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ABSTRACTS

of the

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Papers presented at CERN

Therapy Planning for Heavy Ion Irradiation.

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The main goal of the radiotherapy unit at GSI is to exploit the unique features of heavy ions for cancer treatment.

A magnetic scanner system delivers a well-defined number of particles at well-defined x-y positions. The variation in depth is achieved by varying the accelerator beam energy. No passive shaping elements are used.

The optimization of the 3D dose delivery is performed by a new computer code (TRiP) coupled to an existing planning system (VIRTUOS) for photon therapy. The heavy ion specific code is based primarily on the measured and calculated shape of the Bragg peaks for carbon in water. The increased RBE of the heavy ions is included using precalculated RBE tables together with the spatial distribution of projectile fragments generated by the carbon ions in water. Inhomogenities of the irradiation volume are taken into account via the method of water-equivalent path length based on actual CT data and an experimentally determined table for conversion of Hounsfield numbers to equivalent path length.

The code generates the necessary control data for the magnetic scanner system as well as the spatial physical and equivalent dose distribution. Visualization and dose assessment is the task of the conventional planning system.

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Fast 2D phantom dosimetry for scanning proton beams.

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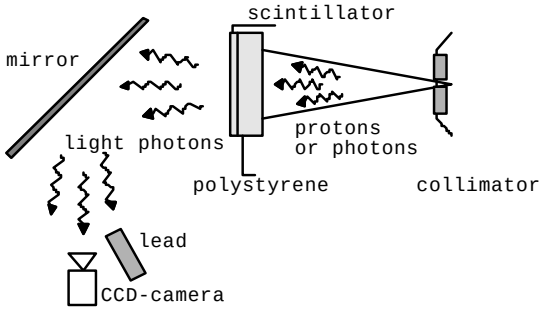
With the introduction of scanning particle beams, there is an increasing demand not only for high precision measurement of the absorbed dose, but also for a position sensitive measurement of the dose distribution. In this contribution we will present the development of a quality-control instrument, especially useful for radiotherapy with a scanning proton beam. Although the advantage of scanning beams is a better flexibility in delivering complicated dose distributions, the much larger local doserates require special beam monitoring and quality control.

Our instrument consists of a scintillator screen which is observed by a dedicated CCD camera. The screen is mounted at the distal side of a stack of phantom



material. In particular we have studied Gd_2O_2S:Tb as a scintillator material, which is commercially available as an intensifier screen for diagnostic radiology ("Lanex"). The advantage of this system for spot-scanning is that it measures 2 dimensions simultaneously, so the probability of missing a spot is low. We have investigated relevant system properties such as linearity, LET dependence, position resolution and signal-to-noise ratio. The experimental results are obtained with 80 MeV (Louvain-la-Neuve) and 175 MeV (Uppsala) protons as well as with 6 MV photons (Groningen).

We have observed a LET dependence leading to some quenching of the signal in the Bragg peak, but the good spatial resolution and SNR make this technique very promising for relative dosimetry with scanning beams.

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A Detection System For the Verification of 3D Dose Distributions.

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The verification of the treatment plans as a routine procedure at GSI requires the determination of the three dimensional dose distribution released by the high intensity heavy ion beam. The measurement of the dose requires a detector with a large dynamic range and a good linearity for high intensity radiation; on the other hand a good spatial resolution is necessary, at least comparable to the dimensions of the voxels as from a typical CT scanner. These requirements can be met coupling a parallel plate chamber, measuring the dose integrated over a relatively large area, with a multi wire proportional chamber that can provide the beam profile and its position with a spatial resolution of 1 mm. With the active beam delivery system developed at GSI, a pencil beam is scanned over the transverse treatment area slice after slice, each one corresponding to a different beam entry energy, until the whole target volume is treated. The beam profile and its position, apart from the uncertainty due to the weak Coulomb scattering, are then independent at every instant from the penetration depth; thus one position sensitive device is sufficient to identify in the complete target volume, the transversal beam profile and its locus. For the longitudinal dose measurement we decided to stack along the beam path 36 ionization chambers with a sensible area of (20 x 20) cm^2 sandwiched between 5 mm thick removable plastic plates. In front of the IC stack a MWPC will provide the bidimensional position information with a spatial resolution of 1 mm over the transverse treatment area. In order to accommodate the detector setup according to the different treatment plans, a range shifter will center the enlarged Bragg peak on the IC stack providing a longitudinal spatial resolution up to 1 mm.

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Routine 3D Dosimetry Of Hadron Beams.

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The full exploitation of the hadrontherapy intrinsic advantages requires at least a dose measurement which has to be accurate in value and spatial distribution. The degree of accuracy should be comparable to the typical accelerator performances. In this way the dose profiles have a precision which matches the dimensions of the voxels as from typical Computed Tomography (CT) scanners.

The requirement is especially true with an active beam delivery system. In this case the beam spot scans over the transverse treatment area while an energy modulation provides the longitudinal spread to match the volume to be treated. Indeed the measurement of the dose 'on line' calls for a detector having a large dynamic range and linearity for high intensity radiation. On the other hand one needs a good spatial resolution, in fact comparable to the beam spot size.

The term 'dose' is used here with the meaning of deposited ionization energy in a sampling medium. The scaling with respect to an homogeneous medium is assured by the fact that one is dealing with hadrons. This statement is not correct when photons or electrons are used.

A 3-dimensional dosimeter with both a transverse and a longitudinal spatial resolution of a few millimeters can be used to check the dose-depth curves as a routine procedure for standard treatment plans. On the other hand it can be a useful tool to implement new treatment plans.

We are building such a detector (nicknamed 'Magic Cube') with the architecture that in high energy physics jargon is called sampling calorimeter. Planes of position sensitive ionization chambers are interleaved with tissue equivalent material. This allows a 25*25*25 cm^2 dosimeter with a spatial resolution in the order of the millimeter. We report on the mechanical construction and details of a set of parallel plate ionization chambers with segmented anode. We then describe the setup, the frontend electronics and the data acquisition system (DAQ) we installed on an ion beam line at Gesellschaft fur Schwerionenforschung (GSI), Darmstadt, Germany to test the chambers. Results are reported and discussed, as well as plans for the final setup to be used end of 1996.

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Three Dimensional Irradiation with Broad Beam for Heavy-Ion Radiotherapy in HIMAC.

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We have developed a new irradiation system for the three dimensional irradiation based on the broad beam method. The method is based on an idea that the target volume is split into thin slices along the beam axis and are irradiated with a thin spread-out Bragg peak (SOBP) by changing the thickness of the wedge absorbers. During the sweep by the thin SOBP, out side of the target volume in the slice is blocked by the multi-leaf collimator. To realize the suitable amount of dose for each slice precisely, the beam was interrupted during the transition time to the next slice. Gate signals to inhibit the irradiation during this period were made from the dose monitoring system for the three dimensional irradiation which synchronously controls the movement of the wedge absorbers and the aperture of the multi-leaf collimator. Depth dose distributions of 10, 8, 6, 4, 2 cm width SOBP made by this three dimensional irradiation system were measured and compared with calculated distributions for the 290 MeV/nucleon carbon beam. The three dimensional irradiation was tested for a target volume of a sphere of 7 cm in diameter. Two dimensional dose distribution on a plane across the center of the sphere has been measured using a small parallel plate ionization chamber. These distributions are compared with those planned.

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Fragmentation of 270 MeV/u carbon beams in water.

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Nuclear fragmentation that occurs along the beam path of heavy ion beams in thick absorbers may cause significant alterations of the radiation field. In previous experiments[1] with beams ranging from carbon to neon we have investigated the build up of the heavier projectile fragments ($Z > 4$). In this work the main attention was paid to the production of light charged particles like protons and helium nuclei. Using 270 MeV/u carbon beams delivered by the heavy ion synchrotron SIS we studied the characteristics of light fragments produced in water targets of 4.26 and 8.52 g/cm^2 thickness. Angular distributions and longitudinal momentum distributions were measured by means of a segmented scintillator wall placed at a distance of 350 cm downstream covering emission angles of up to 40 degrees. The lighter fragments have a rather broad angular distribution and deviations of momentum distributions from predictions of the Goldhaber model are more pronounced. For fragments with $Z = 2$ it was found that both parallel momentum distribution and angular distribution are well described in the rest frame of the projectile by two Gaussians. The widths of the transverse and longitudinal momenta that were derived from the measured data coincide within the error bars for both Gaussians. For protons, however, the angular distribution shows an exponential behaviour. For the two water targets total yields (fragments per incident ion) of 0.242(20) and 0.460(45) for Z=1 and 0.123(11) and 0.257(23) for Z=2 fragments were obtained.

