A Comparison Study of the Solid Phantom and Water Phantom Using 6 MV and 15 MV Photon Energies, Depending on the Depth

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ABSTRACT

Water is such an environmental element that is considered the best human body tissue equivalent. In the field of dosimetry studies, water is frequently used. This comparison study is conducted by a solid phantom and a water phantom with 6 MV and 15 MV photon energies, respectively. A cylindrical-type ionization chamber is used to collect charge when beams are on. The distance between the ray source and the surface of the phantom was fixed at 100 cm i.e. to SSD (Source to Surface Distance) of during the experiment. Chamber travels 1 cm to 20 cm in both phantoms and an electrometer is attached in the experimental set-up to measure the charge. The field size was 10x10 cm2. The relative deviation ratio of the solid phantom to the water phantom was calculated. In the result, the maximum deviation was 0.64%, while the minimum deviation was 0%, corresponding to the depths of 1 cm and 2.5 cm, respectively, for 6 MV and at 15 MV, maximum deviation and minimum deviation were 1.90% and 0.167% respectively, corresponding to the depths of 1.5 cm and 13 cm. Therefore, it can be said that the solid phantom can overcome the disadvantages of installation time required for the water phantom and problems while water level changing for depth measurement, simultaneously can used to measure the radiological dose precisely.

Keywords: Water phantom, solid phantom, charge, absorbed dose.

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INTRODUCTION

Cancer is a growing cause of death, and medical physics is a branch of science focusing on cancer patients and treatment equipment. This field covers quality control, design, and delivery of radiation doses in radiotherapy, such as cobalt units and linear accelerators.

In general, radiation damages normal cells and cancer cells. Radiotherapy is a clinical method that involves radiation with a very short wavelength and high energy that hits the DNA structure of human cells and causes changes in the cells by physical, chemical, and biological processes (1-3). Normal cells can make a quick recovery compared to cancer cells. If limited doses of radiation are delivered to cancerous cells in a periodic manner, the cancerous cell cannot heal itself, and regular radiation to the target damages the cancer cell completely due to a lack of time. Because of this principle, radiotherapy has now become one of the best operating tools in the treatment of cancer. In radiotherapy, the main target is to deliver a sufficient dose to destroy the cancerous cell while spearing the normal cell as much as possible. Dose precision and optimization are the main considerations of this treatment. Water is considered the best human tissue equivalent, so water-based phantoms are widely used for radiotherapy protocols such as yearly, monthly, and quality assurance and control programs. (4). A water phantom usually comes in two sizes: a big water tank (rectangular and cylindrical in shape) for ~ 40x40 cm2 field size, and another one is 1D for ~ 10x10 cm2 field. However, it takes a long time to perform the test with the water phantom. Due to the waterproof nature of the ionization chamber, the time required to place the ionization chamber in the correct position in the water. Firstly, the ionization chamber needed to be fixed with a clamp to set into the water, which is motorized to be driven into the water, which can cause errors in the measurement of depth. Whenever a chamber moves inside the water, waves create and experiment delayed for the water level to settle down. With each movement of the chamber, time is needed to stabilize and check the depth. More time is required to collect data. Undoubtedly water phantom is the best option for dosimetry study, here this study emphasis the usefulness of solid phantom for quick check with a variation of depth.

MATERIALS AND METHODS

This experiment was done at the Institute of Nuclear Medical Physics (INMP), Atomic Energy Research Establishment (AERE), Bangladesh Atomic Energy Commission (BAEC). The linac machine at INMP, consists of two energy's photon beams (6 MV and 15 MV). A linear accelerator (clinic iX: manufactured by Varian), electrometer, cylindrical type ion chamber, solid phantom and 1D water phantom were used in this experiment. During the experiment, water phantom was placed with the linac machine following SAD technique in Figure 1.

