Characterising a Papillon 50 electronic brachytherapy source using a plastic scintillation detector

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Introduction: Electronic Brachytherapy (eBT) is the treatment of cancer with X-rays of energies <100kV. It is considered a safe treatment with good outcome, though reports have shown occurences of unacceptable dose misadministrations[1]. Significant reasons for such misadministrations are the facts that EBT dose prescriptions are almost solely based on vendor supplied dose distribution maps, and that independent dose verification is nearly non-existent. Plastic scintillation detectors (PSDs) have proven feasible for relative dosimetry of low energy X-rays, and could potentially provide a simple procedure for dose verification of eBT units. The purpose of this study is to perform an independent characterisation of the dose output and dose distribution in water of a Papillon 50 (P50) (Ariane Medical Systems) (fig. 1) with a PSD, and investigate the PSDs suitability for this task.

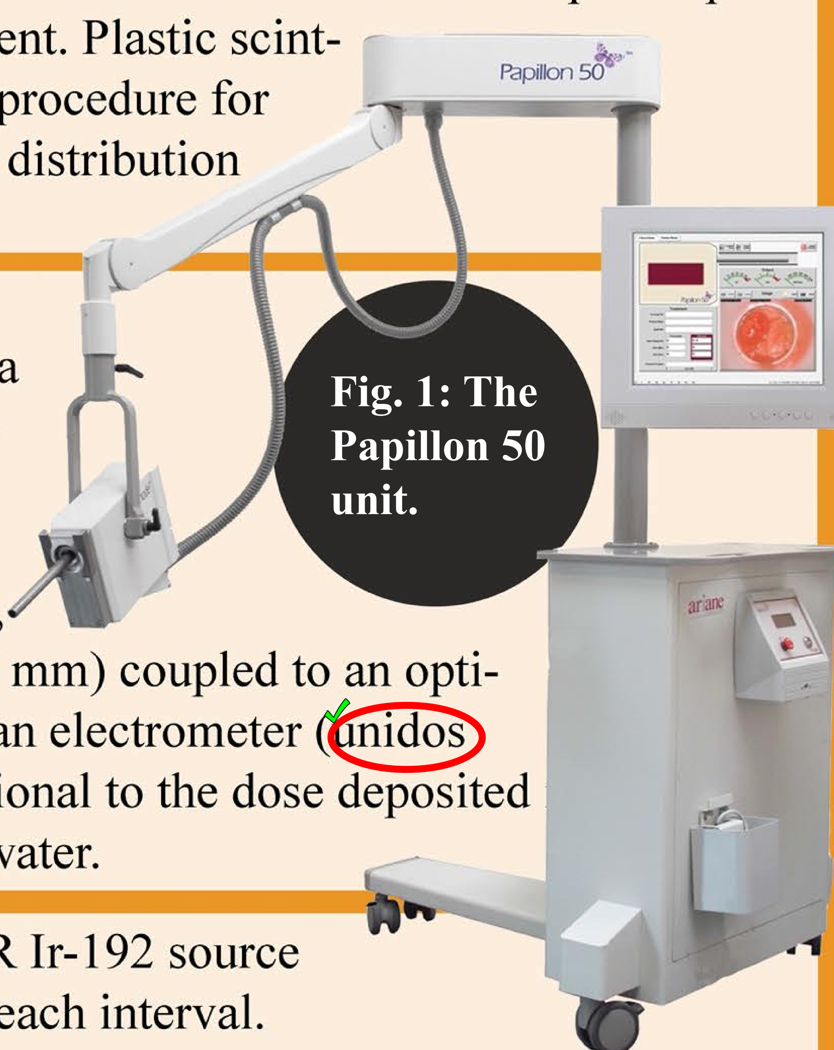

Fig. 1: The Papillon 50 unit.

