The clinical use of OSLD

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Outline

- Introduction
- Dose calculation
- Other practical considerations
- Low-energy applications

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Commercial OSLD

- Nanodot from Landauer
- Al_2O_3:C
- Crystal grown, crushed, mounted onto discs, mounted into light-tight case
- Disc is 4mm in diameter and 0.2 mm thick
- Density 1.41 (average) 3.95 (crystal)
- Effective atomic number: 11.28

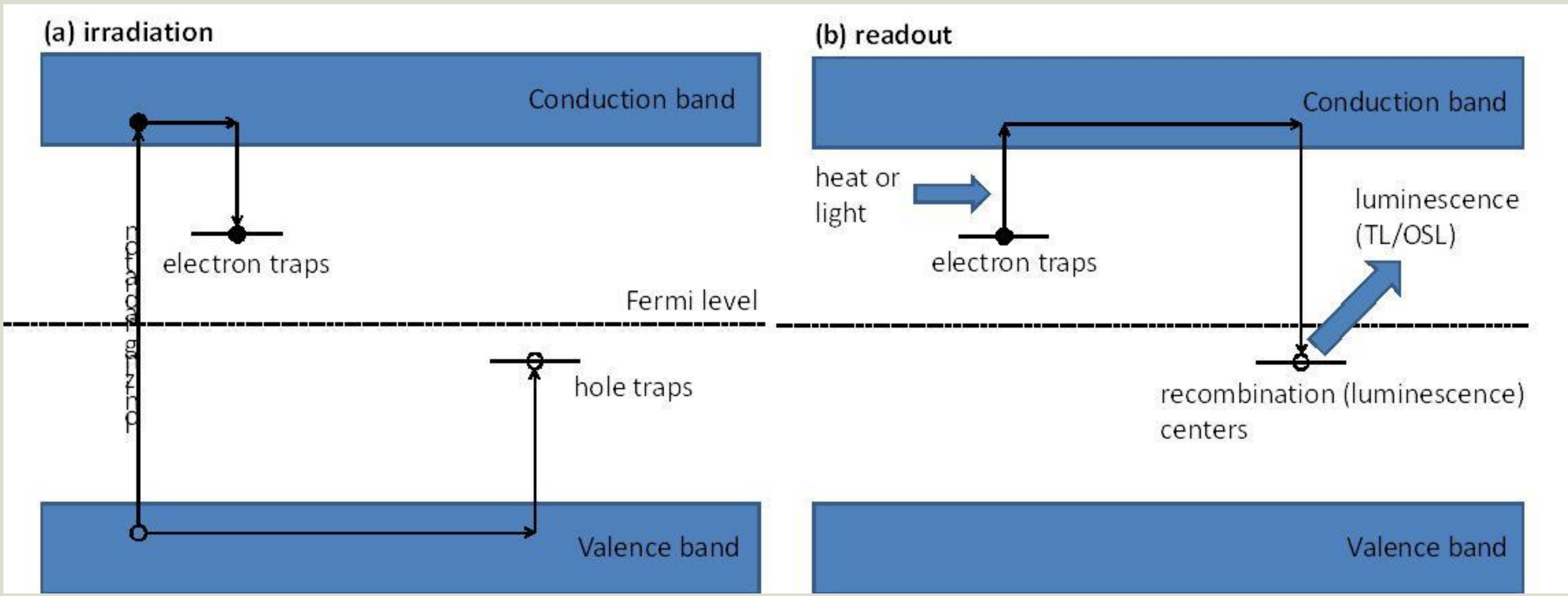
Upcoming relevant TG

- TG-191: Clinical use of luminescent dosimeters: TLD and OSLD

- Stephen F. Kry, Paola Alvarez, Joanna Cygler, Larry DeWerd, Rebecca M. Howell, Sanford Meeks, Jennifer O'Daniel, Chester Reft, Gabriel Sawakuchi, Eduardo Yukihara

- Expected publication date: 2016

Stimulation and Read-out



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Calculating Dose

D = M * N * Correction factors

$$D_w = M_{corr} \cdot N_{D,w} \cdot k_F \cdot k_L \cdot k_Q \cdot k_\theta$$

$$M_{corr} = \frac{k_{s,i} \cdot \sum_j \left(M_{raw,j} \cdot k_{d,j} \right)}{j}$$

