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ABSTRACTS

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Status Report: Proton Therapy Facility Project with a Dedicated Accelerator in Moscow

V. Khoroshkov, K.K. Onosovsky, L.L. Goldin, Institute of Theoretical and Experimental Physics (ITEP) and G.I. Klenov, Moscow Radiotechnical Institute (MRI)

The basic design of the new proton therapy facility project in Moscow and its current status will be reviewed. Modifications to the gantry engineering design and layout of the accelerator and treatment facility will also be discussed.

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H^- Synchrotron for Proton Therapy Facility (PTF) Project

K.K. Onosovsky and V.S. Khoroshkov, ITEP, and V.S. Rybalko and G.I. KIenov, MRI

The main systems of the H- synchrotron for the PTF project and some features of the beam guidance system and redesigned target will be described, including some preliminary results of the vacuum chamber tests. A cost analysis of the H- synchrotron will be presented.

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Use of the H- Synchrotron for Light Ion Therapy

K.K. Onosovsky and V.S. Khoroshkov, ITEP

The applicability of the Proton Therapy Facility (PTF) and H- synchrotron for light ion (up to neon) accelerators will be discussed, including such topics as target design, ion transport channel structures and the relatively small-aperture dose delivery system.

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Preliminary Design of a Dedicated Proton Therapy Linac

R. W. Hamm, K. R. Crandall, J. M. Potter, AccSys Technology Inc.

The preliminary design of a compact proton linac dedicated to cancer therapy has been completed. A 3 GHz side-coupled structure is used to accelerate the low current proton beam from a 70 MeV drift tube linac. Commercially available S-band rf power systems and accelerating structures are employed, significantly reducing the cost of the linac and allowing 20 MeV increments of energy up to as high as 250 MeV. This design also allows the final energy of the system to be chosen at other values. The short beam pulse (1-3 μsec) and high repetition rate(100-300 Hz) make the linac operation similar to many high energy electron linacs now used for therapy, yet produce a proton flux sufficient for rapid treatment of even large tumors. The low power consumption (350 kW) and low stand-by power (25 kW), coupled with the use of proven linac technology, provide an economical, reliable, and easy-to-operate high energy proton accelerator. The high pulse repetition rate permits beam scanning, and the small output beam size and emittance result in a compact isocentric gantry design. Such a linac will reduce the facility and operating costs for a dedicated proton therapy system.

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Initial tests of a beam delivery system

R. Martin, ACCTEK Associates

Initial tests of ACCTEK's 90° bending magnet system, rotating about the incident beam line axis, are shown on video tape. The system contains just over 4 tons including magnets and counterweights and rotates 45° in 10 seconds. A laser pointer indicates reproducibility to better than one mm at a distance of 3 m from the end of the structure. A very fast raster scanning system has been constructed and is under test. It is designed to scan an area of 25 cm by 35 cm at 3 m lever arm in a time of 0.15 seconds. A Phase 1 SBIR grant has been received by ACCTEK from the National Institutes of Health for developing proton radiography as an aid to proton therapy. Tests will be performed at the Indiana University Cyclotron Facility. The above work was supported by grants from NIH.

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Variable energy accelerator vs. fixed energy + degrader

Yves. Jongen, Ion Beam Applications SA, Louvain-la-Neuve, Belgium

The use of a fixed energy accelerator for proton therapy imposes the use of an energy degrader system followed by a beam cleaner. Beam losses through the system can reach a factor of 100. However, the average extracted intensity from the cyclotron is only 65 nA, less than one order of magnitude above the average intensity needed by a variable energy accelerator system (7.5 nA). We show that a typical proton therapy accelerator utilization factor is only 5% when averaged over a year, or 12.5% when averaged over office hours. Secondary neutron influences and radiation doses are estimated. The secondary neutron fluxes and energy spectrum are found to be strongly angle-dependent. Shielding thicknesses are evaluated using data from different authors and these data have been found to be reasonably consistent. Finally, the accelerator system activation problems are evaluated by reference to the experience of the Orsay synchrocyclotron. Taking into account the low current and low utilization factor of the accelerator, it is expected that the induced activity fields will be low (around 1 mRad/hour or less in most places after two days of cooling).

