# *Methods and Applications of 3D Radiochromic Dosimetry*

*No Financial Disclosures*

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Associate Professor, Biomedical Engineering,
Duke University Medical Center, Durham NC

## 3D dosimetry systems ?

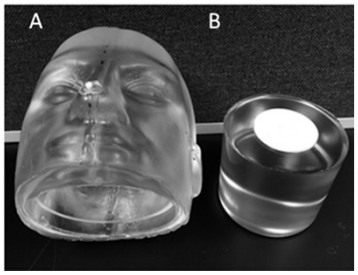
| Material | Read-out |
|---|---|

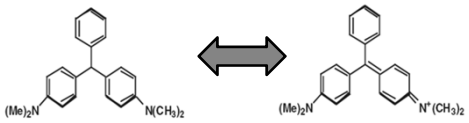
- Polymer gels → MRI
- Radiochromic gels
  - FX-orange → X-ray-CT
- Radiochromic plastics
  - Presage → Optical-CT

Liquid/solid scintillators
Transit dosimetry - EPIDS
Semi-3D systems - diode arrays

## Radiochromic Plastic: Presage

- Contrast: light absorption
- Good dosimetry properties
- Flexible



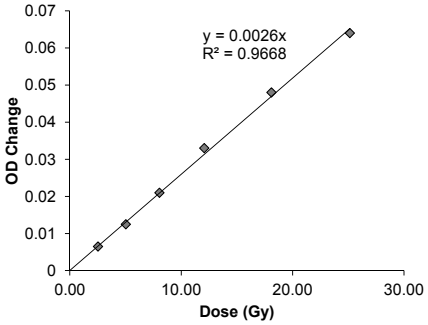

Leuco malachite Green (LMG)

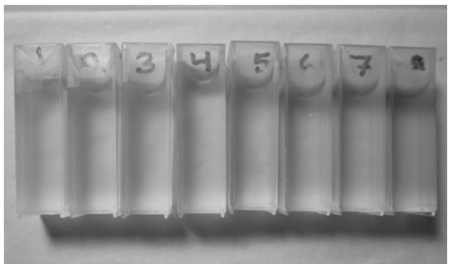
Malachite Green

$\lambda_{max}$ = 633 nm

## PRESAGE (Heuris Inc)

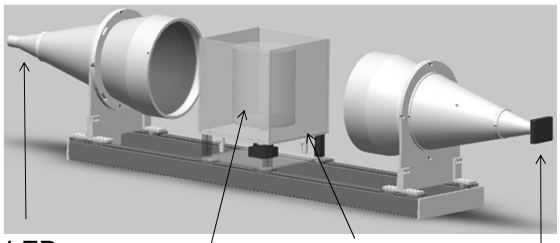
– OD proportional to dose

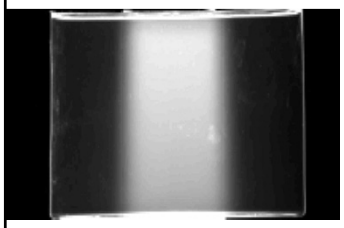


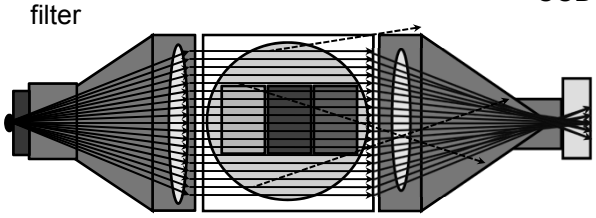



## DLOS : Duke Large Field-of-View Optical-CT Scanner

| Design Specifications | | |
|---|---|---|
| FOV | 240 | mm |
| esolution | 2 - 0.2 | mm |
| Time | 10 - 30 | mins |

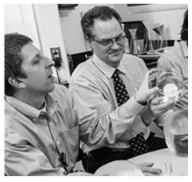




Thomas et al. Med Phys, 2011

## Key developmental milestones



**Commissioning and benchmarking a 3D dosimetry system for clinical use**

Andrew Thomas and Joseph Newton
*Duke University Medical Center, Durham, North Carolina 27710*
John Adamovics
*Rider University, Lawrenceville, New Jersey 08648*
Mark Oldham[a)]
*Duke University Medical Center, Durham, North Carolina 27710*

**Med. Phys. 38 (8), August 2011**

**A method to correct for stray light in telecentric optical-CT imaging of radiochromic dosimeters**

**Andrew Thomas, Joseph Newton and Mark Oldham[1]**
Duke University Medical Center, Durham, NC, USA

Phys. Med. Biol. **56** (2011) 4433–4451

**A method to correct for spectral artifacts in optical-CT dosimetry**

**Andrew Thomas[1,4], Michael Pierquet[1], Kevin Jordan[2,3] and Mark Oldham[1]**

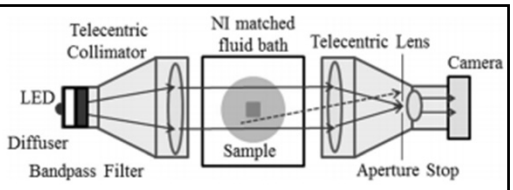
Phys. Med. Biol. **56** (2011) 3403–3416

