1st International Conference on Dosimetry and its Applications

Book of abstracts

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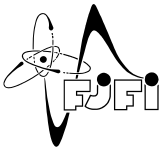

Czech Technical University in Prague

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1st International Conference on Dosimetry and its Applications
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Foreword

The 1st International Conference on Dosimetry and its Applications (ICDA-1) in Prague aims to establish a tradition of dosimetry conferences, held in a three-year cycle under the auspices of the International Society of Radiation Physics. The objective of this conference is to bring together scientists, teachers and students from all over the world to exchange knowledge and to discuss ideas and future issues. We believe that such meetings of the dosimetry world community will serve to advance knowledge in this area of science and also to enhance its existing and potential applications.

This Book of Abstracts offers a summary of all invited lectures and accepted contributed papers received by 7 June 2013. The response of the scientific community has been great, despite the difficulties faced in many parts of the world economy, which is sadly evident in the level of funding for scientific institutions and universities. We hope that the conference reflects the increasing importance of dosimetry in the contemporary world. The proceedings of ICDA-1, with the full texts of the invited lectures and contributed papers, will reflect the state of the art in even greater detail. Elsevier will publish the proceedings as a separate issue of the journal Radiation Physics and Chemistry.

This conference is organised in co-operation with the International Radiation Physics Society, by the Faculty of Nuclear Sciences and Physical Engineering of the Czech Technical University in Prague. This University is the oldest non-military technical higher educational institution in Europe, having been founded by a Decree of the Emperor in 1707. The tradition of university and scientific life in Prague goes back considerably longer than that. The foundation of Charles University dates back to 1348. For centuries, Prague has been at the crossroads of ideas, culture and art, science, technology and research, in the heart of Europe. We will be pleased and proud if ICDA-1 extends this tradition of a rich scientific and cultural life in our city, and we invite all participants to be affected by the city's "genius loci".

I should like to thank all collaborators who have contributed to the preparation of the conference. Special thanks are due to the management and staff of the Faculty of Nuclear Sciences and Physical Engineering for their administrative and technical support.

I welcome warmly all participants in the conference, and wish you a pleasant stay in Prague and many fruitful scientific contacts and discussions.

Ladislav Musílek
President of the International Radiation Physics Society
Chairman of the Organising Committee of ICDA-1

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Development of tailor-made silica fibres for TL dosimetry

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The Ge dopant in commercially available silica optical fibres gives rise to appreciable TL, weight-for-weight offering sensitivity to megavoltage x-rays some several times that of the popular LiF material TLD100 [1]. To-date studies have been made of the response of commercially available telecommunication fibres, to UV light, X-ray beams, a synchrotron microbeam facility, electrons, protons, neutrons and alpha particles, measuring doses from a fraction of ^{1}Gy up to 10 kGy [2]. The response of these fibres has encouraged more comprehensive investigation, in part to seek a more general understanding of the magnitude of the TL signal for a range of dopant concentrations, providing a basis for exploitation of the TL for dosimetry. Presentation is made herein of a consortium effort between Malaysian partners (University of Malaya, Multimedia University, Telekom Malaysia R&D and the Malaysian Nuclear Agency) and the University of Surrey, the intention of the work being to tailor the production of silica fibres towards specific TL dosimetry applications. The work utilises the MCVD doped silica-glass production and fibre-pulling facilities available to the consortium, to design and produce fibres, characterised in terms of radiation response to a range of sources, supported by physical interpretation, provided in part through XANES analysis. The work seeks to define tailored fibers, informed by dopant concentration and production parameters as in for instance pulling parameter effects, including temperature, speed, tension, also providing for spatial resolutions down to $< 10\mu m$, confronting the many limitations faced in use of conventional thermoluminscence (TL) dosimetry. Early results are shown for high spatial resolution ($\sim$100 µm diameter) single-core Ge-doped thermoluminescence sensors, suited to radiotherapy applications, through to undoped flat optical fibers ($\sim$ 3 mm $\times$ 3 mm $\times$ 1 mm), the latter proposed as radiation sensors in medical diagnostic applications.

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Dosimetry for X-Ray Security Screening Systems

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Recent years have seen a dramatic expansion in the application of radiation and isotopes to security screening to detect explosives and other contraband. Enormous global resources are now being devoted to detect explosives, special nuclear material, and other contraband in transportation and commercial venues. This poster reviews the projects at the National Institute of Standards & Technology that have facilitated production of a new suite of national and international standards for radiation safety of systems used to screen luggage, persons, vehicles, cargo, and left-behind objects. In addition, we overview new NIST dosimetry protocols, detectors, and techniques to measure commercial radiation sources such as the Megavolt x-ray beams used in cargo inspection and the very-low-dose and rapidly-rastered pencil beams used to scan persons and vehicles.

This work was funded by the Department of Homeland Security Science and Technology Directorate and the Transportation Security Agency.

Development of CVD Diamond Detectors for Clinical Dosimetry

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The use of chemical vapour deposition (CVD) methods for the manufacture of diamonds could lead to detectors for high-resolution radiotherapy dosimetry that are cheaper and more reproducible than detectors based on natural diamonds. In this work two prototype designs (Diamond Detectors Ltd, Poole) of CVD diamond detectors were considered. The detectors were encapsulated in a water-proof housing in a form-factor that would be suitable for dosimetry measurements in water, as well as solid material phantoms. Stability of the dosimeter over time, the dose-response, dose-rate response and angular-response were examined. The study demonstrated that the detector behaviour conformed with theory in terms of the dose-rate response and had acceptable properties for use in the clinic. An analysis of the response of the dosimeter at microsecond time-scales has lead to improvements in the governing theories and has helped to clarify some contradictory ideas in the literature. Methods for correction of the non-linear dose-rate response of high-purity diamonds were considered. The use of the detectors has been demonstrated in several clinical applications, including the validation of data used in the delivery of intensity modulated radiotherapy (IMRT).

Spectral characterization of mixed radiation fields at accelerators and in space by means of Timepix pixel detectors

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The technological advances occurred during the last few decades paved the way for the dissemination of CT-based procedures in radiology, to an increasing number of procedures in interventional radiology and cardiology, as well as to new techniques and hybrid modalities in nuclear medicine and in radiotherapy. These technological advances encompass the exposure of patients and medical staff to unprecedentedly high dose values that are a cause for concern due to the potential detrimental effects of ionizing radiation in the human health. As a consequence, new issues and challenges in radiological protection and dosimetry in the medical applications of ionizing radiation have emerged.

The scientific knowledge about the radiosensitivity of individuals as a function of age, gender and other factors has also contributed to raise the awareness of scientists, medical staff, regulators, decision makers and other stakeholders (including the patients and the public) for the need to correctly accurately assess the radiation induced long-term health effects after medical exposure. Pediatric exposures and their late effects became a cause of great concern.

The scientific communities of experts involved in the study of the biological effects of ionizing radiation have made a strong case about the need to undertake low dose radiation research and the international system of radiological protection is being challenged to address and incorporate issues such as the individual susceptibility and non-cancer effects.

Some of the answers to the radiation protection and dosimetry issues and challenges in the medical applications of ionizing radiation lie on computational studies using Monte Carlo or hybrid methods to model and simulate particle transport in the organs and tissues of the human body. The development of sophisticated voxel phantoms paves the way to an accurate dosimetric assessment of the medical applications of ionizing radiation.

In this paper, the aforementioned topics will be reviewed and prospective views will be provided on the future of the system of radiological protection and on dosimetry issues in the medical applications of ionizing radiation.

GENII-LIN project: a Multipurpose Health Physics Code to Estimate Radiation Dose and Risk from Environment Contamination

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The aim of the GENII-LIN project is to provide an open source radiation protection software system with capabilities for calculating radiation dose and risk to individuals or populations from radionuclides released to the environment and from pre-existing environmental contamination, to be used for purposes such as siting facilities, environmental impact statements, and safety analysis reports.

The software package can handle exposure pathways that include: external exposure from finite or infinite atmospheric plumes; inhalation; external exposure from contaminated soil, sediments, and water; external exposure from special geometries; and internal exposures from consumption of terrestrial foods, aquatic foods, drinking water, animal products, and inadvertent intake of soil.

The radionuclide environmental concentrations are calculated for each year of the exposure period by modeling appropriate transport phenomena through air, deep and surface water and biotic transport. A well documented and full featured wizard-like graphical interface steps the user through the process of setting up the variables and efficient scenario definition.

Though no programming skills are required for using it, the code is completely open source, i.e., transparent to the final user, who can check himself the correct implementation of the models. The code flexible modular structure and the strictly object oriented software design allow for easy improvement and patching: other modules can be added and the present ones updated, with minimal effort.

Radon dosimetry – state of the art

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Radon as a main source of irradiation embodies a special topic in realm of radiation protection, as studied in the last 50 years. Efforts to lower the radon concentration in dwellings and workplaces aim at decreasing the risk of lung cancer induction. Residential studies up to 2008 reported a positive association between childhood leukemia and radon, which in fact increased the importance of radon protection efforts. Despite the high variability in seasonal radon concentrations and its strong dependence on physical parameters of measured environment, caused by its being a naturally occurring inert gas, presently scientists are able to measure and study radon using sophisticated methods. Radiation protection efforts could be characterized within 3 main interrelated areas. General approach which is based on results of epidemiological studies and dosimetric or micro-dosimetric calculations attempts to find consensus in values of lifetime risks. The European pooling study re-analyzed data from 13 European case-control studies and adopted twice higher lifetime risk that now narrowed the historical differences between epidemiological and dosimetric approaches significantly. Above mentioned studies impact the practical part of radiation protection, generating more accurate recommendations, which enable individual countries legislation to follow the latest conclusions in radon research. The implementation of ICRP recommendations results in better focus of the national radon programs. The dynamic progress in research, measurement and diagnostic methods development leads to more precise datasets, and integrating the above efforts, has positive impact on changing building construction codes and guidelines, covering the radon prevention and radon remediation techniques and procedures.

Radiation Protection and Dosimetry issues in the medical applications of ionizing radiation

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The technological advances occurred during the last few decades paved the way for the dissemination of CT-based procedures in radiology, to an increasing number of procedures in interventional radiology and cardiology, as well as to new techniques and hybrid modalities in nuclear medicine and in radiotherapy. These technological advances encompass the exposure of patients and medical staff to unprecedentedly high dose values that are a cause for concern due to the potential detrimental effects of ionizing radiation in the human health. As a consequence, new issues and challenges in radiological protection and dosimetry in the medical applications of ionizing radiation have emerged.

The scientific knowledge about the radiosensitivity of individuals as a function of age, gender and other factors has also contributed to raise the awareness of scientists, medical staff, regulators, decision makers and other stakeholders (including the patients and the public) for the need to correctly accurately assess the radiation induced long-term health effects after medical exposure. Pediatric exposures and their late effects became a cause of great concern. The scientific communities of experts involved in the study of the biological effects of ionizing radiation have made a strong case about the need to undertake low dose radiation research and the international system of radiological protection is being challenged to address and incorporate issues such as the individual susceptibility and non-cancer effects.

Some of the answers to the radiation protection and dosimetry issues and challenges in the medical applications of ionizing radiation lie on computational studies using Monte Carlo or hybrid methods to model and simulate particle transport in the organs and tissues of the human body. The development of sophisticated voxel phantoms paves the way to an accurate dosimetric assessment of the medical applications of ionizing radiation.

In this paper, the aforementioned topics will be reviewed and prospective views will be provided on the future of the system of radiological protection and on dosimetry issues in the medical applications of ionizing radiation.

The thermoluminescence glow curve properties of pure and doped flat silica fiber as radiation dosimeter

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Pure silica flat optical fiber and Ge-B co-doped flat optical fiber were studied. The fibers were exposed to photon radiation using a linear accelerator, producing photons energies generated at 6 MV and 10 MV. The pure fiber glow curve produced five peaks compared to four in the doped fiber. The presence of dopant in flat optical fiber was found to cause a shift in the glow peak spectrum to higher temperature. The thermal activation energy, E_a of the doped fiber was 33.% higher than that for the pure fiber. The glow peak shift increases with dose, with associated increase in the value of E_a. The reproducibility was within % (one standard deviation) for irradiation energy of photon. The fibers were found to be energy independent within the photon energy range. At room temperature the fading up was at % until 1 month and within the % uncertainty of the sensitivity calibration of the fiber. Re-using the fiber more than 20 times did not significantly alter the sensitivity factor. Both doped and undoped flat fibers are a promising TL dosimeter.

Dosimetric features of strontium orthosilicate (Sr2SiO4) doped with Eu

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Strong thermoluminescence (TL) signal in the range from room temperature to 750 K is reported for strontium silicate synthesized using the solid state reaction method and doped with Eu. It can be excited by UV, X-rays and beta radiation. The TL emission spectrum extends from about 400 nm to 700 nm. The shape of glow curve depends on the concentration of Eu ions. The highest TL intensity was detected for Sr_2SiO_4 with 2 mol% of Eu. Two peaks – about 350 K and 450 K dominate in its glow curve. For higher Eu concentrations – 3 mol% and 4 mol% – lower TL efficiency is observed but in these cases glow curves exhibit more complex structure. One can easily distinguish three peaks around: 350 K, 410 K and 450 K and a wide maximum above 470 K. The parameters of traps responsible for TL peaks were determined by various heating rate method and by fitting the sum of the modeled first-order curves to the experimental data. The lifetime estimated for the TL peak at 450 K suggests that it can be useful for dosimetry purposes. This peak is common in all samples and its intensity shows linear increase with the dose for over four orders of magnitude. However prolonged experiments revealed that this peak fades faster than it could be expected from the trap parameters. Nevertheless, the TL intensity, even after fading, is still high. The aim of this work is to study the mechanism of this fading and to establish the residual level of TL remaining after the long storage. The isothermal luminescence decay was recorded at different temperatures. The trap parameters obtained from these experiments have been compared with results of the glow curve analysis.

Dosimetric characteristics of LKB:Cu,P as a solid TL detector

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We present the dosimetric characteristics of new borate glass dosimeter modified with lithium and potassium carbonate (LKB) and co-doped with CuO and $NH_4H_2PO_4$. The XRD technique shows the amorphous nature of the prepared sample. A simple glow curve of Cu doped sample is observed at 220°C with a single prominent peak (T_{m). The addition of CuO (0.1 mol%) to the LKB compound improved the TL yield by a factor of ∼100 while the addition of 0.25 mol% $NH_4H_2PO_4$ as a co-dopant enhanced the TL yield by a further factor of 3, attributed to the creation of extra electron traps with consequent increase in energy transfer of radiation recombination centres. Although the TL yield of LKB: Cu,P with Z_{eff} of 8.92 is approximately seventeen times less sensitive compared to LiF: Mg, Ti (TLD-100), nevertheless the proposed dosimeter shows good linearity up to 10^3 Gy, minimal fading and photon energy independence. The several attractive features offered by this dosimeter is expected to pave the way for its use in a number of dosimetric applications.

On the correct evaluation of the relative TL efficiency of the thermoluminescent detectors to protons and heavy ions

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The relative thermoluminescent (TL) efficiency is usually defined as a ratio of the emitted light intensity, per unit dose and unit mass, for a given radiation type, to the same quantity for the reference radiation (usually Cs-137 or Co-60 gamma rays) (Sądel, *et al.,* 2013). This quantity is in general not constant, but depends on ionization density. Evaluation of the relative TL efficiency is therefore important especially for correct interpretation of measurements of densely ionizing radiation doses, like, e.g. in proton radiotherapy or in space dosimetry (Bilski and Puchalska, 2010).

The correct determination of the relative TL efficiency is not always straightforward and can be sometimes misleading. This is particularly important when comparing data obtained and published by different research groups. In the present work the various methods of analyzing of TL data and further calculation of the relative TL efficiency will be studied. Several factors which may influence the value of the relative TL efficiency and their significance for the final result, will be discussed. These include for example non-uniform deposition of the dose within the detector volume, self-attenuation of TL light, choice of the reference radiation etc. (Gieszczyk, *et al.,* 2013). The presented calculations will be based on the measurements realized with the LiF:Mg,Ti and LiF:Mg,Cu,P TL detectors.

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Fluorescent Imaging of Complex Radiation Fields, Using a Radio-Fluorogenic Gel ("RFG")

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Effects of Composition Interactions on the Response of a Turnbull Blue Radiochromic Gel Dosimeter

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In this study, the Taguchi statistical method was used to design experiments for investigating the effects of interactions among compositions on the performance of a Turnbull blue gel (TBG) radiochromic dosimeter. Four parameters were considered as the design factors: (A) concentration of ferric chloride, (B) concentration of potassium ferricyanide, (C) concentration of sulfuric acid, and (D) amount of gelling agent added. Two levels were selected for each factor. The change in optical absorbance at 695 nm under UVA exposures was monitored to determine the response of the dosimeters. The results showed that the contributions of factors A to D were 20.01%, 23.16%, 27.03%, and 0.49%, respectively. The contributions of significant interaction effects were AC (8.60%), BC (5.61%), and ABC (10.56%). This finding indicated that sulfuric acid (C) was the most influential factor, whereas gelling agent (D) was the least influential factor. Sulfuric acid had an important function in two two-way interactions and one three-way interaction in the response of TBG to UV exposure.

Special Reference Radiation Fields of PTB

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PTB is the only institute world-wide which offers reference fields for pulsed X-rays and for high-energy photon radiation. But why are these special radiation fields so important? Radiation protection dosemeters are mainly used in the medical sector, at nuclear power plants and at research accelerators. All these applications claim for special requirements on the used dosemeters, e.g. detecting single pulses of less than 10 ms duration or measuring over a huge range of photon energies up to 7 MeV. To judge the suitability of a dosemeter, testing in adequate reference fields is essential. The characteristics of the novel pulsed reference fields at PTB are oriented on standard medical X-ray units in clinics. But in contrast to medical X-ray equipment, all relevant field parameters, like pulse duration, tube voltage, and tube current can be adjusted independently. With that X-ray unit we can generate radiation qualities (N-series) according to ISO 4037-1 and RQR series according to IEC 61267 with pulse durations adjustable from 0.2 ms up to continuous radiation. The characteristics of the high energy photon reference fields at PTB are oriented on the necessary testing conditions needed for dosemeters used in nuclear power plants. The generated radiation fields, R-C (4.4 MeV) and R-F (6.7 MeV), are both produced according to ISO 4037-1 by an induced nuclear reaction. Protons, accelerated by a Van-de-Graaff accelerator or cyclotron, encounter on a target compromised of natural carbon or calcium fluoride, respectively. The produced photon spectra and the unavoidable neutron contribution are well characterised. The characteristics and the resultant irradiation possibilities of these unique radiation fields of PTB will be presented.

A methodology for calibrating eye lens dosemeters in terms of $H_p(3)$ used in interventional radiology

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Recent studies have indicated the increase of the incidence of lens opacities for low radiation doses. Considering epidemiological data, the International Commission on Radiological Protection (ICRP) issued a statement that changed the absorbed dose threshold for the eye lens. The statement also recommends a reduction in the dose limits to the eye lens for occupationally exposed persons; now it is considered to be 20 mSv in a year averaged over five years. As consequence, some planned exposures require the use of additional dosemeter for estimating eye lens dose in professionals; it is the case of the staff in interventional radiology. Nowadays, in the national and international standards there is a lack of specific methodology for eye lens dosimetry. The ICRP recommendation raised the debate on the adequacy of dose equivalent quantities of radiological protection and on the methods for their measurements. The aim of this work was to study the methodology for calibrating personal dosemeters used for assessing the personal dose equivalent, Hp(3). This work was performed in the Dosemeter Calibration Laboratory of CDTN/CNEN; international guidelines and recent literature were adopted for the calibration procedures and tests. The dosimetric system, consisting of a holder and thermoluminescent detector LiF:Mg,Cu,P (TLD-100H), was exposed to standard radiation fields on a cylindrical water phantom that simulated the head. The calibration coefficients of the dosimetric system were determined for tube potential from 20 to 150 kV of the ISO 4037 narrow spectrum series. The results showed to be satisfactory were compared to the literature.

Dose levels of occupational radiation in medicine and industrial exposures in Poland

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Laboratory of Individual and Environment Dosimetry (Polish acronym LADIS) is the biggest dosimetry service in Poland. Service is based on termoluminescent detectors MTS-N(LiF;Mg,Ti) and MCP-N (LiF;Mg,Cu,P), developed at Institute of Nuclear Physics in Krakow in 60's AND 80's. In 2002 laboratory obtained certificate according to the EN-PN- ISO17025 standard from Polish Center of Accreditation. Presently LADIS measures dose levels for almost 5700 institutions in Poland and abroad. Measurements are performed quarterly or monthly for 42\,000 workers exposed to occupational radiation of X-rays, gammas and neutrons.

Current development of technology leads ionizing radiation to being used in many areas of live. In LADIS there are 3 types of dosimeters to measure individual doses Hp(10), Hp(0.07) and Hp(3). According to the LADIS classification in occupational exposure, the radiation workers under control have been divided into seven main categories: (1) interventional radiology; (2) oncology centers; (3) nuclear medicine; (4) dental; (5) industrial radiography; (6) veterinary radiology; (7) radiology.

The paper presents results of statistical evaluation of Hp(10), Hp(0.07) measurements performed in medicine exposures in years 2005-2012. 75% of all individual doses in Poland are on the level of natural radiation background. The dose levels between 0.1 and 5 mSv per quarter are the most frequent in nuclear medicine, while the lowest levels in dentistry.

Design and implementation of an external personal dosimetry laboratory in Venezuela

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In the framework of the project: "Radiation protection to workers exposed to radiation" developed between Cuba and Venezuela was carried out the design and implementation of the External Personal Dosimetry Laboratory based on thermoluminescence dosimetry system. It is located in the Direction of Radiological Health of the General Direction of Environmental Health of the Ministry of the Power Popular for the Health of that country. This laboratory would have the function of individual radiological monitoring of occupationally exposed workers from ionizing radiation linked to medicals practices such as radiotherapy, conventional radiology and odontology. It is contributed to the individual monitoring program for external radiation exposure; provide information for the optimization of protection. This paper describes the design of this laboratory for which was taken into account different aspects such as: persons to include in monitoring program, their roles in the institutions and the characteristics of sources of ionizing radiation used. Although described the features and requirements that should be met to selected the type of dosimetric system, the type of dosimeter used in program monitoring, the composition of the staff who work in the laboratory and their training and training in radiation protection, among others. The systems installed consist of LiF: Mg, Ti, model TLD-100, detectors in Harshaw dosimetry cards (three TLDs per card) and two automatic Harshaw TLD readers. In order to evaluated the performance of the system we were carried out the type test recommended by the International Electrotechnical Commission (IEC) in the IEC 1066 standard. The system was calibrated and main dosimetric parameters of the dosimeters such as: homogeneity, reproducibility, linearity and detection threshold, have been tested. As result of the project was put underway the National External Personal Dosimetry Laboratory, capable to ensure the individual radiological monitoring, through the monitoring of the personal dose equivalent Hp(10) (Sv). More than 1500 workers occupationally exposed are being controllers. The system is able to measure and to provide information to control radiological hazards.

Comparison of Personal Dose Equivalent Measurements by Personal Dosemeters

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Individual monitoring services for external radiation were tested in the Czech Republic. The services authorized in the Czech Republic were required to prepare their dosemeters according to their manual procedures. The irradiation laboratory in the Czech Metrology Institute, Inspectorate for Ionizing Radiation irradiated all dosemeters according to the international standard ISO 4037 and according the irradiation plan. The plan aimed at an estimation of energy and angular dependence. Irradiations were restricted to photons and will be performed in terms of $H_p(10)$ and $H_p(0.07)$ in the following ranges:

Energy: 30 keV to 80 keV

Dose: $H_p(10)$ 4.8 mSv to 5.08 mSv, $H_p(0.07)$ 5.22 mSv to 10.19 mSv

Angle: 0°, 60°and 75°from the beam axis – from the bottom – from the side

X –ray tubes produced relatively low energy photons were used as a source of primary radiation with the aim to use the energy range typical for the application in radiodiagnostics. The participants should evaluate the dosemeters according to the normal routine procedures and reported the results in terms of $H_p(10)$ and $H_p(0.07)$.

For the analysis of the results, the performance limits, known as "trumpet curves", were used. The standard ISO 14146 allows a maximum of one-tenth of the dosemeters to exceed the limits of the "trumpet curves".

The results of the tests show that they are dosimetry systems authorized and regularly tested in the Czech Republic having outliers for low energy region and angle 60 degrees and greater. With the highest probability the processing equipment poorly determines the correct angle of exposure. This cases could cause overestimation $H_p(10)$ in the special conditions appeared e.g. in cardiosurgery.

Pulsed Reference Radiation Fields and Testing of Radiation Protection Dosemeters

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As it is known, the testing of active electronic personal and area dosemeters for the operation in pulsed radiation fields is a necessity to judge the suitability of a dosemeter. Up to now, radiation protection dosemeters have only been tested in continuous fields, although they are used for measurements in pulsed radiation fields as well. The determination of reference fields is a basic requirement for the development, testing and calibration of radiation protection dosemeters as well as for the further development of radiation sources for the range of pulsed radiation. Thus, in cooperation with the Siemens company, a novel facility has been developed which makes it possible for the first time to adjust all parameters of the pulsed X-radiation reference fields. With this X-ray unit it is possible to determine the performance limits of dosemeters with respect to pulsed radiation. Worldwide, it is the first facility of its kind. The new international specification ISO TS 18090-1 "Radiological protection – Characteristics of reference pulsed fields – Part 1: Photon radiation" for pulsed reference fields, which is currently under development, describes requirements for such pulsed reference fields. For active electronic dosemeters, using the counting technique, the IEC TS 62743:2012-09 "Radiation protection instrumentation – Electronic counting dosemeters for pulsed fields of ionizing radiation" describes adequate test procedures. For other measurement principles, up to now, there are no standardized test procedures. The characteristics of the pulsed reference fields of PTB, the basic ideas of the international standards and measurements at commercially available dosemeters in pulsed fields will be presented.

Optimization of the double dosimetry algorithm for interventional cardiologists

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Double dosimetry is a well established approach for estimation of effective dose of a personnel using protective gear (led aprons, collars etc). However, there is no common algorithm, which is accepted internationally. In addition, existing algorithms are, as a rule, insufficiently specific and, therefore, quite conservative.

Our purpose was to elaborate a new algorithm, which, on one hand, should be based on some universal and expandable approach, and, on the other hand, could account for more or less specific conditions of exposure, i.e. in the area of interventional cardiology (IC). At the first step, the source and shielding/scattering structures in the IC operation room were modelled using MCNP-4B Monte Carlo code. ADAM phantom with added led apron and collar was representing a doctor in his typical position and orientation, similar ADAM phantom in a horizontal position was representing a patient (a scattering volume for incident x-rays). A number of simulated Hp(10) dosimeters were placed on the phantom surface – 15 on front in three levels (9 over and 6 under apron), 6 on the back of the phantom (similar layout), one dosimeter on the collar. Doses to organs and dosimeters were simulated for 432 specific irradiation situations ("C-arm angulation"-"x-ray energy"-"FOV") thus producing partial dose values. With respect to the weight (relative frequency) of each situation, contributing to particular irradiation scenario (depends on typical or assumed distribution of parameters of x-ray machine in the IC operation room), total doses can be calculated as weighted sums of partial values. Having those partial values for both organ doses (and E) and dosimeter readouts, it is possible to perform fitting of dose algorithm weighting coefficients in order to obtain most robust and precise estimate of E. This fitting was conducted by least square method as well as by using artificial intelligence neural network. Two-way optimization of the dose algorithm was applied: best pair of dosimeters was chosen and values of respective weighting coefficients were estimated.

It was demonstrated that new algorithm provides less conservative yet robust effective dose estimates and can rely on several plausible combinations of dosimeters.

Dosimetric Properties of $CaSO_4$:Eu with Addiction of Silver Nanoparticles

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Different materials detectors have been proposed in the literature for use in personal and environmental dosimetry. Thermoluminescent detectors are among the detectors most widely used to this purpose. The motivation of this work was to produce crystals of $CaSO_4$ doped with unusual elements such as europium (Eu) and silver (Ag), including in the form of nanoparticles, prepared by an adaptation of the method developed by Yamashita (1971). The interest in the production of these materials was to investigate other methods of producing thermoluminescent materials. In the new growth route, the crystals were produced from calcium carbonate ($CaCO_3$), by incorporating the dopants (Eu_2O_3 or Ag_2O) in a solution of sulfuric acid. Silver nanoparticles Ag(NP) were obtained through a synthesis route so-called polyol method, which is based on the reduction of Ag ions in a polyalcohol. Thermoluminescent (TL) characteristics as sensibility, linearity, reproducibility, energy dependence, minimum detectable dose, fading and kinetics order were evaluated. The composites showed TL emission glow curves with a single peak centered around 200°C. The new routes for the preparation of dosimeters have shown to be viable. The dosimeter based on calcium sulfate doped with europium and silver nanoparticles ($CaSO_4$:Eu,Ag(NP)) provides the most intense TL emission between the preparations studied, with high sensibility, low detection limit and an acceptable fading, being this TL linear, reproducible, and first order kinetics.

Methods of sterilization extremity rings and eye lens thermoluminescent dosemeters

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Medical personnel are exposed to different dangerous factors. One of the risks associated with the conditions of their work can be the ionizing radiation. According to statistics personnel in interventional radiology and nuclear medicine received the highest dose of all medical staff. [1]

The main task of medical centers is to preserve appropriate hygiene standards particularly in operating blocks. According to this all medical equipment has to be sterilized. Dosemeter worn by medical personnel has to be sterilized, too. There are exist many different methods of sterilization, however not all of them are suitable for sterilization of the most commonly used dosemeters.

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Energy absorption-buildup factors, exposure-buildup factors and Kerma for optically stimulated luminiscence materials...

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Optically stimulated luminescence (OSL) materials are found better sensitive dosimeter materials giving an accurate measurement of low ionizing radiation. This low dose measurement with improved sensitivity makes these dosimeters very useful for diagnostic imaging, personnel monitoring and environmental radiation dosimetry. Gamma ray energy-absorption buildup factors and exposure build factors were computed using the five-parameter geometric progression (G-P) fitting formula in the energy range 0.015–15 MeV, and for penetration depths up to 40 mfp (mean free path). The generated energy-absorption buildup factor and exposure-buildup factor data have been studied as a function of penetration depth and incident photon energy. Kerma, mass attenuation coefficients and effective atomic numbers have been computed and tissue equivalence of OSL materials is discussed in detail by comparing with ICRU tissues standard. Buildup factors determined in the present work should be useful in radiation dosimetry, medical diagnostics and therapy, space dosimetry, retrospective dosimetry, accident dosimetry and personnel monitoring.

Occupational exposure in coronary angiography procedures

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Interventional cardiology is the specialized branch of cardiology that treats coronary artery diseases with cardiac catheterization therapies that unblock clogged arteries which supply blood to the heart and stop attacks and relieve angina. The number of interventional cardiology procedures has increased rapidly because of many benefits, but on the other hand, it is also known that these procedures are associated with high radiation doses due to long fluoroscopy time, and large numbers of cineradiography frames. These levels of radiation may even lead to skin injuries under certain conditions.

The objectives of this study were to evaluate the level of radiation dose received by the patients in order to estimate local diagnostic reference level, provide staff dose measurement during cardiologic procedures and estimate the related radiation risks.

Measurements were taken from 86 cardiac catheterization procedures in 3 hospitals ; the medical staff was monitored using thermoluminsence dosimeter (TLD) chips. The radiation doses were measured for the cardiologist at five locations as forehead, thyroid, chest(over the lead apron), waist (over the lead apron) and hand, while the exposure to the assistant was measured at two locations, chest (over the lead apron) and hand.

The mean dose area product (DAP) to patient for diagnostic and therapeutic procedures was 2813.6 μGy $\cdot$ m^2 and the mean fluoroscopic time was 4.788 min. The mean radiation dose for cardiologist from the diagnostic and therapeutic procedures were 0.9 mGy for the forehead, 0.92 mGy for the thyroid, 1.38 mGy for the chest, 1.28 mGy and 1.41 mGy for the waist and for the hand. The total effective dose was 0.07 mSv while the mean radiation doses for assistant, from the diagnostic and therapeutic procedures were 0.72 mGy for the chest, 0.82 mGy for the hand and the total effective dose was 0.04 mSv.

The radiation dose values are comparable with recent literature. Radiation dose is not monitored for the workers in the hospital. Reduction of patient and staff doses is a prime importance and practitioners should optimize the radiation dose for further dose reduction without compromising the diagnostic and therapeutic finding.

Occupational radiation doses in interventional radiology in Poland

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Laboratory of Individual and Environment Dosimetry (LADIS) was formally established at the Institute of Nuclear Physics in 2002 and got accreditation according to EN-PN-ISO/IEC 17025 standards. Now it is the biggest dosimetry service in Poland and one of the largest in Europe. Dosimetric service applies thermoluminescence detectors to individual monitoring in photon radiation fields for ca. 5700 institutions and more then 42000 workers over the whole Poland.

