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Digital Autoradiography of Bone-Seeking Radionuclides in Human

George Tabatadze†, Brian W. Miller‡, Sergei Y. Tolmachev†

†*US Transuranium and Uranium Registries*
College of Pharmacy, Washington State University

‡*College of Optical Sciences, University of Arizona*

iQID: ionizing-radiation Quantum Imaging Detector

THE UNIVERSITY OF ARIZONA®

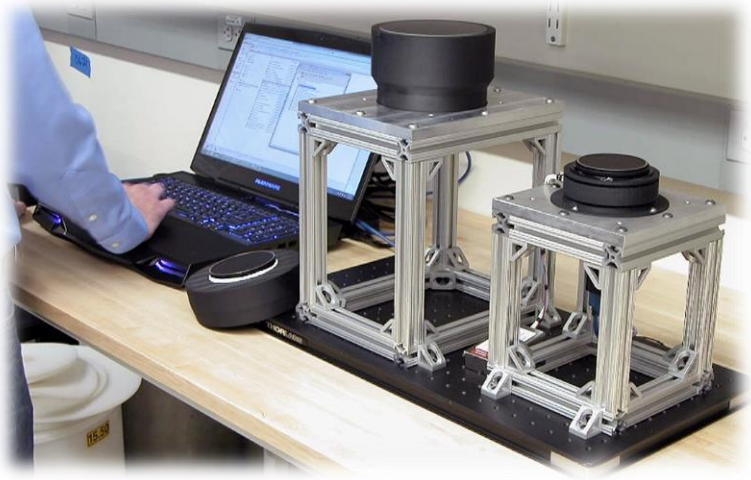
Pacific Northwest NATIONAL LABORATORY

Proudly Operated by **Battelle** *Since 1965*

UNITED STATES TRANSURANIUM AND URANIUM REGISTRIES est. 1968

Ionizing-radiation imaging:

- Gamma/X-rays
- Alpha particles
- Beta particles
- Neutrons
- Fission fragments



Miller BW, Gregory SJ, Fuller ES, Barrett HH, Bradford Barber H, Furenlid LR. The iQID camera: An ionizing-radiation quantum imaging detector; Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, A767:146-152, 2014.

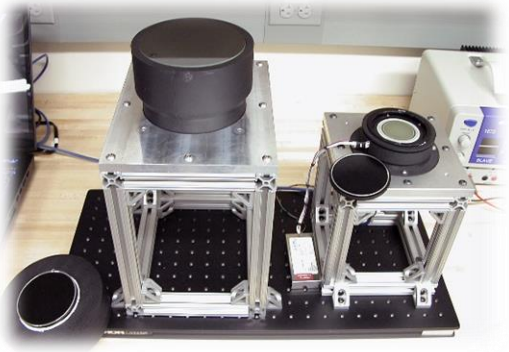
iQID vs Conventional Autoradiography

Conventional Autoradiography
- Fixed exposure time
- Temperature controlled environment
- Extensive sample preparation
- Manual and automated readout

20th Century

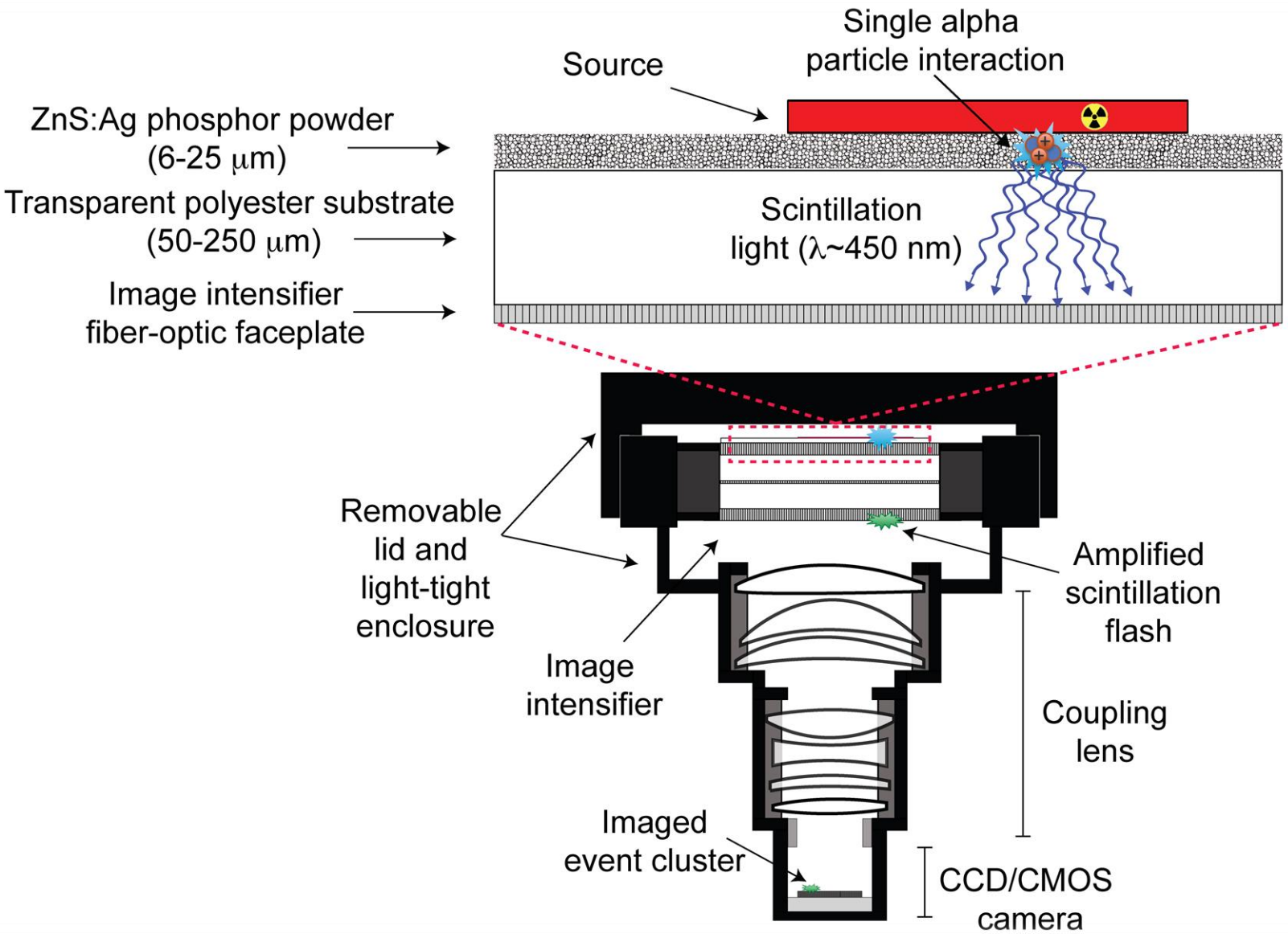
iQID
- Real-time dynamic imaging capability
- No temperature control requirements
- Minimal sample preparation
- Automated readout

Extras
- Portable equipment
- High detection efficiency
- Low background rate
- Broad sensitivity to ionizing radiation



21st Century

iQID: Cross-sectional View



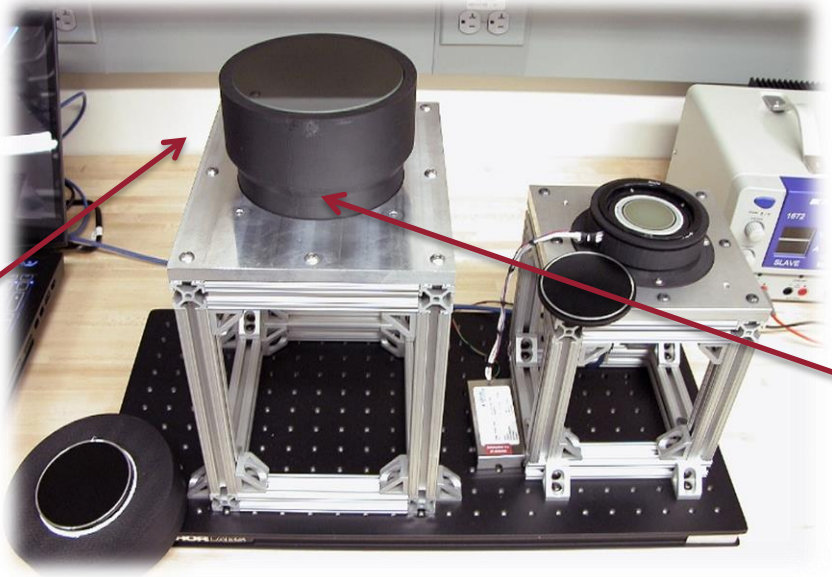
iQID Specifications

Grasshopper® 3 USB 3.0 CMOS detect

- 4.1 MP, 2048×2048 @ 90 fps
- 1" CMOS sensor

Optical pixel size

- 19.5×19.5 μm^2 pixels with 40 mm diameter intensifier and 61×61 μm^2 using 125 mm diameter fiber-optic taper



