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# Abstracts

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**News from PSI Patients.**

L. Wisser, G.Goitein and Team Radiation Medicine, PSI, Villigen, Switzerland

From November 96 until December 09 we treated 41 Patients. 10 suffered from meningiomas, 7 from brain tumours, 9 from cordomas/chondrosarcomas of the skull base and spine. 3 sarcomas, one esthesioneuroblastoma, one nasopharyngeal cancer and the first prostate carcinoma, treated with the spot-scanning-technique completed the curative cases. 9 treatments were palliative. The actual follow-up of the patients will be presented.

In the year 2000 beam period we are planning to have 16 patients until September. The majority presented with cordomas/chondrosarcomas and meningiomas. One recurrent esthesioneuroblastoma, one liposarcoma and one nasopharyngeal cancer in a young girl completed the y2k patients. The single cases will be presented.

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**5- and 10-Year Clinical Results of the Uterine Cervix Cancer Therapy with the JINR Phasotrone Proton Beam.**

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Between 1987-96 at JINR LNP phasotron medical proton beam 35 patients with cancer cervix uteri had treated by combined proton-and-gamma irradiations. Three of them received palliative radiotherapy. Horizontal medical proton beam 130 MaV had been delivered to a target volume (cervix and corpus uteri) transvaginally through a metalic tube collimators 20-50 mm in diameter. Preliminary the target volume was hard fixed with respect to the proton beam axis by a central probe (3 mm in diameter) which was inserted to a cervical canal and fastened coaxial to the proton beam line. Proton dose field had a cylindrical form with high dose gradation by sides. 50% isodose curve of proton dose distribution passed through point A. Fractionation: 10 Gy/fraction a week at p.A; 20 Gy at the centre of the proton dose field. External gammairradiation of a whole pelvis or parametrium and lymphnodes was irradiated by two-axial two-sectoral or two-axial foursectoral rotation technique. Fractionation: 2 Gy five times a week at p.B or the same dose at p.p. A, B (when the whole pelvis was irradiated).

6 patients with T1b Nx MO cervical cancer received preoperative proton beam irradiation of the cervix uteri and of the most part of the uterus to total dose of 30 Gy at p.A. At the same time the external gamma-irradiation of lymph nodes and parametrium to total dose of 30 Gy at p.B was performed. Than the operation of radical hysterectomy and limphadenectomy was done 3-4 weeks later.

26 patients (T Ib Nx MO - 8, T2 Nx MO - 14 and T3 Nx MO - 4 patients) were treated by the radical program of protonand-gamma therapy which consisted of two phases: at the first - the external gamma-irradiation of the whole pelvis (uterus, parametrium and lymph nodes) was performed to total dose of 20 Gy at p.p.A and B; at the second phase 40 Gy at p.A were delivered by transvaginal proton beam irradiation of the uterus and (at the same time) - a total dose 30-40 Gy at p.B with the external gamma-irradiation of the lymph nodes, parametrium were delivered. At the end of a course of the radical program proton-and-gamma therapy p.A had got 66-76 Gy, p.B - 50-60 Gy. The central part of cervix and corpus uteri had a total dose of 100 Gy. Bladder and rectum had received 18-34 Gy only from the external gamma-irradiation.

The proton-and-gamma treatment of the cervical cancer I-III stages gave 100% immediate recovery. Primary tumor lesions disappeared and complete response of cervix uteri were obtained.

For 6 patients with preoperative proton-and-gamma irradiation the disease-free survival at 5 and 10 years were 83%. One patient died 2 years after therapy because of metastases outside the treatment region. 92% from 26 patients with the radical program proton-and-gamma therapy are alive more than 3 years without recurrences and metastases, and 82% - more than 5 years. 8 patients with stage lb had 100% survival rate at more than 5 years after radical proton-and-gamma therapy.

No postradiation complications were observed at the adjacent organs (bladder and rectum). Absence of the postradiation complications after proton therapy of the cervical cancer allows to assume that the total proton dose may be increased at 10-20% and probably that will decrease or exclude of cancer recurrences and improve a survival rate.

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**Proton Radiotherapy of Intraocular Retinoblastoma.**

S. Mukai[1,3], J. E. Munzenrider[2,3], E. Hug2,3, and E. S. Gragoudas[1,3], [1]Massachusetts Eye and Ear Infirmary, [2]Massachusetts General Hospital, [3]Harvard Medical School, Boston, Massachusetts, U.S.A.

Retinoblastoma is a radiosensitive tumor and some cases are treated with external beam radiotherapy or brachytherapy. Complications from radiotherapy are relatively frequent and include cataracts, radiation retinopathy and optic neuropathy, neovascular glaucoma, orbital atrophy, and second malignancies. Frequency and severity of complications increase with greater exposure of the normal tissues surrounding the tumor, and therefore a radiation modality with greater selectivity of the target tissue has the theoretical advantage of reducing the complication rate. To this goal, we have used proton beam radiation to treat cases of intraocular retinoblastoma. We selected cases that most centers would have treated with external beam radiotherapy (e.g. severe disease and/or tumors involving the macula or close to the optic nerve).

CT scans, clinical examination by ophthalmoscopy, and ultrasonography were used to determine the target volume for treatment. For body immobilization, the child was placed in a polystyrene body mold and light general anesthesia was administered. For eye immobilization, the front part of the eye was anesthetized with A topical anesthetic drop, and a suction contact lens containing a gold ring was placed centered on the cornea. The position of the contact lens and therefore the eye was checked by x-ray. A dose of 40 Gy to 46 Gy was delivered in 2 Gy fractions by a lateral approach given four times per week.

We have treated 16 eyes in 12 patients with proton radiotherapy alone in whom we have at least 2 years of follow-up with the longest at 11.5 years. These included 3 eyes with vitreous seeding (stage Vb disease), 2 with subretinal seeding also, and 7 eyes had subretinal seeding without vitreous seeding. In general the tumors responded well, and we were able to control 2 of 3 eyes with stage Vb disease. 5 of the 16 eyes required subsequent enucleation. 4 of the 5 eyes enucleated had vitreous and/or subretinal seeding. One eye developed clinically significant radiation retinopathy and noevascular glaucoma, while another developed radiation retinopathy. Visually significant cataract developed in 3 eyes. Significant orbital atrophy or second malignancy was not seen even in older children.

Proton radiotherapy appears to be more effective than conventional external beam in controlling the tumors even in advanced cases of intraocular retinoblastoma. Short-term complication rate appears to be relatively low, and in the few cases with longer follow-up, the longer-term complication rate appears to be low also.

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**Treatment planning for 3000+ ocular tumors: Our experience with EYEPLAN.**

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Since 1984, more than 3000 patients with ocular tumors have received proton beam radiotherapy (PBRT) at the Paul Scherrer Institute (PSI). All treatments were planned with the treatment planning software (TPS) EYEPLAN, which is based on a simplified ocular model and a simplified dose distribution calculation neglecting all scattering effects.

