THE USE OF COMPACT CYCLOTRONS FOR PRODUCING FAST NEUTRONS FOR THERAPY IN A ROTATABLE ISOCENTRIC GANTRY

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Abstract

This paper discusses the design and performance of a fast neutron therapy system which transports a cyclotron beam onto a beryllium target mounted in a rotatable isocentric gantry structure. Fast neutrons produced by either the proton or deuteron on beryllium reaction are directed towards the isocenter with appropriate shielding, collimation and dosimetry to control and monitor the radiation delivered onto a defined patient area. The beam optics and shielding considerations of such a radiotherapy apparatus are discussed. This paper also presents the dosimetric properties of neutron beams from different proton energies on beryllium and lithium targets.

Introduction

The use of fast neutrons for the treatment of cancer has been investigated and used by many organizations. The neutrons are produced by bombarding a light metal target with charged particles from a cyclotron, and the neutron beam produced by the cyclotron is usually directed in a fixed horizontal position. To overcome the limitations of a fixed horizontal neutron beam, a rotating gantry was designed with 2 bending magnets to transport the cyclotron beam onto a target within a shielded treatment head which can be rotated about an isocenter. This paper discusses the optics of the cyclotron beam as it is transported from the cyclotron onto the moveable target, and the radiation shielding effectiveness for such an apparatus. The neutron dosimetric properties from neutrons produced by different proton energies and targets are also presented. Two isocentric neutron therapy facilities which use 14 and 15 MeV deutrons respectively from compact cyclotrons have been installed, and the operating results from these facilities are described by others.[1 2] An isocentric neutron therapy unit which uses a 42 MeV proton cyclotron is currently being fabricated. Such a neutron therapy unit will meet the current needs for a clinically useful neutron therapy machine.[3 4]

Beam Transport

The cyclotron beam is transported through 45° and 135° bending magnets mounted in a rotatable gantry structure. The magnetic elements in the beam transport line are shown in figure 1.a. Because the focal properties through a bending magnet are quite different in the bend and transverse planes, the effect of edge angles on the entrance and exit ends of the magnet were analyzed[5] and used to achieve a magnetic system that acts optically the same in both planes. With the aid of the Transport[6] computer program to calculate the beam optical properties, it was possible to optimize the beam through a nominal 5 cm diameter isocentric beam tube and diverge the beam to a maximum uniform size at the target for various gantry angles. The results from the Transport Computer Program are shown graphically in figure 1.b. The resultant beam current measured on the isocentric target as the gantry is rotated 240° is shown on figure 1.c.

By using radiographic techniques with polaroid film, the cyclotron beam size and position on the target at various gantry angles were also observed.

Treatment Head Shielding

The shield around the target was designed to attenuate the neutron beam 5 cm outside of the collimated beam to less than 2% of the central axis dose at 125 cm TSD. The design was based on neutron spectra and angular dose distribution data from various sources. The published[7] angular distribution of neutrons produced from 15 MeV deuterons on beryllium is shown on figure 2.a superimposed with the shielding configuration used for this reaction. The shielding material was predominantly Benelex which is a densely compressed wood made by the Masonite Corporation. The measured shielding effectiveness of the treatment head for neutrons produced by 15 MeV deuterons and 26 MeV protons on beryllium is shown in figure 2.b.

The activation of materials in the treatment head by fast and thermal neutrons was measured and various methods were used to reduce neutron activation. Measurements of the activation and background build-up from neutrons produced by 15 MeV deuterons on beryllium is shown in figure 3. A significant amount of residual activity is from activation of the wall of the treatment room.

Neutron Dosimetric Properties

The neutron beams produced by various energy proton beams on a beryllium and a lithium target have been measured and previously published.[8] This data was used to establish the design parameters to obtain a neutron beam suitable for radiotherapy. The tissue kerma rate as a function of energy is shown in figure 4.a and the measured depth for 50% dose as a function of energy is shown in figure 4.b. The penetrability of neutrons produced by the proton on beryllium reaction was found to be significantly enhanced by use of a polyethylene filter. No significant advantage was found in using a lithium target and the technical problems of handling the metal also presents limitations on its use.

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Summary

The use of cyclotrons to produce fast neutrons in a rotatable isocentric gantry permits multi-port and rotational therapy to be used with fast neutrons. A 42 MeV proton cyclotron is economically feasible, modest in size, and produces energetic neutron beams with characteristics comparable to the photon beam from modern 4 MeV linacs.

