Storage phosphor panels for radiation therapy dosimetry

H. Harold Li, PhD
Department of Radiation Oncology
Washington University School of Medicine

Washington University in St. Louis
School of Medicine

Disclosure

- DoseImaging LLC, Founder
- NIH STTR phase 1 grant

Director, RPC 1968-1985

MAILABLE TLD SYSTEM FOR PHOTON AND ELECTRON THERAPY BEAMS

T. H. Kirby, Ph.D.,[1] W. F. Hanson, Ph.D.,[1] R. J. Gastorf, M.S.,[2] C. H. Chu, M.S.[3] and R. J. Shalek, Ph.D.[1]

[1]Radiological Physics Center, The University of Texas System Cancer Center, M.D. Anderson Hospital and Tumor Institute at Houston, Houston, TX 77030; [2]Radiation Therapy Department, Memorial City General Hospital, Houston, TX 77024; and [3]University of Houston, Houston, TX 77004

CHALLENGES IN CREDENTIALING INSTITUTIONS AND PARTICIPANTS IN ADVANCED TECHNOLOGY MULTI-INSTITUTIONAL CLINICAL TRIALS

Geoffrey S. Ibbott, Ph.D., David S. Followill, Ph.D., H. Andrea Molineu, M.S., Jessica R. Lowenstein, M.S., Paola E. Alvarez, M.S., and Joye E. Roll, C.M.D.

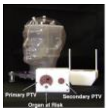
Radiological Physics Center, The University of Texas M. D. Anderson Cancer Center, Houston, TX

Credentialing results from IMRT irradiations of an anthropomorphic head and neck phantom

Andrea Molineu,[a)] Nadia Hernandez, Trang Nguyen, Geoffrey Ibbott, and David Followill
Department of Radiation Physics, The University of Texas MD Anderson Cancer Center, Houston, Texas 77030

Credentialing results from IMRT irradiations of an anthropomorphic head and neck phantom

Andrea Molineu,[a)] Nadia Hernandez, Trang Nguyen, Geoffrey Ibbott, and David Followill
Department of Radiation Physics, The University of Texas MD Anderson Cancer Center, Houston, Texas 77030

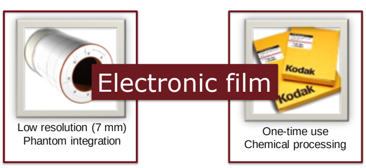


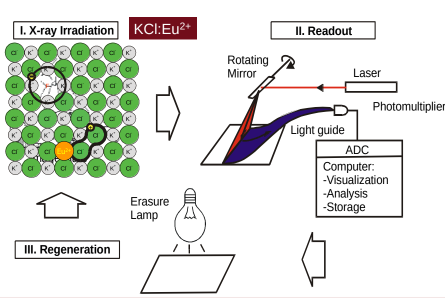
- Institutions asked to image, plan and treat the phantom as they would treat a patient
- Passing criteria: 7% for the TLD in the PTVs and 4 mm DTA between the PTV and the OAR

Results: The phantom was irradiated 1139 times by 763 institutions from 2001 through 2011. 929 (81.6%) of the irradiations passed the criteria. 156 (13.7%) irradiations failed only the TLD criteria, 21 (1.8%) failed only the film criteria, and 33 (2.9%) failed both sets of criteria. Only 69% of the irradiations passed a narrowed TLD criterion of ±5%.

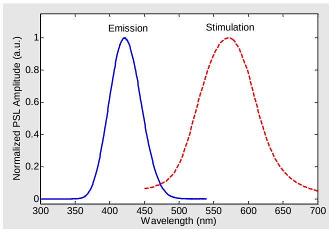
High resolution dosimeter

Problem: An MRI-compatible dosimetry system with water-like response, high spatial resolution and excellent radiation hardness is not currently available





Photostimulation and emission spectra: KCl:Eu^{2+}



Han et al., Med. Phys 2009

Washington University in St. Louis • School of Medicine

Department of Radiation Oncology
Medical Physics Division

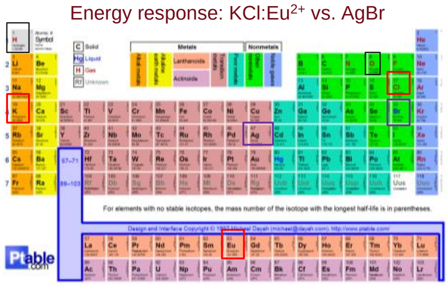
Electro-optical panel

- Energy independence
- Resolution
- Reusability: radiation hardness
- Phantom integration
- Sensitivity
- Large area fabrication
- Readout speed
- Humidity resistance

