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■Papers■

STUDY ON X-RAYS AND NEUTRONS LEAKED FROM A 45 MeV ELECTRON LINAC FACILITY

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Abstract - Spatial and time distributions of x-rays and neutrons from Hokkaido University 45 MeV electron linac facility were measured and compared with the calculation. In the calculation, x-rays in a Pb-target were evaluated using the EGS-code. The x-rays and the neutrons from the target to the facility building boundary and skyshine processs outside the facility building were simulated with the EGS and the MCNP respectively.

INTRODUCTION

Evaluation for skyshine from nuclear facilities is one of the environmental evaluation items. This evaluation has been carried out using some shielding calculation codes. Because of extremely few benchmark data of skyshine, the calculation has to be performed very conservatively. Therefore, the benchmark data of skyshine and the well-investigated codes for skyshine would be necessary for the rational evaluation of nuclear facilities. The purpose of this study is to obtain the benchmark data of skyshine and to investigate the calculation for skyshine.

In this study x-rays and neutrons from Hokkaido University 45 MeV electron linac facility were measured and compared with the calculation. Bremsstrahlung x-rays and neutrons were emitted from a Pb-target irradiated with electrons from the linac. The skyshine process of the x-rays and the neutrons transported through the facility building to the outside were investigated. Dose distributions of the x-rays were measured by the gated counting method, developed for low level pulsed radiation and compared with the calculation using the EGS-code. The Spatial and time distributions of neutrons has been measured and calculated with the MCNP.

The measurements were carried out up to the distance of about 600 m for x-rays and 300 m for neutrons from the facility.

EVALUATION OF SKYSHINE SOURCE

The x-rays and the neutrons were generated in a Pb-target set in front of the electron beam exit window of the linac. A main path from which the x-rays and the neutrons leaked was found to be the stack installed at the accelerator room. The effective source position for the skyshine process of the x-rays and the neutrons was taken at the position of the stack on the roof of the accelerator room. The source intensity was evaluated by the calculation with the EGS and the MCNP-code.

1. Source intensity of x-rays

Energy spectrum of bremsstrahlung x-rays was estimated using the EGS-code. In the calculation the Pb-target with thickness of 9 mm and radius of 20 cm was set at 1 m from the beam exit window. The electron energy was 45 MeV and the beam radius was 0.25 cm. The emitted photons are transported to the stack. Fig. 1 shows the calculated energy spectrum at the stack, which is used as a source spectrum for x-ray skyshine process.

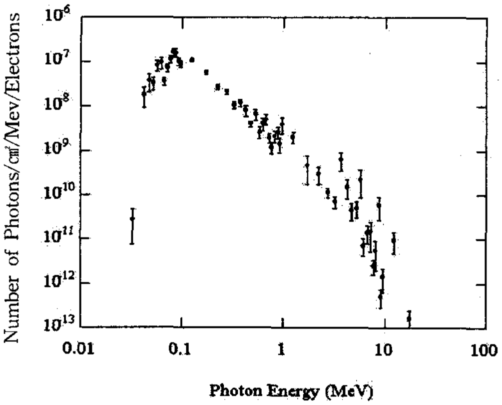

Fig. 1. Energy spectrum of bremsstrahlung x-rays at the duct calculated using the EGS-code

2. Source intensity of neutrons

A water-cooled Pb target (6.4x6.4x5cm) was used for neutron generation. The electron energy was 35 MeV and the beam radius was 1 mm. Fig. 2 shows the photonuclear reaction cross section of Pb[1]. A photoneutron yield was evaluated as the product of the cross section and the bremsstrahlung x-ray spectrum. The total neutron yield was estimated as 8.2×10^{-3}/electron. The produced neutron spectrum was assumed as a Maxwellian distribution with temperature of 1.3 MeV[1]. Simulating neutron transport in the accelerator room with the MCNP, the energy spectrum at the duct was calculated, which was shown in Fig. 3.

