A Newly Developed Compact Cyclotron for Neutron Therapy and Positron Nuclear Medicine

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ABSTRACT

In order to demonstrate effective use of small cyclotron , we have developed a new compact cyclotron (BC2211) which enables neutron therapy and positron nuclear medicine. The energies available for proton and deuteron beams are 22 and 11 MeV respectively. Whereas maximum external current is obtainable 60mA. After a half life irradiation, sufficient activities of positron emitters are obtained. ^{11}C:77.7 GBq. ^{13}N:24.1 GBq. ^{15}O:42.6GBq. ^{18}F:27.8 GBq. A basic experiment for neutron therapy was performed using the $^{10}Be(p,n)^{10}Bo$ reaction at Ep=22MeV. The obtained neutron flux was 7.5×10^9/cm^{2}sec (fast neutrons) and 4.0×10^8/cm^{2}sec (thermal neutrons) on target. The neutron spectrum depicted maximum and mean energies of 21 and 11 Mev respectively. The absorbed dose was 0.14 Gy/min at 125 cm from the target and not sufficient. The target is now under reconstruction to obtain the more refined neutron flux and spectrum.

1. INTRODUCTION

Recently many PET (positron emission tomography) centers have been established round the world. Such centers utilize small cyclotrons only for the synthesis of positron emitters, and substantial machine time of the cyclotron is left unused.From this view point , it is indeed very important to ensure the optimal utilization of unused time for the purposes of producing fast neutrons presently effectively used for various malignant conditions such as cancer of salivary gland , prostatic cancer and sarcoma of bone [1)-2)].

The present study focussed on the developing of a new compact cyclotron for neutron therapy and positron nuclear medicine and evaluate its basic characteristics for neutron therapy.

2. MATERIALS AND METHOD

2.1. Specifications of BC2211

The specifications of BC2211 are shown in Table 1. The geometorical size is almost same as that of BC1710 (p: 17MeV, d: 10MeV) previously developed. The increase in energies of proton and deuteron was achieved by the increase of magnetic field. A diagram of cyclotron and beam transport for neutron therapy is shown in Fig. 1. The details of Be target are also shown in Fig. 2.

Table 1(A). Main specification of BC2211.

ITEM	proton	deuteron
beam ehergy (MeV)	22	11
beam current (μA)	60	60
magnetic field (T)	1.6	
radio frequency (MHz)	49.0	
extraction radius (mm)	420	
magnet size	Φ2150x1500 mm	

Table 1(B) Radionuclide and yield (BC2211)

Nuclides	Chemical Form	Irradiation Time (T 1/2)(min)	Recoverd Activity E.O.B. (GBq)
^{11}C	$^{11}CO_2$	20	77.7
	^{11}CO	20	68.5
^{13}N	$^{13}NO_x$ in water	10	24.1
^{15}O	^{15}O	2	42.6
	$C^{15}O_2$	2	40.7
	$C^{15}O$	2	21.5
^{18}F	$^{18}F_2$	110	27.8 (from Ne)
	$^{18}F^-$	110	40.7 (from $H_2{}^{18}O$)

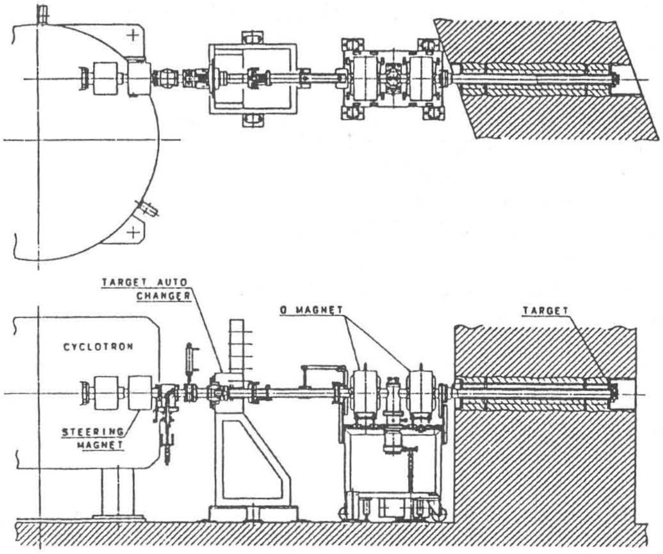

Fig. 1. A diagram of cyclotron and beam transport for neutron therapy.