Reference: (1) I. Schall et al., Nucl. Instr. Meth. B, in print

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Microdosimetrical Aspects of Proton RBE.

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For a long time microdosimetry attended to aims of radiation protection and space researches, mainly in low doses and high LET. It is not completely clear yet, how its concepts apply to proton therapy, which parameters lie far from these conditions. In a set of successive approximations used in radiation physics the "site" and track models of microdosimetry take a certain place. The theory of dual radiation action based on the first of them shows a decrease of the proton RBE vs. dose, due to less influence of high LET components. A track model derived by analogy with superheated liquid processes gives much more smooth energy dependence on RBE than both models.

Single-event spectra yd(y) were measured by several proton treatment centers. These spectra agree, but their presentation is not informative sufficiently for RBE evaluation. Obviously, a special protocol is necessary to evaluate and compare beam quality based on microdosimetric measurement after the manner of neutron beams with knowledge of peculiarities of protons.

Nuclear reactions in beam delivery systems and in a target by itself became sources of secondary radiation including neutrons what can influence on the proton RBE value. This question is discussed using the experimental material measured at ITEP and Loma Linda proton beams.

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Upgrade Program on HCL Large Field Beamline.

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To provide improved penumbra beams, better dose uniformity, easier proton nozzle setup and improved quality control, several changes are completed, or near completion in the large field beam. Providing double and single scattered beams with upstream absorber and optional upstream modulator will produce beams with reduced penumbra. The upstream setups will be accomplished remotely, driven by files that define a particular patient field. Compatibility with the traditional downstream absorber and modulator beams is being maintained. A multilayer Faraday Cup is being used to measure the range of any therapy beams produced to an accuracy of approximately 0.1 mm. The lateral uniformity of the beam is improved by the use of feedback beam centering on the second scatterer. The sensing element is a segmented ion chamber located just upstream of the patient aperture support snout. Computerized monitoring of beamline setup, including both upstream and downstream absorbers and modulators, is nearly complete. The system acts as a test bed for techniques to be used at NPTC.

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Characteristics of proton beam field formed by the double scattering method using a dual-ring second scatterer.

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We are now developing a new proton treatment planning program based on the pencil beam algorithm. The pencil beam algorithm requires the incident proton beam model. The incident beam model depends on the type of employed beam delivery system. In the horizontal beam delivery system at Proton Medical Research Center (PMRC), University of Tsukuba, the double scattering system using a dual-ring second scatterer has been tested for clinical use in the near future. Although the double differential spatial and angular distribution function of the incident proton beam passing through a series of scatters & degraders, and collimators is required for the precise calculation together with the depth-dose curve of pencil beam in water, the scheme of calculation requires much calculation time for complex clinical targets. So a simpler beam model is required. The effective source model was proposed by MGH & HCL group for that purpose. We investigated applicability of the effective source model to our beam delivery system. The effective source point is found to be shifted near the position of the second scatterer because of larger scattering angle in the second scatterer. Since the angular distribution at the radial position r consists of two components, the discrepancy from the simple effective source model becomes apparent as the radial distance increases. Although other scattering materials like the range shifter and the range modulator smear out the initial structure of angular distribution to some extent, there remains the structure of the initial angular distribution. Therefore an improved incident beam model will be necessary.

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Experiments showing the feasibility of uneven cone filter for conformation therapy by proton beam.

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Uneven ridge filter was proposed by one of the authors in 1994 for conformation therapy by proton beam[1]. An uneven cone filter was developed with cone shaped brass piece and Plexiglas plate. The cone shaped brass piece creates Spread Out Bragg Peaks(SOBP) of 50 mm and 30 mm depending on the shape of the brass piece. The alternative cone shaped brass piece were placed every 1.0 cm^2 on the Plexiglas plate so that SOBP can be changed from location to location. For simplicity right half of the cone filter of 100 cm^2 was filled with 50 mm SOBP brass piece, while another half was filled with 30 mm SOBP brass piece. The uneven cone filter was placed 17.5 cm above the surface of water phantom in which semiconductor detector can be scanned to obtain dose distribution. The trace of each cone was apparent at the water surface in the horizontal direction (perpendicular to the beam). The uneven cone filter was heightened to 35.5 cm from the water surface. The dose distribution became flat and no trace of each cone was detected in the horizontal direction. In the above additional copper plate of 5 mm was added to the upstream of the beam to increase the angular distribution of the beam impinging on the cone filter to smear out the trace of cone shaped brass piece. The standard deviation of the angular distribution was 13 degrees. Then the detector was scanned in the vertical direction at the border of different SOBP, and at 1.3 cm right and left from the border. For beam energy of maximum water range of 16 cm and/or 6 cm, the observed SOBP at 1.3 cm right and/or left from the border was coincident with 50 mm and/or 30 mm.

Reference: (1) Y. Hayakawa, Proceedings of NIRS International Seminar on the Application of Heavy Ion Accelerator to Radiation Therapy of Cancer in connection with XXI PTCOG Meeting, Edited by T. Kanai and E. Takada National Institute of Radiological Sciences, Chiba-shi, pp.234-240 (1994).

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Real and Simulated Data Comparative Studies For Proton Energy Loss.

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The comparison between real and simulated data is essential for a better comprehension of phenomena we are facing in hadrontherapy. Simulation programs for studying energy deposition of protons in equivalent tissues rely usually on high energy simulation programs like GEANT. These programs however are not optimized for the energy we are working with. FLUKA (of which an old version is used inside GEANT itself) seems to be a good candidate to be modified in order to better fulfill our requirements. Differences between GEANT and FLUKA and some studies on energy loss for protons in the range from 10 keV to 200 MeV in different elements and compounds are presented in comparison with the published ICRU data. Also the future planned FLUKA improvements for dE/dx, nuclear interactions and an user defined geometry are shown in addition to a proposal for WWW centralized data-base for all the available proton clinical beams.

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Proton Beam Irradiation of Choroidal Hemangiomas.

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Choroidal hemangiomas are benign tumors which may be circumscribed and isolated or diffuse in a Sturge-Weber syndrome. These tumors induce a decrease of vision mainly because of the secondary exudative retinal detachment they produce.

Laser photocoagulation treatment was considered in the past the best therapeutic option (1). The aim of this treatment was to reattach the retina by destroying the most superficial layers of the tumor and reducing by this way the exudation without completely destroying the angioma (2). However, recurrences of the exudative secondary retinal detachment are frequent, modifications of the macula are produced, and loss of the visual acuity is simply delayed (3). In addition, a laser photocoagulation cannot be applied in tumors localized immediately beneath the macular area without serious impairment of vision.

In order to resolve the therapeutic problems of choroidal hemangiomas, we started using irradiation treatment and we applied Cobalt 60 plaques between 1972 and 1993, with satisfactory results. We treated by this way 41 cases of choroidal hemangiomas, the retina was reapplied in all the cases, the detachment never recurred, and we did not observe any secondary radiation-induced complications (4). A positive experience was also reported following an external irradiation treatment with photons (5).

We started using an accelerated proton beam for the treatment of hemangiomas from 1987 and up to now, we have treated 36 cases by this way. This total is composed of 30 cases of isolated hemangiomas and 6 cases of hemangiomas related to a Sturge-Weber syndrome.

The observation period is less than 1 year for 10 cases, 1 to 2 years for 13 cases, 3 to 5 years for 9 cases, and more than 5 years for 4 cases.

The irradiation dose we used is 30 Gy in 4 cases, 22-25 Gy in 3 cases, and 18-20 Gy in 29 cases.

For the majority of the cases, the hemangioma was localized in the posterior part of the eye. The tumor was in contact with the optic disc in 21 cases, and infiltrated the macular area in 26 cases. The retina was detached in all the cases.

Following the irradiation, the retina was reattached in all the cases, and we never observed a recurrence of the secondary exudative retinal detachment. The tumor was reduced, and progressively transformed into a flat scar. We observed that the speed of the regression was dose-dependent.

