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# ABSTRACTS

# of the

# PTCOG XVII MEETING

# held in

# Loma Linda, California, USA
# October 26 & 27 1992

# and

# PTCOG WORKSHOP
**Design specifics for accelerator and beam delivery systems appropriate to a hospital-based proton therapy facility**

# held on
# October 23 1992

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**Review of Clinical Treatment Results** **Page**

## Analysis of Causes of Failure in Choroidal Melanoma Patients

Candace C. Crowell, John E. Munzenrider, Evangelos S. Gragoudas, Massachusetts General Hospital and Massachusetts Eye and Ear Infirmary, Boston MA.

From July 1975 through May 1992, 1780 patients have received treatment for choroidal melanoma at the Harvard Cyclotron Laboratory. Thirty cases (1.7%) have been documented as local failures. Categories of failure included: marginal recurrence (n=16), the presence of extrascleral extension (n=4), uncontrolled tumor growth (n=4), or the diagnosis of ring melanoma (n=6). Each of the patients experiencing local failure had received 70 CGE.

Reasons for failure included difficulty in initial tumor volume identification, modeling issues in the treatment planning process, and/or patient-related abilities in eye fixation or stability. We were able to substantiate tumor volume identification and modeling issues as reasons for at least 50% of the marginal recurrence failures. Reasons for in-field recurrences as extrascleral lesions were not evident; 3 of the 4 cases noted as uncontrolled tumor growth could not be adequately explained.

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## Preliminary results of proton radiotherapy for urinary bladder cancer.

T. Okumura, H. Tsujii, H. Tsuji, Proton Medical Research Center, University of Tsukuba, Japan

From June 1985, we have treated seventeen patients with locally invasive (T2 or greater) and/or histologically anaplastic (grade 3) urinary bladder cancer using protons. Clinical response, acute and late radiation morbidity, and probability of survival by treatment method were discussed. The initial 6 patients were treated by protons alone with a fraction size of 3.0-3.6 Gy. The entire bladder was treated to a dose of 30-40 Gy, followed by irradiation confined to tumor volume, leading to a mean tumor dose of 80 Gy. The complete and partial response rate were 50% (3/6) and 33% (2/6), respectively, while one patient was judged unchanged. There were 3 serious late complications, although acute reactions were not a problem. Two years and 5 years survival rate was 34% and 18%, respectively. The next eleven patients were treated by combined small pelvic X ray therapy (30.6 Gy/17 fr. or 41.4 Gy/23 fr.) and arterial infusion chemotherapy followed by localized boost irradiation by protons ( 45 Gy/15 fr. or 33 Gy/11 fr.). The main chemotherapeutic regimen consisted of methotrexate and cisplatin, and they were administered every three weeks for three courses. The acute and late morbidity were acceptable. Nine out of 11 patients (82%) completely responded, and all of them survive with median follow-up of 22 months. These preliminary results suggest effectiveness of combined X ray, proton irradiation, and infusion chemotherapy as bladder-conserving treatment in patients with locally invasive bladder cancer.

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### Proton dosimetry at the ITEP (Moscow) accelerator using alanine and radiochromic detectors: A Preliminary Study.

S. Zink, Radiation Research Program, National Cancer Institute, Bethesda, MD, B. M. Coursey, C. E. Dick, M. F. Desrosiers, W. L. McLaughlin, M.R. McClelland, J. M. Puhl and D. Schauer, Radiation Interactions and Dosimetry Group, Ionizing Radiation Division, Physics Laboratory, National Institute of Standards and Technology, Gaithersburg, MD, V. I. Kostjuchenko and D. F. Nichiporov, Institute of Theoretical and Experimental Physics (ITEP), Moscow.

Cancer therapy studies using proton accelerators are underway in several major medical centers in the U.S., Russia, Belgium, Japan and elsewhere. New dosimetry systems are needed to facilitate intercomparisons between these laboratories. This paper describes preliminary work to investigate alanine-electron spin resonance (ESR) and radiochromic films for use in measuring proton dose and depth dose curves in high-energy proton beams. The initial irradiations were carried out at the Institute of Theoretical and Experimental Physics (ITEP) Moscow. Dose measurements and depth-dose profiles obtained from alanine samples read out at the NIST ESR facility agreed with the ITEP values to within +/- 5% of the ITEP values for samples irradiated to 100 Gy with 200 MEV protons. More recently measurements have been made at the Harvard Cyclotron, Boston, using the proton beam that has been used for two decades for investigating proton therapy cancer irradiations. Proton beam delivery systems at Loma Linda University, Loma Linda, California, and in St. Petersburg, Russia, will be included in the next round of measurements.

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### Proton Dosimetry Intercomparison: Potential for ESR.

K Gall, Massachusetts General Hospital, Boston, MA. J. Siebers, M. Moyers, D. Miller, Loma Linda University Medical Center, Loma Linda, CA. and B. Coursey, M. Desrosiers, C. Dick, J. Puhl, National Institute of Standards and Technology, Gaithersburg , MD.

