Development of an Optically Stimulated Luminescence (OSL) Dosimetry System for Measuring Medical Radiation Exposure

Matthew Oh[1], Keith Griffin[1], Ronaldo Minniti[2], Michelle O'Brien[2], Roberto Maass-Moreno[3], Choonsik Lee[1], and Matthew Mille[1]

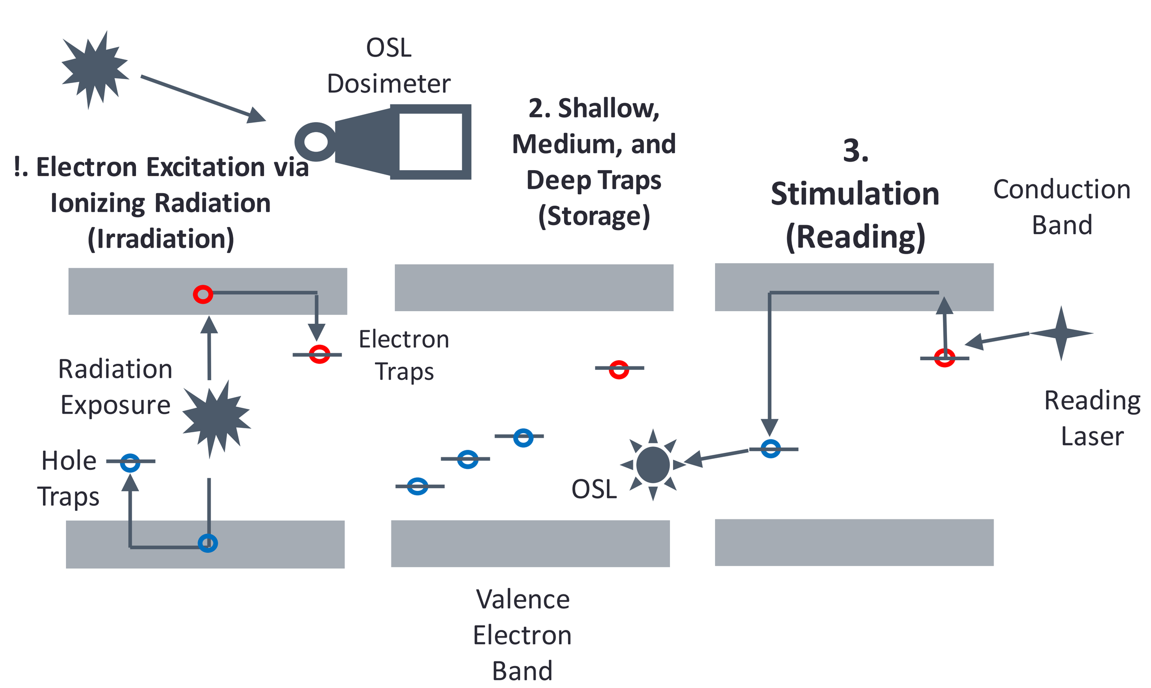
[1]Division of Cancer Epidemiology and Genetics, National Cancer Institute, National Institutes of Health, Rockville, MD

[2]Radiation Physics Division, National Institute of Standards and Technology, Gaithersburg, MD

[3]Department of Nuclear Medicine, National Institutes of Health, Bethesda, MD

BACKGROUND

- The NCI purchased an OSL dosimetry system to measure medical radiation exposure
- Ionizing radiation creates free electron-hole pairs which are captured in a metastable state at impurities in the OSL crystal (AlO_3:C)
- Stimulation of the OSL by reading laser results in recombination of the electron-hole pairs and emission of visible light
- The number of electron-hole pairs and emitted photons is proportional to the radiation dose



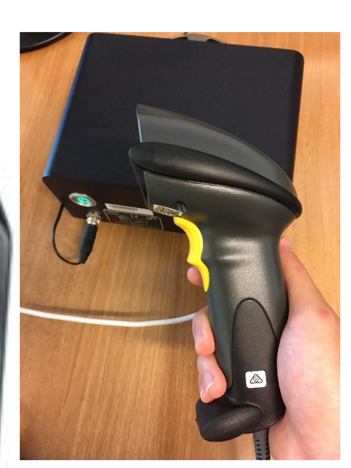
OBJECTIVE

An OSLD program requires a calibrated reader and the ability to clear the signal from the dosimeters for reuse.