The aim of treatment planning is to find a treatment position allowing for irradiation of the planning target volume (PTV) with best sparing of healthy tissue surrounding the PTV. We have reviewed 2426 cases of uveal melanoma treated with PBRT between March 1984 and December 1998. We have identified two kind of failures, analyzed the causes for them and we will propose some remedies:

Local tumor control failure, which can result from a wrong estimation of the location or the size of the target volume, or from a wrong estimation of the amount of healthy tissue (i.e. eyelids) located within the irradiation field. Local tumor control failures were diagnosed in 76 (3.1%) of the 2426 treated cases.

Unexpected complications (i.e. an organ which was not supposed to be irradiated received some dose) is a particularly unpleasant kind of failure, which could be avoided with a more sophisticated treatment planning procedure. This implies an accurate modeling of the eye and thus the location of the tumor within the eye, as well as of an accurate modeling of the dose distribution. Among these 2426 treated cases, 67 (2.8%) presented with radiation induced maculopathy while the macula was not supposed to have been irradiated, and 38 (1.6%) presented with radiation induced papillopathy while optic disc and nerve were not supposed to have been irradiated.

Considering the simplicity of the models used in the TPS, the obtained results are excellent. As a consequence, in Europe, proton therapy has replaced enucleation in many cases. While only 70 uveal melanoma patients received PBRT in 1985, over 700 patients will benefit from PBRT this year. This success has changed the approach in the management of large uveal melanomas. While salvage of the eye, even with no vision, was considered to be a satisfying result years ago, retention of a useful visual acuity has become an important goal today. The elimination of local tumor control failures and unexpected complications are the first step towards this goal. Different approaches are studied, resulting in new TPS and, possibly in new treatment techniques. In respect to the increasing costs of healthcare, the author questions the need for the development of a completely new TPS for PBRT based on high resolution CT's realized for each patient. The experience with the gamma knife treatments for uveal melanomas demonstrates that the treatment technique used with PBRT based on clip surgery and EYEPLAN is most adequate to ensure local tumor control and reduce the complication rates. The use of CT - scans for treatment planning does not contribute to a higher rate of local control nor to a reduction of the complication probabilities. We present our analysis of the situation and the changes that we have already implemented. We also discuss the ongoing work and the planned modifications to EYEPLAN and to the treatment approach as a try to fulfill the requirements for reduction of the complication rates.

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## Clinical Treatments at Clatterbridge: ARMD and Iris Melanomas

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The 60 MeV proton beam at the Douglas Cyclotron Unit mainly treats Choroidal Melanomas. However, other treatments have been developed. In particular, a pilot study and control randomised trial, of the efficacy of low dose of protons, have taken place in treating age-related macular degeneration (ARMD). Patients were entered into the trial, through a defined protocol, and were randomised between treatment and control. 38 and 20 were in the treated and control arm respectively. Patients were treated with 18 proton Gy in 4 fractions, with light field positioning and circular collimators. 12 month follow-up results, representing the majority of patients, in terms of visual acuity and lesion area, will be presented.

The short range and conformal characteristics of proton beams have been exploited in the treatment of shallow iris and ciliary body tumours. Iris tumours are rarer than choroidal melanomas. Other modalities include iridocyclodectomy and radioplaque therapy, which have known side effects, such as photophobia, and possible recurrence. More than 70 patients have been treated with 53 Gy (in 4 fx) with a maximum follow-up of 6 years. Light field positioning, with tumour-shaped collimators, is used. Good local tumour control, with no significant side effects has been noted. The initially small treatment areas have been extended to include whole iris treatments. Protons have now become the treatment of choice, at Liverpool.

Additions to EYEPLAN V.1.6 have enabled the ARMD and iris treatments to be satisfactorily planned.

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## Incorporating the eyelid thickness in proton treatment planning for uveal melanoma.

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Our technique for modeling and verifying the eyelid model in proton therapy for uveal melanoma is in evolution. Often the eyelid is in the proton treatment field. Complete lid retraction may not be possible or desirable. The eyelid thickness affects the range required and must be accounted for in treatment planning. In the past, ultrasound and MRI measurements have been used to estimate the eyelid thicknesses and entered into the EYEPLAN treatment planning program. Recently, we have used simulation films to localize the eyelid with respect to the eye centre. This information is then used to model the eyelid. Subsequent simulation films taken on treatment days are used to verify the eyelid model and to assess the effect on the dose distribution planned. We describe our experience with the eyelid modeling portion of EYEPLAN and the clinical results over three years.

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### OCTOPUS - a new treatment planning tool for therapy of ocular tumours.

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The specific treatment procedure of proton therapy of ocular tumours requires a dedicated planning program. OCTOPUS has been developed to serve this purpose. It uses an enhanced elliptical eye model that can be adapted directly to CT images or by defining model parameters. All structures can be deformed further without restrictions if necessary. 3D diagnostic modalities are supported as well as the fundus photographs in treatment planning and plan evaluation, including the direction comparison of different plans. To achieve an efficient treatment procedure a real time dose calculation and visualisation has been implemented that shows the consequences of changing treatment parameters without further user interaction. To obtain more precise dose distributions to optimize promising plan parameters a pencil beam algorithm developed at the HMI is used by OCTOPUS. This will make many iterative and time consuming dose (re)calculations with conventional algorithms obsolete and compensate for the extra time needed in the more complex eye model definition.

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### Advanced proton dose algorithm for "small field" applications: eye tumour treatment.

C. Rethfeldt, Hahn-Meitner-Institute, GmbH, Berlin

For numerical modelling of proton dose distributions one needs the exact physical characteristics of the given therapeutic beam. In practice, due to the complexity of the treatment set-up along the beamline, including scattering foils, range shifters, modulator wheels and collimators, simple descriptions for the radiation field are inadequate. Mostly are used measured parameter-sets, representing the typical treatment conditions under the assumption that various planning uncertainties could convoluted in the range of well defined safety margins. The premise to safety margins reductions are accurate eye models and the consideration of smaller shape variations in the geometry of the radiation fields.

So systematic measurements and GEANT Monte Carlo calculations were made in search of a proper mathematical description of radiation fields. It takes into account the variations of individual patient set-ups, like the thickness of range shifter and/or wedge applications. The study results in usable approaches for the proton pencil beam algorithm, demonstrated for practical treatment settings.

For verification we used a segmented chamber phantom filled with sugar solutions of different densities in the range of 1.0-1.3 $g/cm^3$. The investigations include CT-scanner images, dose profile measurements at 68 MeV proton beam and the comparison with the dose calculations of the advanced pencil beam algorithm.

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### Development of THE EYE-proton therapy planning program EYEPLAN-PC for Windows operating system

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The eye-proton therapy planning program EYEPLAN-PC for Windows-PC operating system has been developed. The code is based on the EYEPLAN planning program prepared by M. Goitein and T. Miller in the early 80'ties and upgraded later at PSI, Villigen and at the Clatterbrigde Centre of Oncology. The original EYEPLAN was written in FORTRAN and can be run on DEC Alpha and VAX computers under VMS operating system. In the old EYEPLAN all steps of therapy planing were performed in a hierarchical menu which was time consuming when a modification of the treatment plan was required.