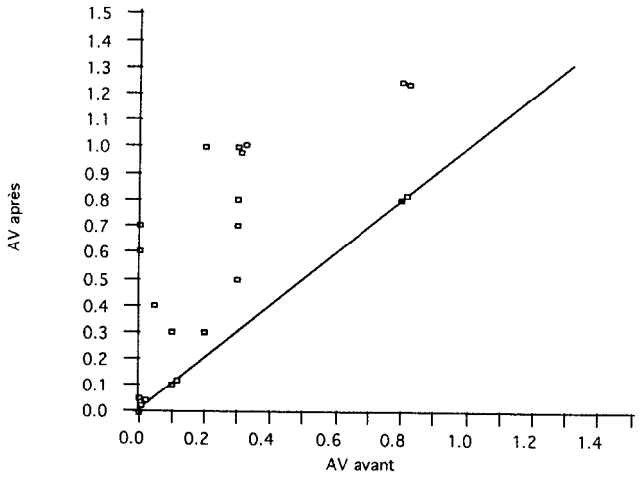
The irradiation of 30 Gy that we first used for the treatment of hemangiomas turned out to be toxic for the circulation of the optic nerve, producing a radiation-induced optic neuropathy in the first 4 cases that we treated. On the contrary, we never observed an alteration of the circulation of the retina and of the circulation of the optic nerve head in cases treated with an irradiation dose ranging from 18 to 25 Gy.

Functional results of the 22 cases of choroidal hemangiomas with an observation period ranging from 1 to 5 years and treated with an irradiation dose between 18 and 25 Gy revealed to be favorable (Fig. 1). In none of these cases did we observe a decrease of the visual acuity, but an important improvement of vision was observed.

In conclusion, proton beam irradiation of choroidal hemangiomas seems to be at present an interesting therapeutic alternative for the treatment of these tumors.

Considering that the speed of regression of hemangiomas following an irradiation treatment is dose-dependent, the use of the high-doses between 22 and 25 Gy may be recommended in cases followed by an important bullous exudative retinal detachment, as well as in cases with prominent subretinal fibrosis. On the contrary, a light dose between 18 and 20 Gy may be sufficient for the treatment of small hemangiomas with flat retinal detachment.

References: (1) Ausberger JJ, Shields JA, Moffat KP. Circumscribed choroidal hemangiomas: long-term visual prognosis. Retina 1981;1:56 61. (2) Anand R, Ausburger JJ, Shields JA. Circumscribed choroidal hemangiomas. Arch Ophthalmol 1989; 107:1338-42. (3) Sanborn GE, Ausburger JJ, Shields JA. Treatment of circumscribed choroidal hemangiomas. Ophthalmology 1982; 89:1374-80. (4) Zografos L, Bercher L, Chamot L, Gailous C. Raimondi S. Egger E. Cobalt-60 treatment of choroidal hemangiomas. Am J Ophthalmol 1996;121:190-9. (5) Alberti WE. Clinical features and management of choroidal hemangiomas, including those occurring in association with Sturge-Weber syndrome. In: Alberti WE, Sagerman RH, editors. Radiotherapy of intraocular and orbital tumors. Berlin: Springer, 1993:87-92.



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Proton irradiation of vascular endothelial cells in vitro.

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In addition to the treatment of cancer, in which vascular damage contributes to acute and late radiation damage effects, proton radiotherapy is used to treat vascular malformations and neovascular eye disease. The possibility that proton therapy may be used at Clatterbridge for senile macular degeneration and the lack of understanding of the radiobiological responses of endothelial cells to proton irradiation has prompted investigation of the biological effects of protons on endothelial cells in vitro.

In these studies, conditions of beam modulation appropriate for the treatment of macular degeneration were used; cells were irradiated within 6 mm of the Bragg Peak. Bovine aortic endothelial (BAE) cells were found to be relatively radiosensitive to protons and survival curves suggested little capacity for repair. Fitting the data from 0-10 Gy to the linear-quadratic multi-target model of radiobiological survival gave an □ value of 0.704 ± 0.055 and a □ value of 0.012 ± 0.006. Following 2 Gy of proton irradiation the surviving fraction was 0.23. Large numbers of non-growing cells were present following proton irradiation of BAE cells. These cells, if present following proton irradiation *in vivo*, could have implications in the generation of late radiation damage.

When compared with photon irradiation, the $RBE_{(s=0.1)}$ values for BAE cells and for the MGH-U1 bladder carcinoma cell line were 1.24 ± 0.22 and 1.22 ± 0.24 respectively. Both cell lines showed decreasing RBE with increasing dose per fraction.

Proton irradiation of proliferating subconfluent cultures of endothelial cells retards their growth but does not cause apoptosis, whereas in confluent, non-growing endothelial cultures, a wave of cell death by apoptosis was induced, peaking around 6 hours after irradiation. The extent of apoptosis was influenced by environmental factors such as cell density and medium composition and showed a linear correlation with increasing dose, but doses of 12 Gy caused only 20% of the cells to become apoptotic. Although contributing to the biological responses of endothelial cells to proton irradiation, initial induction of apoptosis is unlikely to be a major factor in the in vitro clonogenic survival of these cells.

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Dosimetric Corrections In Small Field Proton Eye Therapy.

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This work examines practically, some dosimetric problems encountered when treating smaller fields in proton eye therapy. Also, the effects of treating at other than the standard calibration position are studied. Earlier results (2) led to a more detailed study of proton dose response along the central-axis and included beam area homogeneity and penumbra considerations.

Although output factors are not currently used, the increasing number of relatively small fields required for treatment, especially for iris melanomas, motivated a review of earlier work on output factors (1). Gottschalk et al (3) have described the effects of 160 MeV proton scattering by the final treatment collimator on the depth dose.

Measurements were performed with 5.4 mm dia. Markus chamber and diodes of different size. The response of a series of collimators was measured at different 'treatment' distances with modulated and 60 MeV protons.

Results: Similarly to what was predicted in (3), a dose build-up of up to 12% (for a 7 mm collimator) was noted at 60 MeV; the effect was less with a modulated beam. A drop of dose-response 5%/cm was noted for modulated beams. A Monte Carlo model (TRIM 92.07) indicated that a low energy flux component, with a mean energy of about 30% of incident energy, contributes to the central-axis 'build-up' dose.

Discussion: Results show that detector type and sensitive volume alter the shape of dose responses. Output factors would be unique for collimator, measurement distance, measurement device, beam focal-point as well as required target homogeneity. The effect on dose-volume histograms of increasing beam penumbra with collimator distance was tested on the EYEPLAN program. The effect of collimator-induced low-energy protons on Faraday cup dosimetry, and possible solutions, will also be discussed.

References: (1) Bonnett DE, Kacperek A, Sheen MA, Goodall R and Saxton TE 1993 Brit. J. Radiology. 66, pp 907-914. The 62 MeV proton beam for the treatment of ocular melanoma at Clatterbridge. (2) TJ Chapman M.Sc. Dissertation 1995 University of Leeds UK. (3) B. Gottschalk, Koehler AM, Mayo CS and Wagner MS (Harvard Cyclotron Laboratory) 1994 Proton Beam Technology: I. Slit Scattering. PTCOG XX Chester UK. (4) Ziegler JF, TRIM 92 Vers.07. IBM-Research, Yorktown NY USA.

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Optic Nerve Injury - How to Reduce It?

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Proton beam irradiation has now been used for many years for the treatment of uveal melanomas. The results are excellent in terms of local tumor control (96%) and good in terms of eye retention (90%). However, the functional results are not considered to be satisfying anymore today for tumors located close to the optic disc (distance between tumor and optic disc smaller or equal to 3 mm). Approximately 50% of the tumors treated at the PSI belong to this groups. 80% of these patients present with an optic atrophy leading to a severe functional loss in most cases within 7 years following the treatment. While, in this group of patients, the visual acuity before the treatment is better than 20/200 in 87% of the cases, only 35% of them retain useful vision (20/200 or better) five years after the treatment. The question is studied how the complication rate to the optic nerve could be reduced without jeopardizing the excellent local tumor control probability.

Presently, uveal melanomas are treated with a total proton dose of 54.54 Gy applied in 4 fractions within 4 days. The very high rate of local tumor control probability suggest that this dose might be too high. Results presented by other groups indicate that a total proton dose of 45.45 Gy applied in 4 daily fractions of 11.36 Gy would be sufficient to achieve local tumor control (1). In order to reduce the complication probability of the optic nerve, the ideal case would be to minimize the total dose to this structure without reducing the tumor dose to a value equivalent to these 45.45 Gy in 4 fractions. One possible way to do it, would be to increase the number of fractions, applying 8 fractions within 4 days. Table 1 shows the biological equivalent doses for the optic nerve, the tumor and the skin, calculated as:

$$BED = nD(1 + D/(\alpha/\beta))$$

where n = number of fractions, D = dose per fraction and α/β being 1.6 Gy for the optic nerve, 5 Gy for the uveal melanoma and 10 Gy for the acute reading tissues.

