Development and Implementation of a Remote Audit Tool for High Dose Rate (HDR) ^{192}Ir Brachytherapy Using Optically Stimulated Luminescence Dosimetry

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Radiological Physics Center

RPC MD Anderson Radiological Physics Center

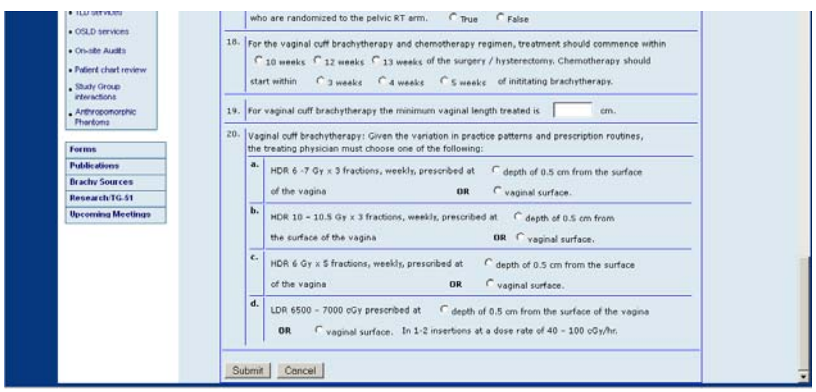
- Founded 1968 – AAPM recommendation
- Mission: *"to assure NCI and the Cooperative groups that institutions participating in clinical trials deliver prescribed radiation doses that are clinically comparable and consistent"*

- **Mailable OSL Dosimeter program – External Beam Machine Output**
  - TLD basis – Photons: 1977, Electrons: 1982
  - OSLD basis – 2010
  - 1,700 institutions/year
    - 14,000 beams/year (2010)
  - Estimated uncertainty = 1.8% (1σ)[1]
  - ±5% acceptance criterion

1) Aguirre *et al.* "SU-E-T-126: Analysis of Uncertainties for the RPC Remote Dosimetry Using Optically Stimulated Light Dosimetry (OSLD)," Med Phys 38, 3515 (2011).

Current RPC HDR Brachytherapy Activities

- **HDR Brachytherapy**
  - Cervical carcinoma: 13.3% (1999) to 85% (2010)
  - Breast cancer: 10x increase from 2002 to 2007
  - RTOG 9517, 0116, 0321, …
- **RPC Activities**
  - Plan Checks
  - Benchmark Plans
  - Questionnaires/Surveys
  - Site Visits (30-50/year)



- OSLD services
- On-site Audits
- Patient chart review
- Study Group interactions
- Anthropomorphic Phantoms

Forms
Publications
Brachy Sources
Research/TG-51
Upcoming Meetings

who are randomized to the pelvic RT arm. ○ True ○ False

18. For the vaginal cuff brachytherapy and chemotherapy regimen, treatment should commence within ○ 10 weeks ○ 12 weeks ○ 13 weeks of the surgery / hysterectomy. Chemotherapy should start within ○ 3 weeks ○ 4 weeks ○ 5 weeks of inititating brachytherapy.

19. For vaginal cuff brachytherapy the minimum vaginal length treated is ____ cm.

20. Vaginal cuff brachytherapy: Given the variation in practice patterns and prescription routines, the treating physician must choose one of the following:

a. HDR 6 -7 Gy x 3 fractions, weekly, prescribed at ○ depth of 0.5 cm from the surface of the vagina **OR** ○ vaginal surface.

b. HDR 10 - 10.5 Gy x 3 fractions, weekly, prescribed at ○ depth of 0.5 cm from the surface of the vagina **OR** ○ vaginal surface.

c. HDR 6 Gy x 5 fractions, weekly, prescribed at ○ depth of 0.5 cm from the surface of the vagina **OR** ○ vaginal surface.

d. LDR 6500 - 7000 cGy prescribed at ○ depth of 0.5 cm from the surface of the vagina **OR** ○ vaginal surface. In 1-2 insertions at a dose rate of 40 - 100 cGy/hr.

