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Dosimetric Characteristics of the KCCH Neutron Therapy Facility

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For the physical characterization of neutron beam, dosimetric measurements had been performed to obtain physical data of KCCH cyclotron-produced neutrons for clinical use. The results are presented and compared with the data of other institutions from the literatures. The central axis percent depth dose, build-up curves and open and wedge isodose curve values are intermediate between that of a 4 and 6 MV X-rays. The build-up level of maximum dose was at 1.35 cm and entrance dose was approximately 40%. Flatness of the beam was 9% at Dmax and less than ± 3% at the depth of 80% isodose line. Penumbra begond the 20% line is wider than corresponding photon beam. The output factors ranged 0.894 for 6×6 cm field to 1.187 for 30×30 cm field. Gamma contamination of neutron beam was 4.9% at 2 cm depth in 10×10 cm field.

Key Words: Neutron Beam, Dosimetry, cyclotron, Tissue equivalent chamber, Depth dose, Build-up, profile, Isodose curve, Output.

INTRODUCTION

The Korea Cancer Center Hospital (KCCH) installed 50.5 MeV cyclotron for neutron therapy and production of radioisotopes. The KCCH-cyclotron, as the first neutron therapy facility in Korea, is hospital based compact cyclotron connected with the rotational isocentric gantry for neutron therapy. Treatment was started from October 1986[1)] after extensive work to overcome mechanical and electrical problems inherent in the machine and to collect the necessary data for the neutron dosimetry, as well as biologic tests[2,3)], for about two years.

The neutron beam is produced by 50.5 MeV protons bombarding a beryllium target which is 106 mm thick, although the cyclotron can accelerate deuteron and alpha particle as well. The impinged protons loss 25 MeV in the beryllium and stop in a water cooled copper block and stainless steel.

This neutron beam is flattened with two sets of iron filters which are alternatively used according to the field size. Beam wedges are installed in the gantry with wedge angles of 30°, 45° and 60°, and is made of tungsten. Dose monitoring of neutron beam is carried out by two ionization chambers as dual monitor system. The collimators are made of steel with Benelex shielding, which are mounted within the gentry for motor driven field shaping ranged from 5×5 to 30×30 cm of square and rectangular fields. The isocentric gantry is capable of 360° rotation and the source to axis distance is 150 cm.

The personnel of the section of radiation physics and biology, Department of Therapeutic Radiology in Korea Cancer Center Hospital, coworked with correspondence of University of Washington, U.S.A. for the measurement of neutron beam and the intercomparison of either results. The obtained data, which is clinically useful, and had been entered into the planning computer, are presented.

MATERIALS AND METHODS

The KCCH cyclotron is MC 50 cyclotron from Scanditronix, Sweden, which accelerates protons to the energy of 18-50 MeV and deuterons to 9-25 MeV at external currents of up to 60 μA. The treatment units (gantry) was assembled at Elven Precision Ltd., England.

The ionization chambers used were the neutron probes from Far West Technology Inc., USA. The ion chambers have A-150 plastic tissue equivalent wall with the capability of tissue equivalent gas flow. Flow rate of TE gas was 5 cc/min. The volume composition of gas is 64.4% CH4, 32.5% CO_2 and 3.1% N2[4]. Calibration of ion chamber was done by Cobalt 60 source.

The measurement of central axis depth dose, beam profile and out put were performed in a 63×60×51 cm three dimensional water phantom (RFA-3) and precision electrometer (RDM-2A) from Therados Instrument Ab, Sweden. The ion chambers used were IC-18 with 0.1 cc chamber volume and IC-17 with 1.0 cc. Build-up region was measured with an extrapolation chamber, EIC-1, with A-150 build-up discs and lucite phantom having central hole, under the connection of collecting electrometer, RDM-2A. All measurement was made at 150 cm source to surface distance.

RESULTS AND DISCUSSION

1. Central Axis Percent Depth Dose

The central axis percent depth dose was measured for the field size from 6×6 cm to 30×30 cm (Table 1). Normalization of depth dose was made at the depth of maximum dose of 1.35 cm from the surface.