The EYEPLAN-PC applies the same model of the eye model, tumour model and the beam model as used in EYEPLAN. The new code is written in C++ and takes advantage of so-called object programming. The central role in the program plays the Data Manager module, which allows for convenient modification of the treatment plan. When some of the plan parameters such as fixation point. beam, wedges, etc. are modified the program recalculates and displays the plan in the real-time. The Graphic Manager module allows for rotation of objects and viewing the eye from an arbitrary side. All the patient data, ophthalmological input data and the result of plans are stored in the single ACCESS database file, which is helpful f.>. Last data edition, analysis, retrieving and storage. Results of tests of EYEPLAN-PC against the VAX EYEPLAN will be presented on the meeting.

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**Application of the dual-ring double scattering method to proton beam with finite emittance.**

Y. Takada, Institute of Applied Physics, University of Tsukuba

The dual-ring double scattering method was developed to obtain the uniform proton field. The formulation was made for zero-emittance beam and the optimum set of scatterer parameters were obtained. A method has been developed of applying the double scattering method to proton beam with finite emittance. Instead of using the real scatterer parameters, effective scatterer parameters have been introduced to relate the beam condition of finite-emittance beam to that of zero emittance beam.

This method makes it possible to relate the optimum solution for the zero-emittance beam to the case of finite-emittance beam if we know the phase space parameters of the incident beam. From the knowledge of optimum parameters for zero-emittance beam and the phase space parameters of the incident beam, we can obtain the optimum scatterer parameters for the given case. By the method, we can apply the double scattering method to beam with relatively large emittance.

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**Proton irradiation techniques by using multi-layer energy filter.**

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A new type of filter for charged particle radiotherapy was developed to reduce unwanted dose transfer to the normal tissues around a tumor. The new filter can make an irradiation field where the width of the spread-out Bragg peak (SOBP) is adjusted to the target as a two-dimensional continuous function on the transverse plane. The filter is made of many layers produced by using stereo Iithography. In the filter, a structure with two regions having different miniaturized shapes of ridge is adopted to get flatness of dose on the spread-out peak. Evidential experiments of the three-dimensional conformal irradiation were performed by using the filter. Proton intensity modulation by two methods (scatterer and spot scanning) was applied to make a conformal field by one directional irradiation.

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**Irradiation of therapeutic proton beams using a rotational gantry system with wobbler magnets.**

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The proton treatment system of the National Cancer Center (NCC), Kashiwa, Japan has been used for clinical treatments from Nov. 1998. During these two years, 38 patients have been treated using proton beams alone. The system h as two rotational gantry ports and one horizontal fixed port. To make irradiation field for the gantry ports, wobbling and double scattering methods are adopted.

In the wobbling method, the transverse uniformity of irradiation field is not so much affected by the initial beam condition. Therefore, it might be easier to make uniform irradiation field by the wobbling method. In this presentation, we will show the results of measurement of dose distributions at a rotational gantry system with wobbler magnets (First gantry). The two wobbler magnets are placed 3.0 meters and 2.4 meters up-stream from the isocenter, and the scatterer is placed between the two wobbler magnets, 2.7 meters up-stream from the isocenter.

We successfully made uniform irradiation fields for 190 MeV proton bean. Detail of the measurements, e.g. field uniformity, beam efficiency, will be presented.

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**A Proposal of Bed-Based Snout for Proton Therapy.**

S. Fukumoto, K. Yamamoto, S. Fukuda, K. Kume, G. Kagiya and M. Kondo, Wakasawan Energy Research Center, Tsuruga, Fukui, 914-0192, Japan

An irradiation system, in which a bolus and a collimator are separated from other beam delivery components, is designed to increase accuracy of patient positioning with a targeting X-ray CT. A template, which is made of a thin metal sheet or a plastic plate and machined to indicate the aperture of the collimator, is set to the bed, and aligned it to the target two dimensionally with the CT. If it is possible to set a bolus simultaneously, patient positioning is confirmed in 3D. Then the bed is moved to the irradiation site keeping both the template and the patient fixed to the bed. One thing to be done there is to match the collimator to its template.

Since the accelerator complex is multipurpose at the Wakasawan Energy Research Center, horizontal and vertical fixed beams are available. Because of disposition of components, it is difficult to install the collimator to due position by hand safely. When the collimator is not always to be fixed to the beam, a multi-leaf collimator can be installed as the final collimator. The system can be easily modified for a rotating gantry irradiation system increasing targeting accuracy with relaxing mechanical tolerances as well as saving patient positioning time at the irradiation site.

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**Design principles of gantries - impact on cost, precision and safety.**

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Interest in hadrontherapy is increasing stability with several new facilities being proposed each year. Novel types of gantries or other innovative equipment are presented. The objective of the present paper is to review certain mechanical principles in gantry design that are included to enhance treatment precision and safety. Existing, as well as proposed, gantry designs are discussed. The range covered spans from the most compact proton gantry at PSI to the latest proposals for large gantries. Gantry issues such as isocentric versus eccentric and space truss versus welded box are compared. Attention is paid to the auxiliary equipment like patient positioning systems and diagnostic devices.

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**Potential capabilities of positron emission tomography for quality assurance of proton therapy**

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On the basis of the positive impact of positron emission tomography (PET) in quality assurance of carbon ion therapy, as proved in the clinical experience at GSI Darmstadt, we investigated the applicability of the PET technique to the in-situ monitoring of proton irradiations. We estimated by means of the FLUKA Monte Carlo code the order of magnitude and the spatial distribution of the $(3^+$-activation of oxygen and carbon nuclei induced by protons of typical therapeutic energies in PMMA targets. The comparison with the activity produced by carbon ions of energies corresponding to the same range in the considered material shows that the useful signal at the same physical dose level should be up to two times more intense for proton beams than the one actually successfully used at the GSI carbon ion therapy facility. Besides, the spatial correlation between the activity and the dose depth distributions, even if poorer for protons than for carbon ions, shows that a control of the particle range, dose localisation and stability of the treatment during all the proton irradiations could be feasible. This is very important for selective heavy charged particle irradiations, where errors in the positioning and unpredictable variations of patient anatomy can lead to deviations of the applied dose with respect to the planned one, as pointed out by PET in the case of carbon ion therapy. Therefore, our preliminary investigation supports the feasibility of a favourable application of PET to quality assurance of proton therapy.

This work is supported by the "Bundesministerium fur Bildung, Wissenschaft, Forschung and Technologie" of Germany (contract no. 06DR825).

