

# Multi-Sensor Fusion and 3D Mapping

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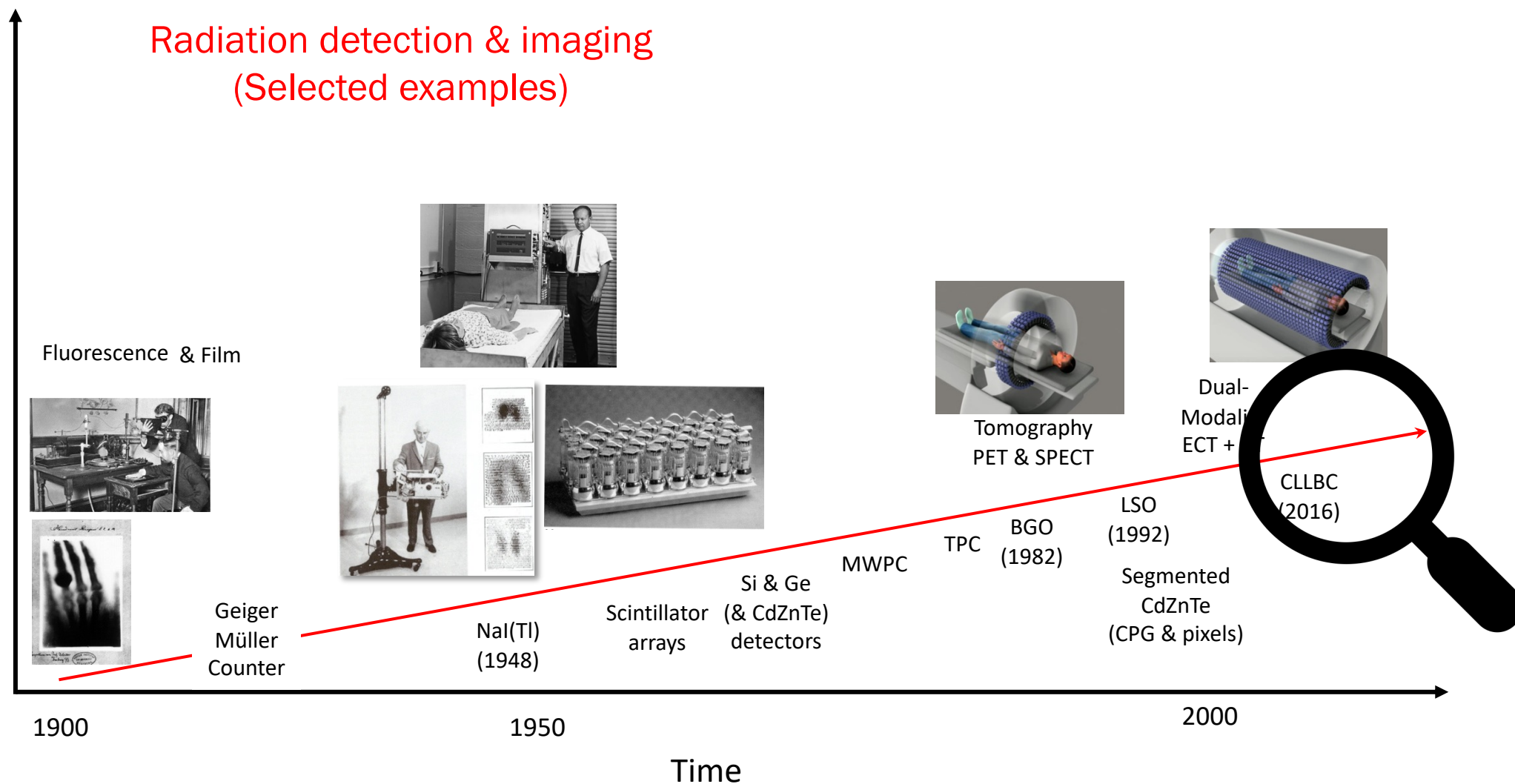
# Introduction and Motivation

- Detection of (dynamic) weak nuclear signatures embedded in (dynamic) naturally occurring and man-made radiological backgrounds
  - E.g. Proliferation detection
- Effective assessment and monitoring of facilities, materials, and operations
  - E.g. Safeguards
- Effective and safe assessment of objects and mapping of contamination and verification of decontamination
  - E.g. Emergency response
- Drive and utilize ( $\sim$ linear) developments in nuclear radiation detection and imaging and combine it with ( $\sim$ exponential) advances in non-radiological sensing, data processing, and computer vision

# Evolution of relevant concepts and technologies

Performance

Radiation detection & imaging  
(Selected examples)