The objectives of this study were:

- To calibrate the OSLDs for measuring dose at various CT and fluoroscopy x-ray beam qualities
- To use the OSLDs inside a physical phantom to measure organ dose received by a patient undergoing a typical brain CT scan
- To create a light box to clear the OSLDs of signal so they can be used in future experiments

Landauer Microstar II Dosimeter Reader



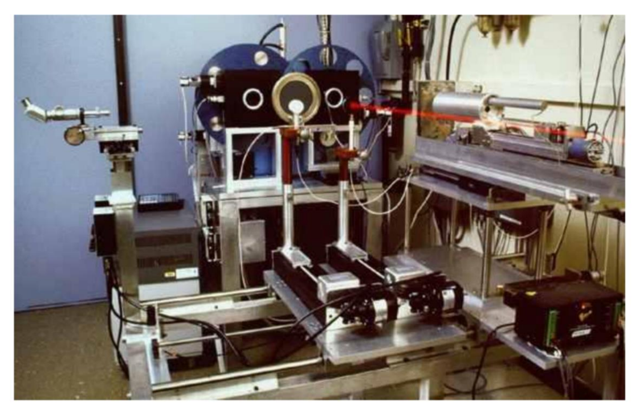
Barcode Scanner

NanoDot OSLD w/Barcode and Crystal Retracted

METHODS

Calibration of Reader

- Background readings on 300+ dosimeters were recorded at NCI
- Dosimeters were irradiated at NIST using x-ray beams similar to those used for CT imaging and fluoroscopy
- National air kerma rate at fixed distance from x-ray source was established using the Wyckoff-Attix free-air ionization chamber
- Calibration factors for various beams were calculated by comparing net raw counts reported by the reader to the known air kerma delivered
- Calibrations factors were calculated for the strong (<50 mGy) and weak reading modes (> 50 mGy)



NIST X-ray Calibration Range

Wyckoff-Attix Free-Air Ionization Chamber

$$Calibration\ Factor = \left(\frac{Average\ OSL\ Reading - Background}{Air\ Kerma\ (mGy) * Sensitivity}\right)$$

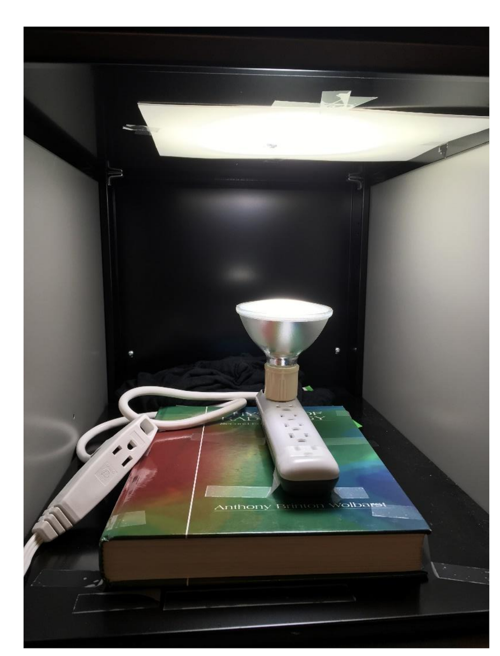
CT Dosimetry at NIH Clinical Center

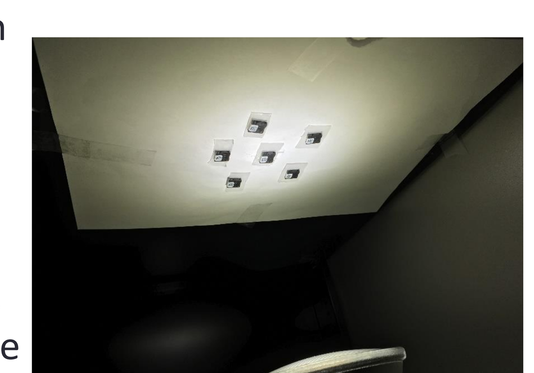
- Background readings on 165 dosimeters were recorded at NCI
- Dosimeters inserted into a pediatric physical phantom to measure dose to selected organs for a typical brain CT scan
- Corrections were applied to account for differences between exposure and calibration conditions

$$Dose\ (mGy) = \left(\frac{Average\ OSL\ Reading - Background}{Calibration\ Factor * Sensitivity}\right) \times \frac{(\mu_{en}/\rho)_{tissue}}{(\mu_{en}/\rho)_{air}} \times k_{\theta}$$

