AAPM Meeting Therapy Physics Review Course Bibliography and Study Questions

19 July 2014

Brachytherapy Sources, Dosimetry and Quality Assurance

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General References and Fundamentals

1. Williamson, J.F., Li, X.A. and Brenner**,** D.A.: "Physics and Radiobiology of Brachytherapy", in Perez and Brady's Principles and Practice of Radiation Oncology, 6th Edition, edited by Wazer, D.A., Perez, C.A, Halperin, E., Wolters-Kluwer/Lippincott Williams and Wilkens, Philadelphia, pp. 422-467, 2013.
2. L. A. DeWerd, "Calibration of brachytherapy Sources," in *Brachytherapy Physics: Second Edition*, edited by B. R. Thomadsen, M. J. Rivard and W. M. Butler (Medical Physics Publishing, Madison, WI, 2005), pp. 153-172.
   A good overview of brachytherapy calibration/source strength standardization practices
3. J. F. Williamson, "Semi-empirical Dose-Calculation Models in Brachytherapy," in *Brachytherapy Physics: Second Edition*, edited by B. R. Thomadsen, M. J. Rivard and W. M. Butler (Medical Physics Publishing, Madison, WI, 2005), pp. 201-232.
4. **Williamson, J.F.** and Rivard, M.R., "Quantitative Dosimetry Methods for Brachytherapy" *in* Brachytherapy Physics, Second Edition: Proceedings of AAPM 2005 Summer School," ed. By Thomadsen, B.R., Rivard, M.R., and Butler, W., Medical Physics Publishing, Madison, WI, 2005, pp 233-294.
5. J. F. Williamson and M. J. Rivard, "Thermoluminescent detector and Monte Carlo techniques for reference-quality brachytherapy dosimetry," in *Clinical Dosimetry Measurements in Radiotherapy*, edited by D. W. O. Rogers and J.E. Cygler (Medical Physics Publishing, Madison, WI, 2009), pp. 437-500.
6. Beaulieu L, Tedgren AC, Carrier J-F, Davis SD, Mourtada F, Rivard MJ, Thomson RM, Verhaegen F, Wareing TA, and **Williamson JF**. Report of the Task Group 186 on model-based dose calculation methods in brachytherapy beyond the TG-43 formalism: Current status and recommendations for clinical implementation. *Med Phys* **39**: 6208-6236 (2012).

References 3 and 4 are recently-written and fairly comprehensive reviews of model- and table-based dose-calculation algorithms. Reference 5 reviews in detail Monte Carlo and experimental dosimetry techniques from speaker's perspective. Reference 6 provides guidance to early adopters of Monte Carlo based dose-calculation, discrete ordinates calculation, and other model-based algorithms that go beyond TG-43 algorithms in which single-source dosimetry, seed-to-seed attenuation, applicator shielding, and tissue inhomogeneities are incorporated into a single unified process.

