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Measuring Beam Energy and Symmetry Constancy With An Ion Chamber Array

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Abstract	This Reference Bulletin provides basic information and procedures as well as a new methodology for measuring beam profile constancy using the Sun Nuclear IC Profiler.
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1 Comparing Ion Chamber Array to Water Phantom for Detecting Changes in Beam Energy and Symmetry

Varian Medical Systems continually strives to improve and simplify clinical workflow through new product development. Varian also recognizes the growing need for development of new, efficient, and increasingly informative system test methodologies to ease the workload of key physics resources responsible for ensuring system operation to performance standards. The initiative reported on herein is development of a new methodology for measuring beam profile constancy using the Sun Nuclear IC Profiler. The focus of this reference guide is on the measurement of beam energy and symmetry constancy.

Background

Historically, the water phantom has been the industry standard for beam profile measurements and the source of beam scan records. However; water phantom systems require substantial time and resources, making their daily use impractical. Beam quality assurance is often measured daily using commercial diode arrays[6-7] or ion chamber arrays, but lack of formal comparison of the data provided by the water phantom and array technologies has prevented Varian from using an array technology in lieu of a water phantom for on-site performance testing.

Varian's prior studies of the ion chamber array technologies have established that for manufacturing testing purposes, the ion chamber array technology provides excellent results. This investigation applies use of the same ion chamber array technology to relative beam profile measurements, specifically to the detection of changes in X-ray and electron energy and symmetry. The device used in this investigation is the Sun Nuclear IC Profiler, Model 1122 (Sun Nuclear Corp., Melbourne, FL).

The investigation has yielded the following results:

1. This device can measure beam energy and symmetry changes with a sensitivity comparable to a Wellhofer water phantom
2. This device can measure beam profiles with a repeatability comparable to a Wellhofer water phantom.

Equipment

The Sun Nuclear IC Profiler, Model 1122, [1,2,3,8] utilized in this study is a two-dimensional ion chamber array consisting of 251 ion chamber detectors that simultaneously measure beam profile on four linear arrays including X axis (transverse), Y axis (radial) and two diagonals (Figure 1). Each detector has an active detector volume of 0.046 cm^3 and is spaced

5 mm apart on X and Y axes and 7.07 mm on diagonals. The maximum measurement range is 32 cm x 32 cm on X and Y axes and 45 cm x 45 cm on the diagonals. The intrinsic buildup of the array is 0.9 g/cm^2.

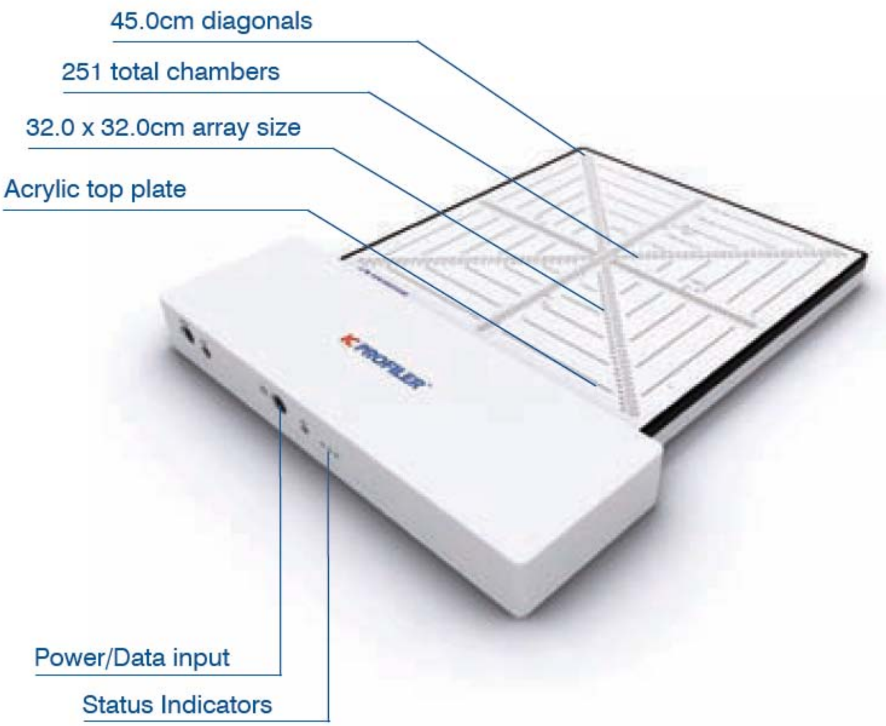


Figure 1: Sun Nuclear IC Profiler, Model 1122

2 Calibration, Measurement Setup, and Procedures

Beam profile measurements were performed using the following setup conditions.

Beam Profile Measurement Conditions				IC Array Calibration Conditions			
Energy	**Buildup**	**SSD**	**Field Size**	**Energy**	**Buildup**	**SSD**	**Field Size**
4 MeV	3 mm	100 cm	25 x 25 cm^2	4 MeV	3 mm	120 cm	25 x 25 cm^2
6 MeV, 6 MeV HDTSE	3 mm	100 cm	25 x 25 cm^2	6 MeV	3 mm	120 cm	25 x 25 cm^2
9 MeV, 9 MeV HDTSE	3 mm	100 cm	25 x 25 cm^2	9 MeV	3 mm	120 cm	25 x 25 cm^2
12 MeV	3 mm	100 cm	25 x 25 cm^2	12 MeV	3 mm	120 cm	25 x 25 cm^2
15 MeV–22 MeV	3 mm	100 cm	25 x 25 cm^2	16 MeV	3 mm	120 cm	25 x 25 cm^2
6 MV SRS (C-series systems only)	1 cm	74 cm	15 x 15 cm^2	6 MV	1 cm	100 cm	35 x 35 cm^2
All other X-ray	1 cm	74 cm	40 x 40 cm^2	6 MV	1 cm	100 cm	35 x 35 cm^2

Table 1: Measurement setup with corresponding array calibration conditions for each energy. A double wedge[4, 5] is used for all electron energy measurements

All electron energy calibrations utilized a 3 mm buildup to ensure quantitative profiles for symmetry measurements in the double electron wedge configuration (described below). The double wedge configuration allows symmetry and energy measurements to be recorded with a single measurement setup. All X-ray mode calibrations and measurements utilized a 1 cm additional buildup.

Since the primary goals of the measurements in this investigation are beam profile constancy and detection of changes in beam energy and symmetry, it is considered acceptable to calibrate the device for electron energy configurations above 15 MeV and all X-ray energy configurations using a single electron energy and a single X-ray energy configuration, respectively.

