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Effect of magnetic field strength on plastic scintillation detector response

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ABSTRACT

Purpose: To characterize the response of plastic scintillation detectors (PSDs) to high-energy photon radiation as a function of magnetic field strength.

Materials and methods: PSDs were placed inside a plastic phantom held at the center point between 2 magnets and irradiated using a 6-MV photon beam from a linear accelerator. The magnetic field was varied from 0 T to 1.5 T by 0.3-T increments. The light emission and stem-effect-corrected response as a function of magnetic field strength were obtained for both a commercial PSD (Exradin W1, Standard Imaging) and an in-house hyperspectral PSD. Spectral signatures were obtained for the in-house PSD, and light emission from a bare fiber was also measured.

Results: Light emission increased as magnetic field strength increased for all detectors tested. The tested PSDs exhibited an increase in light intensity of 10%–20%, mostly owing to the increase in Cerenkov light produced within and transmitted along the optical fiber. When corrected for stem effects, the increase in PSD response went down to 2.4% for both detectors. This most likely represents the change in the inherent dose deposition within the phantom.

Conclusion: PSDs with a suitable stem-effect removal approach were less dependent on magnetic field strength and had better water equivalence than did ion chambers tested in previous studies. PSDs therefore show great promise for use in both quality assurance and *in-vivo* dosimetry applications in a magnetic field environment.

1. Introduction

The use of magnetic resonance imaging during radiation therapy is revolutionary, promising to improve the precision and personalization of treatment delivery. However, the presence of a magnetic field for imaging can reduce the accuracy of existing detectors used for radiation dosimetry and quality assurance measurements (Raaijmakers et al., 2005; Raaymakers et al., 2004). Researchers, therefore, are increasingly interested in studying the behavior of existing radiation measurement devices in the presence of magnetic fields and in developing new ones whose response is less strongly affected by magnetic fields (Agnew et al., 2017; Hackett et al., 2016; O'Brien et al., 2016; Reynolds et al., 2013, 2014). Because they are composed of nonmagnetic materials, plastic scintillation detectors (PSDs) are promising for such applications. PSDs have several advantages over other types of detectors, including their water equivalence, small size, and fast response (Beddar et al., 1992a, 1992b; 1992c). PSDs have also attracted great interest for small-field quality assurance and *in-vivo* dosimetry applications (Kamio and Bouchard, 2014; Klein et al., 2010; Mijnheer et al., 2013; Tanderup et al., 2013). However, Stefanowicz et al. (2013) reported an increase in light intensity of up to 7% when PSDs were exposed to a magnetic field ranging between 0 and 1 T; the underlying causes for this effect were not well understood.

The purpose of the present study was to measure the magnetic field strength dependence of the light response of PSDs. We analyzed the light response from both a commercial PSD and an in-house hyperspectral PSD by measuring changes in the intensity and spectral composition of the emitted light in the presence of magnetic fields of varying strengths. Our goal was to obtain a better physical understanding of the effects of magnetic fields on PSD response.

2. Materials and methods

The responses from a commercial PSD, an in-house PSD, and a bare fiber were obtained for different magnetic field strengths. An insert was used to hold the PSD at the center of a 10 cm × 10 cm × 20-cm acrylic phantom (Fig. 1a). The hole containing the insert was filled with water to prevent the hard-to-predict effects of air gaps in the presence of a magnetic field (Hackett et al., 2016). The phantom was held firmly by its sides at the center point between the 2 magnets. The current applied to the magnets was varied to create magnetic fields ranging from 0 T to 1.5 T in 0.3-T increments. As depicted in Fig. 1b, the magnets and

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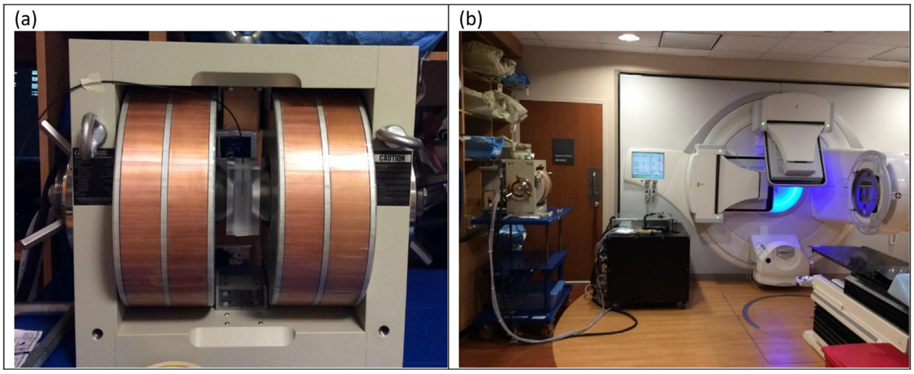

Fig. 1. (a) Plastic scintillation detector held at the center of an acrylic phantom between magnets. The magnetic field strength was varied from 0 T to 1.5 T by selecting the current applied to the coils. (b) Position of the plastic scintillation detector inside the clinical vault. The detector was placed 3.7 m from the radiation source.

detector were placed at the far left end of the clinical vault, with the detector 3.7 m from the radiation source. The field size at the PSD was 3 cm × 10 cm. The detector was irradiated with a 6-MV photon beam from an Elekta Versa HD linear accelerator (Elekta, Stockholm, Sweden), with the gantry positioned at 90°.