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**The System of Broad-Beam 3D-Irradiation (BB3DI).**

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Using the broad-beam three-dimensional irradiation (BB3DI) system installed at HIMAC, only the target region is irradiated at 100% dose level; the dose level at other parts of irradiated tissues is less. This system uses elements from both the broad beam and the scanning techniques, and could also be described as a slice-scanning technique. The lateral spread of the beam is achieved by wobbling magnets and scatterer, but in depth the beam is broadened only slightly by a ridge filter, thus resulting in the application of a high dose slice. A homogeneous high dose region can be achieved by a combination of several appropriately weighted slices. As a range shifter moves each slice a multileaf collimator defines its shape so that the 3D conformation can be realized. In order to apply to the clinical treatment, the optimum condition for the BB3DI, such as wobbler radius and thickness of the scatterer for lateral flatness and the design of the ridge filter for depthdose distribution, have to be studied and the field quality should be assured. And these results have to be fed back to a suitable treatment planning system. For $^{12}C$ 290MeV/nucleon beam, the uniformity within +/- 3% of the field with 100 mm in diameter was secured for range-shift: 0 - 100 mm. In order to make flat SOBP, we developed optimization for the weight of slice. Using this system, we planed some cases of numerical-phantom with an analytical target such as sphere or cross-shape. The data was transferred to the control-system, and then tests of irradiation were carried out. The realized dose- distribution was measured using a multi-layer ionization chamber, which can acquire a depth-dose distribution in one, and a standard ionization chamber for absolute value. The results were compared with that planned, so that the system were checked and evaluated.

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**Visualization of Dose Distribution on CT-Image in Carbon Beam Therapy.**

M. Mizota[1], T. Kanai[1], T. Akagi[2], H. Yamashita[3], M. Shimbo[4], Y. Futami[1], K. Yusa[1] and M. Endo[1] , [1]National Institute of Radiological Sciences, 4-9-1 Anagawa, Inage, Chiba 263-8555, Japan, [2]Hyogo Pref. Hospital Bu., 5-10-1 Shimoyamatedori, Chuo-ku, Kobe 650-8567, Japan, [3]Shizuoka Pref. Gov., 9-6 Ote-machi, Shizuoka 420-8601, Japan, [4]National Cancer Center Hospital East, 6-5-1 Kashiwanoha, Kashiwa, Chiba 277-8577, Japan

Through the parameters made by a radiation treatment planning (RTP) system referring to CT-image of a patient, the therapeutic carbon beam is configured by accelerator system and various devices in irradiation system. The realized dose distribution cannot be measured in the patient body but in water phantom. On the other hand, RTP system provides us the ideal dose distribution on the CT-images. In order to estimate dose distribution in a patient or to compare with the planning, it is necessary to convert the calculated distributions in a patient to those in water phantom or to convert the measured distributions to those on the CT-images. We developed conversion tools for the visualization and comparison of these distributions.

To calculate the distribution on a CT-image from the measured dose, CT-images on the same planes as the measurements are extracted from a set of CT-images in the RTP system. Water equivalent depth to each point on the plane from a beam source is calculated individually and an expected physical dose is derived by mapping from the measured distribution. Fitting of the depth-dose curve to the calculated SOBP curve also gives a residual range, from which a biological distribution can be derived. Once calculated, dose distribution information can be easily handled to make comparison to other calculations or to display in any form, such as color-coded isodose lines, or overlaid on the gray-scale CT-image.

This method has been tested for therapeutic beam of HIMAC treatment system. The realized dose distribution for the area of interest could be measured using a multi-layer ionization chamber, which acquires a depth dose distribution at one time. Some under-dose or over-dose areas near the border of the irradiation field could be distinguished by colors as compared to planned dose distribution.

In this way, quantitative comparison between dose distributions are made with anatomical information, which also gives a verification of the irradiation system in a very straightforward way. Together with developing a rapid dosimetry system, we intend to make use of this method to check the therapeutic beam for each patient.

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**Recent technological developments at C.P.O.**

S. Meyroneinc[1], F. Martin[1], J. D. Bocquet[1], H. Dupuis[1], E. Brot[1], and J.M. Buhour[2], [1]Centre de Protontherapie d'Orsay, France; [2]Institut de Physique Nucleaire-Orsay

The Centre de Protontherapie d'Orsay has now reached a routine rate for the treatments: ophthalmological tumors during the morning and brain and neck tumors during the afternoon. Thus, concerning the technological developments, our main objectives are the industrialization of the experimental systems and the progressive automation of the processes. The major constraint we are now faced is the limited time for experimentation and for access to the treatment rooms.

We'll present three significative developments recently achieved:

- a multichannel readout dosimeter. Based upon the VLSI chip developed by the team of the Magic Cube (Cirio et al), we have developed a personnalized electronic and software solution. Driven by an industrial realtime processor, this system can read continuously 64 channels with a resolution of 600 fC (up to I microA of maximum rate). The linear performance of the chip was confirmed. ,
- a full-automatized binary absorber. This compact version of the "standard" principle is controlled through an industrial PLC. Major efforts have been done to maximize reliability and ergonomy of the supervisor interface.
- characterization of an industrial hardened encoder. After many breakdowns on conventional encoders due to radiations, we have tested successfully a hardened encoder from the civil nuclear industry. First tests for a realtime gating of the beam (wheel of modulation) are encouraging.

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**Neutron Shielding for High-Energy Proton Accelerator Facilities.**

W. D. Newhauser[1], U. Titt[1], D. Dexheimer[3], X. Yan[2], S. Rosenthal[1], J. S. Loeffler[1] and A. R. Smith[1], [1]Massachusetts General Hospital, 55 Fruit Street, NPT-100, Boston, MA, [2]Bechtel Corporation, 50 Beale Street, San Francisco, CA, [3]Harvard Cyclotron Laboratory, 44 Oxford Street, Cambridge, MA.

The neutron shielding at the Massachusetts General Hospital's 235-MeV proton therapy facility was investigated with measurements, analytical calculations, and realistic three-dimensional Monte Carlo simulations. In 37 of 40 cases studied so far, the analytical calculations predicted higher neutron dose equivalent rates outside the shielding than was measured, typically by more than a factor of ten, and in some cases more than 100. Monte Carlo predictions of dose equivalent at three locations are, on average, 1.1 times the measured values. Except at one location, all of the analytical model predictions and Monte Carlo simulations over estimate neutron dose equivalent. For these simulations, a suite of software tools has been assembled, based on the MCNPX Monte Carlo transport code, the SABRINA visualization code, and various GNU/LINUX software packages. In addition, we have developed new codes for pre- and post-processing simulation data and for distributing and balancing the computational load in a massively parallel cluster of workstations.