Washington University in St. Louis • School of Medicine

Department of Radiation Oncology
Medical Physics Division

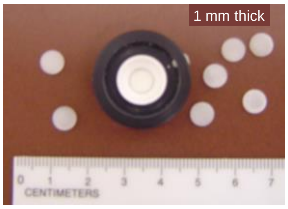
Energy response: KCl:Eu^{2+} vs. AgBr

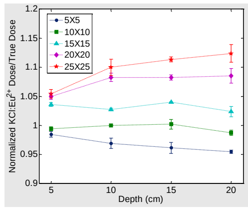


Washington University in St. Louis • School of Medicine

Department of Radiation Oncology
Medical Physics Division

Energy response: KCl:Eu^{2+} vs. AgBr





Radiographic film: overresponse of 8% for 25x25 cm^2 and 20 cm depth

Han et al., Med. Phys 2009

Energy response: KCl:Eu^{2+} vs. AgBr

- Radiographic film has a thickness of 1 micron vs. KCl:Eu^{2+} chip's 1 mm.
- Energy dependence is the result of photoelectric interactions of low energy scattered photons with the dosimetry material, especially those less than 100 keV. **[Palm et al. Med. Phys. 2004]**
- The projected maximum range for, say, a 40 keV secondary electron generated by photoelectric interactions is about 20 μm.
- If the dosimeter dimension is of the order of a few microns, it is highly probable that secondary electrons created in the sensitive volume, so-called starters, deposit a significant fraction of their energy outside the dosimeter's sensitive volume, thus reducing the energy dependent measurement artifact.
- With the increase in dosimeter or cavity dimension, the range of the above starters becomes smaller than the cavity size, and thus starters become insiders. As a result, increased energy dependence occurs.

Zheng et al., Med. Phys 2009

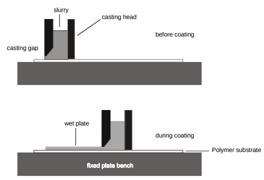
Overresponse as a function of thickness at 5 cm outside the field edge for a 20x20 cm^2 field at 20 cm depth

Material	Thickness (μm)	Over-response (%)
KCl:Eu^{2+}	1	2.6
	3	13.4
	10	35.6
	15	48.7
	20	57.1
	30	63.1
	40	72.0
	100	71.5
Al_2O_3:C*	300	15.5
Radiochromic*	17	−4.2
Radiographic*	0.4	47.2

Zheng et al., Med. Phys 2009

Large area fabrication

Physical vapor deposition



Tape casting

Tape casting

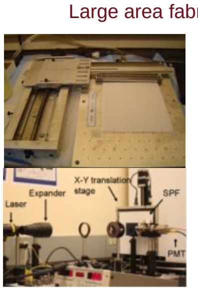
- Create particles with ...
- Optimize binder-to-pa...
- Individual particles ur... ...x but NOT connected: a uniform, raisins-in-a...

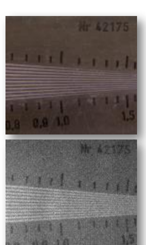
Rational to (nearly) ...

- Low-Z polymer binde... ...ated by the interaction between low energy s... ...rticle
- Prevents them from r... ...imizing energy dependence

Li, US Patent# 8658990 2014

Large area fabrication: tape casting

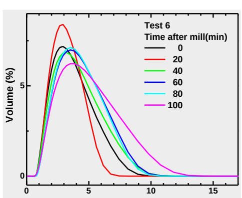




Create micron-sized particles

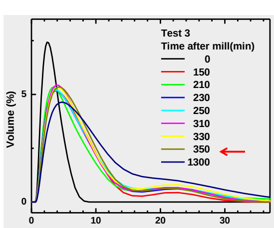
Spiral jet mill

Particle size distribution



Time (min)	D50 (μm)	D99 (μm)
0	2.945	7.76
20	2.818	6.06
40	3.178	8.69
60	3.481	8.78
80	3.454	8.55
100	3.713	10.7

D50: 3 microns
Favorable d50's and d99's after 2 hrs

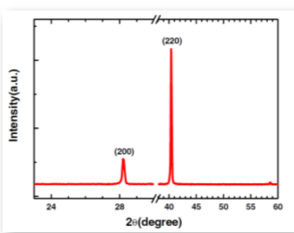


D50 still under 5 microns after 6 hrs

Physical vapor deposition

- Raw materials heated under vacuum
- Deposition rate controlled by a PID controller

X-ray diffraction spectra

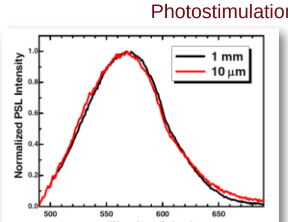


- ❑ 10 µm- thick
- ❑ Highly crystalline
- ❑ No other phases
- ❑ Europium incorporated into the matrix

Xiao et al., PMB 2014

Washington University in St. Louis • School of Medicine
Department of Radiation Oncology
Medical Physics Division

Photostimulation spectra

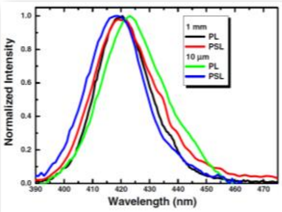


Same type of charge storage centers created

Xiao et al., PMB 2014

Washington University in St. Louis • School of Medicine
Department of Radiation Oncology
Medical Physics Division

Emission spectra



Bulky material's luminescence characteristics transferred to the micron-thick sample

