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The comparison of dose distributions in a water phantom for accelerator-based and reactor-based neutron irradiation fields for NCT.

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1. INTRODUCTION

Accelerator-based neutron irradiation facility for neutron capture therapy (NCT) has been studied mainly in USA and EU since the beginning of 1980's. Compared to reactor-based neutron irradiation facility, accelerator-based neutron irradiation facility has several advantages as follows.

<1> Accelerators are convenient to get epi-thermal neutrons suitable for NCT because it is easy to reduce fast neutrons by selecting the accelerating energy and/or the target material.
<2> There is a possibility that accelerator-based neutron irradiation facility may be constructed near hospitals.
<3> It is easy to start and stop the accelerator.
<4> Irradiation direction is flexible.

^{7}Li(p,n)^{7}Be (Q-value:-1.644MeV, threshold:1.881MeV) reaction for 2.50MeV protons and ^{9}Be(p,n)^{9}B (Q-value:-1.852MeV, threshold:2.059MeV) reaction for around 4.00MeV protons have been investigated mainly considering the yield and the energy of produced neutrons[1,2)].

The purpose of the investigation in this paper is as follows[3)].

[1] To investigate the difference of neutron irradiation characteristics between accelerator-based neutron irradiation facility and reactor-based neutron irradiation facility by means of experiments and simulations.
[2] To estimate the order of the proton current necessary for NCT treatments experimentally.

Li target with 2.50MeV proton and Be target with 4.20MeV proton were examined as accelerator-based neutron facility. Kyoto University Reactor Heavy Water Neutron Irradiation Facility (KUR-HWNIF) which is available for NCT at present was used as reactor-based neutron irradiation facility.

2. THE MEASUREMENT OF NEUTRON DOSE DISTRIBUTION IN A PHANTOM

2.1 Neutron irradiation facility

2.1.1 Accelerator-based neutron irradiation facility

Two types of accelerator-based neutron irradiation facility were used for experiments. Moderators to produce epi-thermal neutron are cylinder-shaped and made of 2mm-thick stainless steel and filled with D_2O. Three kinds of moderators whose inside diameters were 20cm and lengths were 20cm, 25cm and 30cm, respectively, were used to change the degree of moderation.

2.1.2 Reactor-based neutron irradiation facility

As a reactor-based neutron irradiation facility, KUR-HWNIF[4,5)] was used in two modes, OO-0000-F and CO-0000-F with thermal power of 5MW. Irradiation field was collimated into a diameter of 10cm.

2.2 Methods and arrangements for the measurement of neutron dose distribution in a phantom

The phantom is a cylinder made of 2mm-thick acrylic acid resin and filled with natural water. Outside diameter is 20cm and the length is 20cm. The activity of Au wires (0.25mm^d) and Au foils (10mm^d×0.10mm^t) were used to measure thermal neutron flux. Cd tubes of 1mm inside diameter and 2mm outside diameter and Cd-covers of 0.70mm thickness and 17mm diameter were used to measure Cd ratio.

Experimental systems with accelerator-based neutron irradiation facility were as follows: (i) A moderator alone, which has naked and Cd-covered Au foils were placed on the back surface in the distance of 20mm from the center, was set. (ii) The phantom, which has a naked or Cd-covered Au wire along its central axis, was set behind a moderator.

In the case of reactor-based neutron irradiation facility, naked or Cd-covered Au wires along the central axis of the phantom were irradiated separately.

Table 1. The outline of accelerator-based neutron irradiation facility

Nuclear reaction	^{7}Li(p,n)^{7}Be	^{9}Be(p,n)^{9}B
Proton energy	2.50MeV	4.20MeV
Average current	420μA	20μA
Beam size and shape	20mm × 20mm, square	20mm × 10mm , ellipse
Target material	Li metal (^{7}Li > 99%)	Be metal (^{9}Be 100%)
Target size	23mm^d × 150μm^t	60mm^d × 3mm^t
Type of accelerator	Shenkel	Cyclotron
Location	Research institute for radiation biology and medicine, Hiroshima, Japan	Sumitomo heavy industries examination & inspection, LTD, Ehime, Japan

3. RESULTS AND DISCUSSIONS

Figure 1 shows thermal neutron flux and saturated activity of Cd-covered Au foils behind moderators for accelerator-based neutron irradiation facility. Figure 2 shows saturated activity of Au wires along the central axis in the phantom for the 20cm-thick moderator. In Fig. 1, thermal neutron flux and saturated activity of Cd-covered Au foils behind the moderator for Li target were larger than those for Be target. On the other hand, in Fig. 2, saturated activity of naked Au behind the moderator and in the phantom for Be target was larger than that for Li target. When the phantom was combined with a moderator, thermal neutrons and 4.9eV resonance neutrons which were produced in the result of moderation of more energetic neutrons than 4.9eV resonance by the existence of the phantom were considered to make a large contribution in activation of Au because most of the activation is derived from thermal neutrons and 4.9eV resonance neutrons. Therefore the neutron energy spectrum is confirmed to be harder for Be target with 4.20MeV protons than that for Li target with 2.50MeV protons. Neutron energy spectrum is expected to be estimated by analyses of saturated activity in the phantom and behind a moderator.

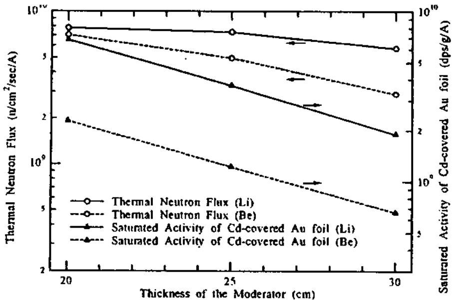

Fig. 1. Thermal neutron flux and saturated activity of Cd-covered Au foils behind moderators.

