PROTON RADIATION THERAPY

STATUS OF THE IUCF PROTON RADIATION THERAPY FACILITY

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For almost two years now, the Department of Radiation Oncology at IUPUI has been working with IUCF to develop the ability to use protons to treat cancer.[1] In the past year, significant progress has been made, with several studies now completed. Since April of 1991, we have had beam for seven runs. During those runs work was done on: beam spreading, range modulation, a preliminary investigation into beam contamination,[2] raster scanning techniques and proton radiography,[3] dose monitoring, detector calibrations, beam profile monitors, and *in vivo* measurements of the beam relative biological effectiveness (RBE).[4] Furthermore, a great deal of work has been done on the final designs for the proton therapy facility.[5]

While the motivation for proton radiation therapy has been discussed before,[1] a brief reminder is in order. Proton radiation therapy has several advantages over the conventional radiation therapy techniques (x-rays and electrons) that are commonly available at hospitals. The first advantage is illustrated by comparing depth-dose curves for ^{60}Co x-rays, 20 MeV electrons, and 200 MeV protons (see Fig. 1). Two advantages are readily apparent: 1) for a fixed dose at the tumor, the protons generally give a lower dose to healthy tissue in front of the tumor, 2) the sharp cut-off of the Bragg peak ensures that healthy tissue beyond the tumor is not damaged by protons. Another advantage comes from the fact that the multiple scattering for protons is small enough that a very sharp lateral dose profile can be maintained, even when treating tumors deep in tissue. This reduces the radiation delivered to tissue next to the tumor, while providing the maximum dose at the tumor site. These advantages have been known for some time,[6] but the cost and/or availability of a suitable proton beam (energy $\geq$ 200 MeV) have limited the number of facilities established.