Central axis percent depth dose curve was made for the different radiations for the field size of 10×10 cm, which are currently using at KCCH (Fig. 1). Penetration depth of 50% depth dose was 14.5 cm in water for the neutron beam. This value lies between the curves for the 4 MV and 10 MV X-ray beams in this figure. In comparison with the results

Table 1. Central Axis Percent Depth Dose

Depth (cm)	Field size (cm x cm)							
	6 x 5	8 x 8	10 x 10	12 x 12	14 x 14	18 x 18	24 x 24	30 x 30
0	43.0	44.5	45.0	47.0	48.5	51.0	53.5	56.0
1.35	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
2	98.4	98.6	98.8	99.0	99.2	99.4	99.6	99.6
3	94.1	94.8	95.5	95.8	95.6	96.1	96.2	96.3
4	88.5	90.0	90.8	91.7	91.5	92.1	92.6	93.2
5	83.0	85.2	86.8	87.7	87.2	88.2	89.0	89.3
6	78.3	80.8	82.5	83.4	83.0	84.2	84.6	85.1
7	73.5	76.3	78.4	79.5	79.0	80.5	81.2	81.6
8	68.4	71.4	73.6	75.2	75.0	76.4	77.5	78.0
9	64.0	67.2	69.5	71.2	71.2	73.2	74.2	74.6
10	59.8	63.0	65.5	67.2	67.7	69.7	70.6	71.2
11	55.8	59.1	61.7	63.7	64.0	66.2	68.0	68.4
12	52.7	55.5	58.1	60.0	60.6	63.0	64.8	65.6
13	48.0	52.0	54.8	56.8	57.4	60.0	61.8	62.6
14	44.6	48.6	51.3	53.3	54.0	56.8	59.0	59.8
15	40.5	45.2	48.3	50.5	51.2	53.8	56.0	56.9
16	38.8	42.5	45.3	47.5	48.2	51.0	53.2	54.1
18	33.0	37.0	40.0	42.0	43.0	46.0	48.2	49.3
20	28.5	32.0	34.8	37.0	38.2	41.0	44.0	45.0
22	24.8	28.0	30.4	32.6	34.0	36.7	39.6	40.8
24	22.0	24.5	26.7	28.9	30.0	32.8	35.5	37.1

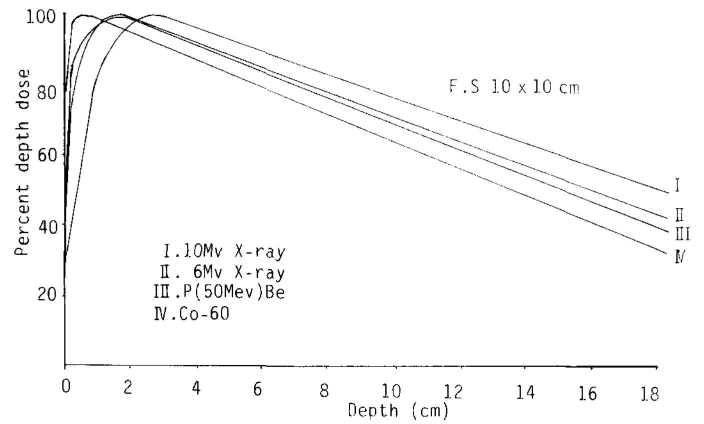

Fig. 1. Percent depth dose curves of Cobalt-60, 6MV and 10MV X-rays from the microtron, and neutron beam from the cyclotron, currently using at KCCH. (SSD of Co-60 : 80 cm, X-ray : 100 cm neutron : 150 cm).

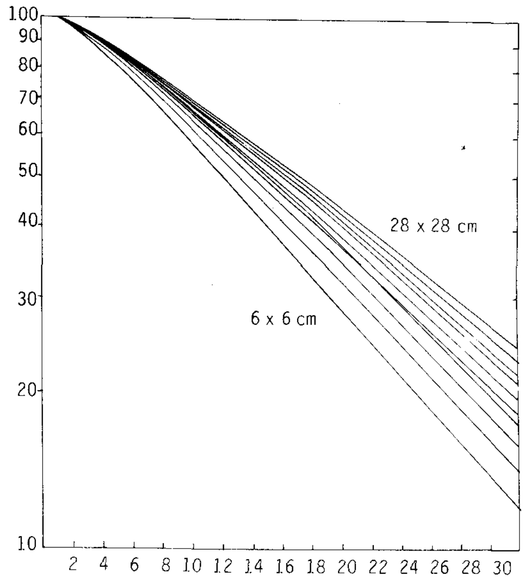

Fig. 2. Percent depth dose curves of neutron beam in various filed size ranged from 6 x 6 cm to 28 x 28 cm.

