# Uranium gamma data needs for microcalorimetry at the IAEA NML


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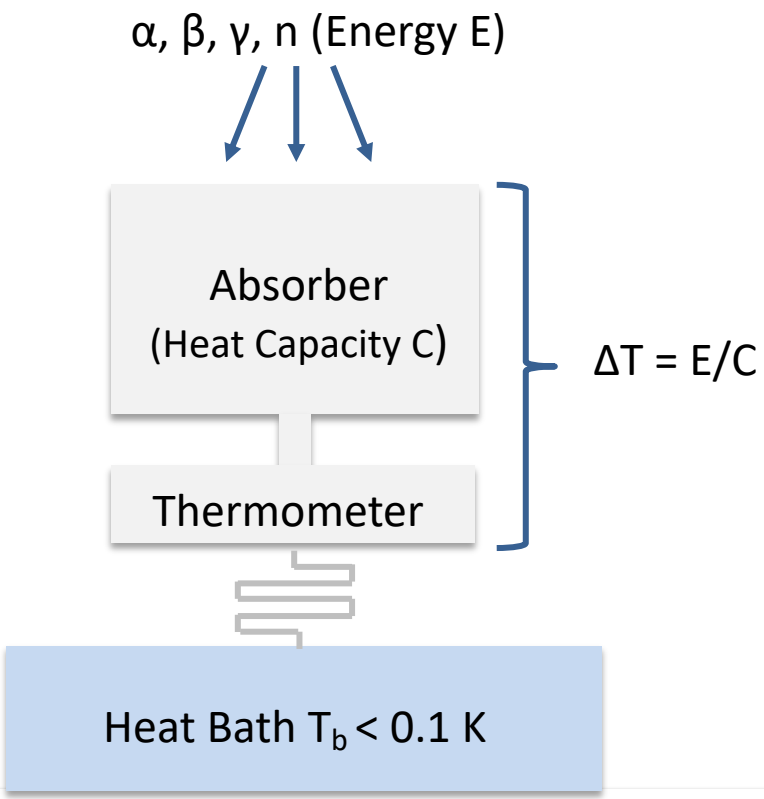
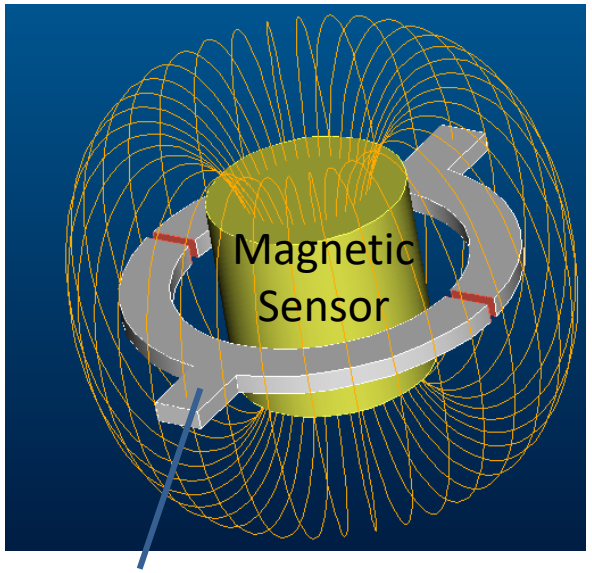
# Microcalorimeters

**Micro-calorimeters:**

- **Measure micro-heat produced by radiation absorption using quantum sensors**
- **Excellent energy resolution of O(10 eV) for ~100 keV gamma-rays**
- **Mature, and accelerator or user facility deployable**

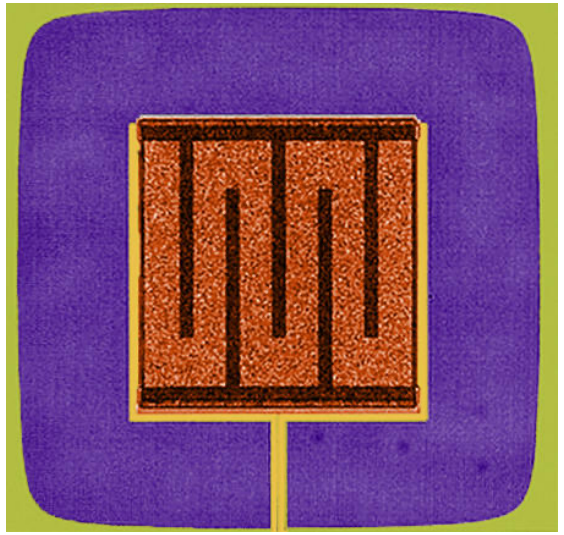



Magnetic Micro-Calorimeter (MMC)



