OPERATION OF THE TRIUMF PROTON THERAPY FACILITY

E.W. Blackmore, B. Evans, M. Mouat
TRIUMF, 4004 Wesbrook Mall, Vancouver, B.C., Canada V6T 2A3
C. Duzenli, R. Ma, T. Pickles, British Columbia Cancer Agency, and
K. Paton, Department of Ophthalmology, University of British Columbia

Abstract

The Proton Therapy Facility at TRIUMF is now in routine operation treating ocular tumours using 70 MeV protons extracted from the 500 MeV H^- cyclotron. This paper describes the proton beam line, treatment control and dosimetry systems which are designed to provide accurate treatment dose delivery. The reproducibility of the shape and range of the unmodulated Bragg peak for various operating conditions of the cyclotron is discussed along with the technique for producing a uniform modulated or spread-out Bragg peak. The patient positioning chair, which has six motorized degrees of freedom, the patient mask and bite-block, and the X-ray verification system ensure sub-millimeter positioning accuracy. Patient treatments are scheduled one week per month with the treatment dose of 50 proton-Gy delivered in four daily fractions.

1 INTRODUCTION

The Proton Therapy Facility is a joint project of TRIUMF, the British Columbia Cancer Agency and the University of British Columbia Department of Ophthalmology. Since August 1995, this facility has been treating patients with ocular melanoma, on a one week per month basis, using 70 MeV protons extracted from the 500 MeV cyclotron. The development of the facility was funded from 1993-95 by a local foundation, and operation is carried out as part of the clinical program of the Cancer Agency.

The TRIUMF cyclotron is a unique particle accelerator for proton therapy as it can provide variable energy proton beams from 65-520 MeV with good energy resolution and with stable and easily controlled beam intensity. These advantages are offset by the fact that the cyclotron is a multi-user facility, so treatments must be compatible with the different operating regimes of the cyclotron.

2 CYCLOTRON AND EXTRACTION

The eye treatment equipment is located on beam line 2C which has an energy range of 65-120 MeV. Figure 1 shows the layout of the Proton Therapy Facility and its location relative to the cyclotron. The acceleration of H^- ions in the cyclotron allows for easy extraction of low intensity beams with the use of a thin carbon wire for stripping the beam to protons. Although reliable 2–10 nA beams can be readily achieved with 150 μA circulating in the cyclotron using a 0.001" diameter wire, for additional safety a "pepper-pot" is inserted in the injection beam line to reliably reduce the circulating intensity by a factor of 40 during patient treatments and high intensity operation. During polarized beam operation no such reduction is necessary. A pneumatically actuated beam stop in the vault section of BL2C, the Fast Shutter with a closing time of 150 ms, is the primary means of controlling the beam during patient treatment.

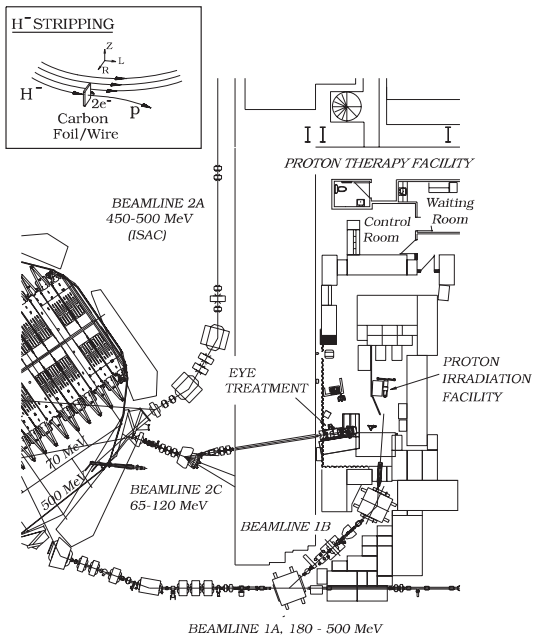

Figure 1: Layout of the TRIUMF Proton Therapy Facility

3 LAYOUT OF EQUIPMENT/PATIENT FIXATION

The equipment for beam preparation and patient fixation, shown in Fig. 2, follows the design at other facilities.[1, 2, 3]The required proton dose distribution is achieved using a passive scattering system and a rotating range modulator. The beam is defined by a first collimator/scatterer (typically 12 mm diameter aperture with 0.8 g/cm^2 thick lead scatterer). A second collimator stops a significant fraction of the scattered beam, with the central part passing through to the proton nozzle. Here the proton field shape is defined

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transversely with a patient specific brass collimator. The treatment depth is varied by a rotating wedge degrader or range shifter located between the first and second collimators. The plastic modulator wheel is CNC machined to provide a flat spread-out Bragg peak (SOBP). This wheel rotates at 240 RPM and has four modulations per rotation.

