Spectroscopic Determination of the Dose-Rate Constant and Air-Kerma Strength

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Outline of Presentation

- Current dosimetry protocol for photon-emitting brachytherapy sources
  - Dose-rate constant, Λ
  - Air-kerma strength, S_K
- Spectroscopic methods for determining Λ and S_K
- Measurements of ^{125}I and ^{103}Pd sources
  - UW REGe Spectrometer
- Comparison of spectroscopic values to current standards
- Monte Carlo calculations of emitted spectra

Current Dosimetry Protocol

- AAPM Task Group 43 Updated Report No.1[1]
- Dose-rate equation:

$$\dot{D}(r,\theta) = \boxed{S_K \cdot \Lambda} \cdot \frac{G(r,\theta)}{G(r_0,\theta_0)} \cdot g(r) \cdot F(r,\theta)$$

product gives the dose-rate at the reference point (r_0=1cm,θ_0=90°)

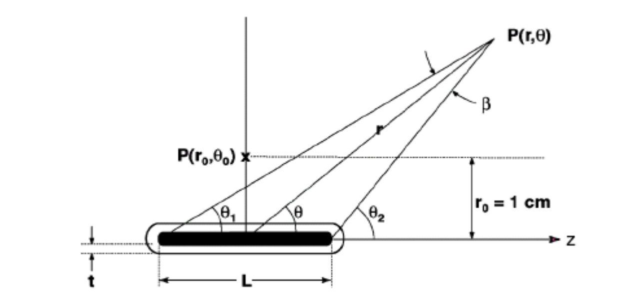


FIG. 1. Coordinate system used for brachytherapy dosimetry calculations.

[1] Rivard et al., Update of AAPM Task Group No. 43 Report: A revised AAPM protocol for brachytherapy dose calculations, Medical Physics 31(3), 633-674 (2004)

Dose-Rate Constant, Λ

- Defined as dose-rate to water at the reference point per unit air-kerma strength:

$$\Lambda = \frac{\dot{D}(r_0, \theta_0)}{S_K}$$

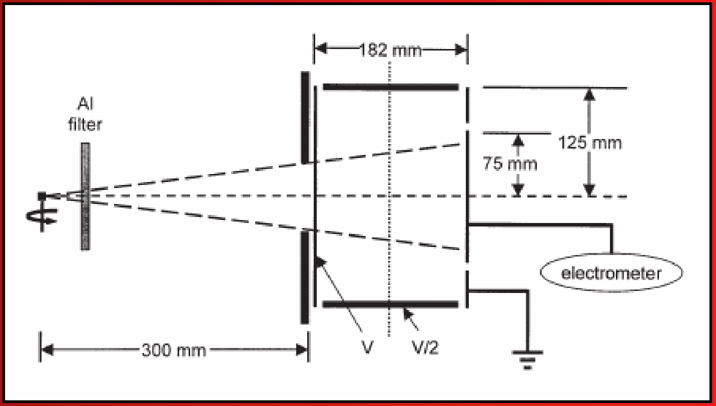
- TG-43U1 consensus values determined with measurements & Monte Carlo calculations
  - Measurements:
    - Usually with TLDs - uncertainties 8 – 9 % (1σ)
  - Monte Carlo calculations:
    - Require accurate representation of source geometry

Air-Kerma Strength, S_K

- Defined as the air-kerma rate at a point in vacuo along the transverse bisector of the source[1]

$$S_K = \dot{K}_{air}(d) \cdot d^2$$

- NIST Wide-Angle Free-Air Chamber (WAFAC)
- 7.8° half-angle



[2] Seltzer et al., New national air-kerma-strength standards for ^{125}I and ^{103}Pd brachytherapy seeds, J. Res. Natl. Inst. Stand. Technol. 108, 337-357 (2003)

Spectroscopic Dose-Rate Constant, Λ_{Spect}

- Chen & Nath[3,4] introduced the method of calculating Λ from the source spectrum:

$$\Lambda_{Spect} = \frac{\sum_i K_{air,i} \cdot \Lambda(E_i)}{\sum_i K_{air,i}}$$

$$\Lambda(E) = \left[\frac{\mu_{en}(E)}{\rho}\right]_{air}^{water} \cdot \exp\left[-\mu_{water} \cdot r\right] \cdot r^{-2} \cdot B_{en}(E)\Big|_{r=1cm}$$