Table 1: Biological equivalent dose for different treatment schemes.

	4 x 13.64 Gy	4 x 11.36 Gy	8 x 7.43 Gy
Optic Nerve	520 Gy (100%)	368 Gy (71%)	335 Gy (64%)
Uveal melanoma	203 Gy (100%)	148 Gy (73%)	148 Gy (73%)
Skin	129 Gy (100%)	97 Gy (75%)	104 Gy (81%)

Proton radiotherapy delivers a homogeneous physical dose to the target volume. Uveal melanomas are also successfully treated with brachytherapy, where an inhomogeneous dose is applied to the tumor. In brachytherapy, the target dose to the tumor apex is 90 Gy, while the dose of approximately 150 to 250 Gy is applied to the tumor base, depending on the tumor thickness. The biological equivalent dose is calculated for a typical example, assuming the dose to the tumor apex to be 90 Gy, the dose to the tumor base being 240 Gy, and the application time being 168 h. The biological equivalent dose is

$$BED = RT\,(1 + (2R/\mu)/(\alpha/\beta))$$

where R is the dose rate, T is the application time and μ is assumed to be $0.5h^{-1}$ (2). It results in a biological equivalent dose to the tumor apex of 130 Gy and 515 Gy to the tumor base.

One could therefor imagine to apply an inhomogeneous dose to the tumor with proton radiotherapy, the minimal dose being applied to the part of the tumor located close to the optic disc/nerve. Converting

the BED of 130 Gy resulting from brachytherapy to a 4 fraction treatment leads to a dose of 10.50 Gy per fraction. Application of such a treatment scheme (4 x 10.50 Gy to optic nerve and part of the tumor located close to it, 4 x 13.64 Gy to the rest of the tumor) would result in the biological equivalent doses shown in Table 2.

Table 2. Biological equivalent dose for inhomogeneous dose distribution.

Optic Nerve	4 x 10.50 Gy	BED = 318 Gy (61%)
Uveal melanoma (5 - 10%)	4 x 10.50 Gy	BED = 130 Gy (64%)
Uveal melanoma (90 - 95%)	4 x 13.64 Gy	BED = 203 Gy (100%)
Skin	4 x 13.64 Gy	BED = 129 Gy (100%)

We plan to submit the following proposal for a randomized study in order to reduce the complication probability to the optic nerve:

1) Control group: presently used treatment scheme; 54.54 Gy applied in 4 fractions of 13.64 Gy within 4 days.

2) First new treatment scheme: 59.44 Gy protons applied in 8 fractions of 7.43 Gy within 4 days. the dose distribution to the target volume being homogeneous.

2) Second new treatment scheme: 4 fractions within 4 days with an inhomogeneous dose distribution; 4 x 10.5 Gy protons to the optic disc/nerve and a small part of the tumor, 4 x 13.64 Gy protons to the rest of the tumor.

References: (1) Castro et al., Long term results of helium beam irradiation for ocular melanomas, Second International Symposium on Hadrontherapy, PSI, September 1996. (2) K. Awwad, Radiation Oncology: Radiobiological and physicological perspectives, Kluwer academic publishers, Dordrecht/Boston/London, 1990.

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Status of the Proton-Ion Medical Machine Study in CERN.

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At the end of 1995, the TERA Foundation and MED-AUSTRON agreed to collaborate in the design of a medical synchrotron for both protons and light ions. The inclusion of light ions determined the choice of a synchrotron rather than a cyclotron. CERN agreed to host this study until the end of 1997 and to contribute one full-time staff member as well as part-time consultant help. The Study Group also has informal contacts with GSI, Darmstadt and KFA, Jülich. The task of the Study Group is to design a second-generation, medical synchrotron using slow extraction with active energy variation and active scanning. The design will embody many features to improve the quality (uniformity) of the slow spill. The use of a synchrotron, rather than a cyclotron, has an influence on the matching to the gantry and the Study Group is therefore also working on the beam distribution in single and multi-gantry systems and on the gantry design proper. Synchrotrons with slow-extraction schemes have existed for many years in accelerator laboratories and several techniques have been developed for improving the spill quality. However, the goals of physics research are rather different to those of cancer therapy and optimising a machine design for tumour irradiation is still a relatively underdeveloped field. The study team started by making a theoretical analysis of the transverse behaviour of the resonance. This led to a better understanding of the particle distribution in the extracted beam and a potential problem with the matching of the machine to the gantry. A tentative lattice was proposed and typical values for many of the parameters were formulated. The study is now continuing with the longitudinal behaviour of the

resonance. This is closely related to the spill uniformity and the sensitivity of the machine to current ripple in the power supplies. It is hoped that, by the end of this year, the machine parameters will be frozen and a detailed design can be started.

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Simple range-measurement method using visible scintillation light.

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Accelerated ions exhibit a flat depth-dose distribution as far as the vicinity of their range, where there is a marked increase in dose, called the Bragg peak. In proton therapy facilities and our HIMAC (Heavy Ion Medical Accelerator in Chiba) such Bragg curve is routinely measured by changing the thickness of a phantom ahead of a detector before patient treatment. This kind of measurement is more or less inefficient in terms of valuable beam time and impossible to monitor the range during patient treatment.

We developed the simple method to measure the range of heavy charged particle in real time using visible light generated in a scintillator. Usually a scintillator is canned in contact with photo multiplier and used for counter experiment. We however placed a bare plastic scintillator (5 cm x 5 cm x 30 cm) on the beam line and video camera beside it. It was irradiated with 290 MeV/u carbon beam of therapeutic intensity which is much higher than that of counter experiment. Through the video monitor we could clearly find the blue-white scintillation light which indicated the track and the range of the beam. The pictures will be shown in our poster presentation.

If this system is placed ahead of a collimator and outside irradiation field, it is possible to monitor the range during patient treatment. We expect that this method is useful as a QA tool of proton and heavy-ion therapy, especially in case of 3D conformation irradiation.

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The Tomographic Facility for Radiation Treatment Planning and Verification at the JINR Phasotron in Dubna.

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Three tomographic installations for radiation treatment planning and verification are realized at the JINR proton phasotron. The first one is a horizontal X-ray tomograph. Its main feature is that it is combined with a rotational chair intended for patient's rotation scanning irradiation with proton beams. It gives us a possibility of performing treatment planning on the basis of tomographic images measured in the same position immediately before the irradiation run during all course of fractional treatment.

The X-ray source with a maximal energy of 140 keV is collimated into a horizontal fan beam. A registration system consists of 128 CsI(Tl) scintillation counters operating together with photomultiplier tubes. For data processing a special logarithmic ADC is developed and constructed in the CAMAC standard.

For conversion of linear attenuation coefficients of X-rays to proton energy losses which are really needed for precise planning another installation for proton tomography is constructed and also combined

with the same rotational chair. A detector block consists of 8 large plastic scintillators and allows one to measure a residual range of protons transmitted through an investigated object to an accuracy of 0.1 g/cm^2. A narrow diagnostic proton beam of energy 660 MeV and 3.8 x 2.8 mm^2 in size is delivered.

For post-irradiation verification of the treatment and may be for diagnostics a single-ring whole-body positron emission tomograph on the basis of a composite scintillator is developed and constructed. The scintillator we designed is a combination of 160 alternating plastic scintillators and lead foil strips 0.15 mm and 0.033 mm thick respectively and has a very low cost. The detection efficiency of this 15 x 20 x 30 mm^3 counter to 511 keV annihilation photons is 45%, the time resolution is 1.7 ns. The tomograph contains 512 such counters 5.2 mm wide. A light coding makes it possible to halve the number of the photomultiplier tubes. The spatial transaxial and axial resolutions in the centre of the tomograph are 4.0 mm and 10.5 mm respectively. The images of several phantoms are measured and reconstructed.

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Clinically useful epithermal neutron beam based on 0.4 g source 252-Cf.

