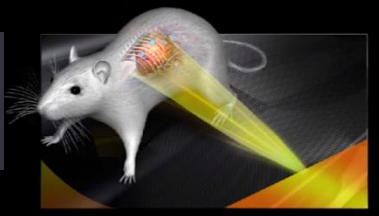
PXi PRECISION X-RAY

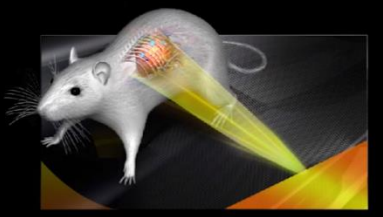


Advances in Preclinical IGRT Commissioning and Quality Assurance

Paul De Jean

Product Manager, Image-Guided Systems

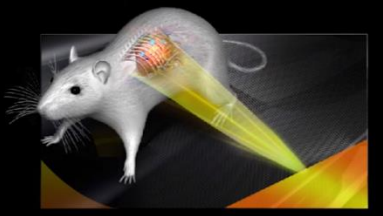
X-RAD Cabinet Irradiators



The X-RAD systems are self-contained X-ray irradiation systems for high and low dose radiation studies normally conducted in research laboratories.

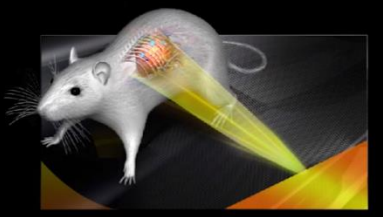
- **High X-ray Peak Energies (160-450kV)**
- **Installations all over the world**

Preclinical X-Ray Applications

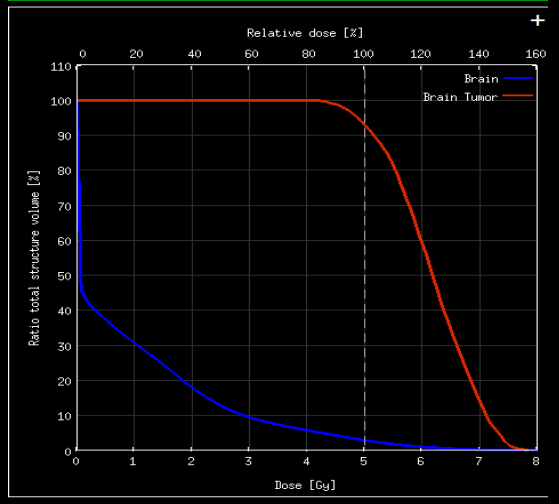


- Whole body radiation
- Partial body (flank, whole brain, etc.) irradiation
  - Targeted irradiation of healthy structures
  - Large subcutaneous tumors
- Bone Marrow Ablation
- Cell irradiation

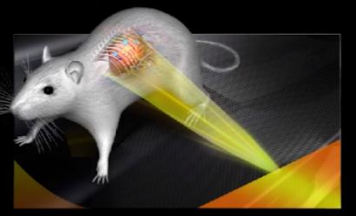
Preclinical Image-Guided Radiation Therapy



- Want to mimic clinical capabilities
- Incorporation of image guidance
- Precise, targeted irradiation
- Treatment Planning Systems needed
  - Employ Monte Carlo calculations
- Incorporation of multiple imaging modalities (BLI, MRI, PET, etc.)



X-RAD SmART IGRT



Small Animal IGRT Platform

8:12 PM
6/1/28
June 1, 2028

Image-Guidance
- Multi-Modality

Cabinet Design
- Flexible

The redesigned cabinet still provides complete shielding from all internal x-rays, while moving to a more flexible design, allowing for installations in just about any laboratory space.

Precision Targeting
- Upgraded

The new cabinet design is not just about increased efficiency, however, as it also has higher precision electromechanics under the hood, allowing for even better targeting accuracy.

Monte Carlo Planning
- State of the Art

X-RAY ON

PXi PRECISION X-RAY

Bioluminescent Imaging
- Fully Integrated

Because the system is fullyintegrated, registration with CT is fully automated, allowing for precise tumor localization for non-palpable tumors. The system can also serve to measure tumor viability across studies. As well, Co-Pilot, developed by the Netherlands Cancer Institute can automatically register DICOM images from other available platforms, effectively providing multi-modality image-guidance.

X-RAD
SmART

Dose Delivery
- Faster

SmART Facts
Accuracy, Reliability, Repeatability

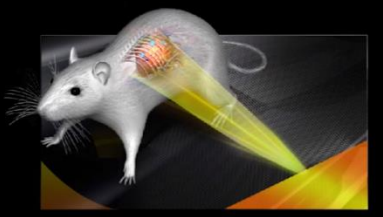
Technical Specifications

Cabinet	Dimensions & Weight
X-RAD SmART:	
Weight	1950kg (4290lbs)
H x W x D	76.5" x 60"x 41"
H x W x D	196cm x 154cm x 103cm
X-RAD SmART Mini:	
Weight	1700kg (3740lbs)
H x W x D	76.5" x 43"x 41"
H x W x D	196cm x 110cm x 103cm
X-RAD SmART Plus:	
Weight	2200kg (5060lbs)
H x W x D	79.5" x 86"x 41"
H x W x D	196cm x 170cm x 103cm

Safety:
Complies with US and European norms for radiation emission limits outside the cabinet
Complies with FDA 21 CFR 1020.40 and IEC 60601-1-3 entitled "Cabinet X-ray Systems"

