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Published in:
Journal of Physics: Conference Series

Link to article, DOI:
10.1088/1742-6596/860/1/012028

Publication date:
2017

Document Version
Publisher's PDF, also known as Version of record

Link back to DTU Orbit

Citation (APA):
Buranurak, S., & Andersen, C. E. (2017). Fiber optically coupled radioluminescence detectors: A short review of key strengths and weaknesses of BCF-60 and Al2O3:C scintillating-material based systems in radiotherapy dosimetry applications. Journal of Physics: Conference Series, 860(1), [012028]. DOI: 10.1088/1742-6596/860/1/012028

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IOP Conf. Series: Journal of Physics: Conf. Series **860** (2017) 012028 doi:10.1088/1742-6596/860/1/012028

Fiber optically coupled radioluminescence detectors: A short review of key strengths and weaknesses of BCF-60 and Al_2O_3:C scintillating-material based systems in radiotherapy dosimetry applications.

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Abstract. Radiotherapy technologies have improved for several decades aiming to effectively destroy cancerous tissues without overdosing surrounding healthy tissues. In order to fulfil this requirement, accurate and precise dosimetry systems play an important role. Throughout the years, ionization chambers have been used as a standard detector for basic linear accelerator calibrations and reference dosimetry in hospitals. However, they are not ideal for all treatment modalities: and limitations and difficulties have been reported in case of (i) small treatment fields, (ii) strong magnetic field used in the new hybrid MRI LINAC /cobalt systems, and (iii) in vivo measurements due to safety-issues related to the high operating voltage. Fiber optically coupled luminescence detectors provide a promising supplement to ionization chambers by offering the capability of real-time in vivo dose monitoring with high time resolution. In particular, the all-optical nature of these detectors is an advantage for in vivo measurements due to the absence of high voltage supply or electrical wire that could cause harm to the patient or disturb the treatment. Basically, fiber-coupled luminescence detector systems function by radiation-induced generation of radioluminescence from a sub-mm size organic/inorganic phosphor. A thin optical fiber cable is used for guiding the radioluminescence to a photomultiplier tube or similar sensitive light detection systems. The measured light intensity is proportional to dose rate. Throughout the years, developments and research of the fiber detector systems have undergone in several groups worldwide. In this article, the in-house developed fiber detector systems based on two luminescence phosphors of (i) BCF-60 polystyrene-based organic plastic scintillator and (ii) carbon-doped aluminum oxide crystal (Al_2O_3:C) are reviewed with comparison to the same material-based systems reported in the literature. The potential use of these detectors for reference-class dosimetry in radiotherapy will be discussed with a particular emphasis on uses in small and large MV photon fields.

1. Background and introduction

Since the discovery of x-ray in 1895, the use of radiation for medical treatment has been revolutionized. Advanced radiotherapy technologies have been continuously improved and refined.

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Nowadays, it has been accepted as an import part of cancer treatments that is offered to about 50% of all cancer patients [1]. Basically, radiotherapy can be separated into two main types: (i) external beam radiotherapy where high energy of ionizing radiations (e.g. x-rays, electrons, and heavy charged particles) generated by a linear accelerator, and (ii) brachytherapy where a small radioactive source (e.g. Iridium 192) is inserted inside a catheter or a slender tube and controlled using the remote after loading system to let it dwell in or close to the tumor volume inside a body cavity. Careful treatment planning and optimization are mandatorily required for both types of cancer treatment aiming to deliver dose to the tumor region effectively, while minimizing any harmful side effects on surrounding healthy tissues. Treatment errors larger than 5% are considered unacceptable [2]. Therefore, accurate and precise dosimetry plays a key role to achieve this goal.