The rapid development of X-ray imaging technology has contributed to the growth of interventional radiology in recent years. Interventional procedures require the physician and assisting personnel to remain close to the radiation sources thus, it is important to ensure that, the annual dose limits are not exceeded. Radiation protection for staff is one of the main issues in Interventional Radiology. A typical personal dosimeter provides two values, Hp(0.07) and Hp(10). These represent the dose equivalent in soft tissue at 0.07 mm and 10 mm below the surface of the body, respectively, at the location of the dosimeter. But the attention devoted in recent years to eye lens dose assessment in interventional radiology was increased due to evidence that cataracts can be induced by ionizing radiation at dose levels lower than previously expected. ICRP itself, in recent recommendations proposed new annual limit of 20mSv for eye lens (presently 150mSv). The studies carried out among the Chernobyl survivors show that cataracts may appear after doses 0.5 Gy and these are the doses interventionists are likely to receive after several years' work. For this reasons, additional value Hp(3) should be measured. Since February 2012 LADIS has provided routine measurement of eye lens doses as a first dosimetric service in Europe.

The paper presents results of statistical evaluation of Hp(10), Hp(0.07) and Hp(3) measurements performed in interventional radiology in years 2010-2012. Interventional procedures are used by a significant number of medical specialties. The results showed that 83% of Hp(10) and 32% of Hp(3) measurements were below 0,1 mSv/quarter, 87% of Hp(0.07) were below 1mSv/quarter which means that there was no occupational exposure. The remaining part of Hp(10), Hp(3) and Hp(0.07) was above 0,1 mSv/quarter and 1 mSv/quarter respectively with cases reaching even several hundreds of mSv/quarter. The cases exceeding the recommended annual limit for whole body (20mSv), skin (150mSv) and new recommended annual limit for eye lens (20mSv) and it will also be discussed in this paper.

Properties of lithium aluminate for application as OSL dosimeter

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Passive dosimetry is one of the most widely used methods in personal and environmental dosimetry. Passive dosimeters are characterized by high sensitivity, small size and ability to register the absorbed dose accumulated in the detector over extended periods of time. Moreover they show resistance to environmental factors such as electromagnetic or mechanical interferences. Two main techniques used in passive dosimetry are thermoluminescence (TL) and more recently optically stimulated luminescence (OSL). OSL method is becoming increasingly popular due to its optical nature of readout, avoiding increased temperature. Although there are many materials showing OSL properties, only two of them, $Al_2O_3 : C$ and BeO, found a way to practical applications and there is still a need for search of new materials and methods based on OSL technique. One of the materials proposed for use as an OSL dosimeter is lithium aluminate ($LiAlO_2$).

Lithium aluminate has lower effective atomic number (10.7) than aluminum oxide (11.3), what results in better photon energy dependence. Moreover presence of Li-6 enables application in neutron dosimetry. Lee et al. (2012) have recently shown that lithium aluminate exhibits higher OSL sensitivity than $Al_2O_3 : C$ under blue LED stimulation and linear dose response characteristic.

The purpose of this study was further research on OSL properties of different samples of lithium aluminate in terms of its application in personal dosimetry. Investigated samples prepared at INP in Cracow were exposed with alpha (Am-241) and beta (Sr-90/Y-90) particles. A Risø TL/OSL reader model DA20 with Hoya U-340 filter was used for the experiments. The OSL response was measured using three modes: continues wave OSL (CW-OSL), linear modulation OSL (LM-OSL) and pulsed OSL (POSL). The measurements were performed in comparison to standard OSL materials: $Al_2O_3 : C$ and BeO. Preliminary results confirmed high OSL sensitivity of lithium aluminate.

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WBC-monitoring of Ukrainian population after ChNPP accident

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Created in the period from 1987 to the nowadays in Ukraine informational and methodical, metrological and instrumental system which rests upon designed conception has been scientifically substantiated and works in practice. The system provides modern monitoring of population at sufficient amount of measurements by direct methods in the case of radiation accident. The scientific and methodical WBC (Whole Body Counter) products (including software, hardware) designed for the program "Dosimetry passportization of settlement of Ukraine" is supported. This is the base for unique system of personal dosimetry of Ukrainian population.

The unique in Ukraine multitask mobile lab for radiation dosimetry needs has been designed and realized. It includes highly sensitive WBC (160 Bq per body for ^{137}Cs) and equipment that gives possibility to carry out comprehensive mass dosimetric inspection (up to 400 persons per day) in places the patient lives.

Created in 1996 unique in Ukraine expert WBC gives a possibility to carry out diversified researches with high precision at new qualitative level. In vivo measurement and determination of ultra low levels of ^{137}Cs (10-15 Bq per body), ^{60}Co, ^{40}K and others radionuclides has become possible. WBC measurements to make examination and metrology in the case of incorporation of mixture alpha-, beta-, gamma- emitting radionuclides, in vivo detection of "hot particles" and others abnormal radionuclides intake, an advanced studying of metabolism behavior also has become possible.

About 600000 WBC-measurements of inhabitants from contaminated regions in Ukraine were carried out during 26 years. Taking into account the uniqueness of ChNPP accident consequences the population internal irradiation doses analyze made possible studying dose forming regularities, that depend on radiation, occupation, season factors, age- and sex-related, social, economical, psychological, preventive and others factors. It made possible to reveal population critical groups, to get a realistic picture of population irradiation covering the whole post-accidental period and to determine it's peculiarities and abnormalities.

Irradiator prototype for research with electron beam from ^{90}Sr + ^{90}Y

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The betatherapy is a type of brachytherapy which uses ^{90}Sr +^{90} Y sources. This therapy uses β particles for prevention and treatment of ophthalmological and dermatological diseases. In this case the dose is deposited directly on tumoral region by applicators flat and concave. Although this therapy reduces diseases recurrence, several late complications have been reported, making these types of sources unused in clinical practice. Thus, many Brazilian hospitals do not longer use this kind source of source, but still remains with them in their facilities, which constitutes a radiation protection problem, considering that half life of ^{90}Sr is approximately 28 years. On the other hand the assembly of a radiator system suitable for accommodating these sources, that presenting safe conditions of handling and high reproducibility in exposure of samples could provide functionality to these applicators, allowing research institutions that develop new types of dosimeters minimize the costs associated with the acquisition of commercial irradiators. In this way, this paper proposes a model of technical preparation, adaptation and evaluation of safety conditions of an irradiator composed of dermatological and ophthalmic ^{90}Sr +^{90} Y applicators. The model uses OSL, TL dosimeters, radiochromic film EBT-3 and transport code MCNPX 2.7. The irradiator was mounted in an acrylic box with rectangular dimensions of $250 \times 300 \times 150$ mm and thickness of 15 mm. We used three sources, two concave and one flat, which were positioned at the center and at the upper end of rectangular prisms also made of acrylic, coated externally with a lead layer of 2 mm thickness. To obtain dose distribution on the surface of the sample holder it was used the radiochromic film EBT-3. These films has allowed to centering the cavity in the region of highest uniformity of dosage. $CaSO_4$:Eu,Ag thermoluminescent dosimeters produced in our laboratory were used to verify the reproducibility of the measurements. For validation of safety conditions it was used MCNPX 2.7 Monte Carlo code and NanoDots OSL dosimeters of Landauer Inc.The placement of the applicators in the interior of the prisms allows samples of up to 3 mm thickness can be irradiated with a source surface distance ranging from 1–3 mm. The model employed demonstrates that the irradiator presents secure conditions for the users, and excellent reproducibility in the irradiation samples.

Synthesis, characterization and investigation of thermoluminescence properties of strontium pyrophosphate

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Strontium pyrophosphate, $Sr_2P_2O_7$, was synthesized by solid-state synthesis method, the reactants strontium carbonate and ammonium dihydrogen phosphate heated at 900°C for 14.5 hours. The product was doped with copper-silver, copper-indium and manganese-praseodymium ions by solid-state reaction. In addition to these processes, characterization and the investigation of thermoluminescence (TLD) properties of strontium pyrophosphate with and without dopants were conducted. For the characterization of strontium pyrophosphate, samples with and without dopants; powder X-ray Diffraction (XRD) were implemented. Fourier Transform Infrared Spectroscopy (FTIR) was used to determine whether the bond structures were affected from the doping or not. Thermal properties of samples were investigated with the help of Differential Thermal Analysis (DTA). Morphology of compounds was observed by Scanning Electron Microscope (SEM). Thermoluminescence (TLD) studies were carried out. The main aim in this study was to specify the effect of metal oxide content on the TL response of strontium pyrophosphate and the effect of different metal dopant combinations on the thermoluminescence response. According to the X-ray diffraction pattern, the production of strontium pyrophosphate was successful. FTIR results proved the presence of pyrophosphate within the structure; and records indicated that the addition of activators; Cu, In, Ag, Mn and Pr caused no noticeable change in vibrational modes which means that the anionic part of matrix compound that is strontium pyrophosphate had structural stability. The results of DTA analysis showed that the compounds were thermally stable. By SEM the morphologies of the doped and undoped strontium pyrophosphate showed that the particle size distributions were not homogeneous and particles had smooth surfaces. Thermoluminescence analyses were conducted on strontium pyrophosphate doped with different amounts of dopants. Glow curves showed that intensities were affected by different amounts of dopants. It can be concluded from the thermoluminescence analysis that strontium pyrophosphate doped with 7% MnO and 1% Pr_6O_{11} had the most powerful peak intensity around 160°C.

Energy response improvement for Photon dosimetry using pulse analysis

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During the last few years, active (real time) personal dosemeters have been developed and were replaced passive personal dosemeters in the some positions. Silicon diodes as detectors are frequently used in the active dosemeters. Silicon diodes are sensitive to photon radiation and for proper dosimetry behavior an energy compensating contacted on the front surfaces of them. In this paper for energy compensating a software process was presented. Selective data sampling based on pulse height was used for measuring of photon doe equivalent. The method has been applied to improve the photon energy response of dosimetry. Incident photons interact with the diode's material produce electrons that can deposit energy in the detector. Special detector design optimized for the response function and determination of the photon dose equivalent. Photon dose equivalent is determined in the energy range 0.1–6 MeV and dose range 10 nSv–10 Sv. In the standard radiation field, a good agreement has been seen.

Fast neutron dosimetry methods based on the personnel active dosimeters

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Semiconductor detectors based on silicon pin diode are frequently used in the detection of different nuclear radiations. For the detection and dosimetry of fast neutrons, these silicon pin diodes are coupled with a neutron converter. Incident neutrons interact with the converter and produce charged particles that can deposit energy in the semiconductor and cause a signal. The present work deals with fast neutron dosimetry based on diode detectors. Three methods were introduced for fast neutron dosimetry, proton spectroscopy, Similarity of response function with conversion function and using of discriminator layer. Dosimetry responses of these methods were determined and compared. Monte Carlo simulations were used for determination of optimum thickness of layers and response of dosimetry methods. In the ^{241}Am-Be neutron source radiation, the comparable response of methods have been seen.

Ambient doserate evaluations in the treatment room of an Elekta Precise accelerator used for radiation therapy

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In radiation therapy commercially available medical linear accelerators (linacs) are used. Heading towards higher primary beam energies, the leakage dose of the accelerator head and the backscatter from the walls, the air and the patient becomes more and more important. Therefore, measurements of photon doserates in the accelerator room and in the maze are performed to quantify the radiation field inside the simulated therapy room of the PTB facility. Since the radiation of the linacs is usually pulsed with short radiation pulse durations in the μs range, secondary standard ionisation chambers are used for evaluation. Electronic dose(rate)meters, which use pulse counting techniques for generating the dose(rate) value from the detector signals, are known to have severe deficiencies in these radiation fields. Therefore different types of electronic dosemeters are used for testing and comparison at selected positions only. The doserates are evaluated for different simulated treatment situations and at selected positions in the accelerator room and in the maze of the PTB facility. The measured time-averaged doserate ranges from a few μSv/h in the maze to some mSv/h in the vicinity of the accelerator head and up to some Sv/h behind the closed shutter in the direction of the primary beam.

Monte Carlo simulations of radiological and nuclear terrorist threat scenarios: preliminary results of REWARD project

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The Real Time Wide Area Radiation Surveillance System project (REWARD) is a collaboration project funded in the framework of the 7th Framework Programme Security of the European Union. It aims at the development of a portable detection system that is able to detect and locate in real time the radiation coming from concealed radioactive sources or nuclear materials presumably used in radiological and nuclear (RN) threat scenarios involving Radioactive Dispersal Devices (RDD) and Improvised Nuclear Devices (IND). The detection system consists of a CZT detector for gamma radiation and a high efficiency silicon neutron detector. The task of the REWARD working package 1 (WP1) is to characterize the reference scenarios associated with RN threats, so the required capabilities of the radiation detectors may be established and subsequently tested and validated.

In order to have a realistic estimation of the radiation levels that can be detected by the detection system, Monte Carlo (MC) simulations were performed. The MC radiation transport programs MCNPX 2.7 and FLUKA were used to simulate the radiological emission, resulting from the potential use of RDDs and INDs.

To simulate the RDD, a source of ^{137}Cs, similar to the one involved in the radiological accident in Goiânia, was used as gamma emitter. Since most of the radioactive sources are sealed, a container was implemented, whose shielding material was varied, to evaluate the effect on the external gamma emission due to attenuation. The flux of particles that reaches the CZT detector was calculated at different distances, from the center of the radioactive source. Concerning the IND, the radiological signatures of two crude devices, with material compositions previously published in open literature, were modeled and simulated: one with a uranium core and other with a plutonium core, using tungsten or depleted uranium as tamper.

For the IND, the results of the gamma and neutron fluxes calculated in the devices' surface using both MCNPX 2.7 and FLUKA are discussed and compared with the results obtained in previous works. The results show the emerging neutron and gamma flux from the IND´s surface is dependent on the choice of the core and

tamper material. For the RDD, the results obtained revealed the gamma fluxes are dependent on the characteristics of the radioactive source used as well as the material and thickness of the shielding.

An overview of the REWARD project, its scope and objectives will also be provided.

Accidental Neutron Dosimetry with Human Hair

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Human hair contains sulphur, which can be activated by fast neutrons. The $^{32}S(n,p)^{32}P$ reaction with a threshold of 2.5 MeV was used for fast neutron dose estimation. It is a very important parameter for individual dose reconstruction with regards to the heterogeneity of the neutron transfer to the human body. Samples of human hair were irradiated in a radial channel of a training reactor VR-1. ^{32}P activity in hair was measured both, directly by means of a proportional counter, and as ash dispersed in a liquid scintillator. Based on neutron spectrum estimation, a relationship between the neutron dose and induced activity was derived. Even if the hair activation method was proposed several years ago, it is not an ordinary practice. The main purpose of the experiment was to get practical experiences and verify the proposed method in practice.

Application of pulsed optically stimulated luminescence from surface soil to retrospective dosimetry

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Optically stimulated luminescence (OSL) from natural quartz and feldspar has been used in retrospective dosimetry, dating of sediment and etc. However, in the application target mineral should be extracted with chemical separation which is robust work. The pretreatment is difficult to purify the mineral completely, depended on the sample. Now a days, pulsed optically stimulated luminescence (P-OSL) was developed to separate luminescence signal from between quartz and feldspar as instrumental separation (C. Ankjærgaard et al., 2010). The luminescence signals from quartz and feldspar have different luminescence lifetimes under the P-OSL. This difference in lifetime can be used to discriminate between the two signals from a mixed quartz-feldspar sample. The purpose of this study tried to apply the P-OSL to Japanese surface soil as retrospective dosimetry with easy physical separation. In this study, P-OSL instrument was developed originally. Performance of the instrument was tested using natural quartz extracted from Japanese surface soil and feldspar in mineral specimens. The signal was integrated for 10 μs after the LEDs were switched off until just before the LEDs were switched on again, with the pulse on-time of 1-40 μs and the pulse off-time of 200-800 μs. It was found that the signal from the feldspar decayed for 2-3 μs and the signal from the quartz was measured over 50 μs after the switch-off of the LED. By using mixture of the quartz and feldspar, the P-OSL protocol was improved to determine irradiation dose. Following irradiation using X-rays, dose recovery test was conducted and then was successful to reconstruct irradiated dose by the P-OSL protocol with the pulse on-time of 4 μs and the pulse off-time of 400 μs. From these results, it was concluded that P-OSL dosimetry is suitable for accident evaluation although further research is required to improve the protocol using actual Japanese surface soil.

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Relationship between effective dose and tooth dose assessed by the electron paramagnetic resonance (EPR) method

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Electron paramagnetic resonance, EPR, method is a dose reconstruction method of measuring free radicals induced by radiation exposure to the calcified tissue (mainly in the tooth enamel or bone) to evaluate the accepted high dose. The purpose of this research is to estimate the relationship between the tooth enamel dose assessed by EPR method and the whole body effective dose assessed by thermoluminescent dosimeter, TLD, method. A Rando phantom which put the tooth enamel samples and TLD-700 LiF chips inside were used. The whole body irradiations were performed by the 6 MV photon beam of a medical linear accelerator (ELEKTA Synergy Platform). The number of 62 purified teeth enamel were collected and used in this work. To assess the tooth doses using EPR method, the EPR signal-to-dose transformation curve was estimated by irradiating different doses from 1 to 20 Gy to the enamel samples. Besides, the tooth doses were also estimated by TLD chips placed at the positions of teeth in the phantom. The TLD-700 chips were put in the radiation sensitive organs recommended by the International Commission on Radiation Protection, ICRP (ICRP-60 and ICRP-103), to measure the absorbed doses and equivalent doses of the sensitive organs. Effective dose was assessed by means of the summation of the multiplications of equivalent dose and tissue weighting factor for each organ. Five whole body irradiation cases including the irradiations from front, rear, left lateral, right lateral and uniform (all 4 directions) were considered. In the case of uniform irradiation, as a 5.35 mGy (assessed by EPR method) absorbed dose was delivered to the tooth; whole body effective dose were 6.04 mSv (ICRP-60) and 6.12 mSv (ICRP-103). The conversion factor of tooth dose assessed by EPR method to effective dose considering ICRP-60 and ICRP-103 were 1.13 and 1.14 (Sv/Gy), respectively. By means of the conversion factors derived from this work, effective dose of people who exposed by photon radiation in high dose, whole body irradiation, accident could be assessed easily.

Investigation of TL properties of mobile phone screen glasses as dosimeters for accidental dosimetry

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Along with the civilization changes there is a growing awareness of risks due to the effects of improper use of radioactive sources. Retrospective and accidental dosimetry are the developing areas due to the need of radiological safety assurance of society and estimation of the potential doses in the case of radiation incident. Electronic components or glasses of portable electronic devices such as mobile phones and portable media player, which are usually placed near the human body, could be considered as a potential personal dosimeter. Especially the glass of a mobile phone or media player, which are nowadays the most popular subjects of personal use, are the interesting objects of research in view of their luminescent properties. It is well known that special kinds of glasses are exploited as radiophotoluminescent (RPL) detectors after their stimulation with UV light. Besides this, the irradiated glasses show also thermoluminescent (TL) signal during heating. The aim of this work was to investigate the TL properties of glass samples coming from different kinds of mobile phone screens in regard to their use as emergency dosimeters.

The glass samples of mobile phone screens coming from different producers, having the square shape and dimension of about 4×4 mm^2, were irradiated in different radiation fields and readout in an automated Risoe TL/OSL reader. The influence of the samples preparation, bleaching with a blue light to simulate the real condition of the mobile phone usage and the readout conditions were checked and optimized. The measurement of the emission spectrum of irradiated glass samples during heating was performed to select the most appropriate optical filters. The dose response of different kinds of glass samples was studied to define their sensitivity and linearity.

Preliminary results showed that the glass samples coming from mobile phones present TL signal sufficient for the estimation of the dose at the level of some dozens of mGy. Mobile phone screen glasses as dosimeters for accidental dosimetry are supposed to be very promising alternative for electronic components of portable electronic devices.

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Dose characteristics in fuel containing material

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Fuel containing material, also called corium, arise during severe nuclear reactor accident by melting of a reactor core and surrounding material. It consists of nuclear fuel, fission products, activation products and materials from control rods, fuel cladding, concrete etc.

The paper deals with dose characteristics inside the spent fuel containing material after transition of the molten mixture to solid state. Absorbed dose in a corium is estimated for different types of radiation. Main part of the dose is from gamma and beta radiation. Contributions of alpha radiation, neutrons and fission fragments are also estimated. Dose rate in a corium decreases during the time, therefore time dependences for radiation components are given. For the dose values estimation, computation code ORIGEN 2.2 with dosimetric library ENDF/B-IV were used.

Estimated absorbed dose characteristics can be used for evaluation of radiation damage and temperature behaviour of fuel containing material. The dose values can be also used for radiation test design of corium simulating materials. Parameters of possible radiation tests are shortly discussed.

High activity dosimetry in hot-cells, semi-hot cells and related facilities in ÚJV Řež

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The aim of the presentation is to introduce the team of dosimetric control in workplaces hot and semi-hot cells and related technologies managing radioactive waste in the Nuclear Research Institute Řež, department high-activity laboratory and irradiation experiments.

Main facility consists of 21 hot, 29 semi-hot cells, complex of alpha boxes and Harwell's laboratories. Hot cells are used for preparatory and auxiliary operations with irradiated materials, e.g. receiving of irradiated materials, unloading of containers and evaluation of detectors to determine the neutron fluence, irradiation temperature and main dosimetric quantities.

Our hot cells are authorized to dispose of activity up to 4,000 TBq. Our primary task is to ensure minimal of external and internal exposure of our employees using all the principles of radiation protection. Introduce selected techniques and equipment that we used to achieve this goal is the subject of this presentation.

In our facilities are dealt with variety radionuclides from transuranic, over activations products from active zone of reactor pressure vessel to nuclides used in radiopharmacy. Main objective of dosimetric control is to identify type of radionuclide and its activity no matter if it's solid, aerosol or liquid. For direct measuring we dispose of HPGe gamma spectrometer with collimator integrated into the wall of hot cell. With this device we are able to estimate specific activity of samples from 1kBq up to ^{1}Tbq per sample.

Group of dosimetry of Division of Integrity and Technical Engineering are dealing with variety tasks such as radiation protection of workers, releasing materials to the environment, designing of shielding, containers designated for long-term deposition, transportation containers or decontamination works. In this presentation we would like to introduce you the most interesting problems we are dealing with.

Comparison of commercial thermoluminescent readers for high-dose high-temperature measurements

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Typical TLD readers realize the TL signal measurements in the temperature range up to 400°C, what is sufficient for all applications in personal and environmental dosimetry. The recently developed method of ultra-high doses measurements, in kGy range [Obryk, 2011], requires an extended temperature range. Nowadays, there are several commercially available TLD readers allowing to measure TL signal up to temperature of 600°C or even higher. However, performance of these readers at the highest working temperatures has not been studied before. The aim of this work was to compare three different TLD measurement systems with respect to high-dose and high-temperature measurements. Studies were realized using the RA'94, Harshaw 3500 and Riso TL/OSL-DA-20 TLD readers and LiF:Mg,Cu,P (MCP) TL detectors. All the readers are able to measure TL signal up to temperature of 600°C or even 700°C, in case of the Riso reader. The temperature profiles and effects of different spectral sensitivity, as well as linearity of dose characteristics of the readers were investigated. It was found that the Harshaw 3500 can be used without any additional light attenuation for measurements of MCP detectors exposed to doses up to 10 Gy. For two other readers, the upper dose limit is about 10 times lower. It also seems that the Harshaw 3500 shows the best thermal stability considering the peak maximum position. At the high-doses the differences in the spectral characteristics of the applied optical filters and photomultipliers, in conjunction with an evolution of the MCP TL emission spectrum with dose, significantly influence the shape of TL glow-curves measured with the Riso reader. The detailed characteristic of the compared readers at high-dose, high-temperature ranges will be presented in the paper.

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TL and OSL Response of β-spodumene synthesized by desvitrification method

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The spodumene ($LiAlSi_2O_6$) is a natural silicate that has thermoluminescent properties exploited in the applications of dating and dosimetry of ionizing radiation. Depending on temperature and pressure, it has been observed in either C2/c (α-spodumene) or P21/c (β-spodumene) symmetries. Objective of this work is to synthetize a β-spodumene by a desvitrification method and to evaluate its OSL and TL response to be used as a gamma radiation dosimeter. Samples were prepared from a mixture of chemically pure materials: 57.75% SiO_2, 24.50% Al_2O_3 and 17.75% of Li_2CO_3.This mixture has been melted and cooled slowly to obtain an undoped polycrystal. On the other hand, samples of β-spodumene were also produced with dopants, Mn (0,5 wt%), and B (0,5 wt %). The samples produced were crushed in a mortar with the aid of a pestle, both of agate, and were sieved to select grains between 0.180 mm (100 mesh) and 0.075 mm (200 mesh). The grains were selected and mixed with PTFE (polytetrafluoroethylene) powder in a ratio of 1:2, β-spodumene and PTFE respectively. The mixture was homogenized and pressed at 1 ton to obtain pellets with 6 mm in diameter, 0.2 mm in thickness and mass of 20 mg. Next, they were sintered at 300°C/30 min and 400°C for 1.5 h in an EDG-1800 oven. For sample characterizations, X-ray diffraction (XRD) and scanning electron microscopy (SEM) measurements were performed. The pellets were irradiated with 50 Gy of gamma radiation of ^{60}Co and the TL glow curves were measured using a Harshaw 3500 reader. The main TL peak was centered at 130°C, 120°C and 180°C for the samples of pure β- spodumene, β-spodumene:B and β-spodumene:Mn, respectively. To study the OSL response the samples were irradiated with 1 kGy and the response was obtained in the continuous stimulation mode during 40000 ms utilizing blue LEDs for the stimulation. The results indicate that the spodumene OSL decay curve is composed of a fast component and a slow component for the three types of samples evaluated. Preliminary results indicate that the synthetic samples doped with manganese has TL peak prominent more stable than the observed for pure β-spodumene or for β-spodumene:B. The luminescence signals show the feasibility of the artificial β-spodumene to be exploited for high doses radiation dosimetry.

Evaluation of radiation-hard Magnetic Czochralski (MCz) Silicon Diodes in Electron Processing Dosimetry

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A dosimetry system using radiation hard Magnetic Czochralski (MCz) silicon diodes has been designed for measurement of high absorbed doses (10 kGy to 2 MGy) and dose rates up to 8 kGy/s in electron processing field. These $p^+ - n - n^+$ junction devices were processed on high resistivity n-type bulk material of 300 μm thickness with junction of 0.36 cm^2 active area by the Microelectronics Center of Helsinki University of Technology in the framework of the CERN RD50 Collaboration. With the diodes unbiased, the dosimetric characterization was performed in the direct current mode by connecting its frontal layer (p) to the input of a Keithley® ^{6517}B electrometer, while grounding its back side (n). The irradiations were carried out in the Radiation Technology Center at IPEN-CNEN/SP with 1.5 MeV electron beam from a DC 1500/25/4 – JOB 188 Accelerator with a dose rate of 4 kGy/s. The current response of the diodes was measured as a function of the irradiation time in steps of 7.12 kGy to achieve an absorbed dose of 2.25 MGy. The results showed a fast and significant current decrease for doses up to 250 kGy, followed by a very small decay even for high doses about 2 MGy. To mitigate this sensitivity loss, the diodes were pre-irradiated with 250 kGy and after this procedure, despite of being less sensitive, the current signals were more stable with coefficient of variation (CV) of 3.1% . This CV value added the accelerator instabilities which are covered up in static dosimeters such as cellulose triacetate (CV≈3.0%) and PMMA (CV≈5%) dosimeters, routinely applied in radiation processing. The dose-response curve of the diodes, given by the charge (integration of the current signal versus time) as a function of the dose, were fitted by a second order polynomial function with correlation coefficient higher than 0.99. To monitor possible electron radiation damage effects produced on the diodes, their dynamic leakage currents were also measured as a function of the absorbed dose. For comparison, the dosimetric response of a standard Float Zone (FZ) diode was investigated at the same experimental conditions. So far, the results evidenced that the MCz diode is substantially more tolerant to radiation hardness than the FZ device, despite of both diodes exhibited high sensitivity and good repeatability. This indicates the potential use of MCz diodes in high dose online radiation processing dosimetry. The reproducibility and radiation damage studies are under way.

Production and characterization of spodumene dosimetric pellets by new routes of preparation

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The safe application of ionizing radiation in many areas requires the use of radiation detectors capable of detecting its presence or quantify it. Thermoluminescent (TL) crystals are extensively used as passive dosimeters. However, hardly a material exhibits all the desired characteristics in a unique dosimeter to ensure the safe use of ionizing radiation. In the search for new materials some most striking features such as high sensitivity, linear response to dose, temperature and wavelength of the emission should be the focus of the research. Spodumene is an aluminosilicate that has shown good results for high-dose TL dosimetry for beta or gamma rays. Due to its chemical composition ($LiAlSi_2O_6$) it is one of the main sources of Li, and has potential as neutron dosimeter as well. The synthetic spodumene has been produced by solid state reaction and conventional sol-gel, whose difficulty arises from the need to employ high temperatures and high cost reagents, respectively. New ways of preparing materials have been studied over the last decades, in order to reduce production costs, environmental impact and also manufacturing several devices, such as radiation dosimeters. Proteic sol-gel and Pechini methods are promising, because they can reduce production costs and the possibility of environmental contamination, in comparison with the conventional sol-gel route. In the proteic sol-gel, a proteic precursor is used as an alternative to alkoxide of the conventional sol-gel method. The Pechini method is based on formation of a polymer chain through chelation and polyesterification reactions, containing the metal ions uniformly distributed. This work aimed to produce the spodumene through these alternative routes: proteic sol-gel (using edible unflavored gelatin) and Pechini method; and characterize the products physically and morphologically, aiming also to investigate its applicability as TL dosimeter. We produced two sets of samples in both methods, one with TEOS ($Si(OC_3H_5)_4$) and one with silica (SiO_2). The materials produced were characterized by X-ray diffraction (XRD), differential thermal analysis (DTA) and thermogravimetry (TGA) in order to evaluate the structural properties, as well as possible changes in physical or chemical properties depending on the temperature. The production of spodumene was successful for both methods, generating crystals in the β-phase with tetragonal structure. Syntherized pellets produced with these crystals were irradiated with beta rays from a $^{90}Sr - ^{90}Y$ source and its TL glow curves were evaluated. Although the samples prepared by proteic sol-gel method with TEOS presented a lower forming temperature, the samples produced with silica showed higher sensitivity to radiation, being those produced by the Pechini method the most sensitive to radiation.

Thermoluminescent Dosimetric Comparison for two different production routes of MgB_4O_7:Dy

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Thermoluminescent (TL) dosimeters are use as passive dosimeters in a wide range of radiation detection. There are a many materials that can be used as TL dosimeter (LiF; $CaSO_4$; LiB_4O_7), but for personal dosimetry, the material needs to be tissue equivalent and have a great sensibility. Magnesium borate is a material that has both characteristics, is about 10 times more sensible than LiF and has an effective atomic number for photoelectric absorption equal to 8.4 compared with 7.4 for water and soft biological tissue. There are several routes employed for the production of synthetic magnesium tetraborate, for example, sol-gel method, combustion synthesis, solid state route and precipitation (crystal growth). The most commonly used synthesis route are the wet reaction using acid (crystal growth) and solid state synthesis, both production routes are efficient, but is very difficult to find a direct comparison for these routes. The present work proposes a direct comparison of both production routes used for magnesium tetraborate synthesis for dosimetry. In this work MgB_4O_7:Dy, were prepared by both routes (Solid state reaction and crystal growth) with the same amount of dopant (0,1%). The starting solid reagents used, in stequiometric ratio, for route 1 (solid state reaction) were: boric acid, magnesium oxide and dysprosium oxide. The starting reagents used for the route 2 (crystal growth), were: Boric acid, magnesium oxide , nitric acid and dysprosium oxide. In the first part of work, the crystalline phases were confirmed by X-ray diffraction (XRD) and was observed that MgB_4O_7:Dy can be obtained satisfactorily, through both routes. At the second part of work, the TL response of pellets produced from powder of both routes were irradiated with ^{60}Co and the TL curves were plotted. The calibration curves were plotted for a dose range between 10 and 100 Gy and the responses were compared with the commonly used dosimeter, TLD-100. Trough X ray diffraction is observed that both methodologies are efficient and confirmed the formation of phase compound, with a excess of acid in the route 2. But solid state synthesis is more viable then the wet reaction, the first one does not require the use of nitric acid to drive the reaction thereby reducing the procedure cost. The materials presents a very good linear range of the TL response as a function of the absorbed (10–100 Gy), as it was expected.

