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A survey of imaging systems for materials and objects in containers

Peter Vanier
vanier@bnl.gov

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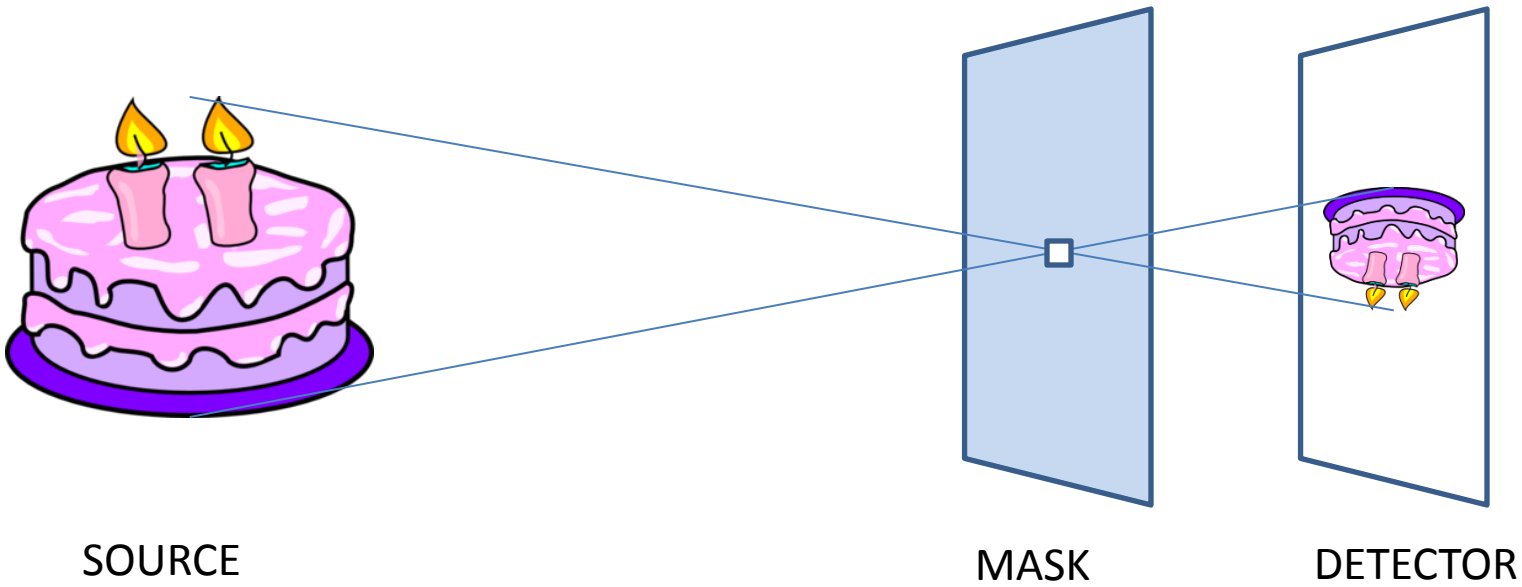
Are the contents of the container consistent with the declaration?

Passive Coded Aperture Imaging Systems

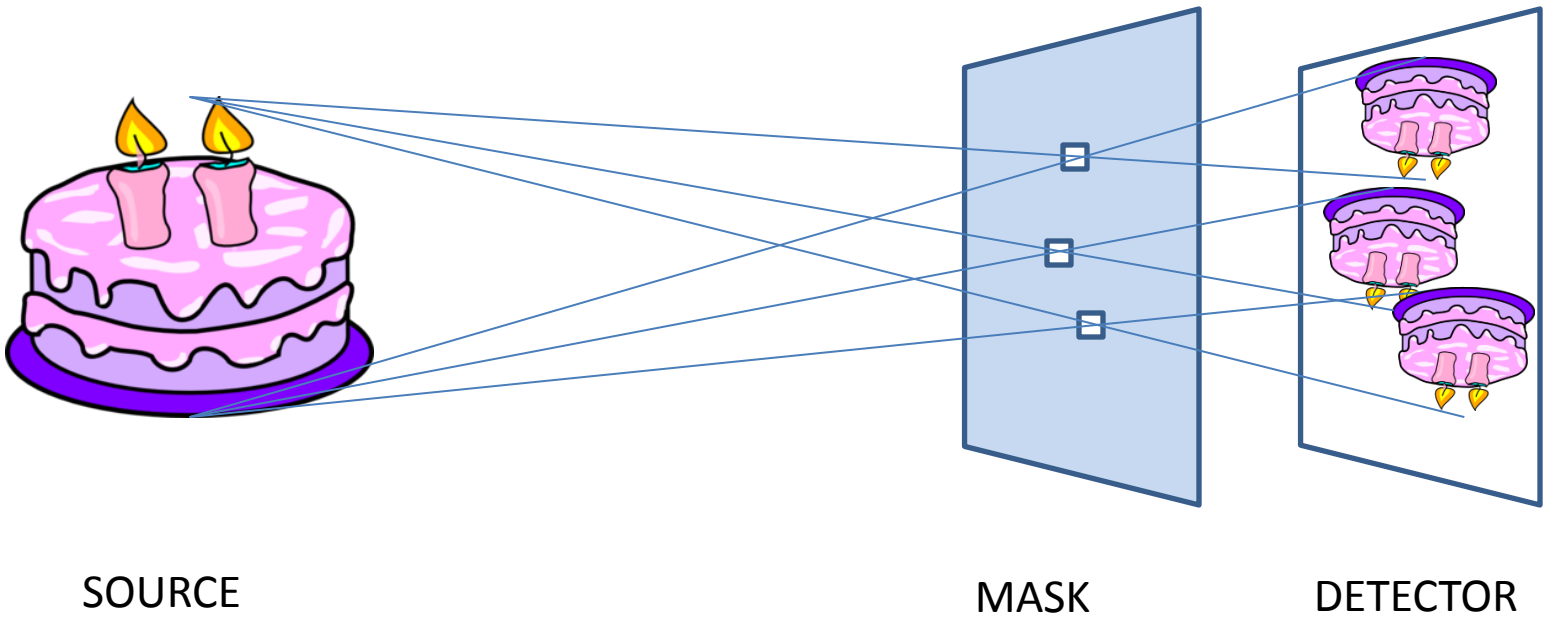
- **Confirm presence or absence of gammas, neutrons**
- **Might show a point source or a needle**
- **Can confirm an extended source**
- **Measures approximate size**
- **Counts multiple sources**
- **Spatial resolution is controlled by hardware design**

How do they work?



A pinhole camera is very inefficient
Most of the emitted radiation is blocked by the mask

How do they work?