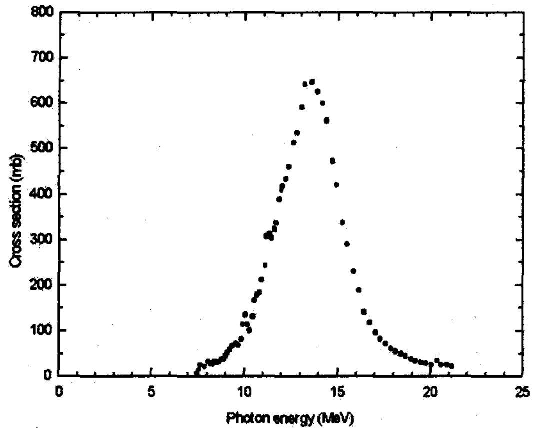

Fig. 2. Photonuclear cross section of Pb1)

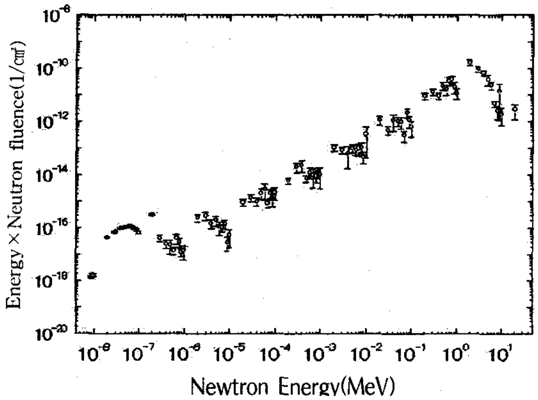

Fig. 3. Neutron energy spectrum at the duct calculated using the MCNP.

SKYSHINE PROCESS :X-RAY

1. Calculation

For the EGS calculation, the gemetry of (D=1.6 km, L_1=1.0 km and L_2=50 m) was used. Eight detectors were set in the west, the east, the south and the north at the distance of 50～700 m[2]. The energy spectrum at 100 m and 500 m in the west are shown in Fig. 4. The calculated dose distributions are shown together with the measured ones in the next section.

2. Experiment

The gated counting method is applied to the measurement of x-rays[3]. The method was developed for measuring low-level radiation from a pulsed source and proved to be very useful for monitoring pulsed leakage radiation from linear accelerator.

Pulses synchronized with the pulsed electron beam are transmitted to the counting system, located at the detector position, so as to generate gate pulses for controlling a scaler. The gated scaler accepts signals from a radiation detector only during the expected time for x-rays produced by the accelerator to arrive at that point. Signals due to natural background radiation are rejected during the time outside the gated pulses, therefore background counts are reduced by a factor of the duty cycle. For a 100sec gate and a repetition rate of 100pps in thé experiment, the background count would be reduced by a factor of 300.

A NaI scintillation detector(3″×3″) was used and pulse height distributions were measured. Exposure was estimated from the pulse height distribution by

$$X = \int G(h)N(h)dh$$

, where was experimentally determined for the NaI scintillation detector used in the experiment [4].

Fig. 5 is the map of the facility and the measurement points in the west. The measured dose distributions are shown in Fig.6 The calculated distribution in the west is shown together with the experimental ones. The calculation fairly agrees with the experiment up to the distance of 300 m. However in the region over 300 m the difference between the calculation and the experiment appears, which suggests that any more consideration is needed.

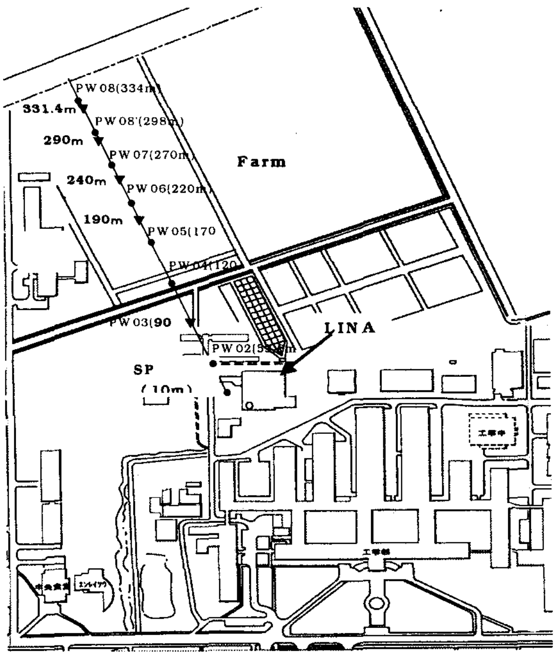

Fig. 5. Map of the facility and the measurement points in the west. (The measurement points : SP PW08).

