Re-evaluations for Heavy Ion SINBAD Experiments with MCNPX and PHITS Monte Carlo Particle Transport Codes

Do Hyun KIM[a], Song Hyun KIM[a], Chang ho SHIN[a], Tai Jin PARK[b], Sang Kyung LEE[b], and Jong Kyung KIM[*,a]
[a]*Department of Nuclear Engineering, Hanyang University, Seoul, Korea*
[b]*Korea Radioisotope Association, Seoul, Korea*
**Corresponding Author: jkkim1@hanyang.ac.kr*

1. Introduction

Accelerator is well known that neutrons in the accelerator facilities are generated by high energy proton or ion collided with target nuclides. The Shielding Integral Benchmark Archive Database (SINBAD) [1] provides high quality benchmark experiments and detail information related with accelerator shielding. In this study, several SINBAD benchmark problems were evaluated for the preliminary study on a strategy establishment of the high energy particle simulations. The Monte Carlo simulations were performed by using TALYS-based Evaluated Nuclear Data Library -2011 (TENDL) [2] with MCNPX and PHITS Monte Carlo Codes [3-4]. The calculation results for the benchmark problems were compared and analyzed to verify the adequacy on the use of the physical models in the given conditions.

2. Simulation Models and Results

In the benchmark problem [1], proton, helium, and carbon ions are accelerated, of which have 590 MeV, 620 MeV, 1.86 GeV, respectively. The TENDL -2011 library is used for the simulation of the 1 keV ~ 200 MeV incident energy particles. Over the energy range, the particle simulation cannot be performed with the library; hence, some physics models are required in the simulation. In this study, both CEM03 model and Bertini model are used, of which are built in MCNP and PHITS codes, respectively. The Monte Carlo simulations were pursued with the models and the results were compared with the experimental results. All calculations were performed within 1 % relative error in total.

2.1 Simulation Results for 590-MeV Protons on a Thick Lead Target

The overview of experiment #1 is given as shown in Figure 1 [5]. In the problem, the 590 MeV proton beam having 2 cm diameter strikes a thick lead target. The target length is 60 cm consisting of 12 cylindrical blocks having 5 cm long and 10 cm diameter. The cylindrical neutron detector has 2.25 cm radius and 3.00 cm height. The detector is located at 90 degree on the proton direction and 100 cm iron collimator is installed between the target and the detector. The details of density information are given in Table I.

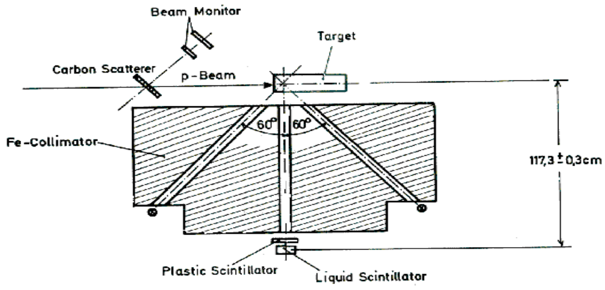

Figure 1. Experimental Structure for 590-MeV Protons on a Thick Lead Target

Table I. Density Information of Experiment Model

	Target	Collimator	Air
Density(g/cc)	11.35	7.874	1.2929×10^{3}

The neutron spectra were calculated and compared with experiment result [5] as shown Figure 2. The results show good agreements under the 200 MeV energy range. However, large differences were observed at high energy range less than 0.24 times as shown Table II.

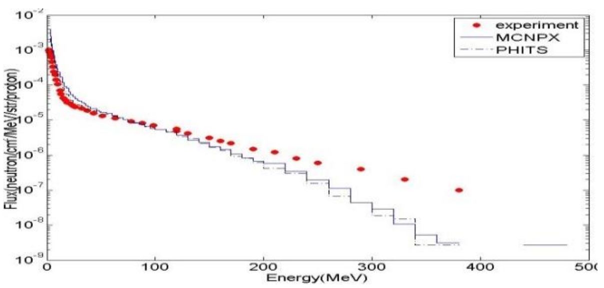

Figure 2. Neutron Spectra Emitted by 590 MeV Proton Beam Collisions at 90 Degree

Table II. Results of Calculation/Experiment (C/E) for Experiment #1

Range(MeV)	0~100	100 ~ 200	200 ~300	300~380
MCNPX	2.16	0.64	0.24	0.035
PHITS	1.26	0.62	0.2	0.037

2.2 Simulation Results for MSU Experiment with He & C ions on Al Target

The setup of the experiment #2 was performed as shown in Figure 3 [6]. In the experiment, the accelerated helium and carbon ion beam having 155 MeV/nucleon are incident into aluminum target. The cylindrical target has 13.34 cm length and 0.89 cm radius. Inside of the target, a cylindrical hole, which has 5.08cm long and 0.785cm radius, is located at the incident side of the ions. The target is surrounded by spherical steel chamber having 45.72 cm and 46.04 cm inner and outer radii. The grouped neutron detectors are located at 10, 30, 45, 60, 90, 125, and 160 degrees. Each detector has 6.35cm radius and 7.62cm thick. The details of the detection locations are given in Table III.

