THE INDIANA UNIVERSITY PROTON THERAPY SYSTEM

V. Anferov, J. Collins, D.L. Friesel, J. Katuin, S.B. Klein, D. Nichiporov, & M.W. Wedekind,
Indiana University Cyclotron Facility, Bloomington, IN 47408, USA

Abstract

The Midwest Proton Radiotherapy Institute (MPRI) is designed by Indiana University to deliver proton radiation treatment to patients with solid tumors or other diseases susceptible to radiation. The IUCF Proton Therapy System (PTS) has four unique subsystems to perform the radiation treatment; Beam Delivery, Dose Delivery, Patient Positioning and Treatment Control systems. MPRI began treatment operations in 2003 with a single Fixed Horizontal Beam Line (FHBL) treatment room (TR1) and is being expanded to include two additional treatment rooms utilizing modified IBA 360^{o} degree rotating gantry systems. The Gantry nozzles use a beam wobbling (scanning) and energy stacking system to produce lateral and longitudinal beam distributions for patient treatment. Preliminary measurements indicate that the Neutron background radiation to the patient is 8 times smaller than produced using the passive scattering system in TR1. A Treatment Room Control System[1] provides a single user interface to the other subsystems to setup, deliver and monitor Proton Therapy treatment. This paper will present a brief overview of the IUCF Proton Therapy Treatment System, the properties and examples of the beam performance of the unique Nozzle design, and a summary of the facility beam operations.

THE MPRI FACILITY

The design of the MPRI Beam Production and Delivery Systems were previously reported [2],[3]. A constant 208.4 MeV proton beam from the IUCF k220 cyclotrons is delivered to a Beam Dump via a 57m Trunk Line, as shown in Fig.1, and delivered on demand to one of three Proton Therapy Treatment Rooms via energy selection beam lines, each containing an energy degrader. The ES lines transmit 65 to 208.4 MeV protons to the three Treatment Rooms. TR1 houses a Large Field Horizontal Treatment Nozzle system which has been treating patients since February of 2003 utilizing passive scattering techniques to provide the lateral beam distribution.

Since MPRI clinical operation began in 2003, IUCF has constructed a second treatment room (TR2) housing an IBA 360^{o} rotating Gantry system [4]. The Gantry incorporates an IUCF designed beam delivery nozzle containing a compact combined function magnet for beam scanning to deliver lateral beam distributions up to 30cm in diameter and an energy stacking method to achieve range modulations of up to 16 cm. A commercial six axis industrial robot, identical to that now used in TR1, has been adapted to the IBA Gantry treatment system to position the patient for treatment, and also to facilitate snout changes and other heavy lifting activities. The Gantry has also been modified to accept a retractable floor within the patient enclosure to permit easy access to a patient when positioned at the isocenter for treatment. These items are pictured in Figure 2. Construction of the Treatment Room 2 systems is complete and accepted by the MPRI Clinic. Final validation testing and clinic commissioning is presently underway. A third treatment room (TR3) is also under construction that will have a

