Characterization of the Sensitivity Profiles of Dose Calibrators for the Measurement of Radium-223

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Introduction

Radium-223 is an alpha emitter, which was recently approved as Ra-223-dichloride for the treatment of castration-resistant prostate cancer and symptomatic bone metastases without visceral metastases. Accurate measurements of Ra-223 activity with ionization chambers are necessary for therapy dosage.
Ra-223 has a physical half-life of 11.4 days, an average decay energy of 5.6 MeV and a decay chain with six particles to stable Pb-207 (1). By the decay of the short-lived daughter nuclides in turn alpha-, beta- and gamma- radiation are released. During the interaction of the emitted alpha particles with matter the particles release some of their energy and slow down. Due to the interaction the matter is ionized and free electrons and bremsstrahlung arise. This radiation can be detected with an ionization chamber.
Previous studies with dose calibrators showed an inhomogeneous sensitivity profile for gamma and beta emitters (2-4). The aim of this study is the characterization of this profile for Ra-223.

Methods and Materials

Measurements were performed in 3 identically constructed dose calibrators (VDC-405, COMECER Netherlands, former Veenstra) with a small Ra-223 point source. The point source is a 1 ml tuberculine syringe (B. Braun Ominifix-F, polypropylene, wall thickness = 1 mm, Fig.1) which were used to fill V = 100 µl of a calibrated 1000 kBq/ml injection solution of Ra-223-dichloride. After filling, the syringe was sealed with a stopper and attached to the positioning device (Fig.1) which is placed above the well of the dose calibrator. The precise position of the point source inside the cylindrical well (diameter = 7 cm, depth = 28 cm) can be read and modified via a measuring scale and a micrometer. The examined chambers were previously calibrated to known Ra-223 solution.
The sensitivity profile was measured for each chamber along the z-axis (increment = 5 mm) from the bottom of the well respectively from the bottom of the well liner (diameter = 5.7 cm , depth = 27.1 cm) up to the top of the chamber. The measured activity values were normalized to its maximum value and averaged. The radial sensitivity was measured along the inner diameter of the chamber (increment = 8.5 mm) at 3 different z-positions (#1 close to the bottom of the well liner, #2 position of the vial and #3 position of the syringe, Fig.2). These activity values were normalized to the center of the position of the syringe (#3) and averaged. The influence of the sample holder to the measured activity was determined.
All activity values were corrected for background signal and radioactive decay. To identify significant inhomogeneities in the sensitivity profile, the measured values were tested by t-tests (α = 0.05) regarding the values at the central vial (#2) or syringe (#3) position.

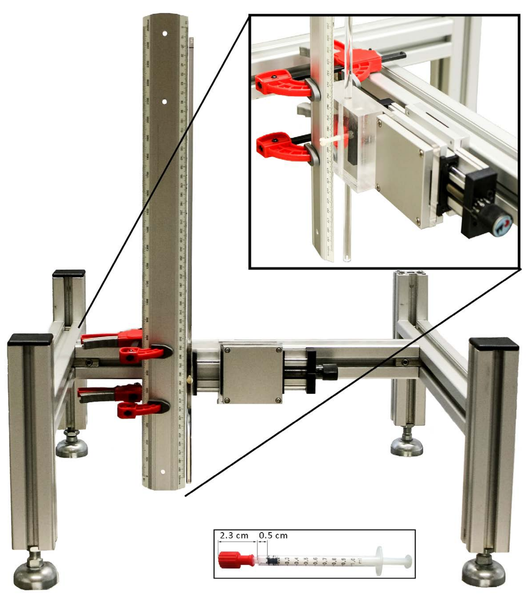

Fig.1. Positioning device of the Ra-223 point source for the characterization of the sensitivity profile. The point source was fixed to a 50 cm long acrylic rod and the positioning device with the rod was centered over the well of the dose calibrator. There was a marker at the rod where the position in the vertical direction (z-axis) can be read on a measuring scale. The position of the point source can be varied along the diameter of the chamber by a micrometer.

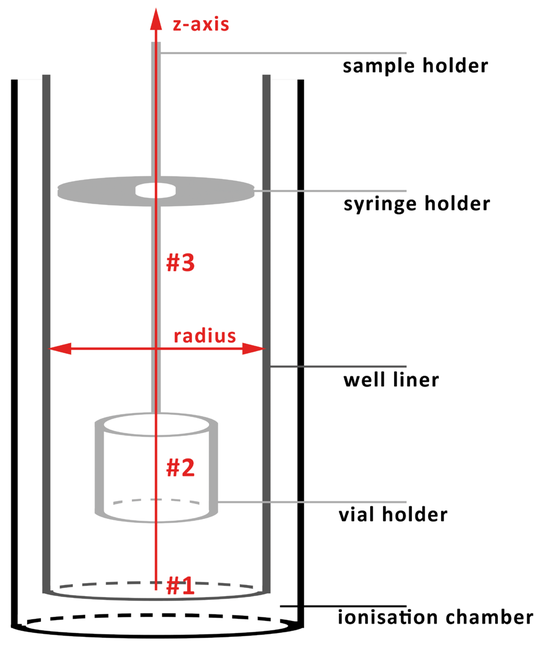

Fig.2. Schematic view of the dose chamber volume with well liner and sample holder. The sensitivity profile was measured along the z-axis for i) an empty chamber (w/o well liner and sample holder), ii) a chamber with well holder (w/o sample holder) and iii) a chamber with well liner and sample holder. The radial sensitivity profile was determined for three different z-positions: #1 close to the bottom of the well liner, #2 position of vial and #3 position of syringe for a chamber with and without well liner.