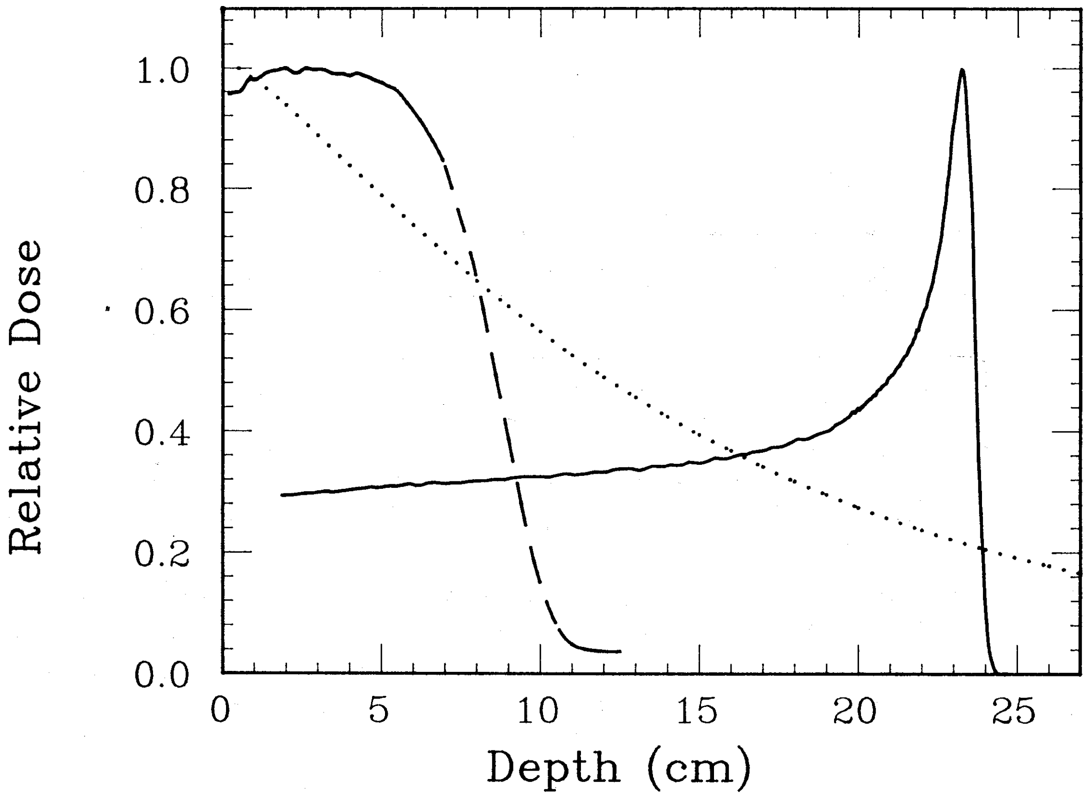

Figure 1. Depth-dose curves for ^{60}Co x-rays (dots), 20 MeV electrons (dashes), and 200 MeV protons (solid).

We have constructed and tested three lateral beam spreading systems, based on the Harvard design.[7,8] These systems use two scattering foils and concentric annuli to allow us to produce flat beam profiles with diameters from 8.5 to 18.6 cm. Table I shows the measured characteristics for each system. Figure 2 shows an example of a lateral dose distribution. While these results are satisfactory, we have noted two significant difficulties with systems of this type.

The first problem is that the concentric annuli type beam spreading systems are very sensitive to alignment and beam position errors. The annuli axis must lie along the treatment axis, and the beam must be centered on the annulus system, as well as collinear. Relatively small deviations can produce large asymmetries in the dose profile. We are planning two projects to address this problem. We are presently constructing a prototype of a multi-wire beam profile monitor. These monitors will give us precise information about the position of the incident beam, and ultimately can be used in a steering loop to maintain a centered, collinear beam. Additionally, we have constructed a second type of lateral beam spreading system, which uses contoured scattering foils.[8] This system should be less sensitive to the beam alignment, a hypothesis which we will test soon.

Table I: Beam Profile Results

Size (cm)	Flatness (%)	Symmetry (%)	Penumbra (cm)
18.6	1.6	1	2.2
11.9	2.6	2	1.9
8.5	1.5	1	1.8

Field **size** is the distance between the 95% points on a beam profile ionization curve, normalized to the central axis value.
Flatness is the variation in ionization profile, measured over the central 80% of the field.
Symmetry is the deviation from 1 of the maximum ratio of ionization readings (averaged over 1 cm) for symmetric points in the flat (central 80%) region of an ionization profile.
Penumbra is the distance between the 90% and 10% ionization points.

Table II: Depth Modulation Results

Modulation (cm)	Surface Dose (%)	Flatness (%)	Distal Falloff (cm)
4.3	59	4.6	.67
7.5	71	2.8	.65
19.0	95	3.3	.70

Modulation is the extent of the depth plateau.
Surface dose is the ratio of the ionization measured near the surface to that measured at the peak.
Flatness is defined similar to that for the profile.
The **distal falloff** is the distance from the 90% ionization level to the 10% ionization level at the distal edge.

