Calibration of Xoft Electronic Brachytherapy Sources

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Development of calibration standard

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

- Electronic brachytherapy (EB) 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

Air kerma standards

- National primary standards for air kerma are based on either free-air chambers or cavity ionization chambers
- Free-air chambers: < 300 keV photons
  - e.g. primary x-ray standards, low-energy brachytherapy sources
- Cavity ionization chambers: > 300 keV photons
  - e.g. ^{137}Cs (662 keV) and ^{60}Co (1250 keV)
- Currently, HDR ^{192}Ir calibrations are based on an ionization chamber calibrated using 250 kV x-rays and ^{137}Cs

Free-air chambers available at NIST

EB sources	40 kV to 50 kV
Wyckoff-Attix	50 kV to 300 kV
Ritz	20 kV to 100 kV
Lamperti	10 kV to 20 kV
Attix	20 kV to 50 kV
WAFAC	Up to 40 keV photons

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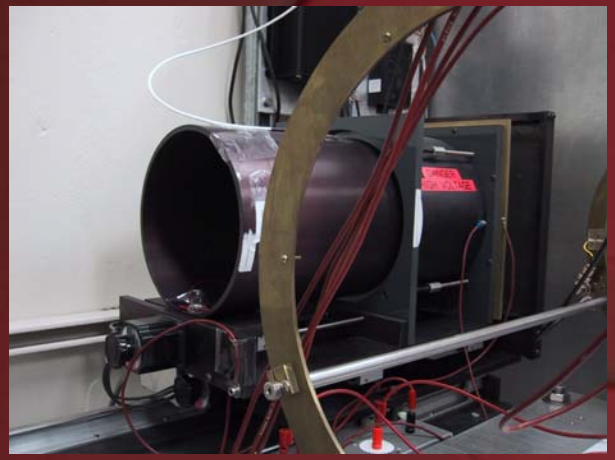
Typical air kerma rates at 1 m

^{103}Pd and ^{125}I	10^{-6} Gy/h to 10^{-5} Gy/h
HDR ^{192}Ir (10 Ci)	$4 \cdot 10^{-2}$ Gy/h
Medium filtered 50 kV x-rays (25 mA)	8 Gy/h
EB sources	$3 \cdot 10^{-4}$ Gy/h to $1.5 \cdot 10^{-1}$ Gy/h

Selection of appropriate free-air chamber



- NIST WAFAC was designed with a wide aperture to collect more signal from LDR brachytherapy seeds
- Unnecessary for EB sources due to high output
- WAFAC can not be used up to 50 kV
- Recombination will be a significant issue, although it can be measured and corrected

Selection of appropriate free-air chamber

- Ritz FAC has an energy range compatible with EB sources
  - Difficult to measure air attenuation correction

