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Conceptual Nuclear Design of a 20 MW Research Reactor with 3 In-core Irradiation Sites

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1. Introduction

Since its first criticality on Feb. 8th of 1995, the HANARO (High-flux Advanced Neutron Application ReactOr) has been operated successfully and the number of users and utilizations has been considerably increased. Based on the HANARO experiences through its design to operation, we are developing a new research reactor named the AHR (Advanced HANARO research Reactor) [1]. A compact core model with one in-core irradiation site has been presented and analyzed [2]. As the core design is dependent on a user's requirements, we are preparing other core models. This paper presents a core model with 3 in-core irradiation sites and the analysis results for the neutronic characteristics.

2. Nuclear Design

We are considering a 20 MW multi purpose reactor with a high performance. From the neutronic point of view, a high neutron flux, safety, and economics were preferentially considered. The nuclear design will satisfy the basic design principles. A core model with 3 in-core irradiation sites is proposed and analyzed.

2.1 Core Concept

The HANARO uses a rod type fuel of U_3Si dispersed in an Al matrix with a density of 3.15 gU/cc. As the AHR requires a higher uranium density fuel for a higher performance, the AHR adopts U_3Si_2-Al fuel of 4.0 gU/cc as a reference fuel. There are two types of fuel assemblies, a hexagonal and circular fuel assemblies like in the HANARO. The AHR core is constructed using two types of fuel assemblies also. The core configuration should be optimized according to its purpose. As the AHR is a multi purpose research reactor, the flux level should be high both at the core and reflector regions. A multi purpose research reactor in general provides at least one irradiation hole at the core region, in which the fast neutron flux can be high. The core design is strongly dependent on the number of in-core irradiation sites. At the reference [2], a compact core was presented for obtaining a high neutron flux at the reflector region. In this paper, a core model with 3 in-core irradiation sites is proposed as shown in Fig. 1.

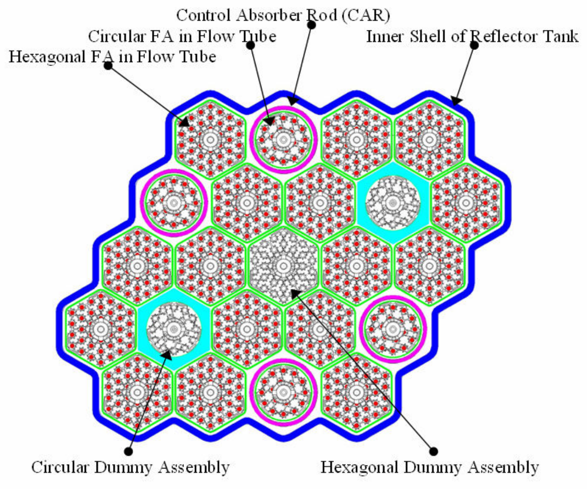

Fig. 1. Cross Sectional View of the AHR Core

This core is composed of 23 hexagonal lattices with its active length of 70 cm. A heavy water reflector tank of 200 cm in diameter and 120 cm in height surrounds the core. The nominal core consists of 16 hexagonal fuel assemblies and 4 circular fuel assemblies. 3 in-core irradiation sites, which are used for the fuel and material irradiation tests and a RI production that require high fast and thermal neutron fluxes, are loaded by two types of dummy assemblies. The reactor regulating system shares its Control Absorber Rods (CARs) with the reactor protection system. The secondary independent shutdown system is a heavy water drainage system. The reflector tank provides sufficient space for the irradiation facilities. The arrangement of the experimental facilities for the AHR was studied by reflecting the HANARO operating and utilization experiences [3]. The selected model in this paper has 4 tangential beam tubes and a total of 18 vertical irradiation holes with different diameters. The final arrangement of the experimental facilities will be determined later, thus a continuous effort is required for the development of appropriate irradiation facilities.

