EVALUATION OF "SOLID WATER" PLASTIC AS A CALIBRATION PHANTOM FOR ELECTRON BEAM DOSIMETRY

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ABSTRACT

In radiation dosimetry protocols, plastic is allowed as a phantom material for electron beams calibration. The water equivalency of the solid phantom should be investigated. This study evaluated a commercially available photon-electron Solid Water phantom as phantom material in terms of output calibration, depth ionization measurements and beam energy characterization by comparing with measurement in water. Measurements were performed for 8, 10, 12 and 15 MeV electron beams with field sizes of 10 x 10 cm^2 and 14 x 14 cm^2. The dosimetry system is a Farmer 0.6 cc graphite walled ion chamber. Ionization measurements were taken at various depths and the depths to the selected percent depth ionization line (R_t, R_{50} and R_p) match to within 2 mm. of those measured in water, which would result in calculated incident energies within + 0.4 MeV. Evaluations compared with absorbed doses calculated from ionization measurements using IAEA calibration protocol resulted in a discrepancy in calculated peak dose rate. Eliminating this discrepancy requires an ionization ratio correction (h_m). The variations lead to the suggestion that any phantom material need acceptance testing before clinical use.

INTRODUCTION

The usually recommended phantom materials for electron beam absorbed dose calibration and dose distribution specification have been water.[1,2,3] Non water solid phantoms are also widely used because it is not always possible and convenient to use water phantom. The dose measured in a solid phantom has to be converted to the dose in a water phantom for reference dosimetry. In the past few years, several solid phantom materials had been developed as being similar enough to natural water that they can be used interchangeably as calibration phantom. The production of solid phantom materials which would have radiation absorption and scattering characteristics closely simulating to those of water, would allow the use of those solid phantoms without the accompanying errors. Such as the original epoxy resin-based phantom material known as " Solid Water ™" (RMI model SW 451; Radiation Measurements, Inc., Middleton, WI 53562) was described by White[4] and evaluated the equivalency between water and Solid Water for transmission of photon beams. Thwaites[5] also evaluated this material for electron beam calibrations and founded that, while better than polystyrene, but Solid Water was " still having significant different from a true water phantom". Constantinou[6] developed a new Solid Water

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formula known as Solid Water for photon and electron (RMI model SW 457). Tello et al[7] evaluated this material and qualified the discrepancies in absorbed doses by comparing electron output measurements in water and the output calculated from measurements in the Solid Water phantom.

The purpose of this study was to evaluate the water equivalency of this Solid Water phantom material for depth ionization measurement, electron beam dose calculation and determination of electron energy using IAEA Code of Practice calibration protocol.[3] The present work compares the central axis depth ionization curves and the ionization at the depth of maximum in water and Solid Water ™ , assuming the use of calibration factors for water. The IAEA Code of Practice calibration protocol[3] has a definition of electron fluence correction factor. The IAEA converts the ionization reading at the ionization maximum in Solid phantom to the ionization reading at the ionization maximum in water using :

$$M^W = M^S h_m$$
$$h_m = M^W / M^S$$

Where M^w and M^S are the electrometer reading in water and solid phantom respectively, corrected for temperature, pressure and ion recombination. h_m is an ionization ratio correction.

The beam energy is expressed as the mean incident electron energy, E_0 . The IAEA protocol recommended to determine the mean electron energy at the phantom surface, using a following relationship between this energy and the depth (cm.) of either the 50% ionization or dose level (R_{50}) :

$$E_0 = 2.33\ R_{50} \qquad \text{(MeV)}$$

MATERIALS AND METHODS

Most experiments were performed with electron beams having nominal energies of 8, 10, 12 and 15 MeV generated by a Mitsubishi ML 15M linear accelerator. All measurements were made at 100 cm SSD in 10x10 cm^2 and 14x14 cm^2 fields using a solid-wall applicator in contact with the phantom surface. A series of similar measurements were carried out in water and photon-electron Solid Water ™ (RMI model SW 457) at various depths. The same dosimetry system was used for all beam measurements. It consisted a NE model 2571, 0.6 cc Farmer type cylindrical chamber with a graphite wall and a NE model 2570 electrometer.

