Analysis of Radioactive Waste and Contamination using 3D Position-Sensitive CdZnTe Detectors

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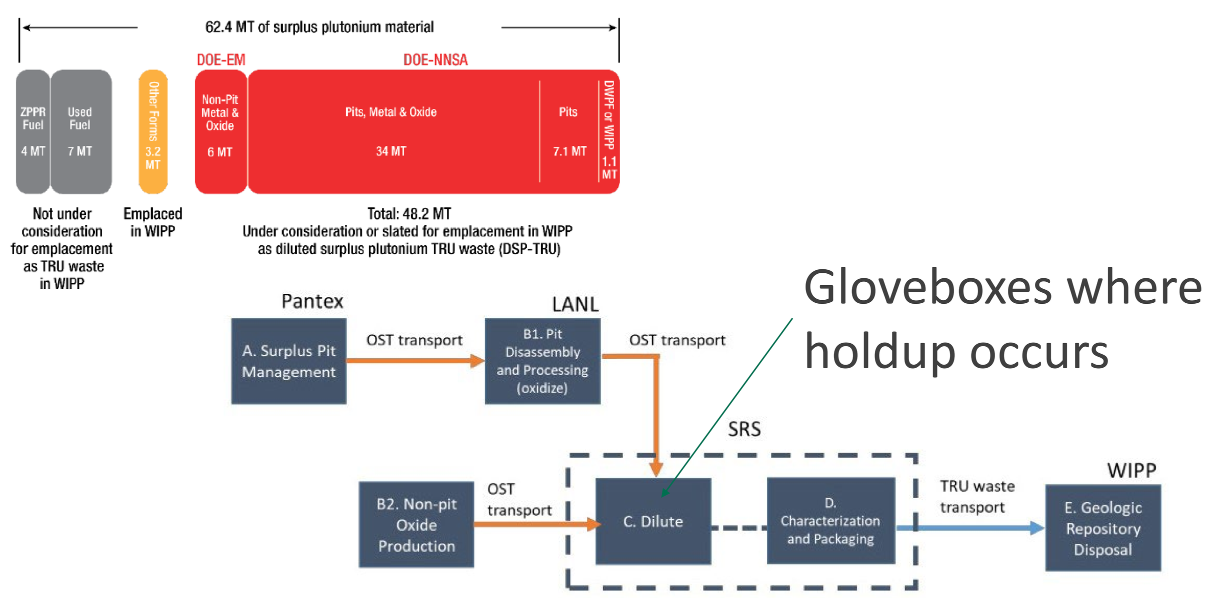
Introduction

The US has surplus plutonium. This material will be diluted in gloveboxes at SRS [Ref 1 and 2]. This process will create holdup.



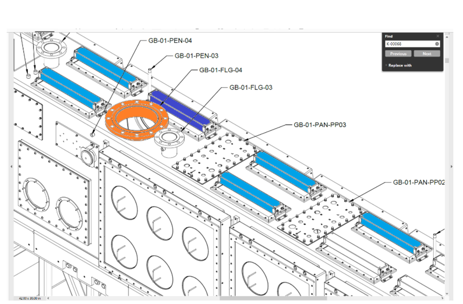
Holdup is material in an unexpected or unwanted location. Because this holdup material is primarily PuO_2, it must be accounted for (measured). This measurement is typically done using a liquid-nitrogen cooled, HPGe detector.

To enable more rapid processing, advanced holdup technologies are being explored [Ref 3 and 4].

Methods

For the surplus plutonium dilute and dispose program, the traditional detector system could slow down the optimal operational tempo of the program.

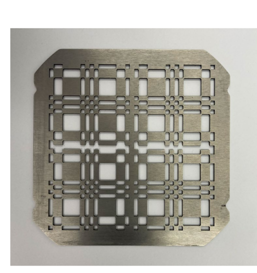
A multiple-detector system, providing complete glovebox coverage, based on CdZnTe crystals, 3D-positioning electronics, and a coded aperture mask, is in the process of being developed by ORNL and SRNL [Ref 4].



