CdTe-based semiconductor detector for ‘correction-less’ small-field dosimetry

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INTRODUCTION

The use of small fields in radiation therapy has recently increased substantially, being employed in stereotactic treatments, and large uniform or non-uniform fields composed of small fields, as in IMRT technique. Small-field dosimetry is error-prone due to inherently present electronic disequilibrium condition and volume averaging effects. Interpretation of small-filed measurements with almost any detector typically requires use of correction factors [1], which depend on the detector construction and measurement conditions.

A recently proposed approach to design of a correction-less detector [2,3] employs mass density as the principal determinant of detector water-equivalence. Since photons with energies in the radiation therapy range interact primarily via Compton scattering, dependent on electron density, a simple mass-density matching may not be well applicable to detectors with electron density significantly different from that of water.

AIM

The purpose of this work is to evaluate the performance of a semiconductor electron-density compensated detector to achieve ‘correction-less’ small-field dosimetry. We evaluated the approach for a range of geometric parameters utilizing Cadmium Telluride (CdTe) and traditional silicon (Si) diode sensitive media.

METHOD

Monte Carlo simulations (MCNP5 package [5]) were conducted to optimize dosimeter designs, combining a semiconductor sensitive volume with an air gap, following a mass-density matching approach for the whole detector.

Si and CdTe of 3, 30 and 300µm thickness were modeled in combination with air gaps varying from 0.4 to 4 mm, and surrounding PMMA layer that extended at least 1 mm beyond the detector in every direction. Detectors were irradiated with 6MV and 6FFF photons, representative of Varian TrueBeam linac sources. Energy deposition was scored with pulse-height tally in semiconductor and equivalent water with air gap volumes. In all the simulations, we set cutoff energies to 0.01 MeV for electrons and photons, with coherent, photonuclear, and Doppler interactions turned off, but Bremsstrahlung was included.

Energy deposited in different thickness of CdTe with various air-gap was compared with that of Si. Changes in electron energy spectra at the interfaces between air, semiconductor, and PMMA were investigated. Energy deposition calculated in the detector voxels were also compared to those calculated for a voxel of water at the same location, to establish values for the dose-to-detector-in-water to dose-to water ratio.

RESULTS

Figure 1 shows schematic diagram of our modeled detector with an air-gap thickness ‘t’ from 0.4 to 4 mm. Three thicknesses d=3, 30, 300 µm for Si and CdTe have been studied. The source model spectra for TrueBeam linac 6x and 6FFF beams are presented in Figure 2.

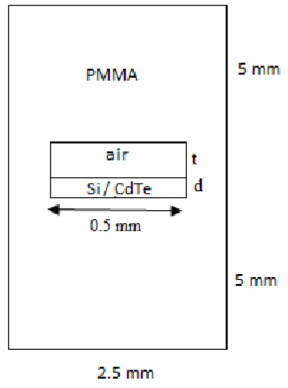

Fig1. Schematic representation of modeled detector design (not to scale)

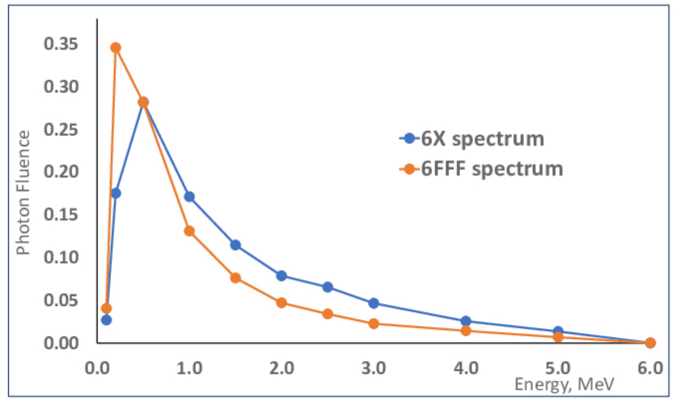

Fig2. Energy spectra of 6 MV and 6FFF beams

Table: Examples of density-matched detector configurations and corresponding energy deposition “signal” scored within the sensitive volume of the detector and equivalent water volume

Spectrum	6FFF		
Configuration	Semiconductor signal	Water + air gap signal	Ratio
CdTe-300µ + 1.45mm	1.10E-04	3.38E-05	3.26E+00
Si-300µ + 0.4mm	1.29E-05	1.37E-05	9.43E-01

Spectrum	6X		
Configuration	Semiconductor signal	Water + air gap signal	Ratio
CdTe-300µ + 1.45mm	8.42E-05	4.36E-05	1.93E+00
Si-300µ + 0.4mm	1.61E-05	1.77E-05	9.10E-01

Results for configurations closest density-matched for 300µm thick semiconductor layers are shown in the table. While obtained signal ratios are close to 1 for Si, they are significantly deviating from unity for CdTe, proving inapplicability of the approach for high-Z detectors.