Materials: Two radiation sources were used. The first was a high-dose-rate (HDR) Ir-192 brachytherapy source (Ir-192 Flexisource, Elekta), whose dose-rate was assumed stable for the duration of the experiments (several minutes). The second source was a P50 unit, that delivers 50 kvP X-rays via cylindrical steel applicators. In this study an applicator with inner diameter of 25 mm was used. The P50 has an internal ion-chamber that measures the current of electrons in the X-ray tube, giving a dose in terms of MUs (100MU~1Gy).

Two detectors were used for independent measurements. The first was a well-chamber (WC) (HDR1000PLUS, Standard-Imaging), which was considered a reliable detector. The second was a PSD system based on a cylindrical BCF-12 scintillator (Ø1 mm, L=0.5 mm) coupled to an optical fiber. The fiber transmits the scintillation light to a photo-multiplier-tube (PMT) (H5783 SEL3, Hamamatsu) that is coupled to an electrometer (unidos webline, PTW). The WC and PSD signal is given as accumulated charge over a user specified time-interval. This charge is proportional to the dose deposited tors during this time-interval. A water phantom with a motorised stage (MP3, PTW, Freiburg) was used for dose measurements in water.

Methods: *PSD dose linearity:* The PSD probe was inserted in a water phantom and irradiated 5 minutes at a time with the HDR Ir-192 source at a fixed distance of 4 cm. The accumulated charge over different time-intervals (range 1 s to 20 s) was measured 20-50 times for each interval.

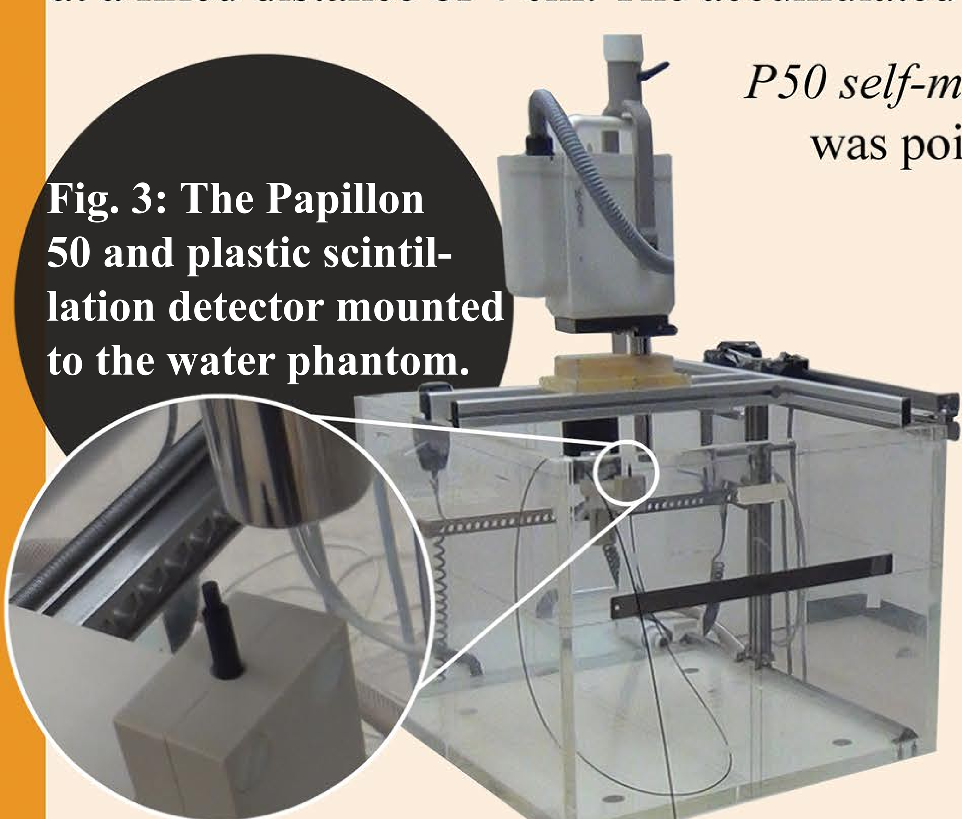

Fig. 3: The Papillon 50 and plastic scintillation detector mounted to the water phantom.

