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Assessing the Accuracy of Ion Chamber Air Kerma Measurements in Synchrotron Produced Monochromatic X-ray Beams

INTRODUCTION

The accuracy of ion chamber air kerma measurements in synchrotron produced high kerma rate monochromatic X-ray beams was assessed. A C-552 walled Exradin A1SL ion chamber was calibrated at the NRCC in a series of narrow X-ray beam qualities to establish its air-kerma calibration factor. The ion chamber was then irradiated at the Canadian Light Source, CLS, using monochromatic beams of 65, 83, 100 and 115 keV energy. The ion recombination, polarity and volume averaging effects were investigated in a series of exposures. The air-kerma rate was measured and compared with nominal values

METHODS

I. NRCC Chamber Air-Kerma Calibration

A C-552 walled Exradin A1SL ion chamber was calibrated at the NRCC using a series of ISO 4037-1 Narrow beams, with effective energies ranging from 65 – 118 keV. The air-kerma rate was determined using the NRCC free-air chamber air-kerma standard. The calibration uncertainty is conservatively taken to be 0.5 %, while the greatest variation between different beam air-kerma calibration factors was 2 %.

II. Ion Recombination and Polarity effect

The A1SL chamber was aligned such that the center of the beam coincided with the geometric center of the collecting volume; this was facilitated by a 4 µm/ pixel SCMOS camera. The irradiation setup can be seen in Figure 1. The polarity effect was determined for each beam. The ion recombination effect was investigated by extrapolating a series of collected charge measurements versus the reciprocal of the applied voltage. The exponential fall off of the synchrotron output was also used to investigate the ion recombination effect at different kerma rates and consequently establish the relative importance of volume and initial recombination. Figure 2 shows the chamber response for the 65 keV beam.

III. Field Size and Volume averaging effects

The field produced by the synchrotron beam is non-uniform in the vertical direction, resulting in a kerma rate drop of 60 % at 1 mm away from the beam center, where the kerma rate is maximum. Gafchromic EBT3 film was used to measure the non-uniformity of the beam over the chamber volume, a typical absorbance plot and an image of the film is shown in Figure 3. The chamber response was corrected for the dose fall-off over the chambers sensitive volume in the vertical direction .

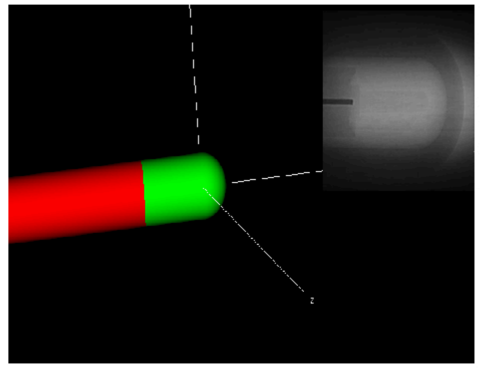

Figure 1. A model of the A1SL irradiation set-up is shown. The beam is incident along the z-axis. The smaller image was produced using a high resolution SCMOS camera and was used to align the center of the chamber with the beam. Live images could also be taken during irradiation to ensure no movement of the beam.

