

# Effect of surface waves on radiotherapy dosimetric measurements in water tanks

Mohammad Bakhtiari

RadAmerica II, LLC, 9501 Franklin Square Dr. Baltimore, MD 21237, Baltimore, USA

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## ABSTRACT

The effect of surface waves, generated by moving the scanning arms in water phantoms, on radiation dosimetry is studied. It is shown that in large water tanks, high arm speeds can result in dosimetric errors of up to 5%. The measurements that are started after damping the water waves can result in about a 50% improvement in accuracy of measurements. It is shown that the water surfaces at the start of the measurements have high fluctuations that transform to a steady phase by elapsing time.

**Key words:** Dosimetry, water tank, waves

## Introduction

During the process of commissioning and annual quality assurance of a linear accelerator, different dose (ionization) profiles must be measured and given as inputs into the treatment planning systems.<sup>[1-3]</sup> Current linear accelerators have different modalities and energies,<sup>[4]</sup> which makes the commissioning of the machines a time consuming process.<sup>[4,5]</sup> Water tanks with remote control arms are widely available in the radiation therapy community, and medical physicists are able to set several desired depths to measure the dose profiles sequentially. The water tanks are usually large enough to give the possibility of measuring fields as large as 40 cm. The medical physicist has the options to select among different arm speeds (for measuring the dose profiles and depth doses, and which can be performed), spatial resolutions, and measurement times. One may set the system in a way that, after measuring each dose profile, the scanner returns to the

starting point to start a new profile measurement at a new depth. However, movement of the arm (during or before measurements) generates unwanted water surface waves with different amplitudes. The maximum amplitude of these surface waves is usually not larger than a few millimeters. A very simple measurement can be carried out by a ruler taped on the edge of a water tank. In Figure 1a and b, we have shown a typical simple measurement demonstrating a wave amplitude of about 1 mm. These waves may affect the measurements in regions where the percent depth dose (PDD) changes quickly. For example, in Figure 1c, we have shown the PDD for a 10x10 cm<sup>2</sup>, 4 MeV electron beam (without applicator). The PDD curves drop almost 65% within a short distance of 5 mm (from 10 mm to 15 mm). The wave amplitudes of 1 mm can cause a water displacement of up to 2 mm over the detector (e.g., ionization chamber).

In this paper, we investigate the effect of the speed of the arms on the accuracy of the measurements. This effect depends on integration times in the detector, too. For the results presented in this manuscript, the dwell time is about 0.3 ms which is nearly instantaneous.

## Materials and Methods

Dose profile measurements were taken using MEPHYSTO mc<sup>2</sup> software and a PTW water tank (50 cmx50 cmx40 cm) filled with water. The detector is attached to a variable speed movable arm that moves in a Cartesian coordinate system. The arm speed in different experiments was 1, 5, 10, 20, and 50 mm/s. The dose collection time was 0.3 ms, and the spatial resolution was selected to be 2.5 mm. The dose collection time is long enough to prevent the

### Address for correspondence:

Dr. Mohammad Bakhtiari,  
RadAmerica II, LLC, 9501 Franklin Square,  
Dr. Baltimore, MD 21237, Baltimore, USA.  
E-mail: mohammad.bakhtiari@medstar.net

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confusion between the random uncertainty introduced by noise to signal ratio and the systematic effect of waves on the dose measurements. Dose profiles were measured for 4 MeV electron beam with no applicator (jaw opening 10 cm × 10 cm). The measurements were carried out at  $R_{50} = 12.9$  mm. Two sets of experiments were carried out: I) after each dose profile measurement, the arm was left at the end point. For starting a new profile, the arm returned to the starting point and immediately began acquiring the new dose profile; and II) after each measurement, the arm was immediately returned to the starting point and the next profile measurements were started with a delay of about 5 min. In this paper, we adopt the term *no-delay* for the cases when a measurement starts immediately, and the term *with delay* for those cases when the arms are returned to a starting point and measurements are resumed after water waves are damped. A diode E type 60012 (from PTW) was used to measure the charge. The sensitive area of the diode is 0.03 mm<sup>2</sup> and the radius of sensitive volume is 0.6 mm. Due to symmetry of the dose profiles, only half of the profiles were studied. While it is acceptable for the present study to only test the half profile, one of the most important tasks of profile measurements is the very assessment of symmetry which is assumed to be acceptable

