Dynamic dose measurements of Gamma Knife ICON using a new scintillation detector system

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INTRODUCTION

Scintillation detectors (SDs) possess several advantages over other radiation detectors. SDs can be small, have fast response time, tissue equivalent, and less dependent on radiation energy and beam incident angle, and no metal allowing it for its use in magnetic fields such as in MR-linac units.[1] Meanwhile, there is a need for array detectors arranged on a plane or in a 3D space for quality assurance of modern radiation therapy delivery techniques. However, so far, there is no detector available with multiple scintillation sensors in one system due to the bulkiness of many cables needed to connect multiple sensors with photodiodes for data processing. We have come up with a solution by using 0.25-mm diameter fiber cables with a specially designed electronic module. Theoretically, the system can accommodate several hundreds of sensors for true 4D radiation field measurements. We used a prototype system consisting of up to four sensors to study the performance of the SD system, primarily for small field dosimetry of a Leksell Gamma Knife ICON radiosurgery unit.

AIM

To characterize the dynamic dose variation of the Leksell Gamma Knife ICON unit by using a new scintillation detector system with one to four 1-mm diameter and 1-mm long cylindrical scintillator sensors connected to optical fibers of 0.25-mm in diameter with a length of up to 20-m.

METHOD

We used a prototype system (Blue Physics LLC, FL) with one scintillator sensor for relative output factor (ROF) and dynamic dose measurements. The sensor was placed in a 3D printed cylindrical insert with the size equal to the Capintec PR05P ionization chamber. The sensor in the Gamma Knife spherical QA phantom was at the beam focus point of irradiation. We recorded the sensor output signal as a function of time. The effects of the Cherenkov lights produced in the transport fiber cable were eliminated by subtracting the signal of the second fiber next to the primary fiber cable. The integration of the signal over time gave us the relative dose delivered to the sensor. Using single shot plans, we measured the outputs of 4 mm and 8 mm relative to 16mm collimators. By analyzing the sensor signal vs. time for two plans made of one shot and four shots with 5 Gy to 50% dose level, we quantified transit, shutter, and flash doses [2-4].

RESULTS

- The output factors of 4-mm and 8-mm relative to 16-mm collimator (ROFs) are shown in Table 1. The differences from the Elekta recommended values [5] were +0.1% and -14.4% for 4 and 8-mm collimators
- Figures 1, 2, and 3 show the measured dynamic dose for the 16-mm collimator shots. The detector signals expressed as the charges collected per one sampling period of 150 ms or the current. One detector unit was made of two fiber cables, one with a scintillation sensor and another without it. The latter was used to remove the Cherenkov light produced along the fiber cable. The sensor signal in the current [nA] is plotted in blue. The curve in orange color is the Cherenkov light signal.
  - In Figure 1, two sharp peaks on both sides of the main square pulse show the ***flash dose***.
  - From Figures 2 (a) and (b), we found that the full-width-half-maximum (FWHF) of those pulses were about 200 ms, indicating that the velocity of the source was 2 cm/s.
  - Figures 1 and 2 show also the ***transit dose***, which was delivered while the patient couch was moving in or out before and after the full dose delivery of the shot, was zero.
  - The ***shutter dose*** is visible in Figures 2 (a) and (b), which show that the measured dose rate neither rose nor fell instantly between zero and the full dose at the beginning and the end of the shot.
  - Figure 3 shows the dynamic dose between two consecutive 16-mm shots. We can observe two flash doses.