Clearing Dosimeter Signal for Reuse

- A box was created to illuminate the dosimeters with LED light (GE Indoor Floodlight, 75 W, 850 lumens) to clear the stored signal
- Preliminary testing was performed using dosimeters irradiated to known air kerma (200 or 300 mGy) using NIST M100 X-ray Beam
- Dosimeters were opened to expose the OSL crystal a distance of 6''
- The fraction of remaining signal on the OSL was recorded as function of illumination time ranging between 12 seconds and 8 hours
- Data were fit to a theoretical model to estimate fraction of signal stored in shallow, medium, and deep traps and the respective clearance half-lives



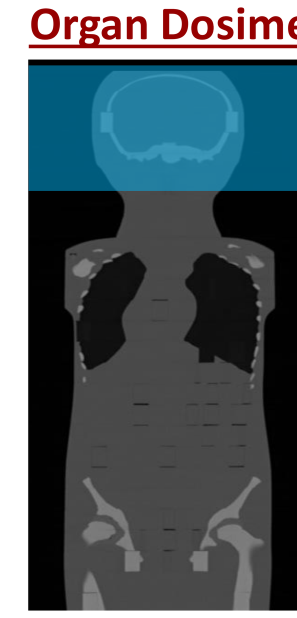


RESULTS

Measured Calibration Factors for Different X-ray Beams

NIST Beam Code	X-Ray kVp	HVL (mm Al)	Calibration Factor (net counts/mGy)			
			Strong Read Beam		Weak Read Beam	
			Mean	COV (%)	Mean	COV (%)
M80	80	3.08	1118	4.4	167	2.7
M100	100	5.10	967	3.3	142	3.0
M120	120	6.77	847	3.0	127	2.9
F6-70	70	7.07	926	2.0	136	3.3
F9-70	70	7.86	895	2.6	131	1.7

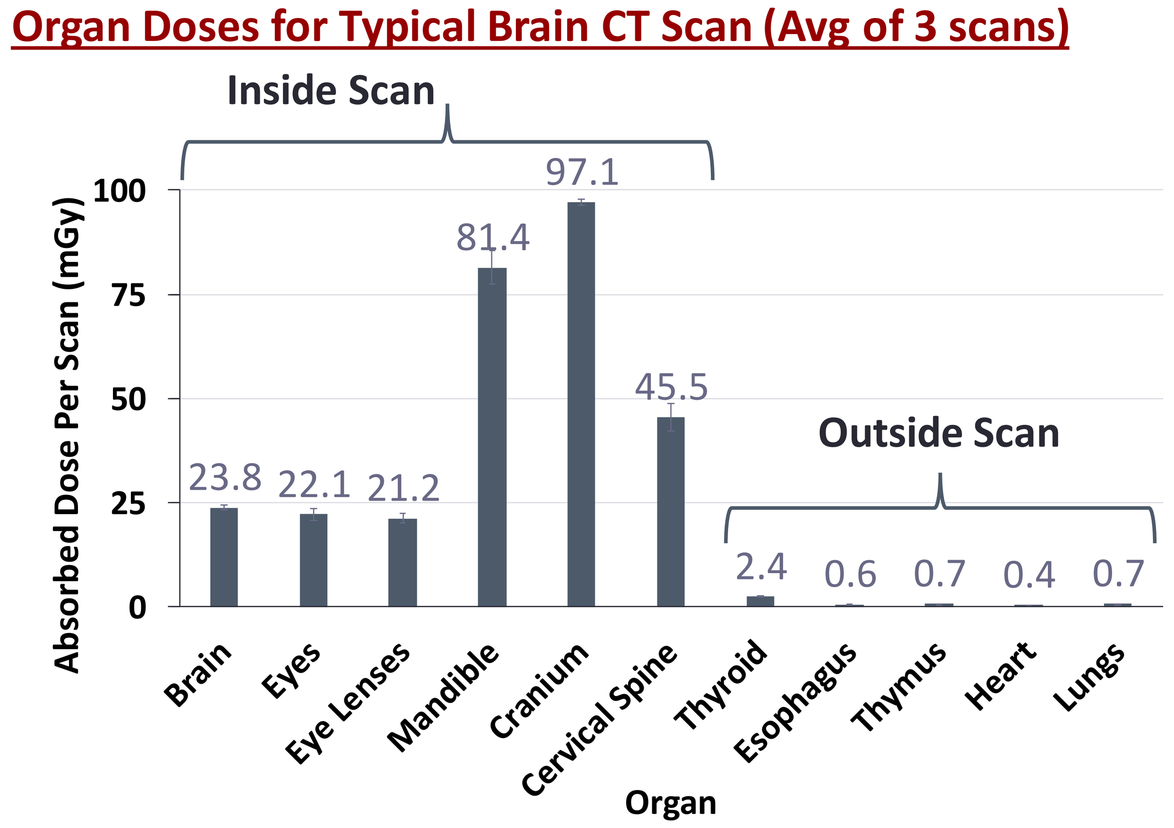
Organ Dosimetry for Typical Brain CT Scan



