Design of a medium-energy free-air ionization chamber

Emily J King, Jennifer L Hull, Larry A DeWerd
University of Wisconsin
Medical Radiation Research Center

Objective: X-rays ranging from 50 - 300 kV are often used for radiobiology experiments. Often, irradiators designed to produce these medium range x-rays for these experiments are not well characterized or calibrated. Free-air ionization chambers (FAC) are absolute measurement devices that measure exposure directly by collecting ions produced by the electrons resulting from x-ray interactions in a known mass of air and can be used as the standard for X-rays. The purpose of this work was to design and build a FAC for the medium X-ray energy range to be used as a calibration tool and for characterizing these types of x-ray sources. The design is based on the UW Attix FAC[1] and the FAC at the National Radiation Standard Laboratory (NRSL, Taiwan)[2], both which employ a cylindrical chamber of variable length. The variable chamber length allows for the effects of electric field distortion at the ends of the chamber to be removed so electric field uniformity and plate alignment does not need to be maintained. This work will outline the design phase of this project.

Methods: The design of the FAC system was made through collaboration with staff mechanical engineers in the UWMRRC. The size of the FAC, a diameter of 30 cm, was based on Attix's advice in his proposed FAC design and was confirmed through the use of a model in the MCNP6 (Monte Carlo N-Particle 6, Los Alamos, New Mexico) transport code and an energy deposition tally in air. Correction factors were calculated using the EGSnrc (Electron Gamma Shower, National Research Council of Canada) application egs_fac, which is a self-consistent approach for calculating correction factors for scatter, electron loss, and aperture leakage. A shadow correction factor, which corrects for electrons striking the collecting rod before depositing their energy, was calculated using egs_fac as well. The correction factors were determined using monoenergetic photons and are convolved with the X-ray spectrum of the beams or sources being used. The results were validated by comparing the correction factors to the NRSL's correction factors for a FAC of similar size and design. Tolerance testing was done using egs_fac and electric field modeling was done with COMSOL Multiphysics (Stockholm, Sweden). The design was then created using SolidWorks (Waltham, Massachusetts).

Results: A 30 cm diameter collecting volume for the FAC was determined to be sufficient in collecting the electrons produced by photons up to 300 keV (Figure 1). The walls will contribute to scatter and electron loss but will be corrected by correction factors.

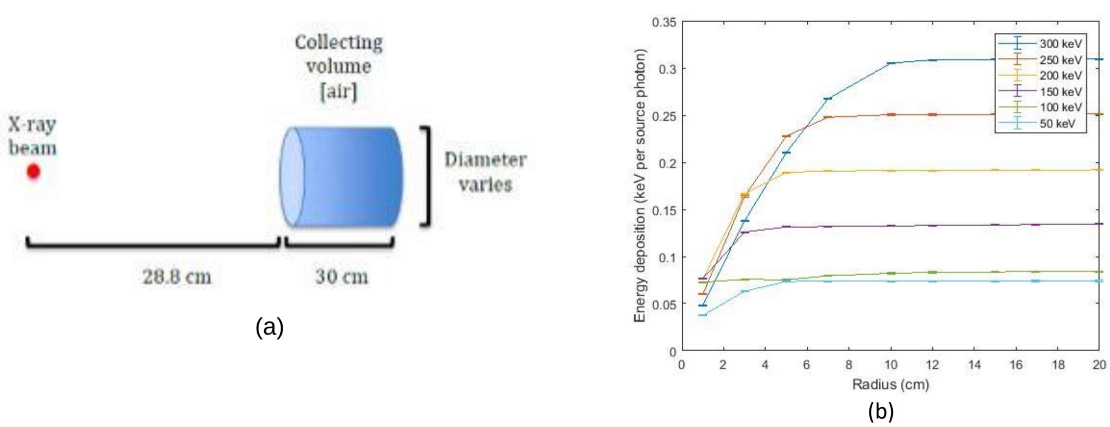


Figure 1: (a) Monte Carlo setup for determining size of FAC. (b) Energy deposited in different radii collecting volumes. Curves level off once all energy is deposited in the collecting volume.

Figure 2 shows the schematic of the FAC in its extended position. The design has three aluminum cylinders: a fixed center cylinder and two cylinders on either end that are connected to motor stages and limit switches. These cylinders will be at high voltage and the aluminum collecting rod will be at ground to create an electric field. The collecting rod passes through an insulator in the back end of the chamber and connects to an electrometer via a coaxial cable. The aperture will be made of tungsten alloy and machined to a diameter of 1 cm. The lead shielding is present to avoid in-scattered external photons from contributing to the signal.

