PROTON THERAPY CO-OPERATIVE GROUP

Chair

Michael Goitein Ph. D.
Department of Radiation Oncology
Massachusetts General Hospital
Boston MA 02114
(617) 724 - 9529
(617) 724 - 9532 Fax

Secretary

Janet Sisterson Ph. D.
Northeast Proton Therapy Center
Massachusetts General Hospital
30 Fruit Street
Boston MA 02114
(617) 724 - 1942
(617) 724 - 9532 Fax

ABSTRACTS

of the XXIX PTCOG MEETING

held in dfkz, Heidelberg and GSI, Darmstadt, Germany

September 14 - 16 1998

INDEX

Update on the World Wide Proton Therapy Experience through 1997.

J. M. Sisterson, Harvard Cyclotron Laboratory, Cambridge, MA 02138.

In 1997, over 2300 patients were treated with proton beams at 14 operating centers worldwide, compared to ~876 patients treated in 1990 at 10 centers. In 1990, ~55% of patients were treated for eye tumors and ~23% for other sites using fractionated therapy. In 1997, these percentages were ~47% and ~46% respectively. Only one operating facility was designed specifically for the hospital setting, but treatments at the second and third hospital based facilities will start in late 1998 or in 1999. Figure 1 shows the relative patient statistics for the the 14 operating centers in 1997.

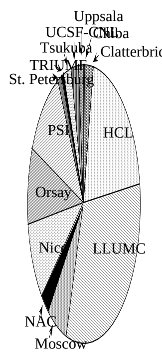

FIGURE 1. 1997 relative patient statistics for all facilities. An estimated 2321 patients were treated world wide.

The increased level of interest in both proton and heavy ion radiation therapy has resulted in proposals for many new facilities world wide. It is projected that there may be 30 or more proton therapy and 3 heavy ion facilities operating early in the next century.

****

Patient positioning systems : the CPO experience.

[1]C. Desblancs, [1]R. Ferrand, [1]S. Delacroix, [1]C. Nauraye, [1]E. Hierso, [2]A. Mazal, [2]J.C. Rosenwald, [1]J.L. Habrand, [1]Centre de Protonthérapie d'Orsay - B.P. 65 - 91 402 Orsay Cedex - France, [2]Institut Curie- Rue d'Ulm - 75 005 Paris - France

The Centre de Protonthérapie d'Orsay has focused on a robotics approach for patient positioning: the first treatment room is set up with a robotics chair (prototype, PC driven, 6 actuators "parallel robot", 6 degrees of freedom), the second one with a patient positioning system based on 6 axis standard industrial robot (driven by AC servo motors, able to carry up to 300 kg and different accesories : table, chair, water tank, etc).

From the experience of both patient positioning systems, we have listed the main aspects to consider :

- the load = accessory + immobilization system + coupler + patient +....(should the system carry more than 200 kg ?)
- the working envelop (especially if several devices should be used) ↔ robot location inside the room (radiation damage on motors ?)
- the number of degrees of freedom (6 ?)
- the precision / repeatability required depending on the positioning method (relative, absolute, DRR ?)

- the reliability (simple maintenance, standard spares, low breakdown risk)
- the man machine interface (fast, easy to use, dedicated) ↔ link to the treatment planning system
- the remote control (for an automatic positioning)
- the safety system: hard and soft (collisions, speed, tilts, acceleration, default detection, etc)
- the open system (able to accept additional devices, dynamic mode, upgrading of the MMI)
- the possibility to set up the patient outside the treatment room
- the norms the system has to fulfill (medical norms more restrictive than industrial on certain points)

Our robot solutions, after seven years of use of the first prototype and more than one year of test of the second one, proved to be very well adapted to precise patient positionning: with the six degrees of freedom, there are simple to use, highly reliable, safe and moreover very "open" to future applications (dynamic moment,...).

However, we had to deal with vibration problems (now solved), working enveloppe limitations (due to multiple devices acrried) and collision risk with the end of the beam line, three aspects not to underestimate.

Our choice for a third treatment room will certainly be oriented to a patient positioning system based on a 6 axis industrial robot of the same kind as the second one, combined with an isocentric gantry.

****

Eyelid imaging as a treatment planning aid in proton therapy for ocular melanoma.

C. Duzenli, R. Ma, K. Luchka and P. Poon, British Columbia Cancer Agency, Vancouver B.C. Canada

Proton therapy for ocular melanoma using a 70 MeV beam at TRIUMF commenced in August 1995 and since then we have treated 47 patients. The Clatterbridge version of EYEPLAN is used for treatment planning because it allows for modeling of the eyelids as 3D structures. Based on earlier experience of other groups we anticipated problems in accurately planning the beam range in cases where complete eyelid retraction was not possible. In approximately 30% of our cases we have treated through the eyelid. The goal of this project was to investigate various imaging techniques for accurate determination of eyelid geometry. Lid markers, ultrasound, CT and MRI were investigated. Ultrasound provides accurate lid thickness measurements but the measurement position is difficult to reconcile with the treatment geometry. The presence of Ta clips in CT obscures the low contrast structures. Comparison of ultrasound and MRI indicates agreement within less than 0.5mm for lid thickness and less than 0.75 mm for axial eye length. The chemical shift artifact (fat/water) in MRI results in ~0.5 mm distortion in the frequency encode direction for an 8 cm field of view (32kHz bandwidth) at 1.5T. A technique is being developed in which MRI image sets are co-registered with the treatment frame of reference via coordinate transformations determined using CT data and simulation films. The accuracy of the transformation is checked using digitally reconstructed radiographs and the transformed MRI image data can be superimposed on the EYEPLAN model as a treatment planning aid.