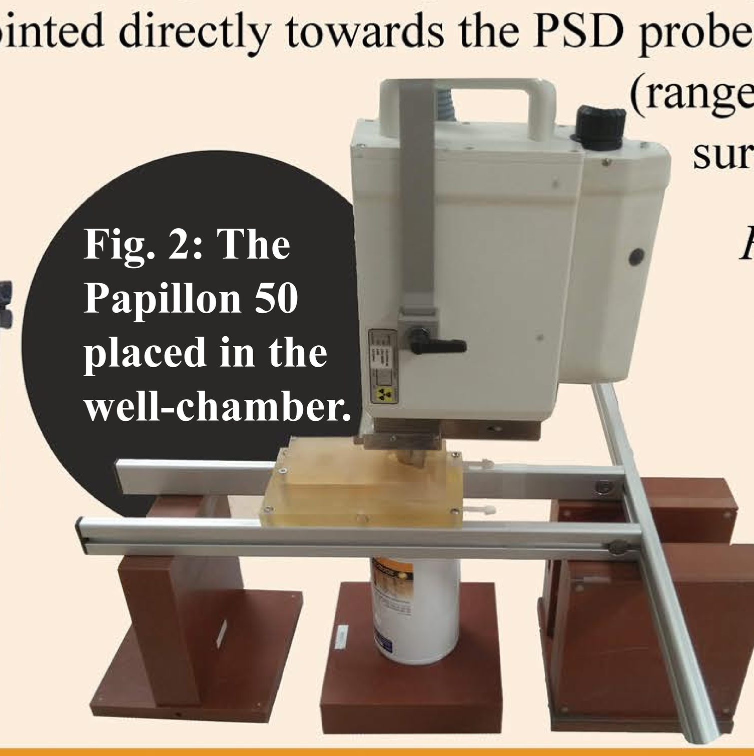

Fig. 2: The Papillon 50 placed in the well-chamber.

P50 self-monitoring vs. PSD signal: The PSD probe was placed in a block of solid water via a drilled hole. The P50's tip was pointed directly towards the PSD probe, separated by 5 mm solid water. The P50 was set to output a specific amount of MUs (range 100 MU to 1650 MU) before turning off. The accumulated charge in the PSD was measured 10 times for each MU value.

P50 temporal stability: The PSD probe and P50 were inserted into the WC (fig. 2). The accumulated charge over 10 s intervals in the PSD and WC were measured repeatedly throughout 8 irradiations of 300 s each.

Depth-dose curves: The PSD and P50 applicator were mounted on the water phantom, such that the PSD was placed on the motorised stage underneath the tip of the P50 applicator (fig. 3). The phantom was filled with water to a level where the P50 tip just breached the surface. The P50 was set to irradiate continously, while the PSD was moved with the stage, measuring the dose in 2 s intervals at various depths in water.