Table 1: Relative output factors

Collimator [mm]	Readings [nA]	Relative Output factor	
		Measured	Elekta default
16	4.476	1.000	1.000
8	3.844	0.901	0.900
4	3.206	0.771	0.814

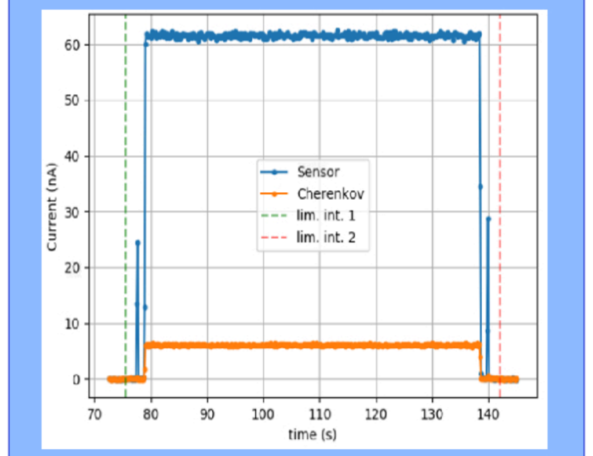

Figure 1: The sensor signal vs. time for a 16-mm shot with a 1-minute shot duration.

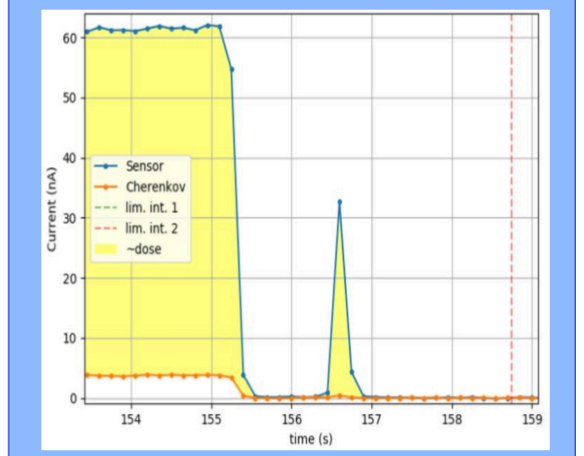

Figure 2 (a): A magnification of the pulse on the right side of the primary signal in Figure 1.

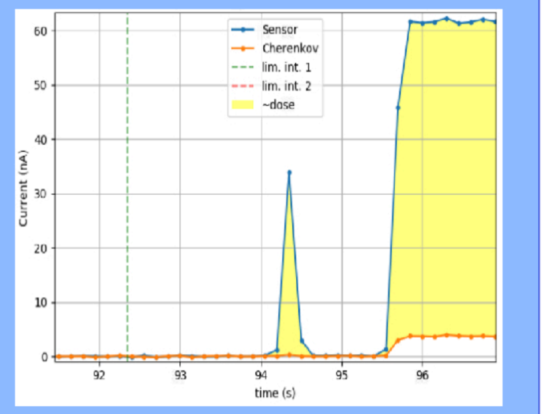

Figure 2 (b): A magnification of the pulse on the left side of the primary signal in Figure 1.

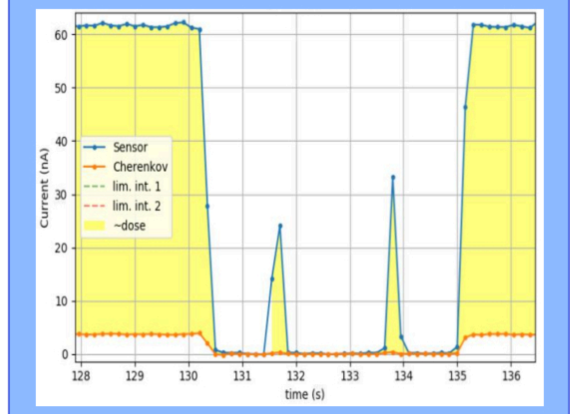

Figure 3: The shutter and flash doses between two 16-mm shorts.

SUMMARY AND CONCLUSIONS

- Measured ROFs were 0.771 and 0.900 for 4-mm and 8-mm collimators, respectively.
- The measured flash dose of a 16-mm shot was 0.5 cGy (325.2 cGy/min at the focus point). The transit doses delivered to the patient while the source moves between the parking position and the 16-mm or 8-mm collimator positions were smaller than 0.01% of the dose delivered by the shot
- We demonstrated excellent performance and its usefulness of the new scintillation detector system for small field dosimetry of the Gamma Knife ICON unit.

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