Test Results and Analysis

Beam energy and symmetry measurements for 6 MeV, 20 MeV, 6 MV, and 20 MV beams were measured using a Wellhofer water phantom (with current Varian protocol) and the Sun Nuclear IC Profiler (with the protocol described in this document). The results were then compared and analyzed.

Electron Beam Energy Measurements

Electron beam energies at different bend magnet currents were measured with the IC Profiler using a double electron aluminum wedge configuration (Figure 2). In this configuration, two aluminum wedges are affixed opposite each other on a frame so that there is an increasing amount of buildup along the diagonal axes moving away from the beam center. Higher energy electron beams will deliver more dose in the region of higher buildup than will lower energy electron beams. As a result, as the electron energy increases, the measured field size along the wedge direction increases (Figure 3). The area surrounding each wedge is filled with a 3 mm slab of solid water; resulting in a total buildup over the non-wedge detectors of 1.2 cm (3 mm buildup plus 9 mm intrinsic to the device).

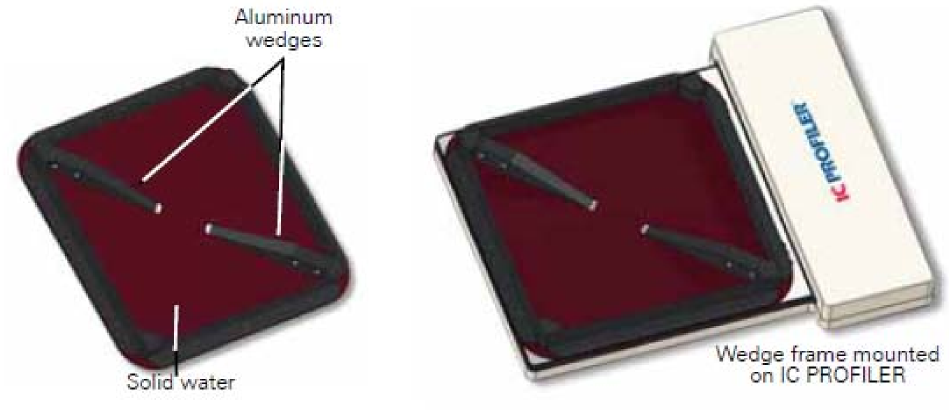
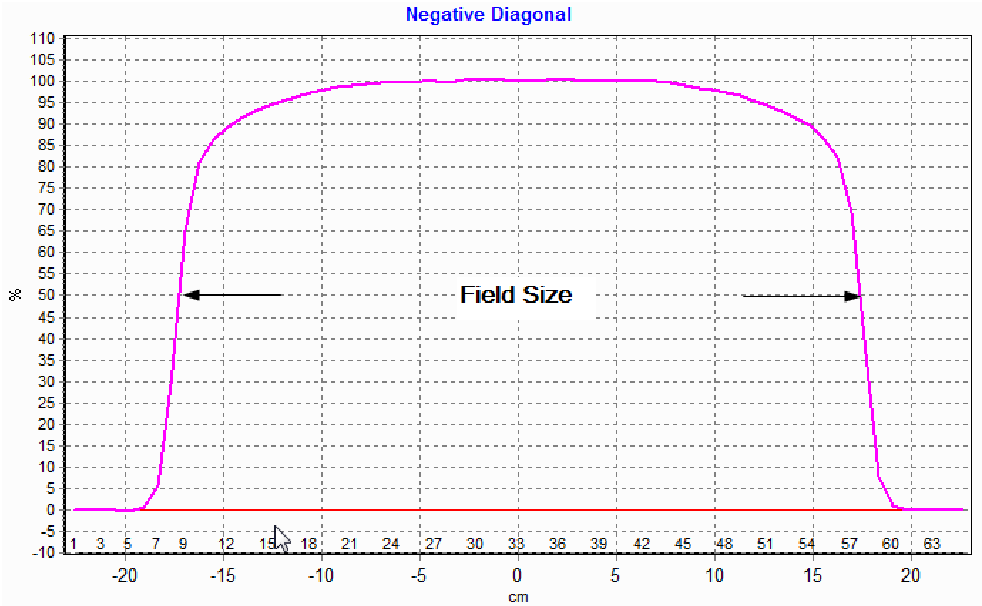
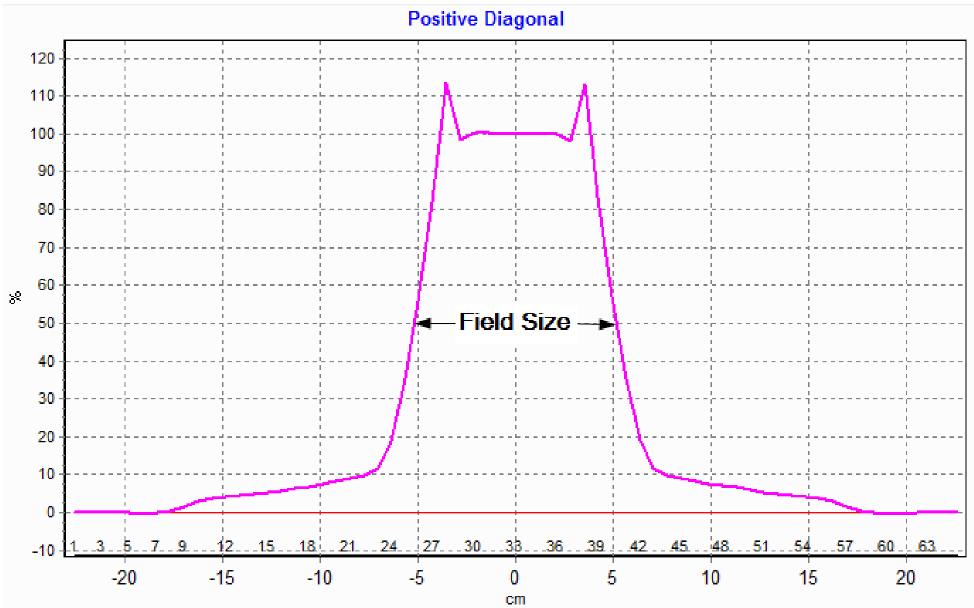


Figure 2: Aluminum double wedge for electron measurements



(a)



(b)

Figure 3: Electron field size (a) without the double wedge and (b) with the double edge

The electron energy field size, as measured by the IC Profiler in the double wedge configuration was compared to the half value depth in water, R50, as measured by the water phantom. R80 was also plotted for comparison. Electron energy measurements were performed at 6 MeV, with energy changes induced by varying the bend magnet current over a range of 1.2 A. Under these conditions, R50 changed less than 0.2 cm, while the field size variation measured using the double wedge configuration of the IC Profiler showed a variation of 0.4 cm (Figure 4), demonstrating improved sensitivity to small energy changes.

