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ABSTRACTS

of the

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Current Status of the Dedicated Monte Carlo Code for the NAC Proton Therapy Beamline.

A. Tourovsky, N. Schreuder, and E. de Kock, National Accelerator Centre, Faure,7131 South Africa.

A dedicated Monte Carlo (MC) code that is capable to model in full the NAC proton therapy beam line has been developed at NAC in the beginning of 1999. The code simulates 3D dose distributions in any 3D object defined as a CT cube. Results of this code have been extensively checked against existing experimental data. The agreement between simulated and measured data for depth dose curves and lateral profiles was found within 2-3% for all analysed virgin beams (from 1 cm to 10 cm in diameter) and SOBPs (from 5 cm to 8.5 cm) for differently degraded beams (R50 from 8 cm to 16 cm). Monte Carlo simulations also showed that for the NAC beam line the 3D dose results obtained in a water tank are relatively insensitive to fluctuations in the beam initial angular-spatial distribution treated as a product of uncoupled 2D Gaussians. For example, an increase of the initial angular standard deviation by a factor of 30 results in only 5% drop in the central part of the deepest lateral profiles.

In September 1999 a multi-field version of the MC code was incorporated into the NAC treatment planning system. This version allows full verification of any treatment plans and is especially useful in cases of complex heterogeneities with high-density gradients traverse to the beam, where results of any analytical calculations due to their inherent restrictions might be in error. The next step in the code development will now consist in building through MC simulations a comprehensive library of phase space distributions on entrance to the patient collimator. Pilot studies indicate that starting MC simulations at this point rather than at the vacuum window will considerably speed up the calculations resulting in - 2 - 15 min per field. Ultimately this might allow building up a treatment planning system fully based on MC calculations.

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The use of Monte Carlo tool GEANT for characterization of dose distributions in narrow proton beams.

S. Vatnitsky, V. Bashkirov and D. Miller, Department of Radiation Medicine, Loma Linda University Medical Center, Loma Linda, CA92354

The Monte Carlo program based on GEANT Detector Description and Simulation Tool, version 3.21 was used for dosimetry characterization of narrow proton beams. Narrow proton beams with diameter down to 2.5 mm could be useful for functional radiosurgery of intracranial targets. Proton beamline elements, including stereotactic radiosurgery cone, were presented with detailed geometry and material description to transport a 250 MeV beam through the beamline to the water phantom. The simulation has been performed in cylindrical geometry to score in detail the energy deposition both laterally and in depth, with control of basic physics processes:

- multiple Coulomb scattering according to Moliere theory
- hadronic interactions with generation of secondaries
- continuos energy loss with generation of delta-rays above 10 KeV and restricted Landau fluctuations below 10 KeV
- decay in flight with generation of secondaries
- photo-electric effect, compton scattering, pair production and bremstrahlung.

Computed off-axis dose profiles and centralaxis depth dose distributions for narrow beams were compared to the data measured with a 10-cm parallel plate ionization chamber (large detector) and a radiochromic film (point detector). The agreement between measured and simulated dose distributions was demonstrated within accuracy of measurement.

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Monte Carlo simulations of collimator scatter in small proton beams

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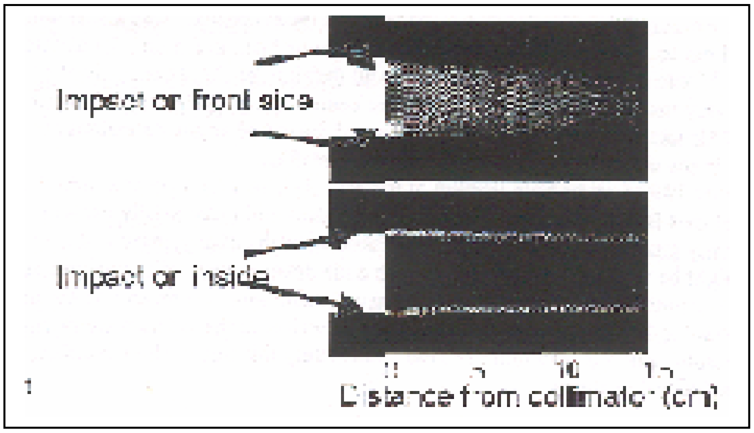
Monte Carlo simulations have been performed to determine the influence of slit scatter on the dose distribution of 150 MeV protons. Slits with a width varying from 2 to 40 mm have been simulated. The Monte Carlo code (GEANT) has been validated against measurements with a scintillating screen, observed by a CCD camera. The spatial resolution of the measurements can be characterized by a Gaussian line-spread function with a standard deviation of 0.22 mm.

The simulations show that protons that enter the collimator on the front side and leave the material through the wall of the aperture are responsible for the largest scatter contribution. At the collimator exit the local contribution to the dose is about 20% and at 15 cm from the collimator it is spread out and drops to a 4% contribution to the dose. The figure shows the dose-contributions of the two impact positions behind a 20 mm aperture.