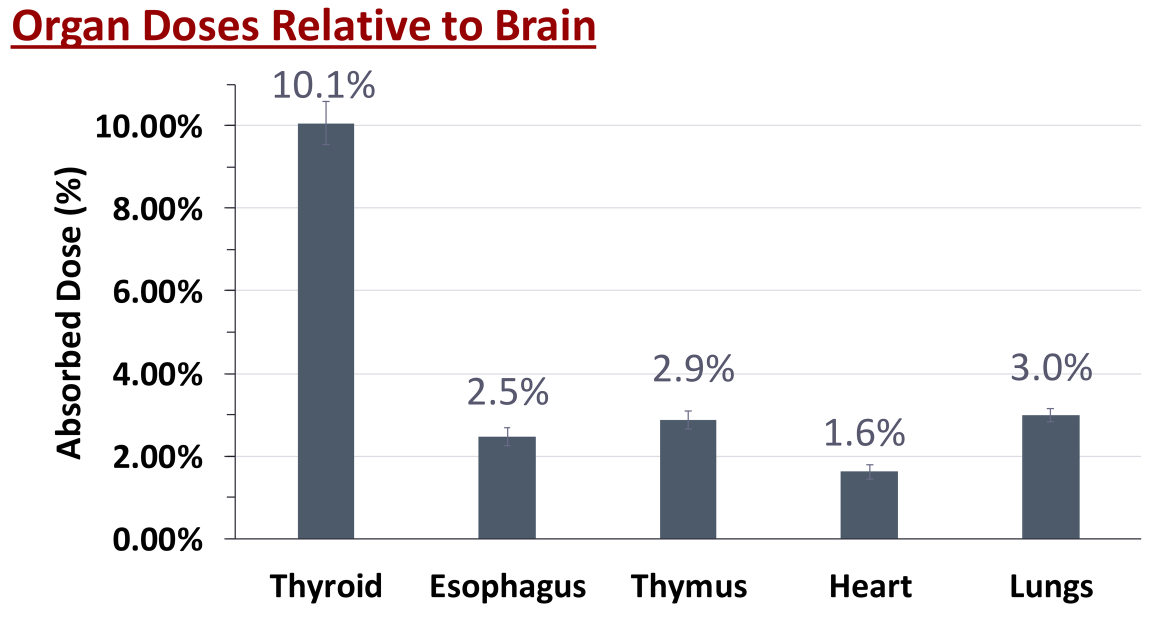
Scan Parameters:

- Rotation Time: 1.0s
- Detector Configuration: 128 x 0.6 cm
- Pitch: 0.85
- Tube Voltage: 120 kVp
- Tube Current-Time Product: 190 mAs
- CTDI-vol: 27.42 mGy 16 cm CTDI
- Automatic Exposure Control: Off
- Caudocranial and Craniocaudal
- Dosimeter Opening on Top of Each Slice

