PROGRESS REPORT ON 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 that are commonly available at hospitals. The first advantage is illustrated by comparing depth-dose profiles for ^{60}Co x-rays, 22 MeV electrons, and 200 MeV protons. (See Figure 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 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 sight. These advantages have been known for some time,[6] but the cost and/or availability of a suitable proton beam (energy ≥ 200 MeV) have limited the number of facilities established.

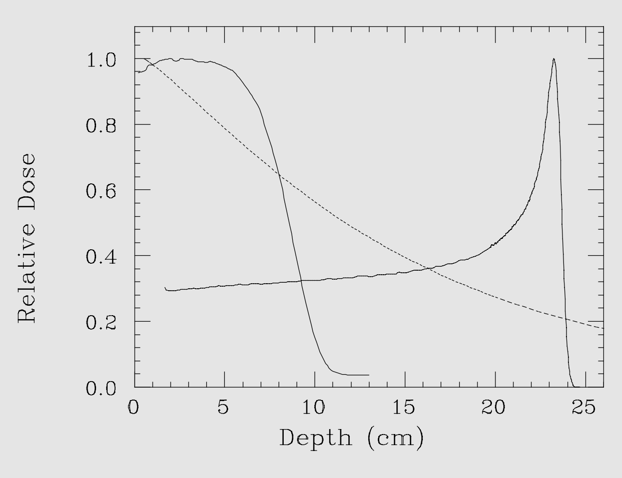

Figure 1 *Depth-dose profiles for ^{60}Co x-rays (dots), 22 MeV electrons (dashes), and 200 MeV protons (solid).*

We have constructed and tested three beam spreading systems, based on the Harvard design.[7,8] The three systems allow us to produce flat beam profiles with diameters of 8.5, 11.9, or 18.6 cm. Table I shows the measured characteristics for each system. The field size is defined as the distance between the 95% points on a beam profile ionization curve, normalized to the central axis value. The flatness is defined as the variation in ionization profile, measured over the central 80% of the field. The symmetry is defined as the maximum ratio of readings (averaged over 1 cm) for symmetric points in the flat region of an ionization profile. The penumbra is defined as the distance between the 90% and 10% ionization points.

TABLE I

Size (cm)	**Flatness (%)**	**Symmetry**	**Penumbra (cm)**
18.6	1.6	1.01	2.2
11.9	2.6	1.02	1.9
8.5	1.5	1.01	1.8

In addition to lateral spreading of the beam, we have developed range modulators[9] to produce a spread out Bragg peak (SOBP). At this point, we have constructed and tested three range modulators. Their measured characteristics are given in Table II. The surface dose is define as the ratio of the ionization measured at the surface to that measured at the peak. The 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.

TABLE II

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

In order to deliver accurate doses, reliable non-destructive beam diagnostics are necessary. We have recently constructed two identical secondary electron monitors (SEM's) Our beam tests of the SEM's measured the response of each device for different beam currents, different beam energies, and different bias polarities. The two new SEM's proved to be quite satisfactory. Figure 2 shows the results from the calibration of each SEM against a Faraday cup over a range of beam currents.

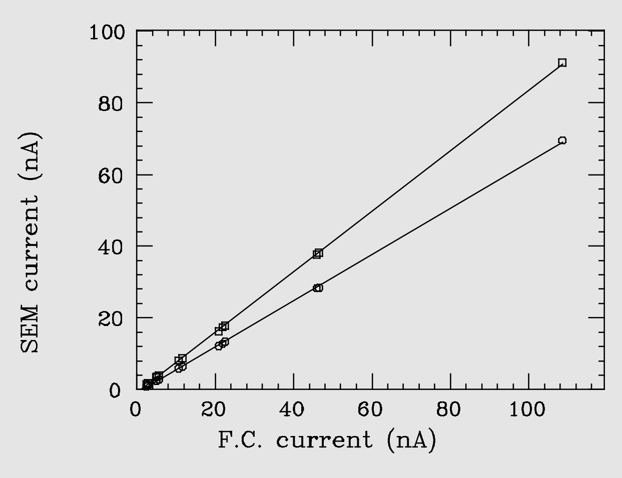

Figure 2 *SEM output current vs. beam current for SEM #1 (circles) and SEM #2 (crosses). Lines represent fits to data.*

In addition to the SEM's, 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 endpoints (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. While we have yet to extract a value for the RBE from this work, this realistic treatment resulted in a complete cure of all 18 mice treated with protons.

The present work is focussing on two areas: 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.

The remaining area of focus is to allow accurate placement of human patients so that treatments can begin. We have acquired a chair that will allow a patient to be positioned for treatment of head and neck tumors. We need to add systems for patient alignment: a laser positioning system, a light field system, and an x-ray port verification system. Our expectations are that the entire system will be completed and ready for patient treatment in the upcoming year.

ACKNOWLEDGEMENT

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