Monte Carlo Modeling of the Xoft Axxent X-Ray Source

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Introduction

Xoft Inc.[1] has recently developed a miniature electronic x-ray source for brachytherapy. The source is able to deliver a dose rate comparable to ^{192}Ir 1 cm from the source, while reducing radiation safety concerns and shielding requirements due to the low photon energy and rapid fall off of dose.

The new EGSnrc user-code BrachyDose[2], has been employed to calculate the photon energy spectrum and TG-43 dosimetry parameters for the source.

BrachyDose has also been used to investigate how dose distributions calculated using the TG-43 dosimetry formalism may differ from a MC calculated dose distribution when full scatter conditions are not met, or dose is calculated in breast tissue instead of water.

Monte Carlo Calculations

Dose calculations were performed with BrachyDose[2], a new EGSnrc[3] usercode for rapid brachytherapy calculations. The source geometry (**figure 1**) was modeled using Yegin's general purpose geometry package[4] for EGSnrc. Electron transport was done within the source only and photons were transported down to 1 keV everywhere. Dose to medium was scored by calculating the collision kerma using a tracklength estimator of fluence and mass energy absorption coefficients calculated using the EGSnrc user code g. All photon cross sections were taken from the XCOM database. Dosimetry parameter calculations were done in a 30x30x30 cm water phantom with rectilinear voxels of size 1x1x1 mm^3.

All calculations were done with the source operating at 50 keV.

Energy Spectrum

The in-air photon energy spectrum was calculated at a distance of 178 cm from the source using the EGSnrc user-codes BrachyDose and FLURZnrc.

The calculated spectrum for the source is shown in **figure 2** alongside measurements made at NIST using HPGe detectors (Rivard et al [5]). Energy bin widths are 0.06 keV and 0.125 keV for the measured and calculated spectra, respectively.

Simulation of electron impact ionization (eii) is a recent addition to EGSnrc and is based on an *ab initio* theory by Kawrakaw of N.R.C., Ottawa, Canada. The inset plot in **figure 2** shows calculations done with and without eii turned on demonstrating that peaks below 12 keV are almost entirely attributed to fluorescent photons from relaxation following eii events.

Agreement between calculated and measured photon spectra is very good over the full range of energies except for a slight energy offset in the lowest energy peaks due to EGSnrc's averaging of M and N shell energies