115mm : 40mm fiber-optic taper

40 mm diameter image intensifier

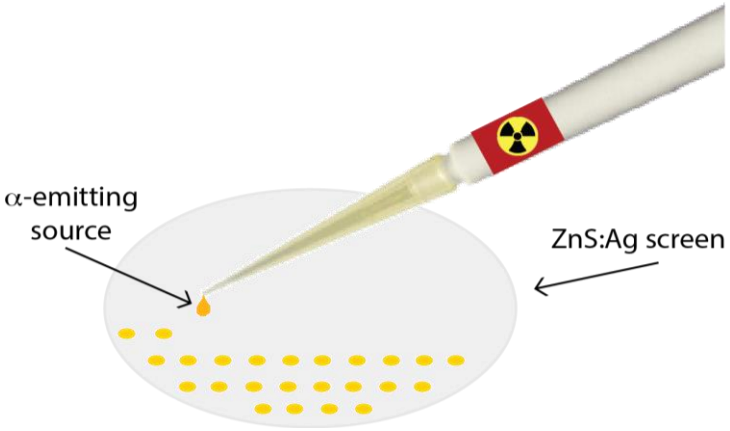
Testing iQID Capabilities

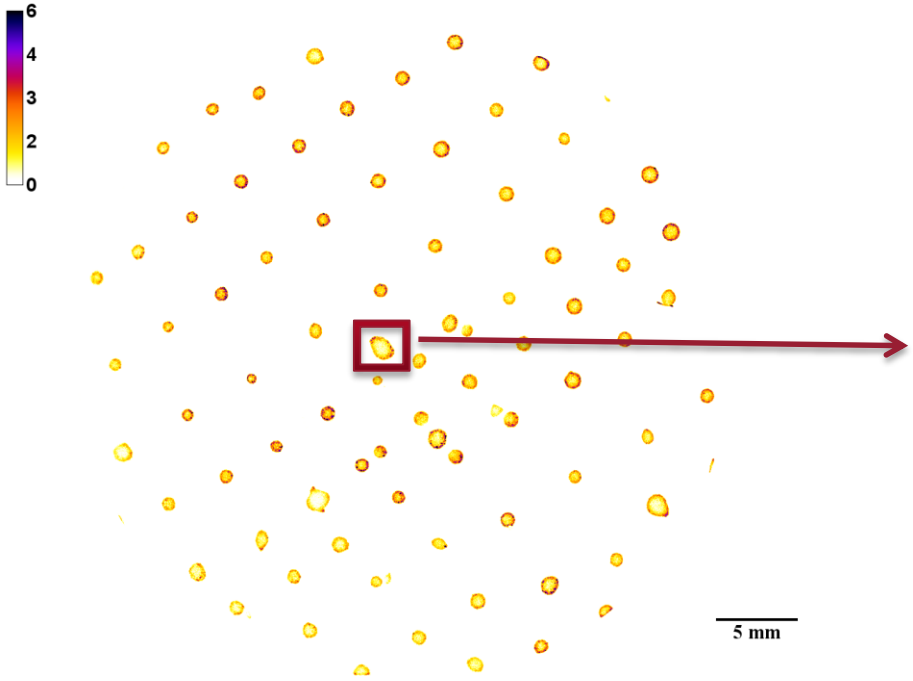
- Feasibility Studies -

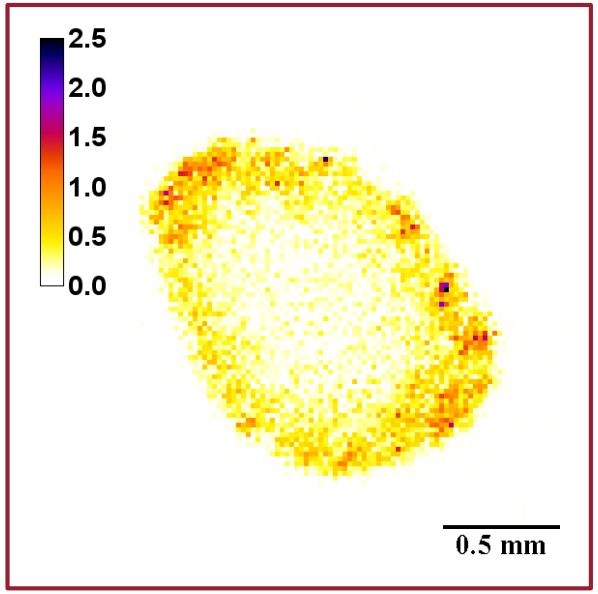
^{252}Cf Alpha Particles and Fission Fragments (I)

Cf-252, mBq scale

- ~100 Bq total, 5 hours acquisition, 40 fps
- ZnS:Ag screen: Eljen EJ-444 (3.25 ± 0.25 mg/cm2 ZnS:Ag)



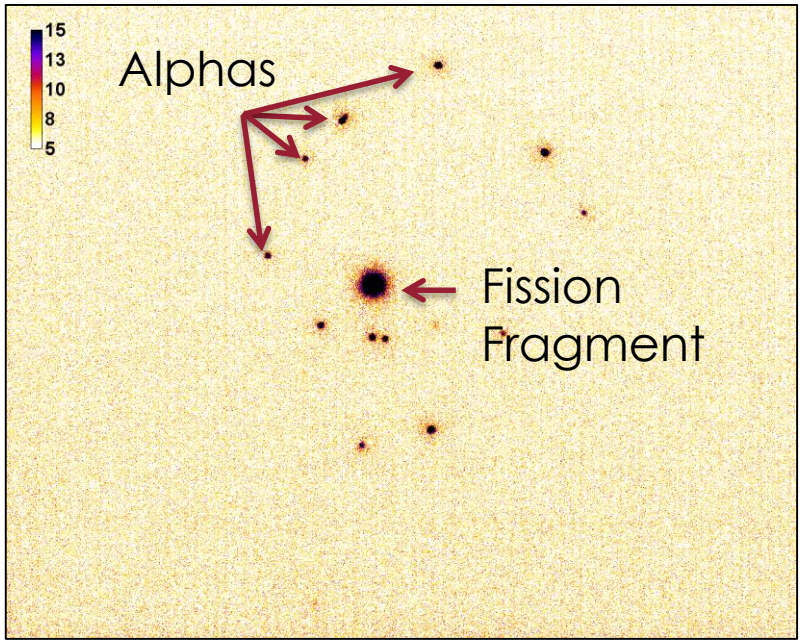


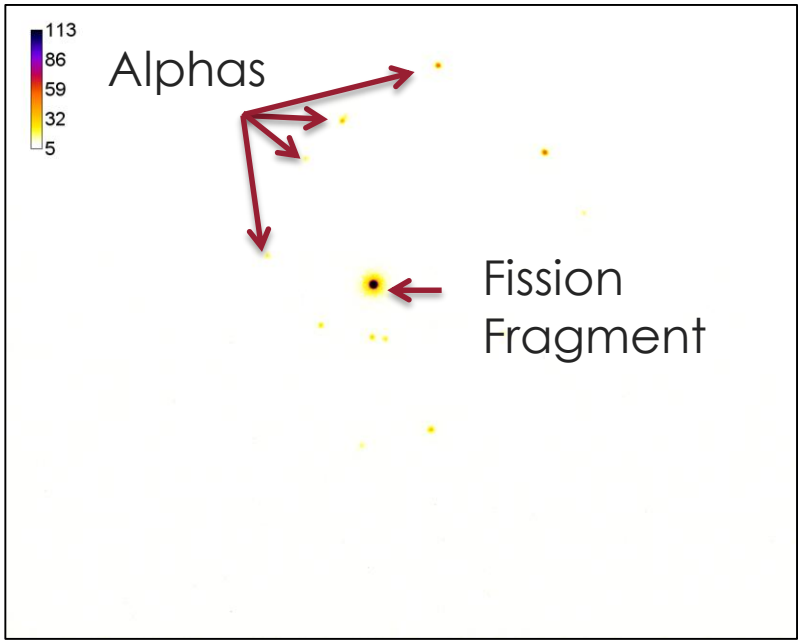


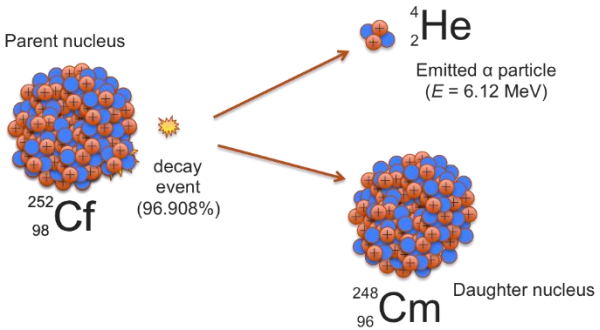
Sub-region: ~21.6k counts over 5 hours → ~1.2 Bq (32.4 pCi)
Centroid coordinate estimate to nearest sub-pixel quadrant (20.7 μm/pixel)

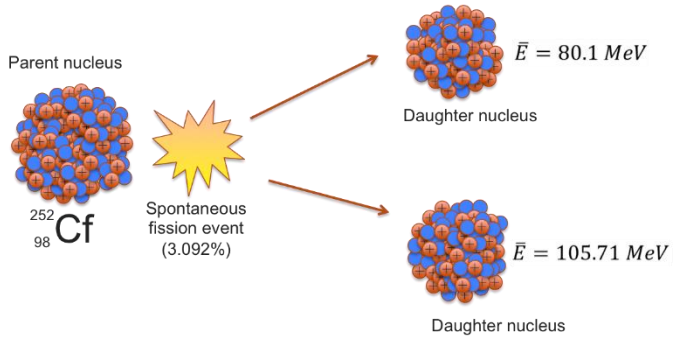
^{252}Cf Alpha Particles and Fission Fragments (II)