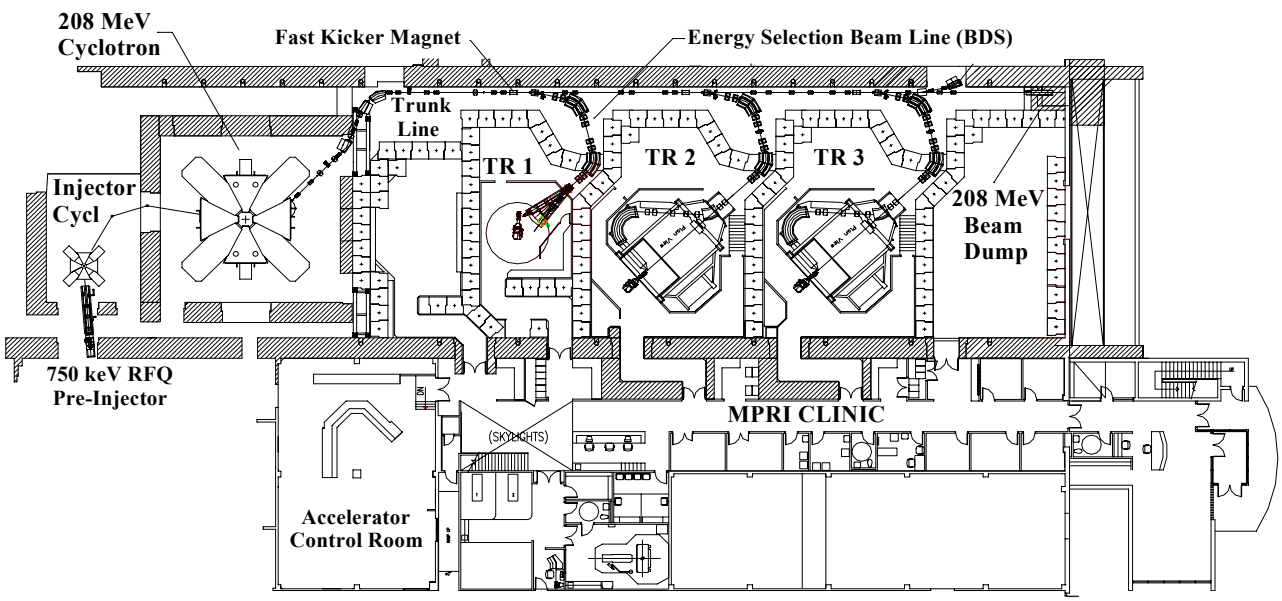

Figure 1. The MPRI facility showing the IUCF Cyclotrons, Trunk and ES lines, Treatment Rooms and Clinic

Figure 2. Photo of the IUCF Gantry enclosure, beam delivery nozzle and patient positioning robot in TR2.

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patient treatment system identical to the one being tested now in TR2. All TR2 construction and commissioning activities were necessarily scheduled around the ongoing patient treatment activities in TR1.

THE IUCF BEAM SCANNING NOZZLE

The clinical design requirements for the Gantry treatment room specified that the beam delivery nozzle system deliver a proton beam with an SOBP adjustable from 2 to 15 cm with a lateral field distribution adjustable from 2 to 30 cm in diameter at depths in water up to 27 cm. Analysis of the IBA Gantry and Nozzle system, which has a maximum SAD of 2.5 m, lead us to conclude that the easiest method of delivering these beam properties was to design a beam scanning nozzle within the IBA Gantry nozzle frame structure.

The IUCF beam scanning nozzle, illustrated in Fig. 3, utilizes several standard commercial devices marketed by

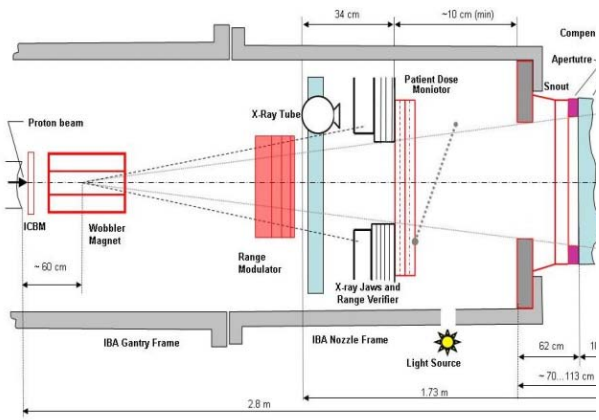

Figure 3. Shown is a schematic diagram of the component arrangement of the IUCF Scanning Nozzle.

IBA (slit assemblies, snout, snout mounting and motion mechanisms, light field and X-Ray tube translation system) for their Gantry nozzle. IUCF designed and installed a compact combined function scanning magnet (wobbler) and control system to produce the desired lateral beam distributions, a computer controlled digital range modulator to produce SOBPs adjustable from 3 to 16 cm via a process called "Energy Stacking", and a redundant multi-plane ion chamber detector system (Patient Dose Monitor) to measure proton dose, position, symmetry and uniformity during treatment. The frequency and amplitude of the scan magnet and the operation of the digital range modulator are calculated, set and verified by the Dose Delivery Control System using patient specific treatment prescriptions retrieved from the clinic Treatment Planning Database prior to the start of patient treatment.

There are several operational advantages of the IUCF scanning nozzle design over a passive scattering nozzle. The operational advantage of the digital range modulator, consisting of 6 degrader plates of varying thickness that are inserted sequentially in a binary fashion to build the SOBP from the distal to the proximal edges of the treatment volume, is that this single programmable mechanical device replaces a library of interchangeable