Variables

- M – signal (counts)
- N – calibration coefficient (cGy/count)
- k_Q – beam quality correction factor
- k_L – dose non-linearity correction factor
- k_F – fading correction factor
- k_θ – angular dependence correction factor
- k_d – depletion correction factor
- $k_{S,i}$ – element sensitivity correction factor

Signal

- M is the number of counts
- Read detector multiple times (3)
  - Improved statistics
  - Verify performance of dosimeter/reader
    - Standard deviation in repeat reads should be <2%, usually <1%

Calibration

- We need to relate number of counts to dose
- Irradiate "standards" to a known dose

$$N_{D,w} = \frac{D_0}{\left(M_{0,corr}\right)}$$

- Similar process as for an ion chamber
- Can determine N for each session
- Can create a calibration curve
  - N across dose ranges – N + k_L

Depletion (k_d)

- Only a small part of signal is lost during read-out
- 0.03 - 0.07 % / reading (high dose scale)
- 0.25 % / reading (low dose scale)
- Usually irrelevant (but not always)
- Varies between readers (must characterize)

$$M_{corr} = \frac{k_{s,i} \cdot \sum_j \left(M_{raw,j} \cdot k_{d,j} \right)}{j}$$

$$M_{corr} = k_{s,i} \cdot M_{raw}$$

Element Sensitivity Correction $k_{s,i}$

$$k_{s,i} = \frac{\overline{M}}{M_i}$$

- Sensitivity of dot vs. ave
- Screened dots
  - Assume $k_{s,i}$ is unity for all dots
  - It's not: ±2.5% uncertainty (1-sigma)
- Unscreened
  - Must deal with variations
    - Reuse detectors
  - Establish and track $k_{s,i}$

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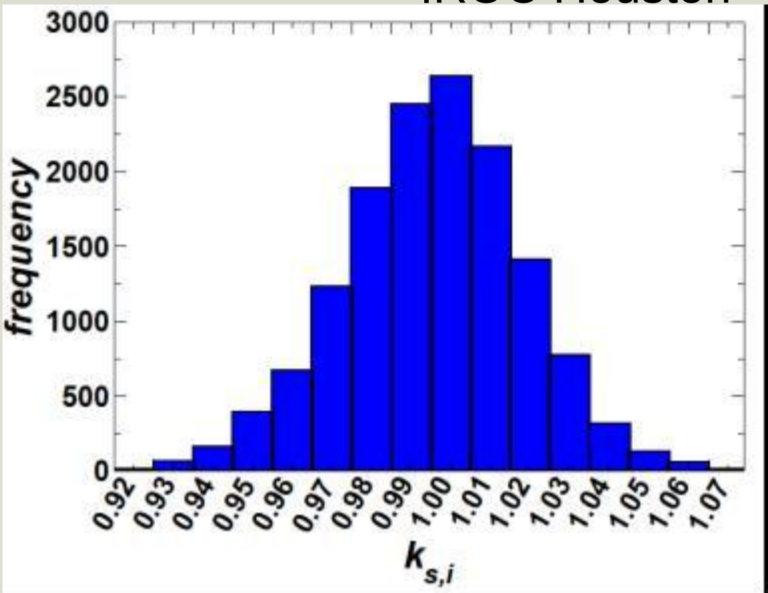
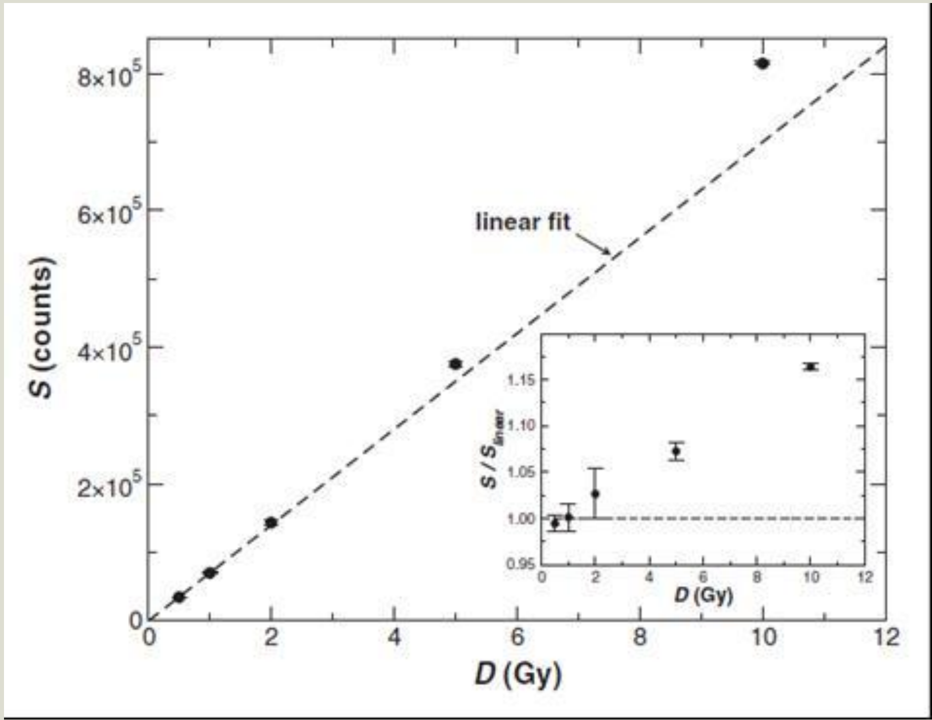


