2nd International Conference on Dosimetry and its Applications (ICDA-2)

University of Surrey, Guildford, United Kingdom, 3-8 July 2016

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University of Surrey

The UK National Physical Laboratory (NPL)

WITH THE SUPPORT

International Radiation Physics Society (IRPS)

SYMPOSIUM VENUE

Austin Pearce (AP) Building, University of Surrey, Guildford, United Kingdom

SPONSORSHIP

International Radiation Physics Society (IRPS)

All the conference talks and poster sessions will take place in the Austin Pearce Building*

Conference Programme

Sunday 3 July

14.00 - 19.00	**Registration**
19.00- 21.00	**Welcome party**

Monday 4 July

8.30 – 18.00	**Registration, help desk**
9.00 – 9.30	**Conference opening**

Time	**Type of lecture/Speaker**		**Code**	**Session Chair**
9:30 – 10:00	Invited Lecture	Prise, K	I-16	***Andrew Nisbet***
10.00 –10.30	**Coffee break and Poster session-1**			
10:30 - 11:00	Invited Lecture	Chantler, C	I-1	***Paddy Regan***
11:00 -11:15	Oral Presentation	Moradi, F.	25	
11:15 -11:30	Oral Presentation	Hawkes, N.	15	
11:30 -11:45	Oral Presentation	Mitu, I-O	24	
11:45 - 12:00	Oral Presentation	Svrcula, P.	34	
12:00 - 12:15	Oral Presentation	Darvish Molla, S	9	
12:15 - 12:30	Oral Presentation	Kessler, P.	17	
12.30 - 14.00	**Lunch break**			

14:00 -14:30	Invited Lecture	Thirolf, P	I-21	***Annika Lohstroh***
14:30 -15:00	Invited Lecture	Oberstedt, S	I-14	
15:00 -15:15	Oral Presentation	Anjomani, Z.	4	
15:15 - 15:30	Oral Presentation	Mostacci, D.	26	
15.30 -16.30	**Coffee break and Poster session-1 (continued)**			
16.30 -17.00	**Take down posters from poster session-1, to be replaced by posters ready for poster session-2**			

Tuesday 5 July

08.30 – 18.0	**Registration, help desk**			
09:00 -09:30	Invited Lecture	Regan, P.H.	I-2	***Stuart Green***
09:30 -10:00	Invited Lecture	Zimmerman, B	I-22	
10.00 -10.30	**Coffee break and Poster session-2**			
10:30 -11:00	Invited Lecture	O'Keefe, S	I-11	***Richard Hugtenburg***
11:00 -11:15	Oral Presentation	Dimitriadis, A.	10	
11:15 -11:30	Oral Presentation	Gurgi, L.	13	
11:30 -11:45	Oral Presentation	Merrett, J.	22	
11:45 -12:00	Oral Presentation	Mulder, J.	27	
12:00 -12:15	Oral Presentation	Schelin	29	
12:15 -12:30	Oral Presentation	Suliman, I.I.	33	
12.30 -14.00	**Conference photo on plazza in front of the AP Building, followed by Lunch Break**			
14:00 -14:30	Invited Lecture	Khandaker, M	I-10	***Silvia Pani***
14:30 -15:00	Invited Lecture	Green, S	I-5	
15:00 -15:15	Oral Presentation	Al-Affan, I.	3	
15:15 -15:30	Oral Presentation	Baptista, M.	6	
15.30 -16.00	**Coffee break and Poster session-2 (continued)**			

16:00 -16:15	Oral Presentation	Liosi, G.M.	21	***Christopher Chantler***
16:15 -16:30	Oral Presentation	Cavalcante, F.	7	
16:30 -16:45	Oral Presentation	Fathi, K.	11	
16:45 -17:00	Oral Presentation	Halato, M.	14	
17:00 -17:15	Oral Presentation	Mishra, D.R.	23	
17:15 -17:30	Oral Presentation	Gambarini, G.	12	
19.30 -21.00	**Concert (a Symphanova performance led by Shelley Katz)**			

Wednesday 6 July 2016

8.30 - 12.00	**Registration, help desk**			
9:00 - 9:30	Invited Lecture	Hudson, L.T	I-7	***Steven Judge***
9:30 -10:00	Invited Lecture	Harkness-Brennan, L	I-6	
10.00 -10.45	**Coffee break**			
10:45 -11:00	Oral Presentation	Abubaker, Y.	2	***Zsolt Podolyak***
11:00 -11:15	Oral Presentation	Stefanik, M	32	
11.15 -11.45	Invited Lecture	Judge, S	I-9	
11.45 -12.45	**Lunch break**			
13.00 -19.00	**Conference excursion**			

Thursday 7 July 2016

8.30 - 18.00	**Registration, help desk**			
9:00 - 9:30	Invited Lecture	Fernandez–Varea, J.M.	i-4	***Larry Hudson***
9:30 -10:00	Invited Lecture	Taylor, M	i-20	
10.00-10.30	**Coffee break and Poster session-3**			
10:30-11:00	Invited Lecture	Otuka, N	i-15	***Jorge Fernandez***

11:00-11:15	Oral Presentation	Al-Sulaiti, H.	1	
11:15-11:30	Oral Presentation	Babor, J.	5	
11:30-11:45	Oral Presentation	Roberts, N.	28	
11:45-12:00	Oral Presentation	Shearman, R.	30	
12:00-12:15	Oral Presentation	Petrie, L. M.	31	
12.15-14.00	**Lunch break**			
14:00-14:30	Invited Lecture	Sumini, M	I-19	***Eman Daar***
14:30-15:00	Invited Lecture	Mahdiraji, G.A.	I-12	
15:00-15:15	Oral Presentation	Larijani, C.	18	
15:15-15:30	Oral Presentation	Kamali-Zonouzi	16	
15.30-16.30	**Coffee break and Poster session-3 (continued)**			
19.30-22.00	**Conference dinner (to be held in The Green Room, Wates House, University of Surrey)**			

Friday 8 July 2016

08.30-12.30	**Registration, help desk**			
09:00-09:30	Invited Lecture	Saegusa, J	I-17	***Ladislav Musilek***
9:30-10:00	Invited Lecture	Starosta, K	I-18	
10.00-10.30	**Coffee break**			
10:30-11:00	Invited Lecture	Currell, F	I-3	***Philip Walker***
11:00-11:30	Invited Lecture	McCutchan, E.	I-13	
11:30-12:00	Invited Lecture	Hugtenburg, R	i-8	
12.00 - 12:15	Oral Presentation	Lillington, J.	20	
12.15 -12.45	Invited Lecture	Ródenas, J	1-23	
12.45	**Closing ceremony**			

List of invited talks

Title	Author		Code
DFT and Plasmon-Coupling Models for New Theory of the Electron Inelastic Mean Free Path for Monte Carlo and Electron Transport	**Chantler**	**C**	i-1
Measurements of Naturally Occurring Radioactive Materials Using High Resolution Spectrometry at the University of Surrey	**Regan**	**P.H.**	i-2
Nanoparticle colloid and liquid sample dosimetric effects	**Currell**	**F**	i-3
Recent developments in fundamental data for photon-beam dosimetry and cell dosimetry	**Fernandez–Varea**	**J.M.**	i-4
PRaVDA: An integrated platform for proton therapy imaging and dosimetry	**Green**	**S**	i-5
Development of a novel gamma-ray spectrometry technique for enhanced nuclear waste assay	**Harkness-Brennan**	**L**	i-6
Applying ISO X-Ray Qualities to Calibrate Energy-Resolving Instrumentation	**Hudson**	**L .T**	i-7
High Spatial Resolution Dosimetry for Microbeam Radiotherapy with a CVD Diamond Dosimeter	**Hugtenburg**	**R.**	i-8
The challenge of measuring radioactivity for nuclear decommissioning	**Judge**	**S**	i-9
Measurements and evaluation of nuclear reaction cross-sections of ^{55}Co, a non-standard positron emitted for clinical applications	**Khandaker**	**M**	i-10
Recent Developments on Optical Fibre Sensors for Medical Oncology Dosimetry Applications	**O'Keefe**	**S**	i-11
New Optical Fiber Technology: A Complementary Material for Radiation Dosimeter Applications	**Mahdiraji**	**G.A.**	i-12
Nuclear Data and High-precision Gamma-ray Spectroscopy for Enhancing Application of Medical Isotopes	**McCutchan**	**E**	i-13
High-precision Measurements on Fission Fragment De-excitation	**Oberstedt**	**S**	i-14

List of oral presentations

Title	Author		Code
An Assessment of the Natural Radioactivity Distribution and Radiation Hazard in soil samples from Qatar Using High-Resolution Gamma-ray Spectrometry	**Al-Sulaiti**	**H.**	O-1
Characterisation of an isotopic neutron source: a comparison of conventional neutron detectors and thermoluminescent commercial glass beads	**Abubakar**	**Y.**	O-2
Monte Carlo modelling and measurement of scattered and leakage radiation from radiation bunkers	**Al-Affan**	**I.**	O-3
A Novel Multi-element Microdosimetric Detector Based on a Thick Gas Electron Multiplier	**Anjomani**	**Z.**	O-4
Remediation of decay vessels for high-activity radioactive waste	**Babor**	**J.**	O-5
Dose distribution and organ dose assessment for Cone-Beam Computed Tomography (CBCT) using measurements and Monte Carlo simulations with voxel phantoms	**Baptista**	**M.**	O-6
Conversion coefficients for interventional cardiac procedure using newborn and adult hybrid phantoms and MCNPX code	**Cavalcante**	**F.**	O-7
(WITHDRAWN) Study of ambient dose rate increase due to rain events on an advanced real time monitoring station using gamma spectrometry	**Corbacho**	**José Á.**	O-8
Recent Progress in Development of a Two-Dimensional THGEM Microdosimetric Detector	**Darvish Molla**	**S.**	O-9
Characterisation of a plastic scintillation detector to be used in a multicentre stereotactic radiosurgery audit	**Dimitriadis**	**A.**	O-10
Monte Carlo simulations and thermal analysis on a novel micro-calorimeter	**Fathi**	**K.**	O-11
Correction method of measured images of absorbed dose for quenching effects due to relatively high LET	**Gambarini**	**G.**	O-12
Isomers close to the 170Dy Valence Maximum: First Spectroscopy of 168,170Tb	**Gurgi**	**L.**	O-13
Monte Carlo simulations of Photoneutrons Production from Flattening Filter Free Medical Linac for Use in BNCT	**Halato**	**M.**	O-14

Feasibility Study of an Innovative Active Dosemeter for Radiation Fields dominated by Fast Neutrons	**Hawkes**	**N.**	O-15
Are thick microbeams from superficial and orthovoltage kVp x-ray tubes of clinical interest?	**Kamali-Zonouzi**	**P.**	O-16
Characterization of the scintillation detectors CeBr3 and SrI2 for the use as dosemeters	**Kessler**	**P.**	O-17
Chemical separation of fission fragments from 236Np produced by proton irradiation of natural uranium target.	**Larijani**	**C.**	O-18
(WITHDRAWN) Investigation of potential use of 124Xe-incorporated amorphous Si films in brachytherapy	**Leal**	**A.**	O-19
Nuclear Reactor Dosimetry Modelling and Applications	**Lillington**	**J.**	O-20
Fricke-gel dosimeter: overview of Xylenol Orange chemical behaviour	**Liosi**	**G. M.**	O-21
Development of a calibration protocol for quantitative imaging for molecular radiotherapy dosimetry	**Merrett**	**J.**	O-22
Multi-Sample Integrated TL/OSL Reader System	**Mishra**	**D.R.**	O-23
Radiological protection assessments at the ELI-NP facility	**Mitu**	**I-O**	O-24
Basic Concepts and Principles in Dosimetry Presentation title: Influence of dose history on thermoluminescence response of silica optical fibre dosimeters	**Moradi**	**F.**	O-25
Air contamination measurements for the evaluation of internal dose to workers in nuclear medicine departments	**Mostacci**	**D.**	O-26
Water calorimetry as a primary measurement standard for proton therapy	**Mulder**	**J.**	O-27
Improved Bonner Sphere Neutron Spectrometry Measurements for the Nuclear Industry	**Roberts**	**N.**	O-28
Dose Reduction through Parameters Optimization in Pediatric Barium Meal Examinations	**Schelin**	**H.**	O-29

Commissioning of the NAtional Nuclear Array, NANA	**Shearman**	**R.**	O-30
TOPAS Calculated Correction Factors for the NPL Proton Calorimeter	**Petrie**	**L. M.**	O-31
Neutron Spectrum Determination of d+Be Source Reaction by the Dosimetry Foils Method	**Stefanik**	**M.**	O-32
Retrospective Estimates of Patient and Operator Eye Lens Doses in Interventional cardiology	**Suliman**	**I.I.**	O-33
Test of biological shielding of hot cells with high active source 60Co (300 TBq)	**Svrcula**	**P.**	O-34

List of posters

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Effect of Gamma Irradiation on Tropomyosin in Black Tiger Shrimp (Penaeus monodon) and Giant Freshwater Shrimp (Macrobrachium rosenbergii)	Abdull Razis	A.F.	P2
Evaluation of annual effective dose from indoor radon concentration in Eastern Province, Dammam, Saudi Arabia	Abuelhia	E.	P3
Measurements of radiation doses in multislice computed tomography examination	Abuzaid	M.	P4
Dosimetry Characteristic of Fabricated Germanium Doped Optical Fibres for Non-Reference Condition Postal Dose Audit	Ahmad Fadzil	M. S.	P5
(WITHDRAWN) Determination of naturally occurring radionuclides and annual effective dose in Disi aquifer water, Jordan	Al-Bedri	M. B.	P6
Occupational Radiation Exposure In Nuclear Medicine	Al-Nuaimi	M.	P7
Dose Enhancement Effects By High Z Element On Synthetic Diamond Sensor For Medical R-Ray Dosimetry	Alamoudi	D.	P8
Lower Limits of Detection in use of Carbon Nanotubes as Thermoluminescent Dosimeters of Beta particles	Alanazi	A.	P9
A survey of awareness of radiation dose among radiology staff in Saudi Arabia	Aldhafeeri	F.	P10
Improvement of the performance of broad energy germanium detectors using pulse shape analysis for environmental applications	Ali	N.	P11
Evaluation of Dose Uncertainty in Radiation Processing Using PR Spectroscopy and Butylated Hydroxytoluene Rods as Dosimetery System	Alkhorayef	M.	P12

Comparison between the mass attenuation coefficients determined by the same atomic composition and coefficients experimental measurements irradiated with ISO X-ray beams	Almeida Junior	A. T.	P13
Dosimetric characterization of small photons beams of a novel linear accelerator using EDGE diode detector	Almonte Reinoso	A	P14
Energy Spectra of Photons in Tissue Equivalent Phantoms	Alrefae	T.	P15
Thermoluminescent properties of lanthanum aluminates doped praseodymium	Alvarez	R.	P16
Calculation of neutron dose to the fetus during commercial flights using a pregnant model and Monte Carlo simulation	Alves	M.	P17
Estimate of fluence-to-dose conversion coefficients using hybrid anthropomorphic phantom in a sitting posture and Monte Carlo method	Alves	M.	P18
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DFT and Plasmon-Coupling Models for New Theory of the Electron Inelastic Mean Free Path for Monte Carlo and Electron Transport

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Key Words: Monte Carlo, Electron Transport, Theory, dose estimation.

We present a new self-consistent model of inelastic electron scattering in condensed matter systems for accurate calculations of low-energy electron inelastic mean free paths (IMFPs) for XAFS, electron and particle transport and detector modelling. Our model implements plasmon coupling mechanisms for the first time, in addition to causally-constrained lifetime broadening and high-precision density functional theory, and enables dramatic improvements in the agreement with recent high profile IMFP measurements.

The accuracy of theoretical determinations of the electron inelastic mean free path (IMFP) at low energies is one of they key limiting factors in current XAFS modeling and Monte Carlo transport [1]. Recent breakthroughs in XAFS analysis show that there exist significant discrepancies between theoretical and experimental IMFP values [2], and that this can significantly impact upon extraction of other key structural parameters from both XANES and XAFS. Resolution of these discrepancies is required to validate experimental studies of material structures, and is particularly relevant to the characterization of small molecules and organometallic systems for which tabulated electron scattering data is often sparse or highly uncertain [3].

We have devised a new theoretical approach for IMFP determination linking the optical dielectric function and energy loss spectrum of a material with its electron scattering properties and characteristic plasmon excitations. For the first time we present a model inclusive of plasmon coupling, allowing us to move beyond the longstanding statistical approximation and explicitly demonstrate the effects of band structure on the detailed behavior of bulk electron excitations in a solid or small molecule [4]. This is a novel generalization of the optical response of the material, which we obtain using density functional theory [5].

We find that our developments dramatically improve agreement with experimental electron scattering results in the low-energy region ($\lesssim$100 eV) where plasmon excitations are dominant. Corresponding improvements are therefore made in theoretical XAFS spectra and detector modelling.

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Measurements of Naturally Occurring Radioactive Materials Using High Resolution Spectrometry at the University of Surrey

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Key Words: Nuclear Spectroscopy; HPGE; NORM measurement; Ac values; underpinning nuclear decay data; uranium isotopic ratios.

A range of experimental studies have been undertaken to evaluate the concentration of naturally occurring radioactive materials from a range of different environmental locations across the states of Qatar [1], Thailand [2,3] and Kuwait [4-6]. These samples have been collected, prepared and placed into sealed, 500 ml marinelli beakers for detailed gamma-ray spectrometric analysis using the high-resolution, low-background, high-purity germanium detection systems at the Environmental Radioactivity Laboratory of the University of Surrey. This analysis focusses on the calculation of activity concentrations associated with members of the 4n+2 and 4n decay chains heading by the primordial radionuclides ^{238}U (^{226}Ra, ^{214}Pb, ^{214}Bi) and ^{232}Th (^{228}Ac, ^{212}Pb, ^{208}Tl) respectively. Our analysis includes evaluations for Activity concentrations (Ac) values associated with members of the 4n+3 actinium decay chain headed by ^{235}U. In particular, the 186 keV doublet transition is used together with the Ac values derived from the decays of ^{214}Bi and ^{214}Pb to establish the ^{226}Ra and ^{235}U specific activity concentrations and related ^{235}U / ^{238}U isotopic ratios. Studies have also been determined for the concentrations of the ^{40}K primordial NORM and the anthropogenic radionuclides ^{137}Cs (from fallout) and ^{134}Cs (from the Fukushima accident). The talk will present a summary review of measurement programme undertaken over the last five years at the University of Surrey, together with the experimental techniques and underpinning nuclear decay physics on which the analysis relies.

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Nanoparticle colloid and liquid sample dosimetric effects

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Key Words: Monte Carlo, nanoparticle, nanodosimetry

This talk will outline a research program aimed at underpinning the understanding of nanoparticles as radiosensitizers. The research program, running continuously from 2006 until the present day has sought to understand the basic mechanisms underpinning radiosensitization by nanoparticles in biological systems through both experimental and computational approaches, particularly Monte Carlo approaches. Nanodosimetric effects have been shown to be of critical importance (McMahon, 2011a) as has the endpoint under consideration (Butterworth, 2008; McMahon, 2011b; McQuaid, 2016). Furthermore unexpected dose rate and chemical effects have been observed (Sicard Roselli, 2014). This in turn has lead to observations of new dose rate effects in simpler liquid systems. These findings will be reviewed and compared with a particular view to dosimetric effects. A pathway to predicting effects in patients will be outlined along with discussion of likely future research directions and application to the clinic.

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Recent developments in fundamental data for photon-beam dosimetry and cell dosimetry

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The presentation will address two separate topics. In the first place I will review the status of the existing tabulations of mass attenuation coefficients, analyzing improvements in the theoretical modelling of cross sections for the photoelectric effect and Compton scattering. In the second part I will present some recent work on the calculation of cellular S-values for dosimetry in nuclear medicine.

PRaVDA: An integrated platform for proton therapy imaging and dosimetry

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Key Words: proton radiotherapy, CT, treatment planning, quality assurance

Proton therapy delivery systems are now capable of delivering treatments to mm precision, however the imaging methods upon which all treatments are based, delivered and measured do not allow planning to better than around 5 mm accuracy. This discrepancy prevents PT attaining its full clinical benefit. Such benefit cannot be fulfilled without the provision of proton CT – using the same radiation type to image and to treat. The Wellcome Trust funded PRaVDA Consortium are pioneering efforts in this area.

PRaVDA is a fully solid-state research platform that combines quality assurance, on-treatment monitoring, and planar and CT imaging capabilities. Custom sensors include silicon strips and radiation-hard CMOS imagers. The overall device comprises of two sets of proton trackers that consist of multiple strip sensors arranged at 120° rotations, followed by a range telescope (energy-discriminating detector) consisting of layers of large-area CMOS imagers, strip sensors or combinations of both.

Design decisions and experimental results are validated using a comprehensive Monte Carlo simulation (SuSi) developed using Geant4. It contains realistic beam line models for the two proton sources where PRaVDA has been tested, full device geometry, and realistic read-out for both the strip and CMOS sensors.

In addition, new CT reconstruction methodologies and algorithms have been developed that promise the availably of clinical-quality CT imagery.

This presentation will describe the current status of the PRaVDA instrument and present the latest results.

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Development of a novel gamma-ray spectrometry technique for enhanced nuclear waste assay

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Key Words: gamma-ray spectrometry, germanium, nuclear waste

Assay of nuclear waste is a problem for both legacy waste sites (decommissioning) and newly developing monitoring solutions for existing facilities and new build. A common assay method is to use gamma-ray spectrometry to both identify and quantify the waste. Germanium detectors are typically employed due to their excellent energy resolution; however, the ratio of gamma rays that are absorbed to those depositing partial energy through Compton scattering limits the Minimum Detectable Activity (MDA). This compromise can be alleviated by manufacturing large volume detectors or by utilising ancillary Compton suppression shields, both resulting in significantly increased system costs.

Digital Compton Suppression (DCS) algorithms are currently under development, which aim to improve the MDA for Broad Energy Germanium (BEGe) detectors at low energies, particularly in measurement scenarios were low activity sources are concealed by the Compton continuum arising from the scattering of higher energy gamma rays from higher activity sources. A typical case would be ^{241}Am obscured by isotopes such as ^{137}Cs and ^{60}Co. The expected outcomes of employing these algorithms for nuclear waste assay would be reduced counting times and improved isotope identification.

The DCS technique will exploit the position dependence in the response of the BEGe detector to the gamma-ray interaction position. The relative probabilities that the interaction corresponded to Compton scattering of a high energy gamma-ray or absorption of a lower energy gamma-ray can thus be ascertained. Collaborative partners in this work are the Nuclear Decommissioning Authority, National Nuclear Laboratory and Canberra Industries. This talk will outline the project motivations and the DCS technique.

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Applying ISO X-Ray Beam Qualities to Calibrate Energy-Resolving Instrumentation

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Key Words: ISO beam qualities, instrument calibration, x-ray dosimetry

The National Institute of Standards and Technology (NIST) formally offers dosimetry calibration services for x-ray measuring instruments from 10 keV to 300 keV. These are performed in terms of the physical quantity air kerma with typical relative standard uncertainties less than 1 %. Separately, we have been actively designing, fabricating, and fielding crystal spectrometers at facilities around the world that are employed as diagnostic instruments to record line and continuum x-ray spectra from high-temperature-plasma and other intense x-ray sources. To improve the quantitative accuracy and interpretation of results, there is an increasing need to absolutely calibrate the sensitivity of these and other energy-resolving instruments over the photon energy range also provided by the ISO and other beam qualities realized at NIST. Our collaboration has begun developing methods whereby the air-kerma "gold" standard beams can be inexpensively and simply applied to determine the energy-dependent response of instrumentation at modest levels of uncertainty. This is accomplished by way of scaling the nominal standardized narrow-width spectral distributions using the measured air-kerma rates and exposure times to produce absolute incident fluence spectra. The utility and limitations of this novel application of dosimetry is gauged by calibrating both the individual components (optic and detector) separately as well as performing an end-to-end instrument calibration, as well as by employing standard reference data and comparisons to model calculations.

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High Spatial Resolution Dosimetry for Microbeam Radiotherapy with a CVD Diamond Dosimeter

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Key Words: Diamond detectors, microbeams, Monte Carlo

Compressed vapour deposition (CVD) diamond detectors are being considered for their potential in a number of radiotherapy dosimetry applications, offering the potential for improved reproducibility and reduced cost of fabrication compared with natural diamond detectors (Piliero et al., 2014). Diamond detectors have been considered in the dosimetry of X-ray microbeams used in a novel radiotherapy modality that exploits the high intensities of 3rd generation synchrotron sources to deliver micron-width beams to tumours. Recently diamond dosimeters, utilising a Schottky diode electronic structure, have been developed and are now commercially available as the MicroDiamond (PTW, Freiburg). Diamond detectors in this format have been shown to exhibit high spatial resolution and excellent linearity, supporting their use in the examination of the dosimetry of X-ray microbeams. Models of the MicroDiamond response have been developed with the PENELOPE and EGS Monte Carlo codes, enabling the effects of changes in the X-ray spectrum, brought about by scattering of microbeams, to be considered. It is important to accurately characterise dose due to scattered X-rays, as it is a limiting factor in the application of microbeams. The effect of electron transport in differing materials, including the high-density diamond and bonding structures, is also been considered. Recent measurements with the MicroDiamond at the ID17 beamline at ESRF are in excellent agreement with Monte Carlo models, supporting the development the detector as a front-line tool for clinical dosimetry.

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The challenge of measuring radioactivity for nuclear decommissioning

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Key words: nuclear industry, decommissioning, radionuclide metrology

Over the next few years, the nuclear industry faces the challenge of decommissioning legacy nuclear sites. The first phase is to characterise the buildings and plant, so that plans can be developed to deal safely and cost-effectively with the enormous quantities of potentially radioactive waste that will arise. This technically demanding work has to be completed against a backdrop of public concern about the industry.

This presentation will explain the infrastructure that is in place to give confidence to the public that any measurements of radioactivity made by the industry are accurate and fit-for-purpose. The presentation explains how independent primary standards of radioactivity are realised, how these standards are checked internationally, the methods that are available to enable the nuclear industry to use these standards, and how powerful techniques such as proficiency test exercises can help the industry demonstrate the accuracy of results.

The nuclear industry is changing, but so is the technology available; the talk will conclude by summarising how developments in detector technology and digital signal processing drawn from nuclear physics have the potential to help the industry deal with the challenges ahead.

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Measurements and evaluation of nuclear reaction cross-sections of ^{55}Co, a non-standard positron emitter for clinical applications

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Abstract

Cobalt-55 ($T_{1/2}$=17.53 h, $E_{\beta^+}^{mean}$ – 570 keV, $I_{\beta^+}^{total}$ – 76%), a non-standard positron emitter finds significance as a potential PET imaging agent in medical applications. The radionuclide ^{55}Co can be produced via several routes in a very broad energy range. The aim of this work is to optimize the production parameters leading to the carrier free production of ^{55}Co via charged-particle induced reactions. All of the suitable routes for the production of ^{55}Co, namely ^{56}Fe(p,2n)^{55}Co, ^{54}Fe(d,n)^{55}Co and ^{58}Ni(p,α)^{55}Co were investigated via series of experiments. Furthermore, all experimental cross-sections of ^{55}Co radionuclide that lies within the scope of this work were renormalized using the latest agreed values of decay data and monitor cross-sections. Simultaneous evaluation on KALMAN (SOK) code combined with least-squares method was applied to the corrected cross-sections to obtain evaluated cross-sections together with the covariance information. Evaluated data are useful to remove the existing discrepancies among the available literature values. Knowledge of the underlying uncertainties in evaluated nuclear data, i.e., covariances are useful to improve the accuracy of nuclear data.

Keywords: Cobalt-55 radioisotope; β^+-emitter; data evaluation; covariance; medical applications.

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Recent Developments on Optical Fibre Sensors for Medical Oncology Dosimetry Applications

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Key Words: Optical Fibre Sensor, Scintillation Material, dose estimation, Plastic Optical Fibre, Dosimetry, Radio-luminescence

A novel extrinsic optical fibre based X-Ray dosimeter for biomedical applications is presented. The scintillation material, Gadolinium Oxysulfide activated with Terbium (Gd_2O_2S:Tb) located at the sensor tip emits visible light (544 nm) upon exposure to ionising radiation and the resultant low intensity light is coupled to a PMMA (poly methyl methacrylate) plastic optical fibre (POF), which guides it towards a distal detector at 30m distance. The detectors used to date have been an Ocean Optics 96000 Fluorescence Spectrometer and more recently a Hamamatsu Multi Pixel Photon Counting (MPPC) detector for improved time resolution intensity measurement.

Initial results have shown the scintillating optical fibre X-ray dosimeter exhibits excellent sensitivity and repeatability upon excitation from a calibrated Clinical Linear Accelerator (Linac) source. Recent results using both types of detector for extensive on-site testing at radiotherapy clinics at UCLA (USA), Belfast City Hospital (UK) and 1st Hospital Harbin (China) are presented and the performance of the sensor assessed. Furthermore, results obtained with the MPPC gate duration set for the maximum time resolution level of 0.1 ms show that the scintillating optical fibre X-ray dosimeter is capable of resolving and capturing the individual X-Ray pulses delivered by the Linac during normal operation.

Additionally, recent results using a similar sensor design are reported for a number of measurements of the radiation dose emanating from brachytherapy seeds. It has been demonstrated that the sensor is sufficiently sensitive to allow continuous monitoring *in-situ* of the radiation dose from brachytherapy seeds over a wide range of time periods.

New Optical Fiber Technology: A Complementary Material for Radiation Dosimeter Applications

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Key Words: Optical fiber technology, radiation dosimeter, thermoluminescence

In recent years, great attention has been paid on optical fibers in radiation applications from different aspects mainly as dosimeter sensor and radiation resistant medium for data transmission. Optical fibers with both high-sensitivity against radiation exposure and radiation hardened fibers would be very useful for these applications. This study demonstrates fabrication process and dose detection sensitivity characteristics of various types of optical fibers including fiber structures, doping elements and different doping concentrations. It has been shown that by varying fiber structure, how thermoluminescence dose detection sensitivity of an optical fiber can be improved up to more than 400 times, while made from the same material. In terms of fiber materials, we have shown different fiber materials that are very resistant to radiation exposure. Finally, potential applications for various types and shapes of optical fibers have been presented.

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Nuclear Data and High-precision Gamma-ray Spectroscopy for Enhancing Application of Medical Isotopes

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Key Words: nuclear data, gamma-ray spectroscopy, medical isotopes

Precise knowledge of the radiation emitted by medical isotopes is needed to determine the total dose received by the patient, the specific dose to targeted tissue, the cost of infrastructure in production facilities (i.e. shielding requirements) and the background in imaging technologies. Relevant recommended decay data is available through the National Nuclear Data Center (NNDC) at Brookhaven National Laboratory. This talk will begin with highlights of the database products and services maintained at the NNDC which can aid in the production and application of medical isotopes.

A number of either well-established or emerging medical isotopes were last studied more than 30 years ago using very primitive detection setups. Since then, the field of gamma-ray spectroscopy has made tremendous advances, now often using multiple high-purity germanium (HPGe) detectors employing Compton-suppression technology. To address deficiencies in the decay data, sources of medical isotopes were produced and purified at the Brookhaven Linear Isotope Producer (BLIP) then shipped to Argonne National Laboratory where high-precision, gamma-ray measurements were performed using the state-of-the-art gamma-ray spectrometer, Gammasphere, consisting of 100 Compton-suppressed HPGe detectors. An overview of results on a number of medical isotopes will be presented including studies of ^{82}Rb, a very common Positron Emission Tomography (PET) radioisotope used in cardiac imaging, and ^{72}As a longer-lived positron emitter which allows for imaging of biochemical and physiological processes and receptor mapping. In all nuclides studied, significant revisions were made to the decay schemes, including the observation of many new levels and gamma-ray transitions. The high-sensitivity of Gammasphere allowed for a significant reduction in the uncertainty of gamma-ray intensities and the deduced beta-feedings. The new decay schemes will be presented and their impact on dose estimates discussed.

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High-precision Measurements on Fission Fragment De-excitation

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Key Words: nuclear fission, nuclear de-excitation, fission gamma-rays, prompt neutrons

In recent years nuclear fission has gained renewed interest both from the nuclear energy community as well as in basic science. The first, represented by the OECD Nuclear Energy Agency, expressed the need for more accurate fission cross-section and fragment yield data for safety assessments of Gen-IV reactor systems. In basic science modelling made much progress on describing the de-excitation mechanism of neutron-rich isotopes, e.g. produced in nuclear fission. Benchmarking the different models require a precise experimental data on prompt fission neutron and gamma-ray emission, e.g. multiplicity, average energy per particle and total dissipated energy per fission, preferably as function of fission-fragment mass and total kinetic energy.

Some years ago, a collaboration of scientists from IRMM and other institutes took the lead in establishing a dedicated measurement programme on prompt fission neutron and gamma-ray characteristics, which has triggered even more measurement activities around the world. I will present the advanced instrumentation and methodology we use to generate high-precision spectral data and will give a flavour of future data needs and opportunities.

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Error propagation in activation cross section measurements

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Key Words: activation cross section, error propagation, uncertainty, covariance

Experimental activation cross sections have been utilised in development of cross section libraries for reactor dosimetry (e.g., IRDF), efficient production of medical isotope productions as well as various other applications. From the viewpoints of both economy and safety, it has been desired to obtain not only the mean values but also their uncertainties evaluated in a reasonable manner from each experiment. In addition, covariances also play an important role if one wants to propagate the uncertainties in the reported values to another quantity. In order to encourage documentation of uncertainty and covariance information in the experimental nuclear reaction data library (EXFOR) [1], some guidelines have been recently published [2,3]. However its implementation by experimentalists is still far from the satisfactory level.

In order to improve the situation, IAEA Nuclear Data Section is collaborating with experimentalists in some universities. Following an introduction and simple hypothetical examples, actual error propagations in data reduction process of charged-particle and neutron activation cross section determinations performed by us will be presented.

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Metal-based nanoparticles as theranostic agents in radiotherapy: Opportunities and challenges

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Key Words: Nanoparticles, Radiosensitiser, Theranostic, Radiotherapy

Nanoparticles have unique properties which offer significant potential for the development of novel materials that provide innovative solutions to both diagnostic and therapeutic challenges in medicine. Metal-based nanoparticles have attracted significant attention due to their inherent physical and chemical properties. In particular, gold nanoparticles are being extensively tested as potential theranostic agents due to their abilities to enhance CT-image contrast and provide radiation sensitisation in combination with radiotherapy treatment in tumours.

The physicochemical properties of gold nanoparticles (AuNPs) have attracted significant attention for wide ranging applications in nanomedicine with a particular emphasis on their potential role in cancer diagnosis and therapy. Previously we have reported that for radiation-sensitisation, the effects observed are driven not only by changes in the mass energy absorption coefficients but related to localised low energy auger electron cascades. Alongside these physical determinants distinct biology involving nanoparticle mediated production of reactive oxygen species also play a role.

More recently we have been testing the requirement of nanoparticles to be present in the nucleus of the cell in close proximity of the DNA to drive radiosensitisation. Using a soft X-ray microbeam we have been able to test the impact of direct cytoplasmic versus nuclear irradiation on cells pre-loaded with AuNPs where radiosensitisation has been observed. Alongside biodistribution studies, it is clear that cytoplasmic irradiation leads to localised ROS production which is amplified in the presence of AuNPs. This leads indirectly to a DNA damage response impacting on survival.

For future clinical application, non-specific protein absorption can be a major limiting determinant of nanoparticle clearance and efficacy. Using a coating currently used clinically for contrast agent delivery, Diethylenetriamine-pentacetic acid (DTDTPA), we have evaluated the theranostic potential of a DTDTPA conjugated AuNP (Au@DTDTPA) for CT-contrast enhancement radiosensitisation in cell models of prostate cancer both in vitro and in vivo. Using a small animal preclinical irradiation system we have been able to show enhanced CT contrast, after AuNP delivery and subsequent enhancement of radiation mediated tumour cell growth in an ectopic xenograft in SCID mice after a single intra-tumoural injection of a AuNP. This study demonstrates the potential of stabilised AuNPs to enhance CT image contrast and simultaneously radiosensitise prostate tumour cells suggesting this as a viable theranostic strategy in prostate cancer radiotherapy.

Nanoscale theranostic approaches, integrating properties for cancer diagnosis and therapy, could offer significant advantages over separately administered diagnostic and therapeutic agents. Taking gold as an exemplar, the challenge is to optimise the design and utility of these taking into account both physical and biological mechanisms of action.

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Radiation monitoring activities by Japan Atomic Energy Agency in response to the Fukushima Daiichi Nuclear Power Plant accident

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Key Words: Fukushima Daiichi Nuclear Power Plant accident, radiation monitoring, decontamination, air dose-rate, radioactivity

The Fukushima nuclear accident in March 2011 resulted in the release of a considerable amount of fission and activation products into the environment. Immediately after the accident, Japan Atomic Energy Agency (JAEA), as the Designated Public Institution for the implementation of emergency response measures against nuclear emergency situation, has started an extensive range of radiation monitoring activities nationwide. These activities have been continued up to the present under the Comprehensive Radiation Monitoring Plan developed by the Monitoring Coordination Meeting which was set by the central government of Japan. According to the plan, JAEA is in charge of a broad range of environmental radiation monitoring off-site the damaged Fukushima Daiichi Nuclear Power Plant. It includes air dose-rates measured with various types of instruments including aerial surveys, radioactivity concentrations of dust in air, soil, index-plants and so on. The acquired data are open to the public via the Internet website of the central government as well as in the public database developed by JAEA. This presentation outlines the framework of these activities and some of monitoring results obtained in the past five years.

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Environmental radionuclide monitoring at the Nuclear Science Laboratory, Department of Chemistry, Simon Fraser Universit

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Key Words: Radionuclide monitoring, Fukushima, Pacific Ocean

While the main focus of research at the Nuclear Science Laboratory, Simon Fraser University is centred on fundamental studies of nuclear properties, the availability of high-performance radiation detectors and its location on the West Coast of Canada triggered an intensive program of radionuclide monitoring in the environment in response to the 2011 Fukushima Daiichi nuclear power plant accident. In particular, the appearance and time profile of ^{131}I activity in Vancouver was measured in March and April of 2011 using high-resolution gamma-ray spectroscopy. This measurement was compared to other similar concurrent studies performed on the West Coast of North America, as well as a to an equivalent measurement done in Vancouver in May and June of 1986 following the Chernobyl accident. This comparison provided a basis for predicting that the environmental impact of the Fukushima accident in Western Canada was insignificant. Following ^{131}I profiling, the laboratory's focus has been directed to measurements of ^{134}Cs and ^{137}Cs in marine biota including Pacific salmon, and various abiotic environmental samples. This effort is undertaken to address concerns of frequent seafood consumers, especially in the aboriginal community, and also to provide input into models of transport and bioaccumulation of man-made radionuclides. For the purpose of these measurements, the laboratory developed and implemented methods optimized for environmental studies, which are not often available to scientists focused on fundamental research. Recently, the laboratory joined the Canadian InFORM collaboration which coordinates measurements of man-made radionuclides in the Pacific Ocean and provides information on impact of the observed radiation levels to the public. The capability of the laboratory, the measurements performed, and estimates of the impact of observed radiation levels will be presented and discussed.

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Dose-Current Discharge Correlation Analysis in a Mather Type Plasma Focus Device for Medical Applications

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Key Words: plasma focus, signal analysis, Wigner transform, dose rate, medical applications

In a Plasma Focus (PF) device the plasma collapses in the pinch where it reaches thermonuclear conditions for a few tenths of nanoseconds, becoming a multi-radiation source. The nature of the generated radiation is a function of the plasma chamber filling gas and of some device parameters. The self-collimated electron beam produced in the backward direction with respect to the plasma motion is one of the main radiation sources of interest also for medical applications. The electron beam may be guided against a high Z material target to produce an X-ray beam. With this technique we obtain an ultra-high dose rate source of X-rays able to deliver up to 1 Gy/shot, as evaluated with EBT3 Gafchromic© film tissue equivalent dosimeter. Given the stochastic behavior of the discharge process, a reliable evaluation of the delivered dose is a very challenging task, in some way preventing a systematic application as potentially interesting therapy device. In our work we present a tool to link the dose given to the EBT3 Gafchromic© films with the information contained in the signal registered during the current discharge process.
Processing the signal with a suitable Wigner distribution we have been able to obtain a spectrogram, displaying the information of the intensity at various frequency scales, identifying the band of frequencies representative of the pinch events and define the patterns correlated with the delivered dose.
The results of the radiobiology analysis with respect to the dose rate effects obtained on highly radiation resistant cell cultures are also presented and discussed.

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Monte-Carlo Calculations in Particle and Radiotherapy

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Key Words: Monte-Carlo, proton therapy, radiotherapy, radiation transport

Calculations utilising the Monte-Carlo method play a key role in many aspects of cancer therapy. Non-more-so than in particle and radiotherapy where it has found uses in treatment planning, dose verification, radiation protection and therapy demand. Furthermore, Monte-Carlo radiation transport simulations often form an integral part of any research undertaken to improve treatment delivery and outcomes. In radiotherapy, Monte-Carlo is often quoted as being the "gold standard" but validation and computation time are often cited as a major factors in their lack of uptake in clinical practice.

The Christie hospital in Manchester is a world leader in the treatment of cancer and is one of the largest single site cancer treatment centres in Europe. The Christie has recently acquired an MRLinac to deliver MRI guided radiotherapy and will soon host a new NHS funded proton therapy facility. An overview of the Monte-Carlo calculations used in particle and radiotherapy research at the Christie will be presented highlighting how the technique is essential to overcoming some of the outstanding challenges in this field of cancer treatment.