Ionization chambers are routinely used in hospitals due to their special characteristics of high reproducibility and long-term stability. Although, they are excellent for basic linear accelerator calibrations and reference dosimetry, they are not universally ideal detectors for all new treatment modalities‒some limitations and difficulties have been observed in small treatment fields as found in the Intensity Modulated Radiation Therapy (IMRT), the Volumetric Modulated Arc Therapy (VMAT) and in strong magnetic fields of the new hybrid MRI LINAC /cobalt systems. Das et al. [3] reported a variation in depth dose profiles of using a 6 MV beam delivery obtained with various types of detectors for small (1×1 cm^2), reference (10×10 cm^2), and large (40×40 cm^2) fields. The study provided unacceptable variation for small and large fields. For small fields, the main problems relate to the lack of lateral charge equilibrium of secondary electrons [4]. Whereas for large fields, the main problem concerns the increased induction of leakage noise current (i.e. large field-size projection compared to the small size of detectors causes more scatter of low energy electrons which contribute to the detector response).

Additionally, ionization chambers are generally constructed out of non-water equivalent materials in term of atomic composition and density. This causes significant perturbation effects that influence the accuracy of absorbed dose determination [5–7]. The studies by Scott et al. [8, 9] based on the Monte Carlo simulation provided important insights into the influence of detector density on detector response in non-equilibrium small photon fields. Three types of detectors were studied: a PinPoint ionization chamber, a diamond detector, and a diode. The study found that the modeled PinPoint detector under responded relative to an ideal, fully water-equivalent detector. In contrast, the high-density material solid-state detectors (silicon and diamond) over responded.

A promising supplement to ionization chambers is fiber optically coupled luminescence detectors. The system basically functions by using the optical sensing technique where the dosimeter probe consists of a small piece of a sub-mm sized phosphor sample attached to a thin optical fiber cable (typically Polymethylmethacrylate (PMMA), Polystyrene (PS) and Polyvinyltoluene (PVT)). Radiation-induced generation of radioluminescence (RL) from the phosphor sample is transmitted through the fiber cable to be recorded by a sensitive light detector. The measured light intensity is proportional to dose rate. At present, the prime phosphors can be separated into two types: (i) organic plastic scintillators (e.g. BCF-12, BCF-60, and BC-400), and (ii) inorganic crystalline phosphors (e.g. Al_2O_3:C, LiF:W, SiO_2:Cu, and KBr:Eu) [10].

For several years, fiber-coupled luminescence dosimetry has been subject of research and development in several groups worldwide (including, for example, University of Sydney NSW, the University of Texas MD Anderson Cancer Center, the Konkuk University, and Technical University of Denmark). The fiber detectors offer several attractive features over ionization chambers including: (i) real-time dose monitoring with high time resolution— this property is particularly used in pulse-to-pulse measurement of doses delivered by pulsed radiation sources like LINACs, (ii) negligible treatment perturbation due to sub-mm detector size, (iii) a wide dynamic range of measured dose from a mGy to several Gy, and (iv) no electrical wire or other electronic devices in the dosimeter probe head to disturb the treatment or cause harm to patient [10–14]. However, the major problem of these detectors is due to the fiber cable itself; radiation also induces generation of fluorescence and Cerenkov light from the fiber material during exposure, so-call stem signal. This contribution signal lead to inaccuracy of the measured doses.

This article presents an overview of the use of fiber-coupled luminescence detectors that focuses on two luminescence phosphors of (i) organic plastic scintillator (BCF-60) and (ii) carbon-doped aluminium oxide crystal (Al_2O_3:C). In the following sections, the basics of luminescence physics and the luminescence detection instruments between two detector systems are introduced, and then the important physical parameters that are necessary to be considered as sources of variability in radiotherapy dosimetry are identified. Finally, the potential use of both detector systems in small and large MV photon fields is briefly discussed.

2. Luminescence mechanisms and detection instruments

2.1. Detector probes

In this article, two in-house fiber-coupled luminescence detectors developed by the Center for Nuclear Technologies, Technical University of Denmark, are reviewed. Both detector probes look physically identical, except their sensitive parts. One was made by a piece of BCF-60 (i.e. 1 mm diameter and 2 mm long from Saint-Gobain Ceramic & Plastics Inc., France) [15], and another was made by a Al_2O_3:C crystal (i.e. 1×1×2 mm^3 from Landauer Inc., USA) [6]. Each of them was polished and mechanically coupled with a polished PMMA optical fiber cable (i.e. 1 mm diameter and 10–15 cm long from Mitsubishi Rayon Co., Japan) using UV-curing glue (NOA68) with a black epoxy cement was coated for light-tighten and bond protection (Fig.1).

