Geometrical effect of asymmetric target in two-step shielding calculation for 70 MeV cyclotron facility

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1. Introduction

Currently, radiation shielding analyses of the cyclotron to be installed into the Institute for Basic Science of Korea are carried out as a way of construction of heavy ion accelerator facility. In the course of radiation shielding calculation for cyclotron, it is known to be easy to have neutron source information in advance, being generated from the reaction between proton and target material. In the case of asymmetric target geometry against the axis of the proton beam direction, it is, however, difficult to accurately generate source terms in two-step calculation as such above. In this work, geometrical effect of target was investigated in the first-step of two-step calculation. As the target geometry, cylinder target was employed because it is widely used in the symmetric condition between beam direction and target.

Neutron source term from proton interaction with the small cylindrical aluminum target employed in this work was firstly calculated as functions of solid angle and energy in order to save the computation time. The calculated source term is used in the second-step calculation (Case 2). The results were compared with those from the direct calculation using proton source (Case 1) in the 70 MeV-cyclotron room.

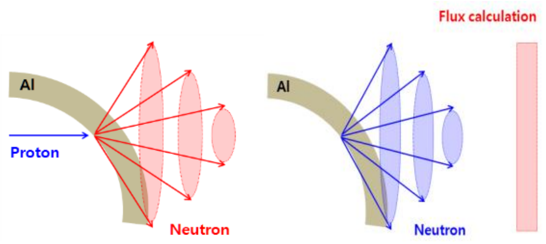
2. Methods and Results

2.1 Computational Code

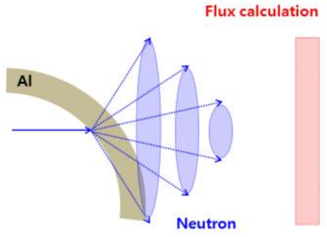
The neutron flux and energy spectrum were, in this work, calculated by using MCNPX ver. 2.7 [1], Monte Carlo N-Particle transport code. The JENDL/HE-2007 was employed as the cross-section library.

2.2 Source term calculation

Negative proton in cyclotron is accelerated in circular magnetic field, and the accelerated negative proton loses 2 electrons by stripping, and the resulting positive proton is extracted to the outside due to the magnetic fields in order to carry out various experiments. At this time, some negative proton loses one electron by stripping, and the resulting neutral proton generates neutrons through the collision with aluminum chamber. The diagram of two-step calculation is shown in Fig. 1(a) together with the direct calculation. From the Fig.(a), it is found that neutron source is made firstly and then second calculation of neutron flux follows by using the neutron source generated in the first-step.



(a)



(b)

Fig. 1. Schematization of two Cases, two-step calculation (a) and direct calculation (b)

Neutron source term was calculated divided by 5 degree solid angle with the incident proton beam direction as the center. The thickness and radius of the cylindrical aluminum target were chosen as 3 cm, and 3 cm, respectively, considering the geometry and generation rate of neutron in the source term calculation.

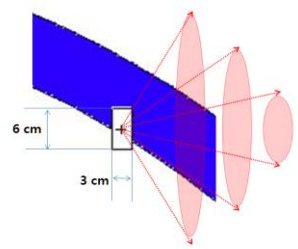


Fig. 2. Cylindrical aluminum target of source term calculation

The region of cylindrical aluminum target was set to void in order to avoid overlap effect by aluminum chamber to be done in the second-step calculation as shown in Fig. 2, because the cylindrical aluminum target region was already applied while generating neutron source.

2.3 Flux calculation

In order to find the effect of target geometry in the first source term calculation, a simple test problem was employed as shown in Fig. 3. Tally region for neutron flux was located at 3 m away from the center of aluminum chamber, and the dimensions of the region were: length of 40 cm, height of 40 cm, and width of 10 cm. 20 tally points was set in this calculation.