Proton beam dosimetry intercomparisons were carried out at Loma Linda University Medical Center (LLUMC) in April 1992 using LLUMC's XRADIN T1 ionization chamber and Massachusetts General Hospital's (MGH) Far West ionization chamber. Using proton calibration factors for these chambers derived from calibrations in a $^{60}$Co beam, measurement of proton doses were in agreement to better than 1% for typical treatment fields. The largest difference observed in three sets of measurements was 0.5%. However MGH uses Faraday Cup proton beam dosimetry for the treatment beams at the Harvard Cyclotron Laboratory, and calibration constants for ionization chambers derived with that method show a 6% difference from proton beam calibration constants derived from $^{60}$Co calibrations. This results in a direct 6% difference in physical dose delivered at LLUMC and MGH in their respective treatment beams. In part to address the need to efficiently compare proton beam doses at different institutions, preliminary measurements have been made of proton beam doses with Alanine based Electron Spin Resonance dosimeters and radiochromic film dosimeters. These rather new systems have several advantages over other methods of comparing doses. Preliminary measurements made at the Harvard Cyclotron Laboratory are presented which show initial agreement with Faraday Cup dosimetry at the 5% level. An outline of necessary investigations to establish these dosimeters as intercomparison bases is given.

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**Automated Measurement of Treatment Beams with a 48 Diode Array in a Compact Water Phantom**

Miles Wagner, Harvard Cyclotron Laboratory, Cambridge, MA 02138

A small water phantom with approximately 15 x 15 cm entrance window and 18 cm depth along the proton beam is supported on a 3-axis computer controlled positioning system that can quickly and reproducibly place the tank anywhere in a therapy field. Within the tank, a 4th axis controls the depth of a detector module containing a thimble ionization chamber, an 8 x 6 array of diodes, a stairstep array of diodes for depth detection, and 3 diodes for edge scanning. The system can be manually controlled either locally or remotely, or by computer command file. Quicker and more detailed scans of patient treatment beams are the result. Examples of system tests and patient data were shown.

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**RBE measurements in the 85 MeV clinical proton beam produced at the cyclotron CYCLONE of Louvain-la-Neuve (Belgium).**

J. Gueulette, V. Grégoire, B. De Coster, J. M. Denis, S. Vynckier and A. Wambersie. Laboratoire de Radiobiologie et de Radioprotection, UCL, Cliniques Universtaires St-Luc, Brussels (Belgium).

The RBE of the 85 MeV clinical proton beam produced at the cyclotron CYCLONE of Louvain-la-Neuve was determined for the survival of EMT6 cells. The cells were irradiated in a water phantom, in the initial plateau of the unmodulated Bragg peak and in the middle of a 0.5 cm spread out peak. Different irradiation modalities were used: irradiation with a single fraction and irradiation with several 2 Gy fractions (up to 6 fractions) separated by a time interval of 3.5 hours. Reference irradiations were performed with 60-cobalt gamma-rays.

We found that proton RBE (Ref. 60-cobalt) was not significantly different from unity whatever were the dose level, the irradiation modalities (single or fractionated irradiation) and the position of the samples in the beam (initial plateau or middle of the spread out Bragg peak). By another way, we subjected the phantom to a constant 5, 10 or 15 Gy modulated or unmodulated irradiation. It was found that the dose/effect relation derived from the variation of the cell surviving fraction in depth takes the exact shape of the cell survival curve obtained after increasing doses given at a constant position in the phantom. This constitutes a further evidence that proton RBE do not significantly vary along the course of the particles. Furthermore, preliminary results obtained for the induction of chromosome aberrations in EMT6 cells also show that proton RBE is invariable and close to unity.

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**A model to determine the neutron dose from heavy-charged-particle radiotherapy**[1]

K.A Frankel, B.D. Anderson†, A.R. Baldwin†, M. Elaasar†, J.I. Fabrikant, W. Gong, L. Heilbronn, M. Htun†, J. Jiang†, D. Keane†, R.P. Levy, M.A. McMahan, R. Madey†, J. Miller, W.H. Rathbun, A. Scott†, Y. Shao†, J.W. Watson†, G.D. Westfall§, S. Yennello†, C. Zeitlin, and W.M. Zhang†. Lawrence Berkeley Laboratory, University of California, Berkeley, CA
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Clinical trials to examine the efficacy of heavy charged particles (e.g., neon ions) for the treatment of malignant disease are in progress. An unknown portion of the dose to the patient comes from neutrons, which are produced by nuclear reactions in the patient's tissues during the irradiation procedure. Experiments were conducted to measure the neutron energy and angular distributions from 250 MeV/n and 400 MeV/n niobium stopping in niobium and aluminum targets. Experimental results were reported for neutron energies above 10 MeV and for angles ranging from 3° to 80°. An initial comparison with theory was presented. A proposed procedure to use the experimental method to calculate the neutron dose from heavy-charged-particle radiotherapy was described .

[1]Research supported by NASA Order No. L14230C, DOE Contract No. DE-AC03-76SF000098, and NSF Grant Nos. PHY-91-07064, PHY-88-02392, PHY-85-01054.