Low Energy Sources: Dosimetry and Calibration Issues

1. S. M. Seltzer, P. J. Lamperti, R. Loevinger *et al.*, “New National Air-Kerma-Strength Standards for ^{125}I and ^{103}Pd Brachytherapy Seeds,” J. Res. Natl. Inst. Stand. Technol. 108, 337-358 (2003).
   Definitive presentation of NIST WAFAC primary $S_{K,N99}$ standard for low energy brachytherapy sources.
2. Williamson, J.F., Coursey, B.M., DeWerd, L.A., Hanson, W.F., Nath, R., Rivard, M., Ibbott, G., "On the use of Apparent Activity A_{app} for Treatment Planning of ^{125}I and ^{103}Pd Interstitial Brachytherapy Sources: Recommendations of the American Association of Physicists in Medicine Radiation Therapy Committee Subcommittee on Low-Energy Brachytherapy Source Dosimetry." *Med. Phys.* 26: 2529-2530, 1999.M. J. Rivard, B. M. Coursey, L. A. DeWerd *et al.*, “Update of AAPM Task Group No. 43 Report: A revised AAPM protocol for brachytherapy dose calculations,” Med Phys **31** (3), 633-74 (2004).
4. Rivard, M. J., Butler, W. M., DeWerd, L. A., Huq, M. S., Ibbott, G. S., Meigooni, A.S., Melhus, C.S., Mitch, M. G., Nath, R., and Williamson, J. F., “Supplement to the 2004 update of the AAPM Task Group No. 43 Report,” Med. Phys. **34**, 2187- 2205 (2007)
   Reference 3 is a major new update of the 1995 TG-43 report. It contains a revised dose-calculation formalism, a modified definition of air-kerma strength, a concise history of source-strength standards, a formal procedure for merging datasets, and consensus datasets for 8 I-125/Pd-103 source models. Essential reading for all medical physicists. Reference 3 provides consensus datasets for 8 additional seed models.
5. Nath, R., Anderson, L.L., Luxton, G., Weaver, K.A., Williamson, J.F. and Meigooni, A.S., "Dosimetry of interstitial brachytherapy sources: Recommendations of the AAPM Radiation Therapy Committee Task Group No. 43", *Med. Phys.* 22: 209-234, 1995.
   Classic 1995 paper outlining the TG-43 dose calculation formalism, although much of its content is superceded by the new 2004 TG-43 report. Excellent review of low-energy dosimetry history and relationship between classical and TG-43 dose-calculation formalisms.

6. Williamson, J.F., Coursey, B.M., DeWerd, L.A., Hanson, W.F., and Nath, R., “Dosimetric Prerequisites for routine clinical use of new low energy photon interstitial brachytherapy sources,” Med. Phys. 25: 2269-2270, 1998.
   Important document, now accepted as a *de facto* industry standard, describing AAPM’s standards for dosimetric characterization and calibration of low-energy brachytherapy seeds for routine clinical use.

7. DeWerd, L. A., Huq, M. S., Das, I. J., Ibbott, G. S., Hanson, W. F., Slowey, T. W., Williamson, J. F., Coursey, B. M., "Procedures for establishing and maintaining consistent air-kerma strength standards for low-energy, photon-emitting brachytherapy sources: recommendations of the Calibration Laboratory Accreditation Subcommittee of the American Association of Physicists in Medicine," Med Phys 31 (3), 675-81 (2004)

8. W. M. Butler, W. S. Bice, Jr., L. A. DeWerd, J. M. Hevezi, M. S. Huq, G. S. Ibbott, J. R. Palta, M. J. Rivard, J. P. Seuntjens et al., "Third-party brachytherapy source calibrations and

physicist responsibilities: report of the AAPM Low Energy Brachytherapy Source Calibration Working Group," Med Phys **35** (9), 3860-5 (2008).

These two short reports outline AAPM recommendations on operational aspects of maintaining NIST traceability of brachytherapy vendor calibrations. Reference 6 describes minimum standards for vendor-NIST-ADCL S_K intercomparisons while 7 discusses the problems encountered by hospital physicists in verifying calibrations of prepackaged seeds previously calibrated by third party calibration services. See reference NN in low energy seed section.

9. Nath,R, Amols, H, Coffey, C, Duggan, D, Jani, S, Li, Z, Schell, M, Soares, C., Whiting, J, Cole, P, Crocker, Schwartz, R., “Intravascular brachytherapy physics: Report of the AAPM Radiation Therapy Committee Task Group No. 60, Med. Phys. 26: 119-152, 1999.
   The dosimetry fundamentals and source strength specification practices for intravascular brachytherapy, especially beta-emitting sources, differ significantly from those of photon-emitting sources.

10. Williamson, J.F., Coursey, B.M., DeWerd, L.A., Hanson, W.F., Nath, R. and Ibbott, G. “Guidance to Users of Nycomed Amersham and North American Scientific, Inc. I-125 Interstitial Sources: Dosimetry and Calibration Changes: Recommendations of the American Association of Physicists in Medicine Radiation Therapy Committee Ad Hoc Subcommittee on Low-Energy Seed Dosimetry,” Med. Phys. 26:570-573, 1999.