****

The in-situ PET Monitoring of the ^{12}C Therapy at GSI Darmstadt.

R. Hinz, W. Enghardt, B.G. Hasch, K. Lauckner, J. Pawelke, F. Pönisch, M. Sobiella, Forschungszentrum Rossendorf, Institute of Nuclear and Hadron Physics, Postfach 510119, D-01314 Dresden, Germany

Since the treatment of patients suffering from head and neck tumours with carbon ion beams at GSI Darmstadt has started in December 1997, the irradiations are routinely verified by positron emission tomography (PET). Although a stable ^{12}C instead of a radioactive ^{11}C beam is used for the therapy at GSI, nuclear fragmentation reactions between a part of the ions of the beam and atomic nuclei of the tissue produce a measurable distribution of positron emitting isotopes.

The positron camera BASTEI (Beta Activity meaSurements at the Therapy with Energetic Ions) operates directly at the treatment site during the irradiation and a few minutes afterwards. There a three major advantages of this in-situ PET monitoring of heavy ion therapy in comparison with PET studies using a scanner beside the treatment place after the irradiation:

1. The very accurate positioning of the patient provided by the stereotactic system. For the superposition of images of the different modalities only a linear coordinate transformation is required.
2. The opportunity to watch the positron emitters at the place of their generation as well as their transport by metabolic washout processes.
3. The time of the irradiation is not increased by the in-situ PET dose localisation. An additional PET study by means of a remote PET scanner, which would prolong the treatment time for the patient, is not necessary.

The PET images from the different therapy fractions are very similar and demonstrate the stability and reliability of the heavy ion therapy. In some therapeutic situations, where the ^{12}C beam has to penetrate highly inhomogeneous structures, the PET results tend to indicate a higher range of the primary particles in comparison with the treatment planning, so that a further improvement of the range calibration seems to be necessary.

****

Neutron therapy for prostatic adenocarcinoma at the cyclotron of Louvain-la-Neuve (Belgium).

P. Scalliet, V. Remouchamps, F. Lhoas, M. Van Glabbeke, D. Curran, T. Ledent, A. Wambersie, F. Richard and P. Van Cangh, Universite Catholique de Louvain, Cliniques St-Luc, 1200 Brussels, Belgium

The present retrospective study evaluates survival and progression free survival (PFS) in a series of 308 patients treated, with p(65)+Be neutrons at Louvain-la-Neuve (Belgium), between January 1990 and December 1996. Mixed irradiation was delivered (3 n and 2 ph fractions per week) up to a total target dose of 66 Gy "equivalent" (n+gamma components), specified at the ICRU reference point. The selected clinical RBE was 2.8. Dosimetry was performed according to ICRU-45. Fifty five patients had previous prostatectomy; 106 patients had neoadjuvant androgen deprivation. Five-year overall survival was 79+4% (26 out of 36 observed deaths were due to intercurrent disease). Progression-free survival (PFS) was 64+5% for the entire series; but it was the same for the patients with initial PSA 20 >= ng/ml. Present results compare well with the US RTOG 77-04 and NTCWG 85-23 studies; especially encouraging results were observed for patients with poor prognostic factors (PSA >= 20 ng/ml).

****

OCTOPUS: a new planning tool for ocular tumor therapy.

K. Pfeiffer, B. Dobler, W. Schlegel, R. Bendl, DKFZ (German Cancer Research Center), Heidelberg, Germany

OCTOPUS (OCular TumOr Panning UtilitieS) is a new planning tool for the treatment of ocular tumors with protons developed at the DKFZ Heidelberg in collaboration with the HMI Berlin. It will be used to supplement the standard planning tool EYEPLAN. E.g.: OCTOPUS supports modern diagnostic image modalities (CT, MR, 3D US) which may be important to fully utilize the high precision of proton therapy.

In an attempt to reduce safety margins and thus lower side-effects of the treatments, correlated MR and CT images are required for critical patients. By segmenting structures in MR images a patient specific eye-model is extracted which allows to display the calculated dose distribution for the patient anatomy. A pencil-beam algorithm developed at the HMI calculates the dose distribution using CT data.

The other aim of the project is to speed up the treatment planning process by providing a graphical user interface and various new tools. E.g.: the clip positions in orthogonal X-rays can be extracted interactively by a pointer device in the graphical user interface, allowing easy input and correction. During treatment planning an approximate dose distribution is calculated in real time and provides an immediate feedback to the physician, the dose can be visualized in the eye-model or in a virtual fundus view to evaluate immediately the selected treatment position. This way it is possible to preselect treatment positions very fast and obtain an optimal plan quickly in contrast to iterative and time consuming dose (re)calculations lasting several minutes.

In the future the dose will be visualized directly on the fundus view photo and on CT and MR slices to allow a better evaluation of a plan and easier comparison of different plans.

This program will be used for treatment planning at the HMI and its final version will be made available to other treatment facilities.

****

Radiobiological significance of beam line dependent proton energy distributions in a spread-out Bragg peak.

H. Paganetti, Northeast Proton Therapy Center, Massachusetts General Hospital

As dose can be described as fluence times LET, it is evident that in a mixed radiation field similar doses can be achieved with different particle energy distributions. Isodose contours are isoeffect contours only if the energy spectra of the accompanying particles remain constant. On this condition, the beam delivery technique used to build a SOBP can influence the RBE.