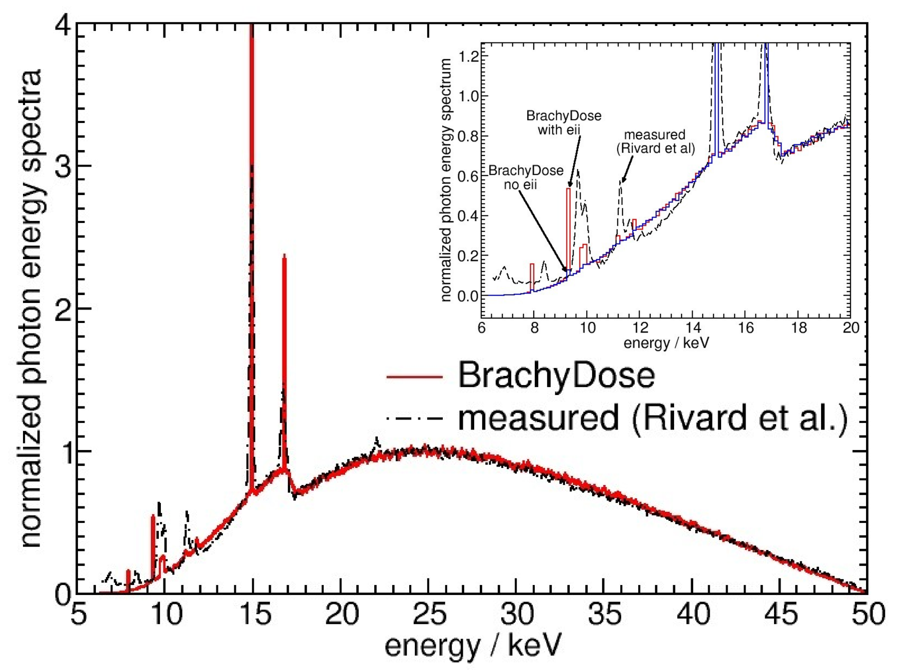

Figure 2: In-Air Photon Energy Spectra

M.C. calculated photon energy spectrum 178 cm from the source. The inset figure shows the effect of electron impact ionization on calculated spectra. Also shown is a spectrum measured using HPGe detectors at NIST (Rivard et al[5]).

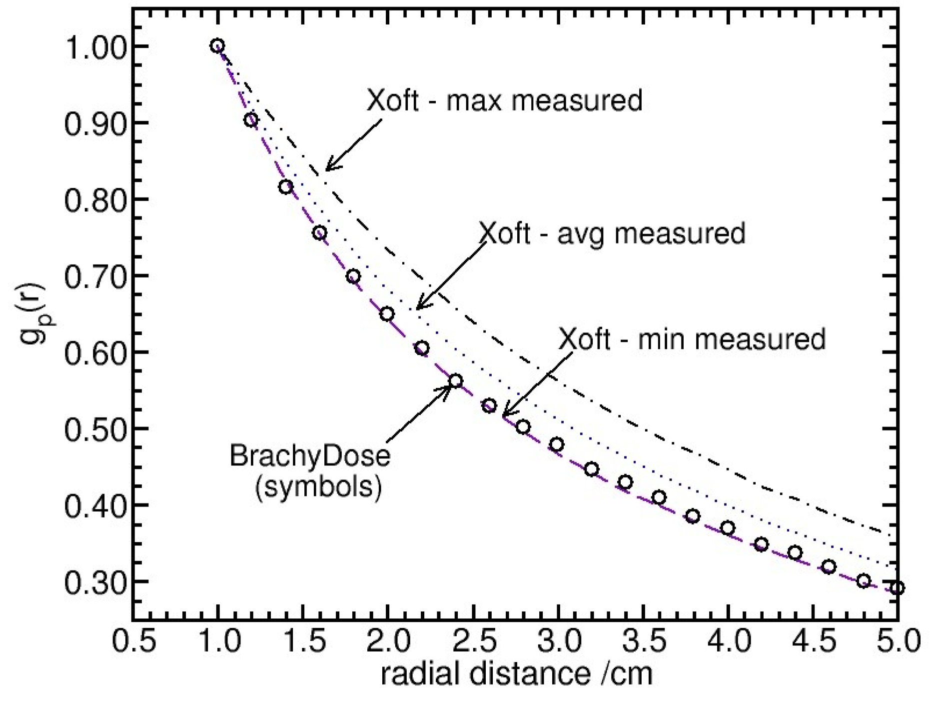

Figure 3: Radial Dose Function

Calculated and measured radial dose functions for the Xoft source operating at 50 kV.

