Radiation Imaging of Dry Storage Casks for Spent Nuclear Fuel

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Pacific Northwest National Laboratory
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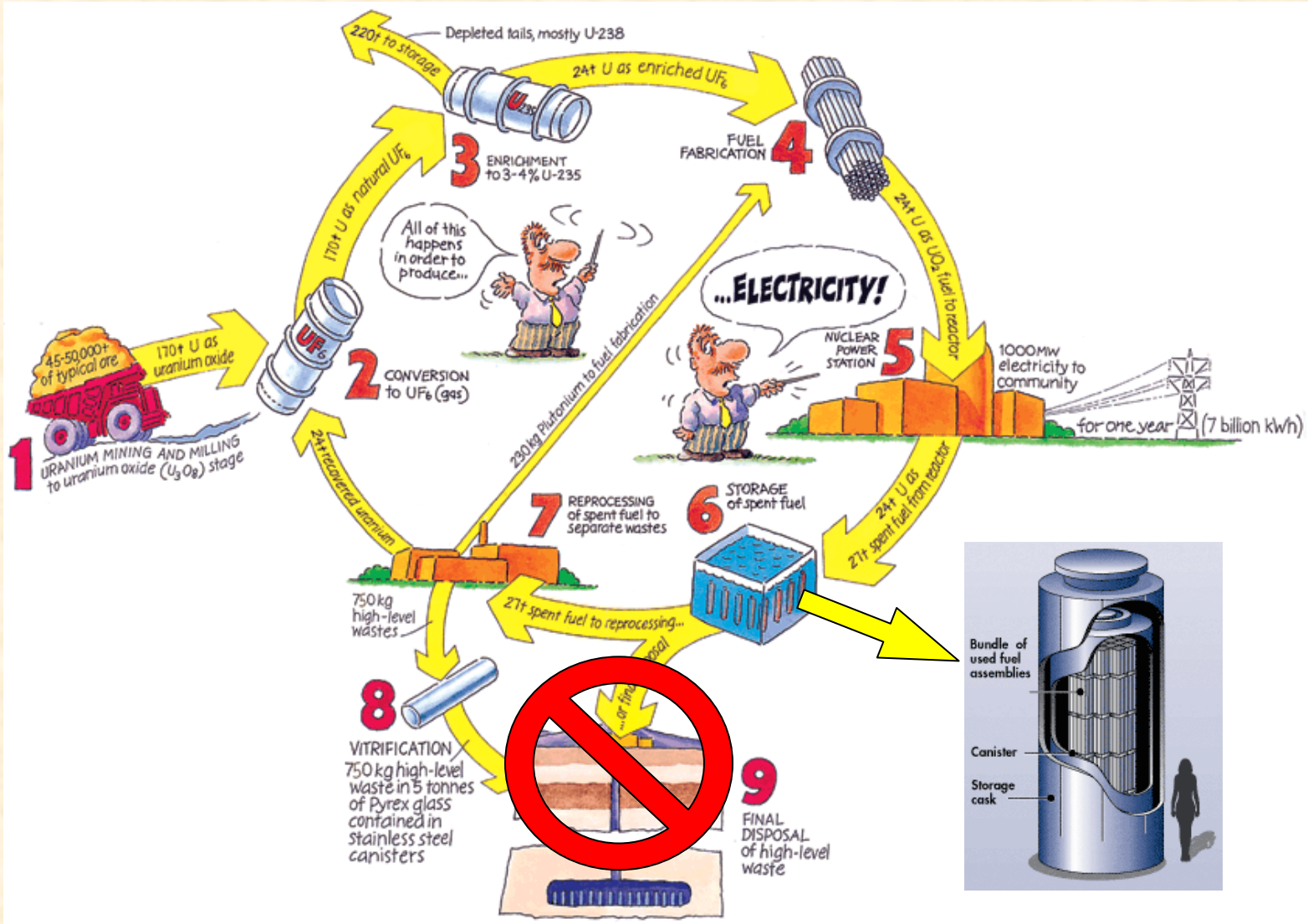
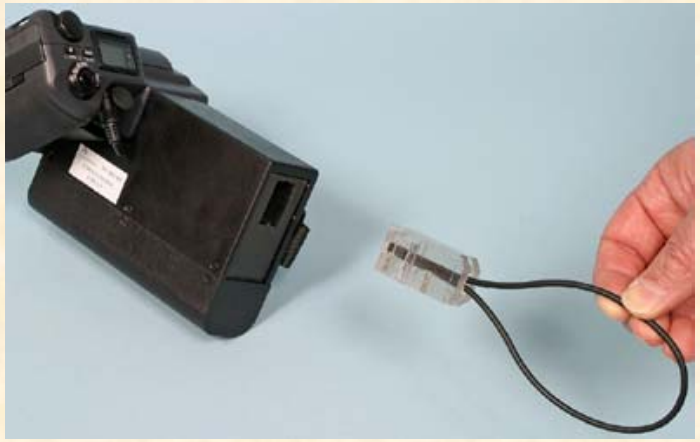
Nuclear Fuel Cycle*



