TREATING PATIENTS WITH THE NPTC ACCELERATOR BASED PROTON TREATMENT FACILITY

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Abstract

The Northeast Proton Therapy Center (NPTC) at Massachusetts General Hospital has been treating patients with proton beams since November 2001. Over 200 patients were treated in the first year of operation. This facility has replaced the program at the Harvard Cyclotron Laboratory (HCL) where proton treatments had been underway for over three decades. Features such has rotating Gantries and deeper proton penetration allow a wider range of clinical applications at this new facility. The requirements of accelerator reproducibility and availability are perhaps at a higher level than those required at an accelerator based physics facility. These requirements and the system performance will be highlighted in this paper. Operation of a proton cyclotron produced by industry (Ion Beam Applications) and the four operating beam lines along with the Gantries and patient-positioning systems will be discussed. Of particular interest in addition to the required availability is the systematic approach to safety and accuracy in the design and implementation.

INTRODUCTION

Proton Therapy has been described and used for decades due to the dose localizing ability of the proton Bragg peak. A spread out Bragg peak is generated by combining Bragg peaks of different proton energies resulting in a flat dose distribution along the depth of the target as shown in the figure below.

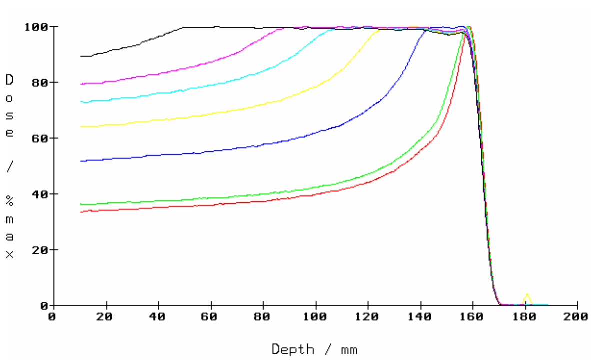

Figure 1: Spread Out Bragg Peak Depth Dose

After more than 30 years of treatment at HCL with good clinical results, but limited by the proton beam energy and the lack of rotating Gantries, the NPTC carries on this work expanding to other treatment sites. Some examples of the HCL successes include:

- Ocular Melanomas – 96% 10 yr. Success
- Chordoma – 98% 10yr success
- Paranasal Sinus - >80% success

In addition to the above head and neck sites, the NPTC includes clinical trials of body sites:

- Prostate
- Hepatocellular Carcinoma
- Lung Cancer
- Rectal Carcinoma
- Pediatric Tumors

The importance of dose sparing to healthy tissue in preventing side effects is shown in the xray vs. proton dose distributions for pediatric meduloblastoma below:

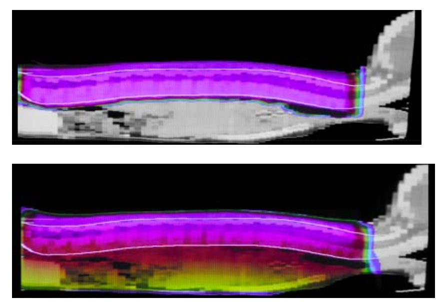

Figure 2: Proton (above) vs. Photon (below) dose distributions for spinal treatment.

The ultimate in conformal dose distribution is achieved in Intensity Modulated Radiotherapy. Photon IMRT dose distributions, in some cases rival conventional Proton dose distributions. However, the physics of the proton dose deposition ensures that IMPT (Proton) dose distributions will produce less collateral damage.

PROTON BEAM DELIVERY TECHNIQUES

The goal of proton beam delivery is to spread out the beam in such a way as to deliver the appropriate dose distribution to the tumor. This can be done in a variety of ways. The Passive technique is so named due to the lack of modifying the proton accelerator parameters, or any direct modification of the beam parameters. The Active technique directly modifies the beam.

Passive Scattering

The passive scattering method uses material to scatter and spread out the beam transversely. Various techniques can produce an optimized uniform distribution. The transverse target shape is achieved by using a collimator of the appropriate projection.

A range modulation system is used for longitudinal dose distribution. A wheel of varying thickness of material is spinning, in the path of the beam. As the beam passes through this wheel it loses energy, the relative intensities of the Bragg peaks is determined by the angular extent of this constant speed spinning wheel. This intensity can be adjusted by varying the beam intensity as a function of the wheel position. Distal Edge conformation can also be accomplished.