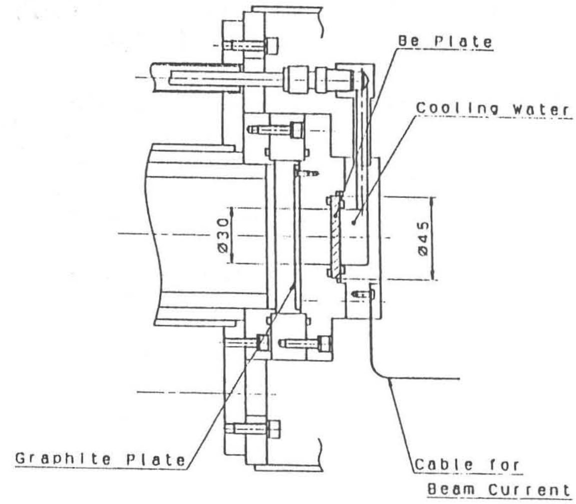

Fig.2. The details of Be target.

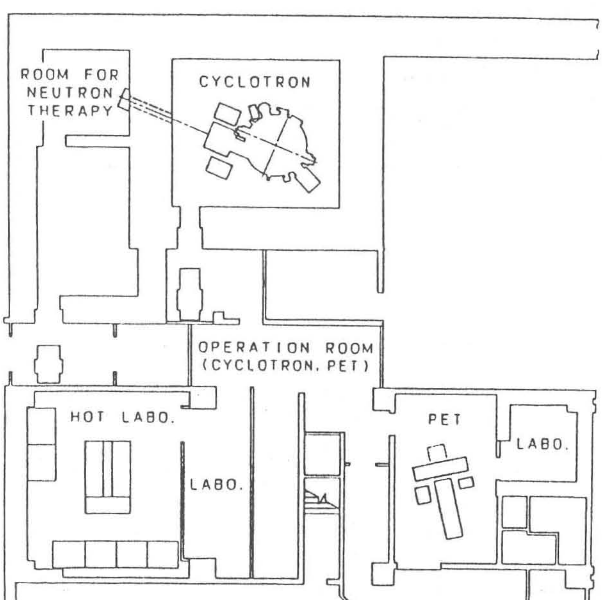

Fig.3. A diagram of our PET center.

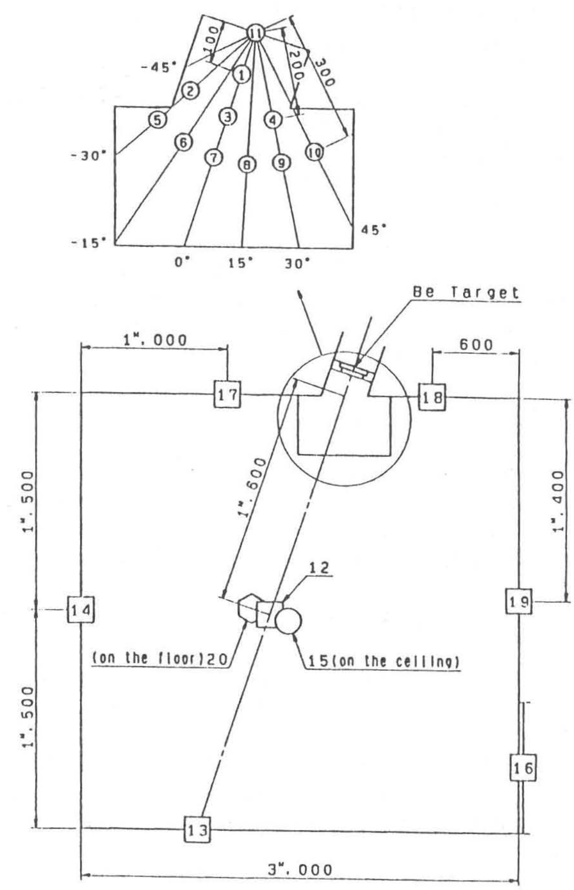

Fig.4. Setting of samples for the measurement of neutron flux.

2.2. PET center of Nagoya university

Our PET center is shown diagrammatically in Fig.3 . The room for neutron therapy is located next to the cyclotron room, whereas Be target exists in the wall.

2.3.Meaurement of neutron flux and energy spectrum

2.3.1.Measurement of neutron flux

Neutrons were produced by bombarding Be target with the proton beam (Ep: 22MeV, external current: 20μA) for a period of 1 hour. The direction and central axis distribution of neutron were measured using radioactivation method. The involved reactions were $^{27}Al(n,a)^{24}Na$, $^{58}Ni(n,2n)^{57}N$, and $^{197}Au(n,g)^{198}Au$. One sample consisted of packed slices of Al x 2, Ni x 2 and Au x 1. Many samples were set in the room for neutron therapy as shown in Fig. 4. After the irradiation, activities of samples were measured with Ge detector and subsequently the activity was converted into the neutron flux.

