Capacitance Methods to Determine Electrode Area and Air Gap for a Windowless Extrapolation Chamber

Jon B. Hansen, M.S.

University of Wisconsin Medical Radiation Research Center

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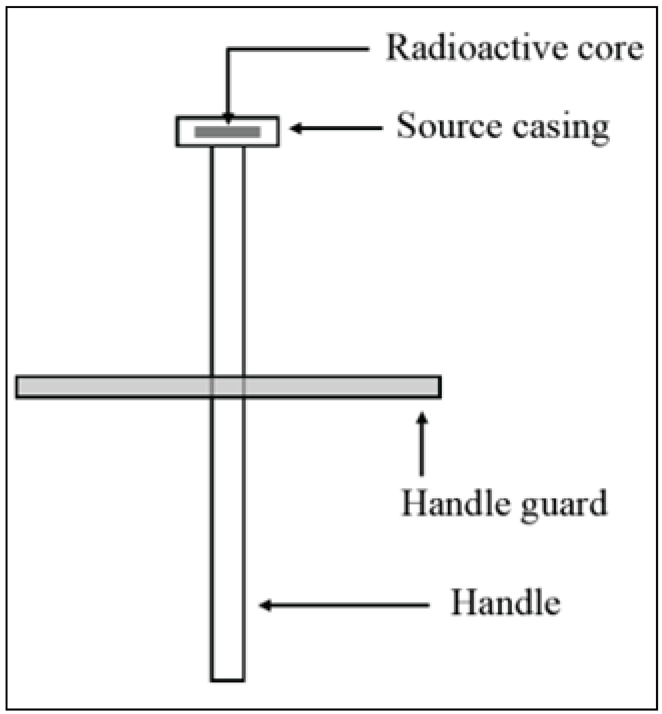
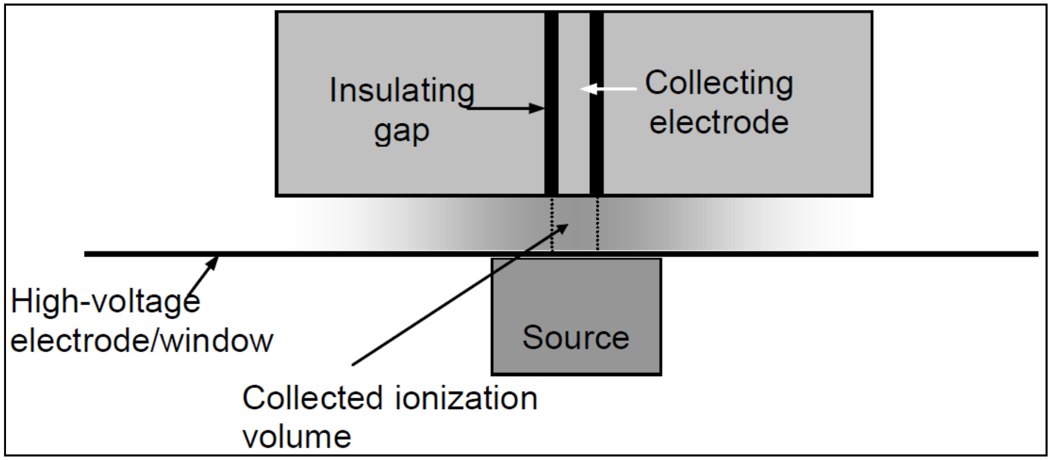
Ophthalmic Applicators