Multiple pinholes increase the signal
Overlapping images can be decoded using the mask pattern

Caveats

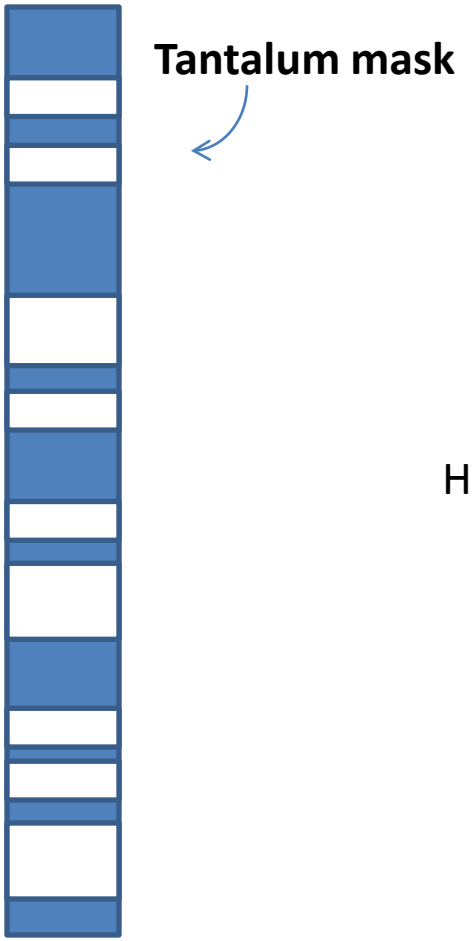
- **May reveal sensitive information if present**
- **May require an information barrier**
- **May require a trusted processor**
- **May be difficult to create algorithms for item confirmation**
- **Templates may be fuzzy, or inexact**

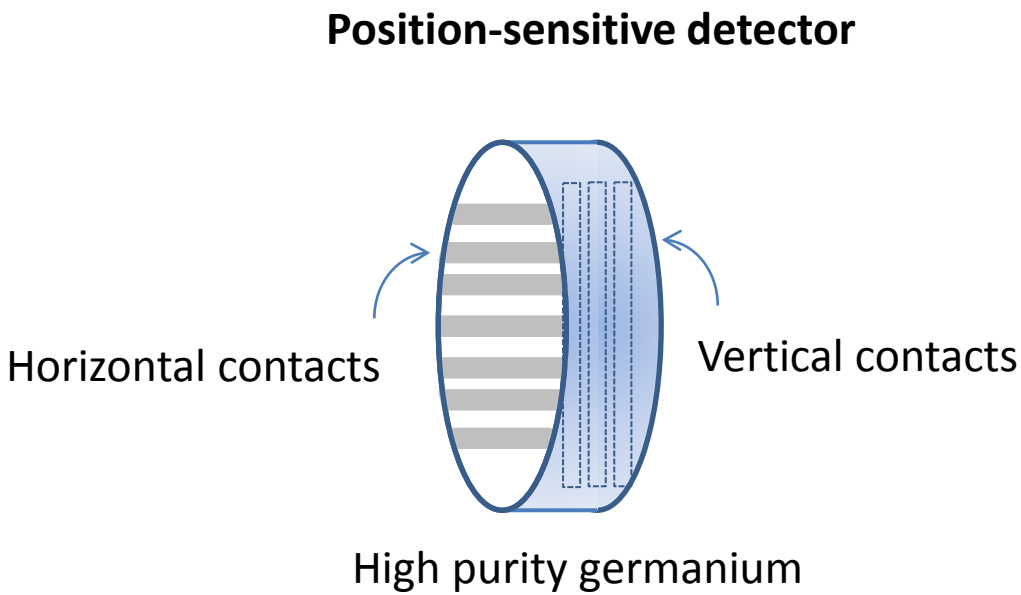
High Purity Ge Gamma imager

ORNL

- **Mechanically cooled HPGe (1-cm thick, 9-cm diameter)**
- **Tantalum coded aperture mask**
- **Translation stage for "zoom" capability**
- **Detects gamma spectra from ^{239}Pu, ^{235}U and ^{238}U, etc.**
- **Can identify isotopes from each pixel in image**
- **Can select specific regions of interest in energy or space**