Submit Cancel

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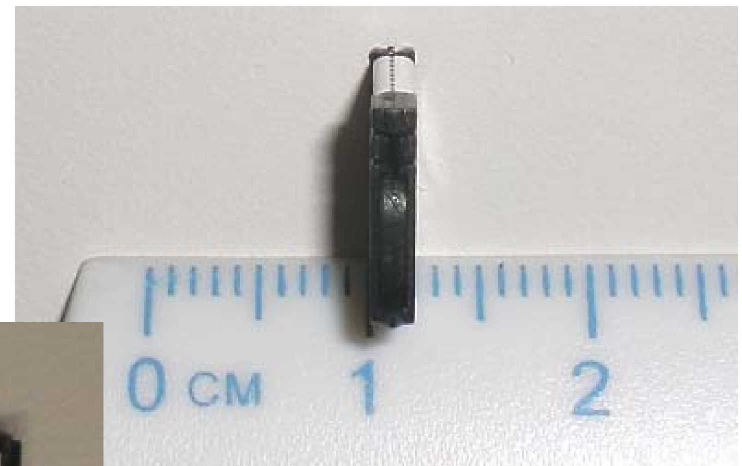
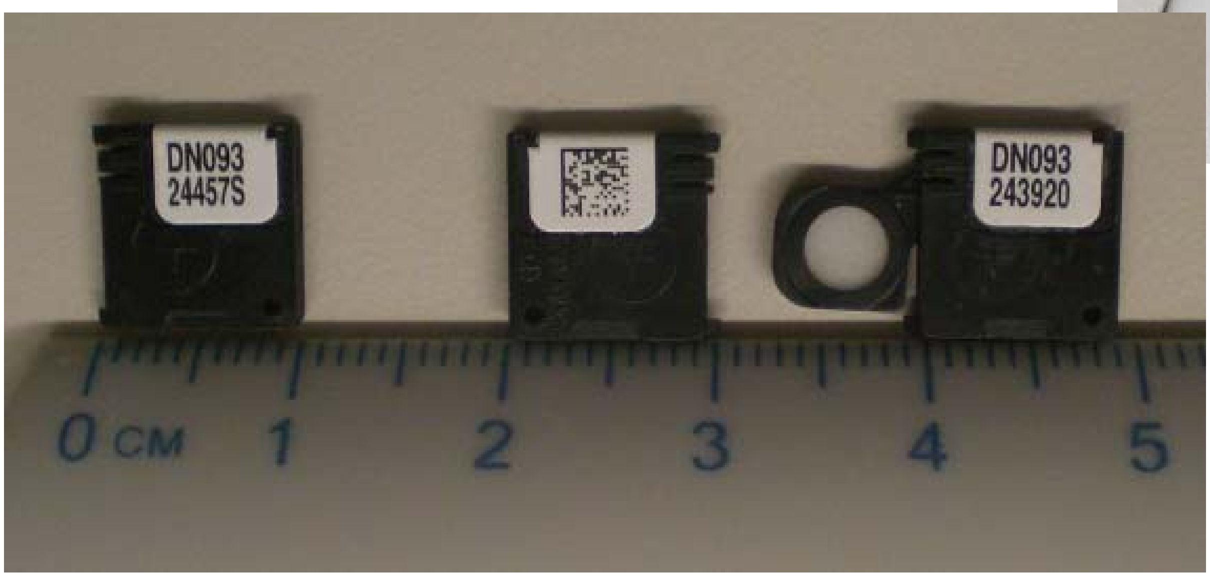
nanoDot OSL Dosimeters

- Landauer, Inc. (Glenwood, IL)
- RPC external beam audit program – 10,000+ in circulation
  - suitably resistant to temperature, humidity changes
- 10 x 10 x 2 mm^3 plastic cassette
- 5 mm-diameter disc of OSL material
- Active dosimeter thickness ~0.3 mm
- Reusable up to 10 Gy accumulated dose