Active Scanning

The active beam scanning technique spreads out the beam transversely by manipulating the transverse position of the beam spot, usually with magnets, either by a continuous raster scan, or by a spot by spot delivery. In both methods, the beam intensity can be varied as a function of transverse position, thus achieving Intensity Modulated Proton Therapy (IMPT).

The range is adjusted by varying the beam energy directly, with no material in the beam.

THE NPTC EQUIPMENT

The NPTC equipment has been previously described. The 230 MeV cyclotron was manufactured by Ion Beam Applications s.a. (IBA). The isocentric rotating gantry was designed by General Atomics and IBA. The treatment equipment was built and installed in the Gantry, by IBA, as shown in figure 3.

Figure 3: The NPTC Treatment Room Equipment in the Rotating Gantry

The Gantry rotates 360 degrees. The Patient Positioning System (PPS) is a couch with six motion axes, which allows a wide range of Gantry/PPS angular combinations.

Presently, the passive scattering technique is used for patient treatment. However the depth dose distribution is fine tuned with cyclotron intensity modulation. Figure 4 below shows the desired beam time distribution for an example compared with the actual extracted beam current from the cyclotron.

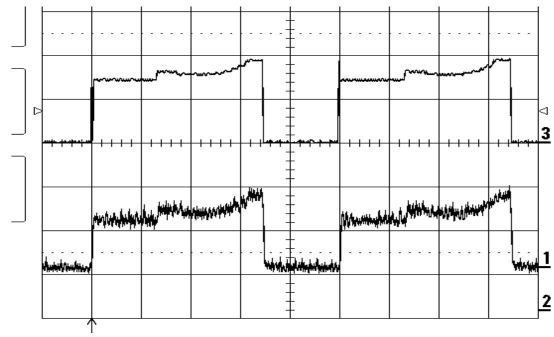

Figure 4: Upper trace is the desired beam current time distribution. Lower trace is the achieved distribution. The period between pulses it the range modulator wheel rotation period.

The modulation width of the SOBP is entered as a prescription parameter, and the system determines the appropriate equipment values. The treatment parameters are continuous over a large range. Figure 5 below shows the algorithmic function for the determination of the beam stop time, and the measured mod width determined over a period of months. The results show millimeter precision. The data for beam range shows sub-millimeter reproducibility.

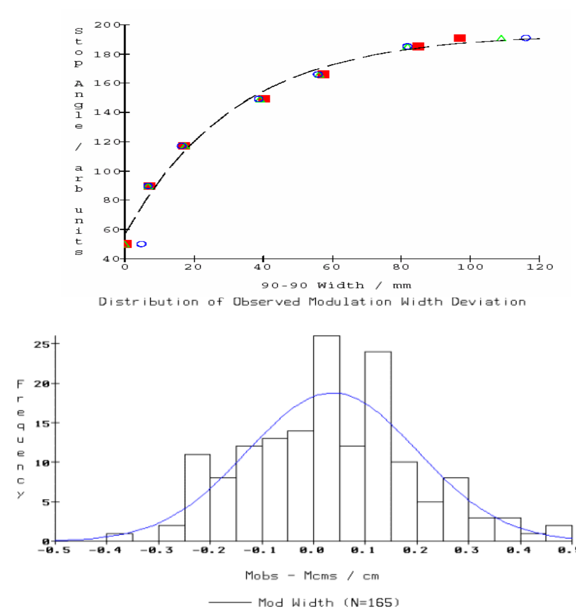

Figure 5: Predicted and Measured Modulation Widths

Tests have been made using the IMPT methodology. Transverse beam distributions are shown in the figure below. This test was done with the present NPTC system, although it is not ready for patient treatment yet.

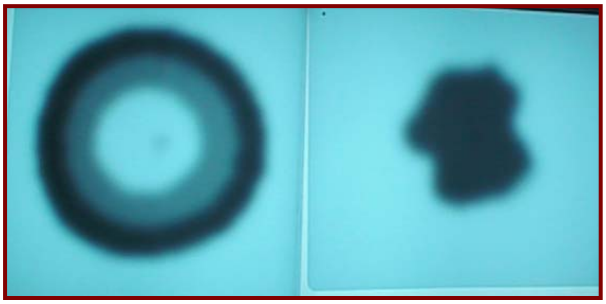

Figure 6: Radiographic film showing beam scanning. The left image is a raster scanned beam using intensity modulation to achieve the varying intensities. The right image only uses beam on and off states.