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The article deals with evaluation of the 252-Cf source of fission neutrons to provide epithermal neutron beam for use in neutron capture therapy. Epithermal neutrons are produced by the gantry which consists of a new type reflector system based on anisotropic scattering of fast neutrons on nuclei of heavy elements, of moderator with reflector of intermediate neutrons and of absorber of thermal neutrons. The Monte Carlo code MCNP was used to design the gantry. The RBE dose rate in ellipsoidal phantom, which is composed of skull and brain equivalent material, was calculated for RBE values 1, 4, 4 for photons, neutrons and 10-B reaction products, respectively. Tallied gamma and neutron doses and tissue kerma from thermal neutron capture on nucleus of 10-B (kerma coefficient 0.76×10^{-7} Gy.cm^2 for concentration 40 microgramme of 10-B per gramme of tumour and 10 microgramme of 10-B per gramme of healthy tissue) were used for the advantage depth (AD) calculation. For the epithermal neutron beam which is characterized by the ADmin=7 cm and ADmax=9.5 cm the RBE dose rate (at the depth of 7.5 cm) of 0.16 Gy per minute based on 0.4 g 252-Cf was obtained. This dose rate is close to those provided by existing reactor sources.

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Progress Report of Treatment Planning at HIMAC.

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A carbon ion therapy treatment planning (TP) system at HIMAC was developed at our institution based on the TP software modules developed at LBL. The graphical system we employed was a X-window based interactive 3D graphical display software package developed for medical use by a local company. It has been in routine clinical use since June 1994 for over 150 patients. We will present progress made hitherto in improving our TP system. These include: (a). Analysis of the accuracy of software tools used for calculating and displaying target and iso-dose contours, dose-volume histograms and 3D surface data. (b). Development of daily required tools used to visualize and edit CT data,

contours, compensators, collimators and so on. (c). Development of image correlation to integrate CT, MRI and PET images. A tool was developed to display 3D surface distributions of planned dose and LET. Post-irradiation skin reaction appearing on photographic images can be correlated to these distributions. Studies on calculating more accurate dose distributions than straight broad beam algorithm now used are in progress.

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The Quality Control Program for the NAC Neutron Therapy Facility.

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A quality control program has been in place since the start of neutron therapy at the NAC. This program consists of daily, quarterly and annual checks on various operational aspects of the isocentric unit as well as several beam parameter checks. The acceptable limits of the individual quality assurance checks are specified in this program as well as the different actions to be taken if any acceptable limit has been exceeded.

Daily non radiation checks (without the neutron beam) include inspections of the operational aspects of the isocentric gantry, the treatment couch, the moving floor system, the room lasers, the room interlock system and the room communication system. The radiation checks involve a constancy check on the beam output using an air-filled ionization chamber in a small easily manageable acrylic phantom. Each measurement is compared with a reference measurement which was made directly after a quarterly absolute calibration of the neutron beam. The alignment of the beam is also checked with quadrant ionisation chambers each day at each gantry angle required for treatment.

The quarterly non-radiation checks involve calibrations of the moving components in the isocentric unit as well as checking the SSD projector, the beam defining lamp and the front pointer device. Monitoring of the background radiation levels in the treatment room and the activation levels of the tungsten shielding blocks is also done quarterly. The quarterly radiation checks comprise an absolute calibration of the neutron beam using two ^{60}Co-calibrated tissue-equivalent (TE) ionization chambers filled with TE gas as well as checking the radiation field parameters such as field size, symmetry, flatness, congruence with X-ray and light fields.

The annual checks concern mainly checking the major beam parameters required for treatment planning such as the percentage depth doses and output factors as well as checking the rate and integral dose monitor linearity. All the TE ionization chambers is also calibrated annually against a secondary standard. An annual determination of the isocentre is also performed.

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Progress in the Hadron Radiotherapy Project at Krakow.

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Since 1978 fast neutron radiotherapy has been carried out at the Institute of Nuclear Physics (INP) in collaboration with the Centre of Oncology in Krakow (COK). Neutrons of mean energy c. 5.6 MeV were produced by 12 MeV deuterons on thick Be target using the U-120 cyclotron. About 500 patients, mainly with head and neck tumours, were treated until June 1995. Ocular brachytherapy has also been carried out

in Krakow at the Clinic of Ophthalmology for the last twenty years and more than 1000 patients were treated.

In collaboration with the Clinic of Ophthalmology, Centre of Oncology and the Institute of Nuclear Physics (INP) in Krakow we proposed to establish a centre of hadron radiotherapy which would exploit beams of 60 MeV protons and fast neutrons produced by the new isochronous AIC-144 cyclotron. This cyclotron, designed and constructed at the INP at the end of 80-ties, has been lately upgraded to obtain 60 MeV protons. The 60 MeV proton beam will be available at INP Krakow since mid 1997. In addition to an existing facility for horizontal neutron irradiations two therapeutical stands will be constructed: a vertical neutron beam facility with a multileaf collimator and a stand for proton ocular therapy. The centre of hadron radiotherapy at the INP, Krakow, would satisfy national needs for treating ocular melanoma and clinically indicated fast neutron radiotherapy.

The total estimated cost of the project is 2.5 million $US, spent within 3 years (1997-1999). The decision about further financing of the project will be taken by the Polish State Committee of the Scientific Research till the mid of 1997.

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Attenuation of Therapeutic Heavy-ion Beams in Various Thick Targets Due to Projectile Fragmentation.

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To superimpose the sharp Bragg Peak over the whole tumor volume, the peak is spread out by the ridge filter and the maximum range is shifted roughly by the range shifter and finely by the three-dimensional bolus at HIMAC. However projectile fragmentation along the beam path in those devices causes an attenuation of a flux of the primary beam and may disturb the depth-dose distribution which is essential in the treatment planning.

We have therefore measured the attenuation of 290 and 400 MeV/u carbon beam and 400 MeV/u neon beam through a thick target such as water, polyethylene, polymethyl methacrylate (PMMA), polytetrafluoroethylene (Teflon), graphite, calcium fluoride, aluminum, copper or lead. We placed the target between two plate-type plastic scintillators along the beam axis. We measured the number of primaries that survived after passing through the target as a function of the target thickness.

The results show that the attenuation of carbon beam in PMMA and polyethylene agrees well with that in water. This means that one can regard PMMA and polyethylene as water equivalent material in terms of nuclear attenuation of the carbon beam. We therefore find that it is appropriate to select PMMA and polyethylene as materials for the range shifter and the bolus respectively in the carbon beam therapy.

We have also determined the total charge-changing cross sections of the carbon and neon beams for the various target materials from the slope of the measured attenuation. These cross sections were compared with both other experiments and the semi-empirical calculation. These obtained data are useful for calculation of Bragg Curve of therapeutic heavy-ion beams.

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Simulation of the Fragmentation of Carbon Ions.

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Writing a treatment planning code to be used with Carbon ions beams means handling two major complications with respect to proton beams: fragmentation and biological effects.

We want to implement a treatment planning using the MonteCarlo technique. For this purpose we use GEANT MonteCarlo (see the abstract 'Treatment Planning of Proton Beams using the GEANT MonteCarlo') with an external fragmentation package.

The theoretical basis of fragmentation of ions with kinetic energies lower than 1 GeV are quite weak due to the behaviour of cross sections. We are using the MonteCarlo code named FREESCO, developed by G. Fai and J. Randrup. This code has been interfaced with GEANT: the former simulates the fragmentation of ions while the latter tracks all secondaries produced in the reaction.

We report the results from comparisons with data taken by other experiments at GSI. We also report the comparison with data taken during a test of the 'Cubo Magico' dosimeter (see the abstract 'Routine 3D Dosimetry of Hadron Beams').

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Fragmentation Fluence of Heavy Charged Particle Therapeutic Beam in a Patient's Body.

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Radiotherapy using heavy charged particle beam has been expected as an efficacious tool for tumor therapy for its many excellent physical characteristics in comparison with other conventional radiotherapy methods. HIMAC, a heavy ion accelerator complex, was established at NIRS for the medical use and clinical trial has been carried out since 1994. It is well known that the beam is to be broken into some fragments in a patient's body by spallation reaction, however, the effects have not been fully installed to our treatment planning system because of the lack of reliable theoretical model.

In this study, the fluences of the fragments were measured for helium, carbon and neon beams with a stack of PMMA (polymethyl methacrylrate, Lucite) plates as a substitute of the body. Results were compared with calculations by a simulation code.