Similar SOBP-plateaus have been obtained assuming different range shifters and modulator wheels for two 70 MeV beams having different intrinsic energy spreads and for a 120 MeV beam. It has been found that the proton RBE depends on the depth of beam penetration. This is because the average proton energy is decreasing with depth and by this the ionization density increases. Besides this general result it came out that the RBE values depend on the beam energy and energy spread used to modulate the SOBP. The differences in RBE found for the center of the SOBP are negligible whereas for the distal part differences up to 8% have been found. This can be explained by different proton energy distributions in the center of the Bragg peak for a monoenergetic Bragg curve. The proton energies are the lower the lower the initial beam energy and the lower the initial energy spread of the beam.

For low energy beams with a very narrow energy distribution like those often used for eye treatment the rise in RBE at the distal end of a SOBP should be much higher as for higher energetic proton beams assuming equivalent targets. As a consequence it is difficult to compare the outcome from different beam lines on the basis of the applied dose, especially for the distal part of the SOBP.

****

An Analytical Description of Proton Depth-Dose Distributions.

T. Bortfeld and U. Oelfke, Deutsches Krebsforschungszentrum (DKFZ), Department of Medical Physics
Im Neuenheimer Feld 280, 69120 Heidelberg, Germany

An analytical representation of a mono-energetic Bragg curve in closed form has been derived based on the following assumptions: (i) the range-energy relationship can be described by a power-law, (ii) the reduction of proton fluence due to nuclear interactions is linear with depth, and a certain fraction of the released energy is deposited locally, and (iii) range straggling is Gaussian. These assumptions are valid for protons in the therapeutically relevant energy range of 60 to 200 MeV. The resulting formula consists of a simple combination of Gaussians and so-called parabolic cylinder functions, which are tabulated and be calculated within mathematical software packages. A computer program for this particular application is available from the authors on request. Energy spectra of real beams can be incorporated into the model using the further assumption that (iv) the energy spectrum is Gaussian with a linear low-energy tail.

With this model measured data in homogeneous phantoms can be fitted within the measurement error. Very good agreement within 2 % relative deviation or 1.5 mm spatial deviation is also found with numerically calculated Bragg curves using other pencil beam algorithms, and with the PTRAN Monte Carlo code. Potential applications of the closed form formula are seen in treatment planning algorithms, where it might help to simplify and speed up the calculation, as well as to reduce the number of required measurements. The generality of the model is particularly useful in basic studies investigating the potential merit of new proton treatment techniques such as intensity modulated proton therapy and distal edge tracking.

As a first application, the model has been used to investigate the merit of using spread out Bragg peaks (SOBPs) in which the depth-dose is not constant. It was found that e.g. with ramp shaped SOBPs it is possible to reduce the integral dose in normal tissue by about 15 % for the same mean target dose. A constant target dose distribution can still be achieved by using opposing ramp-shaped beams.

****

Optimization of IMRT with Charged Particle Beams: Aspects of Inverse Treatment Planning.

U. Oelfke and T. Bortfeld, DKFZ Heidelberg, Department of Medical Physics, Im Neuenheimer Feld 280, 69120 Heidelberg, Germany

The aim of radiation therapy -- the optimal geometrical distribution of dose within a patient -- is achieved by varying a whole spectrum of treatment parameters. State of the art radiation therapy with photons fully utilizes its potential by optimizing a set of transversal intensity amplitudes. Efficient planning of this intensity modulated radiotherapy (IMRT) is achieved by the method of 'inverse planning', a technique currently not available for the optimization of treatments with charged heavy particle beams. Treatment planning for charged particle beams, even more intricate through the additionally available modulation of beam energy, historically relies on the concept of the spread-out Bragg peak (SOBP) . More recently the approach of distal edge tracking (DET) was proposed to fully exploit the favourable depth dose curve of charged particle beams.

We have investigated the combined approach of distal edge tracking and transversal intensity modulation for a simple model problem, the planar irradiation of circular regions of interest. The corresponding 'inverse problem' was formulated and numerically solved for arbitrary rotationally invariant dose distributions. Besides comparing this new dose delivery technique to the commonly employed SOBP approach, various other aspects of the inverse planning process were studied, e.g., to determine whether the method of energy selection for DET - either actively by direct energy variation or passively by degrading the beams energy - significantly influences the obtained dose distributions.

It was found that 'distal edge tracking' in combination with IMRT can only be realized up to a certain target size, i.e., a homogeneous target dose can only be achieved if the width of the used Bragg peak is not 'too narrow' for the chosen target. Additional energy modulation of the charged particle beam is required for a combination of narrow Bragg peaks and large targets. In case the 'inverse problem' for DET can be solved and realized a decrease of integral dose delivered to healthy tissues in the order of 30% and a significant reduction in penumbras was observed in comparison to a dose delivery based on spread-out Bragg peaks. The mode of energy selection employed for DET, i.e., either 'active' or 'passive' energy selection, was found not to be of crucial importance. Corresponding differences for the dose distribution in healthy tissues ranged at the few percent level.

****

Comprehensive electronics for particle beam therapy.

