

# Nuclear Data Needs for Microcalorimetry-based Laboratory Measurement

Presenter: Geon-Bo Kim (LLNL, kim90@llnl.gov)

LLNL: G. B. Kim, I. Kim, T. Parsons-Davis, R. Henderson, K. Thomas, T. Woody

LANL: K. A. Schreiber, K. E. Koehler, E. N. Stark, M. P. Croce, D. G. McNeel

LBNL: M. S. Basunia, A. S. Voyles, A. M. Hurst, L. A. Bernstein

PNNL: B. Peirson, G. Batie, C. Harabagiu, L. Arrigo

INL: E. Seabury, B.M. Bucher, P. Abel, V. Davis, and A. Williams

CU: D. Becker

kim90@llnl.gov

February 9, 2026

LLNL-CFPRES-2015557

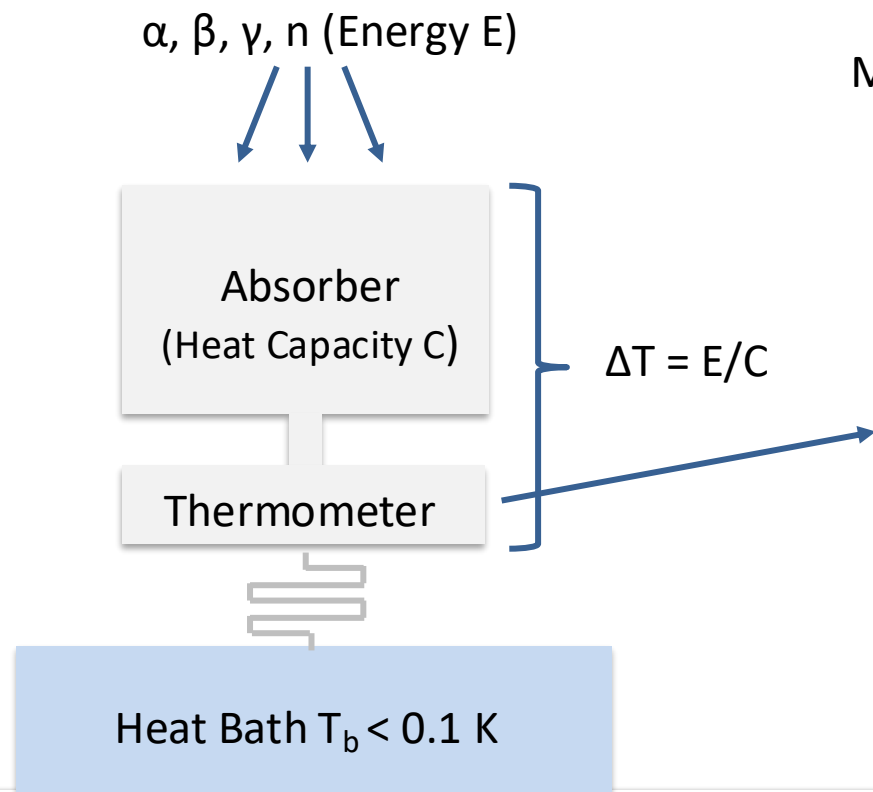
WANDA2026



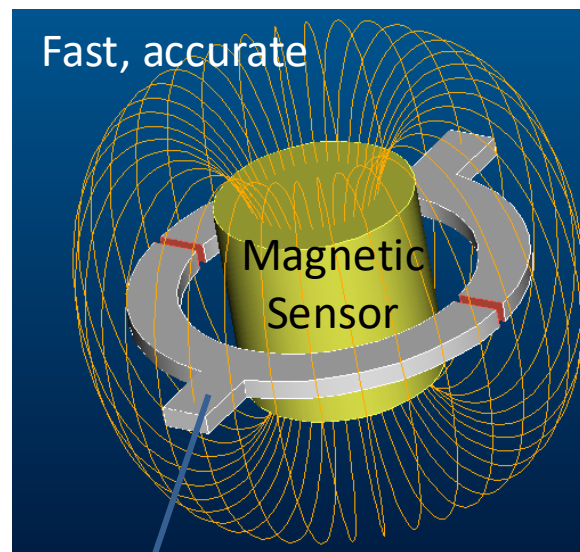
# Microcalorimeters

## Micro-calorimeters:

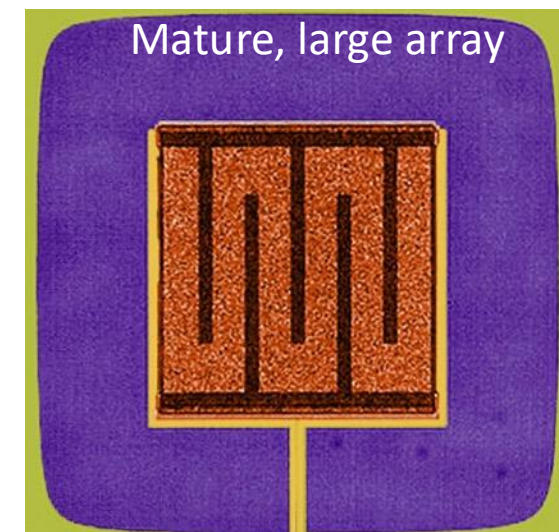
- Measure micro-heat produced by radiation absorption using quantum sensors
- Excellent energy resolution (order of 10 eV) for 100 keV gamma-rays
- Technical Readiness Level 7-8, user facility deployable



Magnetic Micro-Calorimeter (MMC)



