APPLIED RESEARCH

DEVELOPMENT OF A PROTON RADIATION THERAPY FACILITY AT IUCF

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During the past year, the Department of Radiation Oncology at IUPUI has been working with IUCF to develop an ability to use protons to treat cancer. We have made significant progress in several key areas. During three runs we have developed and tested a beam spreading system and range modulator. At the same time, *in vivo* and *in vitro* measurements of the beam relative biological effectiveness (RBE) were made. Finally, our initial successes and future plans have led to additional funding for the coming year.

Proton radiation therapy has several advantages over other methods of cancer treatment. By using the proton Bragg peak to treat tumors, two advantages over ^{60}Co treatments are readily apparent: 1) For a fixed dose at the tumor, the protons generally give a lower dose (and hence do less damage) 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. The main disadvantage of proton radiation therapy is the cost/availability of a suitable energy ($\sim$ 200 MeV) proton beam. The beam splitting capability at IUCF allows us to develop a proton radiation therapy program while making only a minimal impact on the nuclear physics research program. As Cooler experiments become a larger fraction of the nuclear physics research, even more split beam should be available, as the Cooler typically uses less than 10% of the available beam. Before we can take advantage of that, an additional Lambertson magnet (L4) will need to be installed to allow splitting between the Cooler and the γ-cave.

The work on the proton therapy beam delivery system has focussed on three areas: beam spreading, range modulation, and dose monitoring. In order to treat typical size tumors, the beam needs to be spread in a uniform intensity well beyond its typical 2 mm diameter. The beam spreading system is a proton nozzle,[1] designed using a program called NEU (Nozzle with Everything Upstream).[2] A typical beam delivery geometry is shown in Fig. 1. Beam passes through a thick primary scattering foil and after some distance is shaped by two concentric annuli which are immediately followed by a second

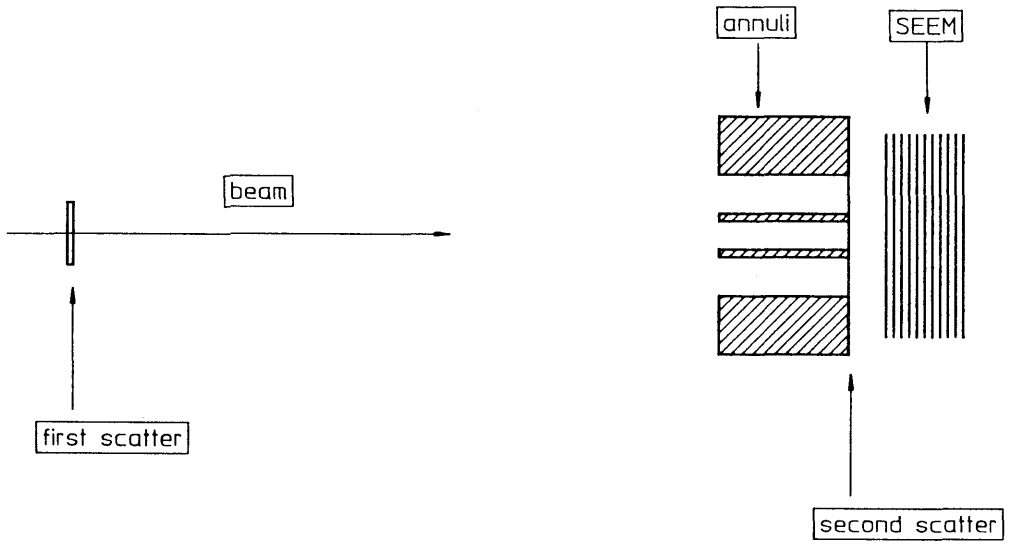

Figure 1. Schematic layout of beam line components.

scattering foil. The foil thicknesses and annuli diameters depend on the field size, beam energy, and relative positions of the scattering foils and target. We have tested two beam spreading systems, which produced flat fields (±5%) of 10 and 15 cm diameter.

The 180-200 MeV proton beams frequently run at IUCF are particularly well suited for proton radiation therapy. The cyclotron's maximum energy of 200 MeV protons gives a reasonable range in tissue ($\sim$ 24 cm in water). This is generally sufficient to reach most tumors. For tumors located closer to the surface, additional tissue-equivalent material is placed in front of the tumor to give the protons the correct depth. In order to deliver a uniform dose to tumors with a large extent in the longitudinal (beam) direction, we have manufactured range modulators of a rotating stepped design.[3] By superimposing Bragg peaks which are shifted in position and varying in intensity, a reasonably flat longitudinal distribution can be obtained. The shift in the Bragg peak position is obtained by having plastic of appropriate thickness rotate into the beam. The intensity of the Bragg peak at that position is controlled by adjusting the length of time that thickness of plastic is in the beam. Fig. 2 shows a typical range modulator, which is rotated through the beam. We have written a computer program that determines the fraction of beam required at each range to give an integrated dose that is flat to better than ±2% over the spread out Bragg peak (SOBP). Thus far, we have tested range modulators designed to produce SOBP's of 4, 8, and 18 cm. Results for the latter are shown in Fig. 3.

