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Design of X-ray and Neutron measurement system for Single-body Multi-Radiation Generator

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1. Introduction

When using a conventional X-ray tube, the radiation security inspection system cannot sufficiently transmit X-rays when inspecting a heavy object including metal, and the distinction between light elements including plastic, water, and oil is ambiguous. In order to solve these problems, researches on a radiation security inspection system using high energy X-ray and neutron source have recently been actively conducted. Such a multi-radiation using neutrons and high-energy X-rays not only provides high-quality X-ray images of heavy and dense objects containing metals and leads, but also facilitates the identification of low-atomic materials through neutron sources. [1-3]

In order to generate neutrons for neutron radiography, we can use neutron sources such as 1) radioisotope neutron sources such as spontaneous fission isotope californium-252, 2) particle-accelerator based neutron sources, and 3) accelerator based photo-neutron sources. [4-6] In addition, high-frequency electron accelerators are mainly used to generate high energy X-rays of several MeV.

In the case of the conventional radiation security inspection system with multi-radiation generator, neutrons and X-rays are generated based on separate generating devices. [7-10] These techniques are used only as a fixed type because each radiation generating device is relatively large in size, heavy, and requires a lot of electric power and cannot be mounted on mobile equipment.

Therefore, in this study, we have conducted research to measure X-ray and neutron generated from high-frequency electron accelerator in order to develop a movable multi-radiation generator. [11, 12]

2. Methods and Results

In this study, a simulation study was conducted to design a system for measuring X-ray and neutron sources generated from a single-body multi-radiation generator. In addition, measurement method and system design were performed considering the energy and flux of multi-radiation generated through Monte Carlo simulation.

2.1 Monte Carlo simulation

Monte Carlo Simulation was performed to calculate flux of neutrons and X-rays generated from a single-body multi-radiation Generator. [13,14] The number of X-ray photons was found to be the largest at 0 ~ 10 ° of the beam direction, but the neutron source was found to have a uniform deviation within 11.3% at all angles. Figure 1 shows the simulation result of neutron flux as a function of the neutron energy, and figure 2 shows angular distribution of neutron and X-ray flux.

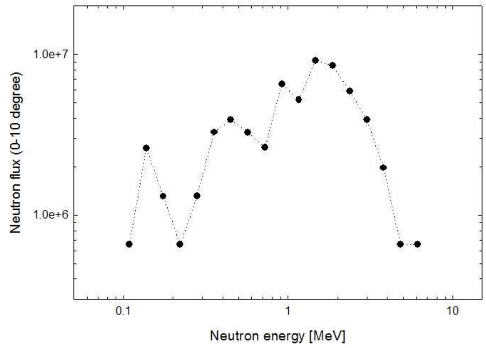

Figure 1. Simulation result of neutron flux as a function of the neutron energy

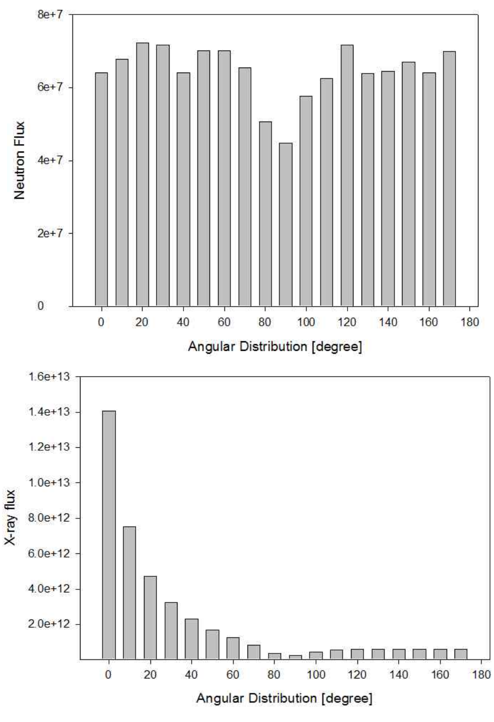

Figure 2. Simulation result of angular distribution of neutron (top) and X-ray flux (bottom)

2.2 Design of multi-radiation measurement system

For the measurement of the neutron flux from a single-body multi-radiation generator, multi-radiation measurement system was designed using passive and active neutron detection techniques. As an active neutron detection techniques, the ^{3}He filled neutron detector may be used to detect neutrons via the following reaction.

$$^{3}He + n \rightarrow {}^{3}H + p \qquad Q = 0.764\ MeV \quad (1)$$

As the ^{3}He filled neutron detector, FHT 752 SH-2 manufactured by Thermo Scientific was selected and its specification is shown in Table 1. [15]

Table 1. Specification of ^{3}He filled neutron detector

Items	***parameters***
Model	FHT 752 SH-2
Type	A proportional counter tube filled with ^{3}He
Dimension	26mm in diameter , 224mm in length
Gas filling	^{3}He; enhanced with CO_2
Filling pressure	2000 mbar
Active volume	56.1 cm^3
Measuring range	From 0.01 to 100,000

Also, the measurement system for the neutron yield of the single-body multi-radiation generator was designed using activation of a natural copper foil. Copper was selected as the foil material due to the following reaction and the activity of the activated foil may be determined via gamma-ray spectroscopy, by counting gamma-rays in the 511 keV peak obtained via electron-positron annihilation. [16]

$$^{63}Cu + n \rightarrow {}^{62}Cu + 2n \qquad (2)$$

The flux of neutrons through the number of measured gamma-rays is calculated by the following equation.

$$A(t) = N_t \sigma \Phi (1-e^{-\ln(2)t_{irr}/t_{1/2}})(e^{-\ln(2)t/t_{1/2}}) \qquad (3)$$

where Φ is the flux of reactant particles incident on the target, N_t is the number of target atoms, σ is a quantity called the cross section, t_{irr} is the time for which the foil was irradiated, $t_{1/2}$ is the half-life of the species, and t is the length of time that has elapsed since the end of irradiation.

In addition, an X-ray measurement system was designed using an ionization chamber, FHT 191N, for X-ray dose measurement and a wedge filter for X-ray energy measurement. Since the maximum value of the energy of the X-ray generated from the electron accelerator is proportional to the energy of the accelerated electron, in this study, the maximum energy of the X-ray is calculated by measuring the energy of the accelerated electron.

3. Conclusions

In this study, fluxes of X-rays and neutrons generated by the single-body multi-radiation generator were calculated using Monte Carlo Simulation. Based on the result of the Monte Carlo simulation, suitable radiation detectors and measurement methods was selected for a single-body multi-radiation generator after considering flux and energy range of X-rays and neutrons. As a future work, we will optimize the Monte Carlo simulation considering the surrounding structures, collimator, and shielding materials, and we will compare the measured values with simulation values by installing the designed measurement system together with the generator. Such data can be used not only for evaluating the performance of the radiation security inspection system with a single-body multi-radiation generator but also for developing a lightweight multi-radiation generator.

It is expected that it can be operated with light weight and low power consumption when using the single-body multi-radiation generator. Therefore, it can be widely used as a portable non-destructive inspection equipment regardless of the place.

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