Fermilab

TM-993
1183.00
9/18/80

THE FERMILAB NEUTRON THERAPY FACILITY : TREATMENT PLANNING for NEUTRON and MIXED BEAMS

M.Awschalom, I.Rosenberg, R.Ten Haken
L.Cohen,MD, and F.Hendrickson,MD

Fermi National Accelerator Laboratory
P.O.Box 500, Batavia, Il.,U.S.A. 60510

Abstract

Treatment planning is routinely done for all patients admitted for radiation therapy at the Fermi Neutron Therapy Facility. A large computer, a two dimensional x-y digitizer, a video display unit and two hard copiers constitute the planning system. The software includes parameters for photon and neutron beams. Details of the facility and treatment policy as well as beam parametrization and typical examples of treatment plans are given.

Introduction

Due to the similarities between neutron and photon radiation transport mechanisms in matter. It is natural to expect comparable approaches in the treatment planning procedures for both modalities. The input/output and photon beam calculations subroutines were adopted from those in use at a neighboring hospital.[1] To these, we added appropriate subroutines for the description of our neutron beams.

Facility Description

The Neutron Therapy Facility (NTF)[2,3] at the Fermi National Accelerator Laboratory has been operating compatibly and harmoniously with the requirements of the high energy physics research program since September 7, 1976. The facility, target optimization studies, and other technical data have been published elsewhere.[2,3,4,5,6] The neutron beam is created by 66 MeV protons irradiating a 22 mm thick Be-target where they lose 49 MeV unless they undergo inelastic scattering.[7] The neutron beamline is supplied with a wide range of collimators made of polyethylene concrete with fixed rectangular openings.[5] The collimators permit the use of wedges, shields, and bolus.[5,8] The collimator angle can be adjusted by coaxial rotation around the beam central axis. The neutron beam is fixed horizontally; however, all the relative movements provided by conventional rotation isocentric therapy can be achieved in this facility. The patient sits in a chair or stands on a pedestal which can move in three dimensions and can rotate about a vertical axis through 360 degrees. The point of intersection of the vertical axis of rotation and the central axis of the beam defines a treatment isocenter which is identified by means of four intersecting laser beams with which the patient is aligned. This isocenter is at 190 cm from the Be-target.

The treatment room is on an elevator allowing patient planning, simulation, and set-up to be done in the same treatment "chair" and room but one floor up, where remanent radiation in the immediate vicinity of the target does not contribute to personnel exposure. The patient is immobilized using the conventional "Litecast" molds for head and neck irradiations and nylon straps for the rest of the body. Laser beams and verification radiographs are used in treatment planning and set-up. The axis of rotation of the chair, the axis of the simulator and the planning level laser beams meet at a planning level isocenter which is on the same vertical line as the neutron level isocenter. After the patient is set up, the elevator is simply lowered to the treatment level. There laser beams are used to help make any needed final adjustments.

Beam Characteristics

The dose distributions obtained with the above system were measured in a tissue equivalent liquid phantom [12], and algorithms were developed to reproduce the observed distributions for a computer-based treatment planning program.[5,8,10]

The dose along the central axis (CADD) was measured for depths from about 1.4 cm to 30 cm for a range of collimator sizes and at different SSDs. Figure 1 shows some of the results at an SSD of 190 cm, all normalized to unity at maximum dose.

The off-axis ratios (OARs) were measured at several depths from 2 cm to 30 cm for a number of collimators and at different SSDs. Figure 2 shows the off-axis ratios for three collimators (6x6, 10x10 and 20x20 cm^2) at two extreme depths (2 cm and 20 cm), all normalized to unity at the central axis.

Two teflon (PTFE) wedge filters were also built with simple triangular cross-sections. They turn the isodoses through 45^o and 60^o. An example of wedge effect on OARs is shown in figure 3.

In the above figures, the symbols represent measured points, while the smooth curves represent mathematical fits described elsewhere.[5,6,8,10] These algorithms closely reproduce the measurements.

Treatment Policy

Some of the policies at the NTF dealing with treatment planning are,

1. All patients are measured and planned unless compound curvatures make it impractical, eg.axillia.

2. The doses prescribed in the protocols are interpreted as minimum target volume doses. In practice this means that the protocol dose is delivered to the 90% or 95% isodose, the point of definition (100%) being taken from ICRP Report No.29.

3. The dose to the spinal cord is limited by the following algorithm:

   $$D(\text{spinal cord}) = D(\text{photon}) + 4\,D(\text{neutron}) \quad 50 \text{ Gy.}$$

4. The total dose from the neutron beam is interpreted as neutron dose.

5. In mixed beam (photon plus neutron) therapy, the neutron dose is delivered to the primary site(s) only. Regional areas at risk receive photon or electron irradiation to 50 Gy levels.

6. Treatment plans must be completed and approved before treatment begins. This is particularly important as we are part of a large referral network.

Treatment Planning

The parametrized expressions for CADD and OAR and the wedge modifications have been combined in a treatment planning computer program. Knowledge of the collimator size, wedge used, SSD and depth of interest is all that is needed to calculate the dose at any point in a tissue equivalent medium. A representative isodose distribution for an open 10x10 cm^2 beam normally incident at an SSD of 190 cm is shown in figure 4.