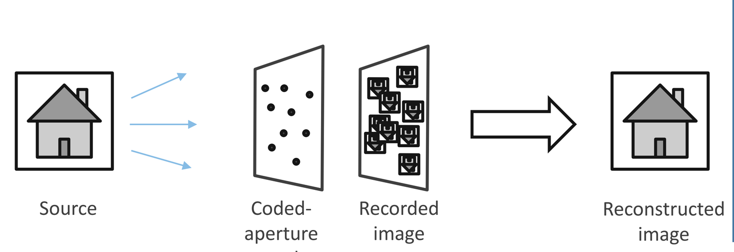
This system will enable:

- Complete measurement coverage of each glovebox
- On-demand holdup or other measurement capabilities
- Increased reliability and uptime (if one detector goes down, others in the system can still provide measurements, although with higher uncertainty)

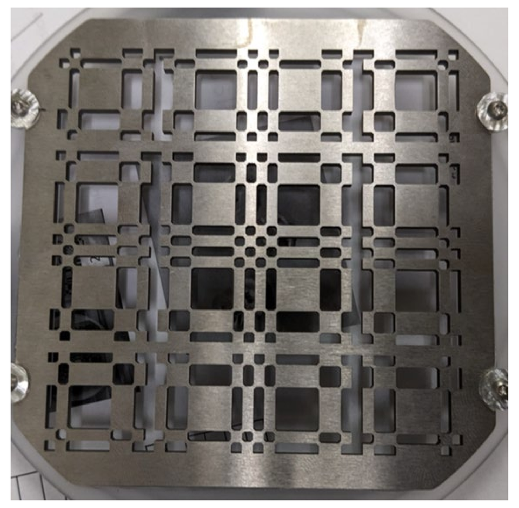
Commercial Imager (H3D)