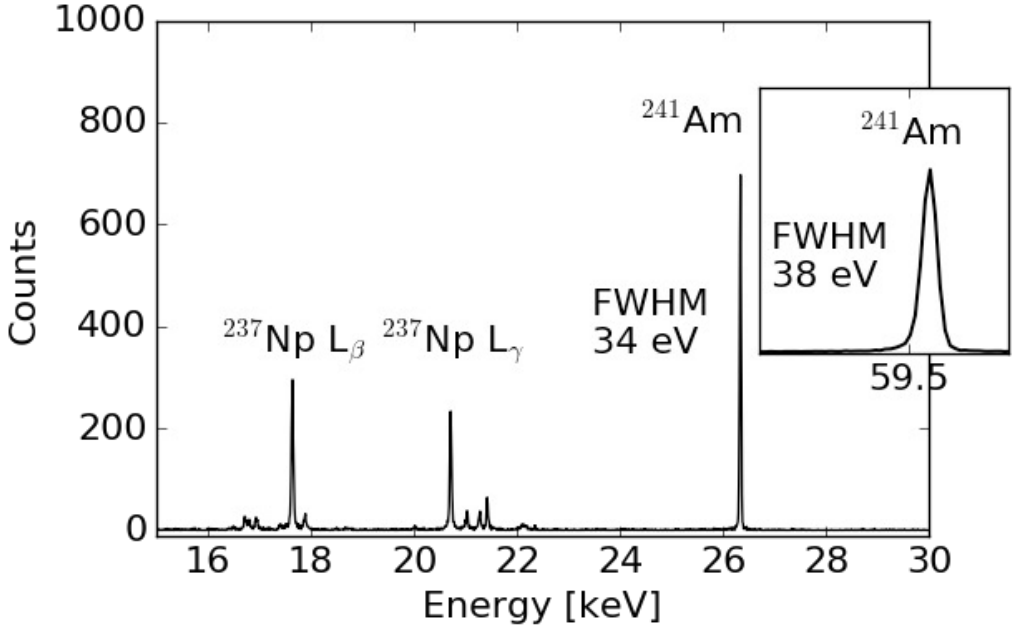

Quantum Magnetometer

Transition Edge Sensor (TES)