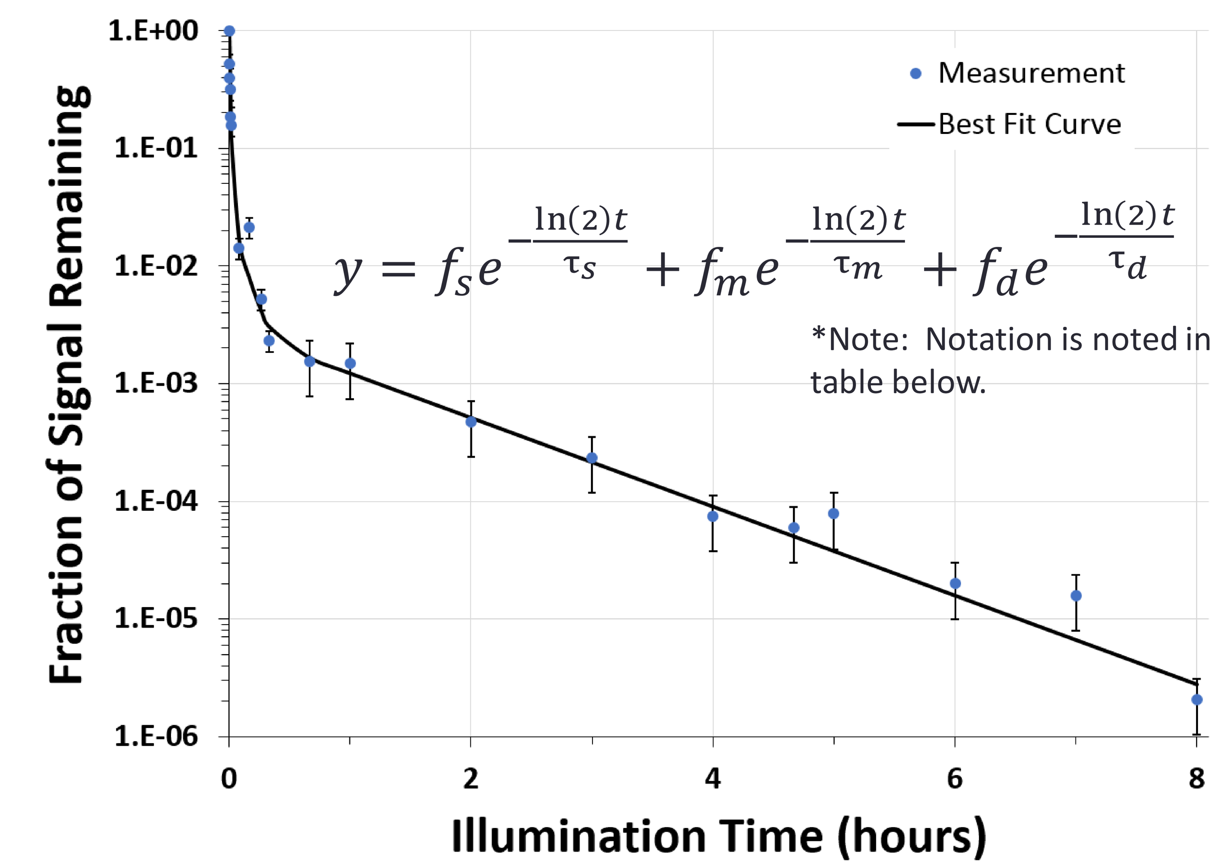
Organ Doses for Typical Brain CT Scan (Avg of 3 scans)



Organ Doses Relative to Brain



Clearing Dosimeter Signal with Light



Trap Depth	Fraction of Stored Signal, f_i (%)	Clearance Half-Time, τ_i
Shallow Traps (s)	96.3	17.2 seconds
Medium Traps (m)	3.4	3.8 minutes
Deep Traps (d)	0.3	47.8 min

CONCLUSIONS

- Traceability of the OSL reader was established to the National air kerma standard for various X-ray beam qualities
- A box was created to clear the dosimeters of 99.8% of the original stored signal within 20 minutes of illumination
- The radiation dose delivered to the brain for a typical brain CT scan was 23.810 mGy and the scatter dose to the eyes, thyroid, heart, and lungs were 22.1, 2.4, 0.4, 0.7 mGy, respectively
- The NCI OSL dosimetry system will be used to experimentally measure radiation dose in support of epidemiological studies looking at health risks associated with medical radiation exposure (e.g. cancer)

324