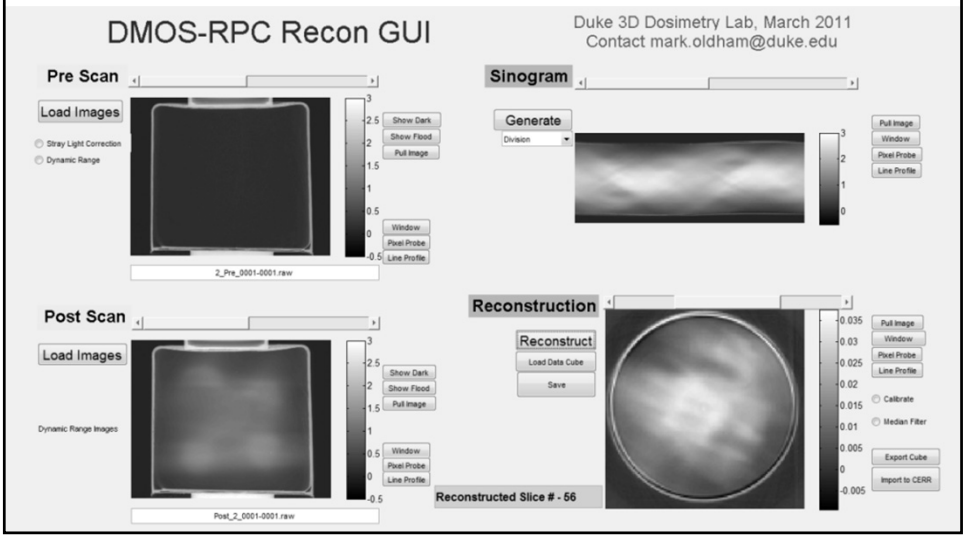
**A Quality Assurance Method that Utilizes 3D Dosimetry and Facilitates Clinical Interpretation**

Mark Oldham, Ph.D.,* Andrew Thomas, Ph.D.,* Jennifer O'Daniel, Ph.D.,* Titania Juang, B.Sc.,* Geoffrey Ibbott, Ph.D.,† John Adamovics, Ph.D.,‡ and John P. Kirkpatrick, M.D.*

International Journal of Radiation Oncology biology • physics
Aug 2012

## 3D Dosimeter read-out by optical-CT




## Duke Collaborations

| | |
|---|---|
| **Brachytherapy** | O Craciunescu, J Chino |
| **4D SBRT** | F Yin, J Wu |
| **Radiosurgery** | Z Wang J Chang, |
| **Gating.** | S Yoo, A Thomas |
| **IMRT, VMAT …** | J O'Daniel J Kirkpatrick, |
| **Deformation** | S Das |

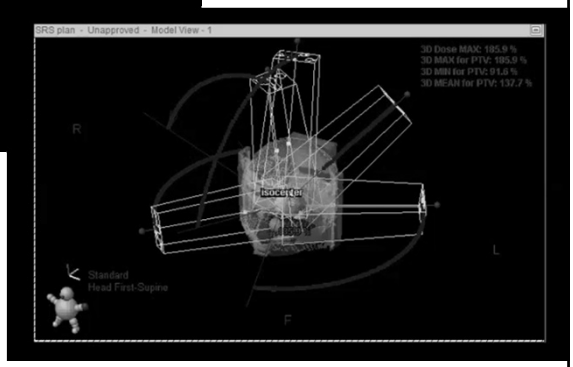
## External Collaborations

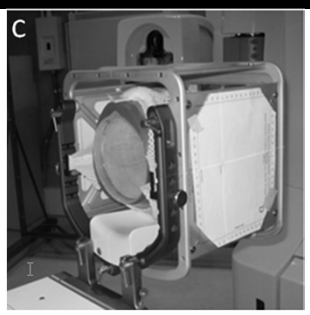
| | |
|---|---|
| **Credentialing and clinical trials.** | Geoff Ibbott, MDACC |
| **Protons** | Indra Das Indiana Univ |
| **Neutrons** | Anuj Kapadia |
| **Anthropomorphic re-useable** | John Adamovics. (Heuris) |
| **deforming dosimeters** | |

## Accuracy of Multifocal single isocenter SRS Treatment ?

5 PTV targets
15 Gy central, 20-24 Gy outer

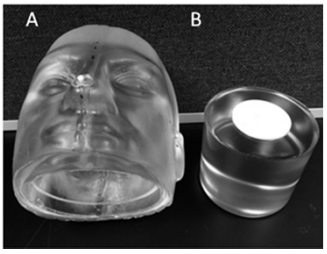
iplan and Eclipse
CBCT set-up

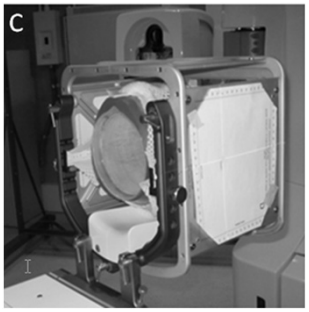



## Objectives

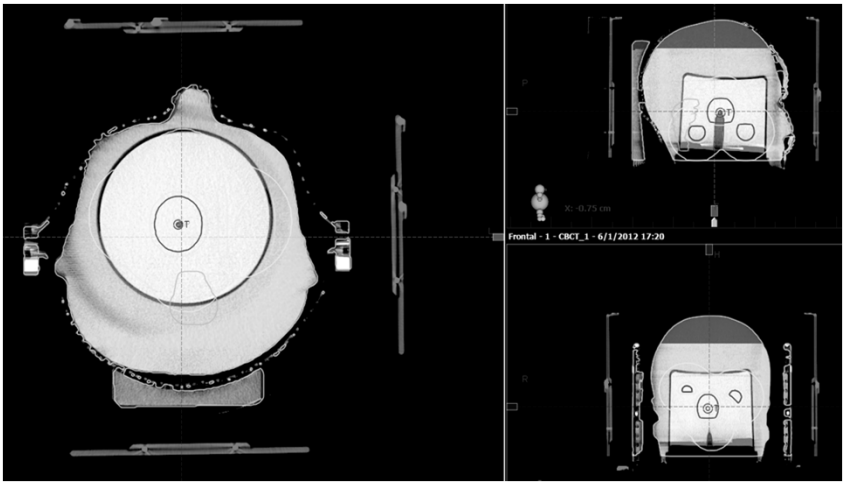
- Evaluate accuracy and reproducibility
  - Novalis Tx delivery
    - 2D kV and CBCT IGRT set-up
- Method/strategy
  - 4 independent deliveries
  - 4 Presage dosimeters
  - Ion-chamber normalised