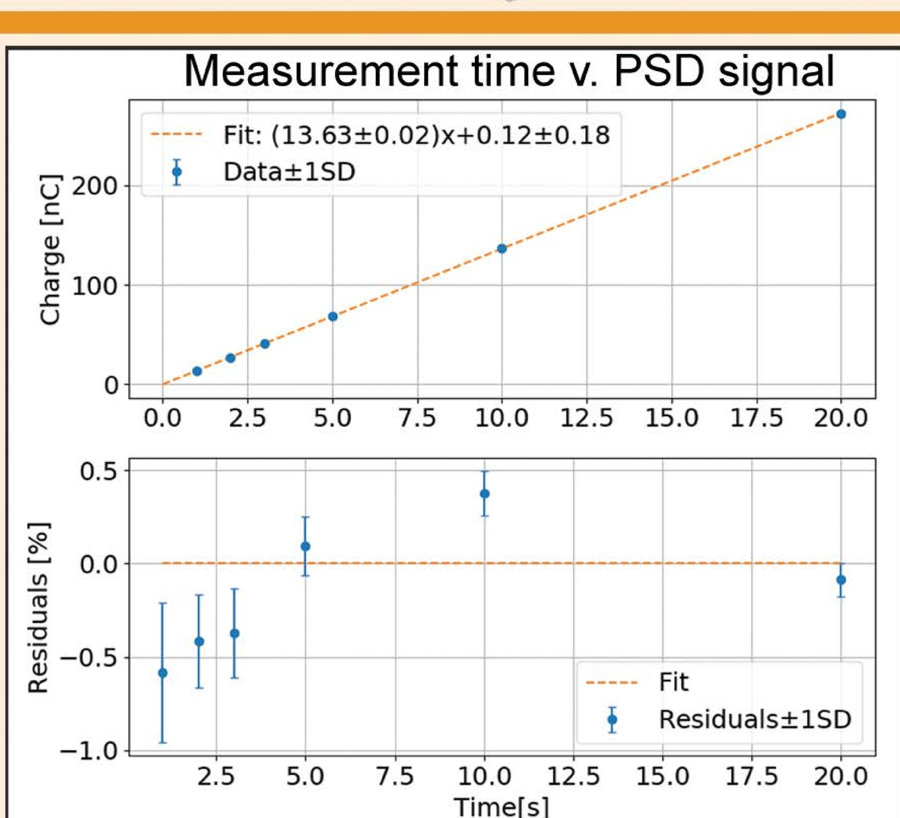

Fig. 4: (Top) Signal measured with the PSD at varying integration times when exposed to an HDR BT Ir-192 Flexisource. The dashed line is a linear fit. (Bottom) Residuals of measurement vs. fit.

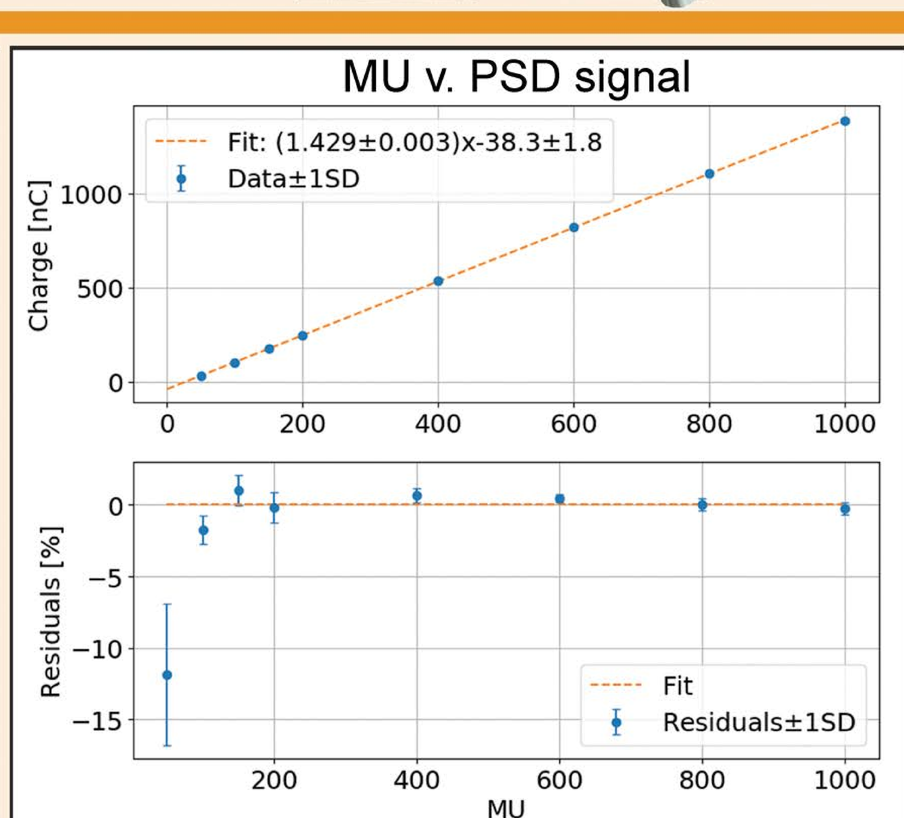

Fig. 5: (Top) Signal measured with the PSD when exposed to a P50 eBT source at varying MU-values. The dashed line is a linear fit. (Bottom) Residuals of measurement vs. fit.