    How to adapt prescribed doses for I-125 implants to accommodate change from classical to TG-43 dose calculations and how to correct for transition from NIST 1985 to 1999 standards.

11. Williamson, J.F., Butler, W., DeWerd, L. A., et al., "Recommendations of the American Association of Physicists in Medicine regarding the Impact of Implementing the 2004 Task Group 43 report on Dose Specification for ^{103}Pd and ^{125}I Interstitial Brachytherapy," Med. Phys **32**: 1424-1239, 2005.
12. Rivard, M. J., Butler, W. M., Devlin, P.M., Hayes, J.K., Hearn, R.A., Lief, E.P., Meigooni, A.S, Merrick, G.S., and Williamson, J. F. “American Brachytherapy Society recommends no change for prostate permanent implant dose prescriptions using iodine-125 or palladium-103,” Brachytherapy 6 (2007) 34-37
    References 12 and 13 provide current guidance on adapting prescribed doses for Pd-103 implants to accommodate transition from old vendor activity standard to NIST 1999 standard as well as revised TG-43 dose-calculation parameters.

High Energy Brachytherapy Sources

1. Goetsch SJ, Attix FH, Pearson DW and Thomadsen BR (1991)"Calibration of ^{192}Ir high-dose-rate afterloading systems," Med. Phys 18: 462-467, 1991.
   Classic paper describing interim secondary standard for HDR Ir-192 sources used in absence of national primary standard.

2. Li, Z., Das, R. K., DeWerd, L. A., Ibbott, G. S., Meigooni, A. S., Pérez-Calatayud, J., Rivard, M. J., Sloboda, R. S., and Williamson, J. F., "Dosimetric prerequisites for routine clinical use of photon emitting brachytherapy sources with average energy higher than 50 kev," Med. Phys. 34, 37-40 (2007).

3. Perez-Calatayud, F. Ballester. R. K.. Das. L. A. DeWerd, G. S. Ibbott, A. S. Meigooni, Z. Ouhib, M. J. Rivard, R. S. Sloboda, and J. F. Williamson, Dose calculation for photon-emitting brachytherapy sources with average energy higher than 50 keV Report of the AAPM and ESTRO," Med. Phys. 39: 2904-2929 (2012).

AAPM dosimetric recommendations, similar in scope to TG-43 reports for low energy seeds, but for Cs-137, Ir-192, and other sources emitting mean photon energies greater than 50 keV. Reference 3, often referred to as the HEBD report, is a major milestone, outlining in detail dosimetric recommendations for high energy sources and presenting consensus datasets in TG-43 format for approximately 20 source models

4. Williamson, J.F., "Monte Carlo-based Dose-Rate Tables for the Amersham CDCS.J and 3M Model 6500 ^{137}Cs Tubes," *Int. J. Radiat. Oncol. Biol. Phys*..41: 959-1970, 1998.
Modern "away and along" dose rate tables for most commonly used Cs-137 intracavitary tubes using Monte Carlo simulation. Analysis of Sievert integral accuracy.

5. Williamson, J.F., "The Sievert Integral Revisited: Evaluation and Extension to ^{125}I, ^{169}Yb and ^{192}Ir Brachytherapy Sources," *Int. J. Radiat. Oncol. Biol. Phys*. 36(5):1239-1250, 1996.
Thorough analysis of accuracy limitations of Sievert integral dose-calculation model for low-energy brachytherapy sources.

More Low Energy Brachytherapy Dosimetry References

1. L. A. DeWerd, J. A. Micka, S. M. Holmes, and T. D. Bohm, "Calibration of multiple LDR brachytherapy sources," Med Phys **33** (10), 3804-13 (2006)
Practical discussion of verifying mean strength of multiple seed assemblies (preloaded needles, magazines, etc.) using reentrant ion chambers.