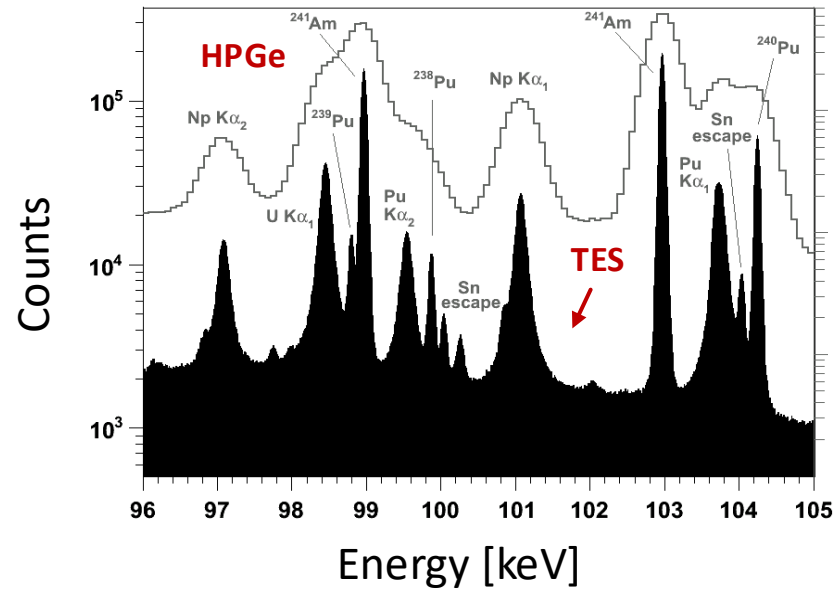
Transition Edge Sensor (TES)



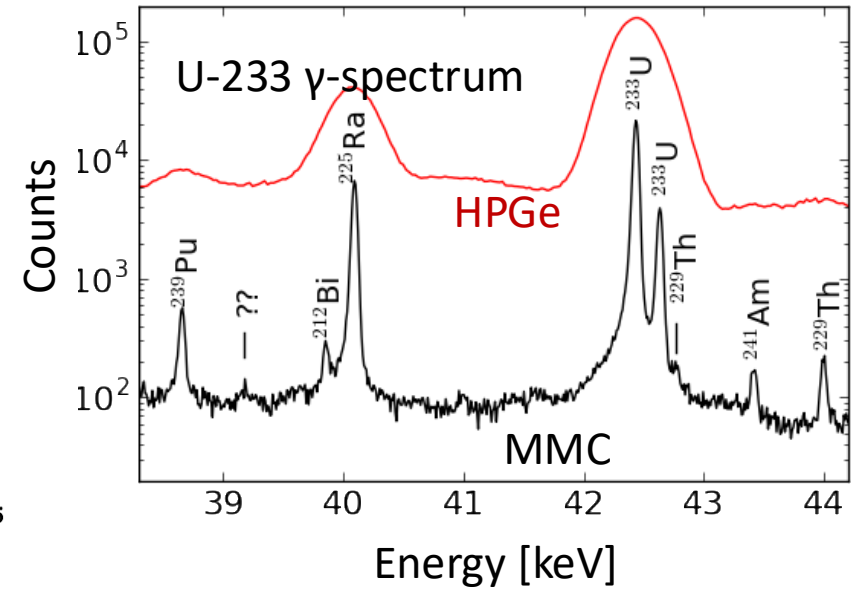
# Microcalorimeters for Gamma-ray Non-Destructive Assay



Hoover et. al., IEEE Trans. Nuc. Sci. 60 (2013)

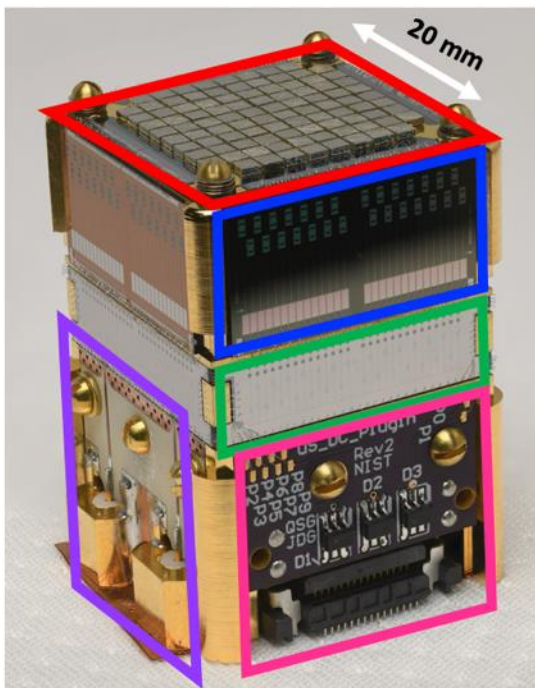


Kim et al., J Rad Nucl Chem 318:803-808 (2018)