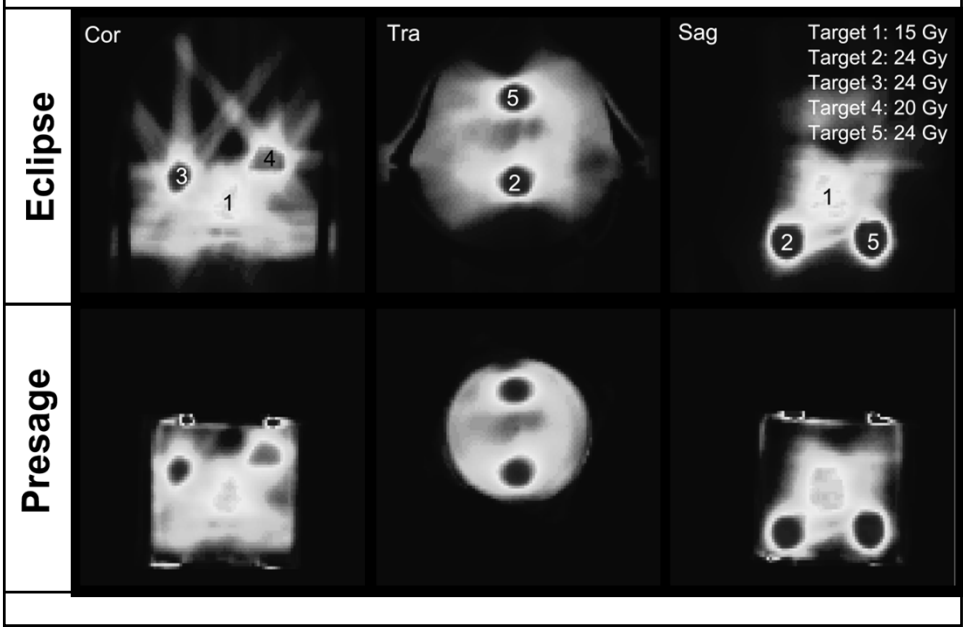



## Treatment Delivery

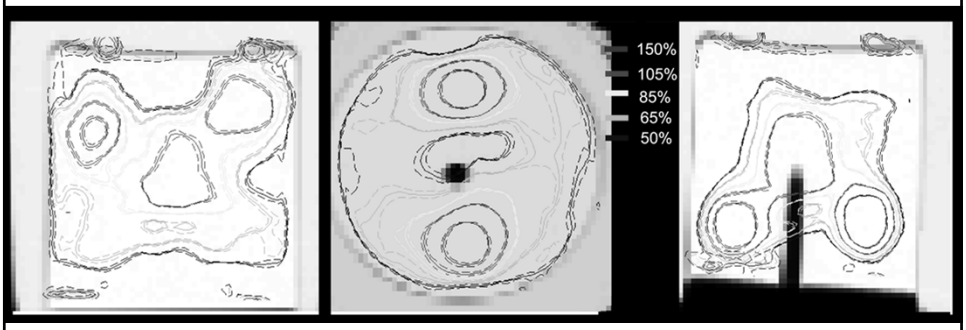
- 4 dosimeters
- 2D KV and CBCT image guidance
- One dosimeter – ion chamber




## 5 lesion VMAT single-iso Radiosurgery



## 5 VMAT single-iso SRS: accurate and reproducible

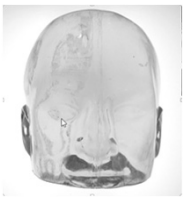


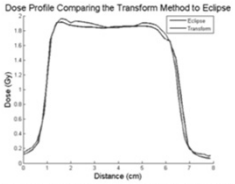

**Average (solid lines)**

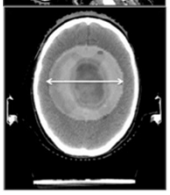
**1 StdDev (dashed lines)**

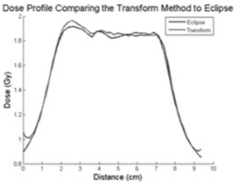
Thomas A , et al. Medical Physics, Dec, 2013

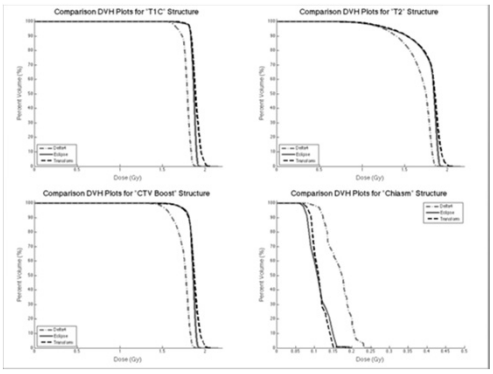
## AAPM 2015:





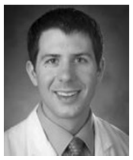


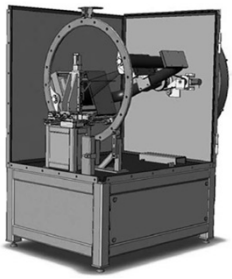




Crockett E, Ren L, Oldham M, AAPM 2015
DVH based Comparison Of True 3D Measurements And Delta4 system

Oldham M , et al. IJROBP, Oct, 2012

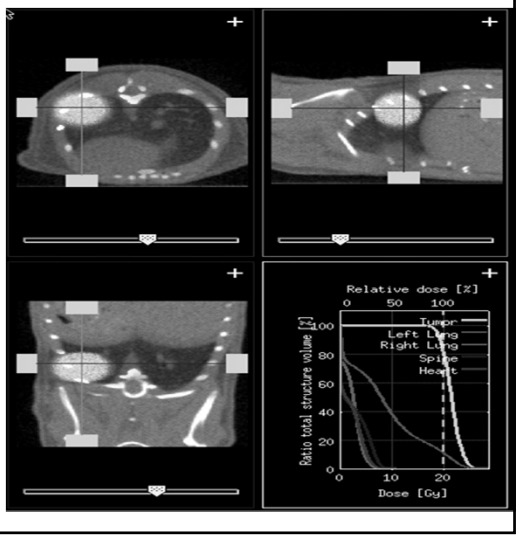
## Micro-irradiator: Lung SBRT

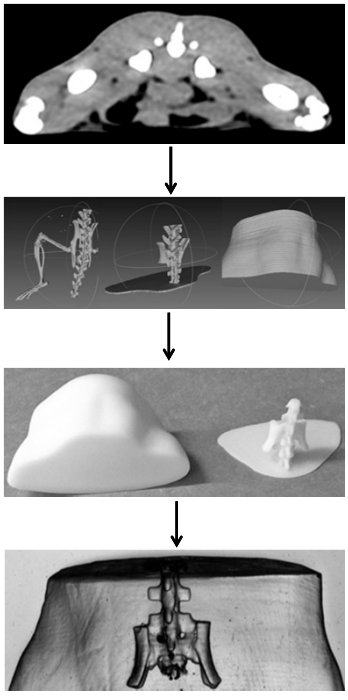




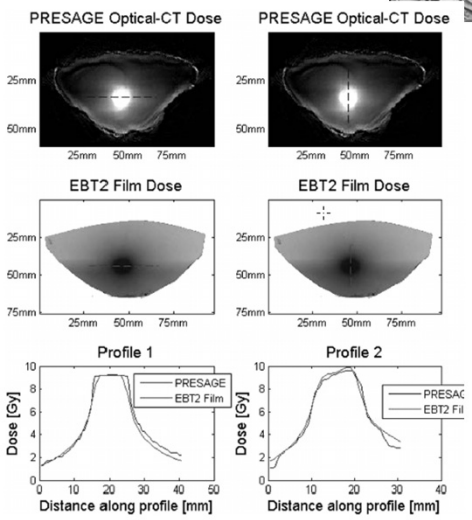
XRAD225Cx from Precision X-Ray Inc.

