Determination of W_{air} in high-energy clinical electron beams using aluminium detectors.

Alexandra Bourgouin[1,2], Malcolm McEwen[1]

[1]National Research Council, Ottawa, Canada,[2] Department of Physics, University of Carleton, Ottawa, Ontario, Canada

Objective::

The recent report on dosimetric key value (ICRU 90) reaffirmed the accepted value of W_{air}, to be a constant, above 10 keV, with a value of 33.97 ± 0.12 eV. A recent publication[1] has showed a possible energy dependence and to investigat this further, an experiment was carried out [2] reproducing the Domen and Lamperti investigation[3]. Although the experiment yielded a value consistent with the ICRU90 value, it highlighted the problems of using graphite detectors[2], particularly related to density variations. The goal of this project is to obtain additional experimental data in high-energy electron beams to determine W_{air} using a different material, namely pure aluminium.

Materials and Methods::

To measured W_{air}, which is the quotient of charge released in dry air, Q_{air}, and energy deposited in this mass of air, $D_{air} \cdot m_{air}$, an ion chamber and a calorimeter have been designed and constructed using pure aluminum. The ionometric, and calorimetric measurements, Q_{air} and D_m respectively, are combined with a Monte Carlo dose calculation (effectively a stopping power ratio) to obtain W_{air}:

$$W_{air} = \frac{D_{air} \cdot m_{air}}{Q_{air}} = \frac{D_{al}}{Q_{air}/m_{air}}\left(\frac{D_{air}}{D_{al}}\right) = \frac{D_m}{Q_{air}/m_{air}} SPR_{al}^{air} \qquad \text{Eq.1}$$

The quantity m_{air} in equation (1) means that the volume of the ion chamber must be determined as for a cavity standard, and both mechanical and capacitive measurements were used. The calorimeter used was an open-to-atmosphere design using calibrated NTC thermistors in an AC Wheatstone Bridge to determine the radiation-induced temperature rise, and thus the dose to aluminium. Measurements were made in electron beams produced by the Elekta Precise linear accelerator at the NRC facility. Twenty-two different configurations were used to provide a range of electron energies at the point of measurement, and also vary the thermal environment for the calorimeter. The primary electron beam energy were 8, 12, 18 and 22 MeV with a range of aluminum buildup thickness between 0.0 to 1.0 cm. The Irradiation time was also varied as was the source-detector distance, to further investigate geometrical and thermal influence quantities.

Results:

Prior to the measurements described above, the ion chamber was extensively tested to demonstrate it met the requirements of a reference-class detector. Results for ion recombination, polarity and leakage current were as expected.

The type A uncertainty for a series of calorimeter runs at a doserate of 3 Gy min^{-1} was consistent with literature values and analysis of temperature-time plots indicates that thermal isolation of the core was superior to the previous graphite calorimeter design. At this time, it has not been possible to carry out the necessary Monte-Carlo simulations to derive the theoretical dose conversion from aluminium to air, so monoenergetic mass stopping powers have been substituted in equation 1. This is a significant simplification but is useful as a first step in analyzing the data (Table 1).

Table 1: Radiation and buildup set-up for all different configurations with associated mass stopping power ratios and W_{air} values calculated. Uncertainties shown are only type A uncertainties.

Nominal Energy MeV	Al. thickness (total) cm	Energy at cavity MeV	Stopping power ratio -	Wair value eV	diff. with ICRU (%)
8	0.194	6.59	1.1300	31.14 ± 0.02	8%
	0.392	5.62	1.1300	31.51 ± 0.02	7%
	0.591	4.65	1.1300	31.94 ± 0.05	6%
12	0.194	10.16	1.1246	30.20 ± 0.02	11%
	0.392	9.10	1.1271	30.37 ± 0.02	11%
	0.693	7.50	1.1299	30.87 ± 0.03	9%
18	0.194	14.99	1.1065	28.92 ± 0.07	15%
	0.392	13.82	1.1109	29.25 ± 0.04	14%
	0.591	12.05	1.1175	29.46 ± 0.06	13%
	0.693	9.11	1.1271	30.17 ± 0.07	11%
22	0.194	19.11	1.0900	28.16 ± 0.05	17%
	0.392	17.85	1.0947	28.45 ± 0.11	16%
	0.591	15.95	1.1027	28.71 ± 0.02	15%
	0.693	12.76	1.1159	29.35 ± 0.09	14%

There is a significant energy dependence of the results and the all the values are significantly lower than the current recommended value. Using aluminium is advantageous in that it is an elemental material with no significant crystalline structure but the higher atomic number means that the fluence perturbation in electron beams could be significant and explain the deviations seen in the final column. Monte Carlo calculations, reproducing the entire geometry of the experiment will show the magnitude of this effect.

Conclusions and Significance:

Although initial measurements with the aluminium ionization chamber and calorimeter indicate expected performance, preliminary analysis of the data yield a value for W_{air} different from recommended data. Further Monte Carlo and thermal simulations are required to investigate this further and additional measurements at higher electron beam energies are planned.

Relevance to CIRMS:

The presented work is the main doctoral project of the first author. This project suite with the conference theme because of the impact of any W_{air} energy dependence would have on radiation measurements and standards. W_{air} is the key ‘constant’ of ion chamber measurement, and this detector is currently the gold standard in medical radiation dose measurement. The first author aims to pursuit a career in metrology, radiation measurement, after her PhD. This project and attending to metrological conference, such as CIRMS meeting, are key step to reach that goal.

References

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