Ionization quenching in scintillators used for dosimetry of mixed particle fields

Ionization quenching in ion beam dosimetry is often related to the fluence- or dose-averaged linear energy transfer (LET). Both quantities are however averaged over a wide LET range and a mixed field of primary and secondary ions. We propose a novel method to correct the quenched luminescence in scintillators exposed to ion beams. The method uses the energy spectrum of the primaries and accounts for the varying quenched luminescence in heavy, secondary ion tracks through amorphous track structure theory. The new method is assessed against more traditional approaches by correcting the quenched luminescence response from the BCF-12, BCF-60, and 81-0084 plastic scintillators exposed to a 100 MeV pristine proton beam in order to compare the effects of the averaged LET quantities and the secondary ions. Calculations and measurements show that primary protons constitute more than 92 % of the energy deposition but account for more than 95 % of the luminescence signal in the scintillators. The quenching corrected luminescence signal is in better agreement with the dose measurement when the secondary particles are taken into account. The Birks model provided the overall best quenching corrections, when the quenching corrected signal is adjusted for the number of free model parameters. The quenching parameter $k_B$ for the BCF-12 and BCF-60 scintillators is in agreement with literature values and was found to be $k_B = (10.6\pm0.1) \times 10^{-2} \mu$m/keV$^{-1}$ for the 81-0084 scintillator. Finally, a fluence threshold for the 100 MeV proton beam was calculated to be of the order of $10^{10} \text{ cm}^{-2}$, corresponding to 110 Gy, above which the quenching increases non-linearly and the Birks model no longer is applicable.