- Single Event Detection

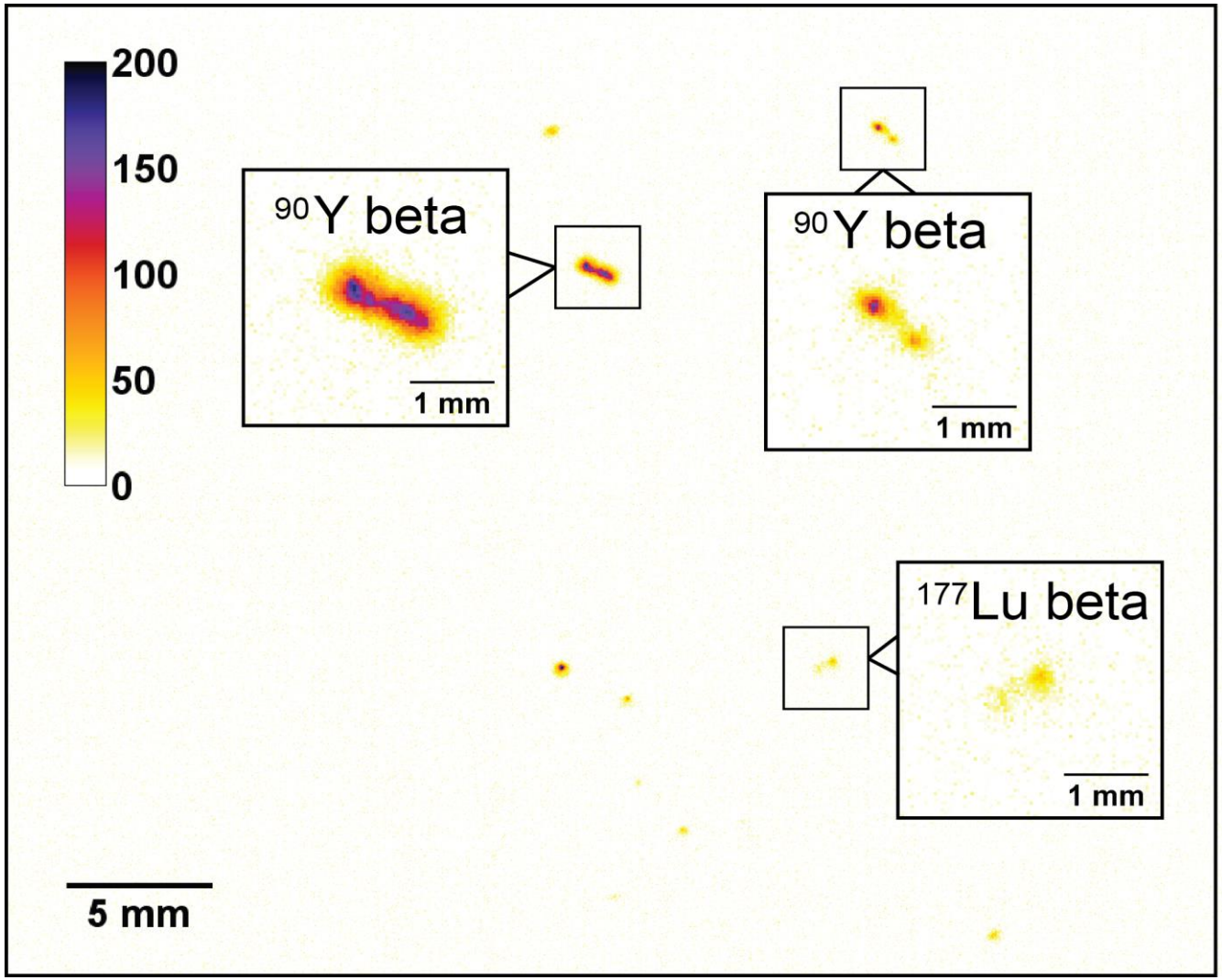




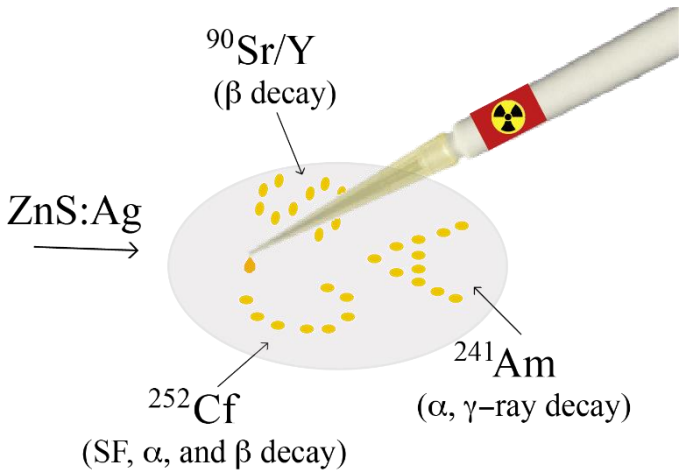


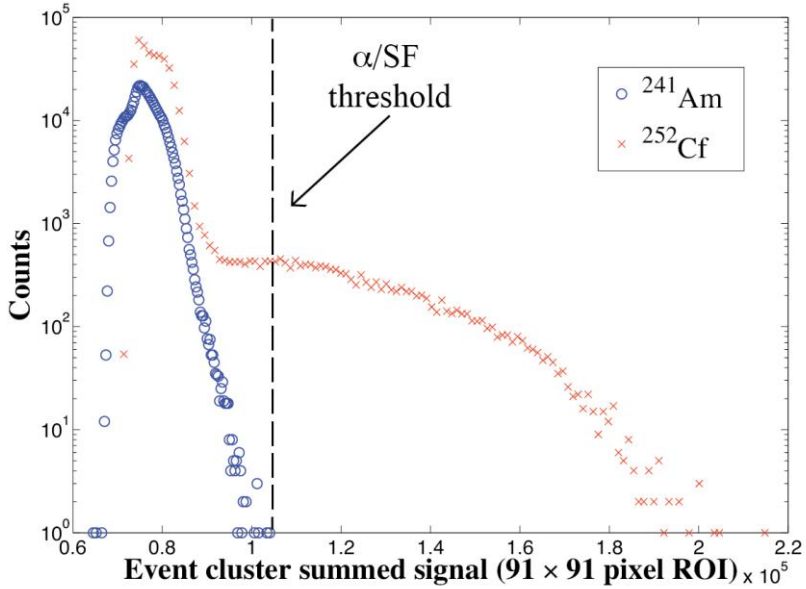


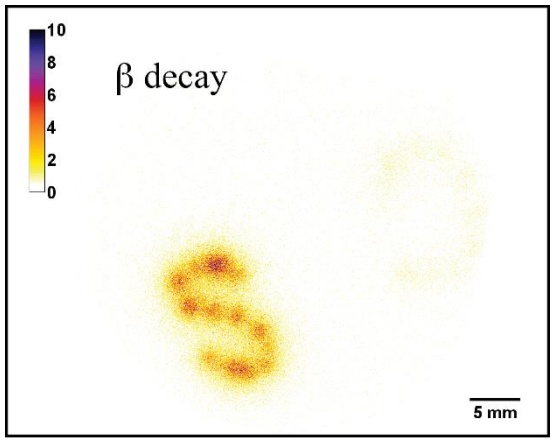
^{77}Lu and ^{90}Y Beta Particles

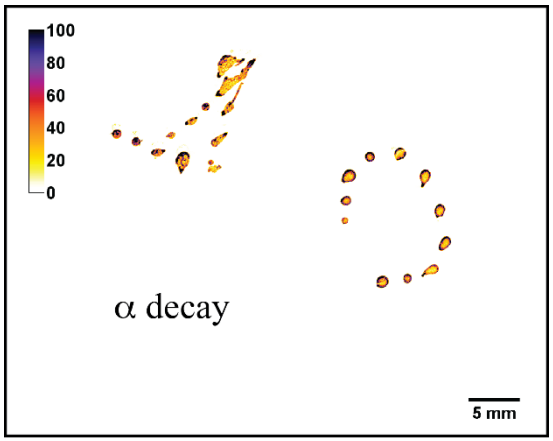


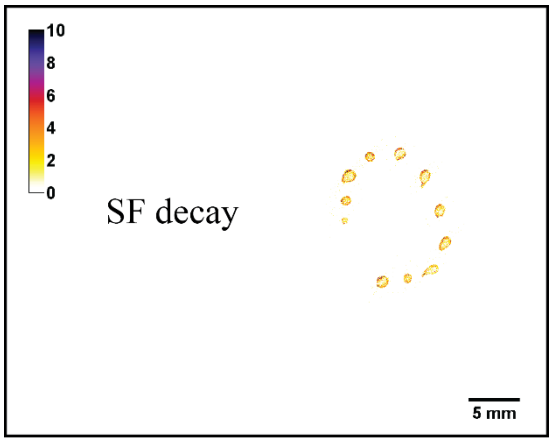
Particle Discrimination











Radionuclide Microdistribution in Bone

- Initial Study -

Radionuclides of Interest

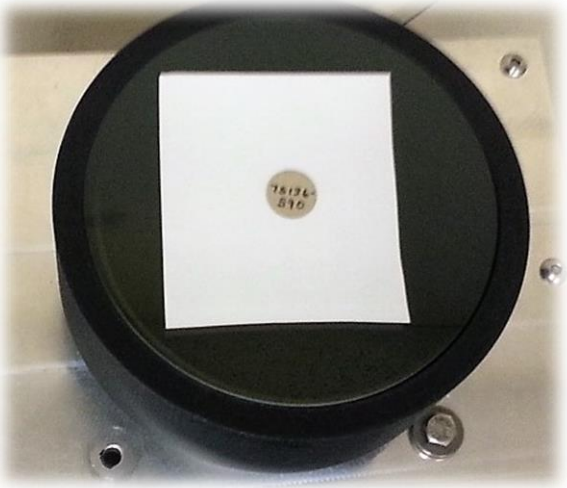
^{241}Am: Case 0246 - "Atomic Man" – ion exchange column explosion accident at Hanford Site (1976)