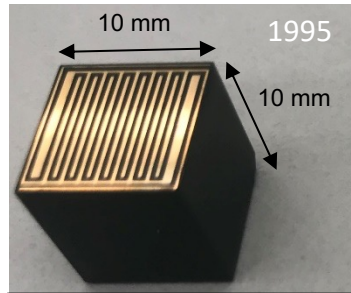


# Selected radiation detection & imaging developments at UC Berkeley and LBNL

Gamma-ray detection and imaging

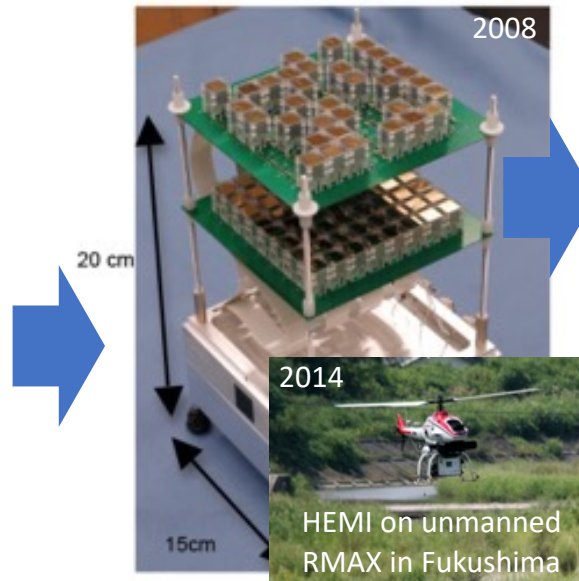
+ Neutron detection mapping

Coplanar Grid CdZnTe  
(CPG CZT)



Compact, room-temperature,  
 $<2\% \Delta E_{\text{rel}}$

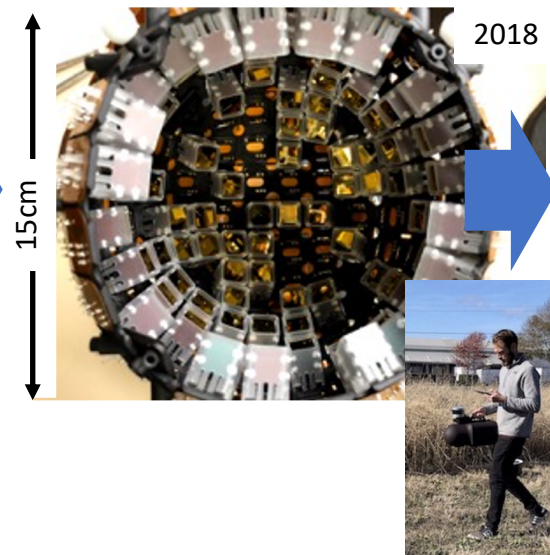
HEMI  
High-Efficiency Multimode Imager



96 (1cm<sup>3</sup>) CPG detectors arranged in 2 planes serving as active coded aperture (FOV<60 deg) and Compton imager (360 deg)

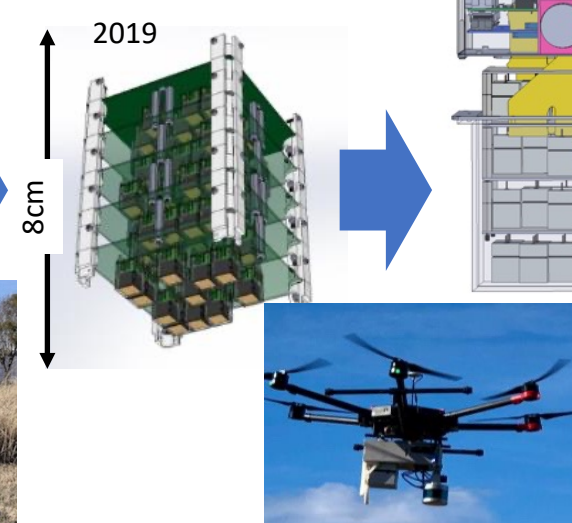
PRISM

Portable Radiation Imaging Spectroscopy and Mapping



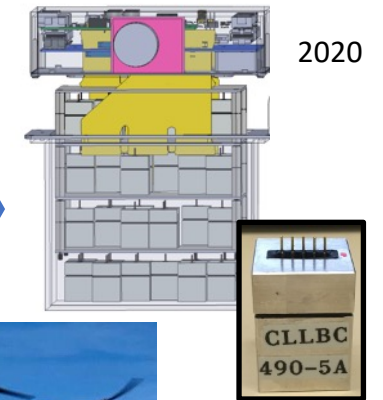
>100 CPG (1cm<sup>3</sup>) detectors arranged on sphere serving as active coded aperture (360 deg) and Compton imager (360 deg)