- MC planning
- 2-40mm fields
- Lung SBRT



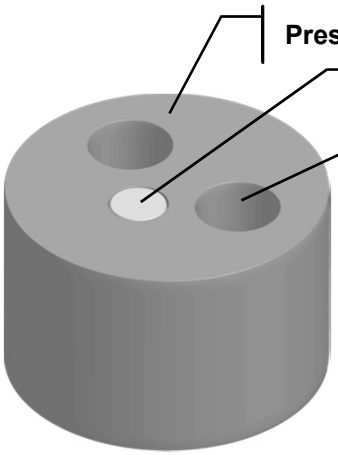



## 3D micro-dosimetry: 3D Printing:

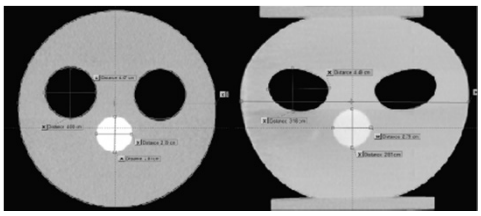



Bache S, et al. Med Phys, 2015

**Can SmartAdapt/Velocity enable next generation gynecological treatments combining IG brachytherapy with RT**

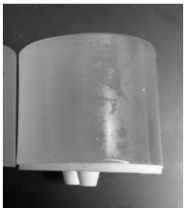



**Complex, Non-Uniform Deformation**



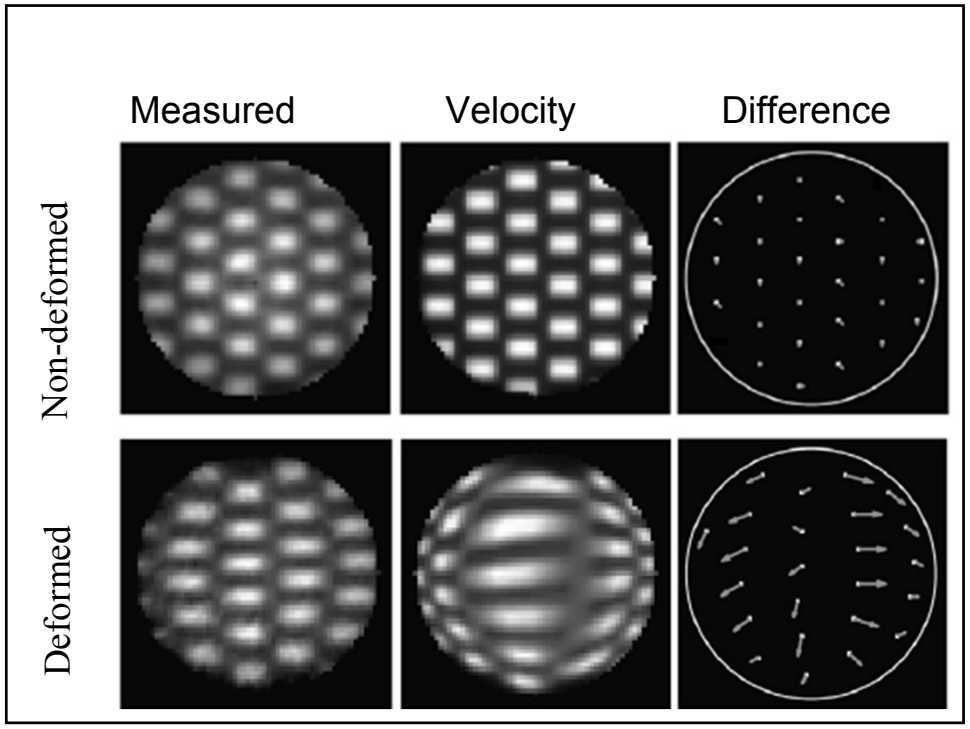
**"On the need for validation of deformable dose accumulation (DIR) with a novel 3D dosimeter."**

**Juang et al. IJROBP, 2013**



Control
(No Deformation)

Deformed
(27% Lateral Compression)

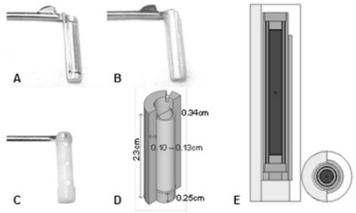

Measured
Velocity
Difference
Non-deformed
Deformed

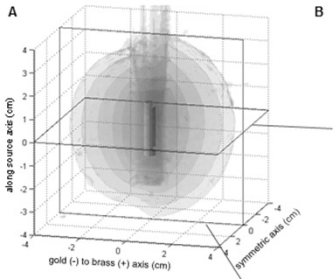
## Results

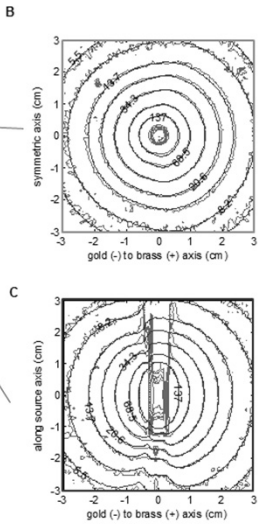

No Deformation
Deformed
VelocityAI
MEASURED
CALCULATED

## Brachytherapy

$^{137}$Cs source in shielded bucket



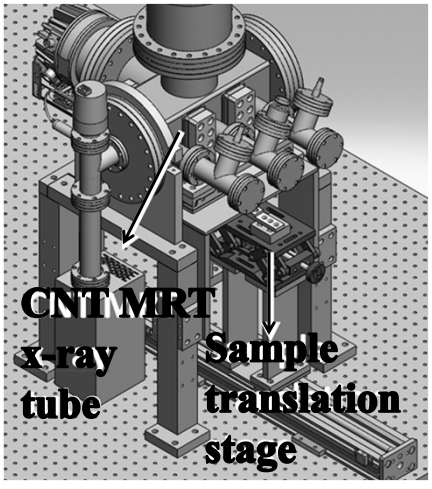




0.5mm$^3$ voxels !

Adamson J et al,
Med Phys 2012

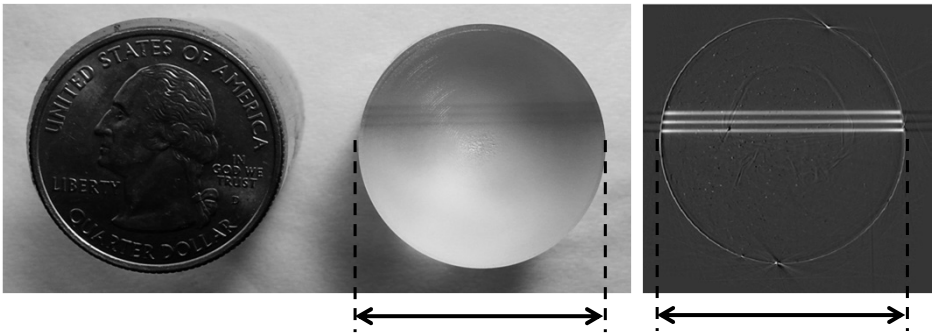
## Micro-radiation therapy (MRT - UNC)




- 3 parallel beams
  - ► 300-400 μm width
  - ► 909 μm spacing
- 32 Gy entrance dose

## Optical-CT Dosimetry

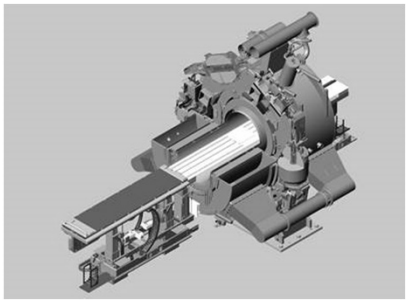
**Scanned in Optical-CT Scanner**
**Reconstructed at 50 μm isotropic resolution**




**20 mm** **400 px**

## Magnetic Resonance Imaging guided Radiation Therapy (MRIgRT

- Remote 3D dosimetry protocol
- Duke and WashU
- Advantages
  - MR independent
- Stage I
  - TG119 irradiations
-