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Development of a Compton camera for prompt-gamma medical imaging

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Key Words: particle therapy, beam range verification, prompt-γ imaging, Compton camera

Purpose of our project is the development of a Compton camera-based detector system for photon detection from nuclear reactions induced by proton (or heavier ion) beams, allowing for the online range verification of the particle beam in hadron therapy via prompt-gamma imaging. The detector is designed to be capable to reconstruct the photon source origin not only from the Compton scattering kinematics of the primary photon, but also to allow for tracking of the secondary Compton-scattered electrons, thus enabling a γ-source reconstruction also from incompletely absorbed photon events. The Compton camera consists of a monolithic $LaBr_3$(Ce) scintillation crystal, read out by a multi-anode PMT acting as absorber, preceded by a stacked array of 6 double-sided silicon strip detectors as scatterers. From the design simulations, an angular resolution of $\leq 2°$ (at 2-6 MeV) and a source image reconstruction efficiency of 10^{-3} -10^{-5} (at 2-6 MeV) can be expected. The detector components have been characterized both under offline and online conditions. The $LaBr_3$ crystal exhibits an excellent time and energy resolution. Using intense collimated (0.6 mm and 1 mm diameter) ^{137}Cs and ^{60}Co sources, the scintillator was scanned on a fine 2D grid to generate a reference library of light amplitude distributions that allows for reconstructing the photon interaction position using the *k*-nearest neighbor (*k*-NN) algorithm developed at TU Delft. The present status of the so far achieved spatial resolution will be shown. Results from online studies using monoenergetic multi-MeV photons, a pulsed deuteron beam and a clinical proton beam impinging on water and PMMA phantoms will be presented together with the envisaged further development of the detector system.

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Radioactivity Standards for Image-based, Patient-specific Nuclear Medicine Treatment Planning

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Key Words:internal dosimetry, nuclear medicine, PET, SPECT, radioactivity, standards

Within the past few years, there has been substantial interest in raising nuclear medicine treatment planning to the same level of rigor that is already required for brachytherapy and external beam radiotherapy. Regulatory requirements, such as those set forth in EU Directive EURATOM/2013/59, as well as government investment in projects such as the proposed Precision Medicine Initiative in the United States, help serve as strong motivators for this trend.

Adoption of this approach has been hampered by the lack of the necessary metrology tools to ensure accurate and reproducible data at each step in the care of the patient. Radioactivity measurement plays a role at nearly every step in the diagnosis and treatment, from the initial imaging procedures, to the treatment and follow-up. Radioactivity standards are needed to ensure accurate and reproducible imaging data and to ensure accurate dosage administration. The National Institute of Standards and Technology (NIST) has a specific program dedicated to the development of radioactivity standards for nuclear medicine applications and transferring those standards to clinical end users. Most of the early work of this program was centered on the development of standards for therapeutic applications. While work on therapeutic radionuclides continues to be an important component, our recent focus has been on developing radioactivity standards for quantitative imaging (e.g., PET, SPECT). The outputs of this program now make it possible to calibrate the radioactivity measurement instrumentation associated with dosage administration and the scanners to the same standards, thereby providing traceability for all the measurements.

In order to realize truly patient-specific treatment planning and bring it into clinical practice, it will be necessary to make the link between measurements of radioactivity and of absorbed dose. Our future work will be expanded to include the development of in-vivo and in-vitro techniques to determine absorbed dose from systemically administered radionuclides in a way that is traceable to standards of both quantities. It is hoped that in this way, quantifiable relationships can be established between administered dosage, absorbed dose, and patient response.

This talk will discuss the recent work being done by NIST to develop standards for quantitative medical imaging and radionuclide therapy, focusing on our recent work on calibrated PET phantoms and new therapeutic radionuclides. Finally, needs for future standards, including linking radioactivity and absorbed dose together, will be presented.

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Application of the Monte Carlo method to estimate doses due to neutron activation of different materials in a Nuclear Reactor

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Key Words: Monte Carlo method, dose estimation, neutron activation

All materials exposed to some neutron flux can be activated independently of the kind of the neutron source. In this study, a nuclear reactor has been considered as neutron source. In particular, the activation of control rods in a BWR is studied to obtain the doses produced around the storage pool for irradiated fuel of the plant when control rods are withdrawn from the reactor and installed into this pool. It is very important to calculate these doses because they can affect to plant workers in the area.

The MCNP code based on the Monte Carlo (MC) method has been applied to simulate activation reactions produced in the control rods inserted into the reactor. The activation is mainly produced in the stainless steel tubes containing the absorber. More exactly in the components of this alloy. The simulation of the reactions permits to obtain a list of the radionuclides generated and its activity. Obtained activities are introduced as input into another MC model to estimate doses produced by them. The comparison of simulation results with experimental measurements allows the validation of developed models.

The analysis of obtained results showed that the rod handle is the most irradiated part of the control rod. Therefore, the dose out of the pool can be highly reduced inverting the position of the rod into the storage pool with the handle at a deeper position under water.

The developed MC models have been also applied to simulate the activation of other materials, like manganese or components of a stainless steel sample introduced into training or experimental reactors.

These models, once validated, can be applied to other situations and materials where a neutron flux can be found, not only nuclear reactors. For instance, activation analysis with an Am-Be source, neutrography techniques in both medical applications and non-destructive analysis of materials, civil engineering applications using a Troxler, analysis of materials in decommissioning of nuclear power plants, etc.

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An Assessment of the Natural Radioactivity Distribution and Radiation Hazard in soil samples from Qatar Using High-Resolution Gamma-ray Spectrometry

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Keywords

Natural radioactivity, HPGe detector, Gamma spectrometry, Activity concentrations, ^{238}U, ^{226}Ra, ^{40}K and ^{232}Th.

ABSTRACT

This study aimed to establish the first baseline measurements for radioactivity concentration in the soil samples collected from the Qatarian peninsula. The work focused at the naturally occuring and technically enhanced levels of radiation associated with the $^{235,8}U$ and ^{232}Th natural decay chains and the long-lived naturally occurring radionuclide ^{40}K in 129 soil samples collected across the landscape of the State of Qatar. Representative samples from various locations across the country have been collected and analysed via high-resolution gamma-ray spectrometry using a hyper-pure germanium detector situated in a low-background environment with a copper inner-plated passive lead shield. A wide range of different gamma-ray energy transitions lines ranging from ~100 keV up to 2.6 MeV associated with decays from the decay products of the $^{235,8}U$ and ^{232}Th decay chains have been analyzed separately to obtain more statistically significant overall results. Using this method, a signficant improvement can be obtained in the statistical uncertainty of the derived activity concentrations. Three radiological distribution maps showing the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K were presented in this work. Five soil samples were found to be elevated to the favour of ^{226}Ra concentration. Two samples out of these elevated samples were significantly above the average value. Notably, these samples were collected from an area contains an oil field (NW Dukhan). The weighted mean of the activity concentrations of ^{226}Ra in the most elevated sample, no. X228 was found to be $201.93 \pm 1.54_{Stat.} \pm 12.9_{syst.}$ Bq/kg. The value of gamma dose rate (D) obtained for sample no. X228 was found to be also higher than the permissible value which is about 51 nGy/h. It was about $92.82 \pm 6.72_{Stat.} \pm 10.23_{Systematic}$ nGy/h. The value of the radium equivalent (Ra_{eq}) in this sample was found to be just below the permissible value of Ra_{eq} of 370 Bq/kg, which corresponds to an annual effective dose of 1 mSv. It was around $367.52 \pm 26.40_{Stat} \pm 41.51_{syst}$ nGy/h. The mean values of activity concentration of ^{226}Ra, ^{232}Th and ^{40}K for the full cohort of samples were found to be 17.22 ± 1.55, 6.38 ± 0.26 and 169 ± 5 Bq/kg respectively. These values lie within the expected range relative to the world average values in soil samples of 30, 35 and 400 Bq/kg respectively. The mean values of D, Ra_{eq}, H_{ex} and AEDE for the complete set of samples were all below the published maximal admissible values and indicate that the State of Qatar can be regarded as having normal levels of natural background radiation, with exception of NW Dukhan [Al-Sulaiti et al., 2012].

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Characterisation of an isotopic neutron source: a comparison of conventional neutron detectors and thermoluminescent commercial glass beads

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Key Words: Neutron detection, glass beads, thermoluminescence, ^{3}He & boron tri-fluoride detectors

As a result of their thermoluminescent response, low cost commercial glass beads have been demonstrated to offer potential use as radiation dosimeters, providing capability in sensing different types of ionising radiation. With a linear response over a large range of dose and spatial resolution that allow measurements down to of the order of 1 mm, their performance renders them of interest in situations in which sensitivity, dynamic range, and fine spatial resolution are called for. In the present work, the suitability of glass beads for characterisation of an Americium–Beryllium (^{241}Am-Be) neutron source has been assessed. Direct comparison has been made using conventional ^{3}He and boron tri-fluoride neutron detectors.

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Monte Carlo modelling and measurement of scattered and leakage radiation from radiation bunkers

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Key Words: Radiotherapy bunker, Monte Carlo, plastic scintillator

Monte Carlo modelling with the FLUKA Monte Carlo code and measurements with a plastic scintillating detector have been used to optimise radiotherapy bunker design. The study answers a need to reduce the cost and architectural foot-print of radiotherapy rooms and examines methods to reduce the length of bunker mazes, including the use of novel materials to reduce scattering (Al-Affan et al., 2015). Measurements of the LINAC spectrum with a plastic scintillator enables the separation and analysis of the scattered and leakage components, but presents challenges due to the pulsed nature of the LINAC source. Mathematical methods to account for pulse pile-up utilise the highly periodic pulsing structure of the LINAC have been examined, differing in this regard from the pile-up effects of high-intensity radioactive sources. Monte Carlo models of reductions in the scattered dose are found to be in good agreement with measurements with the use of lead paneling in the bunker maze, supporting the use of Monte Carlo modelling for optimsation with established and emergent methods of bunker construction.

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A Novel Multi-element Microdosimetric Detector Based on a Thick Gas Electron Multiplier

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Key Words: Microdosimetry, Thick Gas Electron Multipliers (THGEM), Multi-element, Neutron, Radiation Protection

A prototype multi-element gaseous microdosimetric detector using Thick Gas Electron Multipliers (THGEM) has been designed and constructed for monitoring mixed neutron–gamma radiation fields. The multi-element design was employed to increase the neutron detection efficiency, particularly for weak radiation fields commonly encountered in radiation protection applications. The prototype THGEM multi-element detector consists of three alternating layers of tissue-equivalent plastic hexagons and each layer houses a hexagonal array of seven cylindrical gas cavity elements with equal height and diameter of 17mm. The final detector structure incorporates 21 gaseous volumes. Owing to the absence of wire electrodes, the THGEM multi-element detector offers flexible and convenient fabrication. The fundamental signal and stability performance of the THGEM detector was tested using a ^{244}Cm alpha source. The detector responses to various neutron fields were investigated using the ^{7}Li(p,n) neutron source at the McMaster Tandetron accelerator. A preliminary result on the pulse height measurements and microdosimetric response of the prototype detector using the propane based tissue equivalent gas is presented in contrast to the responses of a commercial detector.

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Remediation of decay vessels for high-activity radioactive waste in ÚJV Řež, a. s.

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Key Words: Decay vessel, remediation radioactive waste, radionuclide characterization, extraction high activity waste, decontamination, radiation protection, radiation environmental monitoring

The aim of the paper is to present the work related to remediation of decay vessels for high-activity radioactive waste in ÚJV Řež, a. s. The paper shows the procedures and technologies used for liquidation of contaminated fluid, solid waste and decontamination of surfaces. In the past two decay vessels for high-activity radioactive waste were built to lower its activity over time. This is very effective for ^{60}Co with halftime 5.27 years and other short and medium-lived radionuclides.

Over the years, both vessels were completely filled with both liquid and solid radioactive waste. In 1993, the Czech Government decided to lower the hazard of old environmental burden which originated in the times before the Velvet Revolution in 1989. In 1998 by the government resolution there was reserved 18 million Euro for this project.

In 2006, there was built a structure over the vessels to protect the environment against possible spreading of radioactivity when extracting the nuclear waste. The extraction itself started in 2010.

During the 1st phase 11 m^3 of liquid waste which was extracted and stored in 75 standardized 200 l barrels. In the 2nd phase were 24 workers who participated received collective dose of 40 mSv. Total extracted activity reaches 2 TBq. The 3rd Phase was a decontamination of inner surfaces and facility decontamination which was finished in the 1st half of 2014. The final phase of this work included decontamination of all technology and building which was contaminated during the extraction of the solid waste. The work was completed in December 2014.

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Dose distribution and organ dose assessment for Cone-Beam Computed Tomography (CBCT) using measurements and Monte Carlo simulations with voxel phantoms

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Key Words: Monte Carlo simulations, Cone-Beam Computed Tomography, CTDI measurements, Organ Doses

Cone-Beam Computed Tomography (CBCT) is an emerging technology that enables high-resolution volumetric scanning of the bone and soft tissue anatomy under investigation at the treatment accelerator. This technique is extensively used in Image Guided Radiation Therapy (IGRT) for pre-treatment verification of patient position and target volume localization. When employed daily and several times per patient, CBCT imaging may lead to high cumulative imaging doses to the healthy tissues surrounding the exposed organs.

This work aims at (1) evaluating the dose distribution during a CBCT scan and (2) calculating the organ doses involved in this image guiding procedure for clinically available scanning protocols. Both Monte Carlo (MC) simulations and measurements were performed. To model and simulate the kV imaging system mounted on a linear accelerator (Edge ™, Varian Medical Systems), the state-of-the-art MC radiation transport program MCNPX 2.7.0 was used. In order to validate and support the simulation results, measurements of the Computed Tomography Dose Index (CTDI) were performed, using standard PMMA head and body phantoms, with 150mm length and a standard pencil ionizing chamber (IC) 100 mm long. Measurements for three scanning protocols (head, thorax and pelvis) usually adopted in clinical environment were acquired, using two acquisition modes (full-fan and half fan). To calculate the organ doses, the implemented MC model of the CBCT scanner together with a male voxel phantom ("Golem") were used taking into account different clinical scanning protocols.

The good agreement between the MCNPX simulations and the CTDI measurements (differences up to 10%) presented in this work reveals that the CBCT MC model was successfully validated. The adequacy of the computational model to map dose distributions during a CBCT scan is discussed in view of the need to identify ways to reduce the total CBCT imaging dose. The organ dose assessment highlights the need to evaluate the therapeutic and the CBCT imaging doses in a more balanced approach and the importance of improving awareness regarding the increased risk arising from repeated exposures.

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Conversion coefficients for interventional cardiac procedure using newborn and adult hybrid phantoms and MCNPX code

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Key Words: Monte Carlo, dose estimation, paediatric interventional procedure.

Monte Carlo simulation of radiation transport is a powerful tool for determining organ doses in computational anthropomorphic phantoms. Interventional radiology (IR) procedures are responsible for higher doses in patient and medical staff and the dose conversion coefficients relate protection quantities (H_T and E) with measurable quantity kerma-area product (KAP). In this work, we developed exposure scenarios of paediatric interventional cardiology using newborn (patient) and adult (physician) hybrid phantoms coupled in the radiation transport code MCNPX. The assessment of medical and occupational exposures were performed by simulation of three angiographic projections (PA, LAO45 and RAO45) considering a X-ray energy spectrum of 75 kVp, 3.5 mmAl filtration with 0.4 mmCu additional filtration, focus-skin distance (FSD) not less than 45 cm and a 7 x 7 cm² field size. The exposure scenarios include an IR room of 4 x 2 x 2 m (length, width and height), filled by air and containing a C-arc equipment. A KAP meter was modelled with external dimensions of 10 x 10 x 1 cm and its sensitive volume of 7.84 cm³ filled by air. The patient lies down on the table in supine position. The physician is positioned 15 cm from the right side of patient, with patient table at his waist level. A lead apron and thyroid shield of 0.5 mmPb and leaded glasses of 0.75 mmPb were added to the physician.
The calculated conversion coefficients H_T/KAP of major patient organs for both sexes were similar, except for gonads that presented female values 4 times higher than male coefficients. The patient organs with higher H_T/KAP values were heart (6.89 mSv/Gy.cm^2), lungs (8.18 mSv/Gy.cm^2) and oesophagus (6.49 mSv/Gy.cm^2). The major contributions for patient effective doses were the equivalent doses of lungs (44%), oesophagus (12%), breasts (11%) and stomach (10%). The patient E/KAP values were 2.43 mSv/Gy.cm^2 (PA), 2.19 mSv/Gy.cm^2 (RAO45) and 2.09 mSv/Gy.cm^2 (LAO45). For occupational exposures, the physician organs with higher H_T/KAP values were eye lens (4.96 μSv/Gy.cm^2), skin (3.82 μSv/Gy.cm^2) and residual tissues (1.92 μSv/Gy.cm^2). The highest physician H_T/KAP occurred for eye lens in LAO45 projection (5.93 μSv/Gy.cm^2) due to the greatest amount of scatter photons from the patient. The results of this work show the assessment of medical and occupational exposures during a paediatric interventional procedure. Furthermore, we estimated the influence of personnel protective devices in occupational doses.

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(WITHDRAWN) O-8

Study of ambient dose rate increase due to rain events on an advanced real time monitoring station using gamma spectrometry

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Key Words: ambient dose rate, gamma spectrometry, real time network

The three major sources of natural gamma radiation background are: cosmic gamma radiation, terrestrial gamma radiation and radon (^{222}Rn and ^{220}Rn and their short-live progeny). For the two first sources, the outdoor gamma dose is nearly constant and depends on the location of the monitoring station. Nevertheless, the third one is an important source of natural radioactivity in air, although its contribution to the gamma radiation background is small.

For the present study, an advanced real time monitoring station and a ^{222}Rn monitoring analyser have been used. The advanced monitoring station comprises of: (1) an ambient dose rate monitor; (2) a 2"x2" $BrLa_3(Ce)$ gamma spectrometry analyser for airborne particle radioactive concentration deposited on a glass fibre filter; (3) a 2"x2" NaI(Tl) gamma spectrometry analyser for gaseous radioiodine air concentration retained on an activated charcoal cartridge. Both gamma analysers are coupled to an air sampler with an average air volume flow rate of 25 m^3/h.

The measures obtained during rain events have shown that ambient dose rate can become about 30% higher than the average background. However, under these circumstances, the values of ^{222}Rn activity concentration in air do not always show a statistical increase before and during the rain event. On the other hand, the ^{214}Pb and ^{214}Bi airborne activity concentration values decrease significantly due to the wash effect.

In this work we propose an interpretation of this situation. After precipitation events, when significant amounts of progeny are deposited on the ground, significant temporary rises of gamma dose rate occur and could produce, during one hour or more, an average background radiation dose level 30% above the pre-precipitation average. However, the inhalation dose rate due to radon and its progeny can decrease significantly.

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Recent Progress in Development of a Two-Dimensional THGEM Microdosimetric Detector

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Key Words: Microdosimetry, THGEM, TEPC, Mixed Neutron-Gamma ray Field

The THGEM-based tissue-equivalent proportional counter (TEPC) has been proven to be very useful for microdosimetry due to its flexibility in varying gaseous sensitive volume and achieving high multiplication gain (Byun et al. 2009; Orchard et al. 2011). Aiming at measuring the spatial distribution of radiation dose for mixed neutron-gamma fields, an advanced two-dimensional (2-D) THGEM TEPC was designed and constructed at McMaster University which will enable us to overcome the operational limitation of the classical TEPCs, particularly for high dose rate fields. Compared to the traditional TEPCs, anode wire electrodes were replaced by THGEM layer, which not only enhances the gas multiplication gain but also offers a flexible and convenient fabrication for building 2-D detectors.

The 2-D TEPC consists of an array of 3×3 sensitive volumes, equivalent to 9 TEPCs, each of which has a dimension of 5 mm diameter and length. Taking the overall cost, size and flexibility into account, to process 9 detector signals simultaneously, we developed a multi-input digital pulse processing system using modern microcontrollers, each of which is coupled to a 12-bit sampling ADC with a sampling rate of 42 Msps. The signal processing system was tested using a NaI(Tl) detector, which has proven that it is faster than a traditional analogue system and a commercial digital system. Using the McMaster Tandetron ^{7}Li(p,n) accelerator neutron source, both fundamental detector performance as well as neutron dosimetric response of the 2-D THGEM TEPC has been extensively investigated. Recent progress including detailed results will be presented.

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Characterisation of a plastic scintillation detector to be used in a multicentre stereotactic radiosurgery audit

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Key words: Plastic scintillator, dosimetry, radiotherapy, radiosurgery, audit

Plastic Scintillation Detectors (PSDs) are considered ideal for dosimetric measurement of small fields in radiotherapy due to their near-tissue equivalence and their small sizes. To our knowledge, there is only one commercially available system, the Exradin W1 (Standard Imaging, Middleton, USA), and two published studies on this detector, whose scope was focused on investigating the dosimetric characteristics of the detector (P Carrasco et al. 2015a; Beierholm et al. 2014). The results from these publications differed in some aspects (e.g. energy dependence, long term stability) and the authors highlighted the need for more studies to be published (P. Carrasco et al. 2015b; Beierholm et al. 2015).

In this work, the Exradin W1 was characterised in terms of response to dose, dependence on dose rate, energy, temperature, angle of irradiation and long-term stability. The temperature dependence and energy dependence observed were in good agreement with published data, and should be corrected for in order to achieve low-uncertainty measurements. We did not observe a substantial irradiation angular dependence along the symmetry axis and polar angle of the detector. The long term stability of our detector initially showed resemblance with the behaviour observed by Beierholm et al (2015) but improved to levels similar to those reported by Carrasco et al (2015a). The same behaviour was observed for a second detector tested and therefore adds support to Carrasco's assumption regarding the possible initial instability of a PSD due to the lack of pre-irradiation by the manufacturer.

In addition to the dosimetric characterisation, the main goal of this work was to assess the suitability of the Exradin W1 for its application to measurements in stereotactic radiosurgery. The results confirm that the detector is suitable for use in such situations. With the application of appropriate correction factors, the detector is now utilized in a multi-centre dosimetric audit.

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Monte Carlo simulations and thermal analysis on a novel micro-calorimeter

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Key Words: Monte Carlo, micro-dosimetry, thermal analysis, calorimetry

The high uncertainty in the Relative Biological Effectiveness (RBE) values of particle therapy beam, which are used in combination with the quantity absorbed dose in radiotherapy, together with the increase in the number of particle therapy centres worldwide (62 in operation, 64 under construction and 31 in planning stages) necessitate a better understating of the biological effect of such modalities.

The present novel study is part of performance testing and development of a micro-calorimeter based on Superconducting QUantum Interference Devices (SQUIDs). Unlike other microdosimetric detectors that are used for investigating the energy distribution, this detector provides a direct measurement of energy deposition at the micrometer scale, that can be used to improve our understanding of biological effects in particle therapy application, radiation protection and environmental dosimetry. Temperature rises of less than 1μK are detectible and when combined with the low specific heat capacity of the absorber at cryogenic temperature, extremely high energy deposition sensitivity of approximately 0.4 eV can be achieved.

The detector consists of 3 layers: a tissue equivalent (TE) absorber, a superconducting absorber and a silicon substrate. Ideally all energy would be absorbed in the TE absorber and heat rise in the superconducting layer would arise due to heat conduction from the TE layer. However, in practice direct particle absorption occurs in all 3 layers and must be corrected for.

To investigate the thermal behavior within the detector, and quantify any possible correction, particle tracks were simulated employing Geant4 (v9.6) Monte Carlo simulations. The track information was then passed to the COMSOL Multiphysics (Finite Element Method) software. The 3D heat transfer within each layer was then evaluated in a time-dependent model. For a statistically reliable outcome, the simulations had to be repeated for a large number of particles. An automated system has been developed that couples Geant4 Monte Carlo output to COMSOL for determining the expected distribution of proton tracks and their thermal contribution within the detector.

Preliminary results of a 3.8 MeV proton beam showed that the detector reaches the equilibrium state after 8 ns. It is estimated that 20% of the temperature rise in the superconducting absorber is due to heat conduction from the adjacent absorber which needs to be corrected for. The simulations were repeated for proton beams with energies of 2, 10, 62 and 230 MeV.

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Correction method of measured images of absorbed dose for quenching effects due to relatively high LET

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Key Words: LET, sensitivity quenching, dose image correction, proton beams

Radiation therapies based on charged particle beams are currently in great development for the advantageous characteristic of these particles of reaching higher linear energy transfer (LET) and then higher biological effectiveness at the end of the path. In-phantom measurements for treatment plane control could receive great benefits from the availability of dosimeters that allow to obtain images of the absorbed dose, but usually such detectors require suitable correction to achieve good accuracy of results owing to a progressive decrease in sensitivity with increasing of the LET.
We have studied this problem concerning gafchromic EBT3 films. The under-response vs depth in a water phantom has been investigated for proton beams of various energies and by comparing measured and calculated profiles, the under-response vs depth has been evaluated. A method has been proposed to correct the measured values in a simple and efficient way, feasible in the clinical practice. Considering that, for treatments, hundreds of proton beams are necessary, with different energies, intensities and incidence coordinates, to avoid measurements and calculations concerning all the utilized beams, the proposed method uses preliminarily determined functions of all the necessary data (absorbed dose, under-response, spread of beams versus depth) and then the correction procedure utilizes the treatment plane data file as input of the software.
In order to verify the reliability of the proposed procedure, it was applied to the dose image measured in a configuration of Spread-Out-Bragg-Peak (SOBP) consisting of a uniform dose in a region having the shape of a cube with 60 mm of side, achieved using 31 different proton energies and 571 spot positions. Exposures were carried out at the synchrotron of the Italian National Center for Oncological Hadron Therapy (CNAO, Pavia, IT). Initially, a simple procedure has been tested, in which for each proton energy the averaged value of the intensities of the 571 beams was utilized (Gambarini 2015). Thanks to the uniformity of the chosen dose distribution, the dose profiles obtained after applying the correction software fit very well those calculated from the treatment plane software. Then, in order to obtain good correction of images also for dose distributions with high gradients, the software has been suitably developed considering all the pencil beams, each with its own energy, intensity and coordinates of incidence. The software must be improved, but the first results show that the procedure is very promising and that it will be proposable for the use in the case of the complex dose distributions used for the treatment of patients in hadrotherapy with protons.

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Isomers close to the ^{170}Dy Valence Maximum: First Spectroscopy of ^{168,170}Tb

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Abstract

In-flight fission of a $^{238}U^{85+}$ primary beam of energy 345 MeV/nucleon on thick (2mm) beryllium target has been used to produce and study the decays of a range of neutron-rich nuclei around the valence maximum nucleus ^{170}Dy [1] at the RIBF Facility, RIKEN, Japan. The produced secondary fragments of interest were identified event-by-event using the BigRIPS separator with a decay spectroscopy set-up at the focal plane of the separator used to identify and correlate decays following both beta decay (in the milliseconds to seconds range) and isomeric decay in the nano-to-microsecond range. Discrete γ-ray lines emitted following decays from either metastable states or excited states populated following beta decay were identified using the 84 HPGe detectors of the EURICA spectrometer [2] which was complemented by 18 additional $LaBr_3$ fast-timing scintillation detectors from the FATIMA collaboration [3]. The fragments were implanted into the WAS3ABi position sensitive silicon active stopper which allowed pixelated correlations between implants and their subsequent beta-decay. This presentation will discuss the range of nuclei produced and identified in the experiment, with particular focus on previous unreported isomeric decays in the odd-odd nuclei ^{168,170}Tb. These data represent the first information on excited states in these nuclei, which are the most neutron-rich isotopes of terbium (Z=65) studied to date. Possible configurations for the observed isomeric states will be presented by comparison with Blocked BCS-Nilsson calculations for these axially symmetric, highly deformed nuclear systems which can give information on the proton and neutron orbits which reside close to the Fermi surface at the valence maximum.

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Monte Carlo simulations of Photoneutrons Production from Flattening Filter Free Medical Linac for Use in BNCT

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Keywords: Monte Carlo, Photoneutrons, Flattening filter free (FFF) Linac, BNCT

Studies in Italy have indicated the possibility of using photo-neutrons from high energy linac as a promising alternative neutron source to obtain intense neutron fluence rate for Boron Neutron Capture Therapy (BNCT) applications [1].
In continuation to these efforts, the aims of this study were: 1) to select high intensity linear accelerator that can be used for photo-neutron production; 2) to select the best materials for photo-neutron production. Initially, photon planner fluence and photons distributions have been simulated for a range of medical linear accelerators to study photon intensity using BEAMnrc Monte Carlo code. Due to its high photon intensity, The FFF Linac was selected as a nominal source to study photo-neutrons. Monte Carlo Simulations were then performed for photo-neutrons production from flattening filter free (FFF) medical Linac using lead and tungsten convertors.
Our results showed that photo-neutrons flux and yield increase with both photon energy and convertor thickness, saturating at 7 cm (lead) and 6 cm (tungsten) convertors. The average photoneutrons energy produced ranged from 0.480 to 0.863MeV for the tungsten convertor and from 0.586 to 1.214MeV for the lead convertor. A photoneutrons flux of 3.971×10^{8} n/cm^{2}s and 2.585×10^{8} n/cm^{2}s have been calculated for a 25 MeV medical linac equipped with 7 cm lead convertor and 6 cm tungsten convertor respectively. In conclusion the FFF linac presented a considerable feasibility toward having it as an alternative neutron source for BNCT with lead and tungsten as a suitable photoconverters.

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Feasibility Study of an Innovative Active Dosemeter for Radiation Fields dominated by Fast Neutrons

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Key Words: dosemeter, CLYC, silicon photomultiplier, SiPM, neutron, gamma, pulse shape discrimination

Prototypes of a novel pocket-sized active neutron dosemeter, based on a sensor made from the scintillator material Cs_2LiYCl_6:Ce (CLYC) coupled to a silicon photomultiplier (SiPM), were exposed to several well-characterised neutron fields produced at the National Physical Laboratory (NPL), UK.

^{6}Li-enriched CLYC is extremely interesting as a dosemeter sensor because it can detect not only gamma rays but also thermal and fast neutrons, gammas being distinguishable from neutrons by pulse shape discrimination. Thermal and low energy neutrons are detected by the $^6Li(n, \alpha)^3H$ reaction, which gives rise to a well-defined peak in the pulse height spectrum. Fast neutrons typically interact via $^{35}Cl(n, p)$ or (n, α) reactions, and the kinetic energy of the reaction product gives rise to a pulse height spectrum that relates fairly straightforwardly to the original neutron energy spectrum. Because of this spectrometry capability, such a dosemeter potentially offers a greatly improved accuracy, compared with conventional devices, when used in radiation fields that differ from the calibration field.

SiPMs are low-power and compact, allowing the prototype dosemeters produced for testing to fit entirely within a standard existing personal dosemeter housing. Tests were carried out in the low-scatter neutron facility at NPL, with measurements made both on-phantom and free-in-air. The former were done to evaluate the device's performance as a personal dosemeter, and the latter to explore its potential as a very light neutron area survey meter for radiation fields dominated by fast neutrons. Experimental results and corresponding Monte Carlo simulations will be presented in this paper. Performance issues encountered during the trials will be discussed and preferred application scenarios proposed.

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Are thick microbeams from superficial and orthovoltage kVp x-ray tubes of clinical interest?

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Key Words: *Microbeam radiation therapy, kilovoltage x-ray tube, Monte Carlo*

Spatial fractionation was widely used in radiotherapy before the introduction of megavoltage beams but is still an area of clinical interest. Synchrotron sources over the past few decades have been used to demonstrate an increase in normal tissue tolerance when the irradiated volume is reduced through the use of microbeams. A number of preclinical studies using thin microbeams in the region of 25-100μm wide have provided evidence that at very large doses normal tissues better maintain their vasculature structure than tumour tissues. For x-ray therapy at sufficient dose rates, microbeams 25-100 μm wide can only be produced from synchrotron sources however; recent studies have examined tissue tolerances to thicker microbeams (100-680μm). This work examines the potential for thick microbeam therapy to be delivered from a clinical radiotherapy x-ray tube. Existing preclinical studies of microbeams from synchrotron sources have been reviewed. Basic Monte Carlo simulations using the MCNPX code were then used to study the concept of using a range of beam defining parallel geometry grids to produce microbeams from a radiotherapy x-ray tube. A range of grid systems varying in thickness, slit separation, and material composition, for a range of beam energies were simulated to obtain deposited dose distributions in skin. Irradiations using a clinical radiotherapy x-ray tube and a simple collimator system were then used to validate these simulations. Initial results suggest that thick microbeams could potentially be produced from an x-ray tube, with the microbeam intensities being more closely uniform close to the beam central axis. This is due to the increasing attenuation of the diverging beam in the parallel grid system however; simulations have shown that a flattening filter could help to produce a beam more desirable for clinical use.

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Characterization of the scintillation detectors $CeBr_3$ and SrI_2 for the use as dosemeters.

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Key words: Environmental monitoring, scintillation detectors, Monte Carlo

For the upgrade of the existing dosimetric early warning networks in Europe detectors based on $CeBr_3$ and SrI_2 are investigated as possible substitutes for the current detector generation. These scintillation detector systems have a far better energy resolution (3% to 4%) compared to NaI(Tl) (best: ~6%) and a low inherent background. This will improve the capabilities of the measurement stations of the early warning networks, because not only can dose information be derived, which is the case for the current systems, but also information about the nuclide vector. In the case of a radiological emergency this enables the identification of the nuclides that cause local contaminations and the ability to react based on this information.
Several methods exist to calculate ambient dose equivalent rate values ($H^*(10)$) from gamma spectra. This work focuses on a method where a spectrum is subdivided into multiple bins and for each bin the conversion factor from count rate to dose rate is determined experimentally. These factors are derived from spectra of different quasi monoenergetic gamma sources. For this method it is important to know the angular dependence of the detection efficiency of the system. The possibility to replace these time consuming measurements with Monte Carlo simulations is investigated and the results are compared. The temperature dependence of the calculated dose rate value is investigated and a simple off-line method to correct for the shifting of the spectra due to temperature changes will be presented.
The characterized detectors are irradiated in different photon fields with well known energy spectra and traceable dose rates to verify the calculated conversion factors.

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Chemical separation of fission fragments from ^{236}Np produced by proton irradiation of natural uranium target.

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Key Words- chemical separations, fission fragments, mass chains and natural uranium

The radionuclide ^{236g}Np has a ground state half-life of 1.54×10^5 years [DDEP] and is of interest as a chemical yield tracer for the radiochemical and mass spectrometry analysis of ^{237}Np ($T_{1/2}=2.1\times10^6$ y), a major, long-lived waste product from nuclear reactor operation, arising from the alpha decay of ^{241}Am ($T_{1/2}$ = 433 y). Various production mechanisms of ^{236}Np involving charged particle irradiation of uranium targets (^{235}U, ^{236}U or ^{nat}U) have been studied, with the proton bombardment of ^{nat}U showing most promising results in terms of ^{236}Np production yield and isotopic purity (Jerome et al., 2014). The meta-stable excited state, ^{236m}Np ($T_{1/2}$ = 22.5 h) is also produced in the reaction. The metastable state and ground state of ^{236}Np decay to ^{236}Pu ($T_{1/2}$ = 2.86 y) and ^{236}U ($T_{1/2}$ = 2.2×10^7 y). The ^{236}Pu ($T_{1/2}$=2.86 y) daughter subsequently decays to ^{232}U ($T_{1/2}$=62 y), both of which can be used as indirect signatures of the production of ^{236}Np. The primary challenge in the radiochemical separation of ^{236}Np from the production target material is to isolate trace amounts of ground state ^{236}Np (corresponding to ~400 Bq/ng) from much larger quantities of target uranium as well as a wide variety of additional radionuclides including a wide range of primary and secondary decay products formed as a result of the high-energy proton-induced fission of ^{nat}U (Larijani et al. 2015). A target containing 1.2 g of $^{nat}UO_2$ was irradiated with a beam of 25 MeV protons of typical beam current of 30 μA for approximately 40 hours in May 2014 at the University of Birmingham cyclotron facility.

The ultimate aim of the current work is to develop and validate a novel radiochemical separation scheme capable of separating out (i) ^{236g}Np and (ii) ^{236}Pu from the target uranium, ^{236}U decay products and fission-decay chain residues. Uranium was selectively extracted with diethyl ether from nitric acidic solution, before Np(IV) and Pu(IV) were selectively absorbed onto a TEVA extraction chromatography column with high selectivity towards tetravalent actinides, leading to separation from fission products. The final chemical residues have been analysed using traditional alpha and high-resolution gamma-ray spectrometry to identify the production (and decay) of ^{236}Np in either ground state or isomeric state and the mass distribution of the fission residues created during the target bombardment (Jerome et al., 2014; Larijani et al., 2015). As part of the ongoing chemical separation method development work, the behaviour of the major fission product elements (Zr, Nb, Mo, Ru, Ba, La, Ce, Sb) on TEVA resin has also been studied using mixed stable-element standard solutions, with recovery of the separated fractions measured by mass-spectrometry. A summary of this project progress to date will be presented.

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Investigation of potential use of 124Xe-incorporated amorphous Si films in brachytherapy

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Key Words: Monte Carlo, neutron activation, dose estimation, nuclear reactor

An important and promising application of xenon-incorporated amorphous silicon (Xe@a-Si) films (or matrices) lies on the field of medicine. As already known stable ^{124}Xe atoms can be converted into ^{125}Xe, according to the atomic reaction $^{124}Xe(n, \gamma)^{125}Xe$, that, in turn, decays to the radioisotope 125-Iodine (^{125}I) widely employed in brachytherapy, an invasive anticancer radiotherapy technique applied in some types of cancer, e.g., prostate tumors. The radiation from the radioisotope-incorporated matrix must be effective enough to kill the cancerous cells and simultaneously preserve the integrity of the adjacent healthy tissues. These matrices are in general covered by a titanium (Ti) capsule, a bio-inert material and also transparent to the desired radiation. The complete set, matrix and cover, are named as brachytherapy seed. ^{125}I is an appropriate isotope to be employed in brachytherapy due to its nuclear properties such as low X–ray energies (27.2 – 31.9 keV), low gamma energy (35.5 keV), and half-life of 59.4 days. The proposed seed is composed of a cylindrical ^{124}Xe@a-Si matrix of 5 mm length and of 0.8 mm of diameter covered by a Ti capsule of 0.7 mm thick. In a previous work, it has been shown that an activity up to 1 mCi can be achieved under standard radiation conditions such as the ones mostly used at the nuclear reactors worldwide. In this work, a set of simulations has been run, using MCNP5, in order to obtain the dosimetric parameters of the proposed seed. These parameters shall be used to know the potentialities and difficulties to make a ^{124}Xe@a-Si matrix based brachytherapic seed which presents potential clinical applications.

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Abstracts for the Second International Conference on Dosimetry and Applications
Topic: Dosimetry & Measurement in the Nuclear Industry and at Accelerators
Title: Nuclear Reactor Dosimetry Modelling and Applications

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Key Words: Monte Carlo, neutron irradiation, dose estimation, nuclear reactor

As nuclear reactors age, various key components are strongly affected by the high radiation fields to which they are exposed. The advanced gas reactors (AGRs) and before them the Magnox reactors are moderated by graphite in bricks surrounding fuel and other rods. Under irradiation over many years, the geometry and density of these structures, are substantially changed. Similarly steel structures surrounding the core are also strongly affected.

It is very important to understand the ageing processes in these reactors, many have operated in excess of 30 years. EDF has have recently received permission for further life extension of four AGR reactors for up to seven years, which will provide valuable capacity to fill the electricity generation gap following closure of coal fired stations and the time that any New Build nuclear stations can come on line.

Similarly, crucial safety related components in a PWR are also affected by high neutron fluence. There is no graphite in a PWR but the reactor pressure vessel and core barrel for example receive very significant doses.

The paper will describe some of the dosimetry work that have been undertaken by Amec Foster Wheeler (AFW) relevant to the three reactor technologies of interest to the UK; AGR and Magnox and the Sizewell-B PWR. The AGR and Magnox work has been crucial in extending the lives of these stations. Example dosimetry applications for three reactors are chosen for discussion in this presentation. These include neutron damage of core restraints in an AGR, irradiation of a PWR reactor pressure vessel, and inventory estimates for Magnox plant to assist in decommissioning planning. The codes are validated by in-reactor neutron flux measurements.

The analyses have been carried out in the AFW Gloucester and Dorchester offices with a dosimetry code, MCBEND, developed by the AFW team at Dorchester. MCBEND in a Monte Carlo software tool for general radiation transport analysis for shielding and dosimetry applications. The presentation will describe briefly the MCBEND code methodology together with the reactor applications cited above.

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Fricke-gel dosimeter: overview of Xylenol Orange chemical behaviour

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Key Words: Fricke; Radiation dosimetry; Optical analysis; Xylenol Orange

The Fricke-gel chemical dosimeter was proposed and studied to attain spatial distributions of the absorbed dose for the pre-treatment dosimetry. It consists in an air-saturated acidic aqueous Fe^{2+} ions solution, dispersed into a tissue equivalent gel matrix. The products of water radiolysis cause the oxidation of Fe^{2+} ions and thus, the total absorbed dose is linearly related to the Fe^{3+} ions concentration. The dosimetric signal can be measured by 3D optical CT scan or Magnetic Resonance Imaging (MRI) techniques. The optical analysis has been made possible thanks to the addition of a dye, the Xylenol Orange (XO), which chelates the Fe^{3+} ions, leading to the formation of complexes that mainly absorb at 585 nm [1]. Moreover, the XO-Fe^{3+} complexes show a lower diffusion process within the volume than the aqua ions, so as to better preserve the spatial information even in case of MRI analysis [2]. To date, some open issues still need to be faced concerning the system chemical composition to improve the system sensitivity, stability and reproducibility. In particular, as reported in the literature [3] the XO chemical behaviour and optical properties are affected by the diluent and the pH, as well as the purity. The impurities, present in the salt due to the synthesis method, could compete with the XO for the Fe^{3+} ions complexation affecting the absorption spectra, thus leading to inaccurate evaluation of the absorbed dose, especially at low doses.
In order to study these phenomena, in this work a systematic investigation of the chemical behaviour of both tetrasodium and disodium XO salt has been conducted. HPLC and mass spectrometry analyses have been conducted to characterize salt impurities. In order to investigate the stoichiometry and equilibrium constants of the XO-Fe^{3+} complexes, aqueous solutions at different acidity containing a proper amount of XO and increasing concentration of Fe^{3+} ions have been prepared. Thus, through a proper analysis of the absorption spectra obtained for these solutions, the different XO-Fe^{3+} complexes have been identified and, their molar extinction coefficients, as a function of the wavelength, have been evaluated. No acidity influence has been observed. Different coordination behaviour and purity have been observed between tetrasodium and disodium XO salt.
The acquired knowledge could be applied for address further investigations aimed to completely characterize the physico-chemical properties of the dosimetric system.

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Development of a calibration protocol for quantitative imaging for molecular radiotherapy dosimetry

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Key Words: molecular radiotherapy, nuclear medicine, quantitative imaging, dosimetry, SPECT, SPECT/CT

Within the field of molecular radiotherapy, there is a significant need for standardisation in dosimetry, in both quantitative imaging and dosimetry calculations. Currently, there is a wide range of techniques used by different clinical centres and as a result there is no means to compare patient doses between centres. To help address this need, a 3 year project was funded by the European Metrology Research Programme [1], and a number of clinical centres across Europe were involved in the project. One of the required outcomes of the project was to develop a calibration protocol for three dimensional quantitative imaging of volumes of interest.