Mini-PRISM



~60 (1cm<sup>3</sup>) CPG detectors arranged in cube for 360 deg FOV gamma-ray imaging (coded aperture and Compton imaging)

NG-PRISM or  
NG-LAMP



~60 (1.27cm)<sup>3</sup> CLLBC detectors (3-4%  $\Delta E_{\text{rel}}$ ) as Mini-PRISM for gamma-ray detection and imaging and neutron mapping at ultra-high-count rates (>10Mcps)

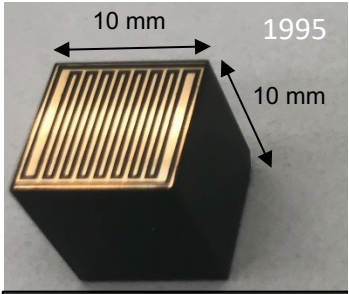
# Selected radiation detection & imaging developments at UC Berkeley and LBNL

Gamma-ray detection and imaging

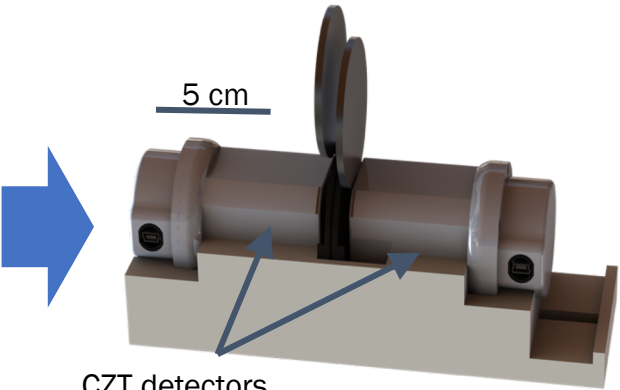
+ Neutron detection mapping

+ Beta-(only) detection (e.g. Sr-90)

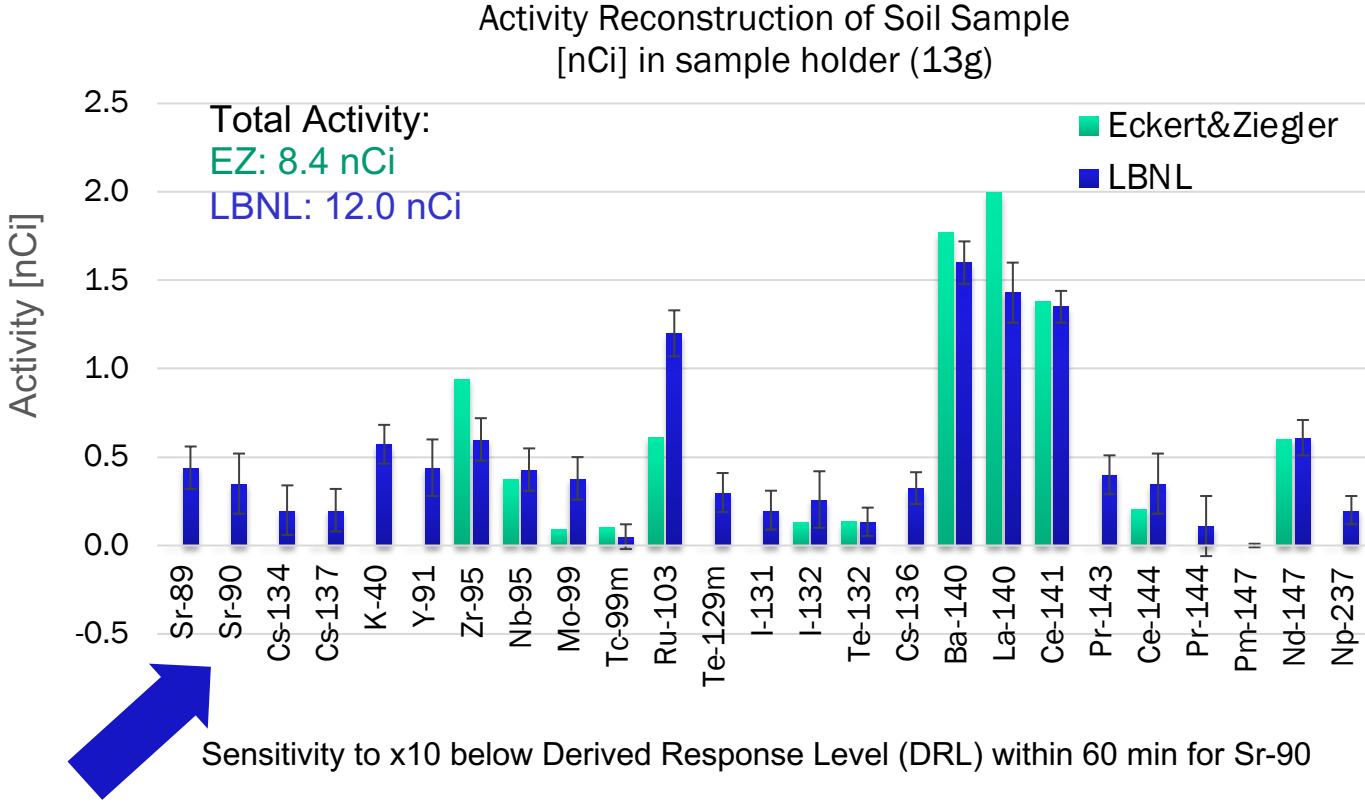
Coplanar Grid CdZnTe  
(CPG CZT)