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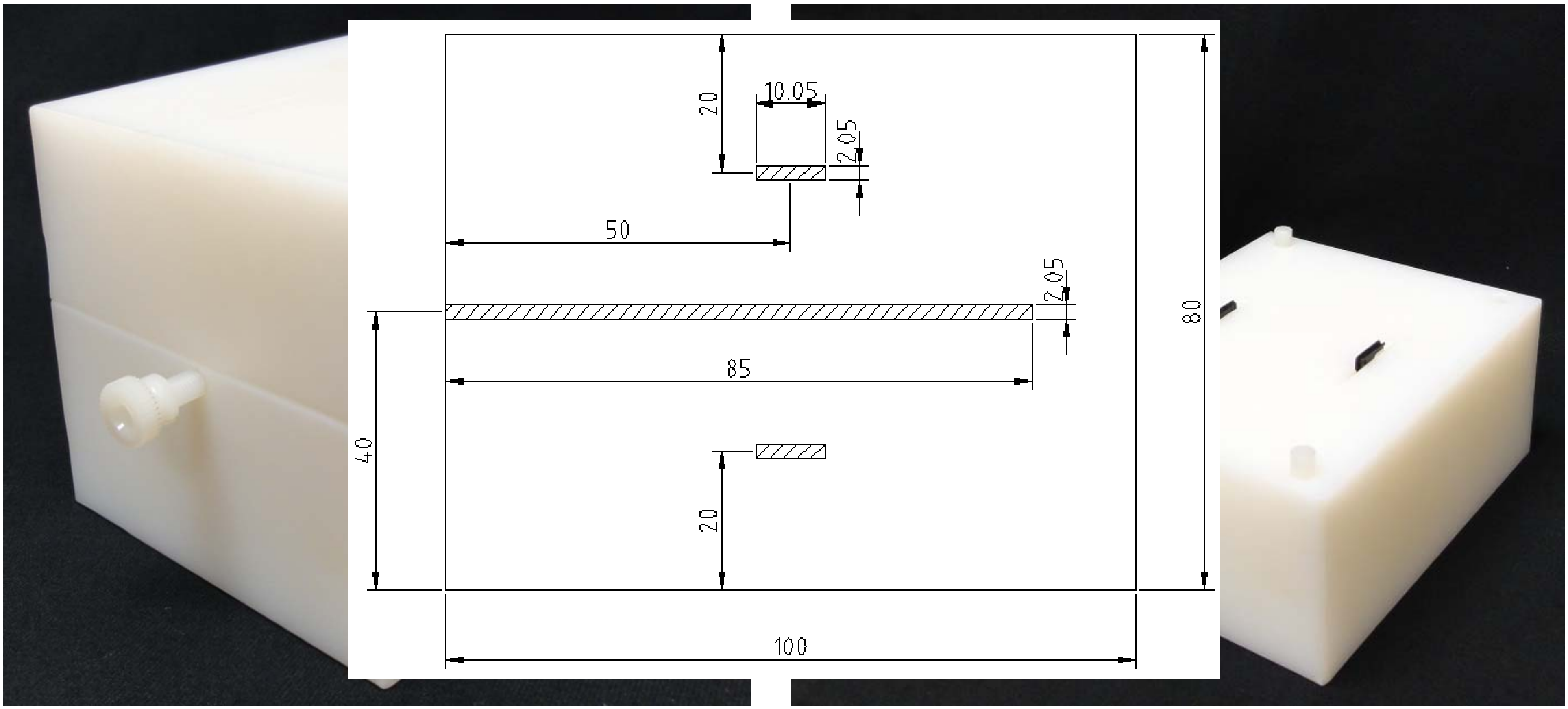
Phantom Prototype



- High Impact Polystyrene (HIPS), $\rho = 1.04$ g/cm^3
- $8 \times 8 \times 10$ cm^3