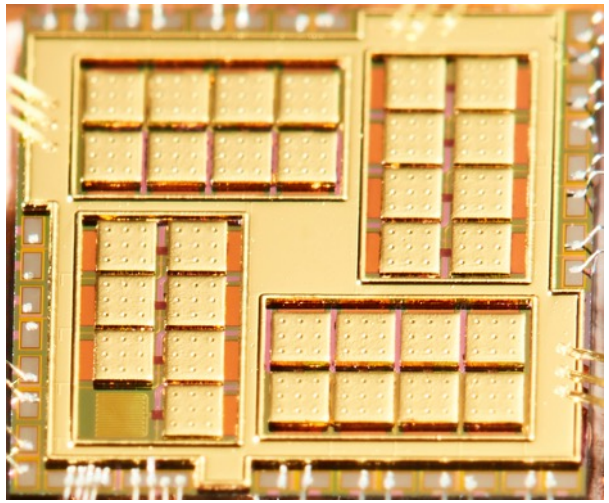


# Microcalorimeter Applications (related to nuclear data)

**X-ray and γ Spectroscopy (Today's talk)**



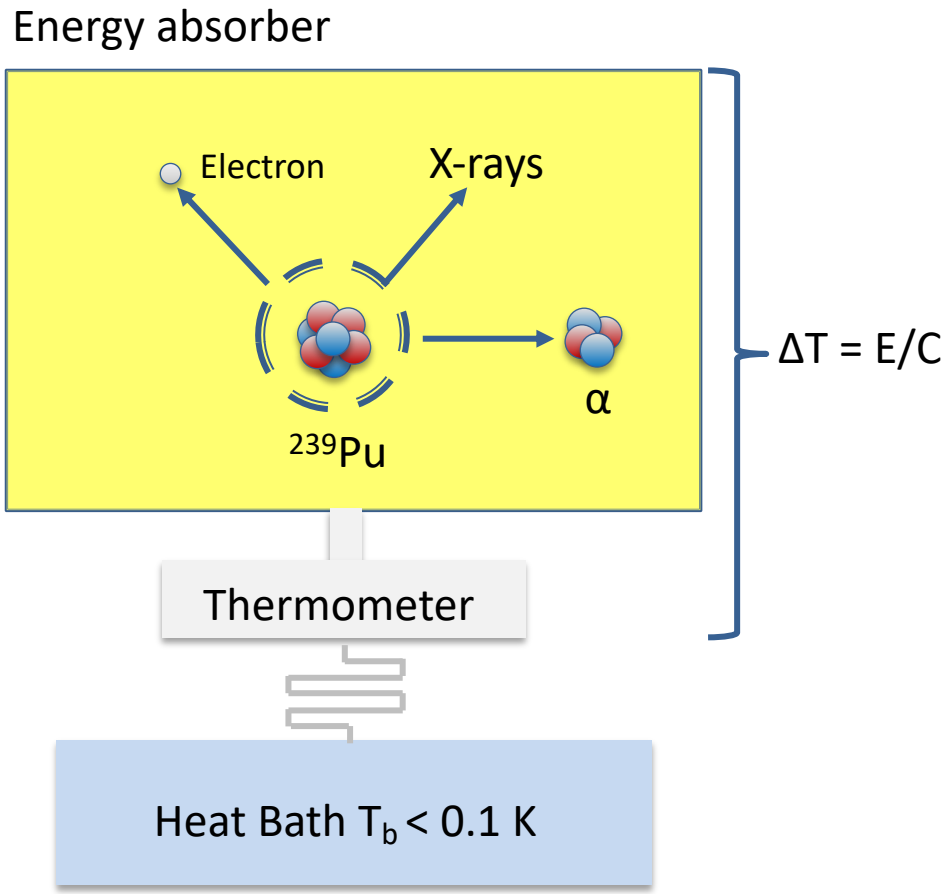

- Quantification of radionuclides
- High Energy Resolution (x10 better than HPGe)
- Operation range: 1 keV – 300 keV
- TRL 7-9



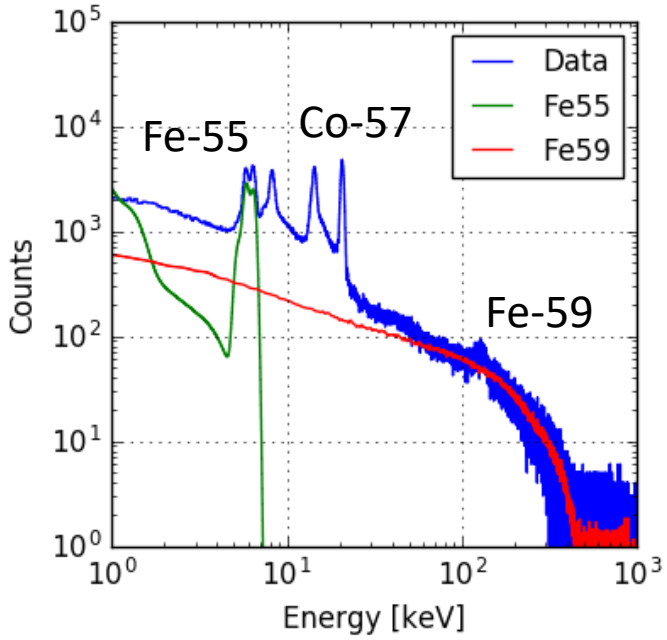
S.T.P. Boyd, JLTP 199:681 (2020)