Figure 1: Experimental setup of ionization chamber set in 1D water phantom

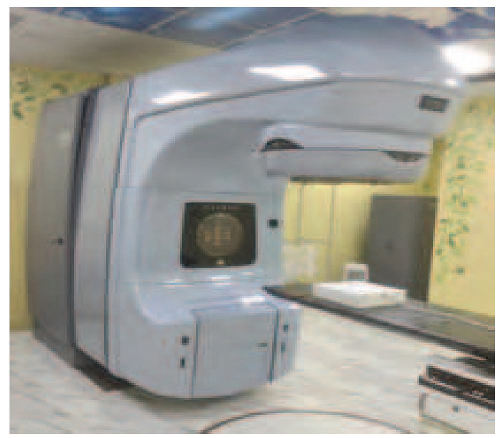

Figure 2: Experimental setup of solid phantom with ionization chamber

The solid phantom and the ionization chamber were also placed in the treatment room in the same way i.e. with the vertical direction of the beam radiation against the linear accelerator in Figure 2.

Figure 3: An electrometer

Figure 4: Cylindrical type ionization chamber

Figure 5: 1D water phantom

Figure 6: Solid phantom

An electrometer in the control room in Figure 3, was connected with the cable of the triaxial ion chamber. The solid phantom used in the experiment consisted of slabs (square in shape, made of water-equivalent material) with a thickness of 0.1, 0.2, and 1 cm and an area of 30×30 cm2. Solid phantom, 1D water phantom and water all kept in same room, so that all equipment were considered of same temperature. All the experiments were performed at a dose rate of 400 MU/min and irradiation doses of 100 MU. The experiment at 100 MU was performed five times to calculate the average charge and the results were analysed based on the water phantom.

For each photon's energy, i.e. 6 MV and 15 MV, charges have been measured by an electrometer through the ionization chamber in Figure 4.

During the calculations the following factors were used:

Pressure, P=1004 hpa, Temperature T=19 0C, Ks=1.0036 kpol=1.007 ktp=0.9937 KQQ0=0.9937 for 6 MV and ks=1.0075 kpol=1.0001 ktp=1.006 KQQ0=0.9937 for 15 MV.

Relative deviations, also calculated for 6 MV and 15 MV photon energy, were arranged in the respective tables. Relative deviation was calculated using the following equation:

$$\text{Relative Deviation} = \left(1 - \frac{\textit{Charge counted in Solid Phanto in a reference depth in a reference condition}}{\textit{Charge counted in Water Phantom with the same depth and condition}}\right) \times 100\%.$$

RESULTS

The chamber travels 1 cm to 20 cm downward in both the 1D water phantom and the solid phantom. The values were registered in Table 1 for 6 MV photon energy. The highest absorbed dose of 1.005 Gy was found at 2 cm of depth in the water phantom, whereas 1.001 Gy was the highest absorbed dose of solid phantom at 2 cm.

Table-1: Absorbed dose and measured charge of 6 MV in solid phantom and 1D water phantom.

Depth (cm)	Solid Phantom			Water Phantom			Relative deviation
	Charge in (nC) for 100MU	Absorbed dose (Gy)	PDD of Solid Phantom	Charge in (nC) for 100MU	Absorbed dose (Gy)	PDD of Water Phantom	
1	20.03	0.963038	95.56298	20.16	0.969289	95.81749	0.644841
1.5	20.96	1.007753	100	21.04	1.011599	100	0.380228
2	20.82	1.001021	99.33206	20.9	1.004868	99.3346	0.382775
2.5	20.48	0.984674	97.70992	20.48	0.984674	97.3384	0
3	19.97	0.960154	95.27672	20.06	0.964481	95.34221	0.448654
3.5	19.534	0.939191	93.19656	19.59	0.941883	93.10837	0.28586
4	19.056	0.916209	90.91603	19.154	0.920921	91.03612	0.511642
4.5	18.608	0.894669	88.77863	18.61	0.894765	88.45057	0.010747
5	18.178	0.873995	86.7271	18.186	0.874379	86.43536	0.04399
6	17.1	0.822165	81.58397	17.14	0.824088	81.46388	0.233372
7	16.5	0.793317	78.72137	16.51	0.793798	78.46958	0.060569
8	15.712	0.75543	74.96183	15.722	0.755911	74.72433	0.063605
9	14.87	0.714947	70.94466	14.89	0.715908	70.76996	0.134318
10	14.1	0.677925	67.27099	14.102	0.678021	67.02471	0.014182
11	13.36	0.642346	63.74046	13.384	0.6435	63.61217	0.179319
12	12.62	0.606767	60.20992	12.66	0.60869	60.1711	0.315956
13	12.05	0.579362	57.49046	12.052	0.579458	57.28137	0.016595
14	11.314	0.543975	53.97901	11.316	0.544071	53.78327	0.017674
15	10.714	0.515127	51.11641	10.718	0.515319	50.94106	0.03732
16	10.12	0.486568	48.28244	10.128	0.486952	48.13688	0.078989
17	9.578	0.460508	45.69656	9.59	0.461085	45.57985	0.12513
18	9.038	0.434545	43.12023	9.054	0.435315	43.03232	0.176717
19	8.556	0.411371	40.82061	8.576	0.412332	40.76046	0.233209
20	8.096	0.389254	38.62595	8.098	0.38935	38.48859	0.024697