2.2 Fresh Core

A basic analysis of the core characteristics was performed for the fresh core condition in which all the fresh fuels with a temperature of 300 K were loaded. The criticality of the AHR core without the irradiation facilities for all rods out (ARO) condition was calculated as 1.25699. The reactivity effect by the irradiation facilities was estimated to be 20.2 mk at the ARO condition. The total control rods worth of the core with the irradiation facilities is 182.4 mk. As the AHR core has a large excess reactivity and enough CARs' worth, it has good characteristics from a reactor safety and a fuel economy point of view.

The neutron fluxes were calculated for an unperturbed clean core using 2x2x2 cm mesh tally. The maximum unperturbed thermal neutron flux ($E_n \leq 0.625$ eV) at CT (Central flux Trap) was estimated to be 4.45E+14 n/cm^2/sec. The maximum unperturbed thermal neutron flux in the reflector region was estimated as 4.09E+14 n/cm^2/sec. The calculated fast neutron flux ($E_n \geq 1.0$ MeV) at CT is 1.47E+14 n/cm^2/sec when the control rods are located at 300 mm.

For evaluating the power peaking factors, all the fuel rods were axially divided into 5 cm each. Linear power was evaluated for every control rod positions because it is sensitive to a control rod's position. The maximum linear power occurred at 300 mm and the maximum total peaking factor Fq is estimated as 2.33.

2.3 Equilibrium Core

An equilibrium core is dependent on an operation strategy, so there may be various equilibrium cores according to a reactor operating strategy. We selected a 6-batch core considering a discharge burnup, a cycle length and an excess reactivity at a BOC and an EOC. The 6-batch core is reloaded with 3 fuel assemblies for one cycle operation. Three of the hexagonal fuel assemblies or two of the hexagonal fuel assemblies and two of the circular fuel assemblies are replaced for every fuel cycle. So the whole core will be replaced for 6 cycles according to the loading strategy. As there are many loading patterns, a sophisticated study is required. In this paper, a selected loading pattern is shown in Fig. 2, in which the corresponding cycle number is indicated with the loading location of the fuel assembly. There is no need to move the loaded fuel assemblies before their discharge.

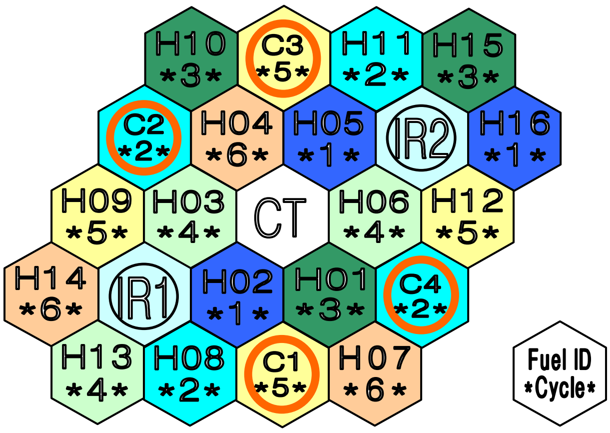

Fig. 2. A Loading Pattern for an Equilibrium Core

As a loading pattern is determined, a fresh core converges to the equilibrium core by repeated core calculations, in which the MCNP/HELIOS system [4] is used for exact evaluations. For the selected equilibrium core, the cycle length was estimated as 38 days long. The excess reactivity at a BOC was 103.4 mk, and at least 24.6 mk was reserved at an EOC. The assembly average discharge burnup was 54.6% of initial U-235 loading. For the proposed fuel management scheme, the maximum peaking factor Fq was calculated as 2.56 and the corresponding linear power was 106.2 kW/m. The shutdown margins by the 1st and 2nd shutdown systems were estimated to be 27.4 mk and 46.3 mk, respectively. Both the isothermal temperature coefficient and the power coefficient were negative, so the AHR core is characterized as being inherently safe.

3. Concluding Remarks

We succeeded in obtaining a new conceptual core with 3 in-core irradiation sites. This conceptual core provides high fast and thermal fluxes. The cycle length is very long when compared with 28 days of the HANARO. The average discharge burn-up is high enough too. This core design is based on proven technology through the HANARO in principle.

Acknowledgements

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