Follow up of the natural radiation exposure from gamma rays in the city of Sao Paulo, Brazil

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The main objective of this study is to follow up the effective doses received by the general population from the natural radioactivity in the city of São Paulo, Brazil, since 2007, over a period of 05 years, as, apart from the variation from place to place, the background gamma levels in air are not constant in time. Twelve monitoring stations were selected, covering an extensive area of the city, considering not so places frequented daily by people with emphasis in the most populated districts but also the absence of influences from man-made ionizing radiation sources and safely recessed places. Thermoluminescense dosimetry was used to carry out the direct measurements of the environmental gamma radiation levels and the data were drawn after every 3-month exposure. The average annual effective dose in the city of São Paulo, found as 1.3 ± 0.1 mSv, is higher than the 0.9 mSv/y^{-1} value, estimated by UNSCEAR 2000 as the world average contribution from terrestrial and cosmic gamma rays. The result is below the annual global *per caput* effective dose due to natural radiation sources of 2.4 mSv and within the annual effective doses range of 1 to 3 mSv, expected to be received by 65% of major population.

Measurements of indoor Rn-222 activity in dwellings and workplaces of Curitiba (Brazil)

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Present work describes principal results of systematic measurements of radon in air, soil gas and water in residential environments and workplaces at the Metropolitan Region of Curitiba (Paraná St., Brazil) during the period 2004–2012. The monitoring was performed by the Laboratory of Applied Nuclear Physics of the Federal University of Technology – Paraná (UTFPR) in collaboration with the National Nuclear Energy Commission (CNEN). For radon in air activity measurements, it was used polycarbonate etched track detectors CR-39 mounted in diffusion chambers protected by Borosilicate Glass Fiber Filter. After the exposition in air, the detectors CR-39 were submitted to a chemical etching in a 6.25 M NaOH solution at 70° C during 14 hours. The alpha particle tracks were identified and counted manually using an optical microscope and using the results of previously performed calibration the indoor activity concentration of ^{222}Rn was calculated. The calibration of CR-39 together with efficiency of used exhalation chambers as well as alpha particle tracks chemical development procedure were performed in collaboration the National Institute of Radiological Sciences (NIRS, Japan). The major part of indoor ^{222}Rn concentration in residences was found below 100 Bq/m^3. In the case of working places, all measurements present ^{222}Rn concentration bellow 100 Bq/m^3. These values are considered within the limits set by international regulatory agencies as EPA and ICRP, adopting as normal concentration levels up to 200 Bq/m^3 and 148 Bq/m^3, respectively. The authors want to thank the agencies CNEN, CAPES, CNPq and Fundacao Araucaria for financial support.

Measurements of Rn-222 activity in well water of Curitiba metropolitan area (Brazil)

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Considering that the ^{222}Rn concentration in well water can contribute to indoor radon concentration levels, which represents a radiation risk for the public, the research group of applied nuclear physics of Federal University of Technology – Paraná (UTFPR), in collaboration with the Center of Nuclear Technology Development (CDTN/CNEN) and the Radiation Protection and Dosimetry Institute (IRD/CNEN), performed the measurements of ^{226}Ra and ^{222}Rn activity in well water in the city of Curitiba – Paraná State of Brazil. Each water sample was submitted to 4 measurements of radon concentration with interval of three days. After two months the same samples were submitted once again to ^{222}Rn concentration measurements with an objective to evaluate indirectly the amount of ^{226}Ra contained in water samples. The ^{222}Rn concentration measurements were performed using AlphaGUARD radon monitor (Saphymo) and ^{226}Ra concentration was evaluated using the decay curves of ^{222}Rn. Within few hours after extraction about 70% of water samples from monitored wells presented ^{222}Rn concentration values above the limit of 11.1 Bq/L recommended by the USEPA. Obtained activity values varied between 1.57 Bq/L – 215.16 Bq/L for radon concentration, and radium concentrations deviated within an interval of 0.61 Bq/L – 6.76 Bq/L. Obtained results showed that the biggest part of ^{222}Rn found in water samples was not originated from the ^{226}Ra compounds soluble in water but from gas exhalation by the soil adjacent to the well. The results of present research show the requirement of radioactivity monitoring of water extracted from artesian wells at Curitiba region and indicate the necessity of mitigation procedure development for better control of global alpha radioactivity in drinking water. The authors want to thank the agencies CNEN, CAPES, CNPq and Fundação Araucaria for financial support.

Ambient dose equivalent and effective dose from X-ray spectra transmitted by mortar barite in X-ray qualities of iec

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The International Commission on Radiation Units and Measurements (ICRU) recommended the use of ambient dose equivalent for area monitoring and the personal dose equivalent for individual monitoring. Both quantities are meant to be applied in external radiation fields for estimating the effective dose which is derived from a mathematical phantom and has been introduced by the International Commission on Radiological Protection (ICRP). Ambient dose equivalent is defined as the dose equivalent that would be produced by the corresponding expanded and aligned field in the ICRU sphere at a depth d, and it can easily be determined (at least in principle). The direct determination of ambient dose equivalent by means of the ICRU sphere is not possible in multidirectional fields; usually, this is done with a suitable field instrument with an isotropic response commonly calibrated in units of air kerma. As, in principle, the photon fluence may be taken as the calibration quantity, accurate conversion coefficients between air kerma or photon fluence and ambient dose equivalent must be known. The main aim of the present work was the experimental determination of the ambient dose equivalent for X ray qualities applied in diagnostic radiology and recommended, for instance, by the International Electrotechnical Commission (IEC) for use in the determination of characteristics of medical diagnostic X ray equipment. Plates of barytes mortar of different thicknesses were prepared.We used a system CdTe spectrometry to acquire the transmitted spectra, with the presence of each plate and combinations thereof. The attenuating properties of barite concrete, widely used in building construction such as nuclear power stations, particle accelerators and medical hospitals were studied and a correlation was made of radiation attenuation, materials properties, calculated spectra and ambient dose equivalent. Results obtained in this work point out the importance of the knowledge of the x-ray spectra for accurate determination of ambient dose equivalent and effective dose values. The photons transmission is one of the used parameters for calculate the shielding material thickness. Was possible verify significant differences on transmission curves by barite concrete for the different studied energies.

UV radiation dosimetry using polymeric films

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Ultraviolet (UV) radiation is produced naturally (by the sun light) or artificially (by passing an electric current through a gas or vapor), this radiation type is used in several human activities areas (medicine, industry, etc). All types of UV (UVA – 320–400 nm; UVB 280–320 nm and UVC 100–280 nm) can cause a photochemical effect within the polymer structure. Changes in UV irradiated polymeric films characteristics can be evaluate by spectrophotometric technique and used to monitor this processes. Polymers, such as polycarbonate, fluoropolymer and polymethylmethacrylate available commercially were analyzed before and after irradiation with a UV artificial source (HBO 200 W – OSRAM mercury lamp) to evaluate the changes occurring in their properties. These polymeric films are UV sensitive and changes were detected in their spectra; optical measures of absorbance can be correlated with the absorbed doses of UV radiation. The UV exposure parameters studied were exposure time (20 minutes – 7 hours); sample-source distance (5–20 cm) and wavelength (280–400 nm). The irradiated dosimeters were measured using Shimadzu UV-2101PC spectrophotometer. The UV radiation exposure leads to the color and brightness instability, and, absorption spectrum changes significantly were observed. Polycarbonate was the more sensitive material.

Retrospective doses for persons living in the most radioactively contaminated areas of Zhitomir region of Ukraine

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The "State Register of Ukraine (SRU) of persons affected by the Chernobyl disaster" has been functioning in Ukraine since 1992. The main task of SRU is informational support of medical, research and public institutions concerning levels of disease among persons exposed to radiation from the Chernobyl accident. One of the most important information components of SRU should be data on the levels of exposure (doses) of individuals whose clinical data are kept in the register. Unfortunately, for a long time dosimetric component was the weakest link in the structure DRU. Now it needs in reconstruction.

During last years new approaches and methods for estimation of retrospective-prospective doses radiation exposure of population were developed in the Radiological Protection Laboratory in the Department of Dosimetry and Radiation Hygiene of Ukrainian National Research Centre For Radiation Medicine. These models have different generalization degrees: individual, average group, average settlement or region, collective. They take into account various sources of "Chernobyl exposure" for nearly all the aggrieved regions of Ukraine. The models are based on the generalization and mathematical processing of the results of ecology-dosimetric monitoring (contamination of soil and food by ^{137}Cs, Whole Body Counter measurements of inhabitants). Central ecology-dosimetric register (CEDR) was created specifically for the storage and processing of this information. Now it is an interactive multi-level system of local databases.

In 2007-2012 the detail analysis and verification of data from SRU that can be used to reconstruction of accident doses was performed for persons who live on the territory of Zhitomir region which is one of the most affected after the Chernobyl disaster.

The set of criteria and conditions for selection the subjects of SRU who have sufficient information to calculate individualized doses has been developed. The radioecological dosimetric matrix was formed for each person from this contingent. The matrix displays the results of annual environmental dosimetric monitoring in settlements where this person lived during the period of supervision in SRU.

Numerical values of individualized doses of external and internal exposure of the whole body in the 1986-2011 and internal exposure of the thyroid gland in 1986 were restored for 41,585 persons from Zhitomir region. The analysis of the results was performed.

Radioecological study of the area surrouding the NPP Temelin, Czech Republic

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The unique monitoring based on studying contamination of the bioindicators by man-made radionuclides has been performed in the area of NPP Temelin for the past twelve years. The increase in radioactivity in the NPP area resulting from its operation is evaluated by comparison with a zero level activities and through the obtained data of trend analysis. The area of interest includes 29 collection sites located along 8 radial profiles, where the measurement points are located at a distance of 2, 5, 10, and 20 km from the Power Plant. For monitoring were selected the following bioinicators: forest humus, Pine bark, Schreber's Moss, the Bay Bolete (mushrooms), and forest berries. To determine the presence of radionuclides and their measurable activity in samples the laboratory gamma spectrometry was found to provide the most realiable results. Each two years the biomonitoring is supplemented by gamma spectrometric in-situ measurements, determining the dosimetric and gamma-spectrometric characteristics of photon fields. In the measured spectra of all the analyzed samples and of all in situ measurement as well, no man-made radionuclides have been identified, with the only exception being radiocaesium (originated from Chernobyl accident). The effective half-live of radiocaesium calculated from forest humus samples measurement (horizon fermenton) is 9 years in average. The variation of the gamma dose rates measured was compared with the results from the power plant continual monitoring system.

Monitoring of solar particle events with planar silicon diode detectors at high-mountain observatories

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At the ground level, space weather has been monitored by a worldwide network of neutron monitors since the beginning of the second half of the 20th century. The neutron monitor was invented by University of Chicago Professor John A. Simpson in 1948 and typically consists of several proportional counters surrounded with a polyethylene moderator and lead multiplier. The monitors measure the intensity of cosmic radiation and its variation caused by solar activity, for instance owing to the 11-year solar cycle, Forbush decreases or ground level enhancements (GLE). During the last decade, several planar silicon diode detectors, also known as Liulin-type detectors, were installed at Moussala (Bulgaria, 2925 m), Jungfraujoch (Switzerland, 3475 m) and Lomnický Štít (Slovakia, 2632 m) observatories. These detectors have spectrometric properties, and thus they can provide additional information to the data collected by neutron monitors. It was shown that Liulin detectors can detect GLEs on board aircraft by registering the GLE60 event on-board a Czech Airlines Airbus A310 during the flight from Prague to New York on April 15, 2001. The question was how much information about solar activity could be obtained from these detectors at mountain observatories.

In this work, the authors used data collected at the Lomnický Štít observatory in February 2011 to determine decision thresholds and detection limits of the Liulin-6I detector for the detection of variations in the cosmic radiation intensity. Moreover, the authors determined the time necessary for detection of the increase or decrease of a particle count rate. For instance it was found that to achieve the detection of a 5% decrease, the acquisition time of about 7 hours would be needed for current position of the detector. Advantages and disadvantages of Liulin-type detectors compared to neutron monitors were discussed.

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NaI(Tl) Scintillation Detector Survey of Terrestrial Gamma Radiation Dose-Rates in Negeri Sembilan, Malaysia

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Baseline data on background radiation levels allows for future assessment of possible changes in natural radionuclide concentrations, either as a result of geological processes or radioactive contamination. We have measured terrestrial gamma radiation dose rates from surface soils throughout accessible areas in the state of Negeri Sembilan in Peninsular Malaysia. Previous studies, carried out in the state of Johor (Ramli, et al. 2003), Perak (Lee, et al. 2009) and Melaka (Ramli, et al. 2005), have established the extent to which terrestrial gamma radiation dose rates vary with soil types and the underlying geological formations of the area. Dose rate measurements were carried out using a NaI(Tl) scintillation detector survey meter, encompassing 1600 locations, covering about 75% of the 6645 km^2 of the land area of Negeri Sembilan. This has allowed development of a terrestrial gamma radiation dose-rate contour map of Negeri Sembilan, achieved using Arch View GIS software. The dose-rates ranged from 71 ± 3 nGy/h to 1000 ± 11 nGy/h. The highest measured dose-rate was obtained in an area covered by soil types originating from igneous rock of granitic formations, while the lowest terrestrial gamma radiation dose rate was observed in area covered by limestone composed of calcite mineral mostly found near river and costal areas. The state of Negeri Sembilan consists of seven districts, the mean terrestrial gamma radiation dose-rate measured across the districts ranging from 244 ± 7 nGy/h to 458 ± 13 nGy/h, the global mean for Negeri Sembilan being 330 ± 8 nGy/h compared to a mean value for Malaysia of 92 nGy/h (UNSCEAR, 2000) and a world average of 59 nGy/h (UNSCEAR, 2000). Using the conversion factor of 0.7 Sv/Gy (UNSCEAR, 2000), the average annual dose from such terrestrial gamma radiation dose-rates to an individual residing in Negeri Sembilan, assuming a tropical rural setting, is estimated to be 2.02 mSv.

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Evaluation of a dose caused by external irradiation from radioactive aerosols

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An Radon Aerosol Chamber with a volume of 10 m^3 (RACH) is located in the area of the National Institute for Nuclear, Biological and Chemical Protection (Příbram, Kamenná, Czech Republic). RACH allows creation of a stable atmosphere containing high concentration of radioactive or non-radioactive aerosols. Aerosol particles are formed by nebulized salt crystals (size mode: 30–200 nm) or by condensation of the carnauba wax vapours (size mode: 200–350 nm). The concentration and the size distribution of aerosol particles are determined by a Scanning Mobility Particle Sizer 3936 (TSI).

As a radioactive medium for testing was mostly used radon because its decay products are deposited inters alia onto injected aerosol particles. The maximal radon concentration is $1\text{Mbq} \cdot \text{m}^{-3}$. It is also possible to label aerosol by means of ^{99m}Tc or ^{24}Na radioisotopes.

Radioactive aerosol is sampled using glass-fibre filter. Afterwards, the alpha radionuclides concentration is determined with an alpha spectrometer 7401 VR (CANBERRA), while the beta and gamma radionuclides concentration is determined using an alpha / beta/ gamma probe SABG-15+ (CANBERRA).

The doses in our experiment were determined using TLD (LiF) detectors placed in plastic holders, which are usually utilized in an ALGADE personnel dosimetric system, and also using DIS-1 (RADOS) dosimeters.

The doses at different locations, where the detectors were applied, have been estimated using the model (MCNPX) as well. The different contributions of radon and its decay products to the total dose were estimated. The portion of the radon decay products, which were deposited on the detector envelope or onto the chamber walls, was also taken into account.

The presented paper describes a comparison between the dose from radon and radon decay products estimation, based on the experimental measurements and based on the results obtained from MCNPX program model.

On application of low doses from beta radiation source in OSL retrospective dosimetry

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In luminescence dosimetry radioactive sources are typically used for delivering exact doses of ionizing radiation to the material. Usually the source is firmly incorporated in the luminescence reader. In such a case the dose value is controlled by establishing appropriate time of the irradiation. The common dose rate of the source is generally assumed in calculations (Oczkowski and Przegiętka, 2000; Bos et al., 2006). However in some applications of retrospective dosimetry and dating of extremely young samples very low doses are needed. We observed that using the common dose rate for very short irradiations can lead to dose overestimation as high as 15%. This differs from previously reported results (Markey et al., 1997; Kalchgruber et al., 2002). It is suspected that the quantitative effect is unique feature of every single equipment. Therefore it should be determined independently. It is suggest that for range of short irradiations special calibration should be performed in order to determine specific correction factor. The presented results can serve as illustrative proposal of such procedure.

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Monitoring of radiation dose rates around a clinical nuclear medicine site

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Introduction The monitoring of radiation dose around the nuclear medicine site has become one important study issue today. In this study, a survey of ambient radiation dose rates was carried out around a clinical nuclear medicine site to investigate the latent hot zones of radiation exposure.

Materials and Methods A total of 552 thermoluminescent dosimeters (TLD) were used to measure radiation dose rates inside and around a nuclear medicine site of a hospital in Taiwan. The background radiation dose was measured in an office where far from the nuclear medicine site. Three TLD chips were arranged on a measurement point. The monitoring radiation dose was carried out for a period of one month. Monitor points around the site for piping system and tank area are included: cyclotron, PET/CT, RIA sink, SPET/CT sink, storage sank connection piping, assigned tank, storage tank and emergency dilution tank. Monitor pointes for PET/CT and nuclear medicine imaging areas are: the control room of PET/CT and SPECT/CT, information desk, waiting areas (inside restricted zone) and public waiting area (outside restricted zone).

Results and Discussion In this study, the radiation doses measured from all piping and storage system were comparable to the background dose. A relatively high dose was observed at the turning point of waste water piping of the PET/CT. The other main finding is that the unexpected high doses were observed at the waiting areas of SPECT/CT. The possible explanation is that ,patients may free of control after radiopharmaceutical injection.

Conclusion This study provides useful information for further determination of appropriate dose reduction strategy to achieve the ALARA principle in a clinical nuclear medicine site.

Verification of the sludge bed after uranium ore mill efficiency redevelopment

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Positive approach of the public as well as the government to old waste disposal issues results in redevelopment of the sludge beds. However the very high concentration of natural radioactive isotopes, collected in the old sludge beds from uranium ore mill, could be the source of the population irradiation. The main hazards are: the increase of the effective dose from internal and also external gamma radiation; the increase of the effective dose from inhalation of radon; infiltration of the radionuclides into the underground water. The sludge beds are usually redevelopment by overlaying one or more layers of inert material. The efficiency of this procedure, leads to decrease of the irradiation, it can be controlled using in situ or laboratory gamma spectrometry method. This method makes it possible to determine dose rates or K, U, Th concentration on the surface of the sludge bed. In the uranium and thorium decay chains can be assumed radioactive equilibrium disturbance.

For verification during redevelopment in one of the sludge beds in the Czech Republic, the following measurements were carried out: in situ gamma spectrometry using scintillation detector NaI(Tl) 3" × 3" in two geometry of measurement, with recording of point location using GPS device: 1 meter above the surface (gamma dose rates results) and at the surface (the results of those measurement were gamma dose rates and K, U and Th concentrations); in situ gamma dose rate measurement using plastic detector; laboratory gamma spectrometry measurement of twenty samples from 4 short depth vertical profiles, using HPGe detector in geometry with Marinelli containers; radon in soil gas sampling from 4 shallow depth vertical profiles measurements, using "lost tip" method and small Lucas cells. The results from in situ gamma spectrometry measurement were processed into maps of dose rate and compared with redevelopment works on the sludge bed. Some difficulties were noticed during the radon measurement in the depth profiles, caused by presence of low level underground water and in the course of gamma spectrometry measurement due to high death time (40%–50%). Our results confirm very high reliability (effectiveness) of the applied inert material and remediation method.

UV Dosimetry and the use of Ge-doped optical fibres

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Previous studies have shown that overexposure to ultraviolet radiation (UVR), either from sunlight or artificial sources, can cause severe biological effects which can be fatal to individuals such as cataracts, photokeratitis and skin cancer. In this respect, there exists the need to introduce a sensitive UV dosimetric material which is capable of measuring radiation dose to high accuracy in order to deliver UVR safely and efficiently. Present study has focussed on the investigation of the potential TL sensitivity of commercially available germanium (Ge)-doped silica (SiO_2) optical fibres subjected to UVR. The main interest of this study is to find out whether these doped SiO_2 optical fibres can be used as a sensible integrator of environmental UV exposures. In present study, use has been made of commercially available Ge-doped SiO_2 optical fibres with a core diameter of 11 µm (CorActive, Canada), 23 µm (India) and 50 µm (India) and a cladding diameter of 125 ± 0.1 µm being irradiated over a wide range of UV dose. Results have shown that these fibres exhibit a linear dose response (with correlation coefficient of > 0.9852). The 50 µm fibre produces better TL response than that obtained for 11- and 23 µm fibres. The result obtained has suggested the possible applicability of these optical fibres as a detector of UV exposures in order to monitor UV exposures to individuals. Investigation on the potential TL sensitivity of blackboard chalk to UVR was also carried out. It was found that the relative TL sensitivity increases with increase in the UV dose delivered, obtaining correlation coefficient of > 0.9958. Therefore, this initial study has demonstrated that board chalk may offer a further promising TL dosimeter for UVR dosimetry The TL results are compared with that of well-established TLD-lithium fluoride dosimeter.

High Sensitivity Flat SiO_2 Fibres for Medical Dosimetry

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While the use of commercial TLD-100 and Ge-doped communication fibres in medical radiation dosimetry has been discussed in considerable detail, conversely in this present work we describe investigation of a novel undoped flat fibre, to be used for the same purpose. Comparison is made herein of the TL yield of flat fibres, TLD-100 chips and Ge-doped fibres, previous research demonstrating a superior TL response for TLD-100 than for Ge-doped fibres irradiated to for instance 6 MeV electrons. Present results show the flat fibres to provide competitive TL yield to that of TLD-100 chips at megavoltage energies, the sensitivity of flat fibres being found to be ∼100 times that of the Ge-doped fibres. Pointing to potential use of the flat fibres in a number of diagnostic procedures, this had lead to investigation of the TL response of the flat fibres, irradiated by x-rays generated at kVp potentials.

Comparison of Ge-doped TL optical fibres and glass beads with ion chamber and Gafchromic film for small field photon dos

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Small field ($\leq 4 \times 4$ cm) photon radiotherapy treatments include intensity-modulated radiation therapy (IMRT) and stereotactic body radiation therapy (SBRT). These require small, high spatial resolution dosimeters of adequate dynamic range. In this study, field sizes of 1 cm × 1 cm, 2 cm × 2 cm, 3 cm × 3 cm, 4 cm × 4 cm, and 10 cm × 10 cm have been investigated using commercially available silica-based fibres and glass beads (GB) as TL dosimeters and a Varian linear accelerator operating at 6, 10 and 15 MV. Ge-doped SiO_2 fibres have previously been shown by this group to offer a viable system for use as dosimeters. The fibres and GB, offer good spatial resolution (∼120 µm and 2 mm respectively), large dynamic dose range (with linearity from tens of mGy up to well in excess of many tens of Gy), a non-hygroscopic nature and low cost. The main aim of this present work is to investigate the use of Ge-doped optical fibres and GBs as thermoluminescence dosimeters in small photon fields for different photon beam energies, comparing the measurements against Gafchromic films, hospital commissioning data obtained from small ionisation chambers and photon diodes and Monte Carlo simulations with FLUKA and BEAMnrc.

Effective dose to immuno-PET patients due to metastable impurities in cyclotron produced zirconium-89

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Immuno-PET is a nuclear medicine technique that combines positron emission tommography (PET) with radio-labeled monoclonal antibodies (mAbs) for tumor characterization and therapy. Zirconium-89 (^{89}Zr) is an attractive radionuclide for tagging. It decays into yittrium-89 (^{89}Y) through $\beta+$ emission (22.7%) and electron capture (77.3%) followed by a prompt-γ at 909 keV. Its long half-life (78.4 hours) gives ample time for the production, the administering and the patient uptake of the tagged radiopharmaceutical. Furthermore, the nuclides will remain in the tumor cells after the mAbs are catabolized so that time series studies are possible without incurring further administration of radiopharmarceuticals. ^{89}Zr can be produced in medical cyclotrons by bombarding an ^{89}Y target with a proton beam through the ^{89}Y(p,n)^{89}Zr reaction. There are several by-products including ^{88}Zr, ^{89m}Zr and ^{90}Zr associated with the irradiation that cannot be separated chemically. ^{90}Zr is a stable nuclide and it does not present radiation hazard to the patient. ^{88}Zr decays into ^{88}Y by electron capture with a half-life of 83.4 days while ^{89m}Zr decays into ^{89}Zr by isomeric transition with a half-life of 4.16 minutes. In this study, we estimated the effective dose to the head and neck cancer patients undergoing ^{89}Zr-based immune-PET procedures. The production of ^{89}Zr and the impurities from proton irradiation of the ^{89}Y target in a cyclotron was calculated with the Monte Carlo code MCNPX and the nuclear reaction code TALYS. The cumulative activities of the Zr isotopes were derived from real patient data in literature and the effective doses were estimated using the MIRD specific absorbed fraction formalism. We normalized the dose to the injected activity of ^{89}Zr in MBq $\cdot$ s. The estimated effective dose from ^{89}Zr is 0.5 ± 0.2 mSv. The highest organ dose is 1.8±0.2 mSv in the liver. These values are broadly compatible with those reported literature. The effective dose from ^{89m}Zr ranges from $(1.5 \pm 0.1) \times 10^{-5}$ mSv when there was a cooling time of 1 hour between the production of the isotopes and the administration of the radiopharmaceutical to $(1.5 \pm 0.1) \times 10^{-2}$ mSv when there was no cooling time. Therefore the ^{89m}Zr dose is about 0.3% of the ^{89}Zr dose in the worst case. Since the ratio of ^{89m}Zr to ^{89}Zr depends on the cooling time as well as the irradiation details. This dose estimation is also important in optimizing the cyclotron irradiation geometry, energy and time.

Determination of the spectral air kerma sensitivity of detectors used in CT dosimetry

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The measurement of radiation dose in medical X-ray computed tomography (CT) is needed for quality assurance and the evaluation of patient dose. Since the introduction of X-ray CT into clinical practice in 1972, there has been a remarkable technical development of new CT facilities. However, CT dosimetry is still based on the CT dose index (CTDI) introduced in 1981, which is measured with pencil-type ionisation chambers free-in-air or at defined positions in standardized PMMA phantoms. The transition from fan-beam to cone-beam CT has led to the development of new methodologies in CT dosimetry. Besides the pencil-type, there are also small ionisation chambers and different types of solid state detectors in use. Typical applications are measurements of axial scan dose profiles free-in-air and in phantoms and dose rate distributions along the shape of a bow tie filter. It is obvious that the spectral X-ray distribution changes significantly at the different positions. Therefore, it is important to know the spectral air kerma sensitivity of the detectors. The goal of this work was to measure these sensitivities for ionisation chambers and solid state detectors and to determine corresponding correction factors. Air kerma sensitivities were measured in narrow-beam radiation qualities (10 kV to 200 kV) using PTB's primary air kerma standard. An algorithm based on the deconvolution of the measured sensitivity to the X-ray spectra resulted in the sensitivity as a function of photon energy. The spectral sensitivity function was used to calculate the sensitivity for any measured or calculated X-ray spectrum free-in-air or at different positions in CT phantoms. The thusly calculated sensitivities of the detectors were verified by different types of comparative air kerma measurements free-in-air and in different types of CT phantoms at the X-ray facilities of PTB. The procedures and results of this work are aimed to be used for the evaluation of the influence of spectral detector sensitivities on measured dose quantities and shall be used for future definitions of requirements for detectors used for advanced CT dose measurements.

Evaluation of radiation dose to neonate in special care baby unit

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Neonates on a special care baby unit often require radiography to monitor the progress of their treatment and as a result can have a large number of radiographs taken during their stay in hospital. The purposes of this study are to: (i) measure patient entrance surface dose (ESD) for neonates in special care baby unit (SCBU) up to 28 days after birth, (ii) evaluate the organ and effective doses.

A total of 132 patients were examined during four months. ESDs were calculated from patient exposure parameters using DosCal software. Effective doses (E) were calculated using published conversion factors and methods recommended by the national Radiological Protection Board (NRPB).

The mean patient dose was 80 ± 0.02 μGy per procedures. The mean and range of the effective dose was 0.02 (0.01–0.3) mSv per procedure.

The radiation dose in this study was higher compared to previous studies. A dedicated X-rays machine with additional filtration is recommended for patient dose reductions.

Effective dose estimation during conventional and computed urography

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Urography has a major role of diagnostic method in medical field and provides the clinicians with useful detailed information in evaluation of urinary system disorders. However, it is the responsibility of radiologist and technologist to determine scanning technique factor that provide balance between image quality and radiation dose and share in keeping patient radiation exposure at lowest as possible. The objectives of this study are to: (i) measure and compare patient radiation dose form computed tomography urography (CTU) and (ii) conventional intravenous urography (IVU) and evaluate the protocols used in CTU and IVU imaging procedure. A total of 141 patients were investigated. A calibrated CT machine (Siemens-Somatom Emotion duo) was used for CTU, while a shimadzu X ray machinewas used for IVU. Thermoluminescence dosimeters (TLD)-GR200A) were used to measure patients' entrance surface doses (ESD). TLDs were calibrated under reproducible reference conditions. Patients radiation dose values (DLP) for CTU were 172±61 mGy·cm, CTDIvol 4.75±2 mGy and effective dose 2.58±1 mSv. Patient cancer probabilities were estimated to be 520 per million per CTU examination for the pancreas and 31 for the testicles. Patients ESDs values for IVU were 21.62±5 mGy, effective dose 1.79±1 mSv. Unlike some previous studies, CT involves a higher effective dose than IVU. A patient radiation risk for particular exam is depend on the radiation dose delivered during the exam, the type of scanner, scan length, patient demographic characteristics and imaging protocol. In this study the radiation dose is considered low compared with previous studies.

Assessment of the dose distribution inside a cardiac cath lab, using TLD measurements and Monte Carlo simulations

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Over the last decade, the number of interventional cardiology procedures increased rapidly and the corresponding ionizing radiation doses for both the medical staff and patients became a subject of great concern. Cardiac interventional examinations can be complex, resulting in long exposure times. Also, these interventions require the operator to work near the patient and, consequently, close to the primary X-ray beam. Due to the scattered radiation in the patient and the equipment, medical staff is also exposed to a non-uniform radiation field that can lead to a significant exposure of sensitive organs and tissues of the body, such as the lens of the eye, the thyroid and the extremities. In order to better understand the spatial variation of the dose and dose rate distributions during an interventional cardiology procedure, we have estimated the dose distribution around a C-arm fluoroscopic system, in operation in a cardiac cath lab at a Portuguese Hospital.

For this work, both Monte Carlo (MC) simulations and measurements were performed. To model and simulate the cardiac cath lab, including the fluoroscopic equipment used to execute the interventional procedures, the state-of-the-art MC radiation transport code MCNPX 2.7 was used. Subsequently, Thermo-Luminescent Detector (TLD) measurements were performed in order to validate and support the simulation results obtained for the cardiac cath lab model.

The preliminary results presented in this study reveal that the cardiac cath lab model was successfully validated taking into account the good agreement achieved between MC simulations and TLD measurements. The simulated results for the isodose curves related to the C-arm fluoroscopic system are also consistent with the dosimetric information provided by the equipment manufacturer (Siemens).

The adequacy of the implemented computational model used to simulate complex procedures and map dose distributions around the operator and the medical staff is discussed, in view of the optimization principle (and the associated ALARA objective), one of the pillars of the international system of radiological protection.

Study of OSL and TL response of $CaSO_4$:Dy, LiF:Mg,Ti and MicroLiF:Mg,Ti dosimeters to beta and gamma radiation

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The Optically Stimulated Luminescence (OSL) is a signal emitted by an insulating or semiconducting material when exposed to light, after being irradiated. The intensity of the OSL signal is proportional to the dose of radiation absorbed by the detector. The process is similar to the thermoluminescence, but differs in the stimulation: instead of thermal stimulation, in OSL defects in the detector are stimulated by optical means. The use of OSL is growing and OSL dosimeters have recently been study and investigated for medical dosimetry applications. These dosimeters share many properties of interest for this application. This paper aimed to study and compare the OSL and TL dose-response, the lower detection limit and the intrinsic efficiency of the $CaSO_4$:Dy, LiF:Mg,Ti and microLiF:Mg,Ti dosimeters to gamma and beta radiation. The $CaSO_4$:Dy, LiF:Mg,Ti and microLiF:Mg,Ti dosimeters were previously selected according to its TL sensitivity to ^{60}Co gamma radiation. The dosimeters were heat-treated using furnaces Vulcan model 3-550 PD and Fanen model 315-IEA 11200 and were irradiated in air at electronic equilibrium conditions using a ^{60}Co (gamma radiation) and ^{90}Sr/^{90}Y (beta radiation) sources with doses ranging from 0.1 up to 10 Gy for both radiation source. The OSL measures were performed using an OSL reader Risø model TL/OSL-DA-20 and the TL measures using a TL reader Harshaw model 4500.