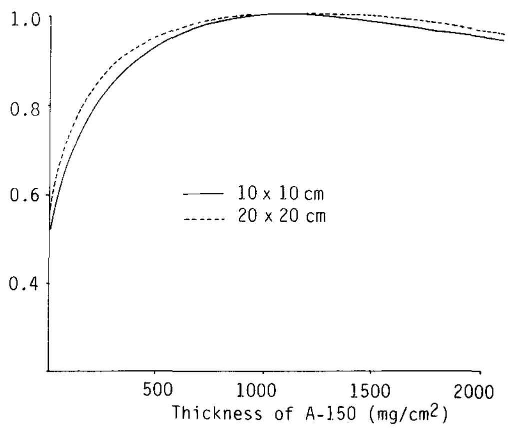

Fig. 3. Relative dose in the build-up region.

of University of Washington (UW: 14.8 cm)[5] and M. D. Anderson Hospital (MDAH: 14.2 cm)[6], KCCH neutron beam is in the middle. This behavior is expected as the UW beam is hardened by the hardening filter and the one thick flattening filter, instead of two thin flattening filters without hardening filter in KCCH even though the incident proton energy is same. The MDAH beam is generated by 42 MeV protons in which they have hardening filter as well.

Observed depth dose of neutron beam revealed greater dependence of field size (Fig. 2) than those of photon beams of 4 MV and 6 MV. This may result from the greater percentage of scatter radiation in the neutron beam compared with either photon beam[6]. The 50% depth dose level of neutron beam for 6×6 cm and 600 cm^2 field were 12.5 and 17.4 cm, respectively. The corresponding values for the same field were 12.6 and 15.5 cm for the 4 MV photon beam, and 14.5 and 16.5 cm for the 6 MV photon beam[7].

2. Build-Up Measurements

The build-up measurements were performed by

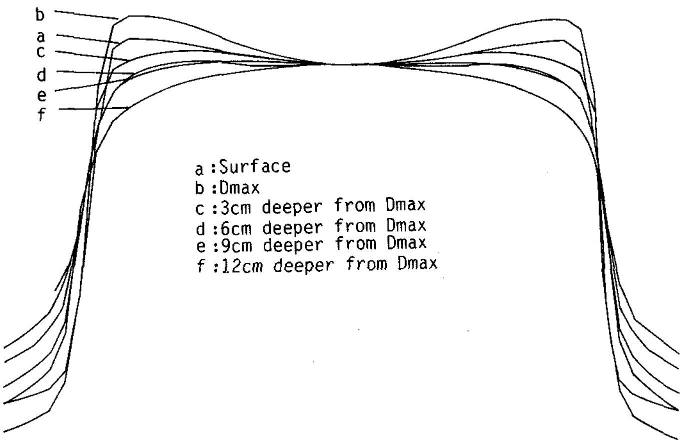

Fig. 4. Flatness of neutron beam at various depth from the surface in field size of 10 x 10 cm.

changing the thickness of tissue equivalent A-150 plastic discs in front of the extrapolation chamber, EIC-1, with TE gas, at the field size of 10×10 cm and 20×20 cm (Fig. 3). The change of the curves representing the build-up thickness was little at the thicknesses near the maximum dose, which defines the depth of maximum dose (Dmax). That thickness was between 1000 and 1400 mg/cm^2 for A-150 plastic which corresponded to between 12 to 15 mm of water respectively. The obtained Dmax, therefore, was 13.5 mm. The entrance dose for 10× 10 cm field was 42%.

These results are comparable with other measurements of literatures. Build-up depth of MDAH was between 11 and 15 mm of water and entrance dose was 33% of its maximum6). P(42)+Be beam of Institute for Nuclear Physics Research, Amsterdam, was between 10 and 15 mm and 60% respectively8). d(50)+Be beam of Louvain-la-Neuve, Belgium, was 7 mm and 60% respectively. d+T neutron of Antoni van Leeuwenhoek Hospital, Amsterdam, was 2.5 mm and 60% respectively8). UW was 10.9 mm and approximately 50% respectively5).