The water phantom was a perspex walled tank of an area of 30x30 cm^2. The Farmer type ion chamber was inside a perspex holder; the chamber was positioned horizontally. All Solid Water phantom consisted of a 30 x 30 cm^2slab of various thickness, ranging from 2 mm to 5 cm, and one slab with a cavity to accept a 0.6 cc Farmer type ion chamber. The required depths (in 1 mm steps) were obtained by adding water or successive slabs to those phantoms for the chamber. To provide an adequate back scatter, at least 10 cm of both phantom materials were placed under the point of measurement at all times.

The phantom materials were left in the treatment room for a period, long enough to establish a temperature and pressure very close to the room temperature before measurements were begun. Temperature and pressure of the room and of the phantom were checked throughout the series of measurement for consistency. All measurements were corrected for temperature and atmospheric pressure. The chamber allowed to equilibrate in each phantom until reading showed no changes in reading and the linear accelerator was brought to operating equilibrium before any measurements by running to a 500 monitor units.

The measurements were made along the central axis and repeated three to five times, and the depths of maximum ionization for both phan-

tom materials were searched in 1-2 mm increment. The absorbed doses to water were calculated from ionization chamber measurements in water and in Solid Water ™ using the IAEA Code of Practice calibration protocol.[3] Absorbed dose to water at d_{max} is considered to be the reference dose. For Solid Water phantom, stopping power data for water were used since such data for Solid Water phantom was not available.

RESULTS

DEPTH IONIZATION CURVES

Fig 1-8 show the comparison of the percentage depth ionization as measured in the Solid Water phantom superimposed on those taken in water for 8, 10, 12 and 15 MeV electron beams respectively of a 10x10 cm^2 and 14x14 cm^2 field sizes. One may notice that the particular values of percentage ionization occur at slightly greater depths in water than in solid water phantom, but the differences are small. Those results are presented in Table 1. for electron beam 10x10 cm^2 and 14x14 cm^2 respectively.

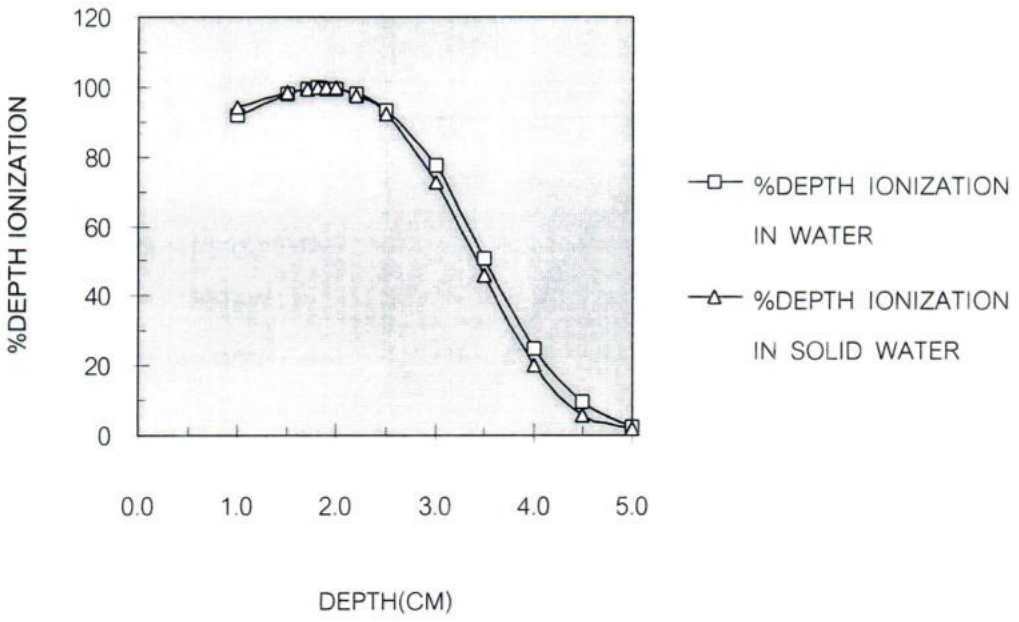

Fig. 1 Central axis depth ionization curver for electron beam 8 MeV measured in water and Solid Water phantom material using 10x10 cm^2 applicator