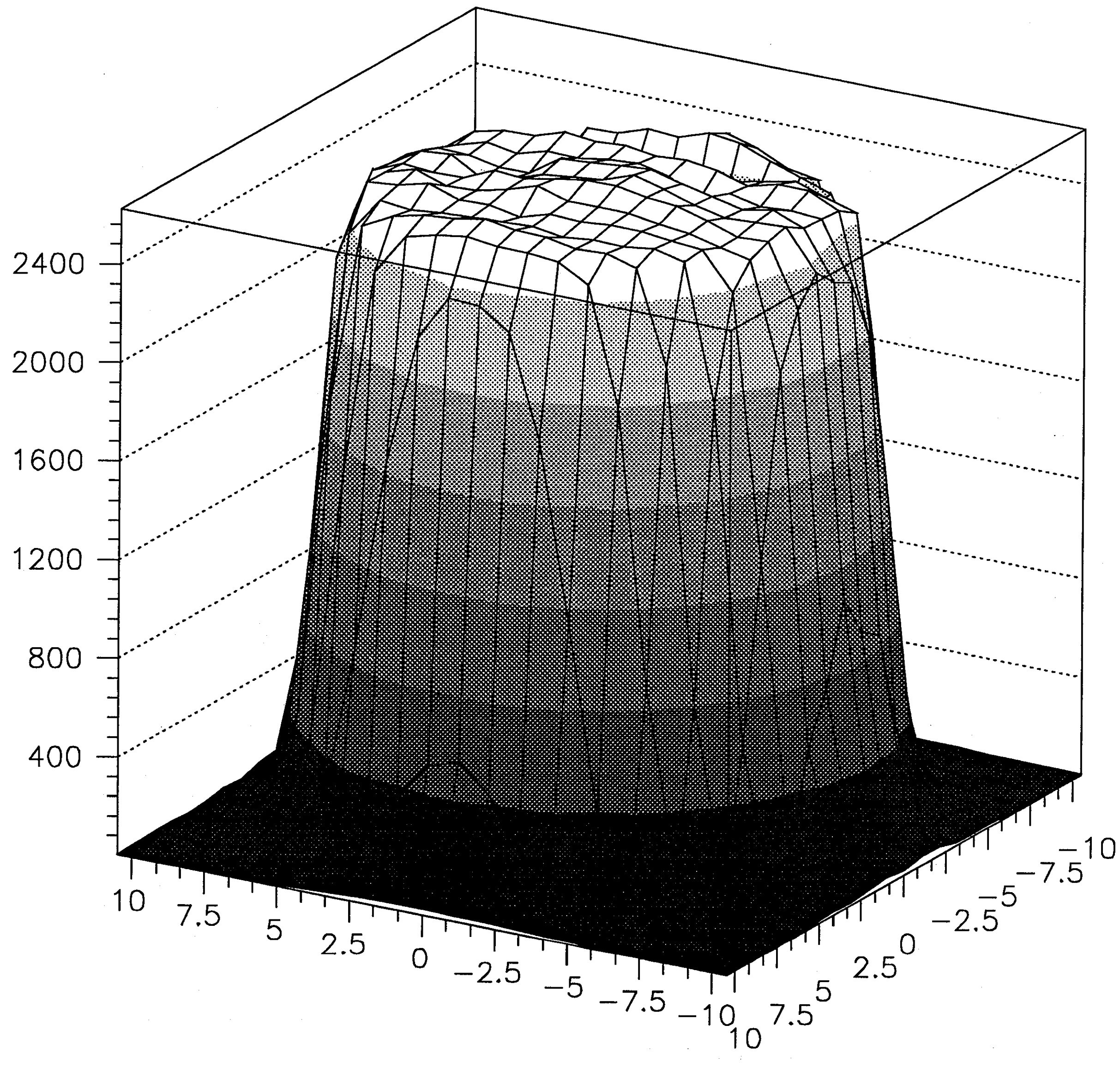

Figure 2. Proton dose vs. horizontal and vertical position (given in cm).