In a well-aligned system the scatter on the aperture wall has a very small effect on the dose distribution. In the simulated setup the 20%-80% penumbra is not influenced by collimator scatter. Air scatter is the dominant contribution (0.8 mm) to the penumbra (total: 1.0 mm).

The energy spectra of the scattered protons indicate that low energy protons (with RBE>1) are subject to strong spreading in lateral direction. Therefore the effects due to high RBE are diluted. The increase of the biological damage due to high RBE is not more than 1% at distances larger than 2.5 cm from the slit.

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Correct solutions to the inverse problem in proton therapy planning.

M. F. Lomanov, Institute of Theoretical and Experimental Physics, Moscow, Russia.

The principle of conformal irradiation accepted already everywhere, practically expresses the same concept that was earlier designated as aspiration towards the solution to the inverse problem in dose planning. In essence its solution assumes consecutive development of analytical calculation by convolution methods. At the same time successfully developing Monte Carlo method goes along a completely opposite way of a direct problem, and it can solve even inverse problems but sometimes at the expense of a very long search. However application of protons in itself creates a prerequisite to simple inverse problem solutions much shorter due to the application of protons. One of such examples is the well known method of dose field homogenization by means of bimaterial scatterer. This problem has a simple analytical solution for a transverse dose distribution. Depth dose can be formed using the principles of inverse problem, while in continuous slowing down approximation (CSDA) this task is reduced to solving an integral Volterra equation of the first kind. These two examples show that in homogeneous media the inverse problem has a correct solution. In case of inhomogeneous media a similar solution method is obtained for a simple model what had been solved earlier by Monte Carlo method (M.Goitein and J.Sisterson). A long bone inclusion parallel to a beam is considered there. For multiple proton scattering an analogue of CSDA approach is constructed, and then it is possible to find a solution to the integral Fredholm equation problem of the inverse problem kind.

The following example is similar to edge effects observed and calculated recently in dose distributions' penumbras ("ears" in dose field). This is seen in dose fields measured at ITEP. A superposition of "reflected" (scattered in collimator walls) beams with the original beam creates an effect of multiple centres of beam focussing. As a result, isodoses become much more parallel to the beam in the area of SOBP. Despite the complex mechanism of these effects, their result allows analytical approach, which also should be considered as a component of inverse problems.

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Use of solid-state track detectors with a Np-237 target for measurement of the mixed proton and neutron radiation behind local radiation shielding.

M. F. Lomanov, and A. S. Gorbatenko, Institute of Theoretical and Experimental Physics, Moscow, Russia.

A proton dose distribution which is distinguished from a photon field by well defined edges, is always accompanied by a field of secondary neutrons, as wide as that around a photon beam. The tolerant value of this neutron background is defined for conventional irradiation by quality assurance requirements and can not exceed a few per mille. Disregard of this question results in the fact the neutron dose in proton beams frequently exceeds this value. Therefore a method of measurements that satisfies three requirements has been applied at ITEP:

(i) processing of results is extremely simple;
(ii) the method is sensitive to neutrons in the required energy range, and

(iii) the method is also sensitive to the primary or scattered fast protons, the dose from which can exceed the dose from neutrons. Most recently these measurements were made at ITEP in February of this year in connection with a reconstruction of a treatment room. Earlier, similar measurement had been made in Loma Linda as well.

Dosemeter of the mixed proton and neutron radiation represents a sandwich containing a foil from U-235, natural uranium or aluminium with a thin layer of Np-237 as a target. In the latter case sensitivity of the gauge is optimal. Actual detector is a glass substrate. After weak etching the nuclear tracks of fission fragments are counted up under a microscope.

The problem of "the all - wave neutron detection" for biologically equivalent dose can be solved in this case as follows. The sensitivity of the gauge is satisfactory for a broad and non-uniform neutron spectrum only in a very rough range of accuracy. It is an undesirable but acceptable error value for the dosimetry of a small dose. The wide use of Monte Carlo methods can solve this problem. The background of secondary radiation can be calculated for each beam delivery system by the GIANT4 program. Along with usual calculations, a correction for spectral sensitivity of the gauge can be taken into account to increase the accuracy of the method. Within the limits of quality assurance requirements the operative check-up of neutron and proton dose background can be executed using this labour-saving method.

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Comparative treatment planning between proton and x-ray therapy in pancreatic cancer

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Purpose: With the utilization of new biologic agents and experimental chemotherapy in the treatment of pancreatic cancer, issues of local-regional control will become increasingly important. The total dose of radiation is limited by the tolerance of the normal tissues in the pancreatic region. This study was undertaken to determine the feasibility of dose escalation using proton therapy by minimizing the dose to normal tissues.