Linearity k_L

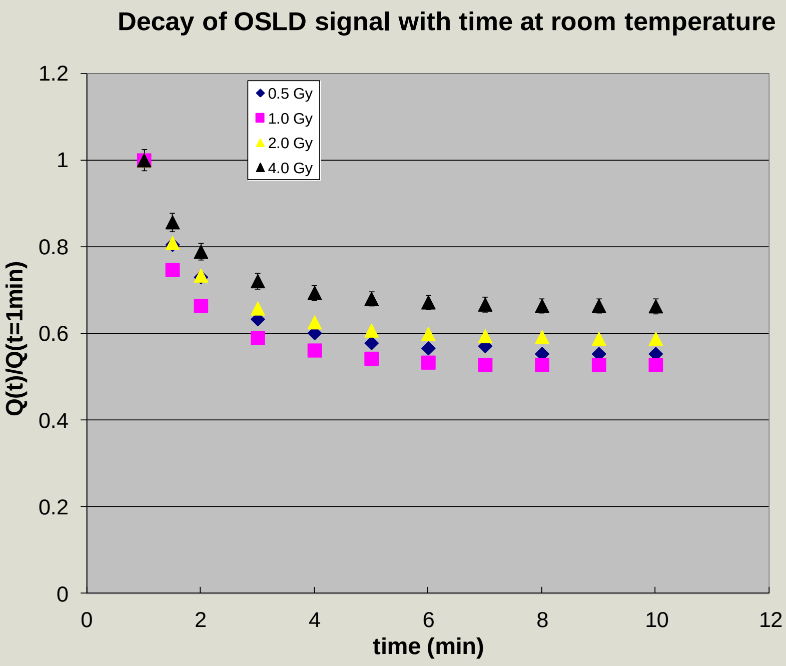
- Response is supralinear over most dose response range
- Correction is notable for 2 Gy
  - 2-3% compared to 1 Gy
  - Roll into calibration curve
  - Create correction curve



Otomaya et al. Med Phys 2012

Fading k_F

- Severe fading in first ~8 minutes
- DO NOT READ!!
  - 10 minute wait
- After this
  - 1 % / month
- Worry about it for long term record