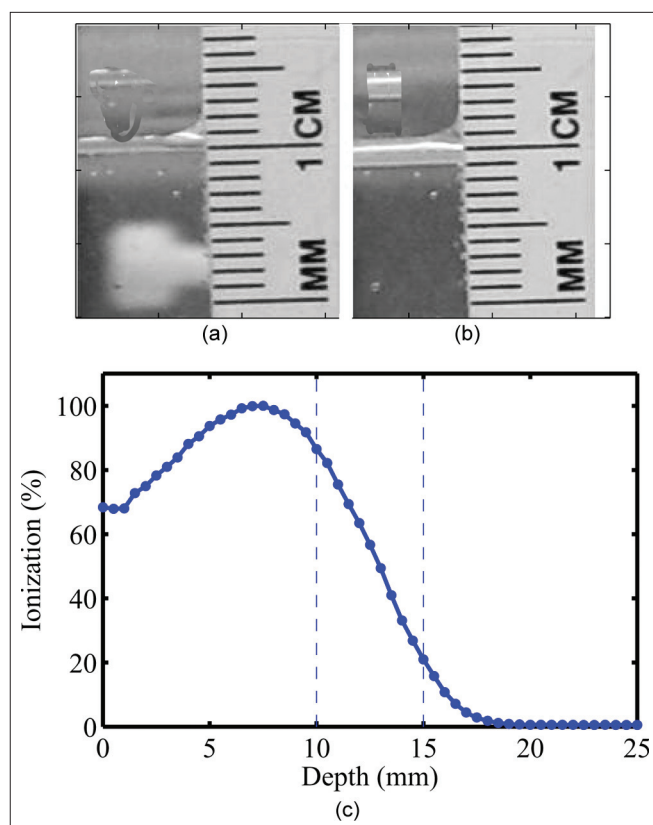


Figure 1: An amateur digital camera image of the surface water displacement at the edge of water phantom at two different timing: (a) before moving the arm and (b) during the arm movement. The amplitude of the waves might be larger than what is seen. Amplitude of 1 mm is observed. This causes a displacement of about 2 mm over the detector. (c) A typical PDD curve for 4 MeV electron beam, 10 × 10 open field with no applicator. The PDD drops ~65% in 5 mm

here. Each measurement was repeated 3 or 4 times in order to study the reproducibility. The direction of the arm movement was from  $x = 0$  to  $x = 120$ .

## Experimental Results

In Figure 2, the dose profiles of 4 MeV beams in the water phantom are shown. The field size is 10 cm × 10 cm with no applicator. The measurement depth was at  $R_p \sim 12.9$  mm. The no-delay measured curves [Figure 2a] show some weak reproducibility with large fluctuations during the first half of the measurements. With delay [Figure 2b] to allow for wave damping, reproducibility is greater and fluctuations have lower amplitude.

The average of the dose profiles and associated standard deviations were calculated. The waveforms for an arm speed of 50 mm/s are shown in Figure 2c and d. The error bars in no-delay cases [Figure 2c] are larger compared to the dose profiles with delay [Figure 2d].

The standard deviation of the measurements is given in Figure 3 for arm speeds of 1 and 50 mm/s. The standard deviation is low at 1 mm/s arm speed [Figure 4a] whilst, at 50 mm/s, the error initially increases and then decreases over elapsed time [Figure 3b].

A summary of the maximum standard deviation for different measurements with different arm speeds are shown in Figure 4. By increasing the arm speed, the maximum error also increases. The measurements with delay have introduced smaller errors compared to the measurements at 50 mm/s. Clearly the measurements at 1 mm/s arm speed have the best reproducibility in this set of measurements. Similar to

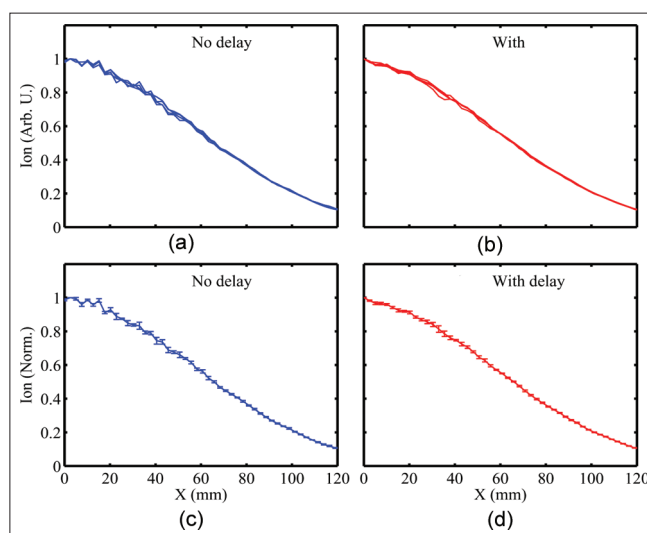


Figure 2: The experimental waveforms of dose profiles for 4 MeV open fields; (a) four different measurements with no-delay in arm movement, (b) four different measurements with delay in arm movement, (c) the averages and standard deviation of data with no delay, (d) the average and standard deviation of data with delay. The speed of the arm was 50 mm/s