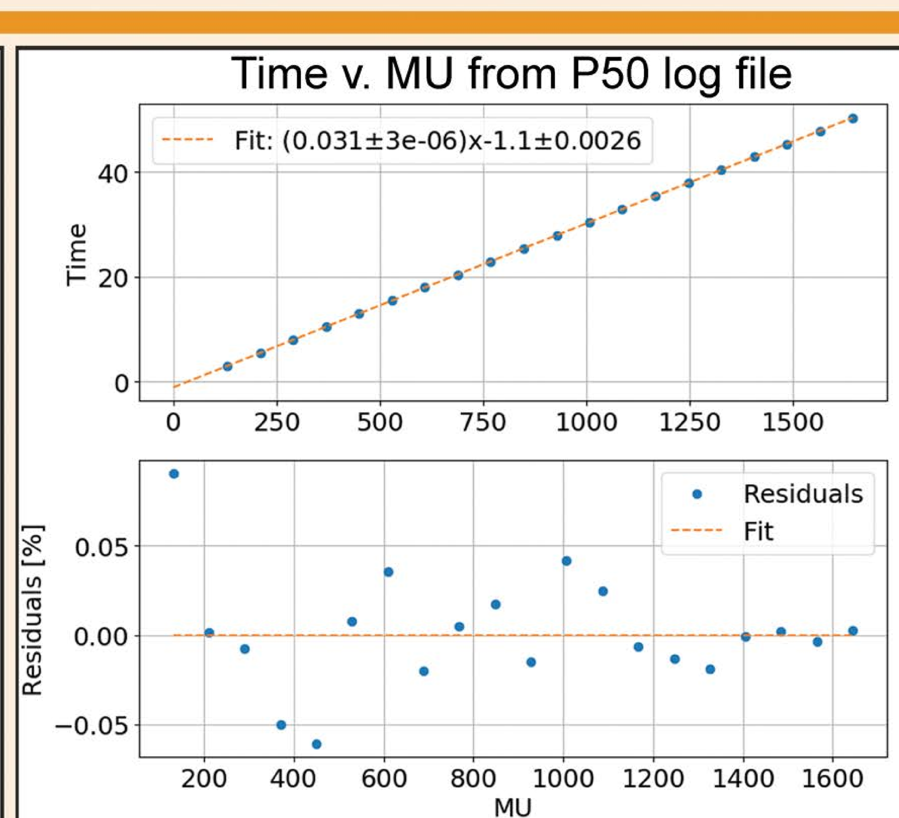

Fig. 6: (Top) The self-monitored radiation time and and dose output of the P50 unit. The dashed line is a linear fit. (Bottom) Residuals of measurement vs. fit.

Results: *PSD dose linearity:* Figure 4 (top) shows the charge vs. time-interval measured with the PSD when continously exposed to an HDR Ir-192 source. The data deviates with less than 1% from a linear fit (fig. 4 bottom).

P50 self-monitoring: Figure 5 shows the charge measured with the PSD vs the dose monitored by the P50. For values below 200 MU the data deviates systematically from a linear fit with up to -12 % (fig. 5 bottom). The P50's internal measurement of time vs. dose is shown on figure 6 with a linear fit (top) and corresponding residuals (bottom).

P50 temporal stability: Figure 7 (top left and right) shows the signal over 10 s intervals from the PSD and WC when continously irradiated by the P50 for 300 s. A decay of about 2 % in signal is observed for both the PSD and WC measurements. The PSD and WC data agree within 0.5% (fig. 7 bot. left). Using the WC measurements the signal vs. time was fitted with an exponential function. Correcting the PSD measurements with this function gives signal values with a standard deviation of 0.315% (fig. 7 bot. right).

Depth-dose curves: Figure 8 shows the relative dose vs. depth in water measured with the PSD and from published MC results[2].