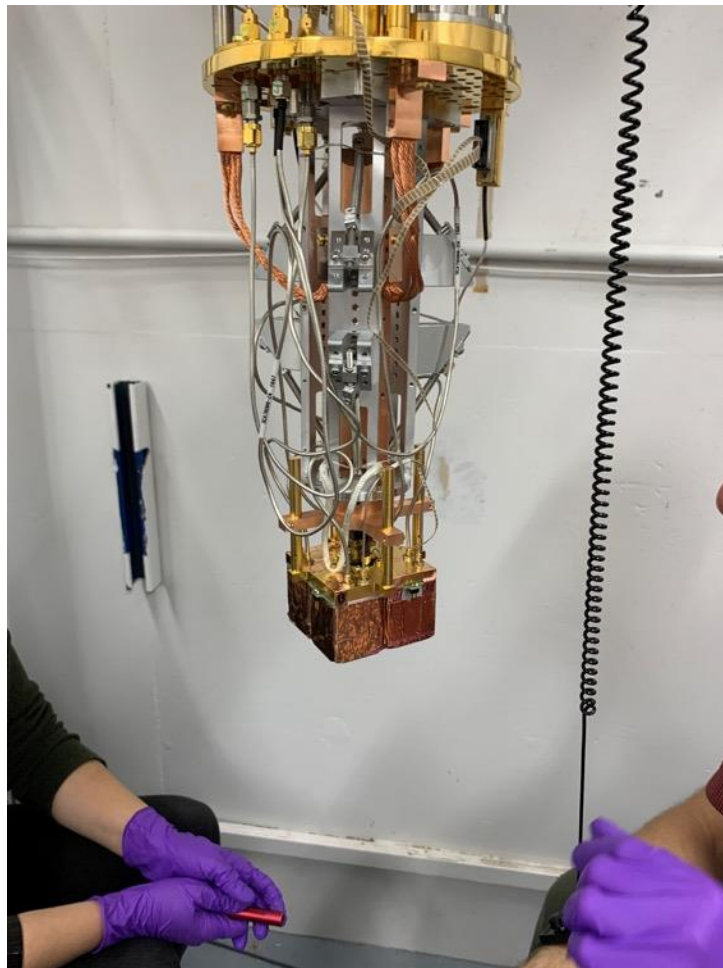


- Key application: High-resolution gamma spectroscopy for *actinide composition analysis*.
- TES microcalorimeters are planned to be deployed for nuclear safeguards and material accounting

# INL TES Gamma Spectrometer



- Detector array: 96 microcalorimeters
- Bias resistors and inductors
- SQUIDs and  $\mu$ wave resonators for readout
- Microwave signals
- DC signals and protection diodes



# Accuracy: What Can Microcalorimeters Achieve?

- Dominant systematic uncertainties: Nuclear data ( $\gamma$  Branching Ratios)

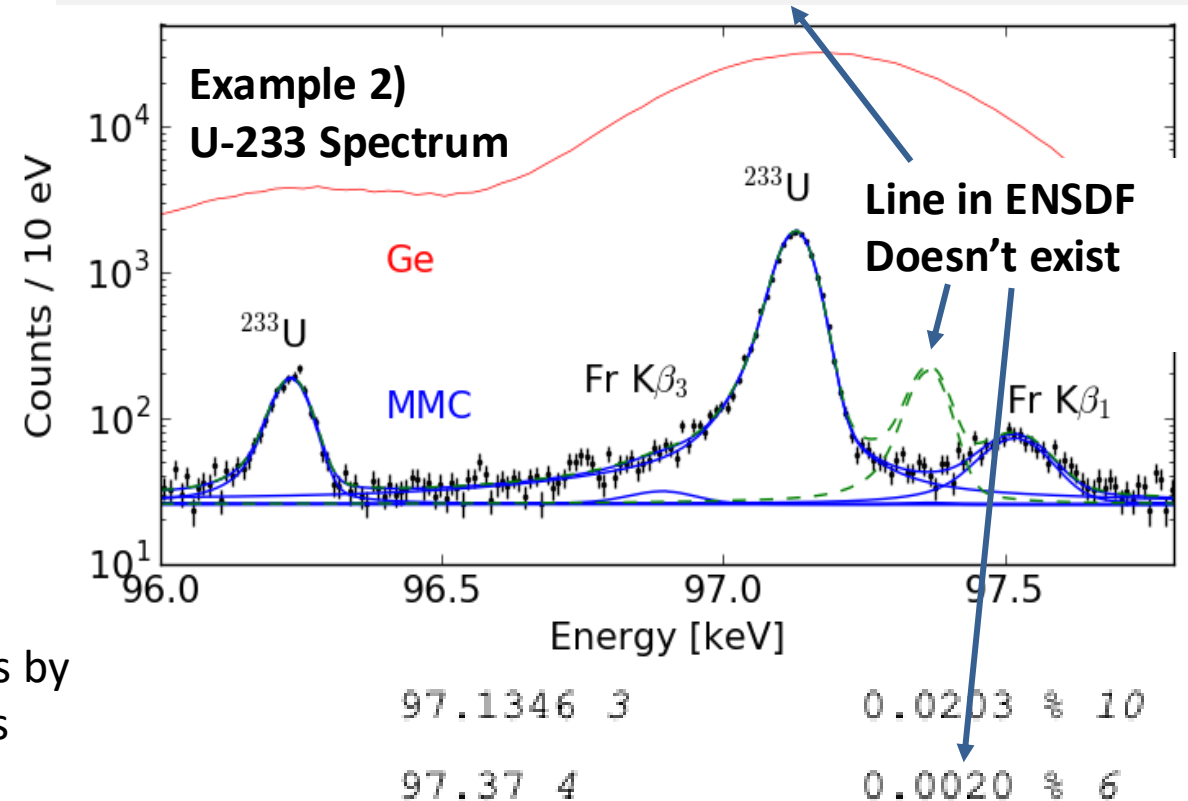
>1% for known gamma lines

| Uncertainty Source | Microcal (%)       | HPGe (%)           |
|--------------------|--------------------|--------------------|
| BRs                | <b>0.82 - 1.24</b> |                    |
| Half Life          | 0.13 - 0.19        |                    |
| Line Energies      | 0.02 - 0.15        | <b>0.18 - 3.1</b>  |
| X-Ray Linewidths   | 0.01 - 0.65        | <b>0.16 - 0.97</b> |