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**Delayed functional, radiologic and histologic changes in rabbit brain following helium-ion and X-irradiation**[1]

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We have developed a rabbit model for delayed radiation injury in the brain. Well-defined focal lesions have been produced using Bragg-peak helium ions (230 MeV/u) and 225 kVp X-rays. The lesions were well-visualized by MRI and PET scanning. T2-weighted MRI scans demonstrated alterations restricted primarily to the white matter tracts and the deep perithalamic and thalamic regions. Gadolinium DTPA-enhanced MRI and $^{82}$Rb PET scans detected focal regions of blood-brain-barrier disruption in the deep white matter and thalamic regions. $^{18}$F-deoxyglucose PET studies demonstrated depressed metabolic activity in the irradiated hemisphere, as compared to the contralateral side. Rabbits may not exhibit neurologic deterioration for 2 years or more after the appearance of the lesions; selected rabbits have now been followed up to 5 years post-irradiation. Rabbits that manifested significant neurologic deterioration were sacrificed, and histology studies were obtained. Regional cerebral blood flow (rCBF) measurements of hemibrain-irradiated rabbits (60 Gy, 225 kVp X-rays) showed significant reductions in rCBF in the irradiated hippocampus and cortex.

[1]Research supported by the Office of Health and Environmental Research, U.S. Department of Energy Contract DE-AC03-76SF00098.

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**Oligodendrocyte response to ionizing radiation: An *in vitro* model of cellular and functional response**[1]

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The cellular and functional response of oligodendrocytes to single-dose $^{60}$Co γ-irradiation at day-in-culture (DIC) 8 was examined in primary glial-cell cultures derived from neonatal rat brain. Oligodendrocytes were quantified by grid-counting with phase contrast microscopy, and their functional capacity was determined by quantitative radioimmunoassay of myelin basic protein (MBP) levels in membrane extract preparations. Oligodendrocyte counts at DIC 14 were 55% to 65% of control values after 2 Gy and 29% to 36% after 5 Gy. At DIC 21, counts returned to near-normal levels in the 2 Gy group and to about 75% of normal in the 5 Gy group. MBP levels after 2 Gy were 45% greater at DIC 21 than at DIC 14, but during this interval MBP decreased, as a fraction of age-matched control values, from 60% to 50%. Following 5 Gy, absolute MBP was markedly depressed and showed little recovery through DIC 21. The temporal patterns of cellular and functional depletion and recovery *in vitro* are analogous to patterns of demyelination and remyelination found *in vivo*. The experimental approach reported here may help elucidate the regulatory control mechanisms of oligodendrocyte proliferation and differentiation required to respond in a coordinated manner to radiation injury. The model is currently being applied to evaluation of brain-cell-specific RBE for charged-particle beams.

[1]Research supported by the Office of Health and Environmental Research, U.S. Department of Energy Contract DE-AC03-76SF00098.

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**Relative biological effectiveness of proton medical beam at the ITEP synchrotron (Moscow) determined by the Chinese Hamster cells assay.**

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RBE values of the ITEP synchrotron proton medical beam have been determined at the entry of the unmodulated 179 MeV beam and in the centre of spread out Bragg peak (SOBP), from measurements of the survival of Chinese hamster cells (clone 431). Gamma-radiation of $^{60}$Co was used as a reference source. According to the linear regression model mean RBE values at 37 per cent survival level were found to be 1.10±0.04 at the beam entry and 1.14±0.05 in the centre of SOBP. RBE values obtained using the linear-quadratic model for 10 and 37 per cent survival levels were 1.09 and 1.07, respectively, at the beam entry and 1.07 and 1.08, respectively, in the centre of SOBP. The data obtained indicate that (i) the RBE values at the entry of the unmodulated beam and at the centre of the SOBP are in close agreement, with an average of about 1.10, (ii) protons are radiobiologically somewhat more effective than $^{60}$Co gamma rays and (iii) high pulse dose rate of the ITEP medical beam does not affect significantly biological effects of the beam.

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## Progress of the irradiation facility at HIMAC.

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The construction of a medically dedicated heavy ion facility at Chiba is proceeding. The ion sources, RFQ and Alvalez linacs are already installed. The magnets of the 40 m in diameter synchrotrons are set forth together with power supplies. Some of the magnets on the beam transport lines are carried in and started to be aligned. Various equipments in the irradiation system are being manufactured. The control system of the irradiation apparatus as well as the accelerator and beam delivery system are developed. The design of the treatment planning system and its programming are in progress. Most of the installations in the four-story building are scheduled to be set by next spring. The injection and acceleration of the beam in the main synchrotron will start next autumn.

In the hospital side, the consideration about the strategy to effectively utilize this facility for treatment of the patients are proceeded among medical doctors at various institutions.