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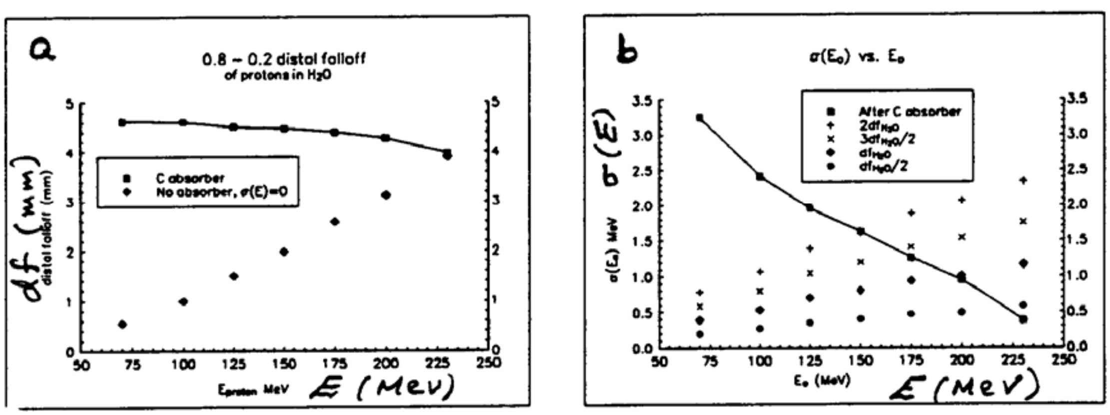
Do we need a degrader in front of the gantry?

Friedel von Goeler and Monroe. S. Z. Rabin, University of Massachusetts

Properties of energy degraded proton beams were studied using Monte Carlo simulation. Among the effects studied are the following two graphs: Plot a: intrinsic distal falloff (df) [0.8→0.2] due to the range straggling of protons in H2O, as well as the total df of a carbon degraded 230 MeV proton beam in H2O; Plot b: proton energy spreads, σ(E), that yield a given fraction (1/2,1,3/2,2) of the intrinsic df inH20, as well as the σ (E) resulting from degrading a 230 MeV [σ initial(E)=0.23 MeV] proton beam in carbon.



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Scanning System for Heavy Charged-Particle Beams

B. Ludewigt, W. Chu, T. Renner, M. Nyman, R.P. Singh Lawrence Berkeley Laboratory

Phase I of the beam scanning system development at LBL has successfully been completed and the clinical use of the system has started. The goal of phase I was to generate large helium and neon fields by deflecting the particle beam in a raster-like fashion with two dipole magnets. Particularly for beams heavier than protons, a magnetic beam spreading system avoids the degradation of beam quality caused by nuclear reactions in the scattering material. The field is fully scanned once with every beam pulse of 1 sec duration by moving the beam spot fast (20-40 Hz) in one dimension and slowly in the orthogonal one. Downstream of the second magnet the Bragg peak is spread by a ridge filter, an assembly of parallel metal ridges, and the residual range is adjusted with a variable water column or with metal range-shifter plates. An ionization chamber located close to the patient with 12 x 12 elements, each a 2.5 cm x 2.5 cm square, is the essential part of the dosimetry system. This detector measures the total beam delivered, monitors the dose uniformity, and safeguards against overdosing a particular spot. Uniform fields of up to 30 cm x 30 cm can easily be generated. The insensitivity of the dose uniformity to the centering of the beam has proven to be a great advantage in comparison to the wobbler or the occluding ring system. Depending onthe field size between 20 and 60 scans are needed to deliver a 2 Gy dose. This corresponds to treatment times between 2 and 4 min.

We have also made significant progress towards the goal of phase II that is the implementation of 3-D conformal therapy by scanning the target volume laterally with a small beam spot and in depth with the Bragg peak. The magnet power supplies have been upgraded for providing variable horizontal and vertical scan speed, and a multileaf collimator has been built for reshaping the field during a treatment. For monitoring the delivered dose distributions a parallel plate ionization chamber with a high position resolution provided by 3600 elements has been fabricated and the necessary readout electronics based on customized ICs are under development. This system will first be employed for treatments with neon beams.

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Update on MGH/LBL chordoma/chondrosarcoma results

J. E. Munzenrider, N. J. Liebsch, W. duBois, P. McManus, K. Convery, M. Urie, S. Birnbaum, J. Phillips, Massachusetts General Hospital

Through September 1990, 215 patients (109 male, 106 female; age range 5-60 years) with chordomas (CH) and low-grade chondrosarcomas (CSA) of the skull base and cervical spine have been treated with fractionated combined proton and photon radiation therapy. 130 patients had CH and 85 patients CSA. The tumor involved the skull base in 176 patients, the cervical spine in 39. Total doses ranged from 56.877.4 CGE; the median dose was 69.9 CGE.