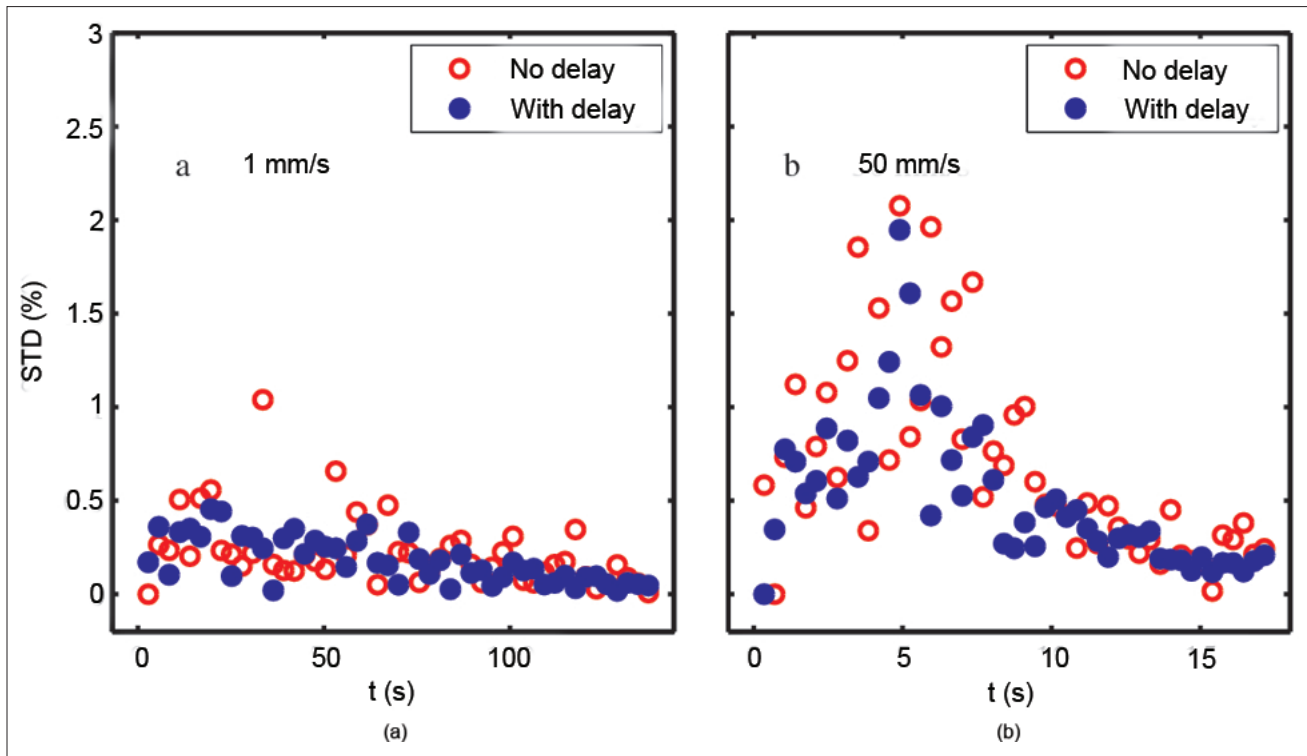


Figure 3: The time evolution of standard deviation (STD) for measurements with 1 mm/s and 50 mm/s arm speed for 4 MeV open fields

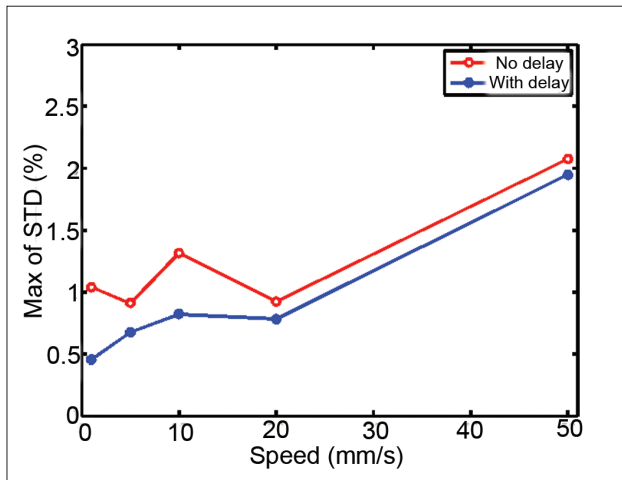


Figure 4: The maximum of the standard deviation for measurements with different arm speeds for 4 MeV open fields

the previous case, the measurements with 50 mm/s of arm speed have the largest error regardless of having delay or not.