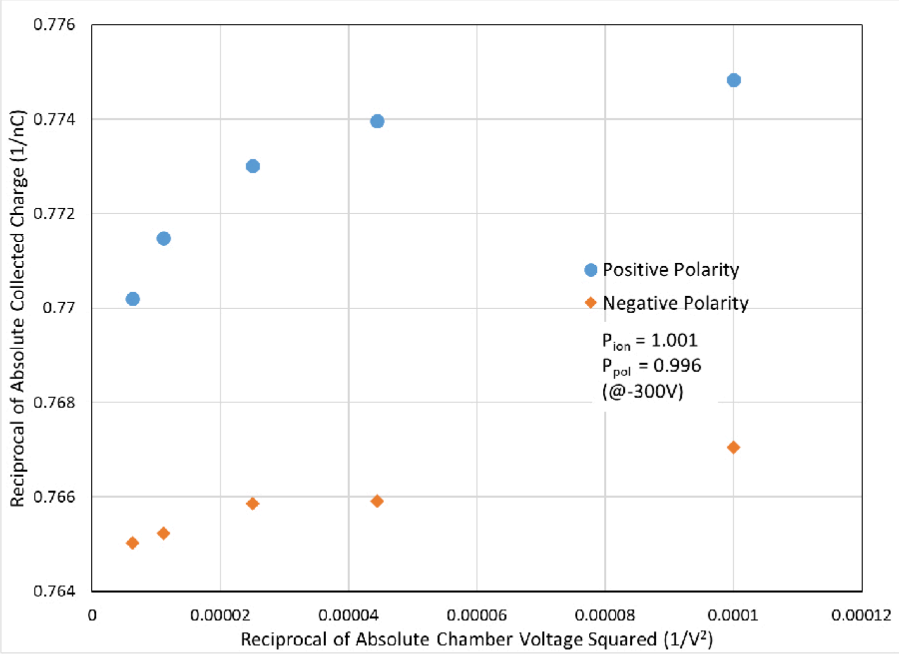

Figure 2. A typical plot for the chamber response, the reciprocal of the absolute collected charge, in a 65 KeV monochromatic synchrotron beam with respect to the reciprocal of the absolute voltage applied. Our analysis shows that the Pion correction is dominated by initial dose rate independent recombination whilst the polarity correction is found to be on the order of 4 %. There is a clear difference in chamber response between both polarities, an effect not seen for this chamber type in Co-60 and higher beam energies.

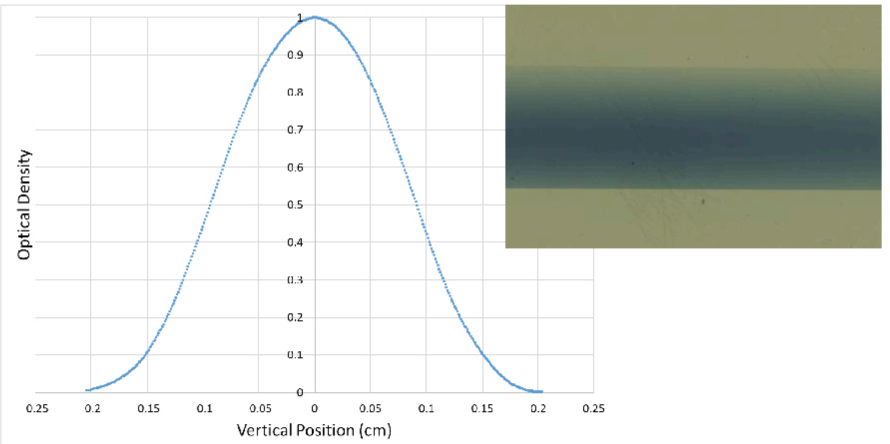

Figure 3. A plot of the normalized optical density of an EBT3 film as a function of vertical position, irradiated using the monochromatic 115 keV beam. The film response was used to correct the ion chamber readings for the effects of the field non-uniformity. An image of an irradiated sample is shown in the top right.

RESULTS

E (keV)	K_{pol}	K_{ion}	K_{non-u}	Difference between nominal and measured air kerma rates
65	0.996	1.000	2.167	4%
83	1.004	1.000	2.211	12%
100	0.997	1.000	2.156	35%
115	1.002	1.000	2.156	30%

Table 1. A summary of the results obtained from measurements in 4 different monochromatic synchrotron beams. The air-kerma calibration factor for each beam was based on the corresponding narrow beam with the same effective energy. The nominal air-kerma rates were provided by the CLS and are based on measurements with a PTW Pinpoint 31014 chamber that was further corrected for volume averaging before comparison could be made with our results.

CONCLUSION

The results indicate that the ion recombination and polarity corrections are an order of magnitude less than the non-uniformity correction of the field over the chamber volume. Compared with the nominal kerma rates provided by the synchrotron facility, which were based on a manufacturer calibrated PTW Pinpoint 31014 chamber, differences ranging from 4 – 35% were observed once both detectors were corrected for field non-uniformity effects. The estimated standard uncertainty on the NRCC chamber measurements is 2.3 % at the k=1 level. This investigation has indicated that the dominant correction factor for ion chamber measurements in the monochromatic synchrotron beams investigated is field non-uniformity. Although the current nominal beam calibration is acceptable for imaging applications, these results suggest that a different detector type and geometry is required for the accurate determination of air kerma, and ultimately, absorbed dose for therapeutic investigations.

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