Two radionuclides were selected as being of particular interest: iodine-131 (^{131}I, used to treat thyroid disorders) and lutetium-177 (^{177}Lu, used to treat neuroendocrine tumours). A small volume of activity within a scatter medium (water), representing a lesion within a patient body, was chosen as the calibration method. To ensure ease of use in clinical centres, an "off-the-shelf" solution was proposed – to avoid the need for in-house manufacturing.

The BIODEX elliptical Jaszczak phantom and 16ml fillable sphere, were selected. The protocol was developed for use on SPECT/CT gamma cameras only, where the CT dataset would be used to correct the imaging data for attenuation of the emitted photons within the phantom. The protocol corrects for scatter of emitted photons using the triple energy window correction technique utilised by most clinical systems. A number of clinical systems were tested in the development of this protocol, covering the major manufacturers of gamma cameras generally used in Europe.

Initial imaging was performed with ^{131}I and ^{177}Lu at a number of clinical centres, but due to time constraints in the project, the final protocol was for ^{177}Lu only. The protocol is relatively simplistic, and does not account for the effects of deadtime in high activity patients, the presence of background activity surrounding the volume of interest or the partial volume effects of imaging lesions smaller than 16ml.

The development of this simple protocol demonstrates that it is possible to produce a standardised quantitative imaging protocol for molecular radiotherapy dosimetry. However, the protocol needs further development to expand it to incorporate other radionuclides, such as ^{131}I, and to account for the effects that have been disregarded in this initial version.

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Multi-Sample Integrated TL/OSL Reader System

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Key Words: α-Al_2O_3:C, $LiMgPO_4$:Tb,B, OSL, TL, Radiation dosimetry

In modern societies ionizing radiation measurements using thermo-luminescence (TL) and optically stimulated Luminescence (OSL) has occupied definite space of the applications extending from medical dosimetry, personnel monitoring, environment monitoring and geological/ archaeological dating. The requirement of low price multi functional TL/OSL reader systems are remains integral need of new age researchers of this field. Only few such type of reader systems exist commercially.

Considering this, a multi-sample integrated TL -OSL reader (MS-ITOR) system has been developed for filling the need of basic research in TL–OSL radiation dosimetry. This reader system can handle 36 sample materials at a time (with dia .8 mm and 2 mm thick) loaded in sample disc. Pneumatically controlled built in Sr^{90} beta source is provided for irradiation of samples with 60mGy/min dose rate at sample position. The reader is capable of providing TL, OSL, irradiation, and optical bleaching. By selecting different sample loading disc, 2 element 18 samples OSL card can also be read in present system. The 470nm /810nm LED stimulation have been used for OSL readout. MS-ITOR system is capable of providing CW-, LM, NL, and Pulsed –OSL.

To study the dynamic dose linearity of reader system CW-OSL dose v/s response of α-Al_2O_3: C recorded. The Minimum Detectable Dose (MMD) also being determined using α-Al_2O_3: C and $LiMgPO_4$:Tb, B (LMP) phosphors.

In TL mode sample can be heated lineally up to 500°C with programmable heading rates from 0.1K/s to 20K/s under inert nitrogen flushed environment. The reproducibly, sensitivity, cross talk and various operation aspects of this reader analyzed using standard TL/OSL phosphors α-Al_2O_3: C, $LiMgPO_4$:Tb, B(LMP) LiF2 and $CaSO_4$:Dy.

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Radiological protection assessments at the ELI-NP facility

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Key Words: Monte Carlo, shielding, beam dump, dose, radiological installation

The new research center Extreme Light Infrastructure – Nuclear Physics (ELI-NP) is under construction in Magurele, Romania. It will host a 2 x 10 PW laser system and a brilliant gamma beam system used for scientific research in nuclear physics. Both systems are at the edge of the present-day technology and when ready, they will define the new state-of-the-art in the related research fields. Besides the technological challenges related to the building of the systems one has to address new issues related to radioprotection assessment such as: definition of source terms, shielding optimization, beam dumps design, access procedures, etc. Ionizing radiations will be a product of the experiments to be performed with these installations, therefore they are included into the radiological installations class, resulting in their accomodation and operation having to fullfill the legal requirements in the field. For this purpose, a series of radiological protection assessments have been performed using Monte Carlo simulation codes MCNP and FLUKA. Based on the European and Romanian legal frame recommendations regarding the personnel and public safety, dose calculations and shielding provisions have been performed in order to fall within the design criteria. Different beam dump arrangements have been designed for each specific experimental setup proposed. The dose accrual resulted following the complex analysis of the ELI-NP facility is considered to be ALARA.

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Influence of dose history on thermoluminescence response of silica optical fibre dosimeters

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Key words: optical fibre, thermoluminescence, dose history, annealing

Nowadays optical fibre thermoluminescence (TL) sensors are becoming a practical option for radiation dosimetry. Performance of various commercially available and tailor made optical fibres as TL dosimeter (TLD) are investigated from various aspects for different applications. The first observations in 1980th that were resulted to expose optical fibre to discussion as a potential candidate for radiation sensing were changing in their different characteristics such as optical absorption and scattering, refractive index, mechanical properties and so on. However when silica based fibres were introduced as TL material in recent years, probable damages on optical fibre structure caused by ionizing radiation and the effect of pre-irradiation histories on their sensitivity were neglected. Furthermore, the effect of post annealing for full removal of fibre dose history is not well investigated. This study reports a detail observation on influence of dose history on performance of silica optical fibres and suggests the potential approach to mitigate this effect. Different Ge-doped and pure-silica optical fibres are considered. The effect of dose histories from 2 to 10^3 Gy with more than 10 repetition cycles (i.e., annealing and irradiation) are investigated using ^{60}Co gamma rays. A commonly used annealing recipe of 400°C for one hour is adopted in this study. The results show that by higher dose histories, the optical fibres' glow peak indicates a bigger shift towards higher temperature, suggesting creation of dipper trap centers. On the other hand, by every irradiation cycle, the TL response of optical fibres increased, in which up to 34% increment in TL yield observed after 10 cycles of 1Gy dose irradiations. Albeit, this TL increment depends on the magnitude of dose history and can be increased up to 60% by applying higher dose of 100Gy. The results suggest radiation induced defects in optical fibres that results in both shifting the glow curve peak to higher temperature and increasing the TL yield. Different annealing approaches and pre-irradiation treatments are investigated to stabilize the TL response of optical fibres against dose history effect. Initial observations show by optimum conditioning process, the variation induced by dose history can be controlled, which results in a reproducible fibre response in acceptable range.

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Air contamination measurements for the evaluation of internal dose to workers in nuclear medicine departments

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Key Words: internal doses; nuclear medicine; airborne radioactivity; air contamination monitoring

Radionuclides handled in nuclear medicine facilities are characterized by high volatility and short half-life. It is generally difficult to measure directly the activity intake of workers, which makes measuring air contamination of utmost interest. The aim of the present work is to provide a method for the evaluation of internal doses to workers in nuclear medicine, by means of an air activity sampling detector, to ensure that the limits prescribed by EURATOM 96/29 are respected.

To this end, air is sampled with a continuous air sampling system with a flow of 3 m^3/h (MecMurphil MP-AIR), and concentration of isotopes is measured using a low background NaI(Tl) detector in Marinelli geometry. Energy efficiency of the detector has been assessed through Montecarlo simulations with GEANT4. The detector response has been validated with known samples of 18F and 99mTc in water. The simulation provided the correction factors for air samples in Marinelli geometry.

After calibration of the detector in term of isotope concentration, air has been sampled in a number of areas of the nuclear medicine department of the IRST-IRCCS hospital (Meldola-Italy). Different exposure times were considered for the different worker categories (doctors, technicians, nurses) as indicated in ICRP-30, ICRP-66 and ICRP-71. The intake dose evaluation has been conducted by analytical models implemented in the Rad Toolbox (N.R.C.-U.S.A.) for biokinetic calculations of cumulative effective doses.

Error propagation for the estimated personal dose has been evaluated, starting from measurement statistics, with special attention to the minimum detectable activity (MDA). This method has been implemented in the planning criteria of a spectrometric environmental dosimeter dedicated to nuclear medicine facilities, in particular for hot-lab rooms.

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Water calorimetry as a primary measurement standard for proton therapy

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Key Words: Primary measurement standard, water calorimetry, dosimetry, proton therapy, radiochemistry, heat defect

The use of beam scanning in proton therapy is rapidly expanding as this technique is adopted in all new proton therapy facilities. Therefore there is a need for an absolute primary standard as a measurement technique for the dosimetry of scanned proton beams. This standard should reach the same level of uncertainty (less than 1 %) as the current primary standard for photons, which is based on ^{60}Co water calorimetry. We are investigating the possibilities of such a standard.

A major challenge is the effect of radiation-induced chemical reactions. They cause percent level measurement errors ('heat defect') which slowly approach zero with increasing accumulated dose. We have adapted existing radiochemistry models to the beam energies, LET-range and dose rates relevant for proton therapy. The model shows that water calorimetry using pure water in clinical proton beams is not feasible due to the amount of beam time that is required to reduce the heat defect to a negligible level. We have studied whether dissolved hydrogen can reduce the required pre-irradiation dose at a high LET, at high dose rates and in the presence of oxygen impurities, while producing a chemical equilibrium with negligible 'heat defect'.

We have used a water calorimeter in the 190 MeV scattered proton beam at KVI-CART. The purified water was saturated with a controlled mixture of hydrogen and oxygen. In a ^{60}Co beam, this mixture causes a very large exothermal peak to appear at a certain amount of accumulated dose, after which the heat defect is predicted to be zero (Krauss & Roos, 1998). We have observed the same effect in our proton beam. Following the peak the experimentally observed slope in response is -4.1(97)E-5 % Gy^{-1} (statistically compatible with zero). The statistical significance of this result is comparable to previous experiments with ^{60}Co (Krauss & Kramer, 2003). We propose to assign the same uncertainty to the heat defect that is also used for ^{60}Co.

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Improved Bonner Sphere Neutron Spectrometry Measurements for the Nuclear Industry

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Key Words: Bonner spheres, neutron spectrometry, UF_6, Monte Carlo, unfolding, neutron survey instruments

Neutron area survey instruments do not have a true dose-equivalent response as a function of energy, hence their readings depend on the fields in which they are used. In some workplace fields neutron survey instruments can over-read by a factor of two. Measuring the neutron energy spectra is therefore necessary to obtain accurate measurements of the dose equivalent in a workplace field. One of the most useful neutron spectrometry techniques is the use of Bonner spheres. This is because they are relatively simple to use, have a high sensitivity and cover the whole energy range of interest in most radiation protection situations. Deriving an energy spectrum from a set of Bonner sphere measurements requires the use of prior information, usually in the form of an initial estimate of the energy spectrum. This *a priori* spectrum can play a significant role in the unfolding of the final energy spectrum.

A novel, two-stage approach has been developed for producing the *a priori* spectrum where neutrons are produced by (α,n) reactions, e.g. in UF_6. The code SOURCES 4C is first used to obtain the energy spectrum of the neutrons inside the material, which is then fed into a MCNP model of the entire geometry to derive the neutron spectrum at the location of the Bonner sphere. Using this as the *a priori* spectrum produces a much more detailed unfolded Bonner sphere spectrum retaining fine structure from the calculation that would not be present if a simple estimated spectrum had been used. This is illustrated using a Bonner sphere measurement of the neutron energy spectrum produced by a cylinder of UF_6. From the unfolded spectra estimates have been made of the neutron ambient dose equivalent, i.e. the quantity which a neutron survey instrument should measure. The difference in the ambient dose equivalent of the unfolded spectrum is over 10% when using the novel approach instead of using a simpler estimate consisting of a single high energy peak, 1/E continuum, and thermal peak.

The derived neutron ambient dose equivalent is also compared with values obtained from measurements made in the same measurement campaign with 3 neutron survey instruments (NMS017, LB6411, BIOREM).

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Dose Reduction through Parameters Optimization in Pediatric Barium Meal Examinations

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Key Words: dosimetry in pediatric fluoroscopy, upper gastrointestinal tract, dose reduction

This work was done in one of the largest pediatric hospitals of Brazil. The aim of this study was to adjust the radiation techniques used in this hospital to the European Communities' recommendations for pediatric barium meal procedures (European Communities, 1996) and to evaluate the change in the air kerma-area product ($P_{K,A}$).
49 patients before the technique optimization and 44 patients after the optimization were studied and the $P_{K,A}$ values were calculated through the use of LiF:Mg,Ti thermoluminescent dosimeters (TLDs). In each patient, three pairs of TLDs were positioned in the center of the upper chest, which provided the mean entrance skin air kerma data. This was multiplied by the field area on the patient to obtain the kerma-area product value. In addition, anthropometric information and technical parameters of each procedure were registered.
During the optimization the following parameters were reduced: number of spot films, total fluoroscopy time, field size area, current-time product and exposure time (in spot films). Also, some technical parameters were increased, such as: kVp (in spot films) and the focus-detector distance. They became adequate to the European Communities' recommendations.
After the optimization, the kerma-area product was reduced by 68%. The new dose values are approximately lower than 73% of the results from similar studies.
Work supported by CNPq, CAPES and Fundação Araucária.

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Commissioning of the NAtional Nuclear Array, NANA

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Key Words: Monte Carlo, Gamma-ray spectroscopy, novel instrumentation

Abstract

The selection and identification of certain radionuclides in nuclear fuel waste materials and in fission fragments is of interest and importance to the civilian nuclear power generation and also the wider nuclear physics research communities. The NAtional Nuclear Array (NANA) is a 12 module $LaBr_3(Ce)$ scintillation detector coincident gamma-ray spectrometer array which can be used to enhance the identification of signature gamma-ray emissions from certain radionuclides within highly convoluted and complex initial singles spectra, such as those observed from nuclear fuel waste. By using digital signal processing following a detailed characterisation of the timing profile of the digital data acquisition system (which uses CAEN V1751C digitisers with a 1 GHz sampling frequency), gamma-ray coincident measurements between the individual NANA detectors have been made and demonstrated to have comparable temporal resolution to analogue systems (Regis, 2012). This high fidelity in the temporal dimension between two incident gamma rays allows for the creation of time correlated gamma-ray energy coincidence matrices from the gamma rays cascades which are acquired. This can then be used as a "map" to identify coincident emissions. Selecting coincidence requirements on one of the discrete gamma-ray energies can significantly improve the peak to background for the coincident projected spectra thereby improved inference and identification of the radionuclides of interest. One of the most significant reactor fuel waste products from thermal reactors is the neutron capture radionuclide ^{134}Cs. This radioisotope decays partially to excited states in ^{134}Ba by β^- decay and can be followed by the emission of a cascade of prompt coincident gamma rays. As such, the decay of this radionuclide and its identification in a complex matrix of other radionuclide waste materials makes it an excellent candidate radionuclide to demonstrate the resolving power of a fast-timing modular spectrometer such as NANA. This presentation will show several studies evaluating the sensitivity of the NANA spectrometer for selecting and identifying different decay channels and radionuclides in a mixed source. Furthermore, Monte Carlo GEANT4 (Agostinelli, 2003) simulations using NPTool will be presented for NANA which can be compared with measured source data.

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TOPAS Calculated Correction Factors for the NPL Proton Calorimeter

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Key Words: Monte Carlo, TOPAS, dosimetry, correction factors, calorimeter, primary standards

Introduction: The NPL (National Physical Laboratory) proton graphite calorimeter is a primary standard level instrument, capable of determining absorbed dose for proton beam radiotherapy dosimetry in the UK. In order to obtain the absorbed dose from the calorimeter measurement data, various correction factors need to be applied, including the gap correction factor (k_{gap}) and the volume averaging correction factor (k_{vol}) which were calculated in this work. k_{gap} quantifies the effect of the vacuum gaps within the calorimeter on the dose to the core, while k_{vol} accounts for the difference between the measurements of dose to the whole core and what is actually required: dose at a point in the centre of the core.

Methods: A simplified model of the calorimeter was created in TOPAS (a Monte Carlo particle transport simulation software based on the GEANT4 toolkit) and simulations were run at five different monoenergetic beam energies (60, 100, 150, 190 & 230 MeV). For the k_{gap} correction factor, the simplified calorimeter model was compared to a compensated model of the calorimeter where the graphite components were shifted towards the beam until they touch and then the vacuum gaps were replaced with graphite. For the k_{vol} correction factor the dose in the core of the calorimeter was compared to the dose in a small volume (0.25 mm radius) in the centre of the core.

Results: The gap correction factor, k_{gap}, had a non-linear dependence on energy, ranging from 0.6% above unity at 60 MeV to 3.6% above unity at 230 MeV. The volume averaging correction factor was found to be negligible, with an uncertainty of 0.065%.

Conclusions: The gap correction factor and volume averaging correction factor, along with their associated uncertainties have been calculated. These correction factors are essential in establishing the calorimeter as a primary standard.

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Neutron Spectrum Determination of d+Be Source Reaction by the Dosimetry Foils Method

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Key Words: Neutron activation, accelerator-based neutron source, neutron spectrum

The cyclotron-based fast neutron generator with the thick beryllium target operated at the NPI Rez Fast Neutron Facility is primarily designed for the fast neutron production in the p+Be source reaction at 35 MeV. Besides the proton beam, the isochronous cyclotron U-120M at the NPI provides the deuterons in the energy range of 10 to 20 MeV. The experiments for neutron field investigation from the deuteron bombardment of thick beryllium at 20 MeV were performed just recently. For the neutron spectrum measurement of the d+Be source reaction, the dosimetry foils activation method was utilized. Neutron spectrum reconstruction from resulting reaction rates was performed by using the SAND-II unfolding code and neutron cross-sections from the EAF-2010 nuclear data library. Results and uncertainty of the validation are discussed in details. High-flux white neutron spectrum from the d+Be source is useful for the intensive irradiation experiments and cross-section data validation.

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Retrospective Estimates of Patient and Operator Eye Lens Doses in Interventional cardiology

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Interventional cardiology is an area with high potential for radiation related risks to patient and staff. Dose assessment is important for optimization and to ascertain compliance with regulatory limits

Patient dosimetric data: kerma-area product (KAP), Cumulative air kerma (CAK) and fluoroscopy time were recorded from DICOM header concerning 250 patients who underwent cardiac angiography (CA) and Pace maker (PI) interventional cardiology (IC) procedures performed using biplane digital fluoroscopy system with flat-panel detectors. Fluoroscopy displayed KAP and CAK meters were calibrated during routine quality control measurements. kerma-area product to eye lens dose conversion coefficients derived from literature were used to retrospectively estimate operator eye lens doses to 8 cardiologist who performed on average 20-40 IC procedures each during three month period. In CA and PCI procedures, Mean KAP values were: 83± 87 Gycm2 and 223 ±254 Gycm2, respectively; CAK values were: 1.2 ±1.4 and 3.5 ±4.7 Gy; respectively. The estimated operator eye lens doses ranged from: 0.25 to 0.5 µSv per year (in CA) and from: 1.2 to 6 mSv (in PCI). Only two cardiologists were observed using eye lens glasses and thyroid gland radiation protection tools. The use of biplane fluoroscopy in interventional procedures reduces the complexity of the procedures, however, increased patients and operator radiation doses are still of concern mainly due to the prolonged fluoroscopy times. The study showed the possibility of predicting patient and operator eye lens doses from patient doses registry without the need for time consuming measurements.

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Test of biological shielding of hot cells with high active source ^{60}Co (300 TBq)

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Key Words: dosimetry, shielding, hot cell, radiation protection, high activity, measurement

The purpose of the paper is to present a test of biological shielding of hot cells facility constructed as a part of the project SUSEN.

In our facility we have 10 hot cells and 1 semi-hot cell. The hot cells are used for preparatory and auxiliary operations with irradiated materials, (receiving of irradiated materials, unloading of containers), but also for mechanical testing and determination of structure characteristics. Semi hot cell is used for microstructure analyse of samples (scanning electron microscope, nanoindenter).

Biological shielding of the hot cells is made by steel plates having a thickness between 300 mm - 500 mm. This biological shielding allows us to work with activity of up to 300 TBq for ^{60}Co. Semi hot cell is suitable for 250 GBq for ^{60}Co.

The purpose of this test was to demonstrate that the biological shielding of the hot cells has the desired efficiency and the measured values at selected points correspond to the contractual values, which were mandatory for supplier of biological shielding. The results are also used as a proof of the optimization of radiation protection for the State Office for Nuclear Safety. Which shows that radiation protection is optimized to safe work in the facility of hot cell.

During this test of biological shielding was revealed that radiation protection in the hot cells facility is optimized for nominal activities of samples.

The only exception is dry pool, which can't be used for samples of a nominal activity 300 TBq for ^{60}Co. However, it can be used under certain security restrictions for the movement of people in the hall over the hot cells, as well as the storage of radioactive samples for total activity, at least ten times lower, ie. 30 TBq for ^{60}Co.

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P1

Evaluation of Patient Effective Doses and Imaging protocols in Cardiac catheterization Procedures

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Key words: Cardiac catheterization, radiation risk, effective dose, dose optimization

Cardiac catheterization is an interventional procedure used for the diagnosis and treatment of coronary arteries diseases. Patients are exposed to prolong radiation exposure during the procedure. Tissue reaction (erythema) effects are now well documented as one of the serious complications of extended radiation exposure procedures. Radiation dose up to 18 Gy were reported. Therefore, accurate dose optimization is recommended to keep the radiation dose as low as reasonably achievable. The objectives of this work are to measure patient radiation dose and effective doses during eight type of cardiac catheterization. A total of 110 patients were examined for different clinical indication. A calibrated X ray machines was used to perform all the procedures. Patient dose measurements were performed using Kerma Area Product (KAP) meter. The mean and range of patient age (year), weight (kg) were 51.9 (22.0-80.0) and 70.1 9(49.0-86.5), respectively. While the mean and range exposure parameters were 84.1 kVp, 338 mA and 0.3 s for tube potential, tube current and time, respectively. The mean number of films per procedure is 7.5 and the mean fluoroscopic time was 5.6 min. The mean cumulative average dose (CAD) was 3342.8 cGy.cm^2. Patients exposed to different dose values based on their clinical indications. Although, no patients developed tissue reaction effect, optimization of patient doses in important especially for young patients.

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Effect of Gamma Irradiation on Tropomyosin in Black Tiger Shrimp (*Penaeus monodon*) and Giant Freshwater Shrimp (*Macrobrachium rosenbergii*)

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Key Words: Food allergen, tropomyosin, shrimp, gamma irradiation

Food allergies are unusual response to a food component triggered by immune system that can cause severe symptoms including death. In developing countries, food allergy has grown into an emerging public health problem. The demand on the methods to reduce food allergy is high and the study on this issue is very popular. Thus, this study was aimed to assess the effect of gamma irradiation on seafood allergen in fresh shrimp. The current study was focused on tropomyosin that present in two species of fresh shrimp which are *Penaeus monodon* (seawater shrimp) and *Macrobrachium rosenbergii* (freshwater shrimp). Tropomyosin is known to be the major allergen found in shrimp with molecular weight of 36 kDa. Peeled shrimp muscle was exposed to gamma irradiation at different doses (3, 5, 7, 10 and 15 kGy) while non-irradiated shrimp muscle was used as control. The irradiated shrimp muscle extract was analysed by SDS-PAGE and immunoblotting using polyclonal anti-tropomyosin antibody produced in rabbit and compared with non-irradiated extract. Immunoblotting showed that *P. monodon* muscle extract exhibited a reduction in tropomyosin with increasing doses. Meanwhile, *M. rosenbergii* muscle extract showed no changes at different doses. From the results obtained, it can be concluded that gamma irradiation give a substantial effect on seafood allergen thus providing a platform to reduce allergenicity.

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P3

Evaluation of annual effective dose from indoor radon concentration in Eastern Province, Dammam, Saudi Arabia

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Key word: Radon ^{222}Rn, Annual effective dose, RAD-7 α-detector

Radon (^{222}Rn) is one of radioisotopes that occur naturally and contributes to approximately 50% of natural background radiation. ^{222}Rn is a decay product of ^{238}U, radioactive noble gas, odorless, and colorless element which has a half-life of 3.82 days. ^{222}Rn enter homes or building via migration of soil gas and represents the largest risk to the human health. Radon and its decay products contribute to half of the total annual effective dose, when it compared to all other natural radiation sources. In this work an attempt has been made to evaluate the annual effective dose received by the residents due to inhalation of indoor radon concentration in Dammam and Al-Khobar city, and compared with new premises built at Dammam University. The measurements were carried out using active detection method; RAD-7, a solid state α-detector with its special accessories. The indoor radon concentration measured varies from 16.1±2 Bqm^{-3} to 26.9±2.1 Bqm^{-3} with an average value of 21.1±2.1 Bqm^{-3} in Dammam old dwellings and from 13±2 Bqm^{-3} to 23.5±2 Bqm^{-3} with an average value of 17±2.1 Bqm^{-3} in Al-khobar dwellings. In University of Dammam new premises, the radon concentration varies from 6.5±1.3Bqm^{-3} to 15.8±1.3Bqm^{-3} with an average value of 8.1±1.3 Bqm^{-3}. These results are helpful for evaluation and estimation of annual effective dose due to inhalation of ^{222}Rn by the inhabitants. The annual inhalation effective dose was found to vary from 0.06mSv/y to 0.71mSv/y with average value of 0.35mSv/y, and 0.05mSv/y to 0.60mSv/y with average value of 0.29mSv/y, and 0.04mSv/y to 0.13mSv/y with average value of 0.08mSv/y, in Dammam, Al-khobar and University new premises, respectively. The annual effective doses due to inhalation of ^{222}Rn in the study areas were compared and within the recommended limits of the world organizations.

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P4

MEASUREMENTS OF RADIATION DOSES IN MULTISLICE COMPUTED TOMOGRAPHY EXAMINATIONS

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Clinical applications computed tomography (CT) imaging has increased rapidly in recent years due to its numerous strengths points. However, the high radiation dose to patients during CT procedures received special This study aimed to measure the radiation dose, estimate the adequate doses during computed tomography (CT) procedures.

A total of 135 patients were examined in two hospitals using two spiral CT scans (64 slices) installed in two hospitals. Experts calibrated the machines from Sudan Atomic Energy Commission (SAEC).Organ equivalent dose and effective radiation dose was estimated using ImPACT scan and National Radiological Protection Board (NRPB) software. The average age of the patients was 45±18 years. The mean effective dose for ANH was 17.4±12.7 mSv, 22.9±14.3 mSv and 2.4±0.9 mSv for the chest, abdomen and brain examinations, respectively. The mean effective doses for ASH specialist hospital were 26.3±7.8 mSv, 47.6±33.0 mSv, and 3.7±1.5 mSv for the chest, abdomen and brain, respectively. The dose of this study is relatively higher compared to previous studies. It can attribute to lack of training in CT dose optimisation and CT modality. The study showed wide variations in radiation dose and effective dose for the same hospital. Continuous training of workers in this field and establishing the diagnostic reference level in the Sudan are critical.

Keywords: Multislice CT, effective dose, dosimetry, radiation exposure

Dosimetry Characteristic of Fabricated Germanium Doped Optical Fibres for Non-Reference Condition Postal Dose Audit

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Key Words: Dosimetry characteristic, fabricated germanium, non-reference condition, postal dose audit

This study was conducted to evaluate the dosimetry characterization of the fabricated cylindrical and flat fibres as a potential dosimeter in the non-reference condition radiotherapy postal dose audit. Basic dosimetry characteristic including linearity, reproducibility, energy dependence, dose rate dependence, angular dependence and fading were evaluated to ensure the optical fibres exhibited ideal features of a dosimeter to be used in non-reference condition radiotherapy postal dose audit. As a preparation, a screening process was carried out for the optical fibres with 6 MV photon beam using a Varian Model 2100C linear accelerator (Varian Medical System, Palo Alto, USA) located at University Malaya Medical Centre. Dosimeters with sensitivity out of ±5% mean sensitivity value were discarded in order to ensure the selected dosimeters have constant response between each individual fibre. The linearity test was performed using 6 MV and 10 MV photon beams and the dosimeter were irradiated with doses ranging from 1000 mGy to 3000 mGy using several dose rates. Fading rate was studied for 60 days post irradiation. The coefficient of variation was observed to be less than ±10% for both cylindrical and flat fibres prior to selection for basic characteristic irradiation. The results revealed that both cylindrical and flat fibres were found to be linear with r^2 more than 0.99 and 0.97 respectively over the entire dose range explored for both 6 MV and 10 MV photon beams. These fibres provide reliable and consistent reading within ±5% over five repeated measurements. Fading rate was higher for flat fibre compare to cylindrical fibre. Both fibres also offer dose rate independence. A comparison of the two results between cylindrical and flat fibre revealed that cylindrical fibre demonstrated greater TL signal compared to flat fibre. Correction factors for energy dependence and fading should be applied in order to determine an absorbed dose to water when the optical fibres will be employed in the radiotherapy postal dose audit. The evaluation on Germanium doped optical fibres showed a highly favourable characteristic exhibited by cylindrical fibre indicates a great potential in radiotherapy postal dose audit.

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(WITHDRAWN) P6

Determination of Naturally Occurring Radionuclides and Annual Effective Dose in Disi Aquifer Water, Jordan

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Key Words: HPGe detector, Disi aquifer water, specific activity concentrations of $_{226}$Ra and $_{228}$Ra, combined radium activity, radium activity ratio, annual effective dose

The Disi water samples were collected from nine different Disi aquifer producing wells in Jordan using clean polyethylene container of 10 liter size. The use of hyper-pure germanium (HPGe) detector in high-resolution gamma-ray spectrometry is one of the most widely used procedures for the identification and quantification of unknown gamma-ray emitting radionuclides in environmental samples. The ranges of specific activity concentrations of ^{226}Ra and ^{228}Ra in the Disi aquifer water were found to be from 0.302 ± 0.085 to 0.723 ± 0.207 and from 0.047 ± 0.010 to 0.525 ± 0.138 Bq L^{-1}, with average values of 0.516 ± 0.090 and 0.287 ± 0.091 Bq L^{-1}, respectively. The combined radium activity of ^{226}Ra and ^{228}Ra, and radium activity ratio ranges were measured in the areas under study. The ranges of estimated annual effective dose reported in this study from ingestion of combined ^{226}Ra and ^{228}Ra were found to be from 0.086 ± 0.064 to 0.381 ± 0.130 mSv y^{-1}, with average value of 0.250 ± 0.067 mSv y^{-1} for adults, 0.039 to 0.173 mSv y^{-1}, with average value of 0.113 ± 0.042 mSv y^{-1} for children and from 0.006 to 0.094 mSv y^{-1}, with average value 0.058 ± 0.0287 ± mSv y^{-1} for infants. Comparison was made between the present results and world mean values reported by WHO-2008, ICRP-1994, and EU-1998, and published data by other countries.

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Occupational Radiation Exposure In Nuclear Medicine

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Key Words: Occupational exposure, radiation dose, nuclear medicine, dose estimation

Objectives: To evaluate the occupational radiation exposure in Kuwait Cancer Control Center nuclear medicine department and to compare it to the dose limits of the International Commission of Radiological Protection (ICRP).

Materials and Methods: The annual average effective whole-body dose Hp(10), extremities dose Hp(0.07), and eye lens dose Hp(3) received by the staff from 2011 till 2015 were measured. The Hp(10) was measured using the thermo luminescent dosimeters (TLD), Hp(0.07) for the extremities using rings TLD, and the Hp(3) using high-sensitive thermo- luminescence detectors MCP-N (LiF:Mg,Cu,P). Six categories of staff grouped as cyclotron staff, hot lab staff, physicians administering therapy dose, PET physicians, PET technologists, and PET nurses were included. The annual average doses were calculated for each group and comparisons were made between the groups and the years. A two-sided Mann-Whitney test was carried out, at the $p = 0.05$ level, to compare the means. The mean Hp(10), Hp(3) and Hp(0.07) were compared with the limits of the ICRP.

Results: Cyclotron staff received the highest dose about 10 mSv whole body dose, 100 mSv extremities dose and 7 mSv eye lens dose. Hot lab staff received about 3 mSv, 1.5 mSv and 43 mSv for Hp(10), Hp(3) and Hp(0.07) respectively. Physicians responsible for administering therapeutic doses receive similar dose to hot lab staff. In addition, the technologist staff involved in performing PET studies received high dose to the eye. Interestingly, PET nurses received higher dose than technologists and physicians, as they are close to patients especially elderly and pediatric. The radiation dose was significantly reduced for PET physicians that are responsible for ^{18}F administration, by about 40% after 2012 due to the introduction and usage of the automatic PET injection system.

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DOSE ENHANCEMENT EFFECTS BY HIGH Z ELEMENT ON SYNTHETIC DIAMOND SENSOR FOR MEDICAL X-RAY DOSIMETRY

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Key words: Chemical Vapor Deposition (CVD) diamond, Monte Carlo (MC) simulation, Dose Enhancement Factor (DEF).

Diamond is an attractive material for medical dosimetry due to its radiation hardness, fast response, chemical resilience, small sensitive volume, high potential resolution, near-tissue equivalence, and energy and dose rate independence. The particular interest for medical dosimetry applications originates in the atomic number (Z=6) of the diamond, which is closer to the atomic number of human tissue than most other semiconductor detector materials. Recent progress in growing synthetic diamond produced by chemical vapour deposition (CVD), single crystal and polycrystalline, has improved by controlling specific properties and producing at a relatively low cost. This study is focused on one of the important factors to consider in radiation sensor design; the influence of dose enhancement from the interfaces between high atomic number Z element and charge transport near the electrodes in synthetic diamond affecting the irradiated photocurrent response of diamond sensors. Monte Carlo (MC) simulations carried out with BEAMnrc code [1], with aim of measuring the dose enhancement factor (DEF), which is defined as the ratio of the dose deposited near high Z element divided by the dose deposited in the diamond without high Z element in the vicinity. Experimentally, we study two single crystal (SC) CVD diamond samples fabricated into detectors' with carbon based electrodes by Boron and Carbon implantation. In addition, one polycrystalline (PC) sample was also fabricated by Boron implantation [2].Subsequently; the samples were each mounted inside a tissue equivalent encapsulation design in order to minimize fluence perturbations. X-ray sets operating at 50 and 100 kVp at a variety of dose rates were used to irradiate the synthetic diamond detectors. For comparison with the simulated DEF, the detectors' photocurrent ratio values have been calculated by the photocurrent response of the diamond near metal divided by the photocurrent response of the diamond without metal. The backscattered dose into the diamond through the metal (high Z) interfaces when the beam passes through diamond/electrode interface causes an increase in the detectors' photocurrent response. Using Copper the measured values of the photocurrent ratio agree well within their uncertainties for a variety of positive bias voltages in both SC detectors with the simulated DEF values of 1.03±0.6% at 50 kVp and 1.13±0.9% at 100 kVp. In contrast, for the PC detector the measured values of the photocurrent ratio were slightly higher than simulated DEF values. The observed discrepancies on the measured values of the photocurrent ratio at applied bias voltages $\geq$ 50 V might be related to the slight sublinearity of photocurrent response against the dose rate. For the measured values of the detectors' photocurrent ratio at applied bias voltages < 50 V were higher than the simulated DEF at both X-ray energies 50 and 100 kVp. Using higher Z metals (Lead or Gold) the photocurrent ratio was slightly higher but below the expected simulated value of the DEF.

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Lower Limits of Detection in use of Carbon Nanotubes as Thermoluminescent Dosimeters of Beta particles

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Abstract

World-wide, there is on-going intensive research into the adaptation of carbon nanotubes (CNTs) for a wide variety of applications, the particular interest herein being sensitivity towards radiation, specifically in regard to thermoluminescent (TL) properties. The inclusion of defects, from strain and impurities, have been shown in earlier work using doses of some 2 Gy to give rise to interesting amounts of TL, providing an initial idea of the extent to which electron trapping centres exist in various qualities of CNT, from super-pure to raw. These indications have pointed to the possibility that there may be considerable advantage in using these for radiation dosimetry applications, in particular for *in vivo* dosimetry. While present dosimeters are dominated by active devices such as semiconductor diodes and graphite ion chambers, these require high voltage and represent a clear risk when considered for *in vivo* work. CNTs also have an effective atomic number similar to that of adipose tissue, making it suitable for soft tissue dosimetry. In present investigations various CNT samples in the form of buckypaper have again been irradiated using a ^{90}Sr beta source, studying the ability of CNTs to detect lower doses, down to 2 cGy, also defining the lower limit of detection (LLD), comparison being made weight-for-weight with the phosphor-based TLD-100 (doped LiF) and Ge-doped silica fibres. The effect of surface area on the LLD of the samples has also been investigated.

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A survey of awareness of radiation dose among radiology staff in Saudi Arabia

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Keywords: radiation, dosimetry, X-rays, cancer, radiation risk, radiologist

Aim: Radiological procedures are progressively being utilised as a diagnostic tool in medicine, however, ionising radiation carries well-known risks. The purpose of this study was to investigate the knowledge of radiation dose and risk incurred in common radiology examinations among physicians, radiologists technologists, radiology technicians and staff in Saudi Arabia.
Materials and Methods: This prospective cross-sectional study was conducted across several hospitals in Saudi Arabia. Ethical approval was obtained from the College of Applied Medical Sciences in University of Hafr Albatin. A multiple choice questionnaire containing 17 questions on various aspects of radiation exposure was designed with an online survey tool and the link was emailed to all physicians, radiologists, technologists, technicians and radiology staff.
Results: A total of 92 responses was received. The mean score was 24% (range 11-63%). Only 14% and 8% were aware of the dose from single view and two view chest X-ray respectively. An underestimation of radiation dose from common studies was made by 59-74% of the respondents. 62-78% underestimated the risk of fatal cancer. The majority of the respondents (80%) were not aware of the course of action according to ACR guidelines when a pregnant woman underwent abdominal CT.
Conclusion: Radiology staff awareness surrounding radiation doses of common radiological procedures is poor. Staff should receive formal compulsory education. This lack of awareness has serious implications on both patients and staff.

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Improvement of the performance of broad energy germanium detectors using pulse shape analysis for environmental applications

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The optimisation of High Purity Germanium (HPGe) detector performance for different gamma-ray interactions is an active area of research in the field of nuclear physics. This goal requires a theoretical study of the detector response from the simulation point of view and experimental sets of measurements for validation. Consequently, simulations were used to model the response of a broad energy germanium (BEGe) detector, produced by Canberra, using unique pieces of software, MCNP4C, GAMOS and MATLAB for analyzing simulation outputs.

In routine sample counting, for instance, the gamma-ray energies are required to be exactly determined so the radionuclides within samples can be identified and quantified. The drawback of germanium detectors is their poor peak to Compton response that can make achieving this objective difficult. Therefore, this work aims to increase the peak-to-Compton (P/C) ratios while maintaining both the excellent energy resolution and the detector efficiency. This will result in an improvement in the detector sensitivity. To achieve this, Digital Pulse Processing (DPP) techniques were applied to gamma spectroscopy measurements which focus on measuring and counting samples. DPP allowed pulse-shaping parameters to be optimised and pulse shapes to be recorded for off-line analysis.

Data from a digital acquisition (DAQ) system has been analysed by sets of sort codes to produce spectra after the application of energy and rise time gates. Several Figures of Merit (FOM) were then constructed each considering a specific class of events which is described as Compton escaped events, in an attempt to expand the proportion of the full energy events in the processed spectra. One of the figures was focusing on the forward scattering events, provided a remarkable improvement in the P/C values compared to those for the original (or ungated) spectrum of all recorded events.

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Evaluation of Dose Uncertainty in Radiation Processing Using PR Spectroscopy and Butylated Hydroxytoluene Rods as Dosimetery System

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Keywords: Butylatedhydroxytoluene , electron paramagnetic resonance, dose.

Abstract

Butylatedhydroxytoluene (BHT) rods response is used in radiation dose measurement with electron paramagnetic resonance (EPR) spectroscopy. However, there are many possible sources of uncertainty, such as sampling and environmental conditions. This study intended to estimate the dose uncertainty in radiation processing using EPR Spectroscopy and BHT rods and to investigate its physical characteristics in different energy regions. BHT, which is white crystalline solid, melting point is 70-73 °C, was developed under gamma irradiation (^{60}Co) for a dose range of 0.1-100 kGy. The intensity of the EPR signal increases linearly in the range of 0.1-35 kGy with the 3rd polynomial function. The radicals formed in BHT provide a stable signal with a good reproducibility (0.214 %), and the decay within one year was 5 %. The uncertainty budget for high doses was 4.69% at 2σ confidence level. Therefore, BHT rods can be used as routine dosimeter in the range 0.1-50 kGy. The decay at room temperature was 5% and 6.54 at dark and daylight conditions, respectively. The BHT rods have good mechanical properties adequate for easy and safe handling. The ratios of the stopping powers and energy absorption coefficients varying within ±5 as a function of energy for the energy range 0.2-10 MeV. The overall uncertainty of dose measurement over the dose range of 0.1- 100 kGy corresponding 2σ (95% confidence level) was 4.69%. Rod form represents the best alternative dosimeter for high level dosimetry with the smallest uncertainty compared to powder form.

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Comparison between the mass attenuation coefficients determined by the same atomic composition and coefficients experimental measurements irradiated with ISO X-ray beams

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Key Words: barite concrete, attenuation coefficients, radiation shielding

The probability of a photon interacting in a particular way with a given material, per unit path length, is usually called the linear attenuation coefficient (μ), and it is of great importance in radiation shielding. Plates of barite concrete with different thickness were fabricated in order to determining their mass attenuation coefficients at different energies. The plates were irradiated with ISO X-ray beams (N60, N80, N110 and N150), generated by Pantak HF320 X-ray equipment, at the IPEN laboratory. The mass attenuation coefficients of barite concrete have been measured using X-ray attenuation for different thicknesses of barite concrete qualities of the ISO. The attenuator material is used from different regions of Brazil. The experimental procedure in this research was validated by comparison between the experimental measurements of mass attenuation coefficients and coefficients determined by the same atomic composition, using as a tool to XCOM. Values of μ/ρ ranged from 1.05 to 1.60 cm2/g for barite concrete, made in the laboratory. The difference of this magnitude was 50% as N60's ISO. This is explained by the wide variation in the density of these materials ranging from 2 to 3 g/cm3. Can be seen that both calculated and measured data for the linear attenuation coefficients increase with the increasing materials density, and the mass attenuation coefficient is constant as it is expected. It can be concluded that the photon attenuation coefficients depends on the photon energy and the materials density is the main contribution to the photon attenuation coefficients, which is important for radiation shielding.