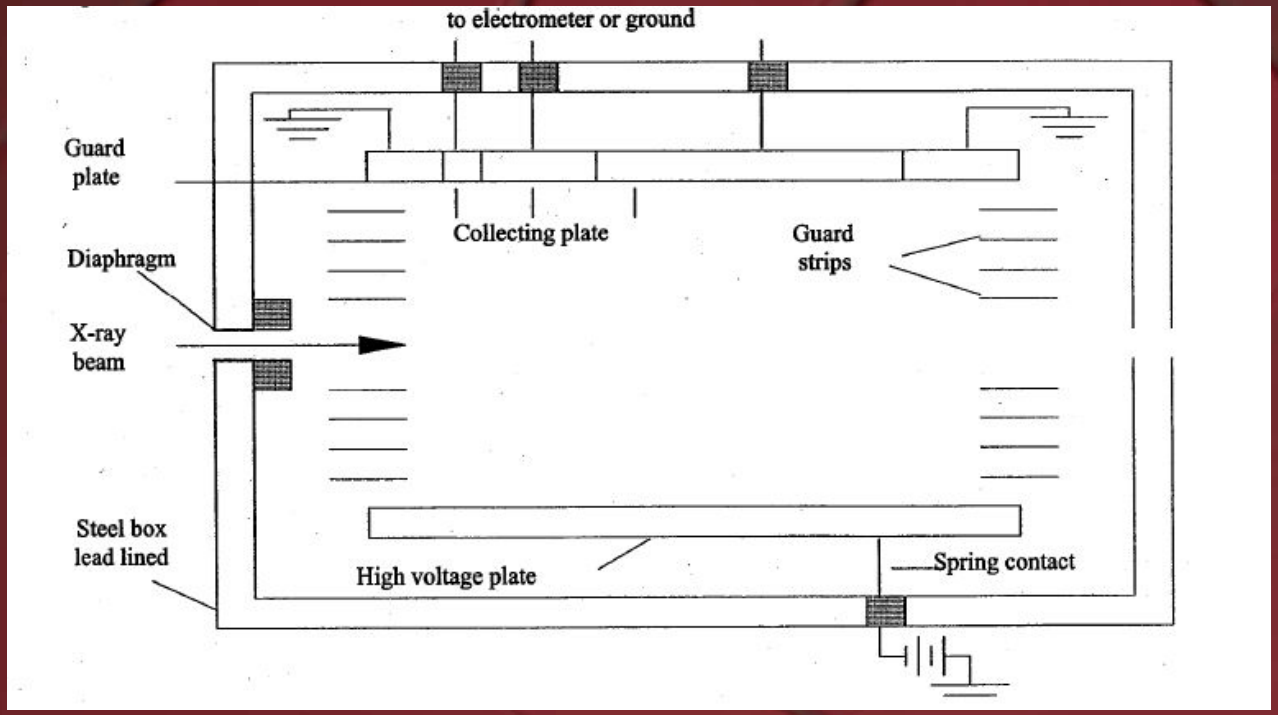


Diagram from NIST Special Publication 250-58

Attix free-air chamber

- Designed to be used for up to 50 keV photons
- Difference technique negates the need for an accurate volume of the sensitive region
- Air attenuation can be measured easily