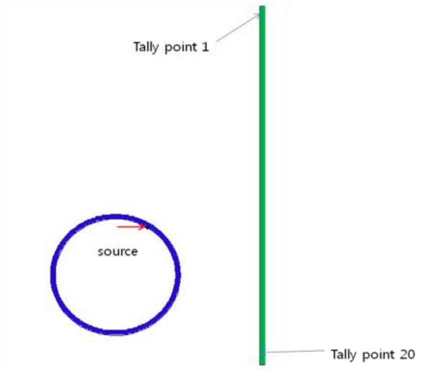


Fig. 3. Geometry of test problem for neutron flux calculation

The thickness of aluminum chamber is 10 cm, having inner radius of 125 cm and height of 40 cm. The proton beam move toward the direction of tangent of rotating beam with a radius of 107 cm. Energy of the proton beam is 70 MeV. Composition of aluminum chamber is shown in Table I and its density is 2.68 g/cc.

Table I: Composition of aluminum alloy 5052

Element	Ratio (wt%)
Mg	2.5
Cr	0.25
Cu	0.1
Fe	0.4
Mn	0.1
Si	0.25
Zn	0.1
Al	96.3

2.4 Results

Prior to compare the results from the two Cases, neutron spectrum for the two Cases were calculated and compared at the tally points showing the highest neutron flux and shown in Fig. 4, and neutron flux per source particle was also calculated at the 20 tally points as presented in Table II. As per the energy spectrum, the two-step calculation with cylindrical aluminum target shows good agreement with the reference calculation (direct calculation). For the neutron flux, maximum difference of 17 % was occurred at tally point 18. Generally the differences at the top and bottom of tally region were shown to be large compared those at the middle points.

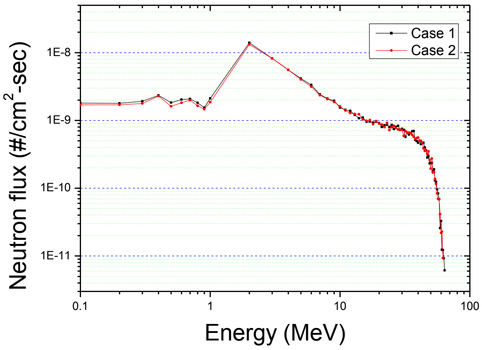


Fig. 4. Neutron energy spectrums of two Cases at tally point showing highest neutron flux

Table II: Comparison of neutron fluxes from two Cases

Tally point	Case 1(ref.) (#/cm^2-sec)	Case 2 (#/cm^2-sec)	Error*
1	1.86E-08	2.00E-08	7%
2	2.10E-08	2.27E-08	8%
3	2.49E-08	2.67E-08	7%
4	2.99E-08	3.04E-08	2%
5	3.57E-08	3.66E-08	3%
6	4.37E-08	4.42E-08	1%
7	5.23E-08	5.36E-08	3%
8	6.25E-08	6.41E-08	3%
9	7.43E-08	7.56E-08	2%
10	8.56E-08	8.53E-08	0%
11	8.98E-08	9.25E-08	3%
12	8.55E-08	8.81E-08	3%
13	7.07E-08	7.31E-08	3%
14	4.91E-08	5.05E-08	3%
15	2.88E-08	2.81E-08	-2%
16	1.49E-08	1.46E-08	-2%
17	8.73E-09	7.76E-09	-11%
18	7.08E-09	5.84E-09	-17%
19	6.46E-09	5.39E-09	-16%
20	6.04E-09	5.11E-09	-15%

*Error=(Case2-Case1)/Case1 × 100

At the top tally region of this test problem, it is found that neutron flux was overestimated, and the bottom region underestimated.

3. Conclusions

Geometrical effect of target was studied in the source term calculation of two-step calculation. In this work, cylindrical target was employed and the results from the two-step calculation were compared with the reference calculation. It is found that two-step method can give large error at the specific points according to target geometry in the source term calculation.

It is, therefore, noted that proper choice of target geometry in the two-step method would be needed in order to get accurate results with time saving, and another research on the different target geometry instead of cylindrical geometry should be made.

ACKNOWLEDGEMENT

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REFERENCES

[1] Denise B. Pelowitz, ed., MCNPX^{TM} User's Manual, version 2.7.0, LA-CP-11-00438, Los Alamos National Laboratory, April, 2011.