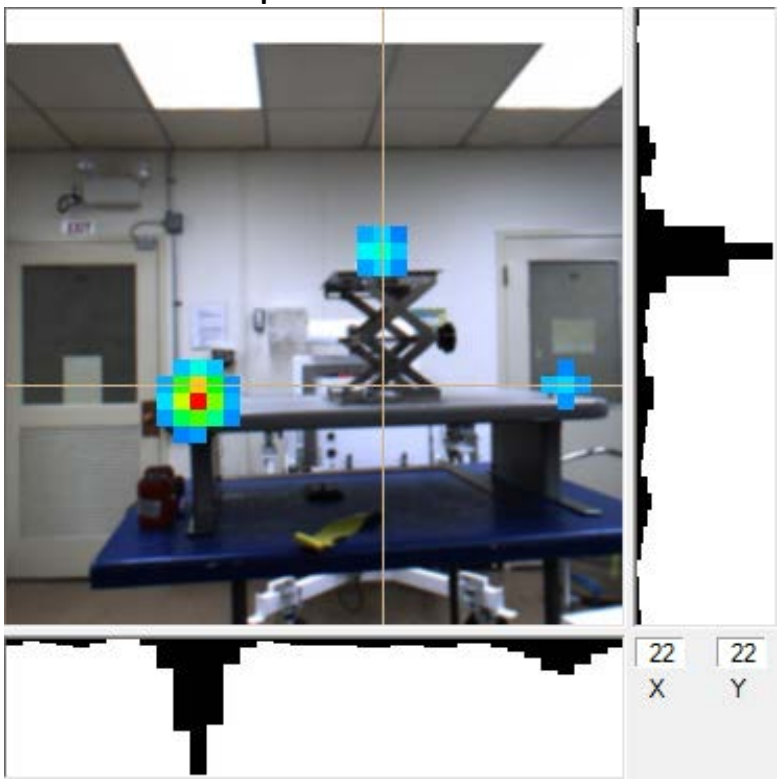
Gamma Spectroscopy and Imaging



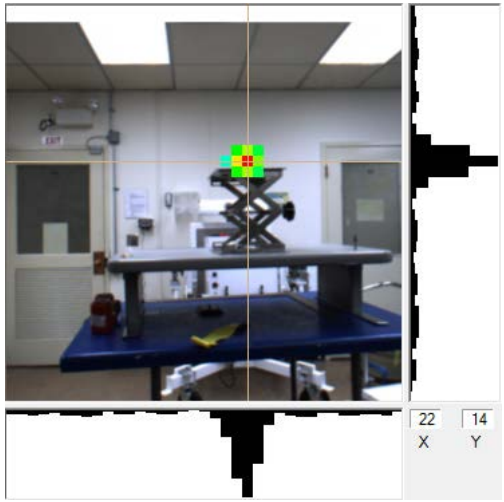


Display images using selected energies

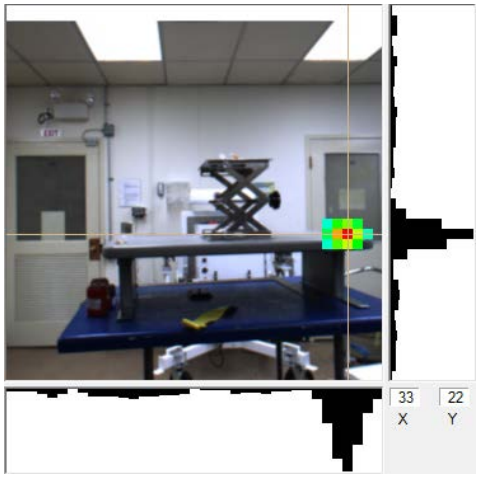
Full spectrum



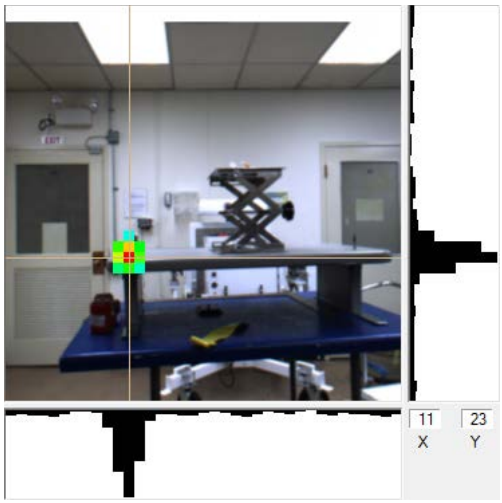
^{57}Co



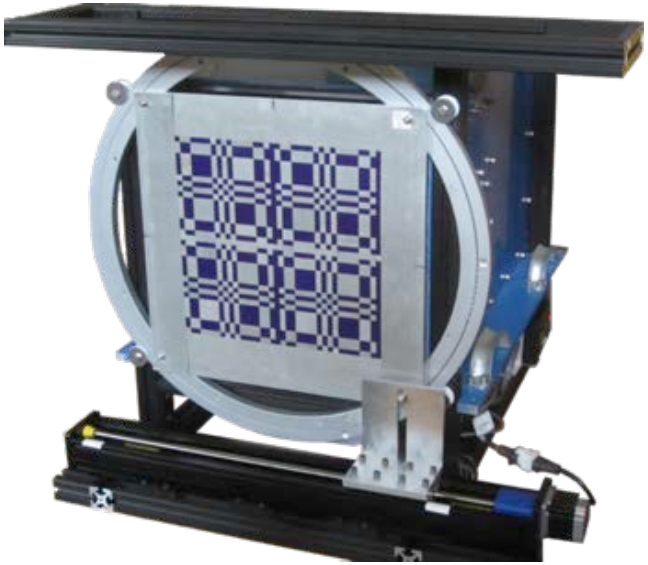
^{232}U



^{133}Ba



Thermal Neutron Imager



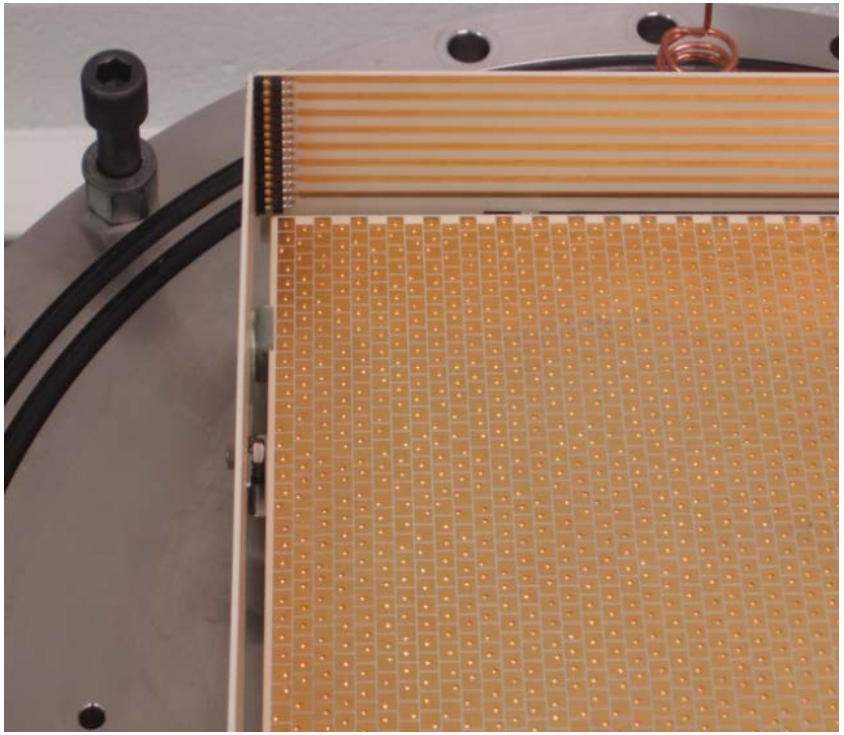
BNL

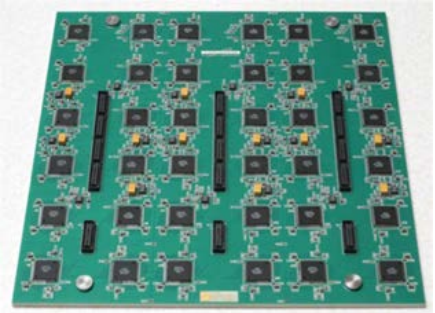
- **Position sensitive ^{3}He chamber (24 x 24 cm^2)**
- **Cd coded aperture mask**
- **2304 readout channels**
- **Requires neutron source close to hydrogenous material**
- **Forms image of outer surface of moderating material**