Compact, room-temperature,  
<2%  $\Delta E_{rel}$



CZT detectors  
2 x 20 x 20 x 5 mm<sup>3</sup>  
& DOI Readout



# Evolution of relevant concepts and technologies

Performance

Computing & sensing  
(Selected examples)

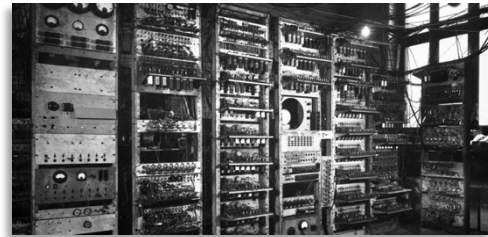


1880's

Analog  
cameras



Z1, ENIAC,  
"Manchester Baby"  
E.g. 1,024 bits &  
1,000 ops



Radar

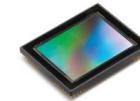
Digital cameras  
(Active pixel/ CMOS)



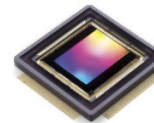
Personal Computer



CCD sensor



CMOS  
(active pixel)  
sensor



Ranging



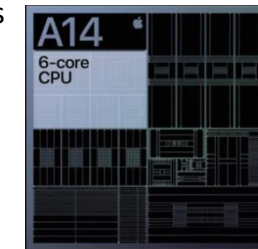
Lidar

2000

Smart  
phones



Laptop



E.g. A14 Bionic with 6-  
core CPU and 4-core  
GPU;  $12 \times 10^9$  transistors  
or  $11 \times 10^{12}$  ops by neural  
engine  
+ 12MP CMOS visual  
& LiDAR sensors



