Air-kerma strength determination of a miniature x-ray source for brachytherapy applications

Stephen D. Davis

Supervisor: Larry A. DeWerd
University of Wisconsin, Madison, WI

June 2009

A miniature x-ray source has been developed by Xoft Inc. for high dose-rate brachytherapy treatments. The source is contained in a 5.4 mm diameter water-cooling catheter. The source voltage can be adjusted from 40 kV to 50 kV and the beam current is adjustable up to 300 μA. Electrons are accelerated toward a tungsten-coated anode to produce a lightly-filtered bremsstrahlung photon spectrum. The sources were initially used for early-stage breast cancer treatment using a balloon applicator. More recently, Xoft Inc. has developed vaginal and surface applicators.

The miniature x-ray sources have been characterized using a modification of the American Association of Physicists in Medicine Task Group No. 43 formalism normally used for radioactive brachytherapy sources. Primary measurements of air kerma were performed using free-air ionization chambers at the University of Wisconsin (UW) and the National Institute of Standards and Technology (NIST). The measurements at UW were used to calibrate a well-type ionization chamber for clinical verification of source strength.

Accurate knowledge of the emitted photon spectrum was necessary to calculate the corrections required to determine air-kerma strength, defined *in vacuo*. Theoretical predictions of the photon spectrum were calculated using three separate Monte Carlo codes: MCNP5, EGSnrc, and PENELOPE. Each code used different implementations of the underlying radiological physics. Benchmark studies were performed to investigate these differences in detail. The most important variation among the codes was found to be the calculation of fluorescence photon production following electron-induced vacancies in the L shell of tungsten atoms. The low-energy tungsten L-shell fluorescence photons have little clinical significance at the treatment distance, but could have a large impact on air-kerma measurements.

Calculated photon spectra were compared to spectra measured with high-purity germanium spectroscopy systems at both UW and NIST. The effects of escaped germanium fluorescence photons and Compton-scattered photons were taken into account for the UW measurements. The photon spectrum calculated using the PENELOPE Monte Carlo code had the best agreement with the spectrum measured at NIST. Corrections were applied to the free-air chamber measurements to arrive at an air-kerma strength determination for the miniature x-ray sources.