Thermal Neutron Imaging

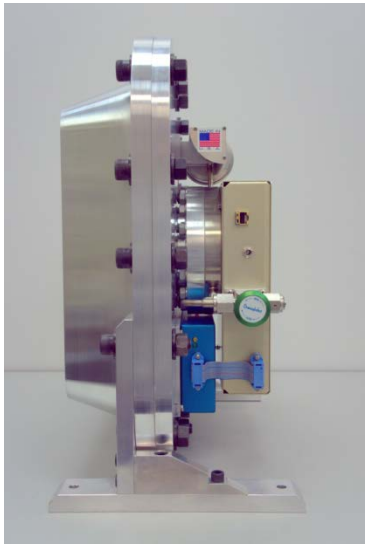
Thin Cd mask

Position-sensitive detector:
2304 copper pads in a ^{3}He ionization chamber





Readout board with ASICS

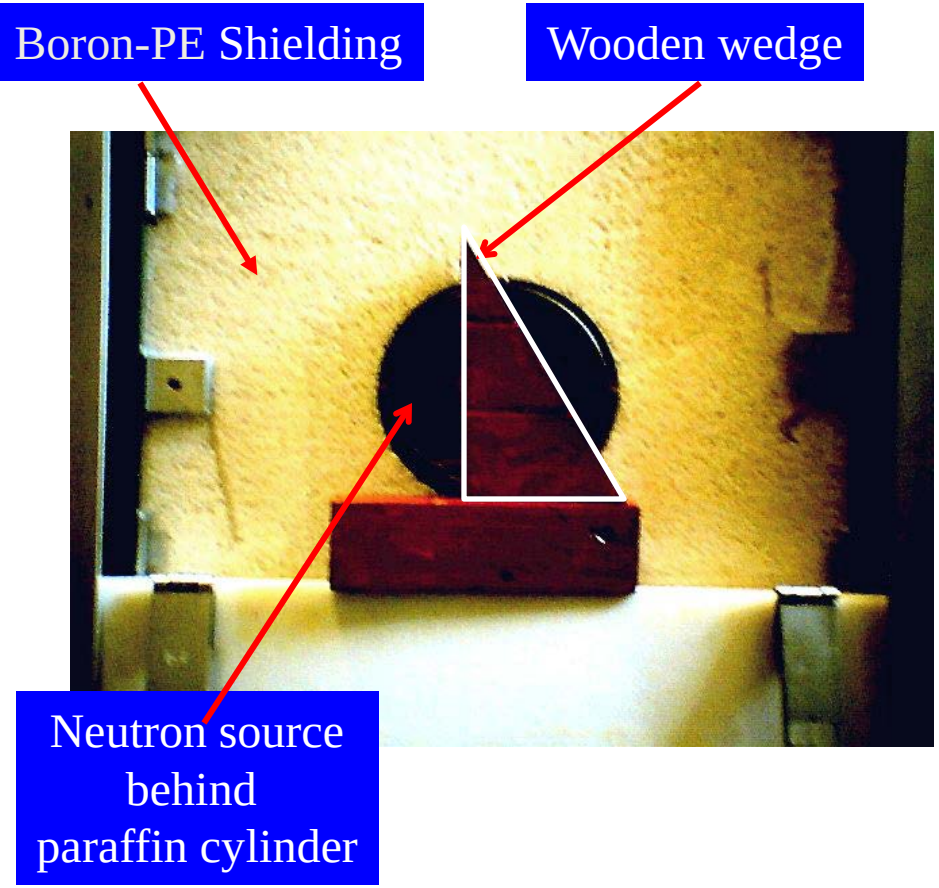


Each pad has an independent shaper, amplifier and digitizer.

