Proceedings of the

WORKSHOP ON RADIATION DOSIMETRY: BASIC TECHNOLOGIES, MEDICAL APPLICATIONS, ENVIRONMENTAL APPLICATIONS

Supplement

FRASCATI PHYSICS SERIES

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Therac 20 (20 MeV) accelerator picture, based on using BEAM (A Monte Carlo Simulation System for Modelling Radiotherapy Sources) and the EGS_Windows graphics package (version 3.2)

(Courtesy of David W. O. Rogers, Ionizing Radiation Standards Group Institute for National Measurement Standards, National Research Council, Canada)

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Volume XXIX

WORKSHOP ON RADIATION DOSIMETRY: BASIC TECHNOLOGIES, MEDICAL APPLICATIONS, ENVIRONMENTAL APPLICATIONS

Editor
A. Zanini

5th National Scientific Committee

Rome (Italy), February 5–6, 2002

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Scientific program

Tuesday, February 5th

Time	Speaker	Title
15:00 – 15:10	**A. Vacchi**	Welcome address

SESSION I - Dosimetry: Basic Technologies

Chairman: P. Cerello

Time	Speaker	Title
15:10 – 15:30	**G. Battistoni**	Development of the FLUKA MC code and of its scientific and technological applications
15:30 – 15:50	**A. Ottolenghi**	From track structure to biological endpoints: models, codes and MC simulations to investigate radiation action and damage formation
15:50 – 16:10	**M. Bruzzi**	Epitaxial SiC devices for radiation dosimetry
16:10 – 16:30	**C. Manfredotti**	CVD diamond detectors and dosimeters
16:30 – 16:40	**C. Manfredotti**	Neutron - Gamma discrimination in space dosimetry by means of active SiC semiconductor detectors
16:40 – 17:00		Coffee break
17:00 – 17:20	**L. Periale**	Neutron and Solar Neutrino Spectroscopy with liquid scintillation detector Gd doped
17:20 – 17:40	**G. Verona Rinati**	Beam control based on CVD diamond

SESSION II - Dosimetry: Medical Applications

Hadron therapy

Chairman: R. Cherubini

Time	Speaker	Title
17:40 – 18:00	**M. Bucciolini**	Chemical vapour deposited diamonds for dosimetry of radiotherapeutical beams

18:00 – 18:10	**S. Onori**	Silicon diode for proton beam dosimetry
18:10 – 18:20	**S. Onori**	Study of the dosimetric and operating characteristics of natural diamond detectors
	P. Fattibene	Retrospective dosimetry by EPR detection of free radicals in tooth enamel
18:20 – 18:40	**F. Marchetto**	Pixel ionization chamber to monitor conformational treatments with hadron and photon beams

Wednesday, Febrary 6th

Hadron therapy

9:00 –9:20	**P. Oliva**	FLUXEN - a portable equipment for absolute quantitative analisys of imaging properties of radiographic systems
9:20 – 9:40	**M. Brai**	Response of GR200 (LiF:Mg,Cu,P) dosimeters to proton and electron clinical beams and recent deconvolution methods

Neutron dosimetry

9:40 – 10:00	**A. Zanini**	A dosimetric system for the evaluation of the undesired neutron dose in radiotherapy treatments with photon: experimental method and MC simulation
10:00 – 10:20	**M. Brai**	A new multicomponent dosimeter for application in BNCT
10:20 – 10:40	**G. Gambarini**	Imaging of absorbed dose in phantoms exposed to high fluences of thermal and epithermal neutrons with separation of all dose contributions
10:40 – 11:00		Coffee break

Diagnostic and photon therapy

		Chairman: C. Birattari
11:00 – 11:20	**S. Pani**	Dosimetric requirements and protocols for "in vivo" breast imaging with synchrotron radiation
11:20 – 11:40	**F. Casali**	Optimization, with the Monte Carlo code "BEAM", of a system for electron beam qualification in Intra Operative Radiation Therapy (IORT)
	F. Casali	Study and development of a new real time dosimetric system, dedicated to IORT (Intra Operative Radiation Therapy)
11:40 – 12:00	**V. Viti**	FRIKE-AGAROSE dosimeter gels: ion diffusion modelling and microdensitometry alternative to MRI

Microdosimetry

12:00 – 12:10	**P. Colautti**	Miniaturized TEPCs for monitoring therapeutic beams
	P. Colautti	Microdosimetric measurements with a miniaturized TEPC at the Nice proton therapeutic beam
12:10 – 12:20	**P. Colautti**	First microdosimetric measurements with a ^{10}B-Loaded TEPC
12:20 – 12:30	**P. Colautti**	Track-nanodosimetry of an alpha particle
12:30 –12:50	**S. Agosteo**	Characterization of a neutron spectrometer based on a P-I-N photodiode
12:50 – 14:30		Lunch

SESSION III - Dosimetry: Environmental Applications

Chairman: M. Pelliccioni

14:30 – 14:50	**B. Alpat**	The Dosimetry of Environmental Radon
14:50 – 15:10	**G. Viesti**	Development of a large area scanning system using tagged 14 MeV neutrons
15:10 – 15:30	**A. Piccotti**	RPC for thermal neutron detection
15:30 – 15:50	**M. Pelliccioni**	Cosmic ray dosimetry at aircaft altitudes (OBD)
15:50 –16:10	**C. Birattari**	Extended energy range neutron dosimetry from thermal to GeV neutron energy
16:10 – 16:30		Coffee break

SESSION VI - Summary Talks

Chairman: A. Vacchi

16:30 – 16:40	**P. Cerello**	Summary of Session I
16:40 – 16:50	**R. Cherubini**	Summary of Session II
16:50 – 17:00	**M. Pelliccioni**	Summary of Session III
17:00 – 18:00		General discussion

PREFACE

This Supplement contains the Abstracts of all the contributions to the "Workshop on Radiation Dosimetry: Basic Technologies, Medical Applications, Environmental Applications". Three contributions not inserted in the main volume, due to editing mistake, are also reported.

Many thanks to Dr. Rosaria Ludovici for valuable collaboration in the Workshop organization.

The Editor
Alba Zanini

CONTENTS
Supplement to Volume XXIX

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*These contributions were not listed in the mail volume.

SESSION II - Dosimetry: Medical Application

P. Fattibene	Retrospective dosimetry by EPR detection of free radicals in thooth enamel

SESSION II - Diagnostic and photon therapy

F. Casali	Study and development of a new real time dosimetric system, dedicated to IORT (Intra Operative Radiation Therapy)

SESSION II - Microdosimetry

P. Colautti	Miniaturized TEPCS for monitoring therapeutic beam

These contributions was not listed in the main volume.

Frascati Physics Series Vol. XXIX, Suppl. (2002), pp. 3-10
WORKSHOP ON RADIATION DOSIMETRY: BASIC TECHNOLOGIES, MEDICAL APPLICATIONS, ENVIRONMENTAL APPLICATIONS, Rome (Italy), February 5–6, 2002

RETROSPECTIVE DOSIMETRY BY EPR DETECTION OF FREE RADICALS IN TOOTH ENAMEL

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Abstract

Free radicals induced in dental tissues by ionizing radiation can be detected by Electron Paramagnetic Resonance (EPR) spectroscopy and therefore can be used as indicators of individual radiation exposure. The method is especially appropriate for the individual retrospective dose assessment following external protracted exposure to low dose values, and is a very valid tool for the epidemiological studies aimed at radiation risk assessment.

1 – Introduction

At the present state of the art, the studies about health effects of ionizing radiation are quite far from being able to provide definitive answers about induced carcinogenic risk in humans. For this reason, epidemiological and experimental studies, focused on the evaluation of carcinogenicity of ionizing radiation, are considered of high priority.

Because of the probabilistic nature of the cancer induction effect of radiation, studies must involve large groups of population and should include control groups. In most cases these studies have been carried out on groups of people exposed to acute radiation contamination, i.e. high doses in short time. However, most of the people are likely to be exposed to low doses and very low dose rates during their lifetime, and it is not known if and to what extent knowledge about cancer induction effects at acute exposure can be extrapolated to prolonged exposure to low dose rates. For this reason, in the last years, attention has been devoted to situations happened in the past where large groups of population were exposed continuously, during tens of years, to low dose rates.

One of the problems posed by this approach is the difficulty of retrospectively reconstructing the dose and the radiation field people have been exposed to. In the cases of professionally exposed people, or of patients exposed to medical examinations or therapy, dose is routinely monitored and this helps dose reconstruction. However, when members of population have been exposed, or the dosimetry of workers or patients is ambiguous, other approaches must be used. The most attractive one is the dose reconstruction by direct measurement of a stable radiation damage induced in a body tissue, which can then be considered a dosimeter itself. A number of bodily materials have been identified to this purpose (blood or blood products, urine, cells, teeth, eye crystalline) and methodologies have been developed for the measurements of absorbed dose in such tissues. Such an approach is very promising and is often adopted also in studies finalized to evaluation of risk induced by agents different from the radiation.

