THE MIDWEST PROTON RADIATION INSTITUTE PROJECT AT THE INDIANA UNIVERSITY CYCLOTRON FACILITY

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Abstract

The IUCF cyclotrons ceased delivering particle beams for physics research and became dedicated medical proton beam accelerators in 1999. Removal of the beam lines and nuclear research facilities associated with the cyclotrons to make room for the new medical beam delivery systems was completed in October, 2000. A new achromatic beam line was completed, extending from the main stage cyclotron and ending at a temporary research platform. This beam line is being commissioned during ongoing applied research. The achromatic line will deliver 0.5 μA of 205 MeV protons from which the treatment room technician may draw current at any time via fast switching, laminated magnets located at the entrances to the energy selection systems upstream of each of the treatment rooms. Three treatment rooms are planned, one containing two fixed horizontal lines and two gantry rooms. The cyclotrons will also support full time research in radiation effects, single event upset, radiation biology and pre-clinical research. This contribution describes the status of the medical construction project.

1 INTRODUCTION

The Midwest Proton Radiation Institute (MPRI) will utilize the Indiana University Cyclotron Facility (IUCF) separated sector cyclotron accelerator system that consists of a 600 kV Cockcroft Walton pre-accelerator, a 15 MeV proton injector cyclotron and a 205 MeV proton main stage cyclotron [1]. These plans are being realized by virtue of recently released State and Federal funding. During the construction phase, cyclotron operations have continued albeit on a significantly reduced schedule in order to provide proton radiation for a variety of commercial, biomedical and radiation effects applications [2]. Conversion of the cyclotron system and construction of the medical facility are proceeding on a fast track with a goal of treating the first patient early in 2003. The main cyclotron extraction system and radio-frequency (rf) cavity structures have been modified to improve extraction efficiency and increase the routine operating energy to 205 MeV. A doubly achromatic extraction beam line, the first of 4 major beam line systems that make up the first phase of the MPRI beam delivery system, has been installed and commissioning began in November of 2000 with 205 MeV protons.

2 CYCLOTRON UPGRADES

A first step toward validating the use of the IUCF cyclotrons as a proton source for medical treatment was a historical review of the operational reliability of all related accelerator hardware systems. The IUCF cyclotrons operated for about 7000 hours annually during its peak operating years (1983-1993), and maintained a user availability of about 90%. The major recurrent sources of downtime for the cyclotrons during that operating period were the polarized ion source and 600 kV Cockcroft Walton pre-accelerator systems, which together accounted for about 50% of the total reported breakdown time. The remainder of the accelerator systems (dc power, water, vacuum, unpolarized ion sources, etc) had a reliability record consistent with the 95% beam delivery reliability required for medical applications. The complex polarized ion source, which alone accounted for 25% of the downtime, is not required for medical applications, and will be replaced with a reliable high intensity unpolarized proton source. The cyclotrons have been reconfigured to operate at a fixed proton energy of 205 MeV. This has the added advantage of removing the variable energy requirement for the pre-accelerator and allows the possibility of using a Radio Frequency Quadrupole (RFQ) Linac for this purpose.

3. MPRI BEAM DELIVERY SYSTEM

The MPRI beam transmission line begins at the main cyclotron exit with an achromatic section followed by a long, straight, trunk line to a beam dump at the far north end of the trunk line corridor. Each treatment or research room connects to the trunk line through a local energy selection system (ESS) that permits independent delivery of the desired beam energy and distribution. In conjunction with the IUCF beam splitting system, this scheme will permit the IUCF cyclotrons to simultaneously deliver different beam energies, intensities and particle distributions to the MPRI treatment and research rooms. Beam development of the newly constructed achromatic section began in November 2000; the trunk line is expected to be completed by November of 2001.