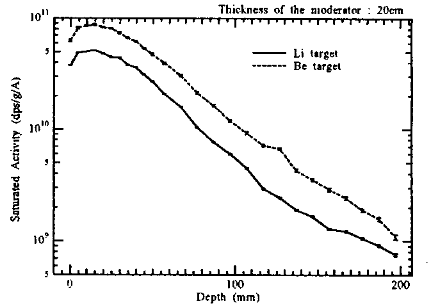

Fig. 2. Saturated activity of Au wires along the central axis in the phantom.

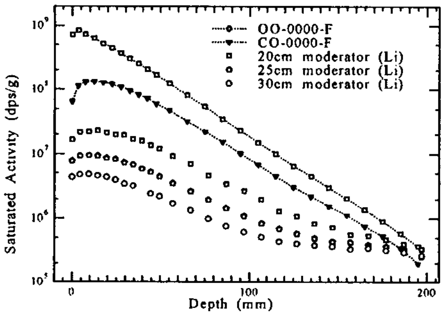

Fig. 3. Saturated activity along the central axis in the phantom.

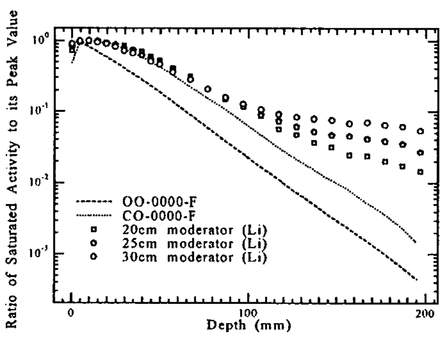

Fig. 4. Relative activity along the central axis in the phantom normalized at the peak.

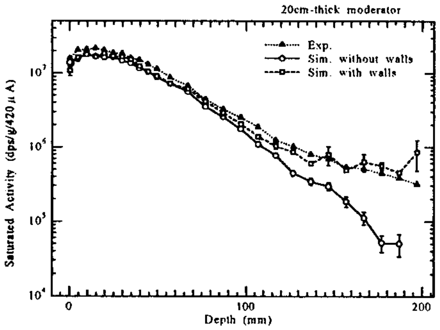

Fig. 5. Saturated activity along the central axis in the phantom for Li target.

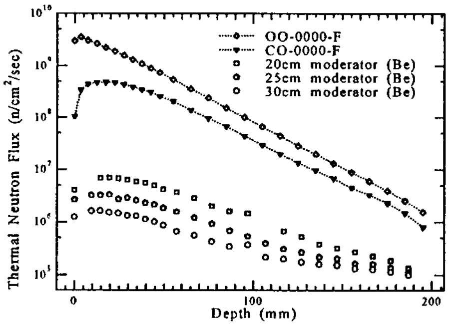

Fig. 6. Thermal neutron flux along the central axis in the phantom.

Figure 3 shows saturated activity of Au wires along the central axis in the phantom for accelerator-based neutron irradiation facility of Li target and KUR-HWNIF. Figure 4 shows relative distribution of data in Fig. 3 normalized at the peak. In Fig. 4, the degree of decrease of saturated activity for Li target eases in the depth around 10cm. This tendency is seen in the case of Be target, too. Since the reason for this might be neutrons scattered by walls of the room, MCNP simulation to check the effect of walls were carried out. Figure 5 shows saturated activity of Au wires along the central axis in the phantom for Li target with the 20cm-thick moderator by experiment and simulation. From Fig. 5, approximate distribution of saturated activity is considered to be simulated by MCNP simulation with walls of the room. Saturated activity simulated without walls decreases in the depth over 10cm more than that simulated with walls, which is in good agreement with the result of experiments. Therefore the degree of decrease of saturated activity at deep area over 10cm in the phantom is thought to ease due to neutrons scattered by walls. In Fig. 4, the thicker the moderator is, the larger the ratio of saturated activity at deep area to the peak is. The reason for this is thought to be that the intensity of neutron in the phantom scattered by walls depends on the thickness of the moderator less than that of neutron without scatter by walls.

Figure 6 shows thermal neutron flux along the central axis in the phantom for Be target and KUR-HWNIF. Equation (1) is used for the absorbed dose estimation of the NCT treatments in KUR-HWNIF. Supposing that physical dose of 15Gy is necessary to destroy the tumor and ^{10}B concentration is 30ppm and treatment time is 1 hour, necessary thermal neutron flux is about 1.7×10^9 n/cm^2/s from equation (1). Roughly estimating from only thermal neutron flux shown in Fig. 6, necessary proton current is expected to be in the order of 10mA.

$$D = (6.78\times10^{-14} \cdot N + 7.43\times10^{-14} \cdot B)\cdot\Phi \qquad (1)$$

D : Physical Absorbed Dose (Gy)
Φ : Thermal neutron fluence (n/cm^2)
N : ^{14}N concentration (%) * 2% is adopted here.
B : ^{10}B concentration (ppm)

4. CONCLUSION

[1] Using only thermal neutron flux in the phantom for Be target as a measure, proton current needed for NCT treatments was estimated to be in the order of 10mA.

[2] Neutron energy spectrum is expected to be estimated by analysing the activity of Au both behind the moderator and in the phantom.

[3] In experiments with accelerator-based neutron irradiation facilities, neutrons scattered by walls of the room contribute largely to the activity of Au in the phantom. MCNP simulation is expected to be applicable for the activity distributions taking neutrons scattered by walls into consideration.

5. REFERENCES

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