Development of a Low Power Research Reactor for Education and Training

Suki Park*, Kyung-O Kim, Hyung Min Son, Dong Hyun Kim, Yeong-Garp Cho, Minkyu Jung, Seung Ki Shin, Sangjin Lee
Korea Atomic Energy Research Institute, Daedeok-daero 989, Yuseong-gu, Daejeon, Korea, 305-353
*Corresponding author: skpark@kaeri.re.kr

1. Introduction

The thermal power of 152 research reactors (RRs) operating all over the world in 2021 is less than or equal to 1 MW. The low power RRs including subcritical reactors is around 68% of all operating RRs. The age of around 67% of the low power RRs is over 40 years [1].

The well-known low power RRs are TRIGA, SLOWPOKE, and MNSR. MNSR developed by China is a modified version of SLOWPOKE of Canada.

This paper deals with a development of low power research reactor (LPRR) focusing on education and training. The LPRR has been developed for export to the countries that want to develop human resource for nuclear technology and industry.

2. Reactor

The thermal power of the LPRR developed is 50 kW. The LPRR aims to education and training. The reactor core consists of 20 fuel assemblies and 60 reflector blocks of Beryllium and Graphite. The reactor core has 6 irradiation holes for radioisotope production and 2 irradiation holes for nuclear activation analysis in the reflector blocks. Each fuel assembly is comprised of 3x3 rods. The fuel pellet is UO_2 with enrichment of 4.65% in weight and the cladding is Zirlo. The design limit temperatures of the pellet and cladding are very high as compared to those of plate type fuels widely used in research reactors [2].

The maximum thermal neutron flux is around 4.0×10^{12} n/cm^{2}s. The excess reactivity is maintained less than 4.2 mk. The reduced excess reactivity due to fuel burnup is compensated by filling the center hole with Beryllium step by step. The reactor is designed to have high negative reactivity feedback coefficients for inherent reactor safety.

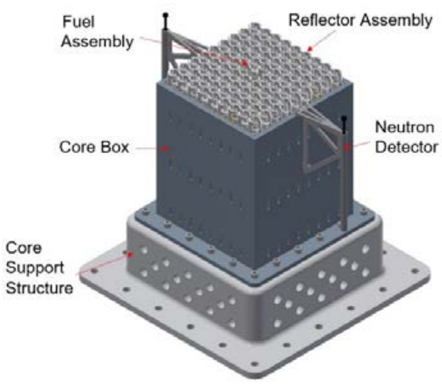

Fig. 1. Reactor Structure Assembly

Figure 1 shows the Reactor Structure Assembly (RSA) consisting of core support structure, core box, and two neutron detector housings. Their materials are Austenitic stainless steel, Zircaloy-4, and Aluminum alloy 6061-T6. The size of core box is around 500 mm in length, 500 mm in width, and 550 mm in height. The core support structure and core box has many holes providing flow path. The reactor has four Control Rod Drive Mechanisms (CRDMs) for regulating reactor power in normal operation and shutting down the reactor in emergency. However, the CRDMs have no safety function for shutting down the reactor because the reactor power is self-regulated by the high negative reactivity feedback in case of the increase of fuel and coolant temperature and the void generation due to boiling. The CRDM is composed of a drive assembly, a connecting wire rope, a pulley assembly, and a Control Absorber Rod (CAR). The drive assembly and pulley assembly are mounted on the reactor pool wall. The actuation of the stepping motor in the drive assembly is rigidly transferred to the CAR through the connecting wire rope and pulley assembly. The CAR is guided by the guide hole in the reflector. The material of neutron absorber is B_4C.

3. Cooling and Purification Systems

The reactor core heat is removed to the reactor pool by natural circulation and the pool water is cooled by the Pool Cooling and Purification System (PCPS) consisting of a pump, a filter, an ion exchanger, a heat exchanger, valves, a water supply tank, and a flow meter. The PCPS also provides functions of purifying and making up the pool water. The pool water is purified through a filter and an ion exchanger and cooled through a plate type heat exchanger. The pool water temperature is maintained below 40℃.