Treatment outcome has been evaluated in terms of local recurrence-free survival (LRFS) and overall survival, as well as treatment-related morbidity. Local failure, defined as progressive neurological deficit with definite increase in tumor volume on CT or MRI scan, occurred in 36 patients (17%), while distant metastasis was documented in 9 (4%), with median follow-up of 37 months (range 2-187 months).

LRFS was significantly better for males than for females (86±7% and 81±9%, vs. 63.9±9% and 53±11 % at 60, and 84 months respectively, p = 0.0034), and for patients with CSA rather than CH (91±6% and 91±6% vs. 65±8 and 53±10% at 60 and 84 months, respectively, p = 0.0012). The sex difference applied only to patients with CH, with LRFS being 84.9±9% vs. 46±12% at 5 years (p = 0.0002). LFRS in patients with skull base tumors was better than in those with cervical spine tumors with the difference approaching statistical significance (p = .0616).

Overall survival was significantly better for CSA patients than for those with CH (94±5% at 40 months and later, vs. 83.8±6% and 69±10% at 60 and 84 months, respectively, p=0.008), and for patients with skull base tumors relative to those with cervical spine tumors (89±5% and 84±6% vs. 75±13% and 48±21 % at 60 and 84 months, respectively, p = 0.0002). Prior Cox regression analysis has shown age, sex, and histology to be significant predictors for local failure. Treatment-related morbidity included endocrine, auditory, visual, and brain complications of 27, 28, 11 and 20 patients respectively.

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Proton Scanning Beam Irradiation of Esophagus Cancer

B.V. Astrakhan, All-Union Cancer Research Center (AUCRC)

A new method of irradiating large cancer tumors at the synchrotron accelerator of JINI, Dubna, with a narrow proton beam by linear scanning and three-dimensional rotation of the patient will be described. Patient immobilization techniques, the method of beam scanning, verification procedures and peak dose localization will be presented.

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Clinical Results of Proton Beam Applications in Oncology at ITEP and JIM

G.D. Monzul, and B.V. Astrakhan, AUCRC, and E.I. Minakova, BNI

A broad overview of 20 years' experience of broad proton beam treatments of 700 oncological patients will be presented. Sites include cancer of the cervix, vulva, prostate, breast, esophagus, larynx, lung, osteogenic sarcoma and skin melanoma. The clinical justification for the PTF facility will be reviewed.

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Comparative Planning for Retinoblastoma

V. Benk, C. Crowell, A. Niemerko, M. Urie, Massachusetts General Hospital & Institut Gustave-Roussy, Villejuif, France.

Retinoblastoma is a pediatric tumor, treated conservatively by irradiation to 45 Gy, 5/w. Sequellae, cataract, bone growth defect and cosmetic problems, and hormonal deficit by the irradiation of the pituitary gland must be avoided as well as secondary cancers. In this study, the goal is to give 10% of the dose to the lens, minimizing the dose to the hypophysis and bone. The conventional treatment is a lateral photon beam (4 MV) for the target, defined as the posterior part of the retina behind the equator. This technique treats the normal structures to a high dose.

Using the beam's eye view to determine beams in different directions and the optimization program to assign weights to these beams, we can obtain the optimal treatment planning for photons and protons. We can also compare the dose volume histograms (DVH) of these different solutions for the studied structures. For photons, the choice is a three field technique (one superior, two obliques with wedges) delivering 50% of the dose to the lens . For protons, the actual choice is a single lateral beam designed with a penumbra of 0.3 cm and delivering 10% of the dose to the lens. Comparing these two solutions by DVH, the best coverage of target and the minimum dose to the normal structures is given by protons.

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Narrow Proton Beam Radioneurosurgery and Large Fraction Radiation Therapy at ITEP

E.I. Minakova, E.I. Luchin, and V.A. Krymsky, Burdenko Neurosurgical Institute (BNI)

An overview of the 20-year experience of clinical work with the ITEP narrow proton beam will be presented, including the treatment technique and clinical results of over 1500 intracranial tumors and arterial-vascular malformations (AVMs). Plans for future studies will also be presented.