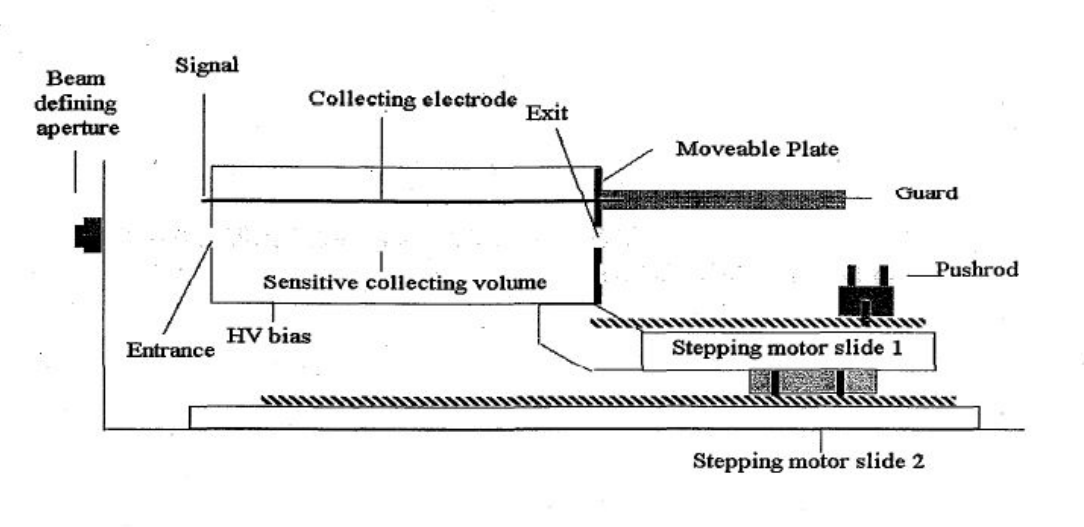
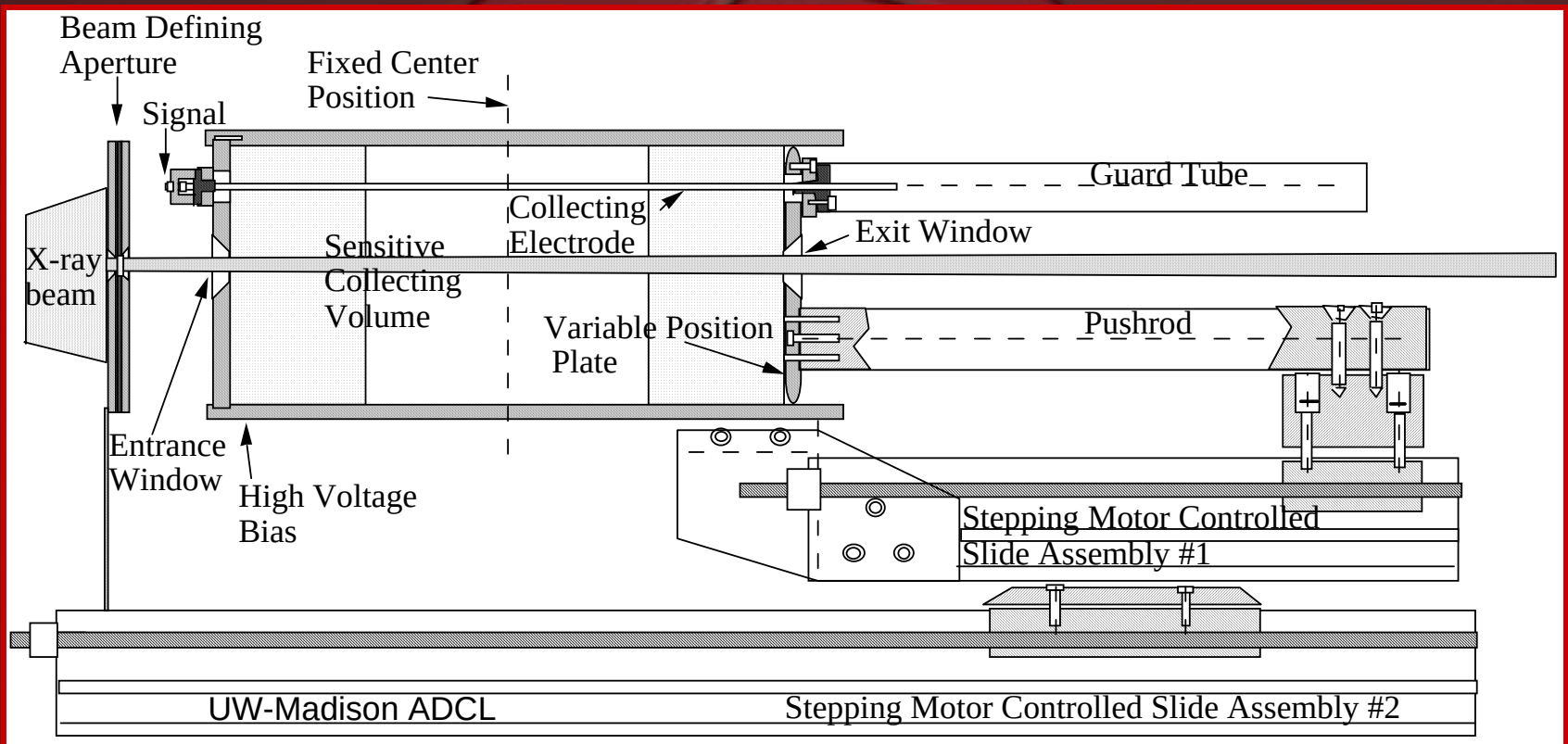


Diagram from NIST Special Publication 250-58

Attix free-air chamber (cont.)



