Air kerma rate measurements from a miniature x-ray source using free-air ionization chambers

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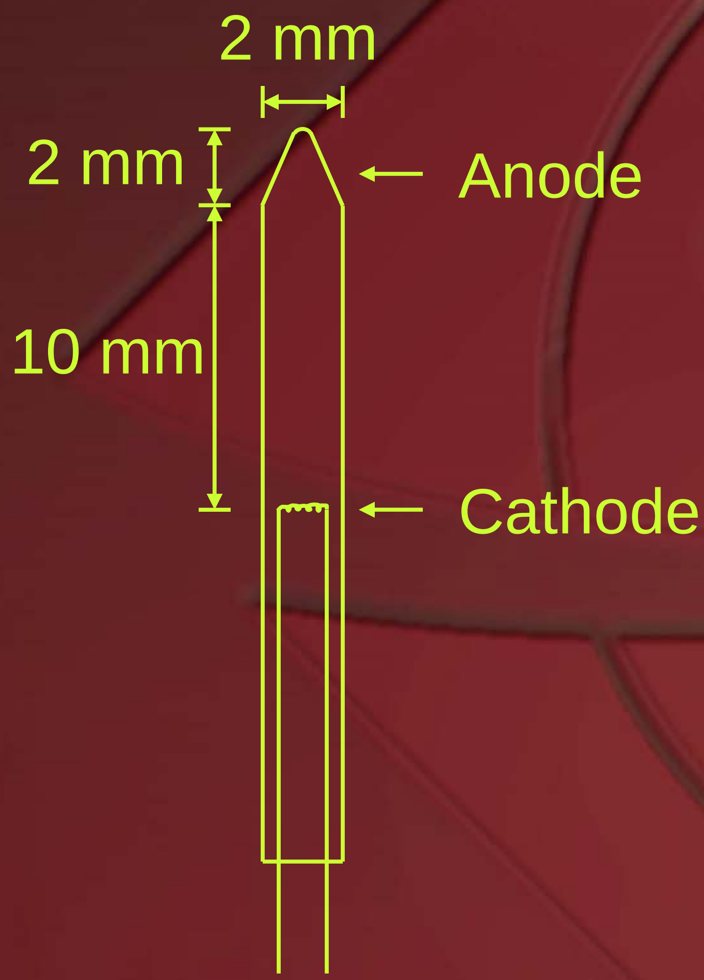
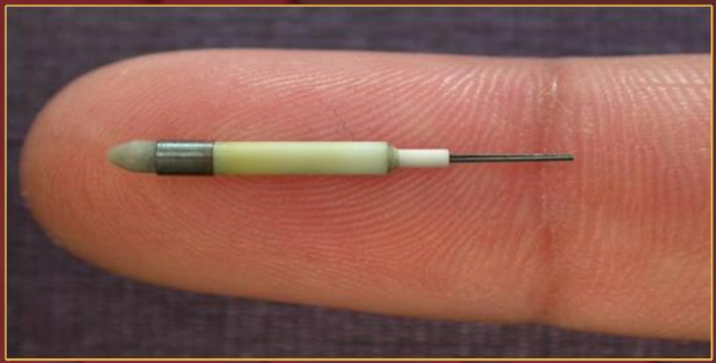
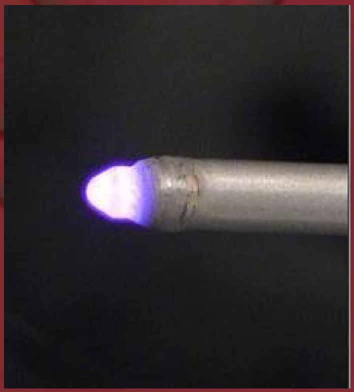
Xoft Axxent^{TM} miniature x-ray source