OSL Dose Calculation

$$Dose = reading \times ECF \times Sensitivity \times K_F \times K_L \times K_B$$

- ***ECF*** =Element Correction Factor
- ***Sensitivity*** = [dose/OSLD count] (referenced to ^{60}Co)
- ***K_F*** = Fading Correction Factor
- ***K_L*** = Linearity Correction Factor
- ***K_B*** = Block Correction Factor (energy, medium, phantom size, angular dependence)

Linearity Correction Factor (K_L)

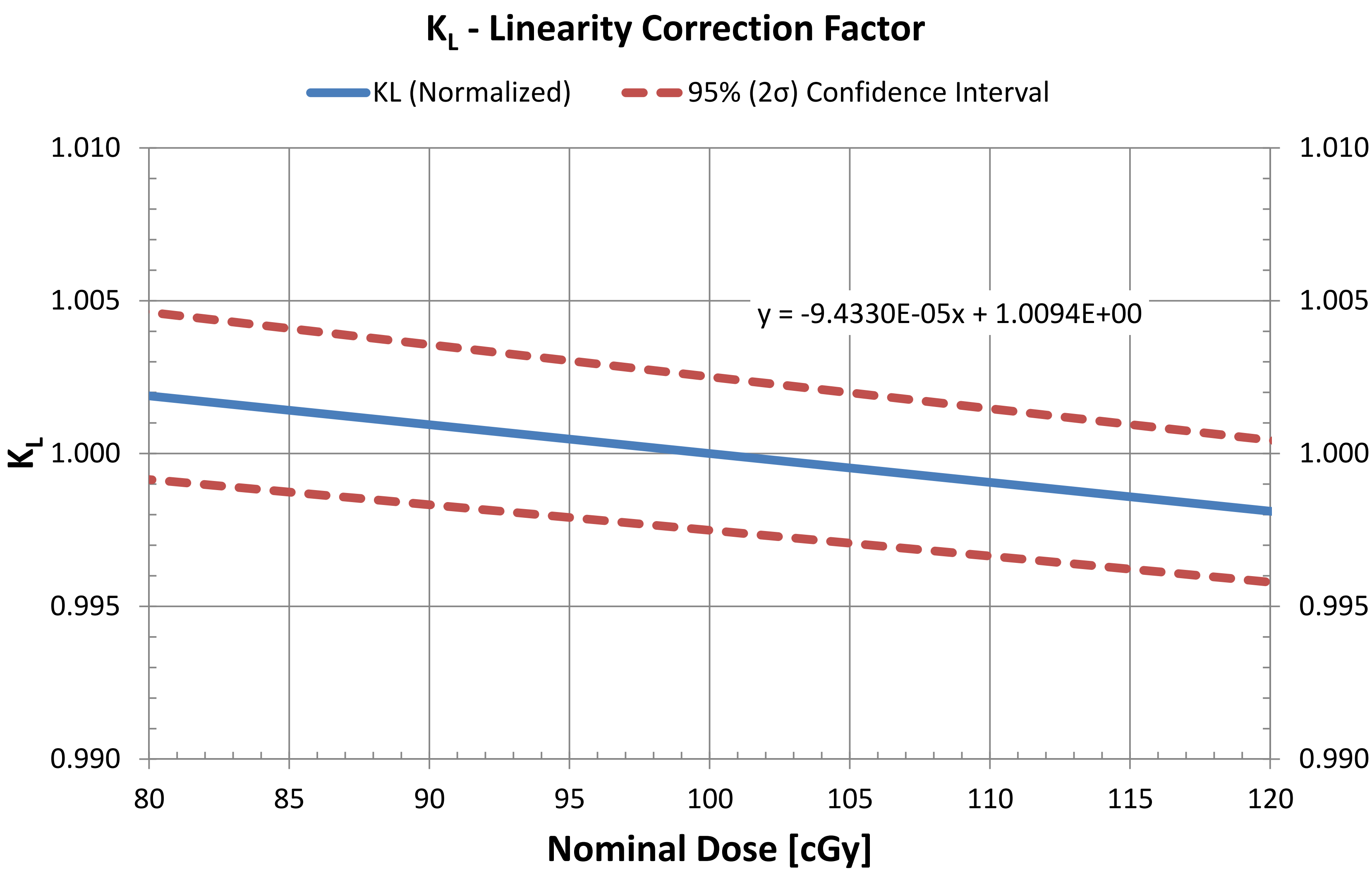
$$Dose = reading \times ECF \times Sensitivity \times K_F \times K_L \times K_B$$