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## Status of the UC Davis Proton Therapy Project*

Jose Alonso, Lawrence Berkeley Laboratory, Berkeley, CA 94720

A strong collaboration has been established between UC Davis and LBL with a goal of construction of a proton therapy facility at the UC Davis Cancer Center in Sacramento California. LBL is assuming primary responsibility for the technical aspects of the project, including establishment of specifications for the accelerator, beam delivery and treatment room components, as well as development of procurement documentation. An updated version of the Clinical Specifications document, originally developed as a joint effort with MGH, has been prepared, and a Performance Specifications document is being written to complement the Clinical Specs document, translating the clinical requirements into accelerator, beam-delivery and control system performance specifications. These two documents together will form the backbone of an RFP for procurement of the technical components. This RFP is anticipated to be ready for distribution in January 1993. UC Davis is working on sighting and architectural plans, and is developing a funding program for design and construction of the proton therapy facility. Space lists have been developed, preliminary layout work is proceeding with the help of an architectural consultant. The selection process for the Project Architect is underway, the chosen firm is expected to be on board before the beginning of 1993. Document preparation is underway for review by the University of California Regents, approval is expected by May 1993. A fundraising feasibility study is underway, results are due in December 1992. If all proceeds according to expectations, the first patient should be treated in calendar 1997.

* Work supported by the National Institutes of Health, National Cancer Institute under Grant No. 56932, through the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

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## Report on the current work at the Douglas Cyclotron Unit, Clatterbridge UK.

A. Kacperek, M.A. Sheen, M.E. Butler, R.D. Errington, T.E. Saxton

Introduction: Proton therapy is now recognized by the Dept. of Health, as the treatment of choice for certain types of uveal melanoma. In the past 3 years, 312 uveal melanoma patients have been treated as well as once case of melanoma of the conjunctiva.

Developments in eye therapy planning: A much improved version of the EYEPLAN program includes more realistic representations of the upper and lower eyelids. The rim of each lid is drawn on a beam's eye view, and its thickness modelled as: (a) a spherical shell of given thickness ("orange peel") or a straight surface in vertical cross-section - like a curtain - with a rim of (b) given thickness or arbitrary parabolic shape. The eyelids are included in the range and dose calculations, and permit a more accurate estimation of the isodose distribution around the tumour.

Proton beam and dosimetry measurements: Recent proton beam dosimetry intercomparisons, using ionization chambers, with NAC (Faure) and the Svedborg Laboratory (Uppsala) yielded overall uncertainties of ±1.3% and ±0.7% respectively. The lower measurements obtained on the Faraday Cup were traced to a higher proportion of scattered protons, by measurement with a proton spectrometer (NE102a plastic scintillator).

Radiobiology: RBE measurements have been performed using 3 melanoma cell-lines (VUP, OM431 and HX34). The proton irradiations, performed in the spread out distribution, yielded RBE values of 1.18 to 1.3. Further work was performed irradiating the HX34 and VUP cells in a fully modulated depth distribution. The Survival Fractions (at 4 Gy) showed a marked decrease with depth.

Progress on proton linac booster: The design of the proton linac 'booster' by AEA Technology (Culham, UK) has completed the technical feasibility study stage. A final proton beam energy of 200 MeV and beam current of 20 nA have now been specified for a 21 cm diameter beam. Two separate additional treatment rooms would enable patients to be set-up and treated alternately.

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## Conformation therapy and control system of HIMAC.

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Our conformation therapy system consists of a pair of wobbler magnets, a scatterer, a ridge filter, a range shifter, a multileaf collimator, a patient compensator and dose monitors. A large uniform field is obtained by the wobbler magnets and the scatterer. The target volume is divided into many slices perpendicular to the beam axis and each slice is irradiated in order. The ridge filter spreads out the Bragg peak to the thickness of one slice for conformal scanning. The lateral shape of field is formed by the multileaf collimator for each slice. The depth of the range is shifted by the variable range shifter which is composed of two wedge shifter. Every time the monitor count reached the preset count at each slice, which is determined by the universal fraction curve associated with spread-out Bragg peak, field shape and depth for next slice is arranged by the monitor control signal. The range is swept several times within target thickness to an average dose at the slice, since the field of the slice may be disturbed by the movement of target. Typically the number of sweeps are repeated 5-10 times back and forth over the target area. The irradiation time is a few minutes when the target thickness is 70 mm and the slice thickness is 5 mm. We are going to start clinical trials of HIMAC in 1994 using the fixed range shifter and after that we will use the high speed variable range shifter.

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**Measurement of Intracranial Motions**

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A patient positioner has been developed at Massachusetts General Hospital and Harvard Cyclotron Laboratory which immobilizes the patients skull and accurately positions the skull with 3 translational and 2 rotational movements. The patients skull may be rotated to positions other that supine during these movements, and therefore there is a possibility of intracranial motions relative to the skull and the proton beam line. Possible sources of the movement are gravity, vascular pulsations, and changing intracranial fluid pressures. Vessel movement during angiography of arteriovenous malformations was measured. For ten patients studied the average movement of any measured vessel was .07 mm and the maximum movement detected was .4 mm. Patients were immobilized in the supine and decubitus position for CT scans. Each patient had 3 fiducial markers implanted in their skull prior to the scans. A selection of intracranial structures were outlined on each scan. With the use of the fiducial markers, the structures outlined of the set of decubitus scans for each patient were superimposed onto the supine data set. Movements of intracranial structures on the order of .5 to 1.5 mm were commonly detected.