B. Gottschalk, Harvard Cyclotron Laboratory, Cambridge, MA, USA

The author has designed an electronic system for dose monitoring and quality control in particle radiation therapy. It is engineered and produced by Princeton Technology Corp. (Hudson, NH, USA). An individually powered stand-alone crate is interfaced either to VME (fast 16-bit parallel) or directly to a host computer by RS-232 (slow but useful for tests). There are no microprocessors and a low-tech approach is used throughout for maintainability. The board population of the crate is flexible and is known to the driver program through a configuration file. The crate and backplane are passive. All connections are made to the rear of the cards for easy troubleshooting by substitution. A CONTROL/HV board does the interfacing and supplies low- and high-voltage power (LV, HV). A DOSIMETRY board integrates current from the beam monitor using a recycling integrator with $\Delta Q = 10$ pCoul. The count is compared with a preset register loaded by the computer and 'fault 0' is asserted when count = preset. A

FAULT board provides most of the safety functions by latching any of a number of fault conditions: end-of-treatment, overdose in any one cycle, LV error, HV error, RS-232 connected. The beam is stopped in hardware (relay and/or optocoupler) when any fault bit is asserted. Finally a QUALITY board provides 16 channels of recycling integrator with 16 bit counters, to be used in multichannel applications such as strip ion chambers for dose uniformity measurements.

****

Track structure calculations of the relation between tissue dependent ???-values and the proton RBE.

H. Paganetti, Northeast Proton Therapy Center, Massachusetts General Hospital

The relationship between the parameters describing the X-ray survival curve and the proton RBE has been studied for different proton energies and doses. The parameters of the linear-quadratic equation, ? and ?, as well as those of the multi-target/single-hit equation, n and E_0, have been considered to describe the X-ray survival curve. Besides the calculations with the original values for n and E_0, calculations varying these values have been made to simulate different ???-ratios for a certain cell line. The RBE has been found to increase with increasing ??? varying n but to decrease with increasing ??? varying E_0. If one assumes similar cross sections for the cell nucleus and similar sizes for the targets in the single-hit/multi-target equation, the difference in RBE for different cells can be calculated from the n and E_0 value and thus from the ???-ratio alone. To understand the behavior on n and E_0 an analysis in the equations of the track structure model has been done. In general, there is no plain correlation between the proton RBE and the X-ray survival curve. For a given ???-ratio there could be a wide range of RBE values corresponding to various tissue characteristics such as different target size parameters. However, there is a tendency for late-responding tissues having higher RBE values than early-responding tissues. This is because the influence of the E_0 value increasing the RBE with decreasing ??? turned out to be higher than that of the n value at low ???-values. The extend of the effect is proton energy dependent as well as dose dependent.

****

The Berlin Eye Treatment Facility.

J. Heese[1], H. Homeyer[1], H. Kluge[1], H. Fuchs[1], H. Morgenstern[1], Ch. Rethfeldt[1], M.H. Foerster[2], N. Bornfeld[3], V. Budach[4], W. Hinkelbein[5], M. Nausner[5], [1]HMI Berlin, [2]Augenklinik, Universitätsklinikum Benjamin Franklin, Berlin, [3]Augenklinik, Universitätsklinikum Essen, [4]Klinik für Strahlentherapie, Charité, Berlin, [5]Strahlentherapie, Universitätsklinikum Benjamin Franklin, Berlin

The Berlin Eye Treatment Facility at the Hahn-Meitner Institute (HMI) started patient treatments in June 1998. After a 1 year review period, the permission for proton treatments was granted on June 12, 1998. The first patient was irradiated from June 22-25. The cyclotron of the Ion Beam Laboratory at the HMI is now delivering the treatment proton beam in 10-11 weeks per year. The patients are prepared and treated in a close collaboration between ophthalmologists and radiation oncologists from university hospitals in Berlin and Essen.

Until September 1998, 10 patients (8 choroidal melanomas and 2 hemangiomas) have been treated in four treatment weeks. The treatments of choroidal melanomas follow the standard fractionation schedule of 60 CGE delivered in four days. Hemangiomas were treated with 20 CGE in four fractions. For all treatment plannings, EYEPLAN is used. The eye modeling and tumor reconstruction procedure using marker clips with fundus photos and ultrasonography was assisted in most cases with CT and high-resolution MRI data.

New technical features of the HMI eye treatment beam line are:

- computerised position settings of the treatment chair,
- use of X-ray image intensifiers instead of polaroid film,
- image processing of X-ray pictures allowing automatic detection of clips and cross wires,
- direct comparison of X-ray images with treatment reference positions as superimposed images.

****

New results from the 'Magic Cube' 3D dosimeter.

S. Belletti[1], R. Cirio[2], G. Degiorgis[2], M. Donetti[3], F. Luraschi[4], F. Marchetto[2], L. Marzoli[1], C. Peroni[2], P. Tabarelli[4], [1]Spedali Civili, P.le Ospedale 1, I-25013 Brescia, Italy, [2]University and INFN Sezione di Torino, Via Giuria 1, I-10125 Torino, Italy, [3]ASP, V.le Settimio Severo 65, I-10133 Torino, Italy, [4]Fondazione TERA, Via Puccini 11, I-28100 Novara, Italy.

