Neutronic Characteristics of the Medical Isotopes Producer

Sang Jun Park, Soo Youl Oh
KAERI, 150 Duckjin-dong, Yusung-gu, Daejon, Korea, 305-353
sjpark6@kaeri.re.kr

1. Introduction

MIP (Medical Isotopes Producer) is a facility dedicated to the production of medical isotopes such as Mo-99.[1] The facility, for which feasibility studies are being carried out, consists of two homogeneous reactors of less than 100 kW each and a series of hot cells for the isotope recovery and purification.

The fuel of the MIP reactor is aqueous uranyl sulfate of about 20 liters. The reactor concept is based on Russian ARGUS type reactor, which uses 90% HEU solution fuel for thermal power of 20 kW.[2][3] The MIP would use LEU and its power increases to, at this conceptual study phase, 50 kW.

This paper presents basic neutronic characteristics of ARGUS reactor and of MIP, for which we used conventional codes, MCNP and WIMS.

2. Calculation Method

2.1 Calculation Models

The reactor vessel of the ARGUS, as shown in Figure 1, is a cylindrical vessel of which lower part is hemisphere. The radius and height of the vessel are 30 and 70 cm, respectively. Three vertical channels are installed to guide the reactivity control rods and as an irradiation hole. The triple cooling coils, which surround the central channel with different radius, are immersed in the core to remove heat.

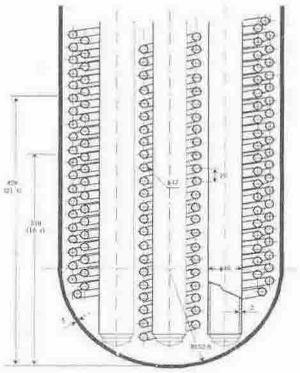

Figure 1. Structures in ARGUS reactor core: vessel, cooling coils, and vertical channels

The vessel for the MIP has the same dimension to that of ARGUS, but the solution fuel fills the vessel as high as 33 cm for ARGUS and 44.5 cm for MIP. The latter was determined, as explained later, by considering the amount of excess reactivity and the magnitude of power defect and of void effect due to hydrogen production.

MCNP[4] code was used for criticality calculations and WIMS[5] for reactivity coefficient calculations. The models for MCNP and WIMS are shown in Figure 2. The axial bucking for WIMS 1-D model was determined from the MCNP calculation. The reactivity control devices are not included in these models and some dimensions were presumed from drawings.

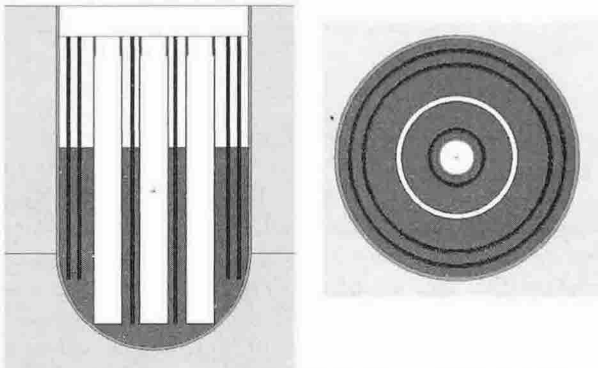

Figure 2. Models for MCNP (left) and WIMS (right) calculation

The specifications of solution fuel for each core are given in Table 1. The reactor powers are 20 kW for ARGUS and 50 kW for MIP.

Table 1. Solution Fuel Specifications

	ARGUS	MIP
Fuel type	Aqueous uranyl sulfate	
U-235 enrichment (%)	90	20
U-235 loading (kg)	1.5	1.8
Total U mass (kg)	1.67	9.0
UO_2SO_4 mass (kg)	2.57	13.85
UO_2SO_4 solubility(g/liter)	123	602
Fuel density (g/cm^3)	1.1208	1.6006
Fuel volume (liter)	16	23

2.2 Results of calculation

The calculated k-effective values for the different fuel volumes are plotted in Figure 3. In this calculation, the minimum critical volumes at room temperature are 14.3 and 16.5 liters for ARGUS and MIP, respectively. The volume required to get initial excess reactivity of 3.1$, which is informed by Russian side at a normal condition of ARGUS with 16 liters of solution, is calculated as 15.7 liters. Thus, there is a relative difference of about

2% between present calculation and Russian value. The suggested fuel volume for 50 kW MIP is 23 liters. The k-effective for this case is calculated as 1.0518 (7.57$), which is 2.4 times greater than that of ARGUS. This compensates the reactivity loss due to power increase while preserving enough excess reactivity at the beginning of fuel cycle. The estimated cycle length of the MIP is 2,050 full-power-days, while that of ARGUS is known as 10 years.