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Dosimetric characterization of small photons beams of a novel linear accelerator using EDGE diode detector.

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Key Words: small field dosimetry, EDGE diode detector, beams matching; SRT; IMRT

Background: UNIQUE (Varian Medical Systems, Palo Alto, California) is one of the latest generation of single low energy linear accelerator with advanced features introduced in the clinical practice. The first application of UNIQUE for clinical radiotherapy was occured in 2012. Reports about its mechanical and dosimetric performances are extremely scarce in specialized and technical literature. One UNIQUE with the capability for intensity modulation radiation therapy (IMRT) and radiosurgery (SRS) treatments are recently commissioned at our Institute.

Purpose: The aim of the present contribution was to measure the main dosimetric quantities of small fields produced by UNIQUE and evaluate its matching with the corresponding dosimetric data of one 21EX conventional linear accelerator (Varian) in operation at the same center. The second step was to evaluate comparative performance of the EDGE diode detector and the PinPoint micro-ionization chamber for dosimetry of small fields.

Methods: UNIQUE is configured with MLC (120 leaves with 0.5 cm leaf width) and a single low photon energy of 6 MV. Beam data were measured with scanning EDGE diode detector (volume of 0.019 mm^3), a PinPoint micro-ionization chamber (PTW) and for larger fields ($\geq$ $4x4cm^2$) a PTW Semi flex chamber (0.125 cm^3) was used. The scanning system used was the 3D cylindrical tank manufactured by Sun Nuclear, Inc. The measurements of PDD and profiles were done at 100 cm SSD and 1.5 depth; the relative output factors were measured at 10 cm depth.

Results: PDD and the profile data showed less than 1% variation between the two linear accelerators for fields size between 2x2 cm^2 and $5x5cm^2$. Output factor differences was less than 1% for field sizes between 3x3 cm^2 and 10x10 cm^2 and less of 1.5 % for fields of 1.5x1.5 cm^2 and 2x2 cm^2 respectively. The d_{max} value of the EDGE diode detector, measured from the PDD, was 8.347 mm for $0.5x0{,}5cm^2$ for UNIQUE. The performance of EDGE diode detector was comparable for all measurements in small fields. Flatness and symmetry were measured as well and compared.

Conclusions: UNIQUE linear accelerator show similar dosimetrics characteristics as conventional 21EX Varian linear accelerator for small, medium and large field sizes. EDGE detector show good performance by measuring dosimetrics quantities in small fields typically used in IMRT and radiosurgery treatments.

Energy Spectra of Photons in Tissue Equivalent Phantoms

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Key Words: Monte Carlo, phantoms, gamma spectrum, Compton scattering

The interaction of photons with matter is an important observable in medical physics applications. Out of the two possible modes of interaction for photon energies less than 1.022 MeV, Compton scatter is the most probable for the ionizing energy range used in radiology, nuclear medicine, and radiotherapy. After partial deposition of energy in the absorbing medium, the Compton scattered photon may undergo a photoelectric absorption where its remaining energy is fully absorbed by the medium. Although less probable, it is possible for this photon to undergo a series of Compton scattering events before leaving the medium. Such repetitive process leads to a successive photon energy degradation that is often difficult to experimentally measure. This shortcoming is due to two main limitations on the spectrometer's performance. First, the time scales of these successive interactions are very short, thus making it faster than what the spectrometer's electronics can distinguishingly register. Hence these multi interactions are seen by the spectrometer as a single event, and therefore the energy decrements are lumped into a single drop. Second, with the decrease of the signal to noise ratio for lower photon energies, the spectrometer's ability to detect the lower limit of the photon energy degradation deteriorates. This deficiency leads to a cut-off of the energy degradation.

It is noteworthy that the previous description applies for interactions taking place within the spectrometer. Not surprisingly, detection of such successive interactions inside a targeted medium is even more cumbersome since photons suffer from energy losses within the medium itself before reaching the spectrometer for another round of interactions. This experimental constraint necessitates careful examination of gamma spectra produced by the spectrometer to indirectly acquire the interactions that take place inside the targeted medium. Undesirably, it is experimentally not possible at this time to acquire more detailed information about the nature of the photon interaction inside targeted media.

Monte Carlo (MC) methods have been shown to be effective in simulating interaction of photons with matter. By combining repeated random sampling with the relevant physics, this class of numerical methods can accurately predict experimental outcome. Therefore, MC are typically utilized in cases that are unavailable for experimental measurement, like at the interfaces of different media, in steep energy gradients, and more relevantly in the above discussed case where photons undergo multi interactions prior to reaching the experimental detection zone.

This work aimed to acquire photon energy spectra in tissue equivalent phantoms. Due to the associated experimental challenges, a numerical approach was adopted that constituted mainly of MC methods. The output of this developed numerical scheme is expected to help in a better understanding of photon-behavior inside human tissues, especially with regard to energy degradation due to successive Compton scatter that precede the photon escape from the targeted tissue. In turn, this knowledge is expected to enhance dosimetery assessment, and hence the overall safety of medical imaging and radiotherapy.

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Thermoluminescent properties of lanthanum aluminates doped praseodymium

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Key Words: Lanthanum Aluminates, dosimetry, Thermoluminescence, Pechini Method

This paper presents the experimental results of the thermoluminescent (TL) characteristics of lanthanum aluminates doped with trivalent praseodymium ion ($LaAlO_3:Pr^{3+}$) powders prepared by Pechini´s modified method for X-ray dosimetry applications. The powders obtained were submitted at different temperatures. Pechini´s modified method was using to prepare praseodymium doped $LaAlO_3$ powders. The structural and morphological characterization were carried out using X-ray diffraction (XRD) and scanning electron microscopy techniques. TL glow curve of the X-ray irradiated samples showed two prominent peaks, the first of them is centred in around of 200°C which could be considered as dosimetric peak and the same glow curve showed a little shoulder in around of 300°C. TL intensity was increased with increasing dose. TL response of $LaAlO_3:Pr^{3+}$ as a function of X-ray absorbed dose was linear over a wide dose range. This new phosphors appears to have potential application for high dose measurements. The technique is low cost, faster and produces well very homogeneous particles TL materials that can be used for X-ray dosimetric applications.

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Calculation of neutron dose to the fetus during commercial flights using a pregnant model and Monte Carlo simulation

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Key Words: Monte Carlo simulation, foetal dose, aircrew dose, pregnant phantom

Aircraft crew members are exposed to cosmic and solar radiation as well as the secondary radiation formed by the interaction of cosmic and solar radiation with the earth atmosphere. Radiation field in flight altitudes are formed mainly by neutrons, protons, electrons, positrons, photons, muons and pions, but generally 50 % of the effective dose in aircrew members is due to neutrons. Care must be taken especially with pregnant aircrew and frequent air travelers in which radiation dose in the fetus have not exceed 1 mSv per year. Therefore, it is necessary evaluate the radiation dose absorbed by the fetus in the mother womb. Only Chen et al. (2005) and Chen and Mares (2008) have estimated foetal dose in commercial flight using the Monte Carlo method and anthropomorphic phantoms. But in these studies, mathematical models of the mother and fetus were used. The aim of this study was calculate the foetal dose conversion coefficients and the whole-body foetal dose rate for neutron beams using a pregnant woman mesh phantom developed by Cabral et al. (2015). The isotropic irradiation geometry was used to simulate the exposure scenario of monoenergetic neutrons from 1.10^{-9} MeV to 100 GeV. The foetal dose rate was calculated folding the calculated conversion coefficients with the spectral neutron fluence rate and the neutron weighting factor. We used the spectral neutron fluence rate measured by Goldhagen in a flight from Trenton, Canada to Koln, Germany on 9 May 1995 at latitude of 55°N and an altitude of 11.3 km presented in Chen et al. (2005). Calculated foetal dose conversion coefficients and foetal equivalent dose rate were compared with results presented in Chen et al. (2005). The calculated equivalent dose rate in the fetus model was 2.35 $\mu Sv.h^{-1}$ which is 46 % higher than the values estimated by Chen et al. (2005) using the fetus with 3 month and 62 % higher than the fetus with 6 month. Differences in conversion coefficients were up to 165 % and 212 % at 1 MeV of neutron energy when compared with the foetal model of 3 month and 6 month respectively.

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Estimate of fluence-to-dose conversion coefficients using hybrid anthropomorphic phantom in a sitting posture and Monte Carlo method

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Key Words: Monte Carlo, photon beam, dose conversion coefficients, anthropomorphic phantoms

For a dose estimation in computational scenarios, it is necessary a radiation transport code that describes the physics of transport and interaction of ionizing radiation with matter, and an anthropomorphic computational phantom as real as possible. Thus, this study compared the dose conversion coefficients from male and female hybrid computational anthropomorphic phantoms in sitting posture with Adult Male (AM) and Adult Female (AF) also in sitting posture, recently reported by Galeano et al. (2016), in ICRP idealized irradiation geometries and monoenergetic photon beam with energies range from 0.010 MeV to 10 MeV. Significant differences were observed up to 100 % for different organs, especially in the anteroposterior and laterals irradiation geometries. In the effective dose conversion coefficient, differences were observed up to 77 %. Such differences occur probably due to anatomical difference of hybrid phantom compared to AM and AF phantoms in a sitting posture, and different position of hand between the two types of phantoms.

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Investigation of silica-based TL media for x-ray dosimetry

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Key words: Ge-doped silica, fibres, TLD, dosimetry

ABSTRACT

We investigate doped-silica fibres thermoluminescence (TL) media. Offering high spatial resolution, in the range 0.1 to 3 mm, the challenge is to develop a material more dosesensitive than LiF (Mg, Ti) as popularly used in x-ray imaging. Interest is in Ge-doped silica telecommunication fibres (SMF) and tailor-made doped photonic crystal fibres (PCF). The PCFs, Ge-doped or also co-doped with boron, are formed of doped capillaries that are subsequently collapsed-down at high temperatures in order to generate strain-related defects, increasing the TL yield and hence dose sensitivity. We test their ability to detect radiation from the low levels of diagnostic chest radiography through to the doses observed in fluoroscopic investigations, use being made of an x-ray tube operated at 80 kVp as typically used in chest radiography. We further examine dose-linearity, energy response and reproducibility.

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Assessment of the efficacy of a thermoluminscent dosimeters holder for a multicentre stereotactic radiosurgery audit

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Key words: Thermoluminescent dosimeters holder, lens dosimetry, Stereotactic radiosurgery, audit

Stereotactic radiosurgery (SRS) is a non-invasive radiation therapy technique which involves delivering a high dose of ionising radiation to a precisely defined target while preserving the surrounding tissue. The use of SRS is rapidly increasing and constantly developing to treat various functional abnormalities, malignant and benign brain lesions. There are several commercial platforms available that can deliver SRS treatments including Gamma Knife, Linac, and Cyberknife. All delivery techniques have demonstrated their usefulness in achieving local tumour control for single and multiple brain metastases whilst maintaining a low rate of complications. The imaging techniques used for localising SRS targets include CT or MRI that are then imported into special treatment planning software that allow simulation and assessment of the most effective treatment approach. However, there are a few different approaches in delivering SRS and it remains a field that will benefit from more investigation and standardisation.

A multi-centre dosimetric audit has been set up to investigate the range of SRS practices for a single brain metastasis using a series of detectors and an anthropomorphic head phantom. As the lens is one of the most radiosensitive organs in the body, one of the aims of this audit has been to determine the dose received by the lens from scattered radiation during an SRS treatment. The imaging dose received during the CT-scan acquired in the planning stage is also a concern. For this purpose, custom-designed holders have been manufactured to carry three types of thermoluminscent dosimeters: Ge-doped optical fibres, glass beads and the TLD-100, the latter being used as a reference dosimeter. The holders are in the form of cylindrical black boxes, the dimensions of which are suited for placement onto the location of the eye surface of the phantom. A bespoke 3D-printed (goggle) insert was produced for the head phantom to allow reproducible placement of the TLD holders for CT and SRS. In this work, we have demonstrated that the goggle insert and the TLD holders produced are suitable for the dosimetric assessment undertaken in the audit.

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Theoretical study of depth profiling with gamma- and x-ray spectrometry based on measurements of intensity ratios

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Key Words: gamma spectrometry, x-ray fluorescence, depth distribution, characteristic x-ray line ratio

The gamma- and x-ray spectrometry is a powerful tool for analysis of materials. Gamma spectrometry (GS) is used to identification and quantification of radionuclides, whereas the stimulated emission of x-ray radiation is applied to elemental analysis with an x-ray fluorescence method (XRF). Samples for laboratory GS and destructive XRF are usually homogenized before the analysis. However, the homogeneous composition is not ensured in the case of in-situ GS or non-destructive XRF.

The principle of the proposed techniques lay in the different attenuation coefficients for at least two x-ray or gamma-ray lines of a certain element or radionuclide, respectively. If an analyte is present at some depth, its radiation has to penetrate through thick layer of the matrix, and the photon fluxes are significantly changed. For instance, ^{214}Bi is a member of the uranium series and in present in soil or walls of building. Two gamma lines of this radionuclide can be detected with an HPGe detector, and thus net peak area ratio of these lines is related to depth distribution of this radionuclide. Analogously in XRF, ratios of Kα, Kβ, and L lines of an element can provide us with information on depth distribution of this element in an analysed object.

We have focused on parameters involving the line ratio, *i.e.* attenuation coefficient, photon energy, detector efficiency, measurement geometry, mass density, and composition profile. The objective was to relate the depth distribution with the line ratio and absolute intensity of the measured count rate. Previously, the similar work was presented with experimental data by so called calibration diagrams [1]. In this poster, the Monte Carlo simulation was used. Possible interferences, matrix effects and the difference among homogenous mixtures and layered structures were also theoretically evaluated.

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Determination of U, Th and K in Bricks by Gamma Spectrometry, X-ray Fluorescence Analysis and Neutron Activation Analysis

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Key Words: gamma spectrometry, neutron activation analysis, x-ray fluorescence analysis, dose rate, environmental dosimetry

The knowledge of the content of natural radionuclides in bricks can be important in some cases in dosimetry and application of ionizing radiation. One of them is, of course, dosimetry of naturally occurring radionuclides in matter (NORM) in general, the other one is the radon exposure evaluation, and finally, it is needed for the thermoluminescence (TL) dating method. The internal dose rate inside bricks is caused mostly by contributions of the natural radionuclides ^{238}U, ^{232}Th, radionuclides of their decay series, and ^{40}K. The decay series of ^{235}U is usually much less important.

The concentrations of ^{238}U, ^{232}Th and ^{40}K were measured by various methods, namely by gamma spectrometry, X-ray fluorescence analysis (XRF), and neutron activation analysis (NAA). These methods were compared from the point of view of accuracy, detection limit, amount of the sample needed and the sample handling, time demands and availability. NAA, at least in its most sensitive form, is not easily available, as it uses a nuclear reactor as a neutron source. On the other hand, NAA has a higher potential for accuracy compared with other trace element analytical methods and has recently been recognized as a primary measurement method. Therefore, we compare the other results with NAA. In addition to internal brick dose rate determination, we present a comparison of different homogenization methods used during preparation of the samples that are evaluated by XRF. We also present brick granulometric characterization, which is useful in the dosimetric applications discussed. It is shown that these characteristics can influence the U, Th and K determination.

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Size-Specific Patient Dose Estimates (SSDE) in CT Examinations of children in Sudanese Hospitals following the recommendations of AAPM

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Keywords: Size-Specific Dose Estimates (SSDE), Computed tomography, Volume CT air kerma index

Size-Specific Dose Estimates (SSDE) is important for more precise Patient radiation dose estimates rather than CTDIvol metric that identify output levels. In this study, we have performed SSDE in Pediatric CT in four MultiSlice CT scanners as preliminary results for a nationwide dose survey in Sudan.

Console displayed CTDIvol were recorded from CT DICOM header of 147 Pediatric patients who underwent MultiSlice CT examinations. SSDE were obtained based on torso diameters measured for individual patients—anteroposterior (D_{AP}) plus lateral (D_{LAT}) from transverse images and D_{AP} or D_{LAT} from scout images. Conversion factors were used to translate the recorded CTDIvol to true measurements of dose on the basis of the patient's size according to the procedure described in the American Association of Physicists in Medicine (AAPM) Report 204.

Mean SSDE (mGy) calculated from transverse (Scout) images of the brain, chest and abdominal examinations were: 36.0 (42.6) , 51.0 (34.7) and 37.4 (36.1); respectively for 0 - < 1 year age child; 56.5 (51.6), 12.1 (12.1) and 39.1(37.6), respectively for 1 - < 5 year age child; 68.7 (61.3), 20.5 (23.0) and 28.4 (29.3), respectively for 5 - < 10 year age child; and 64.5 (56.5), 19.2 (20.1) and 46.1 (48.7),, respectively for 10 - < 16 year age child. Correlation coefficient (R) between SSDE calculated from transverse and scout images with recorded $CTDI_{vol}$ mounted 0.96 and 0.92 respectively. According to our results, console displayed $CTDI_{vol}$ values under estimated SSDE calculated from transverse (scout) images by 18-50% (3-18%) in Brain CT; 34-130 % (33-121 %) in Chest CT; and 46-120 %(41-112%) in abdominal CT.

Results are presented for a nationwide dose survey aimed at updating patient exposure record in pediatric CT and thus have provided first SSDE data for pediatric CT exposure in the country. SSDE could be included in the patient medical record to provide the ability to estimate radiation dose to a volume of tissue for a given patient prior to CT scan.

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Development of a new optical method for gel dosimeters based on the analysis of the scattering light

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Key Words: gel dosimetry, polymer, radiochromic, scattering light analysis, refractive index

Chemical dosimetry is a promising metrology technique for detection of ionizing radiation, in which radiation responses and metrological characteristics of chemical dosimeters are dependent of reagent concentrations. By their constitution, gel dosimeters represent a real three dimensional detectors that can be adapted for different volumes. They are mainly composed of water (like the human body), which gives to gels, a very good water/tissue equivalence. Used as a detector, gel dosimeters are of interest in a lot of areas, especially in medical domain.

First, this presentation summarize the historic and the theoretical approach about gel dosimeters and techniques of their reading. Then, we focus on polymer gels and their chemical aspects, especially about the creation of microdomains. Indeed, the characteristics of the microdomains (size, number) are function of the absorbed dose. We also show chemical aspects of radiochromic gels, namely radiochromic gel with Turnbull blue.

Second, we introduce our new optical reading method, found on and the theoretical principles based on the Lorenz – Mie theory. Then, we explain how the measurement and the correlation between microdomains and the absorbed dose are performed. Different optical parameters were studied. We use specifically the polarisation and depolarisation ratio which depend on the polymer microdomain size, the scattering angle, the wavelength of the source laser light, the absorbance and the refractive index of gels. The gel dosimeters are evaluated with a high spatial accuracy (less than 10 µm) and with a great sensitivity (less than 0.25 Gy) depending of the initial reagents concentrations of the gel dosimeters. The comparison with optical tomography of polymer gels is also presented. All reading methods (scattering light analysis, optical tomography, UV/VIS spectrophotometry) was used for evaluation of gel dosimeters parameters, namely dose dependence of response and time stability.

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Quality Audits for Advanced Technology in Radiotherapy Dose Delivery in Poland

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Key Words: dosimetry audit, Multi Leaves Collimators, small fields dosimetry

Introduction. In the radiotherapy Treatment Planning Systems (TPS) various calculation algorithms are used (Pencil Beam Convolution PBC, analytical anisotropic algorithm AAA, Monte-Carlo). The accuracy of dose calculations has to be verified specifically for the advanced techniques of dose delivery such as IMRT or VMAT. Numerous phantom types, detectors and measurement methodologies are proposed to verify the TPS calculations with dosimetric measurements. A number of quality tests has been designed within a Coordinated Research Project (CRP) of the IAEA. Two of these tests are presented here.

Materials and methods. The purpose of the first test step was to check in the TPS calculation accuracy for small fields shaped with Multi Leaves Collimators (MLC). This was done by calculating the number of monitor units (MU) in TPS for 5 MLC-shaped field sizes to deliver 10 Gy on axis at 10 cm depth at 100 cm source to skin distance (SSD). The dose rate was calculated for fields 2×2 cm^2, 3×3 cm^2, 4×4 cm^2, 6×6 cm^2 and 10×10 cm^2 and normalized to that at 10×10 cm^2 field. Results were compared with the published data sets.
The aim of the second test step, a picket fence test, was to verify the positioning accuracy of MLC leaves. This was done by irradiating an MLC pattern consisting of 5 strips positioned at -6 cm, -3 cm, 0 cm, 3 cm, and 6 cm relative to the central axis on an EBT 3 film. Films were placed for irradiation in a solid phantom at the depth close to the depth of the dose maximum, at 100 cm source axis distance (SAD).

Results. The test on quality audits for dose rate dependence of small fields shaped with MLC was implemented for all 35 Polish radiotherapy centres for different linacs, TPSs, MLC types and beam qualities. In total, 81 beams were checked (Varian 41, Elekta 24, Siemens 16). The beam qualities ranged from 4 MV to 20 MV. The results were evaluated and compared to the published data. When compared to the published values, the TPS calculated mean output factors by participating centres agreed for all field sizes and energies within 1% difference for Elekta machines. For Varian machines the average differences for 3×3 cm^2 and 2×2 cm^2 fields for 6 MV beams were 1.6% and 2.3%, respectively. For Siemens machines the differences for 2×2 cm^2 fields were 1.6% and 1.7% for 6 MV and 15 MV beams.
The picket fence test is undergoing nationwide. The films were sent to 35 centres together with the MLC sequences prepared for different types of accelerators available in Polish radiotherapy centers. To-date 34 participants returned the films irradiated following the indicated MLC sequence. The results are being analyzed.

Conclusions. The comparison of the results of calculations and of measurements allow to the detect limitations of TPS calculation algorithms. The audits performed seem to be an effective tool for detecting the calculation limitations in the TPS and radiotherapy treatment machines. Further tests are being planned within the project.

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Evaluation of the dose received in the tissues of the neck during the quantification of Iodine in the thyroid by X-ray fluorescence spectrometry.

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Key Words: dose estimation, Iodine, phantom, thermoluminescence dosimeter

The determination of the Iodine content in the thyroid is of great interest for many investigations of this gland. The conventional scintigraphic method, using radionuclides, is efficient but delivers a significant dose to the patient.
The X-ray fluorescence spectrometry gives information about the iodine content in the thyroid. The measured signal is obtained after stimulation of the stable iodine contained in the gland by X-rays. The advantage of this technique is the complete absence of radioactive isotope injected into the patient body. By applying this technique, a decrease of effective dose to the patient should be obtained. In this paper, the study of the dose received by a thyroid phantom (surrounded by the different tissues of the neck) was performed. The phantom is made of PMMA. The dose is measured in the optimized conditions defined for the analytical technique. A total head-neck phantom was also used in order to consider the absorbed dose by each different tissues and organs as spinal cord or eyes. TL dosimeters were chosen for their small size, their sensitivity and the easy positioning on the surface of the phantom but also inside of it to evaluate dose to internal organs. Those LiF 100 dosimeters have been calibrated within the X-ray beam also used for the analysis of Iodine. The repeatability and reproducibility of the method has been evaluated. The influence of parameters as concentration of Iodine in the thyroid, distance between the X-ray generator and the neck, thickness of the tissues surrounding the thyroid, has been investigated in term of modifying parameters of the dose received by different tissues situated in the neck and the head.

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Influence detector on measures the parameters to determine the average glandular dose

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Key Words: Mammography, dosimetry, average glandular dose.

In Brazil, breast cancer is the second most common cancer in the female population, are estimated 57,960 newly diagnosed cases for 2016. Mammography is considered as the most suitable method to detect breast cancer early. The dosimetric quantity specific to mammography is the Average Glandular Dose (AGD). The value of AGD can be obtained by measuring the incident air kerma (Ki) by associating the conversion factors that depend on half value layer (HVL), the thickness and glandular breast composition. There are on the market different detectors enabling measurement of the parameters necessary to estimate AGD. The purpose of this study was to compare the responses of two solid state detector and an ionization chamber, as the measures of HVL and Ki to the average glandular dose calculation and the influence of these parameters measured at different voltages, breast phantom thicknesses and different beams. The measurements were made on a Siemens mammography, MAMMOMAT 3000 Nova model, using anode/filter combinations Mo/Mo, Mo/Rh and W/Rh. The detectors used were ionization chamber 10X6-6M Radcal Corporation and solid state detectors, AGMS-M Radcal Corporation and Xi Mammo the UNFORS. The largest difference was found in HVL 3% Mo/Mo. Ki and DGM the largest difference were 5% and 7%, respectively, both in combination Mo/Rh. In terms of radiation protection we can say that the three detectors can be used to estimate the AGD.

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Calculation of cancer risk for patient in proceeding involving C-Arm in kyphoplasty surgery using Monte Carlo Method

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Key Words: Kyphoplasty, Cancer risk, Monte Carlo, computational scenario, anthropomorphic simulator.

Kyphoplasty surgery is widely used for pain relief in patients with vertebral compression fracture (VCF). For this surgery, emitter x-ray equipment that provides real-time imaging is used in order to guide medical instruments and surgical cement used to fill and strengthen the vertebra. Equivalent and effective doses related to high temporal resolution equipment has been studied to assess the damage and more recently cancer risk. The cancer risk at low doses has very much statistical limitation and the concept most well accepted is that the risk has a linear behavior with the dose but without threshold. This is known as "linear-no-threshold" (LNT) model.

For cancer risk calculation, we developed exposure scenarios and implemented computational anthropomorphic phantom (UFHAM) in MCNPX (Monte Carlo N-Particles eXtend) code. Besides simulating the transport of radiation for several particles in a wide energy range, MCNPX code allows users to elaborate complex structures and shapes of exposure scenario, providing more realistic computer simulations. The exposure scenario of this work is described in the input file by objects that provide scattering radiation and can contribute to the increased risk associated with kyphoplasty surgery (e.g.: X-ray equipment, bed, mattress, monitors). For this surgery we used two radiographic projections, Antero Posterior (AP) and Latero Lateral (LL), and for each projection we simulate seven X-ray spectra from 60 to 120 kVp in steps of 10 kVp. In this work, the estimation of cancer risk probability is related to the Kerma Area Product (KAP) provided by C-Arm during the surgery. The results of this work show that it is possible to calculate the risk of cancer to kyphoplasty surgery.

Cancer risk for AP projection varied between 2.80×10^{-6}/Gy.cm² (60 kVp) and 5.66×10^{-2}/Gy.cm² (120 kVp). In LL projection, the risk of cancer varied between 1.85×10^{-6}/Gy.cm² and 4.53×10^{-6}/Gy.cm² for 60 and 120 kVp, respectively. This happened because in AP projection organs are more exposed compared to LL projection. In LL projection, the beam has to penetrate a thicker tissue layer to achieve more radiosensitive organs. Another important factor is the irradiation area in AP projection, which is larger than LL projection, thus more organs are affected. We also calculated cancer risks for each organ. The higher cancer risks are related to organs affected directly by beam and secondary particles produced by surrounding organs. In all organs, it was observed that the risk is directly proportional to the tube voltage (kVp). Finally, it was possible to calculate cancer risk values for each organ, allowing the estimation of developing cancer risk.

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A treatment planning and dosimetric comparison between intensity modulated radiotherapy and volumetric modulated arc therapy plans for lymph node positive breast cancer

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Key Words: lymph node positive breast cancer, IMRT, VMAT

The aim of this study was to compare the dosimetric differences and delivery efficiency between intensity-modulated radiotherapy (IMRT) and volumetric modulated arc therapy (VMAT) plans for lymph node positive breast cancer.

Five patients were selected with breast cancer (three left side and two right side). Each patient was positioned in the supine position for simulation and subsequent treatment. For all cases, the clinical target volume(CTV) was consisted of the breast , axillary and supraclavicular lymph nodes. The organs at risk(OAR) including lungs ,heart, and spinal cord were contoured on the CT image. All VMAT and IMRT plans were produced in pinnacle3 (V9.2). The prescription dose was 50Gy to the planning target volume (PTV) in 2Gy fractions. VMAT and IMRT were designed for each patient . The comparison of PTV coverage and the dose to the OAR, total monitor units (MU), and delivery time were presented. Particular attention was given to the low lung dose (V5Gy and V20Gy) which are considered as important clinical parameters in evaluating the treatment plan.

Both plans were met the clinical requirement. For breast cancer with LN positive , the VMAT showed superior dose coverage of PTV with slightly more low dose wash to heart and ipsilateral lung . For the VMAT, the standard deviation (SD) in percentage (%) was lower for the OARs and higher for the PTV with the exception of heart. The IMRT plans showed the lower value for the V5,V10 and mean dose and the higher value for V15,V20 in the ipsilateral lung. No statistically significant difference was observed in the contra-lateral lung and spinal cord between two plans. The average of the total MUs for VMAT plans were approximately 66% of those IMRT plans. VMAT plans could significantly reduced the delivery time compared to IMRT.

The VMAT achieved better PTV coverage and sparing of OARs, with fewer MUs and shorter delivery time than IMRT. The IMRT plans spare ipsilateral lung better, and lower mean dose in the contra-lateral lung. VMAT offered certain dosimetric advantage over the IMRT which is required regional node coverage at the cost of slightly higher doses to ipsilateral lung. But the other dosimetric parameters did not show better in VMAT compared with IMRT. The aim of the investigation was to identify the optimal technique for the treatment of the case of breast cancer with lymph node positive. The decision for VMAT or IMRT technique in the case of breast cancer, therefore depends on the individual patient anatomy and the location of the PTV.

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The dosimetric effects and calibration of computed tomography on radiotherapy

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Calibration curves of density versus computed tomography (CT) values were established using the Gammex 647 phantom which simulates soft tissues in this study. A linear relationship was found between the physical density (or relative electron density) and CT values, excluding lung materials. In order to quantify the dose perturbation resultant due to the effect of the contrast agent present within living tissues, various concentrations of potassium iodide (KI) solutions were used to simulate the contrast agent. The CT values derived were examined for their linear accelerator photon beam irradiation (LINAC) relationship. According to the Monte Carlo simulations, the dose perturbations were found in the regions of contrast-simulated KI solutions. These phenomena were found to be proportional to the concentrations of the KI solutions. KI solution (2.3 g/cm^3, 25 ˚C) resulted in a 22% higher dose at the interface entry of the KI solution and 15% lower dose at the exit. The effects of the calibration curve of electron-density to CT values on the dosimetry calculation of the treatment planning system (TPS) were similarly investigated in this study. Based on the comparisons of dose calculations of TPS and Monte Carlo simulation, the currently used calibration curves should be modified in order to calculate accurate dose in the case of tissues with contrast agents.

Key Words: Monte Carlo, electron density, CT values, dose perturbation, contrast agent

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Optimization of Dose and Image Quality for the Pediatric Computed Tomography Scan

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The use of Computed tomography (CT) examination has increased in recent years. Due to the higher radiosensitivity of children, the risk of cancer induction through CT scans performed on children requires comprehensive scrutiny. Explicit consideration of the relationship of CT image quality to applied dose is crucial in CT radiation protection. This relationship implies that the dose can be reduced only insofar as clinically significant details remain sufficiently visible to maintain diagnostic accuracy. The challenge remains to reduce the pediatric CT radiation dose without compromising image quality.

This study aims to integrate all possible factors (tube voltage, tube current and iterative reconstruction (IR) algorithm) to find the optimal conditions for pediatric CT scans. The 256-row multiple slice CT scanner has been used with two standard phantoms and one pediatric phantom to test for image quality and dosage. The optimal conditions are decided by figure of merit (FOM) based on CT image quality (CT numbers, noise, signal-to- noise ratio, high and low contrast resolution) and CT dose index ($CTDI_{vol}$) with and without IR. Dependent on the evaluations of dose and CT images, the optimal conditions for pediatric CT scans have been resolved. It was found that both the mAs and IR dominate the dose and CT image quality. The dose can be decreased a máximum of 30% with the proper IR setting while maintaining diagnostic accuracy in image quality.

Key Words: Computed Tomography, pediatric, dose, image quality, optimal conditions

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Using N-isopropylacrylamide Gel Dosimeters to Verify the Dose Distribution of Intensity Modulated Radiation Therapy

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Key Words：NIPAM, IMRT, CT, MatriXX

N-isopropylacrylamide (NIPAM) polymer gel dosimeters were employed to verify the dose distribution of clinical intensity modulated radiation therapy (IMRT) treatment planning systems (TPS). Gel preparation was primarily based on the formula proposed by Senden et al; and 5% NIPAM monomers, 5% gelatin, and 3% BIS were used. Finally, 5 mM of THPC was added to the solution to reduce oxygen content and enhance sensitivity and reproducibility. The gels were irradiated 0, 1, 2, 4, 5, 6, 8, and 10 Gy absorbed doses respectively by a Clinac iX linear accelerator using 6MV X-ray. After polymerization had completed, an X-ray computed tomography HiSpeed scanner was employed to extract the sliced images of the gel. In the present study, five irradiation field IMRT verification plans were created and the irradiation angles were 100°, 135°, 165°, 210°, and 250° respectively. To create these plans, we first extracted the complete treatment plans of brain tumor patients from the Eclipse™ treatment planning system. Cylindrical acrylic phantoms and MatriXX were then selected to simulate the patients. MATLAB was used to analyze the sliced images and the results of the gamma tests (γ-tests) were performed on the treatment plan and the NIPAM gel dosimeters. The results were then compared to those produced by the MatriXX. To verify the IMRT dose, γ-tests were performed according to the gamma criteria of 3% and 3 mm. Results indicated that the NIPAM gel achieved a 95.02% pass rate in the coronal section image and a 97.57% pass rate in the axial section image. The pass rate produced by MatriXX was 98.90%. The results confirmed the feasibility of using NIPAM polymer gel dosimeters to verify clinical radiotherapy doses.

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Estimation Of The Differences Between The Effective Dose And Hp(10) Exposed By Different External Photon Sources

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Key Words: OSLD; effective dose; personal dose equivalent; phantom

$H_p(10)$,personal dose equivalent,defined by the International Commission on Radiation Units and Measurements ,were commonly regarded as conservative surrogates of effective dose and equivalent dose of lens and skin.The study checked the valid of the assumption by experiments.E,effective dose was measured with RANDO phantom and TL system according to ICRP Recommendations.$H_p(d)$ were measured with two kinds of dosimetry badges,Harshaw TLD dosimeters and Landauer OSLD dosimeters.The conversion coefficients of E/Hp(d) and H_T/ Hp(d) were calculated which concerned irradiation by different photon energies (100keV to10 MeV)and irradiation geometries(AP,PA, RLAT, LLAT,ROT). The variance of conversion coefficients with five dosimeter positions in front of the torso which the radiation workers often wear on were discussed. The study also compared the conversion coefficients in this experiment with the published data which were simulated by Monte Carlo N-Particle code. The result showed that $H_p(10)$ underestimate the effective dose in some photon energies,especially low energies, some unfavorable geometries and the structure of the badge design would be one of the major reason.

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Radiation sensitization effect of GNP simulated with nanodosimetry Monte Carlo code - NASIC

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Key words: NASIC code, nanodosimetry, DNA damage, gold nanoparticle, radiation sensitization effect

It has been widely acknowledged that DNA damage in cell nucleus is the most important and primary damage of all the biological effects of radiation. However, the widely used Monte Carlo simulation tools can only simulate particle transportation in millimeter and micrometer scales. There are very few Monte Carlo codes simulating particles in nanometer scale. In order to study the total DNA damage and chromosome aberration, and even the cell death in nanometer scale, we developed a DNA atomic model and a nanodosimetry Monte Carlo simulation code (NASIC) of our own. NASIC consists of physical module, pre-chemical module, chemical module, geometric module and biological module, with inelastic cross section of electrons, protons and hydrogens calculated by ourselves. Using a step by step method, this code can simulate the physical track structure of particles and the generation of chemical species. Besides, an atomic nucleus model with 46 chromatins and 2 nucleoli was developed in the geometric module. Then the DNA strand break and base damage can be simulated, and a relationship between the DSB yield and cell death was established in the biological module.

With NASIC code, radiation sensitization effect of gold nanoparticles (GNPs) was studied. A simple cell with the atomic nucleus model was set up in the simulation under the irradiation of monoenergetic photons. GNPs with different diameters and distributions in the cell were applied. Both energy depositions and DSB yields in the nucleus were calculated, and the ratios of results under situations with GNPs compared to those without GNPs were defined as the enhancement factor. The influence of the photon energy, GNP diameter and distribution on the enhancement factor were also analysed. The results show GNPs distributing on the nucleus surface, the 40 keV photon energy and the diameter of 100 nm have advantage in the enhancement effect of DSB over other parameter values, which can provide a reference on radiotherapy making use of the radiosensitization effect of GNPs.

Further development of NASIC code (DNA damage repair module, cell death module, human genes in the DNA model, etc) is underway, and its application in other research areas such as relative biological effectiveness study is also being explored.

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Reference air kerma rate calibration system for high dose rate Ir-192 brachytherapy sources in Taiwan

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Key Words: Graphite-walled cavity ionization chamber, primary standard, brachytherapy

Ir-192 sources are popular used in brachytherapy and around seven thousand man-times uses the high dose rate (HDR) Ir-192 brachytherapy source per year in Taiwan. To establish the primary measurement stand of reference air kerma rate for the HDR Ir-192 brachytherapy sources in Taiwan, the Institute of Nuclear Energy Research (INER) fabricated a dual spherical graphite-walled cavity ionization chambers system to direct measure the reference air kerma rate (RAKR) of the Ir-192 brachytherapy source.

In this system, the ion-charge were accumulated by the two cavity ionization chamber and after correction for the ion recombination, temperature, atmosphere pressure, room scattering, graphite-wall attenuation, air attenuation, source decay, stem effect, and so on. The reference air kerma rate of the Ir-192 source was obtained in the ambient conditions of 22 °C and one atmosphere. The measurement uncertainty of the system is around 0.92% in 96% confidence level (k=2.0)

A PTB calibrated HDR Ir-192 source was also measured by the system. The ratio of the measurement results between INER and PTB, INER/PTB, was 0.998±0.027 (k=2) which shows good consistency and the performance of the system was verified.

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Using *N*-Isopropylacrylamide Gel Dosimetry to Measure the Penumbras of Photon

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Keywords: Polymer gel dosimeter, Radiation field, Physical penumbra

Polymer gel dosimetry is the only dosimetry tool capable of providing three-dimensional dose distributions. In this study, *N*-isopropylacrylamide (NIPAM) gel dosimetry was used for measuring the penumbras of small-field photon beams. Irradiation was performed using field size selections of 2×2 cm^2, 3×3 cm^2, 4×4cm^2, and 5×5 cm^2. A computed tomography scanner was used to extracted images. The physical penumbras of relative doses between 20% and 80% were calculated. The measurement results were compared with those of EBT3 film. The EBT3 film measurement results for the two-sided physical penumbras with field sizes of 2×2 cm^2, 3×3 cm^2, 4×4 cm^2, and 5×5 cm^2 were 3.56 mm and 3.67 mm, 3.67 mm and 3.70 mm, 3.72 mm and 3.72 mm, and 3.74 mm and 3.76, respectively. The NIPAM gel dosimeter measurement results for the two-sided physical penumbras with field sizes of 2×2 cm^2, 3×3 cm^2, 4×4 cm^2, and 5×5 cm^2 were 4.24 mm and 4.00 mm, 4.12 mm and 4.19 mm, 4.24 mm and 4.28 mm, and 5.48 mm and 5.11 mm, respectively. When different radiation field sizes were measured using NIPAM gel dosimetry and EBT3 film, the average error between the two was approximately 3%.The measurement results of NIPAM polymer gel dosimetry were consistent with the results of the film. However, in contrast to film, polymer gel dosimetry can obtain information on all beam characteristics by performing only one irradiation. It is more convenient than using films. This increases the feasibility of applying NIPAM polymer gel dosimetry to clinical dose verification.

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Measurement Uncertainties Associated with In Vivo Monitoring of Inhaled ^{137}Cs

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Key Words: Internal dosimetry, whole body monitor, BOMAB phantom.

The Dstl *in vivo* monitoring facility primarily exists to monitor for intakes of radioactive material in the event of a nuclear or radiological incident. Three types of monitoring can be carried out: 1) Whole body monitoring is performed using four large-volume sodium iodide (NaI) detectors, positioned at equal distance on the underside of a counting bed; 2) Lung monitoring is performed with two high-purity germanium (HPGe) coaxial detectors that are positioned over the thorax region of the subject lying supine on the counting bed; and 3) Thyroid monitoring is performed with one HPGe detector positioned directly above the mid-point of the patient's neck.

The facility is surrounded by six inches of pre-nuclear steel (originating from HMS Vanguard, a British fast battleship built during World War II) to reduce the effects of natural background radiation including cosmic rays and terrestrial radiation. The steel is itself covered by 3 mm of lead to reduce the bremsstrahlung radiation component.

This work aimed to characterise the uncertainties in measured intake activity when undertaking whole body monitoring of a patient who has inhaled ^{137}Cs. A combination of literature review and experimental measurements with BOttle Mannikin ABsorber (BOMAB) phantoms was used to assess contributions to uncertainty from the following:

- **Background count rate:** *Repeated background measurements.*
- **Detector calibration:** *Repeated calibrations with a phantom of known activity.*
- **Patient position:** *Repeated measurements with the phantom in different* positions.
- **Patient size:** *A literature review, as well as measurements taken using phantoms of different sizes.*
- **Counting statistics:** *Statistical assessment.*
- **Radionuclide distribution in the body:** *A literature review combined with measurements of different BOMAB pieces.*

These individual uncertainties were then combined statistically to obtain the total uncertainty. The main contributions to the overall uncertainty were patient position, patient size and distribution of radionuclide in the body. Further work is now planned to quantify the uncertainties associated with lung and thyroid monitoring.