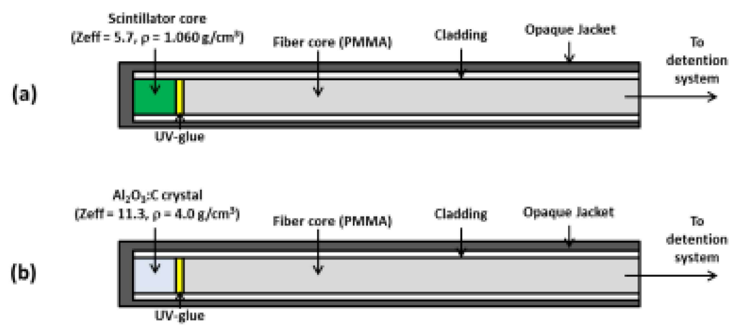

Fig.1. Sketch of the fundamental composition of (a) a fiber-coupled BCF-60 organic plastic scintillator probe, and (b) a fiber-coupled Al_2O_3:C crystal probe. Redraw from Buranurak [16]

2.2. Luminescence mechanisms

In principle, the luminescence mechanism in the organic plastic scintillators is completely different from the crystalline phosphors. When the BCF-60 is exposed, molecules of polystyrene base-substrate doped with perylene are excited, and de-excited after a short while (i.e. in range nano seconds or shorter) with RL emission. Perylene is an organic fluorescence dye used as a wavelength shifter to absorb shorter wavelength of UV released from the relaxation procedures of polystyrene molecules and emit longer wavelength of visible green instead (i.e. spectrum range: ~ (490–650 nm), emission peak: 530 nm (www.crystals.saint-gobain.com)). In case of Al_2O_3:C crystal, it is a perfect insulator with a wide energy band-gap of ~9.5 eV. When the crystal is subject to a beam of ionizing radiation, radiation-induced creation of electron-hole pairs migrate through the crystal via the de-localized conduction and valence bands. Some electrons are trapped in shallow, dosimetry and deep traps caused by dopant materials, impurities and other imperfections in the crystal structure. Other electrons can pass through to recombine with the holes at the recombination centers, resulting in the RL emission (i.e. the main emission from Al_2O_3:C is associated with the F-center luminescence which has the range of ~ (300–520 nm) with the centered at 420 nm and a ~ 35 ms lifetime [10, 17]. Additionally, all electrons trapped during exposure can be released to the conduction band using a stimulating light source. These electrons may recombine with the holes at the recombination centers resulting in the luminescence emission that is so-called the optically stimulated luminescence (OSL) [18, 19].

2.3. Luminescence detection instruments

As previously mentioned, the fiber-coupled luminescence detectors function by radiation-induced RL emissions from the luminescence phosphors which are guided through an optical fiber cable to be detected by a light detector. In principle, the measured RL signal should be proportional to the dose delivery rate. However, the contribution of stem signal, which is caused by radiation-induced generation of fluorescence and Cerenkov radiation in the fiber cable itself, leads super-imposed to the measured light signals that results in an inaccurate dose estimation. Over the years, several methods have been proposed to eliminate the stem effect, for example: background subtraction using dual fibers [12, 13], spectral filtration [20], temporal gate system [21], hollow-core fiber light guidance [22], and chromatic removal [23, 24]. Each method has both advantages and disadvantages depending on luminescence materials used and dosimetry applications.