EPR analysis of free radicals induced in teeth by radiation has established as one of the most accurate and reliable methods for retrospective individual dose reconstruction. It has been enormously developed in the last years [1),2)] and dose assessment of large groups of population has started [3),4)]. However, many problems are still open and many sources of uncertainty still need be identified and either reduced or eliminated. In particular background level, dose response linearity, confounding factors, individual sensitivity to radiation and dependence of the response to radiation quality should be evaluated. As long as concerns the tooth enamel tissue, some of these properties have been known for many years, while some remain to be studied. ISS has been long active in this field and large activity is underway or planned[5),6),7),8),9),10),11),12),13),14),15),16)]. In the following, a brief description of the state of the art and a look at the open problems of highest priority will be presented.

2 – Description of the method

The tooth enamel tissue is composed of carbonated-hydroxiapatite mineral (97%) and of water and organic material (3%). Ionizing radiation induces stable CO_2^- free radicals in the crystals of the carbonated-hydroxiapatite component. Since the concentration of radiation induced free radicals increases proportionally with dose up to at least 20 Gy and is extremely stable in time, the tooth enamel can be calibrated in terms of dose and used as a dosimeter. Therefore, tooth enamel EPR retrospective dosimetry is based on the measurement of the concentration of CO_2^- free radicals and conversion to dose through a calibration curve.

Detection of the CO_2^- EPR signal is not a straightforward measurement. A number of signals are present in the tooth enamel EPR spectrum, which are partly overlapped to the CO_2^- signal and might be confounding for the dosimetric measurement. Such signals may be intrinsic, or induced by sample preparation or orthodontics operations. The most intense signal is originated by radicals present in the organic material of tooth enamel. It is, in first approximation, not sensitive to ionizing radiation and its intensity is about comparable to the intensity of a CO_2^- signal induced by 1Gy ^{60}Co exposure. Figure 1 shows the measured EPR spectra of a 100 mGy and of a 500 mGy irradiated teeth, and Figure 2 presents the same 500 mGy spectrum deconvoluted in the two main signals. Various methods for resolving the ionizing induced signal from the other signals, mainly based on algorithms for separation of the different components of the EPR spectrum, have been developed and many of them have resulted successful [5] for exposures higher than 100 mGy. However, if the tooth has received a dose lower than 100 mGy (which is about the lifetime dose of a member of the public due only to environmental radiation exposure), the radiation induced signal is hidden by the organic signal. Therefore, at such dose level, the measurement is affected by uncertainty of the order of 100% (at 95% confidence level), and, even more important, it may be somehow difficult to resolve between 100 mGy and 200 mGy dose. Present research is devoted to understanding of the origin of the organic component signal and its elimination, which are necessary steps for improvement of accuracy.

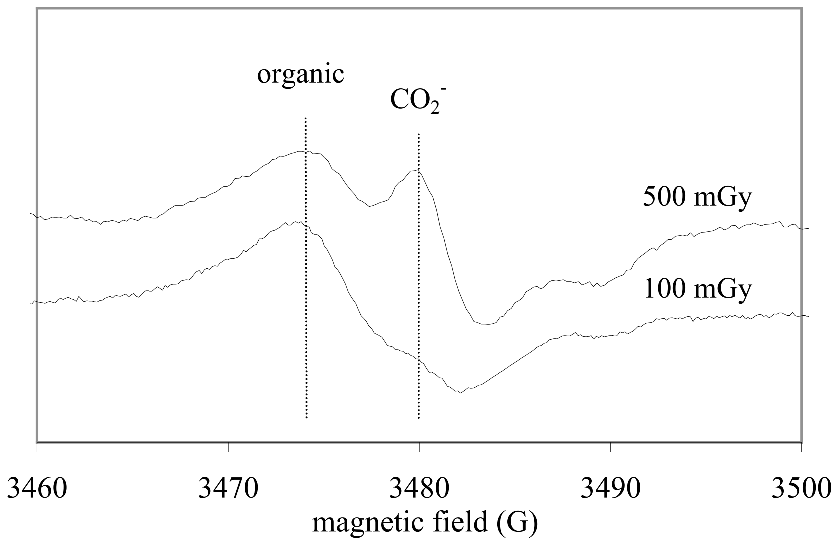

Figure 1 *– EPR spectrum of tooth samples irradiated at 100 mGy and 500 mGy.*

Thanks to the time stability of the CO2- signal, the EPR measurement provides the cumulative number of free radicals induced in the lifetime of a person by many radiation sources, including natural radiation, medical, professional and possibly accident exposures. It can be schematically written as:

$$N_{total} = N_{natural} + N_{medical} + N_{professional} + N_{accident}$$

where each term is the concentration of free radicals induced by the source indicated by the index. In other words, tooth enamel shows a background dose level that depends on the person age and style of life. If an accidental dose has to be reconstructed, the background dose level has to be estimated, and subtracted by the cumulative enamel dose evaluated by the EPR measurement. To this purpose, a file, containing information about personal data (birth year, place of residence, profession, medical exposures, …), must accompany the sample. However, the property of the tooth enamel to keep memory of the cumulative lifetime dose makes the method powerful to provide dosimetric data to support the epidemiological studies aimed to risk analysis. In fact, the total dose absorbed by the individuals during his lifetime can be correlated to the health effects and risk for induction of cancer is evaluated.

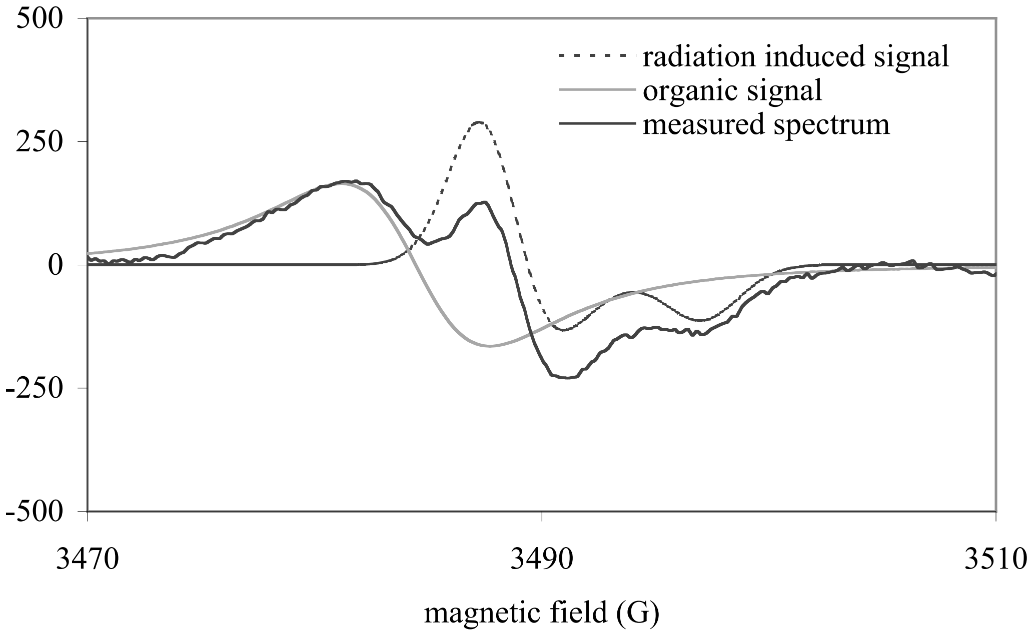

Figure 2 *– Result of the deconvolution of the spectrum of a 500 mGy irradiated tooth in two components due to the radiation induced free radical and to the organic signals.*

Once the EPR signal is converted to dose to the tooth (of scarce radiation protection meaning), the final step is the conversion to the dose to the organs or to the effective dose, which is the important item in the studies based on effect/cause correlation. This aspect, notwithstanding its importance, has been unexplored up to now. It requires the knowledge of the tooth response to quality, energy spectrum and angular incidence of the radiation, in case of external exposure, and of the incorporated radioactivity in enamel, in case of internal contamination. At ISS studies of tooth enamel response as a function of energy for X- and γ-rays, both experimental and by Monte Carlo calculation, have been started [6),16)]. Similar studies could be performed with neutron radiation. The tooth response to internal contamination, even if of extreme interest, because of the similarity between tooth and bone tissue compartments, are more difficult to carry out: animal studied are requested or analysis of teeth (extracted for medical reasons) for patients who have undergone nuclear medicine exams with isotopes of nuclides typical of nuclear accidents (for example $^{85}Sr/^{89}Sr$).