Materials and Methods: The photon treatment plans of 4 patients with unresectable pancreatic cancer treated on a Farnesyl Transferase Inhibitor (FTI) trial were utilized. Each patient was treated using a 3 field or 4 field photon plan with 4500 cGy to the clinical target volume (CTV) followed by a boost of 1440 cGy to the gross target volume (GTV). Using a Helax treatment planning system, proton plans were generated to encompass the same CTV and GTV to the same prescribed dose levels. Dose-volume-histograms (DVH) were generated for the GTV, CTV, spinal cord, liver, right kidney, and left kidney. Each DVH was compared between photons and protons. Proton plans utilized either a 2 field or 3 field technique. Available energies included 130 MeV or 180 MeV. Range modulators and bolus were used as needed to conform to the target volume.

Results: All individual proton plans were superior to the photon plans in terms of a reduction of normal tissue volume receiving a significant radiation dose. Both the CTV and GTV received the same dose from the proton and photon plans. However, there was a significant reduction in dose to normal tissues with each of the proton plans. For the 4 patients, the average dose (Gy) to 50% of the organ at risk is reported for both protons and photons in the following table:

Structure	Photon Dose (Gy)	Proton Dose (Gy)	Dose Reduction	p-value
Spinal Cord	27	6	78%	.003
Liver	22	10	55%	.061
Right Kidney	14	8	43%	.059
Left Kidney	11	3	73%	.025

Conclusions: These comparative treatment plans show proton therapy results in significant reductions of dose to normal tissues compared to conventional photons while treating the same target volumes. This may allow for the design of dose escalation protocols using protons in combination with new biologic therapies and chemotherapy.

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<AntiGANTRY> (<AG>)- a new system of engineering and technology of rotational-scanning proton/heavy ion therapy without GANTRY.

B. Astrakhan, Russian Cancer Research Center (RAMS), Moscow, Russia

In <AG>- system: The patient is put in thin-walled capsule and they fulfilling fixation of all surface of his body with modified Vac-Lok immobilization system. The capsule is established upright (i.e. the patient is standing) on the Stand which carrying out all transposes of the fixed patient during preparation for and into process of therapeutic irradiation (rotation, with transposes in two-dimensional directions). The patients are prepared for an irradiation (including fixation, centretion, serial horizontal CT-tomography) simultaneously and separately in 6 Preparatory procedural rooms, placed outside of a zone of irradiation. The computer aided transport system automatically delivers the next patient from Preparatory procedural room to Radiative one and back together with the Stand, without infringement of quality of fixation and centretion (for example, on a track or magnetic pillow).

In time of therapeutic irradiation vertically located patient is rotated and moved in two-dimensional directions under a horizontal motionless or scanning beam of protons/ions. The design of the Stand allows to place the capsule with patient not only vertically, but also in horizontal or in any intermediate position (for example, for an irradiation in a "laying" position).

Such organization of preparation and irradiation of the patients allows to take the most of throughput of the accelerator (up to 1000-1200 patients per one year) and carry out a rotational-scanning or linear-scanning irradiation of tumours of any forms, sizes and localizations. <AG> can work with any medical accelerator of protons/ ions needlessly either constructive alteration or adaptaton.

The area of 300 sq.m. is necessary for accommodation <AG>-system (without rooms for the accelerator and the stuff). The cost price of a serial copy of system will make about 1 million bucks, including cost of horizontal computer tomographs of an original construction in any of Preparatory procedural rooms.

The offered <AG>-system works as conveyer and practical all of its (not numerous) units can be made by methods of line manufacture, - on conveyer.

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Remark on the report of Dr. Astrakhan about Antigantry System.

M. F. Lomanov, ITEP, Moscow, Russia.

The authors should comment on the previous report, and also state opinion on it of Russian radiotherapeutists and medical physicists, about what they asked, having familiarized with the Meeting schedule. On a number of forums and at expertise of this offer, which is carried out by the experts of the leading radiological centers of Russia, the given variant solving a problem was not maintained. For some reasons in 80 years proton therapy, working on the fixed beams, has gone to impasse, because of caused by it an original manner of irradiation. At an irradiation of the sitting patient the unstable situation of the majority of targets is created. Besides it appears impossible to use the complete information from an arsenal of intrascopy (CT, NMI, PET, gamma camera), as exact (of 30-100 cuts) topometry defines a success of treatment planning. Thus, on the fixed beam there are restrictions in selection of the patients. In result the sphere of diseases accessible for treatment was limited up to Nineties by 5 % of structure of oncological morbidity. Generally speaking, all what has been told is not our reason. All this has passed the analysis of the leading experts and contains in the recommendatory IAEA document, Report on the Utilization of Particle Accelerators for Proton Therapy (7-10 July 1998, Fl-AG-1010, Vienna). There is shown that using gantry and all modern means of topometry, proton therapy applicability could extend up to 24-29% of all oncological morbidity structure. That is, excluding brachitherapy, practically up to a complete set of localizations accessible to external therapy. Certainly, it is possible to carry out revision of almost 50-year's experience of proton therapy. But before introduction in clinical practice of this offer, the cycle of preclinical researches confirming an opportunity of prospective technology to carry out the objective description of a target is absolutely necessary, to check up preservation of a position of the patient and syntopy of a target and organs in a zone of interest at topometry in laying position and irradiation in sitting position. It is necessary also to determine a spectrum of localizations (probably, it will appear again 5 %), by which it is possible to make a dose by the fixed beam, and to solve many other questions.