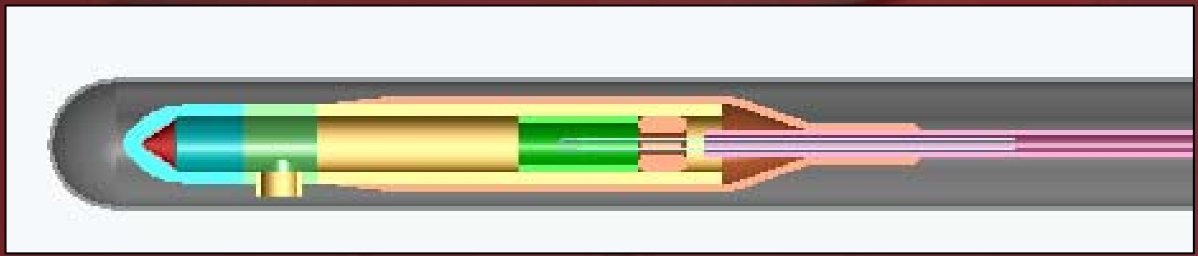






Photos courtesy of Xoft, Inc.

Xoft Axxent^{TM} miniature x-ray source



X-Ray Probe Tip Detail

Photos courtesy of Xoft, Inc.

TG-43U1 protocol

$$\dot{D}(r,\theta) = S_K \cdot \Lambda \cdot \left(\frac{G_P(r,\theta)}{G_P(r_0,\theta_0)} \right) \cdot g_P(r) \cdot F(r,\theta)$$

- Miniature x-ray sources will be characterized using a modification of the TG-43U1 protocol
- NIST-traceable calibration will be through the air-kerma strength, equivalent to traditional brachytherapy sources

Wide-Angle Free-Air Chamber (WAFAC)