Investigation of a new procedure to measure the lead attenuation equivalent of protective clothing materials

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Protective clothing for workers at medical X-ray facilities, such as aprons, gloves and mittens, and protective devices for the patient, such as gonad aprons, scrotum, ovary and shadow shields shall comply with the requirements of the international standard IEC 61331 which is currently under revision. An important requirement is defined for the X-ray attenuation properties of the materials. These shall be characterized by their lead attenuation equivalent thickness (LAET). The revised version of IEC 61331 contains new definitions of radiation qualities and introduces a new method to measure the LAET including scattered radiation. The latter was necessary because the vast majority of commercial shielding garments are nowadays made of lead-reduced or lead-free composites which contain large amounts of elements with atomic numbers close to Z=50. These composites reflect significantly different amounts of scattered radiations in their transmission spectra compared to lead. The new method is an alternative to the usual arrangement under broad beam conditions (BBC) and is referred to as "inverse broad beam condition" (IBC). In contrast to the classical BBC defined by the use of a broad beam and a small detector, the IBC is characterized by the use of a narrow beam and a large detector.

The purpose of this work is to investigate the whole procedure to measure the LAET of protective clothing materials by the use of the new IBC arrangement, together with the newly defined radiation qualities. The results provide testing laboratories with valuable information about the procedure and the requirements for the technical equipment and materials needed for such kinds of tests. The uncertainty of the resulting LAET is influenced by the uncertainties in thickness and purity of the reference lead layers, the technical performance of the large flat radiation detector, the evaluated factor to correct for the spectral sensitivity of the detector, the geometrical set-up, and the method to evaluate the LAET of the test material from the measured lead attenuation factors. The investigation is conducted by performing both real measurements at the X-ray facilities of PTB and supplementary Monte Carlo simulations based on measured photon fluence spectra at the same facility.

Film dosimetry for validation of the performance of 3-D detector arrays for radiotherapy verifications

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Intensity modulated radiotherapy (IMRT) including tomotherapy and volumetric modulated arc therapy (VMAT) is a complex procedure requiring proper dosimetric verification. IMRT dose distributions are characterized by high degree of modulation and by steep dose gradients which allow for sparing organs at risk and for escalation of the dose to the tumor. These techniques require a large number of modulated radiation beams (sometimes over 10) or rotational delivery as tomotherapy or VMAT. The fluence measurements for individual beams or at individual angle are not sufficient for evaluation of total dose distribution and assuring patient safety. A number of electronic systems which allow for a pre-treatment plan verification based on reconstruction of the total dose distributions were developed recently (Delta4, ArcCHECK, Octavius, Compass, etc.). The systems allow for reconstruction of dose distribution over a phantom or a patient computer tomography images based on pre-treatment measurements during delivery of planned beams to the electronic detector set. The method of validation of such systems tested on a Delta4 device is presented here. The method requires an anthropomorphic phantom and dosimetric films. In order to measure dose distributions in various cross-sections of the phantom the film dosimeters were used (radiochromic Gafchromic EBT). The film characteristics were carefully examined. A phantom with the material and shape equivalent to the Delta4 detector array was developed. A methodology of comparing measured and reconstructed dose distributions against the distributions calculated by treatment planning systems (TPS) was developed and tested. This film dosimetry methodology was used as a benchmark to test and validate the performance of commercially available 3-D matrices of detectors (ionization chambers or diodes). The so called gamma formalism was used for evaluation and comparison of the measured and calculated dose distributions. The tolerance levels of these comparisons were set at 3% difference in dose and 3 mm in distance to agreement. The results of these comparisons for a group of test plans of different complexity and the patient plans are presented as the fractions (%) of region of interest for which the gamma index obtained as the result of comparisons performed for three different axial dose distribution calculated with: Delta4, ArcCHECK Pa ^{3}DVH and Eclipse with films irradiated in the test phantom is $\Gamma \leq 1$ (acceptance level).

Study on Ce3+-doped scintillation detectors of different dimensions for in vivo dosimetry in HDR brachytherapy

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High dose rate (HDR) brachytherapy treatments involve complex processes including many consecutive steps. Even if the various steps are carried out with great accuracy, many causes of error can affect the dose delivered to the patient during the treatment, and such a dose may not accurately match the planned one. In vivo dosimetry is a reliable solution to compare planned and delivered dose distributions. Particularly advantageous for in vivo dosimetry are the methods using detectors that allow on-line dose readings, providing real-time measurements during treatments. In this work, real-time miniaturized scintillation detectors of different dimensions applied to in vivo dosimetry in HDR brachytherapy were studied. The active component of the detectors is a Ce3+-doped SiO_2 optical fibre which is coupled by a commercial SiO_2 fibre (by Starlite Srl, Italy) to a system for signal amplification (by El-Se Srl, Italy) connected to a computer for counts per second (cps) recording and analysis.

Measurements were performed with a brachytherapy Ir-192 source of a Microselectron-HDR (Nucletron) remote afterloading device. Reproducibility, linearity, dependence of the detector response on energy, dose-rate and temperature were primarily investigated. To this aim, ad hoc gel and water phantoms with standard source catheters and a specific detector housing were designed and developed at our laboratory. The dose delivered to the detector was calculated by means of the AAPM TG-43 formalism implemented in the clinical treatment planning system.

Cps reproducibility resulted very high, with a maximum standard deviation of the readings at increasing source-detector distance lower than 1.5%. The average cps measured at changing source dwell position resulted to increase linearly with the calculated dose. No evidence of energy and dose-rate dependence resulted from the acquired data, whereas the definition of a linear equation to correct detector sensitivity from ambient to human temperature was necessary.

The obtained results are very encouraging as they indicate that the use of the proposed detector is promising both for quality control measurements and in vivo real-time dosimetry in HDR brachytherapy. Further studies are currently in progress for the application of this dosimeter in urethral dose measurements during interstitial brachytherapy treatments of the prostate.

Evaluation of entrance surface air kerma from exposure index in computed radiography

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The receptors of digital radiography image are gradually substituting the screen-film systems in radiodiagnostic. Currently, computed radiography is the most common method in many radiography services. It is based in the application of photostimulable phosphorus, that are also known as phosphorus storage. When screen-film systems are utilized as image receptors, an inadvertently high dose of radiation in the patient will result in a dark film screen, which inputs immediate feedback to the radiology technician as to the technical factors utilized and the relative dose. However, when digital image receptors are used, a high dose in the patient can produce excellent images which result in a tendency of using higher doses than necessary. The adequate extenuation and optimization of the procedures demand the knowledge of the characteristic dose values in patients in a determined radiodiagnostic service. The term exposure index refers to the absorbed dose in the phosphorus plate. Following the image reading with a laser system the histogram of signs is computed and the exposure index is determined in the basis of picture elements using a logarithmic relationship. The manufacturer of the systems of pixels offer the exposure index as a safeguard against high doses, but the basis for the recommended values are not clear. Moreover, the exposure index is not directly related to the dose in patients. The aim of this work was to establish an indirect method to evaluate the values of entrance surface air kerma in patients who have undergone diagnostic exams in X ray systems with computed radiography based on exposure index. These values of entrance surface air kerma were compared with the values also obtained indirectly based in the measurements of the X ray tubes output.

Calibration methodology application of kerma area product meters in situ: preliminary results

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The kerma-area product (KAP) is a useful quantity to establish the reference levels in diagnosis of conventional X ray examinations. It can be obtained by measurements carried out with a KAP meter with a plane parallel transmission ionization chamber mounted on the X ray system. A KAP meter can be calibrated in laboratory or in situ, where it is used. It is important to use one reference KAP meter to obtain a reliable quantity of doses on the patient. The Patient Dose Calibrator (PDC) is a new equipment from Radcal that measures KAP. It was manufactured following the IEC 60580 recommendations, an international standard for KAP meters. This study had the aim to calibrate KAP meters using the PDC in situ. Previous studies and the quality control program of the PDC have shown that it has a good function in characterization tests of dosimeters with ionization chamber and it also has low energy dependence. Three types of KAP meters were calibrated in four different diagnostic X ray equipments. The voltages used in the two first calibrations were 50 kV, 70 kV, 100 kV and 120 kV. The other two used were 50 kV, 70 kV and 90 kV. This was related to the equipments limitations. The field sizes used for the calibration were 10 cm, 20 cm and 30 cm. The calibrations were done in four different cities with the purpose to also analyze the reproducibility of the PDC. The results give the calibration coefficient for each KAP meter and prove that the PDC can be used as a reference instrument to calibrate clinical KAP meters.

LUTATE dosimetry based in infant phantoms

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The aim of this work is to estimate Dose in children using a compartmental model to calculate ^{177}Lu-DOTATATE kinetic constants assessing published PRRT patient's data that was previously proposed to estimate Dose in adults. The same kinetic constants calculated to the adults, using the Reference Person was extrapolated to infants using only the body mass concept. The infants phantoms considered were: newborn (3,6 kg), 1 year old (9.7 kg), 5 years old (19.8 kg), 10 years old (33.5 kg) and 15 years old (56.8 kg) which were fixed as a partition of the Compartmental analysis software, AnaCompTM. Using intra species scaling equations and curves these Doses may be estimate to all body mass ranges. Estimated Absorbed Dose in the all kidneys volume, that is considered the limiting organs to labeled somatostatina analogous administration, were: 18.42 mGy/MBq (newborn), 6.42 mGy/MBq (1 year old), 3.76 mGy/MBq (5 years old), 2.56 mGy/MBq (10 years old) and 1.81 mGy/MBq (15 years old). Considering early and late effects of radiation in normal tissues and organs with threshold doses for tissue reactions described in the ICRP 118, diagnostic and therapeutic applications of ^{177}Lu-DOTATATE have to be rigorously analyzed. In therapy, survival or irreversibility morbidity should be the first objectives during the treatment.

Dosimetry in HDR brachytherapy with gafchromic EBT3 films

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The continuous development of radiotherapy, aimed to achieve highly conformal dose volumes, has made heavy demands on dosimetry methodology development. Concerning high dose rate (HDR) brachytherapy, the improvements result mainly from the remarkable progresses in 3D imaging, by the development of sophisticated techniques for modern afterloaders and by the constantly increasing speed and capacity of computers. Improvements in the dosimetry methods are therefore mandatory, in order to ensure that the values calculated with computer treatment planning systems, adopted in the clinical praxis, agree with the delivered dose distributions.

The studied method for 2-D dosimetry in HDR brachytherapy is based on Gafchromic EBT3 films because of their good tissue equivalence and their high spatial resolution. We have investigated the response of EBT3 films exposed to the Ir-192 source of a Microselectron-HDR high dose rate remote afterloading device. For the EBT3 optical analysis, a recently established procedure was used, based on suitably designed instrumentation. The proposed system is composed by a planar uniform white light source and a CCD camera with optical filters at 630 nm, 580 nm, 430 nm. Light transmittance images are detected before and after irradiation, and images of the difference of optical density, which is correlated to the absorbed dose, are obtained by means of pixel-to-pixel elaboration of such two images. To this aim, dedicated software has been developed in MATLAB environment. To investigate the advantages of this analysis method based on the CCD camera with respect to conventional methods, dose images have been mostly achieved also by means of an EPSON (Expression 10000 XL) scanner and examined with FilmQAPro software. Optical images were usually acquired one day after irradiation. Furthermore, a study of the trend in time of the response after irradiation was carried out.

The calibration curve has been obtained by exposing EBT3 samples to the Co-60 source of a readiotherapy facility, to uniform and well known doses, placing the samples into a phantom made with solid water, at a depth corresponding to the maximum dose of the build-up region. The possibility of performing calibration with the Ir-192 source was also studied. Some measurements in water phantom were made, determining the error of the measured dose values at various distances from the source, caused by the continuous change in the photon energy spectrum.

Dose and fluence measurements with gel dosimeters at the BNCT epithermal column of LVR-15 reactor

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he dosimetry methods based on laboratory-made Fricke-Xylenol-Orange-infused gels have shown noticeable potentiality for in-phantom or in-free-beam dose distribution measurements at high fluence rates of thermal or epithermal neutrons designed for boron neutron capture therapy (BNCT) treatments. Fricke-gel dosimeters are radiochromic, and the absorbed doses are obtained by pixel-to-pixel manipulation of optical transmittance images detected with a CCD camera before and after irradiation. For such an analysis, the dosimeters are placed on a plane uniform light source. Various dosimeter shapes have been designed, depending on the specific interest, in particular for measurements with the epithermal neutron beam for BNCT of the LVR-15 research reactor in Řež (CZ). Initially, the method was optimized considering dosimeters in form of layers (3 mm thick) having squared, rectangular or circular shape and different width, from 5 cm to 18 cm. Such dosimeters were advantageous in experiments aimed at characterizing the beam at the mouth of the epithermal-column collimator and moreover for measurements in the standard water phantom and in large tissue equivalent phantoms of various shapes and structures. More recently, in order to perform measurements in small phantoms, both thin cylindrical (3 mm in external diameter) and parallelepiped (squared basis of 1 cm in side) dosimeters have been prepared. For each dosimeter shape, dedicated software was developed in MATLAB environment, for providing images of the difference in optical density which is proportional to the absorbed dose. It is important to discriminate the various dose contributions (photon, fast neutron and boron doses) owing to their different biological effectiveness. This separation is obtained by the analytical comparison of dose distributions obtained with couples of dosimeters having a suitable difference in the isotopic composition.

In order to compare measurements performed with different techniques, a suitable method has been also developed for obtaining both photon dose and thermal neutron fluence using a single LiF:Mg,Ti thermoluminescence dosimeter (TLD). The method is based on characteristics of the shape of the glow curve of this TLD.

Furthermore, Monte Carlo simulations with the MCNPX code have been developed in the various configurations of the performed measurements.

Noticeable consistency was obtained between all measurements and calculations.

Dose evaluation of dental cone beam computed tomography using an anthropomorphic adult head phantom

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Dental cone beam computed tomography (CBCT) can provide high resolution images and has been widely applied in the clinics. Therefore, the radiation dose from CBCT examinations has become an important issue. In this study, we developed an in-house anthropomorphic adult head phantom to evaluate the dose of CBCT.

The anthropomorphic phantom was made of acrylic filled with plaster instead of bone. The contour of the head was extracted from a set of adult CT images. The thermoluminicent dosimeters (TLD) were used to measure the dose at 21 locations within the head and neck region of the phantom. For each location, the measurement was performed three times to obtain the mean dose and standard deviation.

The doses from CBCT with the scanning parameters of 65/75/85 kVp, 5.1/7.1 mm^2 field of view (FOV), and 102 mAs were measured. The results were converted to the effective dose by using the tissue weighting factors from ICRP-103 report, and were compared to the effective dose measured from the standard Rando phantom.

At 5.1 mm^2 FOV, the effective doses of three kVp were 40.31, 67.88 and 90.12 μSv, raspectively. At 7.1 mm^2 FOV, effective doses were 81.23, 133.31 and 188.5 μSv respectively.

The percent error between the dose measured from the proposed phantom and the Rando phantom were lower than 15 % for all scan parameters. We thought that the proposed anthropomorphic adult head phantom can be applied in the dose assessment of clinical CBCT.

Investigate optimal refractive index of matching liquid for 3D NIPAM gel dosimeter using optical CT

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The accuracy of optical computed tomography scanners is strongly affected by refractive index of matching liquid. Mismatching refractive index will induce reflection and refraction while laser beam passes through gel phantom. The unwanted rays collected by photo-detector produce image artifacts after performing image reconstruction from collected data. In order to obtain best image quality, this study investigated optimal refractive index of matching liquid for NIPAM gel dosimeter. The NIPAM polymer gel used in the study was composed of 5% gelatin, 5% NIPAM, 3% N,N'-methylene bisacrylamide, and 10 mM Tetrakis (hydroxymethyl) phosphonium chloride. This study used a commercial optical computed tomography scanner (OCTOPUS-10X, MGS Research, Inc., Madison, CT, USA) as the readout tool for NIPAM polymer gel dosimeter. An acrylic cylindrical phantom with 10 cm (diameter) by 10 cm (height) by 3 mm (thickness) was filled with NIPAM gel and was immersed in an aquarium. The matching liquid was prepared using glycerol and deionized water. The refractive indices were varied from 1.3392 to 1.4115, which were measured by a refractometer (ATAGO, Model:PAL-RI, Japan) at room temperature 22°C.

The results showed that the reconstructed image became blurred When refractive index larger than 1.4115. As refractive index decreasing, the central region became flat and the contour of gel container became clearer. The optimal refractive index is from 1.346 to 1.348 and the central flat region attain largest. As refractive index smaller than 1.345, the central flat region decreased and the contour of container became blurred again. This study also investigated the effect of color of matching liquid. Two matching liquids, one mixed with red dye and the other transparent, were compared with same refractive index 1.346. The results showed that maximum average deviation were less than 0.07% for the red color and transparent matching liquids. It concludes that the color of the matching liquid does not affect the measurement accuracy of NIPAM gel dosimeter measured by optical CT.

Dose evaluation of NIPAM polymer gel dosimeter using gamma index

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N-isopropylacrylamide (NIPAM) polymer gel dosimeter has great potential in clinical application. However, the three-dimensional dose distribution needs to be accessed. In this work, a quantitative evaluation of dose distributions was performed to evaluate the NIPAM polymer gel dosimeter using gamma analysis.

A cylindrical acrylic phantom filled with NIPAM gel measuring 10 cm (diameter) by 10 cm (height) by 3 mm (thickness) was irradiated by the 4×4 cm^2 square light field. The irradiated gel phantom was scanned using an optical CT scanner (OCTOPUS™, MGS Research, Inc., Madison, CT, USA) with 1 mm resolution. The projection data were transferred to an image reconstruction program written using MATLAB (The Math Works, Natick, MA, USA). The program reconstructed the image of optical density distribution using the algorithm of filter back-projection.

Three batches of replicated gel phantoms were measured independently and the average uncertainty was less than 1%. It was found that the gel has high degree of dose uniformity in high dose region where dose percentage is from 60% to 100 %, and the gamma pass rates were between 90% and 92% at 40 mm depth with 3% dose difference and 3 mm distance-to-agreement (DTA) criteria. However, if the penumbra region was taken into account, it showed the lower pass rates between 80% and 84% with the same criteria. From the comparison of line profiles between TPS and the data measured by optical CT, it was found that the dose was over estimated in penumbra region which was caused by two factors. The first is the scattering light due to refractive index change in the edge of irradiated field. The second is the edge enhancement caused by free radicals diffusion. But the effect of edge enhancement in NIPAM gel dosimeter was not severe as that in BANG gel dosimeter. To achieve high accuracy of 3D dose distribution, different recipes of NIPAM gel dosimeter will be used to reduce the effect of edge enhancement. The results also reveal that the NIPAM gel dosimeter is highly stable and has potential in clinical radiotherapy.

Feasibility of Using Thermoluminescent Dosimeters to Monitor Entrance Surface Dose in Mammographic Survey

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The anual mammographic survey has been conduted by the Bureau of Health Protectionin in Taiwan since 2003. Due to near 200 mammographic systems in Taiwan, the manpfower and budget for national survey are huge. Hence, using themoluminescent dosimeters (TLD) to monitor enetrance surface dose (ESD) was proposed to replace on-site measurements by ionization chambers. The ESD measuremtns by TLD-100H (Harshaw) have been complete in 66 mammographic units. The ESD distribution was in the range of 2–15 mGy and mostly fell around 7.5 mGy. The ESDs estimated by TLDs are agree (to within 10%) with those by ionization chambers. The influences of TLD calibraion sources and residual doses have be discussed in this study. TLD measurements provided a reliable, simple mean to monitor mammography exposure doses on a periodic basis.

Dosimetry of dose distributions in radiotherapy of patients with surgical implants

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The investigation was performed in order to compare radiotherapy dose distributions in tissues surrounding the titanium or resorbable implants used clinically for joining and consolidating of the facial bones. Inhomogeneous dose distributions can be a reason of the normal tissue complications observed during the radiotherapy of patients after surgery during which the titanium plates were implanted. The knowledge about the distribution of the dose around the implants would help to decide whether to preserve or to remove the implants before irradiation. The commonly available resorbable implants require comparing them with the titanium implants in case of patients requiring radiotherapy after surgery. The dose distributions around the titanium and around the resorbable implants were measured and compared. Nucletron Oncentra MasterPlan treatment planning system (TPS) was used for the calculation of the dose distributions. For measurements, Gafchromic EBT radiochromic dosimetry films were used for recording the dose distributions in tissue equivalent phantoms. The phantoms and films were irradiated with 4 MV photon beams of Varian Clinac 600C/D linear accelerator. The irradiated films were digitized with Epson 10000XL flat bed scanner and the dose distributions were compared using [3]Cognition FilmQA software. The dose measured on the contact surfaces between the titanium implant and the phantom material proximal and distal to the beam source at depth of 2.5 cm were 109% and 92% of the reference dose measured in homogenous tissues without the implants, respectively. For the resorbable implants the doses measured on the proximal and the distal contact surfaces were 102% and 101% of the reference dose respectively. The distortions of the homogenous dose distribution around the implants appear only at the distance of few millimeters. The titanium plates significantly affect the homogeneity of the dose distribution and create the underdose and overdose regions. Apart of these effects the presence of the titanium implants during the computer tomography examination creates the image artifacts which may significantly disturb the target volume delineation as well as the early detection of the recurrent cancer in the cavities after surgery. The resorbable implants affect the homogeneity of dose distributions in significantly lesser degree in the irradiated media and their presence does not generate the image artifacts during CT examinations.

Used the TLD-100H to assess the clinical radiation dose of 64-MSCT coronary angiography

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Purpose: Multi-slice computed tomography (MSCT), in the radiology imaging equipment and technology fields, with the latest progress. However, the radiation dose of MSCT produces far more than conventional x-rays, computed tomography coronary angiography (CTCA) in particular is even. Taiwanese have a high risk for coronary heart disease mortality. Physicians often choose to accept the CTCA. We are very worried about the adverse effects of radiation. So, we do experiments to assess the effective radiation dose of CTCA.

Materials and Methods: In our study we used 64-MSCT (TOSHIBA Aquilion 64 multi-slice CT, Japan), RANDO Phantom and TLD-100H. We follow the actual program execution scan measurement accepted the absorbed dose in cardiac and critical organs. ICRP does not take the heart as the critical organ. This study attempted to use the ICRP 103 report, a proposed value is 0.06, as the heart weighting factors.

Results: The heart of the effective dose was 0.850 mSv, within the scan range, the breast tissue was 1.543 mSv; the liver was 0.542 mSv; lung was 1.637 mSv; esophagus was 0.526 mSv, the stomach was 1.603 mSv; the total body effective dose was 8.405 mSv.

Conclusion: CTCA can achieve reasonable as long as the medical needs of its risks relative to the diagnostic information obtained is smaller. Clinicians should be aware of CT scan radiation can cause potential harm, and carefully assessed and weighed, can reach the most impressive benefits.

Dose Verification of a Clinical Intensity-Modulated Radiation Therapy Eye Case by the Magnetic Resonance Imaging of N-Is

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In this study, N-isopropylacrylamide (NIPAM) polymer gel together with magnetic resonance imaging (MRI), was used to measure the relative three-dimensional dose (3D) distribution of an intensity-modulated radiation therapy (IMRT) eye case. The gels were enclosed in cylindrical acrylic vessels with 10 cm outer diameter and 10 cm length. The gels were subsequently irradiated by delivering 5 Gy of a prescribed dose with a 6 MV linear accelerator using five fields. The 3D maps of the proton relaxation rate R_2 were obtained using a 1.5 T MRI system correlated with the dose. The treatment planning system (TPS) data and NIPAM gel dosimeter data were compared with the experimental results in the form of relative dose distributions, including isodose curves, dose profiles, and gamma index maps. Results indicated that the linear relationship of the R_2–dose for NIPAM gel dosimeters reached 0.999 within the dose range of 0 Gy to 12 Gy. Comparison of planar dose distributions among the gel dosimeters and TPS showed that the isodose lines corresponded to selected planes in the axial plane. For the 50% to 110% dose analysis, the maximum dose differences varied from 4.04% to 13.53%. Gamma evaluation of the planar dose profile resulted in pass rates of 96.84%, 83.16%, and 53.42% when using the acceptance criteria of 3%/3 mm, 2%/2 mm, and 1%/1 mm, were used respectively, in the axial plane. Overall, these results showed that NIPAM polymer gel dosimeters can serve as a high-resolution, accurate, 3D tool for IMRT dose distribution verification.

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Real-time dose profile of volume-scan tube current modulation

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Automatic tube current modulation (ATCM) modulates the tube current in the x-y plane and z-axis according to the patient size and shape, or the attenuation of the body. Adaptive iterative dose reduction 3D (AIDR 3D, Toshiba) is an iterative reconstruction technology to reduce image noise. If ATCM system is properly optimized and combined with ADIR 3D, it can reduce radiation dose while maintaining sufficient image quality. Special attention is needed while scanning multi-anatomy region such as neck and chest in a single volume. The purpose of this study is to evaluate the real-time dose profiles of a cone-shaped phantom in a 320-detector row CT scanner using the Toshiba ATCM system.

A homogeneous elliptical cone-shaped phantom was scanned with a 320-detector row CT scanner (Aquilion ONE, Toshiba Medical System, Japan) equipped with the integration of adaptive iterative dose reduction 3D (AIDR 3D, Toshiba) into the ATCM system ($^{\text{Sure}}$Exposure 3D, Toshiba). Real-time dose profiles were measured by using a high-sampling rate solid-sate detector (CT SD-16, RTI, Sweden). The detector was inserted into the isocenter of the phantom during scan, and placed at the center of scanning volume at different z-axis locations. Images were evaluated on ImageJ, and square regions of interest (ROIs) of 115 mm^2 were measured above the center position of the phatom as a noise measurement.

Peaks of the dose profiles were present when X-ray tube rotated to the short axis of the phantom. The attenualtion of the pathlength in the short axis was smaller than other directions, hence, the probe measured higher dose rates.

Dose Verification of RapidArc with Electronic Portal Imaging Device for Nasopharyngeal Cancer

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The Volumetric modulated arc therapy (RapidArc) was applied in our center since 2010. The beam delivery in Rapidarc has variable factors such as machine dose rate, gantry speed and leaf motion, so the quality assurance of the treatment planning is important. Ten nasopharyngeal cancer patients using Eclipse treatment planning system were selected in our study. The Electronic Portal Imaging Device (EPID) is suitable for the dose verification because of its high spatial resolution and real time image. First, the 6 MV photon beams of RapidArc were delivered to the EPID. Then the planning and the measured dose distributions were analyzed with the gamma method in the EPIQA software. The 3% dose differences and 3 mm distances to agreement were set as the acceptance criteria in the gamma method. Finally, the pixel will be satisfied the acceptance criteria if the gamma value was less than 1. The results shown more than 90% pixels of the treatment planning was agreed with the measured dose in filed region. In a word, dose verification in RapidArc planning was successfully performed by using EPID.

Low-cost commercial glass beads as dosimeters in radiotherapy

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Recent developments in advanced radiotherapy require small detectors to determine the delivered dose in high dose gradient fields.

Commercially available glass jewellery beads exhibit thermoluminescent (TL) properties and have the potential to be used as dosimeters in radiotherapy due to their small size (2–3 mm diameter and 1.1–2.3 mm thickness), low cost, reusability and an inert nature. This study investigated the dosimetric characteristics (radiation response, reproducibility, linearity, fading, dose rate dependence, angular dependence and minimum detection limits (MDL)) obtained for eight colours of acid-washed glass beads (MillHill, Stodard, WI, USA; 2mm diameter), irradiating with 6 MV photons using a medical linear-accelerator and ^{60}Co gamma rays over doses ranging from 1 to 2500 cGy. Measurements were performed in a water equivalent phantom (Solid Water®). A TL system and an electron paramagnetic resonance (EPR) system were employed for read out.

Both TL and EPR studies demonstrated a linear radiation-induced signal, the sensitivity varying with bead colour, presumably due to different impurities. White beads proved to be the most sensitive for both systems and were chosen for further investigations. For the white 2 mm beads the MDL of the TL system was found to be 1 cGy while that for the EPR system was approximately 1000 cGy for the particular spectrometer used. The fading rate was 10% 40 days after irradiation for both systems. The TL system was chosen for further investigations due to its considerably higher sensitivity, lower cost and ease of use.

In order to have sets of similarly sensitive dosimeters, beads were screened in terms of their weight and their radiation sensitivity and grouped in batches. The dose response is linear from 1 to 2500 cGy, with an R^2 correlation coefficient of > 0.999. The batch-to-batch reproducibility of a set of dosimeters after a single irradiation was found to be 3% (1SD). The standard deviation for reproducibility of individual dosimeters was found to be 1.7%. The angular dependence of the beads was measured to be $< 1\%$ for angles of 90°, 45° and 0° from the bead axis taken as that of the hole through the bead. The dose rate response was found to be the same to < 1 % for dose-rates, from 100 cGy/min to 600 cGy/min.

These results demonstrate the potential for use of glass beads as TL dosimeters over the photon dose range commonly applied in radiotherapy.

Dosimetry verification of conformal techniques used in stereotactic radiotherapy at Lower-Silesian Oncology Centre in Wr

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Introduction In radiotherapy the correctness of dose delivery is very importance. In SRT the quality control is usually limited to accelerator control: dose rate control, and geometry. In DCO verification system has been extended with the control of treatment planning system – TPS. Dose distributions have been compared with measurement on the accelerator. %

Objective The objective of the article is an evaluation of the dose calculation correctness for conformal and arc techniques.

Material and Method The verification has been performed for 3D and arc in TPS-iPlan for MLC120 and m3, for 6, 10, 18 MV in Eclipce TPS for MLC120, for 6, 18 MV. The 2-Gy dose has been calculated for 5 cm. Calculations for MLC120, have included fields, for a combination of 13 fields from 10×10 to 1×2 cm. For m3 small fields scope has been extended to 0.6×0.6 cm. The measurements have been performed in water phantom with two chambers type Pin Point PTW (0,015 cm^3), (0,016 cm^3).

Results Differences between planned dose in iPlan system and measured dose for 3D were: for MLC120: for 6 MV ($\Delta_{sr} = 0,3\%, \Delta_{max} = 1,8\%$), for 18 MV ($\Delta_{sr} = 0,5\%; \Delta_{max} = 3,5\%$); for MLCm3: 6 MV ($\Delta_{sr} = 0,7\%, \Delta_{max} = 2,5\%$), 10 MV ($\Delta_{sr} = -0,5\%; \Delta_{max} = -4,6\%$). For arc technique the differences for iPlan system were: for MLC120: 6 MV ($\Delta_{sr} = 0,4\%, \Delta_{max} = 1,9\%$), 18 MV ($\Delta_{sr} = 0,1\%; \Delta_{max} = 3,1\%$); for MLCm3: 6 MV ($\Delta_{sr} = 0,3\%, \Delta_{max} = -4,5\%$), 10 MV ($\Delta_{sr} = -0,7\%; \Delta_{max} = -5,6\%$). Differences in Eclipce for 3D technique were: for MLC120: 6 MV ($\Delta_{sr} = 1,6\%; \Delta_{max} = 3,3\%$), 18 MV ($\Delta_{sr} = 3,9\%; \Delta_{max} = 8,0\%$); yet in the fields scope of more than 3 cm the differences were smaller ($\Delta_{sr} = 2,0\%; \Delta_{max} = 5,1\%$), for arc the differences for Eclipce were for MLC120: 6 MV ($\Delta_{sr} = 1,8\%; \Delta_{max} = 3,9\%$), 18 MV ($\Delta_{sr} = 4,3\%; \Delta_{max} = 7,8\%$), yet in the fields scope of more than 3 cm the differences were smaller ($\Delta_{sr} = 1,7\%; \Delta_{max} = 4,4\%$).

Discussion At the DCO the planning of SRT is performed only in iPlan, whose correctness of working has been shown for 3 energies, 2 types of collimators. Plans for extracranial stereotactic can be additionally calculated in Eclipce. A mutual conformity of these systems in allows the use of two independent calculation methods.

Dosimetric properties and stability of thermoluminescent foils made from LiF:Mg,Cu,P and $CaSO_4$:Dy during long-term use

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A few dosimetric systems based on thermoluminescence [TL] foils were developed in recent years [1-3]. Major application of these systems is mapping of ^{2}D dose distribution for medical treatment plan verification, similarly to photochromic or radiochromic films. The advantage of TL foils comparing to other films is their reusability. The thermoluminescent foils can be used again immediately after thermal read-out or after additional heating (annealing). The TL foils developed at the Institute of Nuclear Physics in Krakow have been successfully applied for mapping of photon, electron, proton and heavy ion radiation doses. One shortcoming of TL foils is that every heat process may have a negative influence on foils properties, causing changes of their sensitivity. We consider, that main reason of these changes are oxidation of organic contamination on the surface and degradation of a polymer which is one of components of the foils.

