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Ionization Quenching Correction of Volumetric Organic Scintillators for use in Proton Therapy

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Ionization quenching is a known phenomenon that causes non-linear scintillation response to heavy charged particles with high ionizing radiation density such as protons. In this work, we compare quenching correction models and their application to volumetric scintillators. We have investigated the feasibility of a volumetric organic liquid scintillator detector to verify and characterize clinical proton beams and intensity modulated proton therapy (IMPT) plans for cancer treatment [1], [2]. However, to fully achieve the potential of this concept, the ionization quenching in scintillators must be addressed to convert the 3D light distribution to its corresponding dose distribution. For the purpose of testing various semi-empirical quenching correction models, we have exposed our detector to five different proton beam energies produced by the synchrotron at M.D. Anderson Cancer Center (85.6, 100.9, 124, 144.9, and 161.6 MeV). We used Monte Carlo simulations to obtain the dose and linear energy transfer (LET) for these beams. The models we focused on are the Birks' formula and its variations, and energy density by secondary electrons (EDSE) model [3]. Birks'formula is a semi-empirical unimolecular model that relates the scintillation rate to specific energy loss. Other models include bimolecular quenching and a differentiation between singlet and triplet states. The EDSE model relates the light production inside a scintillator material to the energy distribution of secondary electrons produced along the ion tracks. Regions close to the particle track are of interest to understand ionization quenching. All models reasonably fit the measurements within 5%. We will discuss the level of agreement between the different models and Monte Carlo simulations. Furthermore, we will discuss quenching model modifications that are needed to describe the light distribution for a range of clinically significant proton energies (70-220 MeV). It will be important to understand the quenching mechanism and the limitations of semi-empirical models for our 3D scintillator detector to reach the clinically acceptable 3% dose accuracy.

[1] S. Beddar et al., "Exploration of the potential of liquid scintillators for real-time 3D dosimetry of intensity modulated proton beams,"Med. Phys., vol. 36, no. 5, pp. 1736–1743, May 2009.

[2] C. Hui, D. Robertson, and S. Beddar, "3D reconstruction of scintillation light emission from proton pencil beams using limited viewing angles—a simulation study,"Phys. Med. Biol., vol. 59, no. 16, p. 4477, 2014.

[3] A. Menchaca-Rocha, "A simplified scintillator-response formula for multiple-ion energy calibrations," Nucl. Instrum. Methods Phys. Res. Sect. Accel. Spectrometers Detect. Assoc. Equip., vol. 602, no. 2, pp. 421–424, Apr. 2009.

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