Characterization of an Extrapolation Chamber for Dosimetry of Low Energy X-Ray Beams

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Key Words: extrapolation chamber, low energy x-rays

Extrapolation chamber was designed to be used for beta radiation and low energy x-ray dosimetry because its small changeable volume complies with the Bragg-Gray cavity principle; besides, when fully characterized it may be used as primary standard dosimeter for absorbed dose in a medium or air kerma measurements.
The International Organization for Standardization, ISO, established series of reference x-radiation for calibrating and determining the energy dependence of dosimeters that are reproduced in metrology laboratories.
The low energy x-ray beams with tube potential below 30 kV are, in most cases, critical as far the determination of their parameters for characterization purpose; additionally, the instrument to be used for dosimetry is requested to have specific properties as far its response to quantities that may influence the measurand.
In this work, the metrological reliability of a 23392 model PTW extrapolation chamber was studied aiming its use for quality assurance measurements in low energy x-ray beams as a reference instrument.
The optimum polarization voltage to be applied to the chamber was determined as 30 $V.mm^{-1}$ based on saturation curves and the true null depth showed different values from 0.015 to 0.218 mm when it was estimated through extrapolation of straight lines of the ionization current from 1.0 to 5.0 mm depths. Results of measurements showed the maximum leakage current of 8.0 fA, repeatibilility of five measurements lower than 0.46% and reproducibility of the ionization current of 0.58% in 300 days, both given by the standard deviation.
The calibration of the extrapolation chamber in N10, N20, N30, H10, H20 and H30 ISO reference radiations against a 2575 model NE ionization chamber traceable to PTB/Germany laboratory showed its low energy dependence of ±4,0% in the mean energy range from 8 to 24 keV.
All measurements helped to assess the values of the main sources of uncertainties of the calibration coefficient of the extrapolation chamber that resulted in an expanded uncertainty (k=2) lower than 2.5%.

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(WITHDRAWN) P39

Radiation Dose Evaluation in Body Scan Inspection System "NUCTECH™ HT2000GA" using Optically Stimulated Luminescent Dosimeter

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Key Words: Body scan inspection system, OSLD, radiation dose evaluation

This paper aims to present a methodology for evaluation radiation doses using Optically Stimulated Luminescent Dosimeter (OSLD) when persons are subjected to inspection in the Body Scan Inspection System NUCTECH™ HT2000GA.
The Body Scan System is the type of transmission and consists basically of three components: the X-ray equipment (160 kV, 0.5 mA), the type scanner to scan body; the radiation detector coupled to the side opposite the X-ray equipment; and a conveyor for moving the person (inspection time of 8 sec). The device can operate in three different modes: High mode (160 kV and 0.9 mA); Normal mode (150 kV and 0.5 mA) and Low mode (100 kV and 0.4 mA).
The Optically Stimulated Luminescent Dosimeter (OSLD) used contains the four (04) Aluminum Oxide (Al2O3) dosimeters sensitive to light with four openings: one with no filter and the other with plastic filters, aluminum (Al) and copper (Cu) respectively. The OSLD system is approved by the Brazilian Regulatory Authority to individual monitoring uses.
The arrangement used in dosimetry was made up of a corkboard with 18 dosimeters OSL setting the dimensions of the human body from head to mid-thigh, ranging from 1.60 m to 1.90 m in height.
The dosimetry arrangement was positioned in the wake of Body Inspection System exactly in position for the person, that is, 39 cm distance between the frame and the equipment of x-rays. The arrangement was subjected to inspection in the three modes of operation for 8 seconds and in each mode were used 18 dosimeters distributed in the frame. For Low mode operation, 500 inspections was performed totalling 4000 seconds of exposure; for Normal mode operation, 230 inspections was performed totalling 1840 seconds of exposure; and for High mode operations, 225 inspections was performed totalling 1800 seconds of exposure.
The radiation doses for one inspection in the three modes of operation were: 0.22 µSv to Low mode; 0.44 µSv to the Normal mode and 0.65 µSv for High mode.
The results show that the radiation doses received by a person in the Body Scan Inspection System NUCTECH™ HT2000GA for one inspection are very low, requiring 4,545 or 2,272 or 1,538 inspections per year for Low, Normal and High modes, respectively, to reach the annual effective dose limit of 1 mSv in a year for public exposure.

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DSC Studies on Gamma Irradiated Poly(vinylidene fluoride) Applied to High Dose Dosimetry

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Key Words: High dose dosimetry, PVDF, gamma irradiation, DSC

Poly(vinylidene fluoride) (PVDF) was investigated for use on gamma high dose dosimetry. Samples were irradiated with gamma doses between 0.1 to 2.75 MGy. Differencial scanning calorimetry (DSC) was used to construct an unambiguous relationship with delivered dose. Measurements were taken immediately after the irradiation process and months after in order to fading analyses. For evaluation the dependence of dose rate, samples were irradiated at two constant dose rate (2.592 kGy/h and 12.0 kGy/h). FTIR spectroscopy was used in order to study the interaction between PVDF samples with atmosphere in the irradiator room, immediately after the irradiation and two months after. Both the very large range of dose measurement (0.1 to 2.75 MGy), stability after irradiation and also the possibility of evaluating high gamma doses until months after irradiation make PVDF very good candidates to be investigated as commercial high gamma dose dosimeters.

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Gamma Beam-127 irradiation dose mapping simulation using the MCNP code for dosimetry systems control

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Key Words: Monte Carlo, MCNP code, dosimetry systems,

The aim of this study was to establish the distribution of the dosimetric quantity within the irradiation room and evaluate comparatively others systems of dosimetry control. A numerical model was developed, including details of the source, to validate the dosimetric quantity at various points of the beam from the source of a Co-60 GammaBeam-127 irradiator. A Monte Carlo model for the irradiator source in a particular material medium and geometry was developed and validated. Until then the only alternative to determine the radiation field from the irradiator source was using experimental measurements. The results present good agreement with the experiments, and may become an alternative to experimental dosimetric measurements to be used in the others irradiators.

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Dosimetry-based Treatment Planning for Metastatic Prostate Cancer Treated with Radiopharmaceuticals

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Key Words: Monte Carlo, molecular radiotherapy, dosimetry, bone metastases

Bone metastases from castration-resistant prostate cancer (CRPC) are often treated with bone-seeking radiopharmaceuticals. Dosimetry is not currently used to guide the level of administered activity. Therefore the development of dosimetry-based treatment planning, as routinely employed in external beam radiotherapy, is of increasing importance for personalised treatment in nuclear medicine. The aim of this study was to demonstrate the feasibility of patient-specific bone lesion dosimetry and the potential for treatment planning using in-house software based on Monte Carlo convolution image-based dosimetry.

Imaging data from patients treated with 5 GBq of ^{186}Re-HEDP as part of a phase II clinical trial were used. SPECT imaging was performed at 1, 4, 24, 48 and 72 hours following administration. Images were quantified using a series of cylindrical phantoms with a volume range of 0.8 to 196 ml to account for partial volume effects. Three-dimensional dosimetry was performed using Qrius™, an in-house application developed in C# and C++ using the .Net framework and the open source library VTK. Dose distributions were obtained from the convolution of a voxelised cumulated activity distribution, obtained from the co-registered sequential SPECT scans, and pre-calculated S-value dose kernel. Dose kernels were generated using a separate application developed using the general purpose Monte Carlo code EGSnrc/EGS++, for 4.67 mm voxels in a soft-tissue medium for ^{32}P, ^{89}Sr, ^{153}Sm, ^{186}Re and ^{188}Re. Simulations were carried out with 10^7 histories to maintain the statistical uncertainty below 1% and the decay spectra was obtained from the RADTABS software. Lesion mean absorbed dose were predicted for a range of typical bone treatments schemes and compared to those delivered by 5 GBq of ^{186}Re-HEDP assuming the same uptake distribution and biological half-life as ^{186}Re-HEDP.These included: 250 MBq of ^{32}P, 150 MBq of ^{89}Sr, 3.07 GBq ^{153}Sm-EDTMP (37 MBq/kg) and 5 GBq of ^{188}Re-HEDP.

The results showed that on average, the lesion mean absorbed doses predicted for ^{89}Sr, ^{32}P, ^{188}Re-HEDP and ^{153}Sm-EDTMP were 28%, 61%, 65% and 80% lower respectively, than those delivered by ^{186}Re-HEDP.

This study shows the feasibility of bone lesion dosimetry calculations and demonstrates the prospects for personalised treatment planning in patients with CRPC metastatic to bone. Prediction of the absorbed doses for any radiopharmaceutical can be made within minutes and the optimal activity that could be administered to a patient could be easily calculated according to any absorbed dose limits to organs at risk.

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X-ray spectra optimization in Cone Beam CT lung imaging: a Monte Carlo study

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Key Words: Monte Carlo simulations, lung Computed Tomography, dose reduction methods, screening

X-ray computed tomography is nowadays largely used worldwide for several diagnostic imaging examinations/procedures. Concerning the effective dose to the patient and the equivalent doses to her/his organs, a great technological effort was performed in the last years in order to attain the As Low As Reasonably Achievable (ALARA) principle and at the same time keeping a good image quality. One of these methods consists in the optimization of the spectrum to be used for each specific imaging task encountered.
In the perspective to introduce the screening of the lung in risk-based population, the aim of this study was to analyze the energies at which it is possible to minimize the dose delivered to the patient taking into account the lung imaging for detection of tumors and calcifications through the Cone Beam Computed Tomography (CBCT) technique. For this reason the state of the art computer program MCNPX, together with an anthropomorphic voxel phantom (ICRP series) was used in order to generate 2D image projections and perform dose assessments. The simulated lesions (cylindrical and spherical calcification and tumor lesions of 4, 7 and 10 mm thick) were inserted inside the lung of the voxel phantom, and different images were generated both with monochromatic energies and voltage spectra. The Contrast-to-Noise ratio (CNR) weighted with the dose, was the parameter chosen for optimization.
Our results were compared with the voltages and mean energies currently used for chest CT. The optimal energies that maximize the CNR parameter for calcification visualization are in average lower than the mean energies used nowadays in clinical CT systems, whereas for tumor detection the optimal energies are more in agreement with the mean energies used in chest CT. Finally our results clearly show that for each detection task (lesion type and thickness) there is an optimal energy that could be used in order to reduce the dose delivered to the patient.

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Influence of X-ray scatter radiation on image quality in Digital Breast Tomosynthesis (DBT)

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Key Words: Monte Carlo simulations, digital breast tomosynthesis, scatter radiation, mean glandular dose

Digital breast tomosynthesis (DBT) is a quasi-three-dimensional imaging technique that was developed to solve the principal limitation of mammography, namely the overlapping tissue effect. This issue in standard mammography (SM) leads to two main problems: low sensitivity (difficulty to detect lesions) and low specificity (non-negligible percentage of false positives).
Although DBT is now being introduced in clinical practice the features of this technique have not yet been fully and accurately assessed. Consequently, optimization studies in terms of choosing the most suitable parameters which maximize image quality according to the known limits of breast dosimetry are currently performing. In DBT scatter radiation can lead to a loss of contrast and to an increase of image noise by reducing the signal-to-difference-noise ratio (SDNR) of a lesion. Moreover in DBT the use of an anti-scatter grid is a concern due to the low exposure of the photon flux available per projection. For this reason the main aim of this study was to analyze the influence of the scatter radiation on image quality and the dose delivered to the breast. In particular a detailed analysis of the scatter radiation on the optimal energy that maximizes the SDNR was performed for different monochromatic energies and voltages. To reach this objective the PenEasy Monte Carlo (MC) simulation tool imbedded in the general-purpose main program for PENELOPE, was used. After a successful validation of the MC model with measurements, 2D projection images (separated images of primary and coherent and incoherent photons were obtained) were generated using an homogeneous breast phantom (2, 4, 6, 8 cm) with three glandular percentages (25%, 50%, and 75%) including tumor and micro calcification lesions with different thicknesses and for each monochromatic and polychromatic x-ray energy in the range from 16 keV to 32 keV. For each angular projection considered (25 angular projections covering an arc of 50 degree) the scatter-to-primary (S/P) ratio, the mean glandular dose (MGD) and the SDNR were calculated with the aim to assess/determine the conditions (i.e. energy, angular projection, breast thickness) where the influence of the scatter radiation could significantly affect the image quality. The obtained results on the aforementioned quantities and topics will be reported.

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Dosimetry assessment of DNA damage by Auger-emitting radionuclides: experimental and Monte Carlo studies

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Key Words: Monte Carlo simulations, DNA damage, nanodosimetry, auger electrons, targeted radiotherapy

In recent years scientists moved towards a deep investigation of the potential use and efficacy of Auger-electron emitters in targeted radiotherapy. Among the Auger-emitting radionuclides, ^{125}I is of particular interest, as it emits about 20 electrons per decay. ^{99m}Tc only emits 4 electrons per decay, but presents some attractive characteristics, i.e. short half-life, availability and ideal imaging properties for therapy monitoring. Auger electrons travel a short distance within human tissues (at nano-scale level) and, therefore, if an Auger-emitting radionuclide is transported to the cell nucleus it will cause enhanced DNA damage.

In order to study the dosimetric behavior of these two radionuclides (^{125}I and ^{99m}Tc) at nano-scale sizes and given the DNA-intercalation properties of Acridine Orange (AO), We have designed ^{99m}Tc(I)-tricarbonyl complexes and ^{125}I-heteroaromatic compounds that contain AO derivatives, in order to promote a closer proximity between the radionuclides and DNA. .

In order to have an insight on the relevance of these radiolabelled compounds for DNA-targeted Auger therapy, different aspects were investigated: i) ability to cause DNA chain breaks; ii) influence of the two different radionuclides in DNA damage; iii) effect of the distance between the AO intercalating unit and the radioactive atom (^{99m}Tc or ^{125}I). To address these issues several studies were carried out: i) evaluation of plasmid DNA damage; ii) molecular docking and iii) nanodosimetric Monte Carlo modeling and calculations.
Results show that the two classes of compounds are able to induce DNA double strand breaks (dsb), but the extent of DNA damage (e.g. dsb yield)is strongly dependent on the linker used to attach the Auger emitting radionuclide (^{125}I or ^{99m}Tc) to the AO moiety. In addition, nanodosimetric calculations (i.e. electron flux, absorbed dose) confirm a strong gradient of the absorbed dose with the DNA-radionuclide distance for the two radionuclides studied. Finally these results show the existence of a critical distance beyond which, probably, the direct effects start to be ineffective in DNA damage induction.

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Evaluation of thermoluminescence response of photonic crystal silica-fibres subjected to photon radiation

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Key words: thermoluminescence response photonic crystal fibres, PCF-collapsed, minimum detectable dose.

The study has been made of evaluation of the thermoluminescence (TL) response of photonic crystal fibres (referred to herein as PCF and PCF-collapsed), to photon (6 MV) irradiation. The photon irradiation was delivered through use of a Varian Model 2100C linear accelerator located at the University of Malaya Medical Centre. The performance parameters include dose response linearity and sensitivity, minimum detectable dose(MDD) and saturation dose. The TL dose response of PCF-collapsed with Ge concentration was found to be 3 times better than conventional cylindrical and flat optical Ge-doped fiber detectors and demonstrated capability for detecting a minimum dose of as low as 25 mGy, comparable to that of TLD-100. The PCF-collapsed fibres offer uniform response, high spatial resolution and sensitivity, providing the basis of promising TL systems for radiotherapy applications.

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CALIBRATION WHOLE BODY COUNTER (WBC) OF THE LDI/CDTN USING TWO PHYSICAL PHANTOMS

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Key Words: Phantom, PET-BOMAB, WBC, Efficiency, Detector System

The Internal Dosimetry Laboratory of the Center for Development of Nuclear Technology (LDI/CDTN) is responsible for the routine monitoring of workers occupationally exposed at the Unit for Research and Production of Radiopharmaceuticals (UPPR/CDTN) and at the Research Reactor TRIGA-IPR-R1/CDTN. The LDI can also be useful whenever there is a potential risk of intakes in emergency situations. The determination of photon emitting radionuclides in the human body requires the calibration of the detection systems in a variety of counting geometries. This paper aims to present the calibration technique applied at the LDI to determine the Counting Efficiency (CE) using a BOMAB anthropomorphic physical phantom as well as an alternative home-made phantom built with PET bottles. In the first step the BOMAB phantom was filled with a solution of potassium chloride (KCl). Six sets of eight consecutive 30 minutes counts were performed, starting at 10 cm from the top of the phantom head and moving the bed 20 cm horizontally between each count. Position 4 was chosen as the standard geometry since it was the point that presented the highest efficiency. In the second phase the BOMAB phantom was filled with a standard cocktail solution containing ^{133}Ba, ^{137}Cs and ^{60}Co in order to determine a curve of counting efficiency covering a broader energy range of interest. A series of six 30 minutes counts were performed with the detector positioned above the pelvic session of the BOMAB at the previously established position number 4. In the third phase a whole-body phantom was assembled using PET bottles for two different geometries, one with 1.81 m and 58 kg and another with 1.81 m and 48 kg. The CE were calculated and the results were compared for the three different phantoms.

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SIMULATION OF INTERNAL CONTAMINATION SCREENING WITH DOSE RATE METERS

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Key Words: Monte Carlo, VMC, Dose Rate Meters, Internal dosimetry

Quikly assessing the intake of radionuclides after an accident in a nuclear power plant or after the intentional release of radionuclides in public places allows dose calculations and triage actions to be carried out for members of the public and for emergency response teams. High energy gamma emitters in the lung, thyroid or the whole body may be detected and quantified by making dose rate measurements at the surface of the internally contaminated person. In an accident scenario, quick measurements made with readily available portable equipment are a key factor for success. In this paper, the Monte Carlo program Visual Monte Carlo (VMC) and MCNPX were used in conjunction with ICRP and MaMP voxel phantom to calculate the dose rate at the surface of a contaminated person due to internally deposited radionuclides. A whole body contamination with ^{137}Cs and a thyroid contamination with ^{131}I were simulated and the calibration factors in μSv/h per kBq were calculated. The calculated calibration factors were compared with real data obtained from the Goiania accident in the case of ^{137}Cs and the Chernobyl accident in terms of ^{131}I. The successful comparison of the calculated and real measurements indicate that the method may be applied to other radionuclides. Minimum detectable activities are discussed.

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Simulation of Both Percentage Depth Dose and Tissue Phantom Ratio in Water Phantom for 6 MV Linac Photon Beam using Different MC Codes

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Key Words: Monte Carlo, Linac Photon Beam, PDD, TPR, Accelerator

At the present time, the Monte Carlo simulations are widely accepted as a reliable tool in medical radiation physics and regarded as the most accurate technique for dosimetric calculations. The Monte Carlo Modelling Expert Group - MCMEG is acting as a network in the field of Dosimetry in general. The purpose of this task was to simulate the 6 MV Linac photon beam using MCNPx, EGSnrc and Penelope Monte Carlo codes and compare with a experimental measurement carried out in a hospital in Brazil. The experimental measurement was performed using an ionization chamber with calibration traceable to a Secondary Standard Dosimetry Laboratory (SSDL) immersed in a water phantom at different depths and one radiation field size 10x10 for means of validation. The validation process is the comparison between the MC calculation results to the measured PDD 20,10 and TPR 20,10. This process establishes the truth in terms of standard deviations of how reliable is the computational model to be used as input for different types of calculations in which they are not possible to perform through a experimental process. Simulations were tuned by reproducing the experimental TPR 20,10 quality index, providing a satisfactory description of both the PDD curve and the transverse profiles at the two depths measured. This paper reports in details the modelling process using MCNPx, EGSnrc and Penelope Monte Carlo codes, the source and tally descriptions, the validation processes and the results.

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Skin dose for head and neck cancer patients treated with intensity-modulated radiation therapy (IMRT)

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Key Words: skin dose, ultrathin thermoluminescent dosimeter, Gafchromic film

This research focused on the reliability of thermoluminescent dosimeters (ultrathin TLD) and ISP Gafchromic EBT film to measure the surface dose in phantom and the skin dose in head-and-neck patients treated with intensity-modulated radiation therapy technique(IMRT). Seven-field treatment plans with prescribed dose of 180cGy were performed on Eclipse treatment planning system (version8.1) which utilized pencil beam calculation algorithm(PBC). In calibration test, the variance coefficient of the ultrathin TLDs is within 3%. The points on the calibration curve of the Gafchromic film are within 1% variation. Five measurements were taken on phantom using ultrathin TLD and EBT film respectively. The measured mean surface doses between ultrathin TLD or EBT film are within 5% deviation. Skin doses of 6 patients were measured for initial 5 fractions and the mean dose per-fraction was calculated. If the extrapolated doses for 30 fractions were below 4000cGy, the skin reaction grading observed according to Radiation Therapy Oncology Group (RTOG) was either grade 1 or grade 2. If surface dose exceeded 4500cGy in 31 fractions, then grade 3 to 4 skin reaction was observed. In future study, more patients should be enrolled and establish the relationship between skin doses and skin reactions more precisely.

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Monte Carlo simulation of a TEPC for microdosimetry of carbon ions

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Key Words: Monte Carlo, microdosimetry, RBE, carbon ions

The increase in the number of therapeutic proton and ion beam centres worldwide has prompted renewed interest in measuring and simulating microdosimetric spectra in order to help understand the complexity underlying the Relative Biological Effectiveness (RBE) of these treatment modalities. In this context we have studied the capability of the Geant4 toolkit to simulate microdosimetric spectra measured with a Tissue Equivalent Proportional Counter (TEPC) in a clinical carbon ion beam.

The simulated spectra were compared with published experimental data obtained along the depth dose curve of a 194 MeV/u carbon beam at the GSI, Darmstadt (Gerlach *et al.*, 2002). The initial beam energy and energy spread employed in the simulation were tuned to match the calculated and measured depth dose distributions. A good agreement was found at most depths after a small shift of 4.025 mm was taken into account with agreement for the microdosimetric derived RBE values to within 0.4% and 11.9% for depths 40 and 66 mm in PMMA (Perspex).

This work demonstrates how the Geant4 toolkit can be used to reproduce experimental microdosimetric data and how this in turn can be used to determine RBE estimates using the equation of Pihet *et al.* (1990). The work highlights the difficulty in using experimental work to benchmark Monte Carlo simulations and the need for detailed descriptions of experimental setups used.

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Pihet P, Menzel H G, Schmidt R, Beauduin M and Wambersie A 1990 Biological weighting function for RBE specification of neutron therapy beams. Intercomparison of 9 european centres *Radiat Prot Dosim* **31** 437-42

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Thermoluminescence dosimeters in radiation fields for neutron capture therapy

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Key Words: TLD, thermal neutrons, BNCT

A method has been developed for evaluating, by means of thermoluminescence detectors (TLDs), both γ-dose and thermal neutron fluence in thermal or epithermal neutron fields with very high fluence rates, as dose typical of nuclear reactor beams designed for boron neutron capture therapy (BNCT). The more convenient choice has resulted to be that of phosphors containing lithium fluoride (LiF).
The proposed method is based on the study of the shape of the glow curve (GC) of a LiF:Mg,Ti phosphor after exposure to a radiation field of only photons, only neutrons or mixed neutrons-photons. The situation is very different from that which occurs in personal or environmental dosimetry, where the neutron component is always very low. In fact, for the high fluence rates of the reactor neutron beams, the response of TLD-700 dosimeters contains a substantial contribution from thermal neutrons, due to the presence of a small amount of the isotope ^{6}Li.
The method exploits the heights of the first and second dosimetric peaks in the measured GC after irradiation at a reactor epithermal or thermal column, correlating such values to the heights of these two peaks after only photon or only thermal neutron irradiation. The method was initially studied regarding dosimeters TLDs-700, containing a small percentage of ^{6}Li (Gambarini 2014). Now the study has been expanded, including the TLDs-100, which contain lithium in its natural composition (7.5% of ^{6}Li). Depending on the relative contributions of photon and neutron components, a different reliability of TLD-100 or TLD-700 has been estimated. The results in various beam configurations have been intercompared in order to better understand the profitable utilization of these detectors in high thermal or epithermal neutron fluence rates (about 10^{8} $cm^{-2}s^{-1}$ or more). The obtained values have been compared with those obtained with gel dosimeters. Irradiations were carried out at the BNCT epithermal neutron column of the LVR-15 research reactor, in Řež.
The good consistency of results has confirmed the validity of the proposed method.

Gambarini G, Magni D, Regazzoni V, Borroni M, Carrara M, Pignoli E, Burian J, Marek M, Klupak V,Viererbl L 2014, '*Measurements of gamma dose and thermal neutron fluence in phantoms exposed to a BNCT epithermal beam with TLD-700*'. Radiation Protection Dosimetry vol. 161 pp. 422-427

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Radiation dose optimization in computed tomography

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Key Words: optimization ,mAs modulation , iterative reconstruction , filtered back projection ,image quality

The study was aimed at evaluating the value of current modulation (mAs) and iterative reconstructions algorithms during in Computed Tomography examinations in terms of dose reduction and image quality. The focus was mainly on non-contrast head and chest-abdomen-pelvis examinations. A total of 40 adult patients with weights between 65 and 80 kg underwent CT examinations (20 head and 20 chest-abdomen-pelvis). All examinations were performed on a 128-slice scanner (Somatom Definition AS from Siemens, Forchheim, Germany) using CARE Dose 4D technology. Images were reconstructed using two methods, Sinogram Affirmed Iterative Reconstruction (SAFIRE) and Filtered Back Projection (FBP). The radiation dose values were compared with standard protocol delivered with the system. Image quality was evaluated both objectively and subjectively using Students' test. The results on the present study showed that through the combination of CARE Dose 4D and SAFIRE; the radiation dose could be reduced by 20.10% and 59 % for the examination of head and chest-abdomen-pelvis respectively. There was a substantial difference in the image quality when using FBP or SAFIRE ($p < 0.05$). The noise level dropped significantly during SAFIRE when compared to FBP by 14.25% for head and by 27.60% and for chest-abdomen-pelvis scans. We conclude that automatic exposure control mechanism based on tube current modulation CARE Dose 4D when combined with iterative reconstruction SAFIRE delivers good image quality with low dose for non-enhanced head and chest-abdomen-pelvis scans.

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Estimation of Effective dose and Radiation risk in Paediatric Renal Scintigraphy

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Renal scintigraphy, which is non invasive procedure, provides essential information that for the diagnosis, treatment for renal disorders due to its high sensitivity. However, renal scintigraphy involves the administration of small amounts of radiopharmaceuticals which exposes the patient to carry a risk to patients. Pediatric are more sensitive to radiation than adults due to their rapidly dividing cells and longer life expectation. Therefore, children are of special concern in radiation protection because they are more vulnerable to radiation injury. Exposure to radiation for different tissues and organs results in diverse cancer/tissue reaction possibilities of cancer effect and diverse severity of radiation effect. Therefore, patient doses during medical exposure are essential step in radiation dose optimisation. The aims of this study are to measure effective doses for pediatric patients undergoing renal scintigraphy procedure using technetium-99^{m}-diethylene-triamine-pentaacetic acid. A total of 88 pediatric patients (36 females and 52 males) were investigated using Orbiter 37 Gamma camera single head. Patients effective dose were estimated using the administered activity. The mean and range of the administered activity is 80.4 (37.0-111.0) MBq per procedure. The mean patient age (years) and weight (kg) were 4.1 (0.1-14.0) and19.1 (4.1-45.0), respectively. The mean and age of effective dose (mSv) per renal scan procedure was 0.39 (0.18-0.54). The radiation risk per procedure is $5x10^{-6}$ per procedure. Patient doses depend on the size of patient, the type of scanner and the imaging protocol used. Effective doses considered low compared with previous studies. The administered activity (4.2 MBq/kg) is higher than recommended (1.9 MBq/kg) and hence the radiation dose is higher compared to previous studies. Although, the patient risk is low, optimisation of patient's doses is required to improve the diagnostic findings using the lowest possible administered activities without significant increase in patient's doses. Adoption of Diagnostic reference level (DRL) based on international guidelines is recommended for patient dose optimisation.

Examination on penetration path and deposition distribution of radionuclides in house

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Key Words: Sheltering, Dose reduction factor, Penetration, Deposition distribution

Sheltering, which refers to staying house, is one of countermeasures to protect the public from external and internal exposure at nuclear accidents. The dose reduction factor of sheltering is often defined by the ratio of dose incurred indoor to outdoor environment. Indoor deposition distribution is necessary to evaluate accurately indoor external dose. The amount of radionuclides which penetrated actually into a house is essential to evaluate indoor internal dose. However these information is unknown. In addition, although the penetration amount can depend on gaps, such as windows, ventilation fans, and doors, main penetration path of radionuclides from outdoor into indoor house is unclear. In this study, therefore, dose rates on indoor floors and ceilings and around gaps were measured to examine main penetration path and indoor deposition distribution of radionuclides.

Dose rates were measured with a NaI scintillation survey meter at the following three places in eight houses located in difficult-to-return zone in Fukushima prefecture in October and November, 2015: Dose 1 was measured at a height of 1 m from ground level at the four corners outside a house; Dose 2 was measured at a height of 1 m from floor level in the centre of a room; Dose 3 was measured at a height of 5 cm from surface of floor, wall, and ceiling. In this abstract, the results of Dose 1 and 2 are abbreviated because of space limitations. Windows, doors, ventilation fans, sockets, and air conditioners were defined as visible gaps in this study. Dose 3 were measured on surfaces about 10 cm and more than 50 cm from the visible gaps to examine the deposition distribution around the gaps and main penetration path. In addition, Dose 3 were measured on surfaces of a bookshelf filled by books and near it to examine the surface area dependence of deposition amount.

There was no significant difference in dose rates among on same walls without the visible gaps. On the other hand, dose rates around windows and ventilation fans were about 25% higher than that on the surfaces distant from the gaps. Dose rates around sockets and air conditioners were same as that on the surfaces distant from the gaps. These results mean that radionuclides can penetrate mainly through windows and ventilation fans, but hardly through sockets and air conditioners. There was no significant difference in dose rates between on surface of a bookshelf and near it. This result implies that an aspect which is large surface area as bookshelves in the microscopic sense can be regarded as one flat surface in the macroscopic sense.

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Research on the Dose Characteristic Analysis Using EPR method for Gamma-ray Irradiated Spices

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Key Words: Electron paramagnetic resonance, gamma-ray sterilization, high dose irradiation

The spice is common required in modern life. The method of gamma-ray irradiation sterilization for spices has used in Taiwan. People is rising awareness of food safety including ionizing radiating irradiated food. Using high doses of ionizing radiation could effectively achieve sterilization of spices, antiseptic, and eliminate the growth of germs. Compared to other sterilization methods, the radiation sterilization would easy, fast, relatively non-perishable and non-chemical residue. Although regulation regarding irradiation radiation types, dose limited and types of irradiation permitted food has been established, but identification, analysis of relevant been irradiated food is not built yet in Taiwan.

In this study, 11 kinds of spice samples were selected and investigated. The individual samples of post-irradiation of different radiation doses irradiated by Co-60 gamma-ray were tested. The dose analysis of the spice samples were performed by an EPR (Electron paramagnetic resonance) spectroscopy.

The EPR signal curve is proportional to the number of unpaired electron concentration induced by ionizing radiation. The spice produced free radicals after radiation exposure, these free radical prompt the EPR signal. Time decay characteristic according to different spices characteristic was investigated. This study established the determined levels for that whether the spice performed radiation sterilization, as well as analysis of EPR signal decay characteristic regarding individual spice.

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Dose Estimation of Eye Lens for Interventional Procedures in Diagnosis

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Key Words: eye lens dose, interventional radiology, occupational exposure

The International Commission on Radiological Protection (ICRP) recommended the equivalent dose limit for the lens of the eye from 150 mSv/y (ICRP, 2007) to 20 mSv/y averaged over five years (ICRP, 2011). How to accurately measure the eye lens dose is therefore concerned recently. In the most of cases, interventional radiologists are at higher risk of radiation-induced eye injury, such as cataract, than all the other occupational radiation workers. The main objective of this study is to investigate the relationship between the doses to the eye lens of interventional radiologist measured by different commercial eye-lens-dosimeters.

This study measured a reference dose of eye lens which is placing thermoluminescent dosimeters (TLDs) chips at 3 mm depth from the surface of eye of the Rando Phantom. Commercial eye lens dosimeters, such as Headband Dosimeter and standard personnel dose badge, were placed at the positions recommended by the manufacturers. The results show that the personal dosimetry badge is not a proper dosimeter to evaluate dose of eye lens. Besides, other commercial eye lens dosimeters can measure the dose to the lens of eye closely to the reference eye lens dose with some deviations. Dose deviations for different dosimeters were discussed and presented in this study.

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Radiation dose measurement of patient eye-lens in brain CT examinations

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Key words: brain CT, organ-based tube current modulation, bismuth shielding, eye-lens dose

Introduction: The purpose of this study was to assess patient radiation dose and image quality of routine brain CT examination using two dose reduction methods for protecting eye-lens doses.

Methods: A number of 63 patients randomized into three groups of scanning protocol. CT scan acquisition was performed with a 128-slice CT scanner (Somatom Definition Flash, Siemens, Germany). Patients of the reference group were scanned with a routine brain CT protocol. The second group was scanned with a new technique of organ-based tube current modulation (OBTCM, X-CARE, Siemens, Germany). The third group was scanned with bismuth shielding covered on patients' eye-lens region. Patient eye-lens doses were measured with thermoluminescent dosimeters (TLD-100H, Thermo Scientific, U.S.A). Organ doses of each patient was calculated. The change of CT number and noise using bismuth shielding was qualified. Eye-lens position related to angular distribution of OBTCM technique was assessed.

Result: The measured eye-lens doses were 46.1±5.3 mGy, 32.0±2.1 mGy, and 38.3±5.7 mGy for groups of reference, OB-TCM, and bismuth shielding, respectively. A reduction of 30.5% and 16.9% of eye-lens doses was achieved using OB-TCM technique and bismuth shielding, respectively. The change of CT numbers using bismuth shielding was 26.6 HU and the image noise increased of 45.9% at patients' eye-lens region. However, the eye-lens is out of diagnosis region in our patients. Eye-lens position related to angular distribution of OBTCM technique was within the range of 120° at anterior of patients.

Conclusion: The OB-TCM and bismuth shielding could be used for eye-lens dose reduction.

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Dose Inspection and Risk Estimation on Radiation Safety for the Uses of Non-Medical 30 to 150 kV X-ray Equipment and Open Beam Devices

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Key Words: dose inspection, risk estimation, radiation safety, open beam X-ray

The characteristic of X-ray equipment is usually indicated based on nominal voltage or radiation energy. In particular the nominal voltage range, although it has the same radiant energy output, but for the different types, purposes and usage situations, the doses to staffs and risk on radiation safety are also different. Therefore, by means of the on-site surveys, investigation on the equipment types and performance data could help to actually assess the radiation doses and radiation risk. This research inspected the radiation doses and made the risk analysis according to the roster provided by Atomic Energy Council (AEC) in Taiwan. The subject of inspections was focus on the X-ray equipment with nominal voltage between 30 to 150 kV including the open beam (or portable) device.

The number of inspected equipment is 401, including 139 X-ray equipment with nominal voltage between 30 to 50 kV, 140 X-ray equipment with nominal voltage between 50 to 150 kV, 122 open beam (or portable) devices. By the on-site inspection, protection procedures in each case of X-ray equipment can be realized and recognized. This work proposes the statistical analysis and survey of the inspection data, and recommendations regarding the risk management of radiation safety. In addition to the normal usage of X-ray equipment, the possibly abnormal usage such as interlock device failure, or deliberately opened the shielding door when X-ray exposed were also considered to assess the doses and risks may result in the staffs. The measured doses at the positions of hand and body of the operator staff were assumed as the hand equivalent dose and effective dose respectively. Measurements were performed with a survey meter of plastic scintillator and a pocket-size personal dosimeters.

The equivalent dose and effective dose were then be used to assess the radiation risk according to the recommendations of International Committee on Radiation Protection. Besides, considerations the data of dose rate in operation, the operating frequency/time of the equipment acquired during the on-site investigations, this work assessed the annual doses (equivalent and effective doses) and risks of the X-ray operator staffs as reasonably as possible. Results of this research will help the competent authority of ionization radiation to improve the management and control of X-ray equipment.

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Evaluation of Optimal Parameters for Using Low-dose Computed Tomography to Diagnose Urinary Tract Stones

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Key Words: urolithiasis, sensitivity, specificity, low-dose CT

The incidence of urolithiasis is up to 10% in Taiwan. In early stead of urolithiasis, patients usually be diagnosed with Intravenous urogram. For computed tomography (CT), sensitivity and specificity of 97% and 96% urolithiasis, respectively, or stone detection rate are better, compared to intravenous urography (IVU) of about 70-90%. In general, dose of 8 to 16 mSv will be delivered to patients when performing abdominal CT, and dose of 2.6 mSv will be delivered when performing IVU check. Although the speed, sensitivity, and specificity is high for CT then IVU, but the dose is relatively much higher. The urolithiasis has a very high recurrence rate, so there must be a lot of control manager on the dose. The use of low dose computed tomography in diagnosis of urolithiasis patients is begun to be explored. Present study is to investigate dose and image quality of the CT scanner use of low-dose CT to diagnose urolithiasis.

The Rando phantom with one self-made layer of acrylic, and several holes were drilled to fill water or porcine kidney. Stone samples were chosen of different material with the same CT values, these samples were simulated the real urolithiasis stones, and were put into the water and porcine kidney and porcine kidney when investigated. Simulated stones was made of graphite and two different types of eraser. The size of all simulated stones were cut into 3 mm, 4 mm and 5 mm. Administered four different doses of irradiation conditions, such as dose of 206.3 mAs, then reduce the dose of 50%, 25% and 15% to investigate the smallest detectable size of stone in the water or porcine kidney under different dose conditions.

In clinical, under standard dose condition, a 3 mm size of stones can be clearly seen. When the dose was reduced to 15%, kidney stones with the 3 mm size was clear, but the stones in the water near the acrylic side of the stone would be more difficult to distinguish. The stones size larger than 4 mm can tell more clearly. In conclusions, the use of low-dose CT (LDCT) would not affect the interpretation of the doctor, and can reduce patient dose. LDCT can be confirmed as a new way to get images to replace IVU to assess the patient's urolithiasis. Optimal Parameters for Using Low-dose CT were suggested in the cases of this study.

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Risk assessment of radiation-induced secondary cancer of treating nasopharyngeal carcinoma with the intensity modulated radiotherapy

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Key Words: effective dose; equivalent dose; intensity modulated radiotherapy; risk assessment; secondary cancer

This paper investigates a method to evaluate the risk of radiation-induced secondary cancer based on whole-body dose measurements on nasopharyngeal carcinoma (NPC) patients undergoing intensity modulated radiotherapy (IMRT).
We determined the relative position and contour of organs at Rando phantom to obtain the accurate dose assessments for out-of-field organs. The treatment planning was simulated for Rando phantom after the verifications of clinical doctors. The thermoluminescent dosimeters (TLDs) were placed in the phantom to estimate the actual organ doses delivered by IMRT.
In this treatment planning for NPC IMRT, the planning target volume (PTV) is 1066 cm3 and the prescribed dose required to deliver 6996 cGy in 33 fractions is 212 cGy for each irradiation. The dose evaluation for the NPC patients receiving IMRT showed that the highest equivalent dose received by lungs was 4013.31 ± 381.19 mSv. According to the tissue weighting factors recommended by the International Commission on Radiological Protection (ICRP) 60 and 103, the whole-body effective doses obtained were 998.11 ± 46.75 mSv and 961.99 ± 46.24 mSv, respectively.
The corresponding risks of radiation-induced secondary cancer obtained were 4.99% Sv^{-1} and 3.85% Sv^{-1}. It was verified that the risk assessments of radiation-induced secondary cancer of NPC IMRT in this paper were in agreement with the previous studies and it proved the feasibility of applying the method suggested in this work.

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Calculation of correction factors for cylindrical free-air chamber

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Key Words: Monte Carlo, free-air chamber, Photon-scattering, electron-loss, shadow-effect

A cylindrical free-air ionization chamber is used as the medium X-ray air kerma primary standard at the Institute of Nuclear Energy Research (INER, Taiwan). Photon-scattering, electron-loss and shadow-effect correction factors are taken into account for the measurement of air kerma by cylindrical free-air ionization chamber. The photon-scattering correction factor is to deduct ionizations caused by scattered photons. The electron-loss correction factor is to compensate for the loss of electrons striking the electrode shell without fully depositing their energies to the charges in the air. The shadow-effect correction factor is to compensate for the loss of electrons striking the collecting rod inside the chamber. The photon scattering and the electron loss correction factors previously used at INER were based on the least-squares fit with the experimental data published in the NBS Handbook 64. The shadow-effect correction factor was not considered.

In this study, photon-scattering, electron-loss and shadow-effect correction factors for each mono-energetic photon were calculated by Monte Carlo code EGS5. Then the mono-energetic correction factors were substituted into the ISO 4037 radiation qualities spectrum and calculated for the energy weighted correction factors. Comparing the calculated correction factors with the previous correction factors, the maximum differences were 0.51 % and 1.22 % for N-250 and N-300 radiation qualities.

In the report of international comparison of air kerma standards for ISO 4037 narrow spectrum series (EUROMET.RI(I)-S3) conducted from 2004 to 2005, the ratio of differences and expanded uncertainties (Di/Ui) for INER's N-250 and N-300 radiation qualities are 0.9 and 1.8. If the correction factors obtained in this study are substituted, the differences can be reduced, and Di/Ui become 0.36 and 0.6.

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A Radiation Protection Concept for the MedAustron Facility

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Key Words: Monte Carlo, Neutron Radiation Fields, Dose Estimation, Ion therapy Facility

MedAustron is a synchrotron based accelerator facility for cancer therapy and research in Wiener Neustadt, 50 km south of Vienna. The facility will provide protons up to kinetic energies of 250 MeV and carbon ions up to 400 MeV/u for medical applications. Additionally, protons up to 800 MeV kinetic energy will be used in a dedicated room for non-clinical research.
Authorities in Austria demand an environmental impact assessment report as a prerequisite for building an accelerator facility exceeding particle energies of 50 MeV. For this report a detailed geometry of the accelerator facility was implemented into the Monte-Carlo code FLUKA and shielding simulations were performed. In the course of these simulations the contributions of different particle types to the mixed fields around the accelerator and behind shielding were analysed. It was determined that the neutron radiation with a wide energy range is the main contributor for ambient dose equivalent rates inside and around the accelerator facility of MedAustron. These findings can be used for the development of an active radiation monitoring system for the MedAustron accelerator facility.

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Dosimetric properties of $CaSO_4$:Tm and $CaSO_4$:Tm,Ag crystals produced by slow evaporation route

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Key Words: Dosimetry, thermoluminescence, optically stimulated luminescence, $CaSO_4$.

The dosimetry of ionizing radiation is an essential tool in diagnostic radiology procedures, radiation therapy and evaluation of doses received by occupationally exposed individuals. Thermoluminescence (TL) is a useful technique in these types of monitoring. Nowadays, optically stimulated luminescence (OSL) technique has been also used, mostly because of no need of heating samples. Thus, the motivation of this work was to produce TL/OSL dosimeters based on crystals of $CaSO_4$ doped with thulium and silver, through a suitable new route.