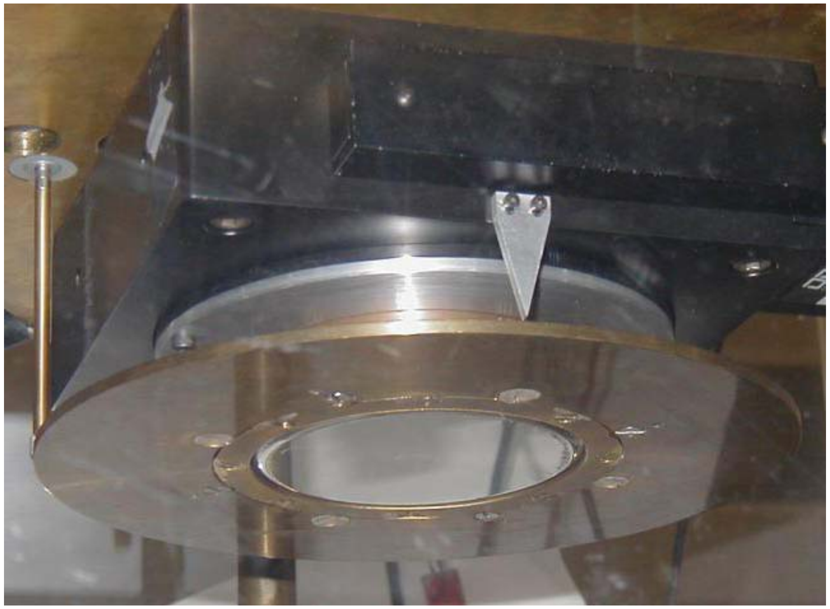
- Treatment of malignant and benign eye disease
  - pterygium (“surfer’s eye”) , uveal melanoma, etc.
- Calibrated using extrapolation chamber



NIST Extrapolation Chamber

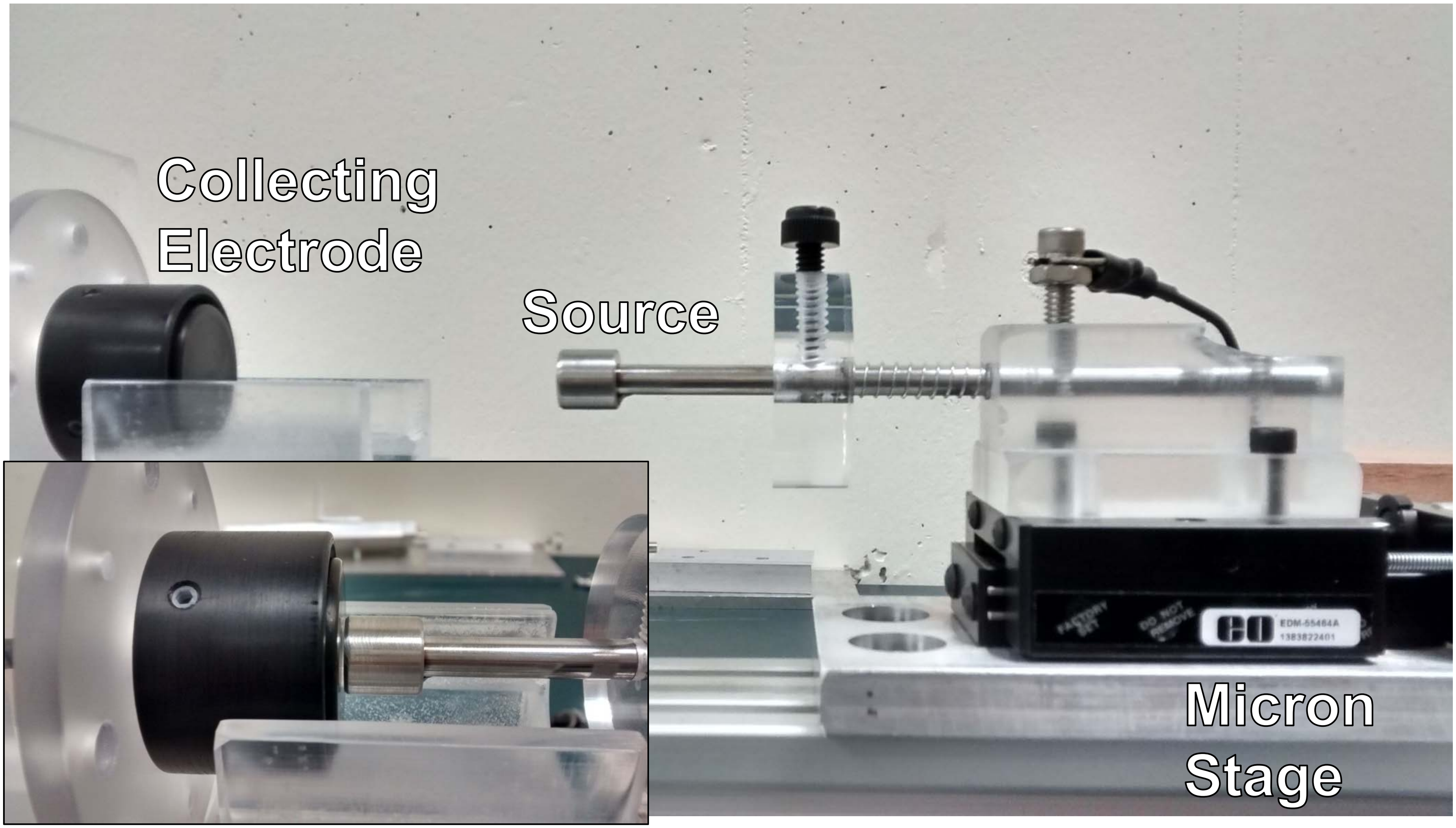
- Parallel plate ionization chamber with variable air gap distance
- NIST extrapolation chamber features Mylar entrance window





