Optimization of Scanning Speed Using a Novel Plastic Scintillation Detector to Achieve Ultrafast Beam Scanning

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ABSTRACT

Purpose: To assess the impact of scanning speed on beam data quality using a novel plastic scintillation detector (PSD) compared with conventional methods, with the goal of enabling ultrafast beam scanning.

Methods: Percentage depth dose (PDD) curves and beam profiles were acquired using conventional beam data acquisition methods and with the new PSD system. For scans acquired with the PSD system, multiple scans were acquired while varying scan speed. Scans acquired with the PSD were compared to those of conventional methods to evaluate the impact of PSD scan speed on data quality. Comparisons were performed visually and via gamma passing rates (GPR).

Results: At a scan speed of 1.0cm/s, PDDs measured with the PSD and an ion chamber (IC) showed good agreement for multiple field sizes and energies (GPR >95% at 2%/1mm), with majority of discrepancies occurring in the shallow buildup region. Profiles acquired with the PSD at 0.3, 1.5, and 2.0cm/s were similarly consistent to IC measurements, with the 2cm/s scan completed in roughly a quarter of the time (GPR >95% at 2%/1mm). Post-processing for PSD data appears to be speed, energy and dose rate dependent, implying a potential upper limit to how fast one can scan for a given beam.

Conclusions: Beam data acquired using the PSD was able to reproduce that obtained with conventional scanning methods while requiring only a fraction of the acquisition time. These substantial time savings have the potential to significantly reduce the duration of beam scanning tasks such as commissioning, annual quality assurance (QA), and post-service QA.

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INTRODUCTION

The Blue Physics plastic scintillation detector (PSD) is a novel radiation detector capable of acquiring data extremely quickly. The PSD has a cylindrical shape of 1mm diameter and length, giving an effective volume less than a cubic millimeter ($0.785mm^3$)[1]. As shown in Fig. 1, there are 2 sensors: one coupled to the active volume, and one not coupled to the active volume (used to correct for Cherenkov light). With this system, data is acquired and read out every 700µs. Compared with modern linear accelerators, which emit a pulse approximately every 2.5ms, the PSD can resolve and measure each individual pulse emitted by the accelerator. The ability to capture all pulses potentially enables faster data acquisition, particularly during beam scanning applications. Investigation of the PSD's ability to quickly acquire beam data is the primary objective of this work.

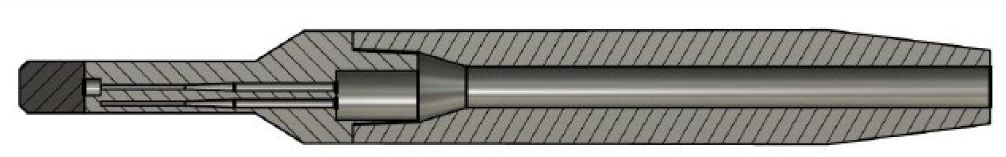

Figure 1: Schematic of the PSD showing 2 readout fibers – one acquiring field signal and the other for Cherenkov correction.

METHODS AND MATERIALS

Percentage depth dose (PDD) curves and profiles were acquired using cc13 ion chambers (IBA Dosimetry GmbH, Schwarzenbruck, Germany) and the IBA Blue Phantom 2 (BP2) equipped with the myQA Accept (v9.1.34.0) scanning software. When acquiring beam data in our clinic, it is standard to collect PDDs and profiles using the following speeds:

- **PDDs**
  - 0.3cm/s from 0-5cm depth
  - 0.5cm/s elsewhere
- **Profiles**
  - 0.3cm/s in the beam penumbra region, defined as the region outside the middle 70% of the expected field width
  - 0.5cm/s elsewhere

Scans for multiple field sizes/energies/modalities were acquired on a Varian TrueBeam linear accelerator (Siemens Healthineers, Palo Alto, CA) equipped with photon and electron energies ranging from 6-18MV and 6-16MeV, respectively.

The BluePhysics PSD comes with a software capable of controlling the IBA BP2. Scans were performed using the PSD in the IBA BP2 for the same field sizes/energies as previously mentioned while varying the scan speed. All raw data from the PSD measurements were saved and available for post-processing. Parameters available for post-processing of PSD data include group size, rolling window, Wiener smoothing, and applying any translational shifts to the data. Combinations of these processing parameters were investigated to best match ion chamber (IC)/treatment planning system (TPS) data. Comparison between the IC, PSD, and TPS data sets were done through gamma passing rates (GPR) and visual inspection.