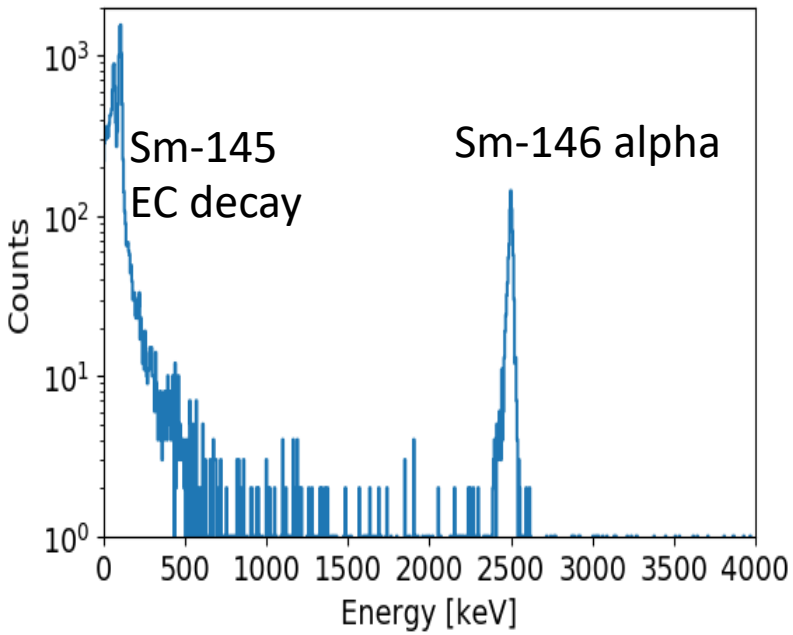
- 16-pixel gamma microcalorimeter array

# Microcalorimeter Applications (related to nuclear data)




**Decay Energy Spectroscopy (Source-embedded 4π detection)**

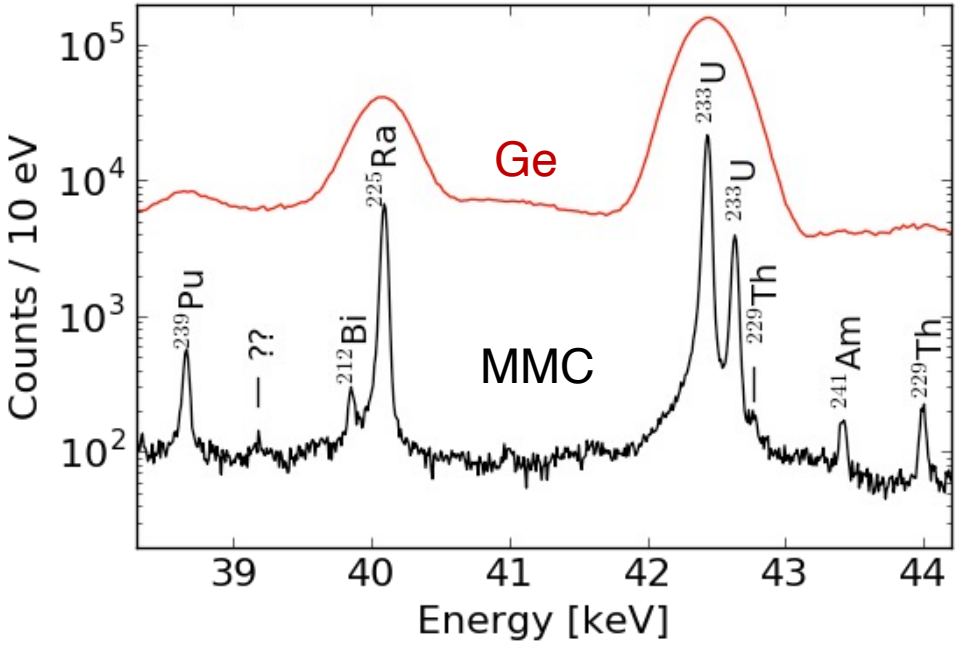


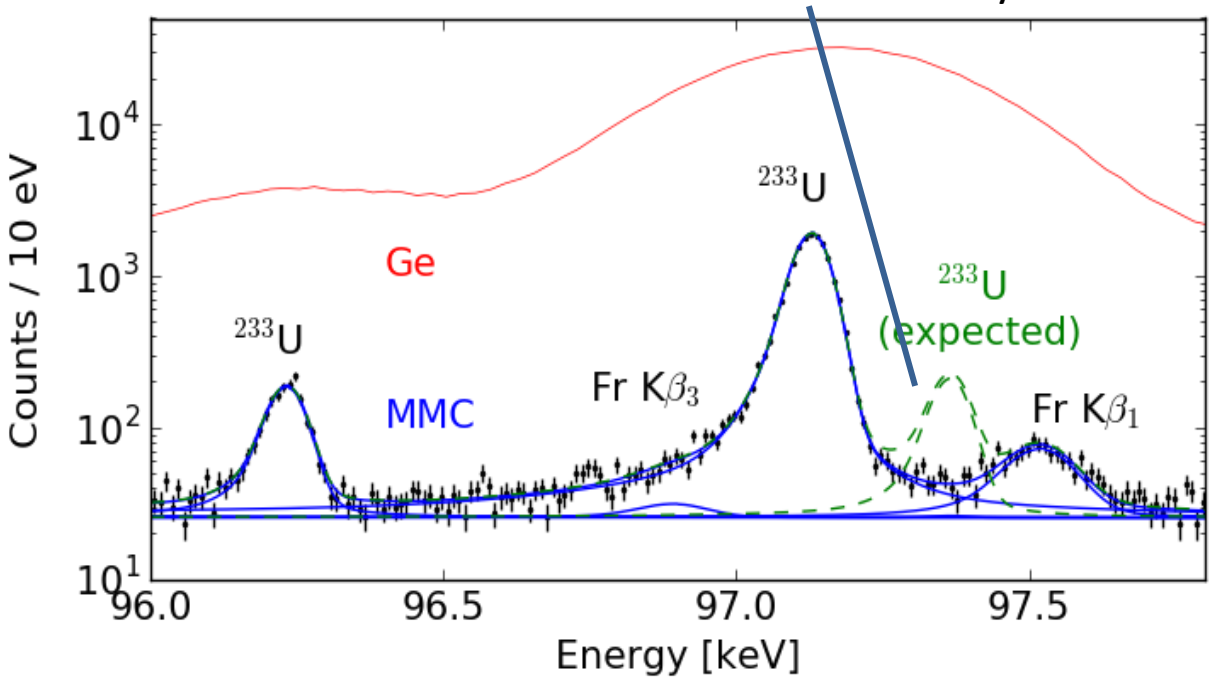

- For β spectroscopy or absolute decay counting
- Radionuclide quantification with 100% detection efficiency
- Fission Total Kinetic Energy measurement
- Half-life measurements for nuclear dating and chronology
- TRL 3-6