* *http://www.uic.com.au/nfc.htm*

The spent-fuel, dry-storage cask problem

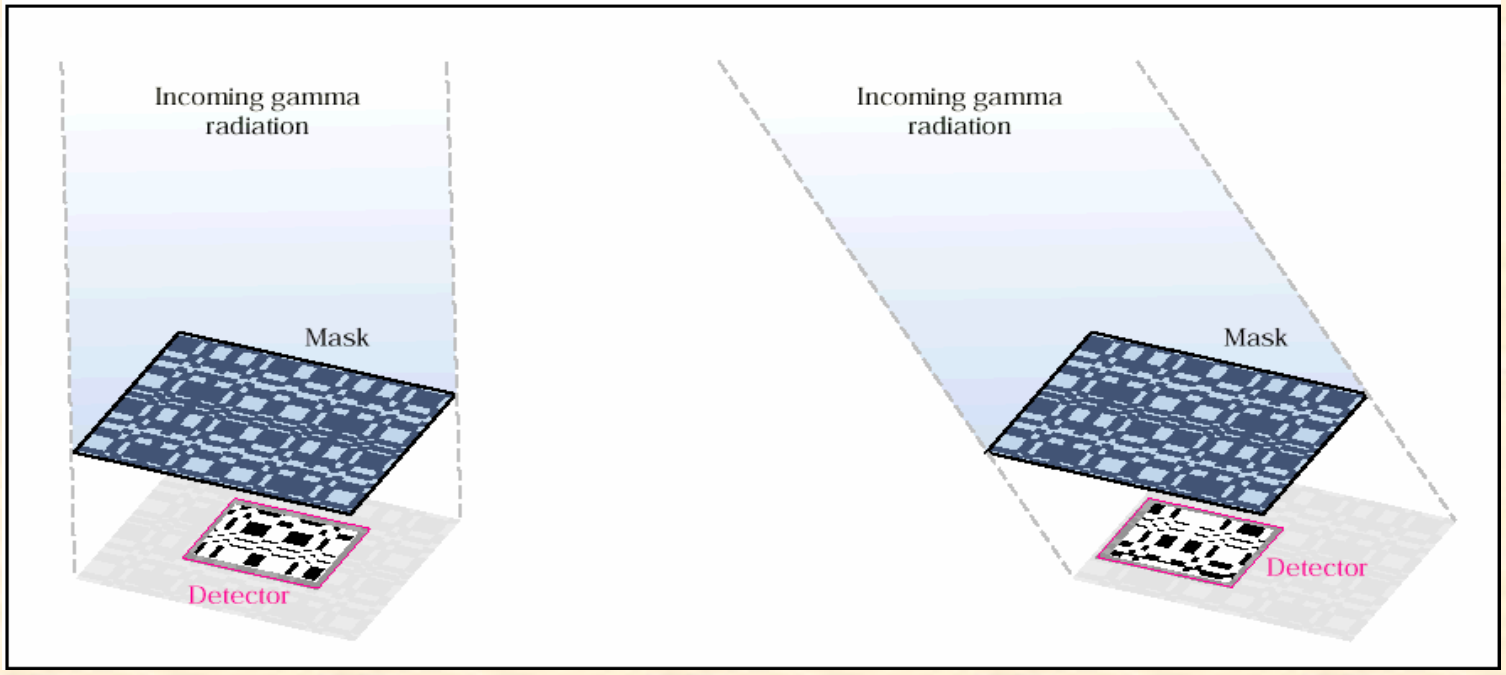
- More and more material is being stored in casks.
- Casks shield the very radiation normally used in safeguards inspections.
- Currently cask loading is observed and tags and seals used to for safeguards.



- Casks are generally exposed to the elements and the tags and seals can fail.
  - There will be great resistance to opening a cask to reestablish continuity of knowledge.
- In March 2003, the IAEA hosted a meeting of experts to look at this problem.
- The panel suggested imaging the radiation field emitted by the cask
  - For thermal reasons assemblies of different burn-ups are distributed in loading
  - This might provide a unique signature to “fingerprint” individual casks