+ Networks  
Optical and wireless  
e.g. 5G

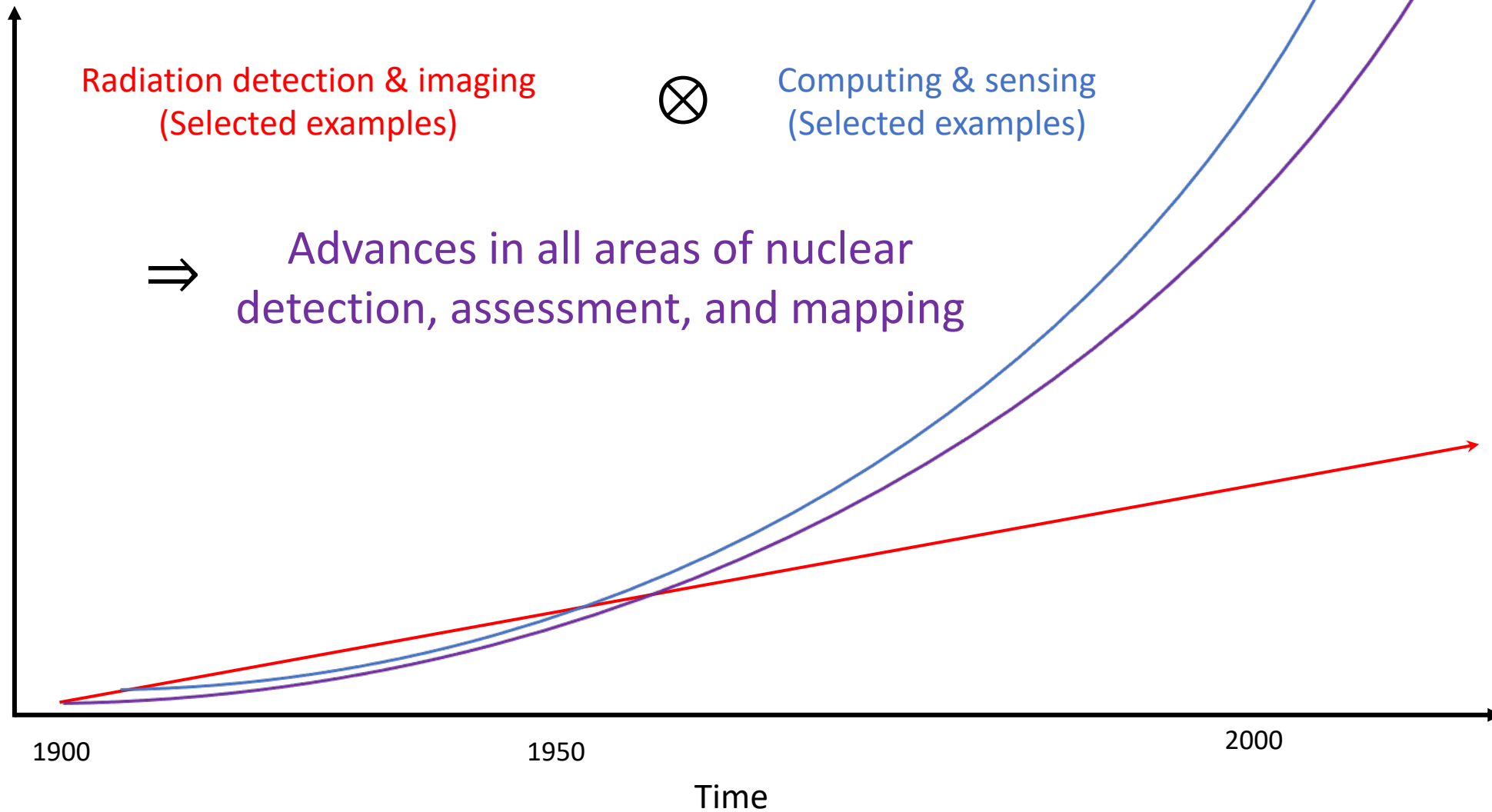
+ Mixed Reality  
AR & VR



Time

# Evolution of relevant concepts and technologies

Performance

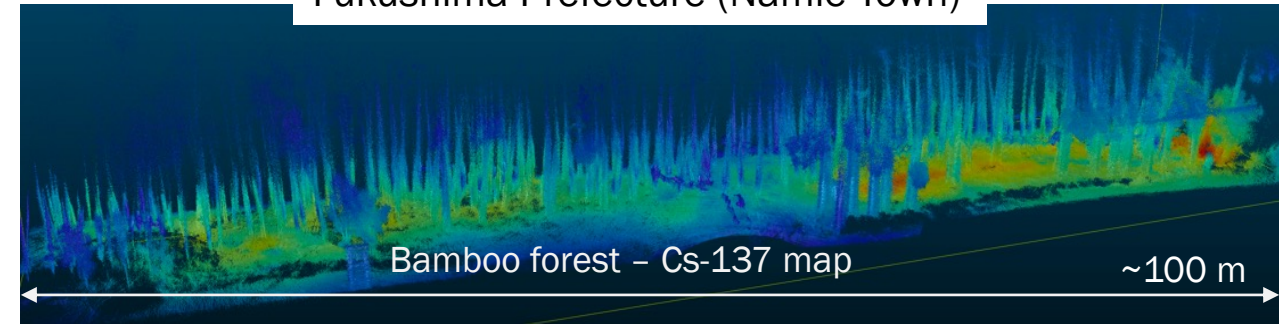


# Technical Approach - 3D Mapping

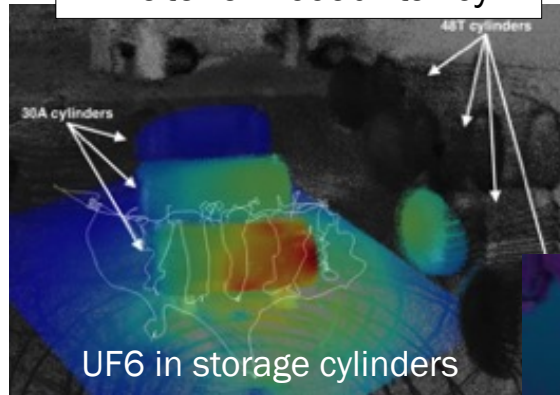
- Combine radiation detectors and imagers with contextual sensors
  - Localization And Mapping Platform LAMP
  - E.g. NG-LAMP w/ LiDAR, visual camera, GPS/IMU