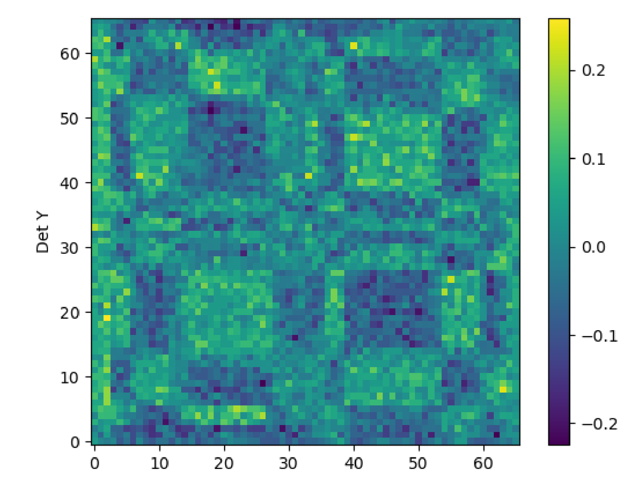
Coded-Aperture Mask



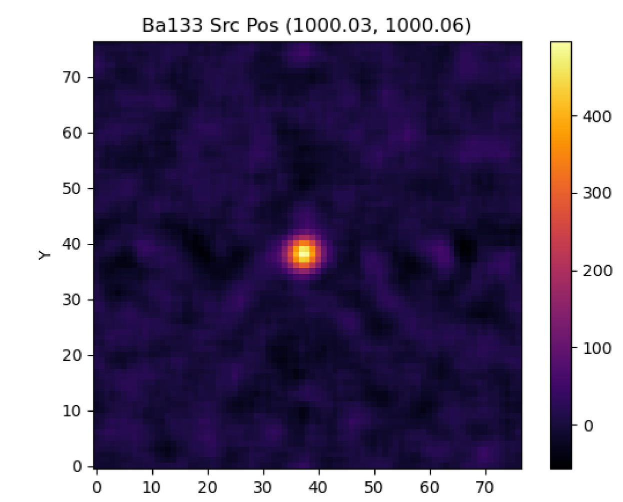
Coded-Aperture Gamma-Ray Imaging



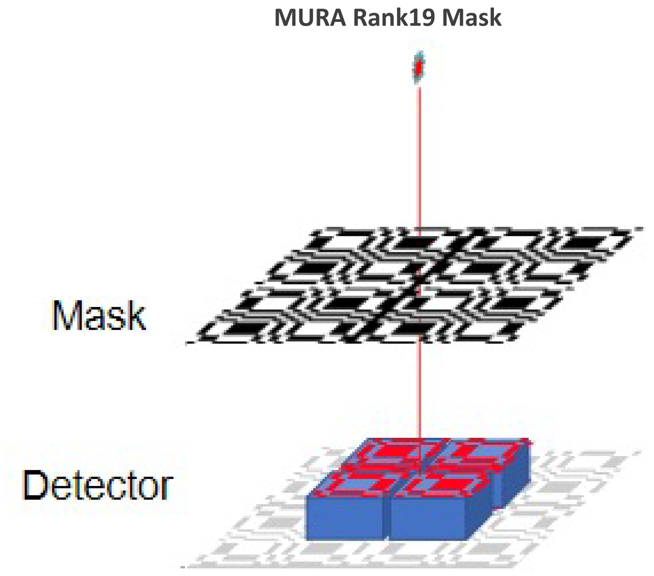
MURA Rank19 Mask



Mask/Anti-Mask raw data

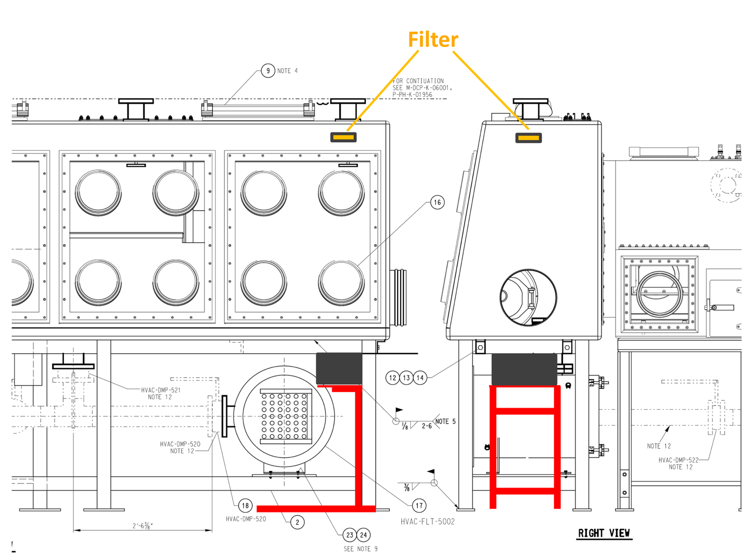


Point Source located

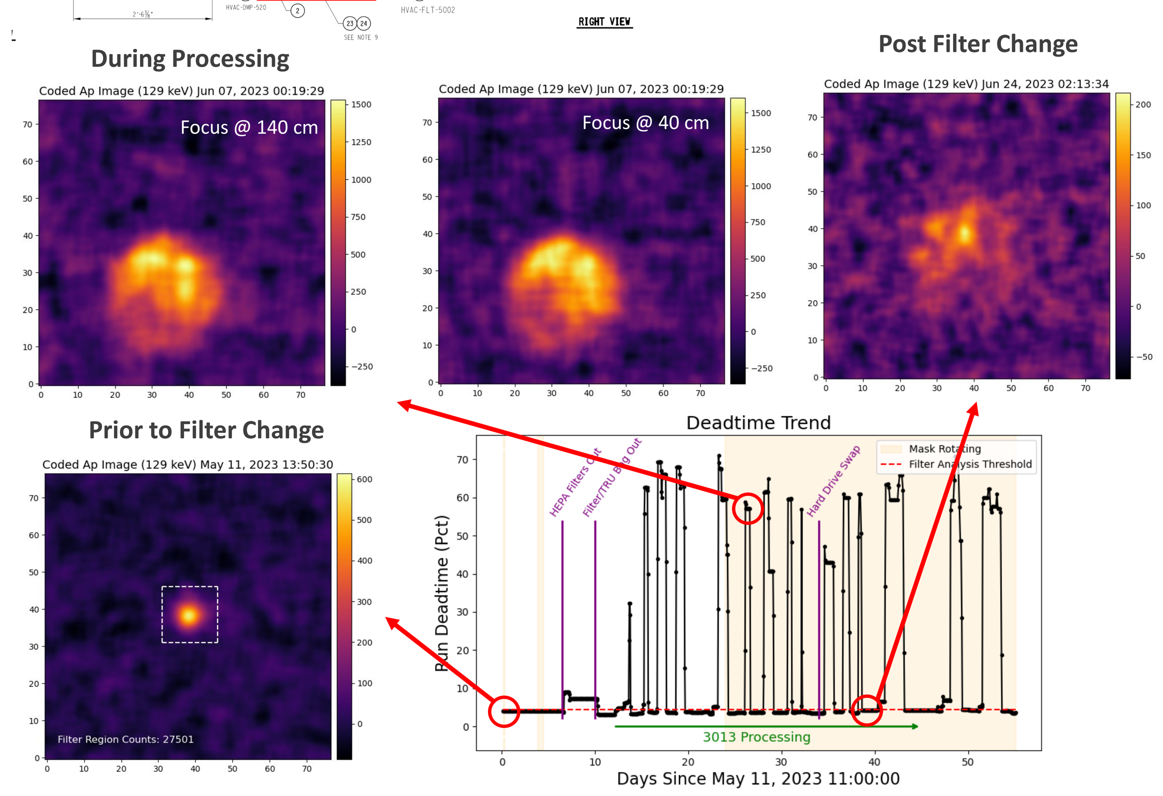


- Gamma ray imaging via coded-aperture imaging yields good angular resolution (~5°) compared to Compton imaging (~20°).
- Images are created by cross-correlating the mask pattern with the observed shadow pattern on the detector.
- Biases in event reconstruction can distort the observed pattern resulting in imaging artifacts (a lot of work has been done to reduce these artifacts [Ref 3]).