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**RBE determination in mouse intestine for the scanning proton beam at PSI, Switzerland. Influence of motion.**

J.Gueulette[1], H. Blattmann[2], E. Pedroni[2], A. Coray[2], T. Bohringer[2], B.-M. De Coster[1], P. Mah[1], A. Wambersie[1], P.Scalliet[1], [1]Universite Catholique de Louvain, Brussels, Belgium, [2]Paul Scherrer Institute (PSI), Villigen, Switzerland

RBE of the scanning proton beam at PSI has been determined for crypt regeneration in mice after single fraction irradiation. Like for all the experiments performed in the framework of intercomparison programmes, a strict experimental procedure was applied, which includes the following elements: use of 13 week-old animals, reference to a local gamma beam, randomisation between protons, gamma and dose level, application of standard dosimetry protocols, double-blind analysis of the results. The mice were irradiated either at the entrance plateau, at the beginning or at the end of a 7 cm SOBP. The RBEs (reference cobalt-60 gamma rays) were determined at the level of 20 regenerated crypts and were found

equal to $1.11 \pm 0.12$, $1.16 \pm 0.15$ and $1.21 \pm 0.15$, respectively (corresponding gamma dose = 14.2 Gy). These values – but their confidence interval - comply with the expectations since they are in the range of 1.10 - 1.20 and exhibit a tendency to increase from the entrance plateau to the end of the SOBP.

However, the individual proton data are over spread in comparison with the individual gamma data. This drew the attention towards the fact that one of the characteristics of the proton beam delivery system might interfere with some parameter of the biological samples and systematically influence their response to radiation. It has been suggested that this could result from motion during irradiation. Therefore intestine motion was studied, which revealed up to 2 mm isotropic displacements of the volume of interest in the course of a 20 minutes irradiation. Simulation of such displacements and impact on dose profiles will be presented and discussed by the next speaker, Dr. Pedroni. It will be showed that movements by a few mm are sufficient to explain the over distribution of the proton data.

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**Dose homogeneity errors due to movements during beam scanning: the simulation of single fraction irradiations of mice as a warning example.**

E. Pedroni[1], J. Gueulette[2], H. Blattmanns[1], [1]Paul Scherrer Institute (PSI), Villigen, Switzerland, [2]Universite Catholique de Louvain, Brussels, Belgium

Dynamic beam scanning methods are finding today quite a large interest because they are well suited for the competition with the new intensity modulation therapy techniques being now developed in conventional therapy. Such dynamic methods (conventional and not) are however more sensitive to organ motion than the established passive scattering techniques, where the beam is delivered simultaneously over the whole target volume. A very practical issue is that these errors do not show up at all during routine dosimetry. There is therefore quite a risk to forget about this problem in new situations. This has been the case in a radiobiological experiment performed at PSI by our group.

The guts of mice were irradiated with the goal of establishing the mean RBE of our proton beam. Dr. Gueulette and the PSI team under the guidance of Dr. Blattmann performed the radiobiological experiment exactly in the same way as this was done already at other institutions. The dose was applied at PSI with a single fraction (of typically IOGy) by scanning a small pencil beam of 7mm FWHM only once (very slowly) over a dose field large enough to cover simultaneously several mice. Larger fluctuations were observed in the radiobiological data of PSI than compared with the results obtained with the cobalt beam and at other proton therapy centres. We refer here to the previous presentation of Dr. Gueulette at this conference. Retrospective simulations now show that sudden movements of the mice by just a few mm during the 10-20 minutes irradiation are sufficient to explain the observed discrepancies.

The sensitivity to organ movements is a very important issue when applying scanning beams. For this reason conformal patient treatments are performed at PSI up to now only on well-immobilised targets in the head and lower pelvis using multiple fields and with full fractionation (30 fractions). If we assume that patient movements in these situations are below 1-2 mm, then an overall dose homogeneity < 5% is achieved. The development of new advanced beam scanning techniques allowing multiple target repainting are required for the future competition with IMRT and for a possible replacement of the passive scattering technique. We will mention our ideas on how to implement a faster scanning on the next compact gantry concepts of PSI.

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**Dose-volume effects in rat spinal cord after proton irradiation. Radiobiological considerations.**

A. W. T. Konings[1], H. P. Bijl[2], R. P. Coppes[1,2], P. van Luijk[3], J. M. Schippers[3], and A. J. van der Kogel[4], [1]Department of Radiation and Stress Cell Biology, University of Groningen, [2]Department of Radiotherapy, University Hospital, [3]KIV, Groningen, KVI, Groningen, [4]Department of Radiotherapy, University Medical Center, Nijmegen, the Netherlands

The spinal cord is a critical organ in Radiotherapy and a typical late reacting tissue in response to radiation. From the limited data obtained after photon irradiation with animals, it is known that for a certain range of cord-lengths the tolerance dose for paralysis increases with decreasing volumes. Especially for very small volumes it is important to deliver the radiation dose with sharp demarcations at the edges of the target field in order to obtain reliable data on dose-volume effects. To reach this goal protons are more suited than photons.

We report on radiation tolerance of rat spinal cord after proton irradiation with single homogeneous doses as well as on radiation tolerance with doses that are distributed inhomogeneously. The range of cord-lengths investigated extends from 2 to 20 mm and is centered at the fourth cervical vertebra.

Irradiation with single homogeneous doses revealed that the ED50 (the dose at which 50% of the rats become paralysed) was more or less constant from 20 to 8 mm cord-length and amounts to about 22 Gy. The ED50's after irradiating 4 and 2 mm were about 55 and 90 Gy respectively: These data are comparable with earlier obtained data after photon irradiation, except for the 2 mm result, which could not be obtained with sufficient accuracy using photon beams. The resemblance of the biological effects after irradiation by the two different modalities points to a RBE between 0.95 and 1.05, a value that may be expected because unmodulated plateau protons (190 or 150 MeV) were used with the "shootthrough" method. The results of these experiments implicate that during irradiation of cancer a high dose may be delivered to cure the patient from a tumor that is located such that a very small part of the spinal cord is in the field of radiation. It was also found that the latency time (time after radiation before paralysis is manifested) decreased with decreasing cordlength in the 8 to 2 mm region (and thus decreases with increasing dose) from about 170 to about 70 days. This suggests that depending on dose, more than one target structure is critical for paralysis.

Preliminary data obtained after irradiation with inhomogeneously distributed doses show that the tolerance dose in a certain area is extremely dependent on (even a low) dose in the direct surroundings.

Biological and clinical implications of these phenomena will be discussed.

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**A possible molecular mechanism of radiosensitivity in mammalian cells exposed to heavy ions**

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Four kinds of cells, B 16, V79, Hela and SMMC-7721, were selected in the experiment. First, the survival of the four kinds of cells irradiated with 125.5 keV/μm'$^{2}C^{6+}$ was measured using clonogenic assay respectively. Their sensitivities described by $D_{50}$ were 0.74 (B 16), 1.70 (V79), 1.87 (Hela), 3.85 (SMMC-7721). Second, of above cells DNA double strand bread (DSB) was measured by inverse pulsed-field gel electrophoresis (FIGE) as well as fluorescent scanning. The DSB yields (DSBs/10OMbp/Gy) were 0.4 (B16), 0.69 (SMMC-7721), 0.82 (Hela), and 0.98 (V79). The results show that there is not a consistent relationship between cellular sensitivity and DNA DSB induction. By studying distribution of DSB fragments expressed by molecular weight in the different cell lines, a possible molecular mechanism of radiosensitivity which was defined as "a complimentary mechanism of DNA sequence sensitive site in cooperation with DNA DSB induction" was put forward. It gaye possible explanation of different sensitivity in different cell lines.