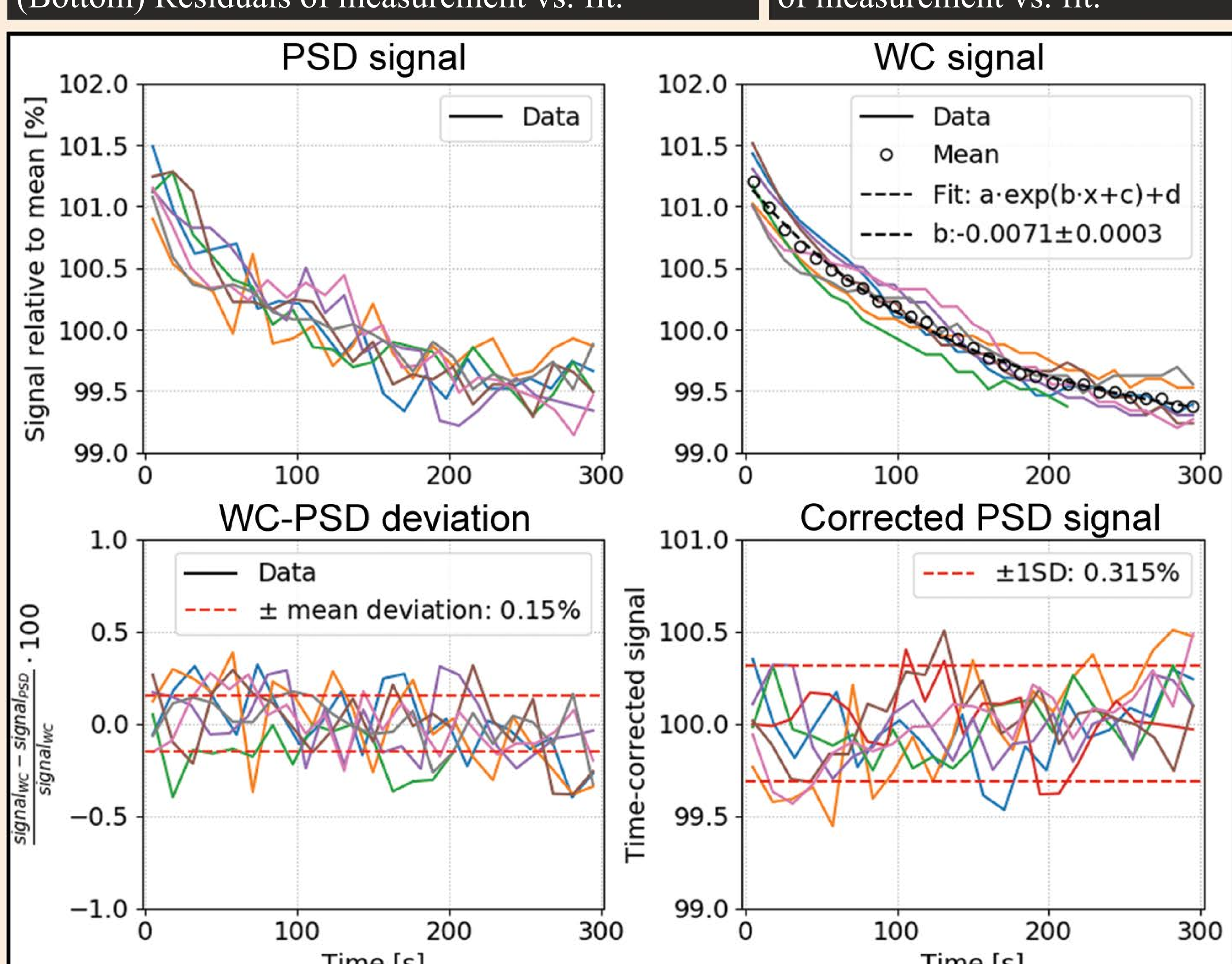

Fig. 7: (Top left and right) The accumulated charge during 10 s intervals measured by the PSD and WC during 300 s irradiations with the P50. The right figure shows the mean values of 7 measurements (circles) and an exponential fit to these values (line). (Bottom left) The deviation of the PSD measurements on the top left figure to the values of the WC measurements on the top right. Dashed lines indicate the mean deviation. (Bottom right) The signal measured with the PSD on the top left corrected for decay with the exponential function on the top right.

