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Monte Carlo calculation for the estimation of the fast neutron distribution from DT neutron generator for air cargo inspection system

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1. Introduction

There is a growing need for security inspection system for air cargo in airport. Existing air cargo inspection technologies use high-energy x-rays to detect distinctive metal objects, but organic materials such as drugs and explosives, are more difficult for them to detect. [1] By combining neutrons and high energy x-rays, operators can efficiently identify suspicious materials by detecting and predicting the composition as well as the shape and density of an object. [2] This is because neutrons are most readily blocked by organic materials and substances with high hydrogen content In contrast to X-rays which are stopped by dense materials such as metals. [2] In Korea Atomic Energy Research Institute, linear accelerator and neutron generator have been installed to develop an air cargo inspection system that can distinguish various materials composition of cargo items. Therefore, as a preliminary study, Monte Carlo simulation and shielding calculation for the safe use of the neutron generator were performed to meet the general radiation dose limits in the public area outside the radiation management area.

2. Methods and Results

In this study, shielding calculation was performed to design a collimator for the DT neutron generator and to satisfy dose limit of 0.5uSv/hr for uncontrolled areas. The calculation was carried out by Monte Carlo neutron transport code MCNP5 with nuclear data of the ENDF/B-VII and 4E+09 particle histories. In order to calculate radiation dose, F4 tally and neutron flux-to-dose conversion factor from ICRP-74 were applied.

2.1 Specification of neutron generator

The neutron generator is located next to the electron accelerator as shown in Fig 1. This device generates neutrons by the D-T reaction, and the energy of the generated neutrons is 14.1 MeV. The neutron intensity of 1.0E+09 Neutron/s is planned to be used in this facility. Therefore, conservative calculation is performed assuming neutron generation of 1.1E+09 Neutron/s after taking 10% neutron generation error into consideration. Polyethylene was used as a collimator for the neutron generator, and the optimum shield thickness was calculated for each direction. The beam irradiation angle of the neutron generator is 25 ° from the bottom, and the beam height is 110 cm from the bottom. The beam spreading angle is 74.5 degree and the beam width is 20 mm.

Table I: Specification of DT neutron generator [3]

Parameters	Value
Energy	14 MeV
Voltage	160 kV
Current	2 mA
Life time	2,000 hr
Flux(Average)	1×10^{9} n/s/4πsr (±10%)
Repetition rate	0 ~ 5 kHz
Rising and falling time	2 us
Head size	Ø 150 mm(Max), 865 mm length
Head weight	27 kg
Quantity of Tritium	720 GBq
Cooling method	Water based cooling

2.2 Design of collimator for neutron generator

For the shielding calculation of radiation dose from DT neutron generator, Monte Carlo simulation was performed. As a collimator material, polyethylene was determined due to its high cross section for neutron. The intricate structures inside and outside the neutron generator could affect the neutron shielding, but they were not conservatively reproduced. A cylindrical source of volume of 6 cm in radius and 100 cm in length was applied. In addition, a space of 30 cm in width, 30 cm in height, and 100 cm in length was set as a space for the accessory device. In the beam direction, the slit is designed so that the neutrons generated from the neutron source can reach the detector. In order to confirm that neutrons are emitted from the designed slit, we can confirm the distribution of neutrons around the collimator and within controlled areas by using Monte Carlo simulation as shown in Fig 2.

Figure 1. Neutron collimator made of polyethylene (left) and installed collimator (right)

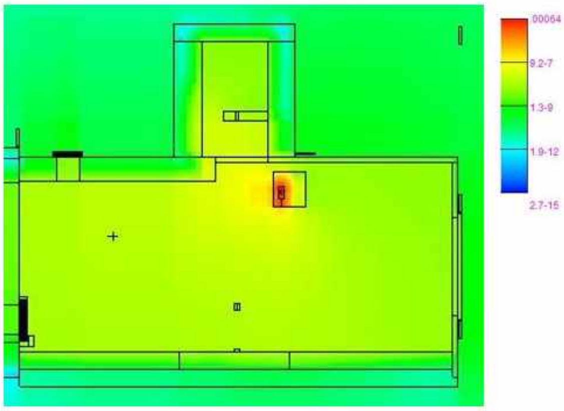

Figure 2. Neutron distribution inside controlled area

2.3 Result of shielding calculation

The radiation dose was calculated in the measurement points 1 to 10. Table 4.1 shows the calculation results of the neutron dose, and Table 4.2 shows the results of calculation of the radiation dose by neutron-induced secondary particles. All areas satisfied the general radiation dose limits, 0.5 μSv/h. In addition, because the electron accelerator and the neutron generator operate simultaneously, the sum of the radiation dose induced by the photon and neutron calculated above must satisfy the radiation dose limit.

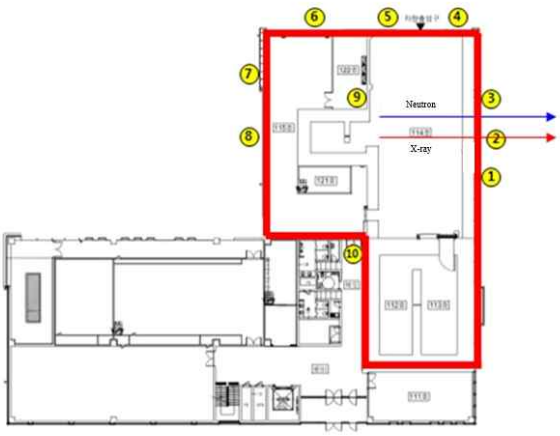

Figure 3. The measurement position of radiation dose outside controlled area

Table II. The calculation results of the neutron dose

Position	Value (uSv/h)	Relative error (%)
①	7.28E-03	6.67
②	1.95E-02	3.83
③	2.53E-02	3.43
④	5.55E-01	1.03
⑤	2.16E-01	1.56
⑥	2.18E-02	5.35
⑦	1.50E-02	4.22
⑧	4.05E-03	8.20
⑨	4.32E-01	1.15
⑩	1.66E-02	4.29

Table III. The results of calculation of the radiation dose by neutron-induced secondary particles

Position	Value (uSv/h)	Relative error (%)
①	7.28E-03	6.67
②	1.95E-02	3.83
③	2.53E-02	3.43
④	5.55E-01	1.03
⑤	2.16E-01	1.56
⑥	2.18E-02	5.35
⑦	1.50E-02	4.22
⑧	4.05E-03	8.20
⑨	4.32E-01	1.15
⑩	1.66E-02	4.29

3. Conclusions

Korea Atomic Energy Research Institute (KAERI) has been installing a 14.1 MeV neutron generator and a 6 MeV electron accelerator to develop air cargo inspection system with material discrimination function. In this study, the shielding calculation of radiation dose in uncontrolled area was performed by Monte Carlo simulation. Also, neutron collimator was designed to meet the radiation dose limits in uncontrolled area around the air cargo inspection room. As a result, the neutron generator was shielded by polyethylene with a maximum width of 1.2 meters to satisfy the radiation dose limit. In addition, the neutron distribution inside the air cargo inspection room was confirmed using Monte Carlo simulation. These results of shielding calculation will be used as a basic data for the optimization of air cargo inspection system in the future and will contribute to the radiation safety inside and outside the controlled area.

ACKNOWLEDGEMENT

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