Notwithstanding the actual limitations of the method, it has been applied to dose reconstruction in some cases of exposure of large groups of people. In particular, the method is forming the main basis of dosimetric data to the epidemiological studies of the cohort of population living in the South Urals in the years from about 1950 up to today. Such a cohort is emerging for importance in the epidemiological studies finalized to cancer induction from low intensity and low dose exposure. Those people have been exposed to a number of accidents and radioactive releases of various nature, leading to both external and internal contamination at very low intensity, prolonged for tens of years, with tens of thousands of individuals involved. The peculiar aspect of this population is that it has been possible to identify many different groups (workers, population, men, women, internally contaminated, externally exposed), and also control groups of people. ISS has been contributing to retrospective dosimetry of both workers of Mayak and population resident in the South Urals region [5)].

3 – Perspectives

Tooth enamel dosimetry has been greatly improved in the last years. Nowadays it is one of the most reliable methods for individual dose reconstruction of large cohorts of population, aimed at risk analysis epidemiological studies. However, some problems remain to be solved. Among others, the following have been identified and given the highest priority at ISS: improvement of the dose estimate accuracy through understanding, reduction or elimination of confounding signals; dose response effectiveness to photon and neutron radiation, at the energy met in environmental and work places.

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WORKSHOP ON RADIATION DOSIMETRY: BASIC TECHNOLOGIES, MEDICAL APPLICATIONS, ENVIRONMENTAL APPLICATIONS, Rome (Italy), February 5–6, 2002

STUDY AND DEVELOPMENT OF A NEW REAL TIME DOSIMETRIC SYSTEM, DEDICATED TO IORT (INTRA OPERATIVE RADIATION THERAPY)

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Abstract

IntraOperative Radiation Therapy (IORT) is a technique based on delivery of a high dose of ionising radiation to the cancer tissue, after tumour ablation, during surgery, while reducing the exposure of normal surrounding tissue.

The Novac7 is a new linear accelerator expressly conceived to perform in the operating room. This accelerator supplies electron beams at several energy, with high dose rate. These peculiar characteristics give rise to some complications with classical dosimetric techniques.

In the framework of a research contract between ENEA and the Physics Department of Bologna, an original system has been developed to study and visualise the Novac7 electron beam in real time. The system is composed by an electron-light converter, a mirror to focalise the light on a CCD sensor and a computer with dedicated software to acquisition, visualisation and imaging.

On the prototype theoretical and experimental studies have been conducted. It was verified that the system is able to get linear and stable responses on changing impulse number and energy. Moreover the experimental results have been compared with the ones obtained from classical instruments.

The results are totally satisfactory: the system is able to get a real time representation of the electron beam and the developed software can give several interesting additional information on beam.

1 – Introduction

The innovative idea in IORT is to irradiate the cancerous tissue just after the surgical excision with open wound. The clear vision of target and surrounding tissues contributes to take the maximum precision in the dose supply and, at the same time, to limit the healthy tissues exposition[1) 2)]. The major obstacle to employ the IORT on large scale is represented by the transport of anaesthetised patient with an open wound, from the operating room to the radiation therapy bunker, with the connected risks and organisational problems. These limitations have been surpassed thanks to a new kind of linear accelerator, the Novac7, expressly studied to work in the operating room[3)]. The accelerator supplies electron beams of several different energies (3, 5, 7 and 9 MeV), with a high dose rate (up to 10 Gy/minute). These specific machine characteristics and its collocation in the operating room, get up the research of new and faster dosimetric control systems to overpass the limits of traditional systems.

In fact, for example, in the case of ionising chamber, the high dose rate, closely connected with Novac7 characteristics, comports a great number of ionic recombination and therefore the measures acquired with this system have to be corrected on the base of working and irradiating conditions [4)]. Instead, using radiochromic films a dose rate independent response is obtained [5)], but only 48 hours after the measure. [6)].

In this view, the need is born of a new dosimetric system expressly conceived for the Novac7 dosimetry and beam quality control.

2 – The new control system realisation

The system developed is entirely contained in an aluminium box (21×21×18 cm^3), without light loss, where there are: a converter (150×150 mm^2), that is a scintillator converting electrons into light, a camera with CCD sensor (768×512 pixel, 9×9 μm^2), cooled with Peltier system, and a mirror. The light produced within the converter, placed in the upper side of the box, is reflected by the 45°-tilted mirror and is focalised on the CCD sensor by a large angle lens. The detector is connected to a personal computer by a 20 meters cable, outside of the operating room, permitting the operator to use PC during the irradiation.

The dedicated software is able to pilot the camera (controlling the cooling system, setting sensor exposition time, getting start the acquisition) and, within some seconds, to visualise 14-bit digital image on the monitor. Moreover, it is possible to elaborate the image calculating several electron beam information such as dimensions, intensity profiles and isodose curves (Fig.1).

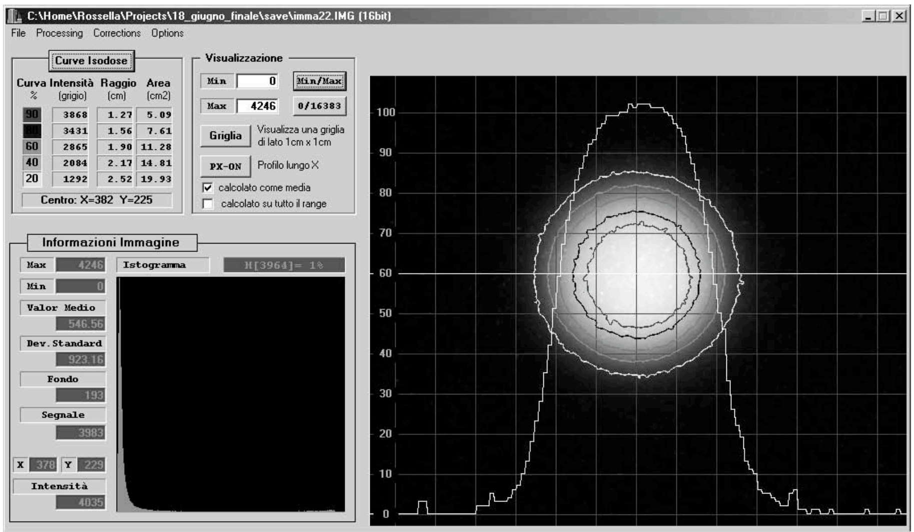

Figure 1 *– A screen of the program: beam image, profiles, and isodose curves.*

3 – System analysis

The instrument has been experimentally and theoretically studied. Measures have been performed at European Oncological Institute in Milano (Italy) and at "Regina Elena" Institute in Roma (Italy), where there are two Novac7 linear accelerator. System stability and linearity have been assessed as a function of impulse number (Fig.2) and electron beam energy (Fig.3). The measures have been taken at several different experimental conditions, using three different converters: a plastic scintillator (the BC-430, produced by BICRON), a Gd_2O_2S:Tb phosphor screen and a ZnS converter.

It is evident, from the graphic in figure 2, that the BC-430 converter better separate impulse number in dynamic range, bringing up more later the system saturation. From these considerations it was determined the choice to conduct first measures principally with this scintillator. Later it became clear that using the Gd_2O_2S:Tb converter the signal/noise ratio gets better.

In fact, a noise source is present within the image in the form of lightly spots with high intensity, but strongly localised. Probably the noise is originated by the Bremsstrahlung radiation generated in one of the system components. We have tried to shield the instrument with lead panels, but it was impossible to appreciate any sensible noise reduction; however the software developed, using "ad hoc" studied filters, is able to erase it almost completely.