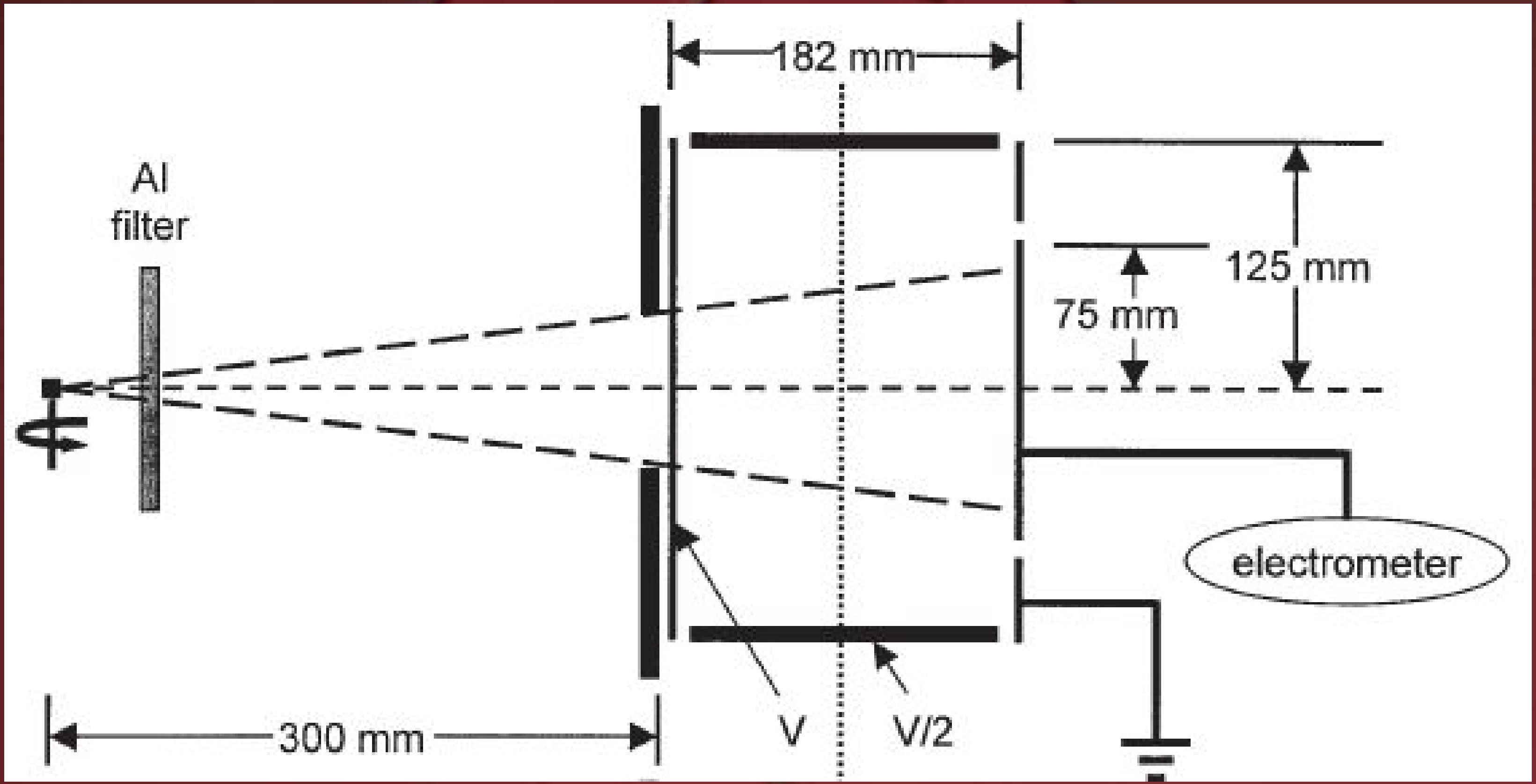


Diagram from Seltzer *et al.* (2003)

Attix free-air chamber (FAC)