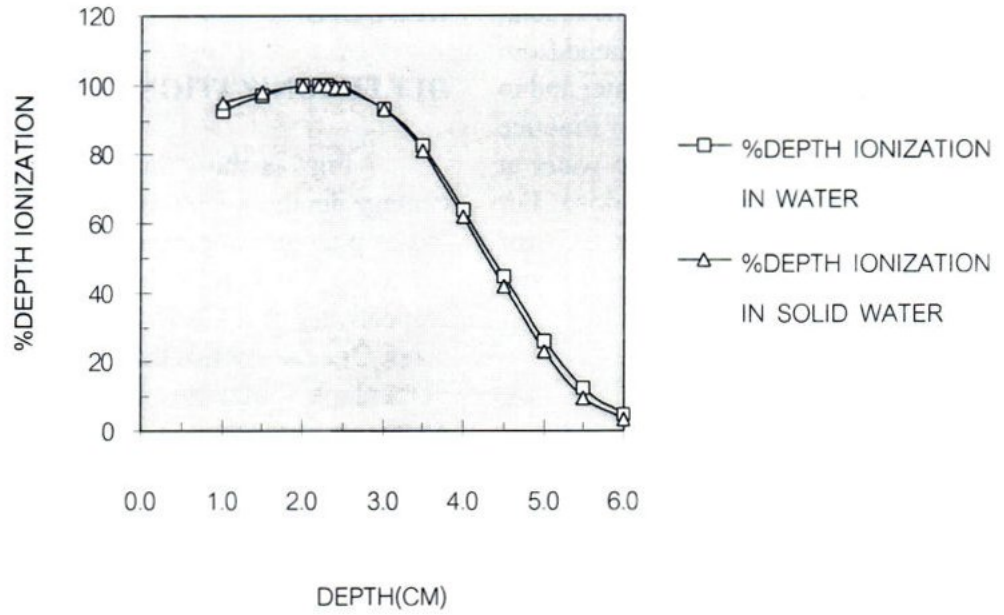

Fig. 2 Central axis depth ionization curver for electron beam 10 MeV measured in water and Solid Water phantom material using 10x10 cm^2 applicator

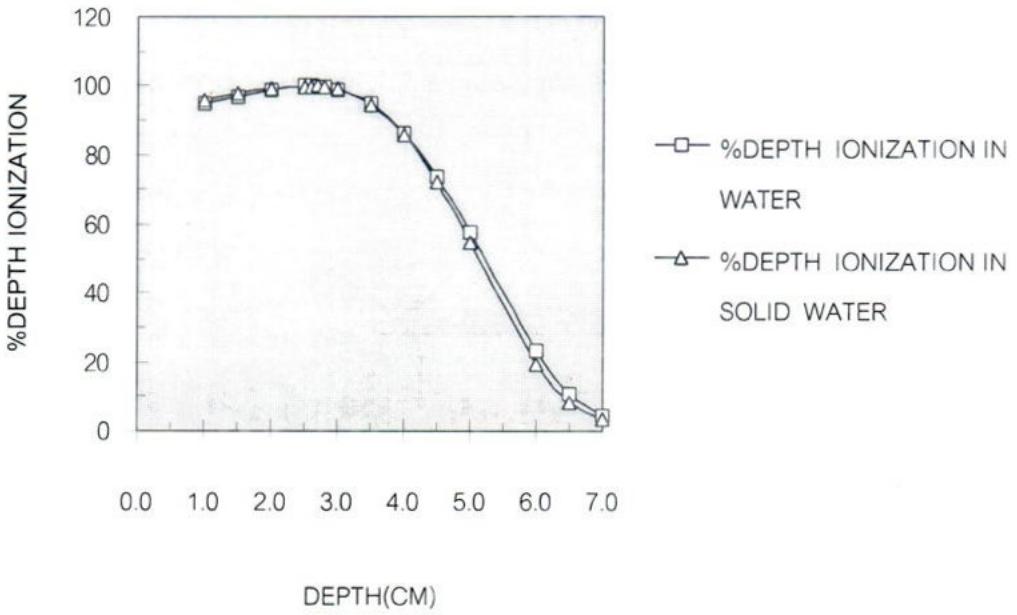

Fig. 3 Central axis depth ionization curver for electron beam 12 MeV measured in water and Solid Water phantom material using 10x10 cm^2 applicator