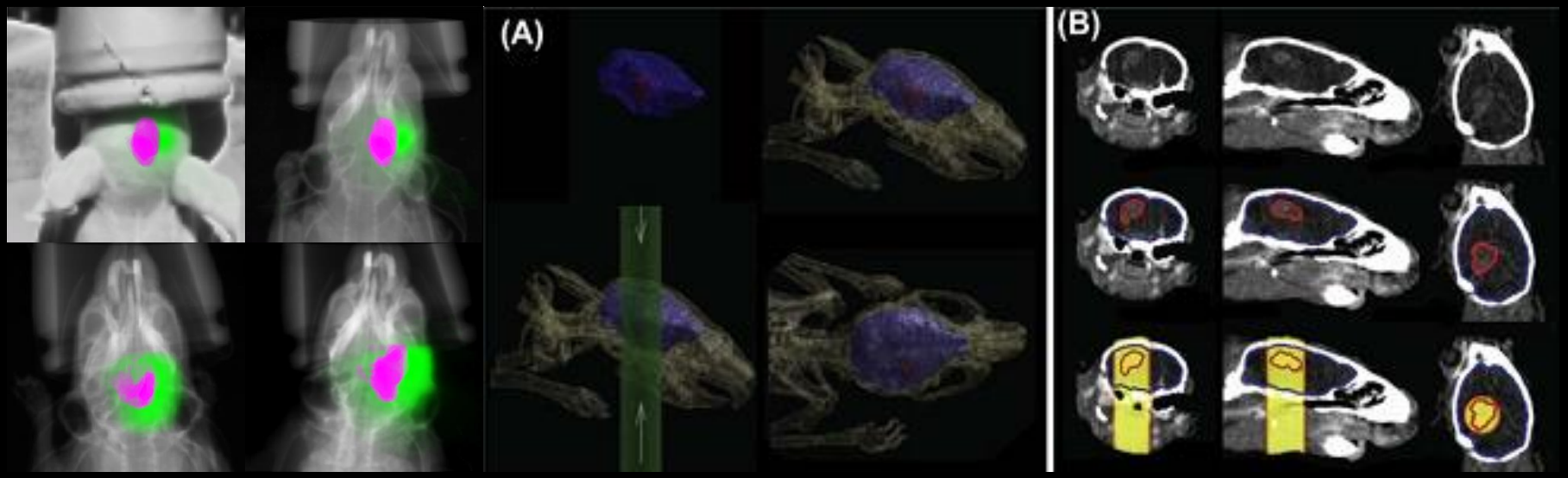
Electrical Requirements:
1N PE 230 V 50/60Hz 35 A
or
3N PE 400 / 230 V 50/60Hz 25A (TN-S or TN-C-S)

Sample Application – Monitoring IGRT Response and Progression

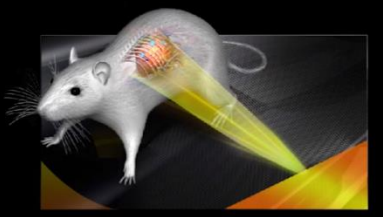


An image guided small animal radiation therapy platform (SmART) to monitor glioblastoma progression and therapy response
Green Journal 2015

Researchers: Sanaz Yahyanejad, Stefan J. van Hoof, Jan Theys, Lydie M.O. Barbeau, Patrick V. Granton, Kim Paesmans, Frank Verhaegen, Marc Vooijs

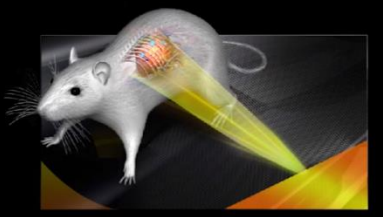


Importance of Commissioning and Quality Assurance



- More capabilities has led to more complex systems
- Commissioning procedure must be robust and conform to existing dosimetric protocol
- QA must be comprehensive and tackle all system aspects
- QA workflow must be simple/automated such that it gets done

System Commissioning and QA Requirements



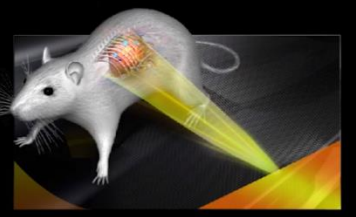
System Capabilities

- High Resolution Imaging
- Precise Radiation Targeting
  - Advanced Tracking
- Rapid, Accurate Dose Delivery
  - Cell/Multi-mouse Irradiation
  - Simple Treatment Plans
  - Complex, Multi-Beam Plans
- Reproducible Delivery Across Many Specimens
- Tumor Viability Tracking

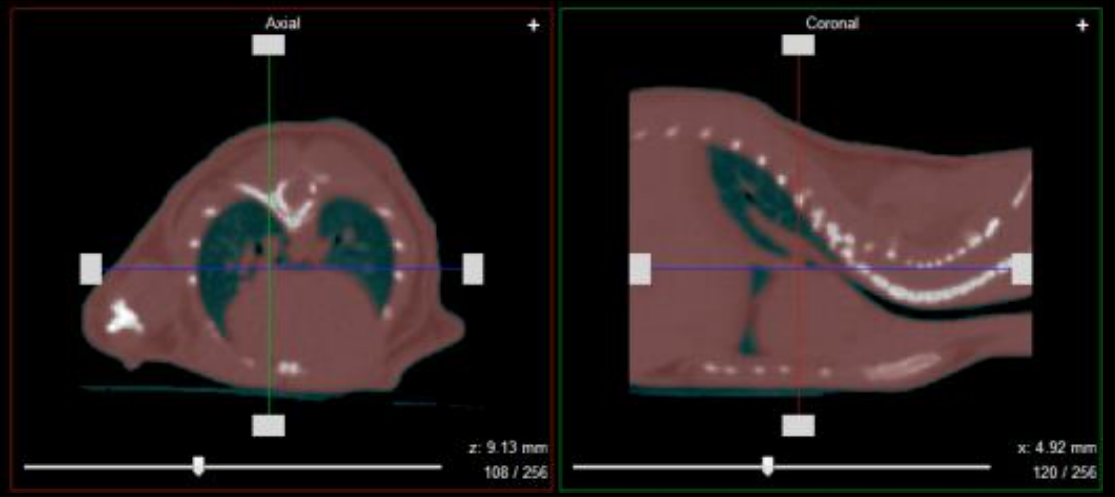
Commissioning/QA Responsibilities

- Flat Panel QA, Geometric Calibrations
- Winston Lutz Tests
  - Basic and Advanced
- Full Dosimetric Commissioning
  - Absolute Dose
  - Percent Depth Dose (PDDs)
  - End to End Tests
- Consistent, Timely QA
- Dedicated Personnel
- Bioluminescence System QA