In this work we present results of a long term study of TL foils made from LiF:Mg,Cu,P or $CaSO_4 : Dy$ phosphors and high temperature polymers. The dosimetric properties like dose sensitivity, fading, repeatability of read-outs were studied. We especially investigated effects of sensitivity loss, changes in the emission spectra for both type of the foils and changes of the absorption spectra for TL foils.

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Fragmentation of 400 MeV/u carbon and neon beams in different targets

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Nuclear and fragmentation reactions modify radiation field behind the shielding; the knowledge of production of secondary particles can be used for completing or specifying of cross sections of heavier ion's interactions. It is important for example in hadron therapy, radiation protection, or designing of the shielding materials. One of the methods suitable for research of fragmentation processes are plastic nuclear track detectors (PNTD).

This work describes fragmentation of carbon and neon ions measured with PNTD. The detectors behind different shielding were perpendicularly bombarded by C and Ne ions, both with primary energy 400 MeV/u; the irradiations were performed at Heavy Ion Medical Accelerator in Chiba (HIMAC) in Japan. The detectors were placed behind several different materials (PMMA, polyethylene, graphite, Al, Fe, Cu, teflon) of various thicknesses (from the entrance up to the depths around Bragg peak).

An attenuation of primary ions in various materials, as well as spectra of linear energy transfer (LET) for all used materials and various thicknesses of shielding is presented and compared. Careful analysis of LET spectra allows identification of the primary ions and the fragments up to $Z > 2$. From the LET spectra, absorbed dose and dose equivalent is calculated. The contribution of secondary particles and fragments to the total measured dose is up to several tens of percents, depending on the material of the absorber.

A 3D superposition pencil beam dose calculation algorithm for a ^{60}Co therapy unit and its verification by MC simulation

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Dose calculation algorithms play a central role for preparation of the treatment plan in radiation therapy. The goal of the algorithm is to predict accurately the dose delivered to the patient in order to decide if a given plan is clinically acceptable or not. The most accurate calculation method considered is the Monte Carlo simulation and even though some treatment planning systems provide this method, the calculation is still very time consuming. Due to these calculation time demands dose engines based on convolution technique with pencil beam are still widely used focusing on the dose accuracy improvements.

The MCNP code was used to simulate the collimating system of the ^{60}Co therapy unit to calculate primary and scattered photon fluences as well as electron contamination incident to the isocenter plane as functions of the field size. On the basis of the calculated photon and electron spectra a Monte Carlo simulation for generation of the polyenergetic Pencil Beam Kernel (PBK) was performed next. This simulation represents the core for the dose calculation algorithm.

The PBK was analytically fitted to speed up the dose calculation by using the convolution technique in homogeneous media. The quality of the PBK fit was verified by comparison of calculated and simulated ^{60}Co broad beam profiles and depth dose curves in homogeneous water media.

Coefficients for inhomogeneity correction were derived by the PBK simulation in a slab phantom consisting of varying materials. The inhomogeneity calculation model is based on changes in radial PBK displacement and in change of the forward and the backward electron scatter. The inhomogeneity correction is calculated from electron densities taken from a complete 3D CT array and takes into account electron densities through which the pencil beam is propagating and also electron densities between the interaction point and the point of dose deposition.

The calculation model also incorporates the influence of non-zero source diameter and different distances of X and Y secondary jaws from the source. An enhanced algorithm for calculation of divergent beam path intersections with 3D CT matrix was also implemented.

Comparison of the proposed dose calculation superposition algorithm shows better agreement with Monte Carlo simulation than algorithm based on widely used Generalized Batho Power Law correction mainly near inhomogeneity boundaries and in lung tissue.

Use of normoxic polymer gel on dose verification of 1-, 3-, 4-, 6-,14- 30-mm cones for stereotactic radiosurgery

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This study demonstrates the use of normoxic polymer gels on dose verification of 1-, 3-, 4-, 6-, 14-, 30-mm cones for stereotactic radiosurgery which is lack of lateral electronic equilibrium. Two different types of normoxic polymer gels – MAGAT and PAGAT are studied in both larger field (10 cm × 10 cm) and small fields to obtain percentage depth doses, dose profiles, and cone factors. These results were than compared to same measurements using other small-volume detectors and BEAMnrc Monte Carlo simulation. Results show that the dose uncertainty of MAGAT is 7% in large field, and can be reduced to 3.5 % by avoiding the inhomogeneous magnetic field and adding more stirring. However, the uncertainty of PAGAT cannot be reasonable enhanced due to its low sensitivity and bubble problems. In small fields, the dose deviation between MAGAT gel and MC simulation is about 9%, however, the space deviation between MAGAT and MC is less than 0.4 mm mostly. Compared to MAGAT gel, PAGAT has lower sensitivity (about 1/10 of MAGAT) and often comes with some manufacture problems. MAGAT shows good agreement in spatial distribution but not so good agreement in dose distribution. Factors for gel uncertainty are studied including MRI magnetic field inhomogeneity, and oxygen leakage. However, these factors are statistically insignificant since the intrinsic MR-R2 %SD could be 8.7% for MAGAT gel.

Radiation dose assessment for coronary artery calcium score with low tube voltages

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The purpose of this study was to assess the radiation dose with low tube voltages for quantifying the coronary artery calcium score CT examination. An anthropomorphic cardiac phantom (QRM-Cardio-Phantom, QRM GmbH, Germany) was scanned in a 320 detector-row CT scanner (Aquilion ONE, Toshiba, Japan). For all volume scans, a protocol with collimation of 320×0.5 mm, rotation time of 0.35 second, reconstruction slice thickness of 3 mm, and reconstruction kernel of FC12 was used. The tube voltage of 120 kVp and threshold of 130 HU is the standard protocol for quantifying the calcium score. We used low voltages (80 and 100 kVp) to scan the phantom in order to reduce the radiation dose. The threshold of low voltages was calibrated according to Thomas et al. previous study. Three methods (Agatston score, volume score, and mass score) for quantification of calcium score were calculated. The volume CT dos index (CTDIvol) and dose length product (DLP) of each scan were used to compare the radiation dose. For comparing the patient size and accuracy of calcium score, a 360×260 mm acrylic ring was added on the phantom to simulate large patient size. The effect of patient size and calcium score was assessed as well.

Estimation of 3D dose distribution in contrast-enhanced digital mammography using gafchromic XR- QA2 films

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This study was aimed to establish 3-dimensional dose distribution curve for contrast-enhanced digital mammography using Gafchromic XR-QA2 films, which is sensitive to dose range 0.1–20 cGy and energy at around 20–200 kVp. The image acquisition was performed on full-field digital mammography system (GE Senographe Essential) with contrast-enhanced dual energy option. The Gafchromic XR-QA2 film (lot number: A07091204) was used to measure the 3-D dose distribution. For dose calibration, film pieces of 2 cm $\times$ 2 cm were irradiated at the 4.5 cm above the image receptor, centered left to right and 4 cm in from the chest-wall edge of the image receptor. All clinical combinations of target/filter/kVp were included in the calibration. After 24 hours from exposure, we used Microtek ScanMaker i800 to scan the film and further established the dose response curve. To simulate the standard breast for further 3-D dose distribution in mammography, four separate triangular acrylic slabs (1 cm for each slab) equipped with GE Senographe Essential system were used. Five shaped films were placed separately on the top of the first triangular acrylic, between each acrylic, and under the bottom of the last acrylic. Clinical exposure parameters for exposing 4 cm breast were used to expose the acrylic and film to estimate the axial dose distribution at the height of 0, 1, 2, 3 and 4 cm above the image receptor. Depth dose distribution profile could also be obtained from the data. We also investigated the relationship between 3-D dose distribution and average glandular dose (AGD) in mammography.

Testing and calibration of ESR response of Fricke gel dosimeters in mixed neutron-gamma fields

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The applications of Fricke type dosimetric gel are continuously increasing worldwide for its favorable properties. The gel matrix limits the diffusion of ferrous and ferric ions so that if the gel is analyzed within a few hours from irradiation, ferric ions remain close to their point of production. Thus, the spatial integrity of the dose distribution in the Fricke gel is maintained.

The gel also contributes to the oxidation of ferrous ions during irradiation, so as to improve the chemical yield of ferric ions in aqueous solution and to increase the dose sensitivity of the dosimeter to the dose.

The aim of this work is the analysis of the Electron Spin Resonance (ESR) signal of the Fricke gel dosimeter and the correlation of these ESR measurements of the concentration of paramagnetic centers (e.g. Fe^{3+}) with direct measurements of NMR relaxometry. The study contributes to analyze and characterize both the background signal in unirradiated samples and the radiation-induced signal in order to identify the best recording conditions and to define the main signal properties (dependence on the microwave power and modulation field amplitude, width of the lines, signal fading).

In order to assess the response and the efficiency for neutron-gamma mixed fields the dosimeters were irradiated with beams of ^{60}Co photons using the IGS-3 irradiator available at DEIM, neutron-gamma beams inside the core of the nuclear research reactor AGN201 of Palermo University and the neutron fluxes produced by ^{241}Am-Be neutron sources available at DEIM.

The results of the realization of calibration curves versus dose are reported and discussed from the point of view of the dosimeter utilization in clinical radiotherapy.

The use of silica dioxide fibre dosimeters for surface dose measurement in lower limb angioplasty procedures

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The aim of this present study is to investigate the alternative use of novel silica fibre as a thermoluminescence (TL) tool in verifying the surface dose for 20 patients undergoing lower limb angioplasty examination. Prior to examination, the amorphous fibres have been screened to establish dosimetric characteristics of these media, including reproducibility, linearity, fading and energy dependence. Fibres offering suitable dosimetric characteristics, in particular limited to those producing a total uncertainty of less than $\pm 5\%$, have been retained in groups of ten and loaded into plastic capsules, ready for use in the study. Irradiations are to be carried out using interventional modalities located at Hospital Serdang (HS), Selangor, a total of 60 capsules being prepared for subsequent surface dose measurements on the neck, forehead and suprapubic regions. Subsequent to irradiations, read-out will be carried out using Nuclear Malaysia TLD facilities and analyzed according to the methods developed by Noor et al [1]. The optical fibre TL yields will be compared with dose determined through the use of the well-established TL lithium fluoride dosimetry system (TLD-100H) and a dose area product (DAP) meter.

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Characterization Tests of a New Parallel Plate Ionization Chamber for Use in Electron Beams

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Linear accelerators with electron beams are used in several Brazilian hospitals. These electron beams emit radiations with high dose rates. The dose needs to vary less than 5% inside the tumor volume. Consequently, there is an increasing demand for parallel-plate ionization chambers, to be utilized for dosimetry of electron beams. In Brazil, the commercial ionization chambers utilized are imported. Therefore, there is a need to study and develop this kind of instrument with national technology. The ionization chambers have usually a simple construction, using different materials and geometries; they are easy to use, and they are less expensive than other radiation detectors as the Fricke dosimeter and calorimeters. At the Calibration Laboratory of IPEN, several ionization chambers of different types were designed and built for diagnostic radiology, mammography, radiotherapy and radiation protection levels to be applied in different radiation beams. They have different collecting electrode materials, presenting different energy dependence of their response. In this work, a parallel plate ionization chamber, with collecting electrode made of graphite, was developed at IPEN for use in electron beams of a linear accelerator ^{2100}C with energies of 4, 6, 9, 12, 16 and 18 MV, at the Israelita Albert Einstein Hospital. The objective of this work was to perform several characterization tests of the homemade ionization chamber, following international recommendations: short-term stability, polarity effect, determination of the ion collection efficiency, saturation curve and linearity of its response. All results obtained showed accordance with the international recommendations.

Quality control measurements of parallel plate ionization chambers

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A good evaluation of the dose deposited in an organ or tissue is one of the main factors responsible for the success of radiotherapy. The IAEA recommends an accuracy of ± 5% in the patient dose received. To ensure reliable measurements with ionization chambers used in beam radiation therapy dosimetry, these instruments must be periodically calibrated using a reference radiation beam in specific laboratories. The specific laboratories are classified as Primary Standard Dosimetry Laboratory (PSDL) and Secondary Standard Dosimetry Laboratory (SSDL). In Latin America there are no PSDL laboratories. With regard to calibration of parallel plates ionization chambers, which are used in low-energy X-rays and electron beams, Brazil does not have a well established methodology to test this type of instrument. In this work, as part of the project for establishment a methodology for calibration of parallel plate ionization chambers with absorbed dose to water for standard beams between 50 kV and 100 kV, was made an assessment of performance tests of quality control of the reference ionization chambers, PTW 23344, serial numbers 0708 and 0709. Tests included measurements of leakage current before and after irradiation, stabilization time, minimum range of effective dose rate measurement, short and long term stability and the polarized voltage effect. For the measurements, it was followed the recommendations from the manufacturer's manual and from the International Electrotechnical Commission, IEC 60731. For the tests, it was used a Sr-90 check source (26 MBq, 2005). Results show that both chambers have good performance as described in the recommendations and that they may be used as reference, However the ionization chamber serial number 709 showed a better performance than the other ionization chamber (serial number 709). This behavior was observed in repeatability tests, leakage current and polarity stability, with the highest variation between both chambers results of 2% in the test polarity. In the future it will be conduct tests in the X-ray radiation system in terms of air Kerma, as previously established in the laboratory and later, new measurements will be made in terms of absorbed dose to water.

A new standard cylindrical graphite-walled ionization chamber for dosimetry in 60-Co beams at calibration laboratories

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The use of ^{60}Co sources is largely disseminated at dosimetry laboratories, in order to calibrate the ionization chambers utilized for radiotherapy dosimetry, mainly in those laboratories where there is no linear accelerator available. In this work, a new cylindrical ionization chamber was developed and characterized to be used as a reference dosimeter at the Calibration Laboratory of the IPEN. This ionization chamber was entirely made of high-purity graphite, with a sensitive volume of 2.34 cm^3 and a wall thickness of 4.0 mm, to allow electronic equilibrium for ^{60}Co radiation. The central collecting electrode has a diameter of 2.0 mm, and is 16.0 mm long. The support of the collecting electrode and the stem are made of Teflon®. The characterization tests were conducted according to the IEC 60731 standard. All tests presented results within the limits recommended by this standard: the ionization chamber achieved saturation on the whole tested interval (−400 V to +400 V), the highest variation in the stability test was 0.23%, the ion collection efficiency was better than 99.9%, the polarity effect was lower than 0.5%, the leakage current was lower than 0.5% for all tests, the response was linear, and the angular dependence (360° around the central axis) was lower than 0.2%. Furthermore, in order to complete the study of this new dosimeter, Monte Carlo simulations with the EGSnrc code were carried out. The wall of the ionization chamber presented an influence of 1.5% and the chamber stem 0.8% on the ionization chamber response. These results indicate a low influence of the chamber components, as expected for a reference dosimeter. Therefore, the ionization chamber characterized in this work presents potential used as a reference dosimeter at calibration laboratories.

Dosimetric study of a brachytherapy treatment of esophagus with Brazilian 192-Ir sources using anthropomorphic phantoms

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At the IPEN several radioisotopes are produced for use in medical treatments, including 192-Ir sources. These sources are suitable for brachytherapy treatments, due to their low or high activity, depending on the concentration of 192-Ir, easiness to manufacture, small size, stable daughter products and the possibility of re-utilization. They may be used for the treatment of prostate, cervix, head and neck, skin, breast, gallbladder, uterus, vagina, lung, rectum and eye. In this work, the use of the brachytherapy source produced at the IPEN was studied for the treatment of esophagus cancer, especially the dose determination of important structures, such as those on the mediastinum. The dose distribution was evaluated with the use of both MASH and FASH anthropomorphic phantoms [1,2], and using the MCNP5 Monte Carlo code to transport the radiation through matter. The results showed a distribution of doses in some organs, considering a 100% dose on the esophagus cancer, as follows: 0.1% bone-marrow, 0.3% colon, 6.2% lung, 2.4% stomach, 1.3% breast, 0.1% gonodas, 1.0% bladder, 2.6% liver, 3.5% thyroid, 5.1% bone, 0.1% brain, 0.6% salivary gland, 0.4% skin and 11.5% for the heart. These results indicate a small dose distribution to important tissues; therefore, the 192-Ir sources produced at the IPEN show usefulness for esophagus brachytherapy.

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Development and characterization of a graphite-walled ionization chamber as a reference dosimeter for 60-Co beams

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Ionization chambers are the detectors of choice for clinical and laboratory applications due to their good reproducibility, stability, linearity and portability. The standards of air kerma are usually graphite ionization chambers of various designs (sizes and shapes): parallel-plate, cylinder and spherical, for example. In this work, a graphite parallel-plate ionization chamber, assembled at the Calibration Laboratory of the IPEN, was evaluated to be employed as a reference dosimeter in ^{60}Co beams. This ionization chamber consists of two thick graphite layers separated by a thin gas (atmospheric air) layer. In the middle of the ionization chamber, a collecting electrode was inserted. This electrode was also made using graphite with density of 1.77 g/cm^3. In order to characterize this ionization chamber, several experimental tests: stability of response, saturation curve, ion collection efficiency, polarity effect, leakage current and linearity of response, were carried out using a Gammatron ^{60}Co irradiator unit. All results obtained in these tests were considered satisfactory. The maximum value obtained in the stability test was lower that 0.5%, therefore within the international recommendations. The ion collection efficiency was better than 99.99%, and the polarity effect was lower than 0.5%. The leakage current was also lower than 0.5% of the minimum current obtained during the measurements. The behavior of the ionization chamber was linear with the increase of the irradiation time. The simulations were carried out with the C++ user code cavity, which is an advanced EGSnrc application. This code was employed to determine the correction factors of the wall, collecting electrode and chamber stem. The results obtained in the simulations presented a low influence of the chamber components on its response. Moreover, these correction factors could also be used to determine the air kerma rates. Therefore, the ionization chamber assembled and characterized in this work presents potential application as a reference dosimeter.

Response of a PMMA graphite coated parallel-plate ionization chamber in 60-Co beams

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The ionization chambers are the most common type of dosimeter employed in radiotherapy dosimetry. In this work, a parallel-plate ionization chamber, developed at the Calibration Laboratory of Instruments of the IPEN (LCI), was tested to be utilized for dosimetry in ^{60}Co beams. The main advantage in the development of an ionization chamber, for a calibration laboratory as the LCI, is that it allows the knowledge of the dimensions, configuration and composition materials. This information is essential to determine the correction factors or the influence of different materials on the chamber response. Furthermore, the dosimeter evaluated in this work showed to be of simple construction, with easily-available materials, and may be assembled and tested in other calibration laboratories interested in the development and characterization of their own dosimeters. The ionization chamber characterized in this work was made by utilizing PMMA coated with graphite with a sensitive volume of 6.3 cm^3. The tests undertaken in order to evaluate the dosimeter in the ^{60}Co beams were: stability, saturation, ion collection efficiency, polarity effect, leakage current, angular dependence and linearity of response. These tests were undertaken according to the IEC 60731 standard, and all results were within the recommended limits. The maximum variation obtained in the stability test was lower than 0.5% and the leakage current was lower than 0.3%. The maximum polarity effect observed was 0.4% and the collection ion efficiency was better than 99.99%. In the test of linearity of response, the correlation coefficient (R^2) was 1.000, and the maximum variation obtained in the angular dependence test was only 0.3%. Besides that, some Monte Carlo simulations, utilizing the PENELOPE code, were made to verify the influence of some components (collecting electrode, stem and insulator) on the ionization chamber response. The simulations showed a small influence of the studied components on the chamber response. Therefore, with the experimental and simulation results obtained, it is possible to verify that the ionization chamber tested in this work has applicability for dosimetry in ^{60}Co beams.

Comparison between two calibration systems for direct and attenuated radiation qualities, diagnostic radiology level

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According to the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), medical exposures contribute about 20% of the average annual per caput dose to the global population. Annually there are approximately 3.1 billion diagnostic medical radiological examinations. Therefore, it is very important to develop and maintain a quality control program for the verification of x-ray systems. A very important step in a quality control program, at calibration laboratories, is the establishment of laboratory intercomparisons. In this work, a comparison between the calibration laboratories of IPEN, São Paulo, and CDTN, Belo Horizonte, Brazil, both from the Brazilian Nuclear Energy Commission, was carried out, as part of the quality control program in the metrological network established by the project "National Institutes of Science and Technology – Radiation Metrology in Medicine". The comparisons were undertaken for direct and attenuated diagnostic radiology beams RQR and RQA. The comparison was based on the determination of calibration factors (N_k) of two ionization chambers and of the PPV quantity. The RQR radiation qualities were compared with a Radcal ^{10}X5-6 ionization chamber and the RQA qualities with a Radcal RC60, both itinerant standards. The PPV quantity was measured for the RQR radiation qualities with a PTW diavolt non-invasive meter. The results showed a good agreement between both calibration laboratories. The results obtained showed a maximum difference of 3.0% for the N_k values and of 0.77% for the PPV quantity. It is possible to conclude that both laboratories are within an acceptable range for their calibration systems, at diagnostic radiology level.

Fabrication of a novel 2D ion detector for nanodosimetry

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Due to the growing interest to analyze radiation induced carcinogenesis, the field of research towards the measurement of cluster size distribution produced by both directly and indirectly ionizing radiation on nanometer scale is increasing rapidly. Available techniques in the field of nanodosimetry explained the interaction properties of directly ionizing radiation alone in nanometric scale but not indirectly ionizing radiations especially neutron and also the relevant research is going on in very few centers worldwide. There are few types of nanodosimeters such as electron counting, ion counting nanodosimeter and Jet counter. Developing a hybrid nanodosimeter which is a combination of electron and ion counting nanodosimeter could be a note worthy step in the field of nanodosimetry. A detector array for single–ion registration was developed. The patterned detector structure, comprising sub-millimetre pitch, ground and ^{2}D readout electrodes, were manufactured using standard PCB technology. A glass cathode was utilized to allow the limited discharge mode of operation. Essentially, the new detector is a combination of a hole-type micro-pattern detector and a resistive plate counter operating at reverse polarity in a low pressure gas. Possible applications of the new ion detector in gas chromatography-mass spectroscopy and track structure imaging for radiation protection and hadron therapy.

Evaluation of entrance surface dose in pediatric chest radiography

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In the present work absorbed doses by pediatric patients in chest radiographies were measured in x-ray examinations in AP/PA and LAT projections. The patients were divided in age groups of 0–1 year, 1–5 years, 5–10 years and 10–15 years. The examinations were made at the pediatric room of the Clinical Hospital of the Federal University of Paraná. The entrance skin dose was measured with thermoluminescent dosimeters TLD-100. The dose was also determined with the software DoseCal that calculates the dose for each patient, from the X-ray equipment yield. The program uses the following data as input: patient mass, age, skin-focus distance, radiographic technique (kV, mAs), and the yield measurement made with an ionization chamber for calibration. The measurements obtained with the TLD dosimeters and the DoseCal software were compared in order to check the reliability of the values obtained with the software. The remaining values of the dose were obtained only with the DoseCal software. The evaluated data showed higher doses for the younger patients. A change in the radiographic technique of the examinations resulted in a reduction of the doses. The obtained results were compared and are within the reference dose values established by the European Community.
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Dose evaluation of a blood irradiator using fricke gel dosimeters

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Blood irradiation is routinely performed as a process of inhibiting the proliferative capacity of lymphocytes and reduces the risk of transfusion-associated graft-vs-host disease (GVHD). The conventional irradiator used for blood sterilization comprises a Cs-137 radiation source and a rotation system. A review of dose distribution at different points inside the irradiator is critical to the quality control of the irradiation process. The Fricke Gel dosimeter allows obtaining phantoms tissue equivalent which enables three-dimensional scanning of the dose distribution when measured by Magnetic Resonance Imaging – MRI technique. The objective of this work is to evaluate the three-dimensional dose distribution of a Gammacel 3000 irradiator employing Fricke Gel dosimeter and magnetic resonance imaging and optical absorption techniques. PMMA cuvettes filled with Fricke Gel solution were positioned mapping the irradiation field (canister), irradiated with 25 Gy and evaluated using both techniques. The Fricke Gel solution dose response curves were obtained to ^{60}Co and ^{137}Cs gamma radiations using the same PMMA cuvettes.

Correlation between OSL signal bleaching of the Al_2O_3:C detectors and effectiveness of ilumination time

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The Optically stimulated luminescence (OSL) technique has already became a successful tool in personal dosimetry, geological and archeological dating, and in radiation diagnostic imaging [1] (Akselrod et al., 2007). High sensitivity, precise delivery of light, fast readout times, simpler readers and easier automation are the main advantages of OSL in comparison with thermoluminescence dosimetry (TLD) [1, 2, 3] (Akselrod et al., 2007; Yukihara and McKeever, 2011). The Al_2O_3:C currently used in personal dosimetry is grown in the form of single crystals. Single crystals of 5 mm in diameter by 0.9 mm thickness cut from boules have been widely used in TL dosimetry since the 1990s [2] (Yukihara and McKeever, 2011). Al_2O_3:C single crystals can be annealed (heated to high temperature) or bleached (illuminated with light of appropriate wavelength) to empty the trapping centers associated with the OSL signal and erase the OSL signal due to natural background radiation or previous irradiation. The single crystals have the advantage that they can be used almost indefinitely, since the detector can be annealed to reset its sensitivity. The disadvantage is the inherent variability in sensitivity from crystal to crystal due to inhomogeneities in the concentration of defects, especially along the length of the original crystal boule. For this reason, pre-selection of the detectors or individual detector calibration is necessary to achieve good precision [2, 3] (Yukihara and McKeever, 2011). This work aims to study the correlation between OSL signal bleaching of the Al_2O_3:C detectors and effectiveness of ilumination time for different doses in beta dosimetry. The Al_2O_3:C detectors were illuminated for increasing times using blue LED coupled in a dark box and the OSL signals were obtained for different doses. The best combination between dose and bleaching time of the Al_2O_3:C detectors was analyzed.

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Energy dependence TL response of $CaSO_4$:Dy for different phantoms and clinical photon beams

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In the last decade radiotherapy has been the object of a technological revolution because of the new techniques developed such as Three Dimensional-Conformal Radiation Therapy and Intensity Modulated Radiation Therapy (IMRT). The clinical use of these techniques requires a complete knowledge of the imaging of the volumes to be treated and also the dosimetry of the clinical electron and photons beams that are used in those cases. Thermoluminescence (TL) or thermally stimulated luminescence has been actively developed in the past years due to its reliability, sensitivity and commercial availability and is currently in use with LiF: Mg, Ti (TLD-100) commercial dosimeters in the dosimetric quality assurance of the output of therapy machines which must be verified routinely. This work proposes the use of $CaSO_4$:Dy sintered discs as an alternative to LiF commercial dosimeters in the radiation therapy dosimetry of photon beams, studying the photon energy dependence response with energies ranging from 33keV to ^{6}MeV using an water filled phantom ($30 \times 30 \times 15$ cm^3), a PMMA and a solid water phantom. $CaSO_4$:Dy was chosen because is one of the most useful and sensitive thermoluminescent dosemeter material for radiation dosimetry, and in the form of sintered discs are very suitable for applications requiring a large number of measurements. The thermoluminescence dosimetry reader 5500 (Harshaw Model) was employed for the readout of the irradiated dosemeters. Results on reproducibility, radiation dose response and energy dependence show the possibility of their use for the dosimetry of clinical photon beams.

Measuring Diagnostic Reference Levels for common diagnostic projections in Sydney hospitals

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Between 1993 and 2010 there has been close to a 30% increase in the number of X–ray procedures performed in Australia per year. Therefore, it is becoming more important to develop methods to monitor and reduce the radiation doses received. A proven method of dose reduction is the implementation of Diagnostic Reference Levels (DRL). Although DRLs have been established in many countries, none have been documented in Australia. The aims of this study are to investigate the current level of patient radiation doses in two practices, introduce local DRLs for 4 common projections, and compare these DRLs to international DRLs. This study will provide a basis for a national DRL measurement framework.

Internationally accepted guidelines and criteria have been adhered to in this project to measure entrance skin doses (ESD) for 4 common diagnostic X-ray examinations; PA chest, supine abdomen, AP pelvis and AP lumbar spine, in two Sydney based radiology practices, one using a CR system and one using a DR system.

The most sophisticated dose measurement material currently available, MCP–N powder has been used. This is an ultra-high sensitive thermoluminescent material (LiF:Mg,Cu, P). MCP–N is useful for measuring low doses and is up to 40 times more sensitive than TLD-100 (LiF:Mg,Ti). Volumetric dispensing was used to divide annealed powder into gelatine capsules. The capsules were exposed to known doses of air kerma ranging from 10 µGy to 4mGy, using Cs-137 sources whose outputs are traceable to the Australian Primary Standard maintained by ARPANSA. Conversion factors for each batch of annealed powder were calculated.

During 10 exposures for each projection, a powder capsule was attached to the skin surface to measure the ESD. The 75th percentile dose will be used to establish the local DRL for each projection.

The DRLS measured for one practice are as follows: Chest = 0.16 mGy, Abdomen = 2.54 mGy, Pelvis = 2.47 mGy and Lumbar spine = 5.96 mGy. These dose levels are comparable, or lower than DRLs in Ireland, UK and those of the European Commission. Analysis on the second centre is currently being performed.

In this study ESDs for four common examinations have been investigated. Local DRLs for these practices are being established and compared to international DRLs. If these DRLs are implemented they would promote a reduction in the variability of ESDs. This project will set the precedent for a national scheme for patient dose reduction.

The Current Situation of Cervical Brachytherapy in Brazil

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In order to check the current status of intracavitary brachytherapy in the treatment of cervical cancer conducted in Brazil, with respect to equipment, planning methods, prescriptions, evaluations and dose fractionings in organs at risk, a questionnaire containing relevant questions to these themes was referred to radiotherapy services throughout Brazil in 2012. The list of the instituitions participants was obtained in the electronic site of the Brazilian Society of Radiotherapy. Previously, the questionnaire was validated by a group of physicists and radiotherapists experts. The questionnaire consisted of 09 multiple choice questions. From the data analyzed, queried the 166 centers, 91 are operational and 73 reply the questionnaire. Approximately 60% of centers reported using only radiographs for performing brachytherapy planning and only 31% said they have equipment capable of supporting planning in three dimensions. The vast majority said that the sessions are held after brachytherapy. There was not much difference between the institutions on the prescribed dose and type of fractionation. All doctors consulted said they use the points described in ICRU 38 to prescribe and evaluate the dose and only 3% reported using some alternative method. Much of the centers of Brazil brachytherapy is provided with sophisticated processing equipment, allowing better tumor localization and most effective treatment. However, what we see is that there is little difficulty in access to routine imaging equipment such as CT scanners and MRIs.

Test of polyethylene phantoms filled with water in peripheral dosimetry in radiotherapy

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Humanoid phantoms, made of polyethylene and filled with water, were developed to be used in peripheral dosimetry in radiotherapy. They represent different groups of patients: two females – in early and late pregnancy, a male and infants of 2, 5 and 10 years. Peripheral doses using a male and an Alderson phantom were compared, both submitted to 6, 15 and 18 MV cranial beams. In regions close to the beam, where cancer induced by radiation occurs more often, the dose difference is not more than 13%, which allows the humanoid phantom to be used to estimate doses in these regions. Uncertainties in the thyroid region grow from 0.7% to 5% with increasing the distance from the beam. In peripheral pediatric dosimetry for cranial treatments, the dose to the thyroid was 0.2% of that delivered to the isocenter in radiosurgery. Cone or mMLC, 0.28% for IMRT sliding window, 1.4% for IMRT step and shoot, 2.9% for compensator-based IMRT and 0.23% for VMAT, were used. It was observed that each pair of double-exposure portal-films of positioning verification added 0.13 cGy to the thyroid. The fetal dosimetry in treatments of breast cancer showed that different field settings and accessories produced quite different peripheral doses. The measurements showed that is important to use a lead shield in the abdomen region, because with it the attenuation of the radiation to the embryo/fetus is significant. Water humanoid phantoms are lightweight, easy to handle and have a low cost. Therefore, it is recommended to use water humanoid phantoms to estimate peripheral doses, in order to help the clinical staff to choose among treatment techniques, create protective shields or even transfer the patient to a more suitable machine. The authors want to thank the Brazilian agencies, SETI, CAPES, CNPq and Fundacao Araucaria for financial support.

Research on Radiation Exposure from CT Part of Hybrid Camera and Diagnostic CT

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This paper deals with the issues of radiation dose estimation from the CT. At first, research on radiation exposure from CT part of hybrid camera exercise in seven different Departments of Nuclear Medicine was conducted. Processed data and effective dose estimations (E) let to idea of phantom verification and comparison of absorbed doses.

Gathering necessary data and entries from examinations, together with basic documentation of the CT devices, was the first part of this research. Thanks to great consequent cooperation with participating DNM personnel, data from about 100 examinations in average from each DNM was gathered. The selected data was then processed and utilized by dose estimation programs (ExPACT, ImPACT, ImpactDose) with respect to the type of examination and examination procedures.