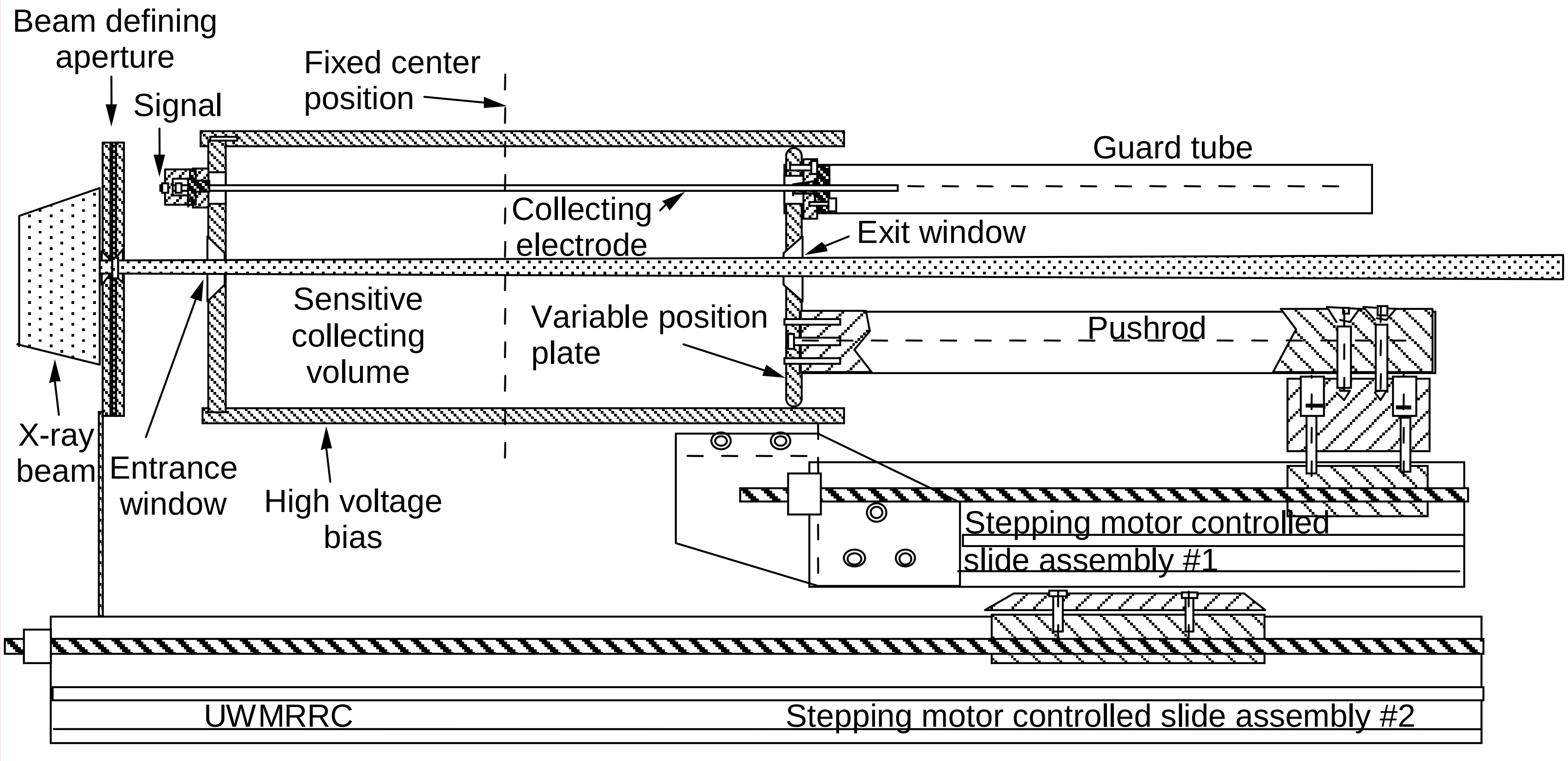


Diagram from Coletti *et al.* (1995)

Air kerma measurements with Attix FAC

$$\dot{K}_{\text{air}} = \frac{dI}{dL} \cdot \frac{1}{\rho_{\text{air}} A_0} \cdot \left(\frac{\overline{W}}{e}\right)_{\text{air}} \cdot \left(\frac{1}{1-\overline{g}}\right) \cdot \prod_i k_i$$

$\dot{K}_{\text{air}}$	Air kerma rate at the free-air chamber aperture	A_0	Defining aperture area
$\frac{dI}{dL}$	Change in current per change in plate separation	$\left(\frac{\overline{W}}{e}\right)_{\text{air}}$	Energy required to liberate 1 C of charge in dry air (33.97 J/C)
ρ_{air}	Density of the ambient air	$\overline{g}$	Fraction of energy lost to radiative events
		k_i	Correction factors

Ritz free-air chamber (FAC)