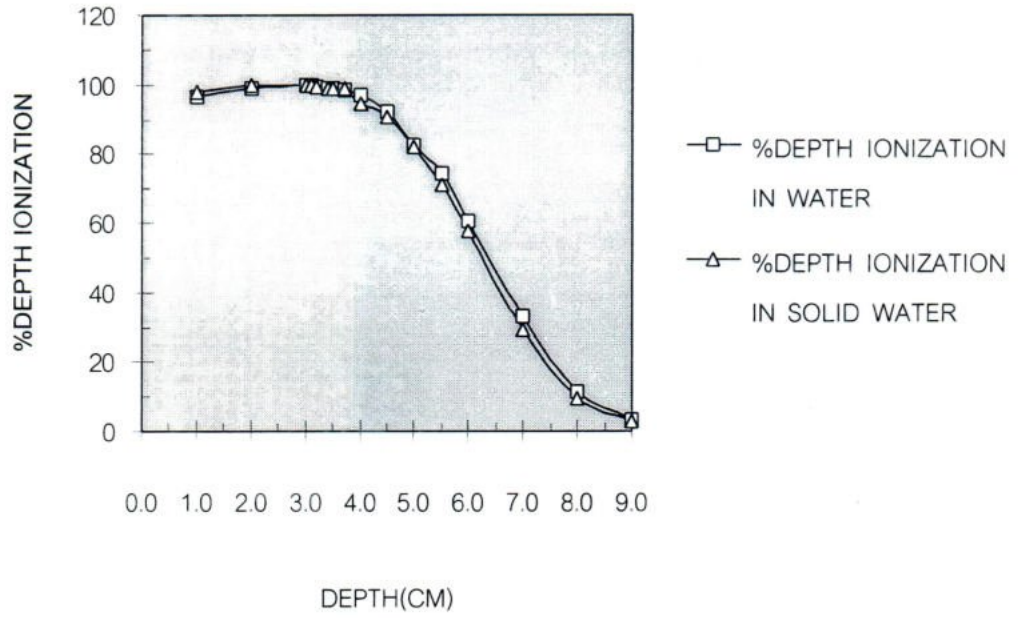

Fig. 4 Central axis depth ionization curver for electron beam 15 MeV measured in water and Solid Water phantom material using 10x10 cm^2 applicator

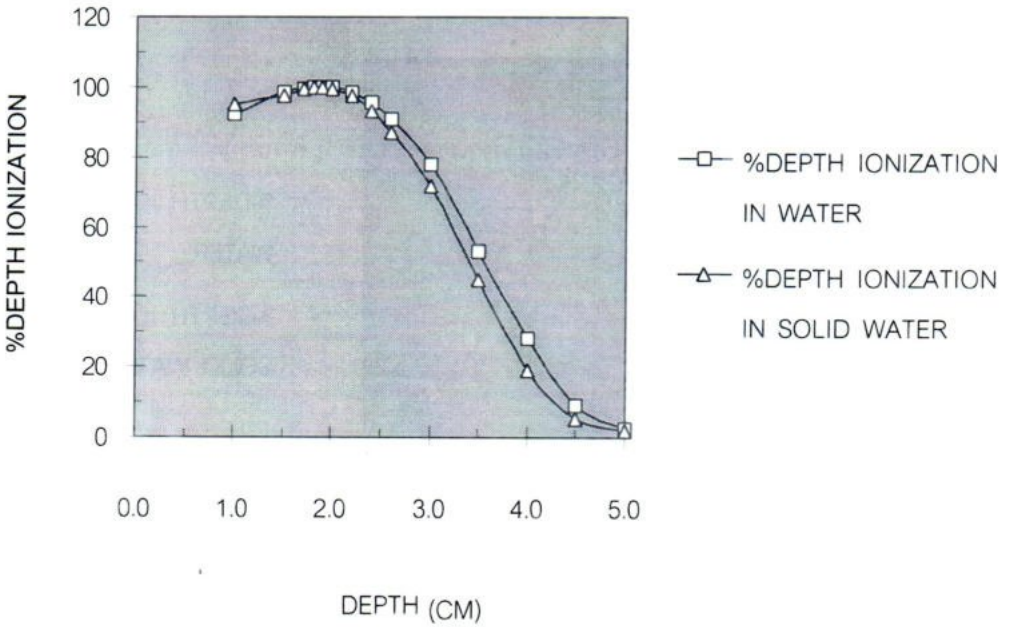

Fig. 5 Central axis depth ionization curves for eletron beam 8 MeV measured in water and Solid Water phantom material using 14x14 cm^2 applicator