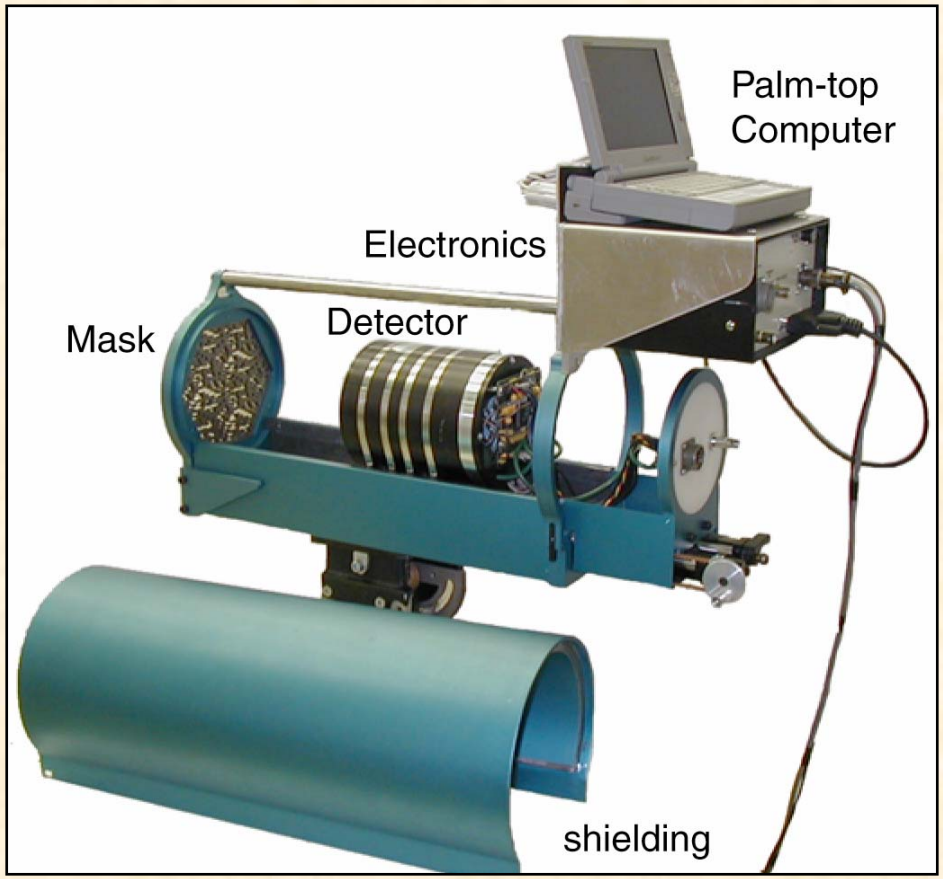
Coded aperture imaging

- Penetrating radiation can be imaged with a position-sensitive detector placed behind a shadow mask.



- Incoming parallel radiation projects one region of the mask
- Different mask regions are “orthogonal”
- Image deconvolution is simple (easily and rapidly achieved in the field)
- Resolution at the source can be varied = distance*(hole size)/focal length

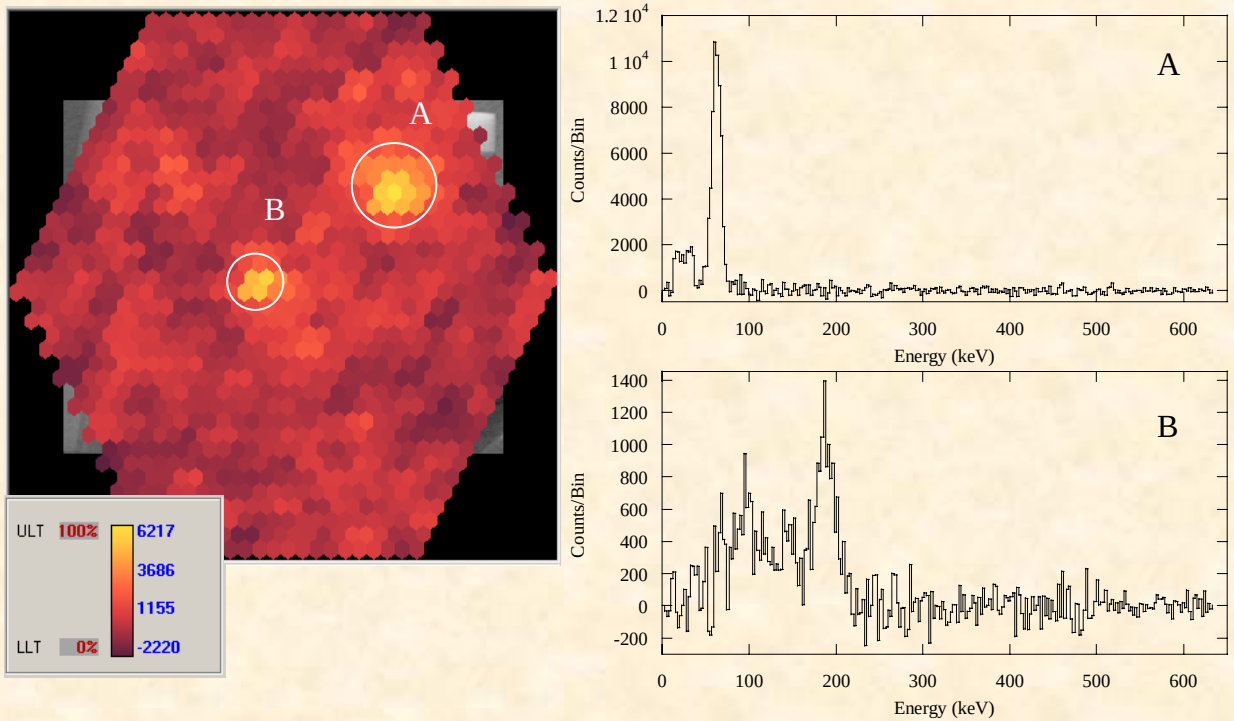
Gamma-ray imaging spectrometer*



- 1-cm thick CsI(Na) crystal on a PSPMT provides ~ 60 cm^2 active area
- 5 mm thick Ta, Rank 9, hex uniformly redundant array mask
- Mask/Anti-Mask equal time integration with 60^0 mask rotation
- 5 preset focal lengths providing 13.5^0 to 50^0 field of view
- Zoom factor of 3.7
- Coaligned video camera for visible light/gamma-ray overlays.
- Removable 1 cm lead shielding
- Upper energy limit ~ 600 keV

** K. Ziock and L. Nakae, IEEE TNS **49**, 1552-1559, 2002*

Gamma-ray imager performance



- Image of ^{241}Am and HEU point sources together with spectra
- Video and gamma-ray images are scaled and overlaid
- Gamma-image is turned clear at settable threshold—typically 50%