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**Specifications for a Proton Therapy Research and Treatment Facility.**

K. Gall[1], L. Verhey[2], J. Alonso[3], J. Castro[3], M. Collier[3], W. Chu[3], I. Daftari[3], Mi. Goitein[1], H. Kubo[4], B. Ludewigt[3], J. Munzenrider[1], P. Petti[3], T. Renner[3], S. Rosenthal[1], A. Smith[1], J. Staples[3], H. Suit[1], A. Thornton[1]. [1]Department of Radiation Oncology, Massachusetts General Hospital, Boston, MA. [2]Department of Radiation Oncology, University of California San Francisco, San Francisco, CA. [3]Lawrence Berkeley Laboratory, Berkeley, CA. [4]Department of Radiation Oncology, University of California Davis Medical Center, Sacramento, CA

In preparation for construction of new proton therapy facilities at the Massachusetts General Hospital and the University of California at Davis Medical Center, a document has been developed to detail the specifications required of the treatment beams and the facilities in general. The first set of specifications address the clinical performance of the treatment beams, and list parameters such as, the maximum and minimum required depths of treatment, dose rate, treatment field penumbra, etc. This approach was taken to specify the performance of the equipment since the clinical performance of the treatment beams are the areas of ultimate concern for the facility. In principle, any accelerator and beam delivery system that can meet the clinical performance specifications at minimum cost (including initial capital and ongoing operating and maintenance costs) is acceptable for a proton therapy facility. Each clinical specification is divided into a “preferred specification” which is the value of that parameter that would be desirable regardless of cost, and a “minimum specification” which is the least acceptable value of that parameter. For example the preferred maximum depth of treatment is 32 $g/cm^2$ and the minimum is 28 $g/cm^2$. Each of the clinical specifications are presented and discussed. Copies of the full Specifications for a Proton Therapy Research and Treatment Facility document can be obtained by contacting Ms. Anne Levine, Administrative Director, Northeast Proton Therapy Center, Department of Radiation Oncology, Massachusetts General Hospital, Boston, MA 02114.

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**Successful completion of a synchrotron by industry on a fixed price basis**

Richard Sah, Maxwell Laboratories, Inc., Brobeck Division, Richmond, CA

Proton-therapy accelerators will be located at hospitals rather than National Laboratories. The successful transfer of accelerator technology to industry means that hospitals now have the option of purchasing complete, turnkey accelerator systems from industry. The synchrotron light source at LSU is the first example of a synchrotron to be built commercially in the United States. Maxwell Laboratories, Inc., had full responsibility for the design, fabrication, installation, and commissioning of this storage ring. The accelerator was purchased on a fixed price basis and was completed on schedule. The customer has successfully taken over the operation of the synchrotron and is constantly improving the machine performance.

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**Neutron Shielding Design for a Proton Therapy Facility**

C. Mayo, A. Koehler, B. Gottschalk, X. Yan, Harvard Cyclotron Laboratory, Cambridge MA
and K. Gall, Massachusetts General Hospital Boston MA.

Designing neutron shielding for a proton medical facility (PMF) is substantially different from design at conventional radiation facilities. The difference is that secondary neutrons are produced with energies up to that of the proton beam, e.g. 250 MeV, whereas at a conventional radiation therapy facility the largest neutron energy of concern is about 20 MeV. These high energy neutrons carry most of the dose equivalent and they require more concrete shielding for attenuation.

We have compared calculation results of Braid et. al., Lundqvist, Hagan et. al. and Siebers and worked out the implications for concrete shielding wall thickness. The largest differences are seen in the forward direction where, for a typical case, Braid's walls are shown to be 16% thinner than Hagan's.

We have compared calculation results of these authors with measurements they report and with measurements carried out at the Harvard Cyclotron Laboratory. The HCL measurements, made with a 10 inch Bonner sphere at 0 degree production angle, were lower but most consistent with the results of Lundqvist.

Based on these comparisons we recommend using the calculation results of Lundqvist to determine the thickness of concrete shielding walls at a proton medical facility. Our measurements and those reported by Siebers, indicate that thinner shielding walls may be adequate. However, there is not yet enough experimental data available to guide design using thinner walls.

An additional half value layer of concrete should be included to account for the imminent increase of neutron quality factors.

We also discuss the derivation of correction factors for neutron dose equivalent measured with a 10 inch Bonner sphere. The correction factor accounts for the diminished sensitivity of the Bonner sphere to neutrons with energies greater than 10 MeV. We use a factor of 2 for neutrons produced in the forward direction by our 160 MeV proton beam.