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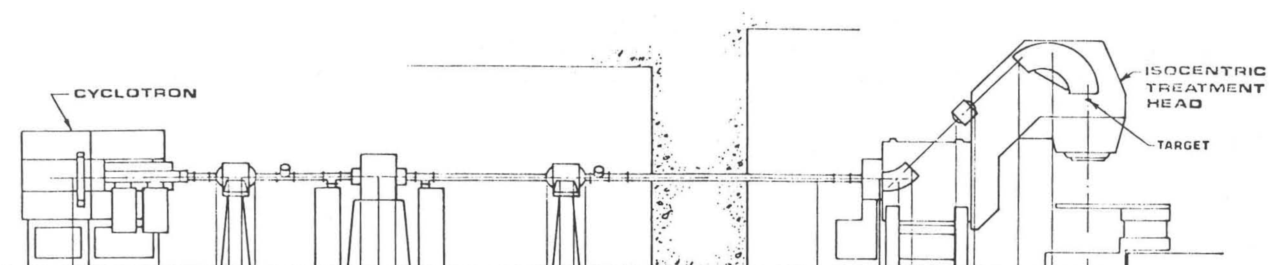

Fig.1.A. BEAM LINE COMPONENTS

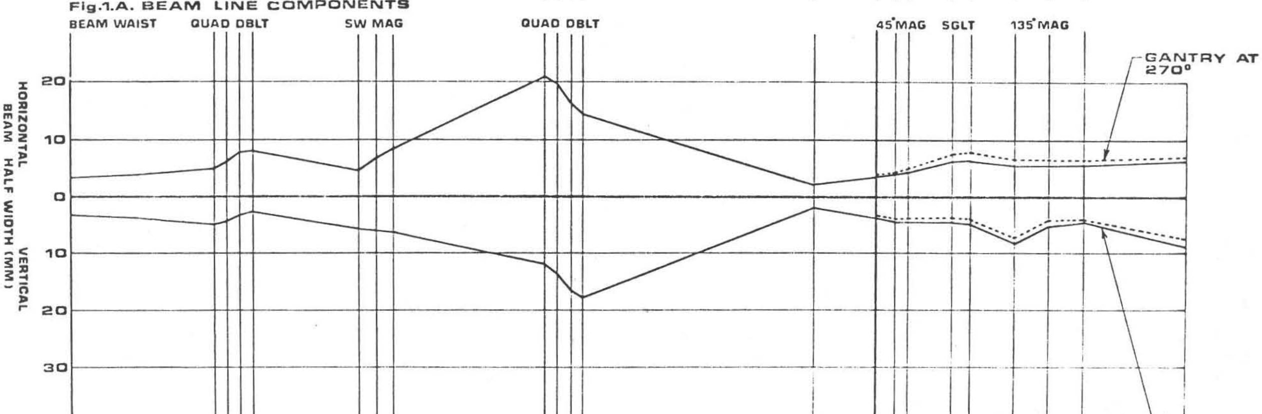

Fig.1.B. BEAM LINE OPTICS

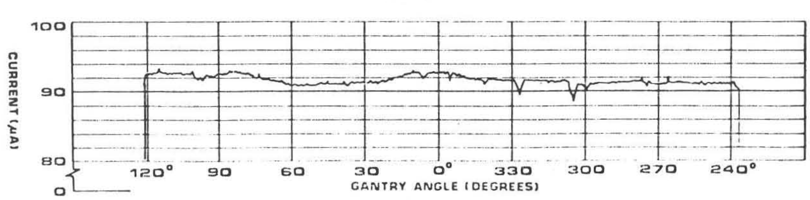

Fig.1.C. BEAM CURRENT ON TARGET OVER 240° ROTATION

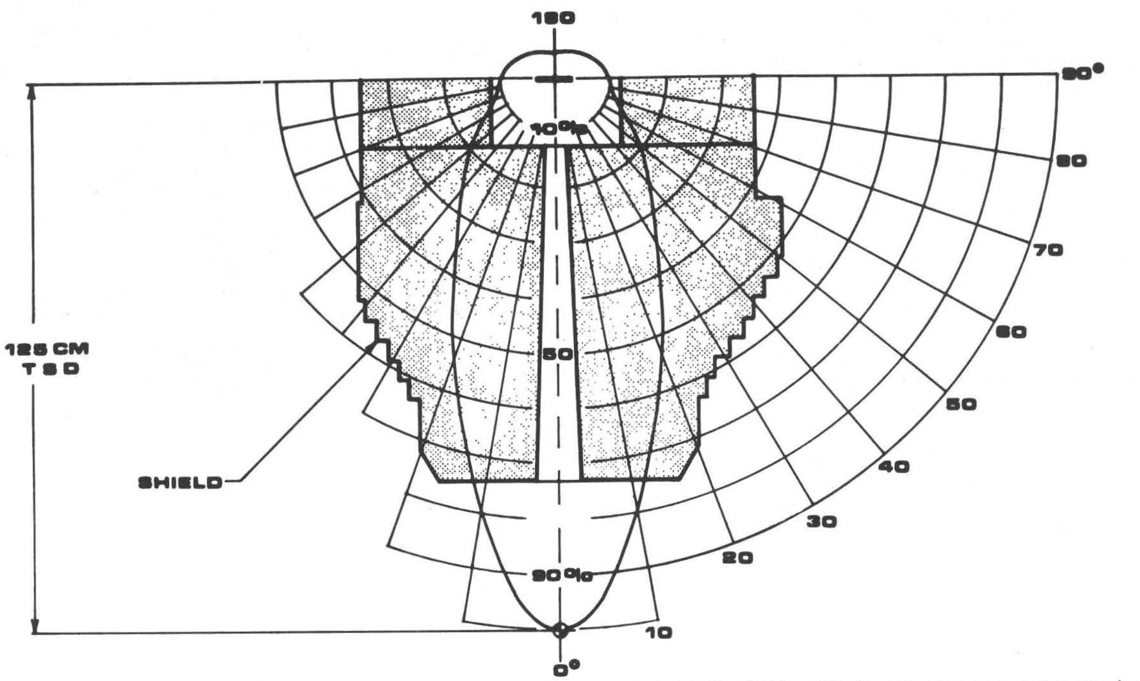

Fig.2.A. ANGULAR DISTRIBUTION OF FAST NEUTRONS FROM 15 MeV DEUTERONS SUPERIMPOSED ON SHIELD DESIGN FOR NEUTRONS FROM d,n REACTION WITH E_d=15 MeV.