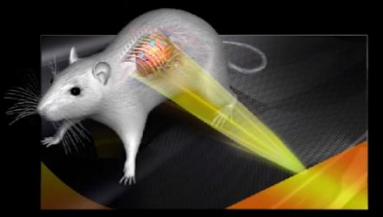
Importance of High Quality Imaging



- The obvious – better images = better guidance
- Image accuracy necessary for Monte Carlo Planning
  - Calculations based on heterogeneous tissue
  - Both material density and atomic structure play pivotal role



CT Imaging Phantoms



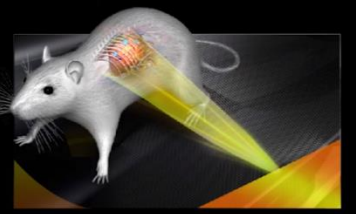
Shelley Medical Micro-CT Performance Evaluation Phantom (Du, 2007)

- Ability to measure a large number of imaging metrics:
  - Qualitative Spatial Resolution through a coil plate (150-500µm)
  - Quantitative Spatial Resolution though a slanted edge plate
  - Geometric accuracy through evenly separated tungsten beads
  - CT Number Evaluation through inserts of known materials (less applicable for CBCT)
  - CT Number Linearity through varied iodine concentrations
  - CT Uniformity and Noise

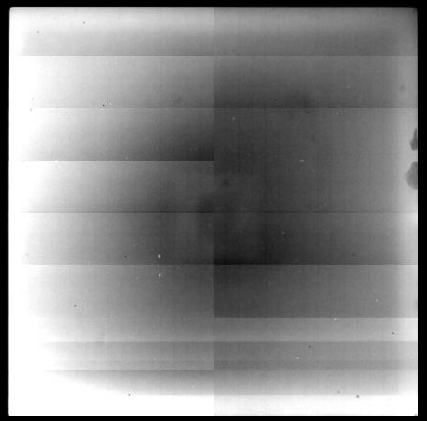
SMART Scientific Solutions Preclinical CT Calibration Phantom

- Miniature Equivalent of Clinical CT Number Phantom
- Materials include: Brain, Adipose, Breast, Solid Water, Liver, Inner (Spongy) Bone, Cortical Bone

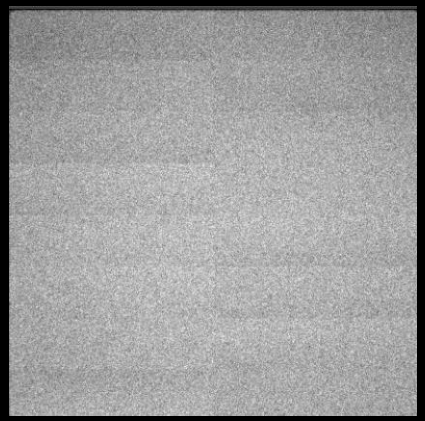
CT Imaging Commissioning



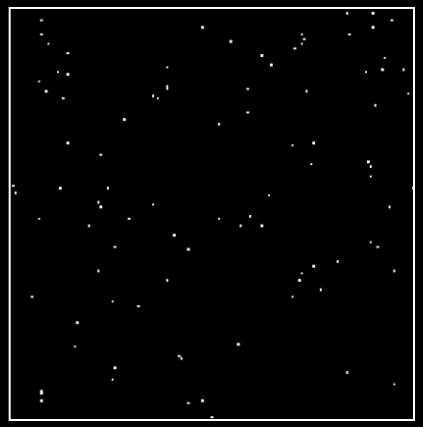
Dark Fields



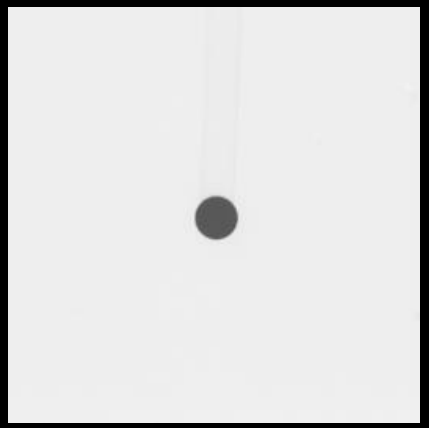
Flood Fields

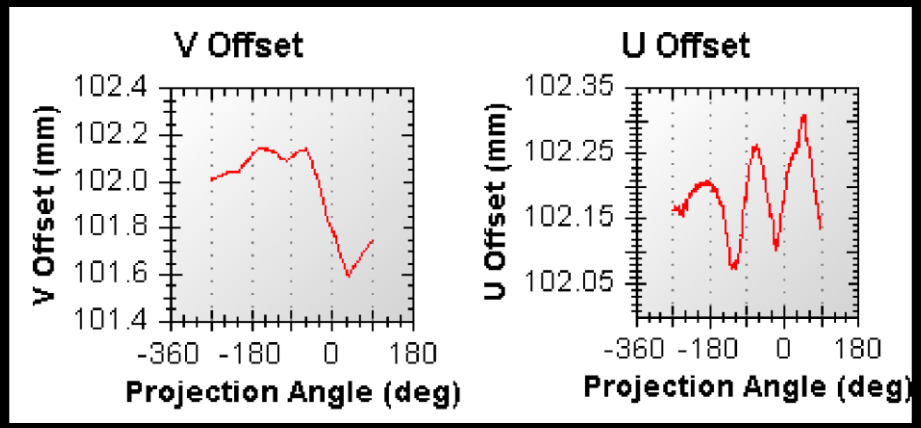


Defect Maps (Dead Pixels)