The same steps were repeated for 15 MV photons' energy. In 1D-water phantom, 1.00821 Gy was the highest absorbed dose at 3 cm, and 0.98926 Gy was the highest in solid phantom, arranged in Table 2.

Table-2: Absorbed dose and measured charge of 15 MV in solid phantom and 1D water phantom

Depth (cm)	Solid Phantom			Water Phantom			Relative deviation
	Charge in (nC) for 100MU	Absorbed dose (Gy)	PDD of Solid Phantom	Charge in (nC) for 100MU	Absorbed dose (Gy)	PDD of Water Phantom	
1	16.55	0.784114	79.26245	16.83	0.79738	79.08835	1.663696
1.5	19.094	0.904645	91.44636	19.464	0.922175	91.46617	1.900945
2	20.32	0.962731	97.31801	20.68	0.979787	97.18045	1.740812
2.5	20.8	0.985472	99.61686	21.16	1.002529	99.43609	1.701323
3	20.88	0.989263	100	21.28	1.008214	100	1.879699
3.5	20.76	0.983577	99.42529	21.12	1.000633	99.24812	1.704545
4	20.52	0.972206	98.27586	20.86	0.988315	98.02632	1.629914
4.5	20.16	0.95515	96.55172	20.54	0.973154	96.52256	1.850049
5	19.834	0.939705	94.99042	20	0.94757	93.98496	0.83
6	19.15	0.907298	91.71456	19.37	0.917721	91.02444	1.135777
7	18.34	0.868921	87.83525	18.58	0.880292	87.31203	1.291712
8	17.604	0.834051	84.31034	17.824	0.844474	83.7594	1.234291
9	16.884	0.799938	80.86207	17.104	0.810362	80.37594	1.286249
10	16.16	0.765636	77.39464	16.384	0.776249	76.99248	1.367188
11	15.484	0.733608	74.15709	15.708	0.744221	73.81579	1.426025
12	14.834	0.702812	71.04406	15.056	0.71333	70.75188	1.474495
13	14.372	0.680924	68.83142	14.396	0.682061	67.65038	0.166713
14	13.562	0.642547	64.95211	13.786	0.65316	64.78383	1.624837
15	12.984	0.615162	62.18391	13.188	0.624827	61.97368	1.546861
16	12.43	0.588914	59.53065	12.63	0.59839	59.3515	1.583531
17	11.914	0.564467	57.05939	12.094	0.572995	56.83271	1.488341
18	11.394	0.53983	54.56897	11.574	0.548359	54.3891	1.55521
19	10.902	0.51652	52.21264	11.062	0.524101	51.98308	1.446393
20	10.502	0.497569	50.29693	10.602	0.502307	49.82143	0.943218

All PDD values plotted against the distance showed in the graph for both 6 MV in Figure 7 and 15 MV photon energy in Figure 8. Graph shows clear agreement that solid phantom can be the replacement of water phantom for daily QC and QA, as PDDs obtained from solid phantom and water phantom, which are superimposed on each other and have less than 2% variation.