NIST IRD-P-09, 2010.

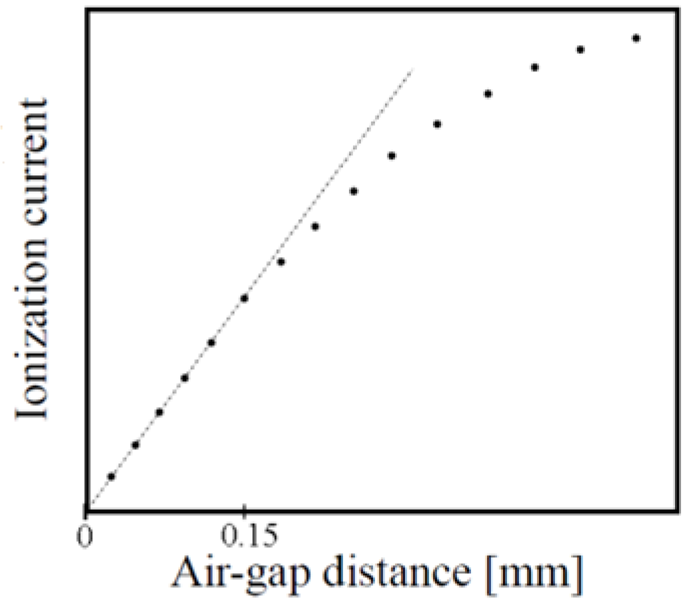
UWMRRC Windowless Extrapolation Chamber



Dose Rate Calibration

Bragg-Gray cavity theory:

$$\dot{D}_{\mathrm{w}} = \frac{\frac{\overline{W}}{e} s_{\mathrm{w,air}}}{\rho_0 A_{\mathrm{eff}}} \left(\frac{\Delta I}{\Delta \ell}\right)_{\ell \to 0}$$