## Magnetic Resonance Imaging guided Radiation Therapy (MRIgRT

- Remote 3D dosimetry protocol
- Duke and WashU
- Advantages
  - MR independent
- Stage I
  - TG119 irradiations
-

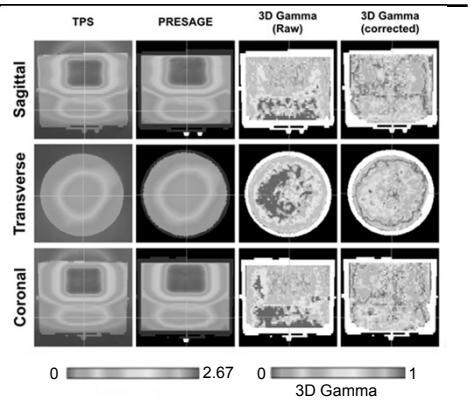
FINAL RESULTS: EXAMPLE

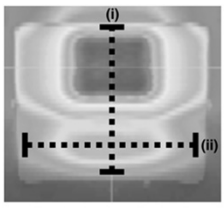
## MULTI-TARGET (TG119)

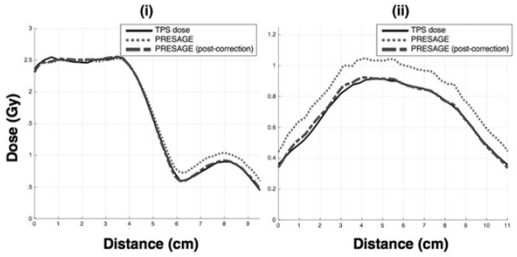
Passing Rate (3%/3mm):

| Raw | Corrected |
|---|---|
| 91.6% | → 98.5% |

**TH-CD-BRA-11**



## Conclusions so far !

- Hi-res 3D dosimetry is feasible
- Remaining challenges
  - Dosimeter development
    - Re-usability, remote, Deformable
    - Optical-CT developments
    - Increased practiclity
  - Applications: Many
    - Advanced Tx
    - Pre-clinical
    - Deformable, IG procedures
    - New devices and techniques

## Radiochromic Dosimetry at CCSEO

Modus QA

*Based on change of optical attenuation coefficients in irradiated dosimeter*

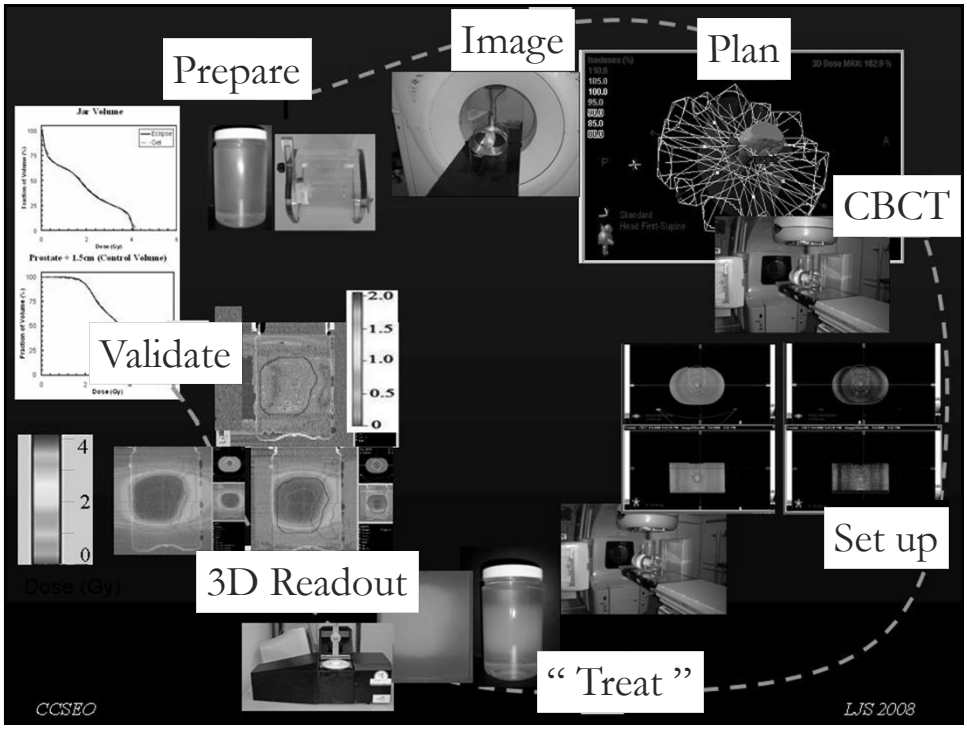
- *Fricke and Radiochromic dosimeters*
  *- Absorption changes*