2. Monroe, J.I. and Williamson, J.F.: Monte Carlo-Aided Dosimetry of the Theragenics TheraSeed® Model 200 ^{103}Pd Interstitial Brachytherapy Seed. Med. Phys., 29:609-621, 2002.
3. Dolan, J., Li, Z., and Williamson, J. F., "Monte Carlo and experimental dosimetry of an ^{125}I brachytherapy seed," Med. Phys. 33: 4675-4684 (2006)
A pair of papers illustrating the speaker's approach to applying Monte Carlo simulation and TLD dosimetry to determination of single-source dose-rate distributions for Pd-103 and I-125 seeds, including the impact of the primary standard calibration device (WAFAC).

4. R. E. Wallace, "LDR sources: design and delivery systems," in *Brachytherapy Physics: Second Edition*, edited by B. R. Thomadsen, M. J. Rivard and W. M. Butler (Medical Physics Publishing, Madison, WI, 2005), pp. 31-45.
Good discussion of LDR sources, including low energy seeds.

Quality Assurance Readings and AAPM Reports

1. J. Venselaar and J. Pérez-Calatayud, "A Practical Guide to Quality Control of Brachytherapy Equipment: ESTRO Booklet No. 8," (European Society for Therapeutic Radiology and Oncology, Brussels, 2004).
2. S. Nag, R. Dobelbower, G. Glasgow, G. Gustafson, N. Syed, B. Thomadsen, and J. F. Williamson, "Inter-society standards for the performance of brachytherapy: a joint report from ABS, ACMP and ACRO," Crit Rev Oncol Hematol **48** (1), 1-17 (2003).
3. Nath, R., Anderson, L.L., Meli, J.A., Olch, A.J., Stitt, J.A. and Williamson, J.F., "Code of Practice for Brachytherapy Physics: Report of the AAPM Radiation Therapy Committee Task Group No. 56", Med. Phys. 24: 1557-1648, 1997.
4. B. R. Thomadsen, *Achieving quality in brachytherapy* (Institute of Physics Publishing, Philadelphia, 1999).
5. G. P. Glasgow, "An apercu of codes, directives, guidances, notices, and regulations in brachytherapy," in *Brachytherapy Physics: Second Edition*, edited by B. R. Thomadsen, M. J. Rivard and W. M. Butler (Medical Physics Publishing, Madison, WI, 2005), pp. 173-186USNRC, U.S. Nuclear Regulatory Commission Regulations: Title 10, *Code of Federal Regulations, Part 20,* "Standards for Protection Against Radiation," and Part 35, "35--Medical Use of Byproduct Material", Available in PDF format at http://www.nrc.gov/reading-rm/doc-collections/cfr/cfr-title-10.zip.
Reference 3 provides the most detailed and comprehensive set of brachytherapy QA guidelines published date. The document mainly addresses device QA; process-oriented QA for LDR non-image-based brachytherapy and treatment planning; and dosimetry practice. The QA recommendations for re-entrant ionization chambers, table-based brachytherapy dose-calculation algorithms, and treatment delivery systems, including remote afterloaders, are still valid today as are interim guidelines for source-strength standardization of HDR Ir-192 sources. Only limited discussion of patient- and procedure-specific QA for image-guided permanent seed implants and HDR brachytherapy is included. See TG-59 for a good discussion of the latter. Reference 2 is synthesizes in one document AAPM and ACR guidance circa 2000 into a single document that is much shorter than AAPM TGs but more detailed than ACR standards. References 1 and 4 are useful and highly detailed QA references. US NRC regulations are required periodic reading to maintain currency of regulatory knowledge. While most states are not regulated directly by USNRC, the Suggested State Regulations and most agreement state regulations adhere closely to NRC regulations.