**Example 1) Uncertainty budget in TES-based Pu Assay (Hoover et al 2014)**

Reduced uncertainties by resolving line overlaps

**Often >10% uncertainties** for newly resolved gamma lines



# MiND-2023 (**M**icrocalorimetry and **N**uclear **D**ata) Workshop



**Goal:** Prioritize nuclear data needs and discuss roadmap for improving data

**Participants:** Microcalorimeter experts and users, Nuclear data evaluators and managers, NA-241. (Six US national labs, NIST, NASA GSFC, NNSA, IAEA, and CEA France)

# Workshop Outcome

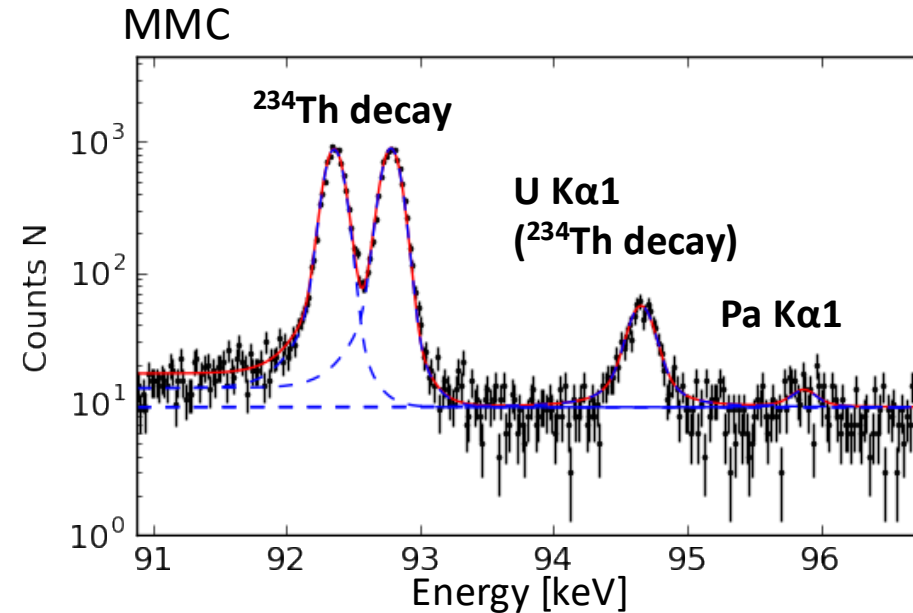
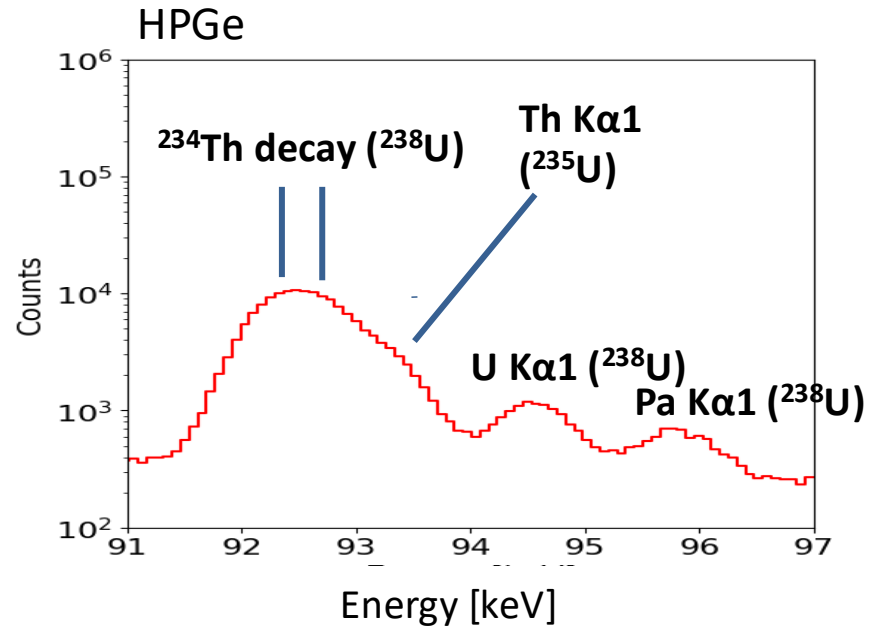
- Identified nuclear data priorities.
  - Key needs include improved U, Pu, Am, and Np gamma-ray data in the 50–250 keV energy range to support current and emerging microcalorimetry capabilities.
- Planned nuclear data Improvement campaign.
  - Nuclear data evaluators, microcalorimetry experts, microcalorimeter users
  - Round-robin Measurement Campaign between LLNL, LBNL, PNNL, INL, LANL  
(Funded by NP and NA-241)
- Project plan
  - Evaluate existing data
  - <sup>169</sup>Yb and <sup>233</sup>U production for calibration
  - Round-robin measurement campaign
  - Integrate and publish results.

