Sensitivity of Moderator Thickness on the Detector Response in PGSFR

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1. Introduction

A Prototype Gen-IV Sodium-cooled Fast Reactor (PGSFR) has been developed by KAERI in collaboration with ANL and KEPCO E&C. This reactor will serve the testing and investigation of the TRU metallic fuel performance, and also will demonstrate the TRU transmutation capability of a burner reactor as a part of the sustainable nuclear power utilization.

In the PGSFR, the neutron flux monitoring system is located in the space between the containment vessel and concrete as shown in Fig. 1. Even though the neutrons generated from the core suffers moderation by coolant and other structure materials, the neutron spectrum is not slowed down enough to be significantly measured by neutron detectors. Therefore, the moderating materials are normally considered to increase the counting rate in the neutron detectors. A moderator such as polyethylene has been successfully demonstrated in the thermal nuclear power plant for the same purpose [1, 2]. The sensitivity of the moderator thickness on the detector performance is presented in this paper for the PGSFR core.

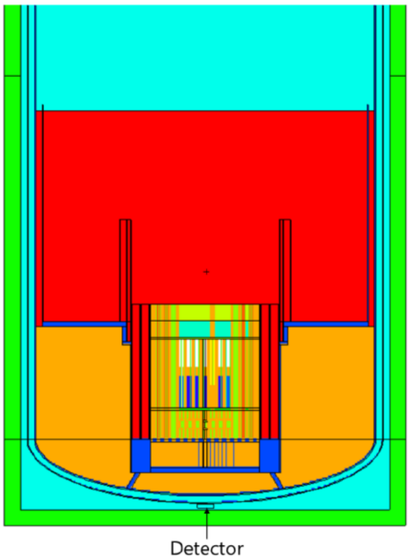

Fig. 1. Detector position in PGSFR

2. MCNP Calculations for Obtaining Accurate Detector Response

A fixed source calculation has been performed by using continuous energy Monte Carlo MCNP6 code [3] with ENDF/B-VII.0 nuclear library. In order to reduce the uncertainty of MCNP results, a weight window map is generated for each case by the ADVANTG code [4]. There are 2 detectors considered in this study, a boron lined detector for shutdown condition and a fission chamber for normal operation. The detector which is located at the center position is modeled as a tube filled with air with the dimension of 5 cm in radius and 50 cm in length. The detector is assumed to be surrounded by polyethylene layer with various thickness. The detector response is scored by using the F4 tally with FM tally multiplication card. Two reactions: $U^{235}(n,f)$ and $B^{10}(n,\alpha)$ are considered to represent the counting rate of fission chamber and boron lined proportional counter respectively.

At the beginning of the MCNP6 calculation, an eigenvalue KCODE calculation has been performed to generate and save the fission source locations into "WSSA" file. Later, this file is used in the MCNP6 fixed source calculation to define the source energy and location. For the simulation, the total number of neutron histories is about 4 million which provides an error for the fission chamber detection rate about 0.3%.

3. Enhanced Detector Response with Moderator

The radial configuration of the core is shown in Fig. 2 below. The reactor is assumed to be operating at hot full power condition. The primary control assemblies are at the critical position, while the secondary control assemblies are fully withdrawn.

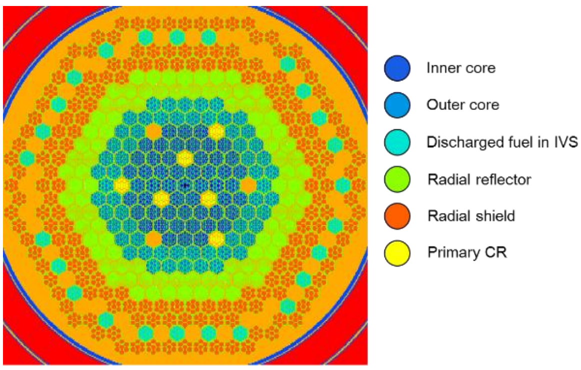

Fig. 2. Radial configuration of the PGSFR core

During the normal operation, fission chambers are utilized to monitor the neutron flux level in PGSFR. So the fission reaction rate at the detector position is investigated with various moderator thickness, and the results are summarized in Table I. The moderator performance is defined by using a “gain ratio” [1] which shows the potential moderated detector performance compared to the case without moderators. It is shown that the gain ratio increases monotonically with the moderator thickness until reaching the maximum value. It is found in this study that the optimum polyethylene moderator material thickness is about 2.5 cm for the fission chamber at normal operation.

Table I. Gain ratio for fission chamber

Moderator Thickness [cm]	Gain Ratio
0.1	1.127 ± 0.006
0.5	1.972 ± 0.009
1.0	3.109 ± 0.015
1.5	3.866 ± 0.019
2.0	4.193 ± 0.019
2.5	4.221 ± 0.019
3.0	4.032 ± 0.019
4.0	3.391 ± 0.017

By using this optimum moderator thickness, the neutron spectrum at the detector position is plotted in Fig. 3. The neutron spectrum was softened compared to the case without moderator, and thus the fission reaction can be remarkably increased.

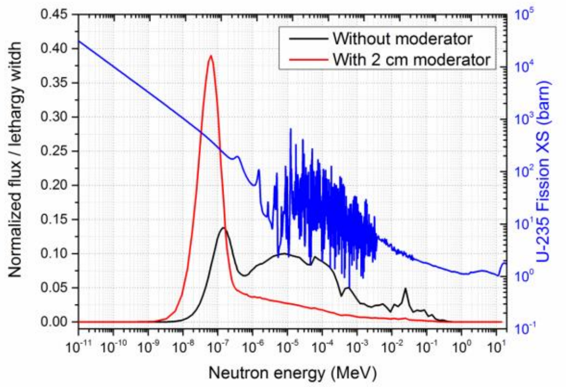

Fig. 3. Neutron spectrum with optimized moderator thickness for the fission chamber in PGSFR

In case of reactor shutdown, fission chambers can hardly sense the neutrons generated from the core, so more sensitive neutron detectors and external neutron sources are required. In PGSFR, boron lined proportional counter is suggested for the shutdown condition, and the same calculation procedure was performed for boron absorption reaction with fully inserted primary and secondary control rods. The results are summarized in Table II. The results are very similar to the fission chamber case, and the highest gain ratio was observed when the moderator thickness was 2.5 cm.

Table II. Gain ratio for boron lined proportional counter

Moderator Thickness [cm]	Gain Ratio
0.1	1.139 ± 0.093
0.5	2.304 ± 0.357
1.0	3.141 ± 0.362
1.5	3.362 ± 0.151
2.0	3.632 ± 0.193
2.5	4.120 ± 0.281
3.0	3.905 ± 0.301
3.5	3.064 ± 0.159

5. Conclusions

The effect of moderator thickness on detector response was invested in this work. In PGSFR, two types of neutron detectors are considered that are fission chambers for operation and boron lined proportional counter for the reactor shutdown. By surrounding the detector with polyethylene, the detector response from both detectors can be improved by a factor of 4, and the optimum thickness of the moderator was observed around 2 cm.

ACKNOWLEDGEMENTS

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