Characterization of changes in scintillation spectrum of plastic scintillator dosimeters after radiation damage under Ultra-High Dose Rate 200 MeV electrons at CLEAR

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Introduction

- Very High Energy Electrons (VHEEs) (>100 MeV) can penetrate deep into tissue and are less sensitive to inhomogeneities than protons[1]
- VHEEs can be delivered at ultra-high dose rates (UHDR) for FLASH radiotherapy (RT)[1,2]
- The FLASH effect is the reduction of normal tissue toxicity at UHDR[3]
- Plastic scintillator dosimeters (PSDs) are a potential alternative to standard dosimeters like ionization chambers or films that have limited application in UHDR VHEE beams[4-7]

Purpose

To characterize the short and long-term effects of radiation damage on the scintillation spectrum of plastic scintillator dosimeters (PSDs) exposed to UHDR VHEEs at the CERN Linear Electron Accelerator for Research (CLEAR) facility.

Method

Dosimetry System

- PSDs made with 0.5x0.5 mm^2 scintillators coupled to 30 m PMMA optical fiber
- Connected to Hyperscint RP-100 dosimetry system (Medscint, Québec)
- BCF12 (polystyrene based, 435 nm emission peak) and proprietary Medscint scintillator (polyvinyltoluene based, 425 nm emission peak) were used

CLEAR Beamline

- 200 MeV electrons
- Charge per train of ~0.2-85 nC
- Train repetition frequency of 0.83 Hz to 10 Hz
- Delivered charge per train measured by an integrating current transformer (ICT)
- Gaussian beam size of ~4 mm 1σ obtained with quadrupoles and a scatterer

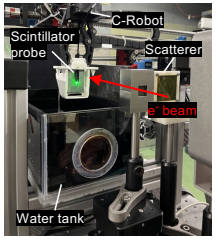

Figure 1. Measurements set up at the end of the beam line.

Radiation Damage Study

- Damage to probes with irradiations of ~18 Gy/train at 0.83 Hz frequency until ~2.5 kGy total dose
- PSD output linearity measured in between irradiations from ~4 to 60 Gy/train (~6×10^7 to 9×10^7 Gy/s for a 66 ns train length)
- Total doses-to-water of 26.2 kGy (BCF12) and 13.8 kGy (Medscint)
- Initial spectra and spectra after 6 months rest measured with kV and MV photon beams (TrueBeam, Varian)

Results

Spectral changes

- Gradual spectral changes with increasing total absorbed dose for both PSDs, (see **Figure 2** and **3**): flattening at the peak of the spectrum and broadening towards longer, greener wavelengths
- Spectral peak positions shifted by +3 nm (±2 nm) after final CLEAR irradiation
- At half maximum, final spectra were broadened towards longer wavelengths by ~35 % for BCF12 and ~24 % for Medscint compared to initial spectra (see **Figure 3**)

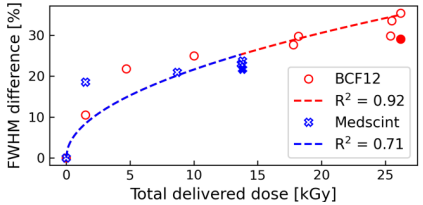

Figure 3. Percentage difference of full width at half maximum (FWHM) of spectra measured at CLEAR for both PSDs compared to the initial spectra. Recovery spectra after 6 months rest is also shown with filled markers.

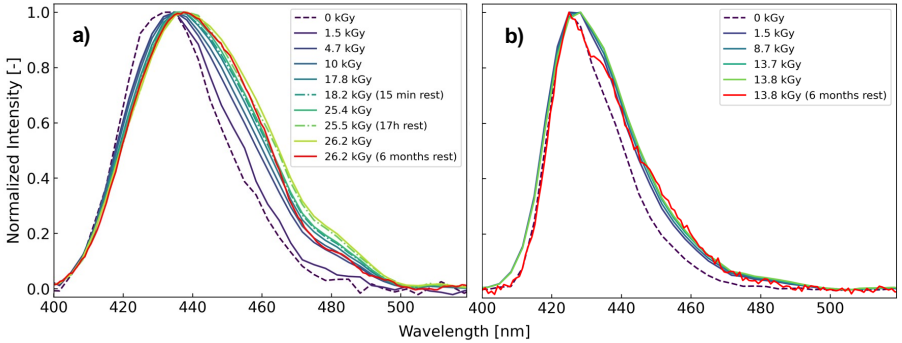

Figure 2. Spectra of a) BCF12 and b) Medscint PSDs with increasing total delivered dose measured at CLEAR, compared to the initial spectra (dashed line) and the recovery spectra after 6 months rest (red line) measured with a kV photon beam.

Recovery

- No short-term recovery of spectral changes observed after either 15 min or 17h rest.
- Peak positions shifted to +(2.5 ± 0.5) nm for BCF12 and (0 ± 0.5) nm for Medscint after 6 months compared to initial spectra
- FWHM of recovery spectra broader by ~29 % (BCF12) and ~22 % (Medscint) compared to initial spectra

Output changes

- Scintillator output decreased by 1.21 %/kGy for BCF12 and 1.51 %/kGy for Medscint during CLEAR irradiations
- BCF12 output recovered up to 99.6 % of its output after 15 minutes rest at 18 kGy total delivered dose
- Scintillator output recovered up to 79 % and 89 % after 4 months rest, then up to 93 % and 98 % after 6 months rest, for BCF12 and Medscint respectively

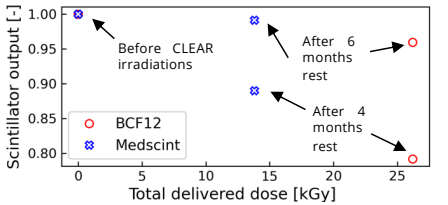

Figure 4. Scintillator output (signal intensity at emission peak) measured before and after CLEAR irradiations with a MV photon beam.

Conclusion

- Lack of complete long-term spectral recovery suggests irreparable damage to both scintillators.
- Long-term recovery of output suggests PSDs could be recalibrated for further use after a rest period
- This work is a critical step toward the use of plastic scintillators for dosimetry in extreme radiotherapy conditions, such as in UHDR VHEE beams.

References

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