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Comparison between the response in air and in water of two ionization chambers exposed to low-energy X-rays

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ABSTRACT

This work investigated the effect of two different media in the response of two Farmer-type ionization chambers exposed to low-energy x-rays from 27 kV – 155 kV. The measurements were performed in air and in liquid water. Independent of the ionization chamber, at effective energies below 30 keV (80 kV), the charges collected in both media diverge from a maximum difference of 84% and converge at 30 keV. This can be associated to the rapid attenuation of the low-energy photon fluence by the water depth. At effective energies greater than 30 keV, the response in water becomes larger than that in air, reaching a maximum of 27% and 35% at 65 keV (150 kV) for A19 and A12 chamber, respectively. The difference in response between the two media is consistently greater for ionization chamber A19 at energy above 25 keV.

Keywords: **low-energy x-rays, ionization chambers, low-energy dosimetry, measurements in water, measurements in air**

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1. INTRODUCTION

To perform reference dosimetry in low-energy photon beams, ionization chambers are considered as gold standard [1],[2]. Generally, the measurements are carried out in air even though the measurements in water are required. The current codes of practice [1],[2] suggest performing measurements in air since the reference standard laboratories do not provide calibration coefficients in terms of absorbed to water for ionization chambers in the low-energy range. Due to the perturbations of the photon fluence by the presence of the ionization chamber in water, dosimetry in these fields is challenging. Calorimetric method has been proposed at the Physikalisch-Technische Bundesanstalt (PTB) to achieve the reference dosimetry in terms of absorbed dose to water for intermediate-energy X-ray beams from 70 kV to 280 kV [3]. However, for energies below, information is not available. So, the response of the ionization chambers situated in water compared to that in air might be a pathway to implement reference dosimetry in low-energy photon beams. Then, to establish reference dosimetry in our lab, this work investigated the effect of two media (liquid water and air) on the charge collected by two ionization chambers after exposure to low-energy x-rays from 27 kV to 155 kV. This is because the perturbation factors due to the presence of the ionization chamber in water are automatically considered when comparing the responses in water and in air for the same chamber.

2. MATERIALS AND METHODS

Two Farmer-type ionization chambers (IC) were exposed in air and liquid water to ten different X-ray beams from 27 kV to 155 kV produced by a YXLON X-ray tube at a current of 2 mA. The ICs Standard Imaging Exradin A12 and A19 with 0.64 cm^3 and 0.62 cm^3 volume, respectively, were used. The beams were previously characterized in our lab. Table 1 displays the additional filtration, effective energy, first half value layer (HVL) and homogeneity coefficient for each beam [3].

For liquid water, the measurements were performed at 2 cm depth and 61 cm source to surface distance (SSD). For those measurements, a homemade acrylic phantom of 30 x 30 x 30 cm^3 with an entrance window of 2 mm thickness was used. Whereas, for the measurements in air, the chambers were situated at 63 cm SSD to conserve the same distance from the focal spot. Figure 1 shows the experimental setup for the measurements in water. According to the quality control protocol in our lab, a stabilization process is followed before each set of measurements and the response of the chambers between one exposure and another should be less than 0.1%, independent of the energy beam. The collected charges were corrected due to the variations of the temperature and pressure during each measurement. The corrections corresponding to ion recombination, P_{ion}, and polarity effects, P_{pol}, have been measured and found to be constant for effective energy range of 12-65 keV, with a value around 1±0.1% [4].

Table 1: Beam qualities used for the exposures.

Voltage (kV)	Additional filtration (mmAl)	Effective energy (keV)	First HVL (mmAl)	HC (%)
27	0.2794	13.48 ± 0.01	0.25 ± 0.19	65
36	0.3048	15.26 ± 0.01	0.35 ± 0.13	61
36	0.508	17.64 ± 0.01	0.51 ± 0.11	67
44	0.889	21.33 ± 0.02	0.85 ± 0.11	68
53	1.0668	23.56 ± 0.04	1.13 ± 0.11	66
60	1.8288	27.28 ± 0.05	1.75 ± 0.11	67
80	2.8702	32.33 ± 0.37	2.83 ± 0.11	68
100	5.2324	40.46 ± 0.03	4.80 ± 0.12	74
118	7.112	47.93 ± 0.02	6.54 ± 0.10	78
145	5.2324+0.254 Cu	65.26 ± 0.01	10.03 ± 0.11	96
155	5.2324+0.254 Cu	67.39 ± 0.01	10.41 ± 0.23	97