Consequence management

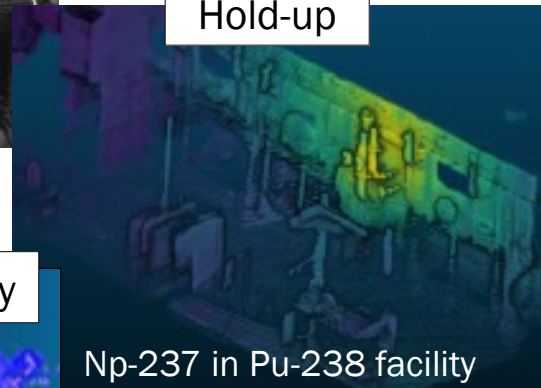
Fukushima Prefecture (Namie Town)



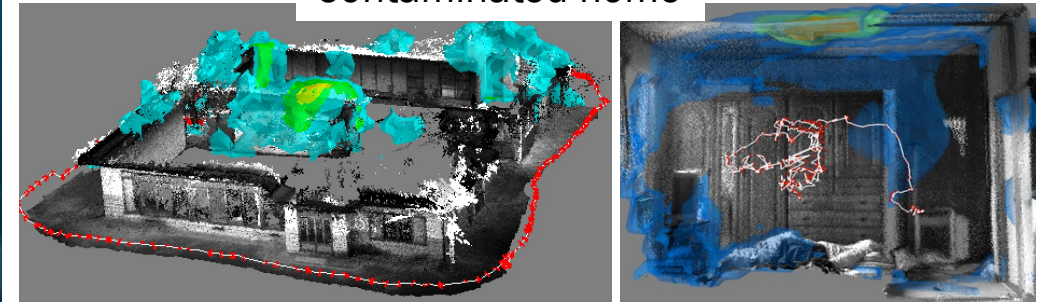
Material Accountancy



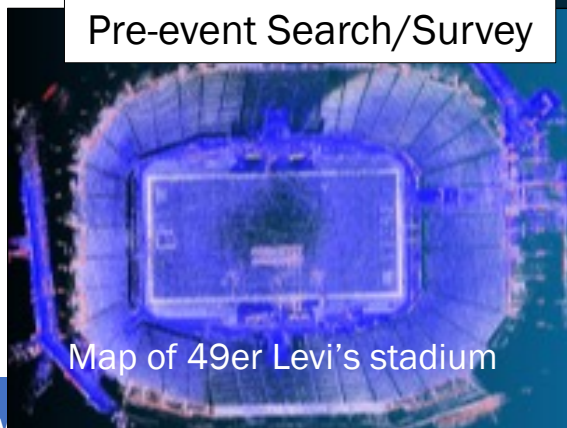
Hold-up



Contaminated home

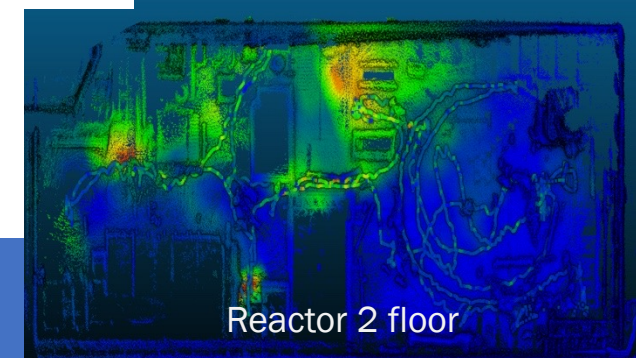
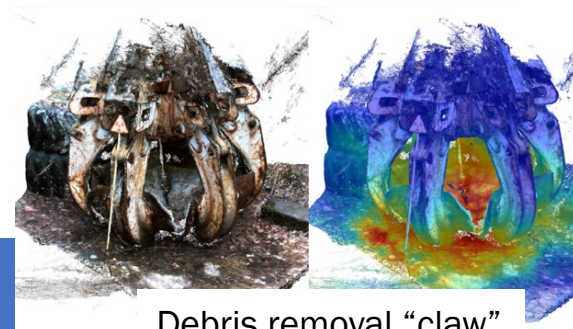


Pre-event Search/Survey



Chernobyl

Cs-137 contamination



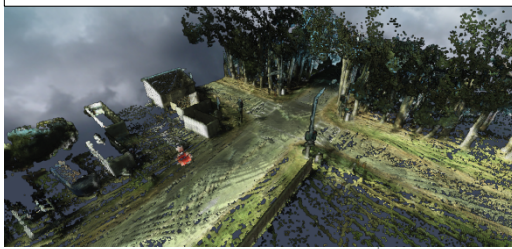
# Technical Approach - Detection, Localization, Visualization and Quantification

- Combine radiation detectors and imagers with contextual sensors

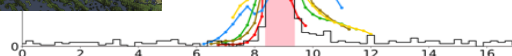
Object racking and attribution from static and mobile systems



