A CONCEPTUAL STUDY FOR THE DEVELOPMENT OF A LOW POWER RESEARCH REACTOR

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ABSTRACT

Research reactors have been regarded as a steping-stone to establish infrastructures for a nuclear power development program. In particular, a low power research reactor whose main purpose is education/training and basic researches on nuclear technology would be of interest to developing countries when taking the economy and level of science and technology into consideration. At present many low power research reactors in operation are obsolete and their numbers are gradually decreasing. In addition, there are few suppliers. Hence, a conceptual study to develop a low power research reactor is being studied for future needs. This paper deals with the fundamental requirements and the preliminary design calculations of a low power research reactor for education and training.

1. Introduction

According to the IAEA research reactor (RR) database [1], around 250 research reactors are in operation around the world. However, the numbers are gradually decreasing on the whole owing to obsolescence and reduced utilization, although new demand appears from time to time. 150 out of 250 RRs are low power RRs with less than 1 MW which are generally used for the education and training in nuclear engineering and technology areas. In particular, many low power RRs have been operated at universities in countries that are advanced in nuclear technology, but recently the numbers have reduced a lot and the situation is similar around the world. Accordingly the infrastructure and related technology for low power RRs seems to be weakened and there are few potential suppliers.

Although the demand for RRs decreased, securing and fostering the human resources remains necessary based on the unique characteristics of nuclear technology. The application of RRs has been expanding to the utilization area of the neutron and radiation technology. An education and training RR is fundamental to meet such demands. In this aspect, Task force, a subgroup of USDOE, recommended supporting the university RRs to allow them to continue their roles [2], and ANS endorsed to maintain and expand the fleet of education and training reactors at US [3]. In addition, old low power RRs generally have certain limitations in terms of performance and safety for modern education programs.

Therefore, a conceptual study to develop a reference model of a low power RR for education and training has been performing to prepare for future needs, which meets the strengthened regulations for safety and the changing circumstances of RRs.

2. Considerations on top-tier requirements

Establishing the top-tier requirements is very important for a reactor system design. It is well known that an improperness or change in the top-tier requirements often costs a lot of time and money. Herein, described the major fundamental requirements for the reference model that should be considered for the design of an education/training RRs.

2.1 Flexbility

Applications of RRs to neutron utilization research areas is increasing and becoming important in modern science technology. Therfore, an education/training RR should be designed considering both the effective experiments for nuclear engineering education and the application to other areas such as NAA and neutron beam utilization research.

1) Core configuration and structure: The core shape and structure will have the following characteristics; a) simple modeling of the core, b) easy change of the core structure, c) easy access to the core and easy installation of the experimental facility

2) Utilization area: As education/training RR is for the public as well as students majoring in nuclear technology, the reactor should be able to accommodate a variety of user demands such as; a) practical in-field education, b) reactor experiments, c) neutron beam utilization education, and d) radiation utilization education

3) Core power: The reactor should be operated with ease in the range of zero to full power including the transient, which is related to the quality of the neutron flux requested in the experiments.

2.2 Safety and Security

The design of an education/training RR should consider the safety of the reactor itself as well as the radiation safety of the users. In addition, requirements for the security should be also considered since visitors from the outside can easily access the facility.

1) Reactivity: The reactor should avoid an unstable power transient or an uncontrolled core condition under any situation, and the inherent and passive safety should be particularly stressed in terms of; a) limited maximum excess reactivity, b) limited reactivity insertion rate, and c) negative reactivity feedback

2) Core cooling; The reactor should be designed to have sufficient coolant flow and inventory, and not need forced cooling. i.e, a) normal operation and shutdown by natural circulation, b) no emergency cooling

3) Radiation safety; The radiation safety equipment and system should be considered for an education/training RR since trainees can have many chances to access the core and experimental facility; a) radiation shielding and confinement, b) radiation protection, c) radiation monitoring

4) Security: Physical protection including nuclear material management and cyber security should be well implemented considering that the facility is accessed by many users.

2.3 Economy

One of reasons for shutdowns of RRs in universities or institutes is a lack of operating costs. In particular, an education/training RR is difficult to make a profit. Thus, the construction and operation costs should be in reasonable range.

1) Construction cost: a) low initial investment cost, b) upgradable with ease

2) Fuel cost: Fuel should be manufactured with proven technology to secure a stable supply and be easy to purchase. (as the fuel burn-up rate in low power RRs is generally low, the economy of fuel management will not be important); a) LEU fuel, b) no cost for spent fuel disposal during the life time of the reactor

3) Minimum operation and maintenance cost; Education organization is expected for main users of a low power RR and it may be difficult to secure enough staff members for operation.

The reactor should therefore be designed to be easily maintained considering ; a) minimum operators, b) maintenance free design, c) minimum amount of spare parts and the use of commercial components

3. Preliminary analysis

The preliminary design features of the reference model under study are listed in table 1. The facility design shall be optimized based on the utilization areas, cost effectiveness and safety.

3.1 Neutronic calculations

The McCARD (Monte Carlo Code for Advanced Reactor Design and analysis) code [4] was used for the neutronic calculations in this study.