- Irradiation of 78 dosimeters to doses between 50-400 cGy

$$dose\ response = \frac{expected\ dose}{raw\ OSLD\ reading} \quad \left[\frac{\mu Gy}{count}\right]$$

- Plot ***dose response*** versus ***nominal dose***
- Apply linear fit
- Normalize to predicted value at 100 cGy

Linearity Correction Factor (K_L)



Block Correction Factor (K_B)

$$Dose = reading \times ECF \times Sensitivity \times K_F \times K_L \times \boxed{K_B}$$

- Energy dependence of OSL to ^{192}Ir spectrum
- Angular dependence of nanoDots
- Polystyrene ≠ H_2O
- Phantom too small for 100% backscatter

$$\frac{Dose}{reading \times ECF \times Sensitivity \times K_F \times K_L} = \boxed{K_B}$$

Block Correction Factor (K_B)

$$\frac{Dose}{reading \times ECF \times Sensitivity \times K_F \times K_L} = K_B$$

Units are $\left[\frac{Dose^{192}Ir_{water}}{Dose^{60}Co_{phantom}} \right]$

- ***Dose*** = dose to water at point of measurement from TPS
  - NIST-traceable (ADCL) calibration of HDR source
  - Clinical TG-43 parameters
- Nucletron: 20 measurements, Varian: 10 measurements
- Average of individual K_B = overall K_B

Block Correction Factor (K_B)

K_B (Nucletron)	
n	20
Average	1.026
Minimum	1.017
Maximum	1.036
Standard Deviation	0.6 %
Standard Error	0.1 %
99% Confidence Interval	1.022 – 1.029

New Batch = 1.018

K_B (Varian)	
n	10
Average	1.000
Minimum	0.992
Maximum	1.013
Standard Deviation	0.7 %
Standard Error	0.2 %
99% Confidence Interval	0.993 – 1.007

New Batch = 1.004

- > 2.5% difference between Nucletron and Varian
  - Source thickness (Nucletron = 0.65 mm, Varian = 0.34 mm)
- K_B is source and batch specific!

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Remote Audits

Trial	Source Model	RPC Measured Dose [cGy]	Institution Reported Dose [cGy]	RPC/Institution
1	Nucletron	99.9	101.0	0.989
2	Varian	100.4	99.9	1.005
3	Varian	100.0	99.9	1.001
4	Nucletron	100.5	100.6	0.999
5	Nucletron	102.1	100.7	1.014
6	Varian	98.3	100.0	0.983
7	Nucletron	101.3	100.1	1.012
8	Varian	99.4	99.8	0.996
			Average	**1.000**
			Standard Deviation	**0.011**

- RPC: 193 well chamber measurements (1994 – 2011)
- Average RPC/Institution = 1.009
- Standard deviation = 0.014

Acknowledgements

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  - David Followill, Ph.D.
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  - Ann Lawyer, M.S.
- Others:
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  - Scott Davidson, Ph.D.
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  - Paige Summers, M.S.
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  - Mitchell Carroll, M.S.
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Thank You!