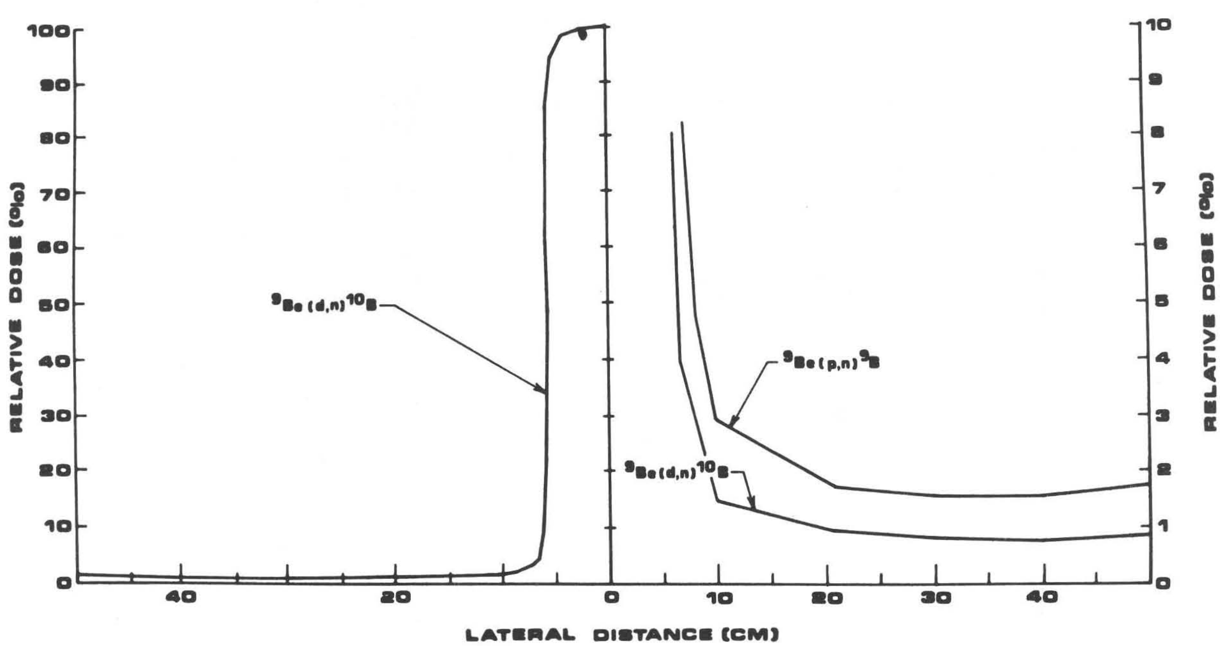

Fig.2.B. DOSE PROFILE MEASURED IN AIR, 10.7 X 10.7 CM FIELD AT 125 CM TSD.