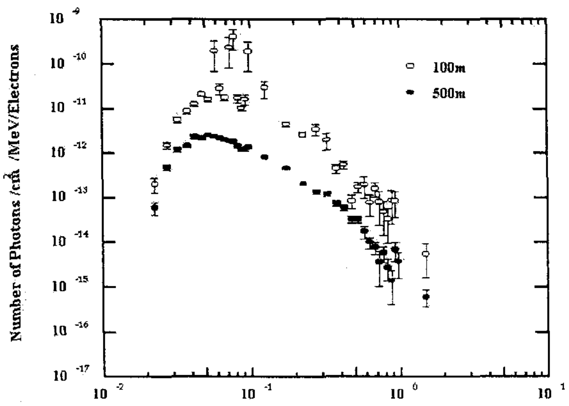

Fig. 4. Energy spectrum at 100m and 500m in the west

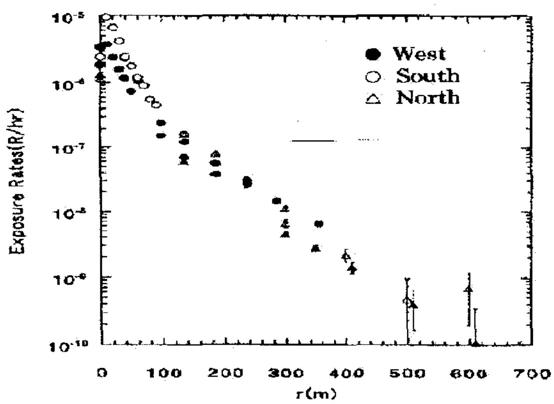

Fig. 6. Measured dose distributions in the west, the north and the south.

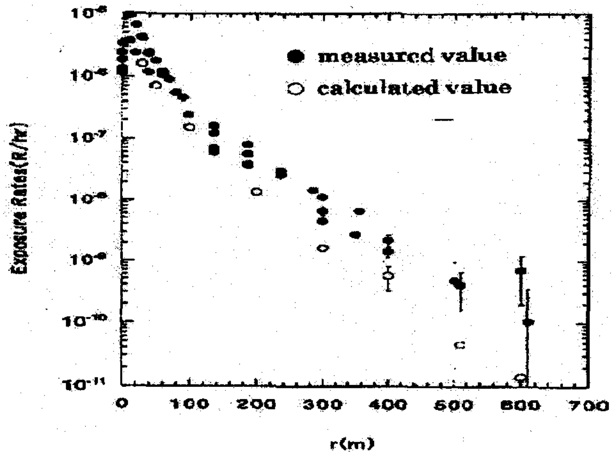

Fig. 7. Measured and calculated dose distributions in the west.

SKYSHINE PROCESS:NEUTRON

1.Calculation

Using the spectrum in Fig. 3 as a source spectrum, the neutron energy spectra and the counts by a BF_3 counter were calculated. Fig.8 shows the energy spectra at the stack and, at the distance of 10,50,150 and 350 m from the stack.

2. Experimental result and comparison with the calculation

The neutrons were measured by two BF_3 counters(BF_3, 700 torr., 1.87'x12.25') and two ^3He counters(^3He, 760 torr. 2.54cm×25.4cm) with a paraffin moderator, which were shown in Fig. 9. The spatial distribution measurement of neutrons was performed by ordinary counting system, as the gated counting method is not effective because propagation time of neutrons extended in wide range. The measured distribution of arrival time from the source to the detector point indicated that it distributed over 100 msec and then effective reduction could not be expected.

