Design of Collimator for Fast Neutron Generator Using Monte Carlo Simulation

Choonsik Lee [a], Chang-ho Shin [a], Jong Kyung Kim [a], Daeyong Shin [b], Dalgyu Ha [b]
a Department of Nuclear Engineering, Hanyang University, Seoul, cslee@itrs.hanyang.ac.kr
b Hitec Holdings Co., Technopark #364, Samjung, Ojeong, Puchun, Kyunggi

1. Introduction

Neutron radiography has a tradition since neutron sources and imaging devices became available. Non-destructive testing with neutrons has been an established method for several years [1,2]. The specific advantage of neutrons compared to X-rays is the higher interaction probability with hydrogen and the lower attenuation in several heavy elements which are just black for X-rays. However, this method cannot compete directly with X-ray methods on a broad scale since most of neutron sources are nuclear reactor. Since the nuclear reactors require a great economic expense, only some sites in different countries are able to study radiography with neutrons. However, onsite inspection is impossible using stationary reactor neutron sources. Some attempts to perform neutron radiography using mobile neutron sources are on the way in Russia [3].

Neutron non-destructive testing system using mobile neutron source also has been developed by company Hitec Holdings and Hanyang University. As a starting stage result, this article describes the design of shield and collimator.

2. Methods and Results

2.1 Neutron Generator Modeling

D-T reaction-based neutron generator GENIE-16 manufactured by the company SODERN in France was adopted for neutron source in this study. The GENIE-16 is a neutron generator that has been specially designed for several uses in addition to neutron radiography. Neutron yield is up to 2×10^8 neutrons/s with the energy of 14.1 MeV from D-T reaction. Typical tube lifetime is 4000 working hours. Source target is composed of tritium-loaded titanium. Fig. 1 shows the photograph of the GENIE-16 and control equipment.

General-purposed Monte Carlo code, MCNPX2.4 was used for the simulation of the neutron generator and collimator [4]. Most of detailed electronics in the generator were simplified in simulation. Only stainless steel housing (8.02 g/cm^3) and titanium target (3.76 g/cm^3) were described.

2.2 Shielding Calculation

3 materials were selected for shield of neutron generator: general polyethylene (density, 0.94 g/cm^3), borated polyethylene (density, 1.4 g/cm^3) and lithium-loaded polyethylene (density, 1.06 g/cm^3). Borated PE (polyethylene) was adopted because of high neutron absorption cross section of boron. Whereas boron shields neutron well, borated PE results in a 0.42 MeV capture gamma. Lithium-loaded PE does not produce the capture gamma ray. General PE is competitive due to its low cost.

Figure 1. Photo of mobile neutron generator, GENIE-16 and control equipment.

In order to shield gamma ray generated from neutron-gamma reaction, lead was used. Neutron shield was designed as cubic box covering neutron emitting module of the generator. 5 mm-thick lead layer was applied to outside of the cubic box. Surface dose rate was calculated on the external wall of gamma shield for various thickness of neutron shield (10-50 cm). Ideal sphere detector (diameter, 5 cm) was positioned on the external wall of gamma shield. **f6 tally* of MCNPX2.4 was performed for neutron and photon with *de/df* card which multiplied the resulting absorbed dose by neutron quality factor. The surface dose rate (mSv/hr) for three shielding materials is depicted in Fig. 2.

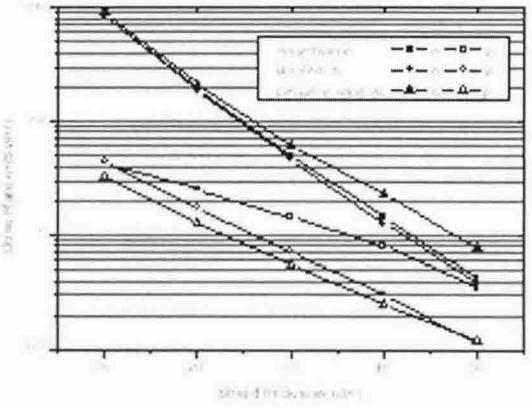

Figure 2. Surface neutron (n) and photon (p) dose rate (mSv/hr) for 3 shielding materials.

There is at most 27% difference between photon dose rate for lithium-loaded PE and borated PE. As the thickness of collimator increases, the difference decreases.

Although lithium-loaded PE reduces neutron capture reaction, the inelastic scattering would be more dominant for high energy neutron (~14.1 MeV) than neutron capture reaction. Moreover, lithium-loaded PE shows up to 50% lower neutron shielding efficiency than other materials. In case of 50 cm-thick shield, total dose rates for three materials are 0.78 (general PE), 0.51 (borated PE) and 0.90 (lithium-loaded PE) mSv/hr, respectively. Borated PE and lead composition was selected as optimal neutron and gamma shield.