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The vanishing boundary between radiosurgety and radiotherapy

Ken Frankel, Mark Phillips, Lawrence Berkeley Laboratory

Stereotactic irradiation of inoperable arteriovenous malformations (AVMs) is being conducted at the Lawrence Berkeley Laboratory (LBL) using the Bragg peak of the helium ion beam at the LBL Bevatron. Treatment of large, irregularly shaped lesions has necessitated the adoption of dose-shaping and target localization techniques that are currently in use or under development for heavy-charged-particle radiotherapy. Stereotactic cerebral angiography and stereotactic (non-contrast and contrast-enhanced) CT studies are conducted. An MRI study is also obtained. Tentative target volumes are defined on the cerebral angiographic AP and lateral radiographs, contrast CT, and MRI studies. The target volume from all studies is transferred to the non-contrast CT scan. Inconsistencies in target definition can occur, and an iterative process is undertaken, until the final target volume is obtained. The treatment planning program is used to generate localization overlays. Beamports are selected, and the treatment planning program is used to design apertures and compensators, and to select beam ranges. Treatment plans are generated using the current LBL 2-dimensional treatment planning system. Research was supported by Office of Health and Environmental Research, U.S. Department of Energy Contract DE-AC03-76SF00098.

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Commissioning studies for the horizontal beam line at Loma Linda

J. V. Siebers, Loma Linda University Medical Center

Commissioning studies have been completed on the Loma Linda proton therapy facility's horizontal beam line. The horizontal beam line delivers 155 and 200 MeV protons through a double foil scattering system to produce a field size of 15 x 15 cm with a uniformity of better than ±3%. Uniform depth dose profiles are achieved through use of a rotating variable thickness polycarbonate modulator wheel. At 200 MeV, treatment depths up to 21.1 cm are achievable; while at 155 MeV, a maximum depth of 13.1 cm can be obtained. Dose uniformity of better than ±2% is observed with modulations from 3 to 10 cm. The penumbra (90% - 50%) on the lateral dose profiles with the 155 MeV beam varies from 0.2 cm at 1 cm penetration to 0.4 cm for 12 cm penetration. At 200 MeV, the penumbra varies from 0.2 cm at 1 cm penetration and to 0.6 cm at 20 cm penetration. Dose rates over 100 cGy/min have been achieved, this results in treatment times under 2 minutes.

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Computer Support for PTF Project

V. M. Breev, ITEP, and S. V. Lebedev and A.J. Silin, MRI

The problems of both hardware and software support for the PTF project are considered. Some of the topics of interest include computer-controlled systems for treatment, treatment planning, simulation, computer networks and databases.

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Tests for Intercomparison of Radiotherapy Treatment Planning Systems for Proton Beams

LA. Ermakov, A.M. Cherviakov, S.M. Vatnitsky, CRIRR

Dose results from five different treatment planning systems were compared for electron and photon beams for the studies described above. Using the experience of intercomparison in these studies, we propose intercomparison tests concerning typical cases of irradiation for proton beams (e.g., regular fields, oblique incidence, compensated fields, etc.). Comparison of dose-volume histograms is also discussed.

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Dose Measurements in Proton Beams Using an Ion Chamber and Diamond Detector

S. Vatnitsky, I. Ermakov, A. Cherviakov, G. Kucholev, I. Gromova, G. Lutina, Central Research Institute of Roentgenology and Radiology (CRIRR)

The comparison of data for a calibrated ion chamber and diamond detector for 100, 250 and 1000 MeV proton beams will be presented, along with a description of the practical procedures for this dosimetry. In addition, the results of a preliminary comparison of the derived dose to water in a phantom irradiated by high energy photon and electron beams using different published protocols for the conversion and correction factors for absorbed dose (AAPM, NACP, HPA, and a new USSR protocol) will also be discussed.

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Water Calorimetry in the Harvard Cyclotron proton beam

R.Schultz, Yale University

The flexible, temperature-regulated, sealed-glass-core, absorbed-dose, water calorimeter developed in our laboratory utilizes nitrogen-saturated, high purity water, and is operated at 4°C so as to avoid convection currents. The temperature changes induced by irradiation, usually about 2 millidegrees, is detected by the resistance change in two thermistors connected into opposite legs of a Wheatstone bridge. As the same bridge circuit is used for the calibration of the thermistors (resistance vs. temperature), the accuracy of the calorimeter depends only upon the accuracy of a precision mercury thermometer. A dummy calorimeter of nearly identical construction supports an ionization chamber at the same position as the thermistors in the water calorimeter. The dose-to-water obtained from the calorimeter has been compared to the dose-towater from the ionization chamber using the TG-21 formalism. The ratio of these doses, the so-called Cal/Ion ratio, has been determined for 60Co and 4, 6 and 25 MV x-rays; the grand mean and standard error of the Cal/Ion ratio for this series of measurements is 1.000 ±.001. During April and August 1990 similar measurements were made using the 160 MeV proton beam at the Harvard Cyclotron Laboratory. The dose-to-water from the ionization chamber was determined in accordance with AAPM Report 16. The Cal/Ion ratio for these two experiments were 0.992 ± 0.004 and 0.990 ± 0.004. The 1 % deviation from unity in these experiments may be due to the straight-line tracks of protons compared with the wiggly tracks of the secondary electrons which traverse the chamber during exposure calibration.