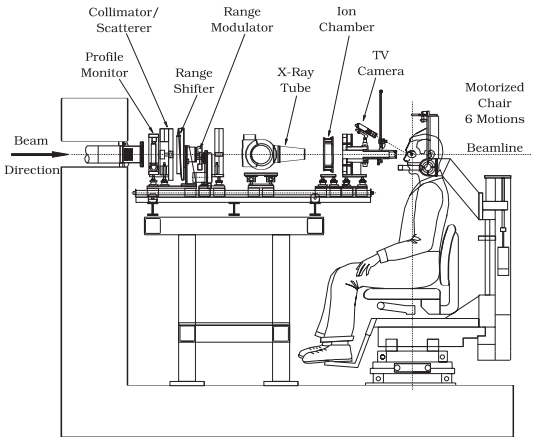

Figure 2: Arrangement of the equipment for beam delivery and patient fixation.

Beam instrumentation consists of a secondary emission monitor (SEM) which measures the total incident proton beam current, a multiwire ionization chamber for the beam profile and centring, a diagnostic ion chamber, and a multiplate transmission ion chamber for dose monitoring. This ion chamber consists of two total plates, one for an independent back-up, and a set of quadrant plates for beam centring. The transmission ion chamber is calibrated for each treatment against a reference ion chamber located at isocentre.

The patient is seated in a treatment chair with precise servo-motor positioning in six motions. The head is immobilized in a face mask and bite-block and the patient is asked to fixate on a blinking light. Two orthogonal X-rays are taken to establish the relationship of four tantalum clips, surgically placed on the eye around the tumour margin, to the output of the treatment plan. The eye position is monitored using a video camera with a magnified image to detect sub-millimeter eye motion during treatment.

Each patient receives 4 daily fractions for a total dose of 50 proton-Gy. The patient setup time is 15-30 minutes, followed by a 75-100 second treatment time.

4 TREATMENT CONTROL SYSTEM

The Treatment Control System (TCS) is based on a VAX computer, Mitsubishi PLC, CAMAC PROM-based controller, standard NIM and CAMAC modules and several TRIUMF built devices. The system provides for monitoring of patient safety, controlling patient dose and operator control.

Patient safety is handled by a combination of the PLC providing digital interlocks and control with the CAMAC controller (TRIMAC) monitoring critical analog values and patient dose through digital scalers. The VAX also performs real-time data checks during the patient run. A stand-alone backup dose counter is connected directly to the TRIUMF Safety System (TSS) which can disable the cyclotron beam in the event of a TCS failure. A watchdog system can also trigger the TSS in the event of failure in any of the three computers.

A treatment starts with the operator loading parameters for the patient through the VAX X-windows terminal which uses the Motif display manager. This information is passed to a CAMAC memory for use by the TRIMAC. If all interlocks are satisfied, an operator using a hand-held switch opens the Fast Shutter, via the PLC. Ion chambers provide a current signal through Ortec 439 integrators read by CAMAC scalers. The TRIMAC controller performs a number of real-time checks on beam positioning, intensity and chamber voltages and monitors the patient dose. On reaching the desired dose, the TRIMAC requests the PLC to close the Fast Shutter. At any time the operator, viewing the eye position by video, can stop the treatment.

There are two operating modes for the controls: the “Normal Mode” is used for calibration, development and testing, and the “Patient Mode” is used for treatment. In the “Patient Mode” a number of additional interlocks have to be satisfied, the “Pepper-pot” must be inserted for unpolarized beam, higher level count ratio checks are carried out, and the area lockup requirements are modified for rapid entry and with the lockup sirens turned off.