The measurement was carried out up to the distance of 330 m from the facility. The results are shown together with the calculation in Fig. 10. The calculated value of BF_3 counts are normalized by the experimental one at the point of 10 m apart from the source(SP in Fig. 5). Up to the distance of 100 m, the experiment corresponds with the calculation. In the region of the larger distance than 200 m from the facility, the measured counts were comparable to the background counts. It needs the more stability of the measurement system and longer counting time for getting more accurate data and discussion in detail.

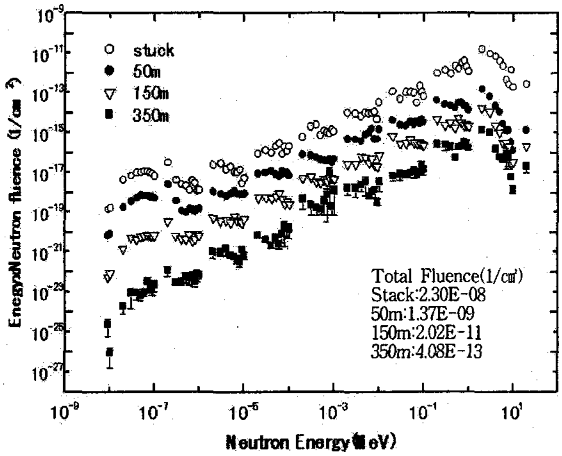

Fig. 8. Calculated energy spectra at the stack and at the distance of 10,50,150 and 350m.

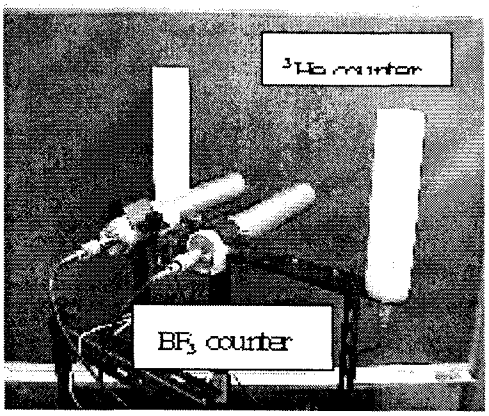

Fig. 9. Photograph of BF_3 He counters.

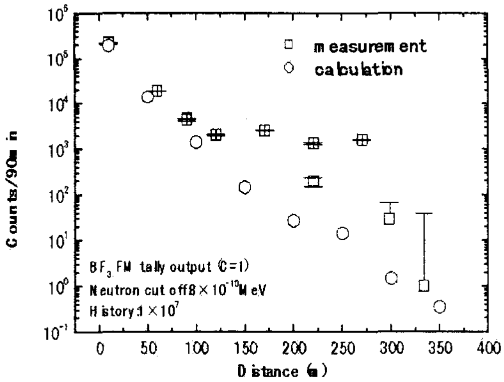

Fig. 10. Measured and calculated counts by BF3 counters vs. distance from the stack.

CONCLUSIONS

Dose distributions of x-rays measured by the gated counting method up to the distance of 600 m from the 45 MeV electron linac facility. The method was effective to discriminate the background radiation from the bremsstrahlung x-rays leaked from the facility. The experimental results up to the distance of 300 m agree well with the calculation using the EGS-code but not over 300m. Neutrons were also measured by standard method. It was found that the gated counting method for neutrons was not so effective as for x-rays, because the spread of the neutron arrival time at the detector points increases with the distance from the facility. In the present status, it was found that up to the distance of 100 m the experiment agrees with the calculation using the MCNP, but stability of the measurement system is not enough for consistent discussion.

REFERENCES

1. W.P.Swanson, Radiological Safety Aspects of Electron Linear Accelerators, Technical Report Series, No. 188, International Atomic Energy Agency, Vienne(1979).
2. M. Hori, N. Niikawa, M. Kitaichi, S. Sawamura and I. Nojiri, Proc. of the 5th EGS4 User's Meeting in Japan.(1995).
3. T. Sawamura, I. Murai and H.Tanida, Health Phys., 49, 120(1985).
4. S. Moriuchi and I. Miyanaga, Health Phys., 12, 541(1966).