The project of a dosimeter capable of reconstructing the three dimensional profile of dose in real time was started 4 years ago. It has been completed in 1997 and tested on proton and carbon ions beams. The present design features 12 parallel plate ionization chambers with the anodes segmented into 4 mm wide and 25 cm long strips, for a total of 768 [1]. Each strip is connected to an individual channel of electronics that allows parallel acquisition of the whole dosimeter. The readout can be performed without disturbing the electronics, allowing deadtime free operation. To achieve this result, a Very Large Scale Integration (VLSI) electronics chip has been designed and realized [2]. Results from the tests will be shown, including homogeneity of response of both detector and VLSI electronics and dose shape reconstruction. The whole project has been passed over to industry (High Vacuum Process, Via Verona 26, I-43100 Parma, I) that has sold two prototypes to LLUMC and IBA. The dosimeters will be delivered by mid october 1998. Results will also be shown on the development of a pixel ionization chamber. We have built and tested on an electron and photon beam a parallel plate ionization chamber with an active area of $4*4\ cm^2$ and 64 pixel, each $0.5*0.5\ cm^2$. Results will be shown on the homogeneity of the system and on the pattern reconstruction capabilities. At the moment we are constructing a 1024 channel pixel chamber with $0.4*0.4 cm^2$ pixels to cover an active area of $12.8*12.8\ cm^2$. It is foreseen an update of the VLSI chip for this application. This will allow both beam monitoring (the chamber is being developed as beam monitor of the TOP linac being built in Rome [3][4]) and dosimetry (used in an array as for the actual version of the Magic Cube).

References: [1] C.Brusasco et al., Strip ionization chambers as 3-D detector for hadrontherapy, Nuclear Instruments and Methodes in Physics Research A389 (1997) 499-512. [2] G.C.Bonazzola et al., Performances of a VLSI wide dynamic range current-to-frequency converter for strip ionization chambers, Nuclear Instruments and Methods in Physics Research A405 (1998) 111-120. [3] L.Picardi et al., The TOP Linac project, July 1997, ENEA Frascati RN/INN/97/17. [4] S.Belletti et al., ISS-TOP project: a preliminary study of beam monitoring system, TERA report 97-3/FAS9.

****

Implementation of ICRU proton dosimetry protocol.

S. Vatnitsky, Loma Linda University Medical Center, Loma Linda CA.

A new protocol for calibration of proton beams was established by the ICRU in Report 59 on proton dosimetry. In this talk we report the results of an international proton dosimetry intercomparison, which was held at Loma Linda University Medical Center (LLUMC) in April 1998. Eleven institutions participated in the intercomparison. The goals of the intercomparison were, first, to estimate the level of consistency in absorbed dose delivered to patients if proton beams were calibrated with the new ICRU protocol, and second, to evaluate the differences in absorbed dose determination due to differences in ^{60}Co-based ionization chamber calibration factors. The ICRU protocol allows proton dose determinations based upon exposure, air kerma and absorbed dose-to-water calibrations in a ^{60}Co beam. Fourteen ionization chambers used by participants were calibrated in terms of exposure or air kerma. Four ionization chambers had ^{60}Co -based calibration in terms of absorbed dose-to-water. Two chambers from LLUMC were calibrated in a ^{60}Co beam at the NIST both in terms of air kerma and absorbed dose-to-water to provide a comparison of ionization chambers with different calibrations. Measurements were performed at a depth of 10 cm water equivalent thickness in a 6-cm modulated beam with a nominal accelerator energy of 155 MeV. The intercomparison showed that use of the ICRU protocol and ionization chambers with ^{60}Co calibration factors traceable to standard laboratories would result in absorbed doses being delivered to patients at their participating institutions to within 0.9 % (one standard deviation). The maximum difference between doses determined by the participants was found to be less than 3 %. The ICRU protocol should be adopted for clinical proton beam calibration. A comparison of proton doses derived from measurements with different chambers indicates that the difference in results cannot be explained only by differences in ^{60}Co calibration factors. To resolve these differences and provide practical recommendations to proton beam users a supplement to ICRU 59 dosimetry protocol should be developed. Some features of this supplement were discussed.

****

Parallel detector dosimetry device for gantry proton beams.

[1]M. Wagner, [1]Y. Orsher, [1]B. Gottschalk, [1]A. Hernandez, [1]J. Bellerose, [1]J. Mitchell; [1]Harvard Cyclotron Laboratory, Cambridge, Massachusetts, USA, [2]M. Goitein, [2]J. Flanz, [2]W. Newhauser, [2]D. Rossellot; [2]Northeast Proton Therapy Center, Boston, Massachusetts, USA.

The task of verifying proton therapy beams delivered by a gantry requires testing the beam properties at any angle of delivery. Lateral uniformity, depth dose, and lateral penumbra must all be measured. We have developed the Gantry QuikScan (GQS) to expedite these measurements. It consists of a water tank containing a detector module that can be accurately scanned within the tank along the depth dimension of the beam. The tank is no bigger than it needs to be to provide dose equilibrium from particles scattered into the module at all depths. The tank can be accurately positioned in the beam by the NPTC patient positioner (PPS) and two GQS rotary motions; one to follow the gantry rotation and the other to rotate the detectors around the beam axis. Arrays of detectors will be used to speed up data acquisition. The entrance face of the tank can be positioned to point along the beam direction at any gantry angle. The

tank has a water seal so that it can operate in any position and bubbles will not appear on the entrance face in the beam pointing down configuration. Software written in C, running under UNIX controls the system.

The presence of wobbled beams at the NPTC requires emphasis on the use of arrays because it may take 30 seconds to deliver a single full treatment pattern resulting in very long dosimetry sessions if only a single detector were used. The GQS includes 3 arrays mounted within a lexan detector module, dry inside, with special coax cables leading through waterproof fittings and hose, to the outside of the tank and on to the integrator box, located away from direct or scattered beam. The arrays are:

A 40 ion chamber linear array on 10mm spacing, with each pad 6mm wide, 10mm high for lateral uniformity measurements.