Setup of Experiments: Experiments were carried out at a biological port of HIMAC. Beam delivery devices were disposed identically the same as those of therapeutic ports. Incident beam was broadened to lateral direction about 10 cm in diameter with a flatness better than +/- 2 % by a pair of wobbler magnets and a scatterer. Measurements were done for the beams of carbon 290 MeV/u (this beam has been used for our actual therapy), helium 150 MeV/u and neon 400 MeV/u by changing the thickness of the PMMA variously. Detector system was based on the deltaE-E counter telescope method with a thin plastic scintillator (deltaE) and a thick BGO scintillator (E). A Si(Li) detector and a large area plastic scintillator

were also used for energy calibration of the system and counting total number of incident primary particles, respectively.

Results: Each fragment particle was clearly identified from primary particle to hydrogen fragment as its kind of element or isotope. Certification the identification was done by comparing reciprocally the position of primary particles on the deltaE-E scatter maps for each incident beam. Fluences of fragments were derived as a function of PMMA thickness. The results were compared with the calculations based on L. Sihver's model and generally showed good agreements with each other, however, disparities were also shown for light fragments, such as hydrogen or helium.

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Treatment Planning of Proton Beams Using the GEANT Montecarlo.

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We report on the work that is being done implementing a treatment planning program that uses a MonteCarlo simulation code. The MonteCarlo code is GEANT, developed at CERN, Geneva, to be used as general purpose simulation tool for high energy physics. The code structure allows very easy construction of complex geometries and handles very large numbers of volumes. This is ideal when one starts from a Computer Tomography (TC) image, with thousands of voxels. The use of MonteCarlo program is ideal also for what concerns the precision of response, provided one implements in such a code all the relevant physics processes.

As GEANT has been developed for high energy physics, as first step we have checked its response against ICRU tables for proton energies of therapeutic interest on water. We have then constructed an interface between TC images and the MonteCarlo program. With such a code we have implemented a procedure that allows the design of a passive delivery system of the 'double diffusion' type (as the one used at HCL), once the treatment planning parameters are given.

We have then written a numerical algorithm that computes the number of protons that one has to deliver, on a voxel-by-voxel basis, to match a given dose distribution. This number of protons is then given as input to the MonteCarlo program to verify the correctness of the algorithm.

Finally we have implemented algorithms to automatically define the 3-D contours; this allows easy calculation of delivered dose on any volume.

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Proton treatment facility at national cancer center hospital east: present status of the Kashiwa project.

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The Ministry of Welfare and National Cancer Center (NCC) determined to build a medically dedicated proton treatment facility on the campus of NCC Hospital East in Kashiwa as already presented at the previous PTCOG XXIV meeting in Detroit. This decision is based on the increasing demand for the cancer treatment modality which is expected to be more effective for cure and preferable from the point of view of quality of life and on the encouraging clinical results experienced at several proton therapy centers, Massachusetts General Hospital (MGH), University of Tsukuba, Loma Linda University Medical Center (LLUMC) and so on. The building construction started in May 1996 as previously scheduled and will complete in March 1997.

This new facility will be in a hospital setting, connected with the hospital building through passageways, and will have three treatment rooms. Two treatment rooms will be equipped with isocentric beam delivery gantries with either double scattering system or scattering/wobbling system for lateral beam spreading and one with a fixed horizontal beam port with double scattering system with the maximum field diameter of 10 cm. Sumitomo Heavy Industries, one of team members for the Northeast Proton Therapy Center (NPTC) project of the MGH, was selected as the prime contractor for our proton therapy system, including a fixed 235 MeV cyclotron, beam transport and delivery system, patient positioning and verifying system and treatment planning system. Most of details of the system are being designed.

This project is being carried out in collaboration with the National Institute of Radiological Sciences (NIRS) in Chiba and Proton Medical Research Center (PMRC) in Tsukuba. Recent progress of this project will be presented.

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VLSI Electronics As Readout For Hadron Dosimeters.

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In the framework of the development of a 3-dimensional dosimeter for hadron beams, the 'Magic Cube',(see the abstract 'Routine 3D Dosimetry of Hadron Beams') we are developing two electronics circuits that use the Very Large Scale Integration (VLSI) construction technique. The reason for using such technology stands in the need of a relatively high number of readout channels (in the order of a thousand) in conjunction with a high readout speed (order of MHz). The high number of readout channels is requested by the spatial resolution that one wants to get (1 mm on the Bragg peak). The high speed is needed to use such a device for routine measurements; this means that a reasonable time for one measure has to be comparable with the time of a treatment (1 minute).

We are developing two VLSI circuits with different architectures: an analog pipeline and a recycling capacitor.

The analog pipeline is a chip with 32 channels and 64 memory cells. It features two independent 'read' and 'write' clocks: this allows an asynchronous readout during the write phase. Independent from these two clocks is the 'integrating gate', which fixes the time during which the charge is integrated. Results from the test of a prototype are reported.

The recycling capacitor chip allows a continuous sample of the beam. In our case the beam of GSI, Darmstadt, has a 50% duty cycle with a spill-on of 2 seconds. For this reason 20-bit counters are implemented on the chip. The first sample of prototypes has been received these days: we report on the preliminary tests of the chip.

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Through bone transmission of acoustic pulse generated by pulsed proton beam in water.

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We have reported previously the detection of acoustic pulse generated in the liver of a hepatic cancer patient during pulsed proton beam irradiation (Y. Hayakawa, J. Tada, N. Arai et al., Radiation Oncology Investigations, vol. 3:42-45, 1995). This time we have shown that acoustic pulse generated in degassed water by pulsed proton beam irradiation was transmitted through bovine bone of approximately 1 cm and sensed by a hydrophone. It may show that acoustic pulse generation phenomenon might be useful for dose distribution monitoring in the head and neck regions. It is considered as a common sense in the field of medical ultrasound, that ultrasound wave cannot penetrate through bone. The reason acoustic pulse penetrated the bone is due to the fact that it contains low frequency component suffering less attenuation by the bone. The wave form, however, was suffering from attenuation of high frequency components. If the thickness of bone were smaller as those at temples, acoustic pulse generated in the brain is certain to be transmitted to the skin surface with the sufficient intensity to be sensed by an hydrophone (S. A. Goss et al., J.Acoust.Soc.Am. vol. 68:93-108, 1980).

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A Small Ionization Chamber for Dose Distribution Measurements in a Clinical Proton Beam.

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Different types of detectors can yield different responses in proton beams. This phenomenon can cause big uncertainties in dose measurements. In clinical proton beams, diodes, diamond detectors and different types of ionization chambers can be used to measure dose distributions while calibrated ionization chambers, Faraday cups or calorimeters are used for absolute calibrations.

At the National Accelerator Centre (NAC) a diamond detector, diodes and ionization chambers were previously used to measure dose distributions in the clinical proton beam. Significant differences were observed in both depth dose and dose profiles. The ionization chambers used were thimble chambers of different volumes and a Markus parallel plate chamber. Some of these discrepancies can be attributed to differences in resolution between the detectors since proton beams exhibit very steep dose gradients, i.e. sharp penumbrae and a very steep distal fall-off of the Bragg peak. Detectors used in the proton beam must therefore be very small in order to obtain good spatial resolution.

A "mini" A150 thimble ionization chamber with an ionization volume of 0.01 cm was constructed at the NAC. This mini chamber produces depth dose curves comparable to those measured with a Markus chamber and a diamond detector which both have very good depth resolution. The curves differ significantly from those measured with diodes in the Bragg peak region. This can be ascribed to the different stopping powers for Silicon (diode material) and air (in the ionisation chamber) for low energy protons. Profile measurements compared favorably with those measured with the diode. The stopping power effect in a diode does not effect profile measurements significantly since the majority of the protons at a given depth in a phantom have approximately the same energy. Owing to the geometry of the Markus chamber it has a poor lateral resolution and is therefore not suitable for profile measurements. The excellent spatial resolution of the mini chamber makes it suitable for both depth dose and profile measurements in a proton beam.

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Biological effectiveness of protons on mammalian cells.

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Introduction "The radiobiological properties of proton beams are less certain than their physical characteristics" (D. W. Miller, 1995). Especially for therapeutic applications the relative biological effectiveness is of interest. We studied the clonogenic survival of mammalian cells and the induction of DNA double-strand breaks. Cells were irradiated with protons in comparison to 120 kV X-rays.