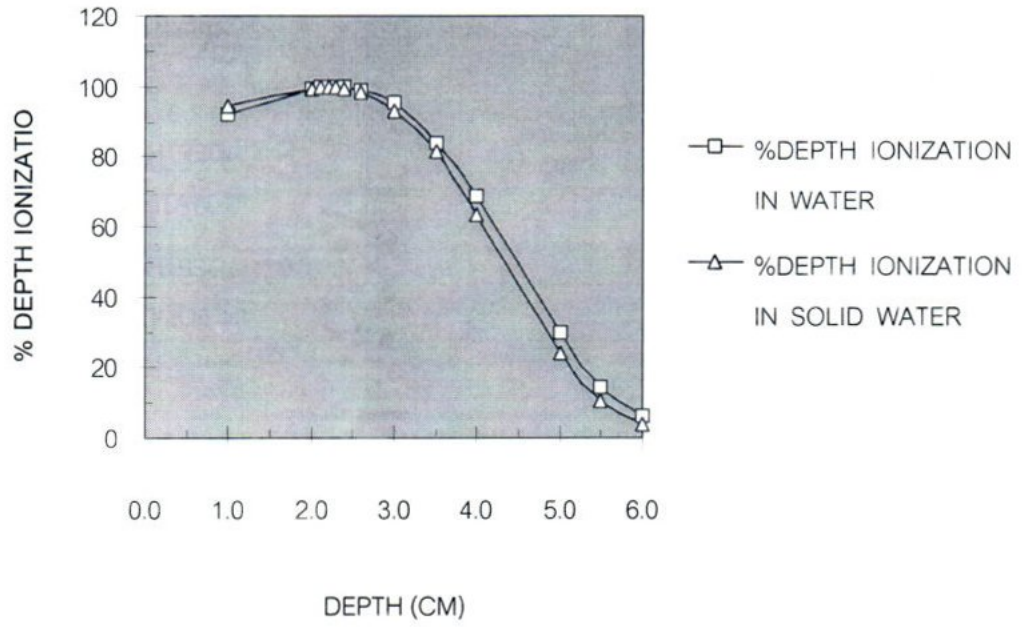

Fig. 6 Central axis depth ionization curves for eletron beam 10 MeV measured in water and Solid Water phantom material using 14x14 cm^2 applicator

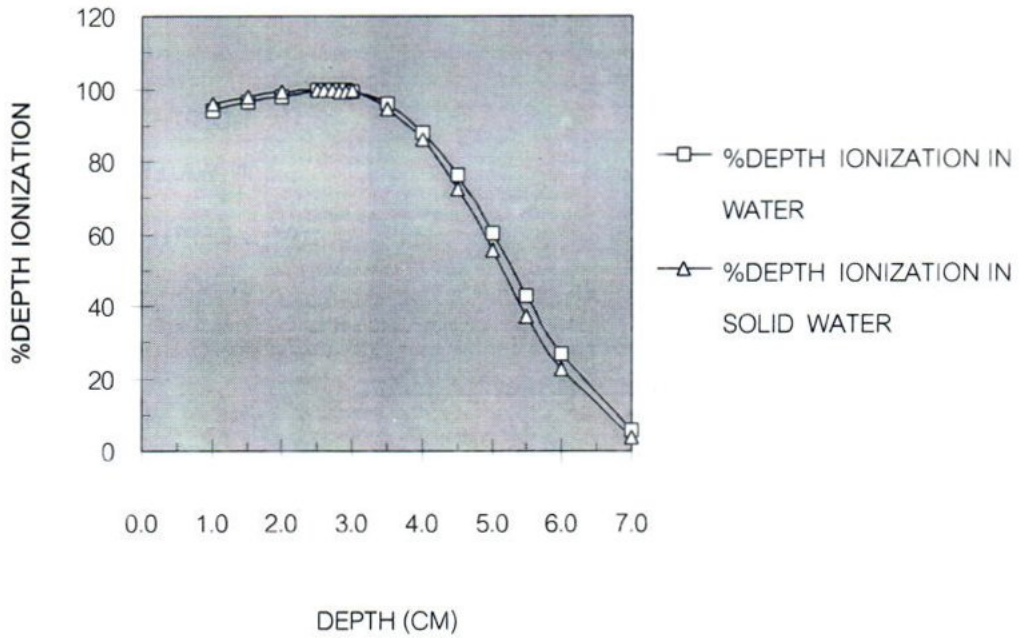

Fig. 7 Central axis depth ionization curves for eletron beam 12 MeV measured in water and Solid Water phantom material using 14x14 cm^2 applicator