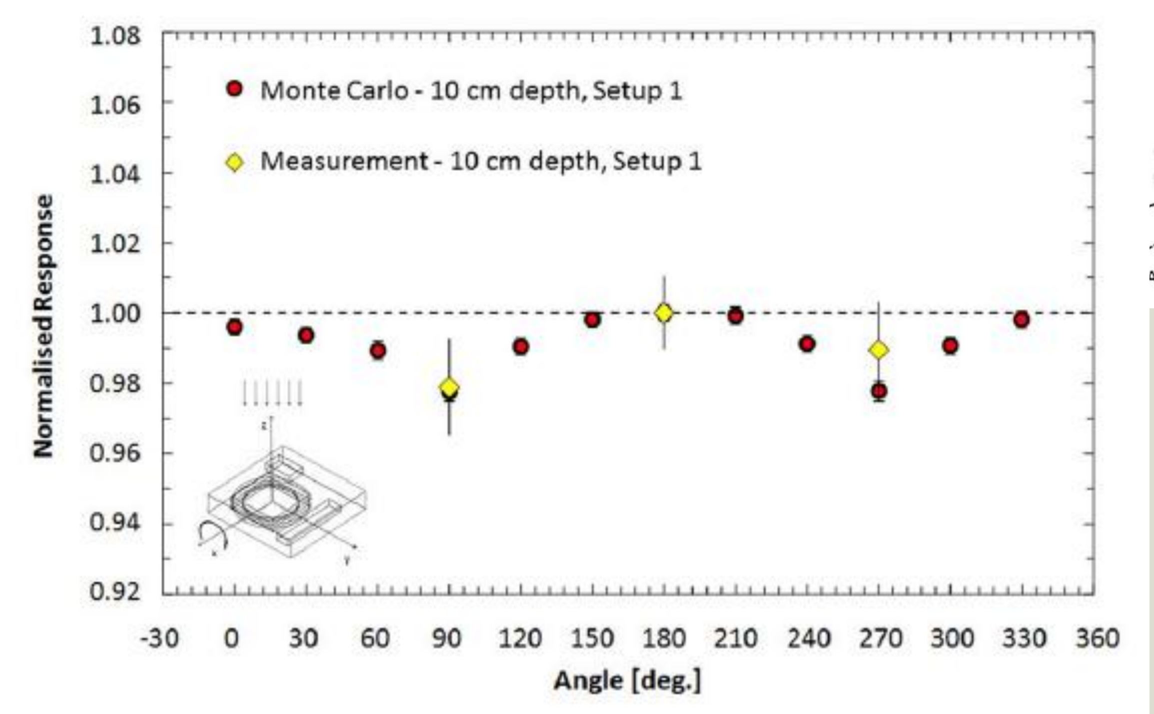
Reft Med Phys 2009

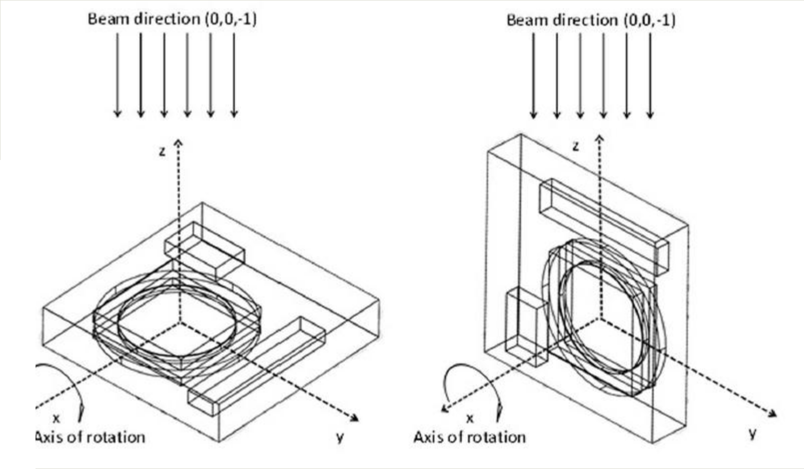
Beam quality k_Q

- At dmax under reference conditions, response changes by ~1% from 6 MV to 18 MV
- As field size and depth change, spectrum changes, effect is up to 3% relative to dmax reference conditions
- Outside the treatment field response can overestimate the dose by 30% or more because of the soft spectrum
- In imaging applications the response can overestimate the dose by a factor of 3+ relative to MV calibration

Angular dependence k_θ

- En-face vs edge on
  - 2% difference in a 6X beam





Lehmann et al Med Phys 2014

Where does that leave us?

$$D_w = M_{corr} \cdot N_{D,w} \cdot k_F \cdot k_L \cdot k_Q \cdot k_\theta$$

$$M_{corr} = \frac{k_{s,i} \cdot \sum_j \left(M_{raw,j} \cdot k_{d,j}\right)}{j}$$