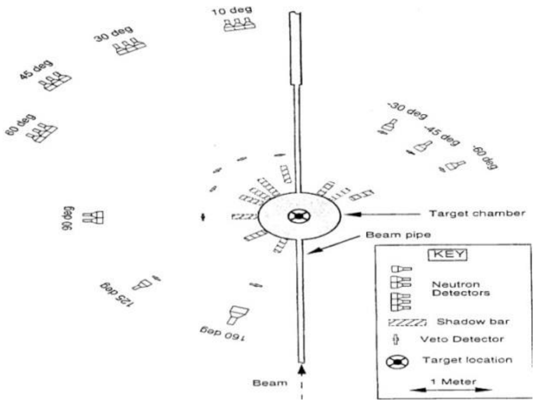

Figure 3. Overview of Experiment #2 Setup

Table III. Information about Detector Positions

Detector angle	10	30	45	60	90	125	160
Distance to target	116.8	125.7	125.1	100.3	106.0	221.0	154.8
Number of detector	3	3	3	3	2	1	1

The simulations were performed with MCNPX and PHITS, and the results are compared with experiment data of L. Heilbronn et al. [6] Figure 4 and 5 show neutron energy spectra generated by the collisions of the helium and carbon ions at 10, 60, 160 degree. Also, the results of C/E are given in Table IV. It is notified that the results show overestimation to 10.4 times in maximum.

Table IV. C/E of Calculation Results for Experiment #2

		Range(MeV)	0~50	50~100	100~268	268~460
10°	Helium	MCNPX	0.53	1.50	4.22	12.81
		PHITS	0.97	1.15	2.02	0.57
60°		MCNPX	1.88	1.74	3.50	-
		PHITS	3.72	1.33	1.28	-
10°	Carbon	MCNPX	1.28	2.58	5.26	5.62
		PHITS	3.45	5.05	6.42	1.84
60°		MCNPX	4.84	2.98	4.25	-
		PHITS	10.4	2.22	2.04	-

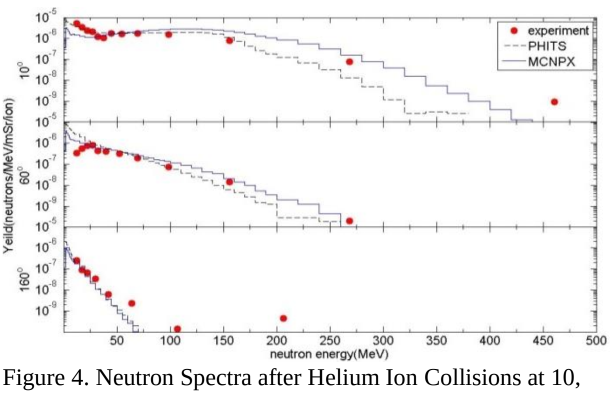

Figure 4. Neutron Spectra after Helium Ion Collisions at 10, 60, and 160 Degrees

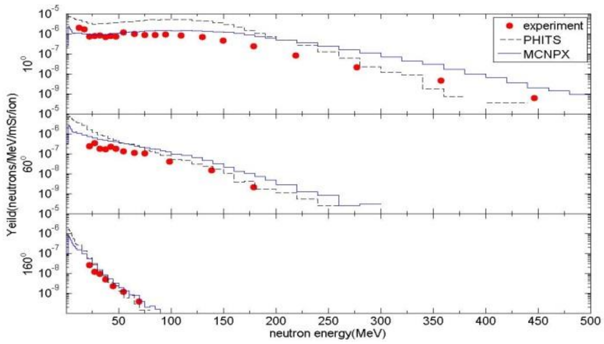

Figure 5. Neutron Spectra Generated Carbon Ion Collisions at 10, 60, and 160 Degrees

3. Conclusions

In this study, the evaluations of the several SINBAD experiments on the heavy ion accelerations were performed using CEM03 and Bertini models which are built in MCNPX and PHITS Monte Carlo code, respectively. Both neutron and heavy ion particles were simultaneously transported, and the neutrons generated by the heavy ion collisions were detected at each detection angle. In the results of the proton and helium ion reactions, the C/E of the neutron yields for PHITS and MCNP code results were estimated to 3.72 and 2.16 within 100 MeV energy range, respectively. Especially, the low energy neutron spectra generated by the results of the carbon ion simulation using PHITS code have significantly overestimated about 10 times. Thus, the results show that the caution should be strongly demanded in using the PHITS code for heavy ion simulation. It is expected that this results will give useful information to simulate the heavy ion transport calculation.

Acknowledgment

This study was supported in part by Radiation Technology Development Program through the National Research Foundation of Korea (NRF) funded by the NSSC (NRF-2012M5A1A2048201), and the Innovative Technology Center for Radiation Safety (iTRS).

REFERENCES

[1] OECD/NEA Data Bank, SINBAD, http://www.nea.fr/science/shie
lding/sinbad/sinbadis.htm.

[2] A.J. Koning, D. Rochman. Talys-based Evaluated Nuclear Data Library Version 4, 2011.

[3] X-5 Monte Carlo Team, "MCNP-A General Monte Carlo N-Particle Transport Code, Version 5, Volume I: Overview and Theory," LA-UR-03-1987, Los Alamos National Laboratory, 2003.

[4] K. Niita et al., PHITS: Particle and Heavy Ion Transport code System, Version 2.23, JAEA-Data/Code 2010-022, Japan Atmic Energy Agency (JAEA), 2010.

[5] Cierjacks S. et al. : "High Energy Particle Spectra from SpallationTargets," Proceedings of the 5th Meeting of the International Collaboration on Advanced Neutron Sources, Jülich, June 22-26, 1981.

[6] L. Heilbronn et al. "Neutron Yields from 155 MeV/nucleon Carbon and Helium Stopping in Aluminum", Nuclear Science & Engineering, vol. 132, p. 1, 1999