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Regulatory and economic issues in proton therapy

A. Morrison, Zelenkofske, Morrison and Associates

A variety of regulatory and economic issues must be considered in evaluating the economic and other feasibility of the development of a clinical facility for proton beam therapy. On the regulatory side, these include compliance with the Medical Device Amendments of 1967 ("MDA") which dictate the Food and Drug Administration's regulation of medical devices and the requirements of the federal Medicare program. Other major economic considerations include development and operating costs, debt service expenses, patient volumes, the mix of services delivered to each patient and payment by insurers. The following is a brief synopsis of these issues based on our work for Loma Linda University Medical Center over the past five years as well as our experience in evaluating the feasibility of a clinical facility for proton therapy for two other domestic teaching hospitals.

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Plans for a proton medical facility at MGH

M. Goitein and K. Gall, Massachusetts General Hospital

A progress report on the planning of a Proton Medical Facility at the Massachusetts General Hospital is given. To date we have reviewed existing programs and facilities, especially those of MGH/HCL and LLUMC, and compiled data to determine the appropriate size and scope of the facility. The site selection process has been concluded with the identification of a preferred location, workable within the MGH Master Plan for development. An initial architectural design has been completed for cost estimating purposes, based on the equipment and configuration of the LLUMC facility. Financial analyses have been conducted to guide the development process and to project the allocation of resources within the existing Radiation Oncology department and the hospital. With the working groups now in place we expect to conclude these initial design studies and proceed with detailed design of a chosen configuration in the next phase of development.

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Design Study for the UC Davis Proton Facility

Jose Alonso, Lawrence Berkeley Laboratory

The University of California at Davis is developing plans to build a proton therapy facility as a part of its Cancer Center in Sacramento. The UC Davis Proton Facility will be installed in a new building to be erected adjacent to the present Cancer Center building. UC Davis and LBL are developing an agreement to advance this project; LBL will design the accelerator, beam transport and beam delivery systems, will oversee their construction, and will be responsible for commissioning and initial operation of the Proton Facility at the Cancer Center. As construction of the accelerator systems will quite probably be finished prior to the new building's completion, we plan at this time for the accelerator to be installed within the experimental area of the Bevalac, and connected to the currently-operating treatment facilities. This will allow for full commissioning of the accelerator, from initial operation to full readiness for clinical use of the proton beam, prior to its transport to its permanent location at the UC Davis Cancer Center. Within a few months decisions will be made on the major specifications and architecture of the technical systems, to allow approximately a full year for performing the optimization, design and costing studies, leading to the production of a Full Design Report. Detailed designs will emerge from very close interfacing between clinical, medical physics, accelerator physics and engineering personnel; final specifications for each element emerging during the course of the year as a result of design, function and cost optimization studies. The design report will include scope and costing of conventional aspects of the project as well; we will be working with the UC Davis A&E office to integrate the UC Davis Proton Facility into the long range Hospital and Cancer Center plans. An analysis of regulatory requirements, and costs for compliance documents will be estimated as well. Finally, a model for operations of the facility will be developed, to identify required ongoing operations costs. The Full Design Report will be a blueprint for the entire UC Davis Proton Facility, it will be a document essentially suitable as a bid package.

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Algorithms for 3-D Treatment Planning

A. M. Cherviakov, I. A. Ermakov, S.M. Vatnitsky and A.V. Miller, CRIRR

Methods of calculating the 3-D dose equivalent to organs due to scattering and leakage radiation from the proton (70-260 Mev) and neutron (d10/Be) beams will be described. The fast algorithm for calculating dose is empirically derived, using basic parameters. Dose-volume histograms and organ dose equivalent have been investigated. Calculations are compared with ion chamber measurements in a human phantom model.

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3-D Treatment Planning for Radiation Therapy: A Decade of NCI-Supported Research

S. Zink, Radiation Research Program, National Cancer Institute

Since 1982, the National Cancer Institute (NCI) has funded a number of collaborative working groups to develop and evaluate the role of three-dimensional (3-D) treatment planning in radiation therapy. The 3-D research had its beginnings in the particle therapy programs and was then expanded to high-energy photon and electron beam treatment planning. Current research is focusing on the portability issues of radiation therapy software and the development of specific tools that will facilitate the implementation of 3-D treatment planning into routine clinical use.

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