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An Analysis on the Radioactivity Uncertainty Caused by Monte Carlo Stochastic Errors Using Sampling Based Method for the Accelerator Activation Problem

Gi Yeong HAN [a], Song Hyun KIM [a], Chang Ho SHIN [a,*]
[a]*Department of Nuclear Engineering, Hanyang University, 222, Wangsimni-ro, Seongdong-gu, Seoul, 133-791, Korea*
[*]*Corresponding Author: gemini@hanyang.ac.kr*

1. Introduction

It is widely used to couple Monte Carlo (MC) transport code and activation code for the activation analysis of the accelerators. MC method is a stochastic approach for the particle transport; hence, the stochastic errors are always included in the MC transport results. Therefore, using MC method, the activation uncertainties are generated from (i) uncertainties of basic data and (ii) uncertainties due to stochastic error of the MC transport calculation. In this study, to estimate the uncertainty caused by the MC stochastic error, the sampling based sensitivity and uncertainty method [1] is introduced. After the estimation procedure was constructed, the activation analyses were performed for the βNMR (beta-radiation-detected Nuclear Magnetic Resonance) facility [2].

2. Methods and Results

For the activation analysis, at first, the particle energy spectrum of a region, which is for the radioactivity estimation, is calculated at a steady-state condition. This information is collapsed to be used as activation parameters (e.g. one group effective cross-section, space-energy integrated flux). Then, time-dependent differential equation as shown in Eq. (1) is used for the activation analysis.

$$\frac{dN_i}{dt} = -N_i(\sigma_i\Phi + \lambda_i) + \sum_{j\neq i} N_j(\sigma_{ij}\Phi + \lambda_{ij}) + S_i \qquad (1)$$

where N_i is the amount of nuclide i, N_j is the amount of nuclide j which are potentially converted to the nuclide i, σ_i is the total cross section for reactions on i, σ_{ij} is the reaction cross-section for reactions on j producing i, Φ is space-energy integrated flux, λ_i is the decay constant of nuclide i and λ_{ij} is the decay constant of nuclide j producing i, and S_i is the production rate of nuclide i. In Eq. (1), both Φ and σ are affected by MC stochastic error. To estimate the uncertainty, in Section 2.1, the flux sampling strategy was proposed. Using the proposed strategy, a preliminary study of the uncertainty for the air activation analysis in βNMR facility was pursued.

2.1 Proposed Procedure

In this study, a total MC method, which is the sampling based method, was used. First, the energy dependent fluxes were sampled from the information of the stochastic errors. Then, the activation analysis was performed with the sampled flux information. After enough iteration of the sampling and activation calculations, the uncertainties of the responses were estimated. For the calculation, MCNPX 2.7.0 [3] and EASY-2010 activation system (FISPACT code [4] + EAF 2010 neutron activation cross-section data [5]) were used.

To sample the flux from MC stochastic uncertainty, a flux generation program based on the C++ language for random sampling of the flux set was developed. Using the program, 300 sets of the flux spectrum were produced. For each flux set, the activation calculation was performed. The flow chart of this methodology is described in Fig. 1.

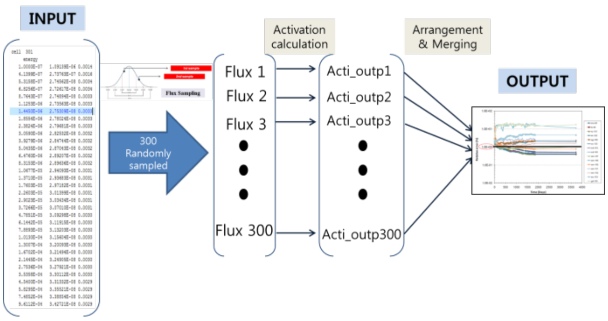

Fig. 1. Overview of the Proposed Procedure Estimating the Uncertainty of Radioactivity

2.2 Estimation and Analysis

In this study, βNMR facility was chosen as the target facility on the activation uncertainty analysis. βNMR is a facility for analyzing micro-structure by using accelerator. In this facility, the 70 MeV proton beam is irradiated to BeO target. The details are given in Fig. 2. It was assumed that the irradiation intensity is 50 μA. And, the irradiations were pursued with the 8 hour/day for 2 months. After the irradiations, decay calculations were performed for 20 years.