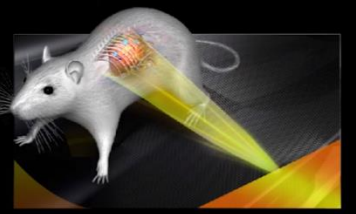


Gantry Flex Correction



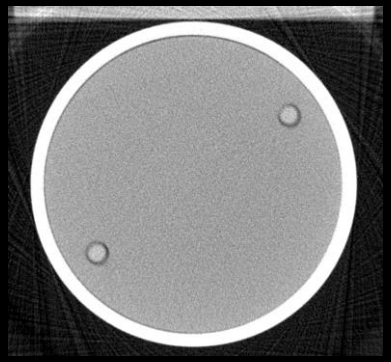


CT Imaging Commissioning

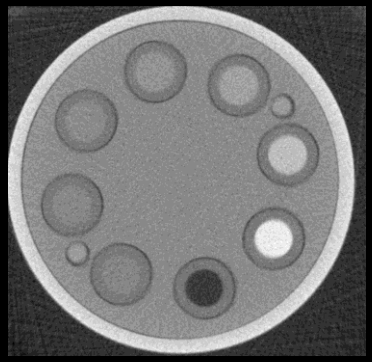


CT Resolution

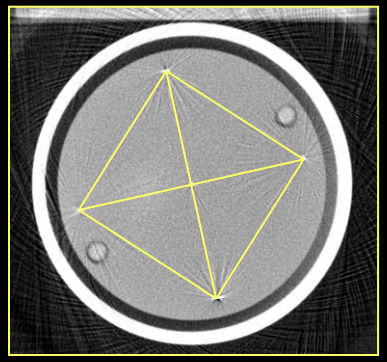
CT Uniformity



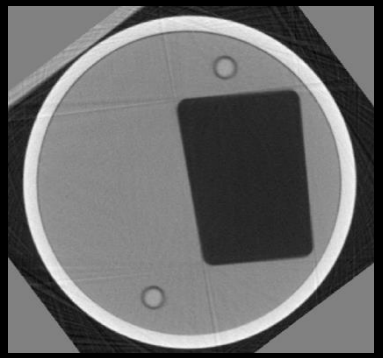
CT Linearity



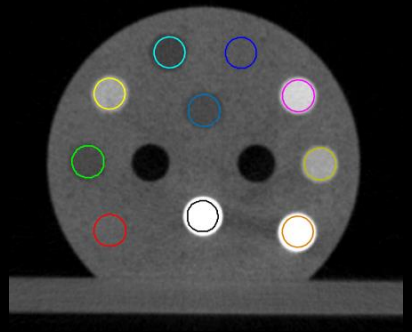
Geometric Accuracy



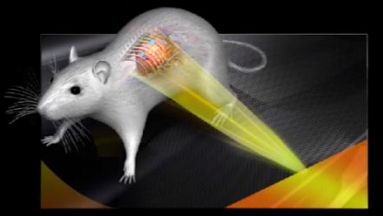
MTF



CT to Material Density

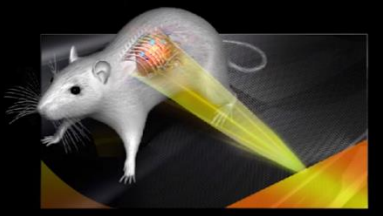


Preclinical Dosimetry

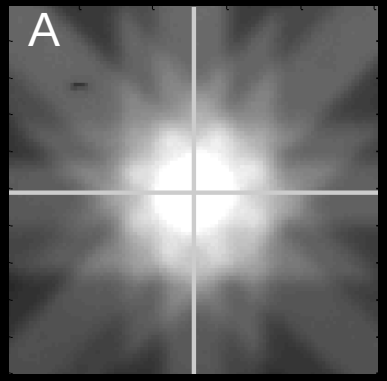


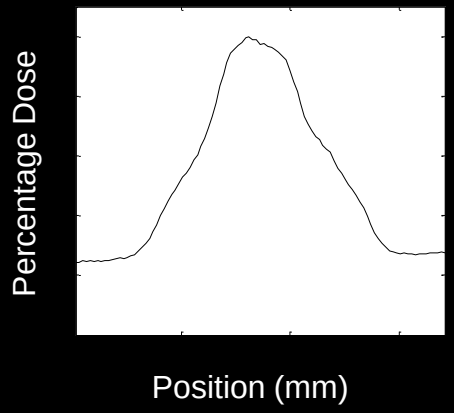
- Bring systems to “clinical” standards
- Kilovolt (kV) energies
  - Less penetration than Megavolt (MV) used in clinic
  - Must calibrate instruments to kV energies
- Small irradiation targets/specimens
  - Precise targeting even more important
  - Much faster computations – smaller beams and volumes
- Even more precise system alignment, positional accuracy (order of µm)
- Must also factor in system specific variables:
  - Tube output, focal spot
  - Gantry flex

