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A platform for multi-point fiber optic base dosimetry

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Summary. — Radiotherapy is in a period of rapid scientific and clinical development and the increasing complexity of modern treatment modalities has also introduced a more comprehensive patient-specific quality assurance programme (QA) to verify an individual patient delivery. Optical fibers offer a solution for *in vivo* radiotherapy dosimetry with many advantages over currently employed clinical dosimetry systems. A new technology is based on the use of luminescent materials with a plastic optical fiber, acting as light guides, to create a multi-point dosimeter. In this study, two different types of optical fibers with a core diameter of 1 mm were used in all the characterization measurements. In both cases the inorganic radiation sensor is based on europium-doped yttrium oxide and emits light slightly above 600 nm. In both configurations, the fibers were connected to a small portable reader. Optical fibers were irradiated in a water equivalent slab phantom, at the nominal photon energy of a 6 MV clinical accelerator for a fixed dose of 1 Gy. Field Output Factors (OF) for photon small beams were measured using the two fibers and a ionization chamber. Several measurements of the signal were performed to test the stability over time and repeatability. The comparison of OF measurements between the two fibers and the ion chamber was performed. In our preliminary measurements optical fibers have been demonstrated to be able to perform accurate radiotherapy dosimetric measurements.

1. – Introduction

The goal of this study was the implementation of a new technology for quality assurance (QA) and *in vivo* dosimetry, based on the use of luminescent materials [1]. It is based on the use of plastic optical fibers, acting as light guides, to create a multi-point dosimeter. Core of the platform is a radiation sensor based on inorganic scintillators.

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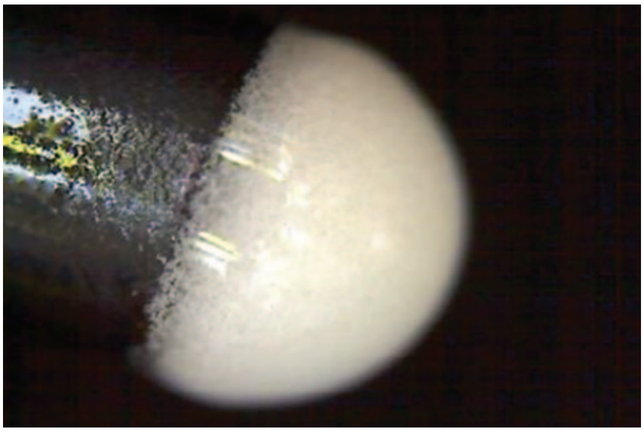

Fig. 1. – Sensor on the fiber for the standard configuration (fiber 1).

These sensors are fixed on one end face of the PMMA fibers and have a half-spherical shape, with a radius of approximately 500 μm, and are therefore particularly adapted for being used in sharp dose gradients and/or in small fields. The shape of the sensors also guarantees an optimal angular response.

The broad adoption of fiber optic technology for dosimetry has been hampered, as of today, by the presence of the so-called stem effect. When a passive (*i.e.*, non-dosimetric) optical fiber is exposed to radiation, it will emit luminescence with a light spectrum extending from ultra-violet up the near infra-red. This signal is proportional to the length of fiber exposed and includes two physical components: fluorescence and Cherenkov light. Whereas fluorescence is present at any energy of the irradiation beam, Cherenkov light is a threshold-related phenomenon and, in PMMA (the material of our passive fibers) at least 190 keV are needed to create Cherenkov light. The intensity of Cherenkov light is also dependent of the angle between the incoming radiation beam and the axis of the fiber [2].

The stem effect is a noise source and must be eliminated in order to obtain correct dosimetric measurements at the level of the sensor (on top of which the stem signal is superposed). In the literature different approaches have been proposed to this end, going from the use of a double fiber (first with a radiation sensor and second without, to account for stem effect though subtraction); a spectral/chromatic approach (requiring a complex calibration and needing a spectrometer instead of a simple photodetector); the replacement of the passive fiber with hollow core light guide and, finally, optical filtration.

In our approach we have opted for optical filtration, obtaining a system where the stem effect is confined to maximum 1.5% of the scintillator signal, for $10 \times 10\,\text{cm}^2$ fields. As such the stem signal is considered negligible up to $10 \times 10\,\text{cm}^2$ fields.