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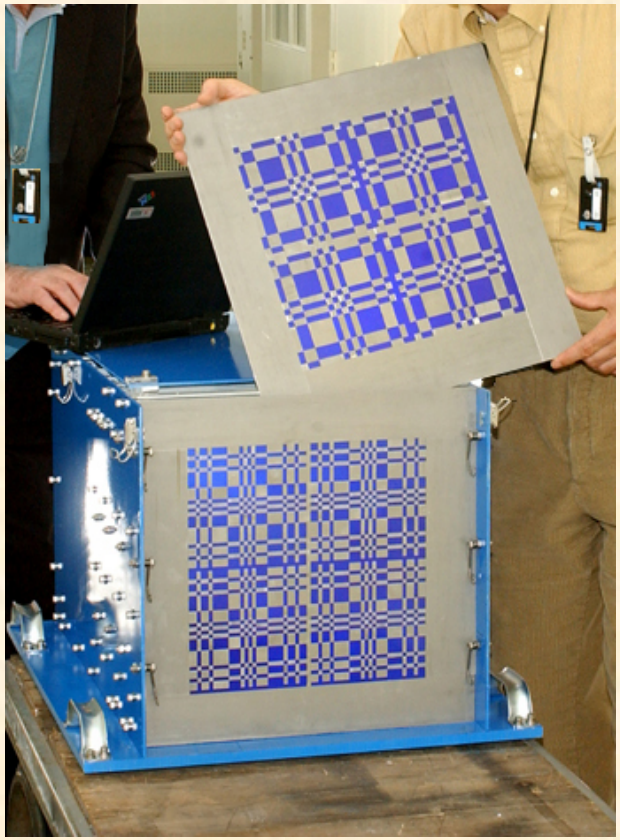
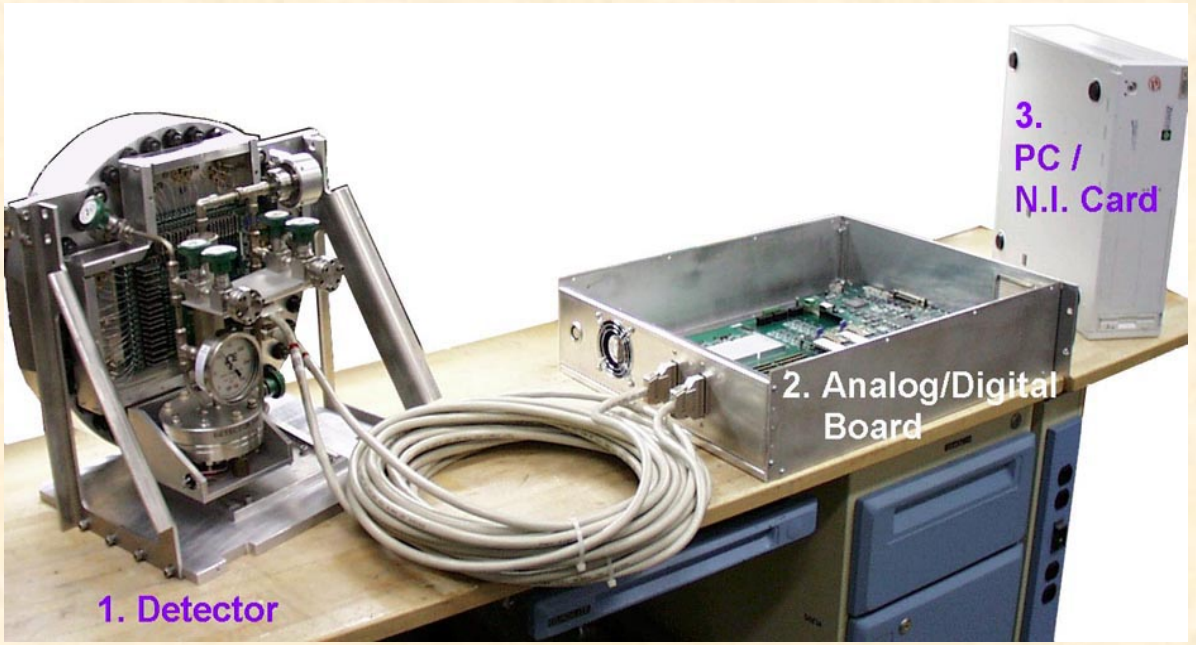
Thermal Neutron Imager*





- Crossed-wire, 20cm x 17cm, 6-bar ^{3}He detector
- Cd-line box and mask
- Masks of 19 x 19, 31 x 31 and 47 x 47 available
- Mask/Anti-mask integrations on 90^{o} mask rotation

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*P. E. Vanier, Proc. SPIE, **5199-A**, pp.124-131, 2003.