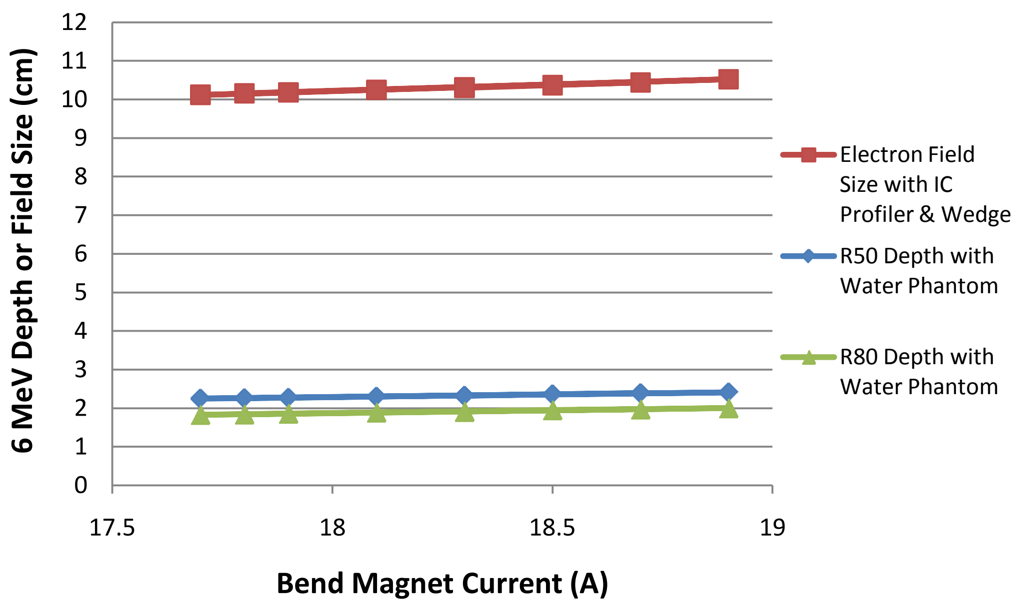


Figure 4: 6 MeV energy changes measured using the water phantom and IC Profiler in the double wedge configuration. Energy was measured relative to the bend magnet current.

The comparative response of the two measurement technologies over a large electron energy range is shown in Figure 5.

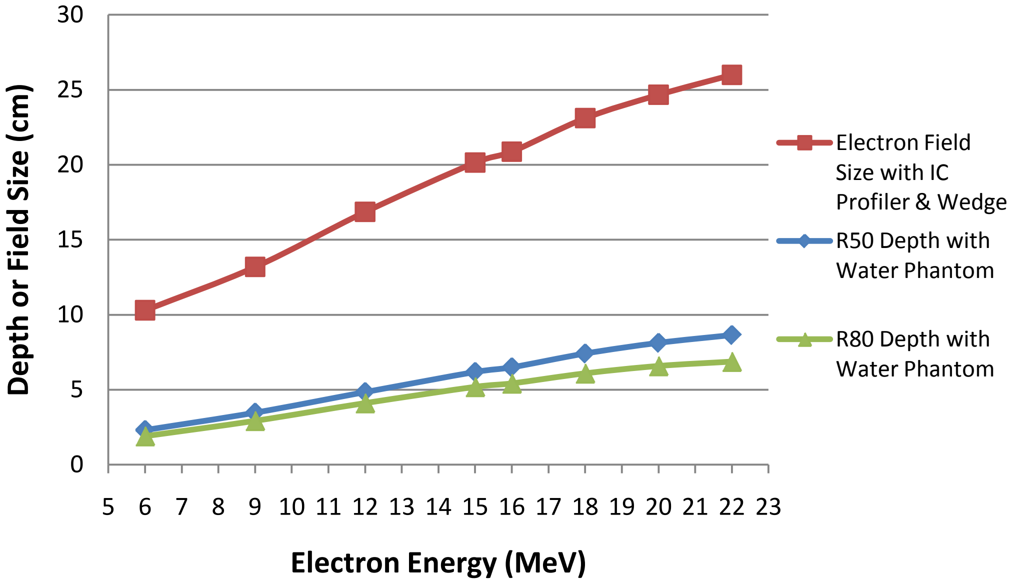


Figure 5: Electron energy scan comparision between water phantom and IC Profiler with double wedge

The results shown above demonstrate that the electron energy, as measured by field size using the double wedge-IC Profiler methodology, provides a significantly larger scale of relative changes of energy than does the measurement of R50 using a water phantom, enabling detection of smaller electron energy changes than water phantom depth scans. Note that although the field size measured with the double wedge-IC Profiler methodology is independent of the alignment along the wedge direction, a misalignment in any other direction can impact the field size results. Therefore, the electron wedge must be well aligned with the IC Profiler and the IC Profiler must be well aligned with the beam. Measurement setup reproducibility is discussed further in “Repeatability” in this document.

X-ray Beam Energy Measurements

A 30 cm x 30 cm field size at a 100 cm SSD was initially considered for this measurement, to reduce the difference in the scattering effect on the IC Profiler between the calibration SSD and the measurement. However, it was found that the sensitivity of horn values was less when measured using a 30 cm x 30 cm field size than when measured using a 40 cm x 40 cm field size. As a result, the final measurements for all X-ray configurations, except the 6 MV SRS, used a 40 cm x 40 cm field size with a reduced SSD of 74 cm to ensure that the IC Profiler electronics were not directly in the beam.

Diagonal horn measurements for 6 MV and 20 MV, as performed using the water phantom and the IC Profiler, are shown in Figures 6 and 7.

