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Realization of the absorbed dose to water for electronic brachytherapy X-ray Sources

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INTRODUCTION:

Today, miniaturized x-ray sources (MXS) are widely used for radiation therapy treatment (RTT) with more than 400 devices worldwide. The German National Metrology Institute (PTB) is developing a primary standard in terms of absorbed dose to water for the two mostly used devices: The Intrabeam®-system from Carl Zeiss Meditec AG and the Axxent® tube from Xofigo (iCad, Inc.).

Both devices emit an X-radiation field with an energy distribution given by a continuous Bremsstrahlung spectrum with a maximum energy of 50 keV superimposed by characteristic fluorescence lines induced by the material of the electron target and the materials in the pathway of the emitted photons. The angular distribution of the emitting field of both MXS is different: The emitting field of the Axxent tube is at maximum perpendicular to the axis of the needle, as it is the case for common radioactive Brachytherapy sources. The Intrabeam®-system has its maximum intensity in forward direction. In this direction the variation of the intensity is small for polar angles less than 30 degree.

The emitted field the dose reference point of the two sources are defined in separate positions due to the different spatial distribution: For the Axxent source it is defined in 1cm distance perpendicular to the axis and for the Intrabeam-system in 1cm distance along the source axis.

MATERIALS AND METHODS:

The spatial and energy distribution of the radiation fields of the sources were characterized with several methods and then detailed MC-models were designed to be consistent with the measurements.

Spectra were measured with an HPGe-Detector in combination with an analogue desktop spectrum analyser with pulse pile-up rejector circuits. Remaining pulse-pile up artefacts were eliminated by an algorithm developed in MATLAB®.

The spatial distributions of the focal spots were measured with a pinhole (1 mm thickness, 50 µm diameter) camera set-up using the camera obscura principle. The detector of this system is based on X-ray storage films.

Relative 3D- dose distributions in distances below 3 cm were determined with radiochromic gel dosimeters. Gels response was evaluated using optical computed tomography resulting in full 3D maps of distribution of relative optical densities in the whole volume of the gels. From the 3D map, 2D planes and 1D profiles were selected and compared to the results of the Monte Carlo simulations. The principle of the primary standard (iPFAC, in phantom free air chamber) is based on a free-air chamber located in a phantom of water-equivalent material. It has parallel-plate geometry, and the gap between the two plates embodying the measuring volume can be varied continuously up to a distance of 20 cm. The proximal front plate is fixed and its thickness defines the depth of measurement.

The evaluation method is based on radiation transport theory. The new method offers a clear analytical expression to determine D_w by applying a conversion factor $C(x_i, x_{i+1})$ to the difference of ionization charges measured at two plate separations x_i and x_{i+1} . This factor is composed of quotients of kerma values determined for different plate separations in the chamber.

Monte Carlo simulations were performed for the characterization of the utilized measuring devices, and to calculate the conversion and correction factors for the primary standard.

RESULTS:

The results of the measurements for the characterization of the sources and the complementary Monte Carlo simulations will be presented with a special emphasis on the information required for the realization and dissemination of the desired quantity absorbed dose to water.

Shown in Fig. 1 are measurements with the iPFAC for the Intrabeam source at 50 kV tube voltages and with 40 μ A beam current. Given are the values of the determined water-kerma rate at plate separation zero for specific plate separations x_{i+1} within the phantom of the primary standard.

From the mean value $K_w^{Ph} = (71.30 \pm 0.006)$ μ Gy/s the absorbed dose rate in 1 cm distance within a water phantom ($10 \times 10 \times 10$ cm³) was determined to $D_w = 65.4$ mGy/s.

CONCLUSION:

The absorbed dose to water for electronic brachytherapy sources has been realized for the first time. It is intended to offer a regular calibration service by the end of 2018. In a further step, transfer standards suitable for the dissemination of the quantity need to be established as well as consistent procedures or protocols.

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