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The trunk line incorporates unique beam intensity modulation and beam splitting tools to facilitate the efficient use of all treatment and research facilities. These beam manipulation tools, pioneered at and used at IUCF since 1986 [3], will permit the simultaneous delivery and monitoring of variable intensity beams to each radiation room. At the entrance to each ESS, the beam from the main cyclotron is alternatively switched between high and low field regions of a vertical bending Lambertson septum magnet located at an optical double waist. Switching between fields is accomplished with a ferrite magnet, just upstream of the Lambertson, operating at an adjustable frequency that will accommodate delivery specifications of up to 10 kHz. The beam will be directed to either the ESS or the trunk line. The portion of the beam directed along the trunk line will be available for continuous energy and intensity monitoring by way of a multi-leaf Faraday cup [4] at the beam dump, and additional splitting into additional treatment or research facilities. Beam sharing by way of this technique will allow for simultaneous research and medical applications as well as enormous capacity to modify the delivery modality.

The first phase of the clinical facilities at MPRI will include a fixed horizontal beam line room that will accommodate large field and stereotactic radiosurgery treatments. The nozzle designs for this room will be based upon two lines previously constructed at IUCF, one for treatment of large field head and neck cancers [5] and one for treatment of choroidal neovascular membrane (CNVM) associated with Age-Related Macular Degeneration (AMD) [6]. The second phase of development will involve the construction of a 360^{o} rotating proton gantry and compact nozzle for complex, off-axis radiation delivery to biological targets susceptible to gravity influenced shifts in relative position. Although not required for all treatments, the ability to manipulate the radiation source relative to the patient is crucial for precision, patient comfort, reproducibility, and ease of operation.

4. MEDICAL FACILITY DEVELOPMENT

4.1 Clinic Layout

Indiana University and IUCF will construct the MPRI medical facility to provide support for the clinical application of the cyclotrons. The clinic will be housed largely within the existing structure, making use of the areas previously occupied by nuclear physics experiment stations and the "low bay" where research support activities were accommodated. The layout is based upon a wheel and hub motif within the physical constraints of the existing structure. This allows the staff to be centrally located. The floor in the clinic area will be raised approximately two feet to allow conduit, ductwork, plumbing and cable accessibility; ease of access to the beam line in the treatment rooms, and increased

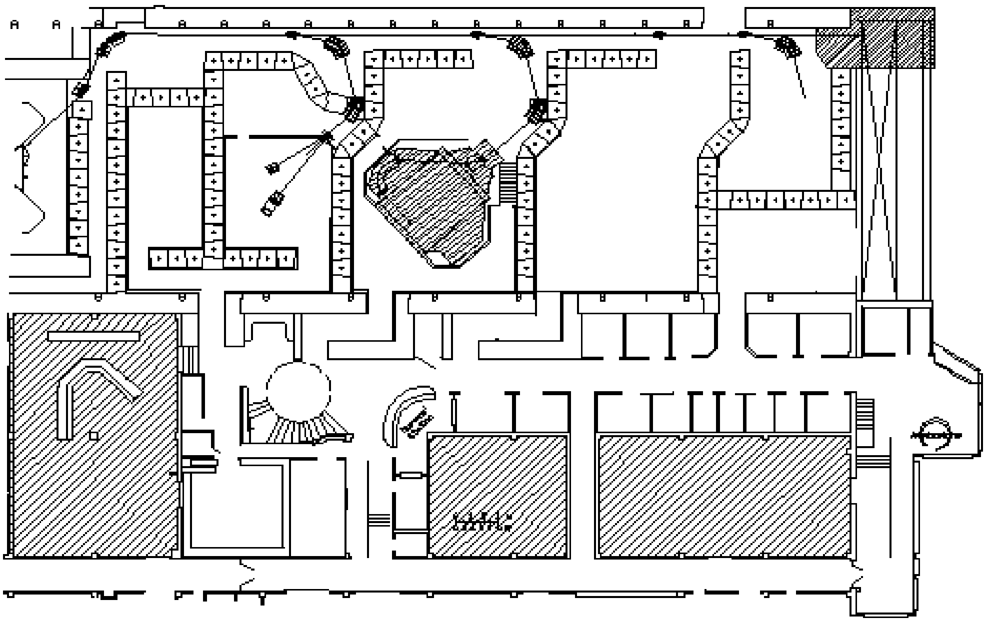

Figure 1. Phase 1 of the MPRI Clinic development Shown are the fixed horizontal lines and the first of two planned proton gantries. North is to the right of this layout.