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Methods of passive proton beam formation for conformal irradiation

V. S. Khoroshkov, M. F. Lomanov, O. B. Ryazantsev, and B. B. Shwartsman, The Institute of Theoretical and Experimental Physics, Moscow, Russia

One of the advantages to proton beam therapy is the flexible approach to dose field formation. This argument was long ago put forward by B. Larsson, and corresponds well with the concept of conformal irradiation. Since then, conformal methods have been extensively developed in conventional gammatherapy. In proton therapy such potentialities are inherently present. It is indisputable, that the most ample opportunities for conformal dose field formation can be provided by active methods, i.e. by scanning a pencil beam over a target. However due to their simplicity, passive methods are widely used, and hardly will be refused in near future. Their basic advantage is realization for many specific tasks of dose field formation by rather simple means, and optimality of their choice has required the analysis included in the presented work.

At ITEP, after the decision to reconstruct one of the three treatment rooms with horizontal beams was accepted, the acute need to sum up this experience became evident, as it happens when a new device is developed. The purpose of the reconstruction is to extend the use of the ITEP proton clinical beam to include prostate cancer radiation treatment. Besides, treatments of other lesions such as bladder cancer, kidney cancer etc. using lateral fields are also planned. These objectives can be met by employing large dose fields.

This report presents a discussion of two approaches to designing a system for large dose field formation. In the first approach, the synthesis of transverse and depth dose distributions is incorporated, completely or partially, in a single constructive site with several elements such as bimaterial scatterer and dose modifiers such as the widely used "propeller" or the axially symmetric ridge filter described in the report by D. Nichiporov. According to the second approach both tasks are implemented by different elements which act independently and may be significantly separated in space. In this case the distance between ridge filter and a target is much less. An example of this approach is briefly described.

Criteria to evaluate the advantages and disadvantages of each of the approaches are proposed. The possibility of using one system with changeable geometry to form dose field of different sizes is also discussed.

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Stopping-power de endence of the light production in a fluorescent-screen based dosimeter.

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For dosimetry applications in proton therapy, successful use is made of a scintillating (fuorescent) screen and a CCD camera. However, similar to many types of dosimetry systems, it has been observed that the response of the system varies with LET. In earlier work [11 it has been shown that in the Bragg-peak region of the proton beam the light yield of the system is up to 8% less than expected. This quenching of the signal is caused by a combination of an averaging of the dose over the finite thickness of the screen and a saturation of the number of available scintillation centres.

We are developing a model that describes the quenching for different beam characteristics. It has been observed (1) that the light yield as a function of dose D *is* proportional to $(D/D_o)/(1+Q\ x(D/Do))$, where Do is the dose at a reference depth and Q is the quenching factor responsible for the effects mentioned above. A systematic study of the quenching using different particle beams has been made. Our data set of quenching with proton beams has been extended by measurements with 157 MeV a-particles from the KVI cyclotron and 130-350 MeV/nucl ^{12}C particles at the heavy-ion therapy facility at GSI. The heavy-ion data have been obtained in two beam-line modes: with and without a ridge filter, which spreads the very sharp ^{12}C Bragg peak over several mm. The fitted values of Q show a clear systematic trend as a function of energy-spread in the Bragg peak. It has been observed that if the highly-ionizing particles are more diluted over different depths due to energy straggling, the quenching decreases. The results of the experiments and analysis will be presented, as well as a recipe for the correction of dosimetric data that suffer from a quenching effect. 1) S.N. Boon. et al., Med. Phys. 25 (1998) 464

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The Development of a Multi-layer Faraday Cup to Characterize the NAC proton therapy Beam.

A. N. Schreuder, A. Tourovski, A. Kiefer and J. van der Merwe, National Accelerator Centre, P 0 Box 7131, Faure, South Africa.

The quality and reproducibility of the proton beam extracted from the separated sector cyclotron (SSC) at the National Accelerator Centre (NAC) for proton therapy treatments are very important. The quality of the beam is defined in terms of its maximum energy and the energy spread in the beam. It is evident that some drifts in the beam characteristics will take place as a result of the rapid energy changes (less than two hours) required by the proton (200 MeV) and neutron therapy (66 MeV) programs. This is due to stabilization effects in the main magnets of the SSC. It is also possible to extract a portion of an inner orbit where the protons have a lower energy from SSC, thus mixing lower and higher energy protons in the beam.