6. B. Fraass, K. Doppke, M. Hunt, G. Kutcher, G. Starkschall, R. Stern, and J. Van Dyke, "American Association of Physicists in Medicine Radiation Therapy Committee Task Group

53: quality assurance for clinical radiotherapy treatment planning," Med Phys 25 (10), 1773-829 (1998).

7. IAEA, "Commissioning and quality assurance of computerized planning systems for radiation treatment of cancer," Report No. Technical Reports Series No. 430, International Atomic Energy Agency, Vienna, 2004.

Reference 6 gives the current AAPM guidance on image-based planning systems. While it mainly addresses external beam, many of the non-dosimetric tests and guidelines are applicable to brachytherapy. The IAEA report is basically a more technically detailed version of TG-53.

8. M. M. Goodsitt, P. L. Carson, S. Witt, D. L. Hykes, and J. M. Kofler, Jr., "Real-time B-mode ultrasound quality control test procedures. Report of AAPM Ultrasound Task Group No. 1," Med Phys 25 (8), 1385-406 (1998)

9. D. Pfeiffer, S. Sutlief, W. Feng, H. M. Pierce, and J. Kofler, "AAPM Task Group 128: quality assurance tests for prostate brachytherapy ultrasound systems," Med Phys 35 (12), 5471-89 (2008).
10. S. Mutic, D. A. Low, G. H. Nussbaum, J. F. Williamson, and D. Haefner, "A simple technique for alignment of perineal needle template to ultrasound image grid for permanent prostate implants," Med Phys 27 (1), 141-3 (2000).
11. Y. Yu, L. L. Anderson, Z. Li, D. E. Mellenberg, R. Nath, M. C. Schell, F. M. Waterman, A. Wu, and J. C. Blasko, "Permanent prostate seed implant brachytherapy: report of the American Association of Physicists in Medicine Task Group No. 64," Med Phys 26 (10), 2054-76 (1999).
12. R. Nath, W. S. Bice, W. M. Butler, Z. Chen, A. S. Meigooni, V. Narayana, M. J. Rivard, and Y. Yu, "AAPM recommendations on dose prescription and reporting methods for permanent interstitial brachytherapy for prostate cancer: Report of Task Group 137," Medical Physics 36 (11), 5310-5322 (2009).

References 8 - 12 represent the available non-dosimetric QA for permanent seed prostate implants. No advisory entity has published guidance on procedure-specific QA and medical error mitigation for or any other example of image-based or -guided brachytherapy.

13. H. D. Kubo, G. P. Glasgow, T. D. Pethel, B. R. Thomadsen, and J. F. Williamson, "High dose-rate brachytherapy treatment delivery: report of the AAPM Radiation Therapy Committee Task Group No. 59," Med Phys 25 (4), 375-403. (1998).

TG-59, which addresses design of non-image-based HDR brachytherapy procedures, is the only AAPM document which focuses almost exclusively on design of clinical process and integrating QA/QC tests into the execution of each clinical procedure.

14. R. Potter, J. Dimopoulos, C. Kirisits, S. Lang, C. Haie-Meder, E. Briot, I. Dumas, E. Van Limbergen, M. De Brabandere et al., "Recommendations for image-based intracavitary brachytherapy of cervix cancer: the GYN GEC ESTRO Working Group point of view: in regard to Nag et al. (Int J Radiat Oncol Biol Phys 2004;60:1160-1172)," Int J Radiat Oncol Biol Phys 62 (1), 293-5; author reply 295-6 (2005).

15. R. Potter, C. Haie-Meder, E. Van Limbergen, I. Barillot, M. De Brabandere, J. Dimopoulos, I. Dumas, B. Erickson, S. Lang et al., "Recommendations from gynaecological (GYN) GEC ESTRO working group (II): concepts and terms in 3D image-based treatment planning in cervix cancer brachytherapy-3D dose volume parameters and aspects of 3D image-based anatomy, radiation physics, radiobiology," Radiother Oncol 78 (1), 67-77 (2006).

