The IUCF Proton Therapy System

Developed for the Midwest Proton Radiotherapy Institute (MPRI)

Background

Because protons are particles, the physics of proton radiation is substantially different from traditional radiation therapies. In most cases, what limits the usefulness of traditional radiation therapy is the oncologist's ability to reach the tumor without damaging healthy tissue. It is this damage to healthy tissue that causes undesirable health effects. Proton radiation can be more precisely delivered, can be delivered to deep tumors, can be delivered to tumors close to critical tissues and can be delivered at higher doses.

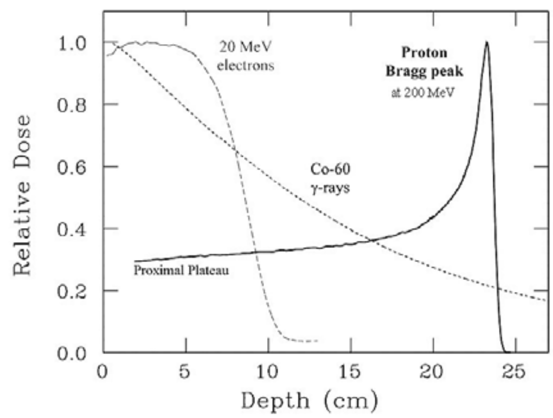

Figure 1: A comparison of depth-dose curves for standard therapy radiation and two particles: electrons and protons.

The application of proton radiation to medicine was first investigated at the University California at Berkeley in 1954. The clinical trial of proton therapy was then initiated by Massachusetts General Hospital. Their patients were treated at the Harvard Cyclotron Laboratory from 1962 until 2002, when the new Francis H. Burr Proton Therapy Center opened within the hospital. IU began treating patients with proton radiation in 1993 using the Indiana University Cyclotron Facility (IUCF) to deliver the treatments.

Figure 2: Dr. Jim Morphis treats the first patient at IUCF.

In 2000, IU received funding from the State of Indiana to begin construction of the Midwest Proton Radiotherapy Institute (MPRI). The radiation machine at MPRI was designed and constructed by IUCF, and MPRI is housed within the IUCF building on the Bloomington campus. Under the medical direction of Dr. Allan Thornton, MPRI opened its doors to patients in 2003.

Proton radiation gains its advantage because, unlike standard radiation, particles have a finite range in tissue. Given the energy of the incident proton and the density of the material through which it passes, it is possible to calculate exactly how deep the particle will penetrate. If all of the particles enter with the same energy, all of the particles will stop at exactly the same depth. The second advantage of proton radiation is that unlike standard radiation which deposits most of the dose just beyond the patient's skin, most of the energy of the proton is released just before it stops, at the tumor.

Figure 3: Plastic block damaged by a very high dose of proton radiation. The beam entered from the left. The precise radiation falloff at the end of range can be seen within the block

The Proton Therapy System

The design and construction of the Proton Therapy System (PTS) in Bloomington was entrusted to the physicists and technical specialists at IUCF. In close collaboration with physicians, researchers, industry experts and the USA Food and Drug Administration (FDA), the dedicated personnel at IUCF produced a state-of-the-art proton radiation delivery machine. The PTS at MPRI consists of a two million pound proton beam accelerator; more than 500 feet of evacuated beam transport line; two 38 foot diameter, 90 ton rotating gantry delivery systems; one fixed horizontal beam delivery system, and three precision robotic patient positioners. The resulting radiation delivery is precise to within one millimeter of the target tumor.

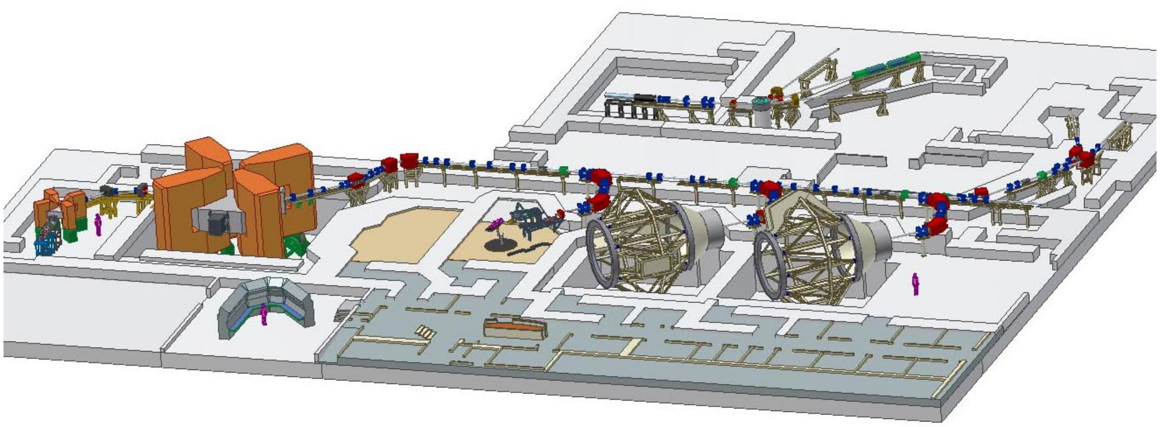

Figure 4: Layout of the PTS. The beam line begins in front of the smaller cyclotron (orange) at the RFQ. It continues through the main stage cyclotron (orange) through a series of bending magnets (red) and optical magnets (blue) to the final diagnostic, the MLFC (far right). Just short of the MLFC, the line feeds the research facility above the trunkline in the plan. Three switching magnets (green) divert the beam from the trunkline into the treatment rooms when requested. The three treatment rooms, below the trunkline, consist of a fixed, horizontal line room and two gantry rooms (left to right). Silhouettes of persons are provided for a sense of scale.