[3] Z. Chen and R. Nath, Dose-rate constant and energy spectrum of interstitial brachytherapy sources, Medical Physics 28, 86-96 (2001)

[4] Z. Chen and R. Nath, Photon Spectrometry for the determination of the dose-rate constant of low energy photon-emitting brachytherapy sources, Medical Physics 34(4), 1412-1430 (2007)

Spectroscopic Air-Kerma Strength, $S_{K,Spect}$

- S_K can be determined using a similar equation:

$$S_{K,Spect} = d^2 \cdot \sum_i \dot{\phi}_{vacuum,i} \cdot E_i \cdot \left(\frac{\mu_{en}}{\rho}\right)_{air,i}$$

- The absolute energy spectrum must be used for the fluence rate, not just the relative spectrum
  - Detector efficiency must be known

Germanium Spectroscopy

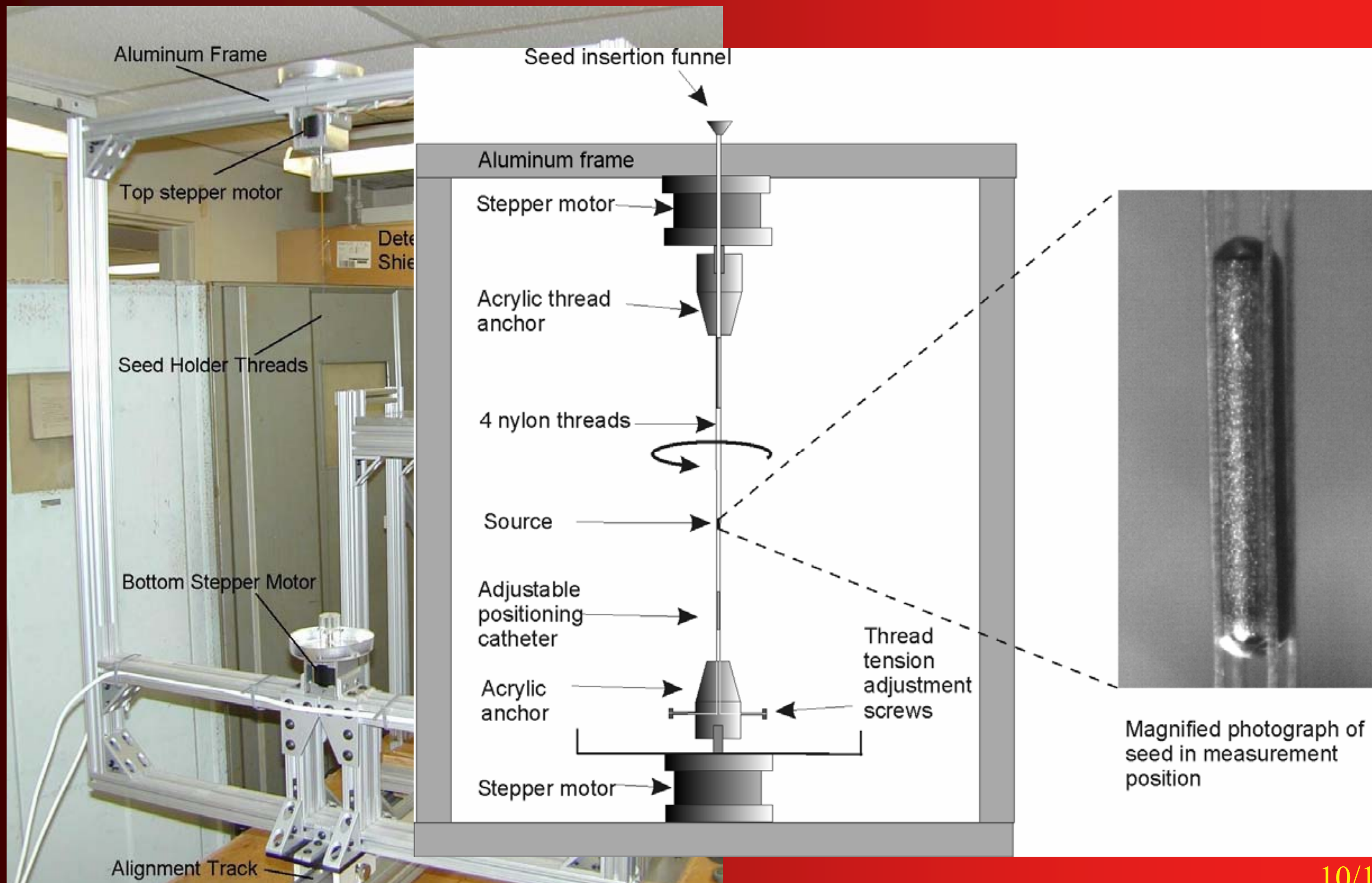
- Small amount of energy needed to produce a charge carrier: 3 eV/e-h pair
  - High sensitivity
  - Good energy resolution
- Low-energy response of the detector must be known
  - Detector efficiency
  - Ge fluorescence peaks ~ 10 & 11 keV
  - Escape peaks ~ 10 & 11 keV below primary peak