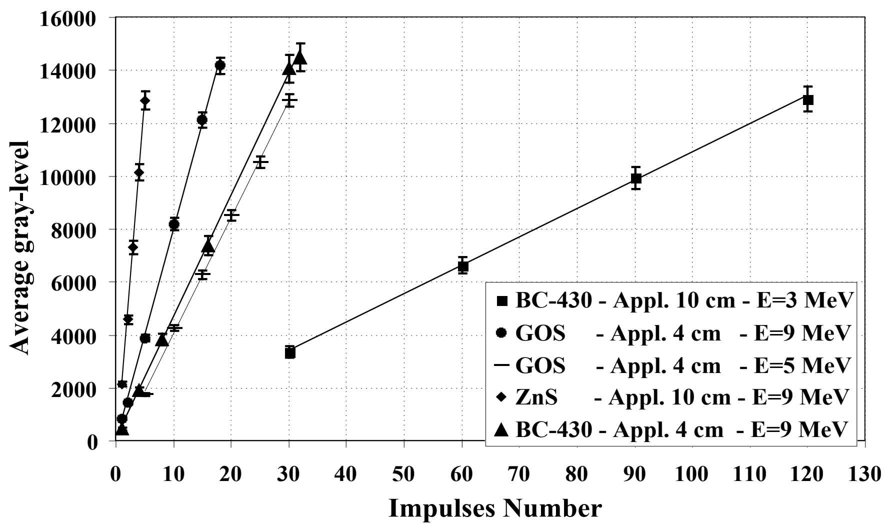

Figure 2 *– System response as a function of impulse number, with different converters.*

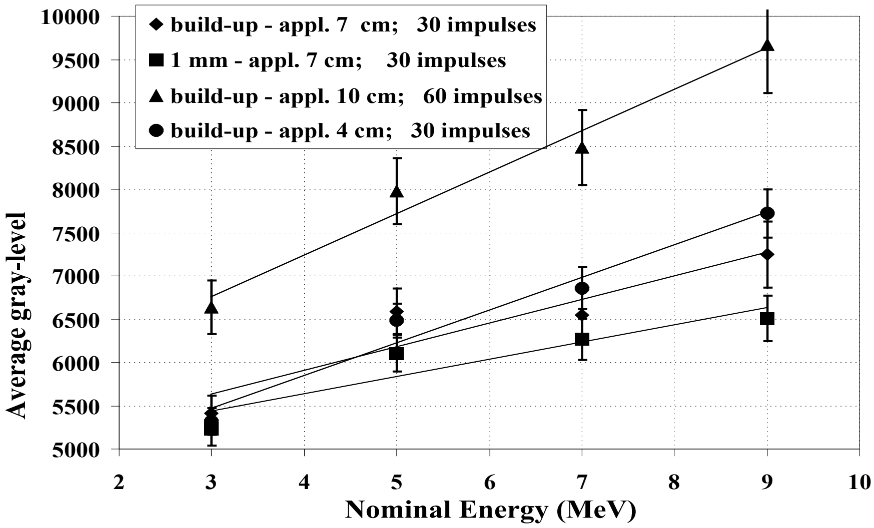

Figure 3 *– System response as a function of beam energy, with BC-430 converter.*

The beam profiles obtained from measures, taken at maximum dose depth and at maximum energy, have been compared with the ones obtained from classical techniques: we have seen a good result consistence, considering the difficulty to take measures with different system in the same experimental conditions.

We have taken also homogeneity and symmetry electron beam, parameters of maximum importance, to determine and to control, in the radiotherapy quality assurance programs.

4 – Conclusions

The obtained results are very satisfactory: we have confirmed the concrete ability of the system to get in real time a spatial bidimensional vision of the beam and its correlated dose; and we have also verified the linearity of the system response as a function of energy and impulse number supplied by Novac7.

In the end, we have seen what powerful instrument is the elaboration software on the digital image, with which it is possible to calculate position, shape, isodose curves and electron beam intensity.

In future, on the base of the acquired knowledge with the study of this prototype, we are thinking to develop another system, to apply for the patient dosimetry in real time.

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WORKSHOP ON RADIATION DOSIMETRY: BASIC TECHNOLOGIES, MEDICAL APPLICATIONS, ENVIRONMENTAL APPLICATIONS, Rome (Italy), February 5–6, 2002

MINIATURIZED TEPCS FOR MONITORING THERAPEUTIC BEAMS

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Abstract

For monitoring the proton radiation quality, a mini-TEPC with a sensitive volume of 0.6 mm^3 and an external diametre of 2.2 mm has been constructed. The counter, inserted in a thin titanium cylinder, is able to collect microdosimetric spectra in proton beams up to 5 10^6 $cm^{-2}s^{-1}$ of intensity.

1 – Introduction

In radiation therapy the key problem of monitoring therapeutic beams is the intensity of radiation fields used. Typical therapeutic hadron beams' fluxes are about 10^8 $cm^{-2}s^{-1}$. Under these conditions pile-up effects, which spoil the microdosimetric spectra, are not avoidable with ordinary TEPCs of about 1 cm in diameter. To cope with such a high intensity beam, miniature TEPCs of about 1 mm^3, which are able to work properly up to 10^5 Hz of counting, have to be developed and fast acquisition systems have to be used.

Since the mini TEPC construction is rather expensive, we have studied the possibility of using simplified mini- TEPCs to monitor therapeutic beams. Accordingly, we have constructed two prototypes TEPCs of 0.8 mm^3, one with and one without field shaping tubes, which are the most complicated parts to manufacture. Both TEPCs have a mini alpha source to perform an accurate energy calibration.

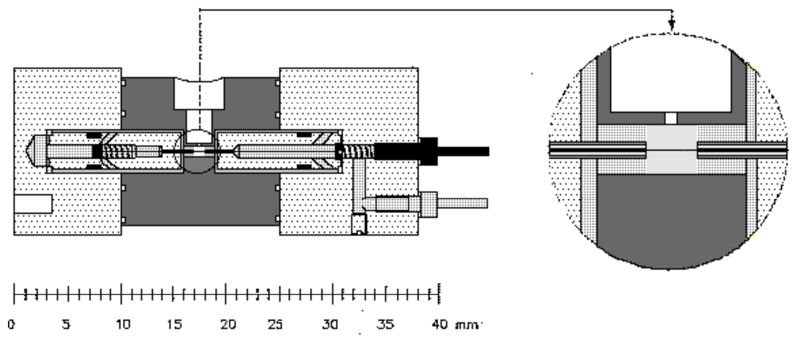
Finally we have constructed a simplified mini TEPC of 0.6 mm^3, where not only the gas cavity but also the external dimensions are millimetric.

Another relevant aspect, which must be taken into account in neutron microdosimetry, is the large dynamic range of energy deposited in the TEPC, which typically covers 4 to 5 orders of magnitude. Usually acquisition of the overall microdosimetric spectrum is made in two separate steps, working the detector at different gas gain, and later analysis of the overlapping region is required in order to reconstruct the full spectrum. That implies not only a great effort in off line analysis, but also the impossibility to perform a true online monitoring of the therapeutic beam. We are developing a dedicated front-end electronic system able to cope with both the high counting rate and the large dynamic range, so that a single measurement could cover the overall spectrum with good linearity and resolution.

2 – Experimental set-up

The first prototype mini-TEPC is drawn in Figure 1. The field tubes of 250 μm in diameter are evident in the zoomed part of the figure. The sensitive volume of the counter is a small cylindrical cavity of 1 mm in diameter and 1 mm in height. This cavity is drilled inside a 13 mm cylinder of the tissue equivalent Shonka A-150 plastic.

The anode is a 10 μm golden tungsten wire. By using a tiny beam port inserted in



the counter, we have studied the accuracy of the anode wire assembly. Results show that in both counters the anode wire eccentricity is better than 0.07[1)]. The counter is enclosed in an aluminium cylinder of 0.2 mm of thickness, which is insulated from the counter cathode with a thin cylinder of Rexolite® of 0.45 mm of thickness. More constructive and operating details are given elsewhere[1)].

A second detector has also been constructed, differing from the previous one in that it has no field tubes. Both TEPCs have a mini alpha source to perform an accurate energy calibration. The alpha beam passes through a 1.4 μm mylar window of 300 μm of diameter.

Several measurements, with neutron beams and with the Nice therapeutic proton beam, have evidenced no relevant difference in the microdosimetric spectra (see Figure 2) and excellent gain stability in both detectors.