## **Nuclear Data Needs for Microcalorimetry and Non-destructive Assay**

Geon-Bo Kim<sup>1\*</sup>, Begona Aranguren-Barrado<sup>2</sup>, Shamsuzzoha Basunia<sup>3,4</sup>, Daniel Becker<sup>5,6</sup>, Lee Bernstein<sup>3,4</sup>, Mark Croce<sup>7</sup>, Joel Ullom<sup>5,6</sup>, Andrew Voyles<sup>3,6</sup>

*A summary paper at the INMM 2024 proceeding*

# Data Needs Example: $^{234}\text{Th}$ 92 keV for U Enrichment Measurement



| Parent                                 | Energy [keV] | Intensity [%] |
|--|--------------|---------------|
| $^{238}\text{U}$ ( $^{234}\text{Th}$ ) | 92.38(1)     | 2.13(20)      |
| $^{238}\text{U}$ ( $^{234}\text{Th}$ ) | 92.80(2)     | 2.10(20)      |
| $^{235}\text{U}$ (Th K $\alpha$ 1)     | 93.35        | 4.7(5)        |
| $^{238}\text{U}$ ( $^{234}\text{Th}$ ) | 63.30        | 3.7(4)        |

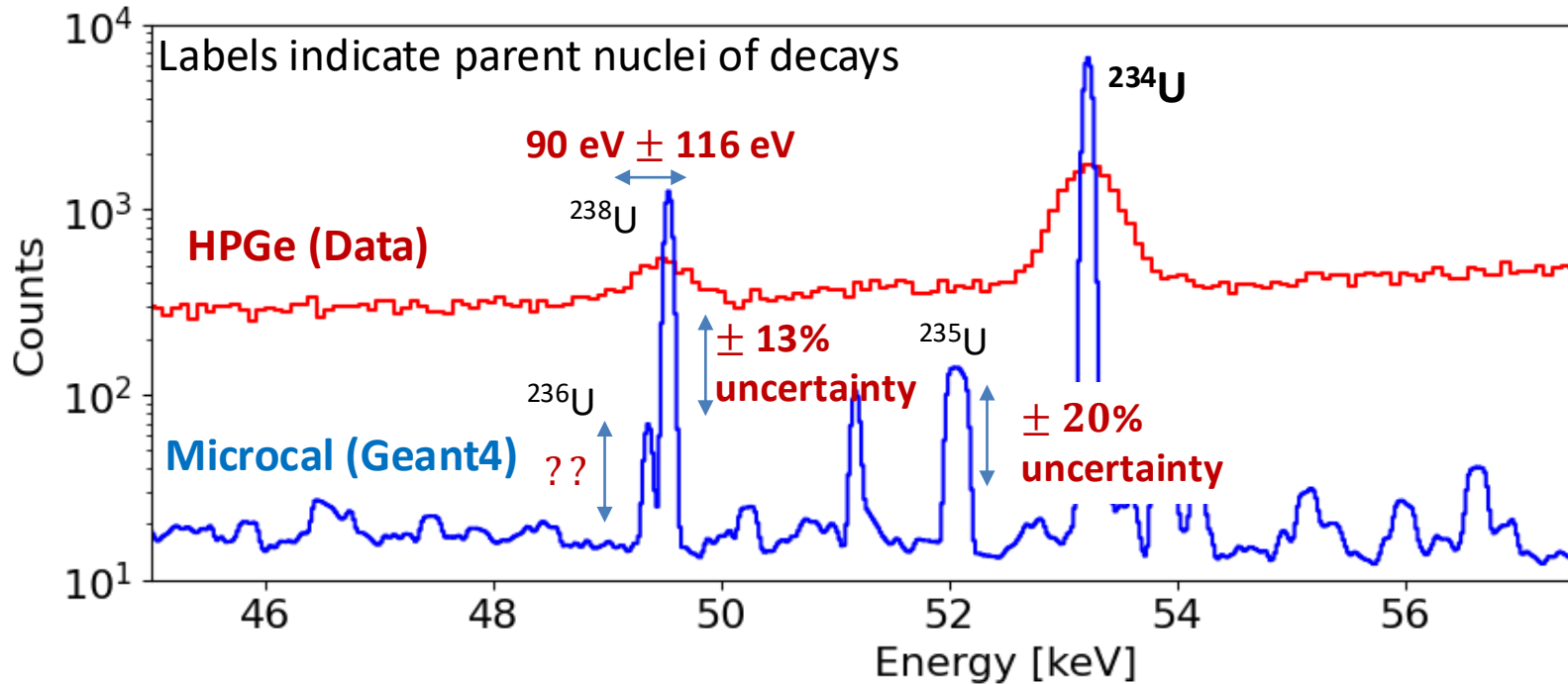
- 92 keV lines are resolved using microcalorimeters
- BR uncertainties (10%) limits the  $^{235}\text{U}/^{238}\text{U}$  analysis precision in microcal analysis.

10% relative uncertainties

# Example: Direct Quantification of $^{238}\text{U}$

Microcalorimeters might be able to quantify  $^{238}\text{U}$  with 49.46 keV gamma line, which is  $90 \pm 116$  eV apart from the  $^{236}\text{U}$  line.