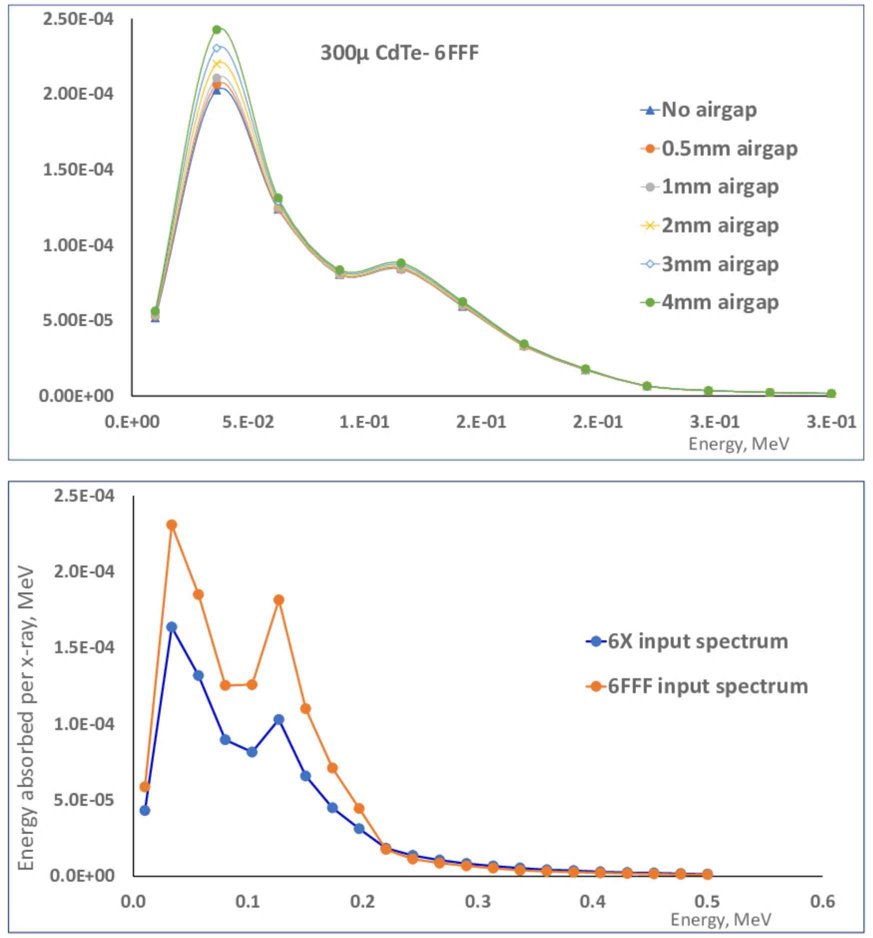

Fig 3. Absorbed energy spectra per incoming photon for 300 µm thick CdTe detector for a) airgap of varying thickness under 6FFF beam and b) 1.44mm density-matched air gap for 6X vs 6FFF beam sources.

For 3, 30, and 300µm thick semiconductor layers the density-matched air gaps are 0.0145, 0.145, 1.45mm for CdTe and 0.004, 0.04, and 0.4mm for Si. These configurations resulted in close water signal matching for Si, but deviated by a factor of 2 to 3 for CdTe. Since the electron density rather than mass-density governs photon interactions under radiation therapy energy range, a more sophisticated matching strategy should be employed for high atomic number solid state detectors, such as CdTe. Details of the input spectra even as close as 6MV and 6FFF further complicate density-matching.

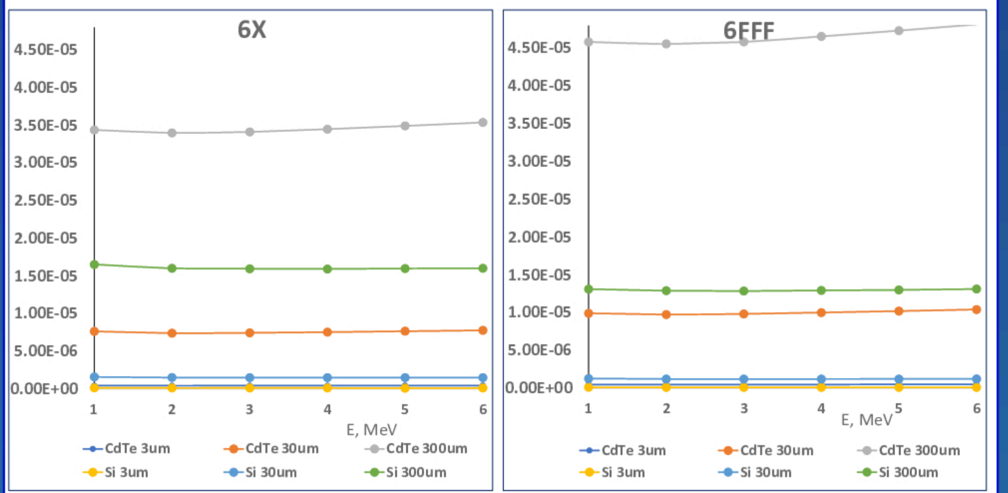

Fig 4. Energy deposition per incoming particle in 300µm thick CdTe under 6FFF and 6MV photon beams

CONCLUSIONS

The main focus of this study was to explore the mass density matching approach to a CdTe-based solid-state detector with high effective Z=50 and compare it to that of silicon diode. Since photons with energies in the radiation therapy range interact primarily via Compton scattering, dependent on electron density (~ρ*Z/A), a simple mass-density matching may not be well applicable to detectors with electron density significantly different from that of water. Combining a high-density solid state detector and air gaps to achieve mass-density matching to water typically results in a detector with low sensitivity, problematic for small-filed dosimetry. Substituting standard Si diode with CdTe offers a significant increase in detector sensitivity, but requires additional considerations for correction-less design, where Monte Carlo method is uniquely suitable for a prototype development.

REFERENCES

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