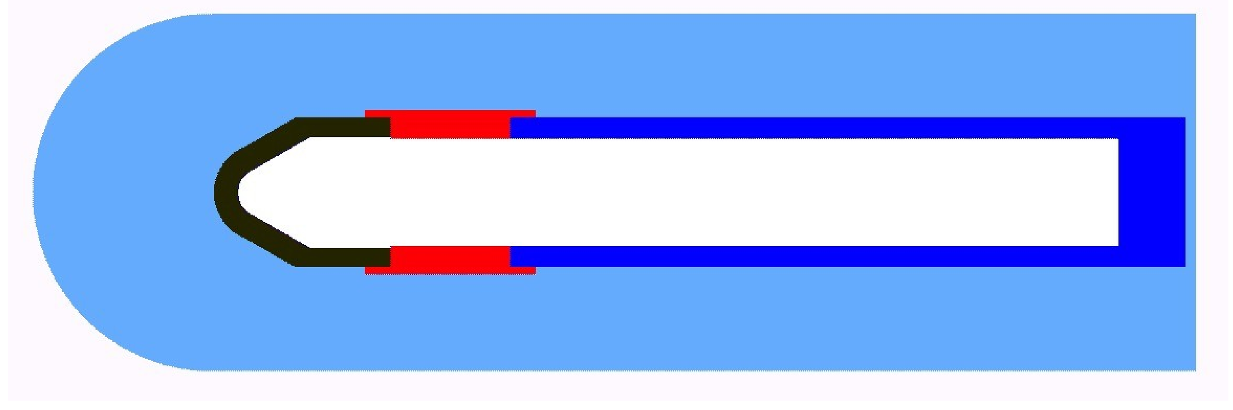

Fig 1: The Xoft Axxent Source

The Xoft Axxent source consists of a source of electrons (filament) in an evacuated tube and a thin target coating on the surface of the anode. The anode is made up of a conical section with a spherical tip. The whole source is surrounded by a water filled cooling sleeve. The source can operate at up to 50 kV with tube currents of up to 300 μA.

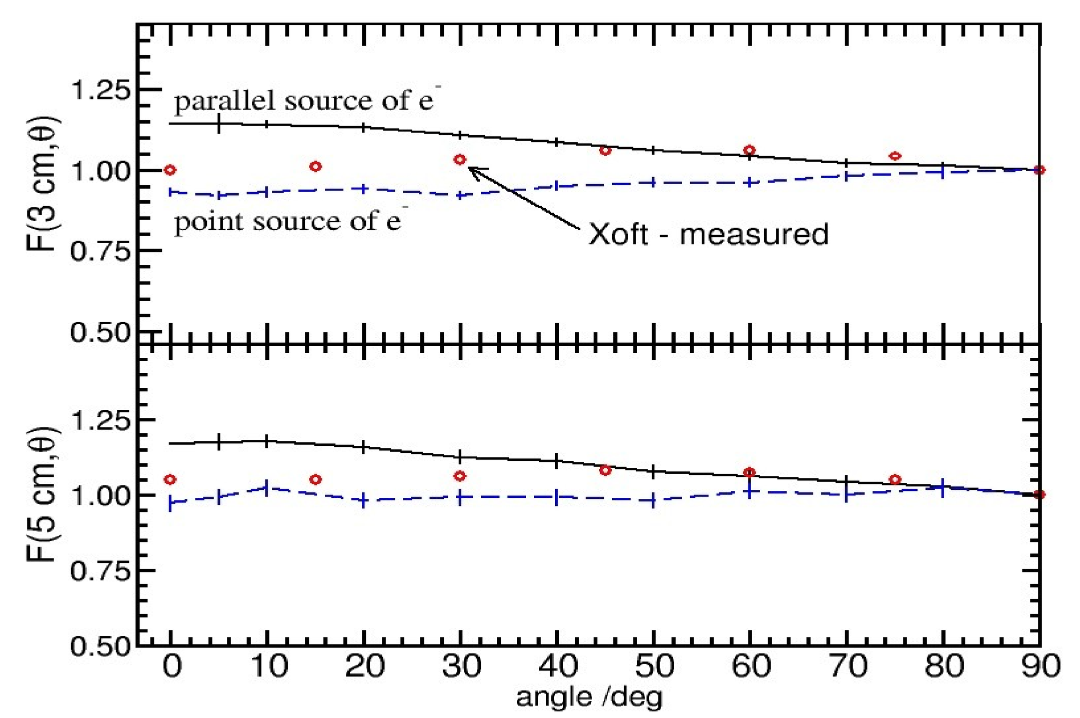

Figure 4: Anisotropy Function

Anisotropy functions calculated* with a parallel beam of electrons filling the tube, and with a point source of electrons located near the anode. F(r,0°) is ~20% higher for the calculations done using a point source of electrons.