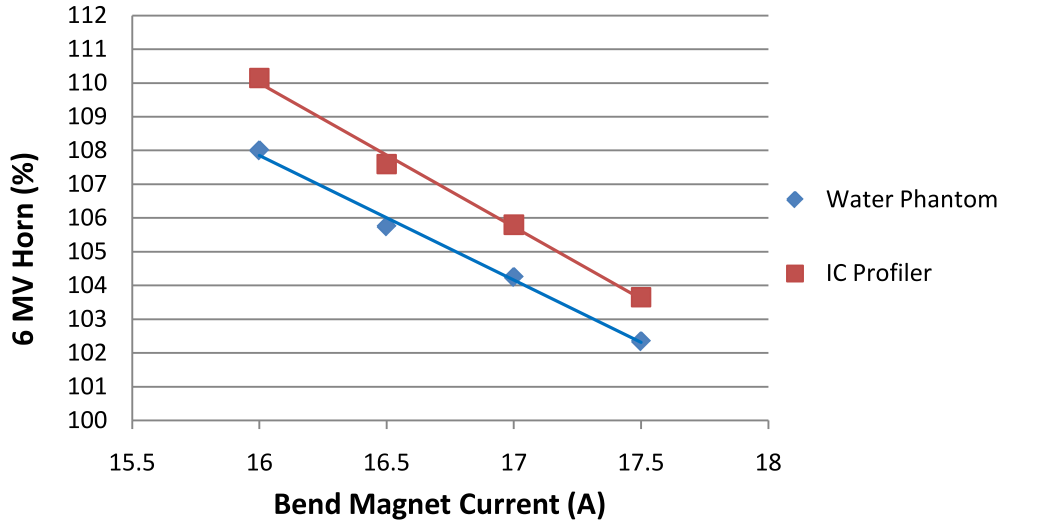


Figure 6: 6 MV horn measurement comparison between water phantom and IC Profiler

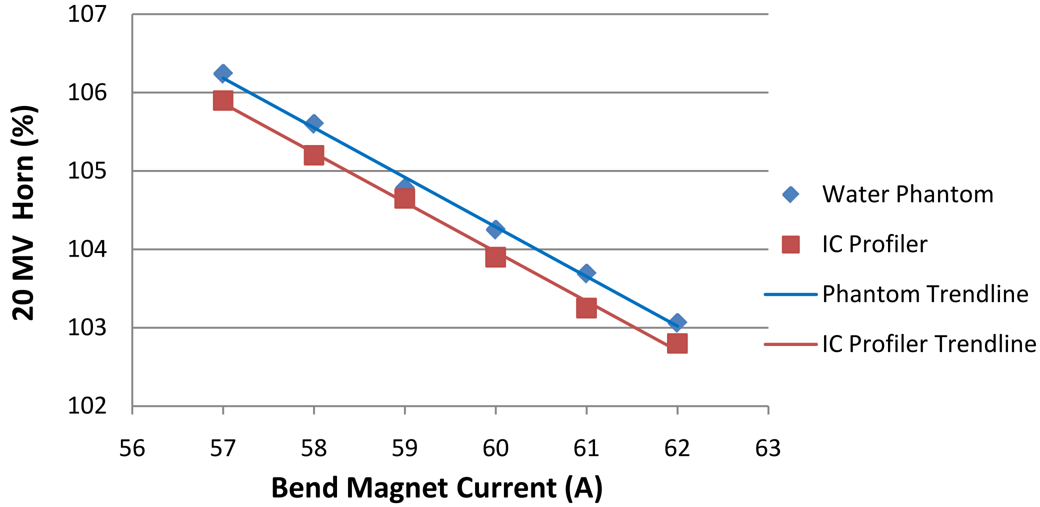


Figure 7: 20 MV horn measurement comparison between water phantom and IC Profiler

The data shown in Figures 6 and 7 demonstrate that measurement of the 6 MV and 20 MV horns using the IC Profiler provided comparable, or in the case of the 6 MV horn measurement, slightly better sensitivity than that provided by water phantom scans.

Symmetry Measurements

Beam symmetry was measured with the water phantom and the IC Profiler using the protocol in Table 1 at different steering coil currents. The beam symmetry was plotted against steering coil currents for comparison between these two devices. For the IC Profiler, a pair of chambers was selected for symmetry performance measurements at the specified locations from the beam center. The pairs of chambers were selected based on their sensitivities to beam symmetry changes as well as their measurement agreements with the water phantom scans.

Energy	Fixed Pairs of Chambers	Chamber Distance from Center
All electron energies	13th, 53th	10 cm
20 MV	29th, 37th	2 cm
6 MV SRS	27th, 39th	3 cm
All other X-ray energies	18th, 48th	7.5 cm

Table 2: Fixed Pairs of Chambers on IC Profiler Used for On-Graph Point Analysis

Electron Beam Symmetry

Electron beam symmetry was measured using the IC Profiler and the water phantom, with symmetry variations induced by varying the steering coil current. Radial and transverse symmetries were measured for 6 MeV and 20 MeV and plotted against steering coil currents, with the results shown in Figures 8 through 11. The term "CPD[1]" in the figures stands for "CAX Point Difference," which is used to evaluate the beam symmetry. Using this method, the beam symmetry was measured on the selected pair of chambers and the differences between these two points were compared.

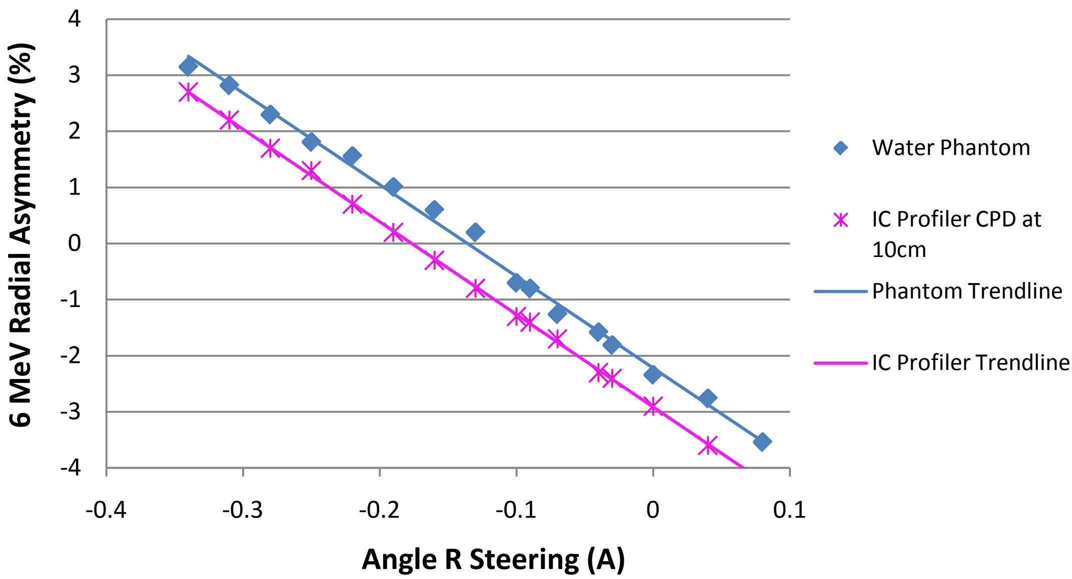


Figure 8: 6 MeV radial symmetry measurement comparison between water phantom and IC Profiler