The effective dose in each program was estimated for each individual case using ExPACT, ImPACT, ImpactDose programs. Preserving the same procedure in dose estimating process allows us to compare the resulting dose computed by each program. E in this research varies from 1 mSv up to 12 mSv (depending on software and type of examination). Some differences and disproportions during dose estimation led to idea of estimated E verification.

Consequently, two different sets of about 100 of TLD ^{100}H detectors in form of round disks were calibrated for measurement within Aldersnon RANDO Anthropomorphic Phantom. Standard examination protocols were examined using a 2 Slice CT- part of hybrid camera. Moreover, patient exposure from body examining protocol for 32 Slice and 64 Slice diagnostic CT scanner was verified too. $D_{T,R}$ measured using TLD detectors was compared with H_T values estimation, computed by Effective dose estimation software. Only limited number of cavities for detectors enabled measurement within the region of lung, liver, thyroid and spleen or pancreas.

As the result, $D_{T,R}$ measured values are smaller than H_T estimated by ImPACT and ImpactDose (30% smaller for lungs and from 5% to 20% within liver and thyroid) for CT Emotion Duo. This may indicate over estimation of the effective dose from the examination. However diagnostic CT measurement indicates possible problems. $D_{T,R}$ measured values are 5% to 100% higher than H_T estimated from examination by diagnostic CTs. Comparison of measured and estimated values for Nuclear Medicine CT and diagnostic CTs indicates some disproportions probably in dose estimation process. Continuation of the research is being planned.

Dosimetry of Electron Beam Extracted from Betatron by Polymer Films Gafchromic EBT 3

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Intraoperative radiotherapy is a treatment modality for a locally advanced tumor of the abdomen, pelvis and breast, which involves the use of large single dose of radiation delivered to the tumor or bed of tumor and areas of potential regional spread during the surgical operation. This treatment modality is mostly based on the electron beams of MeV energies. One chooses the electron beam for such a treatment because of particular dose distribution in the tissue-equivalent environment; namely, a depth dose distribution has a plateau that starts directly at the surface of irradiated volume and a rather steep slope that depends on the electron energy.

Nowadays, most of the clinics worldwide which carry on the IORT procedure use the electron sources based on the compact linear accelerators. However, in Russia historically several clinics have been using the sources based on betatrons that have been manufacturing at Tomsk Polytechnic University. The main advantages of the betatrons are the possibility to change the beam energy in a wide range with small steps (e.g. 1-3.5 MeV with spacing 0.1 MeV), low energy spread of the beam and the relatively low cost of a device (typically $200 000). These days our team develops new generation of betatrons with extracted electron beam for IORT and skin cancer treatment.

For the commissioning of accelerators before operation in a clinic it is necessary to carry out a set of clinical dosimetry procedures, for example, to measure the dose at a reference point or to determine the dose distribution in a reference phantom. One can carry out these procedures using robust ^{2}D dosimeters based on ionization chambers, solid state detectors or polymer films. Due to tissue equivalence and ease of operation the film has become a very attractive option for the dosimetry of the electron beams. This dosimeter type allows to measure at the same time the absolute values and the spatial distribution of the absorbed dose with a high resolution. According to the manufacturer the polymer film Gafchromic EBT 3 can be used both for dosimetry of photon beams and electron ones.

In this report we present the absolute distributions of the absorbed dose of electron beam generated by a prototype of the next-generation betatron for medical purposes. The beam energy varied from 1 to 3.5 MeV at 500 keV step. All measurements were performed in tissue-equivalent phantom with zero air gap. The results show that obtained distributions of the electron beam in a tissue-equivalent environment for all energies of betatron coincide rather well with theoretical simulations.

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Occupational and ambient exposure from patients treated with iodine-131

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Radioactive iodine (RAI) therapy is a targeted treatment improves the survival rate of patients with thyroid cancer with cure rates in excess of 90 percent. The I-131, which is β-emitting (0.61 MeV) and contributes up to 90% of the therapeutic dose, is often the radionuclide of choice for thyroid treatment. As consequence, the patient becomes a source of relatively high energy γ-radiation (364 keV) which considered a potential radiation source for staff, family members and the environment. The objective of this study were to measure the radiation exposure from patient treated with I-131 during hospitalization and estimate staff accumulated dose and related risk during preparation of iodine.

The study was carried out at Almek Nimir University hospital, Sudan. A total of 34 patients were investigated (21 females and 13 males). Radiation exposures to hospital personnel attending these patients were calculated as a function of administered dose distance from the patient and at different times after the administration. A calibrated ionization chamber and thermoluminescent dosimeters (TLDs) were used to measure the ambient dose and staff dose, respectively. The patients received Sodium Iodide I-131 capsules doses ranging from 37 to 4810 MBq at the time of calibration. The radiation dose was measured at three consecutive days after the administration of during patient hospitalization. Data were collected to investigate the rate of iodine decay per days of hospitalization. The mean and the range of patient age, weight and Body mass index(BMI) were 37.5 $\pm$15.3 (20-73), 68.1$\pm$11.2, (47-93), 25$\pm$4.9, (20.0-39.7), respectively. The staff exposure was below the annual dose limits in the light of the current practice and workload. Radioiodine activity depends on many factors such as gender, clinical indication, body mass index and age. Hospitalization of non self-supporting patients for several days can increase exposure of family members. Patient education and proper isolation and waste control are crucial in order to avoid unnecessary radiation exposure.

Evaluation of Radiation Dose To Pediatric Patients During Some Special Procedures

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Diagnostic radiology plays an important role in the assessment and treatment of the patients in the modern medicine. Pediatric are more radiosensitive than adult due their rapidly dividing cells and their long life expectancy thereby providing a extended time for radiation induced cancers to be expressed. In addition, pediatric often have multiple examinations, especially in their early years of life. Therefore, radiation doses to pediatric should be evaluated. This study was intended to measure patient entrance surface dose and effective dose during the following procedures: barium studies (baium meal, enema, and swallow), micturating cystourography (MCU) and intravenous urography (IVU) for pediatric patients.

Entrance surface doses (ESDs) were measured for patient using calibrated thermo luminance Dosimeters (TLDs, GR200A) and DoseCal software. Effective doses (E) were calculated using the national Radiological Protection Board (NRPB) software.

A total of 236 pediatric special pediatric procedures were investigated. 21.7% of the sample was barium procedures, 18.6% were undergone MCU procedures while 59.5% of the sample were IVU procedures. The mean ESD (mGy) were 2.1 ± 0.8, 3.0 ± 23 and 1.2 ± 0.2 for barium meal, enema and swallow at the same order. The mean patient dose for IVU procedure was 12.4 ± 8.7 mGy per procedures and the mean patient dose per MCU procedure was $5.7\ .5 \pm 7$ mGy per procedure. The mean and range of the effective dose was 12 mSv (2.47–64.1) mSv per procedure. The unnecessary radiation exposure can be reduced significantly by reducing the number of films and screening time. The patient doses were slightly higher compared with previous studies. The unnecessary radiation exposure can be reduced significantly by using a good imaging protocol and technologist experience and well defined diagnostic reference level (DRL).

Measurements of radiation dose and risk assessment for patients undergoing multiple radiographs in lumbar Spine and Int

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Patient radiation dose was measured for 120 patient who underwent multiple radiographs in lumbar Spine and Intravenous Urography (IVU) clinical examinations in six hospitals in Khartoum, Sudan. Entrance Surface Air Kerma (ESAK), and kerma area product (KAP) per radiography were determined by using the tube output, the patient exposure parameters and radiation field size at the patient entrance. Body organ dose and effective dose are estimated using CALDOSE software [1]. Average doses are summarised in Table 1. Body organ dose and effective dose will be presented.

References:

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Exam	Sample	Projection	ESAK (mGy)	DAP (cGy cm^2)	Comulative ESAK (mGy)
Lumbar Spine	40	AP	9.5± 2.5	1577±726	
		Lat	19.7±5.3	3471	29.2
IVU	80		3.2±0.7	414±130	12.5±3

Table 1: Typical Doses in lumbar Spine and Intravenous Urography (IVU)

Radiation Doses to children from Multislice CT examinations in Sudan

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Materials: This study was performed to evaluate the radiation doses incurred to patient during CT examinations of the children in six clinics in Khartoum area, Sudan. Patient data and scan parameters were collected from six hospitals and a sample of 161 children who underwent head and abdomen CT examinations.

Methods: The CT dose descriptors ($CTDI_{vol}$; dose length product, (DLP)) were calculated using CT-Expo 2.1 dosimetry software. Body organ dose and effective dose were estimated following ICRP 103 recommendations. Dose optimisation strategies implemented included: Comparison of the obtained CT dose descriptor to the established reference dose levels; compare typical scan parameters for children to those of adults at the same hospital taken from previous survey; and Compare the calculated and the console displayed CT dose descriptors in a selected hospital.

Results: for head CT: mean DLP ranged from 127 for neonate to 415 mGy. cm 10-15 year old child. Volume CT dose index for head projection ranged from 11 mGy for neonate to 34 mGy for 15 year child. For abdominal CT: mean DLP ranged from 46 for neonate to 330 mGy. cm 10-15 year old child. Interhospital doses showed wide variations in scan parameter and hence variations in patient doses. The study showed that reduction in patient doses can be achieved mainly through standardization of scan parameters.

Examination frequency and population dose from medical X-ray procedures in Sudan, 2010

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A nationwide survey was conducted to estimated examination frequency and population dose from medical X-ray procedures in Sudan, 2010. Medical X-ray procedures of Radiography, Computed tomography and Interventional radiology (IR) are included in the survey. Informations on examination frequency were collected from 30 hospitals. The effective dose estimates was determined from measurable dosimetric quantities to effective dose conversion coefficients found in the literature. The estimated annual number of examinations is: 340,593,000, radiographic X-ray procedures, 342,912 CT exams per year (14 % Paediatric CT), 24,750 interventional radiology and cardiology procedures. For the radiographic X-ray procedures, chest X-ray had the highest frequency (22 %). Annual collective effective dose from adult CT examinations was (1482 man.Sv). The highest frequency was for head examination (40%). The highest percentage contribution to the total collective dose from CT examinations was for abdomen examinations (32%). Annual collective effective dose from paediatric CT examinations is (169 man. Sv). The highest frequency was for abdomen (32%) and contributed to the total collective dose from paediatric CT examination to a (49%). For Interventional radiology procedures, the higher collective dose resulted from coronary angiography (CA) (79%) . The calculated annual examination frequency and collective effective dose were compared with the results found in the literature. The study offered the first project of frequency and population dose from medical X-ray examinations in Sudan and will provide valuable

Efective dose for an interventional radiologist using a model of the spatial distribution of scattered X-ray radiation

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A model of the spatial distribution of scattered x-ray radiation produced within a patient's body and x-ray equipment and propagated trough the interventional radiology rooms, based on real diagnostic and interventional x-ray procedures, was used to estimate effective dose for interventional radiologist. Modeled isodose curves and surfaces, used in the model, represent results obtained from experimental measurements performed using twenty active electronic dosemeters (AEDs) ALARA OD 3 properly placed in interventional room.

Model validity is checked because the final goal of understanding the distribution of scattered x-ray radiation is to enable a prompt and easy estimation of maximum exposure for both medical workers and patients and to provide an appropriate level of protection. The example is given to demonstrate how the model of scattered radiation, isodose curves and simple geometry model for interventional radiologist could be used to estimate maximum personal effective dose.

Calculated values of effective dose for interventional radiologist were in the range 30–240 µm per procedure, which could be extrapolated to values of 1,9–15,6 mSv in period of one month. These values are in agreement with regular personal dosimetry data, using TLDs, for interventional radiologists that use the same radiological equipment used for experimental measurements with AEDs.

Characteristics of polyacrylamide gel with THPC and Turnbull Blue gel dosimeters evaluated using optical tomography

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The purpose of this study was to compare characteristics of radiochromic gel – Turnbull Blue gel (TBG) with polymer gel – polyacrylamide gel and tetrakis hydroxymethyl phosphonium chloride (PAGAT) using optical tomography. Both types of gels were examined in terms of dose sensitivity, dose response linearity and background value of spectrophotometric absorbance.

The calibration curve was obtained for ^{60}Co irradiation performed on Gammacell 220 at predefined gamma dose levels between 0–140 Gy for TBG and 0–15 Gy for PAGAT. To measure relative dose distributions from stereotactic irradiation, dosimeters were irradiated on Leksell Gamma Knife Perfexion. The cylindrical glass housings filled with gel was attached to the stereotactic frame. They were exposed with single shot and 16 mm collimator by 65 Gy to a 50% prescription isodose for TBG and 4 Gy to a 50% prescription isodose for PAGAT. Evaluations of dosimeters were performed on UV-VIS Spectrophotometer Helios β and optical cone beam homemade tomography scanner with 16-bit astronomy CCD camera with a set of color filters.

The advantages and potential disadvantages for both types of gel dosimeters were summarized. Dose distribution in central slice and measured profiles of 16 mm shot show excellent correspondence with treatment planning system Leksell GammaPlan® for both PAGAT and Turnbull Blue gels.

Reference exposition evaluation in analogical and digital mammography systems

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In the present work the incident air kerma ($K_{a.i.}$), the half value layer (HVL), the exposition parameters indicated by the automatic exposition control (AEC) and the main characteristics of the x-ray equipments in 28 mammography centers were evaluated in the state of Paraná, Brazil. All the mammography equipments had high frequency rectification, focus-film distance larger than 60 cm, AEC, Mo-Mo anode-filter combination and compression system. 23 evaluations in analogical image units and 21 evaluations in digital image units, two of them DR (digital radiography), were obtained. The $K_{a.i.}$ was measured directly in the radiation beam with a 6 cm^3 ionization chamber, calibrated for the mammography energy range, using a standard ACR mammography phantom simulating the CC incidence. The average, minimum and maximum $K_{a.i.}$ values found were 10.1 mGy, 3.9 mGy and 30.4 mGy respectively. However, when the analogical and digital systems were analyzed separately, these values were 8.1 mGy, 3.9 mGy and 11.8 mGy for the analogical system and 12.3 mGy, 5.2 mGy and 30.4 mGy for the digital system. The results showed that the $K_{a.i.}$ found in the digital systems were higher than for the analogical systems, highlighting the output difference in the systems. As for the HVL, all the values were between 0.33 mmAL and 0.43 mmAl. Despite the average manufacturing time of the mammographs be 146 month ($\approx$ 12 years) the variation of the output was between 0.07 mmGy/mAs and 0.16 mmGy/mAs for the total sample.

Quantitative comparison of normal tissue complication probability model with clinical data

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Modern 3D treatment planning systems and dose delivery methods (as conformal therapy and IMRT) allow exact dose delivery into the tumor, but evaluation of competing treatment plans with respect to organs at risk (OAR) should be done.

For this purpose, normal tissue complication probability (NTCP) models concentrate dose distribution to OAR into one number. For calculation, patient's data – dose volume histogram (DVH) and observed chronic toxicity – are needed.

The most frequently used NTCP model is empirical model by Lyman, called LKB model. For comparison, Källman and Logit+EUD models are also used in our work.

We appplied the models to data of 302 patients with prostate cancer, OAR considered is rectum. Occurrence of complications in the group was 21.9 % (toxicity grade 2 and 3).

Every model has several parameters, which were previously published or can be gained by optimization. Our optimization was done using minimization of Brier score which explains the rate of agreement among prediction of the model and observation (clinical data).

Evaluation of NTCP values was done for several sets of parameters (previously published and optimized) for every model, comparison was done.

Our values of parameters result in more correct predictions as the median of NTCP values was for every model close to real complication rate (about 20 %), but distribution of patients with the same grade of toxicity into quartiles of NTCP values is very similar for each model.

Behavior of air-filled ionisation chambers in proton beam

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Aim: The aim of this work was to show potential problems and risks connected with using incorrect approach in dose measurement for scanned proton beams. The risk of application of well established methods is shown.

Materials and methods: In Proton Therapy Center (PTC) a proton therapy system by IBA (IBA Proton Therapy, Belgium) with pencil beam scanning (PBS) treatment mode is installed. The system is capable of delivering highly focused spots with a very high dose rate. The system is optimized for delivering dose very fast which results in problems with air-filled ionization chambers and its capability of collecting big amount of charge in a very short time. Studies were done with different ionization chambers, both cylindrical and plane parallel.

Results: Behavior of particular chambers was overviewed and an internal set of recommendations was raised. Mainly for patient plan verification it is very important to be very clear and sure about the behavior of measuring equipment under special conditions of PBS.

Conclusion: Currently available recommendations for dose measurement in external beam are not covering the specific situation of fast scanned proton beam. Some general recommendation should be developed as PBS is an emerging technology in the near future.

Effect of Material Composition on Proton Depth Dose Distribution

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In this study, we used Geant4 toolkit to demonstrate the tissue heterogeneity effect on proton depth dose distribution. PDDs of different materials against a 250 MeV mono-energy proton beam were simulate and compared. These simulated material included adipose, heart, brain, cartilage, cortical bone, and water. This study first presents inter-comparison of proton dose distribution in water phantoms using MCNPX, GEANT4 and FLUKA to check the accuracy of GEANT4 setup. Secondly, we compare the dose distribution in several different homogeneous phantoms made of different kinds of materials. In addition, a similar comparison was performed by artificially setting all material density to 1.0 g/cm^3 to evaluate the range deviation due to chemical component alone. The dose distribution in water using MCNPX, GEANT4 and FLUKA for proton beam has only a 0.6% deviation in projected range compared with the value provided by NIST. The result shows significant deviation between the proton ranges in different materials, especially bone. The R_{50} is about 39.55 cm, 35.52 cm, 37.00 cm, 36.51 cm, 36.72 cm, 22.53 cm, and 38.52 cm for adipose, cartilage, tissue, heart, brain, cortical bone, and water, respectively. The largest deviation happened in cortical bone and adipose tissue. The range deviation for cartilage is also observable. The ranges for soft tissue are within from 36.51 cm to 37.00 cm. Physical density or electron density can be used to scale the proton range in different materials, where electron density provides better range scaling. For cortical bone, more aggressive scaling factors are suggested, which are about 13% if using density scaling about 6% if using electron density scaling. Tissue heterogeneity effects due to density variation are more significant, and less for chemical composition variation unless the Z/A is very different.

Dose Escalation to Target in Tonsil Cancer by Using Oblique Beam in Tomotherapy

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The current model of Tomotherapy Hi-ART system is not designed to utilize any oblique beam. This work intends to improve critical organ sparing by introducing a novel patient setup which can utilize an oblique beam. As a preliminary study to assess the feasibility of oblique beam irradiation in helical Tomotherapy, we examined quantitatively a potential advantage of the novel approach for head and neck cancer. An additional table was placed on the Tomotherapy couch. Since the supplementary couch is movable, a patient could be positioned along the oblique line from the view of inferior-superior direction. In order to evaluate the potential advantage of oblique beam, we made the Tomotherapy plans with CT images of an anthropomorphic phantom. The plan with the setup using oblique beam was compared with that with the conventional setup using only perpendicular beams. Considering a typical shape and location of tumor in tonsil cancer, a gross tumor volume (GTV) and a clinical target volume (CTV) were delineated. 66 Gy and 54 Gy were prescribed for the GTV and the CTV, respectively. The plans were optimized on the condition that the coverage and the homogeneity of doses to target volumes should not be different from each other plan. As a critical organ to be saved, the doses delivered to parotid glands and brain stems were compared, bases on the dose volume histogram data. The obtained results are as follows: The maximum doses of GTVs in the case of the conventional setup and the oblique beam setup were 72.6 Gy, and 73 Gy, respectively. The volume fractions of CTVs receiving more than 60 Gy were 9.7%, and 8.8%. There was no significant difference in the volume fraction of CTV receiving less than 50 Gy, 13.1%, and 12.9% respectively. Considering sparing the left parotid glands, the maximum doses were 34.3 Gy and 29.7 Gy. The mean doses were 13.54 Gy and 11.53 Gy. The maximum doses to the right parotid glands were 39.4 Gy, and 30.01 Gy. The mean doses were 17.99 Gy, and 9.51 Gy. Concerning the brain stems, the maximum doses were 45.4 Gy, and 41.9 Gy. The mean doses were not different from each other, 11.65 Gy, and 15.8 Gy, respectively. Especially it was noted that the volume of region of low dose were larger in the case of oblique beam setup. From the preliminary results we can conclude that the novel approach using oblique beams in Tomotherapy might enhance sparing of parotid glands for head and neck cancer.

TL Emission Spectra Measured Using a Spectrometer Coupled to the Risoe TL/OSL Reader

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Although the use of thermoluminescence phenomena for radiation dosimetry ages from the early 1950s, the search for new dosimetric materials and for the comprehension of the thermoluminescent mechanism remains nowadays.

Thermoluminescent dosemeters are organic or inorganic crystals with defects or imperfections in their crystalline lattices. According to the energy band theory of solids, the crystal defects or imperfections give rise to energy levels localized at the forbidden gap which can trap electrons or holes created by ionizing radiation incidence. When trapped electrons or holes are stimulated, they can escape to the conduction band and recombine, emitting luminescence.

The luminescent emission wavelength depends on the recombination centre depth. The deeper the recombination centre is, the smaller the luminescence wavelength will be. The emission spectrum of luminescent materials, along with other studies, helps understanding the defects or imperfections in the crystal lattice and the kinematic phenomenon.

In this work, a Hamamatsu CCD detector with a 2-D arrangement of pixels (1044×64) based spectrometer was connected to a Risoe TL/OSL reader, model DA-20. This connection was made through an optical fibre. This spectrometer is preconfigured for the UV-VIS-NIR region (200–1100 nm). Well-known luminescent materials were used to test the spectrometric arrangement. LiF, $CaSO_4$ and Al_2O_3 are some examples of materials which emission spectra were measured in this work.

Thermoluminescence Properties of Doped Silica Glass for Applications in Radiation Therapy Dosimetry System

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This study is focusing on the TL properties of doped silica optical fibre. The investigations have been made of TL dose response, TL sensitivity, TL reproducibility, TL reusability, the glow curve and TL fading of doped silica optical fibre with clinical photon energies and doses. The TL material that comprises doped silica fibre with different type of core diameter sizes (8 to 50 µm) were used in this work. The TL result will be compared with TLD-100 system as a standard TL dosimeter used in hospital. The fibres were exposed to photon irradiation energies of 6 MV and 10 MV by using linac at Hospital Universiti Sains Malaysia in a fractional dose range of 1 mGy up to 5 Gy. The results shown the dose response was linear within the clinical relevant dose for all these energy. The least squares fit showed the change in TL response, in TL yield per second per unit mass for 50 µm core fibres, to be 39 times greater than that obtained for 8 µm core optical fibres also irradiated at the same photon energy. The optical fibres were found to produce a flat response to fixed photon doses to within better than 4% (S.D) of the mean of the TL distribution, as well as minimal TL signal fading, good reproducibility and reusability. These early results indicate that these commercially available optical fibres, with proper calibration, show promise as high spatial resolution TL dosimeters for verification of complex radiotherapy dose distribution.

Radiation degradation of light-emitting diodes (LED)

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Semiconductor radiating devices – light-emitting diodes (LED) and injection lasers – are the least radiation-resistant elements of REA. It is a serious and difficult surmountable barrier to their wide use in the airborne equipment of space vehicles and other devices functioned in the conditions of the ionizing radiation (IR) influence.

The purpose of this work was the comparative complex research of the LED degradation kinetics in the process of neutron and gamma irradiation and at burn-in loadings without irradiation during the reliability tests. Serially produced LED on the basis of A3V5 compound (arsenide and gallium phosphide) and GaAlAs solid solutions have been investigated. Before and after the irradiation by the IR certain doses and reliability tests the series of LED parameters have been measured, namely: current-voltage, limen-ampere and capacity-voltage characteristics, luminescence spectrums and lifetime of non-principal charge carriers in the LED base.

The following basic results were obtained:

At influence of both radiation and non-radioactive factors the qualitative general multi-staging of LED radiation power change in the function of Co-60 stationary gamma-irradiation dose and in the function of burn-in duration tests was found. It indicates the physical community of rearrangement processes of LED structural imperfection.

The $I(\Phi)/I_0$ dose dependences have the nonmonotonic character — on them two maximum were marked out. Position of the second maximum coincides with the minimum of correlation coefficient $y(\Phi)$:

At the LED irradiation in the direct current mode the maximums are expressed more expressly and shifted to the greater dose directions. For LED on GaAlAs maximums are expressed more noticeable, than for LED on the gallium phosphide.

The light intensity growth at the small irradiation doses (first maximums) was observed for all LED samples and was accompanied by the noticeable increase of charge carriers' lifetime that confirms the correctness of its interpretation as the occurrence of the solid solution structure regulation processes.

It was developed and defended by inventor's certificate the LED culling method in regard to the radiation resistance on the basis of preliminary LED tests at the burn-in loadings and also the determination of coefficients of pair linear correlation of radiation (irreversible) and thermal changes power of radiation. The last are fully restored after stopping of LED heating.

It was suggested and defended by inventor's certificate the method of the radiation power renewal of irradiated LED by means of the direct current impulses influence having the different amplitude and duration. Similar injection radiation defects' annealing in LED was not carried out before.

The semi empiric model for the evaluated calculations of LED degradation contained the coefficients determined at the preliminary researches stage was developed.

Radiation dose measurements at electron losses in the 8-GeV electron storage ring

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Information of electron losses such as the locations and rates is important for radiation safety of accelerators. The information can be deduced from measured doses. In the storage rings of synchrotron radiation facilities, high-intensity synchrotron radiation is produced and scattered (Nariyama, 2007), so that heavily-shielded γ-ray dosimeters or neutrons dosimeters insensitive to γ-rays are necessary for the in-ring measurements of electron losses. In this study, dose measurements were made out in and outside of the ring of SPring-8 for the electron loss information. In the storage ring, solid-state track detectors (CR-39) were set at 26 regular-interval points along the ring of 1.4-km circumference for two months. The result showed the highest doses of 1.0-2.1 mSv near the long undulators of ID07 and ID19. At the next measurement, the detectors were then set at ten places along the long undulators, and the large doses were found at the front and end segments. Outside of the ring, ionization chambers and rem counters were set in front of the ratchet concrete near the electron incidence point from the booster synchrotron, and the doses were recorded in a time series. The γ-ray dose was 1.5 µSv for 10 min at the electron incidence and 20 µSv at the beam disposal. At the beam abort, the dose was 2 µSv. Neutron dose was 0.2 µSv at the electron incidence. From these doses, electron loss numbers were estimated.

Reference: Nariyama, N., Radiat. Mea. 41, S274 (2007).

Dosimetry of ASTRA-M compact pulsed high-current electron accelerator

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X-rays are widely used to solve many practical problems: sterilization of medical devices that are sensitive to heat treatment, suppression of immune cells in the blood plasma for transfusion, disinfection of food, testing of radiation hardness of materials and microelectronic devices, etc. Technologies based on electron accelerators have several advantages compared with the sources on the basis of isotopes ^{60}Co and ^{137}Cs: incorporating into existing production lines, low cost of processing, the ability to "turn off" the source whenever needed, i.e. greater protection for technological complex. To improve the economic efficiency of the technology of radiation treatment in many cases it is advisable to reduce the forwarding costs to transport objects to the radiation sources through the creation of low-power mobile systems based on compact pulsed accelerators.

A ASTRA-M compact pulsed high-current electron accelerator was constructed in order to generate both electron and X-ray beams with energies up to 500 keV that may be used for the problems mentioned above. The accelerator is able to generate the extracted electron beam with the current as high as 1.2 kA (pulse energy up to 12 J) and the pulse repetition rate up to 50 Hz.

In the report we present the results of investigation of the ASTRA-M efficiency as a source of X-rays. Several types of convertors were studied both theoretically and experimentally. Monte Carlo simulation of bremstrahlung generation was carried out using home developed code "PC Lab". The experimental measurements of the absorbed dose in water were carried out using both polymer films Gafchromic EBT3 and thermoluminescent dosimeters. The results obtained show good agreement of measured and predicted doses.

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High-Power p(35)-Be White Neutron Source for Activation Experiments at NPI

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The cyclotron based neutron generators of the white- and quasi-monoenergetic spectra are operated at the NPI Řež Fast Neutron Facility utilizing the variable-energy proton beam (up to 37 MeV) and the D_2O (flow), Be (thick), and ^{7}Li(C) target stations. The intensity and the energy range of the produced neutron fields are suitable for the integral and differential validation of the neutron cross-sections within the ADTT- and fusion-relevant (IFMIF) research programs.

In the neutron activation experiments, the irradiated samples are usually fixed in the vicinity of the source target, and the dimensions of the target and samples are comparable with the target-to-sample distance. Therefore, to determine the neutron spectral flux at the sample position from the cross-section data, a simple employment of the $1/r^2$ law is not relevant. Instead, the MCNPX calculations are required to take into account the space and energy integration of neutron yield observables over the geometry arrangement of activation experiment.

Due to a lack of differential yield data at requested energy and angular range, the MCNPX calculations need to be validated against the independent experiments. Recently, the activation method was successfully used to the validation of the MCNPX prediction of spectral flux characteristics for the p(37) + D_2O (thick) source.

In the present work, this method was employed to determine the spectrum of the Be(p,xn) source reaction at the position of irradiated samples. The wide set of activation detectors in the form of small foils (Al, Sc, MnNi, Fe, Co, Ti, Y, In, Lu, Ta, Au, Nb, and Bi) was selected to cover the energy range under interest. In the experiment, the thick (8 mm) beryllium target was bombarded by the 35 MeV protons at beam current of 9.2 μA. Activated foils were investigated by the nuclear gamma-spectrometry technique (the HPGe detector). To unfold the neutron spectrum from resulting reaction rates, a modified version of the SAND-II code was used. Results and uncertainty of the validation are discussed in details. The high intensity p(35)-Be white neutron field has been developed, and it is convenient for neutron activation experiments and nuclear data validation.

Neutron Field for Activation Experiments in Horizontal Channel of Training Reactor VR-1

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The VR-1 training reactor of the Department of Nuclear Reactors of CTU in Prague is a light water swimming pool-type reactor with thermal power of 1 kWt. The reactor uses the IRT-4M-type concentric fuel moderately enriched to 19.7% ^{235}U. Since 1990, the reactor has served mostly to train students; the possibility to use the reactor for scientific purpose has been tested recently. It is equipped with several vertical and two horizontal channels that allow to study the neutron field and to irradiate samples.

In present work, the feasibility of one of horizontal channels for irradiation application of materials and for nuclear data and calculation codes validation was successfully tested. The neutron multi-foil activation method was used to determine the neutron field parameters in the horizontal radial channel, namely the reaction rates, energy spectral indexes, and neutron spectrum.

In the first experimental period, fourteen variable types of activation and threshold detectors (NaCl, Al, Sc, Mn, Fe, Ni, Cu, Mo, In, Lu, W, Au, Th, U) both uncovered and cadmium covered were irradiated to measure the reaction rates and energy spectral indexes both lengthwise and crosswise the experimental channel. Irradiated foils were processed by using the semiconductor gamma-spectroscopy. From the course of spectral indexes lengthwise the channel follows that the epithermal neutrons quantity decreases due to moderating effects of channel walls; according to the course of spectral indexes crosswise the channel, the epithermal neutrons quantity increases due to a higher number of moderated thermal neutrons coming from a biological shielding of the channel.

In the second experimental period, the set of ten activation foils (Fe, Mn, Cu, Mo, Au, Sc, Dy, In, Ti, Ta) was used to determine the neutron field in horizontal channel by using the neutron activation method together with the HPGe semiconductor and NaI(Tl) scintillation gamma spectroscopy technique. To unfold the neutron spectrum from measured reaction rates, the SAND-II code was employed; the initial guess neutron spectrum for unfolding procedure was calculated in the Monte Carlo code. The MCNP predictions of neutron spectral flux at the position of irradiated samples were successfully validated against the experimental measurements.

The knowledge of neutron field characteristics in the horizontal channel is beneficial for the irradiation experiments and neutron activation analysis.

Böhm extrapolation chamber: study of its behavior in beta radiation fields at the Calibration Laboratory of IPEN

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The absorbed dose rate in tissue is the quantity associated to beta particles, and more specifically, it is determined at the depth of 0.07 mm in water, which is the geometry recommended by international recommendations. The primary standard instrument established for this purpose is the extrapolation chamber which allows the absorbed dose rate determination at different depths in tissue, due to the possibility of variation in its sensible volume. At the Calibration Laboratory (LCI) at the Instituto de Pesquisas Energéticas e Nucleares (IPEN) a Böhm extrapolation chamber PTW, model 23392, is being established as a primary standard system for the dosimetry and calibration of beta radiation sources and detectors. This commercial chamber has already been tested in beta radiation fields of $^{90}Sr + ^{90}Y$ sources of two beta secondary standard systems of LCI: BSS1, Buchler GmbH & Co, Germany, and BSS2, Isotrak, Germany, with a Mylar entrance window. This entrance window was previously used, because the original one was not available; the extrapolation chamber presented good performance and a great possibility to be used as a primary standard system. An electrometer Keithley, model ^{6517}B, was utilized for the measurements. The objective of this work was to perform definitive characterization tests (null depth, stability of response, leakage current, saturation of response, polarity effect, extrapolation curves and variation of response in function of source-detector distance) of the chamber with an original entrance window (acquired from the manufacturer) of Hostaphan (superficial density of 0.72 mg/cm^2), in beta radiation fields, to be used as a primary standard system at LCI.

