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Saturation correction in pulsed fields of high dose-per-pulse

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Current developments in accelerator technology and beam application have the potential to bring pulsed radiation sources with very high dose-per-pulse into clinical application. In particular, laser-based particle accelerators and pencil beam scanning using synchro-cyclotrons provide intensely pulsed beams. Current methods to determine the saturation correction factor ($k_s$) in ionization chambers are not intended for use at such high dose-per-pulse, possibly leading to an inaccurate dosimetry. We present a method based on the numerical approximation of the ionization, charge reaction and transport processes in an ionization chamber, which is able to overcome the limitations of current procedures used to calculate $k_s$. This numerical work is supported by experimental data of a plane-parallel advanced Markus ionization chamber irradiated with a pulsed electron beam of a dose-per-pulse up to 600 mGy. At a low collection voltage of 100 V a satisfactory description of the saturation correction dependency on dose-per-pulse can be achieved using existing models and tuning their parameter values. However, at the reference voltage of 300 V this is not possible and the newly presented method shows marked improvements. Chief among the additional effects considered in the presented numerical method is the shielding of the electric field by the liberated charges, which alters the dose-per-pulse dependency of $k_s$ in a way that can not be replicated by existing approaches.
Investigation of radiation exposure to the ocular lens of urologists due to interventions

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Based on new radiobiological data, the International Commission on Radiological Protection (ICRP) recommends a dose limit of 20 mSv per year to the lens of the eye. Therefore, the annual dose limit in Germany will be reduced to 20 mSv in 2018 from currently 150 mSv. Urologists are exposed to an elevated radiation exposure in the head region during surgical interventions, due to the x-ray tube assembly above the patient commonly used in urology. Technical and/or personal radiation protections for the head are not often used by the urologist. To determine the radiation exposure to the ocular lens, a number of measurements for a variety of dose intensive fluoroscopy interventions were carried out. The impact of the experience of the urologists on the radiation exposure of the patients and the urologists themselves was investigated likewise.

For a period of two months, partial body doses (forehead, apron collar, forearm) for the urologists, surgery staff and anesthetists were measured. All 119 interventions were performed using the Uroskop Omnia Max (Siemens Healthineers, Erlangen, Deutschland). The urological interventions were divided into three groups based on expected radiation exposure. Three different types of dosimeter were applied: calibrated electronic personal dosimeter EPD Mk2 (Thermo Fisher Scientific, Waltham, MA, USA), thermoluminescent dosimeter (TLD-100H, copper-doped lithium fluoride, Thermo Fisher Scientific, Waltham, MA, USA) and RaySafe i2 dosimeter (RaySafe, Billdal, Schweden). The radiation exposure to the patient was documented using the dose area product and the fluoroscopy time.

The study setup allows a differentiated and time-resolved measurement of the radiation exposure during urological interventions. The mean dose value to the lens of the eye per intervention was determined to be 20 ± 75 µGy. Therefore, 1000 interventions can be performed until the annual dose limit to the eye lens is reached. Radiation exposure of the surgery staff corresponded approximately to half the exposure of the physician performing the intervention.
Investigation of the LET-Dependency from BeO using single photon detection for dosimetry in proton beams