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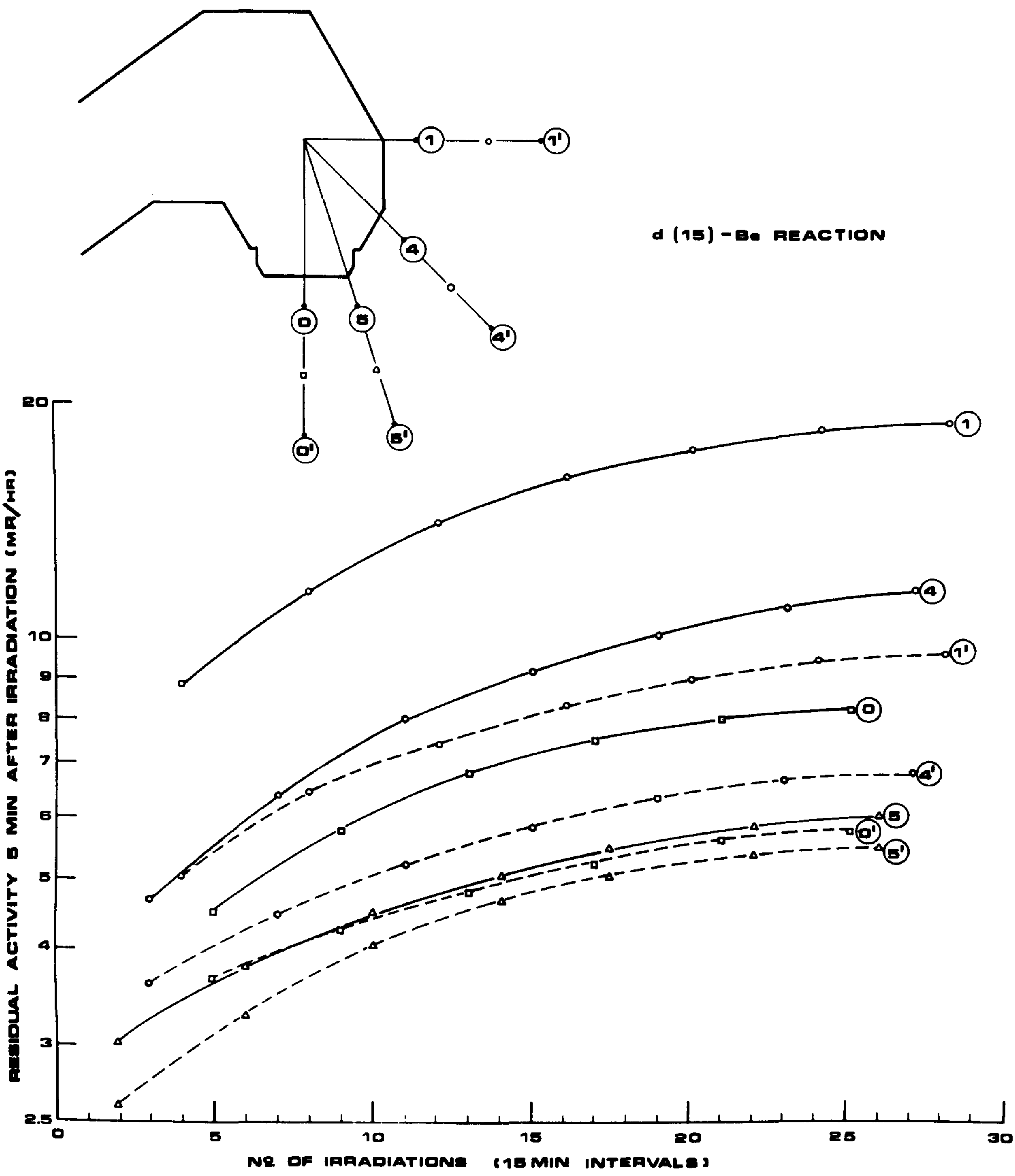