Fricke Gels

Leucodye MicelleGels

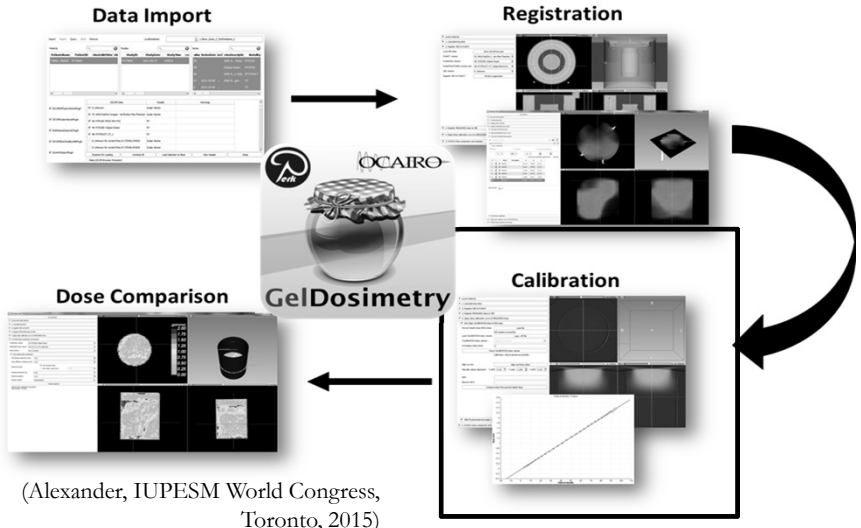
AAPM 2016 JUL 31–AUG 4

KGH Cancer Centre of Southeastern Ontario




## Data analysis

We work in SLICER-RT open source environment



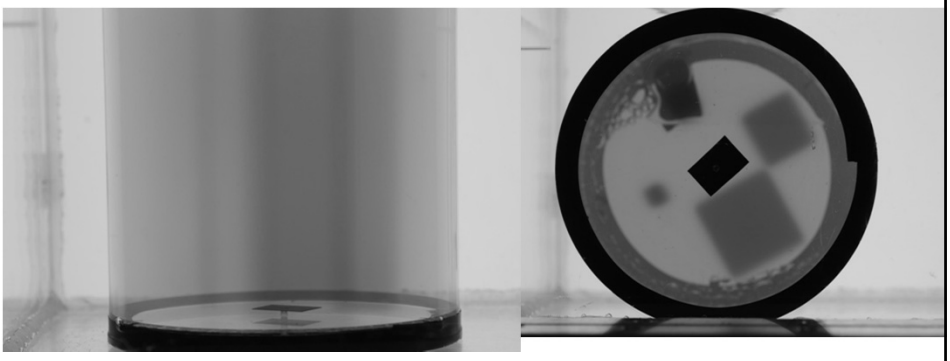

(Alexander, IUPESM World Congress, Toronto, 2015)



AAPM 2016 JUL 31–AUG 4

KGH Cancer Centre of Southeastern Ontario

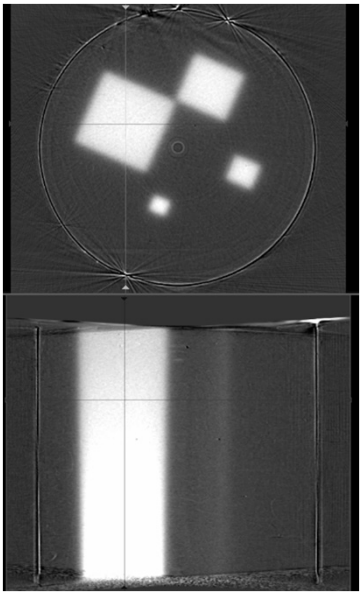
Non-diffusing leuco crystal violet gelatin hydrogel (see IC3DDose16)
~20 Gy per beam, jaw size=3x3, 2x2, 1x1 & 0.6x0.6 cm
AP, 6 MV, 400 MU/min,
“POP bottle vessel”, 11 cm diameter



K Jordan, London Regional Cancer Program

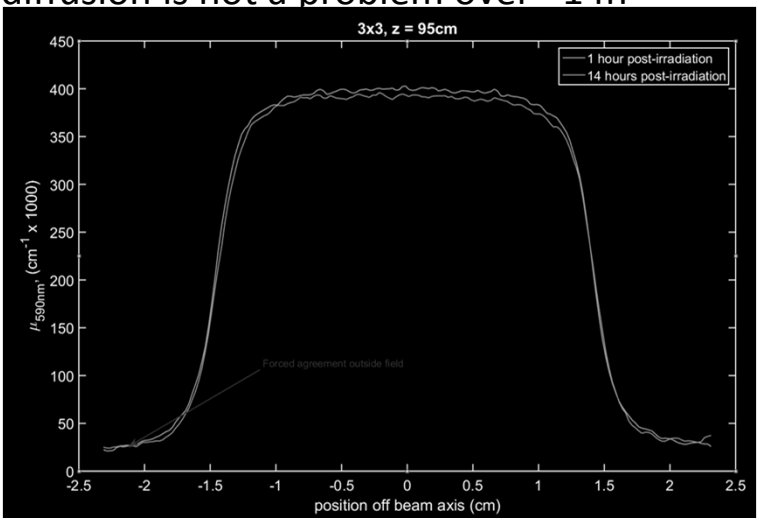
# Reconstruction

- 512 projections, 0.25mm voxels, 10 minute scan time, FDK reconstruction, hamming filter (Modus VistaRecon.exe)
- Vista optical CBCT scanner, custom source (Fresnel lens + LED)



