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A Preliminary Study on Criticality Bias Caused by Uncertainty Factors of Fuel Particles for MHTGR-350 Reactor

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1. Introduction

The High-Temperature Gas-cooled Reactor (HTGR) has been receiving significant attention due to inherent safety and appropriately high temperature heat supply for hydrogen production. These attractive features of the HTGR can be achieved using Tri-isotopic coated fuel particles (TRISO particles). The Prismatic Modular Reactor (PMR) employs hexagonal fuel elements that contain the TRISO particles randomly distributed within the cylindrical fuel compacts. Due to the manufacturing process, the uncertainty factors of the TRISO particles, such as the fuel radius, and fuel density, are generated.

In this study, the criticality biases caused by the uncertainty factors of the TRISO particles were evaluated with MCNP5 Monte Carlo code [1] for MHTGR-350 prismatic reactor.

2. Methodology

2.1 MCNP Modeling of MHTGR-350 Fuel Element

The MHTGR-350 reactor [2] has the hexagonal fuel elements containing fuel compacts, burnable poison compacts, and full-length channels for helium coolant flow in a graphite matrix. The TRISO particles, which are made of uranium dioxide microsphere kernel coated with low-density carbon buffer accommodating fission products, pyrolytic graphite, and silicon carbide as cladding to avoid radioactivity release due to fission products, are dispersed in the graphite matrix and sintered to form a cylindrical fuel compacts. For the evaluation of the criticality biases, one fuel assembly was selected. MCNP modeling based on the reactor design [2] was performed as shown in **Figures 1 and 2**.

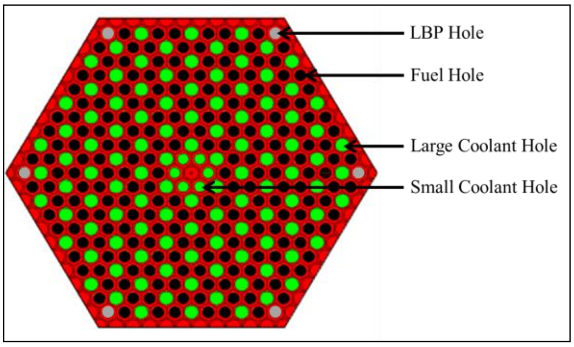

Fig. 1. Radial Layout of Fuel Element

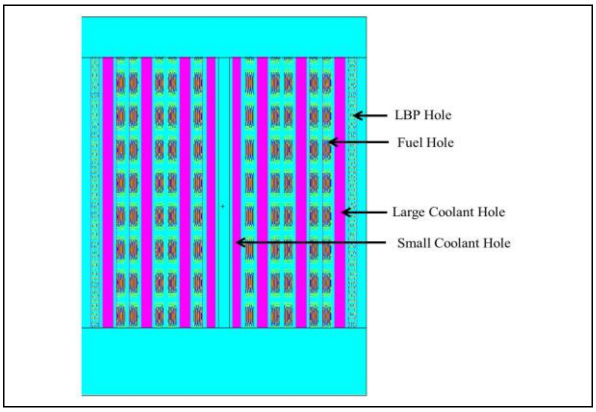

Fig. 2. Radial View of Fuel Element

2.2 Modeling Method of Random TRISO Particles

TRISO Particles are randomly distributed in fuel compacts. To study the effect of the random particle distribution, a particle sampling program based on the C++ language was developed in this study. To simulate the TRISO particles with having high packing fraction, a sampling method based on the cubical mesh is introduced. At first, the region of the fuel compact is divided by cubical lattice as shown in **Figure 3.**

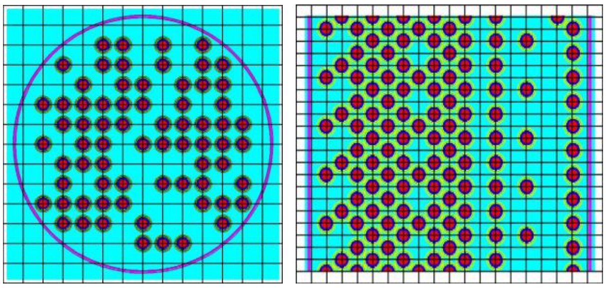

Fig. 3. MCNP Modeling of Fuel Particles in a Fuel Compact

The TRISO particles are sampled at the intersection position of vertical and horizontal lines that randomly selected. If a particle sampled is overlapped by the previous particles or is located the outside of compact region, next sampling is performed without counting the number of the sampling particles. The set of particle random positions was used to create the surfaces of particles in the input files for running an MCNP calculation. Due to limitation of the number of cells and surfaces available for MCNP calculation, modeling of entire particles in the fuel elements is unrealizable. So, in this study, the unit cell consists of 267 particles was repeated in the fuel compact region.