From NuDat 3.0



| Parent                             | Energy [keV]     | Intensity [%]    |
|------------------------------------|------------------|------------------|
| $^{238}\text{U}$                   | 49.55(6)         | 0.064(8)         |
| <b><math>^{236}\text{U}</math></b> | <b>49.46(10)</b> | <b>0.078(12)</b> |
| $^{232}\text{U}$                   | 57.78(5)         | 0.1999(18)       |
| $^{234}\text{U}$                   | 53.20(2)         | 0.1230(20)       |
| $^{235}\text{U}$                   | 51.21(5)         | 0.034(7)         |
| $^{235}\text{U}$                   | 54.25(5)         | 0.015(15)        |
| $^{238}\text{U}$                   | 113.50(10)       | 0.0102(15)       |

- This will be the first-ever direct quantification of  $^{238}\text{U}$  by gamma-spectroscopy
- $^{236}\text{U}$  interference could be resolved by microcalorimeters (unknown)

# Status of $\gamma$ ray emission probability ( $P_\gamma$ ) data

- $P_\gamma$  data from the literature and databases have been investigated for MiND

❖ New measurements are needed for  $P_\gamma$  of

- $^{238}\text{U}$ ,  $^{236}\text{U}$ ,  $^{235}\text{U}$ ,  $^{234}\text{Th}$ , and  $^{239}\text{Pu}$

❖  $P_\gamma$  data are in good standing for

- $^{238}\text{Pu}$ ,  $^{240}\text{Pu}$ ,  $^{241}\text{Pu}$ , and  $^{237}\text{U}$

- $^{169}\text{Yb}$  calibration source for Microcalorimeter

❖  $^{169}\text{Yb}$  was produced at the 88-Inch cyclotron

- Deuteron beam,  $E=25$  MeV, on Tm target
- Based on 2024 LLNL feedback on low specific activity, UCB/LBNL fabricated a new solid target holder to improve production
- Production of  $^{169}\text{Yb}$  activity per gram increased by nearly a factor of 22

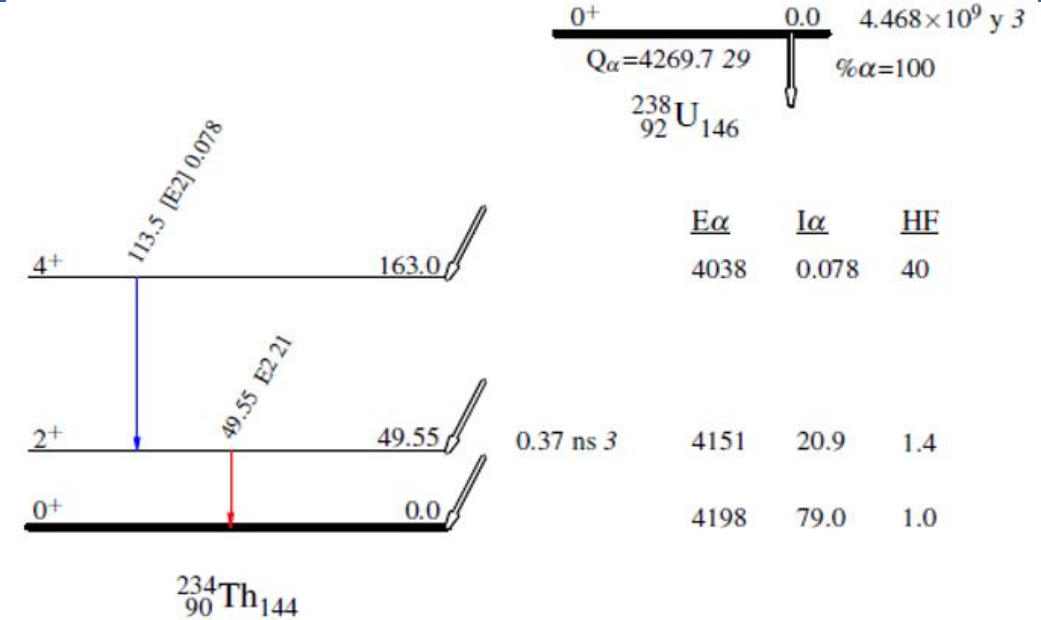
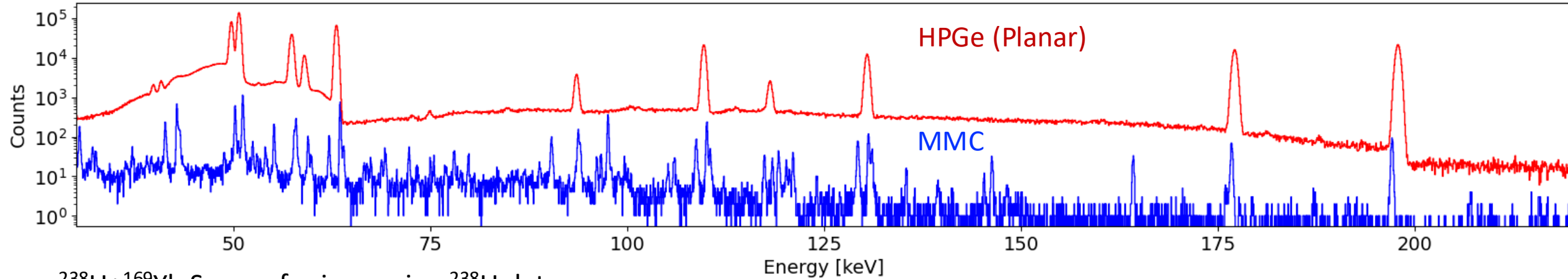


