

Analysis of Uncertainty Caused by Fuel Density for Molten Salt Reactor

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1. Introduction

Korea Atomic Energy Research Institute (KAERI) has developed molten salt reactors (MSR) for a variety of purposes. Molten salt reactor is one of promising generation IV reactor type, which has some advantages in terms of safety, refueling, and operation. Especially, the liquid fuels offer strengths like no fuel melting issue and online refueling. However, there are also problems related to large manufacturing uncertainty of the fuel density.

In this study, the uncertainties of core parameters caused by the fuel density uncertainty was quantified based on the statistical approach. First, sufficient number of inputs for neutronics analysis were generated using the random sampling method with the given standard deviation of the fuel density. Then, the neutronics analysis was repeatedly performed with the sampled inputs and the uncertainties of the core parameters were quantified with statistical processing.

In the next section, the analysis method and tools were described in detail and the analysis results were provided.

2. Methods and Results

2.1 Analysis code system

Figure 1 shows the analysis code system for the uncertainty effect of the density. The TRICX (Transforming ISOTXS to CAPP X-section) code is a simple code for transforming the cross section format from ISOTXS to CAPP cross section library. The ISOTXS is a neutron cross section file format widely used for fast reactors. In this study, it was generated from ENDF/B-VII.1 library. TRICX can read ISOTXS format files and generate temperature dependent nodewise macroscopic and microscopic cross sections for diffusion codes.

The CAPP (Core Analyzer for Pebble and Prism Type Reactors) [1] code is originally a core simulation code based on the diffusion method for HTGR cores. Recently, it has been modified for MSR analysis and is tentatively called as CAPP_MSR.

The TANUA (Tools for Automatic Neutronics Uncertainty Analysis) [2] was developed for assisting the uncertainty analysis based on the random sampling method. It can perform automatic generation of CAPP_MSR input files with material density perturbation and automatic execution, and post-

processing of CAPP_MSR outputs. The tools help the analysis of CAPP_MSR by efficiently processing randomly sampled files without cumbersome work.

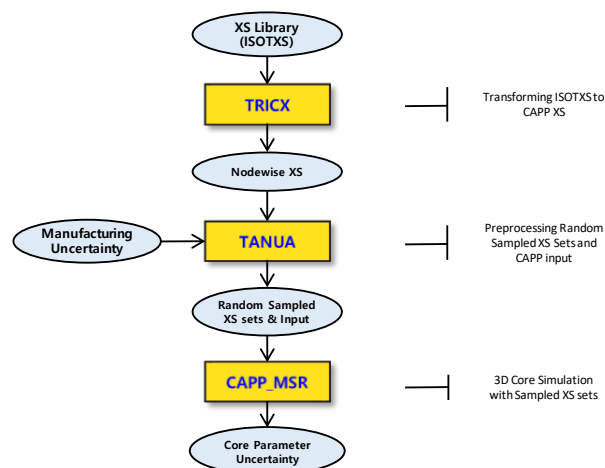


Fig. 1. Code system for uncertainty analysis by random sampling

2.2 Analysis Model Descriptions

Figure 2 and 3 show a micro MSR model for the uncertainty analysis in this study. It is an experimental model with fast spectrum using the conventional molten fuel, KCl- UCl_3 . Also, it is originally designed into a cylinder and but, consists of hexagonal blocks for easy modelling in this study, because CAPP_MSR code can handle only prismatic geometries at present. The evaluation of the difference from the geometry modelling should be performed after developing CAPP_MSR. Also, the density variation by the temperature variation is not considered.

Table 1 shows the material number density for the model. They were determined from conventional micro MSRs.

For evaluating the design parameter uncertainty induced by the fuel density uncertainty, it is assumed that the manufacturing tolerance of the fuel density could be varied according to the normal distribution with the standard deviation given by user. In this study, the standard deviations were arbitrarily selected from 0.02 to 0.1, because the exact value of the density uncertainty is not known at this time. TANUA code applies the Box Muller method [3] for the random

sampling with the standard normal distribution as follows:

$$x = \sqrt{-2 \cdot \log(s) \cdot \cos(2\pi t)} \quad (1)$$

($0 < s, t < 1$: random number)

In addition, it should be considered that the perturbation rate for the fuel densities can variate by the fuel region inside the core, because the liquid fuel made with the different perturbation rate could sequentially enter the core. In this study, two cases were examined, one is that the entire fuel has the single perturbed density and the other is that it has the multiple perturbation rates. In case of the multiple perturbation rates, it is assumed that the fuels with three type perturbation rates could be distributed in the three axial regions.

The number of the random samplings is 300 in this study. It was determined from the previous sensitivity study [3].