Various core configurations with a 20% enriched rod type and plate type fuels, which are basically the same or similar to HANARO fuel [5] and KJRR's fuel [6] except the fuel length, have been examined. Rod type and plate type fuels are depicted in Fig. 1. Uranium density was in the range of 5~8 gU/cc. The effective multiplication factor (k_{eff}) and neutron flux distribution were calculated to check the controllability and performance of the core configurations.

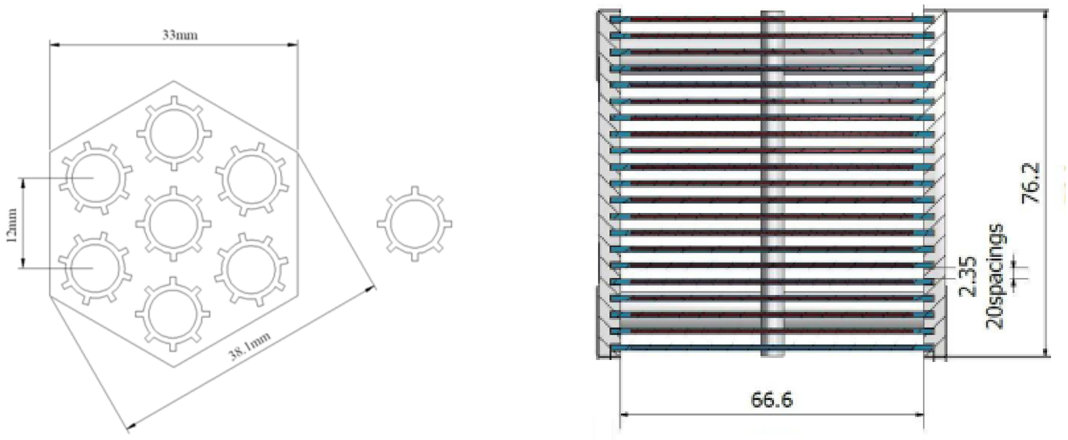
Figure 2 a) shows one of the core models with plate type fuel for the McCARD calculation and neutron flux distribution in the core. The 250kW core consists of 48 fuel assemblies, 4 safety rods and 2 shim rods, and 1 regulating rod. An irradiation hole can be made by removing one or three fuel assemblies. The maximum thermal neutron flux is above 5×10^{12}n/cm^2/s (k_{eff} =1.03336 and 0.91044 for out and in conditions of all control rods).

Figure 2 b) presents a core model with plate type fuels of 5 gU/cc for the McCARD calculation and neutron flux distribution in the core. The core is composed of 11 standard and 4 control fuel assemblies and the power is 250kW. One in-core irradiation hole blocked Al was considered. K_{eff} was 1.10571 and 0.91580 for out and in conditions of all control rods, and a maximum thermal neutron flux of 5×10^{12}n/cm^2/s can be obtained in the in-core irradiation hole.

The results show that both cores can be controllable.

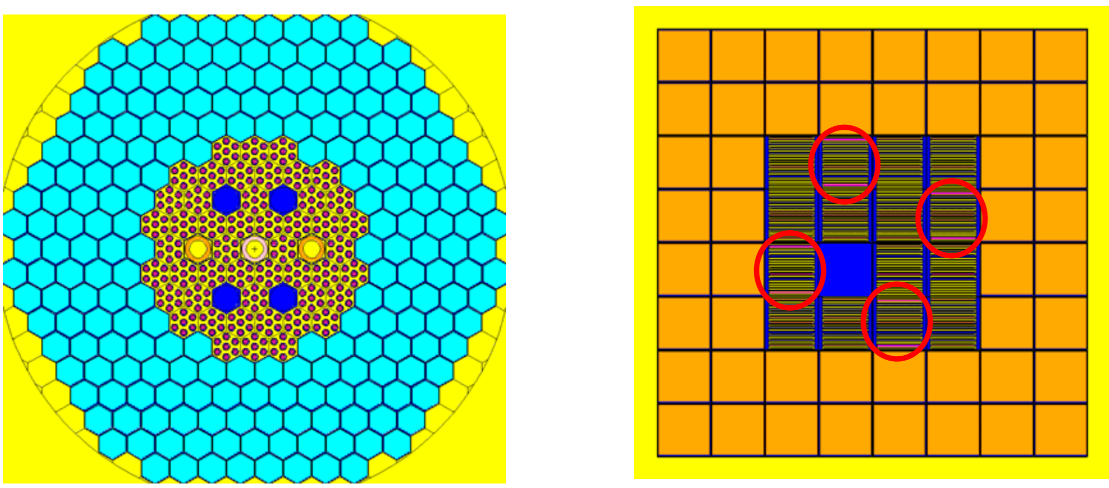
Table 1. Preliminary design features of the standard model

