Indian J. Phys. **65A** (5), 446-449 (1991)

Development of a neutron source for therapeutic investigations

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Abstract : A collimated source is being developed for possible application to neutron therapy. The source is produced by the bombardment of 40 MeV alphas on a thick Be target. Using a tissue equivalent proportional counter, dose distributions were measured along the central and lateral axes. The quality of the radiation is estimated using dosimetric calculations.

Keywords : Neutron therapy, microdosimetry, RBE, depth dose.

PACS No : 87.52. Ch, 29.25. Dz

1. Introduction

Following the successful application of neutrons for therapeutic purposes (Raju 1980), collimated beams of neutrons are being increasingly used because of their low OER, high therapeutic gain factor and response independent of the cell cycle (Fowler 1981). In our laboratory, we are trying to develop a neutron source based on Be (α, xn) reaction. The (α, xn) neutron spectra have a broad hump towards the high energy side (Bandyopadhyay *et al* 1988) and hence, such sources may have a higher penetration power compared to other sources. We have used a sufficiently thick target to stop all the 40 MeV alpha particles. The collimator is composed of paraffin, steel and wood and produces a field of size 10 cm × 10 cm at a SSD of 55 cm.

In this paper, we studied the characteristics of the beam in terms of central axis depth dose distribution as well as dose fractions of various types of radiations, which are indirectly related to radiobiological effectiveness. For this purpose the dose averaged saturated lineal energy $\bar{Y}_N^*$ is calculated for the neutron beam under consideration.

2. Experimental procedure

Neutrons are produced by bombarding a thick Be target with 40 MeV alpha beam from 224 cm Variable Energy Cyclotron at Calcutta. The Be target is cooled by helium jet. The target chamber is isolated from the cyclotron vacuum by a Haver

foil. The collimator in front of the target restricts the beam diameter to about 10 mm.

The neutron collimator design is based on the one used in the Hammersmith Hospital (Braby and Ellett 1972). Wood, paraffin, steel and polythene granules are used in the fabrication of the collimator. The collimator which is 45 cm long is flanked on either side by 90 cm × 90 cm × 200 cm neutron shield consisting of polythene and steel granules.

Measurements are made along the central axis and the transeverse axis inside a water phantom of size 30 cm × 30 cm, using a tissue equivalent proportional counter (Model LET $\frac{1}{2}$, Far West Technology) of diameter 12.7 mm. The counter is filled with the methane based tissue equivalent gas to a pressure of 563 mm of mercury, thus simulating a unit density sphere of diameter 1 μm.

3. Estimation of microdosimetric quantities

The normalised linear energy spectrum $f(y)$ is given by

$$f(y) = \frac{N(Y)}{\int N(y)\, dy} \tag{1}$$

where $N(y)$ is the experimentally measured lineal energy spectrum. $\bar{Y}_F$ the frequency mean of Y is given by (Kellerer and Rossi 1972)

$$\bar{Y}_F = \int_0^\infty Y f(Y)\, dY \tag{2}$$

$$\bar{Y}_F = 0.049\, d^2\, \bar{Z}_1 \tag{3}$$

where d is the site diameter and $\bar{Z}_1$ is the frequency mean of the increment of specific energy in single event.

$\bar{Y}_D$, the dose or energy mean of y is given by

$$= \frac{1}{\bar{Y}_F} \int_0^\infty Y^2 f(Y) dY \tag{4}$$

$\bar{Y}_D$ is related to the energy averaged specific energy ξ by

$$\bar{Y}_D = 0.049 d^2 \xi \tag{5}$$

Further,

$$\bar{Y}_D = \frac{9}{8} \bar{L}_D \tag{6}$$

where $\bar{L}_D$ is the dose average of LET. $\bar{Y}_D$ is larger than $\bar{L}_D$ because of variations in the chord length in the random traversal of spherical volumes and energy loss straggling.

In the calculation of $\bar{Y}_F$ and $\bar{Y}_D$, the integrals in eqs. 2 and 4 have to be carried out between limits 0 and ∞. The upper limit does not pose a problem because, the counts become zero after a certain value of y. However, measurements can not be made below a certain y value because of electronic noise. Hence the $f(y)$ spectrum has to be extrapolated down to 0 keV/μm. In our work, we assume the distribution to be constant below a certain low value of the lineal energy channel. Figure 1 gives the $yD(y)$ distribution for the neutron source. From the figure it is

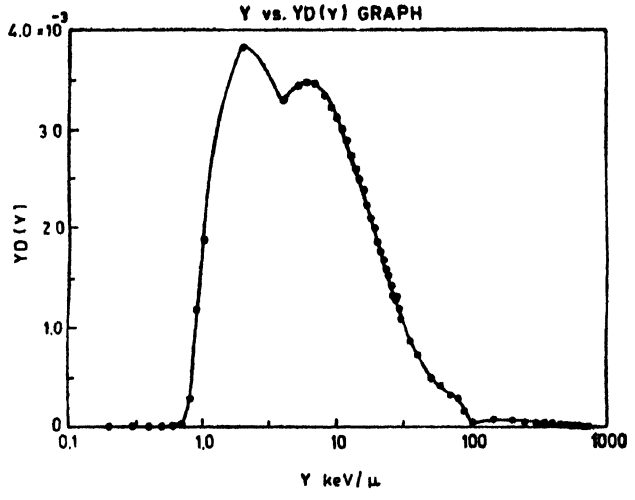

Figure 1. Differential dose per unit logarithm of lineal energy vs lineal energy

observed, that contribution to the dose from the recoils is small. This is expected because of the nature of the neutron source. However the implication on the effectiveness of the source can be judged only after radiobiological studies.

The depth dose along the central axis is measured upto 12 cms. The gamma component increases from 12.7% at the entrance to 26% at 12 cm depth. In air the gamma percentage is 9.8%. The recoil proton contribution is practically constant over the entire water depth. The heavy ion contribution gradually decreases with increasing depth. The high energy bump may broadly explain the absence of the buildup of the gammas at lateral depths. The heavy ion contribution also decreases with increasing lateral depth. There is a perceptible decrease in the values of $\bar{Y}_F$ for protons along the central axis. This small decrease is also observed along the lateral axis upto a depth of 4 cms. $\bar{Y}_F$ values of heavy ions on the otherhand do not show any variation either along central axis or along the lateral axis. These variations are not reflected in the total values and hence the quality of the radiation remains the same inside the water phantom.

4. Conclusions

The studies carried out with Be (α, xn) source indicate that the qualities of this neutron source are comparable to those of (p, xn) and (d, xn) neutron sources. It is necessary to carry out further radiobiological studies to understand other radiobiological parameters.

Acknowledgments

We are grateful to the operating staff of the cyclotron for their cooperation in the operation of the accelerator, to D K Bandyopadhyay for the design of the target system and to Dr D K Ghosh for the design of the helium jet cooling arrangement. Thanks are also due to Prof A M Ghose for his stimulating discussions, we had, during the preparation of the manuscript. We thank Dr Bikash Sinha, Director, VECC for his keen interest in this work.

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