where,

$\frac{\overline{W}}{e}$ = 33.97 J/C for dry air

$s_{\mathrm{w,air}}$ = mass collision stopping power ratio

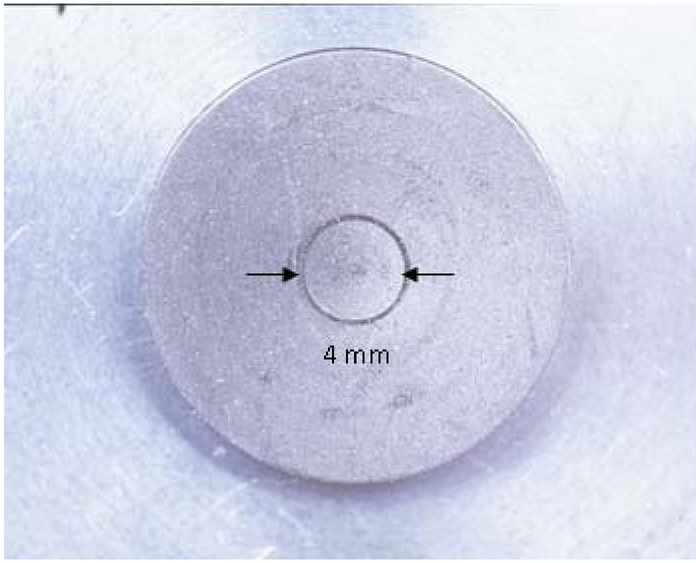
ρ_0 = 1.197 kg/m^3 for air at STP

A_{eff} = effective area of collecting electrode

$\left(\frac{\Delta I}{\Delta \ell}\right)_{\ell \to 0}$ = slope of ionization current with air gap

Effective Electrode Area, A_{eff}

- Diameter of collecting electrode can be measured using traveling microscope
- For NIST extrapolation chamber, reported area uncertainty of 0.6% based on repeated measurements of same collecting electrode



NIST IRD-P-09, 2010.

Capacitance Measurement to Determine A_{eff}

- Use electrometer and voltage supply to measure capacitance for windowless extrapolation chamber with dummy source present
- For ideal parallel plate capacitor:

$$C_0 = \frac{\epsilon_r \epsilon_0 A_{\text{eff}}}{\ell_{\text{meas}} - \ell_{\text{offset}}}$$

where,

ϵ_r = dielectric constant of air

ϵ_0 = permittivity of free space

A_{eff} = effective area of collecting electrode

ℓ_{meas} = measured plate separation

ℓ_{offset} = distance offset

- Plot ℓ_{meas} versus $\frac{1}{C_0}$ to solve for effective electrode area

W. Culberson, "Large-Angle Ionization Chambers for Brachytherapy Air-Kerma-Strength Measurements" (Doctoral dissertation) 2006.

Capacitance Measurement to Determine A_{eff}

- Slope of fit line from six trials used to determine the average effective electrode area:

$$A_{\mathrm{eff}} = (12.58 \pm 0.15)\ \mathrm{mm}^2$$

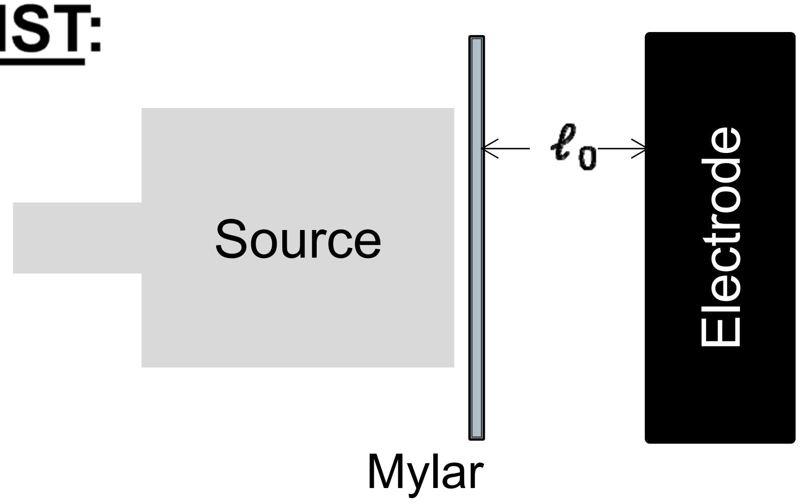
- From manufacturing criteria, expect electrode area of $12.57\ \mathrm{mm}^2$