Positioning

The relative positioning among the beam, the PPS and other patient alignment devices (cross hairs, lasers) must be as precise as possible to minimize the time necessary for patient positioning. The PPS has a load cell which is used to compensate for PPS deflections under load. In addition, the Gantry Nozzle deflections are compensated for by appropriate positioning of the PPS.

Figure 7a shows a polaroid superposition of a beam spot, an xray cross hair and a fiducial attached to the PPS, marking the location of isocenter. Figure 7b is a polaroid film with a superposition of 8 beams from different Gantry angles demonstrating the coincidence of isocenter.

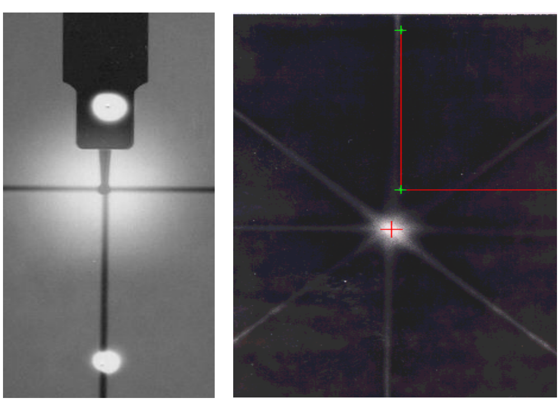

Figure 7: 7a (left) shows beam spot and cross hair; 7b right shows beam from different Gantry angles.

The NPTC equipment has a high level of automation including:

- Automated Conversion of Prescription to Equipment Parameters
- Prototype Automated Cyclotron Beam Tuning
- Automated Rf spark detection and short term processing
- Automated Energy Setup
- Automated Beam Steering
- Automated Positioning Accuracy Corrections

On the one hand, this allows for speed in treatment delivery, while requiring careful planning and implementation of safety checks.

SYSTEM SAFETY

The safety design is done system wide. The safety system protects against mechanical and dose errors. It is a design constraint to ensure that the software is not safety critical, therefore a hardwired interlock system with a redundant PLC deal with safety critical functions. The software is a tertiary redundancy not allowing anything to happen, that the Safety System would react to. In addition the software ensures the accuracy of the treatment delivery. In addition to redundant sensors ensuring that automated settings are correct, the system makes use of functionally redundant sensors. In this way, the final beam parameters are continuously monitored independently of the devices used to control the beam properties.

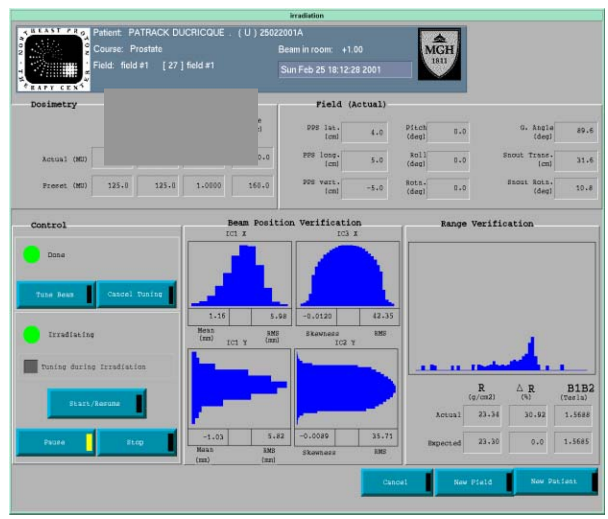

Figure 8: Example of a screen used during treatment showing beam parameters monitored in real time.

Figure 8 is an example of a screen displaying beam properties during treatment. The rightmost plot diplays the beam range. The leftmost plots are the horizontal and vertical beam profiles entering the Nozzle. There are limits placed on the beam position and size at that location. The middle plots are the horizontal and vertical scattered beams upstream of the isocenter. The profiles are not yet uniform at that location, however calculation of the skewness and kurtosis allow the system to determine if the beam profile is appropriate to that which will produce a flat beam at isocenter. These parameters are monitored at 100 msec intervals with warning and error tolerances.

SYSTEM AVAILABILITY

Figure 9 is a plot of the number of fields delivered per day for the first year of operation. The ramp up of patient treatments is evident. Aside from the one gradual dip resulting from a drop in patient load, the other major dips indicate downtime.