The crystals were produced by an adaptation of the slow evaporation route using calcium carbonate ($CaCO_3$) as precursor, and incorporating the dopants (Tm_2O_3, Ag_2O and silver nanoparticles) in a solution of sulfuric acid, which is evaporated resulting in $CaSO_4$:Tm or $CaSO_4$:Tm,Ag crystal powder.

X-ray diffraction analyses showed that produced samples exhibit only a single phase corresponding to the crystal structure of anhydrite. Radioluminescence confirmed the presence of Tm^{3+} in the crystal matrix. TL/OSL characteristics such as glow curves, linearity, reproducibility, fading, kinetics order, and activation energy were evaluated. Samples doped with Tm and silver nanoparticles have shown the highest TL intensity and were compared with commercial TLDs (TLD-100, TLD-900), showing its potential to be used as dosimeters.

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Air Radon equilibrium measurement in a Waste Water Treatment Plant

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Key Words: Radon, equilibrium factor, gamma spectrometry, radon progeny.

Radon-222 is a naturally occurring gas created from the decay of Radium-226. High levels of Radon in a workplace can increase health risks in the employees. We analyze in this paper a Waste Water Treatment Plant (WWTP) located at the Mediterranean coast with radon concentration above Spanish action level. The national Reference Level for radon in workplaces is 600 Becquerel per cubic metre (Bq/m^3) measured over a 3 month period.

When the water containing radium is aerated and backwashed, elevated concentrations of radon are released. Radon remains at the water plant with little ventilation, therefore operators are at increased risk of 222Rn inhalation, which may represent a radiological risk.

According conversion coefficients from ICRP65: "Protection Against Radon-222 at Home and at work", effective dose per unit exposure at work (mSv por mJhm-3) is 1.4 and conversion factor of radon progeny exposition is $2.22 \cdot 10\text{-}6$ $mJhm^{-3}$ por $Bqhm^{-3}$ (assuming equilibrium factor (F) 0.4).

The typical F value of 0.4 recommended by International Commission on Radiological Protection (ICRP) could lead to an error in the estimation of radon doses to the lung.

In order to estimate workers effective dose more precisely, this paper presents the exact method for radon equilibrium determination by gamma spectrometry measuring of radon progeny concentrations in the air.

The method is based on simultaneous sampling of air through a filter paper and alpha spectrometry (RAD7, Durridge) measurement of radon activity concentration in the air.

This work uses a Matlab algorithm (based on symbolic calculation) developed for Bateman equations resolution and to calculate the initial concentrations of radon progenies in the air at the start of sampling.

We present preliminary results for the radon equilibrium determination based on gamma-spectrometry measurements of radon progenies collected on filter paper.

According to measured radon activity concentration in the air of 368 ± 45 Bq/m^3 the equilibrium factor between radon and progenies was estimated to $F = 0.46$ which is in good agreement with values expected.

Noncoplanar Irradiation for Critical Organ Sparing in Helical Tomotherapy

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Key Words: radiation treatment, Tomotherapy, noncoplanar irradiation, critical organ sparing

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. We examined quantitatively a potential advantage of the novel approach by utilizing of oblique beam irradiation in helical Tomotherapy. 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. Considering a typical shape and location of tumor in tonsil cancer, a gross tumor volume and a clinical target volume were delineated. 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 were compared, bases on the dose volume histogram data. The obtained results showed that employing oblique beam could reduce the doses to the parotid glands significantly. The maximum dose to the left parotid gland is decreased by more than 10%, 4.6 Gy. The decrease in the maximum doses to the right parotid glands was 9.4 Gy, 24% of the conventional setup. From the preliminary results we can conclude that the novel approach using oblique beams in Tomotherapy might enhance sparing of critical organs significantly.

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Evaluation of Skin Dose due to the Scattered Radiation by Employing a Blanket for Helical Tomotherapy

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Key Words: radiation treatment, Tomotherapy, scattered radiation, skin dose

We employ a blanket to keep patients' body warm in a too cold room for Tomotherapy Hi-ART system. This study estimated skin dose elevation due to scattered radiation by blanket. We designed to perform comparison of superficial dose of a phantom, considering two plans with and without a blanket. We considered two types of blanket, thin and thick, which are usually used in our institution. After acquiring three sets of CT simulation data of a bare phantom, a phantom with the thin and the thick blanket, we registered all of three images as a phantom for DQA plan of Tomotherapy planning system. For the identical plan of clinical mode for the model patient, three DQA plans were created with three phantoms. With the dose statistics data of planning system, superficial doses were compared with each other. In addition, the phantoms with three setups were irradiated with DQA plans and the superficial doses were measured with the ion chamber at the depth of 0.5cm and 1.5cm. The results obtained from DQA plans showed that the surface dose was 25Gy, 36Gy, and 30Gy in the case of a bare phantom, and the thin and the thick blanket, respectively. The experiment for dose measurement using an ion chamber showed that the dose at the depth of 0.5cm was 2.323Gy when a fractional dose, 5 Gy, was delivered to the bare phantom. In the same setup with the thick blanket, the 0.5 cm depth dose was increased to 2.351Gy. At the depth of 1.5cm, the dose to bare phantom was 1.946Gy and that to the thick blanket was increased by 1.986Gy. It is concluded that skin dose elevation should be carefully examined, when we consider employment of any blanket for keeping warmth in a Tomotherapy room.
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Wearable Glass Beads in In-vivo Dosimetry for Total Body Irradiation and Total Skin Electron Irradiation

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Key words: Radiation therapy, Glass beads, in vivo dosimetry, total body irradiation, total skin electron irradiation

Thermoluminescent dosimeters (TLDs) are common detectors for in-vivo dosimetry of total body irradiation (TBI) and total skin electron irradiation (TSEI) radiotherapy techniques. Currently in-vivo dose measurements in hospitals involve dosimeters and adhesives being placed in direct contact with the skin. This can be uncomfortable for many patients, particularly those with skin conditions (i.e. mycosis fungoides) and radiation induced skin damage.

Jewellery glass beads exhibit thermoluminescent properties for sensitivity, linearity, dose rate independency, being directional independence, and in addition, the low cost, inert nature, reusability and the physical shape of the beads with the whole in the middle have the potential to be used as wearable dosimeters in radiation therapy. Glass beads are novel in that they may be threaded and worn as necklaces, rings, and bracelets at different anatomical sites.

This study investigated the suitability of wearable glass bead for dose measurements in TBI and TSEI treatments. Glass beads are cleaned with acetone solution in an ultrasonic cleaner, irradiated with 6 MV photon and 6 MeV high dose rate electrons (HDRE) beams using a linear accelerator, readout using a 3500 Harshaw TL reader, and glass beads annealed after every dosimetric cycle using a scientific equipment manufacturer (SEM) annealing oven. The dosimetric performance of glass beads is evaluated by comparing the response of the beads with OSLDs at ten different sites for both TBI and TSEI treatments.

This study established the feasibility of employing threaded glass bead dosimeters, worn with minimal direct skin contact, to improve patient comfort during radiotherapy treatment.

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Factors Limiting the Linearity of Response of Tissue Equivalent Proportional Counters Used in Micro- and Nano – Dosimetry

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Key Words: gas proportional counter, tissue equivalent gas mixtures, electron avalanche growth, space charge

The ideal gas detector which may be used in micro- or nano-dosimetry to determine the energy transferred by radiation and its distribution in the biological objects must full feel a number of requirements. From one side, the counter must be microdosimetry and on the other side must be proportional. Most of the currently used microdosimetric detectors are a compromise between the method of their construction and of their use and the extent to which a counter simulates the biological object. The best are spherical gas proportional counters because of their perfect symmetry of the directional absorption of the incident radiation. Cylindrical counters are also used because of the simplicity of their design and construction. Cylindrical counters should have the active length equal to their diameter. This is in contradiction with preserving the counters proportionality. In too short counters there is a deformation of the electric field associated with the fitting of the anode. Of course, the system of potential rings can improve the field distribution but not fully.

In this paper the limitations in counters use from the side of counters proportionality will be presented. Tissue Equivalent Proportional Counters (TEPC) are proportional counters that can be used to simulate interactions and energy transferred to small tissue volumes, which allows the absorbed dose to be determined. TEPCs operate to simulate site sizes in the micro-meter range. To achieve this size scaling, the physical size of the detector and the density of the TEG gas are used as variables, as they form a conjugate pair controlling the site size simulation.

Systematic measurements of the gas multiplication factor over the range 1.0 - 7×10^5 have been made in a cylindrical Methane- and Propane based TEG filled proportional counters as a function of the applied voltage between cathode and anode, for mixture pressure from 9 hPa to 500 hP. For these mixtures following characteristic parameters have been determined: the highest stable gas gain, its dependence on mixture pressure and counter geometry, photon feedback parameters, radius of electron avalanche as the function of gas gain and mixture pressure, the critical current (maximal dose) over which the reduction in gas gain due to space charge is observed.

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Measurements and calculations of gas gain in tissue equivalent gases

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Key Words: TEG mixtures, gas gain, Magboltz simulation

For precise determination of the energy response of the Tissue Equivalent Proportional Counters (TEPC) it is necessary to minimize an uncertainty of the dose equivalent measured by TEPC. This is needed for practical use in radiation protection. As a tool of exploration to evaluate fundamental features of TEPC detectors analytical function describing their properties or numerical simulation software can be used. These two methods complement each other. To simulate the physical processes occurring in TEPC the exact value of cross sections for the processes occurring in the detector are needed. Using the analytical formulae one can get only an average value of some physical parameters characterizing the mixture. The complexity of real gases and electric field distribution in real detectors, make the realistic, analytical models of physical processes in detectors unwieldy. In this work, we want to present the gas gain curves in a wide range beginning from the ionization regime to the breakdown limit (few × 10^5), for mixtures pressures from 9 hPa to 500 hPa, for both Methane- and Propane- based TEG mixtures. The measured data will be fitted using Magboltz simulation program to compare measured and calculated constants characterizing the mixtures.

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The Study of Au/Al_2O_3 Phosphors in Optically Stimulated Luminescence Radiation Response

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Key word: Au/Al_2O_3, Phosphors, Optically Stimulated Luminescence, Dosimetry

Crystal defects such as the doping of a variety of various elements were known for enhancing Al_2O_3 on optically stimulated luminescent dosimeter (OSLD) performance. On the other hand, Au nanoparticles (NPs) have attracted considerable attention due to their Photoluminescence properties. Here in this study, a facile route was proposed to prepare and disperse Au NPs on Al_2O_3 surface. The effects were examined and discussed. Finally, we found a competitive potential compare with commercial Landauer Al_2O_3:C dosimeters.

The Au NPs were prepared under reflux condition with desired amount of sodium citrate and chloroauric acid. The phrase, micromorphology, and atomic ratio of all the samples were examined by XRD, SEM, and EDS mapping, respectively. The size of homemade Au/Al_2O_3 flake is 6 mm in diameter and 0.3 mm in thickness. These materials will undergo radiation by linear accelerator, the irradiation condition was as follows: 6 MV photo beam and different doses, source to phantom surface distance 95 cm, depth 5 cm. We used ion chamber to verify the dose accuracy. The luminescence from irradiated Au/Al_2O_3 was measured using the Dot™ cassette on the Landauer MicroStar™ reader.

The results demonstrate good dose linearity curves from 100 to 2000 cGy, and the sensitivities were tunable by adjusting Au/Al_2O_3 ratio. Au/Al_2O_3 appeared wider radiation dose range and phosphor can be reused for 10 cycles without any change in the OSL output. Au/Al_2O_3 and Al_2O_3:C phosphors were also studied for their optical bleaching durations to which the respective signals get completely removed so that the phosphor can be re-used. It was observed that Au/Al_2O_3 is bleached faster and more easily than Al_2O_3:C.

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In Vivo Dose Verification of Thin Optically Stimulated Luminescence Dosimeter in Head and Neck Cancer for Intensity-Modulated Radiotherapy and Volumetric-Modulated Arc Therapy Techniques

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Key word: Volumetric-Modulated Arc Therapy, Intensity-Modulated Radiotherapy, Thermoluminescent Dosimeter, Optically Stimulated Luminescence Dosimeter

An in vivo dose verification for Intensity-Modulated Radiotherapy (IMRT) and Volumetric-Modulated Arc Therapy (VMAT) treatments of head and neck cancers was developed for several years. Dose results of 100 intracavitary homemade thin optically stimulated luminescence dosimeter (OSLD) measurements from Rando phantom are presented in this study. In this study, we evaluate the skin and organ dose after radiotherapy, the study used OSLD and TLD-100H to measure the dose of surface and critical organ in Rando phantom. In order to reduce skin dose, we had three different planning target volume (PTV) contours, the PTV was subtracted from body skin for 0, 3, and 5mm. Effective dose (E) and Equivalent dose (H_T) of patients undergoing head and neck treatments was evaluated. Effective dose and Equivalent dose were calculated and recommended by International Commission on Radiological Protection, ICRP 60 and ICRP 103. To investigate the potential risk of secondary radiations, the contribution of photon doses delivered outside the treatment field will be measured on the phantom. For sensitivity and linearity calibration, the dosimeters were calibrated using 6 MV photons from linear accelerator.

The results showed 5% variation between OSLD and TLD. For subtraction 0 mm from body skin, the skin in the PTV range of IMRT received 75.1% of prescription dose, and VMAT only received 61.1% of prescription dose. For subtraction 3, 5 mm from body skin, the dose results were similar with 0 mm. For these two radiotherapy techniques, the skin dose might be insufficient for surface tumor. It's worth noting that the VMAT can provide lower skin dose for deep tumor.

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Destructive and non-destructive measurements of NORM in monazite-rich sands of Brazil

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Key Words- gamma-ray spectroscopy, naturally occurring radioactive materials, dose rates

The Earth and its atmosphere contains a range of Naturally Occurring Radioactive Materials (NORMs), with all minerals and raw materials containing trace amounts of radionuclides of natural origin. For most human activities, the levels of exposure to the decay of these nuclides constitute the natural radiation background level. There are areas known for their particularly high levels of background radiation compared to the World average, including some specific Brazilian beaches. These locations have geological and geochemical characteristics which correspond to higher levels of natural occurring radioactivity, an example of which are the monazite sands from the Atlantic coast.

The activity concentration of the sand samples from a range of beach locations in Brazil have been deduced for members of the ^{238}U, ^{232}Th and ^{235}U decay chains, as well as the single primordial radionuclide ^{40}K. This has been performed using a combination of destructive and non-destructive techniques in order to determine the associated radiation hazard indices which can be calculated and compared to the internationally accepted values set by the UNSCEAR, (2000). Non-destructive measurements were carried out via γ-ray spectrometry on the unprocessed sample material. A 50% relative efficiency ORTEC GEM-FX8530-S HPGe γ-ray spectrometer, with a 0.8 mm thick carbon composite window was used to obtain spectrometric measurements from decay products within these samples. Destructive analysis was carried out using fusion methods to dissolve the samples and then via extraction chromatography to chemically separate the NORM materials and their radioactive decay daughters. Once the samples were chemically separated they were measured using inductively coupled plasma mass spectrometry (ICPMS) to determine the ^{238}U and ^{232}Th, content directly. In addition, α-spectrometry measurements were made to determine directly the activity concentration of the 4n+2 decay chain member ^{210}Po. For both alpha and mass spectrometry it is critical that the final spectra are limited from thorium contaminations in the uranium measurements and vice versa. This is of particular importance for NORM measurements using alpha spectrometry where the 4n Thorium series and 4n+2 Uranium series dominate, where interfering alphas lines in the final measurement can hinder the identification and quantification of the isotopes of interest due to spectral overlaps which result from incomplete/failed radiochemical separation. This can degrade the alpha peak spectral response and limit ultimately the achieved energy resolution. A progress report on the analysis performed to date will be presented.

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The Impact of Counting Statistics on the Accuracy of Model-based Range Verification in Proton Therapy Using PET

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Key Words: Monte Carlo, proton range verification, positron emitter

Introduction: Positron emission tomography (PET) measuring the irradiation-induced tissue activation inside the patient can facilitate clinical feedback after each treatment fraction and improve treatment outcomes. The acquired PET images can be indirectly compared to the predicting positron emitter distributions derived from the planned dose (forward filtering approach), or directly used to reconstruct the dose distribution using the analytical filtering model to validate the proton range *in vivo*. The purpose of the study is to assess the impact of counting statistics on the accuracy of the two model-based range verification approach in proton therapy using PET.

Materials and Methods: Homogeneous phantoms (200 mm axial length and 200 mm diameter) with different materials (PMMA, lung, skull and brain) were studied using PET imaging. GATE Monte Carlo (MC) simulation platform were used to simulate proton pencil beams with three energy levels (70, 152.1 and 230 MeV) irradiating the phantoms and be imaged by the Siemens Biograph 6 PET scanner. The developed analytical filtering model was first benchmarked against published data. The accuracy of the two model-based range verification were calculated under different counting statistics conditions.

Results: The range difference from the two approaches at the distal fall-off region are within 1.2 mm for most materials under different energy levels. However, the range difference rises to 4.2 mm for lung phantom. The results not only validated the effectiveness of the analytical filtering model on range verification of proton therapy, but also suggested that an improved filtering analytical model for lung tissue is needed. In addition, MC simulations indicate that the accuracy of range verification using both methods decrease with reduced counting statistics. Compared to forward filtering approach, PET-based dose reconstruction approach is more susceptible to the low counting statistics.

Conclusions: The preliminary study indicates that the accuracy of proton range verification is highly affected by counting statistics, especially using PET-based dose reconstruction approach. A noise reduction or regularization algorithm can be further developed to guarantee the accuracy within 1-2 mm under low counting condition.

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Synthesis and dosimetric characterization of $Sr_4Al_{14}O_{25}$: Ce^{+2}

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Abstract

Strontium aluminates phosphors activated by Ce^{+2} were prepared by combustion method at 600°C and calcined on air and reducing atmospheres. Photoluminescence (PL) and thermoluminescence (TL) properties were investigated and X-ray powder diffraction analysis confirmed the formation of $Sr_4Al_{14}O_{25}$: Ce^{+2}. The PL spectrum shows a peak around 430 nm (330 nm excitation).Thermoluminescence studies were done with two different concentrations of Cerium. According to our studies, the TL intensity is proportional to dopant's concentration, irradiation dose and calcination atmosphere.

Keywords: Phosphors, dosimetric characterization, strontium aluminates

Influence of the operating modes and exposure time of the radiation monitoring instruments for area monitoring used at mammography facilities.

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Key Words: Area monitoring, mammography, survey meter, occupational exposure

Area monitoring ensures radiation exposure at an acceptable level for employees and members of the public, which must be lower than the legal limit. Experimental measurements were taken in an ionizing radiation calibration laboratory. An X- ray generator (GE ISOVOLT TITAN E) high frequency was used. The specified reference radiation for the narrow spectrum series to radiation protection ISO N30 was used. Seven radiation monitoring instruments were used. Dose and dose rate measurements were measured in integrated and rate operating modes with exposure time of 1, 3 and 5 s.

The average dose rate inaccuracy measured in integrated and rate modes were 2.3 and 5.7 % with a rage between 0.2 to 16.4 and 0.2 to 12.7 %, respectively.

The highest average dose rate inaccuracy values for measurements in integrated and rate modes with respect to the exposure time values were 4.1 and 8.5 % for time of 1 and 3 s, respectively. The results show that it is necessary to know the radiation monitoring instrument to improve the accuracy of measurement of area monitoring.

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Scatter radiation dose at height of the cardiologist's eye: A multicentre study

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Key Words: Scatter radiation dose; interventional cardiology; ambient dose equivalent; occupational dose

Cases of radiation induced cataract among cardiology professionals have been demonstrated in studies. In view of evidence of radiation injuries the ICRP recommends limiting the radiation dose to the lens to 20 mSv per year for occupational exposure. Several studies show that radiation protection devices and personal dosimetry are not commonly used by operators during interventional procedures. The aim of this paper is to report scattered radiation doses at the height of the cardiologyt's eye in three interventional cardiology facility without used of the radiological protection devices and to correlate these values with kerma area product at patient for different angiographic projections and operational modes.

Measurements were made in three cardiac laboratories, with angiography X-ray systems, two General Electric, model Innova 2100 IQ and Innova IQ and a Philips Allura Xper FD10 equipped with flat-panel detector. Polymethylmethacrylate plates of 30x30x5 cm were used to simulate a patient with a thickness of 20 cm. A 20 and 25-cm field of view were used, respectively. Measurement were taken in two or three fluoroscopy modes (low, medium and high, 15 pulse/s) and cine mode 15frame/s. Four angiographic projections were used anterior posterior (AP), lateral (LAT), left anterior oblique caudal (spider) and left anterior oblique cranial (LAO45CRA30) and a cardiac protocol for patient between 70 to 90 kg was used.

Measurements of phantom entrance doses rate and scatter doses rate were performed with two Unfors Xi plus, model 8202031-HXi and 8202062-CXi survey detector. The focus to detector phantom entrance distance were 60 and 67 cm, respectively, and focus to flat panel detector distance was 100 cm. The detector measuring scatter radiation was positioned at the usual distance of the cardiologist's eyes during working conditions (1m from the isocenter and 1.7 m from the floor).

There is a good linear correlation between phantom entrance doses rate and scatter dose rate for all projection. There is a good linear correlation between the kerma-area product and scatter dose at height of the cardiologist's eye lens, $R^2 > 0.8257$ considering all projections. The highest scatter dose rate at height of cardiologist's eye were 28; 53 and 60 mSv/h for LAT and LAO45CRA30 projections, respectively.

An experimental correlation factor of 4.8; 5.1 and 5.3 µSv per Gy*cm^2 has been found considering all projections, for each X ray systems.

The average entrance dose of PMMA for fluoroscopy low, medium, high and cine was 15, 37, 41 and 237 mGy/min, respectively.

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The Beam Quality of the New Transmission type X ray Tube

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Key Words: beam quality, Monte Carlo simulation, reflection-target, transmission-target

The target type of X ray equipment's tubes can be divided into two categories, including reflection tubes and transmission tubes. During the past years, the novel transmission tubes X ray equipment was used for clinical tests of diagnostic radiology and radiotherapy.
The radiation output characteristics of the transmission-target X-ray tube are different from those of the traditional reflection-target X-ray tube. The NanoRay Biotech NM08X040 transmission-target X-ray system and Shimadzu CIRCLEX 1/2P33D-85 traditional reflection-target X-ray system were used in this study. The aims of this study were to compare the differences of half-value layer, percentage depth dose curve, dose profile and isodose distribution between these two X-ray tubes under the same conditions. Monte Carlo simulation for dose verification was performed using BEAMnrc to verify the measured results.
According to dose profile results, transmission-target X-ray system without heel effect. From the percentage depth dose curve results, the beam penetration of the transmission-target X-ray tube was higher than that of the reflection-target X-ray tube. In summary, the present study indicates that the transmission type X ray equipment is one of the stable generators for applications in all fields of radiology.

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Monte Carlo simulations for angular and spatial distributions in therapeutic energy proton beams

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Key Words: proton therapy, scattering angle, Monte Carlo simulation, MCNP, FLUKA, GEANT4

Accurate dose detonation or high conformity for a specific target volume is one of the merits of proton therapy. Nowadays, many treatment planning systems are based on the Monte Carlo technique and prediction of patient dose relies on accuracy in simulations. As beam delivery technology and precision in dose detonation evaluation are improving, better conformity is expected. At the same time, improvements with simulations are required.

In our study, results of three different Monte Carlo simulations (GEANT4, FLUKA, and MCNP6) were compared for benchmark verifications with the same geometry. A point source with 80, 160 and 230 MeV protons was passing through 2 cm thick water and 1 cm aluminium targets respectively. At 10 cm plane away from both targets, the spatial distributions are obtained from the concentric rings. For the evaluation of lateral and depth dose distributions in the phantom, the calculations adopted an ideal point proton source and a real proton pencil beam (FWHM=1.1 cm) interacting with the 30x30x40 cm^3 water phantom respectively.

The results showed the differences of scattering angle distributions due to physical models adopted in different codes. FLUKA and MCNP6 were almost identical in target study but the difference in other case could be as large as ~30%-50% in the forward direction at scoring plane downstream of targets. Subsequently, dose distributions at the same plane were different as well. That resulted from different Monte Carlo scattered algorithms which also contributed to the inconsistent lateral dose distribution at Bragg peak depth of the phantom depending on the calculated codes.

Proton scattered angle distributions and dose profile were simulated and compared with these common Monte Carlo codes. It is also very helpful for understanding lateral dose calculations in small-field dosimetry, proton radiosurgery or animal proton irradiation fields getting important recently. In the near future, we are going to carry out relative experiments with our homemade detectors to verify the correctness of the simulations.

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Patient dose reduction using automatic exposure control and iterative dose reduction 3D of abdominal CT examinations

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Key words: abdomen CT, CTDI, SSDE, radiation dose reduction, image quality

Introduction: The purpose of this study was to optimized the radiation dose and image quality for patients undergoing abdominal CT examination.

Methods: One-hundred and forty-four patients (mean age,70.6, range, 60-89) were collected in our study. Patients who underwent routine abdominal CT examination were set of two groups. One was pre-optimization and the other was post-optimization group. Optimized acquisition parameters of adaptive iterative dose reconstruction technique (strength of STD, Adaptive Iterative Dose Reduction 3D, Toshiba, Japan), the automatic exposure control system (NI=8, SureExposure 3D, Toshiba, Japan), and the reconstruction kernel of FC17 determined by our phantom study were applied for patients undergoing CT acquisition . The values of SSDE, organ dose, effective dose, and image quality was assessed for each patient. Regions of interest (ROIs) were defined at the middle of portal vein level, fat, and muscle. Contrast, image noise, contrast-to-noise ratio (CNR) and figure of merit (FOM) were used to assess the quantitative image quality.

Results: The image quality was kept consistent applying with optimized protocol. The optimized protocol showed a reduction of 20% to 27% of $CTDI_{vol}$, 22% to 27% of SSDE and 8% to 17% of effective dose. $CTDI_{vol}$ only indicates radiation output and does not represent to patient dose. SSDE describes the radiation dose according to specific body type and can be use to indicate the radiation dose to a patient.

Conclusion: The acquisition parameter of abdominal CT examination was optimized and resulted in a 20% reduction in radiation dose without impairing the image quality.

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Fricke-gel dosimeters for 3D dose mapping using MRI technique

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Key Words: Fricke; Gel dosimeter; MRI; 3D dosimetry

Fricke gel dosimeters are a suitable tool to perform pre-treatment dose evaluation in radiation therapy, permitting a volumetric dose distribution assessment. These chemical dosimeters are based on the radiation-induced oxidation of ferrous ions, dispersed in a tissue equivalent gel matrix, into ferric ions. The ferric ions concentration is linearly related to the total absorbed dose. Thanks to the different paramagnetic properties of ferrous and ferric ions, the ferric ions concentration can be evaluated through Magnetic Resonance tomographic imaging (MRI) in T1-weighted sequences, obtaining a 3D dose map within the gel phantom. In order to reduce the ferric ions spatial diffusion process and, consequently, to better preserve the absorbed dose spatial information, the chelating agent Xylenol Orange (XO) was added to the recipe. Nevertheless, due to the chelation of ferric ions by the XO, the interaction of the ferric ions with the surrounding water protons is limited, resulting in a reduction of the MRI sensitivity.
A systematic analysis on cylindrical phantoms (7 x 14 cm) was conducted in order to investigate the dependence of the system sensitivity and stability from the dosimeter chemical compositions. Both Gelatin from porcine skin and Polyvinyl Alcohol have been studied and the effects induced by the XO were investigated. The system dose response and the spatial diffusion process were studied as a function of the initial ferrous ions concentration.
In order to calibrate the system dose response, cuvettes (1 x 1 x 4.5 cm) were uniformly irradiated at different dose levels in the range 0-30 Gy. TPS treatment plans (Eclipse v10.0) were calculated on the computed tomography (CT) scans of gel phantoms. Afterwards, treatment plans were delivered on gel phantoms at a medical linear accelerator (Varian Trilogy) with 6 MV photon beams.
Analyses were carried out using two NMR medical scanners, Philips Ingenia 1.5 T and Esaote Artoscan 0.2 T, and the results compared. The calibration cuvettes were also analysed through optical absorption spectrophotometry, used as a reference system.
Thanks to the results obtained in this work, an optimized chemical composition has been proposed. Future studies will be focused on more complex phantoms, able to simulate specific body regions anatomy and tissue discontinuities.

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Simulation of breast deformation for compressed breast thickness estimation in mammography using finite element analysis: a preliminary study

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Key Words: compressed breast thickness, mammography, finite element analysis

Adequate compression during mammography can improve the image quality and lower the absorbed dose in breasts. However, the compressed breast thickness (CBT) is affected by the breast volume and glandularity. This study used finite element analysis (FEA) to simulate the breast deformation and validate the CBT with clinical mammography results. Ten patients who had performed mammography screening for breast cancer were recruited for additional 3D breast magnetic resonance imaging (MRI). Their breast models were created according to the MR images. The skin, glandular, and adipose tissues were manually segmented. The mesh geometry was generated using HyperMesh, and the non-linear tissue deformation for 10–16 daN in the cranio-caudal direction was simulated using Abaqus. When the clinical compression force was used, the CBTs of the FEA simulation and the clinical mammography data were ranged from 3.2–5.9 cm and 3.4–6.3 cm, respectively. The average and maximum differences of CBT were 3.1 mm and 7.8 mm. The simulated CBTs of the ten patients under 10, 12, 14, and 16 daN were 5.91, 5.21, 4.76, and 4.40 cm in average, respectively. The FEA results matched the clinical mammography data very well. Through this study, we can simulate the deformation of breast tissue and estimate the CBT to improve the dose evaluation accuracy and image quality.

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The Estimation of Whole Body Effective Dose with Using Absorbed Dose of Human Tissue

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Key word: Electron Paramagnetic Resonance, Enamel, Fingernail, Skin, Effective dose

Electron paramagnetic resonance (EPR) can be used to detect and measure free radicals, its concentration is proportional to radiation dose the sample has absorbed. The purpose of the research is to establish the relation between absorbed dose(Gy) of tooth, fingernail and whole body effective dose(Sv). Enamel and fingernail powder are placed in the Rando phantom, the absorbed dose of the samples can be estimated with EPR methods. TLD-100 is placed in critical organs, GR-200F is pasted on the Rando phantom surface, the absorbed dose of the samples can be estimated. Use medical linear accelerator to irradiate the Rando phantom with different photon beam(6, 10MV) and electron beam(6, 9, 12MeV), the dose accumulates 10Gy for each fraction, the directions of irradiation come from anterposterior, posteroanterior, Bilateral. The signal-to-dose conversion factors can be obtained from calibration curve, and derive whole body effective dose with ICRP-60 and ICRP-103. The conversion factor(Sv/Gy) between enamel, fingernails, skin absorbed dose(Gy) and whole body effective dose(Sv) can be obtained. The conversion factor between fingernails and whole body is all 0.89 times of that of enamel. The absorbed dose of human organs is lower on electron beam irradiation, but that of teeth, fingernails, and skin is obviously higher, the contribution of dose may come from scattering dose. Compared to ICRP-60, the effective dose of ICRP-103 adds brain, salivary gland, and oral mucosa to be calculated, the research shows the whole body effective dose of ICRP-103 is more than(or equal to) that of ICRP-60. When human gets radiation exposure at similar condition in the research, dose conversion factor can be used as reference.

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The Research of IMRT, VMAT, Partial Arc, and Hybrid 3D/IMRT Techniques for Right Breast Cancer Radiotherapy and Optimization

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Key word: Volumetric Modulated Arc Therapy, Conformal Index, Homogeneity Index

The purpose of research is to use different breast cancer radiation therapy treatment planning to compare and estimate the optimization, whole body effective dose, and critical organ absorbed dose. The four planning are volumetric modulated arc therapy(VMAT), partial arc, hybrid 3D/IMRT, and intensity-modulated radiation therapy(IMRT). Thermoluminescent dosimeter (TLD) is placed in the Rando-phantom, the organs of absorbed dose can be estimated. Each planning comes with 50.4Gy prescription total dose, and treat critical organ including lung and heart. Dose-Volume histogram(DVH) will be used to show the PTV($V_{95\%}$), homogeneity index(HI), conformal index(CI), and others of optimized index. The estimation of whole body effective dose uses ICRP 60, ICRP 103 Publication. The result is as followings: the lowest PTV 95%($V_{95\%}$) is 90.21% with VMAT; the best conformal index(CI) is VMAT; the best homogeneity index(HI) is Partial arc. The heart absorbed dose (V_5) is lower than 0.05%, VMAT and Hybrid(V_{10}) are 0%. The dose of left lung(V_5), the lowest is VMAT(0%). The right lung average dose and V_5~V_{40} are the lowest of VMAT. The delivery time, the fastest is Partial arc(146secs), and the slowest is Hybrid(245secs). The Delivery MU(monitor unit), the highest is VMAT(687 MU). The whole body effective dose, for ICRP-60, the highest is 0.28mSv(VMAT); for ICRP-103, the highest is 0.37mSv(VMAT). Among the four breast radiation therapy treatment plannings, the highest one of PTV $V_{95\%}$ is VMAT; the radiation dose on lung(left and right) and heart gets lower obviously, but the effective dose gets higher relatively because the distribution of low dose area of VMAT is wider, and critical organs absorb more low dose relatively.

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The Research of Estimation of Radiation Dose with Using EPR Methods

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Key words: EPR, Radiation damage, Enamel, Cyclina shell, Clam shell, Chitin

The Electron Paramagnetic Resonance (EPR) method is a tool for estimation of irradiated-biology radiation dose. The purpose of research is to use EPR methods, the signals induced by free radicals to estimate the absorbed dose relation between human tissue(teeth, fingernails) and that of creatures(from sea or land) in the environment. The samples include human enamel and fingernail, ox bone, cyclina shell, clam shell, and chitin from squid. All materials are dehydrated, grinded to powder with different size, then use medical linear accelerator with 6MV, generating photons to irradiate the powder with different dose range from 0.5Gy to 50Gy, finally calculate the EPR signals by the wave magnitude from peak to valley. The result shows that all signals induced by six materials can be estimated with linear regression (R^2: 0.98~0.99), and derives signal-to-dose conversion factor. Conservation experiment: Store chitin, enamel, fingernails at -20℃, bone, clam at -4℃, cyclina at 45℃, the magnitude of signal decay is the least. Grain-size experiment: Get the most clear signal at same dose irradiation, bone at 0.3mm, fingernails at 0.5mm, the others are all 0.1mm. It detects most clear signal R-CO_2^- from fingernails at -20℃, and chitin at -4℃. Unpaired free radicals like PO_4^{2-} (from bone, cyclina), CO_3^- or CO_3^{3-} (from clam, cyclina, enamel), R-CO_2^- (from fingernail, chitin) are induced by irradiation, and their signals can be measured with using EPR techniques. When radiation accident happens, researchers can use this tool to estimate the absorbed dose relation between human tissue and creatures. At same dose irradiation, the magnitude of signals ratio compared to enamel is about 0.16(chitin), 0.173(bone), 2.87(cyclina), 3.43(clam), 0.87(fingernail) times respectively; and the magnitude of signals ratio compared to fingernail is about 0.18(chitin), 0.197(bone), 3.6(cyclina), 3.9(clam), 1.138(enamel) times respectively.

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Study of Heptamethine Iodide and Heptamethine PF_6 Solutions in Different Solvents for the Measurement of Low Doses of X-ray & Gamma Radiation

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Keywords: Heptamethine iodide; heptamethine hexafluorophosphate; gamma-ray; X-ray, dosimeter; low-dose

Heptamethine Iodide and heptamethine hexafluorophosphate solutions in various solvents (chloroform, dichloromethane, ethanol and toluene) were studied spectrophotometrically and spectrofluorimetrically as X-ray and gamma-ray dosimeters for the detection of low-dose radiation. The useful dose range was found to be between 0 to 1 Gy and 1 to 30 Gy for the concentrations studied. The effects of temperature and light on the stability of response during pre-irradiation and post-irradiation storage, the effects of different solvents and dose rates on dosimetric responses of these dyes were also investigated. The results of our studies show that these dye solutions are quite stable in the dark at low as well as room temperature and could be used as dosimeters for low dose X-ray and gamma radiation in medical dosimetry for radiotherapy treatment planning. They can also be used as dosimeters in personal radiation safety applications and environmental radiation monitoring. They have constant sensitivity and their detection limit is an order of magnitude lower than recently reported in the literature. These dyes are and were used in photography industry, so they are cheap and easy to buy.

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Environmental radioactivity analysis by a sequential approach

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Keywords : environmental radioactivity, gamma spectrometry, Bayesian approach, Monte Carlo method, Event mode sequence

Quantitative environmental radioactivity measurements are needed to determine the level of exposure of a population to ionizing radiations and for the assessment of the associated risks.

Gamma spectrometry remains a very powerful tool for the analysis of radionuclides present in an environmental sample but the basic problem in such measurements is the low rate of detected events. Using large environmental samples could help to get around this difficulty but unfortunately new issues are raised by gamma rays attenuation and self absorption.

Candy et al. (2009) have suggested a new method, to detect and identify without quantification, in a short time, a gamma ray of a low count source. This method does not require, as usually adopted in gamma spectrometry measurements, a pulse height spectrum acquisition. It is based on a chronological record of each detected photon by simultaneous measurements of its energy ε and its arrival time τ on the detector, the pair parameters $[\varepsilon,\tau]$ defining an event mode sequence (EMS). The EMS serials are analyzed sequentially by a Bayesian approach to detect the presence of a given radioactive source. This method, proposed for radioactive contraband detection, has been numerically developed later by Xiang et al. (2013) for radioactive materials detection.

The main object of the present work is to test the applicability of this sequential approach in radioactive environmental materials detection. Moreover, for an appropriate health oversight of the public and of the concerned workers, the analysis has been extended to get a reliable quantification of the radionuclides present in environmental samples. For illustration, we consider as an example, the problem of detection and quantification of ^{238}U.

Monte Carlo simulated experience is carried out consisting in the detection, by a Ge(Hp) semi conductor junction, of gamma rays of 63 keV emitted by ^{234}Th (progeny of ^{238}U). The generated EMS serials are analyzed by a Bayesian inference.

The application of the sequential Bayesian approach, in environmental radioactivity analysis, offers the possibility of reducing the measurements time without requiring large environmental samples and consequently avoids the attached inconvenients.

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Computing Calibration Factor with Visual Monte Carlo - VMC simulations of an accidental contamination with ^{99m}Tc.

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Key Words: MC, VMC, Internal Dosimetry, Accidental Contamination, Internal Contamination.

The Laboratory of Internal Dosimetry of the Center for Development of Nuclear Technology – LDI/CDTN in BH/MG Brazil is responsible for routine monitoring of internal contamination of the Individuals Occupationally Exposed (IOEs). In routine measurement of ^{18}F in the skull of IOEs whose are producing ^{18}F-FDG, it was found an unexpected internal contamination of ^{99m}Tc. The challenging of this work was to assess the activity incorporated through inhalation, of an unknown amount of ^{99m}Tc-DTPA type of aerosol used for therapy purpose in nuclear medicine. This study was divided in two tasks, (1) the validation of the Visual Monte Carlo – VMC model with the experimental calibration of ^{18}F and (2) the calculation of the calibration factor (CF) for ^{99m}Tc. For the validation, the VMC model say, the phantom and the 3"x3" NaI(Tl) detector were modeled and the calibration factor was calculated for the ^{18}F in the skull. The result was compared to the CF calculated in the experimental process. And the same VMC model was used to calculate the CF for the ^{99m}Tc. The calibration factor calculated was then, used to estimate the incorporated activity of the ^{99m}Tc for two extreme possible scenarios based on the distribution of this radionuclide in the body. First case, the contamination of the IOE happened early in the morning and second case, the incorporation of ^{99m}Tc happened later in the same morning. The methodology used to calculate the calibration factors using VMC code, the estimation of the activity incorporate and distribution of ^{99m}Tc in different organs in the body are discussed here.

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Statistical process control analysis of Tomotherapy treatment plans for local delivery guideline

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Key Words: Statistical Process Control, Tomotherapy treatment, quality assurance, gamma analysis.

To establish our institutional guideline for pretreatment Tomotherapy patient-specific plan verification, we statistically evaluate the results of dosimetry quality assurance (DQA) measurements by means of statistical process control (SPC) methods, deriving acceptance limits and DQA performance indices (i.e. capability (C_p) and acceptability (C_{pk}) index).

In order to determine treatment site specific DQA tolerances, the pretreatment DQA results of 200 randomly selected verifications were analyzed, of which only 160 were suitable for SPC analysis: 31 abdomen (Ab), 23 brain (Br), 31 prostate (Pr), 53 lung (L), and 22 head and neck (HN) cancer plans. For these verification, a hybrid plan with the same fluence maps as in the treatment plan was generated on computed tomography images of cylindrical water equivalent uniform phantom. Points of dose measurements using 0.125 cm^3 ion-chamber were typically located in the region of high and uniform doses. The planar dose distributions perpendicular to the central axis of the treatment system were measured by using a gafchromic film inside the middle of the phantom with all hybrid plan delivered. Prior to comparison, each exposed gafchromic was scanned by means of flatbed scanner, and corrected for scanner bow effect and converted in dose by means of homemade software. DoseLab® software was used for dose comparisons, using the gamma index (GI) method with the criteria of 3%/3mm, and dose threshold of 10% of maximum measured dose.

The SPC analysis results obtained by means of X-charts were 99.01%, 96.95%, 98.80%, 98.66% and 92.92% for Ab, Br, Pr, L and HN, respectively, with acceptance limits of 96.78%, 90.75%, 96.37%, 95.45% and 78.54% for the same plans. For these plans, the best results were obtained for Ab, Pr and L plans, having a C_p values of 1.65, 1.41 and 1.21, respectively. Considering that a GI analysis results of 100% represent the top agreement between the hybrid and delivered dose comparison, the goodness of the DQA results for Ab, Pr and L plans was also confirmed by the C_{pk} index, equals to 0.33 for all. The worst results were obtained for Br and H&N plans values, whose C_p index value was 0.59 and 0.25, respectively.