Methods: Chinese hamster B14 cells were irradiated with protons of a linear energy transfer of 5.1 keV/□m and 8.2 keV/□m. The colonies of the irradiated cells were analysed by an automatic colony analysing machine which does the scoring and measures the volume of the single colonies, the distribution of colonies' volumes and the total volumes of the colonies. The volume of the colonies is proportional to the number of cells in the colonies. The total volume of colonies includes the number of colonies and the volume of the single colonies and is a more sensitive parameter than the number of colonies. For the measurement of double-strand breaks cells were embedded in agarose plugs of varying thickness and irradiated. The double strand breaks were analysed by constant field gel electrophoresis.

According to the number of colonies the cell survival curves ($\ln S = -\square * D - \square * D^2$) showed with 8.7 MeV protons □ = 0.073 Gy^{-1}, □ = 0.059 Gy^{-2} and with X-rays □ = 0.061 Gy^{-1}, □ = 0.036 Gy^{-2}. The irradiation of cells with 4.9 MeV protons (□ = 0.247 Gy^{-1}, □ = 0.041 Gy^{-2}) leads to a loss of the shoulder of the dose response curve. The total colony's volume decreased more with dose than the number of colonies and reflected the reduced number of cells per colonies. The relative biological effectiveness was lower for number of colonies (1.26/8.7 MeV and 1.39/4.9 MeV) than for total colonies volume (1.40/8.7 MeV and 1.53/4.9 MeV). The double-strand measurements showed more DNA damage for higher LET than for lower LET protons.

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New Methods for patient alignment

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A first step improvement in the patient alignment precision can be achieved using markers for off-line target positioning or an on-line alignment imaging control system. Both these alignment methods, besides a precision improvements with respect to the conventional methods, should increase the patient safety, lower and simplify the patient positioning time and possibly allow the following of a moving tumor. The first method implies the use of IR reflective marker fixed on the patient skin and viewed by CCD TV cameras : off-line target position with respect to the markers is obtained with an X-ray intensified imaging system before every irradiation session. After patient transport in the therapy room e second CCD TV camera system observe both the skin markers and the markers identifying the beam position. Micrometric control of the patient position should allow a precision beam aiming. The markers and TV cameras systems have been developed and tested. Their use for patient alignment is under test and preliminary results are reported.

The second method consists of an on-line continuous low dose X-ray imaging with identification of the tumor position and feed-back control of the beam aiming. Research progress are reported.

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Clinical Proton Dosimetry Investigations.

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Different dosimeters for use in clinical dosimetry of photon and electron beams were tested for their suitability in the proton beam dosimetry of the PSI voxel scanning system. For absolute dosimetry measurements we applied different ionisation chambers (PTW-Farmer, PTW-Markus, PTW-Roos) and a diamond detector (PTW) in a PMMA phantom. Relative dosimetric measurements were carried out in a linear water phantom scanner using the Roos chamber, the diamond detector and a MR-polymer-gel-dosimeter (BANG-MGS research).

The determination of the absolute dose has been carried out by the application of either a modified ECHED-protocol or the N_w-formalism for the ionisation chambers and by the use of the recommendations of Vatnitzky et al. for the diamond probe. Compared to the PSI dose calculation we obtained deviations of -1.14% (Farmer), -4.05% (Roos), and -1.5%-1.1% (Markus) using the ECHED-protocol and 0.54% (Farmer), -4.64% (Roos) and -0.45%-0.45% (Markus) using the N_w-protocol. The diamond detector showed a deviation of 14.9%. Because of the larger diameter of the active volume the Roos chamber seems to be more sensitive to the complicated time structure of the voxel scanning beam.

Measurements of the distal fall-off of a SBP and a SOBP yielded an excellent agreement using the diamond detector, the Roos chamber and the BANG-gel within an error of 1.5%. Thus the 3 methods are

all suited for high resolution measurements within the Bragg peak regions with a strong change of the LET, as there seems to be only a minor LET-influence to the dosimeter response.

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Deviations of Survival Curves from LQ Shape and Cumulative Effect in Fractionation.

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Survival curves for all radiation kinds are commonly assumed to exhibit a linear-quadratic dose dependence, which seems to be a good approximation if a global characteristics is to be represented. However, it follows from the analysis of published experimental data that significant deviations (survival curves with two shoulders) exist at least for pions and practically the same characteristics should be expected for all heavily ionizing particles. Similar non-negligible (even if smaller) deviations have been found for X-rays, too. Consequences of such deviations for evaluation of cumulative effect in fractionation schemes usually applied in radiotherapy will be also discussed.

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RBE for cell inactivation of tumour and normal cell lines of human origin irradiated with low energy protons.

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Inactivation of four human cell lines, two deriving from tumours (SQ20B and SCC25) and two from "normal" tissues (H184B5-F5-M/10 and HF19), has been studied after irradiation with low energy protons of various LET in the range 8-28 keV/μm. The cells that were the most resistant to X- or gamma-rays also appeared the most resistant to protons. However, difference in radioresistance decreased with increasing proton LET. This is due to the fact that RBE of high LET protons was higher for the cells resistant to sparsely ionizing radiation than for the sensitive ones, i.e. radioresistance was decreased at high LET. This phenomenon was more pronounced in tumour cells.

These findings suggest that the use of protons in radiation therapy may improve the effectiveness of the treatment not only for their favourable ballistic properties, but also for their enhanced biological effectiveness in tumours resistant to conventional radiation.

However, more research is need in order to establish:

i) the extent of reduction in radiation resistance for cells exposed to a modulated Bragg peak;

ii) how the results with cultured cell lines can be extrapolated to "in vivo" conditions.

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Do different ways of beam modulation cause different proton RBE values? Calculations using Monte Carlo methods

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In proton radiation therapy the Bragg Peak has to be spread out to irradiate the target volume uniformly. It is, however, not really the dose that has to be uniform over the target volume but the biological effect. A biological dose can be defined as dose times the respective RBE. The proton RBE depends on various physical and biological parameters and increases with depth within a SOBP due to an increasing proton energy loss. As dose can be described as fluence times LET, it is evident that in a mixed radiation field similar doses can be achieved with different particle energy distributions. Isodose contours are isoeffect contours only if the energy spectra of the accompanying particles remain constant. On this condition, the beam delivery technique used to build a Spread-Out-Bragg-Peak can influence the RBE.

We investigated the influence of the beam modulation method on the biological dose distribution. For this, we performed proton transport calculations in order to obtain the dose and the proton energy spectra at given depths. We simulated an active modulation method, thus varying the beam energy electronically, and a passive modulation system, where we distinguish between different initial proton energies entering the absorber material. RBE values were calculated using the track structure model. This model specifies the biological response of a radiation field by the spatial distribution of radiation damage generated by the passage of a particle and its associated d-rays.

Our calculations show that the beam modulation technique influences the proton energy spectra and by this the RBE within a SOBP although the dose remains constant. Within a SOBP (6-13 cm; RBE for aerobic survival of Chinese hamster cells, CH2B2; 2 Gy biological dose) the calculated RBE increases from ~1 to ~1.18 and to ~1.16, for a passive modulation with a 137 MeV and a 250 MeV beam respectively. For a SOBP between 1.5 and 3.2 cm the RBE increases from ~1 to ~1.51 and to ~1.18, for a passive modulation with a 61 MeV and a 155 MeV beam respectively. That means, the RBE is the higher the lower the maximum proton energy entering the modulator is. The RBE for an active modulation system behaves like the respective RBE dependence of a passive system with similar maximum initial proton energy. The reason for the effect we determined are differences in the proton energy spectra. The considered biological endpoint only influences the extent of the effect.

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Experimental biophysical investigations on a 175.5 MeV proton beam.

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The COSY synchrotron, operated at the KFA-Juelich is able to deliver proton pencil beams with energies covering the range of interest in radiation therapy for the treatment of deep seated tumours (100 MeV to 250 MeV). A biophysical program was started, with the aim to gather the necessary dosimetric

and biophysical information for the development of optimal dose calculation routines for treatment planning.

Experiments have been performed to determine the incident beam characteristics. The experiments have been performed in a water and in a plastic phantom. The water phantom has a volume of 50 cm x 50 cm x 40 cm. A 3-axis scanner unit is used to position the detectors within the phantom with an accuracy of better than 1 mm. The plastic phantom is fabricated from Plexiglas and its thickness can be varied between 4 cm and 30 cm. COSY delivered protons of 175.5 MeV (±1%) kinetic energy. The momentum spread was about 5×10^{-3}.