Targeting Correction

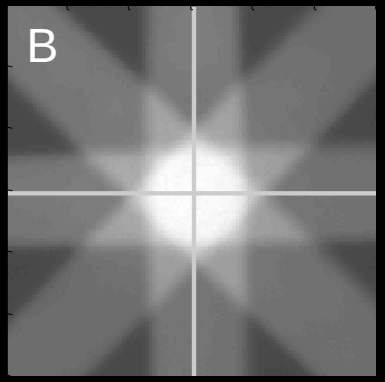


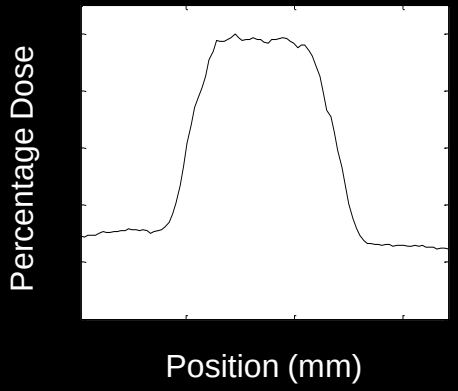
8 Beam Tracking OFF

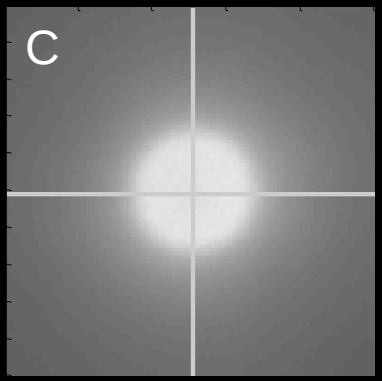


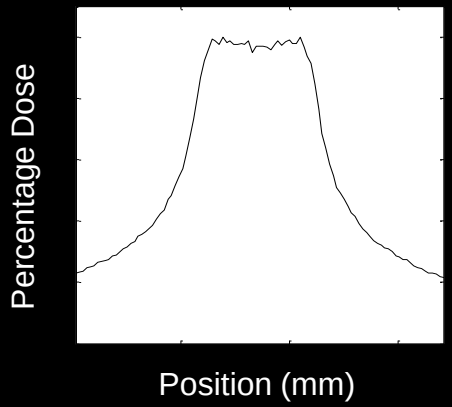


8 Beam Tracking ON





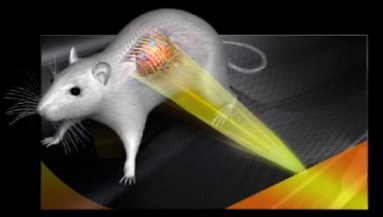




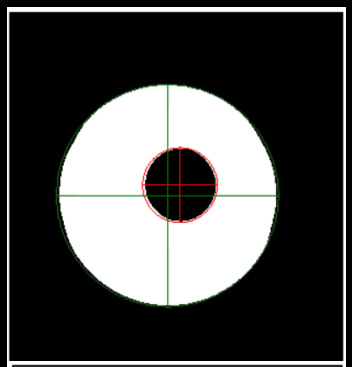
'Arc' Beam Tracking ON

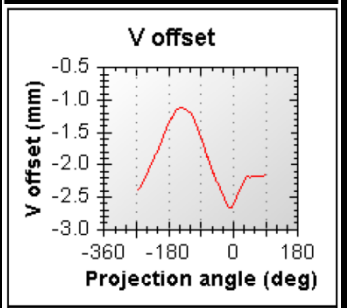
Images From: Clarkson et. Al., Med. Phys., 2011 Feb;38(2):845-56. *"Characterization of image quality and image guidance performance of a pre-clinical micro-irradiator"*

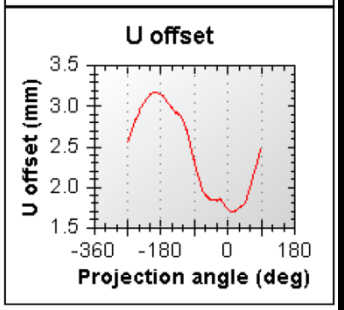
Targeting Commissioning



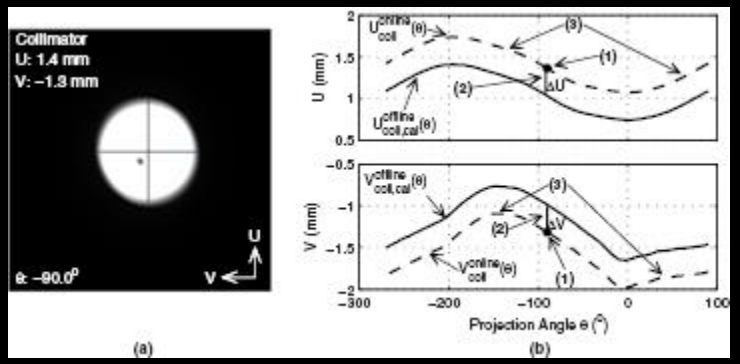
Winston Lutz Map

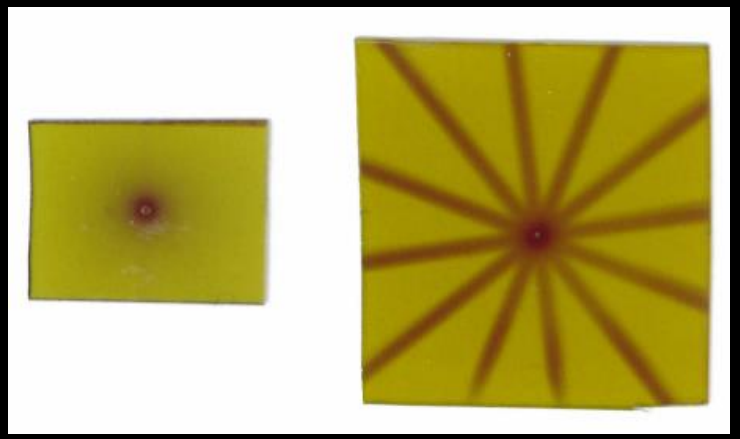




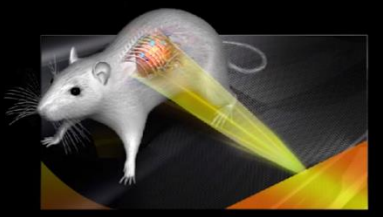


Advanced Tracking
Targeting Accuracy

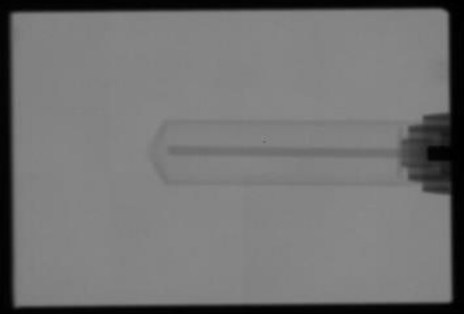




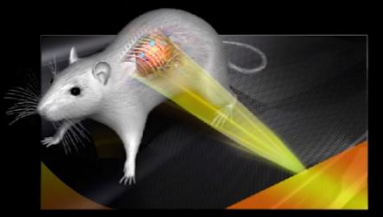
Dosimetric Commissioning – Absolute Dose