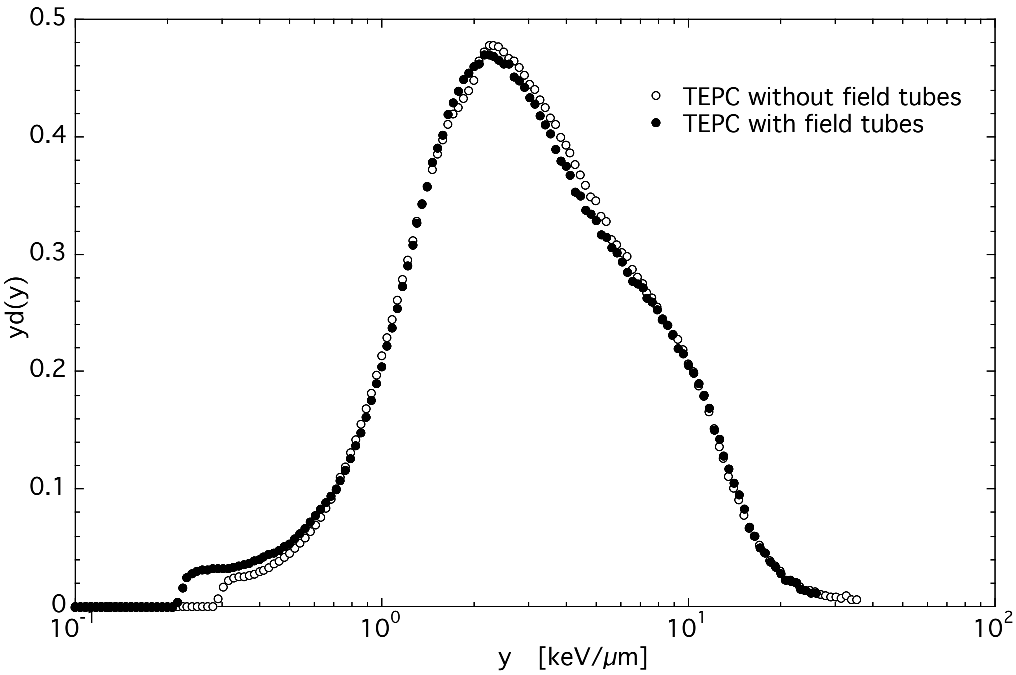


***Figure 2** – Comparison between microdosimetric proton spectra measured with the two prototype TEPCs, one with field tubes and one without.*

We therefore decided to continue the research in the line of miniaturized TEPCs without field shaping tubes, which are the far most complicated parts to manufacture.

The last prototype detector has been miniaturized also in its external geometrical dimensions. This detector is so small that it could be used for in vivo microdosimetry.

The sensitive volume has dimensions of $0.6\ mm^3$ while the external diametre of the TEPC is 2.3 mm. The counter is inserted in a thin titanium cylinder.

For high counting rates a limiting factor in experimental microdosimetry is the dynamic range and the total pulse processing time of the front-end electronics. A low-noise and large dynamic range charge preamplifier has been designed and constructed just for proton microdosimetry. This preamplifier processes pulses from 15 mV to 15 V, allowing for collecting a full microdosimetric spectrum of 4 order of magnitude with a single measurement. Two shaping amplifiers are used to amplify simultaneously the pulses from the preamplifier. The amplifier gains should be set to cover the so-called low-LET region (0.1–15 keV/μm) and the high-LET region (4-1000 keV/μm).

The mini TEPC is a moderately fast detector. The electron pulse collection is of about 7 ns[1)]. Therefore the shaping time of the shaping amplifiers can be set at 250 ns without significative lost of energy resolution. The pulses are converted by CAMAC ADCs and processed with Kmax® software.

In order to evaluate the maximum proton flux tolerable by our experimental set-up without significant pile-up effects, microdosimetric spectra have been collected at different counting rates. Microdosimetric spectra did not show any detectable difference at counting rates less than 10 kHz. At higher rates increasing differences were visible, particularly in the low-LET part of the spectrum. In Figure 3 low-LET sub-spectra are shown for counting rates up to 60 kHz. Taken into account the 3% of calibration uncertainty, statistically significant differences are no evident up to about 30 kHz.

On the basis of these results we concluded that a simplified minicounter without field shaping tubes can properly monitor intense radiation fields up to several tens of kHz. Better performances are expected when pile-up rejection algorithms and circuit will be implemented.

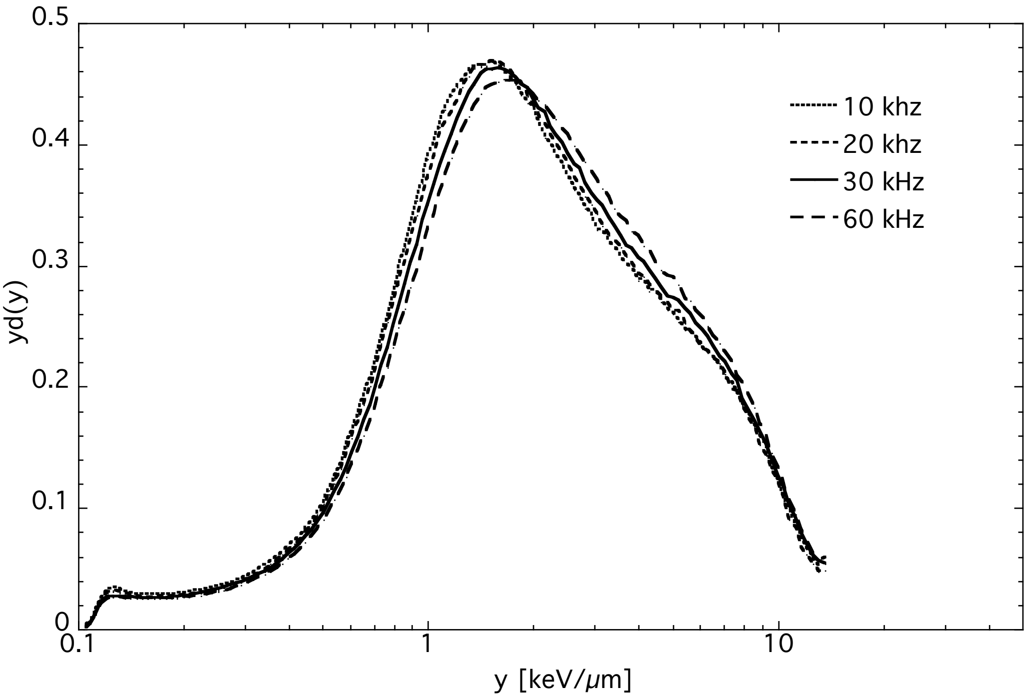


Figure 3 *– The low-LET region of a proton microdosimetric spectrum acquired at different counting rates.*

3 – Acknowledgements

The authors are indebted to G. Donà, M. Lollo and M. Geronazzo of the mechanical workshop of Legnaro Laboratories for their skillful assistance. They have contribute to design and construct the ultra-mini TEPC.

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Abstracts

1. DEVELOPMENT OF THE FLUKA MONTE CARLO CODE AND OF ITS SCIENTIFIC AND TECHNOLOGICAL APPLICATIONS

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Abstract

The basic features of the FLUKA Monte Carlo code are reviewed, giving some detail about the modeling of hadronic interactions. At present, also in the framework of an INFN project, FLUKA is being adopted for different applications in the field of radiobiology. Some of them are here briefly described. The main issues concerning the future developments of the code and of the general FLUKA project are also presented.

2. FROM TRACK STRUCTURE TO BIOLOGICAL ENDPOINTS: MODELS, CODES AND MC SIMULATIONS TO INVESTIGATE RADIATION ACTION AND DAMAGE FORMATION

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Abstract

The investigation of the action of ionising radiation on biological structures requires a detailed analysis of the various stages underlying damage induction and evolution. In order to take into account the stochastic aspects characterising the process of interest, "ab initio" models and MC simulation codes are required, which start from the physical track structure and follow its time evolution, taking into account the various levels of organisation of the biological targets (DNA, chromosomes etc.). Representative examples of the activities in this area of the Universities of Milan and Pavia will be presented, focusing on the development of models aimed: a) to better understand the action mechanisms of ionising radiation, in the framework of the EC project "Low Dose Risk Models" coordinated by the GSF Institute of Munich; b) to study the induction of chromosome aberrations and their possible use as biomarkers, mainly in the framework of the INFN experiment "DOSBI", developed in collaboration with the University of Naples; c) to provide basic data for applicative tools developed for hadron therapy and space radiation protection, in the framework of the INFN projects "ATER.FIBI" and "FLUKA" and the ASI (Italian Space Agency) project "Influence of the shielding in the space radiation biological effectiveness".

3. EPITAXIAL SiC DEVICES FOR RADIATION DOSIMETRY

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Abstract

The current response of SiC on-line dosimeters to γ-radiation from ^{60}Co and ^{167}Cs γ-sources, X-photons and 22MeV electrons from linear accelerator has been investigated. The devices used are 4H-SiC epitaxial n-type layer deposited onto a 4H-SiC n^+ type substrate wafer doped with nitrogen. Single-pad Schottky contacts have been produced by deposition of a 1000Å gold film on the epitaxial layer and ohmic contacts have been deposited on the rear substrate side. The detector has been then embedded in epoxy resin and studied in the dose and dose-rate ranges 0.1-1Gy 0.1-10Gy/min. A signal response comparable to that of silicon standard dosimeters has been measured with the unbiased SiC device. The released charge and induced current have been observed to increase linearly respectively with the dose and dose-rate. A preliminary study on the changes in the sensitivity of the device after a γ-rays accumulated dose up to 10kGy is also presented.