2. – Methods and materials

In this study, two different types of optical fibers with a core diameter of 1 mm were used in all the characterization measurements. Fiber 1 reflected the standard configuration, as shown in fig. 1.

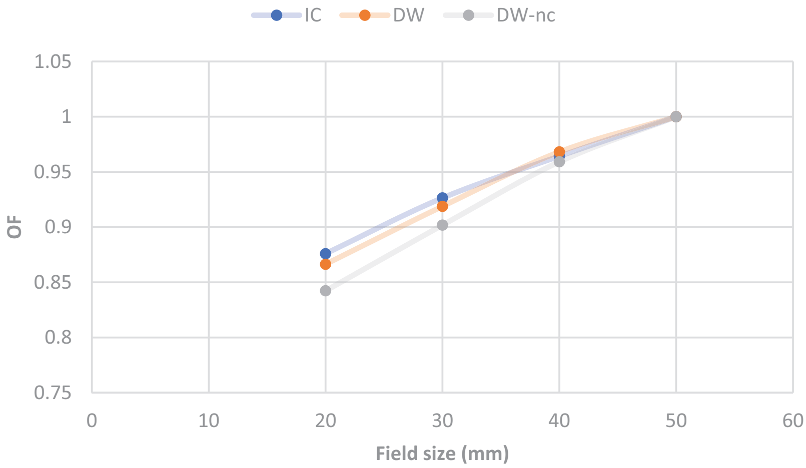

Fig. 2. – OF for the standard configuration fiber (fiber 1), with (orange) and without (grey) correction model, and corresponding data for the reference ion chamber.

In this case, a semispherical radiation sensor was directly connected to the passive fiber. For this standard fiber the stem effect was limited to 1.5% of the sensor signal, for a $10 \times 10\,\mathrm{cm}^2$ field, at approximately 20 cm depth. For the standard configuration fiber, we have developed a model to correct the measured signal as a function of measurement depth and field size. Results related to the correction are shown below for output factor measurements (fig. 2).

Fiber 2 was characterized by the insertion of a hollow core light guide between the inorganic scintillator sensor and the passive fiber. Since the passive fiber was not exposed to the direct irradiation field (but only to the scatter field), the stem effect was also limited. On the other hand, the overall sensor signal decreased by almost a factor 10 with respect to the standard configuration.

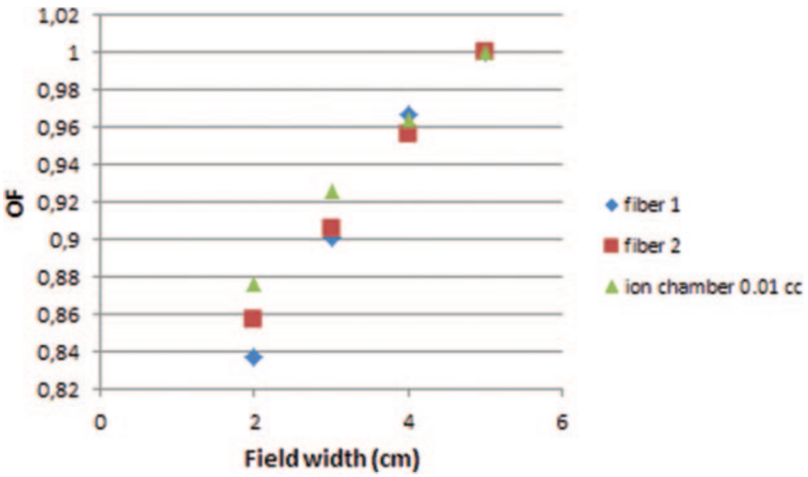

Fig. 3. – Comparison of the OF measurements between the two fibers and the reference ion chamber.