It is standard practice to measure the energy of the proton beam between every two patients treated using a range monitor which comprise of a set of stacked parallel plate ionization chambers in the beam line. This device does not give enough information to detect small drifts in the energy spread of the beam. Furthermore such an energy measurement cannot be done while anybody is in the treatment room which is the case during the patient-positioning phase. A detector was therefore required to measure the beam energy upstream of the treatment room during the patient-positioning phase of the treatment.

It was decided to install a multi-layer Faraday cup (MLFC) in the high-energy beam-line just upstream of the neutron shutter, which stops all the secondary radiation produced (mainly neutrons and gamma rays) while the beam is stopped by the MLFC. The MLFC consists of an 41 mm thick brass block followed by 30 Aluminum plates which are 0.65 mm thick and are insulated from each other by 80 microns thick Kapton foils. The current from each Al plate is proportional to the amount of protons stopping in the plate. Using Aluminum allows spreading the Bragg peak over 13 channels compared to 5 channels if .0.5 mm brass plates would have been used. This allows fitting some analytical functions such as a double Gauss or a cubic spline to the data.

A special software package was developed to interpret the data obtained from the MLFC and to compare a specific measurement with a so-called "golden standard" which was obtained when the beam characteristics were optimally adjusted. The cyclotron operators can now do an energy analysis during the patient-positioning phase. If any drifts in energy or energy spread are detected it can be re-adjusted prior to sending the beam into the treatment room.

The functionality of this package as well as the minimum drifts in energy spread and maximum energy detected will be discussed.

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SOBP Modulator: A New Design for the Old Concept.

V. Kostjuchenko, D. Nichiporov, and V. Luckjashin, Institute for Theoretical and Experimental Physics (ITEP), Moscow.

Principles of conformal proton therapy have stimulated a variety of methods aimed at creation of dose distributions that match the target volume. A general discussion of these principles is given in the report "Methods of "passive" proton beam formation for conformal irradiation" by M. F. Lomanov et al. One of the methods to tailor a dose distribution is the well-known Spread Out Bragg Peak technique used to produce a uniform depth dose plateau of desired length.

While many of the proton treatment facilities employ the propeller wheel-type design of the SOBP modulator, this design cannot be implemented at the beams characterized by high duty factors. We present a new design of a static, compact, and easily manufactured SOBP modulator that may serve as an alternative to the wheel-type design. Implemented at ITEP along with the double scattering system, the compact SOBP modulator allows one to produce dose distributions whose lateral profiles and distal falloffs are on a par with those provided by the traditional wheeltype design. Simple additional shading elements may be used to alter the length of the SOBP plateau, thus making it possible to use one SOBP modulator for production of multiple depth dose distributions.

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Status and prospects of Hadron radiotherapy centre in Dubna.

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A seven-compartment medic-technical complex for hadron radiotherapy of cancer patients based on the 660 MeV proton Phasotron has been constructed and now it is in operation in the Joint Institute for Nuclear Research (Dubna, Russia). It allows tumour treatment with wide and narrow horizontal beams of protons (70-660 MeV), negative pions (30-80 MeV), high-energy neutrons (mean energy 350 MeV), and with their combinations. The complex includes 7 treatment rooms supplied with the equipment required for radiotherapy.

For precise treatment planning and verification new methods of reconstructive X-ray, proton, and positron emission tomography have been developed. Different techniques of irradiation, such as scanning rotation irradiation of deepseated tumours, simultaneous scanning irradiation of a large target with 14 narrow proton beams, the commonly-used method utilising boluses and shaping collimators have also been devised and equipment constructed and the approval has been started.

In 1999 after relatively long idle period (since 1996), which was caused mainly by financial problems, proton irradiation of cancer patients was resumed. Nine patients with malignant tumours seated in the head, neck, and trunk were treated with a decelerated 150 MeV proton beam using the techniques of boluses and a hand-adjustable multi-leaf collimator.

For treatment planning special software was realised. For calculation of dose filed distribution we use X-ray tomographic images measured layer by layer with the help of the horizontal computer tomograph linked with the therapeutic chair, which ensures a high accuracy of irradiation planning.

An important step in the plan of organization of wide treatment of oncological patients with the JINR Phasotron beams was inauguration of the first line of a specialized onco-radiological department for 30 beds in the Dubna Hospital. This will allow us to treat up to 150 patients per year with the JINR medical beams if the extrabudgetary funds are available.

An official license of the Russian Health Ministry for carrying out the clinical researches on hadron radiotherapy of cancer patients in the Medico-technical complex of JINR has also been received.

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Development of new proton radiosurgery technique for large-size intracranial lesions: role of radiochromic film dosimetry.