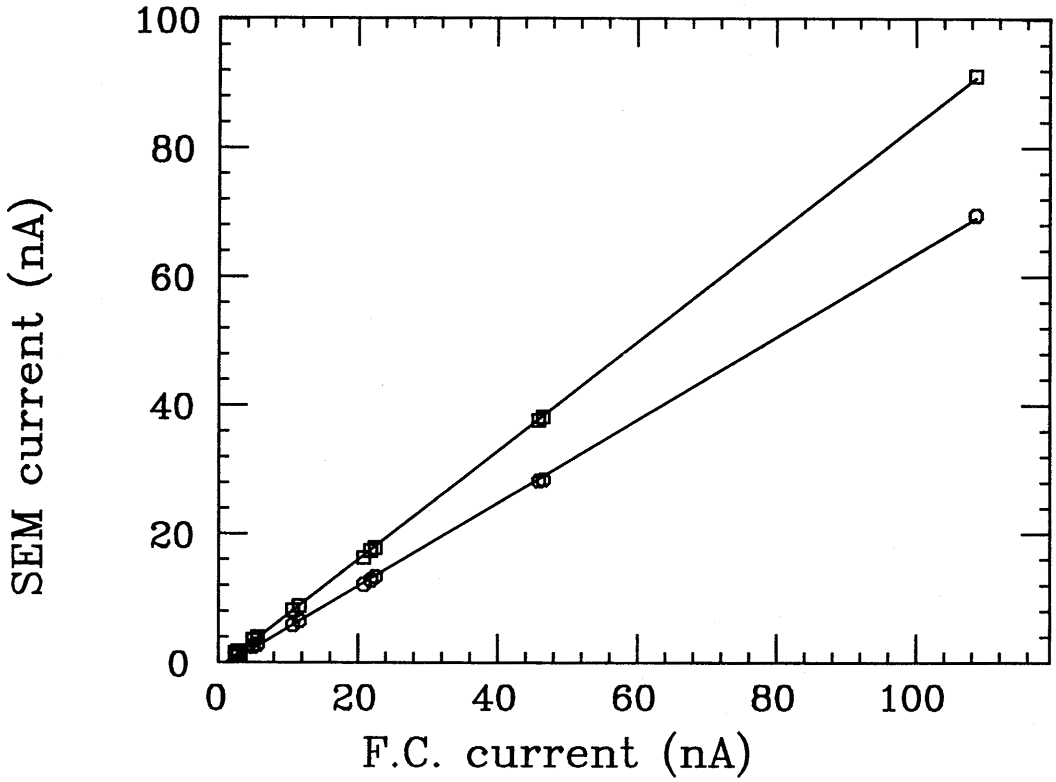

Figure 3. SEM output current vs. beam current for SEM #1 (circles) and SEM #2 (squares). Lines represent fits to data.

The second drawback of the lateral beam spreading systems (which is common to both the annulus and the contoured scatter types), is that each beam spreading system works only for the beam energy for which it was designed. We are just beginning to research ways these systems could be modified to reduce their energy dependence.

In addition to the lateral spreading of the beam, we have developed range modulators[9] to produce a depth plateau, often referred to as a spread out Bragg peak (SOBP). At this point, we have constructed and tested three range modulators whose measured characteristics are given in Table II. While quite satisfactory for the energy for which they were designed (200 MeV, in this case), the range modulators also have the drawback that their design is energy dependent.

In order to deliver accurate doses, reliable non-destructive beam diagnostics are necessary. We have recently constructed two secondary electron monitors (SEMs). Our beam tests of the SEMs measured the response of each device for different beam currents, different beam energies, and different bias polarities. The two new SEMs proved to be quite satisfactory, showing a linear response over a wide range of beam currents. Figure 3 shows the results from the calibration of each SEM against a Faraday cup over a range of beam currents.

In addition to the SEMs, two segmented ion chambers will be used to monitor both the integrated charge, and the field symmetry. Each chamber provides 4 signals: up, down, left, and right. We have established the response of each segment so that on-line comparisons of the different segments will yield information about the field symmetry.

Our first *in vivo* measurements determined the relative biological effectiveness (RBE) of the proton beam. Four different biological end-points (LD_{100}, spleen cell cellularity, lymphocyte proliferation, and frequency of chromatin fragment formation) extracted from total body irradiation of healthy mice yielded an RBE value (compared to ^{60}Co) of 1.27 ± 0.04. More recently we investigated the RBE in a fractionated treatment of cancer cells in mice. Eighteen mice with cancerous tumors on their thighs received local irradiations of protons while the same number received similar treatment with 250 keV x-rays. Each mouse received a dose of 600 cGy three times a week for 2 weeks. We have yet to extract a value for the RBE from this work.

The present effort is directed toward automated dose delivery and patient positioning. A real time computer system will be used to observe the output of all beam monitor devices. This system will stop treatment when the proper dose has been reached, or if the beam fails to meet certain criteria. Eventually, feedback loops will be added so that the system will try to correct problems with the beam (such as a beam position error) based on the information provided by the various beam monitors. We have acquired a chair that will allow a patient to be positioned for treatment of head and neck tumors. Additional systems which we have acquired for patient alignment include: a laser alignment system, a light field port verification system, and an x-ray port verification system. Our expectations are that the entire system will be completed and ready for patient treatment by the end of this calendar year.

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