About the possibility of direct measuring of effective dose of gamma radiation

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According to the publication 103 ICRP 2007, the effective dose in the human body cannot be measured directly.

To estimate an effective dose used an operating value – the equivalent of individual dose.

In this case, the individual effective doses of workers determining by the transition of reading personal dosimeter, calibrated in terms of equivalent of individual dose Hp(10), to effective dose E using conversion coefficient C_k.

The value of the conversion coefficient depends on the radiation conditions. In that case, the critical factors are the anisotropy field of radiation and the human body orientation in the radiation field. Conversion coefficient can balance from 0,64 to 1,27.

At present each NPP in Ukraine is implementing the own calculation of the conversion coefficient for the transition from measured exposure dose or air kerma to the effective dose. Thus the correction coefficient is special for each working place.

The main idea of considering of possibility of direct measurement of effective dose gamma radiation is reduced to create a dosimeter which has the energy dependence of the sensitivity and anisotropy corresponding to a conversion coefficient, linking the basic value- the absorbed dose to the value of effective dose.

The flat ionization detector is the most appropriate coming from the requirements of anisotropy.

For the account of energy of gamma radiation in front of the camera there is a screen made of tissue- equivalent material with some additions.

As a method of measuring, it was chosen the redistribution of charges from charge to measuring condenser through the ionization detector with its radiation. The information about dose is an accumulate charge on the measuring condenser.

Measured value in a spirit of publication 103 it is possible to name the equivalent of effective dose.

A patent was got for an invention and certificate about metrological attestation of device sample. At present the completion of dosimeter is planned with a view to make it direct reading.

Establishment of the IEC 61267 Mammography Qualities in a Clinical System for Instruments Calibration

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Second most common in the world, breast cancer is most common among women, accounting for 22% of new cases each year. The prognosis is relatively good if diagnosed and treated appropriately.

Mammography is the breast radiography, which allows premature breast cancer detection, by the fact that it is capable to show injuries in its initial stage. But, to obtain premature and reliable diagnosis, it is necessary to guarantee that the mammography system is calibrated and working properly.

For this reason it is very important a good quality control of these equipments, especially in terms of the radiation generated by them. This control must be done using a special ionization chamber which must be calibrated. The calibration of these instruments must be done periodically in a laboratory with proper devices.

Usually this calibration is made using industrial X-ray system, in which the irradiation parameters can be totally controlled with low uncertainties, following the primary traceability. However, it is a concern if the Secondary Standardization Dosimetry Laboratory (SSDL) must try to reach the clinical situations, in which the uncertainties are higher. Therefore it is important to know if in a clinical situation, using a mammography system, the performance of the ionization chamber remains the same.

In Brazil, there are just few laboratories which have mammography qualities established in their systems. One of these laboratories is the Laboratório de Calibração de Instrumentos (LCI), at IPEN, which has calibrated about 40 mammography ionizing chambers per year since 2009, using an industrial X-ray equipment (tungsten anode) with the mammography qualities already established.

In this study will be shown the results obtained in the establishment of the mammography qualities in a clinical X-ray system (molybdenum anode). The objective is to develop a calibration method as close as possible to the procedure used in hospitals and medical clinics, and also to create a standardized system which can be used in research about the best methodology to calibrate ionization chamber in mammography.

Determination of Half Value Layer in different X radiation systems using two types of detectors

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The determination of half-value layer or HVL is used to quantify the penetrability of an X-ray beam. The HVL of an X-ray beam is the amount or thickness of absorbing material or filtration that must be placed in the beam to reduce the transmission of the beam by one half. The material predominantly used to determine the HVL of diagnostic radiology X-ray equipment is aluminum (99.99% of purity). The HVL is usually presented in millimeters of aluminum (mmAl) and can be converted to a quantity called the effective energy estimating the penetration power of the X-ray beam. In one laboratory of instrument calibration is one important parameter to the establishment of the standard radiation qualities. In diagnostic radiology beams are often used ionization chambers with a volume of 6 cm^3 to determine this thickness. The use of a semi-conductor dosimeter is allowed in diagnostic radiology dosimetry since it follows the requirements of the standard IEC 61674. The advantage is that with only one shot it is possible to know many parameters of the radiation beam such as dose, kVp, mAs, HVL, etc... which can be very useful in quality control measurements performed in clinical equipment.

The objective of this study was the determination and analyses of the HVL values obtained with one reference ionization chamber and a TNT 12000 solid-state detector. Measurements were performed on radiation qualities beams used for calibration at the Calibration Laboratory of IPEN in constant potential X-ray generator as well as in mammography equipment, and yet in one conventional radiography equipment. It was also evaluated the half value layer for X-ray tubes with thick additional filtration, simulating aging of the equipment. The results showed a variation of up to 15% between the state solid dosimeter response and the ionization chamber.

Characterization of a medical X-ray machine for testing the response of electronic dosimeters in pulsed radiation fields

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Electronic personal dosimeters (EPD) based on solid state detectors have been used for personnel monitoring for radiation protection purpose; they are a practical tool for optimization since they provide the dose rate in the real time and the radiation dose immediately after any task related to radiation exposure. The use of EPDs has been extended to practices with pulsed radiation beams although their performance is not well known. Deficiencies in the EPD response in pulsed radiation fields have been reported; they were not detected before since type tests and calibrations of EPDs were established in terms of continuous x and gamma reference radiations. The International Organization for Standardization (ISO) established a working group for elaborating a standard for test conditions and performance requirements of EPDs in pulsed beams; the German Primary Laboratory, the PTB, implemented a special x-ray facility for generating the reference pulsed radiation beams. In Brazil, there are neither requirements for the response of EPDs in pulsed beams nor a metrology laboratory able to carry out EPDs performance tests. In this work, a VMI 800 Plus medical x-ray machine of the Dosimeter Calibration Laboratory of CDTN/CNEN was characterized to verify the feasibility of using it for EPDs tests. Characterization was done in terms of inherent filtration, tube potential, practical peak voltage, half-value layer, air-kerma rate and energy radiation spectrum. A Xi light UNFORS solid state dosimetric system and a ^{10}X6 RADCAL ionization chamber were used as reference dosimeters; their metrological coherence was initially verified in a continuous x-ray beam from a Seifert-Pantak machine. Two units of RADOS, PDM ALOKA and THERMO-ELECTRON EPDs were exposed to different conditions (air kerma rates and exposure time), according to their operation range, in similar RQA/IEC x-ray qualities. Preliminary results showed relative intrinsic errors in the response of EPDs in terms of personal dose equivalent, Hp(10), higher than 15%, which is the requirement established for continuous beams.

Standardization of dose area product in Taiwan

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Dose area product (DAP) is an useful quantity for diagnostic X-ray examination, which consists of two factors, the entrance surface dose and the field size, capable of reflecting the actual health risks. The purpose of this study is to establish the primary standard of DAP, which can be used for dose tracing back in Taiwan. The existing medium-energy X-ray system equipped in the National Radiation Standard Laboratory (NRSL), with addition of accessories of a transmission ionization chamber frame and an X-ray collimator was used in this study. According to the IEC 61267, the X-ray radiation qualities, RQR and RQA, were established for measuring the respective half value layers (HVLs) and homogeneity coefficients. Comparing the measured HVLs and homogeneity coefficients with those suggested in the IEC 61267, the differences were shown less than 5%. Further, the NRSL free-air ionization chamber was used as the primary standard to measure the air kerma of the radiation qualities. The correction factors, including air attenuation, ion recombination loss, electron loss and photon scattering, were assessed for the NRSL free-air ionization chamber. According to the ISO-GUM, the measurement uncertainties of the DAP calibration system were estimated, including the primary standard measurement uncertainty and the ionization chamber calibration uncertainty. By considering the degree of freedom, the resultant expanded uncertainty was 1.8% ($k = 2$). Additionally, a DAP meter and a transmission ionization chamber (PTW TV34044-1) were purchased, and sent to the Physikalisch-Technische Bundesanstalt (PTB) for DAP calibration. The calibrated DAP meter was then used to measure the established RQR and RQA for comparison with those measured by the NRSL free-air ionization chamber. As a result, the differences between them were ranging from 0.06% to 2.71%.

Dose evaluation of dual source computed tomography in pediatric thorax scan

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Objective The purpose of this study was to evaluate in phantoms the dose reduction to surfaces and the image quality with organ-based tube-current modulation in pediatric thoracic CT.

Materials and methods Organ-based tube current modulation is designed to reduce radiation dose to superficial radiosensitive organs, such as the lens of the eye, thyroid, and breast.

A 16-cm CT dose index (CTDI) phantom representing the thoracic of 1-to5-year-old children, with the linearity being evaluated and calibrated by an ion chamber reader and a pencil-type ion chamber in advanced, was used to investigate the comparison of three different scan protocols, which are Clinical Mode, X-care Mode, and High-pitch Mode. The doses were determined at 12 measurement positions in the phantom.

The radiation dose and image quality of the phantom under the three different protocols were evaluated by t-test and Image J, respectively.

Results For the linearity of the ion chamber, the r-square was 1, and the discrepancy of accuracy was about 3.62%. To the anterior surface of the phantom, comparing to Clinical Mode and High-pitch Mode with the maximum dose reduction by 36.97% and 44.21% respectively, X-Care delivered the least dose. To the posterior surface of the phantom, comparing to X-Care and High-pitch with the maximum dose increase by 13% and16.95% respectively, Clinical mode delivered the least dose. For image quality, there was no significant difference between Clinical Mode and X-Care Mode.

Conclusion Organ-based tube-current modulation can reduce the dose to the anterior surface of the patient but with the increasing image noise and dose to the posterior surface. This technique can be used to reduce the dose to the superficial radiosensitive organs at head and thoracic.

Air-kerma length standardization of computed tomography

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The "Standards for Medical Exposure Quality Assurance" was enacted by the Atomic Energy Council (AEC) in Taiwan. Thus, the performance assessment of QA instrumentation must be calibrated in computed tomography. The INER measurement standard for the air-kerma length from computed tomography (CT) is described in detail. The beam code for CT chamber calibration recommended by the National Institute of Standards and Technology (NIST) was M120, and its added filter was made of aluminum sheets. CT scans are usually operated in 80-140 kVp X-ray range, other beam codes (M80, M100 and M150) were set up for all energy range applications. The HPGe detector and Compton spectrometer spectrum measurements have also been made for several CT beam qualities. Spectrum differences were compared for x-ray irradiation in INER and in hospitals. According to the IEC 61674, a diaphragm aperture design corresponding to 50% of the chamber rated length was used, whose setup resembles more closely to the clinical situation. And over the rated length, the spatial uniformity of the response varies by less than 3.0 %. The expanded uncertainties ($k = 2$) were within 1.0 %, and the x-ray air kerma length calibration factors were evaluated using the ISO GUM. The comparison with the NIST had a difference less than 1.0 % using transfer ionization chambers (Exradin A101). The results indicated that the CT calibration standard was in reasonable agreement within the standard uncertainty, and it appeared to meet the requirements of the criteria and the needs of the users of clinical practices. The air-kerma length standardization could start with routine calibration services for these beam qualities.

Dosimetry and kVp standardization for Quality Assurance of mammography

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After achieving early monitor with mammography screening, breast cancer mortality rates have been creditably reduced in Taiwan. The objective is to establish an appropriate and traceable calibration infrastructure, which offers calibration services for mammography X-ray quality assurance instrumentation performed clinically on a regular basis. For mammography equipment with three different target/filter combinations (Mo/Mo, Mo/Rh and Rh/ Rh), the entrance air kerma, HVL and kVp can be taken as adequate indicators for the level of the average glandular dose (AGD). The primary dose standard in mammography uses a free-air ionization chamber to estimate air kerma rate. Several correction factors were determined by the Monte Carlo EGS5 simulations and experiments. A secondary kVp standard in mammography is in accordance with the IEC 61676 recommendations. The calibration system of kVp meter uses a high-voltage divider, which is traceable to ITRI' primary standard in Taiwan. Dose and kVp verifications were conducted by mammography instruments which were previously calibrated by the NIST and PTB. According to the evaluation results, capabilities of this irradiation system met ISO 4037-1 requirements. The expanded uncertainties ($k = 2$) were 1.03% and 1.6% when the mammography x-ray air kerma rate and kVp meter calibration factors were evaluated using the ISO GUM. The experimental verification and a comparison with NIST using transfer ionization chambers (Radcal 6M) yielded differences in calibration factors. And the comparison with the PTB had a difference less than 1% using kVp meter (RTI Electronics AB). The results showed that dose and kVp standards were in reasonable agreement within the standard uncertainty. The low uncertainties associated with the obtained results in this work pointed out that the standardization employed can be accurately used for calibration of instrument in mammography. The performance characteristics of dosimeters and non-invasive kVp meters were determined for annual calibration in an attempt to ascertain the performance of instruments in daily routine.

Keywords: Dosimetry, mammography, Quality Assurance

Studies of the dose-response for the system ferrous ammonium sulfate-sucrose-xylenol orange in acid aqueous solution

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An aqueous solution of ammonium ferrous sulfate, sucrose, xylenol orange and sulfuric acid (FSX) is proposed as dosimetric system for processes of gamma irradiation in a range between 0.5 and 5 Gy.

This system is based on indirect oxidation of the ferrous ion by an organic compound (sucrose) to ferric ion, and the formation of color complex of Fe^{3+} in an acidic medium with the xylenol orange (a colorant). After irradiation with gamma radiation there is an observable change in color of the system.

Irradiation was carried out at three different temperatures (13°C, 22°C and 40°C). A spectrometric readout method at 585 nm was employed to evaluate the dose response of the system. In all the cases analyzed the responses have a linear behavior and a slight effect of irradiation temperature was observed. Post-irradiation response was also evaluated and show stability of the solutions after 24 hours after the irradiation.

The results obtained show that FSX might be used as a dosimeter for low doses, because it provides a stable signal, good reproducibility, and an accessible technique for analysis

Irradiation of L- aspartic acid at different irradiation temperatures for its possible use as dosimeter

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Some commercial applications increased the efficiency of the reaction at low temperatures due to a decrease of free radicals in the bulk material (Rohani et al., 2007) and to avoid the synergetic effect of heat; also experiments made to simulate the low-temperature conditions of extraterrestrial environments are increasing (Colin et al., 2009). These types of applications have motivated the search for dosimetry at conditions as close to those used during the irradiation when the dose is going to be measured, and a reliable low-temperature dosimeter is needed. With this purposes, polycrystalline samples of L-α aspartic acid have been irradiated with γ rays, at low temperatures and doses in the kilogray region.

The potential use of the aspartic acid system is based in the formation of stable free radicals when amino acids are exposed to ionizing radiation. These radicals can be studied and quantified by electron spin resonance (ESR). With these purpose the aspartic acid samples were placed in a Dewar containing different mixtures of solvents and either ice, dry ice, or liquid nitrogen to produce different temperatures, and then irradiated in a ^{60}Co γ ray source (Gammabeam 651PT) with a dose rate of 106 Gy/min. The samples were exposed to doses varying from 6.5 to 45 kGy. After irradiation, the EPR signal of the dosimeters was recorded as a function of the irradiation temperature and its peak to peak height was measured as a function of the irradiation dose and irradiation temperature.

Response curves at different temperatures show that the intensity of the EPR spectra (the five characteristics lines) depends on doses received and the response of the dosimeter increases with temperature. Their relationship is linear up to 20 kGy. Fading characteristics show that the change of EPR the signal over time is stable and reproducible. On the other hand the dosimeters are easy to handle.

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Characterization of standard beta radiation fields with an extrapolation chamber

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Beta Secondary Standard (BSS) systems were built and sold to metrology laboratories to enable them providing traceability during calibrations of dosimeters. However, calibration must be done at specific and limited geometric conditions; other conditions require a primary standard dosimeter to characterize the radiation field. The metrological reliability in beta radiation dosimetry should start by the realization of the absorbed dose at 0.07 mm depth in tissue, $D_T(0.07)$. For radiation protection purpose, the personal and the directional dose equivalents, $H_p(0.07)$ and $H'(0.07)$, were defined for individual and area monitoring, respectively. This work is part of the characterization the $^{90}Sr/^{90}Y$, ^{85}Kr and ^{147}Pm beta standard fields with a 23392 model PTW ionization chamber that uses the extrapolation to null volume as an absolute method for absorbed dose measurements. Transmission factors were determined for three absorbers of different area densities for chamber electrode distances of 1, 2, 5 and 8 mm. The variation of the H'(0.07, α) was determined for beam incidence angles α from 0 to 80°. Acceptable agreement was found between the results obtained in this work with published one.

Characterization of the new free-air primary standard for low-energy X-rays at CMI

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In 2011 a decision was made by Czech Metrology Institute to build a free-air ionization chamber intended to be used as a primary standard of air-kerma for low-energy X-rays (photon energy below 50 keV, including mammography X-ray qualities) in order to replace currently used secondary ionization chamber and to decrease the uncertainty of air kerma reference value. In period of 2011-2012, the free-air chamber has been designed, manufactured and put into operation. Performance of the free-air chamber was tested using a calibrated secondary chamber and then by an informal comparison with a national primary standard of BEV (Austria). Presented paper describes physical characteristics of the chamber and, in more detail, individual correction factors applied. Procedure of determination of each correction factor is described, focusing primarily on the Monte Carlo methods utilized in their estimation. Summary of the correction factors with the uncertainty budget is presented.

EURADOS intercomparison exercise on MC modeling for the in-vivo monitoring of Am-241 in skull phantoms (Part I).

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An intercomparison on in-vivo monitoring for determination of ^{241}Am in three skull phantoms was launched by EURADOS in 2011. The project focused on measurement and estimation of the activity of ^{241}Am in human skull. Three human skull phantom of different complexity were used. Monte Carlo (MC) exercise with the voxel representations of the real phantom was lunched additionally in September of 2012. The main goals of the action was to investigate usability of MC calibration in complex situation and compare approaches of participating laboratories in order to introduce best practice guidance. The MC exercise consists of three tasks with increasing difficulty, which test participating laboratory in the full extent of needed skills. The first task was to simulate given detector and rather well defined semi-skull phantom. All parameters of the simulation, including photon yield, material property and geometry were fixed. The paper provides overview of the participant's results and analyses of the observed issues.

Improving the MVCBCT image quality by using copper target with flattening filter free linac

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The Megavoltage Cone Beam Computed Tomography MVCBCT is an imaging tool used recently in image guided radiotherapy IGRT for everyday patient repositioning before the treatment course with conventional 6 MV photon beam. The purpose of this work is to study the effect of using a copper Cu target instead of the tungsten and copper (W+Cu) target on the MVCBCT image quality. Several Monte Carlo simulations using FLUKA were carried out with different targets materials and thicknesses (i.e W+Cu, only Cu and only diamond) with 6 MV flattened and unflattened beams in order to calculate the photon spectra on the phantom surface. The results obtained show a good reduction in the mean energy of the photon spectrum when the Cu target and the diamond target used instead of the W+Cu target which is translated to an improvement in the quality of MVCBCT images. The reduction in the diamond target was found higher than that for the copper target but the copper one is already exist in Varian linacs for the 10 MV photon beam and much cheaper. It can be concluded that using a Cu target with unflattened beam will improve the MVCBCT image quality with lower cost.

Dosimetry and Uncertainty Analysis in Gynecologic Brachytherapy

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Intracavitary brachytherapy allows the delivery of a high dose to the tumor, while minimizing the dose received by the surrounding tissues. However, uncertainties in the constituent materials of the gynecological applicator and in the source positioning lead to uncertainties in dose calculation.

The objective of this study is to determine the accuracy of dose calculation obtained by the Treatment Planning System (TPS) and to assess the uncertainties in dose calculation. The methodology used consisted in the comparison between the dose calculation of the TPS in 5 points located at 2 cm away from the source center and the corresponding results obtained using the Monte Carlo simulation program PENELOPE with and without the applicator. The influence of source position variations of 1 mm in the anterior-posterior, right-left and cranio-caudal directions on the average dose to the bladder and rectum through the use of a voxel phantom built from a CBCT image was also investigated.

For the dose results for points at 2 cm away from the source center, without applicator, the relative differences in the calculated dose between the PENELOPE simulated values and the TPS ones were below 3%. With the applicator, the corresponding relative deviation was below 10%. For this study the source position variations in the anterior-posterior direction contributed to a relative deviation of +6.5% in the average dose to the bladder, whereas for the rectum the biggest difference was found in the cranio-caudal direction with a relative deviation of +6.4%. The variation in the right-left direction does not influence significantly the dose received by the organs at risk.

In conclusion, in the PENELOPE calculations if only the source and the capsule in water is considered, the results are very similar to the TPS calculations for the distance analyzed, so for this geometry the TPS features a reasonable accuracy. However, when the applicator is implemented in the PENELOPE Monte Carlo simulations, we can have a significantly dose reduction of 10% in the points of clinical relevance compared to the corresponding PENELOPE calculations without applicator. The used voxel phantom provided detailed information of the different tissues and allowed a non invasive study of source position variations and its influence on the dose received by the organs. In this work the source position variations of 1 mm contributed to an increase of 6.5% and 6.4% in the bladder and the rectum dose respectively.

Monte Carlo simulation of the BEGe detector response function for in vivo measurements

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A project is under way to improve the counting and operating capabilities of the whole body counter installed in SÚRO, v.v.i. (NRPI) Prague, Czech Republic. Possible emergency monitoring should mainly benefit from the rapid, safe and flexible operation of the WBC.

The system of the WBC for the detection of low energy X and gamma radiation comprises four HPGe detectors intended for the routine, emergency, and research measurement of persons internally contaminated with low-energy photon emitters, mainly actinides. Among them, Am-241 is a main subject of interest.

Proper detection efficiency calibration of detectors is required for the measurement of activity in individual organs and tissues. The use of physical phantoms in the calibrations is often supplemented with the application of voxel phantoms and a Monte Carlo technique that are used for the calculation of the detector response function and the peak efficiency. Both experimental and computational approaches have been used for the calibration of a BEGe (Broad–Energy Germanium) detector. In this paper, the process of the Monte Carlo simulation of the detector response function and the peak efficiency calculation is described.

As the first step, the detector was modelled for the implementation to the Monte Carlo computational environment.

The initial detector model was developed using the information from the manufacturer.

Based on the measurement data, the initial model was adjusted with the aid of Monte Carlo method in order to achieve a better conformity with the measurement data.

Measured efficiencies for radionuclide point sources were compared with the Monte Carlo calculations for the modified model and with the ISOCS software calculations for the initial model.

Three physical skull phantoms and their voxel models were available for measurements and Monte Carlo calculations in the frame of the current EURADOS Intercomparison on in vivo monitoring for the determination of Am-241 in skull. The voxel phantoms were implemented into MCNP code and Monte Carlo calculations were run to simulate spectra. Results of the simulations are provided in the paper and discussed.

MCNP Simulation of Radiological Hazard of Used Thorium Nuclear Fuel

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Thorium fuel is considered as a viable alternative to uranium fuel used in current generation of nuclear power plants. Switch from uranium to thorium means a complete change of composition of used nuclear fuel produced as a result of fuel depletion during operation of a reactor. If thorium–uranium fuel cycle is implemented, production of minor actinides in the used fuel is negligible. This is favorable for used fuel disposal. On the other hand, thorium fuel utilization is connected with production of ^{232}U, which decays via several alpha decay into a strong gamma emitter ^{208}Tl. Presence of this nuclide complicates manipulations with irradiated thorium fuel.

Monte-Carlo computation code MCNP can be used to simulate thorium fuel depletion in a VVER-1000 reactor. The calculated actinide composition will be analyzed and dose rate from produced gamma radiation will be calculated. The results will be compared to reference uranium fuel. Dependence of the dose rate on time of decay after the end of irradiation in the reactor will be analyzed. This study will compare the radiological hazard of used thorium and uranium fuel handling.

Dosimetric distribution of the surroundings of different dental crowns and implants during LINAC photon irradiation

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This study investigated the scattering effects of dental crowns and implants on the dose surrounding tissues of patients under LINAC photon radiotherapy. The physical properties (atomic weight fractions, physical density) of several commercially available dental materials (metal crowns, ceramic crowns and metal implants) were measured and used to establish the cross sections. Radiation dose distribution was simulated at the interfaces of oral tissues, various crowns and implants: A 6 MV photon generated by a linear accelerator (LINAC), using EGS4-based Monte Carlo codes (BEAMnrc/DOSXYZnrc) was employed. The increase of dose on mucosa directly adjacent to metal crowns was found to be 26%∼60% and dependent on the electron density per volume of the crowns. The Ti-Al-V alloy implant was found to increase the dose by 30% to the neighboring bones. An inverse relationship between dose and field size exists, which will affect the backscatter phenomenon to the surrounding mucosa. The backscatter doses can be attenuated by 4 mm denture base polymer.

Keywords: radiation dose, dental material, mucosa, LINAC, Monte Carlo.

Patient-specific dose reconstruction using Monte Carlo calculation for pediatric chest CT examination: Preliminary study

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This investigation aims to develop a dose evaluation system for individual patient undergoing pediatric chest computed tomography (CT) examination.

Geometry system of a clinical CT scanner (Aquilion ONE, Toshiba Corporation Medical Systems) was modelled using BEAMnrc Monte Carlo (MC) simulation, all components were modelled inclusive of x-ray tube, bowtie filters (3 types: small, medium and large) as well as collimators. We benchmarked 3 physical characteristic of the CT beams to validate the MC source model: half value layer (HVL), off-axis ratio (OAR), and beam width, which were performed by comparing with experimental results. An algorithm has been written to simulate the x-ray source movement both single axial mode and helical mode. The CT images of patient were implemented into MC code to create a voxel phantom as an object model, every voxel was assigned a material index and mass density according to its original CT number, the interaction between photon and materials was then randomly sampled.

The validation demonstrated that the agreement between simulation results and measured values was within 2%.

Development of the MCNPX model for the portable HPGe detector

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The portable HPGe coaxial detector Canberra BigMAC is used in LVR-15 research reactor for spectrometric measurement of spent nuclear fuel. The fuel is measured in the dedicated system located in the spent fuel pool situated near the reactor. For the purpose of the spectrometric system calibration, the detector was precisely modeled with the MCNPX code. This model was constructed with the data acquired from the technical specification provided by the manufacturer and from the data obtained by the radiography of the crystal. The detector's model was verified on the experimental data measured with available standard radionuclide sources.

Patient-specific organ doses estimation in interventional TAE using Monte Carlo and K-Means medical image segmentation

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The 2010 IAEA report indicated that radiation injuries might result after repeated embolizations and announced a new project to track radiation exposure from medical diagnostic procedures The purpose of this study is to evaluate organ doses using measurement-based Monte Carlo simulation with an adaptive organ segmentation for individual patients undergoing interventional transcatheter arterial embolization.

DOSXYZnrc of BEAMnrcMP 2009 was the Monte Carlo code used to simulate X-ray transport inside patient specific phantom, CTCREATE converted patient CT data to the densities and materials required for the DOSXYZnrc phantom. In calculation of the organ dose, apply threshold for the bone segmentation. K-means clustering algorithm for soft tissue 3-D anatomical medical images. Each iteration consists of two steps: estimate mean intensity at each location for each type, and estimate tissue types by maximizing the a posteriori probability.

An individual dosing system was established for an 64-year old male patient whose height was 168 cm, weight was 94 kg. At the end of the intervention, the dose area product value measured by the built-in transition chamber was 152 Gy-cm^2, the cumulative dose at the IEC reference point was 1095 mGy. The peak skin dose (PSD) for this case was 855 mGy. The organ dose (OD) for i organ was the average dose of the regions of interest.

Anatomical medical images segmentation was a key parameter for organ dose calculations. We have successfully used a semi automated image process to evaluate organ doses for individual patients undergoing interventional transcatheter arterial embolization.

Development and Validation of a Patient-Specific Dose Evaluation System: SimDose

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PET imaging has been widely used in the detection and staging of malignancies and the evaluation of a patient-specific dosimetry has been important in nuclear medicine. However, to implement Monte Carlo for patient-specific dosimetry is usually time-consuming. The purpose of this study was to develop a faster dose evaluation system namely SimDose. SimDose is a Monte Carlo code based on SimSET, and added a dose deposition routine to store the deposited energy of the photons and electrons. Fluorine F-18 is one of the most commonly used radionuclides and decays predominantly by positron emission. A 640 keV(Emax) positron and two annihilation photons should be concerned in radiation dosimetry, hence simulation is simplified. A F-18 point source was placed in a 20 cm diameter water sphere located in an air environment. To evaluate the effects of resolution, the grid size were separately set to 1 mm and 3 mm, since 3×10^7 decays were simulated. The results of point spread function were compared with those of GATE v6.1. Dose calculated on ORNL phantom was also performed to validate the accuracy of SimDose. The grid size of phantom was set as 3 mm and the number of simulation was set as 10^8. The ratios of S values were computed by SimDose to those obtained separately with GATE and OLINDA for liver. At last, the CPU time (AMD FX-8350 4 GHz) of simulations was compared between SimDose and GATE. The dose profiles show the absorption dose located 4 mm outside the center are similar between SimDose and GATE. However 68% (1mm grid) and 20% (3mm grid) differences of the center dose between SimDose and GATE are observed. The differences of the profile lie in the assumption that all electrons are locally absorbed. The ratios of S values (SimDose/OLINDA) were ranged from 0.90 to 1.11 and mean difference is 3.4%, since the ratios of S values (SimDose/GATE) were ranged from 0.96 to 1.04 and mean difference is 1.3%. The ratio of time consumed by SimDose to GATE for 1mm grid, 3mm grid and ORNL phantom were 0.9%, 1.0%, and 1.2%, respectively. In conclusion, SimDose would be an efficient and accuracy toolkit to generate a patient-specific dose distribution in clinical PET application.

Prototype of hand-held Compton spectrometer for the spectrometric and dosimetric control of X-ray generators

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The Compton spectrometer is a device in which radiation coming from a X-ray generator is scattered at a known angle in order to reduce the flux, thus allowing spectrometric measurements without saturating the detector.

A small-size prototype Compton spectrometer usable in the range 20–150 keV was developed, using a pen-type NaI detector. The source spectrum is reconstructed by unfolding the measured spectrum, using the response matrix calculated by the Monte-Carlo method.

The Monte-Carlo geometrical model was validated with gamma radioactive sources. Unfolding is performed using a modified version of the GRAVEL algorithm. Results are presented for the unfolded spectra obtained with several test measurements on a medical X-ray device.

This work was performed in close cooperation with the company Balteau NDT, thanks to a grant of the Walloon region (project FIRST-HE 816824).

The methodology used for optimal shielding layout determination for the 14 MeV neutron generator and isotopic neutron so

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The paper describes the method used for evaluation of shielding materials used for neutrons and gamma radiation (typically concrete, iron and polyethylene, alternatively boron carbide, boric acid) and their mutual combinations from the radiological point of view. The methodology used in MCNPX calculations for the design of multi-layer shielding (of "sandwich" type) for a neutron sources (neutron generator with energy 14 MeV and isotopic Cf-252 neutron source) with accompanying gamma radiation is described. Expected parameters of the neutron sources and legislative limitations for its operation will be discussed. Based on the radiological protection requirements, shielding layers and will be judged; neutron and gamma spectra and dose rates on the cold side will be given.

Based on the results, shielding layers will be optimized in terms of overall thickness and weight (or price respectively). Results will be used to design an additional ceiling and wall shielding of the workplace with neutron generator.

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Benchmark experiments for verification of reaction rates determination in reactor dosimetry

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The precision of Monte Carlo calculations of quantities of neutron dosimetry strongly depends on precision of reaction rates prediction. Research reactor represents a very useful tool for verification the ability of a code to calculate such quantities as it can provide environments with various types of neutron energy spectra. Especially, a zero power research reactor with well-defined core geometry and neutron-physical properties enables precise comparison between experimental and calculated data. Thus, at VR-1 zero power research reactor, a set of benchmark experiments were proposed and carried out to verify the MCNP Monte Carlo code ability to predict correctly the reaction rates. For that purpose two frequently used reactions were used: He-3(n,p)H-3 and Au-197(n,γ)Au-198. The benchmark consists of response measurement of small He-3 gas filled detector (diameter as well as length of active part of the detector was 1 cm) in various positions of reactor core held in critical state at constant power and of activated golden wires placed inside the core or to its vicinity. In the benchmark two different core configurations called C7 and C8 were assembled and large number of experimental data was measured characterizing vertical and horizontal distribution of reaction rates on He-3 and Au-197 in the reactor core. The reaction rates were calculated in MCNP5 code as well utilizing a detailed model of VR-1 reactor which was validated for neutronic calculations at the reactor. The paper describes in detail the experimental set-up of the benchmark, the MCNP model of the VR-1 reactor and provides a comparison between experimental and calculated data.