The Secondary Cooling System (SCS) removes the heat being transferred from the PCPS. The heat is eventually dissipated into atmosphere through the closed circuit screw water chiller. The SCS consists of a pump, an expansion tank, a screw water chiller, valves, and a flow meter. The cooling capacity of the screw water chiller is 75 kW and the SCS provides coolant of 7℃ to the secondary side inlet of PCPS heat exchanger.

Regardless of the reactor power, the PCPS and the SCS are not operating when the pool water temperature is lower than 20℃. The PCPS and the SCS start to operate when the pool water temperature is over 30℃. Coolant is suppled from the water supply tank to maintain the pool water level within the allowable range when the pool water level decreases due to evaporation.

4. Control and Monitoring System

The Control and Monitoring System (CMS) provides the control and monitoring functions for the reactor facility. It measures the reactor power, process variables and radiation from the neutron detectors, process instruments and radiation detectors, respectively. The measured data are delivered to the Operating Work Station (OWS) for display and storage. The CMS also performs the reactor trip in emergency and alarm generation in abnormal conditions.

The CMS consists of one CMS cabinet in the control room and four CMS field cabinets for CRDMs. The CMS cabinet has two working computers to prevent the loss of functions by single failure. Each CMS field cabinet includes the electronics for CRDMs and sensor signal measurement. The CMS cabinet and the CMS field cabinets have bi-directional communication using network. The CMS cabinet and the CMS field cabinets are powered from the uninterruptable power supply (UPS).

The control room has a reactor operation console, a Large Display Panel, a manual reactor trip switch, and other facilities. The OWS receives various information including alarms from the CMS and sends control demands to the CMS.

5. Reactor Building

The Reactor Building (RB) houses and supports the reactor and the essential facilities that must be near the reactor for safe and/or efficient operation and utilization of the reactor. It provides a barrier against the uncontrolled release of radioactivity from the reactor core, pool, and reactor experimental facilities. The exterior structure of RB is a rectangular shape with an area of 28m x 31m and a height of 11m from the ground floor. The RB provides a confinement boundary to minimize air leakage so as to prevent the unintentional release of radioactive materials to the environment. All openings through the confinement boundary are maintained with leak tightness during normal operation and design basis accidents.

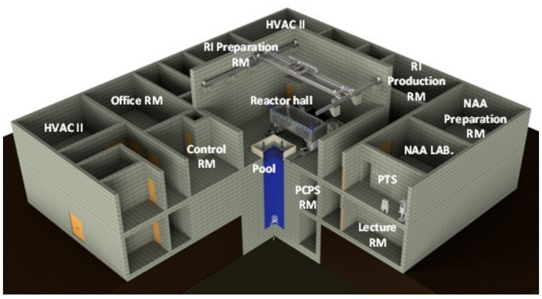

Fig. 2. Reactor Building

The RB is comprised of confinement area, controlled area and uncontrolled area as shown in Figure 2. The confinement area includes the pool crane, operating floor on Reactor Concrete Island (RCI) top level, new fuel storage room, equipment room for PCPS, space for solid rad-waste storage and sump pit. The reactor pool has the RSA, CRDMs, temporary storage rack as shown in Figure 3. The RSA is arranged in the open pool with 2.4 m in length, 2.4 m in width and 7.5 m in depth. The pool water level is 7.0 m.

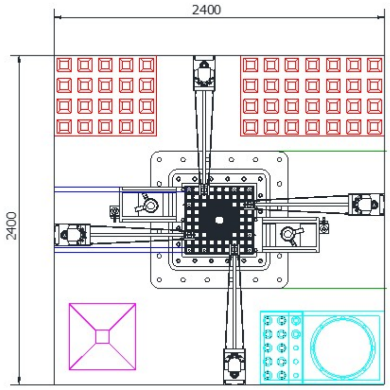

Fig. 3. Top View of Reactor Pool

The controlled area includes the HVAC system for the confinement and controlled area, the hot cell and laboratory for radioisotope production, and the facility for neutron activation analysis. The uncontrolled area has access control area to Reactor Building, Control Room, SCS room, electric equipment room, HVAC system for the uncontrolled area, health physics room, offices and lobby.