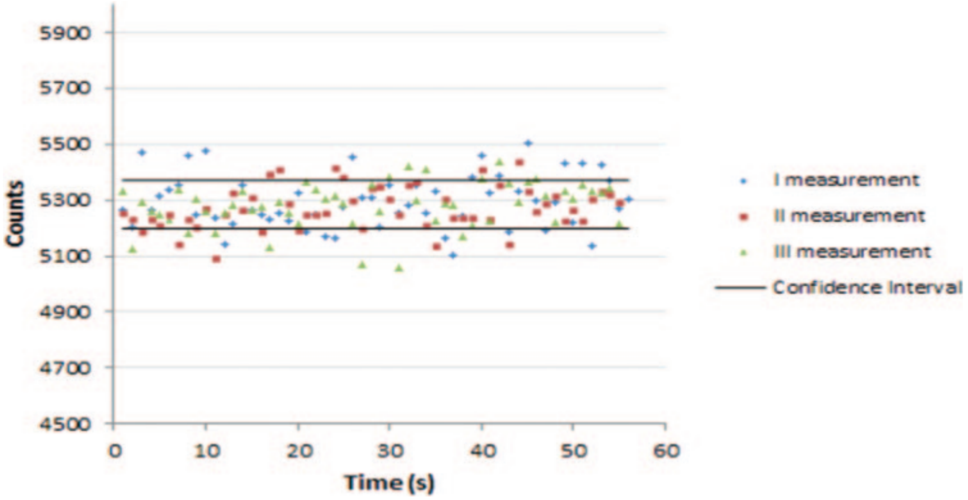

Fig. 4. – Repeatability for fiber 2 (field $2 \times 2\,\mathrm{cm}^2$).

In both cases the inorganic radiation sensor is based on europium-doped yttrium oxide and emits light slightly above 600 nm. This choice is related to the fact that, at this wavelength, the stem effect is much more attenuated than in the blue or UV part of the spectrum.

In both configurations, the fibers were connected to a small, portable reader, controlled wirelessly by a tablet. Optical fibers were irradiated in a water equivalent slab phantom at the depth of 10 cm, Source Surface Distance (SSD) 100 cm, at the nominal photon energy of a 6 MV clinical accelerator for a fixed dose of 1 Gy. Field Output Factors (OF) for photon beams were measured using the two fibers and a ionization chamber (volume 0.01 cc) for fields from $2 \times 2\,\mathrm{cm}^2$ up to $5 \times 5\,\mathrm{cm}^2$. Several measurements of the signal were performed to test the stability over time and repeatability.

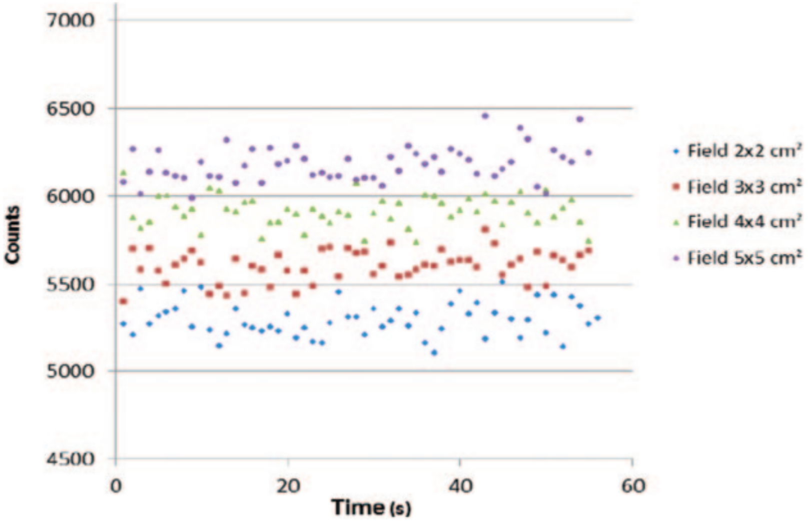

Fig. 5. – Stability over time for fiber 2.

3. – Results

The comparison of OF measurements between the two fibers and the 0.01 cc ion chamber was performed: the variation goes up to 2.2% for the fiber 2 (fig. 3). Fiber 1, when applying its correction model, agrees within 1% with the values obtained with the ion chamber.

In our preliminary measurements, fiber 2 has shown good results in terms of repeatability and stability over time (the relative uncertainty is below 2%) (figs. 4, 5). Similar or better results are obtained for fiber 1 (data from DoseVue and other research groups were analyzed).

We can conclude that the radiation sensor has a water-equivalent response up to fields of at least $5 \times 5\,\text{cm}^2$ and shows very good overall dosimetric performances. Further investigations are required to characterize the detector for the dose response, energy dependence and dose resolution.

REFERENCES

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[2] Beddar A. S., *Radiat. Meas.*, **41** (2006) S124.