The in-house developed ME30 luminescence reader is used for measuring RL signal and discriminating the unwanted stem signal from the fiber-coupled Al_2O_3:C probes. The system consists of four photomultiplier tubes (PMTs) (MP982, PerkinElmer Inc., USA) attached with 395−440 nm optical filters. The PMTs are operated in pulsed mode with a high-speed pre-scaler (1:8). The system basically functions by using the temporal gating circuit (compact-RIO 9074 controller, National Instruments Co. Ltd., USA) which is driven by the linear accelerator synchronization signal to block the counting events for an initial 25 μs after each synchronization pulse. Using this protocol, the main part of RL signal generated from the Al_2O_3:C crystal which has a relaxation time of ~ 35 ms can be measured, whereas the stem signal presented during ~5 μs of each accelerator gun pulse can be blocked. However, the temporal gating system cannot remove the stem signal from the fiber-coupled organic plastic scintillator probes because of the short luminescence lifetime for these materials (typically a few ns as reported by www.crystals.saint-gobain.com). The temporal stem removal technique only works in pulsed beams from linear accelerators when the luminescence time is longer than the pulse width.

The ME40 luminescence reader developed at the Technical University of Denmark is tailored for accelerator dosimetry with the fiber-coupled BCF-60 probes. The system basically functions using the chromatic removal method to separate the scintillation light from the stem signal. The system consists of two optical components of 45^{o} dichroic mirrors (Edmund Optics Ltd., United Kingdom) using to split the total collected light into the blue and the green components. The collected light is firstly entered to the blue component where the stem signal dominated in the visible blue and soft UV light is reflected by a magenta/blue dichroic mirror and further to be deposited in the first PMT. While the scintillation light of BCF-60 dominated in the visible green can pass through this mirror to be reflected by a yellow/green dichroic mirror in the green component and eventually deposited in the second PMT. Figure 2 shows the simple sketches of (a) the fiber-coupled Al_2O_3:C probe equipped with the ME30 luminescence reader, and (b) the fiber-coupled BCF-60 probe attached to the ME40 RL detection instrument.

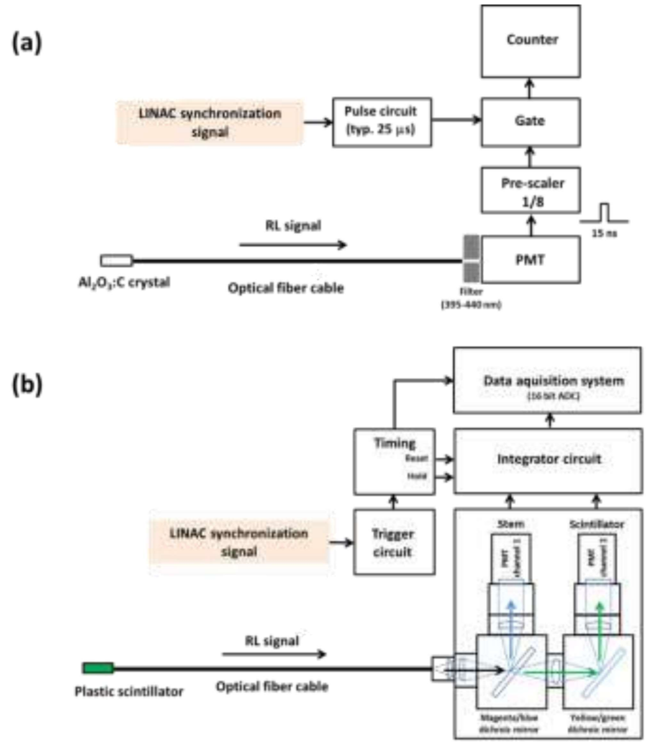

Fig.2. Schematic view of (a) the fiber-coupled Al_2O_3:C detector system applied with the temporal gate pulse circuit in ME30 instrument for stem signal subtraction, and (b) the fiber-coupled BCF-60 organic scintillator system equipped with the optical component of chromatic stem removal system and the data acquisition electronic circuits in ME40 instrument. Source: Buranurak [16].