Strictly speaking, references 14 and 15 are clinical practice guidelines rather than QA guidance documents. They outline modification of ICRU target volume nomenclature appropriate for definitive radiation therapy of cervical cancer.

16. B. Thomadsen, S. W. Lin, P. Laemmrich, T. Waller, A. Cheng, B. Caldwell, R. Rankin, and J. Stitt, "Analysis of treatment delivery errors in brachytherapy using formal risk analysis techniques," Int J Radiat Oncol Biol Phys 57 (5), 1492-508 (2003).
17. J. F. Williamson, "Current brachytherapy quality assurance guidance: does it meet the challenges of emerging image-guided technologies?" Int J Radiat Oncol Biol Phys 71 (1 Suppl), S18-22 (2008).
18. J. F. Williamson, P. B. Dunscombe, M. B. Sharpe, B. R. Thomadsen, J. A. Purdy, and J. A. Deye, "Quality assurance needs for modern image-based radiotherapy: recommendations from 2007 interorganizational symposium on "quality assurance of radiation therapy: challenges of advanced technology", Int J Radiat Oncol Biol Phys 71 (1 Suppl), S2-12 (2008).
19. J. F. Williamson, B. R. Thomadsen, G. S. Ibbott, and S. Mutic, "Failure Modes and Effects Analysis (FMEA) for Accelerated Partial Breast Irradiation Delivered via High Dose-Rate Intracavitary Brachytherapy," in *Quality and Safety in Radiotherapy: Learning the New Approaches in Task Group 100 and Beyond* edited by B. . R. Thomadsen, Medical Physics Publishing, Madison, WI, pp. 273-349, (2013).

This group of references contains a critical assessment of available brachytherapy QA guidance, most of which was formulated in the 2D brachytherapy planning era and is device centered. Reference 16 is one the first publications to illustrate application of industrial engineering approaches to radiation oncology (brachytherapy specifically) in the form of process tree development, fault tree analysis, and taxonomic-based root cause analysis of reported misadministrations. Reference 19 is a detailed application of TG-100 prospective risk-assessment methodologies to quality management program formulation for breast brachytherapy.

19. DeWerd LA, Ibbott GS, Meigooni AS, Mitch MG, Rivard MJ, Stump KE, Thomadsen BR, and Venselaar JLM. A dosimetric uncertainty analysis for photon-emitting brachytherapy sources: Report of AAPM Task Group No. 138 and GEC-ESTRO. Med. Phys. 2011: 38: 782-801.

Major new AAPM task group report demonstrating that total propagated uncertainty for a coverage factor, k= 1.0, is about 4%-5% at 1 cm distance for both high and low energy sources. The analysis includes uncertainties associated with primary S_K standards, source strength transfers into the clinic, TG-43 parameters, and RTP dose-algorithm interpolation errors.

20. Williamson, J.F., Ezzell, G.A., Olch, A. and Thomadsen, B.R. Quality Assurance for High Dose-Rate Brachytherapy. in Textbook on High Dose Rate Brachytherapy, edited by S. Nag, Futura Publishing Company, Armonk, NY, 1994:147-212.

21. **Study Questions and Problems**

1) Which of the following statements best describes the TG-43 dose-calculation formalism?
   a) An accurate analytical model for estimating doses in brachytherapy _____
   b) A protocol for tabulating measured or calculated dose rates around single brachytherapy sources __ ____
   c) Applicable only to sources emitting photons less than 50 keV ____
   d) Uses nonlinear interpolation to estimate dose rates between tabulated data points ____
   e) Requires independent TLD measurements or Monte Carlo simulations as input ____
   f) b) and e) only ____
   g) b), d) and e) only ____
   h) all [a) through e)]of the above ____

   Answer: (g), because the 2004 formalism is applicable to all photon emitting sources.

2) Using the general 2D formula and data tables from the updated TG-43 report (2004), calculate the dose rate at a distance of 1.3 cm and polar angle of 16 degrees from a model 6711 seed that has an apparent activity of 0.6 mCi.