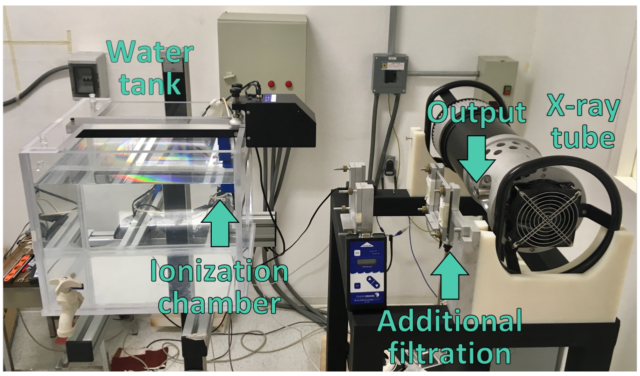

Figure 1: *Experimental setup for measurements performed in water.*

3. RESULTS AND DISCUSSION

Figure 2 presents the charge collected in liquid water Q_w and in air Q_{air}, as a function of photon energy for both ionization chambers. The combined standard uncertainties are included in the figure and are around 0.1%. As can be seen at energies below 30 keV, the response in water increases with the energy while the response in air, decreases as the energy increases. For example, the difference on the response obtained for the two media vary between 84% and 0% from 13 keV to 30 keV. This can be explained as follow: for effective energies below 30 keV, the X-ray beam is rapidly attenuated by the 2 mm entrance window of the phantom and the 2 cm of water, causing a reduction in the photon fluence when reaching the ionization chamber. This is not expected to happen in air since the photon fluence does not rapidly decrease as it does in water due to the photelectric effect. Consequently, the number of ionizations produced within the sensitive volume of the chambers situated in air decreases. In contrast, for effective energies above 30 keV, where the Compton effect starts to be important, both collected charges in water and in air increase independently of the chamber since the attenuation coefficient is proportional to the Z of the medium in this energy range. This increment can possibly be associated to the scattering processes. Note that the differences in the response in water and in air are almost constant with variations between 17% and 25% for A12 chamber and between 22% and 31% for A19 chamber, at energies above 30 keV. This is the consequence of the slight variation on the mass attenuation coefficient between the two media.

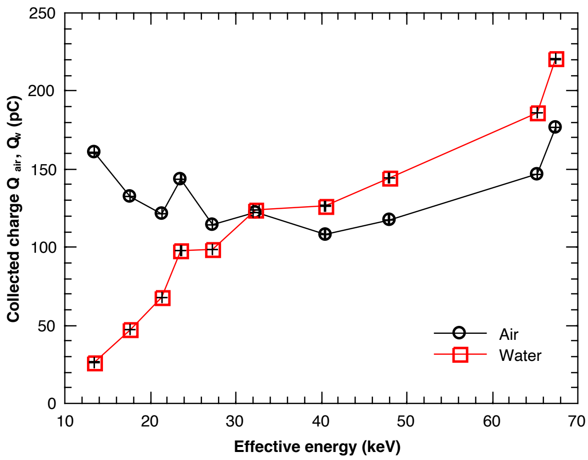

Figure 2a: *Collected charge in liquid water, Q_w and air, Q_{air} for the ionization chamber A12.*

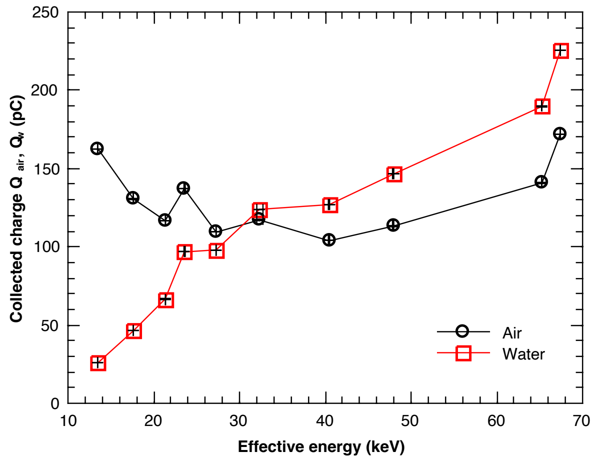

Figure 2b: *Collected charge in liquid water, Qw and air, Qair for the ionization chamber A19.*

Figure 3 presents the ratio of the responses in water and in air for both ionization chambers. The ratio increases, reaches a maximum about an effective energy of 50 keV and thereafter, seems to be constant at higher energies. This behavior suggests that independent of the chamber, the ratio depends on the energy at photon energies below 50 keV, where the lower is the energy, the lower is the ratio. Comparing the two chambers, this ratio is similar, varying from 0.02% to 6.4% over the effective energy range studied. This small difference can be associated with the efficiency of the charge collection by the electrode of both chambers since the wall thickness of their sensitive volume is the same (0.5 mm) according to the manufacturer.

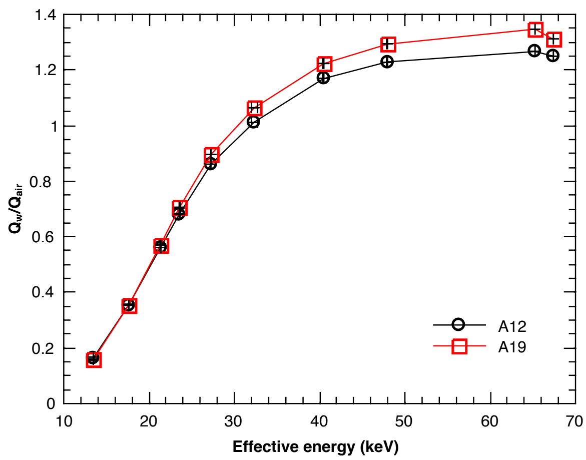

Figure 3: *Ratio of the collected charge in liquid water, Q_w and that in air, Q_{air} for the ionization chambers A12 and A19.*

4. CONCLUSIONS

Difference in the response as a function of energy of two ionization chambers situated in water and in air, exposed to low-energy x-rays in the range of 27 kV to 155 kV (effective energy ~13 keV to 70 keV), was investigated. At energies below 30 keV, the response in air is up to 84% greater than that in water independent of the chamber, which is associated to the attenuation processes. We also observed that for effective energies below 50 keV, the chamber response depends strongly on the energy.

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