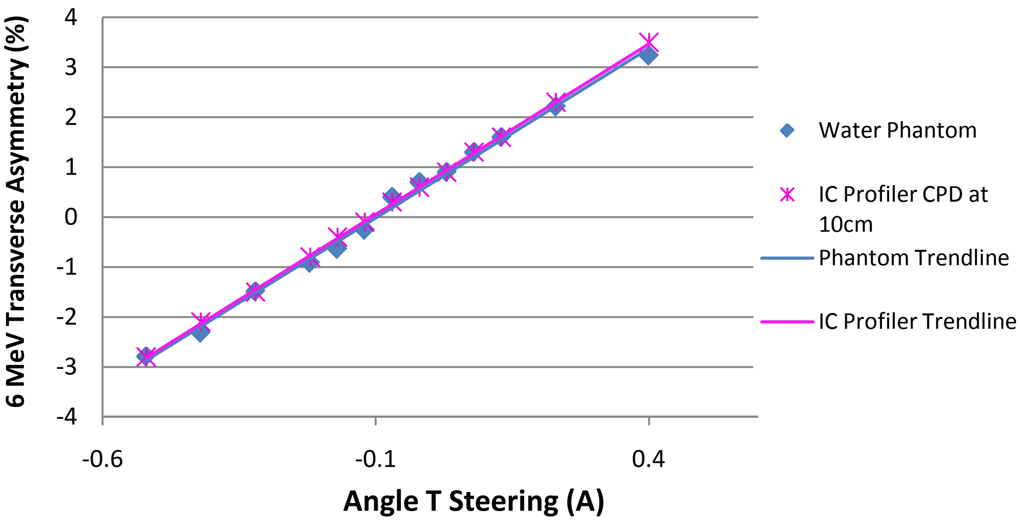


Figure 9: 6 MeV transverse symmetry comparison between water phantom and IC Profiler

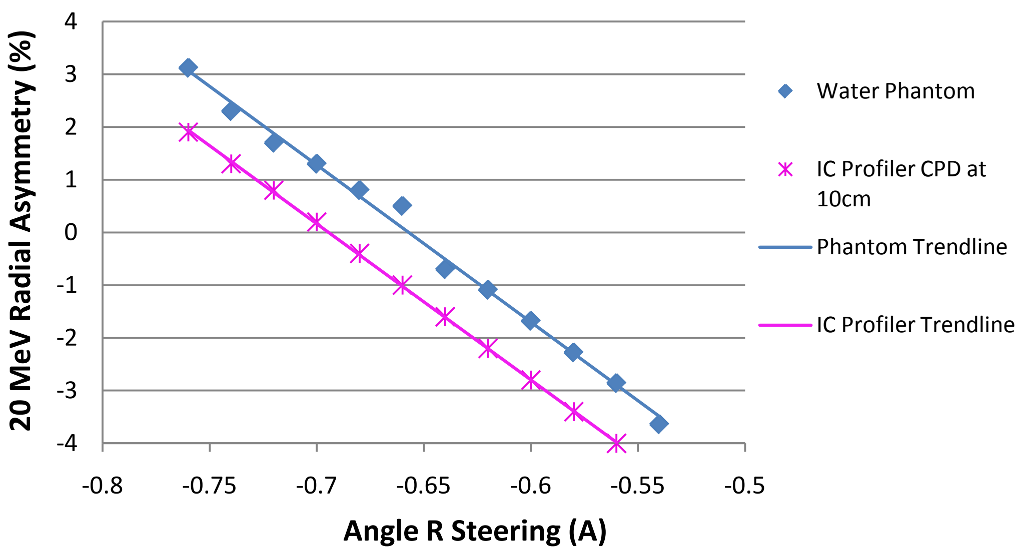


Figure 10: 20 MeV radial symmetry comparison between water phantom and IC Profiler

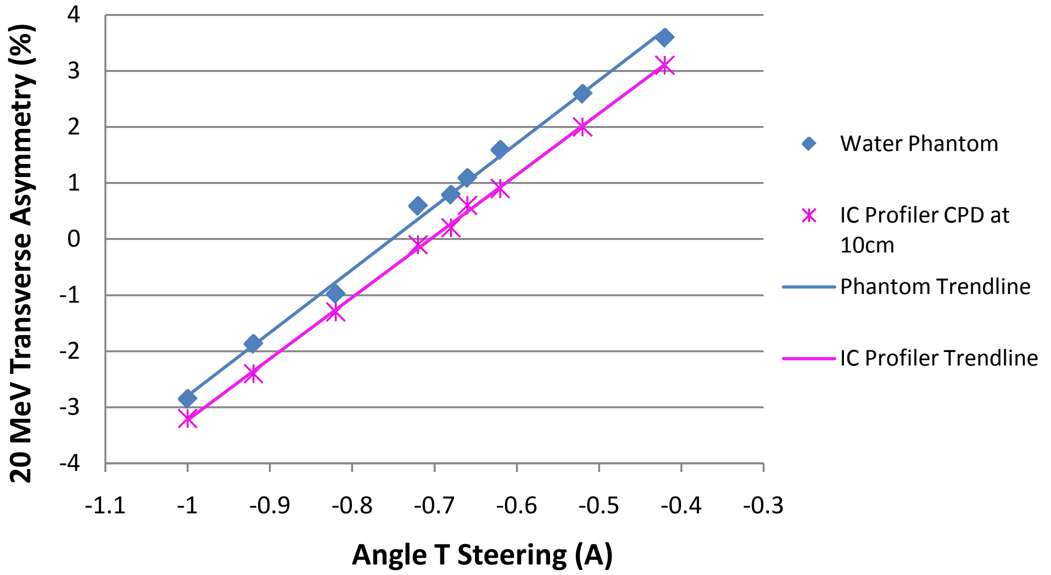


Figure 11: 20 MeV transverse symmetry comparison between water phantom and IC Profiler

The results shown above demonstrate that the IC Profiler can detect beam symmetry changes with a sensitivity comparable to the water phantom.

X-ray Beam Symmetry

Symmetry measurements for 6 MV and 20 MV, performed using the IC Profiler and a water phantom, are plotted in Figures 12 and 13. The results indicate that the IC Profiler data acquired for 6 MV has excellent agreement with the water phantom. However, the measurements collected using the IC Profiler for the 20 MV beam showed slightly less sensitivity than the water phantom. The sensitivity ratio was approximately 1:1.2, IC Profiler scans to Water Phantom scans, as shown on both radial and transverse symmetry measurements (Figures 14 and 15).