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**Support structure for corkscrew-gantry beam-transport system for a proton-therapy facility**

Bruce M. Bailey, Sherborn, MA 01770

Starting in late 1986, a collaboration based at the Harvard Cyclotron Laboratory (HCL) in Cambridge, MA, under the overall guidance of A. Koehler, undertook a study of possible arrangements for a corkscrew-gantry type proton-therapy facility. Mechanical design studies were carried out in conjunction with beam-optics analyses to determine an optimum method of supporting the rotating system of magnets required for the beam-transport system. Several configurations were examined to the level of preliminary system cost/feasibility estimates. This paper is a summary description of the structure of the mechanical assembly which appeared to have the most promising combination of technical and cost-effective attributes.

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## Workshop on Design Specifics and Beam Delivery Systems Appropriate to a Hospital-Based Proton Therapy Facility

**Workshop Summary** -presented at main PTCOG meeting by Jose Alonso

The goal of the Workshop was to provide a forum for a free-wheeling discussion of new ideas and how such new concepts would integrate into an overall Therapy Facility design. The emphasis on integration is most important, because while a new idea may provide a clever solution to one problem, it may introduce difficulties in other areas of the operation of a clinical facility. For example, a new accelerator design might provide economies of size or construction, or may solve an intensity problem, however it might create problems in dosimetry accuracy or in interfacing with a scanning system. By having open discussions, new ideas could be critically evaluated, and in the process be widely exposed to the community. The format of the Workshop was planned to be highly informal. Except for a division into four generic sections, dealing with Beam Delivery, Gantry, Controls and Accelerator systems, no formal agenda with speakers was prepared. The Workshop was highly successful. Over 50 people attended, representing many laboratories, institutions and industrial firms from many countries. Many new ideas were presented, the discussions lasted well beyond the originally scheduled time. Pierre Mandrillon, co-chairman of the next PTCOG meeting in Paris-Nice stated that he would schedule a similar workshop to be held in conjunction with his meeting.

A summary of topics presented will be given below.

Facility size optimization

Khoroshkov (ITEP) argued that if the venue for new proton facilities is major hospitals, space will always be a problem, so minimizing the facility footprint is of critical importance. He proposed a vertically oriented synchrotron, mounted on a rigid wall, with treatment rooms stacked one on top of the other. Such a facility would occupy only 6,000 square feet of space, less than one fifth of the Loma Linda footprint. Accelerator access and alignment problems were viewed as an inconvenience, but not insoluble problems.

Gantry optimization

Onosovsky (ITEP) presented two gantry options, the first now in final design stages for the Moscow $H^-$ machine, a "classical" (as opposed to "corkscrew") design occupying a space of 7 x 7 x 7 meters and using less than half the magnets of the corkscrew. The distance from last magnet to isocenter is 1.5 meters, a single sweep magnet upstream of the last 90° magnet provides spreading via line-scanning in one plane, the second plane is provided by either moving the patient or rotating the gantry and pivoting the last magnet in the fashion proposed by Uppsala many years ago. Very small aperture magnets are used, (11 mm typical) due to extremely low emittance of beams extracted from their $H^-$ ring.

A second gantry proposed by Onosovsky is a flat "slinky" design, with magnets riding on vertically-mounted tracks, stretching to bring the beam in to isocenter over a 200° range from just beyond vertical upwards, through just beyond vertical from below. A drawing of this concept is included with Onosovsky's abstract.

Silvestrov (Budker Institute, Novosibirsk) proposed an ultra-compact gantry based on very high field pulsed magnets (not superconducting). The size of the gantry would be close to that of a conventional photon gantry, about 3.4 meters diameter, but could be used only with very short pulses of beams, without scanning. It is the ultimate in compactness.

Scanning systems

Pedroni (PSI, Switzerland) reported on progress with the voxel scanning system under development. All components have been tested with beam, and a sample treatment volume actually irradiated to very acceptable levels. A remarkable achievement considering the complexity of the system. The test area has been dismantled now as they are beginning installation of their gantry system; scanning system components will be installed on the gantry. Operation expected by end of 93.

Silvestrov reported on the status of his scanning system built and operated (without beam) at Novosibirsk. The two-magnet system of 55 cm length could be easily adapted to the Loma Linda gantry and produce fields of about 30 x 30 cm for maximum-range beams. This raster scanner operates at 1 kHz for the fast sweep and 10 Hz for the slow sweep.

Superconducting technology

Gross (GE) argued that niobium-tin technology is ready for fabrication of magnets suitable for gantry use. Advantages over the conventional niobium-titanium are a higher operating temperature, very simple cryosystems (without liquid helium) being sufficient. The all-gas system avoids problems of liquid spillage from cryostats rotating on a gantry. Suitable fabrication techniques are now available to deal with the extremely brittle nature of the $Nb_3Sn$ material. Although Gross presented a sample super-ferric (2 Tesla) design, this concept is less interesting than would be a much higher-field 6 Tesla magnet. This would allow either for a very compact proton gantry, or a carbon gantry that would occupy the same space as the existing Loma Linda design. Gross pointed out that further study would be needed on the feasibility of such higher field magnets with $Nb_3Sn$.