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Optically stimulated luminescence (OSL) is gaining greater importance in the field of personal dosimetry in the last few years. Its principle is based on the release of small amounts of light induced by the prior absorption of ionizing radiation. One suitable luminophore for OSL is beryllium oxide (BeO). Because of its near tissue equivalent effective atomic number of 7, it is excellent for personal dosimetry. Furthermore, the luminescence signal has a wide dose linearity ranging from the µGy region up to few Gy. For this reason, this ceramic can be used for several different areas of application. A new generation of measurement systems based on the OSL of BeO, which has a very low OSL light intensity, was developed by the radiation physics group at TU Dresden. This property allows single photon detection which is superior in contrast to other detection methods. Therefore, a single photon sensor was used as a detector. The single photon mode of the detector in combination with the so called timestamp detection method allows accessing the greatest possible information of the OSL light. This work applies the new system to dosimetry of a proton beam. Because of the LET-dependencies of the luminescence light, this presents a challenge. Common problems of solid state dosimetry are local saturation effects, which were investigated for BeO. Opportunities for correction in terms of the LET-dependency of the luminophore are being discussed. For the empirical determination of the behavior of BeO in proton beams, measurements at the medical proton therapy facility at the University Proton Therapy Dresden (UPTD) were carried out. All collected data were analyzed for LET-dependency on the response signal. For the measurements, BeO ceramics were placed at different depth infront and inside the spread out Bragg peak (SOBP). The dose read from dosimeters was analyzed with respect to the applied dose and the LET. All measurements infront of the SOBP shows no deviation of the estimated dose. The dose determination in the SOBP yielded an underestimation by 15%. This is object of current investigation.
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A novel primary method for the determination of dose to water for kilovoltage X-rays

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Kilovoltage X-rays are primarily used for treating skin cancers. Other applications include the treatment of Kaposi’s sarcoma, rectal cancer, palliative radiotherapy and keloid treatments. Dosimetry protocols for these qualities are traditionally based on detectors calibrated in terms of air kerma $K_a$. In recent years, a paradigm shift has led to dosimetry protocols based on detectors directly calibrated in terms of $D_w$. These are traced back to new primary standards at the national metrology institutes.

At PTB, the calibrations in terms of $D_w$ are performed with two transfer chambers which were calibrated directly against the primary standard water calorimeter in 2010. The measurement of $D_w$ for a range of kilovoltage X-ray qualities with the calorimeter occupies the X-ray calibration facility for several months. However, after seven years of use, a re-calibration of the transfer chambers seemed necessary. Therefore, a new, less time-consuming procedure for measuring $D_w$ was developed and will be presented. It is based on ionization chambers calibrated in terms of $K_a$. The calibration factor $N_{D_w}$ is calculated using the mean ratio of mass-energy absorption coefficients of water to air, a method known from dosimetry protocols such as TRS 277 or AAPM TG61. An additional quality-dependent correction factor $k_{ch}$ is required to take into account the altered spectra in water, the angular response of the detector, and the different materials of the chamber brought into the water for calibration. The mass-energy absorption coefficients can be calculated precisely with the Monte Carlo code system EGSnrc using measured spectra from our X-ray tubes. Measurements for ionization chambers of the types PTW TM30013 and NPL 2561 (with protective covers) show that the additional correction $k_{ch}$ for the TH series is smaller than 1 %. This is therefore a viable option as a primary method to determine $D_w$ for these qualities.
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Quantification of patient exposure reduction with dynamic collimation for large detector CTs

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Good image quality at low radiation dose is an important task in modern computed tomography (CT). CT scanner development led to multi-detector-scanners with up to 320 detector rows for fast image acquisition needed for example in CT coronary angiography. When these large detector CTs are used in routine spiral image acquisition, they are subject to “overscanning”, which describes the half rotation at the begin and end of an spiral acquisition needed for image reconstruction of the first image slice. Therefore, overscanning results in unwanted dose deposition in adjacent body regions next to the scanning region. To reduce this exposure dynamic collimators were introduced which open and close the primary beam collimation at the begin and end of the spiral acquisition.

Aim of this study is to evaluate the influence of dynamic collimation with different pitch settings on patient exposure and image quality (image noise).

Radiochromic film with a scale was scanned in a defined position on two different CT scanners with and without dynamic collimation. The scan was performed with 64x0.625 mm total collimation and different pitch settings. Additional an anthropomorphic phantom was scanned with different pitch values to demonstrate the independence of pitch and image quality in terms of image noise. Subsequently we put a ROI (region of interest) in defined image positions in the phantom scan and compared the image noise.