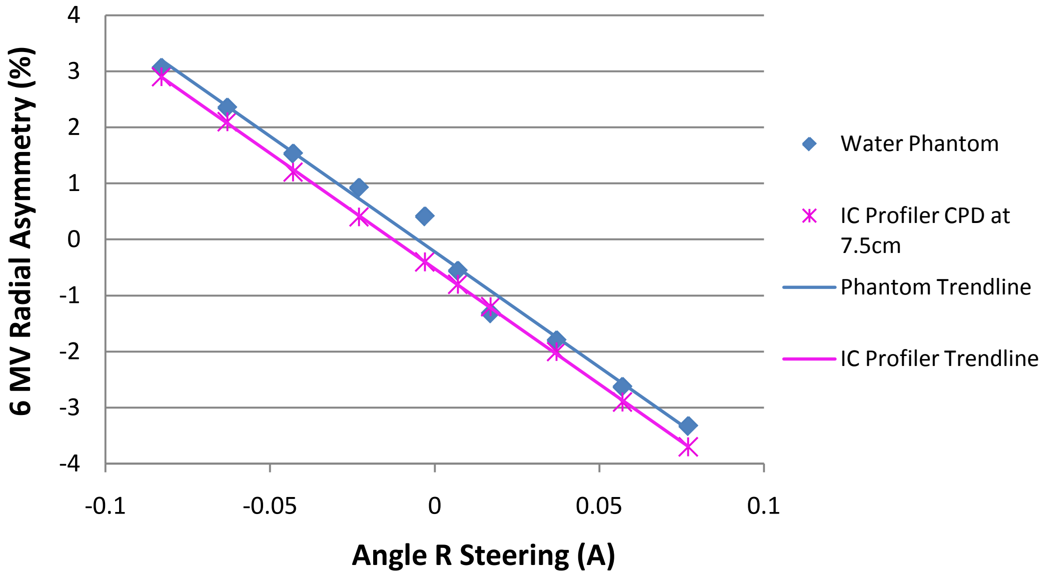


Figure 12: 6 MV radial symmetry comparison between phantom and IC Profiler

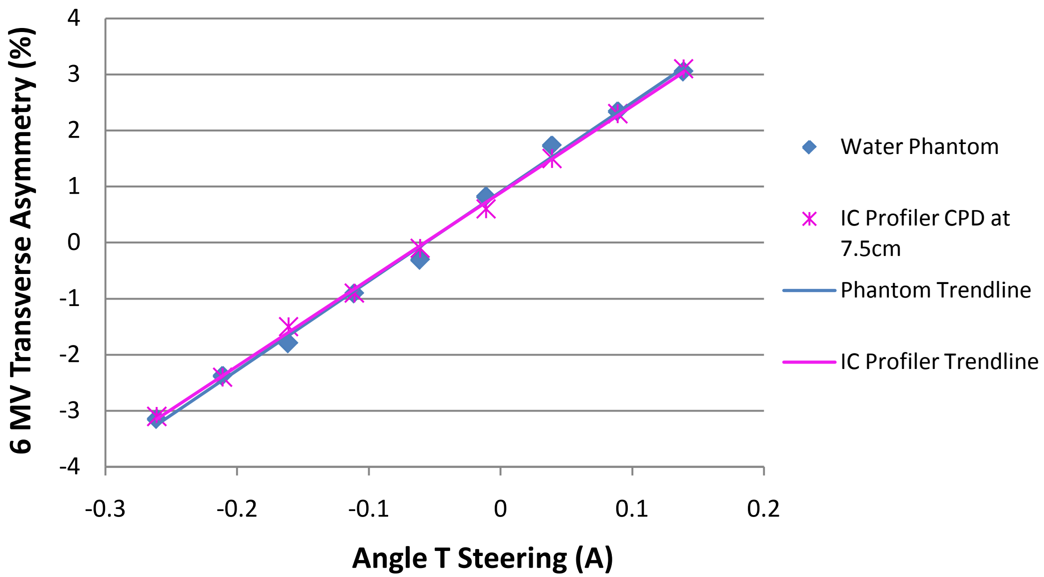


Figure 13: 6 MV transverse symmetry comparison between phantom and IC Profiler

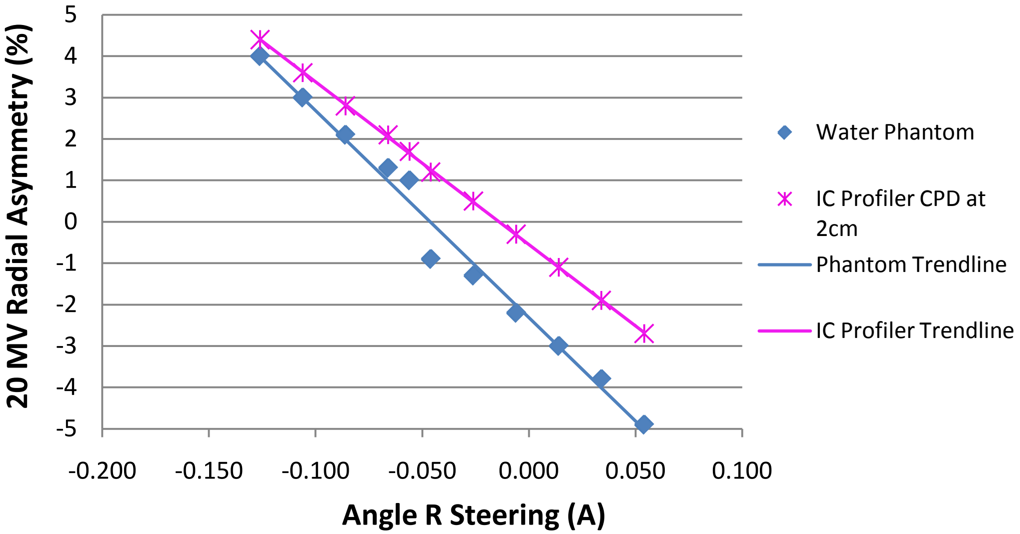


Figure 14: 20 MV radial symmetry comparison between phantom and IC Profiler

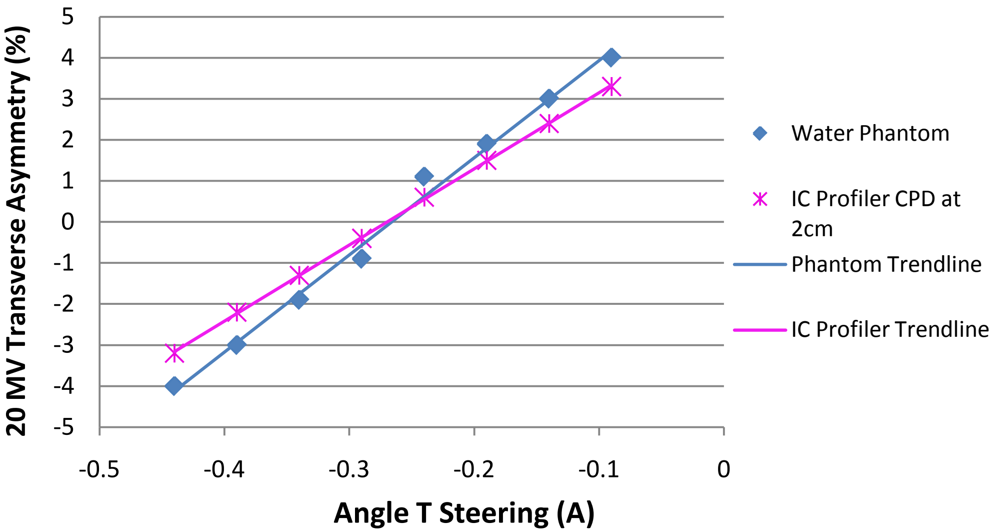


Figure 15: 20 MV transverse symmetry comparison between phantom and IC Profiler

Addition of 2.5 cm buildup to the measurement setup for 20 MV symmetry measurements (bringing the total buildup equivalent to 20 MV d-max) resulted in an improved sensitivity ratio of 1:1.1, IC Profiler to water phantom (Figure 16).