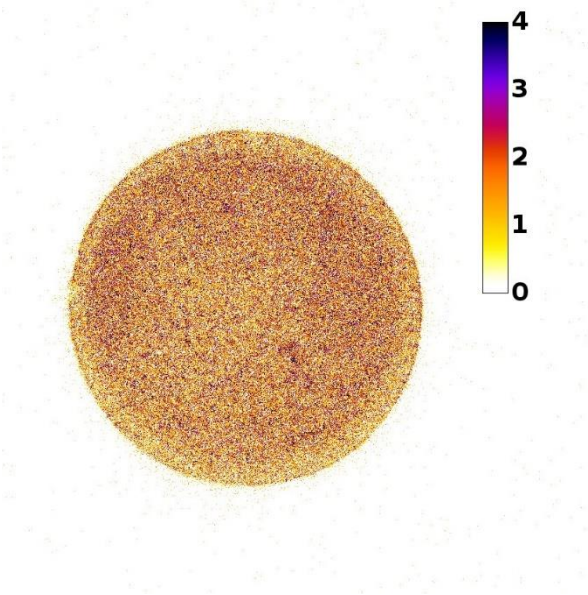
- ^{239}Pu: CHI-1 (40-004) – plutonium injection study at Billings Hospital of the University of Chicago (1945)

- ^{226}Ra: 03-210 – therapeutic radium injection case (1926)

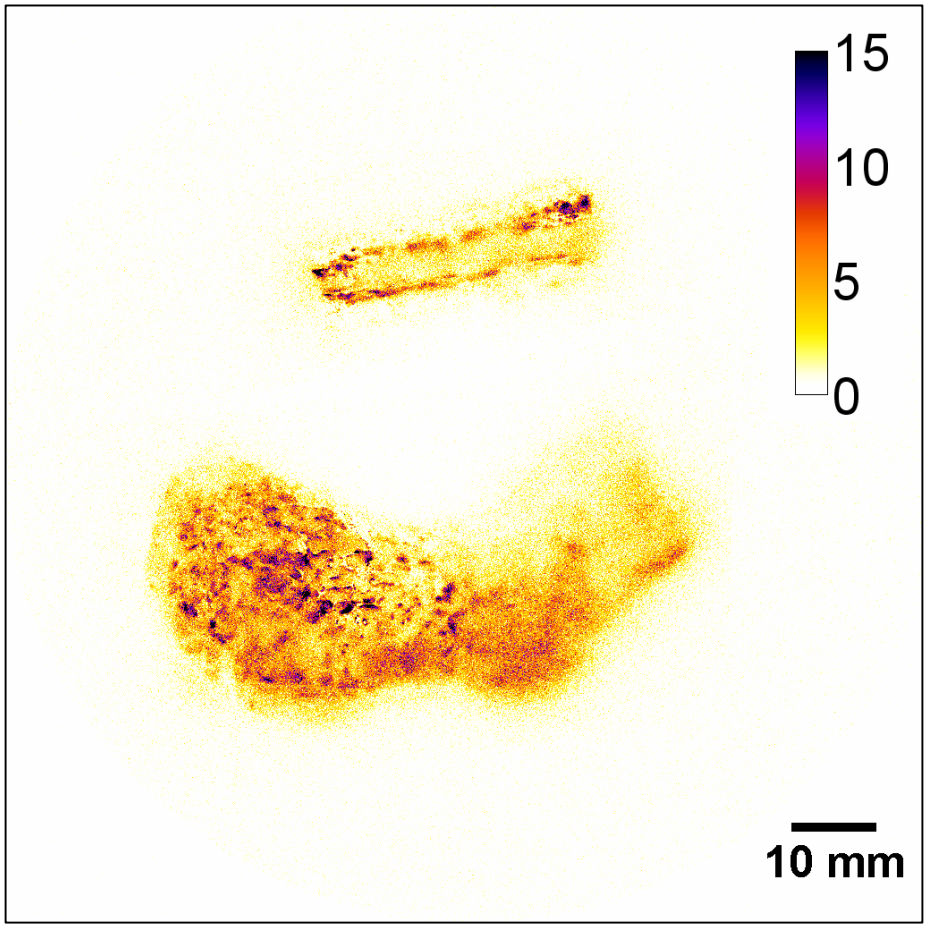
iQID Calibration

- Source: ^{242}Pu, ^{239}Pu, ^{241}Am (87 dpm, E&Z Analytics)
- High detection efficiency
  - ✓ Ø115 mm detector: 93.4% (84.9% with background reduction)
  - ✓ Ø40 mm detector: 92.3% (68.9%)

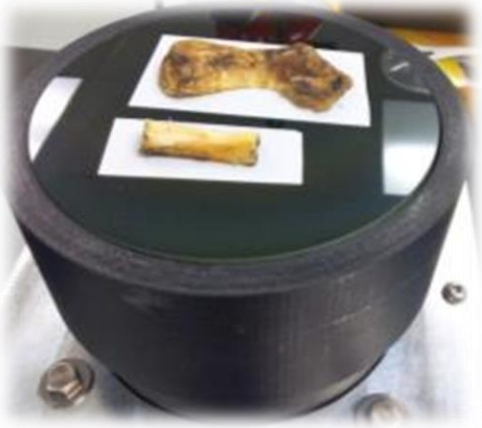




^{241}Am Distribution in Bone



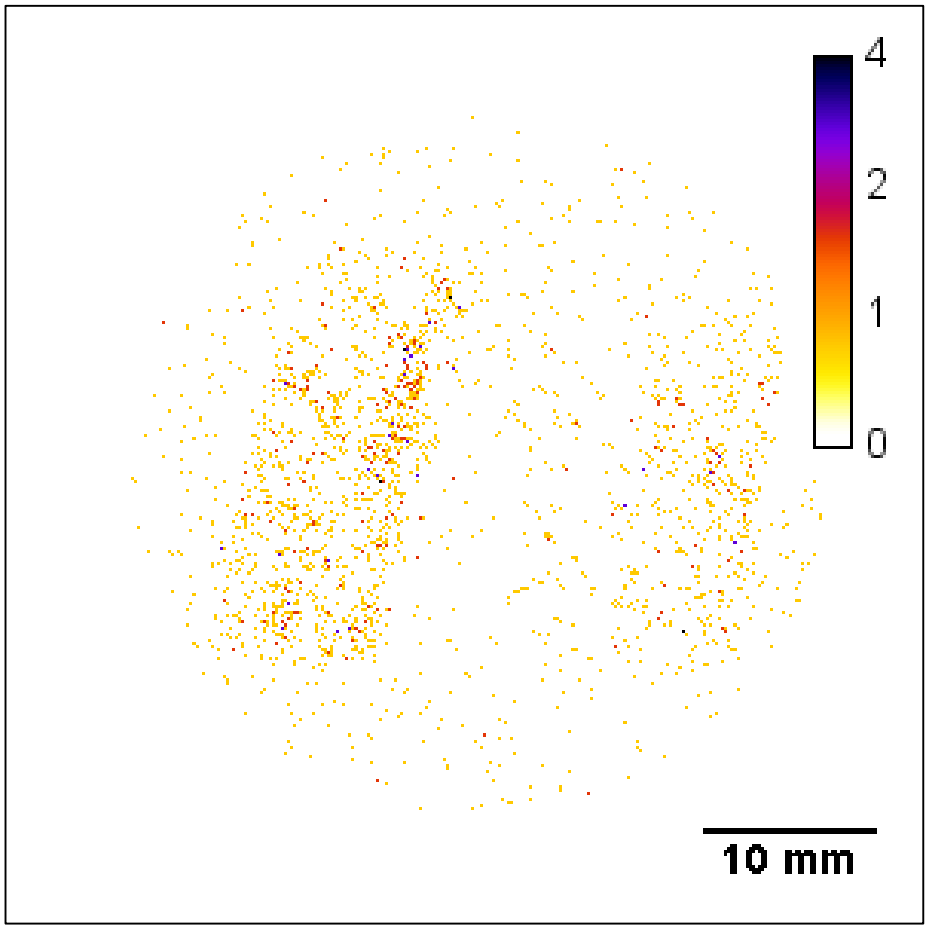
- Clavicle Acromial End
- Clavicle Shaft
- Imaging time: 64 h



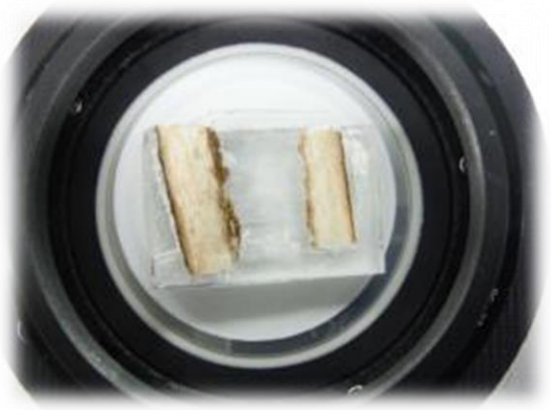
- Surface activity range:

  1.4 – 17.0 mBq mm^{-2}

^{239}Pu Distribution in Bone



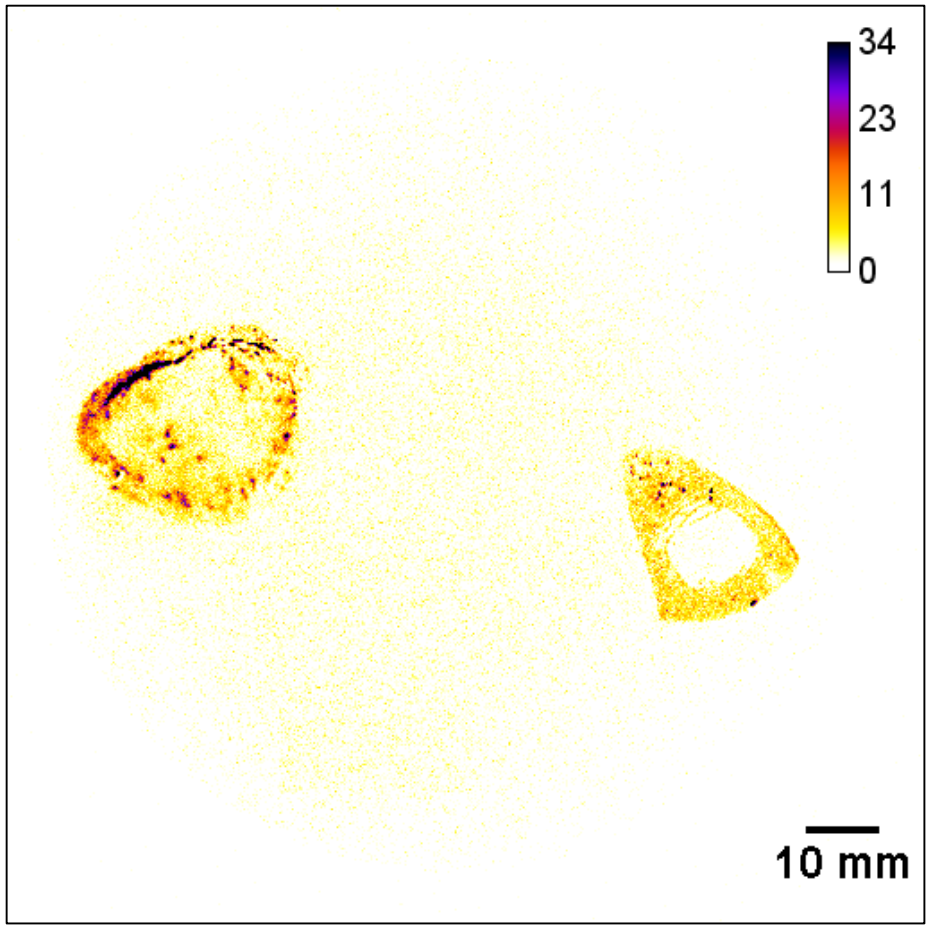
- Femur: Middle Shaft
- Imaging time: 408 h



- Surface activity range:

0.001 – 0.014 mBq mm^{-2}

^{226}Ra Distribution in Bone



- Femur: Distal End
- Tibia: Middle Shaft
- Imaging time: 235 h

- Surface activity range:
  0.1 – 4.1 mBq mm^{-2}

Image Processing: ROI Segmentation (I)

Case 0246: Clavicle (R) Acromial End

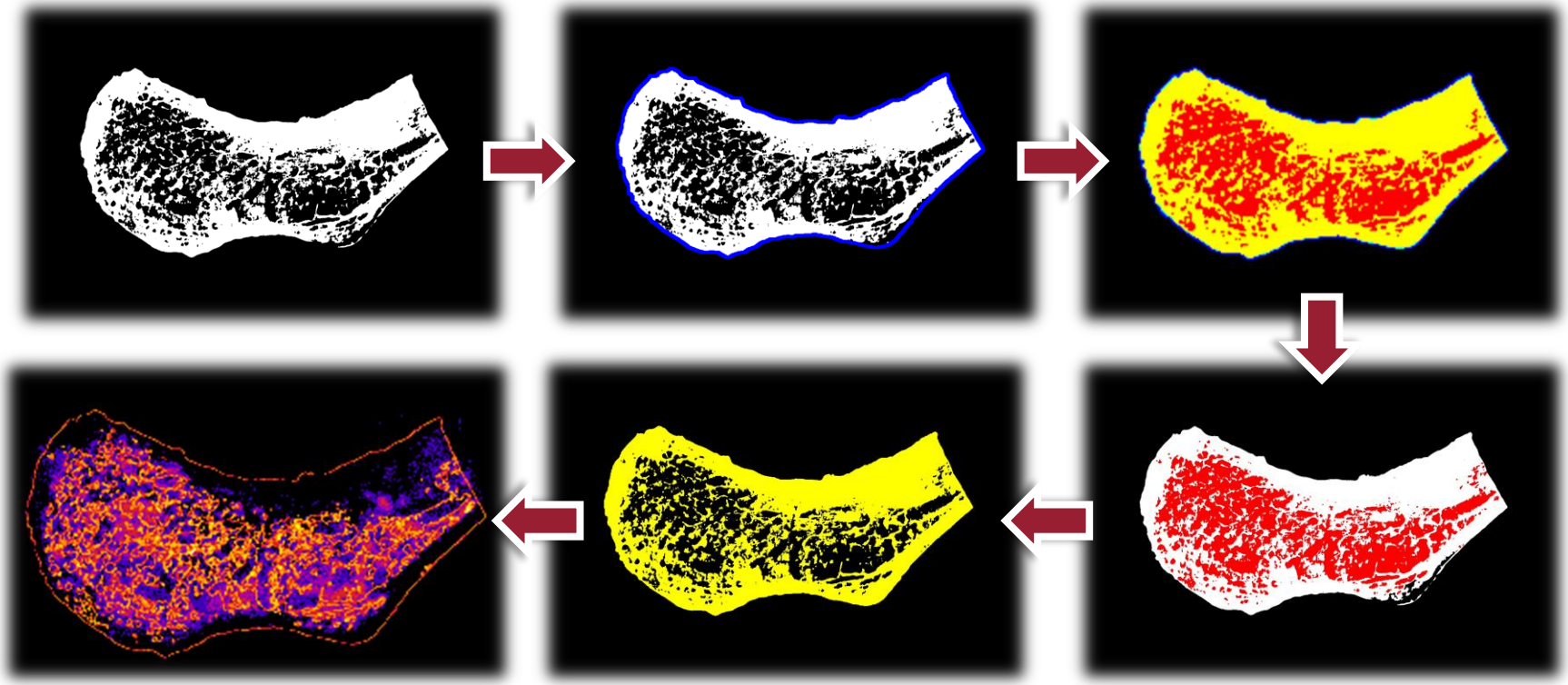
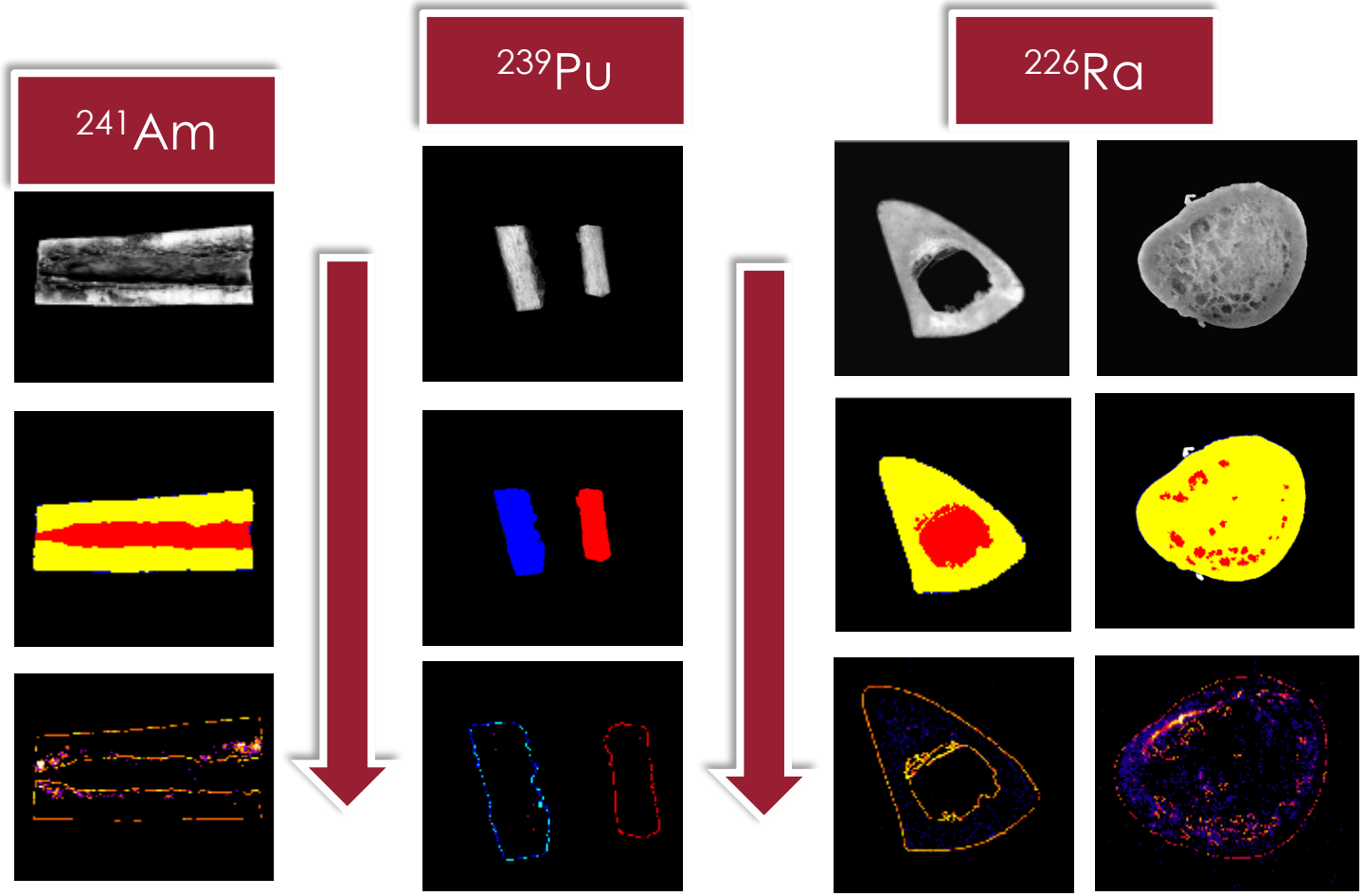
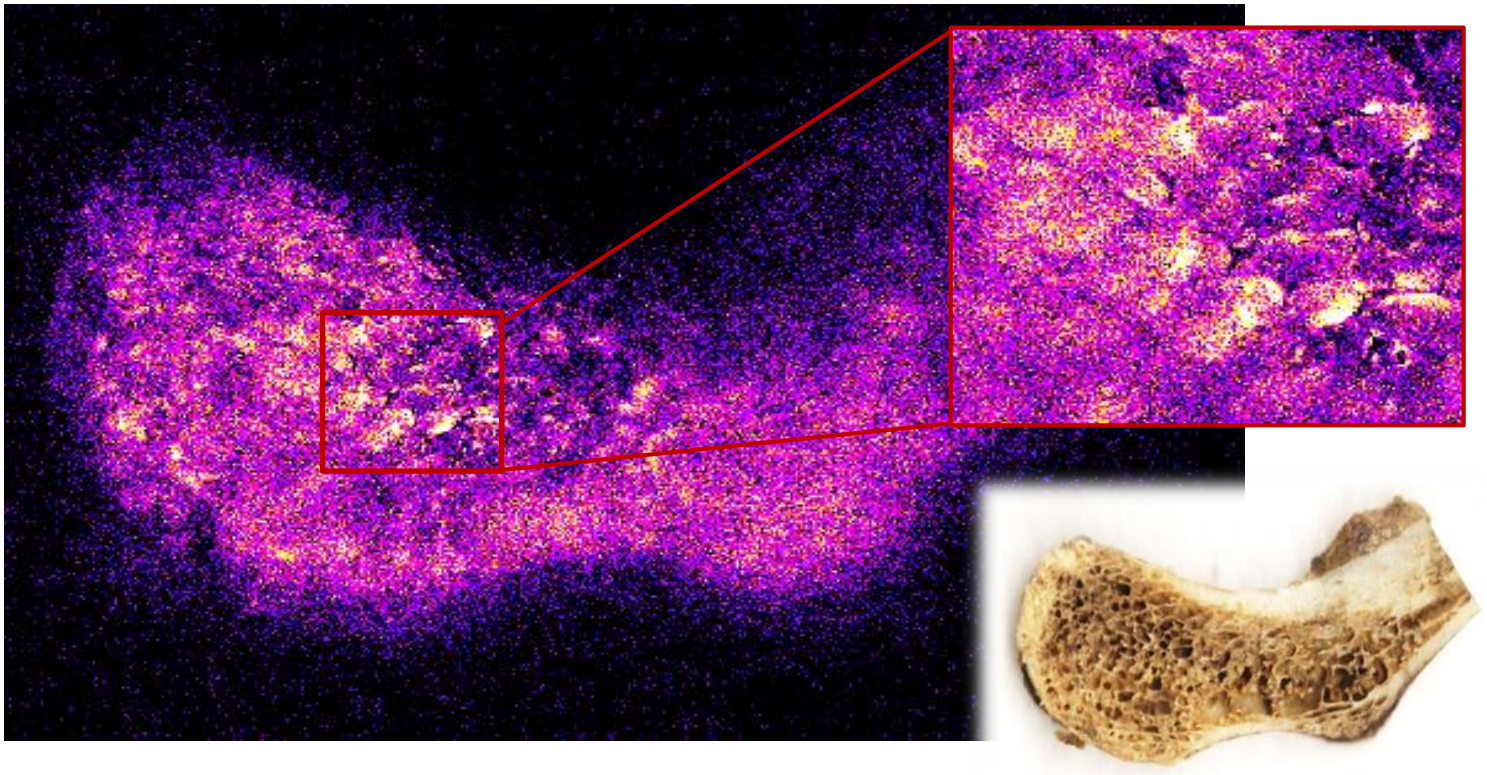