3. Beam Profiles

Isodose curves and flatness had been plotted on the X-Y recorder which is connected to the electrometer (Fig. 4). The flatness filter is made of pure iron. Thickness of filters is 26 mm (filter #1) and 14 mm (filter #2). Filter #1 is used for the small fields less than 12×12 cm. If the field size becomes larger than this, the filter #2 enters to the place beneath the filter #1 automatically. Thus in the small field, when the filter #1 is being used, the flatness makes large horn at the edge of the field. Figure 4 is the flatness curve obtained at different depths of phantom. The largest variation of flatness is seen at the Dmax, which was 9%. The flatness returns to ± 3% at the level of 3 cm deeper from Dmax which corresponds to 80% isodose. If the thicker filter is used, the flatness would be better. However, the thicker the filter is, the more beam current is needed to produce adequate dose rate.

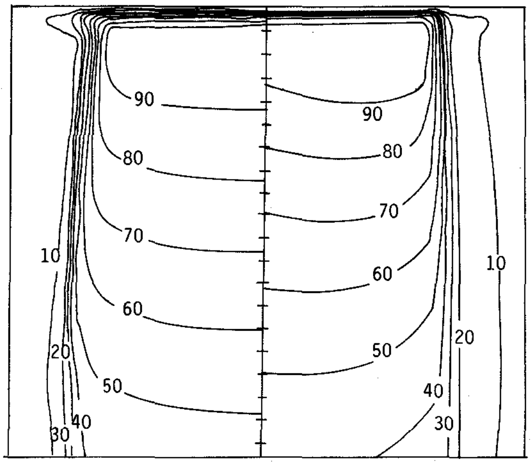

Fig. 5. Isodose curves fro 20 x 20 cm field. Left side is a 6MV X-ray field from microtron. Right side is neutron field.

The isodose curves for the field size of 20×20 cm were compared with 6 MV X-ray which is produced from the microtron of KCCH photon treatment facility (Fig. 5). Penetration depth of X-ray beam was greater than neutron beam a little. This may partly result from the difference of SSD, 100 cm, on 6 MV instead of 150 cm of neutron.

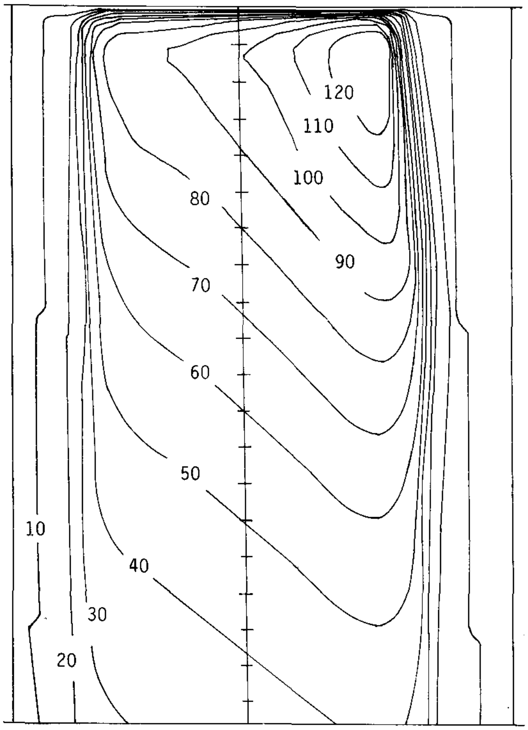

Fig. 6. Isodose curves for 10 x 10 cm neutron field with a 45° wedge.

Penumbra of the two beams was approximately the same to the 20% level. But the distance from the central axis to the 10% level was singificantly greater for the neutron beam than the X-ray beam. This may result from the greater percentage of scatter radiation in the neutron beam compared with the photon beam[6].

Modfication of isodose curve had been made by wedge filters (Fig. 6). The wedges placed within the collimator mounting assembly were made of sintered tungsten. There are three wedges of which wedge angle at the 50% isodose curve is 30°, 45° and 60° each at 10×10 cm field.