This program, which includes input capabilities from a digitizer tablet[11] and from a CRT terminal, and graphic output facilities for both CRT terminal and incremental plotter, has been adapted to run on a time-sharing CYBER 175, with terminal access at 1200 baud. Typical computing time for any beam is a few millisecond, while a complete plan can be drawn on either device in under one minute. Prompt low resolution isodose plots are obtained using thermally sensitive paper. Once a suitable treatment plan for a patient is selected a permanent high resolution record is made.

At present, the program only calculates correctly in two dimensions in the principal plane of coplanar rectangular beams, and assumes that the patient has a uniform cross-section perpendicular to this plane. However, it incorporates a contour definition subroutine, which is utilized to correct the beam calculations for non-uniform SSD across the beam widths. No corrections are presently made for density variations inside the patient contours.

Treatment plans are either isocentric, or at a fixed SSD , or a combination of both. The particular method is chosen to optimize dose distribution and/or ease of set-up reproducibility. The graphic input is used to trace the external contour and to indicate the extent of tumor and the position of critical structures, as drawn by the physicians.

The program also incorporates some common photon beams characterizations and the ability to add beams from different machines in the same plan. This important feature is extensively used in our mixed beam and neutron boost therapy. As the accepted neutron beam RBEs for tumor control and for cord damage differ, it is important that the separate plans calculated for each individual modality be summed with different weighting factors depending upon the particular site(s).

Four examples of plans obtained from this system are presented in figures 5 to 8. Detailed explanations are contained in the figure captions.

Acknowledgements

John Ingebretsen, Fermilab computing department, helped greatly in rewriting the computer programs and in implementing many conveniences. This work was supported in part by a grant from the National Cancer Institute of the National Institutes of Health, No. 5P01 CA18081.

References

1. Thomas Wachtor, Presbyterian-St.Lukes Hospital, Chicago, Il. Private communication.

2. L.Cohen, M.Awschalom, Appl.Radiol 5 (6), 51, (1976)

3. M.Awschalom, L.Grumboski, A.F.Hrejsa, G.M.Lee, I.Rosenberg, IEEE Trans.Nucl.Sci. NS-26 (3),3068,(1979)

4. H.I.Amols, J.F.DiCello, M.Awschalom, L.Coulson, S.W.Johnsen, R.B.Theus, Med.Phys 4 , 486, (1977)

5. M.Awschalom, I.Rosenberg, Fermilab Report TM-834 (Dec 6, 1978)

6. I.Rosenberg, M.Awschalom, to appear in Med.Phys.

7. M.Awschalom, I.Rosenberg, to appear in Med.Phys.

8. M.Awschalom, I.Rosenberg, to appear in Med.Phys.

9. R.W.Goodwin, M.F.Shea, IEEE Trans.Nucl.Sci. NS-25 , 496, (1978)

10. J.van de Geijn, Brit.J.Radiol 38 , 369, (1965), Brit.J.Radiol. 38 , 865, (1965), Comp.Prog.Biomed 1 , 47, (1970), 2 , 153, (1972)

11. Summagraphics Corp., Fairfield, Conn. 06430, USA

12. N.A.Frigerio, R.F.Coley, M.J.Sampson, Phys.Med.Biol. 17 , 792, (1972)

Figure Captions

Fig.1 . Normalized central axis depth doses for various collimators at 190 cm SSD. The dots are data. Dashed and solid curves represent parametrized fits.

Fig.2 . Normalized off-axis ratios for the 6x6, 10x10, and 20x20 cm^2 collimators,at 180 cm SSD,for 2 cm and 20 cm depth in tissue equivalent liquid.The symbols are data. The curves are parametrized fits.

Fig.3 . Wedged off-axis ratios, normalized to unity at the central axis. 10x10 cm^2 collimator at an SSD of 180 cm and at a depth of 2 cm in tissue equivalent liquid. 45^o and 60^o wedges are shown. Symbols are data. The curves are parametrized fits.

Fig.4 . Isodose distribution for the 10x10 cm^2 collimator at an SSD of 190 cm inside a tissue equivalent liquid phantom.

Fig.5 . Neutron treatment plan for salivary gland tumor. Beams are equally weighted. 60^o wedges are used to increase the dose at the medial edge of the tumor.

Fig.6 . Neutron treatment plan for a H & N primary with one involved node. The first 35% of the dose is given through the opposing fields 1 and 2. Fields 3 and 4 are weighted 7:3 (contribution at isocenter). The primary disease and the involved node are treated to the specified minimum tumor dose, here prescribed to the 90% isodose, while the contralateral side is treated prophylactically for microscopic disease. The cord, even with its higher RBE , remains within tolerance.

Fig.7 . Neutron treatment plan for pancreatic tumor. All three fields deliver equal doses at the isocenter.

Fig.8 . Mixed beam H & N plan.
(a) Photon portion using tele-cobalt machine. Fields are weighted 5:5:4:4 to a total dose of 45 Gy at midline.
(b) Neutron portion using p (66)Be (49) beam at Fermilab. Fields are weighted 2:1 to a total dose of 9.1 Gy to the 95% isodose line.

(c) Approximate composite plan formed by weighting the 100% isodose line of plan (b) by an RBE of 3.0 and adding it to plan (a). The 100% isodose is approximately 74 Gy equivalent. Cord dose is not estimated from this plan but it is obtained from separate calculations of the photon and neutron contributions using the information in plans (a) and (b), respectively, taking into account the higher RBE (taken as 4.0) assigned to the neutron portion.