3. Important dosimetric characteristics of the fiber-coupled luminescence detectors

In order to evaluate the performance of detector systems used in radiotherapy, these following dosimetric characteristics are necessary to be concerned.

3.1. Reproducibility

Measurements are always subject to various sources of uncertainty that will cause the measured result to differ from the true value [25]. In practical, such deviations are therefore required to be within an acceptable limit. Reproducibility is defined as the variation in measurements made on a subject under changing conditions (i.e. differences of measurement methods, instruments, observers, or observed times) [25, 26]. Therefore, reproducibility is a measure of the stability of measurement system.

Reproducibility of the fiber-coupled Al_2O_3:C detectors carried out using a 50 kV x-rays was found to be within 0.2% (1 SD) [11]. Additionally, the study by Aznar et al. (2004) reported that the reproducibility of the fiber-Al_2O_3:C system performed using the clinical photon beams of 6 MV and 18 MV (Varian Clinac 2300EX, Varian Medical System, Palo alto, USA) under reference conditions was found to be within 0.3% (1 SD) and 0.5% (1 SD), respectively. However, the RL/OSL signals from Al_2O_3:C fiber system was observed to have the day-to-day variability of the gain coefficient up to 2%. This suggests that the fiber-Al_2O_3:C system using the combined RL/OSL readout protocol requires frequent re-calibrations.

In case of the fiber-coupled BCF-60 organic scintillation detectors, the recent study by Beierholm et al. [14] reported that the reproducibility of this system carried out using a Varian TrueBeam^{TM} in different beam quantities under the reference conditions was found to be within 0.4% (1 SD). While the day-to-day variability of the gain coefficient was found up to 2.5% (1 SD).

3.2. Detector density

The impact of detector density on the response of various detectors in small-field radiotherapy dosimetry was studied by Scott et al [8, 9]. It was found that a density correction factor is required to improve the accuracy of dose calculation. The density correction factor is defined as the ratio of Monte-Carlo calculated dose delivered to water and detector voxels at the same reference condition. As briefly mentioned in the introduction part, the studies observed under response for the gas-filled PinPoint detector (i.e. a low-density detector material), whereas over response was observed in the high-density solid-state silicon diode and diamond detectors. Based on Scott's concept, Monte-Carlo computations of density correction factors were carried out by Buranurak [16] without detailed modelling of the accelerator head. For the sensitive volume of the fiber-coupled BCF-60 detectors, a voxel of polystyrene-based organic scintillator was modeled. Additionally, a voxel of Al_2O_3:C crystal was also modeled to represent the sensitive volume of the fiber-coupled Al_2O_3:C detectors. The study found an overdose response up to 27% for the Al_2O_3:C voxel at the smallest field size of 0.25×0.25 cm^2. In contrast, no change was observed for the polystyrene voxel at the same field size. Therefore, the impact of detector density on the dose-response was found to decrease with increasing field size. For field size larger than 2×2 cm^2, it was found to be negligible. For the modeled voxels of air and silicon, the profiles of the density correction factors with field sizes were found to be consistent with the Scott's study. Interestingly, the profiles of the density correction factors with field sizes of the polystyrene-based modified-density materials such as polystyrene-based Al_2O_3:C, polystyrene-based silicon, and polystyrene-based air were found to be correlated as mirrored to their originals, with deviation ~13% was observed. This study suggests that the density effect was mostly related to field-size dependent changes in electron fluence spectra created in the water phantom. In other words, the density effect reported by Scott et al. [9] was reproduced on the basis of a simplified model for simulation without any changes of the primary photon fluence with field size. This study indeed supports that the polystyrene-based organic plastic scintillators can be used for small field dosimetry without any requirement of the density correction factors. This is also supported by Monte-Carlo studies [27, 28] and experimental studies [29, 30].