4. CVD DIAMOND DETECTORS AND DOSIMETERS

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Abstract

Natural diamond, because of its well-known properties of tissue-equivalence, has recorded a widespreading use in radiotherapy planning with electron linear accelerators. Artificial diamond dosimeters, as obtained by Chemical Vapour Deposition (CVD) could be capable to offer the same performances and they can be prepared in different volumes and shapes. The dosimeter sensitivity per unit volume may be easily proved to be better than in standard ionization microchambers. We have prepared in our laboratory CVD diamond microchambers ("diamond tips") in emispherical shape with an external diameter of 200 μm, which can be used both as X-ray beam profilometers and as microdosimeters for small field applications like stereotaxy and also for "in vivo" applications. These dosimeters, which are obtained on a wire substrate that could be either metallic or SiC or even graphite, display good performances also as ion or synchrotron X-rays detectors.

5. NEUTRON-GAMMA DISCRIMINATION IN SPACE DOSIMETRY BY MEANS OF ACTIVE SiC SEMICONDUCTOR DETECTORS

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Abstract

Silicon Carbide semiconductor detectors display performances similar to silicon ones, while offering the possibility of working at high temperatures (600 °C) and a much better radiation damage resistance. These characteristics represent a big advantage for space applications, where neutron dosimetry seems to have acquired a strong importance. In fact, apart from direct ion detection, SiC could be used to monitor neutrons in real time by placing a suitable converter, like LiF enriched in Li-6, in front of the detector and by carrying out a spectroscopy of alpha particle produced in the converter. This design is going to be used from thermal neutron - gamma discrimination in nuclear reactors, since SiC in itself is relatively insensitive to gammas and neutron detection can be carried out even in a large flux of gammas. In this work we will investigate the possibility of using SiC as an active neutron dosimeter for space applications and we will draw some conclusions.

6. NEUTRON AND SOLAR NEUTRINO SPECTROSCOPY WITH LIQUID SCINTILLATION DETECTOR Gd DOPED

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Abstract

A relative wide energy range of neutrons have been counted with high efficiency by the neutron, gamma reactions in liquid scintillator gadolinium-loaded. The gadolinium is a complexed-metallorganic acid and dissolved in a mixture of white spirit, PPO and POPOP scintillator wave length-shifter. A cilindrical prototype counter filled of liquid scintillator loaded with different percentage in weight of Gd, watching by two 5'' photomultipliers, gave a counting efficiency of 85% for neutrons in the energy range between 2 and 10 MeV. We determine the required calibration parameters and report the detailed procedures for the experimental data handling. A preliminary dedicated Monte Carlo simulation of the 500 liters spherical detector response and efficiency has been performed. The results from this calibration are necessary for a detailed study of the neutron spectrum of the Neutron Time of Flight Facility at CERN.

7. BEAM CONTROL BASED ON CVD DIAMOND (MONITOR DI FASCIO BASATI SUL DIAMANTE SINTETICO)

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Abstract

L'estrema resistenza del diamante alle radiazioni rende possibile l'utilizzo di questo materiale per la realizzazione di monitor di fascio in grado di misurare "in beam" il profilo degli intensi fasci di particelle prodotti da acceleratori. Un caratteristica essenziale di questi dispositivi è legata al loro relativamente basso spessore consentendo di realizzare monitor pressoché trasparenti a fasci di particelle cariche anche a basse energie. Questa caratteristica risulta di estrema importanza essendo in questo caso possibile una caratterizzazione dettagliata del profilo e dell'intensità del fascio mentre lo si utilizza.

Prototipi di monitor di fascio a quattro pixel sono stati realizzati depositando su substrati di silicio film di diamante sintetico ottenuto per Microwave Plasma Enhanced Chemical Vapor Deposition (MW-CVD). Monitor di questo tipo sono stati testati posizionando tali dispositivi nel fascio continuo di protoni di 26 MeV prodotti dall'acceleratore TANDEM dei Laboratori Nazionali del Sud (Catania). Il segnale da tale rivelatore si è dimostrato stabile e riproducibile. Si è in particolare osservato, su un campione di 65 μm di spessore, un guadagno di un fattore 20000 elettroni per protone incidente. Il campione è stato irraggiato con circa 10^{14} protoni per centimetro quadrato senza osservare alcun evidente degrado del segnale.

Gli sviluppi futuri di questi monitor di fascio prevedono la caratterizzazione sistematica della resistenza alle radiazioni nonché lo sviluppo dell'elettronica per il controllo di monitor con elevato numero di pixel. E' inoltre in corso di allestimento un test di questi sensori per la misura di fasci impulsati di elettroni e successivamente si conta di provarli sotto intensi fasci di neutroni.

8. CHEMICAL VAPOUR DEPOSITED DIAMONDS FOR DOSIMETRY OF RADIOTHERAPEUTICAL BEAMS

M. Bucciolini[1], S.Mazzocchi[1], E. Borchi[2], M.Bruzzi[2], S. Pini[2], S.Sciortino[2], G.A.P.Cirrone[3], G.Cuttone[3], L.Raffaele[3], M.G.Sabini[3]

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Abstract

This paper deals with the application of synthetic diamond detectors to the clinical dosimetry of photon and electron beams. It has been developed in the frame of INFN CANDIDO project and MURST Cofin. Diamonds grown with CVD (Chemical Vapour Deposition) technique have been studied; some of them are commercial samples while others have been locally synthesised. Experiments have been performed using both on-line and off-line approaches. For the off-line measurements, TL (termoluminescent) and TSC (thermally stimulated current) techniques have been used.

9. SILICON DIODE FOR PROTON BEAM DOSIMENTRY

C. De Angelis[1], S. Onori[1], M. Pacilio[1], G. Cuttone[2], P.Cirrone[2], L. Raffaele[2], G. Sabini[2], A. Kacperek[3]

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Abstract

Preliminary results obtained with a new Scanditronix p-type stereotactic silicon diode, PFD, dedicated to proton dosimetry are reported. The behaviour of the detector was investigated in proton beams with energy up to 60 MeV.

10. STUDY OF THE DOSIMETRIC AND OPERATING CHARACTERISTICS OF NATURAL DIAMOND DETECTORS

C. De Angelis[1], S. Onori[1], M. Pacilio[1], G.A.P. Cirrone[2], G. Cuttone[2], L. Raffaele[2], M.G. Sabini[2], M. Bucciolini[3], S. Mazzocchi[3]

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Abstract

Main properties of PTW natural diamond detectors have been studied in photon, electron and proton beams. Suitability for depth dose and dose profile measurements in proton beams has been investigated. The necessity to characterise each detector sample before its clinical use has been addressed.

11. RETROSPECTIVE DOSIMETRY BY EPR DETECTION OF FREE RADICALS IN TOOTH ENAMEL

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Abstract

Free radicals induced in dental tissues by ionizing radiation can be detected by Electron Paramagnetic Resonance (EPR) spectroscopy and therefore can be used as indicators of individual radiation exposure. The method is especially appropriate for the individual retrospective dose assessment following external protracted exposure to low dose values, and is a very valid tool for the epidemiological studies aimed at radiation risk assessment.

12. PIXEL IONIZATION CHAMBER TO MONITOR CONFORMATIONAL TREATMENTS WITH HADRON AND PHOTON BEAMS

F. Marchetto[d] on behalf of the collaboration ATER-PIXE:
S. Belletti[b], A.Boriano[c], F. Bourhaleb[e,h] , R. Cirio[d] , M. Donetti[d], B. Ghedi[b,c],
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[g] *IBA, Ion Beam Applications, Louvain la-Neuve - Belgium*
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Abstract

A pixel ionization chamber together with the read out has been developed and tested with hadron and photon beams. A short description of the system and a brief summary of the results are presented.

13. FLUXEN - A PORTABLE EQUIPMENT FOR ABSOLUTE QUANTITATIVE ANALISYS OF IMAGING PROPERTIES OF RADIOGRAPHIC SYSTEMS

Piernicola Oliva[1]
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Abstract

The proper use of imaging equipment in radiological units is conditioned by an appropriate knowledge of the physical characteristics of the X-ray beam used. A portable equipment able to perform an exact spectral reconstruction of the radiation produced by an X-ray tube, used with imaging and a dedicated software to perform an absolute characterization of the imaging properties and performances of these systems is the aim of this work.

The detection system is based on a commercial CZT produced by AMPTEK and modified in the shaping electronics so to obtain a faster response. The acquiring section lies on a NuDAQ I/O card with a sampling time up to 20 MHz. The signals produced by an X-ray tube is entirely acquired and an off-line analysis is made so to make possible an accurate recognition of pile-up events and a reconstruction of the emitted spectra.

Resolution properties of imaging system are evaluated via Modulation Transfer Function, while noise properties are evaluated via Detective Quantum Efficiency.