2.3.2.Measurement of neutron energy spectrum

As already described neutrons were produced by bombarding Be target with the proton beam (Ep: 22MeV, external current: 0.1μA) for 5373 and 3671 sec. A simple collimator was used to direct the neutron beam and reduce the scatter. A collimator is shown in Fig.5.

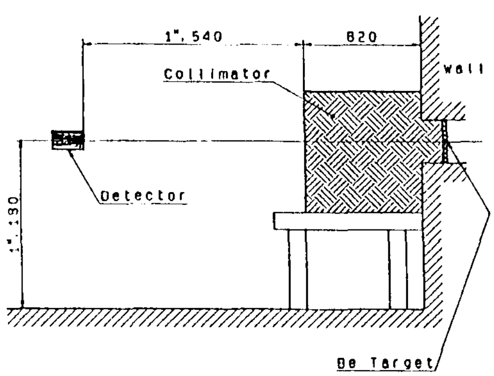

Fig. 5. The diagram of apparatus for the measurement of neutron energy spectrum.

The neutron energy spectrum was measured by proton recoilling method using a organic liquid scintillator (NE213). The measurement was done for two times. Second measurement was done with shadow-bar to evaluate the scattered neutrons. Shadow-bar was made of paraffin and a mixture of Li_2CO_3.

3. RESULTS

3.1. Measurement of neutron flux

Direction distribution of neutrons is shown in Fig. 6. Fast neutrons were measured by $^{27}Al(n,a)^{24}Na$ (En >5 Mev) and $^{58}Ni(n,2n)^{57}Ni$(En >13MeV) reactions. Fast neutrons showed a significant direction dependence. In particular high energy fast neutrons (En >13MeV) showed a sharp distribution. Thermal neutrons were measured by $^{197}Au(n,g)^{198}Au$ reaction and their distribution did not reveal any direction dependence . The neutron flux was observed to be $7.5x10^9/cm^2$sec (fast neutrons En >5 MeV), $3.5x10^9/cm^2$ (fast neutrons En >13 MeV)and $4.0x10^8/cm^2$sec (thermal neutrons) on target. Fast neutrons decreased according to inverse square law on the central axis (Fig. 7).

3.2. Measurement of neutron energy spectrum

The energy spectrum of neutrons is shown in Fig. 8. The energy spectrum thus obtained by us resembled with one obtained by Lone et al[3] further confirming the methodological precision and accuracy of measurement. The maximum and mean energy of neutrons were found to be 21 and 11 Mev respectively.

4. DISCUSSION

The cyclotron currently used at our center is considered to be rather underutilized even though it is used for routine production of positron emitters for PET studies. In view of this the basic experiments related to neutron flux and energy measurements were performed to explore the feasibility of using neutron beams for therapy of malignant disorders.However, neutron flux and energy spectrum were not enough for the practice of neutron therapy. The calculated absorbed dose using the results of this study is about 0.14 Gy/min at 125 cm from the target (external current : 60 μA). This absorbed dose is not sufficient and hence the target is now under reconstruction to obtain the more refined neutron flux and spectrum. After the target reconstruction a practical collimetor will be planned. Furthermore the low energy neutron shows a high RBE. Therefore the effect on normal tissue should be evaluated before clinical use.

5. REFERENCES

1) Battermann, J.J. & Breur, K.: Results of fast neutron teletherapy for locally advanced head and neck tumors. Int J. Radiat. Oncol. Biol.Phys. 7:1045 (1981)
2)Tatezaki, S.: Systemic multimodal treatment of osteosarcoma, with special reference to the role of fast neutron radiotherapy. J. Jpn.Orthop. Ass.53:831 (1979)
3)M.A. Lone et al., : Thick Target Neutron Yields and Spectral Distributions from the $^7Li(d,n)$ $^7Li(p,n)$, $^9Be(d,n)$ and $^9Be(p,n)$ reactions. Nucl. Inssstr. Meth. 143:33(1977)