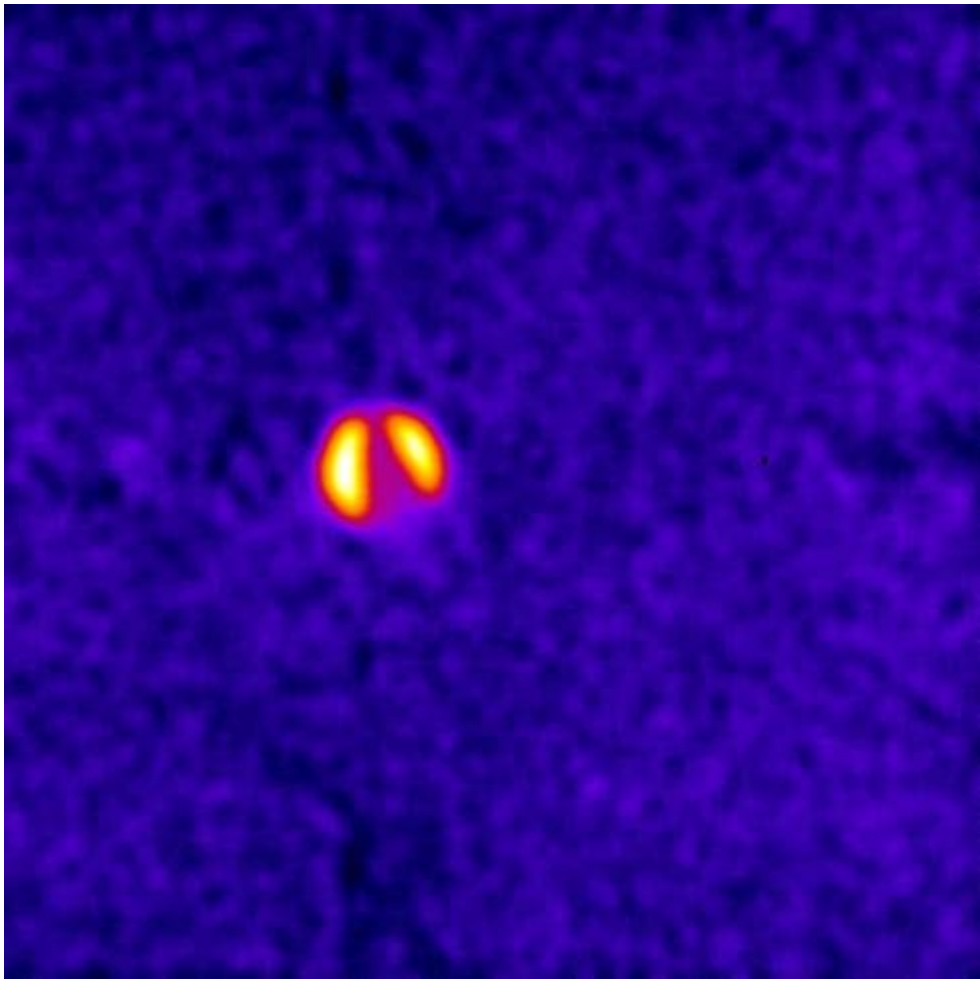
BNL

Tests of thermal neutron imager

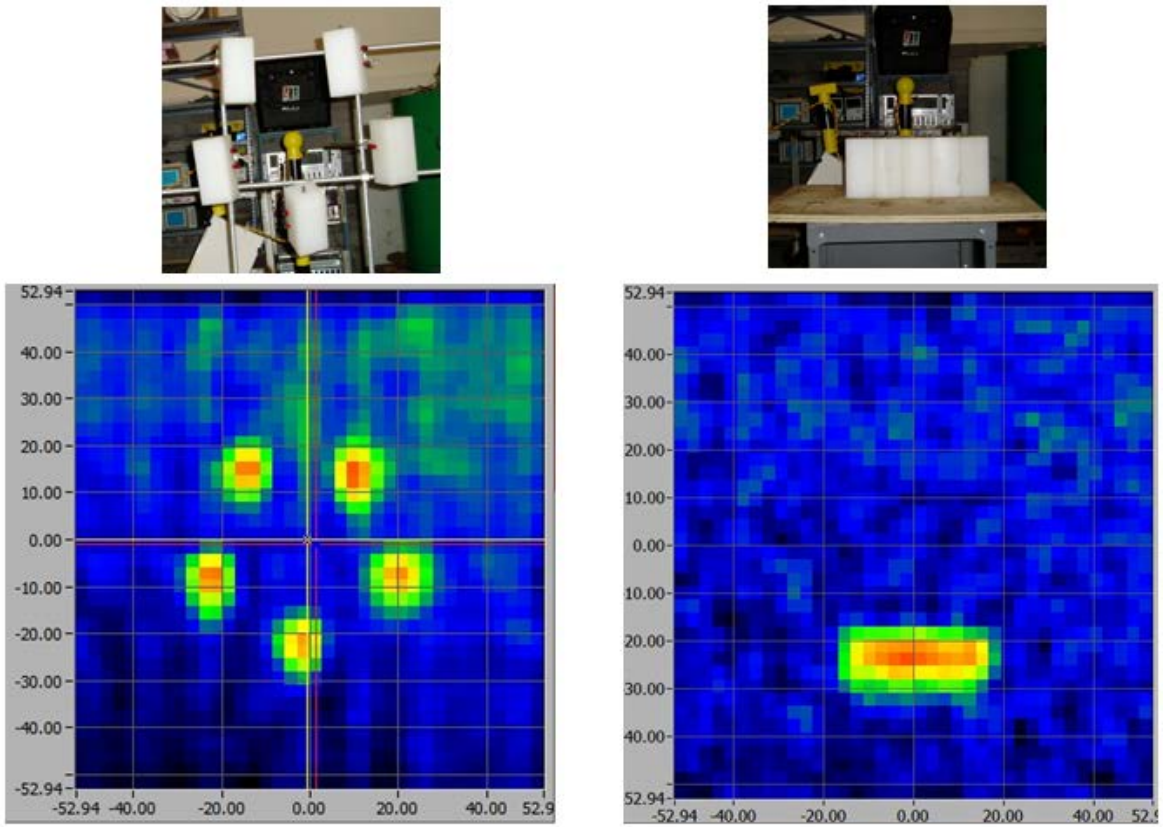
Photograph



Neutron Image



Counting 5 sources using thermal neutrons



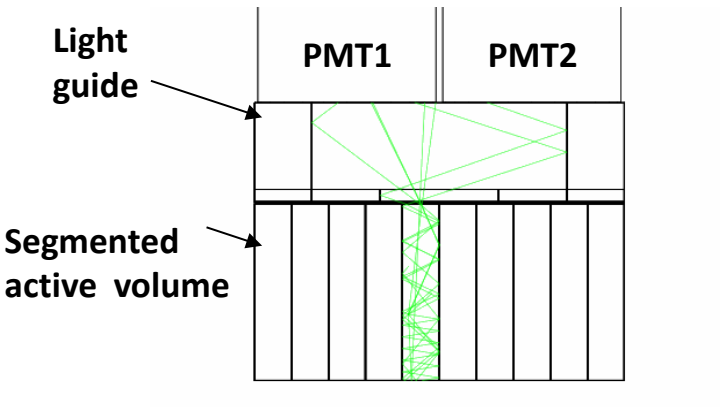
Five sources in circle (left) and line (right)

Fast Neutron Imager

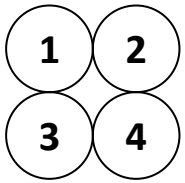
ORNL/SNL

- **Pixelated plastic scintillator detector array (2400 1-cm pixels)**
- **Uses Pulse Shape Discrimination to identify gammas and neutrons**
- **High Density Polyethylene coded aperture mask**
- **Translation stage for "zoom" capability**
- **Detects fast neutrons from source materials, e.g. Pu, ^{252}Cf, etc.**
- **Also images gamma source**

Fast Neutron Detectors

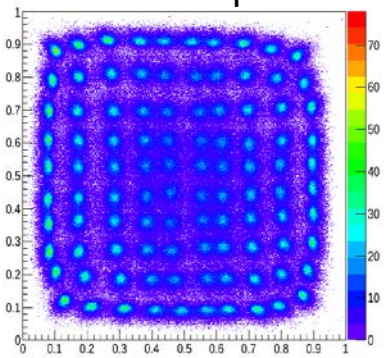


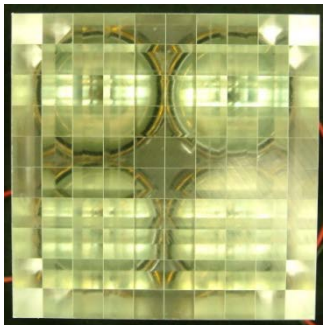
$$Y = \frac{1+2}{1+2+3+4}$$



$$X = \frac{2+4}{1+2+3+4}$$

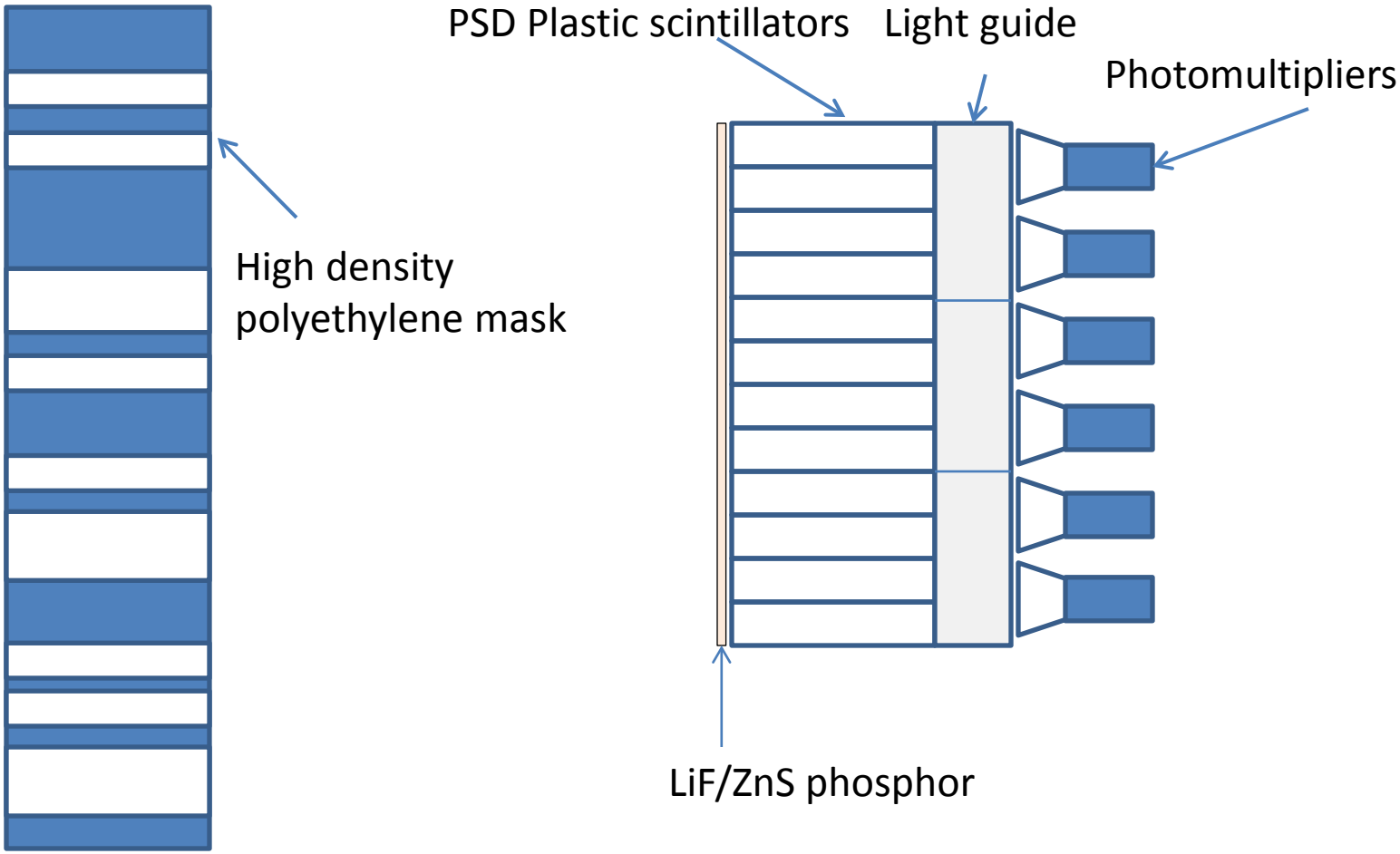
Position response





- Thick, neutron-sensitive organic scintillator detectors for efficiency and fast timing
- Active volume optically segmented into pixel block for position resolution
  - Many pixels per photomultiplier tube (PMT) for efficient use of electronics
  - Pixel of interaction inferred from four-PMT centroid (Anger logic)