3.3. Energy dependence

In principle, changing in energy spectrum of ionizing radiation influences on the dosimetric response of a detector. Energy dependence therefore is an important physical parameter in dosimetry whenever the detector is used under conditions that are not identical to the conditions under which the detector was calibrated. For the fiber-coupled Al_2O_3:C detectors, the variation of output signals was observed to be 0.6% (1 SD) for both RL and OSL signals, when the detectors were exposed using 6 and 18 MV photon beams with a 2 Gy dose delivery at a 10 cm depth in water [11].

For the fiber-coupled polystyrene-based organic scintillation detectors, the detector sensitivity was observed to be energy independent for both photon and electron beams [13, 24]. This was confirmed by the Monte-Carlo studies [31]. However, in practical, the magnitude of the stem effect is of more concern because small systematic errors may lead to a large effect on the detector reading. For this reason, stem effect baseline correction is necessary to be taken into account. The study by Beierholm et al. [14] observed the energy dependence in the in-house fiber-coupled BCF-60 detectors within 0.4% (1 SD) for energies ranged from 6 MV to 15 MV. This was found to be consistent with the commercial fiber-coupled polystyrene organic scintillation detectors called Exradin W1 [32, 33].

3.4. Temperature dependence

Temperature effect in the fiber-coupled organic plastic scintillation detectors was firstly studied by Beddar et al. [13]. The study was performed using polyvinyltoluene-based organic scintillators which were exposed to 4 MV x-ray beam under the controlled temperature of 0 – 50 ^{o}C, no significant difference of the overall measurement uncertainty was observed. However, temperature effect in the fiber-coupled organic scintillators was revisited and studied again by Beddar [34] and Buranurak et al. [35]. According to the Buranurak's study, temperature effects in four polystyrene-based organic scintillators were investigated. All tests were carried out using a 50 kV x-ray source where Cerenkov light generation in the fiber cable would not influence the results. The temperature was controlled in the clinical range of 15 − 40 °C. Different temperature coefficients were observed for the four-tested scintillators with the maximum of –(0.55 ± 0.04)%/K for BCF-60. This was found to be consistent with the study by Wootton and Beddar [36].

Investigation of temperature dependence in the fiber-coupled Al_2O_3:C detectors was reported by Andersen et al [37]. All measurements were carried out using a 50 kV x-ray source with 10 − 40 °C temperature controlled. The study was found a temperature coefficient of –(0.21 ± 0.01)%/°C.

3.5. Dose-rate dependence

Ideally, the detector response for overall dose should remain constant regardless with the accelerator dose delivery rate applied [38]. Dose-rate effect is interesting for radiotherapy dosimetry. This is due to the fact that dose rate applied for detector calibration generally uses 600 MU/min but only low dose rate is practically used for preventing or reducing late side effects of radiotherapy [39, 40].

Dose-rate effect in fiber-coupled organic scintillation detectors was firstly investigated by Beddar et al. [13]. The effect of dose-rate was found to be nearly independent; 0.05% deviation of the detector response was observed when the delivered dose rate was changed from 100 − 400 cGy/min.

For the fiber-coupled Al_2O_3:C detectors, a small, but highly significant dose rate effect was found using the saturated RL readout protocol. The study by Andersen et al [37] reported a change in RL signal of –(0.22 ± 0.01) % when the delivered dose rate was increased from 100 to 600 MU/min. However, there was no clear explanation whether this effect was a feature of the luminescence mechanisms inside the crystal itself or the specific instrumentation used. The problem of dose-rate effect in the Al_2O_3:C fiber detectors was therefore further investigated by Buranurak and Andersen [41]. An iris collimated to 2 mm diameter was used to limit the intensity of RL transmitted to the PMT. All measurements were carried out using 6 MV x-ray to deliver dose of 300 MU with dose rate was varied from 100 to 600 MU/min, and source-to-surface distance (SSD) was varied from 70 to 140 cm. Measured RL counts between with and without iris were compared. The study found that the effect of dose-rate could be resolved using an iris to reduce RL signal which lead to the reduction of count-rate. Additional measurements indicated that the dose-rate slope was found to be decreased with increasing SSD; because of count-rate decreased. This study provided a clear evidence that the dose rate effect was mainly caused by a dead-time problem in the PMT rather than the RL kinetics of Al_2O_3:C crystal. Therefore, a simple dead-time correction factor can be used to provide dosimetry also under a wide range for clinically relevant dose rates.