Parameter	Requirements
Power	• **~250kWth**
Reactor type	• Open-tank-in-pool
Fuel	• UMo-Al (5.0gU/cc) or UO_2-Al of 20% enrichment • Rod type or Plate type
Coolant/Moderator	• Light water
Reflector	• Graphite (Al canned) or Al
Maximum Neutron flux	• 1.0×10^{13}n/cm^2/s (Thermal neutron)
Refuelling cycle	• > 3 years
Core Safety	• Inherent & passive safety • High negative reactivity feedback
Core cooling	• Natural circulation by pool water • Pool water cooling system
Reactor pool	• Hot water layer system • Spent fuel storage > 50 years
Reactor shutdown	• Digital technology • Hafnium control rod
Reactor building	• Negative pressure during normal operation
Experimental facilities	• Vertical holes for RI production, NAA, irradiation etc. • Beam tubes (2) for NR, BNCT etc. • Others; PTS, HTS



A) Rod type fuel b) Plate type fuel

Fig. 1 Rod and plate fuels



A) Rod type fuel core b) Plate type fuel core

Fig. 2 MCNP model for a rod type and plate type fuel cores

3.2 Thermal-hydraulic calculations

Preliminary thermal hydraulic calculations for the cores in Fig. 2 were performed by the MARS code[6] which has options to select the heat transfer correlations for both rod and plate type fuels. The coolant velocity, coolant and fuel temperatures and CHFR were calculated to check the cooling of the core under the following assumptions: a) a pool temperature of 35^{o}C, b) elevation of pool and core in Fig. 3, and c) total and axial peaking factors of 3.0 and 1.339. A quasi-steady state was calculated by the MARS code and the nodalization is shown in Fig. 3. For these cores, the ONB temperature as an important design variable for RRs is around 120^{o}C based on the Bergles-Rhosenow correlation [8]. The predicted results are summarized in Tables 1 and 2 for rod type and plate type fuel cores, which show that the cores in the Fig. 2 can be cooled through natural circulation at up to 250kW and 1000kW, respectively.

Table 2. Predicted thermal hydraulic parameters for the rod type core

No.	Power (kW)	Avg. Linear rate (kW/m)	Coolant velocity (m/s)	Coolant temp. (℃) ***	Fuel temp. (℃)	CHFR
1	500	3.17	0.27*/0.23**	86*/66**	132*/109**	8.7*/-***

2	250	1.59	0.19*/0.15**	59*/50**	120*/95**	13.0*/-
3	100	0.64	0.12*/0.09**	49*/43**	103*/70**	-/-

*: hot channel,   **: average channel,   ***Core exit

Table 3. Predicted thermal hydraulic parameters for the plate type core

No.	Power (kW)	Avg. heat flux (kW/m^2)	Coolant velocity (m/s)	Coolant temp. (℃)	Fuel temp. (℃)	CHFR
1	1000	57.32	0.25/0.21	83/57	117/80	35.7/-
2	750	42.99	0.23/0.18	74/55	110/74	- / -
3	500	28.66	0.20/0.14	66/52	94/67	- / -
4	250	14.33	0.13/0.093	58/48	78/54	- / -
5	100	5.732	0.076/0.052	51/44	63/51	- / -

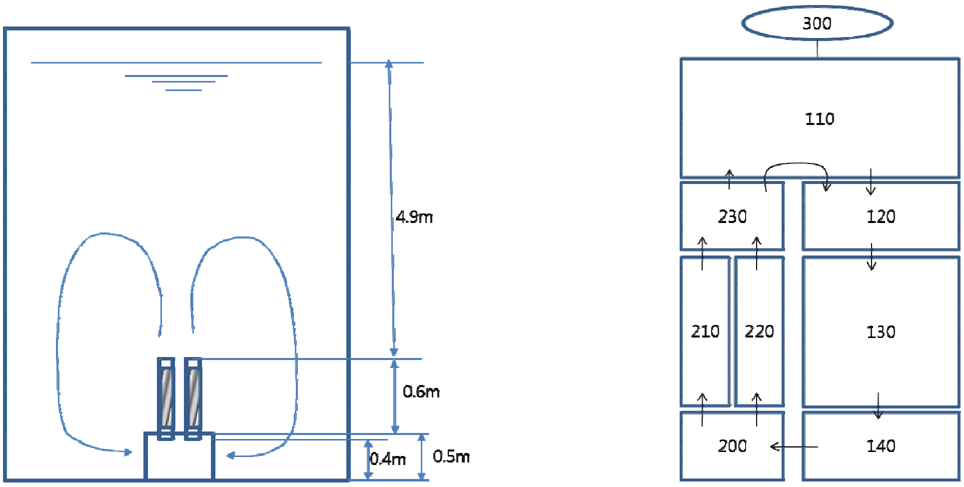


Fig. 3 Assumed pool and core elevations and the nodalization for MARS simulation

4. Concluding remarks

In spite of the aggravated nuclear environment, nuclear power and technology is expected to continue its role for the considerable future. RRs for education and training are also required, and old ones will be replaced. Therefore, a conceptual study to develop a reference model of a low power RR is being performed to prepare for future needs, based on the experiences on the RR's design and operation. The reference model is hoped to have high safety and economics together with flexibility in use.

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