RESULTS

When comparing PDDs acquired with the PSD at a scan speed of 1.0cm/s to the TPS and IC measurements (acquired per our clinical protocol), good agreement was observed for photons and electrons across a multitude of energies and field sizes. Figure 2 shows PDDs acquired with the PSD compared against TPS or IC data.

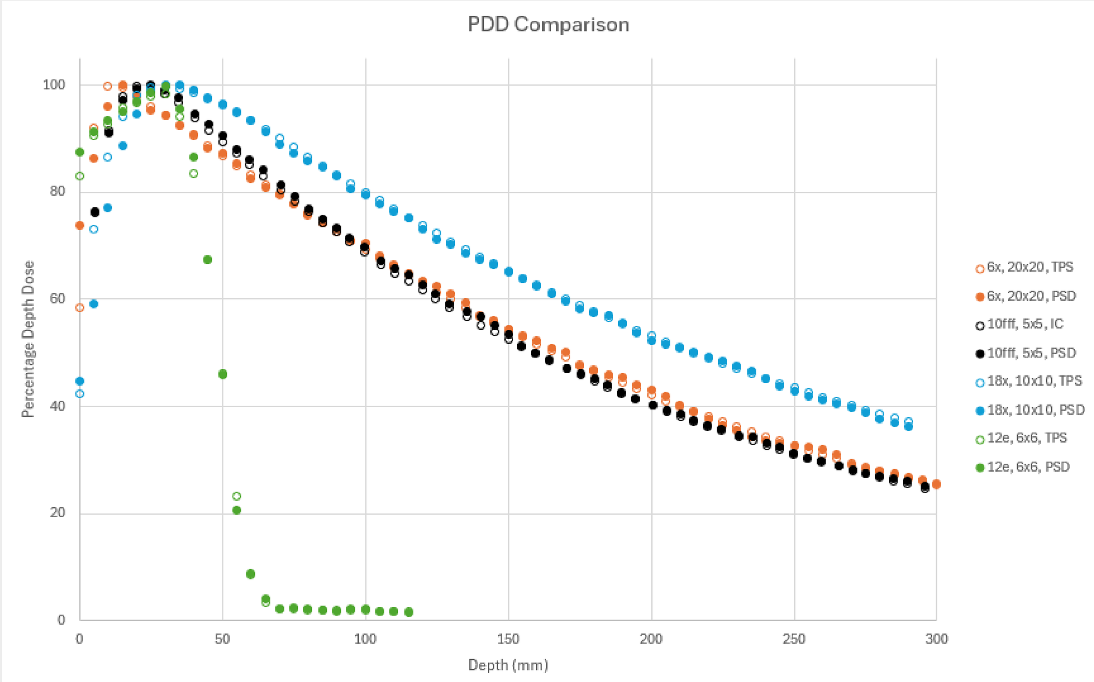

Figure 2: PDDs measured with the PSD versus TPS and IC data. All comparisons had a GPR >95% using 2%/1mm dose difference and distance to agreement criteria.

The general shape of all PDDs acquired with the PSD are consistent with those acquired with the IC while being acquired in roughly half the time. Gamma agreement is sufficient, although visually the PSD curves are not entirely as smooth as the IC data.

When adjusting the scan speed of the PSD from 0.3-2.0cm/s, profiles acquired with the PSD showed good agreement when comparing to IC measurements (acquired with our scanning protocol) for a 6x, 10x10 field at 10cm depth. These profile comparisons are shown in Fig. 3.