- Most important measurement
  - All others derived from it
- Ion chamber calibrated to correct kV energies
- Conform to AAPM TG-61
- Many variables to consider
  - Temp/Pressure
  - Beam Spectrum (HVL)
  - Backscatter
  - Ion Collection Efficiency
  - Polarity Effect
  - Tube End Effect



Dosimetric Commissioning – Film Measurements

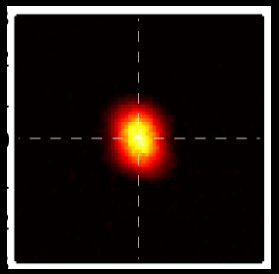


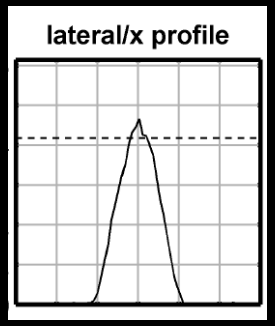
Setup

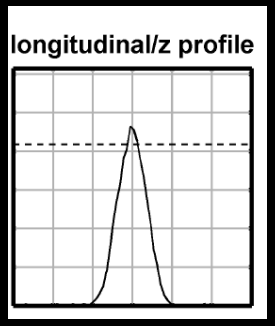
Employ stack of solid water and EBT3 film

Scan 24 hours later

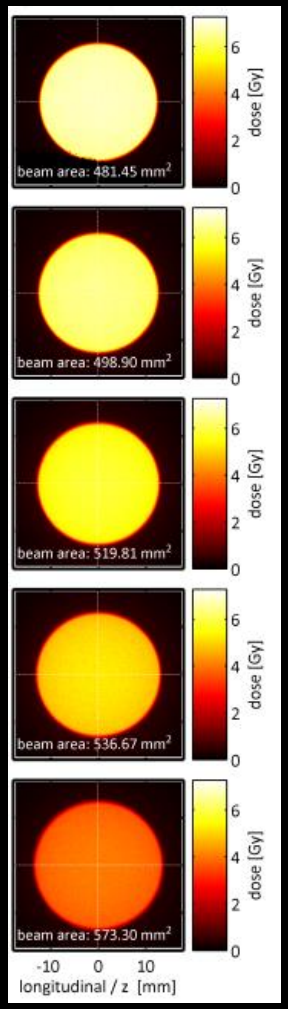
ROF (small fields)