If this is not a long term record or maximum precision scenario:

$$D_w = M_{raw} \cdot N_{D,w} \cdot k_L \cdot k_Q \cdot k_{s,i}$$

If using a calibration curve N and kL are combined
If using screened dosimeters ks,i assumed to be unity

$$D_w = M_{raw} \cdot N_{D,w}(Dex) \cdot k_Q$$

If you generate a calibration curve for each energy:

$$D_w = M_{raw} \cdot N_{D,w}(Dex, Qex)$$

Calibration

Ion Chamber

- $D = M\ N\ P_{tp}\ P_{ion}\ k_Q$ ….
- D and M are related by N under calibration conditions
- Calibration conditions more than just 10x10 at 100 cm SSD
  - Full ion collection, STP, Co-60
- The corrections relate the measurement conditions to the calibration conditions – where N is defined and valid
- The calibration conditions are logical
  - STP, full ion collection, reference beam

OSLD

- $D = M\ N\ k_L\ k_F\ k_\theta\ k_Q$ ….
- Same relationship
- Calibration conditions include
  - Dose, beam quality, time, orientation
- Corrections also relate measurement conditions to the calibration conditions – where N is defined and valid
- Calibration conditions are less natural
  - What dose? what time after irradiation? What angle of incidence? What beam?

Calibration conditions

- For ion chamber
  - Logical reference conditions
    - Co-60, STP, full ion collection
- For OSLD, no natural default
  - Can pick arbitrary calibration conditions
  - Flexible – minimize corrections for given application
  - Requires application of appropriate correction factors to get back to the calibration conditions selected
  - N is a function of the irradiation conditions of the standards

N = N (dose level, time since irradiation, beam quality, orientation, reader mode, reader……)

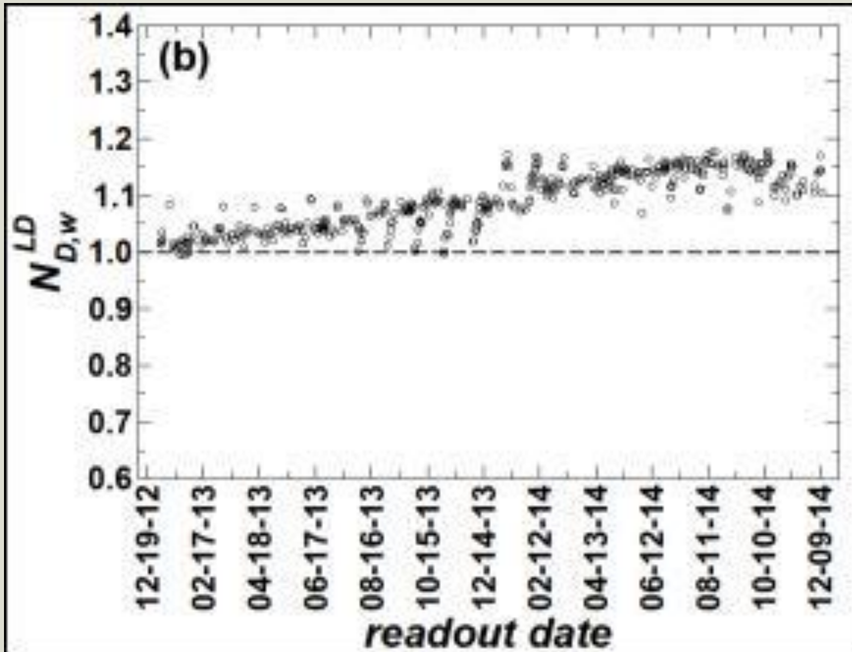
Calibration option 1

- Shoot standards and determine N for each session
  - Match experimental conditions most closely
  - Minimize correction factors
  - Account for any changes in reader performance

- Minimize uncertainty
- More work
  - Shoot standards for each session
  - Characterize detectors so can correct because it won’t be a perfect match

Calibration option 2

- Create a calibration curve
  - Provides a one-time N and k_L relationship to get dose from signal
  - What about k_Q, k_θ, k_F.
    - Manage or ignore with increased uncertainty.
- **Stability/consistency in N?**
- Big differences between readers
- 1.2% variation (1-sigma) day-to-day
- Can see large scale drift
- Must monitor stability in N!



Constancy dosimeter

If you generate a calibration curve, keep an eye on it:

Irradiate a constancy dosimeter (irradiated to a known dose and corrected for fading a depletion).

1. Correct for session-specific reader output to determine N (scale output)
2. Use N established at the time of the calibration curve – verify no large scale drifts with constancy dosimeter.