Without dynamic collimation an overscanning of 108.1 ± 6.3 mm was found. With dynamic collimation this effect was reduced to: 52.8 ± 2.2 mm. Image noise was found to be constant as expected.

The overscanning effect can cause an unnecessary increase in dose of 10% - 30% depending on the scanning lenght. This dose can reduce by dynamic collimators and a low pitch which does not influence image quality.
Influence of a magnetic field on the response of the MR-compatible Exradin A19MR farmer-type ionization chamber

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Recently, dedicated MR-compatible ionization chambers have become commercially available for dosimetry in hybrid devices for MR-guided radiotherapy (MRgRT). The response of ionization chambers is known to depend on the chamber type, the magnetic field strength and the orientation between chamber axis, beam and magnetic field [Meijsing PMB 2009, Reynolds Med Phys 2013]. The aim of this study was to investigate the response of the MR-compatible Exradin A19MR Farmer-type ionization chamber in magnetic fields of different field strengths and field orientations.

The chamber response to a 6MV photon beam was measured in a water phantom positioned in an experimental electromagnet (magnetic field strengths 0 - 1.1T). The magnetic field was aligned perpendicular to the chamber and beam axis.

The experiment was reproduced using the EGSnrc [Kawrakow Med Phys 2000, NRC PIRS 2009] Monte-Carlo code egs_chamber [Wulff Med Phys 2008] including a macro for particle transport in a magnetic field [Kawrakow]. Moreover, the chamber response was calculated for a magnetic field parallel to the chamber axis as well as parallel to the beam.

For a magnetic field perpendicular to chamber and beam axis, the measured dose response increased up to 8.7% at 0.9T and decreased for higher magnetic field strengths. Reversing the magnetic field direction yielded a maximum increase in response of 6.6% at 0.9T. The measured response agreed with the Monte-Carlo simulations within a statistical uncertainty below 0.2%. For a magnetic field parallel to chamber, the calculated dose response varied within ±0.5%, while it slightly increased by 0.7% at 1.1T for a magnetic field parallel to the beam.

The response of the Exradin A19MR chamber perpendicular to beam and magnetic field was well-predicted by the simulations, and in the other orientations, only small effects of the field were observed. The chamber appears suitable for measurements in hybrid MRgRT devices.
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In-phantom dosimetry near a $^{192}$Ir brachytherapy source

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Quality assessment or individualized therapy requirements may necessitate the direct dose or dose rate measurement in a water phantom surrounding a small applicator containing a single $^{192}$Ir photon source. We propose a cross-calibration method analogous to the small calibration field method known from teletherapy photon dosimetry, but with the axis of the reference ionization chamber in the midplane of the $^{192}$Ir photon source and pointing towards the source center. The method contains the following steps: a) Accurate localization of the source in the applicator by means of the water-phantom maximum-search function. b) Measurement of the relative radial dose profile with a small solid detector, using its known $k_{Q,M}$ values, and assessment of the radial range in which the dose rate is proportional to $r^{-2}$. c) Correction of the ionization chamber signal by the volume averaging effect correction factor $k_V = 1 + \sigma^2/\bar{r}^2$ where $\sigma^2$ is the variance of a rotation-symmetric Gaussian distribution describing the response of the ionization chamber. d) Choice of the ionization chamber’s effective point of measurement, guided by the requirement that the $k_V$- and $k_{Q,M}$-corrected ionization chamber signals also vary in proportion to $r^{-2}$. e) Cross-calibration of the small solid detector by assessment of the ratio between the two $r^{-2}$-proportional dose profiles at a recommended source-center distance, e.g. 30 mm. f) The calibrated small solid detector can then be used to measure dose or dose rate values under conditions deviating from the cross-calibration conditions. We illustrate the performance of these cross-calibration steps and the subsequent application of the small solid detector. In earlier work by U. Quast and U. Bormann, Medizinische Physik 1980 (ed. U. Rosenow), ISBN 3-7785-0669-2, p.495-500, a similar method of detector cross-calibration has been recommended.