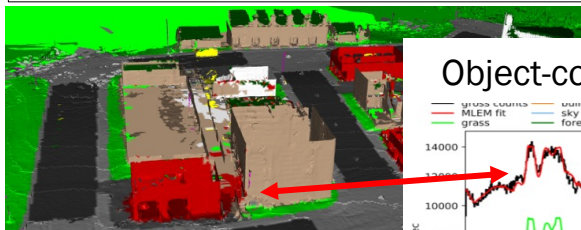
Vehicle-based Urban Search



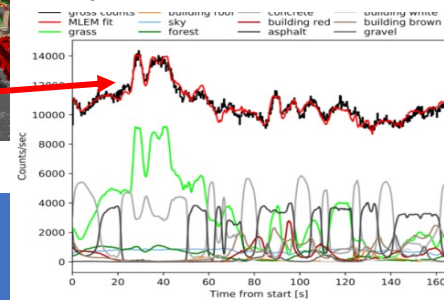
Utilize advanced detection and identification algorithms: Non-negative Matrix Factorization, Dense Autoencoder, Convolutional and Recurrent Neural Networks



3D Semantically labelled scenes

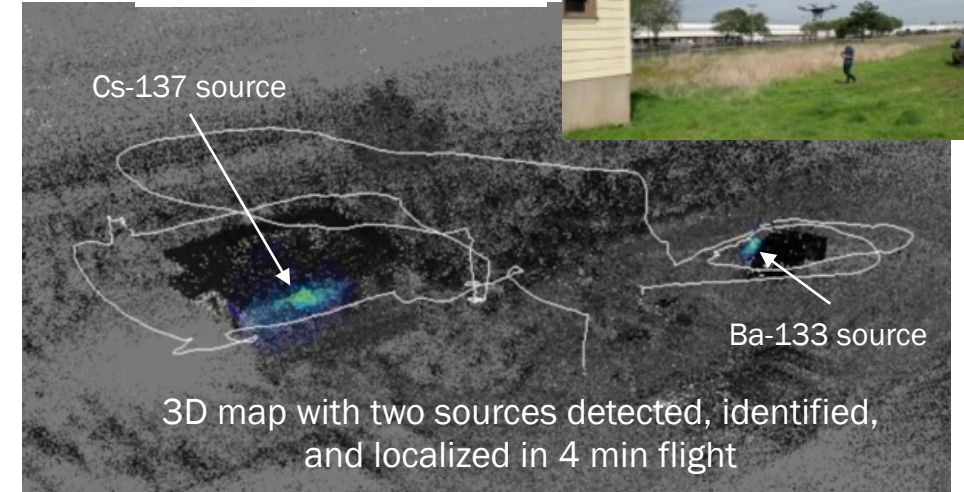


Object-count attribution

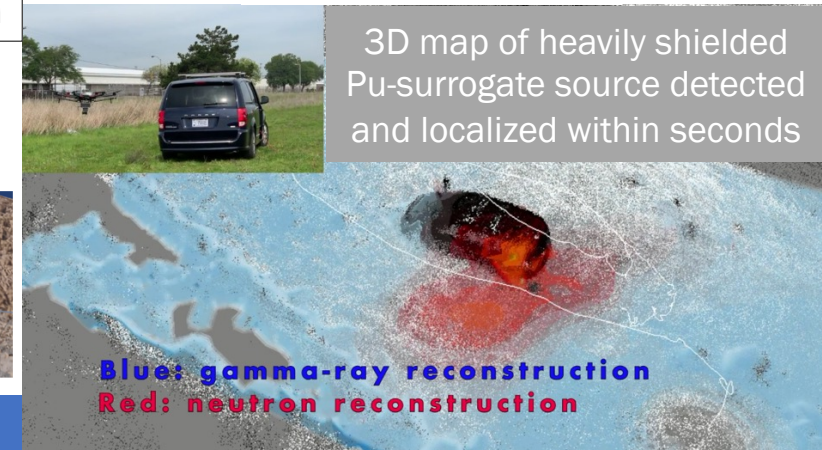


UAS-based search

3D Gamma-ray imaging



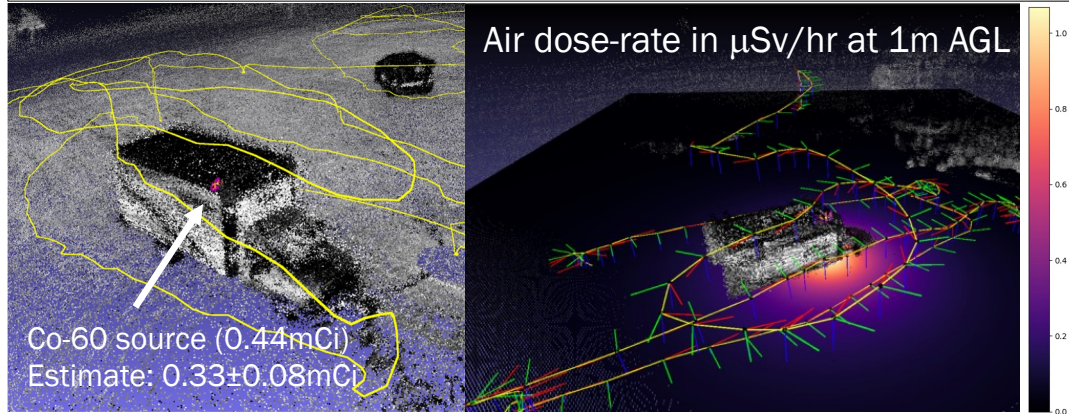
3D Neutron mapping



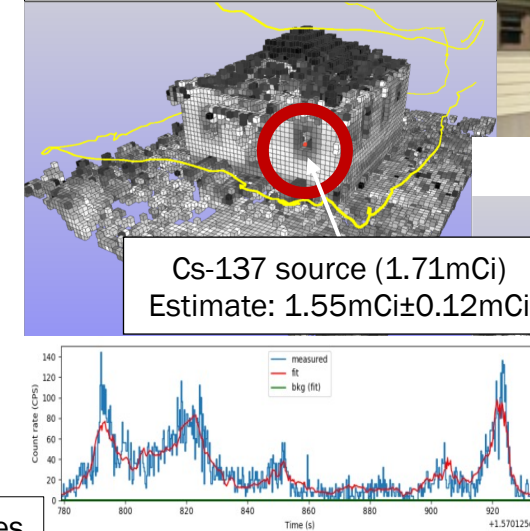
# Technical Approach - Detection, Localization, Visualization and Quantification

- Combine radiation detectors and imagers with contextual sensors

Accurate and fast detection and (3D) localization AND  
Estimation of source activity and dose rates with uncertainties



Activity and attenuation  
estimation



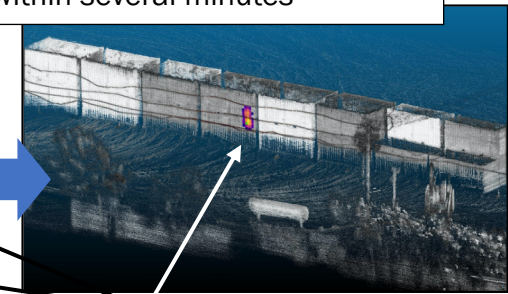
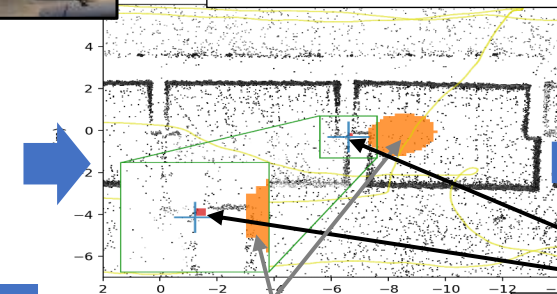
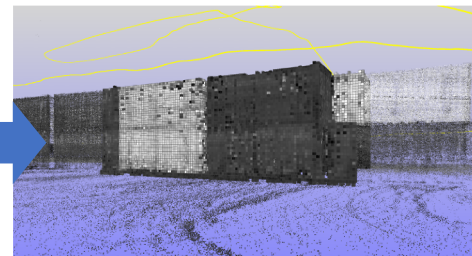
Top-down view of 3D Model



Scanning, detection, 3D localization, and activity estimation of containers within minutes



Accurate mapping of container stack, detection,  
identification, 3D localization, and activity estimation of  
Cs-137 source within several minutes



Localization of Cs-137 w/  
attenuation (within 30 cm)

# Conclusion

- The integration of recent developments in radiation detection and imaging and advancements in computer vision and data processing provide new means to detect, map, and visualize nuclear materials.
- Multi-sensor fusion provides
  - Enormous potential for enhancing capabilities across several missions in nuclear security and nonproliferation;
  - Outstanding opportunities for students and the next generation to engage in multi-disciplinary research and teams;
- Excellent opportunities exist for collaborations to integrate nuclear and non-nuclear instruments and fuse their data and to optimize the extraction of relevant features and quantities for specific needs.

# Acknowledgements

- All Members of the Berkeley Applied Nuclear Physics Program
- Our Sponsors from DOE/NNSA, DOD/DTRA, DHS/CWMD, and JAEA