Image Processing: ROI Segmentation (II)



Findings

- Radionuclide distribution visualized on a micro scale
- Low signal-to-noise ratio

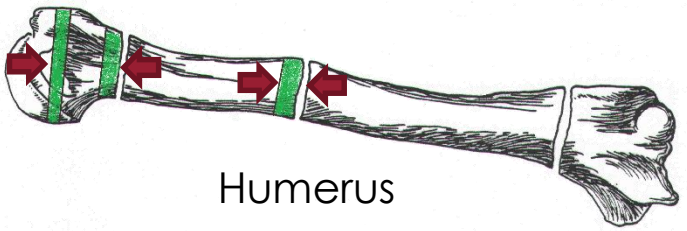


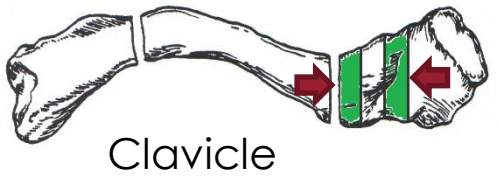
Radionuclide Microdistribution: Next Step

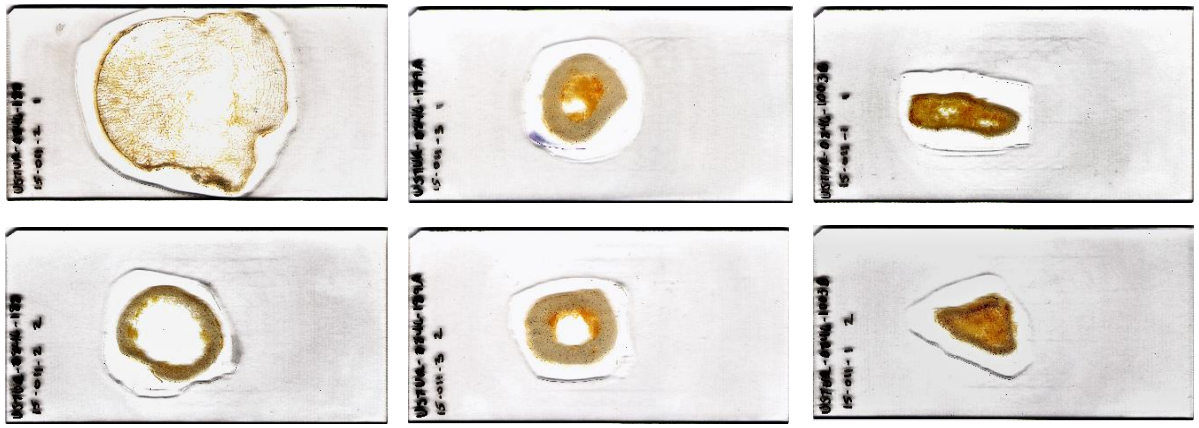
- ^{241}Am Case Study -

Sample Preparation

- Exposure: ^{241}Am chronic inhalation
- Skeleton activity: 29.6 kBq
- Bones: humerus proximal end, humerus proximal shaft, and clavicle acromial end
- Samples: Plastic embedded 100-µm thick bone sections