Trial	Diameter (mm)	A_{eff} (mm^2)
1	3.998	12.55
2	3.971	12.38
3	4.028	12.74
4	3.971	12.38
5	4.016	12.67
6	4.028	12.74
Average	4.002	12.58
Standard Deviation	0.026	0.17
% Standard Deviation of Mean	0.66	1.33

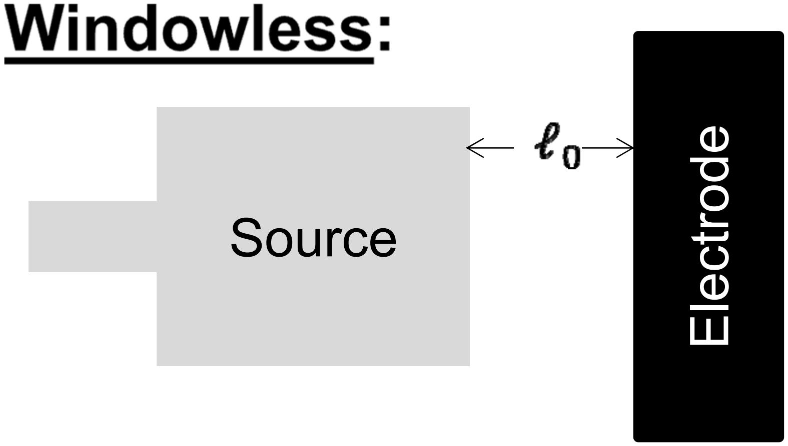
Relationship Between Capacitance and Gap Width

- Initial air gap width:
  - For NIST extrapolation chamber, the gap width between the entrance electrode & collecting electrode consistent between measurements
  - For windowless chamber, initial gap width between electrode & applicator must be found before each set of calibration measurements
  - Seek method to determine initial gap width without physical contact between the source and electrode to minimize stress on source surface

NIST:



Windowless:



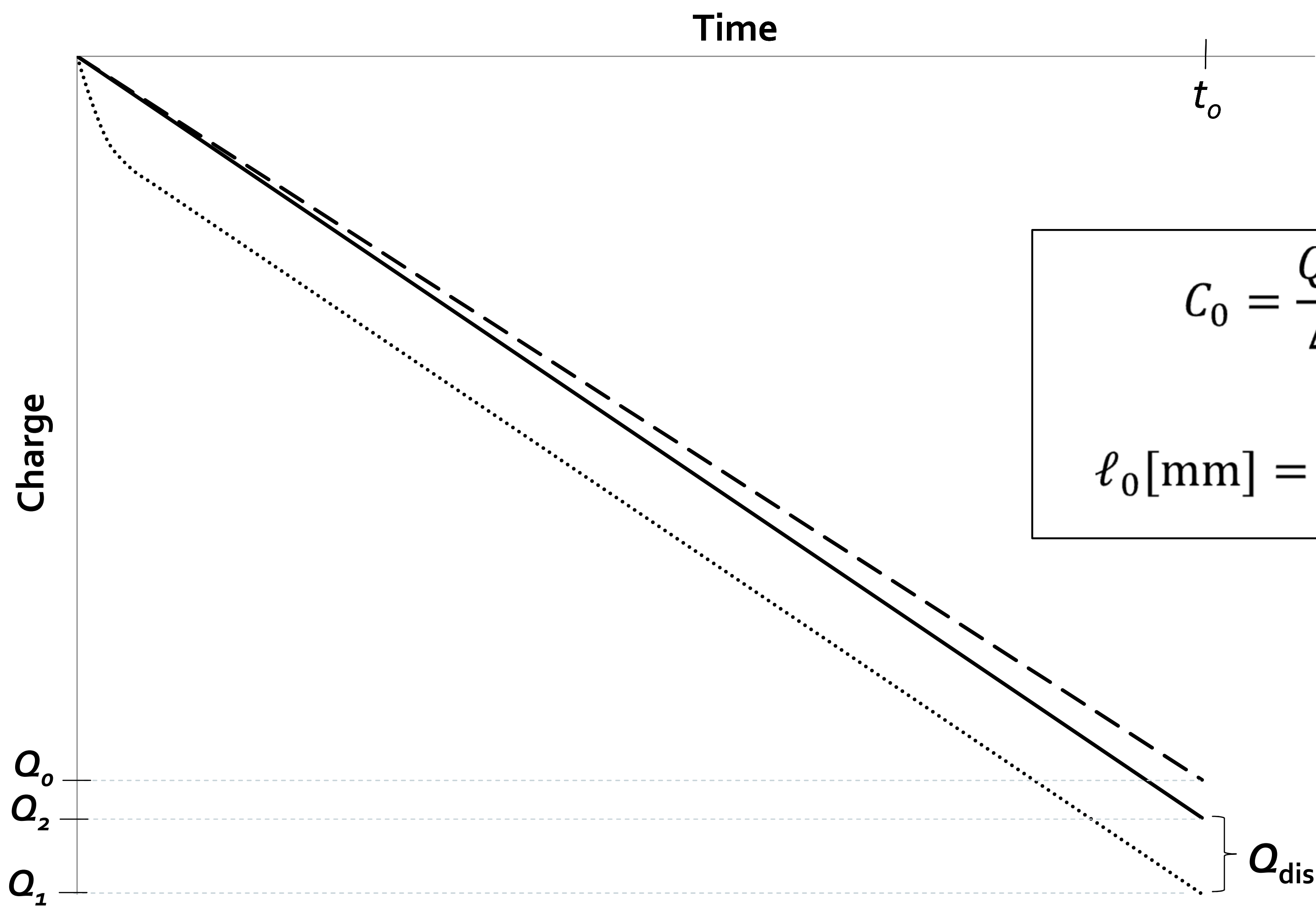
Relationship Between Capacitance and Gap Width

- Measured current includes:
  - Displacement current
  - Ionization within collection volume
  - Direct β-particle deposition on electrode

$$I_{\text{tot}} = I_{\text{dis}} + I_{\text{ion}} + I_{\beta}$$

- Utilize voltage increase method to measure chamber capacitance with radiation source present

Voltage Increase Method to Measure Capacitance with Source



$$C_0 = \frac{Q_{\mathrm{dis}}}{\Delta V}$$

$$\ell_0[\mathrm{mm}] = \frac{0.1114}{C_0[\mathrm{pF}]}$$

Voltage Increase Method to Measure Capacitance with Source

- True air gap determined from extrapolation to x-intercept during calibration measurement

Trial	Estimated gap width from capacitance (mm)	True gap width from extrapolation (mm)	Gap offset (mm)
1	0.047±0.001	0.061	+0.014
2	0.054±0.003	0.065	+0.011

- Comparison of repeated calibration measurements with same source suggests that dose rate results agree within experiment uncertainty for an offset <0.025 mm

Conclusions

- Capacitance measurements can be used to determine electrode area for extrapolation chamber
  - Uncertainty comparable to the use of a traveling microscope
- Capacitance measurements also used to determine the initial air gap between the applicator and collecting electrode
  - Resulting offset value <0.014 mm considered acceptable for dose rate calibration measurements
  - Avoids physical contact between source and electrode
  - Similar technique may be possible to determine gap width for convex extrapolation chamber for calibrating concave episcleral plaques