Application of dosimetry measurements to analyse the neutron activation of a stainless steel sample in a training nuclea

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All materials present in the core of a nuclear reactor can be activated by neutron irradiation. When activated materials are withdrawn from the reactor a dose is produced around them. This dose is a potential risk for workers and people staying in the surrounding area. Therefore, it is necessary to assess activity generated and dose produced. In previous works, neutron activation of control rods and doses around the storage pool where control rods are placed have been calculated for a Boiling Water Reactor using the MCNP5 code based on the Monte Carlo method. On the other hand, most of the activation is produced in stainless steel components of the control rod. Indeed, many components in the nuclear reactor core are made of stainless steel. Therefore, the Monte Carlo model can be applied to the activation produced in a piece of stainless steel exposed to some neutron flux in a reactor. As well the dose rate around the activated piece can be measured. In this work, a stainless steel sample is irradiated in the Training Reactor AKR-2 of the Technical University Dresden. Dose measurements around the sample have been performed for different times after the irradiation. Experimental dosimetric values are compared with results of Monte Carlo simulation and the comparison shows a good agreement. It is an attempt to have an indirect validation of the activation Monte Carlo model for the neutron activation. That is, activities obtained with the Monte Carlo model of the neutron activation are used as input data for a second Monte Carlo model simulating the dose produced around the irradiated piece. These doses are compared with dosimetry measurements. As comparison shows a good agreement between measured and simulated doses, the activation Monte Carlo model can be considered as validated.

Three dimension dose distribution in phantom using diagnostic transmitted X-ray tube

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The purpos of this study was to investigate the three-dimensional dose distribution from a new type of diagnostic X-ray energy spectra generated by the transmission tantalum target.

PENELOPE (PENetration and Energy LOss of Positrons and Electrons) code (version 2011, RSICC), a kind of monte carlo simulation method, was used :(1) to assess the flux distributions, the energy flux distributions of the transmission tantalum target X-ray energy spectra; (2) to assess the depth-dose distribution, lateral dose distribution, and incidenct surface dose within or on the water phantom. Mesurements using thermoluminicent dosimetors (GR-200A, Beijing) and an ionization chamber (Model 9015, RadCal) were compared with simulated data. We used 11*11 TLD array to measure the x-y dose distribution at several depthes. Figure 1 is the energy spectrum of transmitted X-ray tube with tantalum target and beryllium filter with 90 keV electron beam incident. Figure 2 shows three-dimensional dose distribution for an oval abdomen phantom using 90-kV x-ray with tantalum target and beryllium filter.

X-rays generated by the transmission tantalum target can be applied to the diagnostic X-ray radiography. The three-dimensional dose distribution has been investigated in this study. Howerver, transmission X-ray flux ratio is much lower than general reflected X-ray. The challenge of using transmitted X-ray is to design a sensitive image dtector to compensate for the small x-ray photon flux.

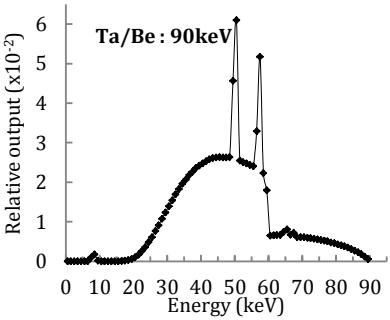

Figure 1. Energy spectrum of transmited X-ray tube with tantalum target and beryllium filter with 90 keV electron beam incident.

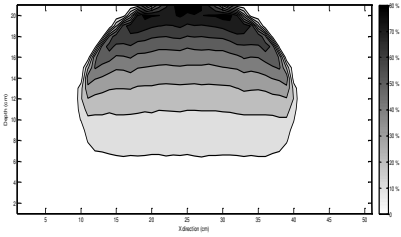

Figure 2. Three-dimensional dose distribution for an oval abdomen phantom using 90-kV x-ray with tantalum target and beryllium filter.

Estimation of the Radiation Field Homogeneity in Co-60 Blood Irradiator

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The usual life span of high-level active sources in radiotherapy cobalt unit is about 10 years (maximum 15 years), after which they should be replaced. Although the sources still provide activity in thousands of Curies, they usually end up being disposed of.

The aim of this work is to estimate the homogeneity of the radiation field in various configurations and relative activities of the "disposed" but still relatively highly active sources for their potential use in irradiation of blood (or blood derivatives). Small dose rate, which is already unusable/inappropriate for the teletherapy, may be still utilized by simultaneous use of multiple sources or reducing the distance to the irradiated object (blood unit). To estimate the homogeneity of the radiation field a modeling approach was chosen in which Monte Carlo code MCNP has been employed. (In-) homogeneity of the radiation field has been estimated on the basis of isodoses in the water phantom and various configurations and relative activities of the cobalt sources. The results are further discussed with regard to optimization (homogeneity of the sample irradiation, costs, radiation protection of service staff, availability of a sufficient number of resources, etc.).

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A design of a NaI(Tl) crystal used in a high throughput system for an emergency measurement of I-131 in human thyroid

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A development of a high throughput system for the measurement of the iodine 131 in human thyroid was initiated by the Fukushima accident in 2011. The system is required to be capable of measuring adult as well as child subjects across a wide range of age during a large-scale monitoring of population. For the detection unit, a crystal of NaI(Tl) coupled with a photomultiplier has been chosen with the intention of the optimizing its detection properties in the cooperation with a manufacturer ENVINET NUVIA GROUP. The crystal should have a favourable ratio of the detection efficiency at 364 keV to its sensitivity to higher energy gamma radiation emitted by radionuclides in a background and in the rest of the subject's body. At the same time, the uncertainty due to the variations in the anatomy of a thyroid gland should be minimized by the crystal design. Also, operational consideration should be made. The design of the NaI(Tl) crystal was based on Monte Carlo (MC) simulations supported by literature. The MC study began with an examination of dimensions and shapes of the crystal. Three different shapes and several dimensions were simulated and their efficiency was compared with a standard 2×2 inch NaI(Tl) crystal used in SÚRO, v.v.i. (NRPI), Prague, Czech Republic, for thyroid measurements. Two prototypes of detectors with a crystal diameter 80 and 73 mm were manufactured and tested. The detector with the crystal diameter of 80 mm provided better results and has been chosen for the further production. A tungsten collimator was designed for the detector and optimized in MC simulation involving the use of voxel phantom of a reference woman. The distribution of the radioiodine in a human body at the time of the measurement and an optimum length and shape of the collimator with respect to its mass were taken into consideration.

A PENELOPE And TLDs For Dose Verification Of Breast Cancer With INTRABEAM And A Spherical Applicator In IORT

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The purpose of this study is to verify the dose distribution of the transmitted X-ray generator (INTRABEAM, Carl Zeiss Surgical, Oberkochen, Germany), which is used for further breast cancer treatment in auxiliary during breast surgery [1]. In the treatment plan, the electron beam incident from different beam angle may cause the various dose distribution to breast tissue. It is important to verify the dose distribution and understand the treatment plan uncertainty. The X-ray generator tube is designed to deliver a 50 keV of electron beam, which is different from electron energy, i.e. MeV, used in general radiotherapy. The generator's specific structure utilizes electron beams to hit the gold target to generate a forward bremsstrahlung radiation [2]. The dose profile, provided by the vender in the treatment planning system, was verified by TLDs (thermoluminescent dosimeter) to record the dose around the surface of the generator with different-sized spherical applicators. TLDs (TLD-100H, Harshaw Chemical Company, American) are conformal to the spherical applicators to get the excellent dose distribution on the surfaces of spherical applicators [3]. In addition, we apply a PENELOPE Monte Carlo (MC) tool in simulating the X-ray generator's dose distribution [4-5]. The PENELOPE simulation algorithm for electrons reproduces the actual transport process to a high degree of accuracy and is stable even at low energies in our cases. Finally, we compared the dose distribution from treatment plans with those from TLDs and PENELOPE.

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Dual resolution Monte Carlo dose analysis for stereotactic radiosurgery of skull base tumor

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Purpose: The purpose of this study was to examine in detail the dose distribution of target skull base tumor and surrounding critical structures in response to a single-fraction high-dose stereotactic radiosurgery (SRS) with Monte Carlo (MC) simulation using a dual resolution (DR) phantom.

Methods: The BEAMnrc MC code was used to simulate a 6 mm diameter SRS photon beam transported through the Varian [21]EX linear accelerator treatment head attached with an SRS cone unit. In this simulation, a parallel circular electron beam with a Gaussian energy distribution (meanenergy = 6.3MeV and FWHM = 0.12 cm) was incident on the photon target. Variance reduction with directional bremsstrahlung splitting (DBS) was applied. The Russian roulette plane was fixed at 0.318 cm above the bottom of the flattening filter. The global electron transport cutoff (ECUT) and photon transport cutoff (PCUT) energies were set at 0.5210 and 0.01 MeV respectively. DOSXYZnrc was used to simulate a single 6 MV photon beam delivering 12 Gy in 1 fraction to the skull base tumor. A DR phantom for MC simulation was created based on the patient's CT scan of a skull base tumor [gross tumor volume (GTV) = 64 mm^3 near the right 8^{th} cranial nerve. The phantom consisted of a 12 mm thick skull base region with a $0.5 \times 0.5 \times 1$ mm^3 voxel resolution sandwiched in between a $0.5 \times 0.5 \times 3$ mm^3 voxel resolution head phantom. A coarser $2 \times 2 \times 3mm^3$ voxel single resolution (SR) phantom was created for comparison with the sandwich dual resolution phantom. A particle history of 5×10^8 was used for both SR and DR phantom simulation to achieve a statistical uncertainty of $< 2\%$.

Results: The maximum/mean doses to the GTV for the DR and the SR phantoms were 1401.5 /798.6 cGy and 491.3/491.3 cGy respectively. While the maximum/mean doses to the brain stem, right internal carotid artery, right mastoid, right external auditory canal, and right cochlea for the SR and DR phantoms in MC did not show any difference. While the DR phantom simulation showed higher maximum/mean doses than the SR phantom for the right 8^{th} cranial nerve (1028.5/372.2 cGy vs 491.3/339.9 cGy) and right internal jugular vein (1205.6/67.3 cGy vs 340.0 cGy/26.2 cGy).

Monte Carlo Simulations for Radiation Shielding Optimization in a Medical Accelerator

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Medical linear accelerators operating above 10 MV require door shielding for neutron as well as photon. Thermal and epithermal neutrons are absorbed with great effectiveness by ^{10}B. Inelastic scattering or absorption may again produce potentially hazardous gamma rays. Neutron capture in hydrogen and boron releases a gamma ray. In this study, the photoneutrons and photons generated by linear accelerator of 18 MeV energy electrons were simulated using radiation transport code MCNPX. Dose equivalent and fluence for neutrons and photons were calculated at various points inside treatment room and outside door. The shielding performance of borated polyethylene (BPE) and lead as shielding material was evaluated. The calculation of the reduction in neutron and photon fluence was performed for various shield thickness as well as the secondary radiation generated by the reaction with BPE and Lead. To determine an optimal arrangement of lead and BPE for neutron and photon shielding, shielding performance was evaluated considering arrangement of BPE and lead. The dose from neutrons is about one order of magnitude higher than the photon dose inside the door. In the case for the BPE thickness – 40mm, the fluencies from additional photons generated by the reaction between neutrons and shielding material is about 6.58%, 29.89% of the neutron fluencies at the surface on the source side and outside, respectively. However, for lead, the ratio of additional photon fluence is much smaller than that of BPE. The obtained results suggest that an additional lead is necessary to attenuate neutron-capture gamma ray.

Image quality and dose assessment in Digital Breast Tomosynthesis: a Monte Carlo study

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Mammography is considered the standard technique for the early detection of breast cancer. However, its sensitivity is limited essentially due to the issue of the overlapping breast tissue. This limitation can be partially overcome, with a relatively new technique, called digital breast tomosynthesis (DBT). For this technique, optimization of acquisition parameters which maximize image quality, whilst complying to the ALARA principle, continues to be an area of considerable research.

The aim of this work is to study the best quantum energies that optimize the image quality with the lowest achievable dose in DBT. Monte Carlo simulations were performed using the state-of-the-art computer program MCNPX 2.7 in order to generate the several ^{2}D cranio-caudal (CC) projections obtained during an acquisition of a standard DBT examination. Moreover, also glandular absorbed doses and photon flux calculations, for each projection images, were performed. A homogeneous breast computational phantom with 50%/50% glandular/adipose tissue composition was used and two compressed breast thicknesses were evaluated: 4 cm and 8 cm. The simulated projection images were afterwards reconstructed with an algebraic reconstruction tool, which allowed us to measure the signal–difference to noise ratio (SDNR) in order to evaluate the image quality in DBT.

Finally, a thorough comparison between the results achieved in terms of SDNR and dose assessment in DBT and the ones currently used in standard mammography is performed.

Comparative analysis of bricks by NAA, alpha counting and XRF for thermoluminescence fine grain dating method

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The internal dose rate for fine grain samples in the thermoluminescence (TL) dating method is based on the concentrations of natural radionuclides ^{238}U, ^{235}U, ^{232}Th and members of their decay series, and also on ^{40}K, and is influenced by water content. The dose rate fraction from ^{238}U and ^{232}Th can be calculated, e.g., from the alpha count rate, or from the concentrations of ^{238}U and ^{232}Th, measured by neutron activation analysis (NAA). The dose rate fraction from ^{40}K can be calculated from the concentration of potassium measured, e.g., by X-ray fluorescence analysis (XRF) or by NAA. To make an evaluation of the age from the equivalent dose and to obtain an optimized and efficient procedure for TL dating, an analysis is needed of both the internal and the external dose rates from dated samples and their environment. The measurements described and compared in this paper refer to bricks from historic buildings and a fine grain dating method. It is therefore not necessary to measure external doses from the soil, but the alpha dose rate must be taken into account. The alpha dose rate can be determined from the natural U and Th concentrations, and the beta and gamma dose rate can be determined from the natural U, Th and K concentrations. Alpha counting on Intelligent Alpha Counter Model 583 and XRF is used in the laboratory at FNSPE. These methods can proceed immediately after collecting the samples. NAA is more accurate, but it requires more time and more handling samples, and is also more expensive, as it needs a nuclear reactor as a neutron source. A comparison of the methods will allow us to decide whether the time and cost saved by using the simpler alpha counting and XRF procedures introduces unacceptably high uncertainty. In the age equation algorithm, the dose rate can be calculated directly from the alpha count rate, without using exact concentrations, but a fixed Th:U ratio must be assumed. Thus, a comparison of the dose rates from U and Th calculated from alpha counting and from NAA can provide information about the degree of approximation introduced by alpha counting. In addition, a comparison of concentrations of K measured by NAA and XRF has been carried out, from which the dose rate from ^{40}K is computed. The same formula is used in this case, but XRF is less sensitive and less accurate than NAA. The optimum method for dated samples, from the point of view both of accuracy and of time, can be selected by comparing the analytical methods that are used.

Radioactive Waste Disposal Fees – Methodology for Calculation

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Radioactive waste and spent fuel are generated in the Czech Republic as a consequence of the peaceful use of the nuclear energy, health care, research and industry. In comparison to other hazardous waste, it possess about one hundredths of the total hazardous waste generated. In the Czech Republic, the radioactive waste management policy is based on the Concept of Radioactive Waste and Spent Nuclear Fuel Management up to approximately 2025 (affecting policy up to the end of the 21st century).

Radioactive waste is usually classified according to the concentration of radionuclides and by the period of time during which the waste will remain radioactive. Depending on the concentration of radionuclides and intensity of emitting radiation, radioactive waste is classified as low, intermediate or high-level waste; depending on the period of time required for decay, as short-term and long-term.

Czech legislation complies with the four main categories as per the recommendations of the IAEA[1]. These categories of radioactive waste correspond to three main ways of disposal – storage until the time of natural decay, surface and subsurface disposal of short-lived radioactive waste, and the geological disposal of long-lived radioactive waste.

The main aim of the study is to propose the methodological approach that can be used for the calculation of fee for low – and intermediate – level radioactive waste disposal and for spent fuel disposal. The proposed methodology is based on simulation of cash flows related to the operation of system for waste disposal. This paper is also providing the reader with all the necessary assumptions that are needed in order to develop a valid economic model.

According to the above mentioned categorization the methodology of calculation is split into two relatively independent tasks:

- Methodology for calculation of the fee for ILW and LLW disposal in existing repositories (Richard, Bratrství, Dukovany)

- Methodology calculation of the fee for future disposal of spent fuel in deep geological repository

[1] IAEA Safety Series No. 111-G-1.1 Classification of Radioactive Waste, Vienna 1994

Sorption of radionuclides by the crown ethers immobilized in a polymer matrix

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The spent nuclear fuel and radioactive waste have high activity because of presence of the long-lived isotopes among these are ^{60}Co, ^{90}Sr and ^{137}Cs.

None of the existing methods of radiation control don't make possible determination of low concentration ^{60}Co, ^{90}Sr, ^{137}Cs without them previous concentrating. Selective sorption ^{60}Co, ^{90}Sr, ^{137}Cs is difficult scientific and technological problem.

Great interest for extraction of ^{60}Co, ^{90}Sr, ^{137}Cs is represented sorbents impregnated by crown ethers, allowing selectively to extract it from solutions with high content of salts.

A set of new sorbent were obtained by impregnation different amounts of endoreceptor crown ethers (benzo-15-crown-5, 7-tia-benzo-15-crown-5, dibenzo-18-crown-6 and dibenzo-24-crown-8) in the styrene-divinylbenzene polymer matrix "Porolas-T".

Sorption properties of sorbents on the base of dibenzo-18-crown-6 are investigated with strontium extraction, namely isotherm of sorption, dependence of the distribution coefficient on the concentration of nitric acid in a solution and concentration of crown ether in the sorbent, kinetics of sorption and desorption of strontium. The selectivity of strontium sorption was studied to the alkaline, alkaline-earth metals and cobalt.

Sorption properties of sorbents on the base of benzo-15-crown-5, 7-tia-benzo-15-crown-5 and dibenzo-18-crown-6 are investigated with cobalt extraction, namely distribution coefficients, sorption capacity, percent of cobalt sorption, regularity of change of distribution coefficient depending on pH of initial solution and the presence of complexing agents are defined.

Sorption properties of sorbents on the base of dibenzo-24-crown-8 are investigated with cesium extraction. Parameters of cesium sorption from water-ethanol solution in presence of picric acid were estimated.

Dosimetry study of low-energy X-ray using doped iodide normoxic polymer gels

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Polymer gel dosimeters are used for three-dimensional (3D) dose distribution in radiotherapy. Polymer gels have been confirmed to be proportional to the absorbed dose in a polymerization reaction; however, the doses are in Gy range. In this study, we attempted to develop a low-dose 3D dosimeter in mGy range for diagnostic radiology.

The effect of the iodinated compound was used as a dose enhancement sensitizer to improve the dose sensitivity of the normoxic polymer gel dosimeter.

The aims of this study were to use N-isopropylacrylamide (NIPAM)-based gel and methacrylic acid (MAGAT)-based gel to evaluate the potential dose enhancement sensitizer, such as the clinical iodinated contrast medium agent (Iobitridol, Xenetix® 350), and to compare two gels which may be suitable for measuring low radiation doses. The suitable formulation of NIPAM gel (5% (w/w) gelatin, 5% (w/w) NIPAM, 3% (w/w) Bis, 10 mM tetrakis(hydroxymethyl)phosphonium chloride (THPC), and 87% (w/w) deionized distilled water) and MAGAT gel (9% methacrylic acid, 8% gelatin, 83% deionized water, and 10 mM THPC) were used and loaded with Xenetix®350. Irradiation was performed with X-ray computed tomography. The irradiation doses ranged from 0 mGy to 120 mGy. Optical computed tomography was the gel measurement system used. The results indicate that the iodinated contrast agent leads to a quantifiable dose enhancement ratio. The dose enhancement ratios of NIPAM and MAGAT gels are 2.5±0.4 and 7.7±0.6, respectively, when NIPAM and MAGAT gels were irradiated with x-ray photons whose most probable energy was close to the K-edge absorption of iodine (∼33 keV). The dose enhancement ratio of MAGAT gel, which ranges between 0 mGy to 120 mGy, is higher than that of NIPAM gel. This finding indicates that MAGAT gel is more suitable for measuring low radiation doses. In the future, MAGAT gel will be used to assess 1 mGy to 15 mGy irradiated doses using clinical X-ray equipment.

A preliminary study of the thermal measurement with the nMAG gel dosimeter by MRI

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For the last decade, many types of gel dosimeters have been widely used to verify the radiation dose in the field of radiation therapy. The nMAG dosimeter which is a less toxic normoxic polymethacrylic acid gel proposed by De Deene *et al.* is expected to be an effective tool for three-dimensional quality assurance for therapeutic systems. In addition to radiation induced polymerization, the nMAG dosimeter also responds to temperature variations. In this study, we proposed a new way to evaluate the thermal response using the gel dosimeter. The nMAG was prepared using ultra-pure deionized water, 8% gelatine (porcine skin, 300 bloom, Sigma Aldrich), 8% methacrylic acid (∼99% titration,Sigma Aldrich), and 2mM tetrakis(hydroxymethyl)phosphonium chloride(THPC). The test tubes of nMAG were heated for 1 and 10 minutes, respectively, using the double-boiling method with the temperature ranging from 30°C to 80°C. A 1.5T MR scanning (Siemens Sonata, Erlangen, Germany) with a total of 32 multi-spin echo pulse sequence was performed. Several properties of nMAG have been investigated including the relaxivity rate R2 (= 1/T2) of MRl, the temperature sensitivity, and the linearity of temperature response. The R-square values for 1 min and 10 min heated were 0.832 and 0.851, respectively, ranging from 30°C to 80°C. In which, under the temperature of 40°C to 70°C, the R-square values were increased to 0.988 and 0.951, respectively. The measured data showed that the nMAG gel dosimeter had a linear response to the temperature. Moreover, the nMAG gel dosimeter has a higher linearity and sensitivity in the range of 40°C to 70°C. In the future, we will investigate the precise limitation of thermal response to the nMAG gel dosimeter. We conclude that the polymer gel dosimeters have the potential as a measurement tool for evaluation of the thermal surgery.

Calibration of spent fuel measurement assembly

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Within the RERTR program for HEU fuel minimization, the LVR-15 had converted from the HEU IRT-2M to the LEU IRT-4M fuel. For the possibility of the independent pre-transport evaluation of IRT-2M burnup, a spectrometric system was developed. This spectrometric system consists of the fuel holder, the collimator and the portable HPGe detector Canberra Big-MAC.

In order to have well reproducible and reliable experimental data for modeling of the measurement system, calibration with the Ag-110m isotope with known activity was performed. The Ag-110m isotope was prepared by irradiating of the silver foil in LVR-15 research reactor; its activity was evaluated in the LVR-15's spectrometric lab. From the measured data, an efficiency curve of the spectrometric system has been determined. The experimental data were compared to the calculation results with the MCNPX model of the spectrometric system.

The utilization of LR-0 for reference neutron spectra

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Well-defined neutron spectra are crucial for calibration and testing of detectors for spectrometry and dosimetry purposes. As a possible source of neutrons nuclear reactors can be utilized. In reactor core most of the neutrons are originated from fission and neutron spectra is usually some form of moderated spectra of fast neutrons.

The reactor LR-0 is an experimental light-water zero-power pool-type reactor originally designed for research of the VVER type reactor cores, spent-fuel storage lattices and benchmark experiments. The main reactor feature that influence the performance of experiments is the flexible arrangement of the core. Special types of the possible core arrangements on the reactor LR-0 can provide different neutron spectra in special experimental channel. These neutron spectra are modified by inserting different materials around the channel and whole core is driven by standard fuel assemblies. Fast, epithermal or thermal spectra can be simulated using graphite, H_2O, D_2O insertions, air, Cd foils or fuel with different enrichment.

Reference: Košťál, M., Rypar, V., Švadlenková M., Cvachovec, F., Jánský B., Milčák, J. Irradiation capabilities of LR-0 reactor with VVER-1000 Mock-Up core, will be published

Multi-shape pulse pile-up correction: the MCPPU code

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In spectroscopic measurements under high rate photon detection, pulse pile-up (PPU) is a common distortion of the spectrum. It is fully ascribable to the pulse handling circuitry of the detector and it is not comprised in the detector response function which is well explained by a purely physical model [1]. Since PPU occurs after the transport inside the detector, this is the first correction to perform in case of spectrum unfolding.

Even if many producers include electronic rejection circuits to limit the appearance of PPU, this is never suppressed completely. Therefore, it is always necessary to correct the PPU distortion after the measurement.

Different methods have been developed for characterizing the MC by exploiting either analytical techniques [2-5] or Monte Carlo (MC) simulation [6,7]. To be applied, all of these techniques need the knowledge of the pulse shape, the shaping time and the dead time.

In the present work it is described the post-processing code MCPPU (Monte Carlo Pulse Pile-Up) which applies the MC algorithm developed by Gardner et al. [6,7] for correcting the PPU effect. The additional capability of allowing the selection of different pulse shapes makes the code suitable to be used with different detectors.

It is worth noting that the nominal parameters of pulse shaping are modified by the PPU rejection circuitry, which makes it necessary to identify the new parameters in order to apply the correction. A special strategy has been developed to this end. The code is capable to perform the correction without the need of an additional low rate measurement of the spectrum.

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Comparative study of semiconductors detectors to use in radiodiagnostic energy range.

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This work aimed to compare responses of two semiconductors systems, one HPGe with an analog multichannel analyzer and other CdTe whith digital pulse processing. Measurements were carried out using point sources of Am^{241} and Eu^{152} with an energy range of 17–121.78 keV corresponding to diagnostic radiology energy range applications. Were used distances between 0.30–1.5 m to obtain different count rates. The results obtained to the HPGe system had bigger dead time than CdTe due to the shaping time be higher to HPGe (ms–μs) than the CdTe (μs–ns) . Both systems showed able to detect the spectra in diagnostic radiology energy range but should take precautions against the loss of information by saturation, it is suggested the use of collimators and attenuators mainly at short distances.

OSL and TL response of blue apatite from Brazil

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Natural apatite is part of a mineral group extensively studied due to their wide variety. Apatite is part of the phosphate group and can been found in nature as: hydroxyapatite, fluorapatite, chlorapatite and so are named like these since they have higher concentrations of hydroxide (OH-), fluoride (F-) and chloride (Cl-) in the crystal structure, respectively. Many studies have shown that apatite exhibits quite pronounced luminescence when stimulated with X-rays and light of different wavelengths. As has also been observed, natural apatite exhibits a thermoluminescent signal that may have applicability in radiation dosimetry. Since then, the electronic structure and defects creators of luminescent centers in material have been the focus of these studies. The main objective of our study was evaluate the luminescence of blue apatite from southeastern of Brazil (state of Minas Gerais. At present work the optically stimulated luminescence (OSL) and thermoluminescence (TL) were evaluated after the mineral has been submitted to electrons beams. It was observed that the samples exhibits linear behavior for high radiation doses, which shows that blue apatite from southeastern of Brazil can be applied in radiation dosimetry.

Assessment of the contamination with the trace elements and man made radionuclides around the Temelin Nuclear Power Plan

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The results of atmospheric deposition of radionuclides and trace elements determined in moss Pleurozium Schreiberi collected around the Temelín Nuclear Power Station in the Czech Republic in the year of 2011 are presented. The monitored area around NPP Temelin comprises 29 sampling sites located along 8 profile radii stretched as of 2, 5, 10, and 20 km from the NPP. In the study area some of pollution sources are allocated. A certain amount of heavy metals and other toxic elements (such as: ^{129}I, ^{137}Cs, ^{14}C, ^{3}H, ^{84}Kr, etc.) is being released into the soil, water and air. The use of terrestrial mosses as biomonitors in large-scale multi-element studies of atmospheric deposition of trace metals and manmade radionuclides is a well-established technique. Moss, in general, differs from chorioidal plants by absence of real roots, but only attachment fibers connecting its bryophytes to the underlay. Moss receives neither water nor sustenance from soil because it is adjusted to taking in nutrients only from the atmosphere. Monitoring utilizes only the uppermost segments of stalks collected directly at the selected locations (passive moss monitoring). The whole living part corresponding approximately to the three years growth was subjected to analysis. Therefore, the results from the survey represent the average deposition situation over the period 2009-2011. A total of 42 elements (Na, Mg, Al, Cl, K, Ca, Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Zn, As, Se, Br, Rb, Sr, Zr, Mo, Ag, Cd, In, Sb, I, Cs, Ba, La, Ce, Sm, Eu, Tb, Hf, Ta, W, Au, Hg, Pb, Th, and U) were determined by epithermal instrumental neutron activation analysis with the neutron flux density $\Phi epi. = 3.6 \times 10^{11}$ n/(cm^{2}s) at the pulsed fast reactor IBR-2, FLNP, JINR. To determine the presence of radionuclides and their measurable activity in samples (IAEA 2003), laboratory gamma spectrometry was found the best. A coaxial HPGe detector with samples in the geometry of Marinelli containers was used. To assess the influence of NPP Temelin on the Biomass in a 20 km radius, measurements determine the mass activity of ^{137}Cs (Bq/kg) and no other short-term radionuclides have ever been identified in any spectrum.

Feasibility of radiochromic gels for 3D dosimetry of narrow low-energy X-ray beams

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This paper describes determination of relative 3D dose distributions in narrow low-energy beams with gel dosimeters. X-ray tubes with a maximum voltage from 30 to 50 kV are used in various techniques of structural and chemical analysis such as X-ray radiography of small object or X-ray fluorescence analysis and microanalysis. Narrow beams are achieved with collimators or collimating/focusing X-ray optics. Even low-power X-ray tubes are usually used the doses could be relative high (especially for focused beams or in the case of long term exposures). Radiochromic gel dosimeters were irradiated and then evaluated with optical computed tomography. Optical transmission images of irradiated gels were processed to obtain detailed 3D optical density maps inside the gels that correspond to dose distributions. In addition, ^{2}D beam profiles were also done with gafchromic film dosimeters and integral doses were measured with thermoluminiscence dosimeters.

Spectrometric approach to initial estimation of the dose rates in an X-ray micro-beam focused with polycapillary optics

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X-ray tubes are widely used X-ray sources producing radiation in an energy range from a few keV up to several hundreds of keV. Apart from the classical instruments, X-ray sources with a micro-beam are nowadays available. These ones contain microfocus X-ray tube supplemented with polycapillary X-ray optics. The emerging divergent X-ray beam goes through the optics consisting of glass capillaries and it is focused. The beam diameter depends on the distance from the end cap of the optics and can be reduced down to several micrometers in the focal spot. Thus, very high X-ray flux is archived in this small volume. It is beneficial in radiation exposures of very small areas or in instrumental techniques of structural and chemical analysis. However, such high X-ray flux represents potential risk of radiation exposure to investigated objects. Therefore, it is essential to know the irradiation in microscopic volume in a focal spot. Spectrometric approach was applied to initial estimation of the dose rates and it is described in this contribution. The measurements performed with silicon semiconductor detectors included determination of a beam profile, an X-ray spectrum, and a flux of photons in the X-ray microbeam. All this date was then used for calculation of volume distribution of dose rates in various materials.

Characterization of the Risoe TL/OSL DA-20 reader for application in practical TL dosimetry

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The automated Risø TL/OSL reader systems are used worldwide for more than two decades. They were originally developed for application in luminescence dating. Nowadays they are also often used for retrospective dosimetry and material characterization. The reader is equipped in a sample carousel allowing 48 samples to be processed in a single run. The built-in radiation sources enable easy calibration of samples. The automatic features of this reader could make it interesting to use this instrument also for practical TL dosimetry.

The goal of the present work was to investigate the performance of the most modern of the long Risø reader series – model DA-20, in perspective of its application in personnel or environmental dosimetry. The studies were realized using standard thermoluminescent detectors LiF:Mg,Ti and LiF:Mg,Cu,P and included such properties as stability, repeatability, background level, lowest detection limits etc. The measurements were conducted in comparison with the Harshaw 3500 reader, a standard instrument commonly used in TL dosimetry. The another studied topic was quantification of the effect of the presence of strong radiation sources in the reader: cross-talk (irradiation of the adjacent samples) and radiation leakage, when source is not in operation, which were found to be not negligible.

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A simple method for absolute power measurement of radioisotopic neutron source

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Fluor activation technique well-known manganese bath is the most important and usual method for the absolute power determination of neutron sources. In this paper, a new simple method for measurement of radioisotopic neutron source yield is done. Neutron source put inside of the polyethylene moderator and several foils array on the exterior surfaces of polyethylene. Neutrons emitted from source and transport in the moderator media and activate the foils. A gamma spectroscopy system measured the made activation of foils and then absolute power of neutron source was determined. Moderator response, proper geometry and optimum dimensions determine using of the MCNP4C code. Measurement results have good agreement with standard data.

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