Results

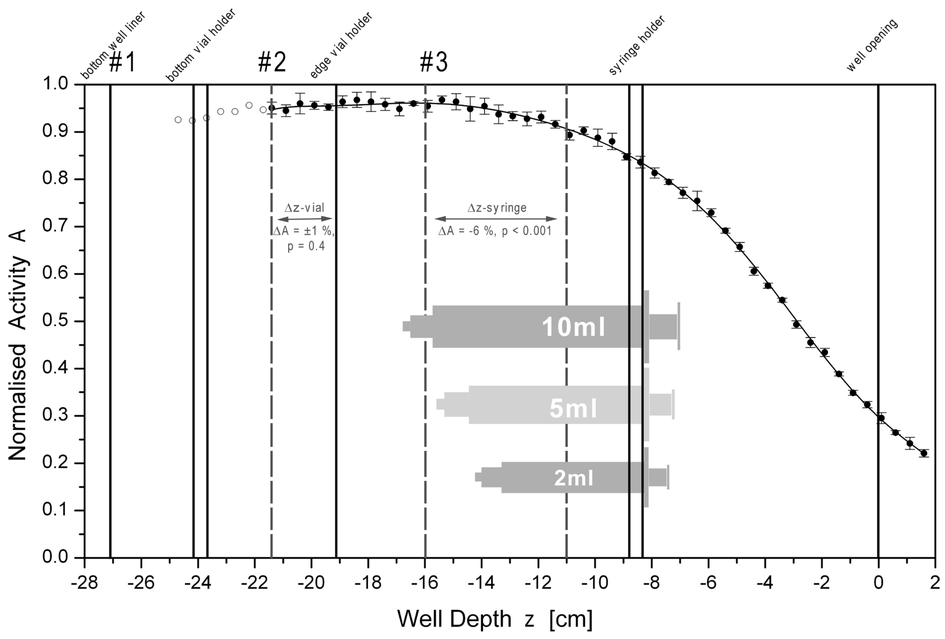

Fig.3. Sensitivity profile of a Ra-223 point source along the centerline from the bottom of a sample holder up to the opening of the well. Points of orientation along the depth of the well. The geometries of typically used syringes were drawn to scale.

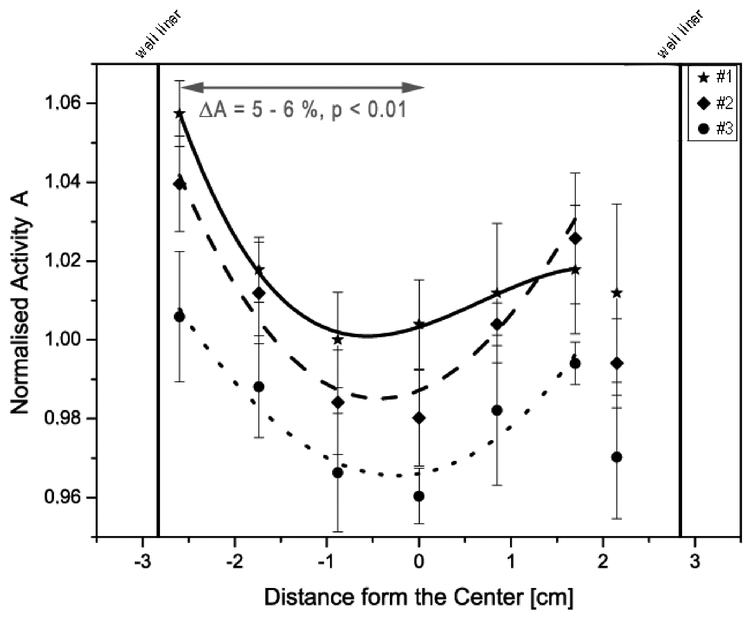

Fig.4. Sensitivity profile of a Ra-223 point source along the cross section of the well liner for three different z- positions (#1 = -27 cm, #2 = -21.5 cm and #3 = -16 cm).

The sensitivity profile within the vial volume (#2, Δz = 2.0 cm) was constant in z-direction and varied only slightly by ΔA_{max} = ±1.0 % (p = 0.4) for all dose calibrators. Meanwhile, the sensitivity varied significantly by ΔA_{max} = -6.4 % (p < 0.001) along the z-direction in the volume used for syringe measurements (#3, Δz = 5.0 cm). The intra-chamber variability of the activity values at the z-positions #2 and #3 varied only slightly by ΔA_{max} = 0.6 % (p = 0.2). The inter-chamber variability of the activity values was not significant at the vial position (#2, ΔA_{max} = ±1.4 %, p = 0.1), but there was a significant difference between the chambers at the position of the syringe (#3, ΔA_{max} = ±2.0 %, p < 0.01).

The radial sensitivity for the different z-positions (#1, #2 and #3) increased significantly from the centre towards the edge (ΔR = ±2.85 cm) of the well liner up to ΔA_{max} = 6.1 % (p < 0.001). Within the radius (Δr = ±2.15 cm) of the vial holder at z-position #2 the activity increased up to ΔA_{max} = 3.2 % (p < 0.01).

Conclusion

Sensitivity profiles were estimated for Ra-223 point sources. Our measurements revealed a spatial sensitivity variance of ≤ ±3.2 % at positions which are typically used for measuring vial geometries. This variance is comparable to values specified by technical documentations for gamma and beta emitters (max: ±3 %). The spatial sensitivity variance was more pronounced at positions used for measuring syringe geometries. Here, activity decreased up to -6.4 %.

Reference

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