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Miniature inorganic scintillation detectors for on-line treatment verification during brachytherapy

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Scintillation based point detectors have been used in radiation therapy since the early 1990s [1] primarily for pre-treatment quality assurance of patient plans and radiation sources. One common treatment modality is brachytherapy (BT) in which a sealed radioisotope is guided inside pre-inserted catheters in the tumor volume to deliver high radiation doses to the tumor with steep dose gradients to spare adjacent organs and normal tissue. The scintillation detectors could have an important role as on-line verification during BT treatments to detect errors that can lead to harmful consequences for the patient [2]. However, on-line treatment verification is presently not performed during BT, partially because commercial technology does not exhibit adequate signal intensities over the entire range of absorbed dose rates during BT treatments, which spans >2 orders of magnitude. The limited use of treatment verification is problematic because errors can occur unnoticed during single treatments or systematically over longer time periods [3].

We have developed miniature inorganic scintillation detectors (ISDs) for BT that are based on the scintillators Al₂O₃:Cr, Y₂O₃:Eu, YVO₄:Eu, Y₂O₂S:Eu, Gd₂O₂S:Eu, ZnSe:O or CsI(Tl). The ISDs consist of a 1 mm-size scintillator that is optically coupled to a 1 mm-diameter and 15 m-long fiber-optic cable made of poly(methyl methacrylate). The fiber-optic cable transmits the scintillation to the photodetector system which consists of a charge-coupled device camera or a spectrometer spectrograph. We have tested the ISDs under BT treatment irradiation conditions using a 10 Ci (370 GBq) ¹⁹²Ir source, and compared their performance with organic scintillators BCF-12 and BCF-60 which are the current standard for scintillation detectors in radiotherapy.

We will discuss the characteristics of our scintillation detectors and read out systems and their suitability for on-line verification of BT treatments, based on radiation exposures to the BT photon energy in water (average 300 keV) and the clinical range of dose rates (1-500 mGy/s). Our measurements show that the scintillation intensity of the inorganic materials are up to 3 orders of magnitude larger than those of the organic scintillators, and that the miniature ISDs exhibit the required dynamic range for precise dose rate measurements in the steep dose gradients near BT sources. The accuracy of the ISDs are furthermore not significantly affected by the stem signal, which is the contaminating Cerenkov and radioluminescence induced in the fiber-optic cable. Some of the inorganic scintillators exhibit unstable scintillation intensities for the larger dose rates and afterglow components with order of 1 s time constants, and we will describe how these luminescence properties can introduce inaccurate dose measurements during BT. Finally, we will discuss the promising potential for some of the inorganic scintillator materials for on-line treatment verification during BT, and describe the required detector characteristics.

[1] Beddar AS, Mackie TR, Attix FH. Water-equivalent plastic scintillation detectors for high-energy beam dosimetry. Phys Med Biol 1992;37:1883-1900.

[2] Tanderup K, Beddar S, Andersen CE, Kertzscher G, Cygler JE. In vivo dosimetry in brachytherapy. Med Phys 2013;40:1-15.

[3] IAEA Safety Report Series 17. Lessons learned from accidental exposures in radiotherapy. Vienna, Austria: IAEA; 2000.

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