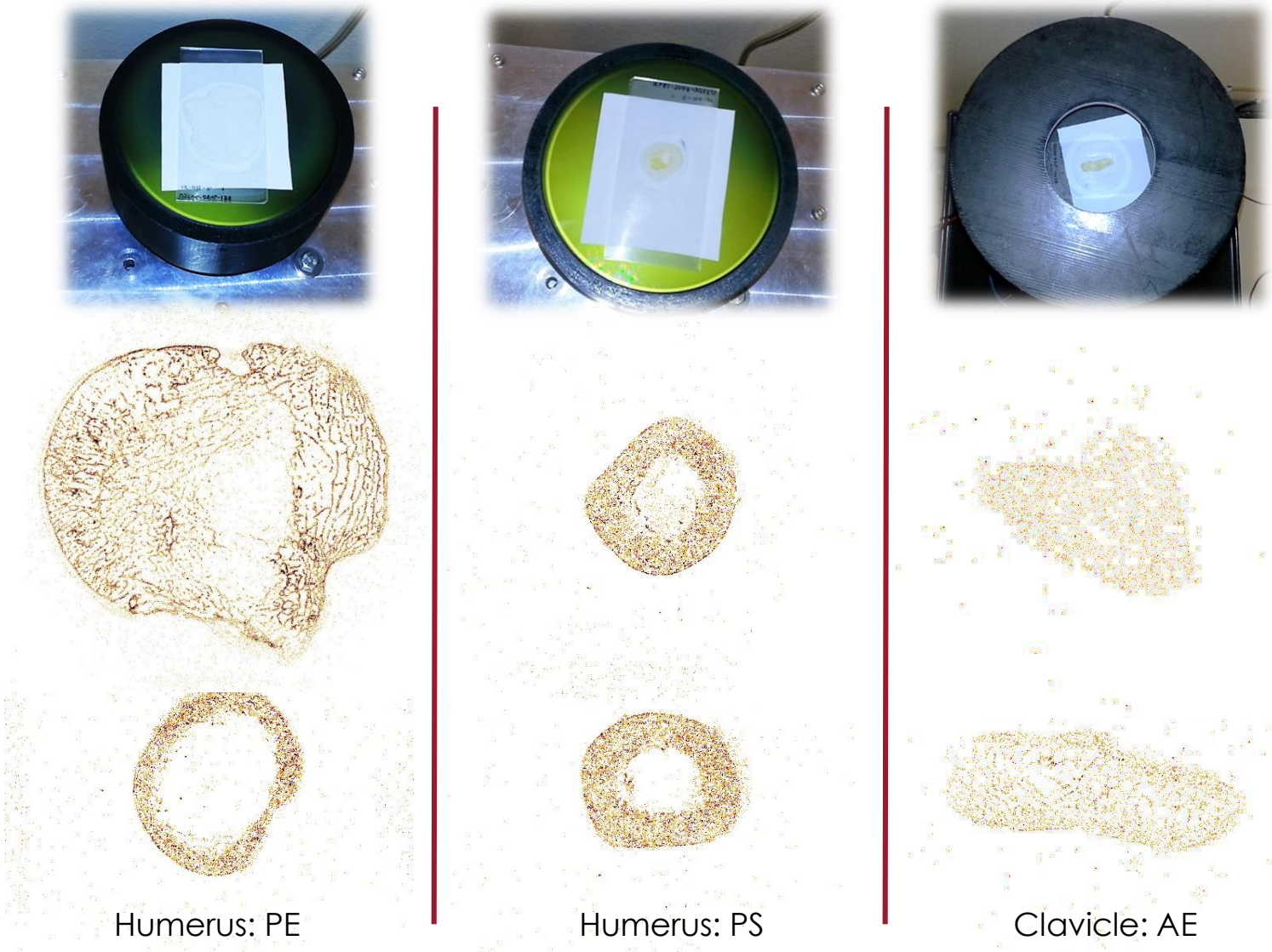






^{241}Am Microdistribution in Bone

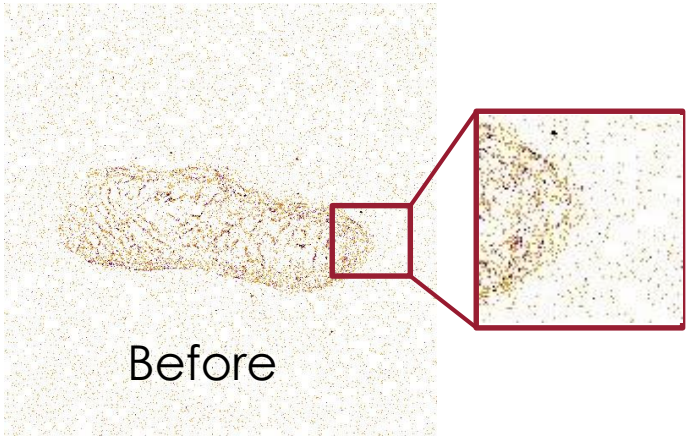
- Counting time: 300 – 1,600 hours

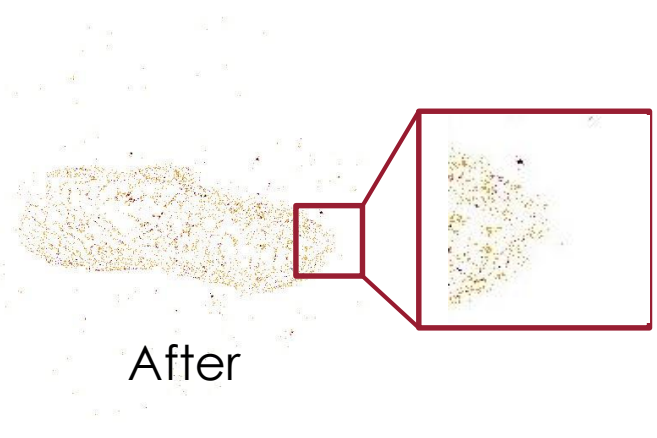


Humerus: PE | Humerus: PS | Clavicle: AE

Image Data Processing

- Raw iQID images were processed using MatLab® Code (Octave® software) to reduce background

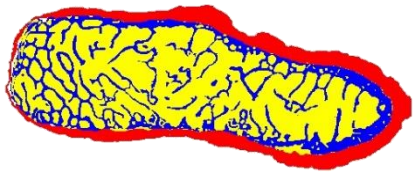




- Cortical and trabecular bone volumes were defined using Fiji® (i.e. ImajeJ®) software

Original Image

Segmented

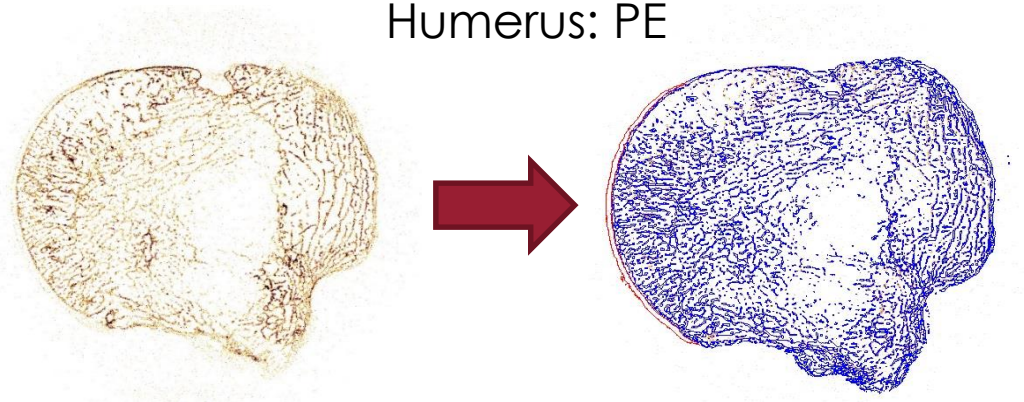


ROI

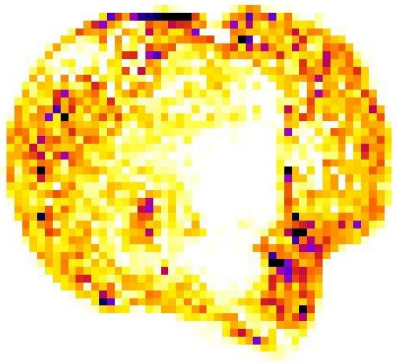
iQID: Surface Activity

- Average surface activity (A_s): ROI based
- Max. A_s : 1 mm^2 binning & max. pixel value (ImajeJ)

Humerus: PE



Pixel size: 1 mm^2

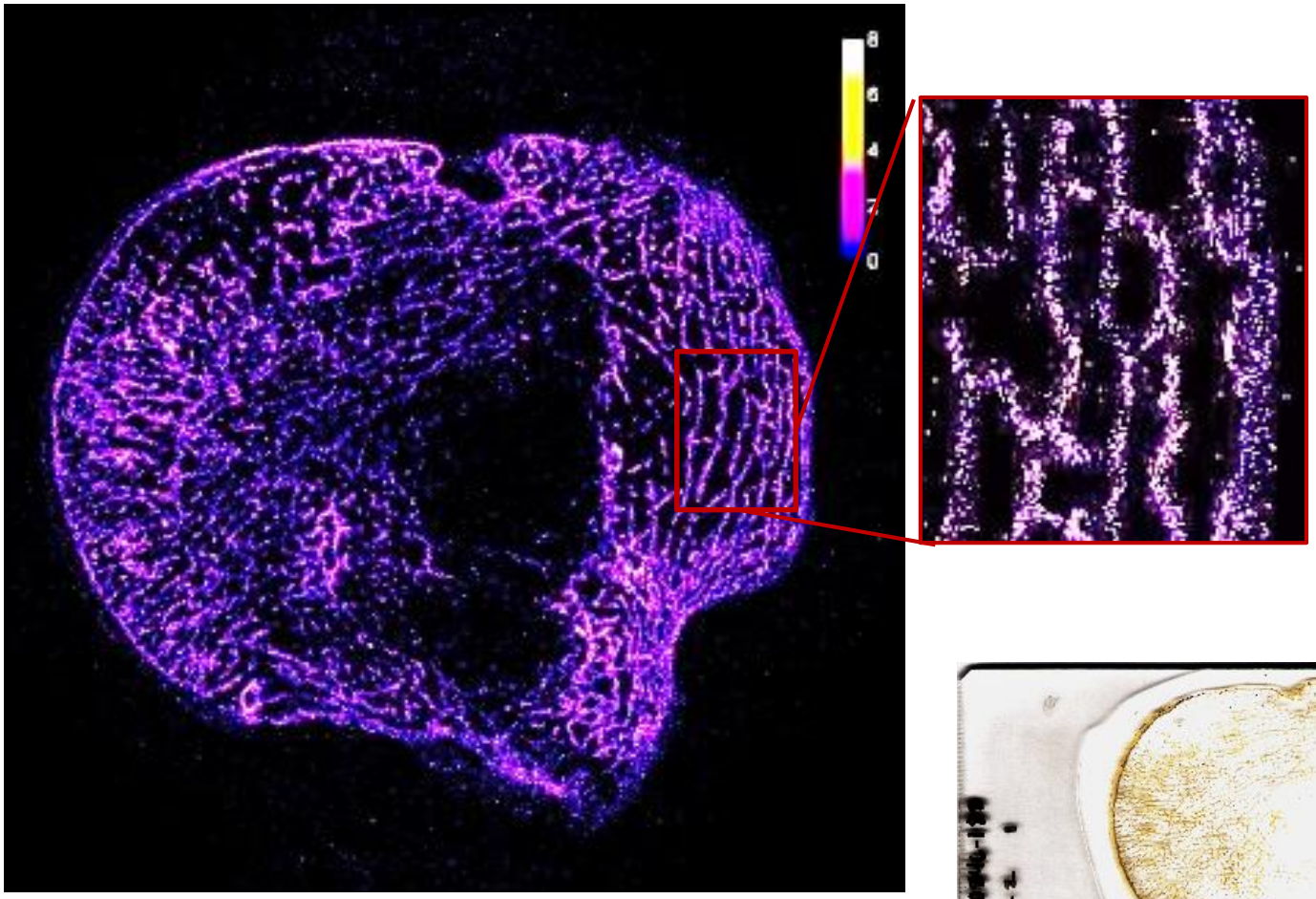


Bone	Surface activity, mBq mm^{-2}	
	†Average	‡Max
Humerus		
PE (188-1)	0.198	0.251
PE (188-2)	0.084	0.034
PS (189A-1)	0.074	0.031
PS (189A-2)	0.074	0.028
Clavicle		
AE (1003B-1)	0.057	0.033
AE (1003B-2)	0.033	0.016