The commercial detection system was composed of an Exradin W1 scintillator (Standard Imaging, Middleton, Wisconsin, USA) connected to a 2-channel Supermax electrometer (Standard Imaging). The readings from each channel were used to correct for stem effects according to procedures detailed by Guillot et al. (2011). The in-house PSD system was composed of a 3-mm-long BCF-60 scintillating fiber coupled to a 15-m-long optical fiber (GH-4001, Mitsubishi, Tokyo, Japan) connected to a spectrometry system consisting of a Shamrock spectrograph (Andor, Belfast, Ireland) and a charge-coupled device camera (DU-420, Andor). The in-house system allowed us to ascertain the spectral response of the incoming light, kept the photodetection system outside of the room, and enabled us to use the hyperspectral approach for stem-effect removal, following the method previously described by Therriault-Proulx et al. (2013). The same spectrometry system used with the in-house PSD was also used with a bare fiber to study the stem effect. The PSDs' responses as a function of magnetic field strength incorporated measurements of signal intensity, spectral signature, and stem-effect-corrected signal.

3. Results

3.1. *Light intensity*

The light intensity as a function of magnetic field strength for both channels of the commercial (W1) PSD, the in-house PSD, and the bare fiber is shown in Fig. 2. Responses were normalized to the response without a magnetic field (B = 0 T). In all cases, light intensity increased as the magnetic field strength increased; this effect was particularly noticeable for the bare fiber.

3.2. *Spectral study*

Fig. 3 shows the measured spectra with a 1.5-T magnetic field and without a magnetic field (B = 0 T), normalized to the area under the curve. From the shapes of the spectra, it can be inferred that the different components of the signal were affected differently by the magnetic field. The spectral signatures of the components of the signal (scintillation, Cerenkov stem effect, and fluorescence stem effect) were also obtained and are shown in Fig. 3. These signatures were used to implement the hyperspectral approach for stem effect correction, which accounted for both Cerenkov and fluorescence effects.

3.3. *Stem-effect-corrected measurements*

Fig. 4 shows the stem-effect corrected response of the commercial and in-house PSDs, determined using the 2-channel and hyperspectral approaches, respectively. The behavior of the detectors in response to the magnetic field strength was similar. Most of the increase in light intensity shown in Fig. 2 was corrected for, with a remaining difference of about (2.4% ± 0.3%) for the commercial PSD and (2.4% ± 0.1%) for the in-house PSD. Possible causes for this difference are discussed in Section 4.

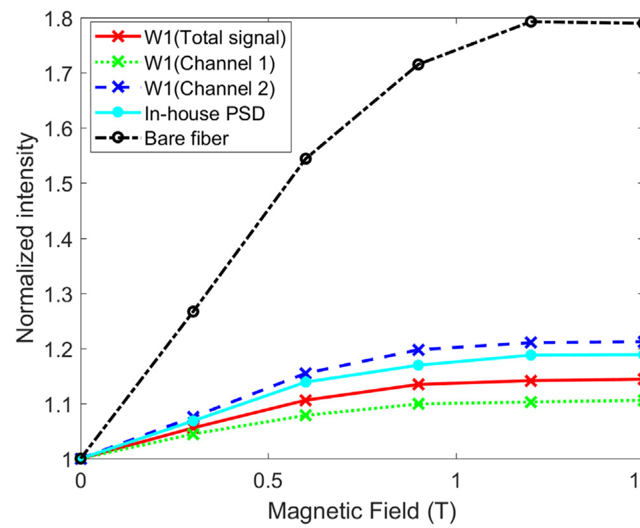

Fig. 2. Light intensity as a function of magnetic field strength. Responses were normalized to those obtained during magnetic-field-free (B = 0 T) irradiations.

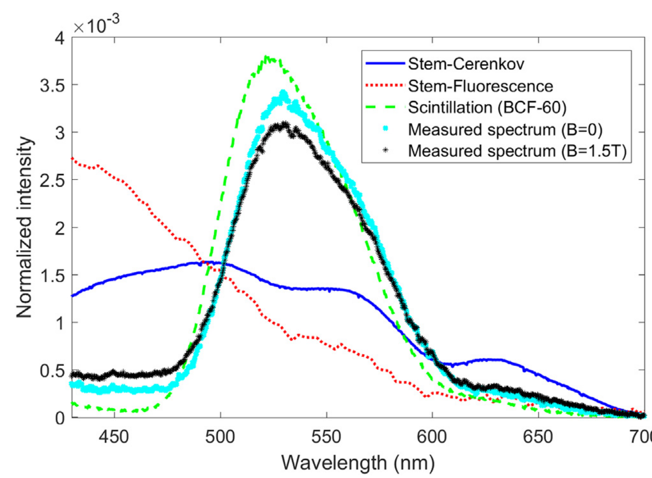

Fig. 3. Optical spectrum response of the in-house PSD with (B = 1.5 T) and without (B = 0 T) a magnetic field. The scintillation and stem effect signatures from both Cerenkov and fluorescence are also shown.