Table 2. Out-put Factor of Neutron Beam

Field size (cm x cm)	Out-put factor
6 x 6	0.894
8 x 8	0.952
10 x 10	1.000
12 x 12	1.045
14 x 14	0.995
16 x 16	1.035
18 x 18	1.064
20 x 20	1.092
22 x 22	1.120
24 x 24	1.139
26 x 26	1.159
28 x 28	1.174
30 x 30	1.187

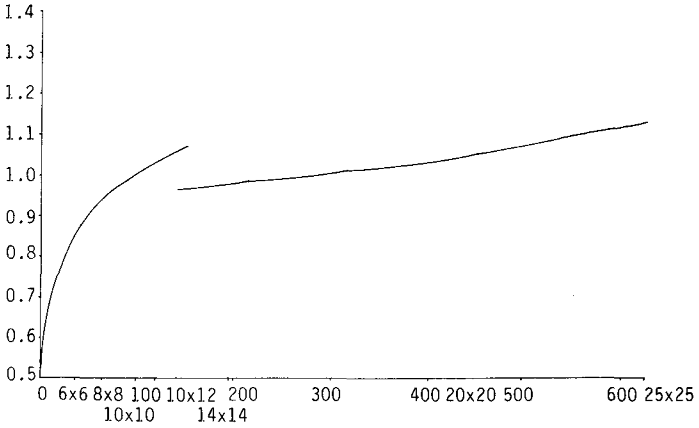

Fig. 7. Field size correction factor of neutron beam normalized at field size 10 x 10 cm. Discontinuity comes from change of filter # 1 and # 2.

4. Output Factors

Output factor was measured with the IC-18 probe placed at Dmax. All readings were normalized to a 10×10 cm field. The obtained values according to the field size ranged from 0.894 for the field size of 6×6 cm to 1.187 for 30×30 cm (Table 2). The field side factors were plotted for the use in calculation of the equivalent rectangular fields (Fig. 7). Discontinuity at the field size of around 12×12 cm came from automatic change of flattening filters.

Detection of gamma contamination in the neutron beam is another problem specific to neutron[9]. Tissue equivalent ion chambers respond almost equally to the neutron and gamma ray. Such instruments give directly the distribution of total dose, Dt, or (Dn+Dr). If Dr can be measured separately, Dn can be found by subtracting Dr from Dt. The authors measured Dr by magnesium ion chamber, IC-17M, which has high purity magnesium in the chamber wall and does not respond to the neutrons in the mixed beam field. The physical size of this ion chamber is 1 cc, which is the same as tissue equivalent IC-17 chamber for concurrent measurement of Dt. The result obtained was 4.9% at the depth of 2 cm on the 10×10 cm field. For this result, the part of the photon beam due to gamma contamination has been included in the expression of total dose.

CONCLUSION

The physical characteristics of the central axis percent depth dose, build up curves and open and wedged isodose curves of the KCCH cyclotron produced neutron beam were intermediate between that of 4 MV and 6 MV X-rays. The 50% depth dose corresponds to 14.5 cm and Dmax is 1.35 cm. The difference from that photon beams was greater field size dependence of the central axis percent depth dose and wider penumbra beyond the 20% dose level because of the large amount of scatter radiation in the neutron beam. The results obtained are comparable to the other insitutions.

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국문초록 ═

원자력병원 중성자선치료기의 물리적특성

한국에너지연구소 원자력병원 치료방사선과

류성렬 · 노성우 · 정현우 · 조철구 · 고경환

싸이클로트론 연구실

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줄리 인마

한국에너지연구소 원자력병원 싸이클로트론에 의해 생산되는 중성자를 임상에 적용시키기 위해, 이의 물리적 특성을 알기 위하여 방사선선량 측정실험을 시행하였다. 여기서 얻은 결과를 외국의 다른 치료기관에서 얻은 데이타와 비교 분석하였다.

중심축 선상의 심부선량백분율, build-up 곡선, open과 쐐기등선량 곡선의 값이 4 MV와 6 MV X-ray값의 중간에 위치하였다. 최대선량의 build-up은 피부아래 1.35 cm에 위치했으며 입사 선량은 약 40%였다. 출력인자는 6×6 cm의 조사야에서 0.894, 30×30 cm의 조사야에서는 1.187이었다.

중성자선의 X-ray 오염도는 10×10 cm 조사야에서 심부 2 cm에서 4.9%였다.