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**Present status of proton therapy facility in University of Tsukuba.**

Y. Takada, A.Maruhashi[1], T.Sakae[1], K.Yasuoka[2], A.Nohtomi, Y.Akine1, K.Hasezawa[1], T.Okumura[1], and Y.Shioyama[1], Institute of Applied Physics, University of Tsukuba, [1]Institute of Clinical Medicine, University of Tsukuba, [2]Institute of Basic Medical Sciences, University of Tsukuba

Construction of building for the new proton therapy facility has been completed by the end of March, 2000. All the equipment including the 250 MeV proton synchrotron and two iso-centric rotating gantries has been installed in the new building. The iso-center precision of the gantries with the rigid cylindrical structure has been measured. It was found to be within a cube of diameter of 1 mm as foreseen by the finite-element analysis of the structure. The control system of the new facility will be presented together with the current status of the various equipments. We are now in the final stage of tuning of equipments. Beam test is scheduled to start from the end of August, 2000.

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**Monte Carlo Simulation for Verification of 3D-Dose Distribution in a Patient at PMRC.**

K. Yasuoka and Y. Takada, Proton Medical Research Center (PMRC), University of Tsukuba

A Monte Carlo simulation code has been developed to verify 3D-dose distribution for each patient in the proton treatment planning system. The simulation has been fully and realistically performed with GEANT3.21 package in the proton exposure system of the current and new PMRC proton beamlines. A structure of a patient has been constructed as a group of small voxels, each characterized by physical properties; a physical density, an effective atomic number, and an effective atomic weight, determined by CT data of each patient. We present 3D-dose distributions reconstructed in the simulation and compare with the one produced in the treatment planning. This method is useful in verification of complex structure in 3D-dose distribution and is applicable to improve the QA in the exposure system. The results may be compared with a precise measurement of the 3D-dose distribution, which is planned in the new PMRC facility, in a water phantom for each patient.

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**Present Status of Proton Therapy Project at the WERC Japan.**

K.Yamamoto, S.Fukuda, K.Kume, G.Kagiya, T.Hasegawa and S.Fukumoto, Medical Division, the Wakasa-wan Energy Research Center, Fukui 914-0192, Japan

Proton cancer therapy project has been proceeded at the Wakasa-wan Energy Research Center (WERC), Japan. The construction of an accelerator complex at WERC with a tandem for 10MeV p and a synchrotron for 200MeV p (W-MAST; WERC Multi-purpose accelerator complex with a synchrotron and a tandem) has partially been finished. The synchrotron can now emit 100, 120, 140, 160, 180 and 200MeV p with the maximum intensity of 3nA. The measured beam profiles of p with the above energy range are reported together with the construction status. The machine stability was also tested.

Final completion of the whole construction is scheduled by the next fall, which will include the clinical beam line with the X-ray CT for patients' precise positioning using a movable bed. By that time, some more machine time is planned, for widening the p energy range down to 80MeV, for measuring the relative biological effectiveness, and so on.

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**A new system of engineering and technology of rotational-scanning Hadron-therapy without GANTRY.**

B. V. Astrakhan, Russian Cancer Research Center of Russian Academy of Medical Sciences (CRC RAMS), Moscow

The on principle new system of rotational-scanning Hadron-therapy of cancer, termed <AntiGANTRY> (<AG>), is offered.

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.

The patients are completely prepared for an irradiation 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 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 narrow beam of hadrons. 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>-system can work with any medical accelerator of hadrons needlessly either constructive alteration or adaptation.

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 <AG>-system will make about 1 million bucks.

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**New proton synchrotron devoted for medical treatment**

K. Prokes[1], M. Lokajicek[1], J. Sedlak[1], A. Molodojentsev[2], V. Makoveev[2], V. Minashkin[2], A. Sidorov[2], G. Sidorov[2], and V. Shevtsov[2], [1]Foundation Oncology 2000, Charles University, Institute of Physic, Prague, Czech Republic, [2]JINR, Dubna Russia,

Beams of heavy charged particles represent the most advanced tools for external therapy of deep seated tumours. The most important requirements for a medical accelerator are safety, reliability, beam stability, low energy consumption, efficiency of beam delivery to the treatment rooms and of course low initial cost. The proposed proton synchrotron has all above mentioned features including raster scanning for 3D conformal treatment of tumours.

General project of the whole system has been already finished, the manufacturers of the majority of the parts are prepared and we are looking now for investors of the whole "protontherapy" complex.

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**The GSI Patient Treatment Chair for Heavy Ion Radiotherapy in Seated position.**

P. Heeg[1] and D. Schardt[2], [1]DKFZ, Heidelberg, Germany, [2]GSI, Darmstadt, Germany

In the irradiation facility at the Gesellschaft fuer Schwerionenforschung (GSI), Darmstadt, Germany, mainly head tumors are treated with carbon ions accelerated by the heavy ion synchrotron (SIS). The beam is delivered by an intensity controlled raster scanning technique with active energy variation, resulting in a high degree of dose conformation. The combination of the horizontal beam and the patient couch allows irradiations within a frontal plane of the patient's head. In many cases this technique yields satisfying dose distributions, however more patients could be treated and the dose in the organs at risk could be further reduced if more irradiation angles would be accessible. Therefore a patient chair will be installed which will allow treatments in a vertical position, enabling irradiations from any direction within a transversal plane of the patients head. The possibility to incline the chair will provide an additional degree of freedom for treatment planning.

The fundamentals of the construction are given by the conditions in the irradiation room: the compatibility with the existing patient couch requires that the chair can be driven away from the irradiation position into a parking position. A very serious constraint for the construction is the beam height above the floor of only 135cm. Chair motions are possible in five degrees of freedom: two horizontal translations with a range of 240mm each, one vertical translation with a range of 500mm, a 360-degree - rotation and a possibility to tilt within a limited angular range around a horizontal axis perpendicular to the beam. The mechanics for both rotations and for the horizontal translations are mounted under the patient's seat and need less than 35cm of height. Rotation and tilting are isocentric with an intersection of the axes fixed in the room. The nominal mechanical tolerances for the position of the isocenter (0.5mm) demand high precision adjusting possibilities and are a challenge for the quality insurance.

Due to the isocentric construction an analoguos stereotactical positioning technique can be applied as with the patient couch, i.e. at zero rotation and tilt the stereotactical coordinates are adjusted by means of 3 translations and subsequently the two angles are adjusted. Also for treatment planning only moderate modifications are needed, since no angle dependent translations are necessary. For the planning practice it is an important advantage that couch and chair irradiations can be planned using the same routines.