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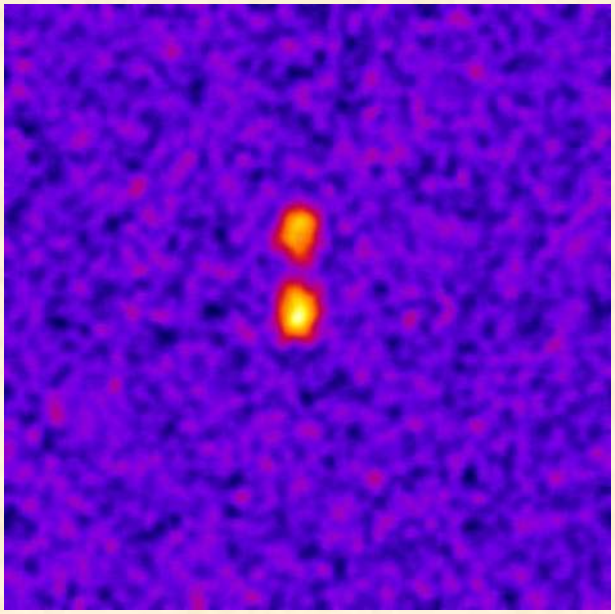
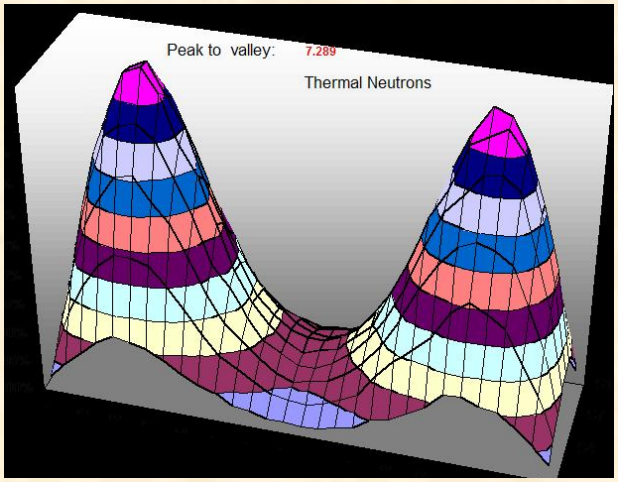
Thermal neutron imager performance





- ^{252}Cf sources in 10 cm polyethylene cubes
- The neutron diffusion length is less than the 10 cm cube size so the center cube is suppressed
- Agrees with Monte Carlo results (right)

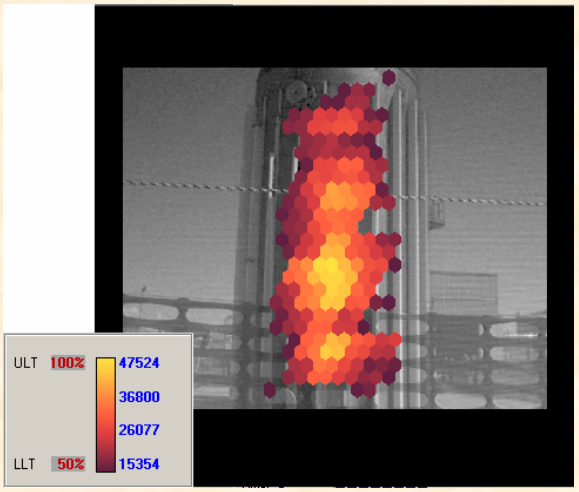
Experiments conducted at INL with 6 casks available

MC-10 125-B V/21 REA-2023

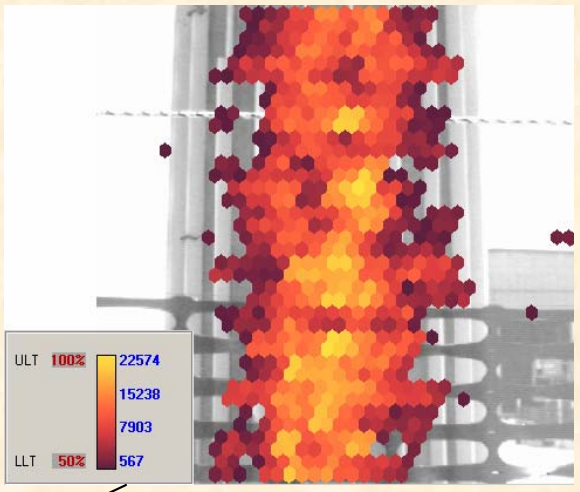
TN-24P VSC-17

Cask	Fuel Elements	MTHM
MC-10	34	14.99
NuPac 125-B	2	0.02
Castor V/21	21	9.27
REA-2023	14	1.79
VSC-17	17	5.31
TN-24P	19	8.04