The results obtained from the SPC analysis are based on the assumption that all analyzed data must be "in control", i.e. the whole dataset considered must be between an upper acceptance level (set to 100% for complete agreement between compared doses) and lower acceptance level (i.e. the acceptance limit), obtained as: mean-2sd (being sd the standard deviation of the data set considered "in control"). The SPC analysis considers only those data that respect the acceptance limits derived from its statistical analysis. This means a stringent condition on the data considered, together with the possibility to define the goodness of the results in terms of the potential of the data set to stay within specification limits (C_p) and near one of them (C_{pk}), defining eventual corrective actions to adopt. On this basis and even if in specification for the TG 199, all plans reached good DQA performances, with the exception of Br and H&N, where the ion-chamber position in a uniform target region, but with little target dimensions (for Br plans) and high dose gradient (both for Br and H&N plans), were the principal cause of the little DQA performances.

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Investigating the Self-Assembly of Crown Ether-Carbon Nanotube Hybrid Systems for the Sequestration of Radionuclides

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Key Words: Sequestration, Carbon nanotubes, Crown ether, Radionuclides

The potential use of carbon nanotubes (CNTs) has been investigated in a vast range of technological applications over the years on account of their highly attractive intrinsic properties. These properties include high mechanical strength, electrical and thermal conductivity. Furthermore, an extremely high surface area to volume ratio enables the surface of the CNTs to be chemically functionalised. This potentially enables covalent coupling of mutually beneficial materials such as crown ethers (CEs) to CNTs to form enhanced hybrid nanomaterial systems. It is in this context that such systems may be considered as ideal materials for the sequestration and eventual separation of radionuclides for nuclear medicine applications. Whilst, there has been a great deal of research investigating the delivery of cargo species, such as biomolecules, within singular nanomaterial systems; there exists little research evidence for the self-assembly and delivery of radionuclides within hybrid nanomaterial systems. Therefore, we aim to present a brief report on the progress recently made towards the synthesis of these novel hybrid nanomaterials designed with specific radionuclide loading capabilities. To achieve this aim, a series of microscopic, spectroscopic and X-ray based characterisation techniques are planned to help understand the interaction of radionuclides with hybrid nanomaterial systems.

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Dosimetry Audits and Intercomparisons in Radiotherapy: a Malaysian Profile

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Key Words: Quality audit, intercomparison, radiotherapy, Malaysia

Quality audits and intercomparisons are greatly important in ensuring control of processes in any system of endeavour. Present interest is in control of dosimetry in teletherapy, there being a need to assess the extent to which there is consistent radiation dose delivery to the patient. In this study we review significant factors that impact upon radiotherapy dosimetry, focusing upon the example situation of radiotherapy delivery in Malaysia, examining existing literature in support of such efforts. A number of recommendations are made to provide for increased quality assurance and control. In addition to this study, the first level of intercomparison audit i.e. measuring beam output under reference conditions at eight selected Malaysian radiotherapy centres is checked; use being made of 9 μm core diameter Ge-doped silica fibres (Ge-9μm). In conclusion, following review of the development of dosimetry audits and the conduct of one such exercise in Malaysia, it is apparent that regular periodic radiotherapy audits and intercomparison programmes should be strongly supported and implemented worldwide. The programmes to-date demonstrates these to be a good indicator of errors and of consistency between centres. A total of eight beams have been checked in eight radiotherapy Malaysian radiotherapy centres. One out of the eight beams checked produced an unacceptable deviation; this was found to be due to unfamiliarity with the irradiation procedures. Prior to a repeat measurement, the mean ratio of measured to quoted dose was found to be 0.99 with standard deviation of 3%. Subsequent to the repeat measurement, the mean distribution was 1.00, and the standard deviation was 1.3%.

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Angular dependence of the response of optical fibre Thermoluminescence dosimeters

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Key words: optical fibre, thermoluminescence, angular dependence, Monte Carlo simulation

Optical fibre thermoluminescence dosimeters (TLD) have been studied and developed in recent years because of their potential advantages to be used in radiation therapy and other applications. Practical use of this new option for dosimetry still demands deeper awareness about probable different parameters affecting its precision. One of these aspects which has not been investigated thoroughly, is their angular dependency. Previous studies reported that optical fibre is angular independent due to the isotropic nature of the amorphous structure in optical fibre. In these studies, fibre axis was placed perpendicular to the beam direction which is not the only possibility and may not be practical in real clinical situations. In this study, we investigated the effect of changing the incidence angle of the beam to be parallel, normal or in 45 degrees to the axis of the optical fibre. The thermoluminescence response of fibre after irradiating with kilovoltage (kV) and megavoltage (MV) photon beams with different angles of incidence was measured. Different trends were observed for the responses of fibres to kV and MV photon energies. In case of kV beams, fibre's response increases when the angle changes from parallel to normal condition. With increasing the beam energy, angular dependence disappears for a range of kV beams and then an inverse trend is observed for MV beams. Monte Carlo (MC) modeling was used to explore angular dependency of the absorbed dose in optical fibre under photon irradiations. Different mono-energetic beams and spectrum of photon energies were simulated to clarify the experimental observations. MC simulations confirmed the experimental results and showed different trends in angular dependence for fibres irradiated with kV and MV photon beams. We also investigated the effect of irradiation medium for MV photons and angular dependence effect was compared in three distinct conditions: free-in-air, on phantom surface and inside phantom irradiations. To complement the experiment, the effect of changing fibre dimensions on angular dependence effect was explored by simulation to find probable optimized dimensions to decrease the angular dependence effect. Generally, results indicated a significant differences in absorbed dose in fibre TLDs with changes in the angle of incidence. This can be explained by the micrometer diameter of the fibre and limited range of low energy secondary particles inside the fibre optic. We concluded that practical dosimetry with optical fibre TLDs is not possible without considering remarkable outcome of this study on angular dependence.

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COMPARATIVE EVALUATION OF THE TECHNICAL PERFORMANCE OF DIGITAL MAMMOGRAPHIC AND SCREEN-FILM MAMMOGRAPHY

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Key Words: Mammography Digital, screen-film mammography, image quality, average glandular dose.

Mammography is the best method for breast-cancer screening and is capable of reducing mortality rates. The breast is made of low density tissues that are formed by structures with very close densities; this increases the difficulty to get the contrast that is wanted for the image produced by the x-ray. Other factors that can influence the contrast of the mammographic image are the quality of the radiation, compression of the breast, use of gratings, film-ecran system, and the processing of the films. Digital mammography has been proposed as a substitute for film mammography given the benefits inherent to digital technology. This work intended to get an overview of the mammographic services in the Minas Gerais state concerned to image quality and radiation protection and to compare the technical performance of digital mammographic and screen-film mammography. A PMMA phantom with objects to simulate breast structures and detectors to measure the entrance surface kerma were used to evaluate both the performance of the mammography and the processing units and the image quality. The average glandular dose can be obtained by methods based on the measurement of the incident kerma (K_i) associated with the tabulated conversion factors that depend on the half-value layer of the composition of the glandular breast and breast thickness compressed. For the screen/film (SF) technique the results showed that 54 per center mammography units did not achieve the minimum acceptable performance as far the image quality. Besides, 67 per center services showed inadequate performance in their processing systems, which had significant influence on the image quality. At the mean glandular dose only 44 per center of digital systems evaluated were compliant in all thicknesses of PMMA. The Dg was 60 per center higher than in screen/film systems.

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Kinetic, isotherm and thermodynamic modelling for radioactive cesium removal from aqueous solution by modified conducting polymer: A radiotracer study

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Key Words: Adsorption, conducting polymer, nuclear activation, cesium radioisotope, kinetic, isotherm, surface morphology

Increasing population growth and modern industrialization have contributed immensely to the shortage of clean water supply and the increasing rate of water body pollution across the globe. Among the most active pollutants in the water and wastewater today is ^{137}Cs radioisotope which takes its origin from the use of radioisotopes in medicine, operation of nuclear power plants, mining and milling industries. Because of its acute toxicity, non-biodegradability, long physical half-life and easy migration within the environmental compartments, ^{137}Cs creates serious problems once ingested into the body via various routes. Therefore, it is important to remove ^{137}Cs from the aqueous industrial wastes before disposal into water and landfills for human and animal safety. Some conventional methods such as chemical precipitation, biosorption, ion exchange, membrane process, adsorption, etc are found efficient and effective for the removal of pollutants from water and wastewater. However, adsorption is widely accepted as the most economically viable in developing nations owing to easy operational requirements, available low cost materials and possible reusability. As a result, a novel polypyrrole-grafted granular activated carbon composite adsorbent was prepared for the adsorption of ^{137}Cs from its synthetic radioactive waste solution. The aim of this research work is to enhance the sorption capacity of polypyrrole conducting polymer for ^{137}Cs by the grafting approach. Since the adsorbent preparation method plays a vital role in sorption process, particular attention is made to the preparatory conditions of the composite adsorbents. Several factors were tested on the adsorption process to optimize the application of the adsorbents on wastewater treatment. The as-prepared composite adsorbents were characterized for surface morphology, functional groups, thermal stability and particle surface area by FESEM-EDAX, FTIR, XRD, TGA-DSC and BET analysis, respectively. The composite adsorbents exhibited good radiation stability and high sorption capacity for ^{137}Cs.

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Radiation Levels and Image Quality in Patients Undergoing Chest X-ray Examinations

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Key Words: patient dosimetry; X-ray chest examination; radiation protection

Patient dose monitoring for different radiographic procedures has been used as a parameter to evaluate the performance of radiology services; skin entrance absorbed dose values for each type of examination were internationally established and recommended aiming patient protection. In this work, a methodology for dose evaluation was applied to three diagnostic services: one with a conventional film (A) and two with digital computerized radiography processing techniques (B and C). The x-ray beam parameters were selected and "doses" (specifically the entrance surface and incident air kerma - $K_{a,e}$ and $K_{a,i}$, respectively) were evaluated based on images approved in European criteria during postero-anterior (PA) and lateral (LAT) incidences. For evaluation the image quality parameters, radiologists scored images according to European Community criteria. Data were collected from 200 patients related to 200 PA and 100 LAT incidences. Results showed that doses distributions in the three diagnostic services were very different. The $K_{a,i}$, evaluated in clinic A for chest examinations in PA incidences was about six times lower than the $K_{a,i}$ from other clinics, for a similar image quality. The average $K_{a,e}$ in patients of the clinic A was 0.06 ± 0.03 mGy, whereas for the clinic B, average $K_{a,e}$ was 0.29 ± 0.10 mGy and for clinic C 0.40 ± 0.12 mGy. The expanded uncertainties are given for a coverage factor k equal to 2. The best relation between dose and image quality was found in the institution with the chemical film processing. This work contributed for disseminating the radiation protection culture by emphasizing the need of a continuous dose reduction without losing the quality of the diagnostic image.

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ESTIMATION OF BREAST DOSE AND CANCER RISK IN CHEST AND ABDOMEN CT PROCEDURES

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Key words: CT chest and abdomen, radiation dose, radiation risks

Objectives: The aims of this study were to measure patient doses during CT chest and abdomen procedures, estimate the radiation dose to the breast, and to quantify the radiation risks during the procedures.

Methodology: A total of 30 female patients were investigated in this study (12 chest CT procedure and 18 CT abdomen procedures). The patient's dose values were obtained from four hospitals in Khartoum. The departments were equipped with CT four different CT modalities. Data were collected to study the effects of patient-and exposure-related parameters. The organ dose conversion factor f (organ, z) was obtained from the NRPB datasets (NRPB-SR279) based on the Monte Carlo simulations.

Results: The mean patient dose values (DLP) were 165.9-3353.0 mGy.cm and (217.5-1790) mGy.cm for CT, chest and abdomen procedures respectively. Radiation dose to the breast ranged from1.6 mSv to 32.8 mSv for the chest and 2.3 mSv to 18.8 mSv for the abdomen. The overall patient radiation risk estimation for fatal cancer per procedure was found to be 8.1 × 10-6.

Conclusions: It was concluded that current clinical chest and abdomen protocols result in very high radiation doses to the breast. A large variation of mean organ doses among hospitals was observed for similar CT examinations. These variations largely originated from CT scanning protocols used in different hospitals as well as scanner types. Lack of trained personnel and absence of breast shielding during CT abdomen are additional sources of increased dose to the patients.

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Computed tomography Dose Index and dose length product during Abdominal Investigations As radiation Dose Indicators

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Key Words: Computed tomography, Abdomen, DLP, CTDIs

Introduction: The study addressed the measurement of radiation doses indicators during abdominal CT investigation by computed tomography, as the results of a relatively high doses for patients during this type of examinations, so study aimed to measure these indicators and then compared the results with different literature.
Materials and methods: The radiation doses indicators were measured for number of 29 patients at King Abdul Aziz Specialist Hospital in Taif after bio-data (height, weight and body mass index) was recorded , computed tomography dose index (CTDI) and dose length product (DLP) have been used to indicate the radiation dose ,which were pre-existing on computed tomography devices made by Siemens. And then a Microsoft Excel program used to analyze the data, in turn interpreted in the form of graphs and curves.
Main results: The average CTDI and DLP for CT abdomen was 13.56 ± 3,98, 538,3 mGy per centimeter ± 193,4 respectively. Also study revealed that there was correlation between CTDI and DLP, also correlation between patient body mass Index and DLP was found , No a correlation between the time and DLP or even between ages and CTDI were gathered .
Recommendations: The study recommended the establishment of local diagnostic references level corresponded to international diagnostic references level if available.

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DOSE ASSESSMENT AND CANCER RISK FOR CHILDREN AND ADULTS FOR PROTOCOL HEAD AND CHEST IN SEVERAL MULTIDETECTOR TECHNOLOGIES

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Key words : Dose Dosimetry in CT , Cancer Risk .

Summary

Computed tomography (CT) is a diagnostic method that has grown in recent years. This growth has brought as a consequence the increase of the collective doses. For better image quality, it is common in clinical practice the use of adult skull protocols in children due to bone formation of the skull. Even low levels of radiation is important to assess the risk of asymptomatic patients, especially involving children. This study aims to estimate and compare the equivalent dose in the skull, lens and thyroid for a skull routine protocol and lung and breast tenderness for chest routine protocol in two CT scanners Siemens 64 and 128 detectors using the Impact software CT and estimate the risk of cancer induced by radiation at different ages according to the recommendations of the BEIR VII Committee. The highest value obtained was 6.4 mGy to the breasts in routine protocol chest and 22mGy for the crystal skull routine protocol in CT scanners 128 and 64 detectors respectively, decreasing with age.

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Comparison of the Evaluated Neutron Spectra between the methods of Traditional and Extended-Range Bonner Spheres

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Key Words: Bonner spheres, Extended-Range Bonner Spheres, gold foil, neutron spectrum

For heavy-charged particle therapy, such as Boron Neutron Capture Therapy (BNCT) and the high-energy proton beam of radiation–therapy, can produce the alpha particles or protons to kill the tumor cells precisely and make the normal tissue less damage. Although there are many advantages of BNCT and proton therapy, the secondary particles should be concerned. Among the induced secondary particles, neutrons are of primary concern due to their high relative biological effectiveness and would make the unexpected dose to patients. This work using the traditional and extended-range Bonner-sphere spectrometers to investigate neutron spectrum that can provide us the information regarding the induced secondary neutrons.
According to previous studies, the traditional Bonner sphere spectrometer is not sufficient to measure high energy neutron field, a series spheres called extended-range Bonner sphere were made in this study. Monte Carlo code: MCNPX was used to calculate the response functions for both traditional and extended-range Bonner-sphere systems. Gold foils were used with the Bonner sphere system to measure neutron spectrum from a standard neutron source Californium 252 for calibration. Besides, the neutron spectrum of neutron beam for Boron Neutron Capture Therapy (BNCT), performed by Tsing Hua Open-pool Reactor in National Tsing-Hua University, was estimated by both methods. Both estimated spectrum results were analysed and compared. From the MCNPX result shows that self-made Bonner spheres have the higher response function than tradition spheres in high energy range.

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Patients' organ dose and risk assessment in interventional cardiology procedures

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Key Words: organ dose estimation, LAR risk assessment model, interventional cardiology, Monte Carlo.

Interventional cardiology (IC) procedures can be complex, leading to long exposure times and a prolonged use of fluoroscopy and resulting in patient exposure to high radiation doses. This excessive radiation exposure may cause deterministic effects and increase the risk of stochastic effects. Therefore, this work aimed at estimating the absorbed doses received by target and critical organs, and at assessing the lifetime attributable risk (LAR) for patients in interventional cardiology procedures.

A female voxel phantom, LAURA, has been implemented to get a more realistic description of the human body anatomy. Using the Monte Carlo computer program PENELOPE we calculated the organ doses per dose-area product (DAP), both in target and critical organs, for typical projections used in IC procedures: posterior-anterior (PA), right-anterior-oblique at 30° (RAO30), left-anterior-oblique at 45° (LAO45) and right-lateral (RLAT). Two x-ray beam energies, 80 and 100 kVp were considered. In order to get the organ doses, an evaluation on a demographic patient data, accessed from patients' database, was made to obtain the median values of DAP for two IC procedures: coronariography (CA) and coronary angioplasty (PTCA). For the risk analysis, the LAR was determined by multiplying the absorbed organ doses by the appropriate risk factors defined at BEIR II report.

The obtained results show that for the target and critical organs the higher value of dose/DAP was observed for the projection RAO30, using both energies. An exception was observed for the breast and stomach, receiving higher dose/DAP for RLAT projection. Our results also indicate that, despite the projection or energy, the lung was the organ in which the dose/DAP coefficient was higher. Consequently, LAR analysis showed that the risk of lung cancer incidence is, up to 20 times, higher compared with other critical organs such as breast and thyroid, considering the RAO30 projection and a 100 kVp x-ray beam. Our results pinpoint that patients follow-up is crucial due to the higher risk of cancer incidence (e.g lung cancer incidence of 1/585).

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P101

Study of Dose Profile in Head CT Scans

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Key Words: dosimetry, computed tomography, medical images

The diagnostic images of computed tomography (CT) generate higher doses than those generated by other methods of diagnostic radiology using X-ray beam attenuation. Technological advances have increased the clinical applications of CT scans causing the Brazilian technological park presenting a wide variety of scanners. Dose reduction strategies are difficult to implement because of the lack of proper guidance on computed tomography examinations. However, the TC scanners present possibilities of acquisition parameter adjusts according to the patient's physical profile and diagnostic application for which it is intended the scan. The knowledge of the dose distribution is important when thinking about changes of image acquisition parameters aiming at reducing the dose. In this work, we used a cylindrical head phantom in PMMA with 5 openings that allow dose measurement in 5 regions. In a GE CT scanner, Bright Speed model of 4 channels, the central slice of the head phantom was irradiated and the doses were measured using a pencil ionization chamber. Radiochromic film strips were placed in the peripheral and in the central region of the head phantom and was performed a scan of 10 cm in the phantom central region. The scan was performed using the head scanning protocol of the radiodiagnostic service, with a voltage of 120 kV. After scanning, the radiochromic film strips were digitalized and their digital images were used to have the dose longitudinal profiles. The dose values recorded have variation in a range of 21,61 to 23,16 mGy. The results compare the dose index values obtained by the pencil chamber measurement with the dose longitudinal profiles recorded by the film strips.

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P102

Development of a chest phantom for testing in Computed Tomography scans

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Key Words: chest phantom, dosimetry, computed tomography

Computed tomography (CT) has been one of the most important radiological techniques in medical uses of radiation. Widespread use of this technique has a significant increase in population dose. The risk associated with a radiological examination may be considered quite low compared to the natural risk. However, any additional risk, no matter how small, is unacceptable if it don't bring a benefit to the patient. Knowledge of the dose distribution is important when thinking about varying the acquisition parameters in order to reduce the dose. The aim of this study is to evaluate, in scanning of the chest, the variation of dose in CT between regions using two phantoms chest. In this study we used a cylindrical chest phantom made in polymethylmethacrylate (PMMA) and a second object was developed in PMMA with the same volume and an oblique shape, based on the dimensions of an adult human chest. The two phantoms have five openings, one central and four peripheral out of phase 90°, which allow to place a pencil chamber aimed to measure doses in 5 positions. In a CT scanner GE, Discovery model with 64 channels, the central slice of the two phantoms were irradiated successively to obtain dose measurements using the pencil chamber. The central slice irradiation was performed using the acquisition protocol to chest scan of the radiology service. From the measurements obtained in the five points of the object it is possible to compare the variation of radiation dose for the object shape. The dose values recorded demonstrated that the the oblique phantom with the nearest human chest shape showed higher doses, specially in the anterior, posterior and central region. The results allowed the comparison of the CT dose index obtained from measurements with the pencil chamber.

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Response Evaluation of a phosphor plate used in CR mammography

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Key Words: computed radiography, mammography, medical images

According to the National Cancer Institute of Brazil about of 57,120 new cases of breast cancer occurred in 2015. Mammography today is one of the most widely used imaging techniques around the world for the early diagnosis of breast cancer. The boards of computed radiography (CR) are used to obtain digital radiographies, and are widely used in Brazil for digital mammogram production. This work aims to evaluate the response of a mammographic CR plate in expositions on a mammography device. To carry out the study was used a mammographer Graph AF Mammo VMI and a mammography CR plate model Regius. Using two beams of 30 and 35 kV were made successive exhibitions of the CR plate doing a variation of exposure time in a range of 0.5 to 2.5 s. These expositions were held to obtain images and later for the measurement of time, dose and dose rate using a Ray Safe Xi, with five steps to each exposure time. From the raw images *.raw* using imageJ software was selected in the central region of each image an array of 21 x 21 pixels and obtained the darkening value for each exposure time. From these data was made a correlation of the degree of the image darkening with the exposition time and the air Kerma. The two curves obtained showed that the behavior of the average values of the central pixels with time and air Kerma variations are similar to two voltages, an initially linear behavior and then a plate saturation region, which occurs first at the greatest value of the voltage applied. The knowledge of the saturation characteristics versus exposure times allow the choice of the most suitable parameters of time to work with these stresses without approaching the saturation of the CR Board. Two select images obtained for each X-ray beam in linear response region were used to show the darkening variation in the plate area. The darkening area presented a variation of 11.48% and 7.11% to the voltage of 30 kV and 35 kV, respectively.

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Radiochromic Film Calibration for the RQT9 Quality Beam

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Key Words: radiochromic film, dosimetry, computed tomography

When ionizing radiation interacts with matter it generates energy deposition. The radiation dosimetry is important for the medical applications of ionizing radiation, due to increasing demand for diagnostic radiology and radiotherapy. Different dosimetry methods are used and each one has its advantages and disadvantages. The film is a dose measurement method that records the energy deposition by the darkening of its emulsion. The radiochromic films have little visible light sensitivity and respond better to exposure to ionizing radiation. The aim of this study is to obtain the resulting calibration curve by the irradiation of radiochromic film strips, making it possible to relate the darkening of the film with the absorbed dose, in order to dose measurement in experiments with X-ray beam of 120 kV, in computed tomography (CT). The film strips of GAFCHROMIC XR-QA2 were exposed according to RQT9 reference radiation, which defines an X-ray beam generated from a voltage of 120 kV. The strips were irradiated in the "Laboratório de Calibração de Dosímetros do Centro de Desenvolvimento da Tecnologia Nuclear" (LCD / CDTN) at a dose range of 5 to 30 mGy, corresponding range values commonly found in CT scans. Digital images of the irradiated films were analyzed using the ImageJ software. The darkening responses on film strips according to the doses were observed and allowed the obtaining of the corresponding numeric values to the darkening of each specific dose value. From the numerical values of darkening was obtained a calibration curve, which correlates the darkening of the film strip with dose values in mGy. The calibration curve equation is a simplified method for obtaining dose absorbed values using digital images of radiochromic films irradiated. With the aid of the calibration curve, experiments on TC scans using X-ray beam of 120 kV, we can apply radiochromic films on their dosimetry and thus make imaging with diagnostic quality which are acquired with protocols that promote lower dose deposition.

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P105

Pechini´s Modified Method to prepare LaAlO3:RE Thermoluminescent materials

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Key Words: Lanthanum Aluminates, dosimetry, Thermoluminescence, Pechini Method

This work presents an alternative method to synthesize rare-earth doped lanthanum aluminates materials for thermoluminescent (TL) dosimetry applications. Pechini´s modified method was using to prepare praseodymium doped $LaAlO_3$ powders. $LaAlO_3:Pr^{3+}$ powders were prepared $La(NO_3)_3 \cdot 6H_2O$, $Al(NO_3)_3 \cdot 6H_2O$, $Pr(NO_3)_3 \cdot 6H_2O$, citric acid, and ethylene glycol. The solution was heated to 80 °C for its polyesterification reaction. The obtained powders were submitted at different thermal treatment from 800 up to 1600°C. The structural and morphological characterization were carried out using X-ray diffraction (XRD) and scanning electron microscopy techniques. TL glow curve of the X-ray irradiated samples showed two peaks centred at 200 and 300°C respectively. This TL material appears to have potential application for X-ray dose measurements. The technique is low cost, faster and produces well very homogeneous particles TL materials that can be used for X-ray dosimetric applications.

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P106

Pechini´s Modified Method to prepare LaAlO3:RE Thermoluminescent materials

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Key Words: Lanthanum Aluminates, dosimetry, Thermoluminescence, Pechini Method

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Whole-body ^{18}F-FDG PET-CT scanning: radiation levels for oncologic diagnosis

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Key Words: PET-CT, ^{18}F-FDG, dose estimation, whole-body scanning

The PET -CT is a method capable of detecting with great precocity minimum tumor areas (up to 4 mm) that can´t be seen in other tests, but later, when the tumor already has large and therefore more serious for the patient. PET- CT is a diagnostic technique that combines techniques nuclear medicine (PET), which gives rise to metabolic images, and radiology (CT), responsible for producing anatomic images, thus producing an image only with anatomical and functional information. To determine the effective dose from PET-CT exam was used two steps, one to determine the effective dose contribution caused by CT and another to evaluate the contribution from the radiopharmaceutical activity. For the evaluation of the effective dose from the CT imaging modality was used lithium fluoride thermoluminescent detectors activated with magnesium and titanium (LiF: Mg, Ti - TLD-100) Rod, inserted in anthropomorphic Alderson Randon® male phantom points corresponding the most radiosensitive organs and greater likelihood of exposure. After thermoluminescent detectors insertion, the phantoms were subjected to the same protocol of image acquisition which the patients were submitted, and the irradiation field of the CT skull base at the root of the thigh. As for the contribution determiner effective dose of the PET, we used estimates according to the biokinetic model proposed by ICRP 106 for the radiopharmaceutical 18F-FDG. In diagnostic PET scans, the activity radioactive injected into the patient is calculated based on their body mass. This work was considered a factor of 3.7 MBq / kg of patient. The average effective dose from the examination of PET-CT protocol for cancer study was (8,51 ± 0,17) mSv in male patients and (5,80 ± 1,57) mSv in female patients. Exams in male patients were possible to observe the high level of radiation in the thyroid, since this organ dose is derived mostly by CT irradiation, since this body is within the field of radiation during CT image acquisition. Exams in female patients was possible to observe the high level of radiation in the bladder, marrow and stomach, since this organ dose is derived mostly by CT irradiation, since this body is within the field of radiation during CT image acquisition. The effective dose from CT corresponds to approximately 43% of the effective dose in a PET-CT. Study about dose reduction in PET-CT exams is necessary to the reduction radiation levels during CT image acquisition and activity factor for mass patients decreased for ^{18}F-FDG incorporation and image acquisition of PET.

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Monte Carlo Based Calibration Of An Airborne radioactivity monitoring system

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Key Words: Monte Carlo, air monitoring

Air monitoring in nuclear medicine laboratories is part of the internal dose assessment program to evaluate the radiological conditions in all areas potentially contaminated with airborne radioactivity. Monte Carlo simulations offer a practical way to calibrate systems composed by gamma detectors measuring the airborne activity in a controlled geometry.
In this study, the calibration through Monte Carlo simulation of a NaI(Tl) detector inserted into a chimney with intake in a controlled area is presented. The absolute detection efficiency for the full-energy peak is presented for photons of different energies and for beta+ emitters.
Simulated spectra will be compared with the ones observed in the clinical practice.
The systematic uncertainties affecting the efficiency calibration constants are estimated through the comparison of the results obtained by varying the simulation parameters.

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Application of PTTL (phototransferred thermoluminescence) method for dose reassessment in individual and extremity dosimetry

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Key Words: dose reassessment, phototransferred thermoluminescence (PTTL), MTS-N (LiF:Mg,Ti), individual dosimetry

Reassessment of doses in film and OSL dosimetry is well known and standard method in contrary to TL dosimetry. By using the phototransferred thermoluminescence (PTTL) method which consists of the first readout, UV exposure and second readout it is possible to reassess doses in TL dosimetry. This method was applied to reassess doses in whole body and ring dosimetry.
Standard MTS-N (LiF: Mg,Ti) sintered detectors (4.5 mm diameter and 0.9 mm thickness for whole body dosimeters and 0.7 mm thickness for ring dosimeters) have been applied. Some of them were used in routine control for 12 years long. The TL detectors were read in automatic RE2000 (Rados Oy, Finland) readers. After readout the PTTL method was applied. Detectors were subjected to UV radiation (254 nm length) and read once again.
The PTTL method was applied to dose reassessment in individual and ring dosimetry. Due to checking behaviour of different detectors from different batches and different dose history it is possible to observe influence of residual dose to the PTTL effect. The reassessed doses are observed to be linear over the dose range 5-100 mSv in individual and 5-1000 mSv in ring dosimetry.
The dose reassessment method based on PTTL phenomenon elaborated in LADIS Laboratory was applied to MTS-N detectors used in individual and ring dosimeters. Due to applying this method it is possible to reassess dose and check the measurement correctness. It is especially required in case when the dose excided the annual dose limit.

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Dosimetric Evaluation of Radiographic Examinations of Premature Patients During their Hospitalization Period in a NIC Unit

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Key Words: premature patients, chest radiographies, abdomen and combined chest–abdomen radiographies, entrance surface air kerma

The objective of this study is to evaluate the radiation dose received by premature newborns during their stay in a NICU.

We studied the examination histories of the patients with a birth weight of less than 1500 g hospitalized in the NICU of a pediatric public hospital in Curitiba (Brazil) between January 2013 and December 2014. Full-term patients with birth weight greater than 1500 g and patients who died during the hospitalization period were excluded from the analysis. The histories of the 57 premature babies with an average birth weight of 1128 g and an average gestational age of 29 weeks were included in this study. The average time of permanence in the NICU was 73 days. 1128 radiographies were performed, giving an average of 20 radiographies per patient.

The entrance surface air kerma was calculated based on the X-ray equipment output and the exposure parameters of each examination. On average, patients received 14 μGy/day during their stay in the NICU. It was found that with the increase of hospitalization time the dose rate increases.

We also analysed characteristics such as number of radiographies and cumulative dose as a function of birth weight and dose in one examination vs patient weight.

Work supported by CNPq, CAPES and Fundação Araucária.

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Staff Dose Evaluation through Parameters Optimization in Pediatric Barium Meal Examinations

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Key Words: occupational dosimetry, upper gastrointestinal tract, dose reduction

This work was done in one of the largest pediatric hospitals in Brazil. The aim of this study was to adjust the radiation techniques used in this hospital to the European Communities' recommendations for pediatric barium meal procedures (European Communities, 1996) and to evaluate the change in equivalent dose in the region of the lens, thyroid and hands of two staff members.
49 patients before the optimization and 44 patients after the optimization were studied. For each patient, anthropometric information and technical parameters of each procedure were registered.
For the analysis of occupational equivalent doses, LiF:Mg,Cu,P thermoluminescent dosimeters, in pairs, were positioned near the eyes, on the thyroid shield and on each hand of both professionals who remained inside the room.
During the optimization, the following technical parameters were reduced: number of spot films, total fluoroscopy time, field size area, current-time product and exposure time (in spot films). Also, some technical parameters were increased, such as: kVp (in spot films) and the focus-detector distance. They became adequate to the European Communities' recommendations. At the same time, both staff members were instructed to remain the shortest time possible inside the examination room and as far as possible from the patient (when remaining inside the room).
It was found that after the optimization the annual equivalent doses in all regions became lower than the international guidelines and that 67% of the results from other studies were above the present results.
Work supported by CNPq, CAPES and Fundação Araucária.

European Communities, 1996. European Guidelines on Quality Criteria for Diagnostic Radiographic Images in Paediatrics. Office for Official Publication of the European Communities, Luxembourg.

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P112

Dose evaluation in Pediatric Patients Undergoing Chest X-ray examinations

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Key Words: dosimetry, entrance surface air kerma, phantom, newborn

The aim of this study was to evaluate the entrance surface air kerma in pediatric chest radiography in one of the largest pediatric hospitals in Brazil.
A follow up and evaluation of 300 radiographical examinations in anterior–posterior (AP) and posterior–anterior (PA) and lateral (LAT) projections was done.
Data were collected from patients such as height, weight, sex, age. Clinical indication and the repetition rate of the examinations with their justification and physical parameters, such as the techniques employed were also collected. The radiation output was measured with a calibrated ionization chamber. The analyses were performed on patients grouped by age; the groups included ages 0–1y,1–5y, 5–10 y, and 10–15 y. The entrance surface air kerma was then determined. The results obtained were compared with other investigations and the reference dose values established by the European Community.
Work supported by CNPq, CAPES and Fundação Araucária.

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Dosimetric Simulation in Newborns Undergoing Chest X-ray Exams through the Caldose_X Software

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Key Words: dosimetry, Monte Carlo simulation, phantom, newborn

The objective of this study is to estimate the average dose absorbed in the lungs and the effective dose received by newborns admitted to a Neonatal ICU who underwent radiographs of the chest and to calculate the estimated risk of cancer incidence in the same sample of newborns.
This work was carried out with the Caldose_X software, which is based on the Monte Carlo method.
25 chest exams were followed in the antero-posterior projection, performed in a large pediatric hospital in Brazil. The sample is composed of different newborns, up to 28 days of age, premature and not premature, both male and female, with weights ranging from 590 grams to 3,545 grams.
Information was collected regarding the radiographic techniques applied to each exam, such as: kVp, mAs, focus-detector distance and image receptor size used.
To obtain the Kerma-air in the skin entrance surface, the same information collected was reproduced in exams with a newborn phantom, in which thermoluminescent dosimeters were placed on the chest region.
The results of the study for the average absorbed dose, effective dose and the estimated risk of cancer incidence were compared with results obtained by other similar studies.
Work supported by CNPq, CAPES and Fundação Araucária.

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Development of an Optimized Methodology to Measure Low Radium Activity Concentration in Water

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Key Words: radioactivity, radon, radium, water, activity measurements

This work addresses a new methodology for measuring low ^{226}Ra activity concentration in bottled mineral water commercialized in Brazil. It makes use of a modified RAD7 (Durridge Company) experimental setup developed to measure as low as 0.1Bq/L of ^{226}Ra activity by means of ^{222}Rn activity measurements in secular equilibrium. This modified apparatus was achieved by implementing valves, which allow switching samples, cleansing radon from within the system and drying up the air without external contamination. Furthermore, this new methodology leads to measure and decrease the background, as well as reduces statistical errors by repeating the WAT250 protocol four times. Also, in between the experiments, the air is dried up. This optimized methodology showed that 24 tested samples of bottled water had activity concentration below the limits established by the World Healthy Organization (WHO) and their values agree with those already found in the literature. Therefore, this modified RAD7 setup can be successfully used to measure ^{226}Ra concentration activity as low as 0.1Bq/L in water.

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Incident Air Kerma and Mean Glandular Dose Measurements for Augmented Breasts Mammograms

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Key Words: digital mammography, incident air Kerma, mean glandular dose, augmented breasts

We have measured the incident air Kerma ($K_{i,a}$) and the Mean Glandular Dose (MGD) for patients with augmented silicone breast implants who underwent mammography examinations in digital mammographs.

140 examinations were evaluated in a clinic in Curitiba, Brazil using the American College of Radiology (ACR) and the European Organization for Quality Assured Breast Screeening and Diagnostic Services Protocol (EUREF) protocols.

The average range, and minimum and maximum values of the following parameters were collected: kVp, mAs, compressed breast thickness (CBT) in routine medio-lateral oblique projection (MLO), cranio-caudal projection (CC) views and Eklund modified compression technique in MLO and CC views for the right and left breasts of female patients.

The $K_{i,a}$ was measured in the beam radiation with a 6 cm^3 ionization chamber, calibrated for a mammography range of energy. A standard ACR mammographic phantom was used for the measurements.

The obtained results of $K_{i,a}$ and MGD were compared with literature data for women without prosthesis, with other similar investigations and with the reference dose values established by the European Community.

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Assessment of Human Exposure to Radon and Other Radioisotopes Present in Building Materials of Workplaces

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Key Words: radon, radioisotopes, workplaces, building materials

The purpose of the present work was to evaluate the activity concentration of ^{222}Rn and other radioisotopes related to building materials at workplaces in Curitiba, Brazil.
The instant radon detector AlphaGUARD (Saphymo GmbH) was used to measure the average concentrations of ^{222}Rn in building materials, which were also submitted to gamma spectrometry analysis for qualitative and quantitative evaluation of the radionuclides present in samples of sand, mortar, blue crushed stone, red crushed stone, concrete and red bricks.
The main radionuclides evaluated by gamma spectrometry in building material samples were ^{226}Ra, ^{232}Th and ^{40}K.
The results of the survey presented the concentration values of ^{222}Rn related to construction materials in a range from 427 ± 310 Bq/m³ to 2053 ± 700 Bq/m³.
The results of gamma spectrometry analysis show that specific activity values for these isotopes are similar to the results indicated by the literature. Nevertheless, the present survey is showing the need of further studies and indicates that building materials can contribute significantly to indoor concentration of ^{222}Rn.
Work supported by CNPq, CAPES and Fundação Araucária.

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Determination of Levels of Naturally Occurring Radioactive Materials in Lagoon Samples Containing Produced Water from the Minagish Oil Field in the State of Kuwait

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Keywords: Secular equilibrium; HPGe detectors; gamma-ray spectrometry; Naturally Occurring Radioactive Materials.

Abstract

An evaluation of the activity concentration associated with both naturally occurring has been undertaken as part of a systematic study to provide a radiological map of a Wastewater lagoon located in the Minagish oil field in the south west of the State of Kuwait. The lagoon contains material from the discharge of produced water which is a by-product of oil production in the region. The lagoon samples have been prepared and placed into sealed, Marinelli beakers for a full gamma-ray spectrometric analysis using a high-resolution, low-background, high-purity germanium detection systems. Of particular interest are the calculation of the activity concentrations associated with members of the decay chains following decays of the primordial radionuclides of the ^{238}U chain (^{226}Ra, ^{214}Pb, ^{214}Bi) and the ^{232}Th chain (^{228}Ac, ^{212}Pb, ^{208}Ti). The paper presents an overview summary of the experimental samples which have been analyzed to date.

The Evaluation of the characteristics of high-energy electron beams with N-isopropylacrylamide gel dosimeter

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Key words: Electron beam, n-NIPAM gel, Percent Depth Dose

The advantage of electron beam radiotherapy is that the absorbed dose rapidly decreases with the depth increases, which can avoid damage to deep tissue. Therefore, accurately and simultaneously evaluating the absorbed dose of the superficial tumor and deep critical organs is imperative. This study assessed the characteristics of electron beams with the N-isopropylacrylamide (n-NIPAM) gel dosimeter. The n-NIPAM gel dosimeter was composed of 6% gelatin, 5% monomer, and 2.5% cross-linker with 5 mM tetrakis (hydroxymethyl) phosphonium chloride for deoxygenation. The gel was irradiated with 6–12 MeV electrons with a dose rate of 100–600 MU/min and readout by computed tomography. The energy dependence and dose rate dependence of the electron beam were assessed, The percent depth dose (PDD) was measured and compared with the results of the ion chamber and gafchromic film. The readout of the gel was through computed tomography. The linearity of the 6-, 9-, and 12-MeV electrons was 0.992, 0.990, and 0.990; the energy dependence was minimal. The sensitivity of 100-, 200-, 300-, 400-, 500-, and 600- MU/min were 0.546, 0.546, 0.530, 0.550, 0.516, and 0.528 HU/Gy, respectively; the maximum difference was 6%. The results of PDD among the n-NIPAM gel dosimeter, ion chamber, and gafchromic film were consistent. Previously, gel dosimeters are used in photon beam measurement. This study revealed that the possibility of using the n-NIPAM gel dosimeter in electron beam measurement, which could be further used in quality assurance of electron radiotherapy.

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Dosimetric Characteristics of Fabricated Ge-Doped Silica Optical Fibre for Small Field Dosimetry

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Key Words: fabricated Ge-doped silica fibre, thermoluminescence, megavoltage radiotherapy, small field dosimetry

A study is presented on the dosimetry characteristics of the fabricated Ge-doped Silica optical fibres intended for use in small field dosimetry specifically, stereotactic radiosurgery (SRS). In small field dosimetry, the dosimeter size relative to the treatment field size is imperative, especially in measuring output factors, central axis depth dose distribution and cross-beam profiles. The charged particle disequilibrium exists when the detector size is not well encompassed by a uniform radiation field size, resulting in dose deviation from the intended treatments. In our study, the usage of in-house fabricated Ge-doped silica fibres of 3 mm in length overcomes the issues mentioned earlier and yields better spatial resolution. The thermoluminescent (TL) properties of these fibres have been investigated, namely two types of in-house fabricated Ge-doped Silica optical fibre (cylindrical and flat in shape) and the commercial Ge-doped Silica optical fibre (CorActive, Canada). The mapping analysis of EDX shows that the composition of the Ge in the in-house fabricated cylindrical fibres is 2.58 weight%. This composition is relatively higher than the commercial fibre with Ge composition of 1.40 weight%. Prior to the TL studies, screening of the samples was carried out to ensure the TL responses with coefficient of variation less than 5%.This was done for a group of 12 to 15 fibres selected from a batch of similar type of fibres with mean readings ± 5%. The effect of the heating rates on the shape of the glow curves of fibres is presented. The glow curves serve the criteria in choosing specific time-temperature profile setups in the TL readout of the silica fibres. Subsequently, the desirable characteristics study of the fibres when exposed to 6MV photon beams were carried out. In this study, we have included dose linearity, reproducibility, fading rate, and angular dependency. A perspex phantom was designed to study the angular dependency of the fibres, in which the fibres were positioned in this rotatable phantom at 0° to 90° with 15° increments and irradiation field size of 5 x 5 cm^2. The TL readout using a Harshaw 3500 reader with a heating rate of 30°Cs^{-1} was chosen. The average TL responses of 161 flat fibres and 131 cylindrical fibres are 141.6 nC and 852.1 nC respectively, as compared to the average TL responses of 259.3 nC for 190 commercial fibres.