Absolute dose, microdosimetric energy deposition distributions, energy loss spectra and high resolution dose profiles have been measured as a function of depth. For these purposes different kinds of detectors were applied. Depth dose profiles have been measured with the small-volume (0.1 cm^3) ionisation chamber. In addition we used TLDs in biological stack experiments as on-line dosemeters. Microdosimetric dose distributions have been measured at different depth along the beam axis. The shift of the spectra to higher lineal energies reflects the increase in proton stopping as they are slowed down. No significant contribution of high energy neutrons have been detected from the spectra. Two dimensional dose profiles have been measured with a Si-microstrip detector in the horizontal plane perpendicular to the beam. The plastic phantom was used for these measurements. Clearly the beam broadening with depth has been shown, as well as the thin down behind the Bragg Peak. The Si-microstrip detector and a fibre hodoscopes were either placed in front or behind the phantom. Initial biological experiments concentrate on the determination of cell killing as a function of position on the Bragg curve for different dose levels in the Bragg Peak. For the selected V79 hamster cells RBE values have been determined.

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Palatial Salivary Gland Tumors Treated With Neutron Therapy: Should the Bite Block Be Built Up To Reduce the Air Gap?

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Most salivary gland tumours of the hard and soft palate are resectable but this produces variable morbidity depending on the size and location of the defect and its effect on swallowing and speech. Neutron therapy may be an acceptable alternative.

Twenty patients with salivary gland tumours of the hard and soft palate, which could also involve the inferior antrum and nose, were treated at the National Accelerator Centre (NAC) from March 1990-February 1996. They received a minimum tumor dose of 20.4 Gy in 12 fractions in 4 weeks. The complete response rate was 75% (15/20) but there were relapses in 2 patients at 28 and 35 months, one patient dying at 36 months and the other having stable disease at 43 months. The remaining patients had either stable or regressing disease when last seen. The disease free probability (Kaplan-Meier) was 61% at 5 years and the survival probability was 89% at 5 years.

There was concern that the mucosal reaction was less than expected in some patients.

A wax bite block is usually used to depress the tongue and lower lip out of the radiation field but this produces an air-gap below the palate. Could this air gap together with the air in the nose and sinuses affect the dose distribution?

Axial planning CT scans were performed on 5 patients with a conventional flat wax bite block and a larger bite block moulded to conform to the palate. Using the Theraplan planning system 2D plans were calculated on several slices using bolus and (a) no inhomogeneity corrections (plan) (b) full bite block and inhomogeneity corrections and (c) flat bite block and inhomogeneity corrections. They were repeated with obliquity correction and without bolus and (a) no homogeneity corrections (plan), (b) full bite block and inhomogeneity corrections and (c) flat bite block and inhomogeneity corrections.

The dose was less homogeneous with the flat bite block and there was also an apparent increase in dose to the spinal cord in 3 patients which was evident when obliquity correction was used.

Dose volume histograms of integral dose, target, spinal cord and brain dose were then done in 2 patients.

The average dose to the target was similar in all plans with bolus but with obliquity correction and inhomogeneity corrections it was 4% higher than the plan in one patient with a full bite block and 2% higher with a flat bite block. Although the integral dose was less than the plan with the flat bite block, 6% less with bolus and 2% without, the maximum cord dose was 26% higher than with the full bite block and plan when the bolus was used and 31% higher when obliquity correction was used.

Further patients are required to verify this but in the meantime, unless inhomogeneity corrections are used the full bite block is probably closer to the planned dose as there is less variation within the target volume, the cord dose is not increased and it obviates uncertainties with internal build up after the air gap.

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Fast Neutron therapy In Treatment Of Prostate Cancer: Orleans Experince On 167 Patients

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In 1985, after the first results were published by Franke in Hamburgh and by the RTOG in the USA, the prostatic stage B2, C and D1 carcinomas were included in a phase II trial. The Orleans facility use- four days a week p(34)+Be(15.8) vertical fast neutron beam, with irregular chapes. Depth dose are similar to 4 MV X-rays . 27 patients were treated with mixed schedule protocol (3Ph, 2n/week - 9Gy n +γ - total dose 65 EqGy) and 140 with a neutron boost (6.7 Gy n + γ - total dose 65 EqGy). 74 patients out of 167 were referred to neutron therapy for local failure whether after radical prostatectomy in 39 cases or after hormontherapy in 35 cases. Considering the whole population, the survival rate at 5 and 9 years was respectively 78 and 67%. The survival rate was significantly influenced by the stage (B2 - C = $p<0.001$, C - D1 = $p<0.01$) and the Gleason score (≤ 7 vs 7 $p<0.02$).

Concerning the treatment modalities (mixed vs boost), results in term of survival and complication reached the signification limit ($p<0.05$) but were still in favour of the neutron boost.

The mean PSA rate before radiotherapy was 32.4 μg/L (from 2 to 2.50 μg/L). 84% of the patients had normalized PSA after a mean delay of 6 months. No correlation were found between PSA evolution and persistent local control or survival, even when considering a normalization rate lower than 4.

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Chemical Phase of Radiobiological Mechanism and Effectiveness of Individual Water Radicals and Other Substances in DSB Formation.

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The effect of radiation in tumour treatment may be changed when used in combination with some chemical agents (e.g. in combination with chemotherapy). To understand better all consequences much more detailed knowledge of the role of individual substances during the chemical phase of radiobiological mechanism seems to be necessary. The processes in this phase have been simulated by a mathematical model which has been tested with the help of published experimental data indicating the dependence of DSB numbers (in water solutions) on oxygen concentration in two different gas mixtures (with nitrogen and nitride oxide).The effectiveness of individual radicals in DSB formation has been estimated.

Influence of cluster diffusion during radical recombination have been taken into account. The model opens the possibility of analysing a more detailed role of different agents with the help of corresponding experiments.

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Real Time Tracking of Tumor Positions for Precision Irradiation.

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Due to peristaltic motions and motions induced by the lung activity, abdominal tumors move within the patients body. Motions of liver tumors, e.g., by ±3cm are possible. Tumor treatment with hadron beams can create precise and optimal 3-dimensional conformal dose distributions. To exploit this for an abdominal tumor, its position must be measured in real time with the appropriate space resolution. Beam gating or even beam steering in response to this information will improve the irradiation precision.

We are developing a novel method for real time tumor tracking. A miniaturized antenna will be implanted such that it is connected to the tumor and moves with it. The magnetic dipole field created by the antenna penetrates the human tissue unaffected. With the help of magnetic gradiometers situated outside the patients body the position of the dipole antenna will be continuously evaluated ("dipole tracking") and with it the position of the tumor. Field modulation and corresponding signal filtering suppresses background from stray fields by other sources. We have demonstrated the feasibility of dipole tracking in a lab experiment.

Besides this specific one we envisage other applications of our method in the general field of survey and alignment within medicine and outside.

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A Method For Depth-dose Profiling With Millimetric Resolution In Tissue Exposed To A Proton Beam.

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Reliable experimental information regarding depth-dose profile in tissue exposed to a proton therapeutic beam is fundamental for the therapy treatment planning, to correctly define the parameters of the modulated beam. The proposed method allows a very precise determination of the shape of the modulated Bragg peak, with an error lower than one millimeter.

The technique consists in sticking in a tissue-equivalent phantom an array of slender tissue-equivalent dosimeters, located at increasing distances from the exposed surface. The proposed dosimeters are composed of a ferrous sulphate solution incorporated in a proper gel, contained in thin glass capillaries 1 mm internal diameter. As a consequence of exposure to a proton beam, oxidation of ferrous ions (Fe^{2+}) to ferric ions (Fe^{3+}) occurs. Owing to the different moments of the paramagnetic Fe^{2+} and Fe^{3+} ions, a variation in the relaxation rates of the hydrogen nuclei of the solution is detectable by means of a Nuclear Magnetic Resonance (N.M.R.) analyser.

To verify the validness of the technique, capillaries were sticked in a Plexiglas phantom and, after the phantom exposure to protons, examined in a research N.M.R. analyser . The comparison of the experimental results with calculated values shows that the maximum of the Bragg peak is determined with about a tenth of a millimeter uncertainty, and the widening in the ramps of the peak is within 1 mm.

The consistence and correctness of the results obtained from the N.M.R. analyser were tested by examining irradiated and non-irradiated gel also by means of spectrophotometric analysis.

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