Fig. 3 RESIDUAL ACTIVITY MEASURED 5 MIN AFTER IRRADIATION AND 20 CM FROM THE SURFACE AT DESIGNATED LOCATIONS. (SOLID LINE). BUILD UP WAS SIMULATED FOLLOWING A TREATMENT SCHEDULE OF 4 100 RAD FRACTIONS PER HOUR. BACKGROUND ACTIVITIES MEASURED 5 MIN AFTER IRRADIATION AND 1 M FROM THE SURFACE. (DASHED LINE).

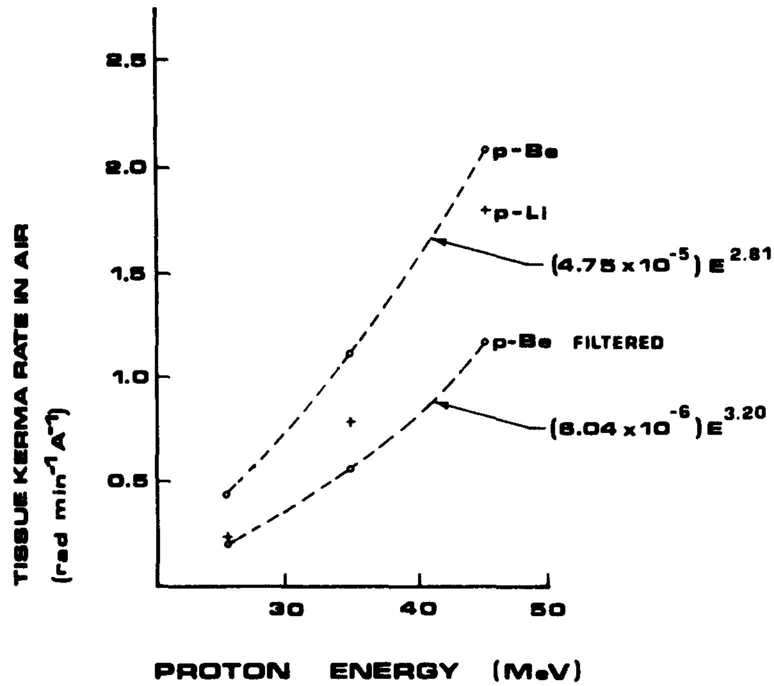

Fig.4.A. TISSUE KERMA RATE (n+γ) IN AIR FOR 10.7 x 10.7cm NEUTRON BEAMS AT 125cm TSD.

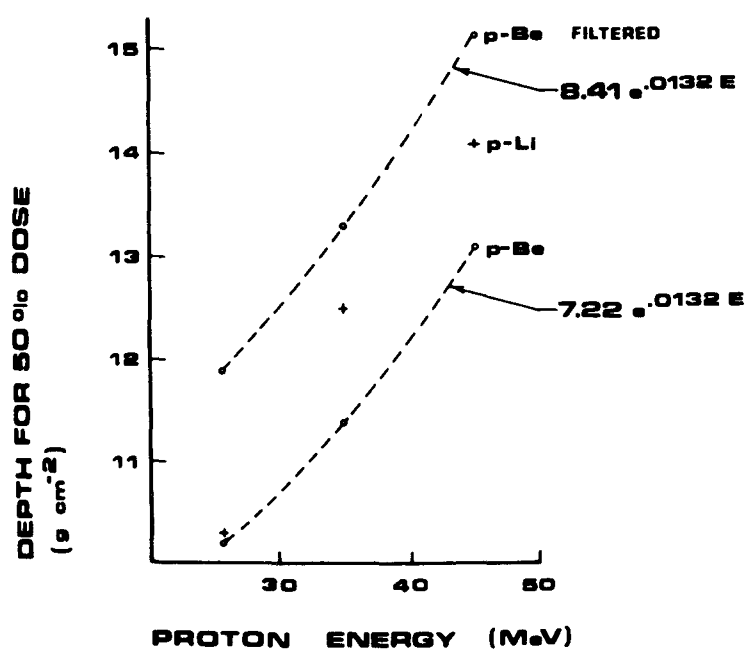

Fig.4.B. DEPTH FOR 50% DOSE RATE.

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