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Estimate of S-values for children due to six positrons emitting radionuclides used in PET examinations

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Key Words: Positron emission tomography, Monte Carlo, Absrobed specific fractions

The positron emission tomography (PET) has revolutionized the diagnosis of cancer since its inception. When combined with computed tomography (CT), PET/CT performed in children produces a diagnosis of high accuracy on the images of regions affected by malignant tumors. Considering the high risk for children when exposed to ionizing radiation, a dosimetric study for PET/CT procedures is necessary. Absrobed specific fractions (SAFs) were determined by monoenergetic photons and positrons, as well as the S-values for six emitting radionuclides (C-11, C-13, F-18, Ga-68, Rb-82, O-15), and 22 source organs. The study was conducted for six pediatric anthropomorphic hybrid models, including the newborn and 1 year hermaphrodite, 5 and 10-year-old male and female, using the code Monte Carlo N-Particle eXtended (MCNPX) version 2.7.0. The results of the SAFs in source organs and S-values for all organs were inversely related to the age of the phantoms, which includes the variation of body weight. The results also show that radionuclides with higher energy peak emission produces S-values self-absorbed higher due to local deposition of doses by positrons decay. The S-values for the source organs are considerably larger due to the interaction of tissue with non-penetrating particles (electrons and positrons) and have a linear relationship with the masses of the bodies. The results of the S-values determined for positron-emitting radionuclides can be used to assess the radiation dose delivered to pediatric patients subjected to PET examination in clinical settings.

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Study of Dietary Supplements Compositions by Neutron Activation Analysis at the VR-1 Training Reactor

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Key Words: Neutron activation analysis, gamma-ray spectrometry, training reactor

The VR-1 training reactor operated by the Czech Technical University in Prague is utilized mainly for education of students and training of various reactor staff, however, R&D is also carried out at the reactor. Experimental instrumentation of the reactor can be used for the irradiation experiments and neutron activation analysis. In this paper, the neutron activation analysis (NAA) is used for a study of dietary supplements containing the zinc (one of the essential trace elements for the human body). This analysis includes the dietary supplement pills of different brands; each brand is represented by several different batches of pills. All pills were irradiated together with the standard activation etalons in the vertical channel of the VR-1 reactor at the nominal power (80 W). Activated samples were investigated by the nuclear gamma-ray spectrometry technique employing the semiconductor HPGe detector. From resulting saturated activities, the amount of mineral element (Zn) in the pills was determined using the comparative NAA method. The results show clearly that the VR-1 training reactor is utilizable for neutron activation analysis experiments.

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Assessment of Medical Radiation Exposure to Patients and Ambient Doses in Certain Diagnostic Radiology Departments

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Keywords: Radiation Dosimetry, X-rays, ESAK, Quality Control, patient exposure

Diagnostic medical exposures make a large contribution to the public exposure to ionizing radiation. It was estimated that diagnostic radiology and nuclear medicine contributed 96% to the collective effective dose from man made source. Medical imaging now contributes about 50% of the overall radiation dose compared with about 15% in 1980.This study was intended to evaluate the radiation protection status and patient doses for certain radiological procedures in four radiology departments. Radiation exposure survey was carried out using a survey meter and quality control test tools. A total of 299 patients were examined in four radiology department. Entrance surface air kerma dose (ESAK) was determined from exposure settings using DosCal software and Unfors -Xi-meter. Finally collects other data using questionnaires. This dosimeter was calibrated by the manufacturer and reported to have accuracy better than 5%.

The overall mean tube current was 69.4±5.8 kVp, the mean tube current time product was 23.62±5.8 mAs per procedure and the mean body mass index (BMI) was 23.7±5.4 Kg/m^2. The mean ESD for the chest procedure was 0.3±0.1 mGy, for the Skull procedure was 0.96±1.2 mGy, for the abdomen procedure was 0.85±0.2 mGy, for the Spine procedures were 1.3±0.8 mGy and for the Limbs procedures were 0.43±0.2 mGy. The ambient doses in the reception, door dose were 100μSv/h. The protection status was acceptable in three departments and high on one department. The dose for technologist was acceptable in three centers. Patient doses showed wide variations due to filtration and generator type in addition to the operator skills. The measured ESAK in this study was higher than the previous reported studies in the literature. A corrective action is required for one department and regular quality control is recommended. A local diagnostic reference level will help to evaluate the practice.

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Measurement of Effective Radiation Dose to Patients in Certain Radiographic Examinations in Alkharj City

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Keywords: Effective dose , radiation exposure, cancer risk, CT.

Abstract

Radiation exposures from medical applications contribute more than 90% of radiation exposure from artificial sources. This medical exposure is increasing to the increasing use of computed tomography (CT), which contributes over 70% of the collective dose. In last three decades, effective dose per –capita increased six fold, from 0.5 mSv to 3.0mSv. The radiation risk is increased with the amount of exposure, with repeated exposures, and when the patient is young. Therefore, evaluation of radiation exposure from medical exposure is required for accurate justification and optimization to ensure that the radiation dose is low as reasonable achievable.

The current study intends to: (i) evaluate the radiation dose to patients during certain computed tomography (CT) and conventional radiological procedures, (iii) Estimate the risk of the aforementioned procedures. Calibrated X ray machines were equipped with KAP meter will be used in this study. Software from National Protection board (NRPB) was used to estimate organ and effective doses. A total of 159 patients were examined at the Department of Radiology, King Khalid Hospital, Alkharj, Saudi Arabia. A Siemens Sensation Multislice CT Scanner (MSCT) (16 slice) was used. All patients with clinical indications and request form were referring to the CT department. Data were collected to study the effects of patient-related .The exposure-related parameters were taken in consideration (gantry tilt, kilovoltage (kV), tube current (mA), exposure time, slice thickness, number of slices.

The mean patient effective doses (mSv) for CT chest, abdomen, spine and brain was 7.1±2.3 (3.2-10.5), 6.7±1.52 (4.5-9.5), 13.2±2.0 (4.7-26.7), 1.7±0.8 (0.31-2.6). The eye lens dose is same values of 1.47 mSv per procedure. Patient radiation doses for chest, abdomen and pelvis X ray procedures range from 0.1 mSv to 0.5 mSv from digital radiographic procedures. The patient radiogenic risk per procedures ranges between $10x10^{-6}$ to $10x10^{-5}$ per procedure.

Patients' doses, which comparable with previous studies, showed wide variations. In general, these variations of doses can be attributed to the differences in exposure settings, scan length. This study showed that almost 65% of CT procedures are with normal findings. Therefore, a prompt evaluation of referral criteria is important.

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Radiation Exposure in Direct Digital Radiography and Potentials for optimization: Measurements and Retrospective Dosimetry

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Keywords: Digital radiography, Patient doses, Entrance Surface Air Kerma, Kerma-area Product, Exposure Index

The gradual increase in the use of digital radiography in the region, has raised concerns over dose consequence of DR, therefore, it becomes necessary to study the radiation exposure and explore potentials for optimizations.
Estimates radiation doses were carried out for 558 patients who underwent digital radiography X-ray examinations in our Hospital. Doses were estimated from measurements of X-ray tube output and typical patient exposure factors [1]. Console displayed dose information (kerma-area Product (KAP) and Exposure Index) were recorded from DICOM header and were used for retrospective dose analysis.
For Chest PA, Chest LAT, Skull (AP/PA), Skull LAT, Abdomen (AP), Pelvis (AP), Lumber spine AP, Lumber Spine LAT, Cervical Spine AP, and Cervical Spine LAT examinations, mean ESAK (mGy) values were: 0.31, 1.15, 0.88, 0.53, 0.89, 1.56, 2.78, 4.00, 0.35, and 1.40 mGy; respectively. Retrospectively estimated mean KAP (µGy.cm2) values were: 1.86, 3.28, 2.1,1.9, 11.32, 11.5, 12.2,11.98,1.36,2.05, respectively. Statistical analysis were performed to determine correlation between measurement retrospectively estimated KAP and EI values. The results were compared to diagnostic reference levels for dose audit and optimizations.
The study provided the first dose projection in DR and is thus important for derivation of local diagnostic reference levels. The study emphasizes the importance of using KAP and EI dosimetric information for retrospective dose analysis for departmental dose optimizations.

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A Monte Carlo Model for Photoneutron Generation by a Medical LINAC

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Key Words: Monte Carlo, photoneutron, dosimetry, LINAC, flattening filter

For an optimal tuning of the radiation protection planning, we have built a Monte Carlo model using the MCNPX code allowing an accurate estimate of the spectrometric and geometrical characteristics of photoneutrons generated by a Varian TrueBeam Stx© medical linear accelerator. We considered in our study a device stemmed from a Varian Clinac© 2100 modeled starting from data collected thanks to several papers available in the literature. The model results were compared with neutron and photon dose measurements inside and outside the bunker hosting the accelerator obtaining a complete dose map. Normalized neutron fluences were tallied in different positions at the patient plane and at different depths. A sensitivity analysis with respect to the flattening filter material were performed to individuate aspects that could influence the photoneutron production.

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Occupational doses of medical staff in interventional cardiology procedures and link to the patient dose levels

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Key Words: eye lens dosimetry, Hp(3), thermoluminescence, personal dosimetry

Introduction: Radiation exposure in interventional procedures has recently been the subject of numerous studies. Because of the introduction of new techniques and equipment and the ever-increasing use of radiation ionizing in medicine, it is important to continue to assess the doses resulting from medical exposure to radiation. Also the attention devoted in recent years to eye lens dose assessment was increased due to evidence that cataracts can be induced by ionizing radiation at dose levels lower than previously expected. Because of the potential for doses received by interventional radiology personnel to be high, it is important that they are monitored properly and the dose to the eye lens should be evaluated more carefully.

Material and methods: Data obtained during 60 Interventional radiology procedures were collected. Patient kerma–area product P_{KA}, cumulative kerma in the air K_{IRP} for patient were recorded. To measure personal doses for medical staff were used whole body personal dosemeters for the personal dose equivalent quantities Hp(10) worn on the trunk, ring dosemeters worn on finger to measure the quantity Hp(0.07) and specially dedicated dosemeters EYE-D™ for the dose quantity Hp(3) are used. Correlations between patient doses and staff doses, between eye lens doses Hp(3) and other personal doses were investigated.

Results: The measured occupational and patient`s doses varied considerably among procedure. In general, within the medical team, operators always received the highest doses, followed by nurses and technicians. No meaningful correlation could be established between occupational doses and patient exposure, however some degree of correlation was observed between values of dose to the eye lens and whole body dose. Annual eye lens doses received by the operators in 8% cases were above recently recommended annual dose limit of 20 mSv.

Conclusions: Results indicate the necessity of radiation protection measures in interventional cardiology and demonstrate that only monitoring of the eyes with specific dosemeters for yearly follow-up can provide the accurate doses.

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A New Nuclide Transport Model in Soil in the Genii-Lin Health Physics Code

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Key Words: Radiation protection, Environmental impact, Health physics, Safety analysis, Soil contamination

GENII-LIN (Teodori & Sumini 2014) is a multipurpose health physics code, that has been developed at the University of Bologna. The code has capabilities for calculating radiation dose and risk to individuals or populations from radionuclides released to the environment and from pre-existing environmental contamination. The aim of the GENII-LIN project is to provide a reliable tool to be used for purposes such as siting facilities, environmental impact statements, and safety analysis reports.

The code can handle a variety of 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 soil intake. The radionuclide environmental concentrations are calculated over time up to the end of the exposure period by modeling appropriate transport phenomena through air, deep and surface water, deep and surface soil and biotic transport.

The original nuclide transfer model in soil was intended for residual contamination from long term activities and from waste form degradation. Short life nuclides were supposed absent or at equilibrium with long life parents. Here we present an enhanced transport model, where short life nuclide contributions are correctly accounted. This improvement extends the code capabilities to handle incidental release of contaminant to soil, by evaluating exposure since the very beginning of the contamination event, before the radioactive decay chain equilibrium is reached.

References

Teodori, F. & Sumini M. 2014, "GENII-LIN project: a multipurpose health physics code to estimate radiation dose and risk from environment contamination", Radiation Physics and Chemistry, vol. 104, pp 15–22.

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Evaluation of Radiation Doseduring Percutaneous Angioplasty for Arteriovenous Shunt Assembling

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Key Words:percutaneous angioplasty (PTA), radiation protection, optically simulated luminescent dosimeter (OSLD)

Abstract

Percutaneous angioplasty for dysfunctional hemodialysis is usually performed by radiologists but not cardiologistsin Taiwan so that the radiation dosage in patients and physicians are usually unknown and related study is rare. In this study, we pioneering investigated the radiation dose in percutaneous angioplasty for arteriovenous shunt assembling and the effect ofRADPAD, a lead-free surgical drape containing Bi and Ba, on the decrease of radiation dose in non-target organs of the patient and the operator. The radiation dose in typical digital subtraction angiography (DSA) by PTA protocol under fixed field of view (FOV) was measured with optically simulated luminescent dosimetersarranged in a PIXY RS-102 anthropomorphic phantom.

The results indicate that there is a significant dose reduction at the hands (0.022±0.002 mGy before treated vs. 0.014±0.001 mGy after treated; P=0.021) but not at the lens (0.027±0.003 mGy before treated vs. 0.018±0.001 mGy after treated; P=0.058) and the gonads (0.026±0.003 mGy before treated vs. 0.020±0.001 mGy after treated; P=0.058) of the cardiologist/operator after treated with RADPAD. At the abdomen in patient, the dose significantly decreased from 1.597±0.104 mGy to 0.031±0.002 mGy (P<0.001) after RADPAD treatment. For the chest, lens and thyroid in patient, the doses were respectively 0.154±0.100 mGy (compared to 0.049±0.001 mGy of after RADPAD treatment; P=0.0002), 0.066±0.001 mGy (compared to 0.021±0.001 mGy after RADPAD treatment; P=0.009) and 0.208±0.002 mGy (compared to 0.042±0.003 mGy after treated with RADPAD; P<0.0001), which represents an apparent reduction in dose. However, no significant difference was found in the dose-area product between two groups (179.9±0.132 mGy·cm^2 vs. 177. 4±2.64 mGy·cm^2; P=0.38).

In conclusion, the RADPAD significantly reduced radiation exposure to patient during PTA for arteriovenous shunt assembling, which is suggested applied to current cardiac catheterization.

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Secondary neutrons in wobbling scattered proton treatment nozzles

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Key Words: Monte Carlo, Proton therapy, Secondary neutrons

Proton beams used for radiotherapy will produce neutrons when interacting with matter. Neutrons are generated both in the treatment head (external neutrons) and inside the patient (internal neutrons) through proton–nuclear interactions. The purpose of this study was to assess the relative contribution of these two neutron sources to the lateral out-of-field secondary neutron equivalent dose in wobbling scattered proton treatment nozzles. We used TOol for PArticle Simulation (TOPAS), a Monte Carlo radiation transport code (version 2.0p3) for simulating the proton therapy beam delivery system. The Monte Carlo simulation method was used to calculate absorbed dose from primary protons, stray neutrons originating in the treatment head and stray neutrons originating within the phantom. The major component of neutron dose is typically caused by external neutrons originating in the treatment head rather than to internal neutrons created in the phantom. The dose from internal neutrons increases with field size and modulation width. Thus it is important to assess and, ideally, minimize, the potential for second cancer induction by secondary neutrons between different treatment machines, and techniques have to be performed under similar conditions.

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IMRT plan verification with EBT2 and EBT3 films compared to PTW seven29 detector

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Key Words: IMRT verification, Gafchromic films, film calibration, gamma analysis

The aim of this study is to compare dosimetry with Gafchromic EBT2 and EBT3 films to an ion chamber array PTW seven29 in terms of their performance in clinical IMRT plan verification.

A methodology for film processing and calibration was developed, testing the performance of films and scanner in use (EPSON Perfection V700 Photo). Calibration curve was obtained in MATLAB and in FilmQA Pro. Both polynomial fits with a fourth degree polynomial and rational functions as proposed in FilmQA Pro were tested. Different calibration curves were used and impact of calibration accuracy was assessed. The best result was then used to calibrate EBT2 and EBT3 films for IMRT plan verification measurements.

Films were placed in several coronal planes into an RW3 slab phantom and irradiated with a clinical IMRT plan for prostate and lymph nodes using 18X photon beams on a Siemens Artiste linear accelerator in the Thomayer Hospital in Prague. Individual fields were tested and irradiated with gantry at 0°. Results were evaluated using gamma analysis with 3 %/3 mm criteria in OmniPro I'mRT.

The same measurements were performed with an ion chamber array PTW seven29 in RW3 slabs (different depths) and in the OCTAVIUS II phantom (isocenter depth only; both original and nominal gantry angles). Results were evaluated in PTW VeriSoft using the same criteria. Altogether, 45 IMRT planes were tested.

Film measuerements show different results than ion chamber matrix measurements. With PTW seven29 detector in RW3 phantom, gamma pass rates range between 93.56 and 95.73 %. Worse results are obtained if the detector is placed into the OCTAVIUS phantom – gamma pass rates between 87.00 and 92.41 % for measurements with gantry at 0° and 60.94 to 88.22 % with gantry in original angles. EBT2 films show inconsistent results. Gamma pass rates range between 52.55 and 99.43 % and can differ significantly for different planes in one field. EBT3 films give the best results of all the tested configurations. Gamma pass rates range between 93.59 and 100 %.

Inconsistency with EBT2 film might be due to film inhomogeneity and mechanical properties of different film sheets. Results obtained with the ion chamber matrix are systematically worse than with EBT3 films due to its poor spatial resolution (1 cm distance between detector central points). Great results can be obtained with EBT3 films when proper film handling and precise calibration curve is applied. This finding is contrary to a previous study (Nalbant, Kesen & Hatice 2014). It indicates that EBT3 film can be an excellent tool when proper care is taken. Although use of different software for gamma evaluation for films and PTW detector must be taken into account in this case.

Results of clinical plan verification depend on the type of detector used and good understading of the detector's performance is needed to safely and reliably check individual clinical plans.

Reference: Nalbant N, Kesen ND, Hatice B (2014). Pre-Treatment Dose Verification of Imrt Using Gafchromic Ebt3 Film and 2DArray. *J Nucl Med Radiat Ther*, 05(02).

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New Neutron Detector Design Optimization by Monte Carlo Simulation

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Key Words: Monte Carlo, neutron dosimetry, conversion layer

The main aim of the project Advanced Detectors for Better Awareness of Neutrons and Gamma Rays in Environment (Czech-Norwegian Research Programme) is to develop a portable highly efficient and large area neutron sensitive detecting device for measurement of composition and spectral characteristics of mixed radiation fields. The device development tends to use in environmental and health research with a special attention to radiation protection and medical use of radiation
One of the goal is to provide simulation results of developed device under irradiation from different radiation sources. Monte Carlo code MCNPX has been employed for particle transport (as well as nuclear reactions) simulations in the matter. The paper presents results of simulation of different structures to be etched into sensors (to increase neutron detection efficiency) over plain planar configuration as well as different conversion layer materials. Further, influence of various dead layer thickness and aluminum contacts in/on silicon detector layer has been compared and evaluated in the context of the neutron detection efficiency. Results of the simulation have been utilized in design of sensor by cooperating Norwegian organization.

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Experimental characterization of the neutron spectra generated by a high-energy clinical LINAC using neutron activation metal detectors

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Medical linear accelerators (linacs) are being routinely used for cancer treatment. Electron linacs accelerate high-energy electron beams to impinge on high Z targets, usually made of tungsten or copper, producing high-energy gamma rays (bremsstrahlung photons). Due to high operational energy of this type of linacs (between 6 and 45 MeV with most common energies at 18, 20, 25 MeV) a significant number of neutrons are created by (γ, n) reactions. The average threshold energy of the (γ, n) reactions varies from 4-8 MeV to 10-19 MeV for heavy and light nuclei materials, respectively. These reactions occur at the accelerator head, flattening filters, shielding materials and collimator jaws inside the Linac head.
The biological effectiveness of neutrons is substantially higher than that of photons and electrons and even a small neutron dose will increase the risk for secondary cancer. Furthermore, in 2007 ICRP (International Commission on Radiological Protection) published a new set of radiation weighting factors indicating that neutrons with energy of about 1 MeV is judged to be the most hazardous (w_R = 20.69). Therefore a precise understanding of the photoneutrons production is imperative.

Although, there have been several Monte Carlo studies to report the contaminant neutron spectrum, the number of experimental studies is small due to the difficulties arise from the intense mixed photon-neutron field. The main objective of this work is to report the results of an experimental characterization of the neutron spectra generated by a high-energy clinical LINAC. The photoneutron contamination of an ELEKTA linear accelerator is investigated in detail in its 15 MV photon mode at the isocenter (100 cm distance from the accelerator's target).

We have developed a technique for neutron dosimetry based on neutron activation of different metal detectors. The Monte Carlo code Geant4 is used to optimize the spatial arrangement of the detectors. This system offers the possibility to measure neutrons over a wide energy range (from thermal up to a few MeV) at intense and complex mixed n–g fields. To obtain the neutron spectrum of a medical Linac from the activation technique, measurements must be unfolded. A method for unfolding the neutron energy spectra has been developed using the Minuit minimization. It is based on the expansion of the neutron energy distribution on a set of parameters that are fitted to minimize the square sum of differences between the measured and

Optically Stimulated Luminescence characterization of three different borate glasses

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Key Words: borate glasses, OSL, LKB

Over the past two decades optically stimulated luminescence (OSL) has been used as a tool for several dosimetric application assessments. Varieties of compounds have been tested and even though the majority of them are crystalline, non-crystalline solids like glasses could be useful for some applications as they may present advantages over other types of materials, such as ease of acquisition and transparency in the wavelength range of visible light.

The main goal of this work is to evaluate the dosimetric properties of three different borate glass compositions based on OSL technique. Glasses were produced by the rapid cooling process and after the production, they were milled (granulometry between 150 and 75 μm) and mixed with Teflon to form tough pellets of 6 mm diameter and ~50 mg mass (of which 12.5 mg was Teflon). Structural and dosimetric characterizations were done using different techniques. $^{90}Sr+^{90}Y$ (β-) source with a dose rate of 0.1 Gy/s and a Risφ TL/OSL reader were utilized in the dosimetric tests.

Glass compositions:

20 Li_2CO_3 – X K_2CO_3 – Y B_2O_3 [LKB]
20 Li_2CO_3 – X MgO – Y B_2O_3 [LMB]
20 Li_2CO_3 – X CaO – Y B_2O_3 [LCB]

X =	10	15	20	25	30	mol%
Y =	70	65	60	55	50	mol%

LX(K,M or C)B – sample's name

Dose-response curves obtained using the mean of at least three measurements of the maximum value of the OSL signal for each dose.

OSL curve decay was also analyzed in their fast and slow components in order to obtain information about the traps that origin the signal.

We could see a greater response, based on the parameters we have been working with, of the batch LKB that also presented a different OSL decay behavior in comparison with the data obtained for L30MB and L30CB.

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TL dosimetric properties of lead borate glasses containing Dy^{3+} and Eu^{3+} ions for UV and gamma dosimetry.

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Abstract

Dy^{3+} and Eu^{3+} doped the borate glasses samples containing Ag nanoparticles were prepared using a conventional melt-quenching method. The synthesized materials were characterized by scanning electron microscopy (SEM) and their morphology and sized distributions were determined. The photoluminescence (PL) spectra as well as UV-Vis absorbance were also analyzed and show the presence of the rare-earth in the matrix. The thermoluminescence (TL) response of Dy^{3+} doped lithium borate glasses irradiated with ultraviolet (UV) radiation was studied in detail before and after doping with silver.

Keywords: Thermoluminescence, Borate glasses, Ag nanoparticles; rare earth.

Effects of Distribution of Glandular Tissues on Glandular Dose in Mammography Based on a Detailed Breast Model

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Key Words: glandular dose, mammography, detailed breast model, TLD measurement, Monte Carlo

Mean glandular dose (MGD) is not only determined by the compressed breast thickness (CBT) and the glandular content, but also by the distribution of glandular tissues in breast. Depth dose inside the breast in mammography, which is expressed as percent depth dose (PDD) or relative depth dose, has been widely concerned as glandular dose decreases rapidly with increasing depth. In this study, an experiment using thermo luminescent dosimeters (TLDs) was carried out to validate Monte Carlo simulations of mammography. Half value levels (HVLs) at different X-ray tube voltages were measured with TLD GR200A using GE Senographe DS Mammomat. PDDs at different depth values were measured inside CIRS breast phantoms of different thicknesses. The experimental values were well consistent with the values calculated by Geant4. Then a detailed breast model with a CBT of 4 cm and a glandular content of 50%, which has been constructed in previous work, was used to study the effects of the distribution of glandular tissues in breast. The detailed breast model includes skin, subcutaneous fat, Cooper's ligaments, intraglandular fats, ductal trees and lobules, retromammary fat and so on. The model was reversed in direction of compression to get a reverse model with the same CBT and glandular content but a different distribution of glandular tissues. Relative depth doses and glandular tissue dose conversion coefficients at different HVLs were calculated with Geant4. It revealed that relative depth doses changed less rapidly for a larger HVL. The conversion coefficients were about 10% larger when the breast model was reversed, for glandular tissues in the reverse model were concentrated in the upper part of the model.

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Studies of mass attenuation co-efficient of decorative building materials as for the shielding of ionizing radiation

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Key Words: HPGe gamma ray spectrometry, mass attenuation coefficient, decorative building materials, Bangladeshi dwellers

Following the rapid growing per capita income, a major portion of Bangladeshi dwellers are upgrading their non-brick houses by rod-cement-concrete materials and simultaneously curious to decorate the houses using luxurious granite and marble stones. Present study concerns the investigations of gamma-ray attenuation co-efficient of decorative materials leading to their suitability as shielding of ionizing radiation. A number of commercial grades decorative materials (Perlato Flower, Mermars White, Rosalino R, Crema Nova, Karana marbela and granites) were collected from home and abroad following their large scale uses. A well-shielded HPGe gamma-ray spectrometer combined with associated electronics was used to evaluate the mass attenuation coefficients of the studied materials. Present results are compared with the available literature and theoretical values. A number of related parameters such as mass energy-absorption co-efficient, the total interactions of cross-section, the molar extinction co-efficient, the effective atomic number and the electron density are derived from the obtained mass attenuation coefficients. Present results find significance in industrial, biological, agricultural and medical sciences, and have direct impact on human life.

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Monte Carlo Evaluation of Acuros XB Dose Calculation Algorithm for Intensity Modulated Radiation Therapy of Nasopharyngeal Carcinoma

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Key Words: Monte Carlo, Acuros XB, Nasopharyngeal Carcinoma, Intensity Modulated Radiation Therapy

Intensity modulated radiation therapy (IMRT) is a proven and effective treatment modality for the nasopharyngeal carcinoma (NPC). One important aspect of IMRT for NPC patient is the need to have an accurate radiation dose calculation algorithm to deal with the head-neck region's complex air/bone/tissue interface effects on the radiation dose distribution and to achieve cure without radiation-induced toxicities.

The Acuros XB dose calculation algorithm (AXB) was developed to replace the older anisotropic analytical algorithm (AAA). AXB solves the linear Boltzmann transport equation (LBTE) directly to account for the effects of tissue heterogeneities such as lungs, bone, air, and soft tissues found in the cancer patient's treatment field receiving radiotherapy. The LBTE describes the macroscopic behavior of radiation particles (neutrons, photons, electrons) transport through the heterogeneous matter.

The IMRT plans of 5 NPC patients were calculated using the version 13.0.26 AXB algorithm and compared with BEAMnrc/DOSXYZnrc Monte Carlo (MC) simulation. The prescribed dose to the planned target volume (PTV70) was 70 Gy. Analysis showed a mean difference of < 0.5% between MC versus AXB calculations for the mean PTV (71.6 Gy vs 71.4 Gy), and the V_{PTV95}, which is the PTV covered by $\leqq$ 95% of prescribed dose (97.2% vs 96.8%). The normal organs-at-risk (OARs) surrounding the high dose area showed a much greater mean dose difference of > 0.5% between MC and AXB for the left cochlea (0.85%), right cochlea (4.39%), and spinal cord (11.4%).

The AXB is adequate for clinical use in IMRT dose calculation. However BEAMnrc calculations showed a dose difference in dense bone enclosed OARs. More studies should be done to clarify the significance of our findings.

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CT-based Monte Carlo dose calculations for gynaecology brachytherapy employing a Henschke applicator

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Key Words: Monte Carlo, ^{192}Ir, Brachytherapy, Henschke applicator

Recently in Taiwan, the Henschke applicator has been widely used for gynaecology brachytherapy. However, the commercial brachytherapy planning system (BPS) does not properly evaluate the dose perturbation caused by the metal ovoid structures of the Henschke applicator. This dose perturbation of the Henschke applicator is a major concern for the dose accuracy of the BPS. Monte Carlo N-Particle Transport Code eXtended (MCNPX) was used to evaluate the brachytherapy dose distribution of a Henschke applicator embedded in a water phantom and a heterogeneous patient computed tomography (CT). In homogeneous phantom study, the comparison between the Monte Carlo (MC) dose and the film measurements with CT geometries of Henschke applicator were in good agreement. Furthermore, in heterogeneous phantom study, the MC dose discrepancy in the heterogeneous patient CT with the Henschke applicator and the homogeneous phantom CT with the Henschke applicator showed no significant deviation (-7.0%±11.6%). However, the MC dose with the Henschke applicator showed significant deviation (-80.6%±7.5%) from those without the Henschke applicator. This study demonstrates that the metal ovoid structures of the Henschke applicator cannot be disregarded in brachytherapy dose calculation.

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Assessment of radiation dose and induced risk of cancer in multislice CT and cone beam CT exams for dental implant planning.

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Key Words: radiation protection, radiology, diagnostics, tomography, dental implant

Pre-surgical evaluation for implant dentistry planning requires diagnostic methods such as computed tomography that allow detailed and precise examination. This study evaluated and compared the radiation dose and estimated radiation induced risk of cancer in cone beam computed tomography (CBCT) and multislice computed tomography (CT) exams for implant dentistry planning. Thermoluminescent dosimeters (TL) of LiF: Mg, Cu, P were placed in an Alderson-Rando type anthropomorphic phantom, female model, in regions corresponding to the crystalline, parotid, submandibular and thyroid glands, and ovaries. The exams were performed using CBCT Kodak 9000C 3D® and multislice CT SOMATOM Definition®. The estimated radiation induced cancer risk was established according to the reports of Biologic Effects of Ionizing Radiation (BEIR VII) that considers age, sex and body mass as measurement parameters. The highest values for entrance skin dose (ESD) were observed in the region of the parotid, in multislice CT and CBCT exams: 55.1mGy (±7.3) and 8.818mGy on the right side and 58.8mGy (±5.8) and 7.912mGy on the left side, respectively. It was also observed that the highest absorbed dose (AD) values were found in the parotid region 39.3mGy (±7.3) and 3.424mGy on the right and 39.5mGy (±5.8) and 3.332mGy on the left in the multislice CT and CBCT exams, respectively.
The multislice CT imparted the highest values for ESD and AD in the region of the parotid and the submandibular glands. This study demonstrated a dosimetric preponderance for salivary glands, such as increased risk structure, in relation to other regions of interest (crystalline, thyroid, and ovarian). In relation to radiation induced risk of cancer, the 20-year age range presented a greater risk of cancer occurrence compared to that 80-year age range in both exams. A lack of studies was observed in the literature reviewed. This allowed the creation of a mathematical and elementary way of calculating the dose and risk, with more accurate results, and it let us make a more effective contribution to scientific knowledge in the dosimetry area in dentistry.

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Primary investigations on a Phosphorus doped silica rod as real time X-Ray dosimeter

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Key Words: Radioluminescence, LINAC, Dosimetry, Fiber Optic Dosimeter

Studies in the last decade have shown that Radioluminescence phenomenon could be a strong candidate as real time dosimetry technique. Fiber optics has been verified to exhibit useful Radioluminescence when exposed to ionizing radiation (commonly attributed to trap centres and crystal defects formed owing to strain on the Si-O bonds). In this study, primary investigations have been carried out on a phosphorus doped silica rod (p-doped core and silica cladding) fabricated using the MCVD process. A high energy X-ray beam (6 MV and 10 MV, Bremsstrahlung) was used to irradiate the rod connected to a remote readout system via a PMMA cable. Response was recorded for six dose rates lying uniformly between 100 MU/min and 600 MU/min (where 100 MU would deliver 1 Gy of absorbed dose in tissues). Linearity of response under varying dose rates, consistency of response in repeated and prolonged exposure, photon counts for arbitrary absorbed doses were studied and found to be within convenient range. Effects such as memory, afterglow and plateau were also investigated for, and were found to be minimal. Exhibition of dosimetric properties of a P doped silica rod lays down a promising avenue to pursue further research with this material.

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Estimation of entrance surface dose rates for exposure scenarios of Total Body Irradiation using MCNPX code

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Key Words: Total body irradiation, Monte Carlo, dose rate.

The treatment of patients diagnosed with leukaemia and other onco-hematological diseases can be done by combining chemotherapy with Total Body Irradiation (TBI). TBI has immunosuppression function, bone marrow ablation and destruction of malignant cells. For this procedure, organ doses should be maintained uniform and this is affected by several exposure parameters and conditions. These parameters and conditions must be properly chosen in order to compensate differences in organ thickness and densities of human body. The analytical calculation of organ absorbed doses is made through skin surface doses obtained by measurements with dosimeters positioned in regions of interest. In this work, we developed 4 exposure scenarios of TBI for estimating entrance surface dose rates over chest, abdomen, leg and thigh regions and comparing our results with literature values. For each simulation, we considered a ^{60}Co gamma source positioned at 220 cm from entrance surface, with 100 x 100 cm² field size and dose rate of 22 cGy/min at 1 m in air. We modelled air detectors positioned according with average positions of ionizing chambers from experimentally work in literature. The photon flux in detectors was calculated using tally F5 and converted to dose rate through conversion factors from ICRP 21. For representing the patient undergoing a TBI procedure, we used a hybrid female adult phantom (UFHADF) in sitting posture or a water mathematical phantom.
The results compared with literature showed a relative difference up to 9.1% for exposure scenario containing only detectors, irradiated without the TBI room and phantom. For exposure scenario which TBI room was added, the entrance surface dose rates presented an increasing of 2% due to backscatter contribution of room walls. These values were higher with the implementation of a sitting hybrid phantom in exposure scenario, providing relative differences of 5.6%. Due to differences between patient posture from literature work and hybrid phantom, the fourth exposure scenario contains a mathematical water phantom which arms and legs were modelled as the same position of experimental work. The estimated entrance surface dose rates for this scenario showed minimum relative difference of 4.1% (thorax detector) and maximum relative difference of 6.2% (thigh detector). Despite few information about clinical procedures being available, the estimation of entrance surface dose rates in this work showed reliable values with differences lower than 10% compared with literature work.

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Synthesis of $BaHfO_3:Eu^{3+}$ for ultraviolet radiation detector

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Key Words: $BaHfO_3$ ceramics, ultraviolet radiation, dosimetry, detectors

A class of novel ceramic based on barium hafnate ($BaHfO_3$) polycrystalline powders doped with trivalent europium (Eu^{3+}) ions has been developed by co-precipitation method for non-ionising radiation detection. Appropriate annealing procedures ceramic powders were submitted. If there are multiple affiliations among the authors, superscript numbers should be used to indicate the respective affiliations. Depending on its phase the polycrystalline powders can act either as ultraviolet (UV) radiation detectors. The powders were submitted at different thermal treatment of calcinations 800°C during 16 h. X-ray diffraction XRD measurements were performed on BRUKER diffractometer D8-Advance using Cu Kα 1.54183 radiation. The surface morphology was studied by using scanning electron microscopy (SEM) JEOL Model JSM-6390LV. Thermoluminescence (TL) studies were carried out using a manual TL 3500 reader. The XRD pattern shows pure barium hafnate oxide $BaHfO_3$ with a cubic structure. Thermoluminescence (TL) glow curve was recorded form room temperature up to 350°C. TL response of $BaHfO_3:Eu^{3+}$ exhibits a broad glow curve with one peak centered at around 180°C. Finally, recent results on Eu doped $BaHfO_3$ powders prepared by co-precipitation method will be presented, which presents optical advantage for ultraviolet radiation detector.

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Pressure Sensitive Adhesives with Carbon Nanotubes for Tissue Equivalent X-ray Dosimetry

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Key Words: Carbon Nanotubes, Tissue Equivalent, X-ray Dosimetry, Pressure Sensitive Adhesives

In this study, we fabricated X-ray detectors of colloidal nanocomposites that develop tacky behaviour. The Latex we are using possesses a glass transition temperature of -50 °C and therefore it is tacky and soft at room temperature. Polymers have a low average atomic number, which makes them equivalent to human tissue when used in X-ray dosimetry in clinical applications. DC and AC conductivity measurements show that the electrical properties are enhanced after the incorporation of SWCNTs. A low concentration of 0.1 wt. % nanotubes provides pathways that can collect the carriers at the electrodes and enhances the X-ray detection and adhesive properties in the colloidal nanocomposite. The X-ray detection of a polymer colloid upon the addition of a small amount of SWCNTs is enhanced, due to the efficient charge separation at the interface of the latex and the SWCNTs. Irradiation with X-rays produced a linear increase in photocurrent over a dose rate range from 0.18 to 54.99 mGy/s. AFM, Raman, XPS and FTIR characterisation indicate no degradation of the material due to the X-rays. We show that, although the resulting devices are low cost, they have a relatively high detection efficiency and may provide large surface area detection as a viable alternative to more traditional device materials for tissue equivalent dosimetry

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The Adsorption of ^{223}Ra(II) ions on Borosilicate Glass Surfaces

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Key Words: ^{223}Ra, $RaCl_2$, adsorption, borosilicate glass, citric acid

Targeted clinical trials have highlighted radium dichloride ($^{223}RaCl_2$) as a promising new radiopharmaceutical for the treatment of symptomatic, skeletal metastases associated with castration-resistant prostate cancer (CRPC), advanced lung cancer and breast carcinoma[1–4]. The United States Food and Drug Administration (USFDA) approved the use of $^{223}RaCl_2$ (Xofigo®), as a radiopharmaceutical in May 2013[5], followed by the European Commission, who granted marketing authorisation in Europe upon recommendation from the European Committee for Medicinal Products for Human Use in September 2013[6].

When handling low concentrations of radionuclides, as is the case for $^{223}RaCl_2$ used in the radiopharmaceutical industry, adsorption onto the surface of the containment vessel may take place. This prompted a study focusing on the adsorption of radium on borosilicate glass from aqueous solutions containing $^{223}RaCl_2$. The present study investigates the adsorption of radium as a function of pH, citric acid concentration and surface area.

The kinetics of adsorption is rapid, with 50% uptake occurring within 80 min and reaching a maximum approximately 24 hrs after the start of the experiment. Increasing the available surface area increased the adsorption of radium with a distinct dependence on pH. At pH $\leq$3, adsorption of radium was negligible, however increasing rapidly with the decrease of solution acidity, reaching a maximum of at the neutral pH range before decreasing again for alkaline solutions.

The presence of the complexing agent citric acid was found to reduce the absorption of Ra(II) ions significantly, reduced radium adsorption; no adsorption was observed at concentrations greater than 10^{-2} M.

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A Cell-recognition MATLAB Code to Measure The Frequent Induction of Giant-nucleated Cells In The Progeny of Normal Human Fibroblasts Post Exposure To X-irradiations *In Vitro*

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Key Words: Giant-nucleated cells(GCs), AG1522 normal human-diploid fibroblasts, Cell-recognition MATLAB code, Radiation therapy

Radiation-induced giant-nucleated cells (GCs) occur in the progeny of irradiated populations during or after cell division. Although the potential fate of most of the GCs is death, however, some of them may escape instead dividing to asymmetrical semi-normal daughter cells. In this study, normal human-diploid fibroblasts (AG1522) were exposed to single equivalent clinical doses of 0.2, 1 or 2 Gy of X-irradiation. Post irradiation, the AG1522 cells were incubated and maintained active for up to 24 population doublings (PDs). At different intervals, a fraction of cells from each dose point including non-irradiated cells were fixed and labeled with a DNA fluorochrome reagent and imaged microscopically then analysed using a cell-recognition MATLAB code. The yield of the GCs formed in the progeny of either irradiated or non-irradiated populations was measured at 8, 16 and 24 PDs post irradiation. Underlying these measurements is the need to understand the potential role of GCs in carcinogenesis and to enhance radio-therapeutic efficacy of specific types of ionizing radiation. Our results demonstrate that the induction of GCs in the X-ray survivors increased in a dose-dependent manner for up to 16 PDs. However, the frequency of GCs formed in the 0.2 and 1 Gy populations was significantly higher than those formed in the non-irradiated populations at the statistical significance level of 5% ($p < 0.05$). These results suggest that the frequent occurrence of GCs in the X-ray survivors might lead to increase radio-resistance since more copies of crucial genes available are reducing the efficiency of radiotherapy. Our studies may be useful at evaluating the effectiveness of radiotherapy treatment and determining the risk estimates for the low-doses of radiation received by normal cells adjacent to a targeted tumour volume during radiation therapy treatment.

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Evaluation of a semi-automatic program of image quality control of the phantom's Brazilian Radiology College

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Key Words: Mammography, Quality Control, Processing Digital Image.

Breast cancer is the most common type of cancer among women worldwide and in Brazil, accounting for about 25% of new cases each year. Estimated new cases in Brazil are 57.960 and 5.160 the state of Minas Gerais. In order to ensure that the mammographic diagnosis is done properly and efficiently, Secretary of State for Health of Minas Gerais, through the Superintendence of Health Surveillance created the State Program for Quality Control in Mammography. A goal of the program is the monthly monitoring of image quality; it is the visual periodic assessment of the quality of the image produced in mammography services. In order to decrease the subjectivity of visual assessment, this work developed algorithm as part of a program for semi-automatic evaluation of the image of the Brazilian College of Radiology (BCR) breast phantom using processing techniques and digital image analysis. Images were acquired in mammography unit MAMMOMAT 3000 model, manufactured by Siemens with system CR (Computed Radiography). The images were made using different acquisition parameters to voltage values (kV), load (mAs) and anode/filter composition. It was defined as a standard image that gained from closer to clinical practice parameters (28 kV, 125 mAs, Mo/Mo). For the detection of structures were selected regions of interest (ROIs) on which were carried out pre-processing procedures using the appropriate filtering, segmentation techniques were applied and morphological operators to put processing. The algorithms were developed in MATLAB and evaluations of test objects were made following the parameters given by the manufacturer. In this paper we present the results for test objects of breast phantom as are the microcalcifications, masses and fibers. The semi-automatic quality control reduces subjectivity in the evaluation of the images in quality control in mammography.

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