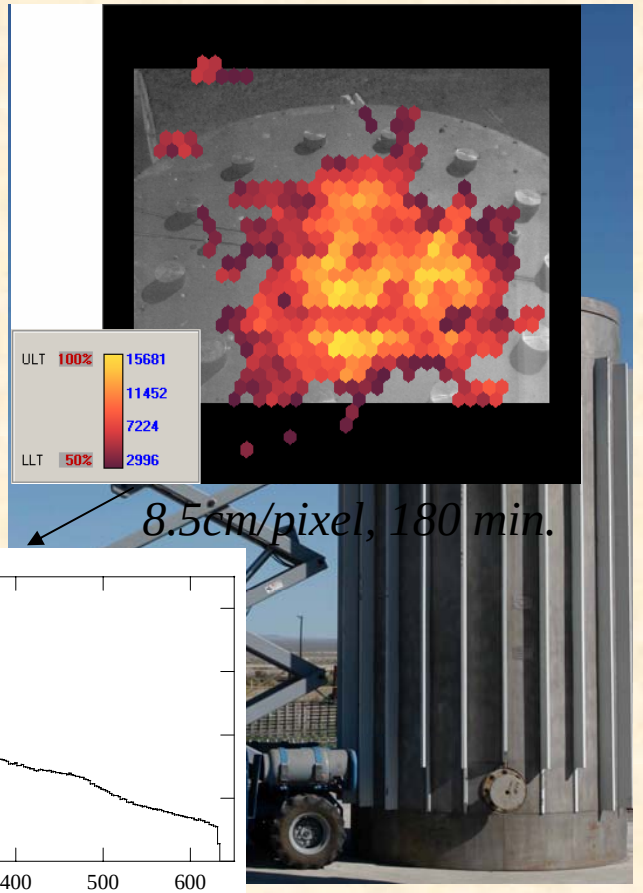
MC-10 Gamma-ray imager results



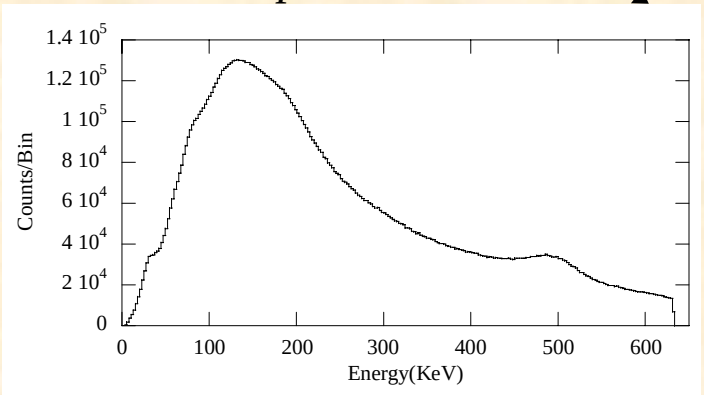
13.6 cm/pixel, 120 min.

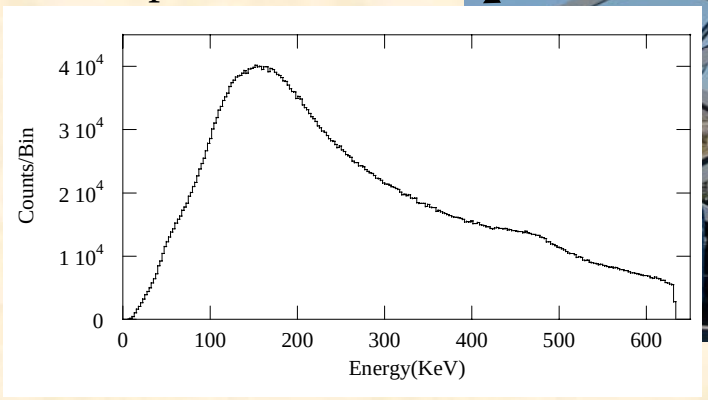


8.5cm/pixel, 180 min.



8.5cm/pixel, 180 min.





- Pixels are half the resolution element of the imager
- 34 PWR Fuel units giving 15.0 metric tons heavy metal (MTHM)

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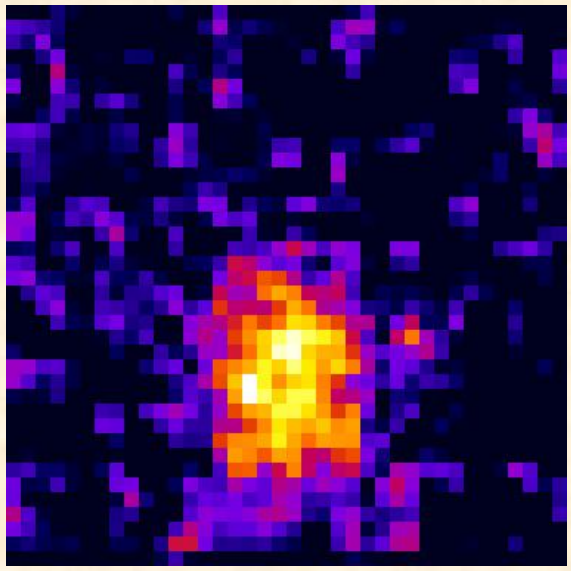
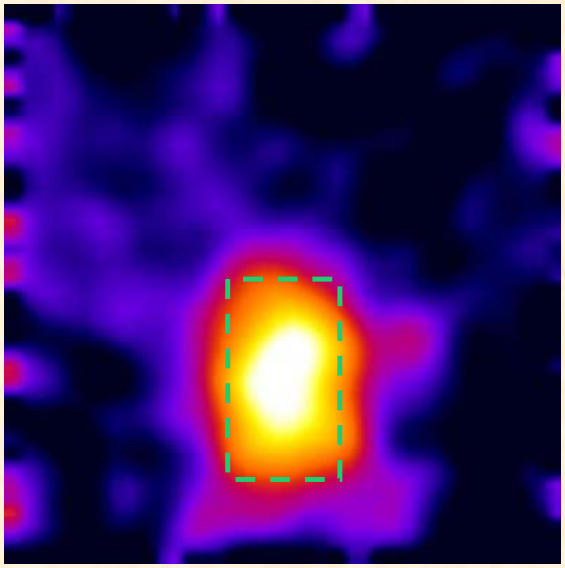
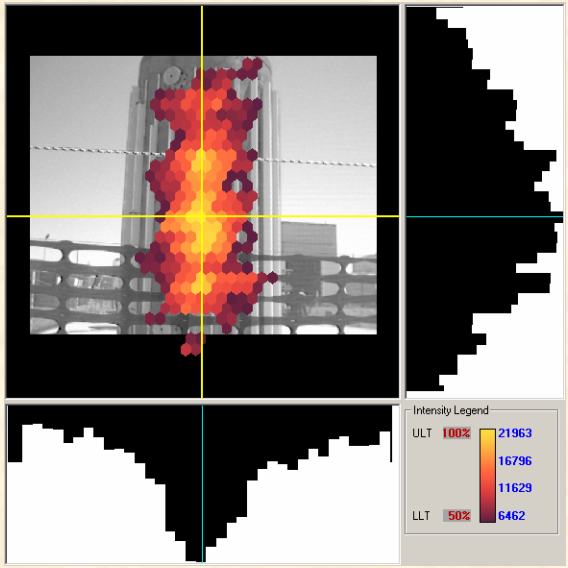
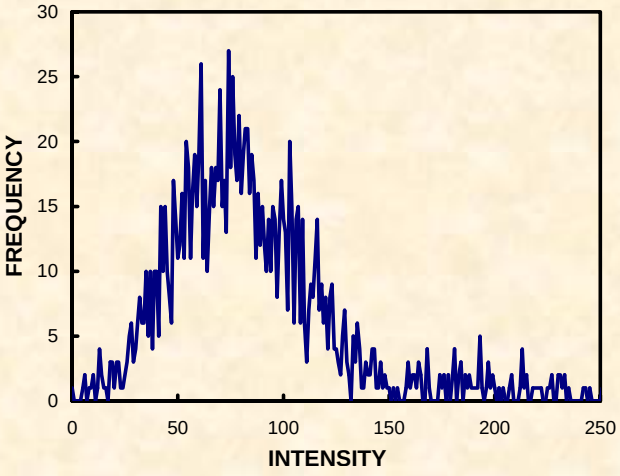
MC-10 thermal neutron results