cushioning to reduce job related fatigue. Patients will enter MPRI by way of a newly constructed parking lot, lobby and reception area at the north end of the building. IUCF staff will continue to use the parking facilities and entrance on east side, upper level, facilitating the ease of operations of all IUCF supported activities.

4.2 Patient Positioning

MPRI will use a commercially available Motoman UP200 robot to precisely position patients at the treatment location. Commercial robots offer a number of advantages. They are relatively inexpensive; they have een engineered with an eye toward precision, and robots have an extensively documented operational history. Patient positioning will rely upon three independent technologies. The robot will translate the patient to a predetermined configuration in the beam coordinate system. An optical tracking system will follow the robot movement, provide a collision safety mechanism, and direct the robot to compensate for differences between the predicted patient position and actual position by using patient specific markers. Digital radiography will be used to verify the accurate location of the biological target at the beam isocenter, and direct any fine adjustments required to match the treatment prescription. The robot will be also fitted with accelerometers, allowing verification of the internal robot guidance system readout. Supplementary mechanical and software mechanisms will ensure the absolute safety of this robotics application.

5. ASSOCIATED RADIATION APPLICATIONS

The primary mission of Indiana University and IUCF is to increase understanding through innovative research and technology. To enable the cyclotron facility to actively pursue applied research in radiation effects, a research station will be constructed at the north end of the medical facility. Continuously available proton beam will be delivered to this station in a manner analogous to the treatment room delivery. Beam sharing technology will allow pre-clinical, radiation biology and applied research to continue as a priority interest of IUCF, at all times when the cyclotrons are operating. A brief example of some of the ongoing research efforts follows.

5.1 Dose Delivery Verification

A small percentage of the protons interact with the nuclei the target material, generating positrons. Positron Emission Tomography (PET) imaging can detect these interactions, and thereby verify the location of delivered dose in 3D space. If this image can be compared to the precise biological target location, particle radiation can be delivered with a precision unattainable with photons.

5.2 Eye Disease

From July 1998 to January 2000, MPRI participated in a clinical trial evaluating proton therapy for choroidal neovascular membrane (CNVM) in age-related macular degeneration. The trial afforded IUCF the opportunity to develop a small field, low energy proton therapy nozzle, and to gain clinical experience by using that facility to treat a relatively small number of patients.

A concurrent research application is being carried out to further understanding of the CNVM radiation biology. Mouse retina can be made to present much of the pathology of human CNVM via photoablation It is hoped that the therapy can be optimised in terms of dose, dose rate, fractionation scheme, and radiation physics.

5.3 Cardiology

Characterization of myocardial and cardiovascular radiobiology is relevant to both targeted and incidental radiation exposure but because the myocardium seldom produces tumors, the radiobiology has not been well characterized. The same technology used for beam sharing and phase modulation have been used to accurately deliver pulsed therapeutic proton beam to beating hearts.

5.4 Micro-Electronics Research Program

The IUCF cyclotrons are used to simulate aspects of the radiation environment to which devices are exposed when in space. Measurement of the responses of micro- and opto- electronic devices and systems to protons allows determination of their sensitivities to single event effects, total ionizing dose degradation, displacement damage and both recoverable and non-recoverable system failures. The long range of 200 MeV protons is particularly useful for cost-effective screening of commercial-off-the-shelf systems to assess the nature and risk of failures due to both the proton and heavy ion space radiation environment.

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