5 DOSE PROFILE MEASUREMENTS AND CALIBRATIONS

The proton dose distributions have been measured for a variety of beam conditions by scanning diodes or miniature ion chambers in a water box.[4] In addition X-ray and radiochromic film have been used to confirm the measurements. An avalanche photodiode, type BPW-34, has been found very satisfactory for most measurements, and compares well to the 0.05 cc Markus ion chamber measurements, which are slower because of the smaller signal. The distal penumbra (90% to 10%) was determined to be 1.2 mm in eye tissue and the lateral profile 1.7 mm. A calibrated Exradin T1 0.05 cc ion chamber connected to a Keithley 616 electrometer provides the absolute dose calibration. This system has been checked in dose intercomparison studies with other laboratories and RBE measurements have been carried out at TRIUMF using V79-WRNE chinese hamster cells.[5]

The daily calibration procedure consists of a range shifter scan to determine the proton range for the raw Bragg peak using the diagnostic ion chamber for normalization. For a standard configuration, a calibration of the primary ion chamber is carried out using the Exradin T1 chamber at isocentre. The calibrations for each individual patient are

performed on the day before the start of treatments. The standard deviation in the daily range measurements over a 16 month period is less than 0.1 mm and the standard dose calibration is within 1%.

6 MODULATOR DESIGN AND VERIFICATION

The raw Bragg peak has been found to be sufficiently similar for different operating conditions of the cyclotron that the spread-out Bragg peak (SOBP) produced using a rotating range modulator is not dependent on the cyclotron operating mode.

A program has been written to find the best range modulator function for generating the SOBP, using as input the measured raw Bragg peak, the measured scattering function for the modulator position, the desired width of SOBP in mm, the maximum number of steps in the modulator and the desired precision.[6]A second program generates the CNC code for machining the modulator wheels. An inventory of modulators for SOBP from 10–23 mm in 1 mm increments has been machined and measured. Figure 3 shows the input information for the modulator design and a typical measured result.

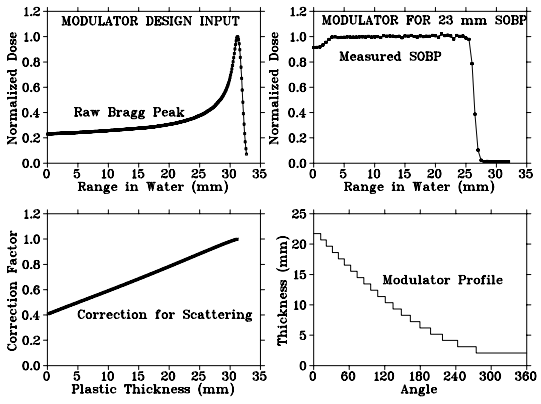

Figure 3: Input data for the modulator design and a measured result.

7 TREATMENT PLANNING AND PATIENT ALIGNMENT

Fundus photographs, ultrasound measurements, and surgically placed tantalum scleral clips are used to determine the location and size of the tumour. In some cases, MRI scans are used to determine the configuration of the overlying eyelid. This information is input into the treatment planning program EYEPLAN[7] for calculating the optimum set of treatment parameters: the location of the fixation light, the maximum beam range and modulation required, and the profile of the beam aperture of the patient collimator. In addition a set of reference X-ray transparencies are prepared showing the desired alignment of the tantalum clips relative to the beam axis for confirming the correct patient alignment.

Recently the use of wedges for modifying the contour of the distal end of the dose distribution has been implemented. Aluminum wedges with a tissue equivalent angle from 5^o to 60^o have been machined and measured. The wedges are mounted a few cm from the eye on a rotating holder attached to the nozzle and can be easily adjusted in angle and lateral position to the EYEPLAN value. In many cases the use of wedges is essential in reducing the dose to the macula or optic nerve.

The twenty-five patients treated to date range in age from 36 to 88, with a median tumour height of 6 mm and diameter of 13 mm. Early clinical follow-up is showing the expected tumour shrinkage and toxicity seen at other proton therapy centres.

8 FUTURE DEVELOPMENTS

At the present time patient referrals for choroidal melanoma have come only from the four western provinces of Canada. It is anticipated that the number of patients per year could double once patients are referred from eastern Canada. Other potential uses of protons for therapy are being considered. These include treatment of conjunctival melanoma and macular degeneration. The proton therapy beam line can provide 120 MeV protons which have a range in tissue of 9–10 cm, so other tumour sites in the head and neck could be envisaged.

9 REFERENCES

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