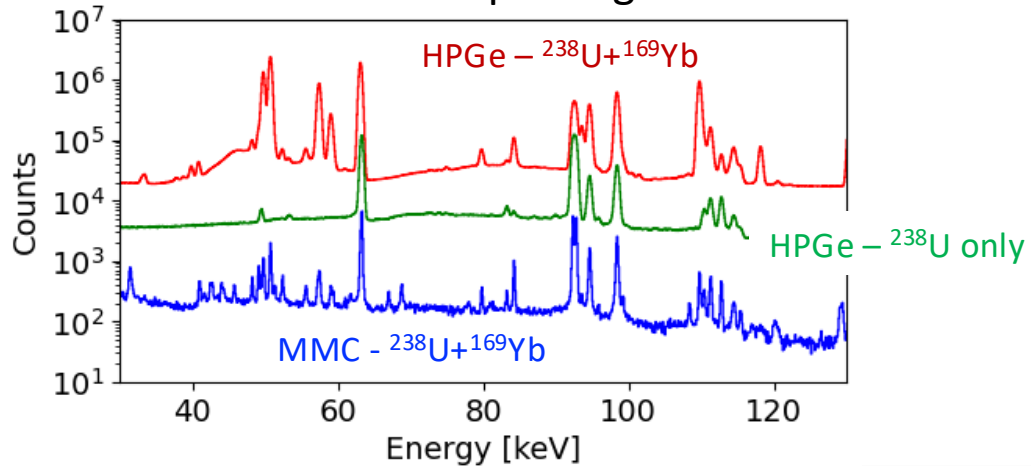
Fig. 1: Decay scheme of  $^{238}\text{U}$

# LLNL $^{238}\text{U}/^{233}\text{U}$ Measurements

$^{233}\text{U}+^{169}\text{Yb}$  Source for improving  $^{233}\text{U}$  data



$^{238}\text{U}+^{169}\text{Yb}$  Source for improving  $^{238}\text{U}$  data



Experiments have been conducted with combinations of

- Source:  $^{238}\text{U}$ ,  $^{238}\text{U}+^{169}\text{Yb}$ ,  $^{233}\text{U}$ ,  $^{233}\text{U}+^{169}\text{Yb}$
- Detector: HPGe, MMC

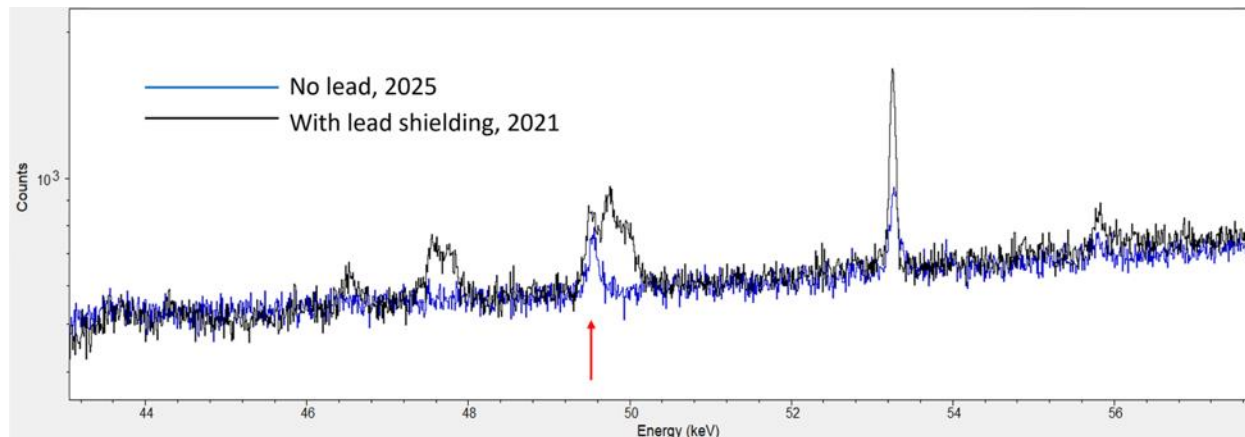
To improve  $^{233}\text{U}$  data as a new microcal calibration standard

To improve  $^{238}\text{U}$  data (49 keV, 92 keV, 113 keV) using  $^{233}\text{U}$

# Los Alamos measurements with SOFIA

## SOFIA: Spectrometer Optimized for Facility Integrated Applications

- 256 gamma-ray pixel microcalorimeter array
- LANL will perform plutonium measurements for the nuclear data project
- Removed lead shielding which was making an interfering peak around 49.5 keV



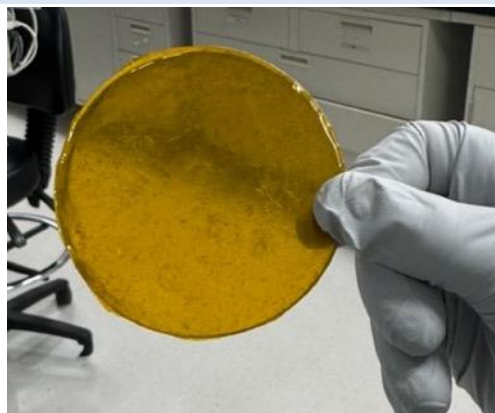
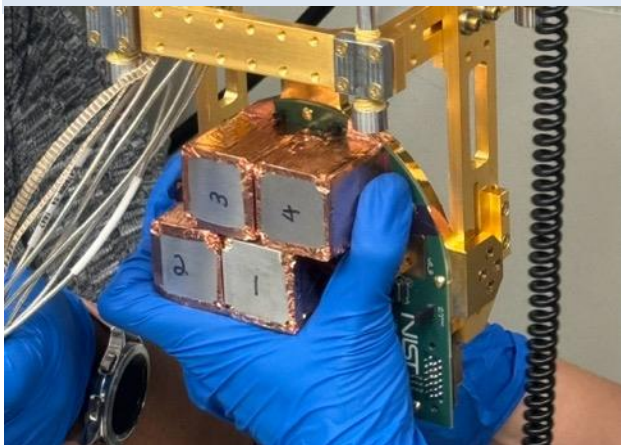
**Figure 1-2:** 49.55 keV peak shown in spectra of NBS071-107 (natural uranium) taken with (black) and without (blue) lead shielding. Interference from lead x-ray escape peak is removed in the later spectrum.