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Proton-beam radiosurgery technique delivers less dosage to normal brain for large, peripherally located and irregular shape lesions in comparison to other modalities such as Leksell Gamma Unit and multiarc photon beams from a linear accelerator. Based on above conclusion the proton radiosurgery technique for large-size brain lesions has been developed in Moscow during last year. Characteristic features are as follows: proton beam energy - 160 MeV; diameter of the beam up to 6 cm; maximum water-equivalent penetration - 12.8 cm; patient is in sedentary position; immobilization with individual thermoplastic mask; beams approach the target from any angle in axial plane of the head. Treatment chair allows three axes linear translation and 3600 rotation around the vertical axis. Laser beams and stereotactic X-ray films are used for target alignment.

PURPOSE: To apply radiochromic film dosimetry for the verification of new proton radiosurgery technique; to evaluate dose calculation algorithm of the 3-D image-based treatment planning system TPN, developed at the LLUMC and modified to accommodate treatment delivery apparatus of ITEP.

METHODS AND MATERIALS: Measurements of Bragg peak proton dose distributions have been performed using MD-55 radiochromic film. These distributions were compared to the dose distributions calculated with treatment planning system, TPN. Two experiments have been performed. The first one simulates relatively simple plan with two beams in homogeneous Lucite phantom. The second experiment evaluates real patient treatment plan with four beams to test new features for ITEP treatment techniques: the use of CT data for anatomy delineation and beam range calculation, irregular aperture design and Lucite range shifters. In order to match patient dose distribution and dose in a Lucite phantom each beam in the phantom plan was allowed to penetrate to the same distance as in CT-plan.

RESULTS: The absolute doses at the reference points of exposed films were compared with the dose delivered at ITEP using a local dosimetry monitor and the agreement close to the accuracy of film dosimetry (+/- 5%) was demonstrated. An agreement between measured and calculated profiles was to within few millimeters at a high isodoselevel, but at the lower isodose level the difference is about 5-8 mm. The observed difference can be attributed to theuncertainties in matching of dose profiles from tilted film and calculated distribution, the difference of theradiochromic film sensitivity at the very distal end of the Bragg peak and less accuracy of radiochromic film for lowdose region.

CONCLUSIONS: Based on this comparison, one may expect similar agreement during patient treatment, except for some additional uncertainties (patient set-up errors, motion errors etc.) that were not simulated in this experiment verification.

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The evaluation of magic cube dosimeter for mapping of dose distributions in proton beams

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The Magic Cube dosimeter was designed at the University of Turin to monitor and characterize the performance of proton beamlines. The device has 12 transmission parallel plate strip ionization chambers separated with plastic absorbers to set the chambers at different depths. Data acquisition system is controlled by PC-based software. Commercial version of the Magic Cube produced by the High Vacuum Process, Italy was evaluated at the Department of Radiation Medicine, Loma Linda University Medical Center for measurements of relative dose distributions in clinical proton beams. Depth dose distributions and lateral profiles at different depths for modulated proton beams registered by the Magic Cube were compared to the data obtained from dose measurements with ionization chamber and with radiographic films.

The tests indicate that the MC dosimeter registers proton dose distributions with accuracy comparable to the other detectors (film, parallel plate ionization chamber). This result allows to use the MC dosimeter instead of radiographic film for mapping

lateral dose distributions in proton beams in order to speed up measurements during beam line alignment or tuning scattering foil system, or scanning beam system. Due to the size and weight of the device (about 100 kg) it is problematic to use the MC dosimeter for routine QA in clinical proton facilities.

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Dosimetry of Small Proton Fields for Eye Treatments.

J. Heese, H. Morgenstern, H. Kluge, H. Fuchs, H. Homeyer, C. Rethfeldt, and I. Reng, Hahn-Meitner Institut, Berlin, Germany.

In proton beam treatments of ocular tumors, wedge filters are often inserted in order to obtain a better protection of the optic nerve or the macula. However, the treatment planning program EYEPLAN calculates the corresponding isodose distributions in eye tissue a very simple way. This may cause deviations between the actual isodoses in tissue and EYEPLAN calculations when collimators with wedges are used. Two effects occur which are not implemented in the EYEPLAN isodose calculation:

1. a dose maximum of 5-10%, dependent on the wedge angle and distance from the collimator, arises at positions corresponding to the edge of the wedge,
2. the proximal penumbra is broadened behind the collimator area covered by the wedge.

The latter effect displaces isodoses in comparison with EYEPLAN calculations. During treatment planning, this can be taken into account by changing the patient-wedge distance or the collimator outline.

Isodoses behind collimators have been measured with ionisation chambers, high-purity silicon diodes and a scintillator/CCD system. We report on the measurements and simple calculation formulas for the isodose displacement due to wedges for the Berlin setup. Comparisons with EYEPLAN calculations will be presented.