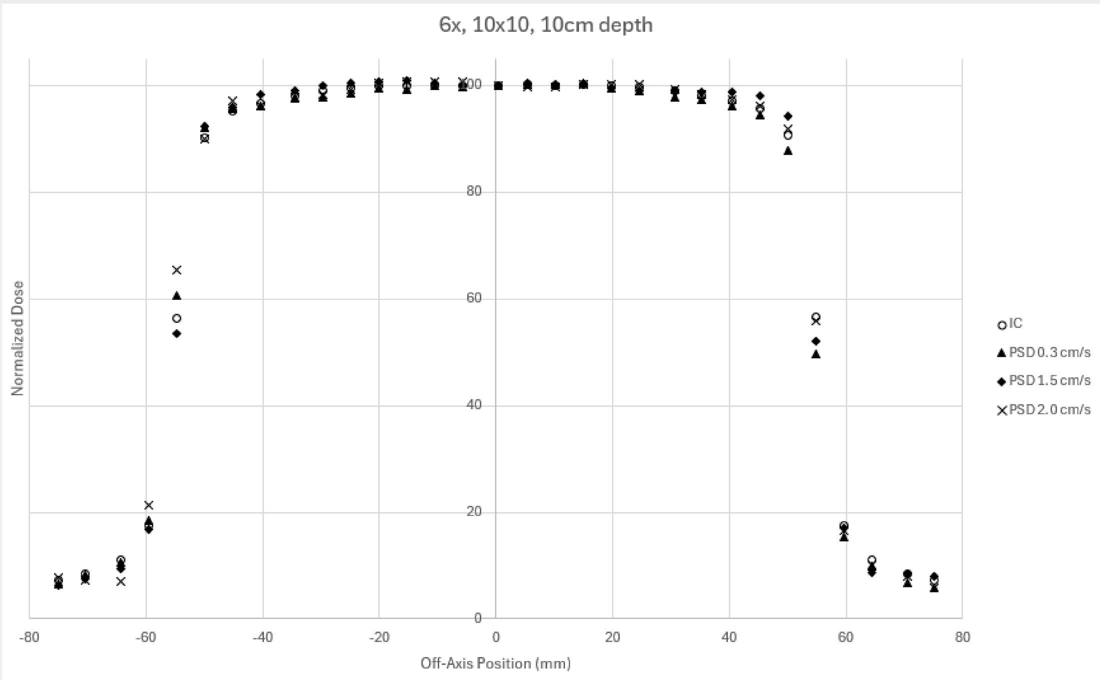

Figure 3: Profiles measured with the PSD at varying speeds versus IC data. All comparisons had a GPR >95% using 2%/1mm dose difference and distance to agreement criteria.

At 2.0cm/s, the PSD acquires this profile roughly 4x as fast as the IC using our clinical scanning protocol.

The degree of smoothing and post-processing for data acquired with the PSD was very dependent on the speed of the acquired scan and the dose rate of the beam being examined. In general, the following trends were noticed:

- Lower dose rate beams (those with flattening filters) require smaller group sizes, leading to higher resolution data (at the expense of increased noise)
- Slower scan speeds allowed larger group size, leading to smoother data (at the expense of lower resolution)

DISCUSSION

Based on our acquired data, it is clear the PSD can replicate IC and TPS data at a variety of energies, modalities, field sizes, and scanning speeds. The increased acquisition speed has numerous benefits, the main being shortened time to complete labor intensive tasks such as commissioning and QA. As an example, by following the logic and assumptions outlined in Equation 1 of TG-106[2] and assuming ion chamber measurements, beam scanning for a linear accelerator with five photon energies and five electron energies is estimated to require approximately 30 hours (not including setup time, etc.). If we assume we can acquire quality data in half the time with the PSD system (possibly even faster), we could reduce beam scanning time to just 15 hours, thereby freeing up time to move on to other commissioning tasks. This could significantly accelerate the timeline required to commission a new machine for clinical use and make annual QA and post-service QA much more efficient.

As with other commissioning detectors, there appears to be a tradeoff between quality of data and acquisition speed. Based off these initial scans and investigation of post-processing, there comes a speed at which no amount of post-processing would lead to high quality data, and, by extension, good agreement with IC/TPS. Determining the exact numerical value of this maximum speed is likely a multifactorial (dose rate, energy, field size, depth, etc.) problem and warrants further investigation.

One idea to obtain better data relates to the use of a reference detector. Currently, all PSD scans were performed with no reference detector. It was conjectured that resolving all pulses would mitigate the need for a reference detector. However, noisy data can be observed when using the PSD, even after post-processing. Future studies will include investigation of a reference detector with the PSD, which would eliminate any noise attributed to variations in linac output. This could further increase scan speed and standardize the amount of post-processing necessary to obtain high quality data.

CONCLUSIONS

The PSD can acquire high quality beam data in a fraction of the time when compared to conventional acquisition methods. The increase in speed has the potential to greatly enhance clinical efficiency when it comes to time intensive tasks such as machine commissioning, annual QA, and post-service QA. Use of a reference detector may further enhance the speed at which the PSD can acquire data, which would further elevate the time savings afforded through use of this new system.

REFERENCES

1. Blue Physics Instructions for Use (version 1.4) for Plastic Scintillation Detector Model 11.
2. Das IJ, Cheng CW, Watts RJ, et al. Accelerator beam data commissioning equipment and procedures: Report of the TG-106 of the Therapy Physics Committee of the AAPM. *Med Phys. 2008;35:4186-4215.*