Combined Gamma, Fast- and Thermal- Neutron Imaging



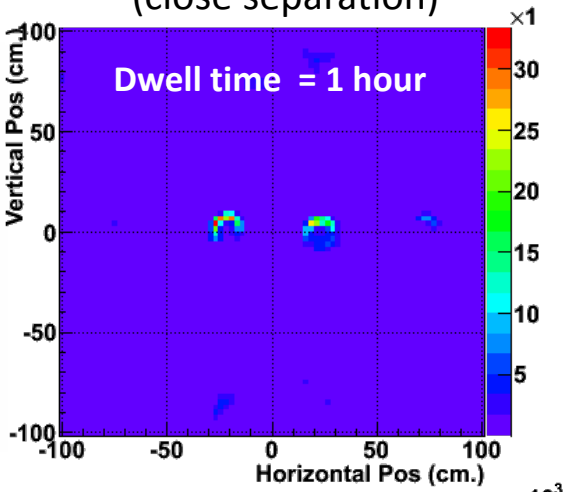
Gives gamma and neutron images, using Pulse Shape Discrimination

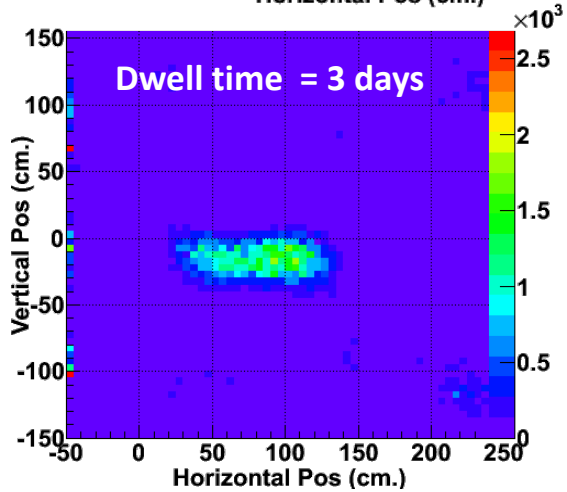
Why Coded Aperture?

ORNL/SNL Coded Aperture Imager

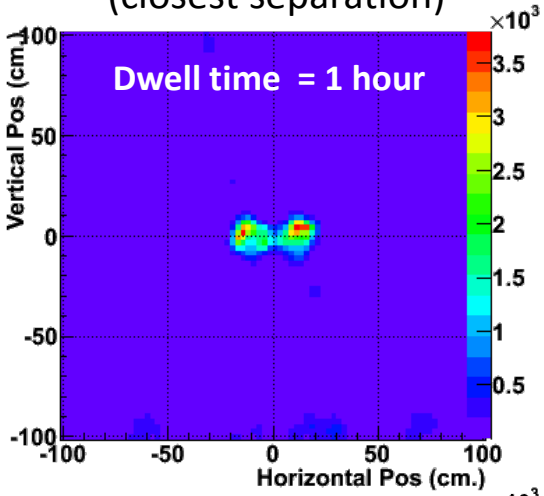
SNL Scatter Camera

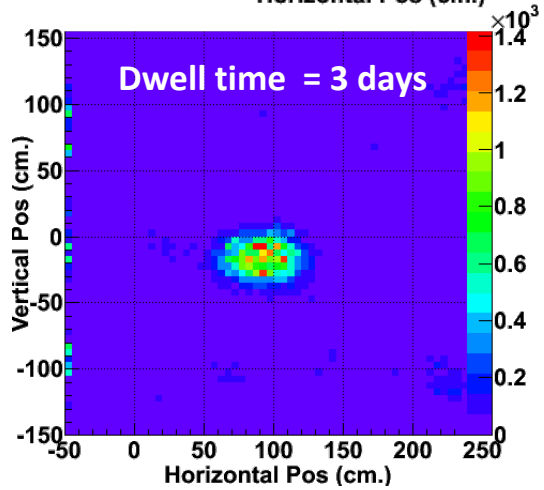
Two Extended Sources (close separation)





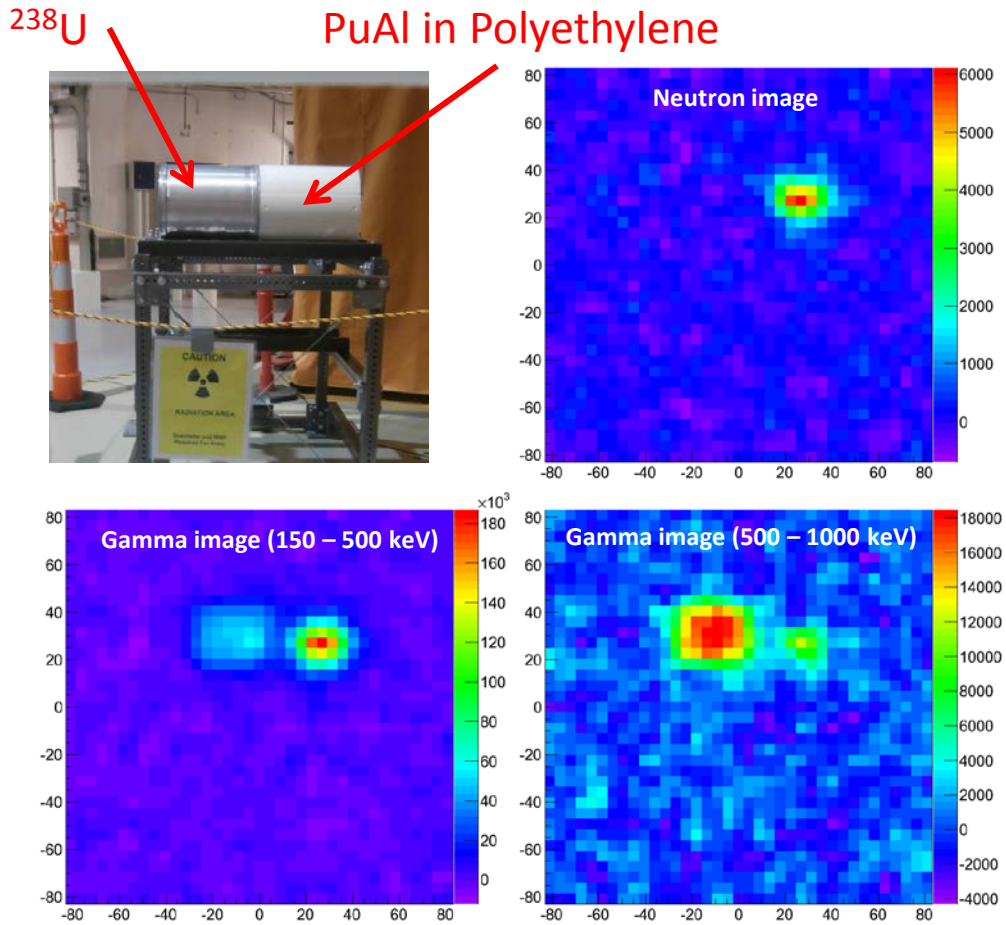
Two Extended Sources (closest separation)