2.3 Collimator Design

Neutron collimator was designed as the expansion of 50 cm-thick borated PE neutron shield to the direction of neutron emission (-y direction). Fig. 3 shows view of 3-dimensional neutron generator with collimator.

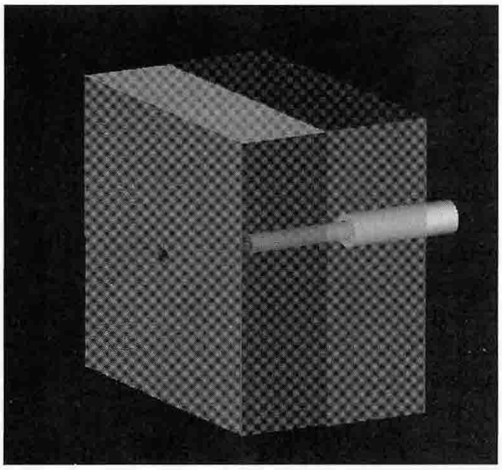

Figure 3. View of 3-dimensional neutron generator with 50 cm-thick shield and 30 cm-long collimator (rendered by SABRINA4.12)

Performance parameters for the description of the system properties were adopted as followings. Neutron and gamma flux (#/cm^2/s) were computed. Depending on the applied detector, high background of gamma can give disadvantageous fog in the resulting images. Therefore, higher neutron flux with lower background gamma is the final goal of collimator design. L/D ratio is calculated by geometric consideration of the beam collimator design. D is inlet aperture diameter facing the source and L is length of collimator. Higher L/D represents more parallel neutron beam. However, long collimator reduces neutron flux since the flux follows a 1/R^2-law. Neutron and gamma flux were calculated using ideal spherical detector (diameter, 10 cm) just in front of the outlet of beam with various L, the length of collimator from 0 cm (no collimator) to 50 cm. Table 1 tabulates the neutron and background gamma flux, and L/D ratio for several lengths of collimator.

As L/D ratio about 5 times increases, neutron flux is reduced to 1/5 in case of the collimator length of 10 and 50 cm. Although more parallel beam will be obtained using longer collimator (high L/D ratio), the low neutron flux will cause the longer time to get a neutron radiography image. Optimal length of collimator will be decided when the minimum required time for image acquisition will be fixed.

Table 1.Neutron/gamma flux and L/D ratio for various collimator lengths (0-50 cm)

Collimator length (cm)	Flux (#/cm^2/s)		L/D ratio
	Neutron	Gamma	
0	6.20×10^4	1.87×10^4	0.00
10	2.86×10^4	1.85×10^4	1.54
20	1.55×10^4	9.56×10^3	3.08
30	9.00×10^3	5.15×10^3	4.62
40	5.91×10^3	3.04×10^3	6.15
50	3.71×10^3	1.36×10^3	7.69

3. Conclusion

Shield and collimator for D-T reaction-based neutron generator GENIE-16 were designed by using Monte Carlo code, MCNPX2.4. Borated polyethylene was chosen as an optimal shielding material for neutron, and 5 mm-thick lead shield was used to reduce gamma ray. Cubic-shaped collimator composed of borated PE was designed, and neutron/gamma flux and L/D ratio for various collimator lengths were calculated. As L/D ratio increases, neutron flux decreases. Low neutron flux will cause longer irradiation time in radiography. Optimal design of collimator will be decided when the minimum required time for image acquisition will be fixed. The result of this study will be used as reference data for development of neutron radiography equipment using mobile neutron generator.

Acknowledgement

We wish to acknowledge the support by Hitec Holdings. Also, we give special thanks to the Innovative Technology Center for Radiation safety (iTRS), Hanyang University, Seoul, Korea for partial support to this work.

REFERENCES

[1] J. P. Barton, "Contrast Sensitivity in Neutron Radiography," Applied Materials Research, **April**, 90 (1965).

[2] H. Berger, "Radiography, Methods, Capabilities and Applications," Elsevier (1965).

[3] V. Mikerov, W. Waschkowski, "Fast neutron fields imaging with a CCD-based luminescent detector," Nuclear Instruments and Methods in Physics Research Section A, **424**(1), 48 (1999).

[4] S. W. Laurie, Ed., "MCNPX users manual, version 2.4.0," LA-UR-02-2607, Los Alamos National Laboratory (2000).