*Moving SOFIA from ORNL to LANL in a box truck*

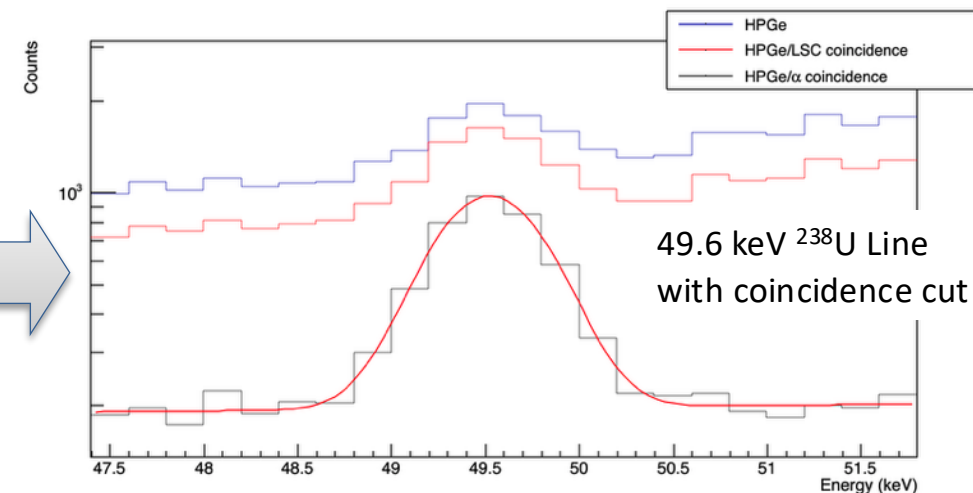
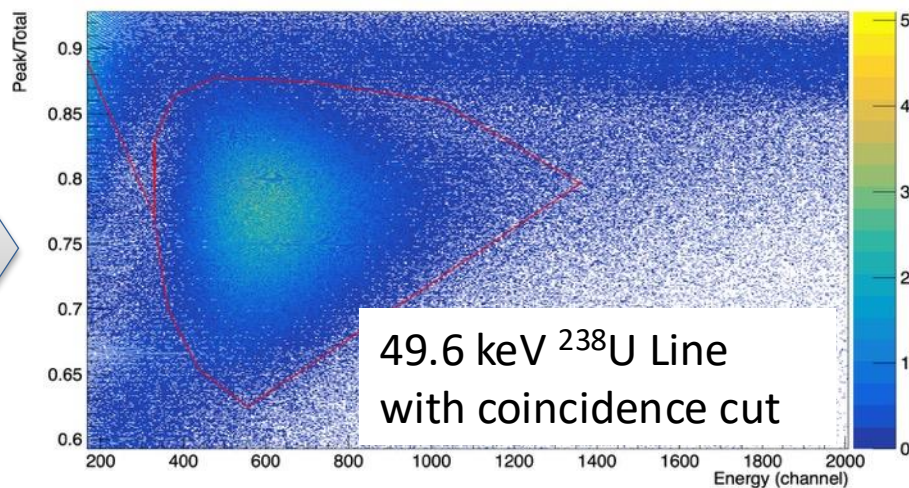
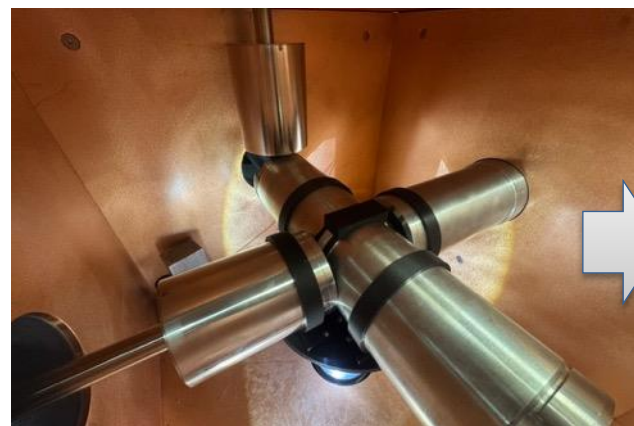
# PNNL – Alpha-Gamma Coincidence

Absolute branching ratio measurement with alpha-gamma coincidence



Kapton<sup>®</sup> wrapped U source

- Support co-measurement of sources via microcalorimetry
- Source measurements:
  - ~21 ug of 99.9998% pure U238
  - Preliminary measurements with traditional DU
- Measure dissolved sources via alpha-gamma coincidence



# Summary

---

- Microcalorimeters with Technical Readiness Level (7-8) are now available for users.
- Ultimate accuracy of microcalorimetry is predominantly limited by gamma and X-ray branching ratios ( $>1\%$ ).
- New analysis capabilities are identified with microcalorimeters; however, this is limited by large BR uncertainties ( $>10\%$ ).
- Multi-institutional collaboration effort is improving U and Pu gamma data.

## Acknowledgement

The work presented in this presentation was funded by the National Nuclear Security Administration of the Department of Energy, Office of International Nuclear Safeguards, the U.S. Department of State, Bureau of International Security and Nonproliferation.

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract DEAC52-07NA27344.



**Disclaimer**

This document was prepared as an account of work sponsored by an agency of the United States government. Neither the United States government nor Lawrence Livermore National Security, LLC, nor any of their employees makes any warranty, expressed or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States government or Lawrence Livermore National Security, LLC. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States government or Lawrence Livermore National Security, LLC, and shall not be used for advertising or product endorsement purposes.