The Beam Handling System

The Beam Handling System (BHS) accelerates protons extracted from hydrogen gas to 208 MeV and delivers it to each of the three treatment rooms, the Radiation Effects Research Stations (RERS) and the multilayered Faraday cup (MLFC) diagnostic device at the end of the beam line. The BHS devices include the Radiofrequency Quadrapole injector (Accel), the injector cyclotron, the main stage cyclotron, and the trunkline. The trunkline shapes the beam to produce a very small, well defined spot at the entrance of each treatment room beam line.

The Beam Delivery System

Figure 5: The trunkline during construction.

The Beam Delivery System (BDS) for each treatment room begins with a fast switching magnet, the "kicker". This magnet, (green in Fig. 5) and every device beyond it is controlled by the therapist at MPRI. When this magnet is energized, the beam is deflected from the trunkline and is sent into the treatment room through an Energy Selection System (ES). The ES consists of two sixty-three degree bending magnets (red in Fig 5), a beryllium energy degrader, and a removable MLFC to verify the beam characteristics prior to delivery to the patient. In addition to the ES, two of the BDS include rotational gantries (BSA Life Structures). The gantry is a structure that supports the final section of the ES line and allows it to rotate around the patient. Although the rotating part of the beam line and the gantry weigh nearly 100 tons, the beam is delivered from any angle to a spot at the center with less than a millimeter variation. The BDS is responsible for limiting the greatest depth of the dose in the patient.

The Dose Delivery System

Figure 6: Installation of a 90 ton gantry.

The Dose Delivery System (DDS) hardware is installed in the last several feet of the treatment beam line. The original system, in the fixed horizontal beam line room (Treatment Room 1), was designed to shape the beam passively using a double scattering system. In this design, the scattering foils enlarge the beam spot size and a tissue equivalent range modulator (propeller) spread out the Bragg peak to increase the depth of the 100% dose region. An active system was developed later and commissioned in the second treatment room. This system increases the size of the beam spot by defocusing the beam and "wobbling" it rapidly within the treatment profile and uses a set of shifting carbon plates to expand the Bragg peak. This system reduces the neutron dose to the patient and can be readily modified to generate pencil beam scanning. The end of the DDS, the "nozzle", supports the beam shaping devices manufactured by the clinic-generated treatment plan: the aperture and the bolus. These devices match the lateral and depth profiles of the beam to the target tumor. The DDS is therefore responsible for the shape of the dose in the patient.

The Patient Positioning System

The Patient Positioning System (PPS) consists of an industrial robot, a patient bed that couples to the robot and a gurney that supports the bed for transportation into and out of the treatment room. It is the juxtaposition of the PPS and the gantry that allow beam to be delivered to the patient from any angle, making the PTS an incredibly functional system. The positioning accuracy of the robot is better than half a millimeter.

Treatment Room Control System

The Treatment Room Control System (TRCS) software was developed by IUCF to integrate the software, firmware and electronics of all of the PTS systems into a single user-friendly interface. Each of the systems described above includes a significant software component. How ever, the Radiation Therapy Technologist (RTT) approaches the device from a medical perspec tive. The TRCS allows the RTT to enter clinical parameters, such as patient identity, fraction number, field number, date and so on. The software translates this information into mechanical parameters such as magnetic field, beam current, beam energy, and such. The PPS can operate outside of the control of TRCS in order to enable positioning corrections for patient or target relocation.

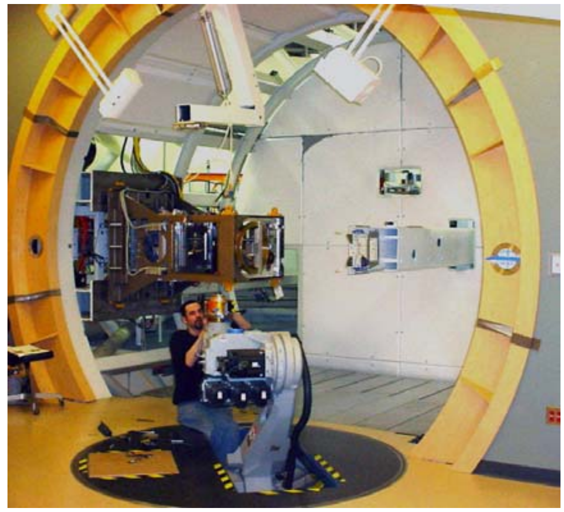

Figure 7: The Patient Positioning robot and DDS exposed during the final stages of construction. This is the view of a gantry from the Treatment Room.

The PTS also includes two safety systems: the Kicker Enable System (KES) and the MPRI Interlock and Radiation Safety System (MIRS). The KES is responsible for patient radiation safety. This system will not permit the kicker magnet to be energized unless all of the other systems are in an “allowed” configuration. The MIRS system is responsible for staff and public radiation safety. This system will not permit radiation delivery under any circumstances where someone other than the patient might be exposed.

The development and operations of the Midwest Proton Radiotherapy Institute have been a major component of the IUCF scientific endeavor for nearly a decade. We at IUCF are indescribably proud of our efforts and overjoyed at our contribution to the health and wellbeing of so many wonderful people. It is a rare opportunity.