meet the needs of newcomer countries considering a low-power research reactor as the first step toward nuclear research, as well as in countries considering the replacement of existing aged low-power research reactors.

5. References

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