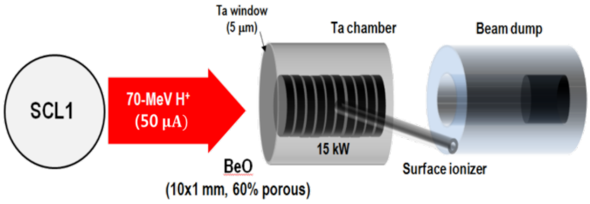

Fig. 2. Schematic Description of βNMR Facility

To analyze the air activation, the concrete shielding was set to be the same geometry as given in the previous design value and the MCNPX modeling result is described in Fig. 3.

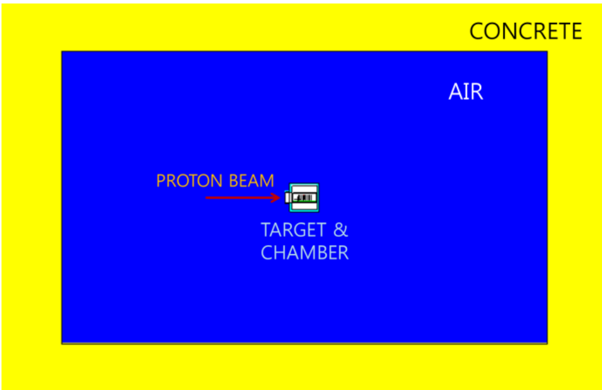

Fig. 3. MCNPX Modeling Result for Air Activation Analysis

The activation uncertainties were pursued with the change of the particle histories in MC transport calculation. Fig. 4 shows the relative standard deviations (RSD) of the fluxes using the program developed in this study.

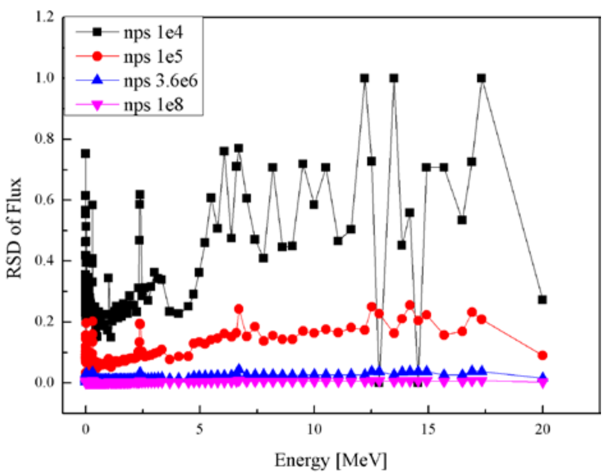

Fig. 4. The Relative Standard Deviation of Flux Energy Spectrum for Air Activation Analysis

Fig. 5 shows the results of the radioisotope activities with the given condition. It is notified that Cl-39 is mainly affected by the flux uncertainty for the air activation calculation. Also, the analysis shows that 3.6 x 10^6 particle histories are required to deduct a reliable result within 2% relative error. Also, from the results, it is recommended that the activity analysis should be performed more than 10^8 particle histories.

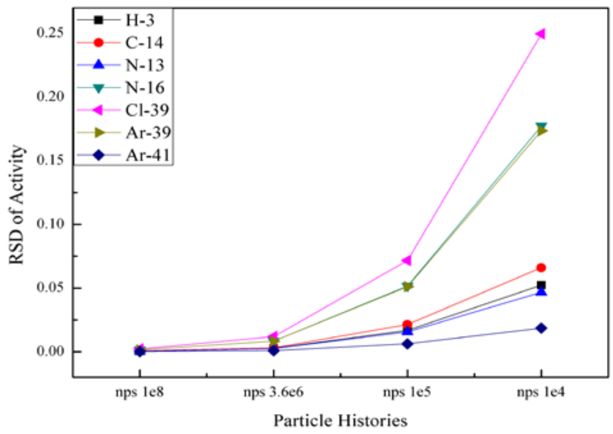

Fig. 5. Relative Standard Deviation of Each Radioisotope Activity for Air Activation as the Particle Histories

3. Conclusions

In this study, procedure and program to analyze the activity uncertainty caused by stochastic error of MC method were developed. Using the flux and standard deviation information in MC transport output, 300 randomly sampled flux sets were produced to calculate the uncertainty. Using the developed procedure, the air activation calculation in βNMR facility was performed. From the results, the major nuclide affected by the flux uncertainty was analyzed. Also, the guideline on the number of particle history is proposed to have a reliable result of the activation. The developed method and procedure will contribute to increasing the accuracy and reliability on the activation calculation.

Acknowledgement

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