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Uncertainty Analysis

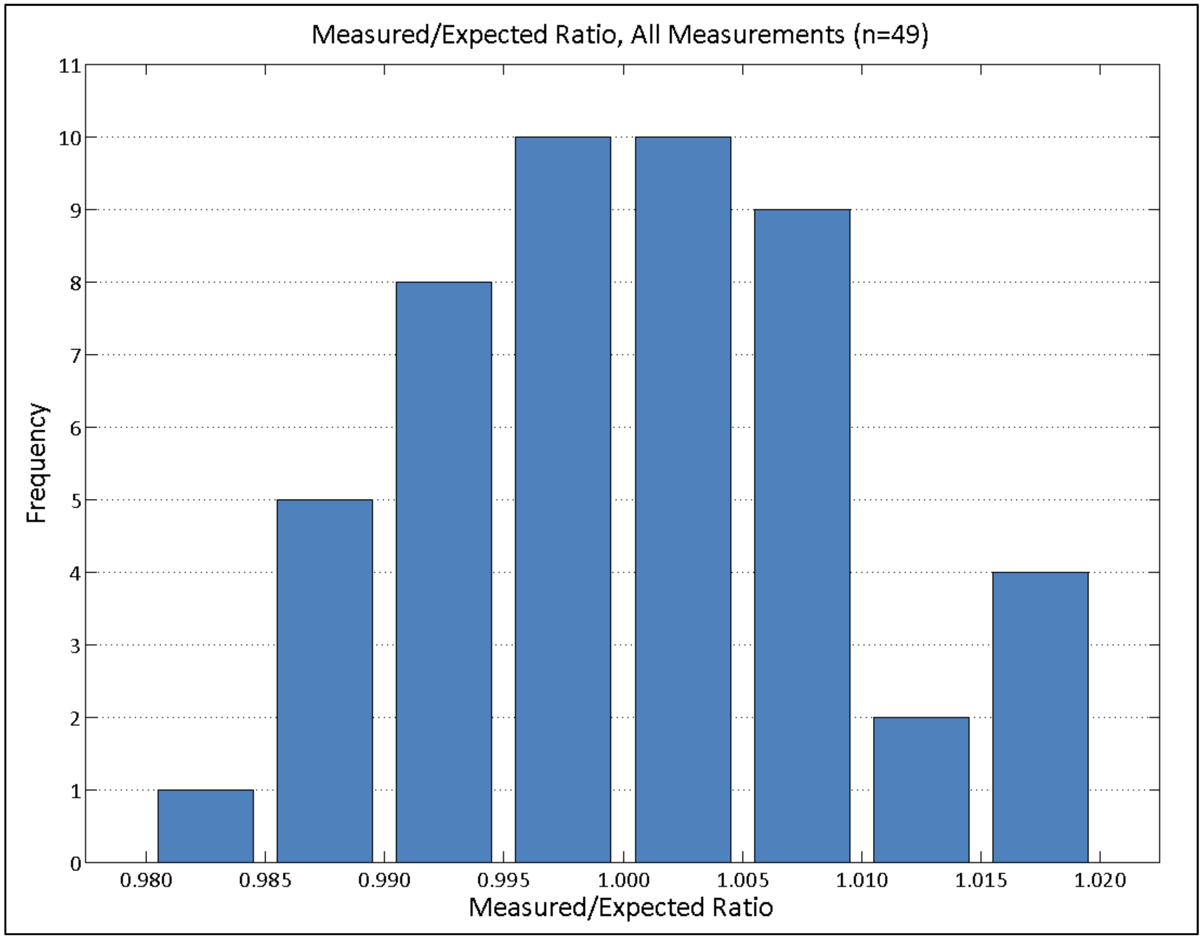
$$Dose = reading \times ECF \times Sensitivity \times K_F \times K_L \times K_B$$