Use common sense with a constancy dosimeter. Reader performance should not change drastically!

Let’s put this all together

- Calculate dose
- High precision vs. high efficiency

Dose calculation

High Precision

- N is determined for each session to optimally match the experimental conditions
- Determine relative sensitivity of each dot ($k_{s,i}$)
- Batch-based correction factors: k_L, k_F, k_Q, k_θ are determined at commissioning and applied
- Multiple detectors are used and read multiple times
- Correction factors are minimized to minimize uncertainty

$$D_w = M_{raw} \cdot N_{D,w} \cdot k_L \cdot k_F \cdot k_Q \cdot k_\theta \cdot k_{s,i}$$

High Efficiency

- Generate a calibration curve over range of relevant doses at most common energy (N, k_L).
  - Verify curve with constancy dot for each session
- Use screened dots (ignore $k_{s,i}$)
- Ignore k_F, k_Q, k_θ
- Detectors are read multiple times
- Minimize correction factors – match experimental conditions and calibration conditions to the extent possible

$$D_w = M_{raw} \cdot N_{D,w}(D_{ex})$$

Dosimetric Uncertainty

	OSLD			
	High Precision		High Efficiency	
Variable	Controlled	Less Controlled	Controlled	Less Controlled
D_0	0.6	0.6	0.9	0.9
M_0	0.8	1.6	1.4	2.0
M_{raw}	0.8	1.6	0.8	1.6
k_L	0.3	0.6	0.3	0.6
k_F	0.1	0.2	1.0	2.0
k_Q	0.9	2.9	1.0	3.0
$K_{s,i}$	-	-	2.5	2.5
K_θ	0.0	1.0	0.0	1.0
Total (1-sigma)	**1.6**	**3.9**	**3.4**	**5.3**
Total (2-sigma)	**3.2**	**7.9**	**6.9**	**10.6**

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Handling

- Background signal
  - Can subtract pre-irradiation signal from M_{raw}.
  - For un-irradiated dot: not necessary unless monitoring very low doses (imaging)
    - Assumes you don’t deliver super-high dose to dot
- You can immerse in water for a reasonable period of time
- If detector pops open, don’t lose a lot of signal
- Warm up reader before use (or leave it on continuously)
- Operator can influence precision
  - Knob turning is a skill! 1-2% extra uncertainty for novice operators

Re-use: Bleaching

- Not recommended to use signal differential
  - don’t accumulate signal and measure the signal difference before and after each irradiation
- Bleaching is easy and works well
- Expose the detector to light: empty traps
  - Revert to background counts
- Light source doesn’t matter too much
  - Don’t have a UV component
    - Adds signal

Re-use: Limits

- Bleaching does not empty deep traps
- This affects relative trapping and recombination efficiency
  - **Changes sensitivity!**
  - **Changes supralinearity!**
- Relationship is complicated
  - Depends on bleaching regimen = messy
- Do not use past 10 Gy

Commissioning and QA

- TG-191 details commissioning and QA procedures
- Commissioning Reader
- Commissioning Detectors
- Per-session QA
- Annual QA

- Tests and tolerances depend on calibration approach – high precision vs high efficiency

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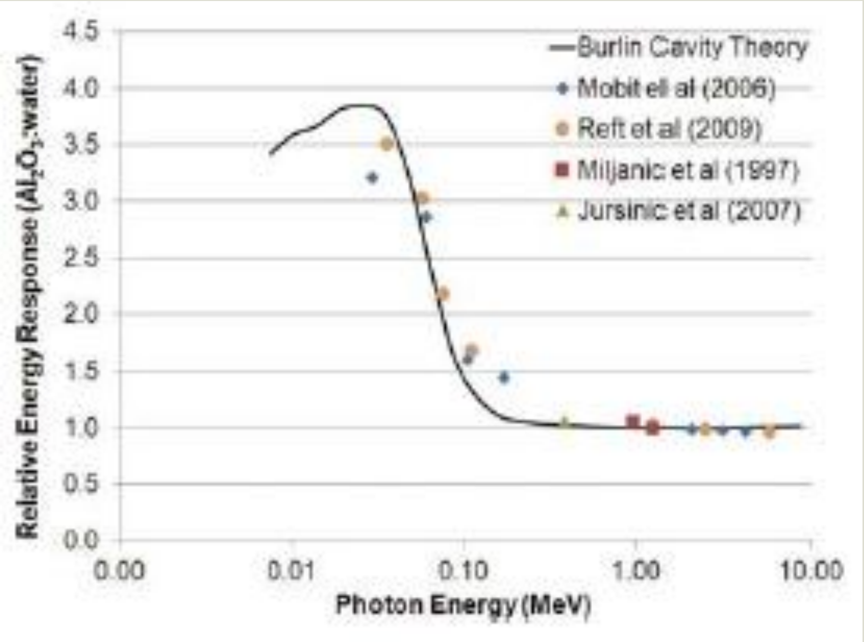
Low Energy Applications