*Note: Anisotropy function calculations were made with an approximate source geometry.

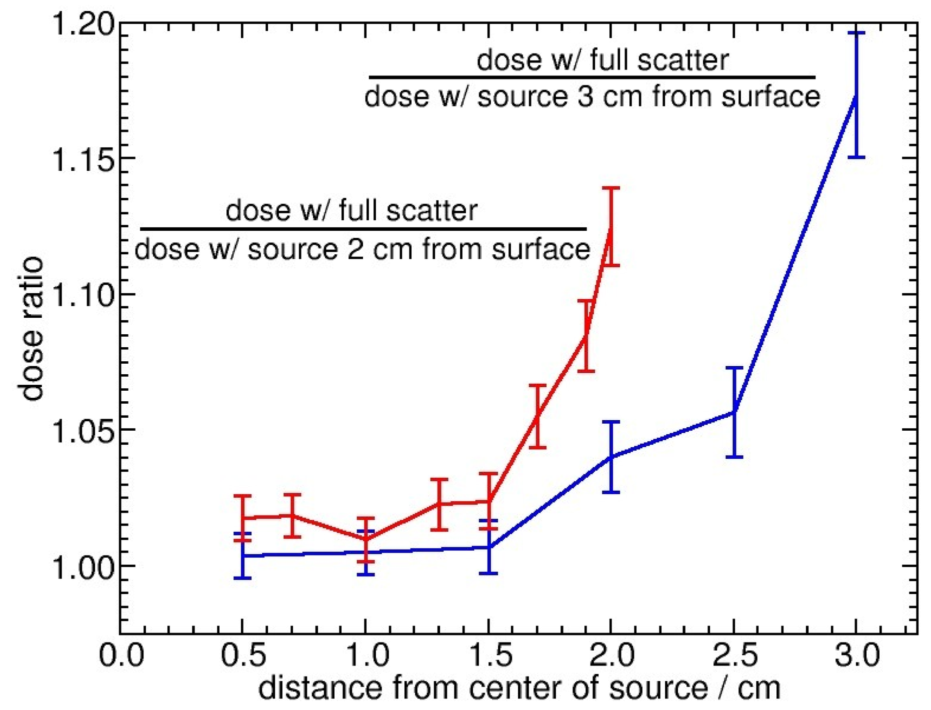

Figure 5: Effect of Scatter on Dose Calculations

A dose calculation assuming a full scattering medium overestimates the dose near the surface by greater than 15% when the source is placed 3 cm from the surface of a water phantom.