<table>
<tr><th colspan="2">Quantity</th><th colspan="2">Value (Percent)</th><th>Source</th></tr>
<tr><td colspan="2"></td><td colspan="2">0.57</td><td>Aguirre[2]</td></tr>
<tr><td colspan="2"></td><td colspan="2">0</td><td>Aguirre[2] (included in)</td></tr>
<tr><td colspan="2"></td><td colspan="2">0.8</td><td>Aguirre[2]</td></tr>
<tr><td colspan="2"></td><td colspan="2">0.3</td><td>Aguirre[2]</td></tr>
<tr><td colspan="2"></td><td colspan="2">0.15</td><td>68% Confidence Interval of K_L from 90 to 110 cGy</td></tr>
<tr><td colspan="2"></td><td rowspan="2">0.56</td><td rowspan="2">0.67</td><td rowspan="2">1 standard deviation, measured</td></tr>
<tr><td>Nucletron</td><td>Varian</td></tr>
<tr><td colspan="2">Total (2σ)</td><td rowspan="2">2.4</td><td rowspan="2">2.5</td><td rowspan="2"></td></tr>
<tr><td>Nucletron</td><td>Varian</td></tr>
</table>

- TLD program: ±5% acceptance criterion based on 93% confidence level[3]
- ±5% represents approximately 4 standard deviations (~99.99% assuming normal distribution)

2) Aguirre et al. "SU-E-T-126: Analysis of Uncertainties for the RPC Remote Dosimetry Using Optically Stimulated Light Dosimetry (OSLD)," Med Phys 38, 3515 (2011).
3) Kirby *et al.* "Uncertainty analysis of absorbed dose calculations from thermoluminescence dosimeters", Med Phys 19, 1427-1433 (1992).

Measured Uncertainty



- Average = 1.0007; Standard Deviation = 0.009; 2σ = 1.8%
- Without K_B measurements: $2\sigma_{Nucletron}$ = 2.4% $2\sigma_{Varian}$ = 2.5%
  - n = 19; average = 1.0012; standard deviation = 0.012; 2σ = 2.4%

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Remote Audit Instructions

Instructions for Irradiating OSL Dosimeters with HDR

Please find enclosed:

1.) One polystyrene miniphantom containing two OSL dosimeters. The phantom has a single channel with a plastic thumbscrew at its mouth as seen in Figure 1.
2.) An HDR OSLD Irradiation Form

Figure 1: The HDR remote audit phantom.

General Audit Instructions:

1.) Set up, plan, and irradiate the OSLD as instructed below.
2.) The phantom contains sensitive dosimeters. Do not expose it to radiation until ready to deliver the plan described below.
3.) Fill out the enclosed Irradiation Form. Include a print-out of your treatment plan, showing the 100 cGy isodose line.
4.) Return the HDR remote audit phantom, Irradiation Form, and plan print-out to the RPC in a box. For your convenience, UPS shipping instructions and label are enclosed.
5.) Please try to irradiate and return the phantom within two weeks of its receipt.

Setup Instructions:

a) The two halves of the phantom should remain firmly pressed together at all times. Do not attempt to separate the phantom or remove the dosimeters.
b) Loosen but do not remove the thumbscrew.
c) Insert a single 2mm-diameter (6 French) catheter through the thumbscrew and into the channel. The distal end of the catheter should be positioned against the end of the channel. The other end of the catheter should be connected to your HDR unit.
d) Tighten the thumbscrew to secure the catheter in place. The thumbscrew should be snug enough to resist movement of the catheter, but not enough to inhibit the passage of the source. Make sure that the catheter does not get pulled out of the channel as the screw is tightened.
e) During irradiation, the phantom may be placed in whatever orientation is convenient, as long as the two halves remain pressed together and the source can move freely within the catheter.

Planning and Irradiation Instructions:

a) Use 10 dwell positions, with 5 mm spacing.
b) Use only the most distal dwell positions available, skipping none.
c) Optimize dwell times individually for each dwell position in order to deliver **100 cGy** to a line located 2 cm away and parallel to the catheter channel. (see Figure 2)
d) Record the dose to a point 2 cm away from the center of the channel laterally and on a line bisecting the source train. ("Point A" in Figure 2)
e) Deliver the plan only once.
f) Record the dwell times and dose to "Point A" on the enclosed HDR OSLD Irradiation Form.
g) Print out a copy of your treatment plan showing the 100 cGy isodose line (additional isodose lines may be included if convenient) and include this print-out with the Irradiation Form.