At present investigations are performed concerning modifications of the patient mask, displacements of the patient's head inside the mask when changing from horizontal to seated position and the general patient immobilisation. The installation of the chair will take place in 2000, first treatments are planned for 2001.

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**A parallel computing system for radiation treatment planning using a workstation cluster.**

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To provide a more accurate radiation treatment planning, we need to accept a longer calculation time. We have developed a parallel computing system using workstations. We are targeting reducing the CPU time of radiation dose calculations and DRR (Digitally Reconstructed Radiograph) calculations. Our workstation cluster consists of 10 Digital Alpha boxes based on 21164 CPUs. One of them is a server which have two Ethernet cards and connected to an outside LAN. The others work as clients. The operating system is Linux and PVM (Parallel Virtual Machine) is used as a data communication library. An original middleware has been installed in to automatically 4istribute jobs to clients depending on the work load. Initial implementation was done with fast Ethernet switch and network cards; however, we are targeting Gigabit Ethernet configuration for maximum data transfer inside the cluster. As a benchmark test, proton beam was irradiated to a water phantom. The dose distribution was calculated using a ray-tracing method. It was found that the CPU time was reduced to about 1/7 by 10 CPUs compared to the results using a single CPU. The reason is that the data transfer time is relatively long compared to the dose calculation time. It is anticipated that more time-consuming job such as pencil beam or Monte Carlo dose calculation provides superior parallel performance. For the DRR calculation, CPU time was reduced to about 1/9 because the transferred data was smaller.

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**Development of Range Evaluation System with Positron-Camera.**

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A range evaluating system has been being constructed at the secondary-beam line of HIMAC. With this system we can see the heavy-ion range in each patient directly with good spatial resolution less than 1 mm at each treatment. Before therapeutic-irradiation, an examination beam of $^{11}C$, which is collimated with a pencil-beam collimator, is scanned laterally with a pair of scanning magnets and distally with a range shifter up to a point of interest, e.g. quite close to a critical organ. A positron-camera, which consists of a pair of Anger-camera-like scintillation detectors without the collimator, detects the pair of gamma rays and determines the stopping position of the beam. Each detector is equipped with a NaI(Tl) crystal having a diameter of 600 mm and a thickness of 30 mm. To get good spatial resolution, the surface of the crystal processed diffusively refractive at the front and absorptive at the side-edge. In this paper we report the performance of this system according to the results of test experiments using $^{11}C$ beam at the secondary-beam line at HIMAC.

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**Treatment of skull base chordomas and low grade chondrosarcomas with carbon ion radiotherapy: preliminary results of a phase I/II study.**

D. Schulz-Ertner[1], J. Debus[1,2], O. Jake1[2], T. Haberer[3], F. Wenz[1], C. Thilmann[2], W. Enghardt[4], D. Kraft[3], W. Schlegel[2], and M. Wannenmacher[1], [1]Dept. of Clinical Radiology, University of Heidelberg, Germany, [2]DKFZ (German Cancer Research Center), Heidelberg, Germany, [3]GSI, Darmstadt, Germany, [4]Forschungzentrum Rossendorf (Research Center), Rossendorf, Germany

Purpose: compared to photon irradiation carbon ions provide physicals selectivity and additionally an increased biological effectiveness. Outcome is evaluated in patients with skull base chordomas and low grade chondrosarcomas after carbon ion therapy.

Materials and Methods: between 8/98 and 2/00 we have treated 68 patients. This report includes 3 2 patients with chordomas (19) and chondrosarcomas (13) have been treated with carbon ion beams at a basic physics facility (GSI) in Darmstadt, Germany, within a clinical phase UII study. Ten patients have been treated for recurrent tumors including prior irradiation with photons or protons in 4 of them. Tumor-conform application of carbon beams was realised by intensity-controlled raster-scanning with pulse-to-pulse energy variation. Patients had 3D treatment planning including a biologicaloptimisation using the treatment planning program TRIP. In chordomas and chondrosarcomas a full course of carbon ion therapy with a median total tumor dose of 60 GyE (weekly fraction 7 x 3.0 GyE) has been applied. In 4 patients with recurrent tumors after prior irradiation was performed with reduced total tumor dose of 45 - 54 GyE.

Results: median follow-up was 8.5 month (range 2 - 16 months). Local rate after 12 months was 100% for low grade

chondrosarcomas. In chordomas local control within the planning target volume was achieved in 14/15 patients who received a full course of carbon ion radiotherapy with a total tumor dose of 60 GyE. In chordoma patients reirradiated with reduced total tumor dose local control was achieved in 3 or 4 patients. A reduction of tumor size after carbon ion radiotherapy was observed in 3 patients with chordomas. Treatment related toxicity was mild.

Conclusion: the treatment of skull base chordomas and low grade chondrosarcomas with carbon ion radiotherapy is feasible and safe. The preliminary and observed radiological responses in patients with chordomas are encouraging, although follow-up is still too short to draw any conclusions concerning outcome.

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**Simulated treatments: Results at the NPTC and their role in the startup of a new particle treatment facility.**

A. Smith, S. Rosenthal, S. Michaud, J. Adams, W. Newhauser, S. LaShell, M. Collier, J. Flanz, S. Bradley, M. Wagner, B. Gottschalk, A. VanMeerbeeck, J. Bailey, J. Schubert, and M. Goitein

During the startup phase of a new particle treatment facility there are a number of important tasks that must be carried out including verification and validation of treatment, safety, and control systems, as well as acceptance tests and clinical commissioning. In addition to these widely accepted processes, simulated treatments can play an important role in the testing of the complete range of systems required for patient treatments. They can serve to help verify that all systems are working correctly and to identify problems that may be detected only in a realistic clinical situation when a set of complex, sequential tasks are carried out. In particular, using an anthropomorphic phantom and in-phantom dosimetry, simulated treatments can test: immobilization, CT simulation, and treatment planning of the phantom; aperture and compensator design and fabrication; laser and x-ray alignment; stereotactic positioning; gantry and couch performance; beam tuning and stability; energy selection; dose delivery; and treatment room safety systems. It must be stressed that simulated treatments alone are not sufficient to thoroughly check out treatment systems, however they can be an important supplement to other necessary tests. In March and April 2000, we carried out simulated treatments for skull-base and prostate tumors - the results of these treatments will be presented. We plan to carry out a simulated treatment for a lung tumor in September 2000 after completion of the final control and safety software integration and will test treatments at other anatomical sites before the initiation of actual patient treatments.