Accelerator concepts

Klenov (Moscow Radiotechnical Institute) presented the current status of the Moscow $H^-$ synchrotron. Such a machine has a very large diameter (≈20 meters, compared with the Loma Linda design (≈6 meters), but is built of inexpensive components. Extraction of beam can occur at many points, 6 are planned, by insertion of a tiny needle-point into the beam to cause stripping. This extremely small source size produces very low emittance beams and hence small magnet transport systems to the treatment rooms. These rooms are arranged around the outside of the ring. Prototyping of components is proceeding, a vacuum chamber has been built and tested, two magnet types have been built and are being measured. The injector has been built and is being tested. No completion date for the facility was given, a shortage of funds has caused delays in further construction.

Tronc (CGR-GE, France) discussed ideas for a compact s-band (traveling wave) linac with very high accelerating field gradients. This idea, presented at the 1991 Particle Accelerator Conference by Hamm (AccSys), is being further developed to address rep-rate issues and feasibility of achieving the high gradients.

Ankenbrandt (Fermilab) presented design parameters for a rapid-cycling proton synchrotron. Such a machine would have excellent intensity and low operating costs, but would have a very low duty factor.

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**Compact linac therapy unit predesign**

D. Tronc, General Electric Medical Systems, CGR, 551 rue de la Miniére, BP 34, Buc, France

A 250 MeV linac of full length 12 meters uses few traveling wave sections. A new accelerating cell geometry is derived from the ELETTRA electron linac under test at Trieste, Italy. The paraxial dynamics of protons have been simulated under realistic focusing. The associated isocentric optics uses superconducting coils to reduce its size. Such very compact and relatively cheap instrument is required to democratize proton therapy.

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**Computer-aided Proton Therapy at ITEP: Computer Control Systems**

V.M. Breev, A.V. Furtichev, Ja.L. Kleinbbock, V.Eg. Luckjashin, ITEP, Moscow

The PC-based control system for the ITEP three-channel proton therapy facility uses standard CAMAC data acquisition electronics, interfaced to the computer via a special add-on adapter card. Another card manages the television video signal input/output. Additional keyboard and display units have been supplied for operator convenience. The computers used in the facility are connected through a local area network built around a 1 Megabit/sec bus. The ITEP computer system services a variety of therapy needs, including specialized irradiation units (gynecological, intracranial, eye and eye orbit irradiations), beam extraction and transport, ridge filter fabrication and treatment planning.

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**A Compact Superconducting Proton Therapy Magnet System**

Dan A. Gross, Applied Superconductivity Program, General Electric Corporate Research and Development, POB 8, K1-EP111, Schenectady, New York

A 2.2 Tesla cold iron superconducting magnet system is proposed for the new MGH proton therapy facility. $Nb_3Sn$ superconductor is operated at 10 K, with a thermal shield at 40 K, by means of a cryocooler. Since the magnet is conduction cooled no liquid cryogens are used, hence magnet mobility is unimpeded. A light weight conductor, ferromagnetic shield, cryostat and gantry structure are then possible. A 180 degree dipole is designed at less than 2 Tons, with a 0.1% homogeneous gap of 8x8 $cm^2$, 150 Amps and 1.1 m proton bend radius at 250 MeV. Within a 3.5 m gantry radius and a dipole to isocenter distance of 2.2 m, this yields direct access to a 16x16 $cm^2$ field of view (FOV) at the isocenter. Larger distals yield proportionally larger FOV's. While a 2 second field reset from 250 to 70 MeV may be possible, a 5 second full current reset is practicable. However, traversal of this energy range in about

10 steps is insensitive to field distortions due to eddy currents and superconductor magnetization effects. A compatible full turn gantry, with roughly 30 microradians and 0.1 mm full flexural distortions weighs about 4.5 Tons. Design parameters, prior experience with this technology in full body MRI and other applications, quench protection and performance will be presented. Auxiliary quadrupoles of the magnet train may be addressed with the same superconducting technology.

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**Flat variant of gantry system**

K.K. Onosovsky, M.M. Katz

To decrease the GANTRY system volume it is proposed:

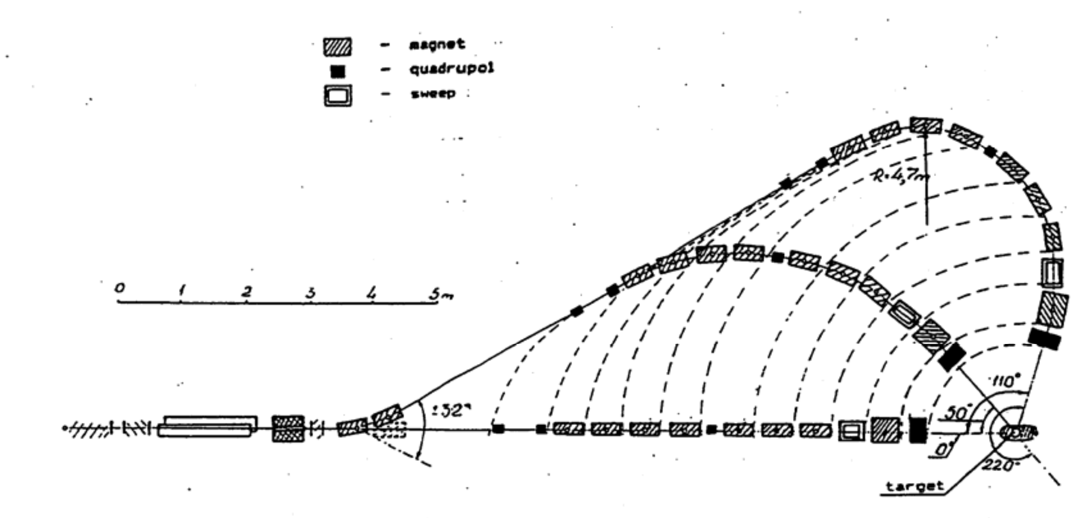
1. To eliminate the rotating magnet system.
2. To position a lying patient not along the direction of the extracted accelerator proton beam, but in the perpendicular direction.
3. To provide irradiation from various directions from the plane perpendicular to sagittal patient axis, flexible magnet system elements of which move in this plane along guiding rails fixed on a vertical wall is used for this purpose.
4. To use irradiation interval 220 degrees for irradiation of patient, lying with his head to the right; if necessary the deck can be turned in the opposite direction without changing patient position on the deck.