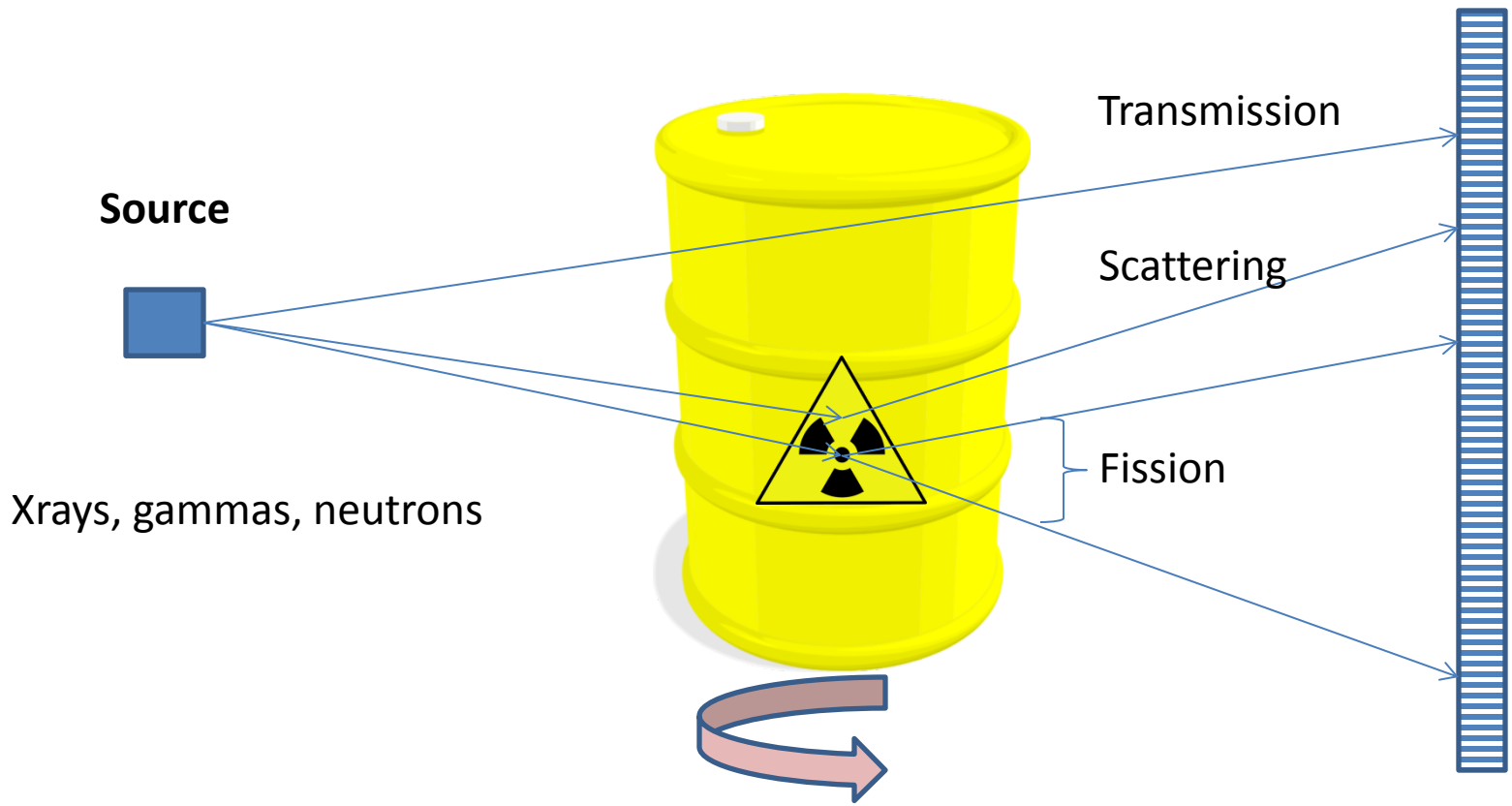
- Coded-aperture method achieves ~an order of magnitude improvement in efficiency and resolution compared to its competitor, kinematic imaging

Passive Measurement of Extended Sources



The position and extent of gamma and neutron sources are readily found

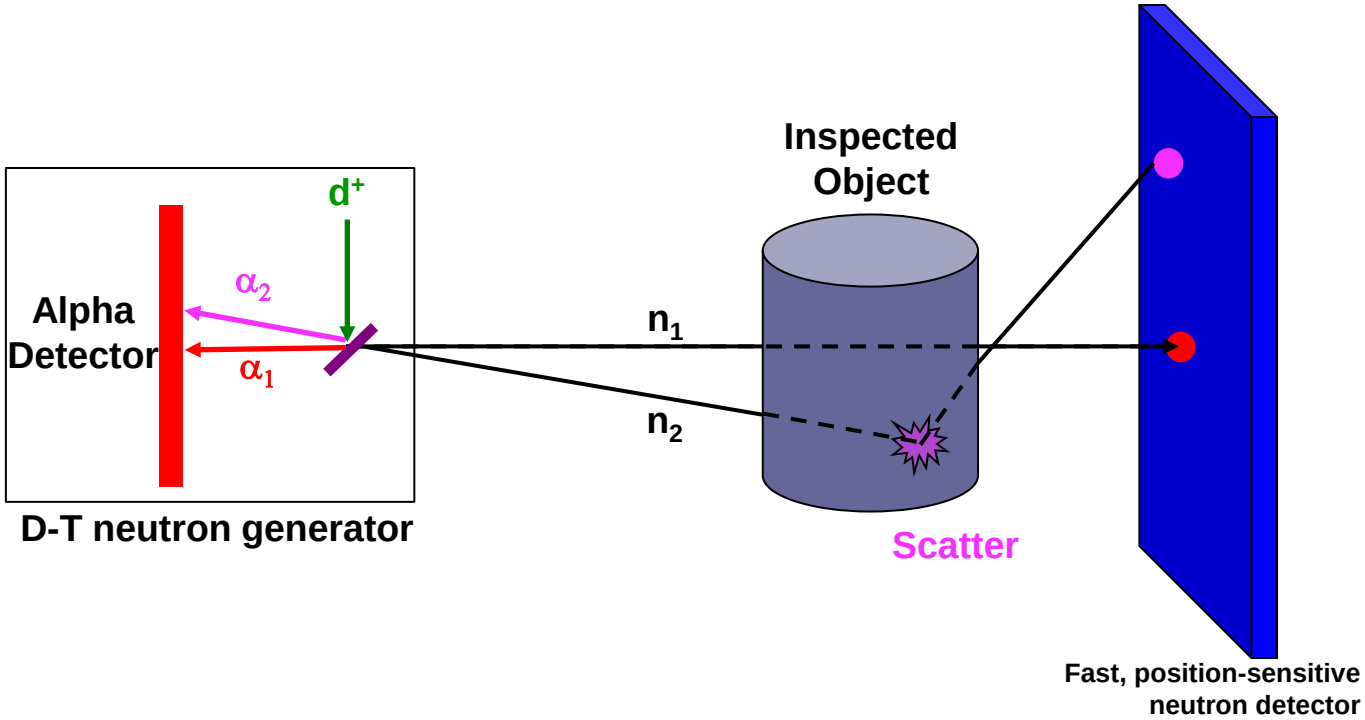
Active methods



Rotate object for Computed Tomography and 3-D reconstruction
Has potential for revealing many sensitive details

