Progress Report of the Department 'Fundamentals of Dosimetry'

L. Bueermann and B. Großwendt
Physikalisch-Technische Bundesanstalt, Braunschweig, Germany

Air kerma standards

The PTB operates primary standard measuring devices (free-air and cavity ionisation chambers) for the realization of the unit of air kerma for x-rays (10 kV - 400 kV) and γ-rays (^{137}Cs, ^{60}Co). No substantial changes were made since the last progress report in 2005 because all devices are well established and run with high stability.

New radiation qualities used for calibration and type testing of diagnostic dosimeters in mammography beams

New mammography radiation qualities were established at PTB. An overview is given in Table 1. All combinations are available for tube voltages between 20 kV and 50 kV with and without 2 mm of Aluminum as additional filtration.

Table 1: New mammography radiation qualities realized at PTB
(IEC 61267: Medical diagnostic X-ray equipment – Radiation conditions for use in the determination of characteristics. EPQC: European protocol for the quality control of the physical and technical aspects of mammography screening. Philips: private communication)

Anode	Filter	Reference
Mo	30µm Mo	IEC 61267
Mo	25µm Rh	EPQC
W	60µm Mo	EPQC
W	50µm Rh	EPQC
W	40µm Pd	EPQC
W	0,5 mm Al	Philips
Rh	25µm Rh	EPQC

The distributions of the photon fluence spectra as a function of energy were measured with a high purity Germanium detector, some of them are shown in Figure 1. Beam characteristics like mean energy and aluminium half value layers and mean correction factors for the primary air kerma standard were calculated based on the measured spectra. Since April 2007 it is possible for clients to calibrate dosimeters in terms of air kerma in the fields of the new mammography qualities. Further, it is intended to use the new radiation qualities for a study of the energy dependence of the air kerma response of diagnostic dosimeters as used for quality assurance measurements at diagnostic mammography facilities.

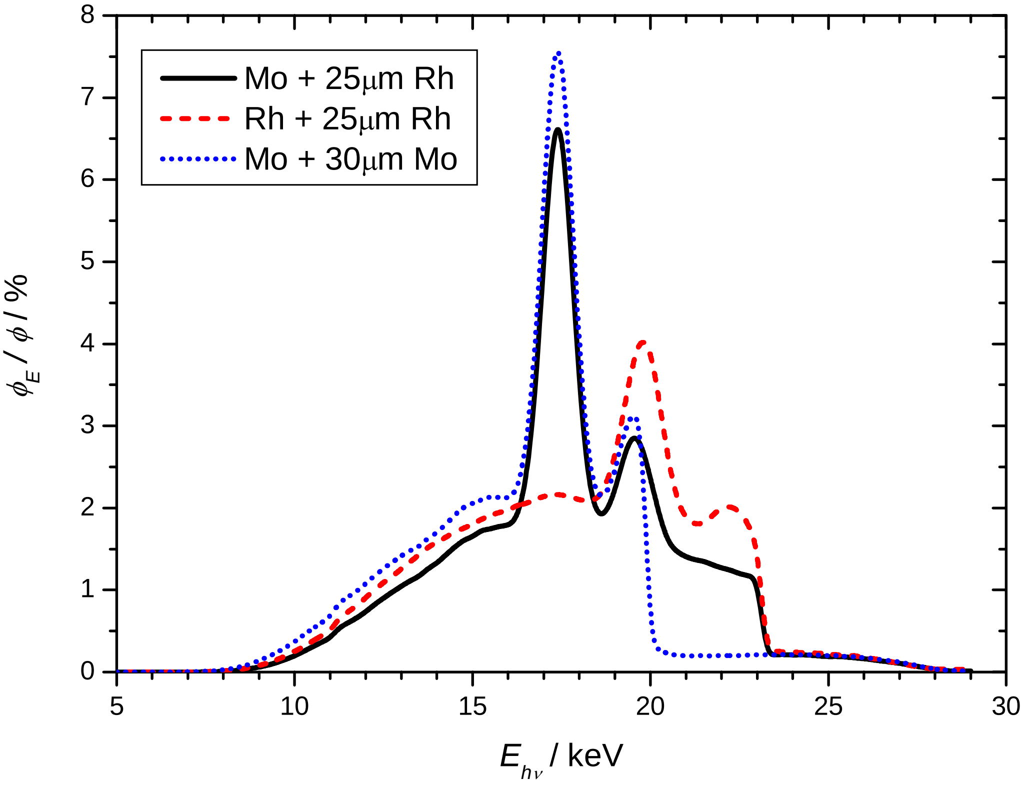

Figure 1: Normalized distributions of the photon fluence as a function of the photon energy measured with a high purity Germanium detector. All spectra are measured at a tube voltage of 28 kV but for different combinations of x-ray tube anode and filter materials as described in the legend. Clearly visible are the fluorescent lines of Mo anode at about 17.4 keV and 19.6 keV and the Rh anode at about 20 keV and 22.7 keV and the K-edges of the Mo filter at about 20 keV and the Rh filter at about 23 keV.

International comparisons

(i) PTB acts as pilot laboratory in the supplementary comparison of NMI air kerma standards for ISO 4037 narrow spectrum series radiation qualities (EUROMET PROJECT 545, MRA-Appendix B Identifier: EUROMET.RI(I)-S3). The comparison was conducted from February 2004 until October 2005. Measurements are completed and the Draft A report was sent to the participants. In essence, all participants agreed with the Draft A report. Currently, Draft B is in preparation.