2.3 Random Selection Method of Fuel Densities and Radii with Normal Distribution

The fuel density and the radius of the TRISO particles have uncertainties because of the mechanical difference during the manufacturing process. It is noted that the mechanical difference has a normal distribution with a given standard deviation as shown in Eq. (1). Therefore, the densities and radii of the TRISO particles can be sampled by using CDF function given as the Eq. (2):

$$f(\rho) = \frac{1}{\sqrt{2\pi}\sigma_\rho} e^{-\frac{(\rho-\mu)^2}{2\sigma_\rho^2}} \quad (1)$$

$$F^{-1}(\xi) = \rho \quad (2)$$

where *f(ρ)* is a function of normal distribution with variable ρ and μ_ρ and σ_ρ are average and standard deviation of the variable ρ, respectively.

The MHTGR-350 is under the conceptual design; hence, the mechanical difference is not well defined. In this study, the information of mechanical differences was introduced from the HTTR reactor [3] presented in Table I with the designed value of MHTGR-350.

Table I. Specifications of the Density and Radius of Kernel

	Unit	Designed Value ± 1σ
Density of Kernel	g/cm^3	10.5 ±0.26
Radius of Kernel	cm	0.02125 ±0.00275

By using the Eq. (2) with the standard deviations, the fuel radii and densities were automatically sampled with a C++ program developed in this study. To estimate the criticality bias of the individual variable, 30 fuel elements were sampled for each uncertainty factor. Also, each fuel element has 267 different fuel densities or radii with an explicit particle model. To conserve the average value during the random sampling process, the radius or density sampling is repeated until the average value of the sampled particles are matched to the designed value.

3. Results and Discussion

The criticalities were evaluated with the variables, which are the particle position, fuel density, and radius. In each variable, 30 inputs were generated as stated in the previous sections. The calculations were perused by using the MCNP5 code with ENDF/B-VI cross sections and SAB2002 thermal cross section library. The results of the multiplication factors are given in Table II.

Table II. Results of Criticality Calculations with 30 Inputs of Each Variable

Variables	Average k_{eff}	k_{eff} without Variation
Position	1.17645 ±0.0004	1.15105 ±0.00161[a)]
Density	1.17831 ±0.0005	1.17494 ±0.00181
Radius	1.17777 ±0.0004	1.17222 ±0.00161

[a)] *The result was calculated by using repeated structure.*

The bias of the multiplication factor caused by the random particle distribution was estimated to 2,540 pcm compared with that of the repeated structure. Also, the biases of the multiplication factors caused by the normal distributions of fuel densities and radii were calculated to 337 pcm and 555 pcm, respectively.

4. Conclusions

In this study, the criticality biases caused by the uncertainty factors, which are the TRISO particle position, fuel density, and fuel radius, were evaluated. For the evaluations of the effect of the particle random distribution, the position sampling method in the lattice structure was proposed. Also, the random sampling method of the fuel density and radius was induced by using the normal distribution. In each case, 30 samples are randomly selected and criticalities were evaluated with the given core conditions. The results show that the bias caused by the normal distribution of fuel radii is more than that produced by the normal distribution of fuel density. It is expected that the results in this study can be utilized for the understanding of how the mechanical differences affect the criticality analysis.

ACKNOWLEDGMENTS

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REFERENCES

[1] X-5 Monte Carlo Team, MCNP-A General Monte Carlo N-Particle Transport Code, Version 5, LA-UR-03-1987, Los Alamos National Laboratory, 2003.
[2] Bechtel, Preliminary Safety Information Document for the Standard MHTGR, GA Technologies, MHTGR-86-024, Rev. 13, 1992.
[3] K. Sawa, S. Ueta, T. Iyoku, M. Ogawa, and Y. Komori, Research and Development Program of HTGR Fuel in Japan, IAEA-TECDOC-CD-1614, pp.208-218, 2009.