4. Potential use of fiber-coupled luminescence detectors in small and large MV photon fields

Throughout the years, the use of fiber-coupled luminescence detectors with both organic plastic scintillators and Al_2O_3:C crystals have been applied in variety dosimetry applications. Some of these applications have been reported in literature, for example: dosimetry applications in external beam radiotherapy [37, 42, 43], brachytherapy [43–48], particle therapy [49–52], and total body irradiation [41]. In this part, benefits and drawbacks of both detector systems applied in the external beam radiotherapy with comparison of small and large MV photon fields are discussed.

4.1. Small-field dosimetry

Current and future treatment modalities such as intensity modulated radiation therapy (IMRT), Stereotactic radiotherapy and volumetric modulated arc therapy (VMAT) tend to employ smaller treatment fields to ensure optimal dose conformity over a small target volume while minimizing damage to surrounding healthy tissue. However, accurate dose measurement in small treatment fields is a well-known challenge for many detectors due to a large degree of uncertainty was observed [3, 53, 54]. Basically, the uncertainty is mainly caused by (i) partial occlusion of the primary beam by collimating devices, (ii) lack of lateral charge-particle equilibrium, (iii) inhomogeneity of dose-averaging over the sensitive volume of detectors, and (iv) density differences between detectors and their surrounding media [4, 55]. Therefore, a detector-specific correction factor in small fields is necessary to take into account [29, 54].

Fiber-coupled organic plastic scintillation detectors have been hypothesized to have a minimal perturbation to the treatment due to a sub-mm size diameter. Additionally, they provide many favorable dosimetric characteristics of nearly water-equivalent, independent of energy, angular, and dose delivery rate, dose linearity and resistance to radiation damage [13, 14, 28, 56]. Based on these benefits, the organic scintillation detectors look promising for reference measurements in order to determine the small-field correction factors for ionization chambers and other commercial detectors. An interesting study was conducted by Beierholm [29] to assess the current status of reference dosimetry and small-field dosimetry in clinical practice. Experimental study was carried out at six Danish clinics. Small-field correction factors for a PinPoint chamber and a diamond detector were estimated using the output factors measured from both detectors relative to the in-house fiber-coupled BCF-60 detectors used as reference. The small-field correction factors were also corrected for volume averaging. Deviation within 2% (1 SD) was observed at 1×1 cm^2 field size.

For the fiber-coupled Al_2O_3:C detectors, the experimental study related to the use of this detectors for small treatment field dosimetry and investigation of small-field correction factors has never been reported in literature. However, Monte-Carlo simulation indicated that a discrepancy in the output factors between the Al_2O_3:C and polystyrene-based organic scintillator probes of up to 4.3% [57].

4.2. Large field dosimetry

Total body irradiation (TBI) is classified as a large field radiotherapy treatment technique where a homogeneous dose is delivered to treat the entire body of patient. In practical, TBI is used for treatment of specific hematological diseases [58]. Additionally, it can be applied to be used as part of conditioning regimen for bone marrow or hematopoietic stem cell transplantation [59–62]. Throughout the years, the fiber-coupled luminescence detectors with both organic scintillators and Al_2O_3:C crystal offer the capability to be used in a wide range of dosimetry applications, and may be used as a reference dosimeter in small-field radiotherapy. However, the use of fiber detectors either coupled with organic scintillators or crystalline phosphors applied for large-field dosimetry as TBI treatment has not been reported previously. In practice, large-field dosimetry is challenge for the fiber systems due to the fact that the influence of the stem effect on the measured RL signals is increased proportionally with the increasing length of fiber cable subject to the primary beam. The recent study by Buranurak and Andersen [41] demonstrated the efficiency of stem signal subtraction comparing between the temporal gating circuit in the ME30 instrument used for the fiber-coupled Al_2O_3:C detectors and the chromatic stem removal system in the ME40 instrument used for the fiber-coupled BCF-60 organic scintillation detectors. Measured doses with field size variation from both detector systems were compared between two configurations: (i) minimum configuration where the detector probe was arranged in the solid phantom as the same calibration setup, and (ii) extra-fiber configuration where a ~ 2.2 m fiber cable was looped and placed on top of the phantom. The extra-fiber configuration was used to simulate the situation as TBI treatment where an approximately 2 m of the cable length was subject to the treatment beam. The study demonstrated failure of the chromatic system to remove the substantial amount of stem signal generated in the extra-fiber configuration. The inadequacy of the chromatic stem removal technique in large fields could be due to violations of the basic assumptions behind the technique: (i) that the spectrum of the stem signal remains constant regardless of the irradiation conditions, and (ii) linearity of the detector over the range of the light levels experienced by the system. In contrast, the study found the temporal gating system to essentially remove stem signal perfectly, no matter how much of the cable length is exposed.