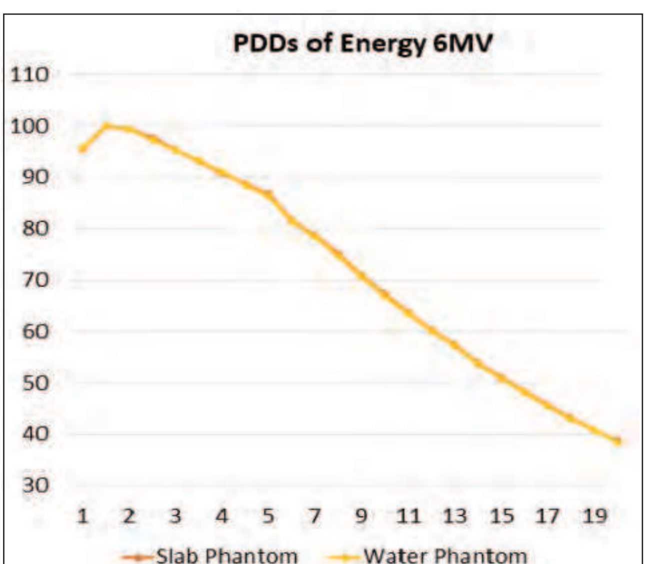

Figure 7: PDD vales comparison of solid phantom and water phantom with a variable depth for 6 MV.

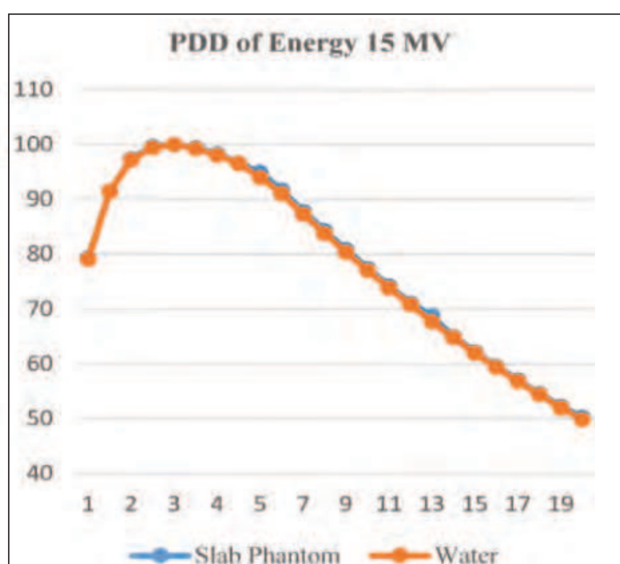

Figure 8: PDD vales comparison of solid phantom and water phantom with a variable depth for 15 MV.

DISCUSSION

In high-energy radiation, it is critical to monitor the treatment dose precisely and evaluate inaccuracy. Water is typically advised for the precise measurement of the absorbed dose; nevertheless, there are several drawbacks to this method, such as the need to take your time positioning the ionization chamber in the water to ensure it is watertight. Thus, the solid phantom is effective in terms of time needed and user-friendliness, barring exceptional uses such as obtaining the beam data for the treatment plan system or calibrating the linear accelerator's output. By comparing the radiological dosages of the two types of phantoms according to their depths, this study aimed to evaluate the therapeutic usefulness of the solid phantom, which may counteract the drawbacks of the water phantom.

In this study, results of solid phantom and 1D water phantom mostly overlapped. Air gaps between the plates are very common. If plates of solid phantom deformed, displaced and vary from its original shape, air gaps between the plates can become an issue and put impacts on dose calculation.

Hong JW (5) compared photon charge between water and solid phantom and found the minimum and maximum errors depending on the depths of the measurement for the various mediums and energy levels are -0.457% and 1.199%, respectively, which conform to the recommended values.

CONCLUSION

In this experiment, when 6 MV photon beam used, 0.64% was the maximum deviation at 1 cm depth and 0% was the minimum deviation at 2.5 cm. For 15 MV photon beam, maximum deviation found 1.90% where minimum deviation was 0.167%, respectively, corresponding to the depths of 1.5 cm and 13cm. The recommended value of the relative error in the absorbed dose based on the water phantom is ±2%. solid phantom can be considered a good option for QA and QC work.

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