- 6 hours of neutron data at ~ 64 cm/resolution element
- Pixel size is 16 cm at the source plane
- Statistical noise dominates “raw” image (histogram at left)
- Gamma-ray histograms along yellow cursor lines for comparison.
- Smoothed image shows the radiation is brighter at the center of the cask

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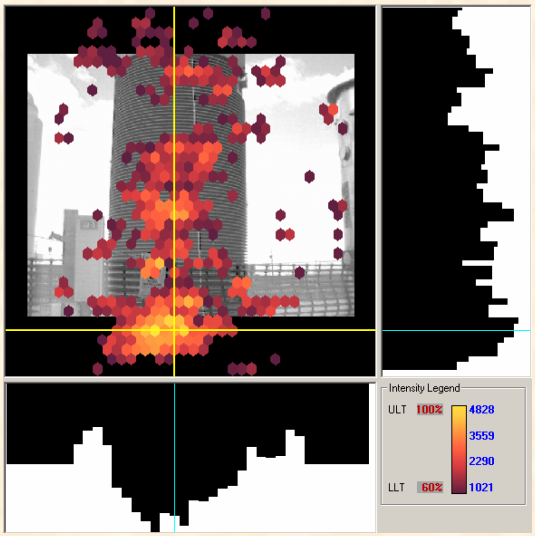
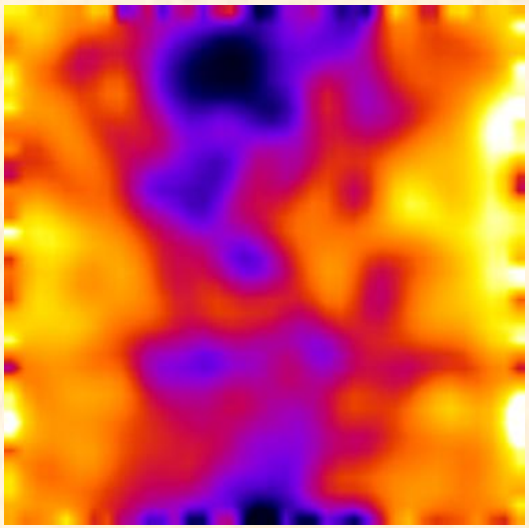
Other Casks

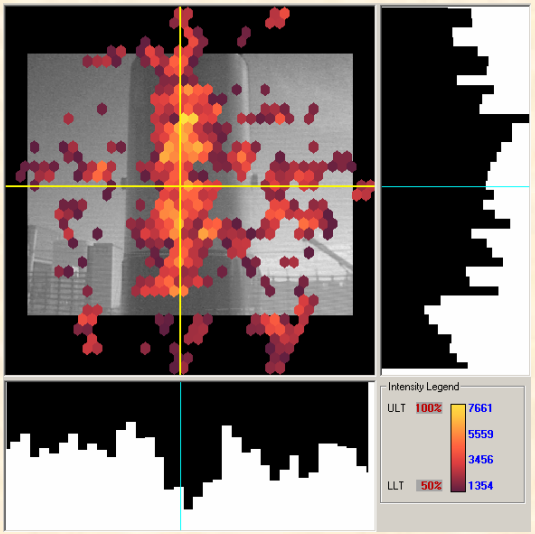


Gamma-ray

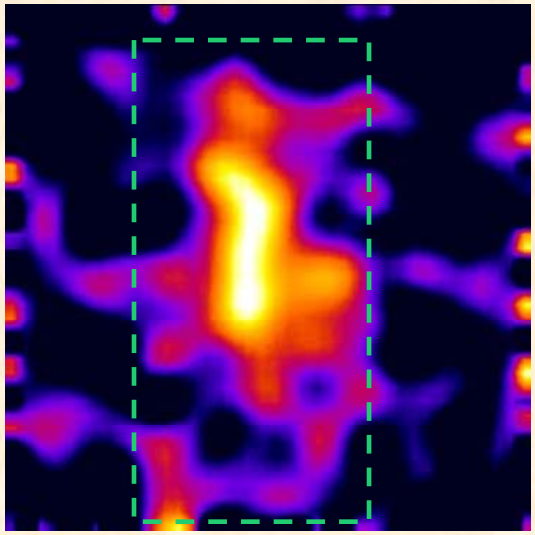
- Castor V-21 with 9.3 MTHM
- High gamma flux leaking out cask bottom is scattered into the line of sight
- Shows high neutron dose rate
- Thermal neutron image shows a “hole” in the ambient flux