5. Conclusions and future perspectives

Nowadays, the tendency in radiotherapy is going toward the development of precise beam-delivery machines and more conformal treatments to a small and well-defined tumor. To achieve this goal, the extensive QA programs together with accurate and precise dosimetry system play a key role in this work. Therefore, the development of improved detectors that potentially can be used as reference measurements in various applications remains relevant. Fiber-coupled luminescence detectors have been developed over two decades to fulfill this demand. The systems provide several attractive features for radiotherapy dosimetry including real-time in vivo dose monitoring with high time resolution, minimal perturbation to the treatment, high dynamic range of dose measurements, reliability and robustness. Especially, the fiber detectors coupled with organic scintillators offer favorable dosimetric characteristics of nearly water equivalent, high reproducibility, independency in energy, angular, and dose delivery rate, and negligible density effect. However, as general solid-state detectors, thermal effect has been observed in this fiber system. The correction factor for the influence of temperature variations is required for in vivo dosimetry.

Regarding these impressive characteristics, up to now, the fiber system based on organic plastic scintillators looks promising as the best candidate to be used for reference measurements in small treatment fields, rather than other real-time detectors. However, the problem of parasitic stem signal contribution is necessary to be concerned, and the stem effect is more significant relative to the increased length of fiber cable in the treatment beam. The chromatic stem removal technique used for the fiber-coupled organic scintillators is inefficient for large-field dosimetry as TBI treatment. The reason is possible due to the failure of fundamental assumptions in the chromatic technique−either the linearity in dose response when a huge amount of stem signal is generated, or the requirement of constant spectra of the stem signal. Background subtraction using dual fibers is a conventional technique to remove stem signal from the fiber-coupled organic scintillators alternative to the chromatic removal technique. This technique looks promising to remove the huge stem signal generated during TBI treatment. However, the practical use of this technique for large-field dosimetry needs to investigate further.

In contrast, the temporal gating circuit used for the fiber-coupled Al_2O_3:C crystal offers the perfect stem signal subtraction; even if the huge stem signal is generated. However, this detector system provides unimpressive dosimetric characteristics, thus many correction factors are required for more accurate dose estimation.

It is the opinion of the authors that the fiber-coupled luminescence detectors with both organic scintillators and Al_2O_3:C crystal provide good potential to be used for radiotherapy dosimetry, but in different circumstances. The organic scintillator system is suitable for small-field dosimetry due to nearly perturbation-free in small treatment fields, whereas the crystal system can be used in large-field dosimetry of pulsed accelerator beams based on the near-perfect stem signal subtraction of the temporal gating technique.

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Acknowledgments

On behalf of co-author; Claus E. Andersen, and myself, I would like to thank Lars R. Lindvold, senior scientist at DTU Nutech for very kind suggestion and support. I would also like to thank all staff of the International Nuclear Science and Technology Conference (INST 2016) for organizing a good conference and giving me an opportunity to present this work with a registration fee waiver awarded.