- Low energy applications
  - Brachytherapy, imaging, out of field
- k_Q
  - Corrections are large relative to MV
  - Highly sensitive to spectral variations
- k_θ
  - 5% in brachytherapy
  - 10% in CT
  - 70% in mamo
  - Depends on scatter
    - complicated

Scarboro Rad Prot Dosim 2013



Low Energy Applications

- k_Q can be factor of 3-4
  - Overestimates dose if not accounted for
    - Out of field vs in-field: 30% difference
    - kV imaging signal/dose: 3X signal/dose in MV beam
- k_Q varies with measurement condition
  - 10% variation with measurement location for Ir-192 (2 cm vs. 10 cm of solid water)
  - 3% difference between Varian and Nucletron Ir-192 sources
  - >25% variation with CT scan parameter/measurement conditions

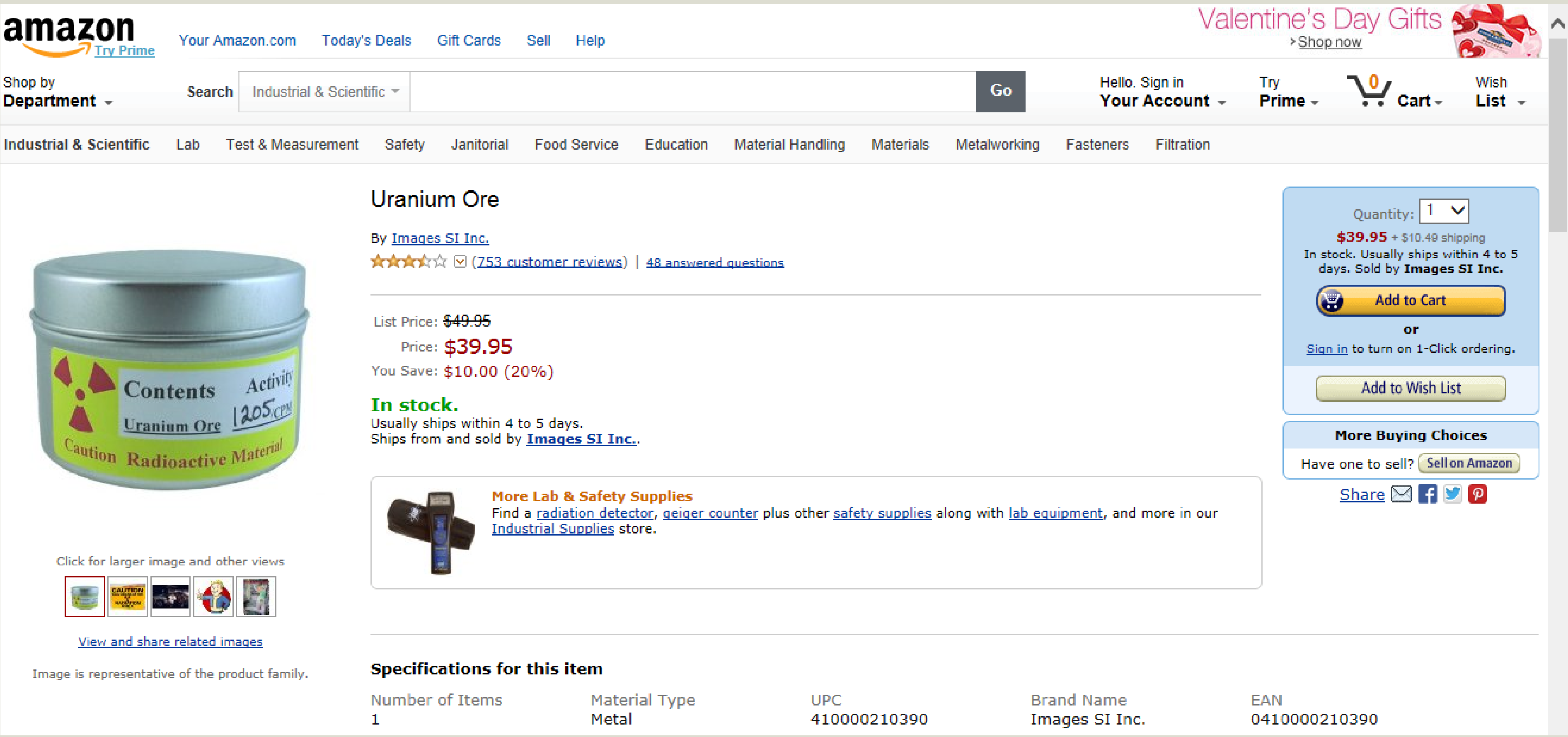
Low Energy Applications

- Determine and apply large correction factor
  - Use a known dose in the low E environment to determine relative signal/dose
  - Correct with k_Q
- Calibrate in low-E conditions
  - Determine N_{DW} or a calibration curve in the beam of interest
    - Roll into N_{DW}
  - Still may need to correct for specific conditions
    - Smaller k_Q

Summary

- Versatile point dosimeters
- Offer good accuracy/precision
- Flexible implementation
  - With documented associated uncertainties

Thank You!



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Selected references

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Q1: What is the maximum cumulative dose that should be given to OSLD?

20%	1.	1 Gy
20%	2.	2 Gy
20%	3.	5 Gy
20%	4.	10 Gy
20%	5.	15 Gy

10

A1: 4

- 10 Gy
- Sensitivity and non-linearity characteristics change beyond this dose

Mrcela et al PMB 56: 6065-6082; 2011

Omotayo et al Med Phys 39: 5457-5468; 2012

Q2: What approximate precision in absolute dose (1-sigma) is possible with an OSLD program measuring dose in a controlled setting?