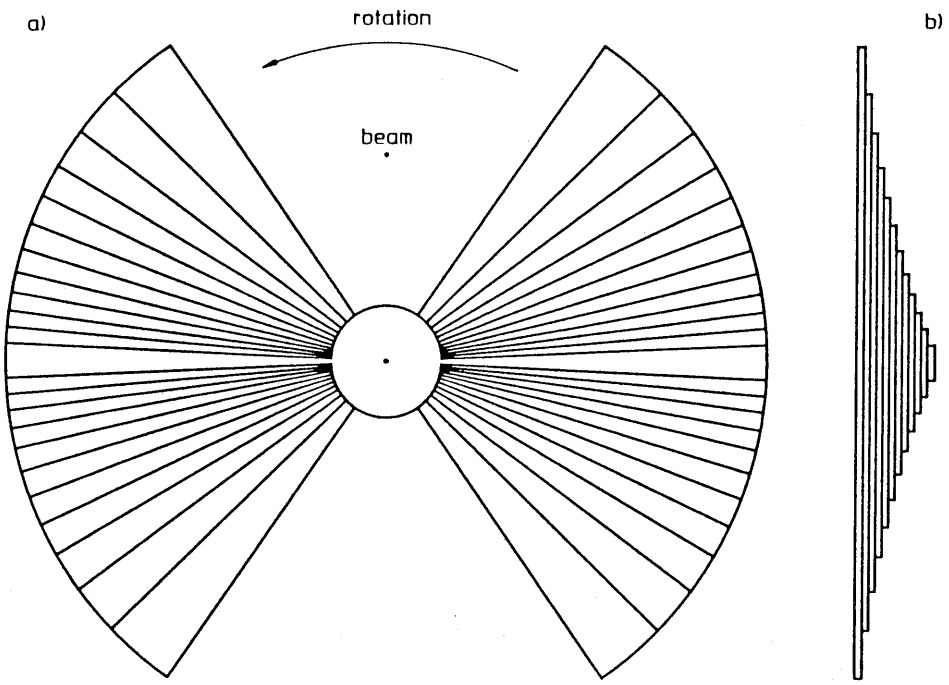

Figure 2. a) beam view of range modulator; b) side view of range modulator.

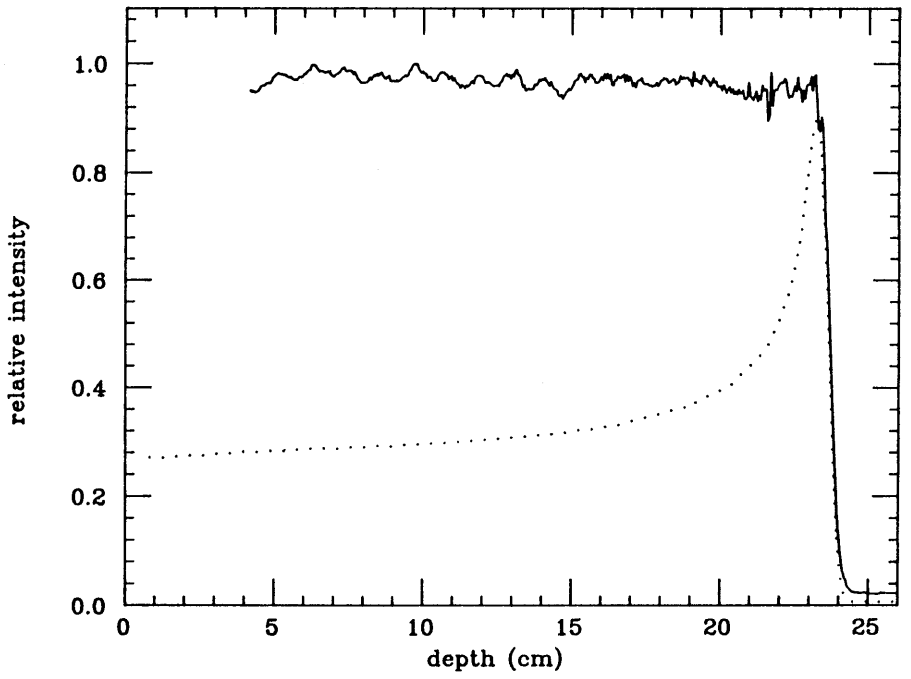

Figure 3. Unmodulated Bragg peak (dots) and SOBP (solid) for 18 cm range modulator.

In order to deliver accurate doses, reliable non-destructive beam diagnostics are necessary. Since typical beam currents (in our development mode) are on the order of 1 nA or less, normal electrostatic pick-ups are too insensitive. Instead, a secondary electron emission monitor (SEEM) is used in the proton therapy beam line. The SEEM consists of several layers of aluminized mylar, with alternate layers biased with a negative voltage and the remaining layers acting as electron collectors. The electron current is read on a current integrator. The SEEM does not affect the beam quality for proton therapy as the energy loss in the thin mylar is less than 1 MeV compared with $\sim$ 15 MeV throughout the remainder of the beam spreading system. The SEEM is calibrated against a Faraday cup and an ion chamber so that integrated proton flux and the dose can be measured simultaneously. A pair of split ion chambers have been acquired and will also be used in the future.

Finally, we have measured the relative biological effectiveness (RBE) of the beam produced in our delivery system. Fifteen cell cultures and 67 mice have been irradiated with 200 MeV protons in doses of 150, 400, and 800 cGy. The RBE has been evaluated using mouse LD100, spleen cell cellularity, lymphocyte proliferation, and frequency of chromatin fragment formation as indicators. Our preliminary results give an RBE value (compared to ^{60}Co) of 1.24 $\pm$0.12.

Our success thus far has led to a commitment of funds from the Lion's Club of Indiana. They will donate $300,000 for the development of the proton therapy facility to the point where first patient treatments can be done. While there remains a considerable amount of work to be done, we project that the first patient will be treated as early as June of 1992.

1. A. M. Koehler, R. J. Schneider, and J. M. Sisterson, Am. Assoc. Phys. Med. **4**, 197 (1977).
2. B. Gottschalk, Harvard Cyclotron Laboratory internal report.
3. A. M. Koehler, R. J. Schneider, and J. M. Sisterson, Nucl. Instru. and Meth. **131**, 437 (1975).