6. Safety Analysis

The postulated initiating events (PIEs) for the LPRR are identified based on the list of PIEs in the IAEA safety standard documents, extensive survey on the safety analysis reports and operating experiences of RRs, and the close examination of the design characteristics together with engineering judgments.

MARS-KS is used for the thermal hydraulic transient analysis of PIEs [3].

The reactor heat is removed to the pool by natural circulation. Therefore, the loss of electric power and the loss of pool cooling are not concerned. In these events, the reactor power decreases due to the negative reactivity feedback with the increase of pool water and fuel temperatures although the CARs do not drop into the reactor core.

An excess reactivity insertion can be caused by an inadvertent withdrawal of CARs. The reactivity of 5 mk (0.768$) is assumed to be inserted by the withdrawal of all CARs. The maximum withdrawal speed is 1 mm/s. The core power is assumed to be 1 W at the initiation of the event. The present investigated reactivity is over the excess reactivity of 4.2 mk allowed in operation. The reactor power rapidly increases up to 586 kW at around

103 seconds as shown in Figure 4. After that, the core power oscillates for short time and decreases gradually in long term phase by the negative reactivity feedback. The Critical Heat Flux Ratio (CHFR) reaches the minimum of 2.96 at 112.8 seconds, which is greater than the design limit CHFR of 1.86. On the other hand, the peak fuel centerline temperature reaches the maximum of 665℃, which is much lower than the design limits of 2788℃ for pellet and 1204℃ for cladding.

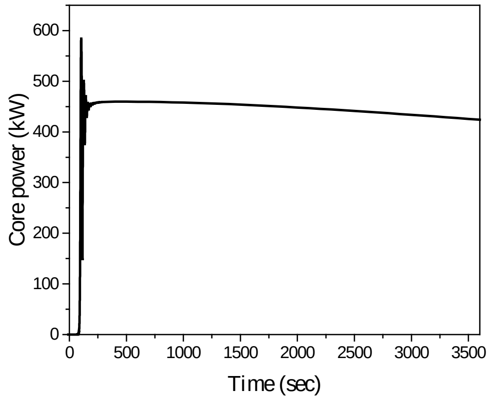

Fig. 4. Core Power in Inadvertent Withdrawal of CARs

A damage of the pool liner and pool wall can cause leakage of the pool water. The final pool water level depends on the damaged location. The worst event is a failure of the pool bottom. In the event, all the pool water can be leaked and the fuels are exposed to air. The core power decreases automatically due to a loss of moderator as the pool water level reaches lower than the top of the fuels. The residual heat of the fuels is cooled by natural circulation of air. The maximum fuel centerline temperature increases up to around 848℃. It is remarkably lower than the design limit.

7. Summary

The low power research reactor of 50 kW focusing on education and training has been developed. The fuel is UO_2 with enrichment of 4.65%. The reactor has 20 fuel assemblies and each fuel assembly consists of 3x3 fuel rods. The reactor has radioisotope production facility and 2 pneumatic transportation systems for neutron activation analysis. The maximum thermal neutron flux is around 4.0 x 10^{12} n/cm^{2}s. The size of core box is around 500 mm in length, 500 mm in width, and 550 mm in height. The reactor structure assembly is installed in the open pool with 2.4 m in length, 2.4 m in width and 7.5 m in depth. The pool water level is 7.0 m. The core heat is removed to the pool water by natural circulation. The reactor is inherently safe due to the high negative reactivity feedback coefficients and the excess reactivity limited to around 4.2 mk. The reactor power is self-regulated even in the event that all control rods are withdrawn. Also the core residual heat is cooled by natural convection of air without fuel damage in the event that all the pool water is leaked out due to a failure of the pool liner and concrete wall. The minimum CHFR and the maximum fuel temperature meet the design limits in all PIEs.

Acknowledgement

This work was funded by the Ministry of Science and ICT of Korea. (NTIS-1711139363)

References

[1] IAEA, Research Reactor Data Base, 2021. (https://www.iaea.org/resources/databases/research-reactor-databases-rrdb)

[2] Park, S., et. al., Low Power Research Reactor for Education and Training, KAERI/TR-8686/2021, 2021.

[3] MARS-KS CODE MANUAL Volume II: Input Requirements, KINS/RR-1822 Vol. 2, 2018.