20%	1.	0.5%
20%	2.	1.0%
20%	3.	1.5%
20%	4.	2.5%
20%	5.	5.0%

10

A2: 3

- 1.5%
- This is following a high precision protocol
- This is under controlled irradiation conditions
- Clinical applications (lower precision and less control of irradiation conditions):

  3-5% (1-sigma)

Kry et al Med Phys 41: 394; 2014

Q3: Compared to a calibration in a megavoltage beam, by how much does OSLD over-respond in a CT environment?

20%	1. A factor of 1.1
20%	2. A factor of 1.3
20%	3. A factor of 2
20%	4. A factor of 3
20%	5. A factor of 10

10

A3: 4

- A factor of 3

- Reft Med Phys 36:1690-1699;2009
- Scarboro et al Radiation Protection Dosimetry 153: 23-31; 2013

Q4: Shallow traps fade rapidly after irradiation. How long must one wait after irradiating OSLD before reading them out to avoid this signal loss?

20%	1.	1 minute
20%	2.	10 minutes
20%	3.	1 hour
20%	4.	12 hours
20%	5.	24 hours

10

A4: 2

- 10 minutes

- Signal drops by ~40% between 1 min and 10 min

Jursinic Med Phys 34: 4594-4604; 2007

Reft Med Phys 36:1690-1699;2009

Q5: Which parameter does not affect the calibration coefficient

20%	1. The specific reader used
20%	2. Time between irradiation and readout
20%	3. Dose level
20%	4. Leaving the reader on continuously
20%	5. Beam quality used to irradiate standards

10

A5: 4

- Leaving the reader on continuously
  - This is a reasonable approach to ensuring the PMT is warmed up for use

- The relationship between signal and dose (N) is defined for a specific condition on a specific reader
- The calibration coefficient will depend on which reader you use, the time between irradiation and readout, dose level, and the beam quality.

- Jursinic Med Phys 34: 4594-4604; 2007
- Mrcela et al Phys Med Biol 56: 6065-6082; 2011
- Dunn et al, Radiation Measurements 51-52: 31-39; 2013