A 16 ion chamber depth array, with spacing in depth of 5mm between chambers, that samples 8cm in depth in a single reading cycle. These chambers are arrayed in staggered rows so that the area covered by the device is about 6cm x 7cm. The SOBP of a full energy beam at the NPTC can be measured at 5mm spacing in 5 samples, with an additional 4 samples to give distal falloff data at 1mm spacing. Ideally, these 9 readings (144 data points) can be taken in 5 minutes.

A 16 diode edge detector array for measuring penumbra is oriented so that the very thin detection areas are parallel to the beam, with a spacing of 2mm. This gives a one-cycle sample of 3.2cm of lateral falloff at 2mm spacing. Four such samples with 0.5mm movement between would produce 0.5mm resolution in lateral falloff.

****

Experimental indication of nuclear build-up in Bragg peaks measured at the NPTC.

[1]B. Gottschalk, [2]Y. Jongen, [2]J. Mandin and [2]D. Prieels, [1]Harvard Cyclotron Laboratory, Cambridge, MA, USA; [2]Ion Beam Applications s.a., Louvain-la-Neuve, Belgium

Usual depth-dose measurements with (say) a Wellhoefer do not probe the first (approximately) 2 cm because of tank wall thickness and restricted travel of the dosimeter. Measurements with a vertical beam at NPTC can however easily cover this region and show a small but repeatable dose buildup of a few percent in the first one or two cm. We argue that this is probably due to the buildup of dose from secondaries (mostly protons) of inelastic nuclear collisions of the primary beam. Despite the fact that such collisions also occur in air, longitudinal equilibrium does not obtain because the buildup distance in air is tens of meters. Almost all the air secondaries scatter out and there is no compensating in-scatter because the beam is relatively small transversely. Therefore the effective buildup begins only in the water itself. In the depth-dose this effect is only a few percent because of the much larger dose from the primary beam. However the buildup region is seen strongly if we measure stopping *charge* versus depth as in a multilayer Faraday cup, because there is no background from the primary beam. Both the depth-dose and charge vs. depth data should eventually be useful in benchmarking Monte Carlo calculations which claim to predict inelastic nuclear effects.

****

The risk of second malignacies after radiotherapy with high-LET.

H. Engels and A. Wambersie, Universite Catholique de Louvain, Cliniques St-Luc, 1200 Brussels, Belgium

The risk of induction of a second primary cancer after a therapeutic irradiation with conventional photon beams is well recognized and documented. However, in general, it is totally overwhelmed by the benefit of the treatment. The same is true, to a large extent, for the combination of radiation and drug therapy. After fast neutron therapy, no human data are at present available. Most of the animal data were obtained for fission neutrons for which a RBE for tumour induction of about 20 is a reasonable assumption. For fast neutrons, due to the energy difference, a risk for second cancer induction of 10 can be assumed, compared to photons. For protons (low LET radiation), a risk estimate of 1/3 compared to photons seems reasonable due to a reduction in the integral dose. For heavy ions (C ions), available data indicate that RBE for tumour induction is similar to that for fission neutrons. In therapy, because of the beam selectivity similar to protons, a RBE between 5 and 10 can thus be assumed compared to photons. This estimate is probably pessimistic since most of the normal tissues (at the level of the initial plateau) receive low-LET radiation.

****

Technological Upgrading from the First (1991)
to the Second Proton Treatment Room (1998)

[1]C. Desblancs, [1]C. Nauraye, [1]R. Ferrand, [1]S. Delacroix, [1]S. Meyroneinc, [2]A. Mazal, [1]J. L. Habrand,
[1]Centre de Protonthérapie d'Orsay - B.P. 65 - 91 402 Orsay Cedex - France, [2]Institut Curie- Rue d'Ulm - 75 005 Paris - France

Since 1991, the Centre de Protonthérapie d'Orsay has treated more than 1100 patients in the first treatment room set up with a fixed beam line delivering a maximum energy of 200 MeV and a robotics chair for patient positioning.

For the second treatment room scheduled to open at the end of 1998, an automation of the second beam line and a new patient positioning system have been developed.

Automation of the new proton beam line : Efforts have been devoted to interlocks and remote control of the elements : range shifters, carousel of scatterers, multitracks modulator (4 tracks ↔ 4 SOBP, selection by translation, 1 position out of the beam, double check system for position and rotation). Commands and interlocks input in the Programmable Logical Controller (8600 I/O managed) give a global control of the beam from the source to the patient.

Specific features for radioprotection have been set-up: a bunker (50 cm concrete) has been added between the scattering devices and the patient with a remote controlled air ventilation system inside.

A new patient positioning system : The new patient positioning system developed by a private compagny (Aripa, Champagne, France) is based on a 6 axis standard industrial robot (Fanuc Robotics, Japan) able to carry up to 300 kg. At the end of the 6th axis, a pneumatic coupling device has been added to allow the use of different accessories (a chair, a couch, a water tank, etc). The table and the chair are carried by a rolling trolley when non-coupled to the robot. The patients can be prepared outside the room. The standard positioning procedure consists in 4 steps: load of the patient with its contention through a loading gauge fixed to the floor, large movements to an approximative position in front of the beam line, radiological check and adjustments to the correct position, after irradiation, remove the patient from the beam line and bring him back to the initial position.