UW REGe Spectrometer

- Reverse-electrode coaxial Ge spectrometer (CANBERRA - GR2519)
- Dr. Stephen Beach characterized the response of this detector
- Deconvolution algorithm is used to remove the detector response function from the measured spectrum

[4] Beach et al., Deconvolution and reconstruction techniques of closely spaced low-energy spectra from high-purity germanium spectrometry, Nuclear Instruments and Methods in Physics Research A572 (2007)

UW REGe Spectrometer



Measuring and Correcting Spectra

- Measured spectra of Theragenics® Model 200 (^{103}Pd) & Best® Model 2301 (non-silver containing ^{125}I) sources
- Peak analysis performed using Genie 2000 software – interactive peak fitting
- Correct the peak areas to vacuum:

$$\phi_{vacuum,i} = PeakArea_{decon,i} \cdot CF_{att,i} \cdot CF_{scatt,i} \cdot CF_{trans,i}$$

CF_{att} - photons removed from beam by air attenuation

$$CF_{att;i} = \exp\left[d \cdot \left(\frac{\mu}{\rho} \right)_{air} \cdot \rho_{air} \right]_i$$

CF_{scatt} - photons that are scattered into the detector's field of view

CF_{trans} - photons that are transmitted though the shielding

Results: Λ (cGy $h^{-1}U^{-1}$)

Model	Λ_{Spect}	Λ_{CON} [1]	Λ_{EXP} [1]	Λ_{MC} [1]	Λ_{PST} [4]
200 (^{103}Pd)	0.690 ± 3.9%	0.686 ± 7.3%	0.682 ± 7.3%	0.691 ± 2.9%	0.677 ± 3.8%
2301 (^{125}I)	1.031 ± 3.4%	1.018 ± 8.3%	1.025 ± 8%	1.01 ± 3%	N/A

Overall combined uncertainties at 1σ (k=1)

% Difference: Λ_{Spect} vs. Λ_{CON}	
Model 200:	0.60%
Model 2301:	1.30%

[1] Rivard et al., Update of AAPM Task Group No. 43 Report: A revised AAPM protocol for brachytherapy dose calculations, Medical Physics 31(3), 633-674 (2004)

[4] Z. Chen and R. Nath, Photon Spectrometry for the determination of the dose-rate constant of low energy photon-emitting brachytherapy sources, Medical Physics 34(4), 1412-1430 (2007)