(a) Chamber fully extended

Diagram from Coletti et al. (1995)

Free-air chamber measurement progress

- Measurements using UW Attix FAC from June 2004 to September 2005
- Preliminary measurements using the Ritz FAC and Attix FAC at NIST in October 2004
- Preliminary measurements continued using the Attix FAC at NIST in February 2005
  - Discovered significant leakage contribution from room scatter

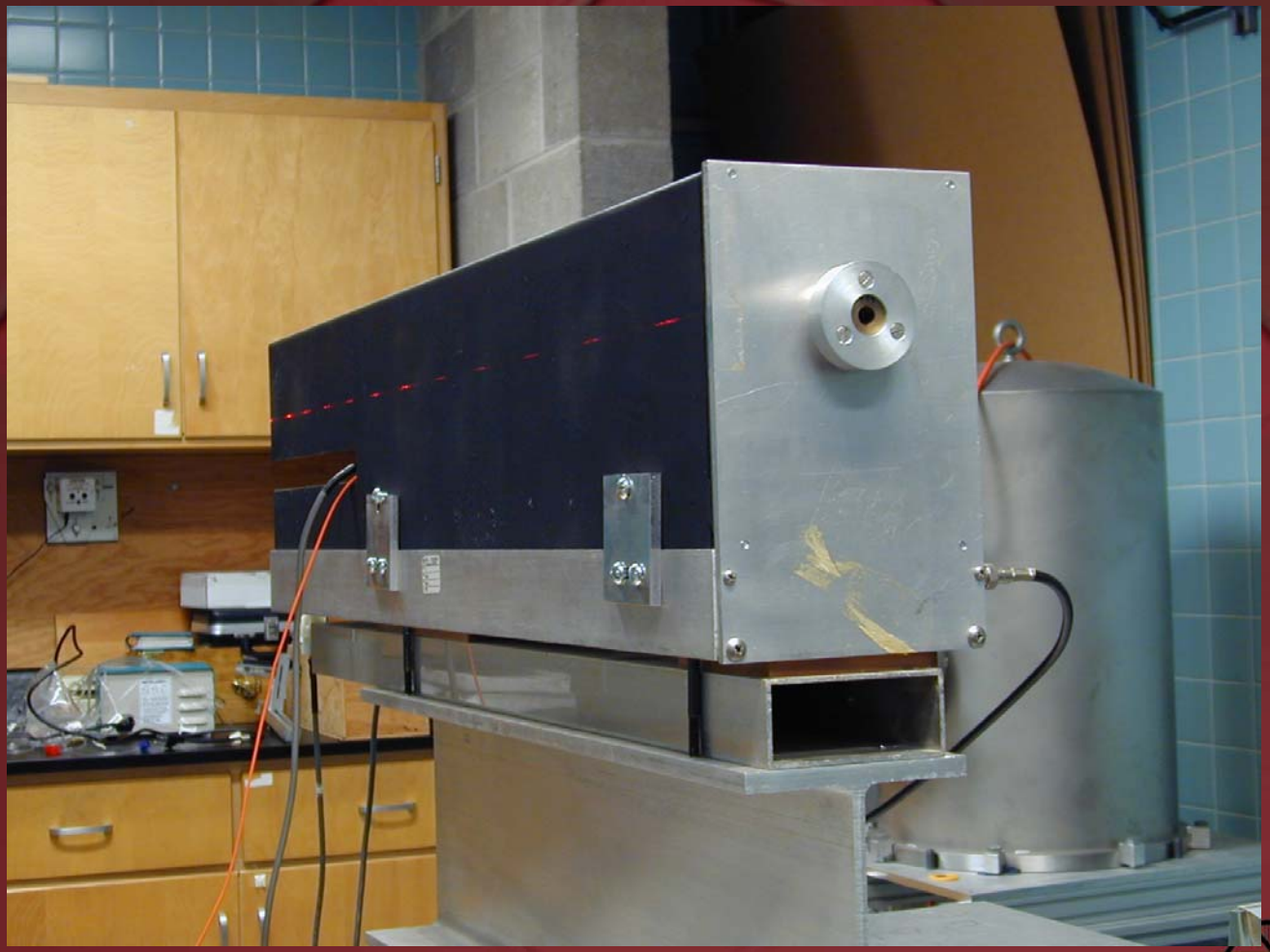
Scattered photon contribution

- Normal x-ray sources are well collimated, but EB source is emitting in 4π
  - Room scattered photons were entering the sides of the FAC
- Scatter component was measured by placing a lead block over the FAC aperture
- Measured scatter component at UW was comparable to the measurements at NIST

Scattered photon contribution (cont.)

Energy	Scatter at NIST	Scatter at UW
40 kV	1.8 %	2.7 %
45 kV	4.5 %	4.4 %
50 kV	7.4 %	7.2 %

UW Attix FAC shielding



Scattered photon contribution (cont.)

Energy	Scatter at UW before shield	Scatter at UW after shield
40 kV	2.7 %	< 0.1 %
45 kV	4.4 %	< 0.1 %
50 kV	7.2 %	0.1 %

Air attenuation measurements over 19 cm

Energy	NIST Attix FAC (1 source)	UW Attix FAC (4 sources)
40 kV	1.046 ± 0.9%	1.040 ± 0.2%
45 kV	1.043 ± 0.2%	1.037 ± 0.2%
50 kV	1.036 ± 0.4%	1.036 ± 0.1%

Air attenuation

- Air attenuation doesn’t change much with increasing kV because no additional filtration is added, so the low energy component is basically unchanged
- Measurements agree well with calculations based on measured photon spectra

Well chamber transfer standard

- All free-air chamber measurements have corresponding well chamber measurements using the HDR 1000 Plus
- Well chamber insert is an important component

Well chamber calibration coefficients (Gy/C)