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Cosmetic Aspects of Proton Irradiation for Retinoblastoma.

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Purpose. The superior dose localization properties of protons compared to photons can minimize the development of adverse effects in non-target tissue. This is especially important in the treatment of growth centers in children. We have analyzed the facial development of the first six patients treated for retinoblastoma with proton therapy at the Harvard Cyclotron Laboratory (HCL).

Material and Methods. Between 11/86 and 12/91, six patients with the diagnosis of retinoblastoma were treated at HCL with 160 MeV Protons in collaboration with Massachusetts General Hospital (MGH) and Massachusetts Eye and Ear Infirmary (MEEI). All six suffered from the hereditary or bilateral form of disease. In all patients only one side was treated with radiotherapy. The other side was treated either with conservative methods (N=3) or enucleation (N=3). The median dose delivered to the treated eye was 42.6 Cobalt Gray Equivalent (CGE, 1 proton Gray = 1.1 CGE; range 42.6 - 49 CGE), delivered with protons only, at 2.13 CGE per fraction. Follow-up examination was performed at regular intervals. Serial facial photographs were available to assess the effect of proton irradiation on facial development.

Results. Median age at treatment was 5.2 months (range 0.9 - 30.3 months). At a median observation time of 9 years (range 6.6 - 11.6 years), all patients are alive and well. With one exception, patients have good or excellent vision in the treated eye. Abnormalities of the bony orbit and the surrounding soft tissues were minimal on the treated side when compared to the non-enucleated untreated eye (N=3). The facial asymmetry was more pronounced on the enucleated side than the irradiated side in 2 patients, while the third patient had a normal appearance on both sides. Only two of the six patients had growth retardation recognized by their peers at school. The observed growth retardation was related to the amount of the bony orbit irradiated. No patient has shown radiation related abnormalities in teething. Serial facial photographs, correlated to 3D-dosimetry, demonstrate the excellent cosmetic results.

Conclusion. Proton irradiation minimizes the amount of non-target tissue receiving dose. This translates into the absence or near absence of adverse effects on the growth dynamics of several normal tissues: the interorbital area, the contralateral orbit and the maxilla.

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Patients treated in 1999 at the PSI Gantry including first experiences with proton therapy in children.

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Objective: We report on the results from the 40 patients treated up to now at the PSI Proton-Gantry inclusive our first experience of proton treatment in children at our institute.
Materials and methods: A follow up analysis of the patients since 11/1996 and clinical and treatment data of the patients from 1999 including 3 children will be presented. In 1999 we treated for the first time children with protons. There were 2 children with a brain tumour and one child with a schwannoma of C7.
Results: The analysis of clinical data received from the patients or from the referring clinicians showed excellent local control rates with moderate side effects in the 1996, 1997 and 1998 patients. In 1999 we treated 21 patients. 6 meningiomas (1 with multiple foci), 3 chondrosarcomas (2 base of skull, 1 thoracic spine level Th 8), 3 low grade gliomas, 2 chordomas (C5 resp. clivus), 1 malignant neurofibroma, 1 synovial cell sarcoma, 1 preirradiated recurrent esthesioneuroblastoma, 1 preirradiated recurrent basalioma invading the base of skull, 2 nasopharyngeal cancers, one of them recurrent after chemotherapy, and a prostate cancer.
We present especially the case of a seven year old boy with an atypical meningioma temporo-frontal right. After partial tumor exstirpation he was sent to PSI, where he was irradiated with 32 x 2 CGE (Cobalt Gray Equivalent) using 3 noncoplanar fields. The positioning was done with an individual vacuum cushion and a vacuum bite block. Prior to each therapy session he received 5 mg of Chlorpromazine as premedication. The positioning was checked daily by CTreference slices & orthogonal topograms before treatment. The actual positioning was then compared to reference points in the initial planning-CT. This comparison was computer aided and gave us precise information about possible rotation or shift of the head in any direction. The analysis of these data showed a remarkably good position of the patient's head throughout the whole treatment period.
Conclusions: In 1999 therapy was delivered to 21 patients without problems in setup or treatment performance. Doses reached from 46 up to 74 CGE. Even for relatively young children, proton irradiation can be performed using a vacuum bite block for daily positioning. Excellent compliance of these children and satisfying precision of the daily positioning speak for a well-tolerable, non-traumatic delivery of proton therapy, also for pediatric tumours, at PSI.

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Proton Beam Eye Treatments in Berlin: First Experiences.

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From June 1998 to March 2000, 118 eye tumor patients have been irradiated at the Berlin eye treatment facility. Strong competitors in the treatment of uveal melanomas are transpupillary thermotherapy, brachytherapy, and combinations of both. About 70% of the proton beam indications are medium-sized, posterior uveal melanomas close to the optic disc and/or macula (distances to tumor base < 3 mm). Other indications are hemagiomas (15%), iris melanomas (10%) and conjunctival melanomas (5%). The average patient age is 54 years. In the follow-up of the first patients, tumor regression is clearly visible. However, the average follow-up time of 11 months is still too short for conclusive results concerning tumor control and side effects.