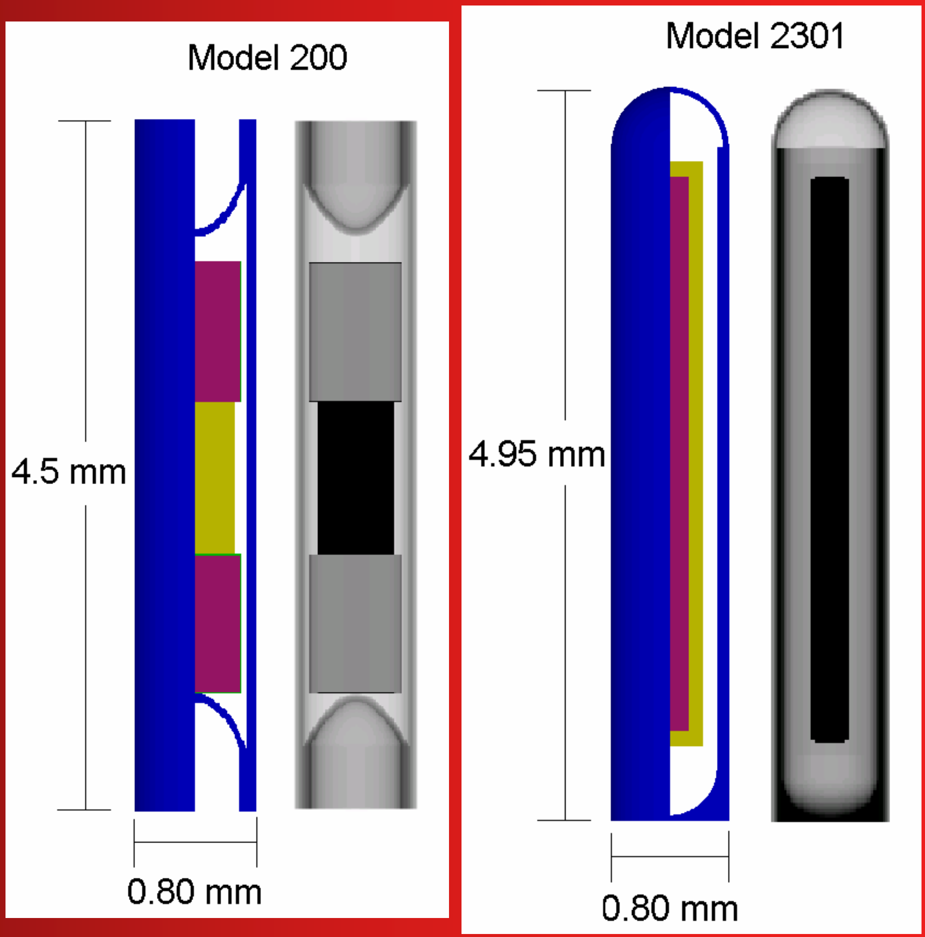
Results: S_K

Model	Lot #	$S_{K,Spect}$ [U]	$S_{K,WAFAC}$ [U]	% Difference in S_K Spect vs. WAFAC
200 (^{103}Pd)	0638H	2.72 ± 2.2%	2.76 ± 1.0%	-1.2%
	0641C	2.39 ± 2.0%	2.42 ± 1.0%	-1.1%
	0648G	2.81 ± 2.0%	2.91 ± 1.0%	-3.5%
	0710C	4.44 ± 2.1%	4.57 ± 1.0%	-2.9%
2301 (^{125}I)	20072	5.87 ± 2.1%	5.99 ± 1.0%	-2.1%
	20072	7.47 ± 2.1%	7.65 ± 1.0%	-2.4%

Overall combined uncertainties at 1σ (k=1)

MCNP5 Simulations

- Used source geometries from TG-43U1[1]
- f2 photon flux tally
  - 0.1 keV bins
- Calculated the relative emitted spectra



[1] Rivard et al., Update of AAPM Task Group No. 43 Report: A revised AAPM protocol for brachytherapy dose calculations, Medical Physics 31(3), 633-674 (2004)

Relative Spectra

Energy (keV)	Relative Spectra (%)				
	Bare ^{103}Pd[2]	Encapsulated ^{103}Pd Source[2]	Chen & Nath[4] Model 200	This Work: Model 200	
				REGe	MCNP5
20.1	83.9	79.3	79.9	80.2	81.2
22.6	13.5	17.3	19.3	16.4	15.7
23.1	2.51	3.21		3.18	2.97
39.7	0.001	0.16	0.47	0.12	0.13

Energy (keV)	Relative Spectra (%)				
	Bare ^{125}I[2]	Encapsulated ^{125}I Source[2]	Chen & Nath[4] Model 6702	This Work: Model 2301	
				REGe	MCNP5
27.4	78.8	75.8	76.6	76.2	76.9
31.0	13.7	15.6	18.5	15.3	14.5
31.7	2.97	3.47		3.46	3.16
35.5	4.53	5.21	4.90	5.05	5.07

[2] Seltzer et al., New national air-kerma-strength standards for ^{125}I and ^{103}Pd brachytherapy seeds, J. Res. Natl. Inst. Stand. Technol. 108, 337-357 (2003)

[4] Z. Chen and R. Nath, Photon Spectrometry for the determination of the dose-rate constant of low energy photon-emitting brachytherapy sources, Medical Physics 34(4), 1412-1430 (2007)

Conclusions

- Λ_{Spect} of the Theragenics® Model 200 and Best Medical Model 2301 compare well with consensus values (within 1.3%)
- S_K can also be determined using spectroscopic methods
- MCNP5 simulations of the emitted spectra show good agreement with measured spectra

Future Work

- Extension of spectroscopic methods to additional source models
- Measurements of spectra in liquid water to avoid air-to-water conversions for determining Λ_{Spect} and other TG-43U1 parameters

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