   Answer

   From Table III: $g_L(1) = 1.0$ and $g_L(1.5) = 0.908 \Rightarrow g_L(1.5) = 0.945$

$$\text{From Table V: } F(r,\theta) = \begin{cases} 0.537 & (r,\theta) = (1,10°) \\ 0.705 & (r,\theta) = (1,20°) \Rightarrow F(1,16°) = 0.638 \\ 0.580 & (r,\theta) = (2,10°) \Rightarrow F(2,16°) = 0.688 \\ 0.727 & (r,\theta) = (1,20°) \end{cases} \Rightarrow F(1.3,16°) = 0.653$$

$$x = 1.3\sin 16 = 0.3583,\ L = 0.3$$

$$y = 1.3\cos 16 = 1.2496$$

$$G(1.3,16) = \frac{\Delta\beta}{Lx} = \left[\tan^{-1}\left(\frac{1.2496+0.3/2}{0.3583}\right) - \tan^{-1}\left(\frac{1.2496-0.3/2}{0.3583}\right)\right]\frac{1}{0.3583\times 0.3}$$

$$= [1.3202 - 1.2588]/(0.1975) = 0.5989$$

$$G(1.0,90) = \frac{2}{Lx}\tan^{-1}\left(\frac{L/2}{x}\right) = 0.9926$$

$$\Lambda = 0.965$$

$$S_K = A_{app}\Gamma\left(\frac{W}{e}\right) = 0.6\times 1.45\times 0.876 = 0.762\ \mu\text{Gy}\cdot\text{m}^2/\text{h}$$

$$\dot{D}(r,\theta) = S_K\cdot\Lambda\cdot\frac{G_L(r,\theta)}{G_L(r_0,\theta_0)}\cdot g_L(r)\cdot F(r,\theta) = 0.762\times 0.965\frac{0.5989}{0.9926}\times 0.945\times 0.653 = 0.274\ \text{cGy/h}$$

3. Assume that you are asked to establish a low-energy seed prostate brachytherapy in a clinic that has not previously performed this procedure.
   a. Describe the process, including equipment selection, you will use to provide a secondarily traceable measurement of air-kerma strength to verify the vendor's calibration assay. Describe the commissioning procedures that TG-56 requires.

b. Describe how you will implement dose-calculation around the selected I-125 or Pd-103 seed and how you will verify the accuracy of the calculated doses before treating patients. (Hint: review the "clinical implementation" section of the 2004 TG-43 report.)

4. Define the concepts of direct and secondary traceability.

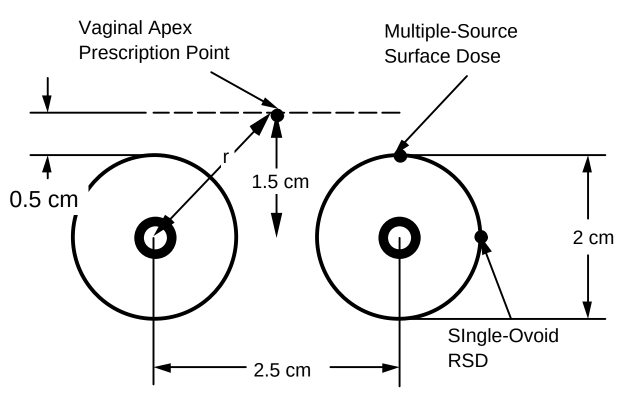
5. Explain why the dose-rate constant for the Model 6711 seed published in the 1995 TG-43 report differs by 15% from the value derived from the classical (1983) dose-calculation model. Explain why the 2004 TG-43 report has changed the dose-rate constant from 0.88 to 0.965.

6. Nuclear medicine dose calibrators are often used as calibration transfer instruments in the clinic to verify air-kerma strength calibrations. They come equipped with radionuclide push buttons, e.g., "Cs-137", "I-125", etc., that provide direct readout in mCi for the selected radionuclide. Explain why you can not calibrate an I-125 seed by pressing the "I-125" button and converting the mCi readout to air-kerma strength.