Xiao et al., PMB 2014

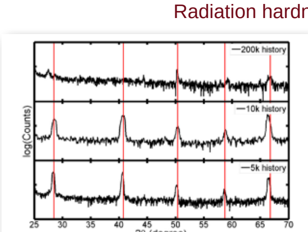
Sensitivity

MU setting	Ionization chamber (cGy)	$KCl:Eu^{2+}$ (cGy)	Error (cGy)
3 MU	0.012	0.013 ± 0.002	0.001
9 MU	0.035	0.030 ± 0.003	0.005
27 MU	0.110	0.122 ± 0.013	0.012
36 MU	0.142	0.138 ± 0.012	0.004

$KCl:Eu^{2+}$ can accurately measure a dose-to-water as low as 0.01 cGy

Li et al., PMB 2013

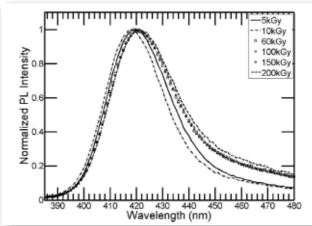
Radiation hardness



- ❑ LSU synchrotron
- ❑ Highly crystalline at 5 and 10 kGy
- ❑ XRD peaks still observed at 200 kGy but not clear and distinct
- ❑ Large radiation dose introduces lattice distortions and defects

Hansel et al., NIMB 2014

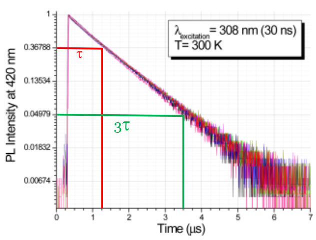
Radiation hardness



- Intense luminescence peak at 200 kGy history
- Signal retains 70%
- Energy storage and photo-stimulation remain efficient

Hansel et al., NIMB 2014

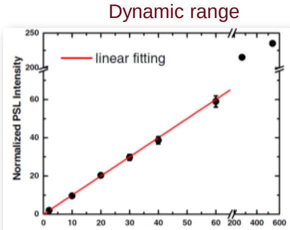
Readout speed: luminescence lifetime



- $KCl{:}Eu^{2+}$ has a luminescence lifetime of 1.2 µs
- Constant for zero to 5000 Gy history
- Assuming a 20x20 cm^2 $KCl{:}Eu^{2+}$ panel with 0.5x0.5 mm^2 pixel resolution and a readout dwell time of 3 times the luminescent lifetime, the minimum time to read the dosimeter would be 0.6 s (=3×1.2 µs/pixel×400×400pixel)

Driewer et al., Med. Phys 2011

Dynamic range



Xiao et al., PMB 2014

Humidity Resistance

- ❑ Bake under vacuum to remove any water content
- ❑ Apply conformal coatings of polymer: Parylene C

Specialty Coating Systems

Humidity Resistance

- ❑ Irradiated coated chips to 2 Gy
- ❑ Dosimeters remained intact and showed no change in PSL intensity after 8 hours of submersion in water
- ❑ Un-coated chips dissolve in water within minutes
- ❑ Marginal worsening of PSL signal after bleaching, irradiating again, then submerging in water for 24 hours

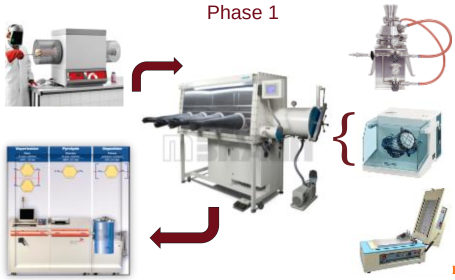
Mazur et al. AAPM 2015

STTR Phase 1

- ❑ DoseImaging LLC (Harold Li, Thomas Mazur)
- ❑ Goal: To manufacture near commercial-grade panels using micron-sized europium doped potassium chloride ($KCl:Eu^{2+}$) dosimetry particles
- ❑ Phase II and R01 grants
- ❑ Venture capital financing
- ❑ Strategic collaboration with Agfa, Fuji, Carestream

DoseImaging
High-definition

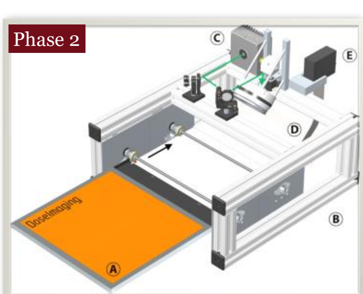
Phase 1



DoseImaging
High-definition

Detector panel using non-hygroscopic $BaFBr:Eu^{2+}$ particles

Dense packing   Inhomogeneous loose packing



DoseImaging
High-definition

Acknowledgment

Harold Li Laboratory

Thomas Mazur, PhD

Yuhe Wang, PhD candidate

Past members:

Joseph Driewer, PhD

Zhaohui Han, PhD

Rachael Hansel, PhD

Baozhou Sun, PhD

Zhiyan Xiao, PhD

National Institutes of Health

R21CA131690
R01CA148853
R41CA202980

DoseImaging

BIOGENERATOR

Washington University in St. Louis • School of Medicine

Department of Radiation Oncology
Medical Physics Division