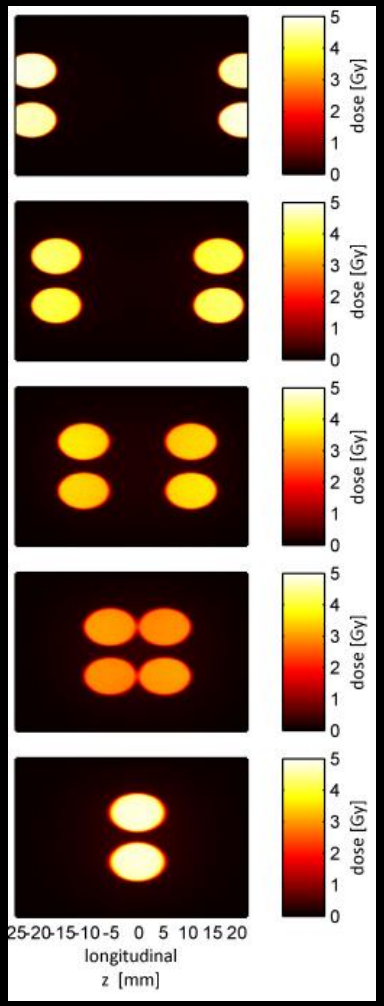




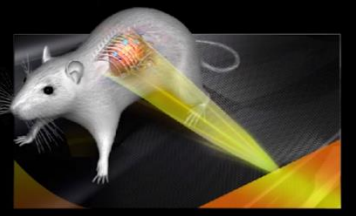
Percent Depth Dose



End-to-end Dosimetry

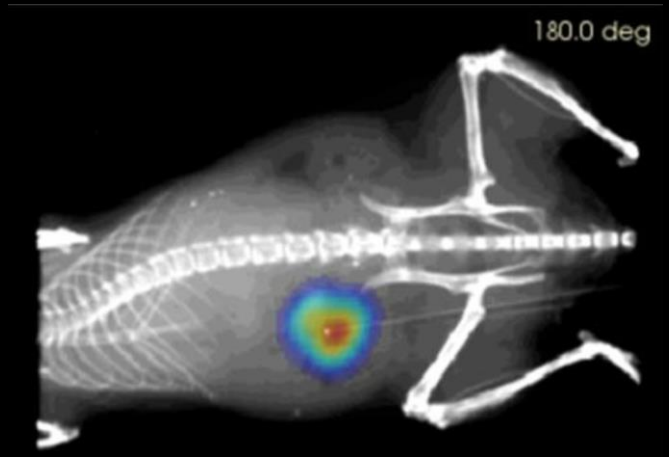


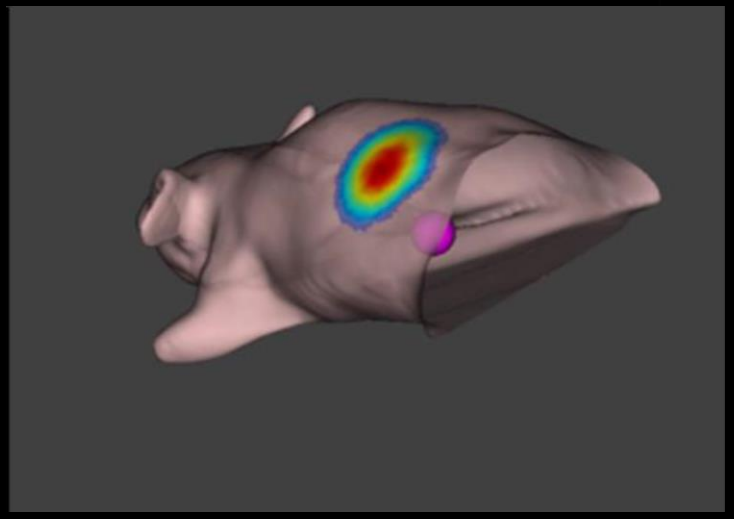
Bioluminescent Imaging



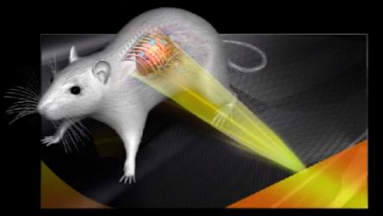
- Light Emission from Living Organisms
  - In Nature: Fireflies, Glow Worms, etc.
- In scientific studies: Inject Luciferase (light emitting enzyme) to latch onto specific tissues (tumour, infection, etc.)

- BLI Integrated into Cabinet
  - Mounted to same gantry as X-Ray Tube and FPD
  - Easily co-register images
- Additional imaging capabilities
  - Visualize structures non-palpable in CT
  - Track tumor viability

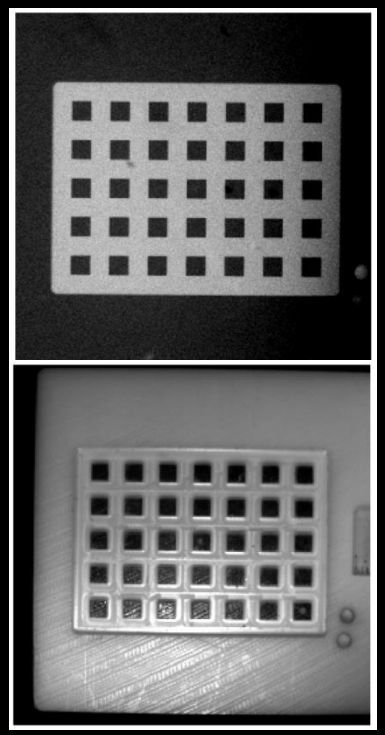




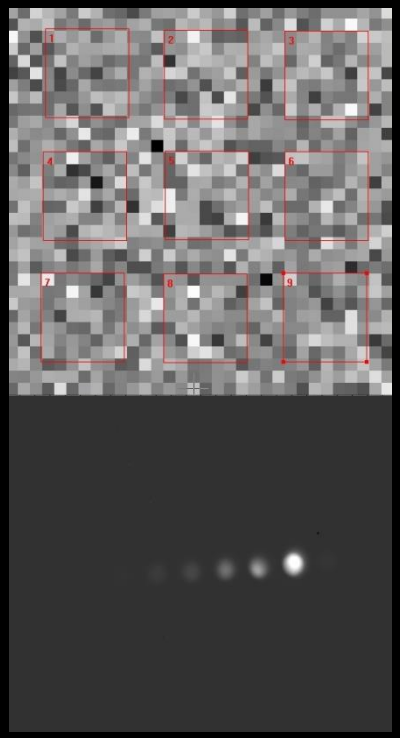
BLI Calibrations



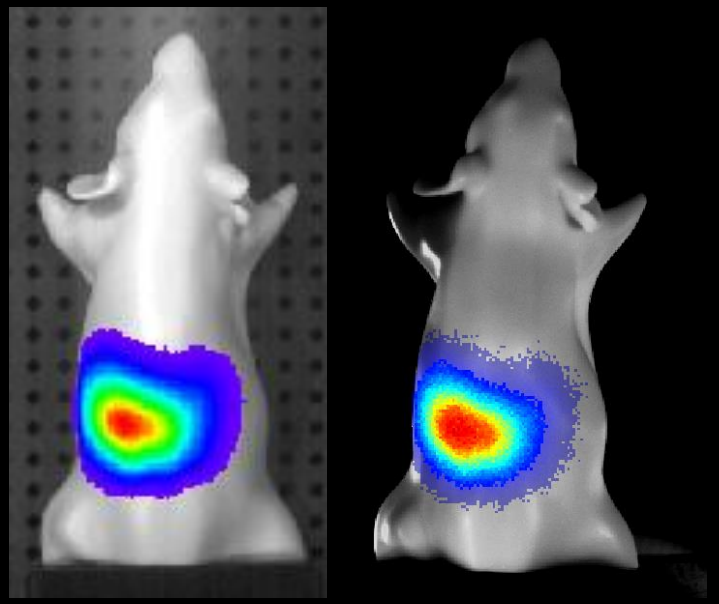
Coordinate System Registration



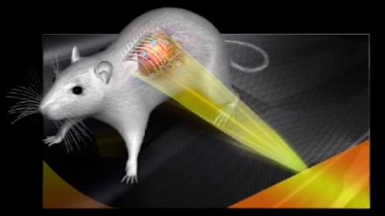
Light Leakage and Intensity



Phantom Comparison with IVIS systems



Quality Assurance



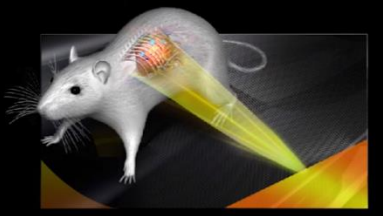
Imaging QA

- Dark Field Calibrations (every scan)
- Geometric Flex Calibration (monthly)
- Flood and Defect Map Calibrations (bi-annual or as needed)
- BLI intensity calibration (bi-annual)
- BLI realignment (as needed)