Associated Particle Imaging

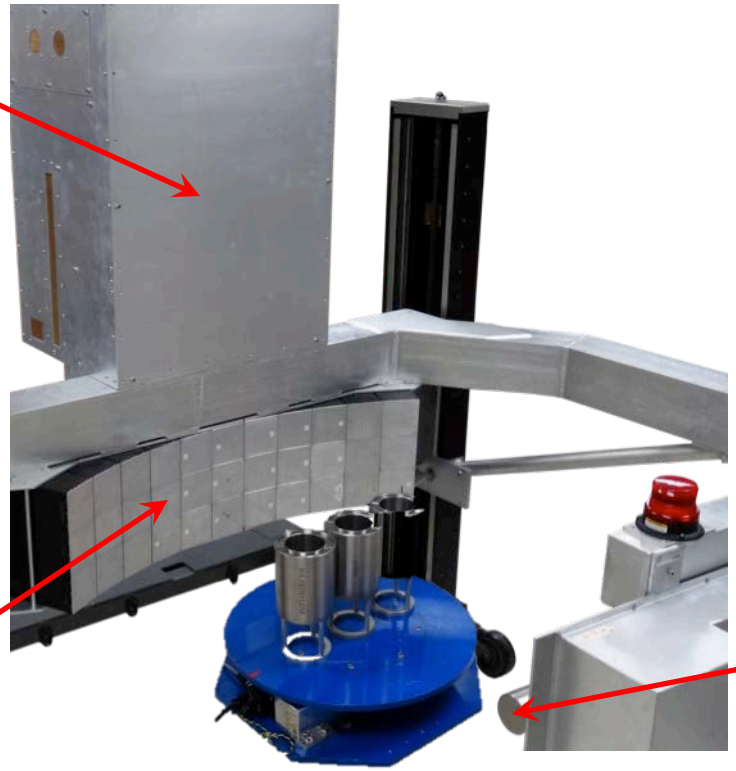
- Fast neutrons from the $d + t \rightarrow \alpha + n$ reaction
  - Time and initial direction of the neutron known by detecting the alpha particle



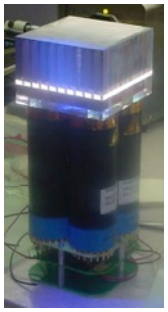
Associated Particle Imaging System

- Highly-pixelated neutron and alpha detectors with commercial PET data acquisition system

Siemens Inveon preclinical PET data acquisition system

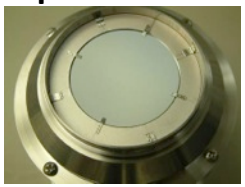


Plastic scintillator block detector

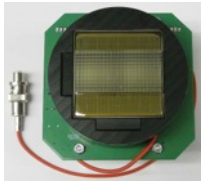


Fast, position-sensitive neutron detectors (3300 total pixels)

YAP:Ce alpha detector



Pixelated Readout

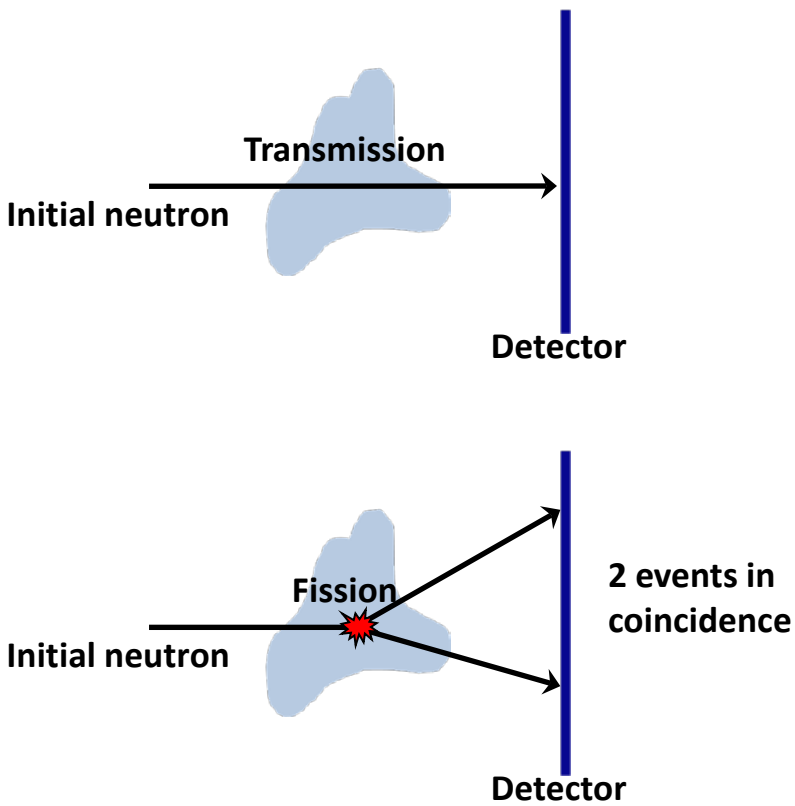


DT neutron generator with alpha detector (512 initial neutron directions)

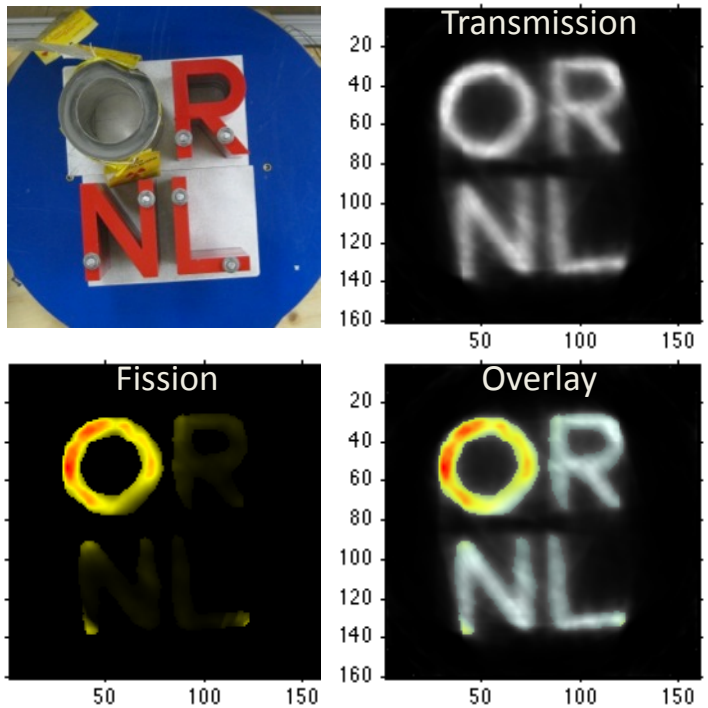
ORNL

Active Imaging Results

- **Transmission and induced-fission imaging capabilities have been developed**
- **Elastic scatter imaging under development**



Target consisting of DU "O" and steel "R", "N", and "L"



Conclusions

- **Radiation imaging can be useful to evaluate the contents of containers**
- **Passive imaging**
  - **gamma sources**
  - **neutron sources**
  - **hydrogen near to a neutron source**
- **Active imaging**
  - **Transmission radiography shows high density material**
  - **Neutron coincidences indicate fissionable material**
  - **Time of Flight and die-away time are important**
- **These technologies may be most useful in confirming ABSENCE of an item**