   <u>Answer:</u> The dose calibrator pushbuttons are designed to approximately (within 10%) realize the NIST radioactivity standards assuming that the sample being measured is in aqueous solution in a standard NIST glass ampoule. Hence the pushbuttons are irrelevant to brachytherapy because they provide inadequately accurate traceability to the wrong standard and assume a source geometry far different from that of an encapsulated seed. This is one of my favorite oral board exam questions.

7. Convert the following to air-kerma strength
   (a) 4.0 mCi ^{125}I seed
   (b) 22 mgRaEq ^{137}Cs source
   (c) 1.5 mg ^{226}Ra needle
   (d) 15 mg ^{226}Ra intracavitary tube

8. Your treatment planning computer is down and an HDR patient is waiting on the treatment table for a post-op endometrial cancer treatment using small (2 cm diameter) Fletcher colpostats.



Manually calculate the dwell time/position needed to deliver 600 cGy to the vaginal apex at depth of 5 mm. Assume that the colpostat centers are separated by 2.5 cm and that the source strength, S_K = 2.50 cGy m^2h^{-1} at the time of treatment. Further assume that dwell positions 1, 2 and 3 are activated uniformly and that the spacing is 5 mm**.**

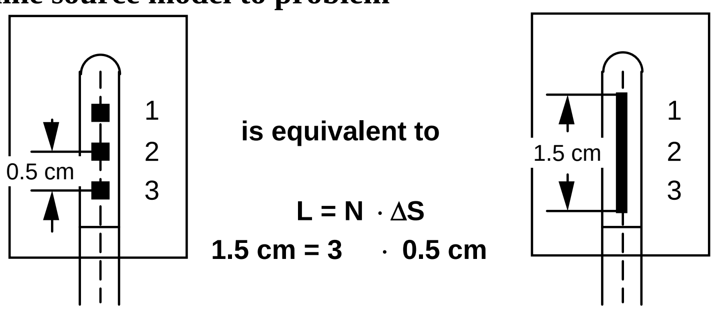
Solution:

(1) Find dose-rate per second at 1 cm from single dwell position

$$\Lambda = S_K \cdot \left[\frac{10^4 \text{ cm}^2/\text{m}^2}{3600 \text{ s/h}}\right] \cdot \left(\mu_{en}/\rho\right)_{air}^{wat}$$

$$= 2.5 \text{ cGy} \times \text{cm}^2 \times \text{h}^{-1} \cdot \left[\frac{10^4 \text{ cm}^2/\text{m}^2}{3600 \text{ s/h}}\right] \cdot 1.11 = 7.71 \text{ cGy} \times \text{cm}^2 \times \text{s}^{-1}$$

(2) Adapt line source model to problem



$$r = \sqrt{1.5^2 + (2.5/2)^2} = 1.95 \text{ cm}$$

(3) Write equation relating, t, dwell time/position to Dose

$$\text{Dose} = 2 \text{ ovoids} \times 3 \text{ dwell positions/ovoid} \times t \cdot \Lambda \cdot \frac{\Delta\theta}{L \cdot r}$$

$$= 6 \cdot t \cdot \Lambda \cdot \frac{2 \cdot \tan^{-1}(L/2r)}{L \cdot r}$$

(4) Substitute values into equation

$$\text{Dose} = 2 \cdot 3 \cdot t \cdot \Lambda \cdot \frac{\Delta\theta}{L \cdot r}$$

$$600 \text{ cGy} = 6 \cdot t \cdot 7.71 \cdot \frac{2 \cdot \tan^{-1}(0.75/1.95)}{1.5 \cdot 1.95}$$

$$= t \cdot 46.3 \cdot \frac{2 \cdot 0.3672}{2.925} = 11.62 \cdot t$$

$$\Rightarrow t = 51.6 \text{ seconds/position}$$