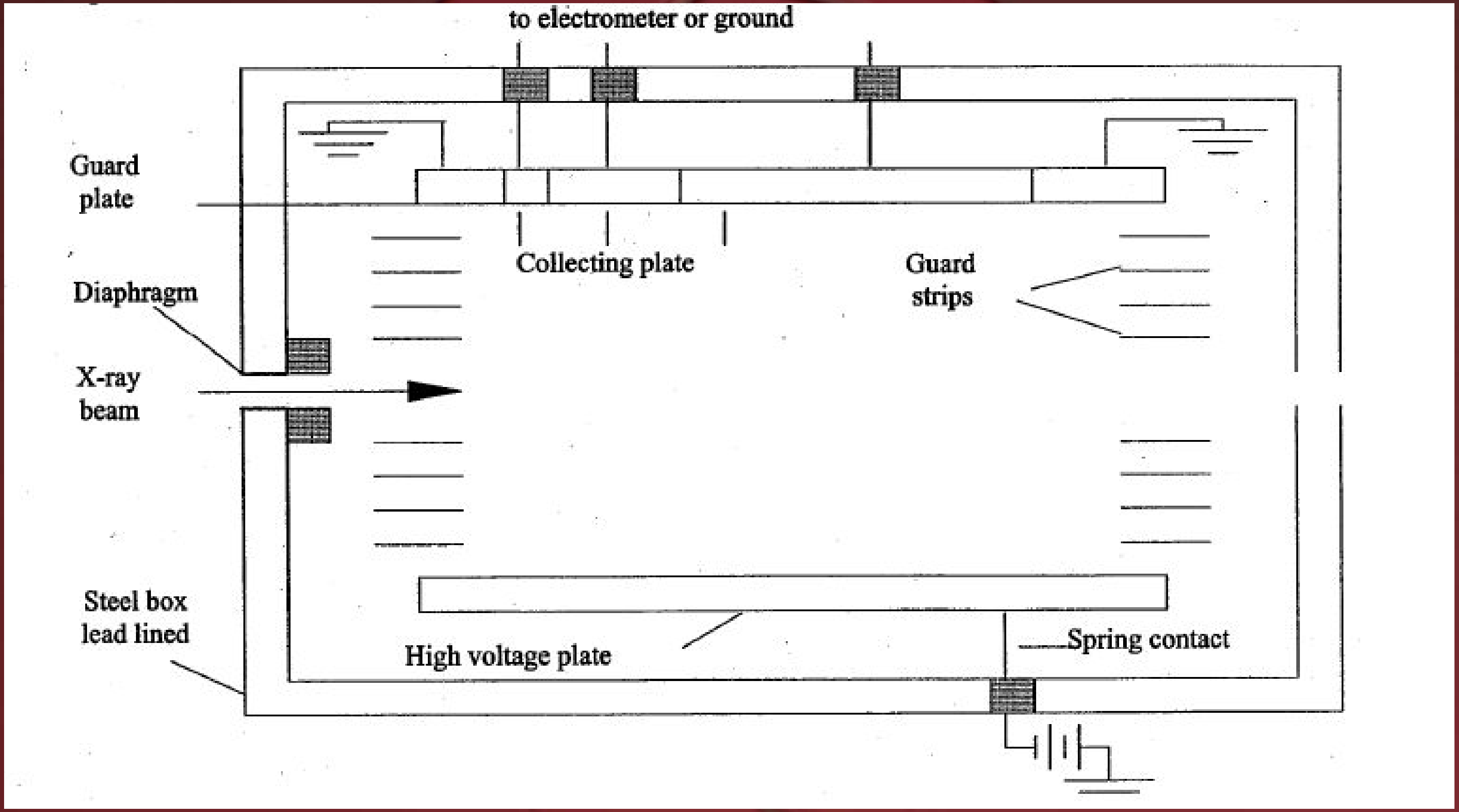


Diagram from NIST Special Publication 250-58 (2001)

Air kerma measurements with Ritz FAC

$$\dot{K}_{\text{air}} = \frac{I}{L} \cdot \frac{1}{\rho_{\text{air}} A_0} \cdot \left(\frac{\overline{W}}{e} \right)_{\text{air}} \cdot \left(\frac{1}{1-\overline{g}} \right) \cdot \prod_i k_i$$

$\dot{K}_{\text{air}}$	Air kerma rate at the free-air chamber aperture	A_0	Defining aperture area
I	Measured current	$\left(\frac{\overline{W}}{e} \right)_{\text{air}}$	Energy required to liberate 1 C of charge in dry air (33.97 J/C)
L	Ionization chamber collecting length	$\overline{g}$	Fraction of energy lost to radiative events
ρ_{air}	Density of the ambient air	k_i	Correction factors

Free-air chamber correction factors

- Air attenuation from the beam-defining aperture to the center of the collecting volume
- Ionization created by scattered photons
- Energetic electrons reaching the chamber walls or collecting electrode
- Recombination of ions in the air volume
- For S_K determinations, the air kerma measurements must be corrected to *in vacuo*

HDR 1000 Plus well chamber

- Sources will be measured with the well chamber prior to treatment to measure the air-kerma strength (S_K)
- Special aluminum insert designed by Standard Imaging

Well chamber calibration

$$N_K = \frac{\dot{K}(d)}{I}$$

N_K Well chamber calibration coefficient (in Gy/C)

$\dot{K}(d)$ Air kerma rate in air at 100 cm (in Gy/s)

I Well chamber current (in C/s)

HDR 1000 Plus well chamber calibration coefficients from FAC measurements (50 kV)

Free-air chamber	N_K (×10^2 Gy/C)
UW Attix (5 sources)	3.419 ± 2.2%
NIST Attix (3 sources)	3.717 ± 5.6%
NIST Ritz (4 sources)	3.537 ± 5.3%
Average across all 12 measurements	3.545 ± 5.3%

Possible explanations for variability

- Azimuthal asymmetry in output from x-ray sources
  - Sources were not rotated during FAC measurements
- Source alignment at NIST
- Very small differences in spectra in air
  - Air attenuation measurements were fairly consistent
- Different measurement geometry in well chamber
  - Very sensitive to any differences in the 3-D distribution of source output since it basically measures a large solid angle

Conclusions

- Air kerma rates at 100 cm in air have been measured using free-air chambers at UW and NIST but further work will be necessary to develop methods suitable for traceability to national measurement standards
- Conversion to air-kerma strength *in vacuo* will require measurements and Monte Carlo simulations to determine accurate photon spectra

Acknowledgements

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