Many features have been added to improve the safety of the system (interlocks, accelerometer, inclinometers, collision detectors, speed sensors, etc).

The repeatability obtained with the system is better than 1/10 mm and 1/10° for each axis.

****

Progress Report of Beam Test at National Cancer Center, Kashiwa.

I. Kohmura, T. Tachikawa, H. Nonaka, T. Kimura, T. Satoh, T. Ogino[1], M. Numano[1], S. Katsuta[1] and S. Murayama[1], Sumitomo Heavy Industries Ltd., [1]National Cancer Center

After the successful beam extraction from the 235 MeV cyclotron, the nozzle beam test in the proton treatment facility of NCC, Kashiwa was started in this April. Among the three irradiation ports the gantry no.2 with the double scattering system was selected for the first target (other two ports are the gantry no.1 with the wobbling system and the fixed horizontal port).

The data show that the double scattering system can realize a good field uniformity (typ. less than +- 2.5%). Excellent depth dose uniformity within the SOBP can be obtained by a carefully designed ridge filter. Distortion of depth dose distribution caused by a fine degrader inserted for range adjustment is proved to be within a tolerance.

****

Project of proton beam line for eye treatment at CyLab, Bratislava.

A. G. Molokanov[1], P. Kováè[2], E. Boljeíková[3] and V. Laginová[3], [1]Laboratory of Nuclear Problems Joint Institut for Nuclear Research Dubna, RUSSIA, [2]Department of Nuclear Physics and Technology, Faculty of Electrical Engineering and Information Technology, Slovak University of Technology, Bratislava, SLOVAKIA, [3]St. Elisabeth Hospital of Oncology, Bratislava, SLOVAKIA

The cyclotron laboratory (CyLab) is being built in Slovak Institute of Metrology, Bratislava. It will be equipped with a 72 MeV heavy ion cyclotron DC-72 which is under construction in Flerov Laboratory of Nuclear Reactions, JINR, Dubna. Prevailing part of the cyclotron usage is planned for medical applications - radioisotope production and both neutron and proton therapies. For the later a beam transporting and forming system has been designed, allowing the treatment of eye tumours. The beam formation system - optical bench - starts at the vacuum window of the dedicated beam line, where the parameters of the proton beam are as follows: beam energy - 72 MeV, energy straggling $\Delta E/E \leq 1\%$, beam current up to 100 nA, current stability $\geq 1\%$, beam spot - 20 mm^2, beam divergence ≤ 8.7 mrad, accuracy of beam positioning $\pm$ 1 mm. Based on these parameters, configuration of the elements of the optical bench was calculated, yielding the total length to the isocenter of 2.4 m. Only one scattering Pb foil (400 $\mu g/cm^2$) was considered to provide an irradiation field of 35 mm diameter.The first collimator cutting out 95% of the beam is combined with the neutron and gamma shielding to prevent redundant patient irradiation. Other elements of the optical bench (range shifter, range modulator, further collimators, boluses, etc.) are designed similar to other proton therapy centers worldwide. For the patient positioning a moveable chair with head mask and bite block is proposed. During the treatment the dose of 60 Gy should be delivered in 4 fractions to the irradiated volume, at a dose rate of 20 - 90 Gy/min, which corresponds to the irradiation time of 40 to 10 s per fraction. The treatment of the first patient is planned in 2003.

****

A New Idea for Conformal Radiotherapy with Heavy Ion Beam.

Q. Li, Z. Wei and W. Li, Institute of Modern Physics, Chinese Academy of Sciences, Lanzhou 730000, P.R.China

A new method of heavy-ion conformal therapy, called patient rotation slice-therapy, was suggested and the realization of this irradiation modality was described in detail. The key of the new idea is to utilize the patient's movement such as rotation slice by slice and displacement to form multiple fields instead of ion gantry system. In the conceptual design for the new method, an empirical formula used to calculate average range of therapeutic beam was obtained, then Bragg peak of irradiation beam can be located swiftly through the empirically analytical expression. Meanwhile, an algorithm of depth-dose for rotational target was deduced. When the patient rotation slice-therapy was preferred, absorbed doses of target volume and body surface for a modeled body slice image were calculated and 80%, 50%, 20% and 10% isodose distribution were obtained by using the depth-dose algorithm. Results display the advantage of the new irradiation method over dose distribution. Thus the excellent characteristic of the new method in heavy ion radiotherapy application was analyzed.

****

A Combined Function Proton Synchrotron Dedicated for Cancer Therapy.

A. Noda, M. Inoue, Y. Iwashita, A. Morita, T. Shirai, M. Nishi*, K. Hiramoto*, M. Tadokoro* and M. Umezawa* Institute for Chemical Research, Kyoto University, * Hitachi, Ltd.

A combined function proton synchrotron has been proposed as a dedicated machine for cancer therapy. It can accelerate proton beam from 7 MeV to 250 MeV with the average current of 10 nA, which enables the dose rate of 5 Gy/min when operated with the repetition rate of 0.5 Hz. The energy range of the extracted proton beam can cover from 70 to 250 MeV according to the depth of the tumor. Its mean radius and the circumference are 3.8 m and 23.9 m, respectively. A combined function lattice is adopted because of its easiness for daily operation because no tracking-control between dipole and quadrupole magnets are

needed, which we believe, is most suitable for medical dedicated machine. It is anticipated that the initial design of the combined function synchrotron is difficult because it has no flexibility although the non-flexibility leads to easiness of operation once a good design has been established. In order to establish a good design, we have studied a six-fold symmetric lattice with the structure of OFDFO. Based on three dimensional computer calculation of the combined function magnet with use of the code TOSCA, we have made a model magnet of the full scale. The fabricated magnet is evaluated by three-dimensional Hall-probes. The field distribution is almost similar to the one obtained by the three dimensional computer calculations. The design of the combined function medical synchrotron is considered to be established.