Patient positioning is done with the usual setup. Special features of the Berlin facility are the new treatment chair (Schar Engineering AG, Switzerland) and the use of X-ray image intensifiers instead of polariod film. We report on first experiences concerning the accuracy and reproducibility of the patient setup system.

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Are Protons necessary during evolution of retinoblastoma ?

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Now again the basement of conservative treatment of retinoblastoma is radiotherapy ; but if later a new irradiation is necessary, protons are very useful. The 3 following cases illustrate this indication.

1st case: a 8 years old boy with bilateral non familial retinoblastoma presents a late anterior recurrence of retinoblastoma in the remaining eye which has been conservatively irradiated at age 10 months

2nd case: on October 1997 a 20 years old man was diagnosed an ethmoidal and sphenoidal sarcoma. This sarcoma was a 2nd non-ocular tumor occurring inside irradiation field of a bilateral retinoblastoma, which has been treated at 6 months age.

3rd case: on September 1994 this 28 old man was diagnosed a chemodectoma of left jugular glomus. Surgery was not possible so he was irradiated with photons plus protons from may 1995 to July 1995. The patient comes regularly to follow-up: last IRM on March 1998 didn't present any evolution he was in good health on last follow-up in October 1999. This chemodectoma is a second non-ocular tumor occurring outside irradiation field of the retinoblastoma but close to critic organs.

Conclusion

Proton beam treatment is very useful or necessary for late relapse of retinoblastoma or head and neck second non ocular tumors.

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Development of a digital X-ray-imaging system at the National Accelerator Centre.

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Correct patient positioning is very important in radiation therapy treatments. This is particularly true for proton therapy, because of the precise nature of the treatment. At the National Accelerator Centre X-ray images are taken on radiographic film to verify the patient position before each field of treatment. The patient position is verified by comparing a radiographic X-ray image of the patient to the DRR (digitally reconstructed radiograph) obtained from the treatment planning system.

Due to the limitations of X-ray film, i.e. long processing time, fixed display contrast and limited dynamic range, it was proposed to develop a digital portal X-ray imaging system. The most important advantage of a digital system is the short time in which the image can be obtained and examined. Other advantages include optimisation of the image display by adjusting the grey levels over the desired dynamic range, effective archiving of the digital images, access from various locations through data networks, and lower operational costs.

Our digital system consists of a Gd2O2S:Tb scintillator screen for converting X-rays to visible light, a protected aluminum front silvered mirror to direct the light to a CCD (Charge Coupled Device) camera for capture and a personalcomputer for data acquisition, translation and display. Compared with other digital imaging systems, this is a simple, compact and affordable set-up.

The spatial resolution for our set-up was measured using the Modulation Transfer Function from the Edge Spread Function of the system. For a field of view (FOV) of 290 x 190 mm2 the measured resolution was 1.3 lp/mm. Since the maximum obtainable image resolution depends on the pixel size, where the effective pixel size is given by FOV Matrix Size it was possible to improve the resolution to 2.4 lp/mm by decreasing the field of view to 160 x 106 mm2. The measured resolution is very close to the Nyquist frequency for the CCD chip, which shows that the achieved resolution is limited by the CCD camera.

The detective quantum efficiency (DQE) of the system is optimised by using a scintillation screen with high emission efficiency (16%) and a spectral emission that matches the quantum efficiency of the CCD camera. A large aperture lens (f/1.0) was chosen to obtain the highest possible light yield.

Intrinsic detector noise determines the lower limit of the dynamic range of the detector and is reduced by cooling the CCD camera. A dark current exposure is subtracted from the image to remove the bias signal and thermal noise. Photon noise, beam in-homogeneity and efficiency variations across the CCD chip are corrected for by flat fielding.

The digital images obtained with this system compare very well with the currently used radiographic film images and they are satisfactory for the purpose of patient positioning.

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Daily QA Device for Continuously Selective Energy Proton Beams

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A daily QA device that is marketed for x ray and electron beams has been tested to determine its suitability for use with a proton therapy system capable of delivering, for a specified patient's portal, any energy between 70 and 250 MeV. The device, consisting of five parallel plate ionization chambers lying in a plane at a uniform depth, is used in concert with a two-thickness bolus to measure both dose per monitor unit on the central axis and range at several points off-axis. A method was developed that should allow a therapist to perform the daily QA procedure in less than 15 minutes (beam tests only). The device was found adequate for portal specific energy delivery and probably for energy stacking; however, several desirable improvements were noted. A set of requirements has been determined for a standalone clinical device and production of a new device is proceeding.