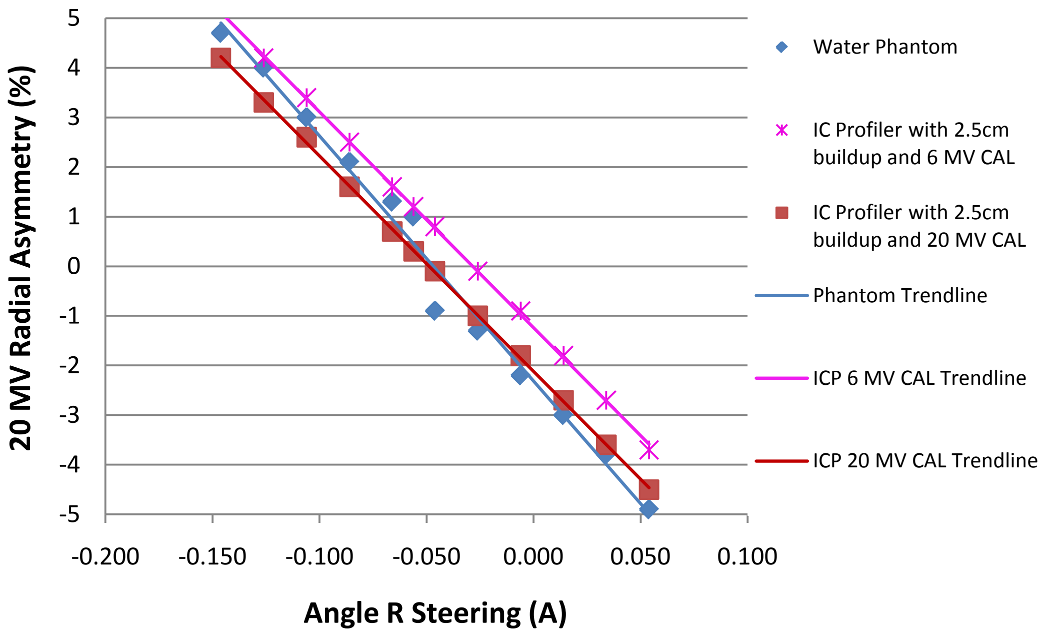


Figure 16: 20 MV radial symmetry comparison between water phantom and IC Profiler

Note that the Wellhofer water phantom OmniPro scan analysis reports the worst symmetry over the entire field. The results from both devices, as shown in Figure 17 are comparable (1:1 ratio) if a similar analysis is performed on the IC Profiler, using the "Panel Analysis" feature. However, this analysis results in a non-linear response, particularly between asymmetry values of -1% to +1%, in a manner similar to that shown for the water phantom. Therefore, although the panel analysis feature on the IC Profiler shows better agreement with the water phantom scans, the use of this feature is not recommended for m the beam profile constancy due to this non-linear behavior.

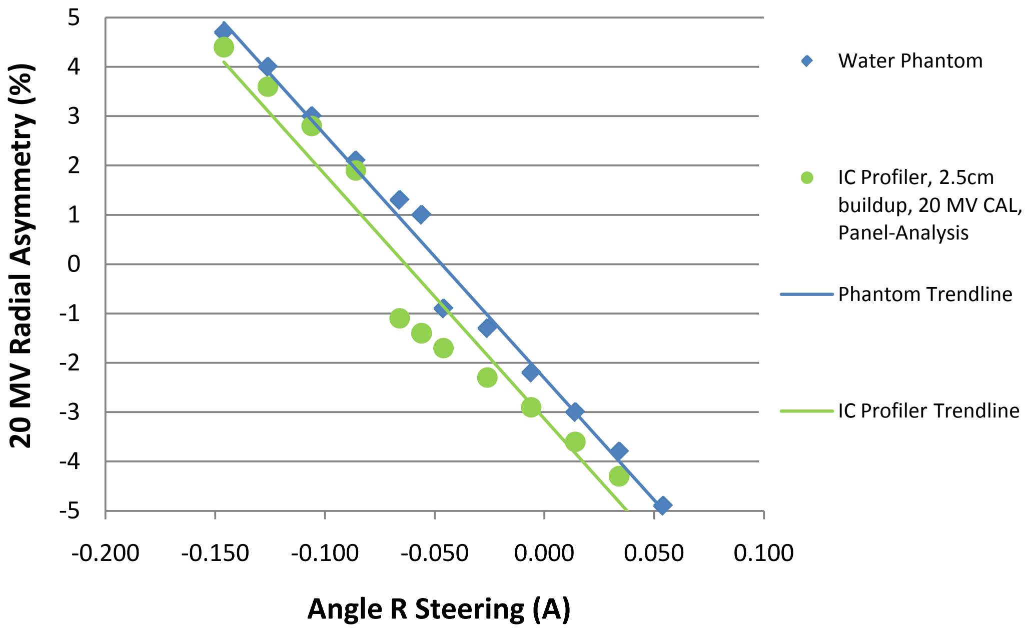


Figure 17: 20 MV radial symmetry comparison between water phantom and IC Profiler using Panel Analysis

Repeatability

Because of the measurement uncertainties, a short study of the measurement repeatability including the device setup repeatability was performed. The following measurements were repeated three times on the same linear accelerator system without modification of the measurement setup. The results are summarized and compared in Tables 3 to 6 below.

