Monochromatic Beam Characterization for K-edge Capture Dosimetry and Radiotherapy at CAMD

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Purpose: Dosimetry and dose calculation for monochromatic, keV photon beams, such as those used for K-edge capture radiotherapy, requires knowledge of beam characteristics, particularly for Monte Carlo simulations providing dose per incident particle. This study characterized a synchrotron-generated beam, measuring photon energy, spatial and angular distribution, and fluence.

Method and Materials: X-rays were produced at the LSU CAMD synchrotron by passing a 1.3 GeV electron beam (200-mA maximum) through a 7-T superconducting wiggler. The resulting polychromatic beam passed through a W-B4C double multilayer monochromator generating a ~0.1x2.8-cm2 beam. Photon spatial distribution and beam divergence were measured using radiochromic film (GAFCHROMIC EBT). Incident beam energy and fluence were determined from spectra of photons Compton scattered at 15-60 degrees by thin polyethylene targets and measured with a 1-mm thick, 2.54-cm diameter NaI(Tl) scintillation detector. Fluence was calculated from net peak counts by applying the Klein-Nishina collisional cross section for polarized radiation and fitting percent polarization to results at 2-4 spectrometer angles. Energy was also determined via Si640c x-ray powder diffraction and monochromator k-edge absorption calibrations. Dose from a 2.5x2.8-cm2 broad-beam, produced via oscillation of phantom and dosimeter by a triangular waveform, was measured versus depth in a polymethylmethacrylate (PMMA) phantom with a 0.23-cm3 Farmer-type ionization chamber. Results were compared with MCNP5 simulations of dose distribution in a PMMA phantom using beam characterization data.

Results: Photon distribution was uniform vertically across well-collimated beams, but varied by as much as 16% per centimeter horizontally. Beam divergence was greater vertically than horizontally with respective virtual source-to-surface distances of approximately 3.8 and 15.7 meters. Energy measurements agreed to within 0.5 keV for 15-40 keV beams. Incident fluence rates for a 35-keV beam at 100 mA synchrotron ring current ranged from 9.58+/-0.08x10^10 to 2.36+/-0.05x10^11 photons·cm-2·s-1 with high polarization (97%) in the plane of the synchrotron. MCNP5-simulated dose distributions in the PMMA phantom, converted using measured fluences, agreed well with ion chamber dose measurements.

Conclusion: The demonstrated methods provided practical characterization of the 35-keV beam, allowing subsequent dose calculations using MCNP5 Monte Carlo simulations that are needed for planning future animal radiotherapy studies.

KEYWORDS: K-edge capture radiotherapy, monochromatic x-rays, beam characterization