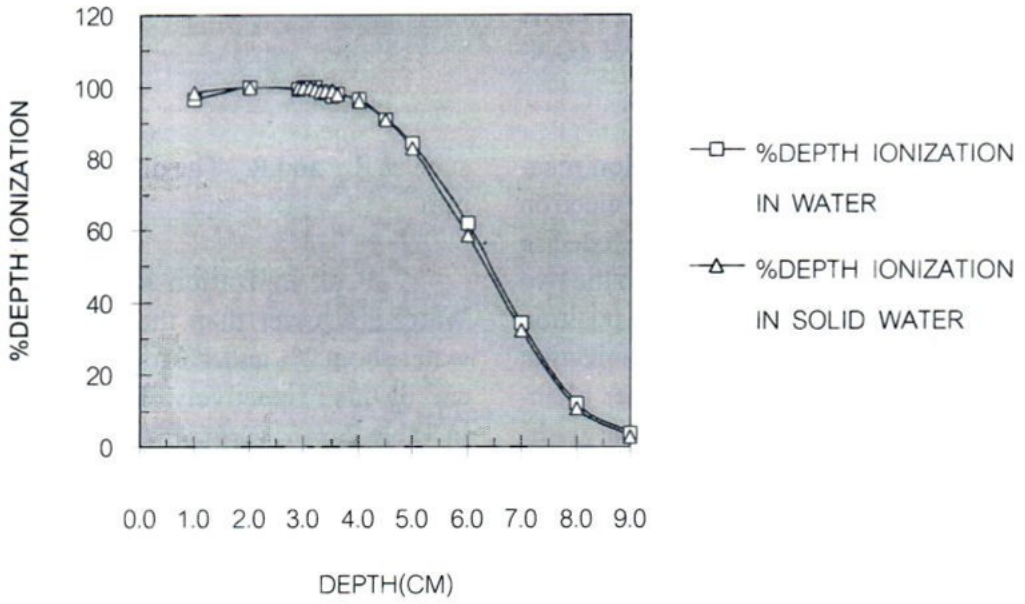

Fig. 8 Central axis depth ionization curves for eletron beam 15 MeV measured in water and Solid Water phantom material using 14x14 cm^2 applicator

Table 1. Characteristics of the electron beams (8, 10, 12 and 15 MeV) E_n, nominal energy; E_0, mean electron energy at the surface; R_{100}, R_{90}, R_{80} and R_{50}, depths of the 100, 90, 80, and 50 % points on the central axis ionization curves; R_p, practical range, determined by measurements in water and Solid Water ™ for applicator 10 x 10 cm^2 (A) and 14 x 14 cm^2 (B)

A

E_n (MeV)	E_0 (MeV)	R_{100} (cm)	R_{90} (cm)	R_{80} (cm)	R_{50} (cm)	R_p (cm)
			Water			
8	5.87	1.8	2.60	2.92	2.53	4.48
10	10.09	2.2	3.15	3.57	4.33	5.64
12	12.26	2.6	3.77	4.24	5.26	6.66
15	14.87	3.0	4.61	5.17	6.38	8.30
			Solid Water			
8	5.61	1.8	2.55	2.88	2.41	4.33
10	10.23	2.3	3.13	3.53	4.39	5.59
12	12.00	2.7	3.75	4.20	5.15	6.52
15	14.54	3.0	4.55	5.10	6.24	8.10

B

E_n (MeV)	E_0 (MeV)	R_{100} (cm)	R_{90} (cm)	R_{80} (cm)	R_{50} (cm)	R_p (cm)
			Water			
8	5.83	1.9	2.62	2.94	2.50	4.57
10	10.35	2.3	3.24	3.63	4.44	5.62
12	12.30	2.8	3.87	4.34	5.28	6.72
15	15.03	3.1	4.57	5.20	6.45	8.47
			Solid Water			
8	5.69	1.8	2.50	2.78	2.44	4.45
10	10.16	2.3	3.14	3.54	4.36	5.52
12	11.98	2.7	3.77	4.22	5.14	6.57
15	14.77	3.0	4.57	5.13	6.34	8.24