Demonstration of System



- Imagers have been installed at SRS for two 60-day campaigns (2023 and 2024), and 2025 (upcoming)
- Operational during filter change out (high holdup) and during normal dilute and dispose operations
- Mass of holdup on filters have been estimated and acquired data has enabled detailed evaluation of analysis methods



- Prior to Filter Change, filter imaged and mass estimated
- Weigh pan moved between detector and filter and imaged (top left two images).
- Post Filter Change, filter holdup is diffuse and near background in number of counts (as expected).
- Empirical calibration performed (post acquisition) and mass of Pu-239 on calculated, using 414 keV gamma)

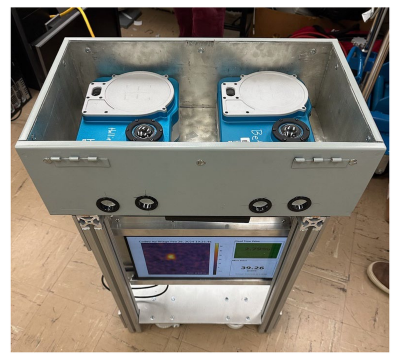
Imager system: 25.7 +/- 3.2 g
ISOCS system: 24.9 +/- 7.0 g

Results

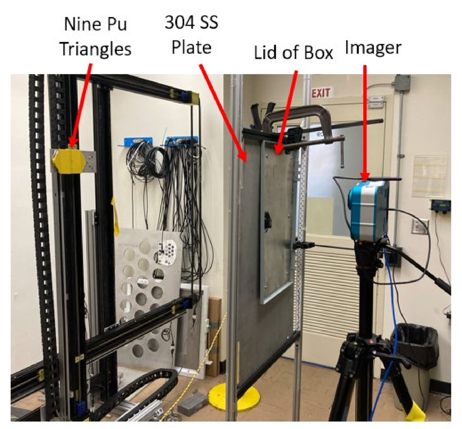
Results from the 2023 deployment demonstrate the applicability of gamma-ray imaging for localization and quantification of radioactive materials in various applications using a 3D position-sensitive CdZnTe (CZT) commercial spectrometer.

A similar deployment was conducted in 2024, after additional development/refinement of the image reconstruction algorithms, user interface refinements, and other improvements. This work provided real-time estimate of Pu-239 mass on the filter. At the end of this campaign, the results were:

Imager system: 21.3 +/- 1.7 g
ISOCS system: 29.3 +/- 13.0 g



Multidetector system

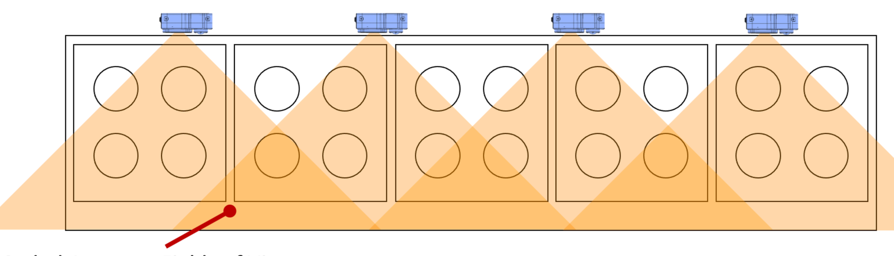


Empirical Calibration Setup

This work highlights the advantages and challenges faced in real-world radioactive contamination monitoring and verification measurements.

Conclusion

- Gamma-ray imaging shows promise for holdup measurements in glovebox (IMAGER RESULTS SIMILAR TO HPGE)
- Creative thinking required to avoid being intrusive (LIGHT FIXTURE CONCEPT)
- Careful consideration required to present data that brings clarity, during normal operations, and allows flexibility during off-normal circumstances (USER INTERFACE)



Coded Aperture Fields of View

References

1. National Academy Report 25593: Review of DOE's Plans for Disposal of Surplus Plutonium in the Waste Isolation Pilot (2020).
2. National Academy Report 25272: Disposal of Surplus Plutonium at the Waste Isolation Pilot Plant: Interim Report (2018).
3. Daughhetee, J. Detailed Characterization of CZT Detector Response for Improved Coded-Aperture Imaging Performance. 65th INMM Annual Meeting, July 2024.
4. Schmitt, et al. Progress Toward Gamma-Ray Imaging for Automated Holdup Measurement in Gloveboxes. 65th INMM Annual Meeting, July 2024.

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