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**Developments of the TULOC (TUmor LOCation) Project.**

J. Verwey[1], P.G. Seiler[1], H. Blattmann[1], S. Kirsch[2], R.K. Muench[1], and Ch. Schilling[2], [1]Department of life sciences, Paul Scherrer Institut PSI, CH 5232 Villigen PSI, Switzerland, [2]Mednetix AG, CH 5232 Villigen, Switzerland

Changing tumor positions induced by organ motion can impede the full exploitation of the strengths of conformal radiotherapy. The unnecessary irradiation of healthy tissue surrounding the target volume can be the consequence. To overcome this, one should measure tumor positions directly and continuously with high resolution in space and time. We have developed a novel tracking technique, which will allow this. The method can also be used to survey and monitor the patient positioning. The proper functioning of our method has been technically demonstrated at PSI with the help of phantom irradiation with protons, however nearby conducting objects can impede the full accuracy of the developed tracking technique. Field correction calculations are being made to compensate for the disturbing effect of nearby conducting objects. To start the clinical implementation of the magnetic tracking devices, a phantom patient has been developed which enables the testing of the position measurements in the clinical environment. First results of the phantom patient application in a laboratory environment and in an environment with a nearby conducting object are presented which demonstrate the suitability of the phantom for clinical testing.

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**Target moving and its effect on the respiration-gated proton irradiation.**

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Precise measurements of target position in proton radiotherapy are performed in PMRC to estimate the accuracy of the target adjustment in the irradiation synchronized with respiration cycle. To get the target position in X-ray projected images, pattern matching of the moving region of interest is calculated fo, a frame of pictures one by one. The correspondence between the respiration signal given by the tension measurement and the motion of target organ is investigated. Position deviation of the target during the irradiation period is estimated as a function of discrimination level making the irradiation gate. By using the data of target moving, distribution of the effective dose on the target is calculated for gated and non-gated irradiation.

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**Inverse treatment planning for intensity modulated scanned ion beams**

M. Kraemer, O. Jaekel, O. Geiss, T. Haberer, M. Scholz, D. Schardt, and U. Weber, GSI, Darmstadt, Germany

One of the main objectives in radiotherapy is the precise delivery of dose to the prescribed target volume whilst healthy tissue should be spared as much as possible. Compared to photon and even proton beams, therapeutic carbon ion beams offer the advantages of a depth dose profile with a pronounced Bragg maximum, a well-defined range, little lateral scattering and an increased biological effectiveness towards the end of the particle range. The unique GSI raster scan device combines magnetic lateral deflection of ion beams with active energy variation in order to yield dose conformation in 3D. Typical tumor sizes require several ten thousands of single beam positions and intensities to be determined.

A physical as well as a universal radiobiological beam model has been developed to describe the characteristics of ion beams. With the software package TRiP developed at GSI we perform inverse treatment planning with the biologically effective dose as an objective function for all kinds of ions from protons to carbon. The TRiP package is in clinical use for all patients treated at GSI with carbon ions since 1997. Excellent target conformation and sparing of healthy tissue could be achieved with only two fields in most cases. TRiP supports various dosimetry systems (I-chambers, films, TLDs) and good agreement between planned and measured doses is found. For the first time a treatment planning system is in clinical use which fully supports active 3D dose shaping together with the radiobiological properties of ion beams.

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**Experimental Assessment of a Proton Pencil Beam Algorithm: Radial Spread Modeling and Reduction of Computation Time.**

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An experimental procedure for evaluating physical models and computational parameters used in our proton pencil beam algorithm is presented. The calculation of the dose delivered by a single pencil beam relies on a measured spread-out Bragg peak, and the description of its radial spread at depth features simple specific parameters accounting individually for the influence of the beam line as a whole, the beam energy modulation, the compensator, and the patient. For determining the experimental values of the physical parameters related to proton scattering, a simple relation between Gaussian radial spreads and the width of lateral penumbras has been used. Using penumbra measurements in air, a linear variation of the contribution due to the beam line with the distance collimator-point has been adopted. Analytically predicted radial spreads within the patient were in good agreement with experimental values obtained in water under various reference conditions. Results indicated no significant influence of the beam energy modulation. Using measurements in presence of Plexiglas slabs, a simple assumption on the effective source of scattering due to the compensator has been stated, leading to accurate radial spread calculations. Dose distributions in presence of complexly shaped compensators have been measured to assess

the performances of the algorithm supplied with the adequate physical parameters. From these measurements, an experimental method for investigating a set of computational parameters decreasing the calculation time while maintaining a high level of accuracy is also presented. Faster dose computations have been performed for algorithm evaluation in presence of geometrical and patient compensators, and have shown a good agreement with the measured dose distributions.

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## Abstract submitted to the PTCOG XXXII meeting, Uppsala 16-19 April 2000

**Meningiomas treated with association photons and protons: preliminary results.**

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**Aim:** Preliminary analysis of photons and protons irradiation for meningiomas.

**Patients and methods:** From 05/94 and 02/00, 25 patients have been treated with proton irradiation for meningioma at the Centre de Protontherapie d'Orsay. There were 9 males and 16 females. Median age and Karnowski *performance status* at time of radiotherapy were 54 years [11-72] and 100 [60-100], respectively. First symptoms were cranian nerve palsies in 27% of cases, headaches in 24%, crisis, motor or sensitive deficit in 24%, exophtalmy in 12%. Meningiomas invaded parasagital false in 7 cases, one or more brain lobe in 6 cases, orbital area in 5 cases, cerebellopontine angle in 4 cases and sphenoid wing in 3 cases. Median diameter of the lesion before radiotherapy was 40 mm [10-100]. Histologic verification of meningioma was available in 22 patients, the diagnosis was made radiographically in 3 cases. There was 15 cases of meningotheliomatous meningioma, 4 cases of atypical meningioma and 3 malignant meningiomas. Nine patients underwent 2 operations before radiotherapy. Last surgery was incomplete in 19 cases and complete in 3 cases. Radiotherapy was performed for relapse after surgery in 16 cases and immediately after partial removal of tumor in 6 cases. Interval between last surgery and beginning of radiotherapy was 7 months [3-155]. Median GTV and CTV were 39 cm3 [2-80] and 123 cm3 [45-122], respectively. Median total dose delivered was 60.6 GyEC [ 10-67], median dose delivered with photon and proton beams were 39.6 Gy [0-54] and 21 GyEC [ 10-34], respectively. Three patients with malignant meningioma received 68 GyEC and the others 60 GyEC. One patient received only proton irradiation, 15 patients received about 70% of dose with photon and 9 patients received half dose with proton and half dose with photon. Median duration of radiotherapy was 50 days [5-76].

**Results:** Seventeen files were analyzable for acute and late radiotherapy-induced complications. Median follow-up was 31.6 months. There was one case of headache during radiotherapy, 8 of grade >_ 2 alopecia and 5 cases of grade 2 erythema in front of beam fields. One patient had have crises during radiotherapy. There was not death meningioma-related and one patient died of lung cancer at 37 months after radiotherapy performed. Disease-free and specific survival rates were 100%. One, 2 and 3-year overall survival rate were 100% and 4 and 5-year overall survival rates were 80%.

**Conclusion:** Radiotherapy was proposed for treating recurrent or aggressive meningioma. Preliminary results compared favorably with those previously published in literature. More patients and longer follow-up are, however, needed for definitive conclusion

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