Dosimetric QA

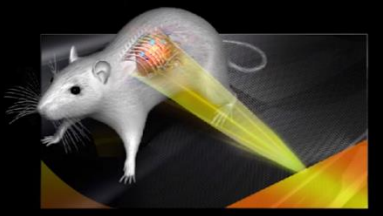
- Absolute Dose measurements (monthly)
- HVL measurements (bi-annual)
- Winston-Lutz Test (monthly)

Logistic considerations



- Need dedicated staff for operations and QA
- If processes are overly complicated, it leads to more errors
- Shared lab space have less resources than hospital
  - Can't earmark entire medical physics dept.
- Automated QA is essential

What makes a good plan?



- Good question! It's why we're doing this research!
- Have guiding principles:
  - Maximum dose to targeted areas
  - Minimize to those outside target
- What makes a plan "best"?
  - Proportion of intended treatment outcomes
  - Ideal system workflow

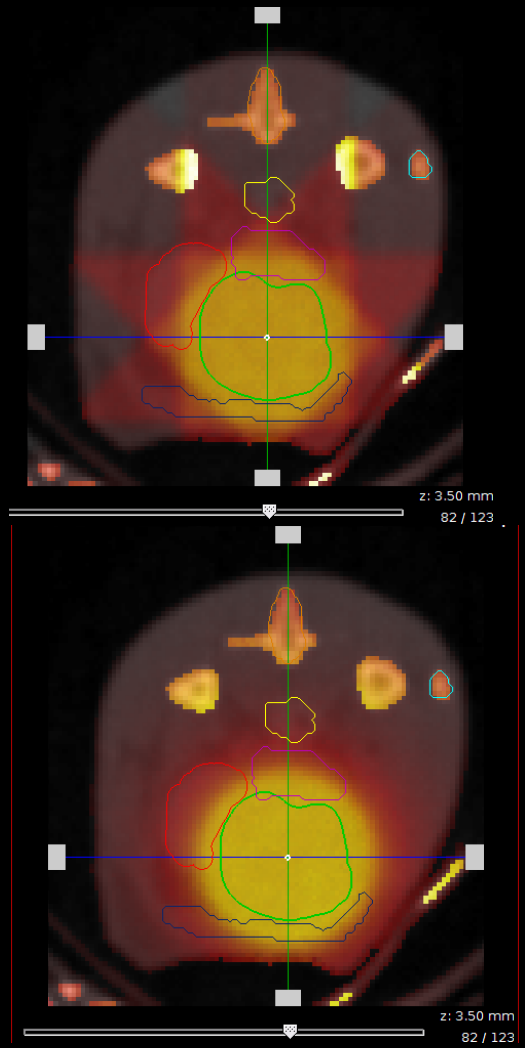
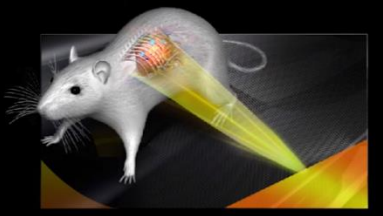


Image taken from Chaudary et. Al, 2015

Future innovations



- Semi-Automated Inverse Planning
- Greatly simplify workflow
- Additional QA needed
- Consider users expertise
  - Need automated planning feedback
  - Build database through network of users

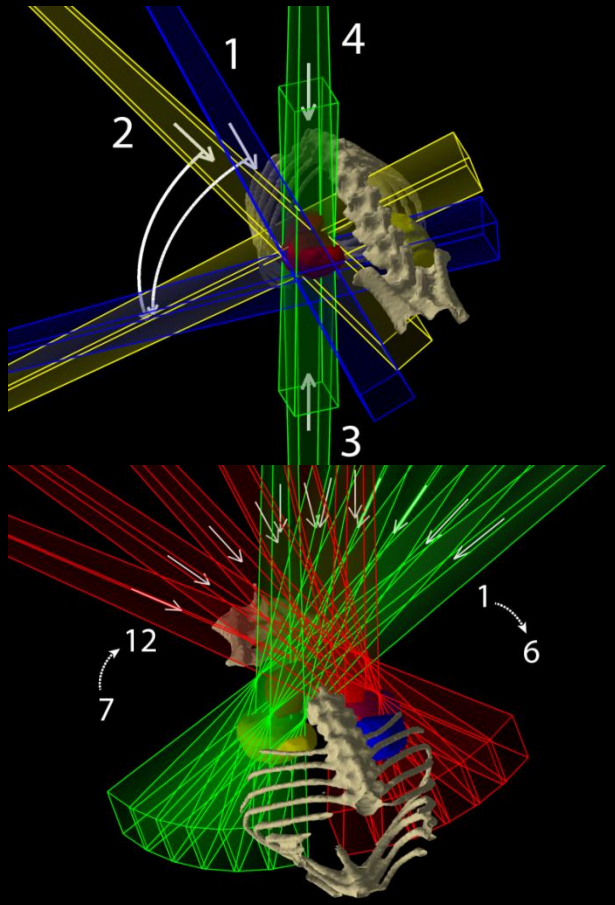
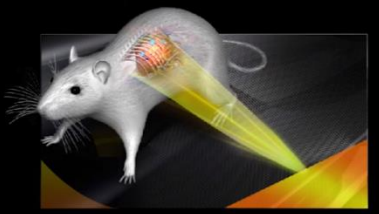


Image taken from Balvert, Van Hoof *et al,* 2015

What Next?



- Standardize QA and Commissioning across all sites
  - Collaboration between boards, academia and industry
- Incorporate automation for compliance
- As new features added, new protocols must arise as well

Thank You!