† Counts averaged over original pixel area (816 μm^2 or 389 μm^2 for large and small detectors, respectively)

‡ Counts averaged over 1 mm^2 pixel

Improved Signal-to-Noise Ratio

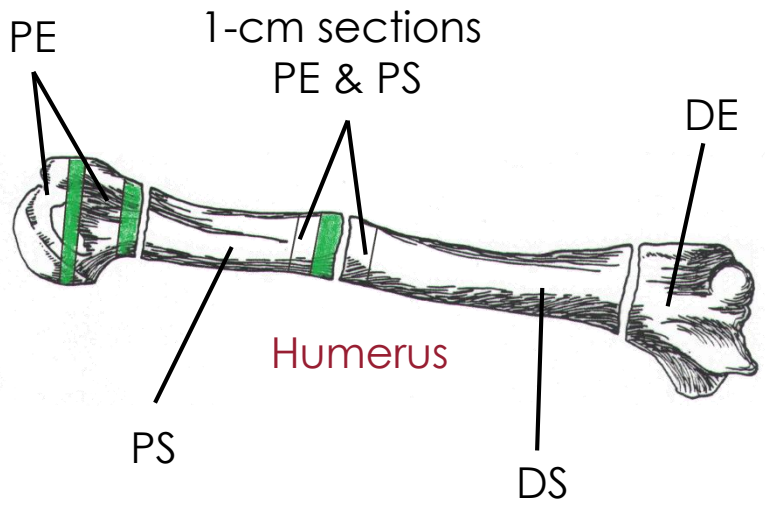


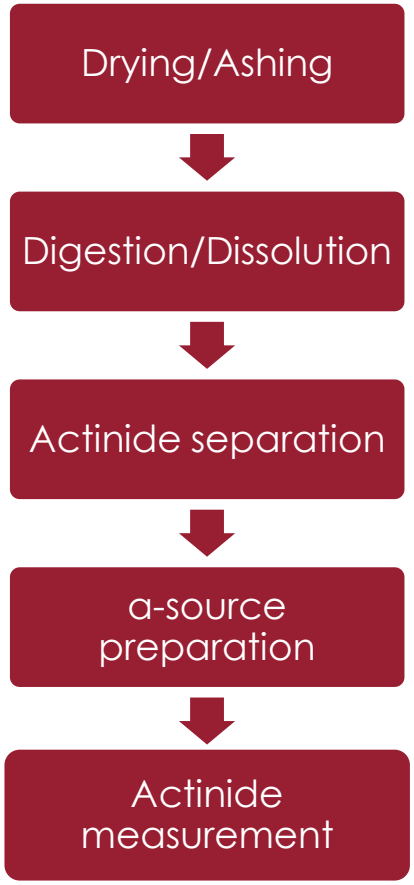
Moving Toward Microdosimetry

- iQID *vs* Radiochemistry -

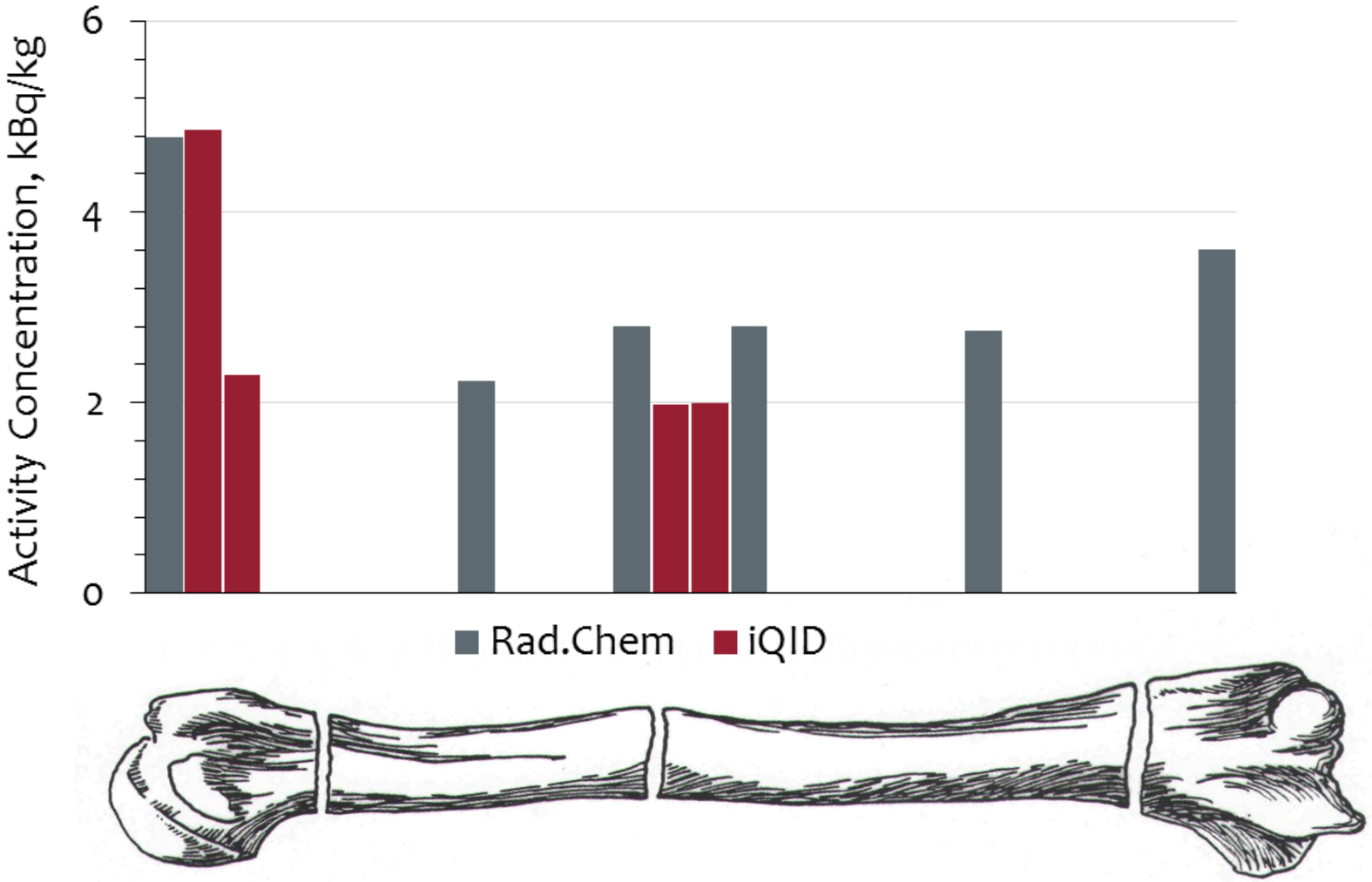
Radiochemical Analysis

- Bone sections adjacent to those used for plastic embedding were selected for radiochemical analysis



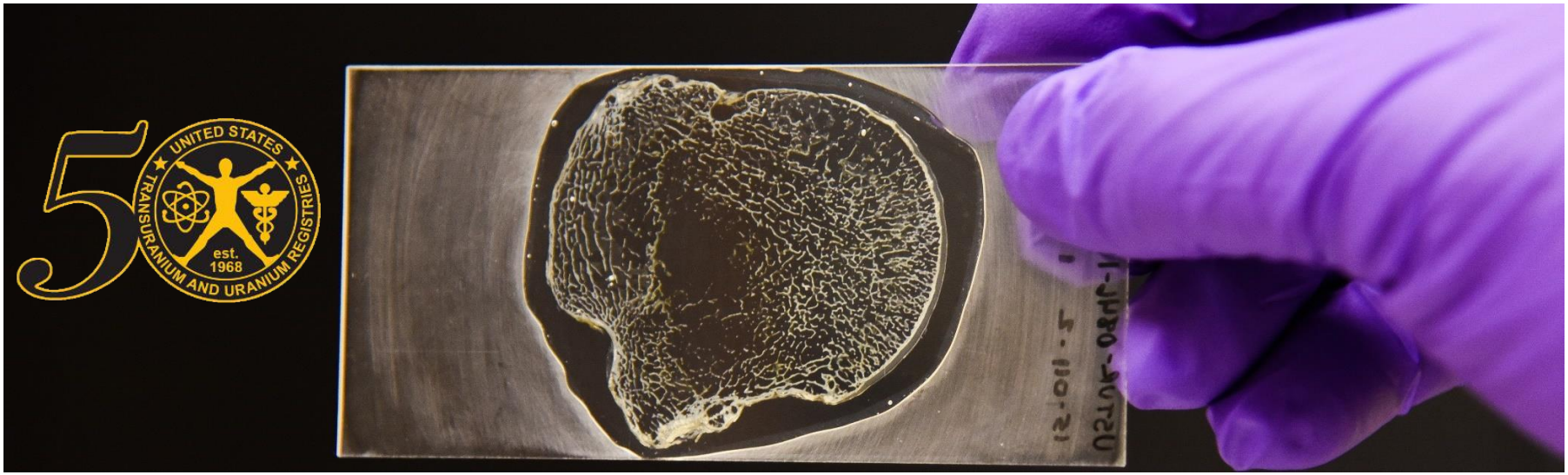


iQID & Radiochemistry: Activity Concentration



Summary

- iQID allows for real-time quantitative autoradiography at 20-μm resolution for ^{226}Ra, ^{241}Am, and ^{239}Pu
- Microdistribution of ^{241}Am in bone was visualized and quantified
- iQID measurements are within 30% of radiochemistry results
- iQID is an effective technique for studying the heterogeneous distribution of alpha-emitters on a micro scale



Thank you for your attention!