****

Monte Carlo studies for beam line design and treatment planning.

H. Paganetti, Northeast Proton Therapy Center, Massachusetts General Hospital

Monte Carlo simulations of the beam lines at the HMI-Berlin eye treatment facility as well as for the gantry-nozzle at the NPTC in Boston have been done. The proton tracking included detectors, beam shaping devices and magnetic fields thus including all the scattering and absorbing material in the beam path.

The HMI-simulation deals with the Monte Carlo prediction of the primary proton fluence and the influence of various beam-modifying devices introducing a description of the beam properties by the use of the phase space distribution. This distribution is usually defined as the multi-dimensional scatter plot of the particles impulse as a function of its position. The proton energy has been separated from the phase space, leading to a phase space distribution in position and angle and the proton energy distribution. The simulations were based on a detailed realistic model of the HMI beamline. It has been shown that for Monte Carlo or analytical treatment planning calculations the proton energy distribution and the phase space distribution in position and angle can be used to characterize a specific beam line, e.g. for each modulator wheel. With this beam characterization as input, specific calculations on a treatment field including the patient specific devices can be done. The dependence on the modulation is manifest in the phase space distribution with a rotation of the phase space distribution ellipse. The presented concept is not only useful to define an input for treatment planning but as input for dosimetric calculations or to investigate improvements in beam line design.

The simulations for the gantry-nozzle at the NPTC are in progress. As preliminary results the 3D-modeling of the nozzle including all beam modifying and beam monitoring devices has been presented. The magnetic field of the scanning magnets was fully implemented. The complexity of the nozzle makes it difficult to predict analytically the scattering effects for the proton beams to be used for therapy. The Monte Carlo simulation of the system should provide information on the amount of scattered protons and secondary particles, e.g. neutrons. The simulation will thus be helpful to improve certain components of the nozzle and will be used to investigate possible high-LET protons responsible for high RBE components at the surface of the patients body.

****

New project of proton therapy facility with a dedicated accelerator in Tsukuba.

Y. Takada, A. Maruhashi, T. Sakae, K. Yasuoka, A. Nohtomi, Y. Hayakawa, Y. Akine, T. Okumura, and K. Hasezawa, Proton Medical Research Center, University of Tsukuba.

The new project constructing proton therapy facility with a dedicated accelerator has been approved finally by National Government. This facility will be built next to the University Hospital of Tsukuba and be connected with it. Building construction will start in early 1999. We hope that we'll treat the first patient in 2001. The 270 MeV proton synchrotron with a 7 MeV L INAC injector has been constructed. Beam test of the injector is in progress. Preliminary results show the specified performance. Two rotating gantries of the same design will be used for proton radiotherapy. The beam nozzle will adopt the double scattering method using the dual-ring to obtain the stable beam for treatment of moving organs in the thorax and abdominal regions . The accelerator will be able to supply the stable beam by the difussion resonant extraction method giving the beam transverse RF perturbation, which keep the sepratrix constant. The respiration-gated irradiation will be made by pre-triggering the accelerator. The beam delivery system will be upgraded to make an energy-scanning and to make the 3D conformal therapy. Two fixed beam ports will be used for research and development. The one will be used for development of conformal irradiation technique. The other will be use d for biological research. Two perpendicular X-ray sources with DRs will be mounted on a rotating gantry and be used for efficient patient alignment.

****

Detectors for ion therapy.

B. Voss, GSI Darmstadt

The treatment of patients with heavy ions requires to measure and control particle fluences with high speed (every 12.5 μs) and beam position and width (every 150 μs) with a precision of 1 mm.

To serve this purpose a set of 3 Parallel-Plate Ionization Chambers (PPIC) and 2 Multi-Wire Proportional Chambers (MWPC) with an active area of 200 x 200 mm^2 has been mounted on a common support in front of the patient couch in the medical cave at GSI. In case of failures, the entire set will be replaced by a spare one kept ready for operation throughout treatment periods.

All detectors are operated with a constant flow of Ar/CO_2 gas (80/20%)with 2l/h at atmospheric pressure. The high voltage is kept at +1000 and +1600V for the ICs and MWPCs, respectively. To monitor the proper working conditions each chamber has been equipped with sensors for gas flow, pressure, temperature and high voltage. An efficiency of 99.5% can be reached by applying +1000V to the ICs. A spark-free operation is possible up to -2300V for the mesh-type ICs now installed. For foil-type ICs also been tested a decreasing efficiency due to foil bumping by the electrostatic force was measured. No saturation effects could be measured within the therapeutic fluxes of 2×10^6 to 2×10^8 carbon-ions/second. The position dependency of the IC signals has to be taken into account if a spatial homogeneity of the applied dose within ±5% over the full active area is required. The readout, control, interlocking and online treatment-visualization is done by electronics and software developed at GSI. The intensity measurement corrected for changes in pressure and temperature is stable over weeks within 0.5% with respect to the monitor calibration. The position of the beam can be measured by the MWPCs with an accuracy of better than 0.5 mm and its width (4-10 mm) with an accuracy of 10%. All ICs and MWPCs behave identical within 1%.

****