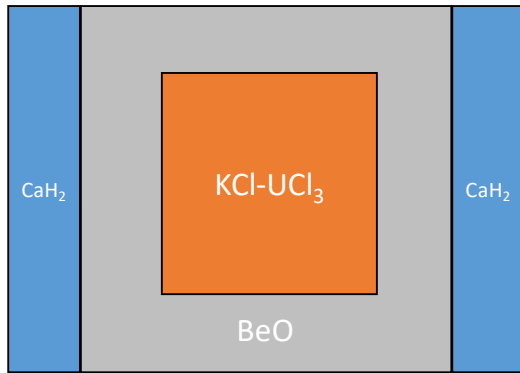


Fig. 2. Axial view of the core configuration

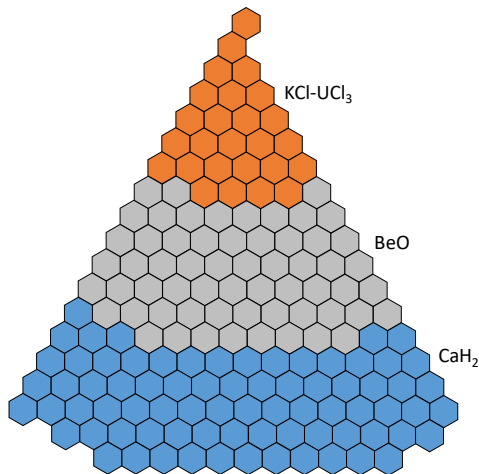


Fig. 3. Radial view of the 1/6 core configuration

Table I: Number Densities for Core Materials

	Material	Number Density (#/barn·cm)
Fuel	U235	1.08E-03
	U238	4.33E-03
	K39	4.28E-03

	K40	5.37E-07
	K41	3.09E-04
	Cl35	2.08E-04
	Cl37	2.05E-02
Inner Reflector	Be9	6.86E-02
	O16	6.87E-02
Outer Reflector	H1	7.61E-01
	Ca40	9.30E-03
	Ca42	5.91E-05
	Ca43	1.20E-05
	Ca44	1.82E-04
	Ca46	3.25E-07
	Ca48	1.49E-05

2.3 Uncertainty Analysis Results

Table II shows the results for the multiplication factor uncertainty induced by the density uncertainty with the same perturbation rate for all fuel region. It can be observed that the uncertainty varies proportionally to the density uncertainty and it is 635 pcm in the case of the 5% density uncertainty. Figure 4 and 5 show the uncertainty of the relative radial power. It also reveals that the uncertainties increase proportionally to the density uncertainty and are distributed from 0.065 to 0.802 in the case of the 5% density uncertainty.

Table III shows the results for the multiplication factor uncertainty effect by the density uncertainty with the different perturbation rate for axially three fuel regions. However, it is observed that the uncertainties are very similar to those for the first case. It can be seen that the effect by the different perturbation rate inside fuel region is small and the density uncertainty is more important. Also, they show that the uncertainty at 0.1 std.dev. in three perturbation rates is slightly larger than the case of the single perturbation rate. It might be the stochastic uncertainty, because the difference between two cases is 66 pcm for k_{eff} and 54 pcm for uncertainty.

Figure 6 and 7 show the uncertainty of the radial power distribution in the case of the different perturbation rates for three axial fuel regions. They are also indicating the similar results to the first case.

3. Conclusions

In this study, the uncertainties of the multiplication and power distribution induced by the fuel density uncertainty was quantified based on the statistical approach. The analysis results show that the uncertainty of the multiplication factor in the case of the 5% density uncertainty is 635 pcm and the uncertainty of the relative power is the maximum 0.802%.

As a future work, the total uncertainty including the cross section uncertainty for MSR would be quantified.

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Table II: k_{eff} Uncertainty by Single Perturbation Rate		
Density Std.Dev.	k_{eff}	Uncertainty (pcm)
0.02	1.16896	243
0.05	1.16893	635
0.10	1.16853	1159

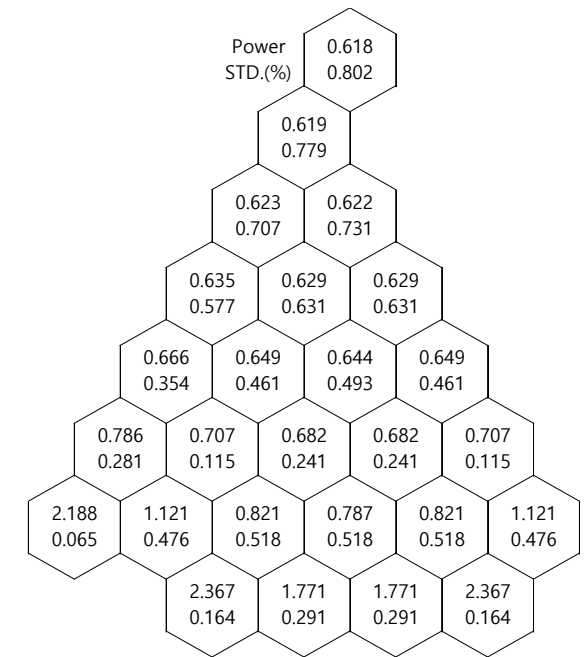


Fig. 4. Relative Radial Power Uncertainty by Single Perturbation Rate with 0.05 Std.Dev.

