# Analysis of the Effective Neutron Generation Time Using the MCNP6 Code

Kyung-O KIM*, Han Jong YOO, and Beom Woo PARK
*Korea Atomic Energy Research Institute, 1045 Daedeok-daero, Yuseong-gu, Daejeon, Korea*
**Corresponding Author: k5kim@kaeri.re.kr*

## 1. Introduction

The knowledge of kinetic parameters (e.g., effective delayed neutron fraction and neutron generation time) is necessary for the operation and transient analyses of a nuclear reactor. Especially, the effective neutron generation time ($\Lambda_{eff}$) is defined as the average time from the birth of neutron to absorption including fission, and depends on several core conditions such as fuel enrichment and neutron flux distribution. Most researches are based on the calculations to determine its values in a specific situation, due to the difficulties in measuring kinetic parameters. The calculations for obtaining these parameters are commonly performed with deterministic codes (DIF3D, CIATATION, and VARI3D) [1].

If the active core is small and the neutron leakage is large, the kinetic parameter $\Lambda_{eff}$ is extremely affected by the shape and material composition of the reflector region. Due to this, it can be difficult to evaluate reliable kinetic parameters with deterministic codes. Hence, some researchers investigate the application of Monte Carlo codes for the calculation of the kinetic parameter $\Lambda_{eff}$, and there are some methods available for this: Adjoint Weighted Method, Perturbation Method, and Iterated Fission Probability Method [2]. In this study, it is focused on the calculation of kinetic parameter $\Lambda_{eff}$ using the MCNP6 code [3] with the two former methods. The benchmark calculations are performed for the university of New Mexico's research reactor (AGN-201), and calculated results are compared with respect to the trends and accuracy.

## 2. Methods and Materials

The AGN-201 reactor (see **Figure 1**) is a low power research reactor and designed/produced by Aerojet General Nucleonics for nuclear physics education and research [4]. It is usually approved to operate at 100 mW, and the maximum neutron flux in the core is about $4.5\times10^6$ #/cm$^2$·sec. The reactor core is a right circular cylinder (Radius: 12.8cm and Height: 24cm) and is filled with a homogeneous mixture of polyethylene and uranium dioxide (Uranium Enrichment: ~20%). It is fully surrounded by multi-zone reflector. The first zone is a graphite 20cm thickness, the next zone is a lead 10cm thickness, and the last zone is a water 55cm thickness. The material composition of each region is shown in **Table 1** [5]. The calculations for evaluating kinetic parameter $\Lambda_{eff}$ are performed on four cases: (1) the bare core, (2) the core + the graphite reflector, (3) the core + the graphite reflector + the lead shield, and (4) the core + the graphite reflector + lead shield + water shield.

**Figure 1.** AGN-201 Reactor Named as CONSTANZA

**Table 1.** Material Composition of AGN-201 Reactor

| Region | Material | Atom Density [cm$^{-3}$] |
|---|---|---|
| Core | $^{235}$U | $1.379\times10^{-4}$ |
| | $^{238}$U | $5.552\times10^{-4}$ |
| | C | $3.701\times10^{-2}$ |
| | $^{16}$O | $1.386\times10^{-3}$ |
| | $^{1}$H | $7.402\times10^{-2}$ |
| Graphite Reflector | C | $8.420\times10^{-2}$ |
| | Cd | $4.400\times10^{-8}$ |
| Lead Shield | Pb | $3.300\times10^{-2}$ |
| Water Shield | $^{16}$O | $3.346\times10^{-2}$ |
| | $^{1}$H | $6.691\times10^{-2}$ |

The effective neutron generation time, $\Lambda_{eff}$, is defined, as follows:

$$\Lambda_{\text{eff}}=\frac{\langle\phi_0^+,\ \frac{1}{v}\phi_0\rangle}{\langle\phi_0^+,\ F_0\phi_0\rangle}$$

where $\phi_0^+$ is the critical adjoint flux, $v$ the neutron speed, $\phi_0$ is the critical flux, and $F_0$ is the total fission operator in the reference critical configuration. If the influence from the reflectors is significant, the difference between adjoint weighted and the non-adjoint weighted kinetic parameters can be huge. In the MCNP6 code, it can simply evalute the adjoint weighted kinetic parameters ($\beta_{eff}$, $\Lambda_{eff}$, and Rossi-α) by invoking options on the KOPTS card. In addition, the kinetic parameter $\Lambda_{eff}$ is

the negative value of the slope of the reactivity curve, and its first-order perturbation formula is as follows ($c$: amplitude parameter);

$$\Lambda_{eff} = \frac{-\triangle \rho}{c}$$

The simplest method to make uniform $c/v$ perturbation in the reactor is to add an artificial material having a 1/v capture cross-section. Typically, it is applied in Monte Carlo codes by uniformly adding the $^{10}$B isotope in the whole reactor system.

## 3. Results and Discussions

**Table 2** shows the kinetic parameter $\Lambda_{eff}$ of AGN-201 reactor evaluated by the adjoint weighted and perturbation methods. A series of calculations are performed by the MCNP6 code with the ENDF/B-VII.1 library, and standard deviation of criticality calculations is less than about 10 pcm. As shown in the table, the value of the $\Lambda_{eff}$ parameter gradually increased as the reflectors are further considered in the calculations. In the case of the bare core, the $\Lambda_{eff}$ value evaluated by two methods is almost same each other, whereas the differences in other cases are assessed to be increasing. In order to investigate the cause of this phenomena, the prompt neutron generation times in the core ($\Lambda_c$) and reflector ($\Lambda_r$) regions are analyzed through the perturbation method (see **Figure 2**). As shown in the figure, the $\Lambda_c$ value is not significantly affected by adding the reflectors, whereas it is confirmed that the $\Lambda_r$ value is exponentially increased.

**Table 2.** Effective Neutron Generation Time of AGN-201 Reactor Evaluated by the MCNP6 Code [Unit: μsec]

| Method | Case (1) | Case (2) | Case (3) | Case (4) |
|---|---|---|---|---|
| Adjoint Weighted Method | 45.9 | 50.3 | 60.8 | 73.2 |
| Perturbation Method | 45.4 | 49.6 | 58.9 | 67.2 |

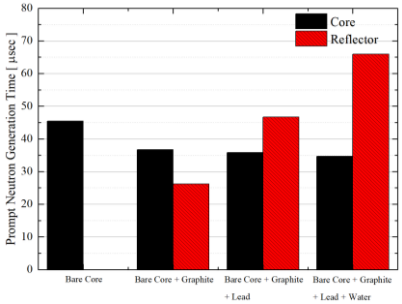


**Figure 2.** Prompt Neutron Generation Time in the Core and Reflector Regions

## 4. Conclusion

Using the MCNP6 code, the benchmark calculations of the effective neutron generation time are performed for the AGN-201 reactor. The adjoint weighted and perturbation methods are applied in these calculations which are carried out on four cases. As a result, the kinetic parameter $\Lambda_{eff}$ evaluated by two methods is 73.2 μsec and 67.2 μsec, respectively, and this difference arises from a significant increase of the $\Lambda_r$ parameter by adding the reflectors. That is, the kinetic parameter $\Lambda_{eff}$ can be extremely affected by the shape and material composition of the reflector region. Therefore, it is expected that the Monte Carlo codes are actively utilized for the calculation of the kinetic parameters, compared to the deterministic codes.

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