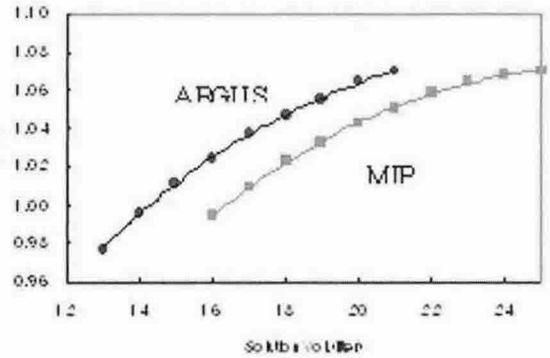

Figure 3. k-effectives varying with fuel volume

The axial and radial thermal neutron flux distributions for ARGUS and MIP are compared in Figure 4. In the figure, the solid line indicates thermal neutron flux and the dotted line indicates fast neutron flux above 1 MeV. For the ARGUS the maximum thermal neutron flux is 7.1×10^{11} n/cm^2-sec and core average thermal neutron flux is 4.8×10^{11} n/cm^2-sec, which agrees with 5×10^{11} n/cm^2-sec informed by Russian side.

In the homogeneous reactor, the temperature change and void formation in the solution are the most important factors affecting the reactivity. Calculated temperature coefficient and void coefficients are shown in Figure 5. The temperature coefficient of ARGUS is reported as –0.058 \$/°C at 80°C by Russian side, which corresponds to –0.377 mk/°C assuming the β_{eff} = 0.0065. It is very close to the calculated value of –0.380 mk/°C. For the MIP, it is –0.343 mk/°C at the same temperature.

Void coefficients are calculated in the range of void fraction from 1% to 60%. In this range, the calculated values are –5.78 ~ –11.66 mk/%-void for ARGUS, and –4.91 ~ –11.29 mk/%-void for MIP.

4. Conclusion

To clarify some obscure neutronics information for the Russian ARGUS reactor and to confirm the feasibility of

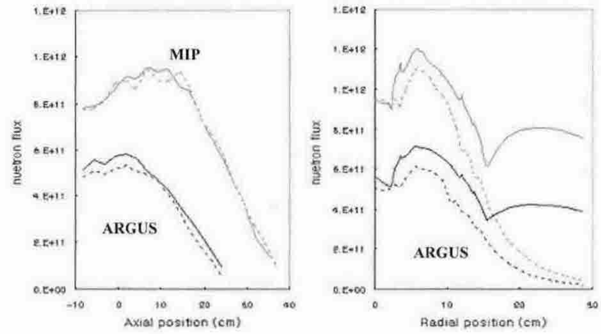

Figure 4. Neutron flux distributions

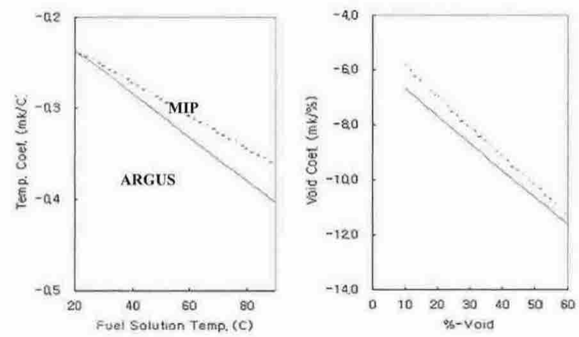

Figure 5. Reactivity coefficients

MIP from the viewpoint of neutronics, we carried out basic neutronics calculations.

The results for ARGUS reactor agrees in general with the values informed by the Russian side. In addition, calculations for the MIP confirm the feasibility of the designed core as an inherently safe nuclear reactor.

We may need to further verify neutronics codes for the full-scale design and/or audit purposes, but it seems that conventional codes are appropriate for the nuclear design of a homogeneous reactor like the MIP.

References

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