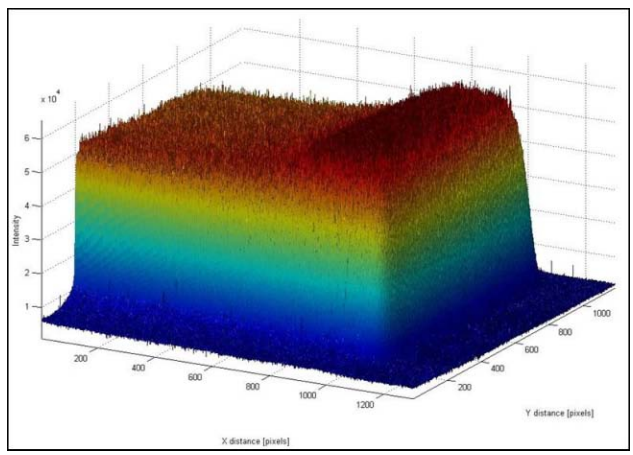

Figure 4. A 3D graph of a 3 cm SOBP measured at 16 cm depth in water using Gafchromic EBT film in the water phantom.

modulator propellers needed to produce prescribed SOBPs at all treatment depths. This is done automatically, reducing the workload of the radiation technologists significantly and eliminating the cost of manufacturing, cataloging and storing a propeller library.

Another benefit of this nozzle design is that the neutron background level produced by the passive scattering foils, which accounts for about 80% of the neutron background measured recently in Treatment Room 1, is eliminated [5]. This significant reduction in the neutron background is a major improvement for the treatment of pregnant or pediatric patients with protons. An example of the dose delivered to a treatment volume with this scanning nozzle is given in Fig. 4 above.

PHASE II CONSTRUCTION STATUS

MPRI Phase II construction (i.e. TR2) is complete, and the Gantry treatment room system verification and validation testing is in progress now in preparation for submittal of an application for 510(k) approval to the FDA in July. The clinic Medical Physics staff has conducted beam performance testing and accepted the Gantry treatment system from IUCF. MPRI has also submitted an addendum to the TR1 IDE to the FDA that could permit the start of patient treatment in TR2 before the 510(k) approval is received.

Construction of TR3 has continued at a somewhat reduced pace. The Beam Delivery Lines and the Gantry Structure have been installed, aligned and tested. All major components for the Gantry Nozzle and treatment room support equipment have been fabricated or procured from the appropriate vendor. Final Assembly and testing of TR3 is continuing as manpower permits, but will commence in earnest following the successful completion of TR2 verification testing. TR3 is scheduled for completion during the first quarter of 2007.

SUMMARY OF MPRI TREATMENT OPERATIONS

a) Cyclotron Operational Reliability

The MPRI clinic began treating patients in Treatment Room 1 in February of 2003. Operational reliability of the IUCF cyclotron was about 94% during treatment operations during 1995, where any accelerator system failure during scheduled clinic operations is counted in the reliability percentage above, whether it affects the treatment schedule or not. The daily reliability of the cyclotrons is closer to 98%, although several times consuming failures have brought the average down to 94%. One recurrent source of downtime is the new 750 keV CW RFQ pre-injector. The innovative RFQ structure, designed and manufactured by AccSys Technology Inc. [6], and the commercial RF power amplifier system, were delivered to IUCF barely 6 months prior to the start of treatment owing to fabrication and commissioning delays. This RFQ significantly improved the reproducibility of setting up the cyclotrons from a cold start, and contributes to the present stability of beam extracted from the cyclotrons when operating properly [7]. The energy of the proton beam extracted from the cyclotrons is routinely measured and maintained at 208.4 MeV to within +/- 100 keV. However, this system has recently experienced several RFQ and amplifier system failures that required significant equipment and maintenance procedure upgrades. Some of these problems were manufacturer design flaws while some were the result of our operating and maintenance procedures. The commercial RFQ power amplifier required extensive redesign by the IUCF staff. Some of this can be expected from a newly installed system, and it is anticipated that this device, with continuing experience and maintenance, will be made as reliable as the rest of the IUCF cyclotron systems.

b)MPRI Clinic Operations

The medical clinic has treated approximately 190 patients with protons in Treatment Room 1 (TR1) since operations started under an IDE in February of 2003. A full spectrum of disease sites have been treated, including prostate, pelvic, thyroid, skin, spine, lung, bone, head and neck and brain[8]. There has been a strong demand for the treatment of pediatric patients, which began at IUCF in 2005. The reliability of the TR1 treatment system has excellent, averaging well over 97%.

CONCLUSIONS

MPRI Phase II construction is complete and TR2 system verification and validation testing is proceeding on a fast track for submission of the FDA 510(k) application in July. MPRI clinic acceptance testing is complete and clinic commissioning is underway in preparation for the start of patient treatment. The MPRI clinic should be operating with two treatment room by August 2006 with 2 treatment rooms. Treatment Room 3, an identical copy of TR2, should be operational 6 months later.

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