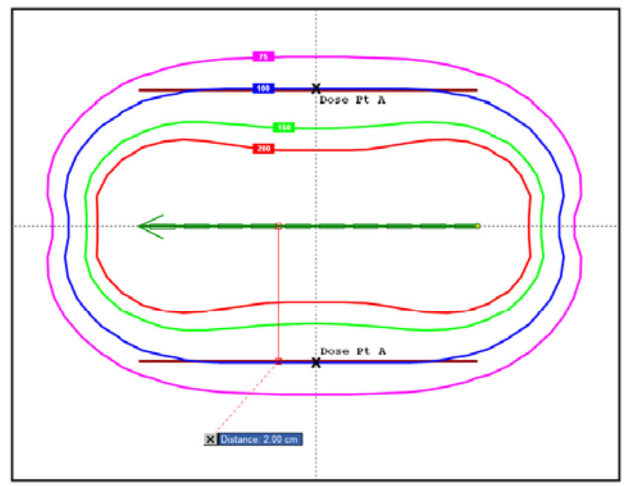


Figure 2: Example isodose lines for the HDR audit are shown above. Dwell times should be optimized to deliver 100 cGy along a line 2 cm away and parallel to the catheter channel. Additional non-100 cGy isodose lines are shown for illustrative purposes, and need not be matched by your plan exactly or included on the Irradiation Form. The dose Point A is located 2 cm away from the catheter channel laterally and along a line which bisects the source train. The dose at this point should be calculated during treatment planning and reported on the Irradiation Form.

Remote Audit Irradiation Form

RPC MD Anderson
Radiological Physics Center

Radiological Physics Center
1515 Holcombe Blvd., Unit 607
Houston, TX 77030
Tel (713) 745-8989
Fax (713) 794-1364
Email: rpc@mdanderson.org
http://rpc.mdanderson.org

Ir-192 HDR OSLD Irradiation Form

		Correct?	
Institution Name:	____________________	☐ Yes	☐ No
Person to receive report:	____________________	☐ Yes	☐ No

Email Address of person to receive report: ____________________

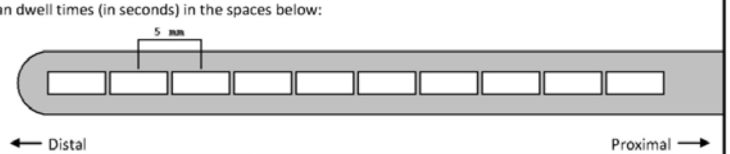
Person irradiating OSLD, if different from above: ____________________
Phone Number: (____) ____________ Email address: ____________________

Person creating treatment plan, if different from above: ____________________
Phone Number: (____) ____________ Email address: ____________________

For questions regarding OSLD irradiation, if different from above: ____________________
Phone Number: (____) ____________ Email address: ____________________

Afterloader Manuf.: ____________	Source Model: ____________
In-House Designation: ____________	Source Serial #: ____________
Afterloader Model: ____________	Date of Calibration: ____________
Afterloader Serial #: ____________	Activity at Calibration: ____________ Ci
	Air Kerma Rate at Calib.: ____________ µGy m^2 h^{-1}
Planning System: ____________	Date of Irradiation: ____________
Vendor: ____________	Activity at Irradiation: ____________
Version Number: ____________	Air Kerma Rate at Irradiation: ____________ µGy m^2 h^{-1}
Dose Calculation Algorithm: ____________	

Enter plan dwell times (in seconds) in the spaces below:



Using your Treatment Planning System, calculate the dose at a point 2.0 cm away from the center of the channel laterally and along a line bisecting the source train ("Point A"). Record the point dose below:

Point A Dose: ____________ cGy

Include a print-out of your treatment plan showing the 100 cGy isodose line.