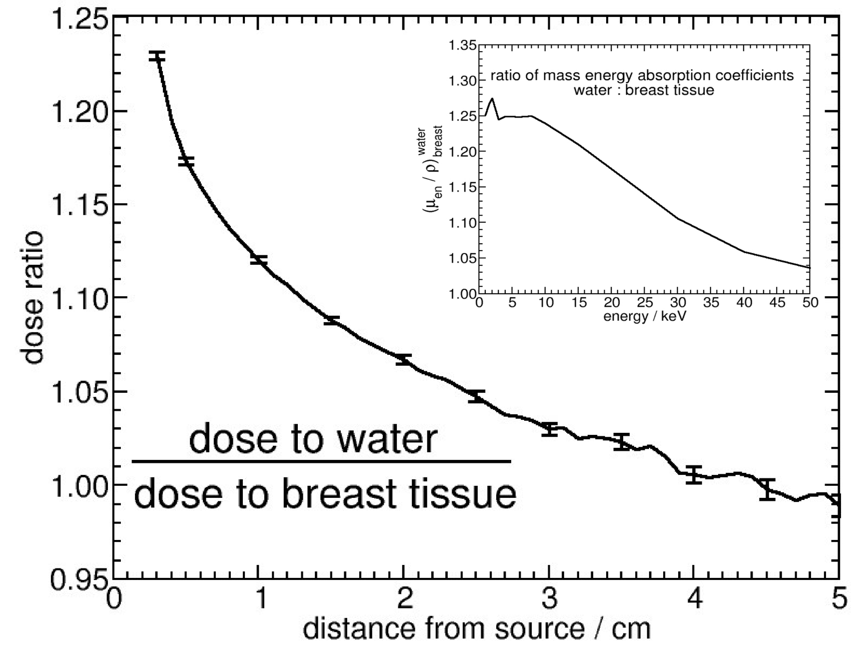

Figure 6: Dose in Breast Tissue vs. Water

Ratio of dose in water to dose in breast tissue (ICRU 44) as a function of distance from the source. Dose calculated in water overestimates the dose to breast tissue by 11%, 1 cm from the source and underestimates the dose by 1 % at 5 cm from the source.

TG-43 Dosimetry Parameters

Figure 3 shows calculated radial dose function values for the Xoft source. The calculated radial dose function shows good agreement with the least penetrating source measured by Rivard et al[5].

Figure 4 shows anisotropy function calculated* both with a parallel beam of electrons filling the tube and a point source of electrons located close to the anode. The anisotropy function , F(r,0°) is ~20% lower for the point source than it is for the parallel beam.

*Note: Anisotropy function calculations were made with an approximate source geometry.

M.C. for Treatment Planning

TG-43 dosimetry parameters are calculated in homogenous water phantoms with a full scattering medium . Therefore, dose distributions calculated using the TG-43 formalism may not accurately reflect the real dose distribution in a patient when full scatter conditions are not met or when the tissue is not well approximated by water.

Effect of Scatter: To investigate the effect of scatter on dose, calculations were done with the source placed 2 or 3 cm from the surface of a water phantom. Calculations made assuming full scatter conditions over estimate the dose 2 cm from the source by ~17% when compared to calculations with the source located 3 cm from the surface of a phantom (**figure 5**). Since full scatter conditions may not always exist during a treatment, dose calculations made using the TG-43 dosimetry protocol may significantly over estimate the dose delivered to a patient.

Effect of Tissue: When compared with dose to water, dose calculated in breast tissue is 12% lower and 1% higher at distances of 1 cm and 5 cm respectively. These distance dependent differences are the result of differences in the mass energy absorption coefficients of water and breast tissue. Since the composition of breast tissue is significantly different from water, calculations using the TG-43 formalism may lead to significant errors in estimating the dose delivered to a patient.

Conclusions

Monte Carlo calculations of photon-energy spectra and TG-43 dosimetry parameters have been calculated for Xoft Inc.'s miniature x-ray source for brachytherapy.

The calculated 50 kV photon energy spectrum shows very good agreement with the measured spectrum. Inclusion of electron impact ionization in EGSnrc results in better agreement between calculations and measurements (**figure 2**).

TG-43 dosimetry parameters show good agreement with measurements made by Rivard et al.[5] It was observed that the angle of incidence of electrons on the target had a significant impact on the calculated anisotropy function.

MC calculated dose distributions accounting for tissue type and lack of scatter due to patient geometry may differ significantly from those calculated using the TG-43 dosimetry protocol. Improved accuracy in dose calculations by using MC methods in treatment planning may lead to better understanding of treatment outcomes.

References

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2. I. Kawrakaw & D.W.O. Rogers, The EGSnrc Code System: Monte Carlo simulation of electron and photon transport, PIRS-701, N.R.C. Ottawa Canada, (2000).
3. G. Yegin & D.W.O Rogers, A fast Monte Carlo code for multi-seed brachytherapy treatments including interseed effects, Med. Phys **31**, 1771 (abs) (2004).
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5. Rivard et al (Med. Phys. submitted)

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