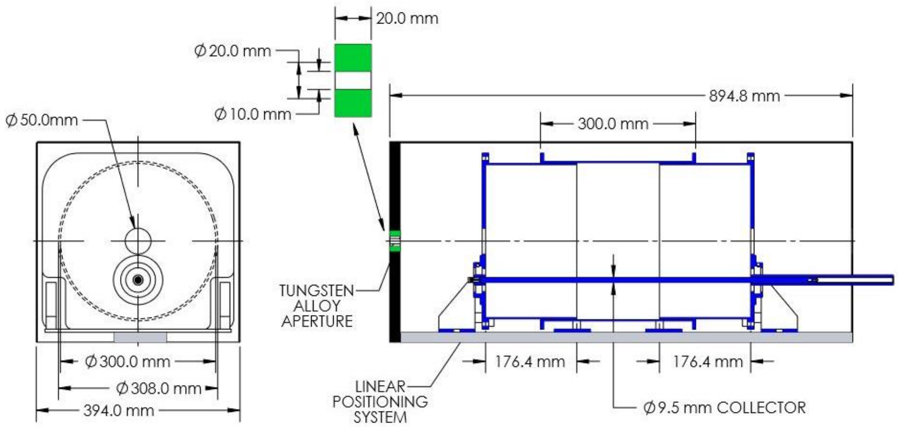
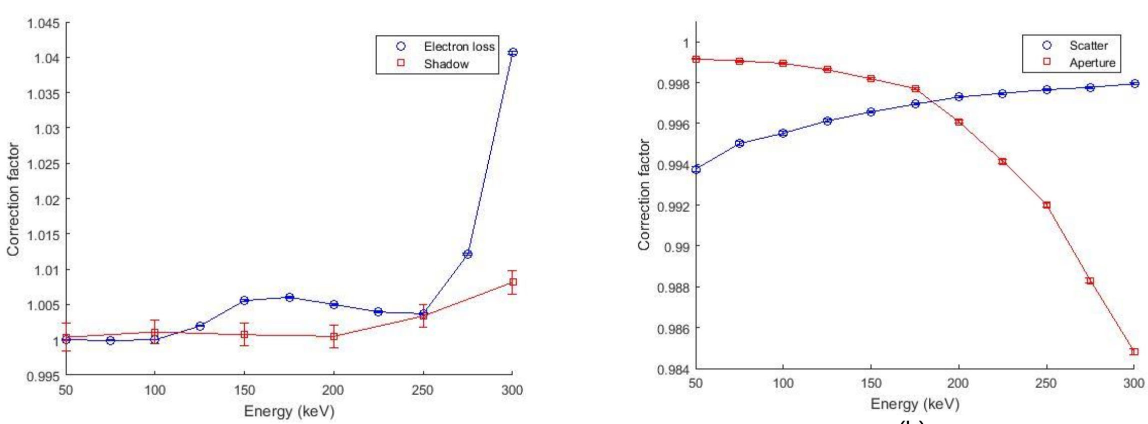


Figure 2: Schematic of the front view and lateral view of the FAC where it is partially extended. The colors denote materials: green is tungsten alloy, black is lead and blue is aluminum.

The scatter correction factors for monoenergetic photons, in increments of 25 keV, are shown in Figure 3. The correction factors approach a value of 1 as energy increases, as higher energy scattered photons more easily leave the chamber without depositing energy first. The electron loss and shadow correction factors for monoenergetic photons are also shown in Figure 3. When the energy of the photons is less than 125 keV, the electron loss correction is approximately 1 because the walls of the chamber are outside of the range of the electrons. Likewise, the shadow correction is approximately 1 until the photon energy reaches 100 keV. The energy is lower because the collecting rod is closer to the beam than the walls. The correction factors have small peaks where the main interaction type switches from photoelectric effect to Compton scatter. The aperture correction for monoenergetic photons is also shown in Figure 3.



(a) (b)

Figure 3: (a) Calculated results of monoenergetic electron loss and shadow correction factors. (b) Calculated results of monoenergetic scatter and aperture correction factors.

Conclusion: A FAC suitable to measure the medium x-ray energy range was successfully designed. The design outlined here is currently in the process of being built. Future work will include testing the FAC with x-ray beams with known air kerma rates.

Relevance to CIRMS mission and first author's goals: This work is a portion of the master's level work performed by the first author involving the design of a medium-energy FAC. This work relates to the CIRMS mission as it can be used directly for dosimetry and calibration with a focus on medium energy x-rays that were previously unable to be measured at the UW. Presently there are no standard beams for the radiobiological X-ray beams. The first author's goal is to become a clinical/academic medical physicist and currently works in a laboratory focused on metrology.

References:

1. J.G. Coletti et al. Mammography exposure standard: Design and characterization of free-air ionization chamber. *Rev. Sci. Instrum.*, 66(3):2574-2577, 1995.
2. W.L. Chen et al. Improved free-air ionization chamber for the measurement of x-rays. *Metrologia*, 26(1):19-24, 1999.