Results on spectrum/flux characterization system are reported.

14. RESPONSE OF GR200 (LiF:Mg,Cu,P) DOSIMETERS TO PROTON AND ELECTRON CLINICAL BEAMS AND RECENT DECONVOLUTION METHODS

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Abstract

Within the more general context of dosimetry in radiotherapy, the thermoluminescence dosimetry (TLD) has attracted a lot of attention because TL dosimeters have a large linearity range, small size and good reproducibility and, using chemical mixture can be made tissue equivalent. The glow curve of an irradiated thermoluminescent dosimeter is made up by contributions due to the activation of different electron-hole traps of various energies and then by different peaks; a good glow curve deconvolution (GCD) is needed to obtain a reliable estimate of the kinetic parameters (activation energy, peak temperature and FWHM) and to improve the dose evaluation.

15. A DOSIMETRIC SYSTEM FOR THE EVALUATION OF UNDESIRED NEUTRON DOSE IN RADIOTHERAPY TREATMENTS WITH PHOTONS: EXPERIMENTAL METHOD AND MC SIMULATION

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Abstract

Linear accelerator is nowadays the most used radiotherapy device to treat tumor disease. In a number of cases secondary malignancies, due to the undesired dose delivered to the patient, could arise. The optimization of radiotherapy treatment can be obtained only through an accurate evaluation of the undesired dose. A method is presented to evaluate the photoneutron dose produced by GDR during cancer radiotherapy with energetic photon beams. It consists of a computer simulation code based on MCNP4B, in which the new routine GAMMAN was implemented, for the accurate study of photoneutron production in high Z and low Z elements. An experimental technique, based on a bubble passive spectrometer, allows direct measurements of photoneutron spectra at the patient plane, also inside the treatment zone. For the evaluation of neutron contribution to the dose at critical organs, a new anthropomorphic phantom has been designed and realized, following ICRP60 recommendations. The results are presented for medical accelerators, equipped both with traditional collimator system and with multileaf collimators.

16. A NEW MULTICOMPONENT DOSIMETER FOR APPLICATION IN BNCT

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Abstract

Boron Neutron Capture Therapy requires dosimetric techniques able to discriminate the dose contributions due to radiation with different RBE. Our research group has realized a multi-component system, using BeO thermoluminescent dosimeters, and electron spin resonance dosimeters realized both with an alanine–^{10}B compound and with alanine alone. Samples of each dosimeter type were irradiated at the TRIGA MARK II water-pool type research nuclear reactor at Pavia University with thermal neutron fluence in the range 10^{13} – 10^{14} cm^{-2}. The signal intensity in alanine–boron dosimeters resulted 40 times stronger than in alanine

17. IMAGING OF ABSORBED DOSE IN PHANTOM EXPOSED TO HIGH FLUENCES OF THERMAL AND EPITHERMAL NEUTRONS WITH SEPARATION OF ALL DOSE CONTRIBUTIONS

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Abstract

A method has been studied for imaging and profiling the absorbed dose in tissue-equivalent gel-phantoms exposed to thermal/epithermal neutrons at radiotherapy dose levels. The proposed method allows measuring the spatial distributions of each secondary-radiation component of the neutron field, and is aimed at supporting the planning of boron neutron capture therapy (BNCT). Dose-images are obtained by means of gel dosimeters, analysed with optical technique. The separation of the various dose components is achieved by the differential analysis of images obtained with gels having different isotopic compositions.

18. DOSIMETRIC REQUIREMENTS AND PROTOCOLS FOR *in vivo* BREAST IMAGING WITH SYNCHROTON RADIATION

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Abstract

The SYRMEP/FRONTRAD experiment, active at the synchrotron radiation facility ELETTRA in Trieste, is developing a system for digital mammography with synchrotron radiation. Images of test-objects and of in vitro breast tissue samples have been acquired with both a custom developed linear array Si pixel detector and conventional film-screen system.

The beamline is currently being upgraded for *in vivo* experimentation. The X-ray beams used for the SYRMEP experiment are monochromatic and laminar, and images are acquired by scanning the sample through the beam. Thus, it is not possible to use the instrumentation and dosimetric protocols used in conventional mammography, in which polychromatic cone beams are used. In this paper, we describe the protocols under development for *in vivo* breast imaging.

19. OPTIMIZATION, WITH THE MONTE CARLO CODE "BEAM", OF A SYSTEM FOR ELECTRON BEAM QUALIFICATION IN INTRAOPERATIVE RADIATION THERAPY (IORT)

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Abstract

The work presented at this Workshop concerns the optimization of a system designed to qualify electron beams from linacs, before IORT treatments on patients.

The answer of the instrument to high-energy electron beams from a NOVAC 7 linear accelerator has been analyzed through simulations with the Monte Carlo (MC) code named "BEAM".

Before simulating the system, we have built a MC model of the linac adequate for our purposes, as shown by the comparison between the obtained MC data and the experimental ones.

Through MC simulations, we managed to optimize the instrument, but we could not complete our work, because of bugs found in a part of the "BEAM" code used to simulate a component of the system.

20. STUDY AND DEVELOPMENT OF A NEW REAL TIME DOSIMETRIC SYSTEM, DEDICATED TO IORT (INTRA OPERATIVE RADIATION THERAPY)

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Abstract

IntraOperative Radiation Therapy (IORT) is a technique based on delivery of a high dose of ionising radiation to the cancer tissue, after tumour ablation, during surgery, while reducing the exposure of normal surrounding tissue.

The Novac7 is a new linear accelerator expressly conceived to perform in the operating room. This accelerator supplies electron beams at several energy, with high dose rate. These peculiar characteristics give rise to some complications with classical dosimetric techniques.

In the framework of a research contract between ENEA and the Physics Department of Bologna, an original system has been developed to study and visualise the Novac7 electron beam in real time. The system is composed by an electron-light converter, a mirror to focalise the light on a CCD sensor and a computer with dedicated software to acquisition, visualisation and imaging.

On the prototype theoretical and experimental studies have been conducted. It was verified that the system is able to get linear and stable responses on changing impulse number and energy. Moreover the experimental results have been compared with the ones obtained from classical instruments.

The results are totally satisfactory: the system is able to get a real time representation of the electron beam and the developed software can gives several interesting additional information on beam.

21. FRICKE-AGAROSE DOSIMETER GELS: ION DIFFUSION MODELLING AND MICRODENSITOMETRY ALTERNATIVE TO MRI

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Abstract

Ferric ion diffusion is one of the main problems that still restrains the dosimetric application of Fricke-agarose gels. In this work, we model this process within finite length gel samples. The temporal evolution of the ion concentration as a function of the initial concentration is derived by solving Fick's second law in two dimensions with boundary reflections. The influence of ion concentration gradient, elapsed time, diffusion coefficient and spatial resolution is studied. Due to the main drawbacks of MRI for studying these systems, i.e. high cost and acquisition time often non-negligible compared to diffusion time, we also investigate the possibility of using a microdensitomer. The application of this technique for Fricke gel dosimetry is proposed here for the first time. The estimate of the ion diffusion coefficient is in a very good agreement with those reported in literature.

22. MINIATURIZED TEPCs FOR MONITORING THERAPEUTIC BEAMS

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Abstract

For monitoring the proton radiation quality, a mini-TEPC with a sensitive volume of 0.6 mm^3 and an external diameter of 2.2 mm has been constructed. The counter, inserted in a thin titanium cylinder, is able to collect microdosimetric spectra in proton beams up to 5 10^6 $cm^{-2}s^{-1}$ of intensity.

23. MICRODOSIMETRIC MEASUREMENTS WITH A MINIATURIZED TEPC AT THE NICE PROTON THERAPEUTIC BEAM

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Abstract

In this paper we present first microdosimetric data, collected with such a mini TEPC, of the therapeutic proton beam of the Centre A. Lacassagne of Nice. By using the response function $r_D(y)$ for early intestine damage in mouse at 2 Gy, the RBE has been calculated in different therapeutic situations. The comparison between the relative physical dose (derived from microdosimetric spectra) and available radiobiological data is satisfactory.

24. FIRST MICRODOSIMETRIC MEASUREMENTS WITH A ^{10}B-LOADED TEPC

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Abstract

The BNCT (Boron Neutron Capture Therapy) is a cancer treatment technique which could be the best one for those skin tumours (melanomas) which are nowadays resistant to ordinary therapy. It makes use of thermal or epithermal neutrons to irradiate tumours previously loaded with ^{10}B. Thermal neutron absorption on the ^{10}B nucleus gives rise to the production of two particles, ^{4}He and ^{7}Li, whose ranges in tissue are as short as the diameter of a cell nucleus. Because of such short ranges, all the energy is released inside the tumour cell, which is killed with high probability, while the neighbouring cells are not damaged.