6 MeV Energy	1st time	2nd time	3rd time	Maximum Variation
Water Phantom (R50)	2.32 cm	2.32 cm	2.32 cm	0
IC Profiler (Field Size)	10.31 cm	10.30 cm	10.30 cm	0

20 MeV Energy	1st time	2nd time	3rd time	Maximum Variation
WaterPhantom (R50)	8.13 cm	8.12 cm	8.14 cm	0.3%
IC Profiler (Field Size)	24.67 cm	24.67 cm	24.67 cm	0

22 MeV Energy	1st time	2nd time	3rd time	Maximum Variation
Water Phantom (R50)	8.65 cm	8.65 cm	8.65 cm	0
IC Profiler (Field Size)	26.00 cm	26.00 cm	26.01 cm	0

Table 3: Electron Energy Measurement Repeatability Comparison

6 MV Energy (Horns)	1st time	2nd time	3rd time	Maximum Variation
Water Phantom	105.5%	105.5%	105.5%	0
IC Profiler	107.1%	107.2%	107.3%	0.2%

20 MV Energy (Horns)	1st time	2nd time	3rd time	Maximum Variation
Water Phantom	105.5%	105.6%	105.7%	0.2%
IC Profiler	105.3%	105.3%	105.3%	0

Table 4: X-ray Energy Measurement Repeatability Comparison

6 MeV Radial Symmetry	1st time	2nd time	3rd time	Maximum Variation
Water Phantom	0.2%	0.1%	0.3%	0.2%
IC Profiler	-0.5%	-0.5%	-0.5%	0

6 MeV Transverse Symmetry	1st time	2nd time	3rd time	Maximum Variation
Water Phantom	0.3%	0.3%	0.3%	0
IC Profiler	0.2%	0.2%	0.2%	0

20 MeV Radial Symmetry	1st time	2nd time	3rd time	Maximum Variation
Water Phantom	-0.8%	-0.7%	-0.7%	0.1%
IC Profiler	-1.8%	-1.8%	-1.7%	0.1%

20 MeV Transverse Symmetry	1st time	2nd time	3rd time	Maximum Variation
Water Phantom	1.1%	1.0%	1.1%	0.1%
IC Profiler	0.5%	0.6%	0.6%	0.1%

Table 5: Electron Symmetry Measurement Repeatability Comparison

6 MV Radial Symmetry	1st time	2nd time	3rd time	Maximum Variation
Water Phantom	0.5%	0.3%	0.4%	0.2%
IC Profiler	1.3%	1.3%	1.3%	0

6 MV Transverse Symmetry	1st time	2nd time	3rd time	Maximum Variation
Water Phantom	-0.3%	-0.2%	-0.4%	0.2%
IC Profiler	-0.9%	-0.8%	-0.9%	0.1%

20 MV Radial Symmetry	1st time	2nd time	3rd time	Maximum Variation
Water Phantom	1.7%	1.7%	1.5%	0.2%
IC Profiler	2.7%	2.7%	2.7%	0

20 MV Transverse Symmetry	1st time	2nd time	3rd time	Maximum Variation
Water Phantom	0.6%	0.7%	0.6%	0.1%
IC Profiler	1.1%	1.1%	1.1%	0

Table 6: X-ray Symmetry Measurement Repeatability Comparison

The following measurements were performed on the same linear accelerator system, with the measurement setup removed and re-installed by the same operator, in an effort to quantify the device setup uncertainty.

6 MeV Energy	1st time	2nd time	3rd time	Maximum Variation
Water Phantom (R50)	2.28 cm	2.28 cm	2.27 cm	0.4%
IC Profiler (Field Size)	10.32 cm	10.33 cm	10.33 cm	0.1%

6 MeV Transverse Symmetry	1st time	2nd time	3rd time	Maximum Variation
Water Phantom	0.3%	0.2%	0.3%	0.1%
IC Profiler	-0.4%	-0.4%	-0.4%	0

Table 7: Electron Energy and Symmetry Measurement Setup Repeatability Comparison

6 MV Energy (Horns)	1st time	2nd time	3rd time	Maximum Variation
Water Phantom	106.1%	106.0%	106.0%	0.1%
IC Profiler	107.1%	107.0%	107.1%	0.1%

6 MV Transverse Symmetry	1st time	2nd time	3rd time	Maximum Variation
Water Phantom	0.5%	0.6%	0.3%	0.3%
IC Profiler	-1.1%	-1.1%	-1.0%	0.1%

Table 8: X-ray Energy and Symmetry Measurement Setup Repeatability Comparison

The results suggest that overall the IC Profiler has very similar or slightly better measurement repeatability than the water phantom. However, in terms of overall measurement setup efficiency and simplicity, the IC Profiler is superior.

Environmental Effects

All chambers on the IC Profiler are vented; therefore, for normalized measurements such as beam profile scans, the IC Profiler is immune from variations in atmospheric pressure. Temperature changes will result in relative changes between chambers if the IC Profiler is not allowed to reach the thermal equilibrium. If all chambers are at the same temperature, then any relative temperature change will be equal across the array, and thereby be cancelled in the normalization process. For the best results one should allow at least 30 minutes of dwell time before making any measurements.

Summary

The IC Profiler has been demonstrated to be an acceptable alternative to the water phantom for measurement of beam energy and symmetry changes. The measurements documented in this report show that the IC Profiler is capable of detecting beam energy and symmetry changes for electron and X-ray beams with a sensitivity comparable to that provided by a water phantom, and with a similar or better repeatability than the water phantom.

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References

[1]. Sun Nuclear IC Profiler Reference Guide, Rev C, July 15, 2010.

[2]. Wide Field Calibration of a Multi-Sensor Array, Simon et al. United States Patent, Patent Number: 6,125,335. Sep. 26, 2000.

[3]. Wide field array calibration dependence on the stability of measured dose distributions, Thomas A. Simon, et al. Med. Phys. 37 (7), July 2010.

[4]. Using Ion Chambers with wedge-shaped absorbers for electron energy measurements, Stanley W. Johnsen, Med. Phys. 13 (2). Mar/Apr 1986.

[5]. Electron energy constancy verification using a double-wedge phantom, Derek M. Wells, et al. Journal of Applied Clinical Medical Physics, Volume 4, #3, Summer 2003.

[6]. A 2-D diode array and analysis and analysis software for verification of intensity modulated radiation therapy delivery, Paul A. Jursinic, et al. Med. Phys. 30 (5), May 2003.

[7]. Evaluation of a 2D diode array for IMRT quality assurance, Daniel Letourneau, et al. Radiotherapy and Oncology 70 (2004) 199 – 206.

[8]. Characterization of multi-axis ion chamber array, Thomas A. Simon et al. Med. Phys. 37 (11), November 2010.

Appendix

Data presented in this report were collected from the listed items below:

IC Profiler REF: 1122800

IC Profiler SN: 6622115-2010-05

IC Profiler Software Version: 3.1.0.10

IC Profiler Firmware Version: 2.4.8

Electron Energy Wedge Model: 1122602

Electron Energy Wedge SN: 1122210AW6748602

Systems: TrueBeam SN#3; TrueBeam SN#1044, TrueBeam SN#1047

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