Magnetic-optic characteristics of the calculated beamline are provided in this paper. Proton beam scanning, change of proton energy and slow movement of patient allow irradiation of targets of various sizes: from 2 mm in diameter to 400 x 300 x 300 $mm^3$.

Proposed Gantry system has a volume of about 10 x 1 x 9 $m^3$.

SCHEME OF FLAT VERTICAL GANTRY SYSTEM

**SCHEME OF FLAT VERTICAL GANTRY SYSTEM**

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**Gantry for PTF**

K.K. Onosovsky, V.S. Khoroshkov, M.M. Katz, I.S. Vorontzov

Gantry system is designed and has began to be manufactured in ITEP.

Gantry parameters are as follows:- $\phi$ = 6.5 M; Volume 7 x 7 x 7 $m^3$; Total weight about 7 tonn; Weight of magnetic system - 2 tonn; Gap between magnet poles 11 mm; Max. magnetic field - 1.5 T; Max. rigidity - 2.4 Tm; Volume of irradiation target - 300 x 300 x 300 $mm^3$; Irradiation interval - 360°.

3 D scanning delivery system and usually delivery system with bolus and collimator are provided. The skin injury is minimal.

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**Second version of the Russian PTF project**

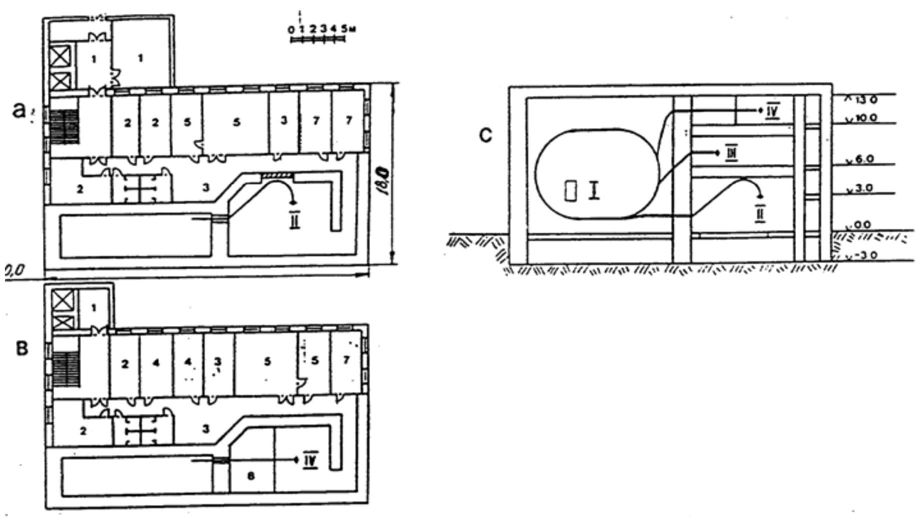
V.S. Khoroshkov, K.K. Onosovsky, A.Je. Bolshakov, ITEP, Moscow

This version of the Proton Therapy Project (PTF) project is an attempt to minimize the construction area for PTF. This seems to be extremely important for the possibility to house PTFs inside big and well-equipped hospitals, where vacant areas are usually limited.

The aim is achieved by means of vertical positioning of the accelerator. In this version all the basic approaches of the Moscow project have been repeated ($H^-$ synchrotron, independent ejection and beam delivery systems for each treatment room, small phase volume of the external beam, 5Hz repetition rate). At the same time, the vertical position of the accelerator demanded certain changes in its construction. The report presents the basic data of the vertical accelerator.

General layout of the PTF is clear from the diagram where the building cross-section (c) and two (a and b) of the four floors are presented. The variant with three treatment rooms is presented. The footprint area is about 600 $m^2$. On all the floors, compartments have been envisaged for treatment and patient preparation.

There is a possibility in principle, to house three extra treatment rooms on the opposite side of the accelerator; this will result in footprint increase up to 820 - 850 $m^2$.

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