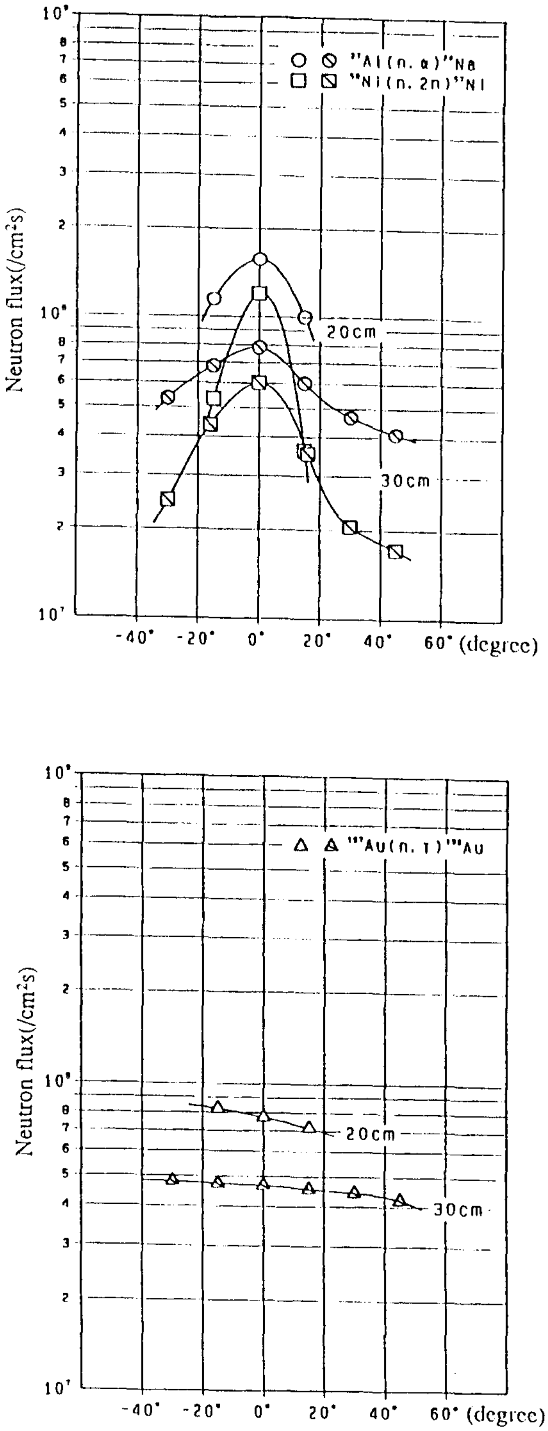

Fig.6 Direction distribution of neutrons.

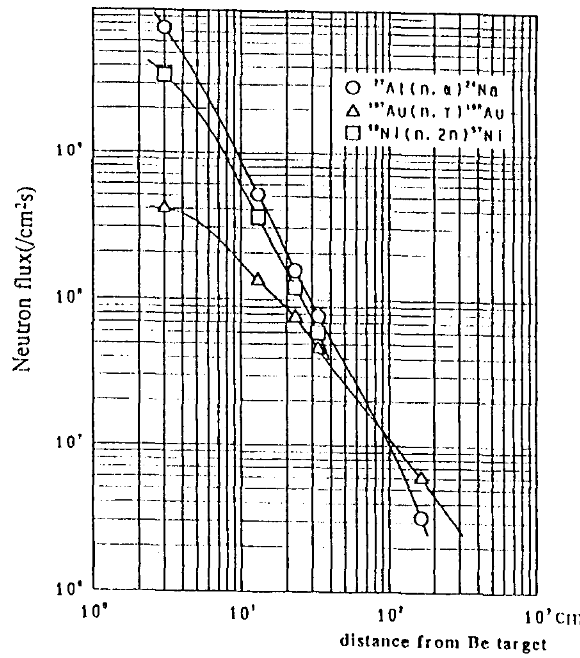

Fig. 7 Axial distribution of neutrons.

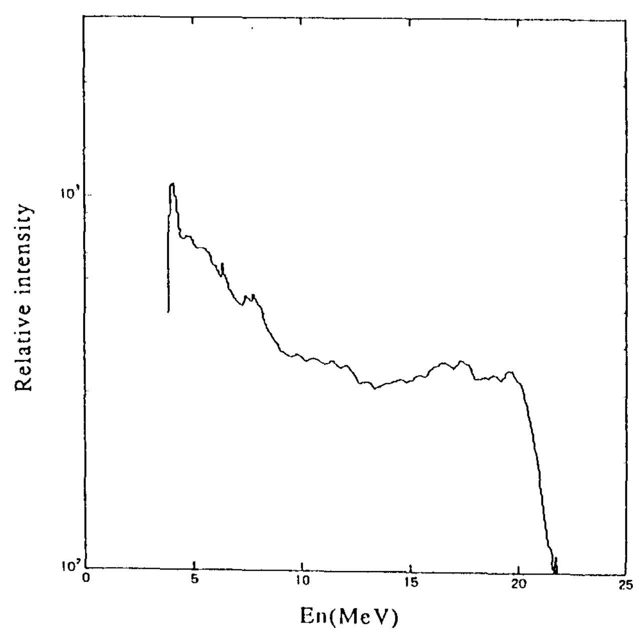

Fig.8 The energy spectrum of neutrons.