Thermal neutron



- VSC-17 with 5.3 MTHM
- Weak central gamma-ray flux
- Neutron flux is also well localized to the central area of the cask



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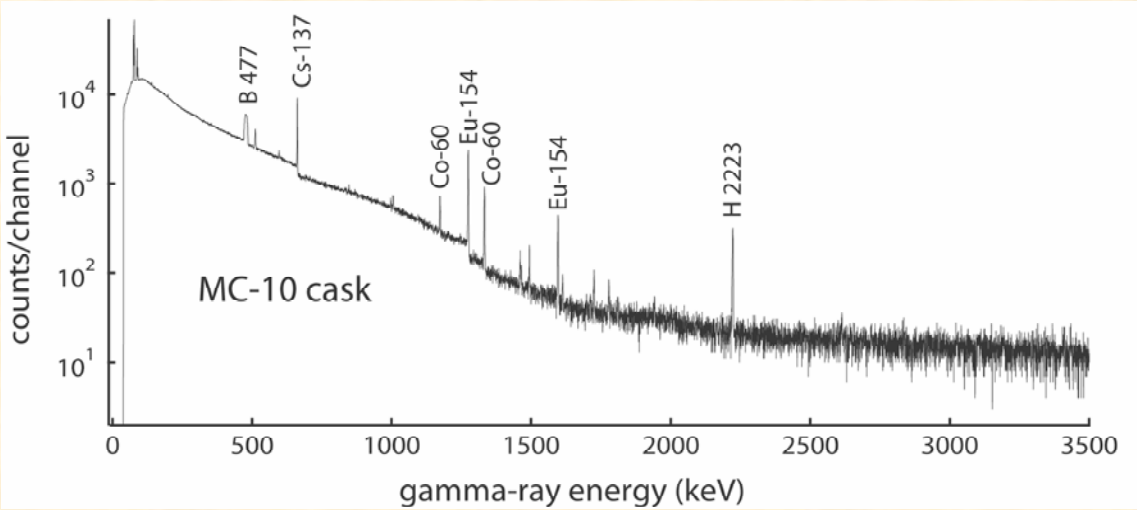
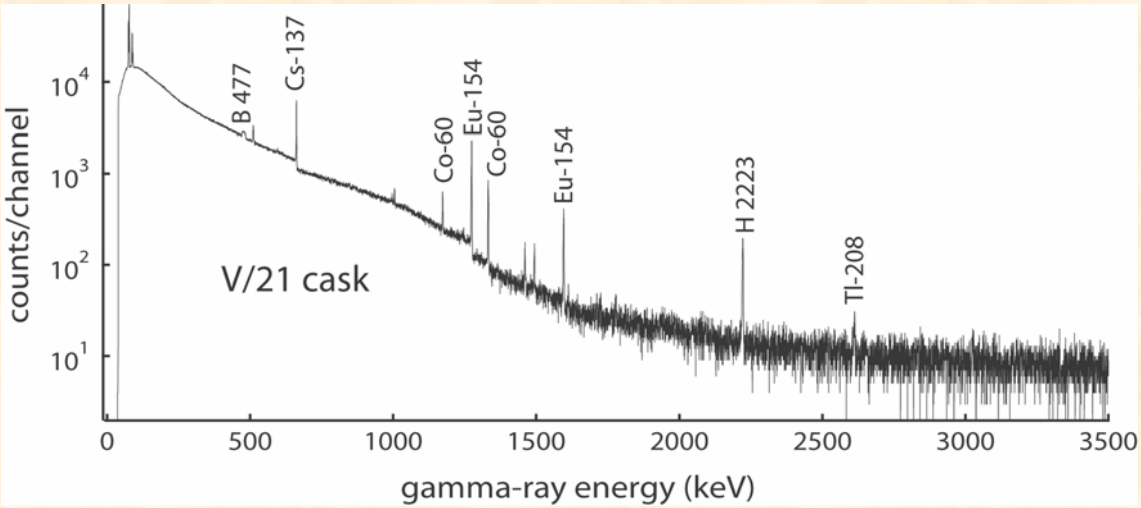
Ge spectrometer results





- Passively collimated, spectrometer obtained cask γ-ray spectra
- Cask spectra are similar
- There are significant photopeaks visible
- Ratio of Signal to background counts in the ^{137}Cs photopeak ranges from 0.5:1 to 1.2:1
- This is sufficient to image

Photopeak image sees through the cask walls

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Conclusions

- **Images are different for different cask types**
  - Gamma-ray images are dominated by diffuse effect of shielding
  - Neutron images are dominated by thermalization in the shielding
- **Detail is insufficient to identify individual casks**
- **Gamma-ray spectroscopy indicates that unscattered radiation does reach the cask surface**
- **The signal-to-noise of photopeaks is sufficient to merit an imaging attempt**
- **We hope to return with a Ge-based gamma-ray imager[1]**
- **Fission spectrum neutron imagers under development may allow similar images through the shielding[2]**

1) *K. Ziock et al., IEEE TNS **49**, 1552-1559, 2002*
2) *P. Vanier et al., Proc. SPIE, *****, 2005.*