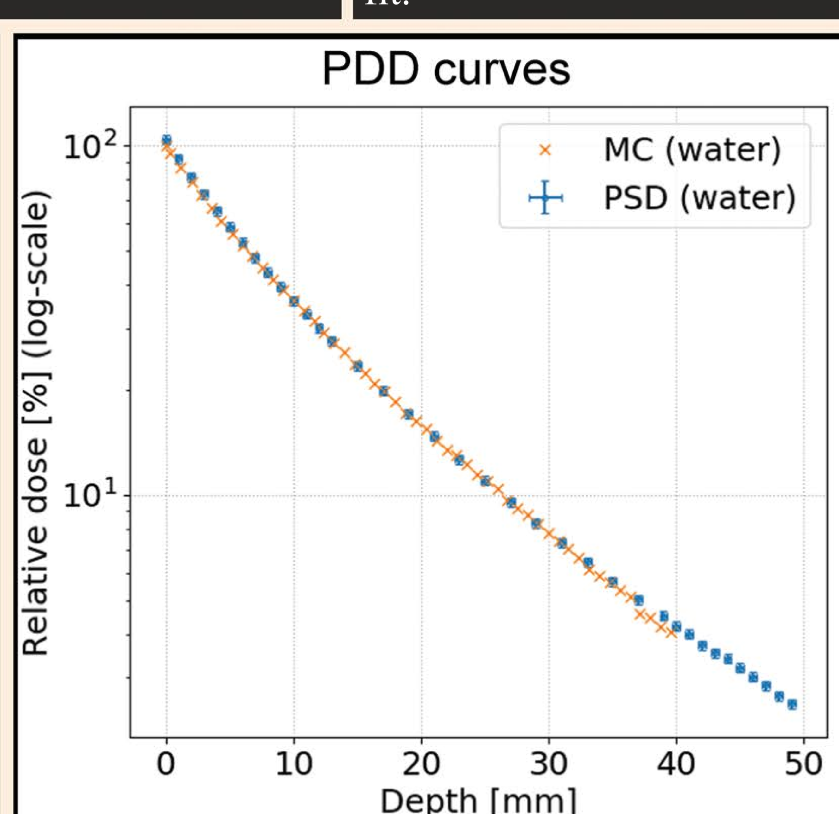

Fig. 8: The relative dose as function of depth in water measured with the PSD (blue dots) and from Monte Carlo simulation[2] (orange dots).

Discussion: The results indicate that the PSD is a reliable detector with good dose-respons linearity (fig. 4) and agreement with WC measurements (fig. 7 bottom right). The P50s internal ion-chamber underestimates the dose at MU values below 200 when compared to the PSD measurements (fig. 5). This is due to the P50 measuring a constant dose-rate during irradiations, seen on the strong linear relation of MU and time (fig. 6), in contrast to the PSD and WC measurements, that show a consistent decay in dose-rate (fig. 7). The decay is thus likely due to some effect happening between the P50s ion chamber and the X-ray tube's tip. The PSD and water phantom provided a simple depth-dose measurement in good agreement with MC results. The dose at arbitrary points in water could easily be measured with the PSD and phantom.

Conclusion: The measurements showed that the P50 output decays over time, when continously running. This decay is not monitored by the P50s internal ion-chamber. A PSD based system was shown to be a good candidate for eBT dose-verification. It showed good dose-signal linearity and agreement with WC measurements. A simple method for dose distribution measurements in water with a PSD and a motorised phantom showed good agreement with MC results.

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References: [1] PRISM-eBT publishable summary: http://www.ebt-empir.eu/wp-content/uploads/Publishable-Summary-M18.pdf
[2] O. Croce, S. et al. Radiation Physics and Chemistry 81 (2012) 609-617