However dosimetry for BNCT is complex. The radiation field can be divided in two parts. The first one is caused by the products of the BNC reaction and depends on the concentration of ^{10}B atoms in the irradiated cell and on the neutron thermal flux. The second part is due to residual fast neutrons, slow neutrons and gamma rays produced by the neutron source and by the moderating facility. Therefore it is necessary to perform an accurate monitoring providing the relative doses of all these components. The only instrument which can satisfy these needs with a single measurement is the TEPC (Tissue Equivalent Proportional Counter). Moreover TEPCs, loaded with and without ^{10}B, can be also used to estimate the thermal neutron flux and to predict the RBE for cells loaded with and without ^{10}B.

25. THE DOSIMETRY OF ENVIRONMENTAL RADON

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Abstract

The accurate measurement of the ^{222} Rn concentration in air is important in different fields of interest such as indoor measurements for classification of buildings and rooms, the environmental monitoring of the air especially near uranium mines and the soil, in dosimetry and medical diagnostics in radon baths, the Rn background measurements for experiments that searching for rare-decays, the long term monitoring over the national territory, the study of the correlations between seismic events and the radon release occurring prior to seismic activities. In Terradex experiment the continuous monitoring of the radon concentration in air is based on the observation of alpha and beta particles produced by the decay of ^{222}Rn and its daughters. The active detector used for the project (silicon) with its associated readout electronics and the unique monitoring technique makes this instrument competitive with respect to the commercially available and scientific instruments developed nowadays thanks also to its capabilities of real time, low background and high efficiency measurements of the radon concentration in air. In this work we will discuss the necessity of performing precise measurements of the Rn concentration as well as the description of the proposed monitoring instrument by comparing its capabilities to those available at present.

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26. TRACK-NANODOSIMETRY OF AN ALPHA PARTICLE

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Abstract

Effects of radiation are primarily determined by what happens in individual small volumes representative of DNA segments. Such sites are so small that the interactions due to the radiation are very few and it is necessary to consider the stochastic of the number and nature of primary interactions and of secondary processes in order to understand the subsequent biological effects. Track-nanodosimetry has the objective to investigate the stochastic aspect of energy deposition in particle tracks, by measuring the ionisation distributions induced by a charged particle in nanometric volumes of tissue-equivalent matter, positioned at different distances from the track. This paper is concerned with measurements and Monte Carlo calculations of ionisation distributions produced in a site of about 20 nm by a ^{244}Cm alpha particle.

27. CHARACTERIZATION OF A NEUTRON SPECTROMETER BASED ON A P-I-N PHOTODIODE

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Abstract

A proton-recoil spectrometer for neutrons was realized by coupling a commercial P-I-N photodiode with a polyethylene radiator. The minimum and maximum neutron energies which can be detected depend on the thickness of the depletion layer (i.e on the diode bias voltage). It is worth mentioning that the detector has proved to work unbiased, exploiting the field funnelling effect. This effect is due to a local distortion of the electric field in the depletion layer, leading to the collection of pairs produced in the substrate. The response functions were measured by irradiating the spectrometer with monoenergetic neutron beams, generated at the Van De Graaff accelerator of the Legnaro National Laboratories. Monte Carlo simulations were also performed with the FLUKA code. The effect of secondary charged particles produced by thermal and fast neutrons interactions in the silicon device was also investigated.

28. DEVELOPMENT OF A LARGE AREA SCANNING SYSTEM USING TAGGED 14 MeV NEUTRONS

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Abstract

A new, large area scanning system using 14 MeV tagged neutrons has been constructed and commissioned at the Laboratori Nazionali di Legnaro (Italy). This device was designed to be part of a vehicle mounted land-mine detection system using nuclear techniques, but it can be used in several applications where non-destructive assays are needed.

29. RPC FOR THERMAL NEUTRON DETECTION

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Abstract

The possibility to detect thermal neutrons with single gap Resistive Plate Chambers has been investigated. The development of the detector has been performed in the frame of the DIAMINE European Project for humanitarian de-mining. The Resistive Plate Chambers are simple devices widely used in many particles physics experiments as trigger detectors because of their fast response and good spatial resolution. The RPC detects the charged particles generated by neutrons via the (n,α) reaction on Boron. A $^{10}B_4C$ thin coating on the inner surface of one RPC electrode is used as thermal neutron converter. A simulation study has been performed to optimize the converter thickness and the RPC working parameters. Preliminary tests on converter samples have been performed at Laboratori Nazionali Legnaro with a thermalized ^{252}Cf source in order to evaluate the conversion efficiency. A first detector prototype of small dimensions has been realized and tested with cosmic rays and neutrons from the thermalized ^{252}Cf source at LNL. Results of simulation and experimental measurements of conversion efficiency, together with the description of the RPC prototype are presented.

30. COSMIC RAY DOSIMETRY AT AIRCRAFT ALTITUDES (OBD)

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Abstract

Within the OBD experiment, the spectra of secondary particles resulting from interactions of primary galactic cosmic rays with the nuclei in the atmosphere have been calculated using the Monte Carlo transport code FLUKA. The simulations have been carried out for several values of the solar modulation parameter and the vertical geomagnetic cut-off. Effective dose rate and ambient dose equivalent rate as a function of position (vertical cut-off rigidity), altitude (atmospheric depth) and date (solar modulation) have been obtained using appropriate sets of conversion coefficients.

31. EXTENDED ENERGY RANGE NEUTRON DOSIMETRY FROM THERMAL TO GeV NEUTRON ENERGY

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Abstract

Neutron dosimetry is an important task around hadron accelerators in intermediate and high energy range. Additionally the exposure of aircraft personnel during flight at cruise altitudes is considered be occupational.

Neutron energies for these radiation fields extend over a wide energy range from thermal to several hundreds MeV.

In the past neutron monitors used for radiation protection purposes have a response range limited to about 10 MeV.

A Bonner Sphere Spectrometer (BSS), to evaluate neutron energy distribution, and a rem-counter (LINUS), to evaluate the ambient dose equivalent, with a response range extended to GeV energies have been designed with FLUKA computer code.

The BSS and LINUS counter were calibrated with monoenergetic neutron beams to 19 MeV and validate in the stray neutron fields at CERN to GeV energies.

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A DOSIMETRIC SYSTEM FOR THE EVALUATION OF UNDESIRED NEUTRON DOSE IN RADIOTHERAPY TREATMENTS WITH PHOTONS: EXPERIMENTAL METHOD AND MC SIMULATION

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ERRATA CORRIGE p. 95

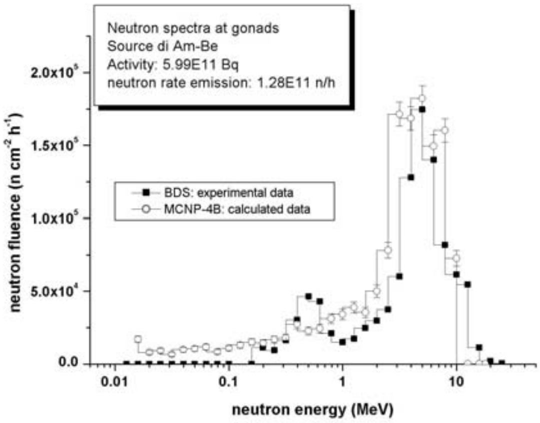

Figure 4: *Neutron spectra in a cavity inside the phantom*

The neutron doses (expressed in terms of dose equivalent) have been evaluated in the cavities in correspondence of critical organs by using integral detectors (BD-PND 100 keV - 20 MeV) and the results of the two exposures are shown in figure 5.

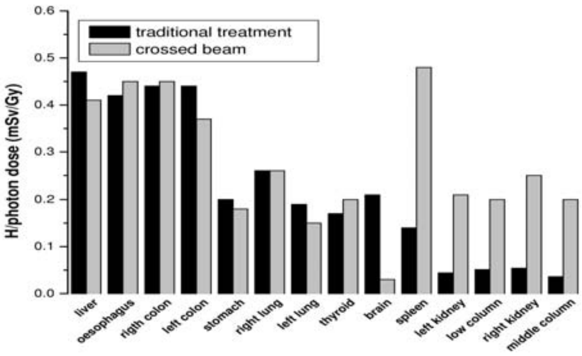

Figure 5: *Neutron dose equivalent in two different exposures*

It is evident that the undesired photoneutron contribution to deeper organs is more important during the crossed beams treatment. In fact, in this case a remarkable photoneutron production is due to the lead blocks used for modelling the two lateral gamma beams.

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