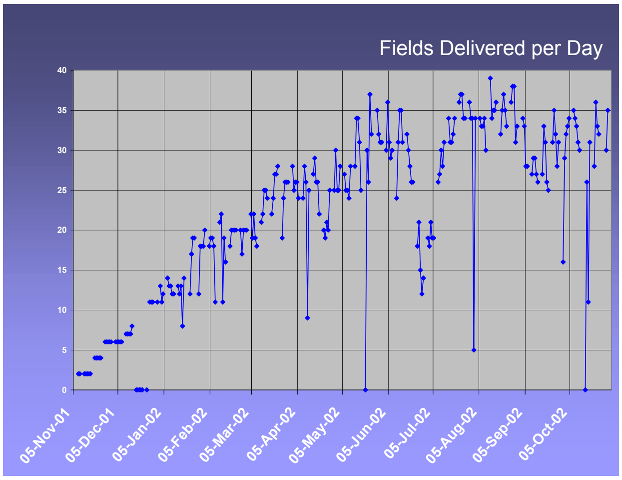

Figure 9: Plot of fields per day for the first year.

The original specification for availability of the facility was 95%. However with 20 treatment slots scheduled per Gantry this allows only ½ hour per day, or 1.5 minutes per treatment. It is desired to reduce the time for the treatment slot from 30 minutes to 20 minutes. In this case it will be necessary for less than 1 minute of delay per treatment.

In addition it is the case, due to the nature of fractionated radiotherapy, and the statistics of patient accrual, that any downtime of more than 2 days, in addition to a weekend, will require a patient to go off protocol. Therefore, it is very difficult, and would require a sharp reduction in patient treatments for a period of weeks, to schedule an extended shutdown for maintenance or other activities.

Figure 10 shows the availability for the first year of patient treatments. This availability is calculated by dividing the accrued downtime in the day by the time scheduled for the treatments. Even if all treatments are completed in the original scheduled time, there may still be downtime. The tolerance in a Hospital environment for downtime is extremely low. Linac based radiotherapy machines have less than 2% downtime

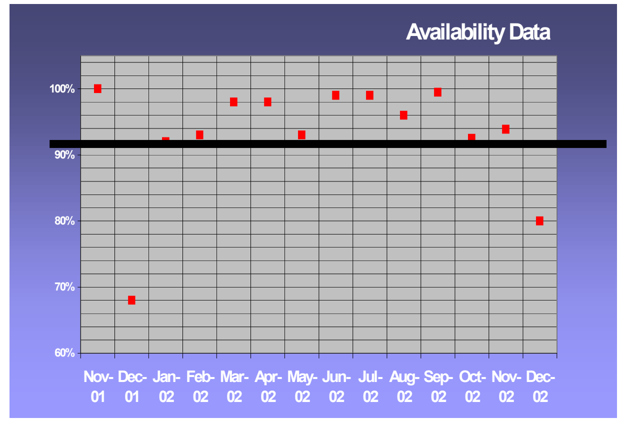

Figure 10: Availability; the black line at 94%

CONCLUSIONS

Patient treatment has been underway for about 1 ½ years. Patients are being treated safely and accurately. Developments are continuing to increase patient numbers and develop more advanced beam delivery techniques. For the most part the system performs well.

The real challenge of this endeavor was not the development of the equipment needed to produce and deliver an appropriate beam; but to produce this beam on demand 24 hours a day, 7 days a week with few personnel. A Hospital environment is used to the operation of an MRI machine or a LINAC, the closest relatives to the technology involved in Proton Therapy.

This facility is the result of over 30 years of the work of Medicine, Industry and Physics Laboratories. While the technology exists to build the accelerators, and beamlines and patient devices, the experience to provide the ultimate automation and extremely high availability is not yet mature. For a variety of reasons, it is not in the mission a laboratory to develop a completely automated system. Each system is different and constantly changing. Industry is good at developing production methods, and making it possible to build more than one machine and assemble the paperwork needed for qualifying and validating the equipment. However, without a clear direction from experience, the idea of fully instrumenting and fully optimizing the system equates to increasing expense. There is a low incentive on the part of industry to build this capability into a machine with the complexity of a proton therapy machine.

High availability, extensive diagnostics and full automation is required for widespread use. The lack of this capability may eventually limit the number of such facilities that will be operating. However, the motivation to continue to build these facilities can easily be seen in just the treatment of one patient.