In order to study whether other arm speeds can give comparable results, we have compared the dose profiles obtained by arm speeds of 5 mm/s and higher with those carried out at 1 mm/s speed. The level of consistency was measured by defining the *Diff*(%) as

$$Diff(\%) = 100 \frac{|I_{1mm/s} - I_{Vmm/s}|}{I_{1mm/s}}$$

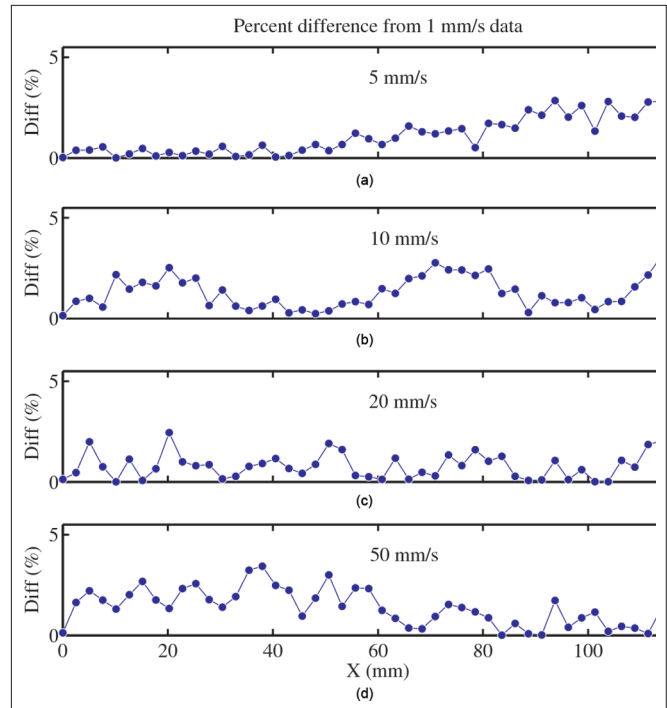


Figure 5: The difference between the measurements with arm speed of 1 mm/s with those with arm speed of larger than 1 mm/s for 4 MeV open fields

The results of comparisons are shown in Figure 5. The parameter *Diff*(%) has values larger than 1% for all cases except at 5 mm/s speed. In that case, for distances about 50 mm from the center, the discrepancy is fairly low.

However, as the amount of collected charge decreases, the discrepancy increases.

## Discussions

As was seen in Figure 3, the standard deviation continuously increases at the beginning of the measurement and then decreases with elapsing time. The large standard deviation around  $t \sim 6$  s is because of the superposition of the waves generated by the arm with those generated earlier and reflected from the wall. For example, at 50 mm/s arm speed and assuming the same speed for the first waves in a water tank with  $L = 400$  mm ( $L/2 = 200$  mm), the first waves are reflected from the closest wall within 4 s. These waves meet the detector and associated generated waves somewhere away from the starting point.<sup>[6-8]</sup>

Waves in the water are unavoidable.<sup>[6-8]</sup> Solutions to improve the accuracy of dosimetric measurements, as was shown in results section, are 1) to set a low speed for the arm movement and 2) to extend the time between consequent dose profile measurements to a few minutes.

## Conclusion

The moving arm in large water tanks can have an impact on dosimetry. It was found that the surface waves can cause errors as large as 5% in the measurements. The most accurate measurements are obtained with arm speeds of 1-5 mm/s. In general, the measurements that are started after damping the waves are more accurate. However, at the higher speeds, errors of up to 5% occurred even after wave damping. It was shown that, because of the step moving arms, the water surface waves can have a transient phase and a steady phase. In the transient phase, which is caused by initial movement of the arms, the errors in dose measurements are as large as 5%. The transient phase is followed by a steady phase

that causes smaller errors in dose measurements. The steady phase indicates that the water waves are unavoidable, and they always exist during the dose measurements. Similar experiments under different conditions, such as with 6 MeV beams, have led to similar results.

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