Acknowledgements

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- Jeffrey Radtke, MS

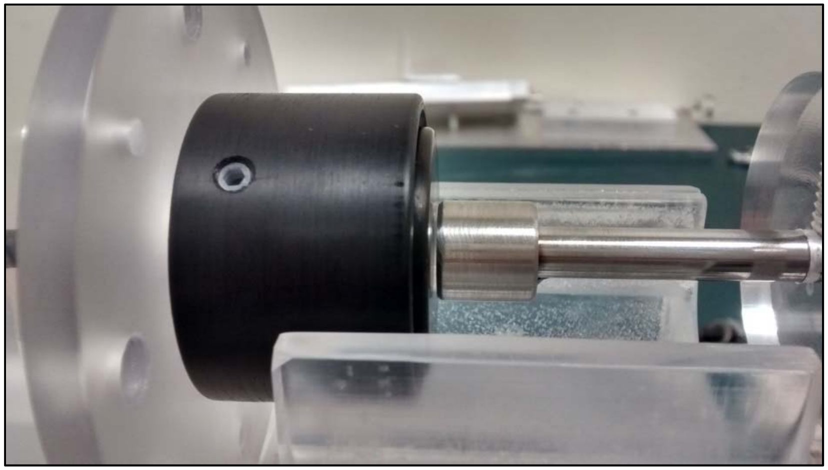
- Staff and students of the UWMRRC

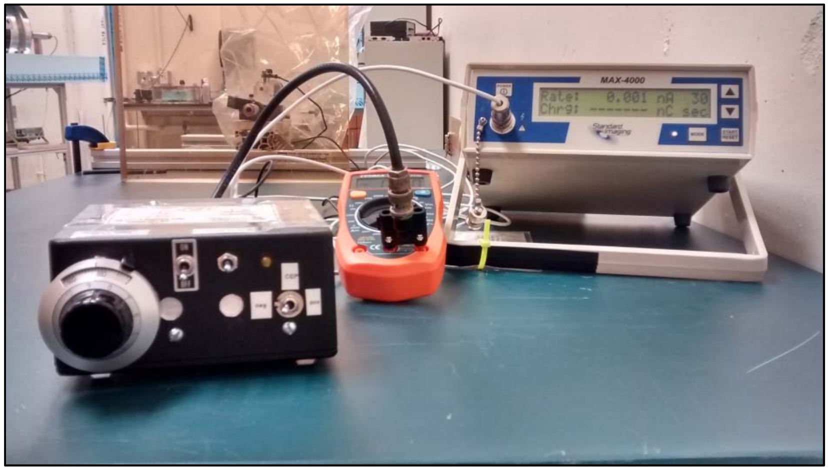
- UWADCL customers

Questions?

Capacitance Measurement to Determine A_{eff}

- Capacitance measurement procedure:
  - Position "dummy source" at arbitrary gap width
  - Collecting electrode potential from 0 → +10 V using external source (also took measurements with voltage decrease +10 V → 0)
  - Electrometer used to measure charge transfer between plates
    - Threshold start: 0.02 pA Threshold stop: 0.01 pA
    - Current saturates back to zero after ≈15 s
  - Take charge measurements at different gap widths





Voltage Increase Method to Measure Capacitance with Source

- With source in place, allow system to stabilize at nominal +5.00 V bias on collecting electrode (Q_0)
- Begin 30 s charge measurement and immediately increase bias full turn ($\Delta V \approx 2\ \mathrm{V}$) with external source ($Q_1$)
- Allow system to stabilize at *new bias* and take multiple charge measurements (Q_2)

$$Q_1 = \delta t \cdot Q_0 + (1 - \delta t) Q_2 + Q_{\mathrm{dis}} \quad ; \quad \delta t \cong 0$$
$$\cong Q_2 + Q_{\mathrm{dis}}$$

$$\therefore$$

$$Q_{\mathrm{dis}} = Q_1 - Q_2$$

$$C_0 = \frac{Q_{\mathrm{dis}}}{\Delta V}$$

$$\ell_0[\mathrm{mm}] = \frac{0.1114}{C_0[\mathrm{pF}]}$$