(ii) PTB acts as pilot laboratory of the COOMET key comparison of the national measurement standards of air kerma for ^{60}Co γ radiation (COOMET Project 318). The comparison started in August 2005 and ended in June 2006. Participants of the comparison were PTB (Germany, pilot institute), VNIIM (Russia), SMU (Slovakia), BelGIM (Belarus), CPHR (Cuba) and RMTC (Latvia). PTB, VNIIM and SMU had previously taken part in a key comparison with the Bureau International de Poids et Mesures (BIPM) and operated as link laboratories in order to evaluate the degree of equivalence of the participants results with the key comparison reference value (KCRV). These data form the basis of the results entered into the BIPM key comparison database (KCDB) for comparison COOMET.RI(I)-K1. Draft A report was sent to the participants and all of them agreed with the content. Currently, Draft B is in preparation.

Measurement of the x-ray mass energy-absorption coefficient of air using 3 keV to 10 keV synchrotron radiation

(Phys. Med. Biol. **51** (2006) 5125-5150)

Abstract: For the first time absolute photon mass energy-absorption coefficients of air in the energy range 3 keV to 10 keV have been measured with relative standard uncertainties less than 1%, significantly smaller than those of up to 5% assumed hitherto for calculated data. Monochromatized synchrotron radiation was used to measure both the total radiant energy by means of silicon photodiodes calibrated against a cryogenic radiometer and the fraction of radiant energy that is deposited in dry air by means of a free air ionization chamber. The measured ionization charge was converted into energy absorbed in air by calculated effective *W* values of photons as a function of their energy based on new measurements of the *W* values in dry air for electron kinetic energies between 1 keV and 7 keV, also presented in this work. The measured absorption coefficients were compared with state-of-the art calculations and found to agree within 0.7% with data calculated earlier by Hubbell at energies above 4 keV but were found to differ by values up to 2.1% at 10 keV from more recent calculations of Seltzer.

Significant discrepancies in air kerma rates measured with free-air and cavity ionization chambers

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Abstract: Air kerma rates were measured in the same narrow x-ray beams in the range from 300 kV to 400 kV with both a free-air and a graphite cavity ionization chamber. The graphite-to-air stopping-power ratios that are necessary to determine the air kerma rates according to the cavity theory were calculated by means of Monte Carlo methods based on measured energy distributions of the photon fluence and the ICRU 37 stopping-power values. As a result, it was found that the air kerma rates obtained with the cavity chamber were significantly higher, by up to about 2%. The discrepancies disappeared when different stopping-power values for graphite were used in the calculation of the graphite-to-air stopping-power ratios. The ICRU 37 values were calculated on the basis of a mean excitation energy in graphite of I = 78 eV, in contrast to I = 86 eV used for the calculation of those values solving the discrepancies obtained in the first approach. The results are of fundamental interest for primary standard dosimetry laboratories because all of them employ graphite cavity chambers to realize the unit of air kerma for ^{137}Cs- and ^{60}Co-γ radiation.

Basic physical radiation quantities like the W value and the Fano factor cannot be applied to segments of the DNA

By a Monte Carlo simulation of the track structure of electrons at energies between about 10 eV and 100 keV, it was shown that the formation of ionization cluster size in target volumes of liquid water which are comparable in size with sub-cellular structures, strongly depends on electron energy and on target size. Whilst the cluster-size formation can be described satisfactorily by macroscopic quantities like the W-value or the Fano factor at lower electron energies in target volumes representing a nucleosome, a segment of the chromatin fibre, and a cell nucleus, it cannot be described accordingly in a target volume representing a DNA segment. Here, the formation of ionization clusters is much more determined by single ionizations and by the stochastics of secondary-electron production. In this respect, the setting in motion of secondary electrons at energies between about 100 eV and 300 eV by light ions is of particular interest.

Radiation quality of light ions from the point of view of nanodosimetry

Based on track structure simulations, it could be shown that highly sophisticated measurements of ionization cluster-size distributions due to electrons, protons and α-particles in nanometric volumes of a low-pressure gas, can be applied successfully to determine cluster size distributions that are very similar to those which would be caused by ionizing radiation in specified nanometric volumes of liquid water. From the point of view of radiation damage to the DNA, the probability of forming a cluster size $\nu = 1$ and the cumulative probability of cluster size $\nu \geq 2$ for DNA-segment-like liquid water targets are of particular importance because they show, after normalization to the energy absorbed in the target volume, a similar dependence on energy or on linear energy transfer as the yields of single- or double-strand breaks in the DNA. As a final result of the simulations, it can be emphasized that the moment ratio M_2/M_1 of the cluster-size distributions for nanometric liquid water targets due to protons and α-particles shows a similar dependence on linear energy transfer as the yield ratios of double- to single-strand breaks induced in the DNA.

The W values of protons in liquid water are markedly smaller than in water vapour

The W value (mean energy required to form an ion pair upon the complete slow down of ionizing particles) is one of the basic physical quantities needed for determining absorbed dose from ionization measurements. When neutrons penetrate through tissue, a large number of low energy protons are produced as secondary particles the ranges of which are of the order of a few micrometers. The knowledge of proton W values in water may, therefore, be helpful in assessing radiation-induced effects on a microscopic level. In view of this fact, the W values of protons in liquid water were calculated for energies between 100 eV and 10 MeV based on the continuous-slowing-down approximation, using three different sets of differential ionization cross sections of water for protons. The resulting W values differ only marginally from each other, with values of between 25 eV and 26 eV at proton energies above 5 MeV. This high-energy W value is smaller than the corresponding value in water vapour by about 3 eV.

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