IONIZATION MAXIMUM AND OTHER PARTICULAR VALUES OF PERCENT IONIZATION

The depths of maximum ionization measured in water and in Solid Water for the electron beams of 8, 10, 12 and 15 MeV that are listed in Table 1. The difference of these depths in the two materials are very small (+1 mm). The position of R_{90} and R_{80} obtained from the depth ionization curves agree within +1 mm for Solid Water phantom material and water phantom. The dose gradient is usually higher for depths larger than R_{80} such as R_{50} and R_p. The difference are less than 2 mm

Peak ionization measurements in Solid Water are lower than the ionization reading in water about 2% and 4% for 10x10 cm^2 and 14x14 cm^2 beams respectively. These results are shown in Table 2.

Table 2. Peak ionization measurements in water and Solid Water ™ corrected for temperature, atmospheric pressure and ion recombination.

Nominal energy (MeV)	Ionization measured in water (nC)	Ionization measured in Solid Water (nC)
	Applicator 10 x 10 cm^2	
8	25.25	24.22
10	25.08	24.26
12	25.34	24.37
15	25.63	24.71
	Applicator 14 x 14 cm^2	
8	24.77	24.49
10	25.10	24.67
12	25.70	25.14
15	25.90	25.38

IONIZATION RATIO CORRECTION FACTOR (H_m)

For the values of the ionization ratio correction factor (h_m) for Solid Water™ with a 0.6 cc graphite wall Farmer ion chamber for the beams of 8, 10, 12 and 15 MeV are presented in Table 3.

Table 3. Water to Solid Water ™ ionization ratio at depths of maximum ionization h_m for electron beams of 10 x 10 cm^2 and 14 x 14 cm^2

Nominal energy (MeV)	Electron applicator (cm^2)	
	10 x10	**14 x 14**
8	1.0425	1.0114
10	1.0338	1.0174
12	1.0398	1.0223
15	1.0372	1.0205

DISCUSSION

Our results show that the maximum discrepancy of the depth of peak ionization is at 1 mm and the peak ionization measurements in Solid Water ™ appear to be consistently lower than the reading in water by approximately 4 % for 10x10 cm^2 and 2 % for 14x14 cm^2 beams. The underresponse of this Solid Water ™ follows from their characterization design. The resulting photon-electron Solid Water ™ has the mass angular scattering powers that differ from water by more than 2 %,[2] resulting in the underestimation of dose at peak depth.

For depth ionization curves, in the region from near the surface to R_{80}, the difference between the two results are within at +1 mm. And the percentage depth ionization in Solid Water predicts R_{50} values to within + 2 mm of those measured in water which would result in the calculated incident energy within + 0.4 MeV that were shown in Table 1. From this agreement, it was suggested that the beam energy characterization with Solid Water ™ is acceptable.

Taking comparative measurements in water and Solid Water ™ for graphite walled Farmer ion chamber in our experiment, h_m is about 1.04 for 10 x 10 cm^2 and 1.02 for 14 x 14 cm^2 in electron beams with nominal energies of 8, 10, 12 and 15 MeV (Table 3). Comparing the h_m values for the same type of ionization chamber to the other published values at similar energy range,[5,8] and the published experimental data for IAEA 's h_m, they show considerable variation and a single set of these values cannot given, since this factor depends on various measurement conditions. Thus h_m values should be measured experimentally for a particular condition of interest.

In this work, we did not calculate the depth scaling factor for non-water phantom materials that had been recommended by AAPM TG25,[2] since the difference of the depth in these two materials are very small (about 2 mm).

CONCLUSION

The use of a solid phantom makes dosimetric measurements easier and the uncertainties in dosimeter positioning and the problems of chamber water proofing can be eliminated. Our study shows that dose measurements in a commercial available photon-electron Solid Water phantom material (RMI model SW 457) is good to be a water substitute for electron beams calibration in this energy range. Measurements for R_{90} and R_{80} (therapeutic range), R_{50} and R_p may be made in this material without any correction. But peak dose calibration still required a correction factor to account for the approximate 2 to 4 % discrepancy observed between the properties of Solid Water ™ and those of water. From the variation in dose measurements in Solid Water and natural water detected, it is suggested that before any solid phantom material is used as a water substitute, it should undergo acceptance testing for water equivalency or the determination of correction factor before putting to clinical uses.

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