Source #	40 kV	45 kV	50 kV
1336	$5.911 \cdot 10^2$	$4.285 \cdot 10^2$	$3.412 \cdot 10^2$
2535	$5.547 \cdot 10^2$	$4.186 \cdot 10^2$	$3.470 \cdot 10^2$
2634	$5.743 \cdot 10^2$	$4.268 \cdot 10^2$	$3.460 \cdot 10^2$
2684	$5.354 \cdot 10^2$	$4.115 \cdot 10^2$	$3.284 \cdot 10^2$
Average	$5.639 \cdot 10^2$	$4.214 \cdot 10^2$	$3.407 \cdot 10^2$
1σ	4.3%	1.9%	2.5%

Possible explanations for variability

- Azimuthal asymmetry in EB sources
- Signal-to-noise issues with the free-air chamber
- Very small differences in spectra in air
  - Some correlation with air attenuation measurements
- Different measurement geometry in well chamber
  - Very sensitive to any differences in the 3-D distribution of source output since it basically measures in 4π

Comparison to ^{125}I

- Well chamber was also calibrated at UW using a 6711 ^{125}I seed for interim NIST traceability
- In the same units as the earlier slide, the calibration coefficient for ^{125}I is $4.214 \cdot 10^2$ Gy/C

Energy	Ratio to ^{125}I
40 kV	2.900
45 kV	2.167
50 kV	1.752

Conclusions

- Attix free-air chamber (after shielding) seems to be well suited as a primary standard for the EB sources
- Future work at NIST will hopefully confirm UW results

Future work

- Compare response of calibrated well chamber to several different well chambers with different inserts from the manufacturer
- Full uncertainty budget
- Use measurements and Monte Carlo calculations to convert from air kerma rate calibrations to air kerma strength calibrations (1 m in air vs. 1 m in vacuum)
- Determine the effect of air density on measurement of EB sources with the HDR 1000 Plus well chamber, using Monte Carlo techniques

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