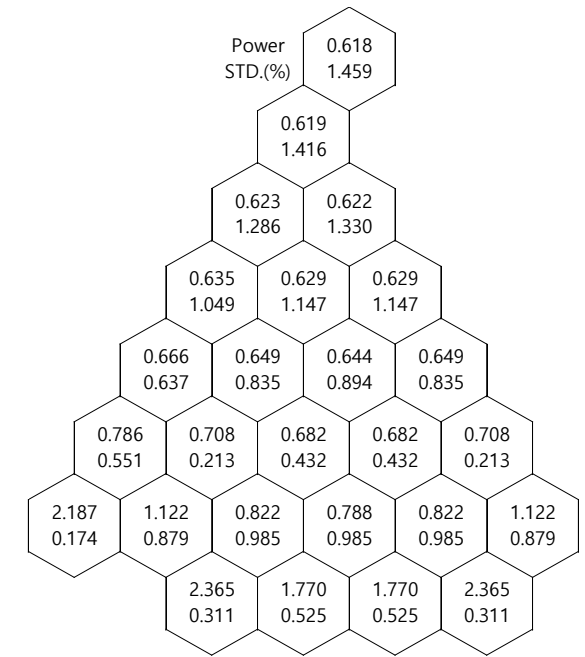


Fig. 5. Relative Radial Power Uncertainty by Single Perturbation Rates with 0.1 Std.Dev.

Table III: k_{eff} Uncertainty by Three Perturbation Rates		
Density Std.Dev.	k_{eff}	Uncertainty (pcm)
0.02	1.16895	231
0.05	1.16935	610
0.10	1.16987	1213

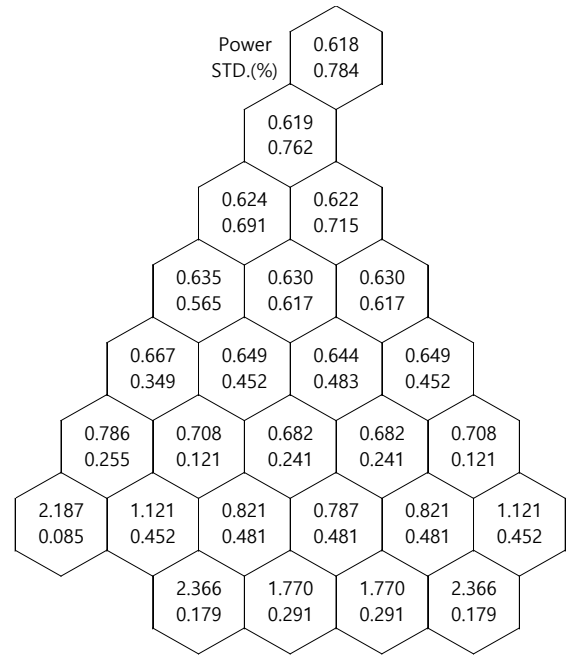


Fig. 6. Relative Radial Power Uncertainty by Three Different Perturbation Rates with 0.05 Std.Dev.

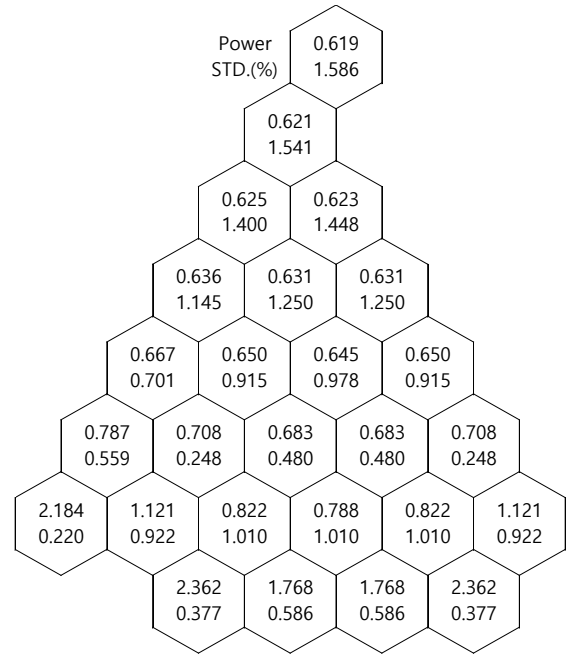


Fig. 7. Relative Radial Power Uncertainty by Three Different Perturbation Rates with 0.1 Std.Dev.

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