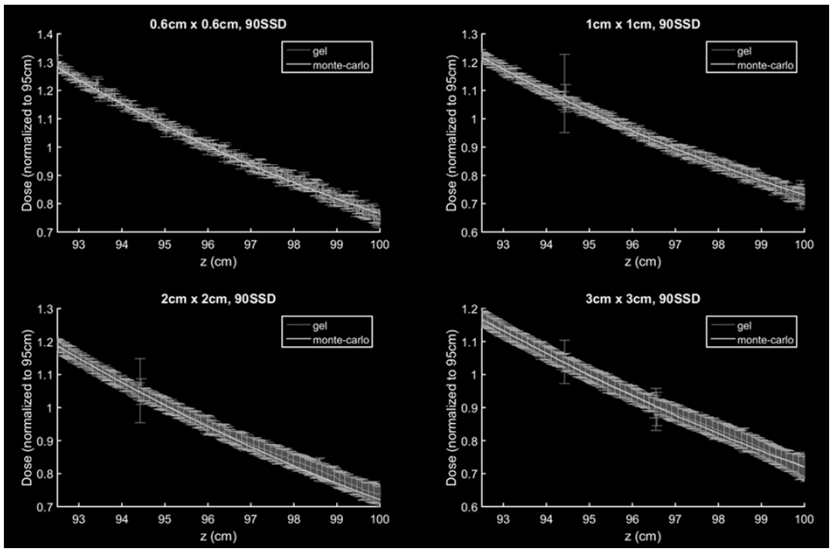
K Jordan, London Regional Cancer Program

- diffusion is not a problem over ~14h



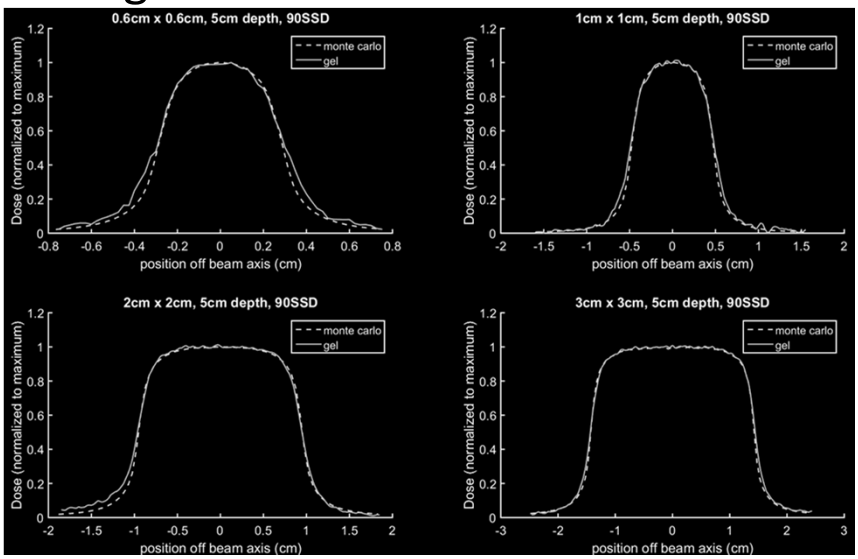

K Jordan, London Regional Cancer Program

# Background-Corrected, Depth Dose Curves




K Jordan, London Regional Cancer Program

# Background-Corrected Beam Profiles




# Resources for future reading

Oldham M 2014
in: Advances in Medical Physics
Godfrey D et al (ed)
(Medical Physics Publishing, Madison WI)

CHAPTER 5

Methods and Techniques for Comprehensive 3D Dosimetry

Mark Oldham, Ph.D.
Professor, Department of Radiation Oncology
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Schreiner LJ and Olding T 2009 Gel dosimetry
in: Clinical Dosimetry Measurements in Radiotherapy

(AAPM Medical Physics Monograph No. 34)
Rogers D and Cygler J (ed.),
(Medical Physics Publishing, Madison WI)

**Chapter 30**

**Gel Dosimetry**

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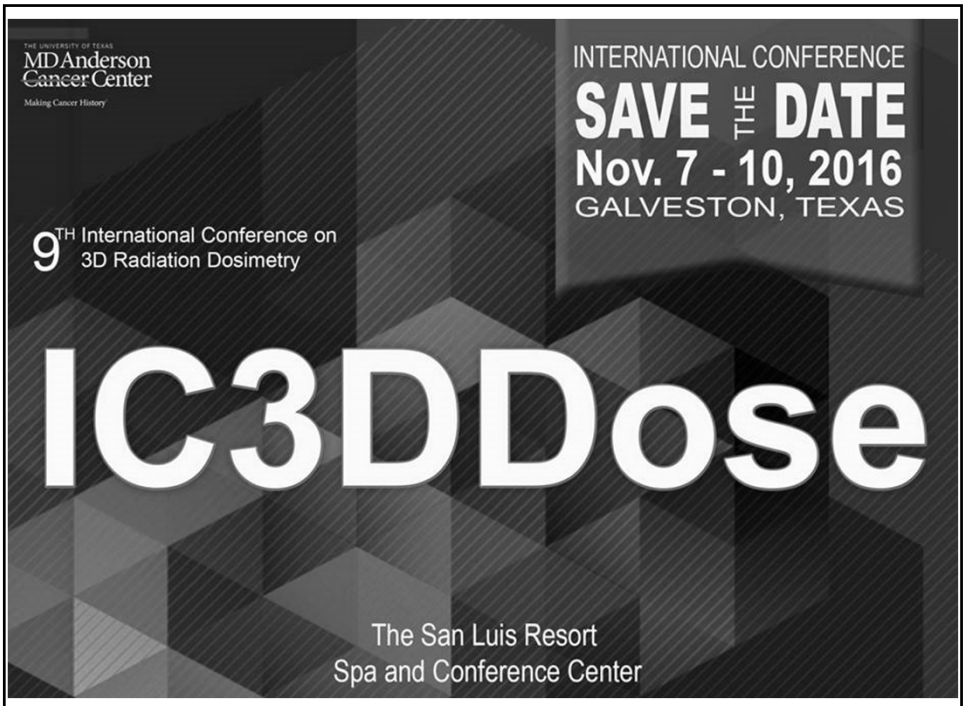



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