# Gamma Microcalorimeter Performance

High precision γ-spectroscopy of U-233




Found an error in decay data




**$\Delta E_{FWHM}$ = 38 eV @ 60 keV (x 10 better than planar HPGe)**

# Microcalorimeters at the IAEA Nuclear Material Laboratory

https://discover.lanl.gov/news/0331-sofia/
Source: D. Calma/IAEA

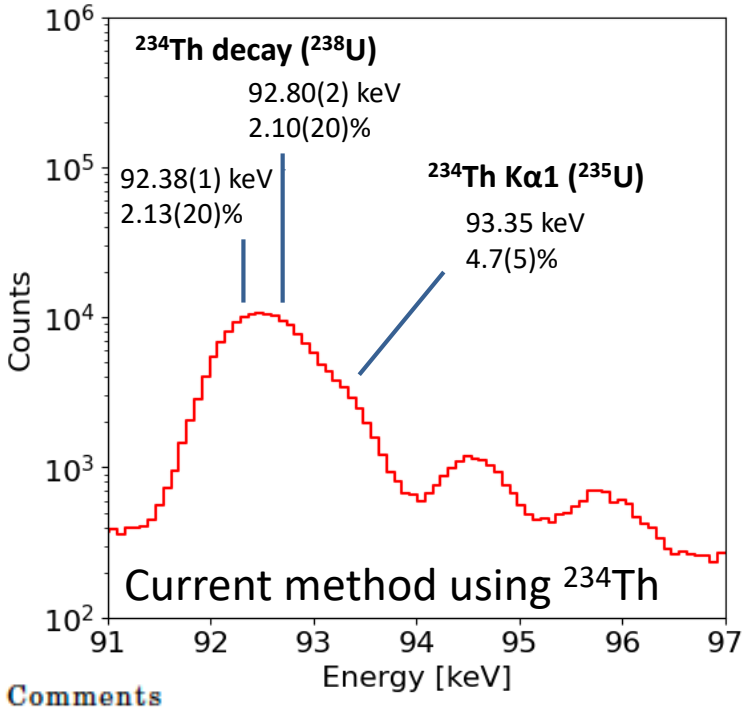
**SOFIA Gamma Spectrometer**
(NIST/LANL)


Planned deployment of Microcal. Systems at IAEA NML in 2025

**New capabilities and needs of nuclear data by deployment of microcalorimeters**

# Uranium Enrichment Measurement at the IAEA NML

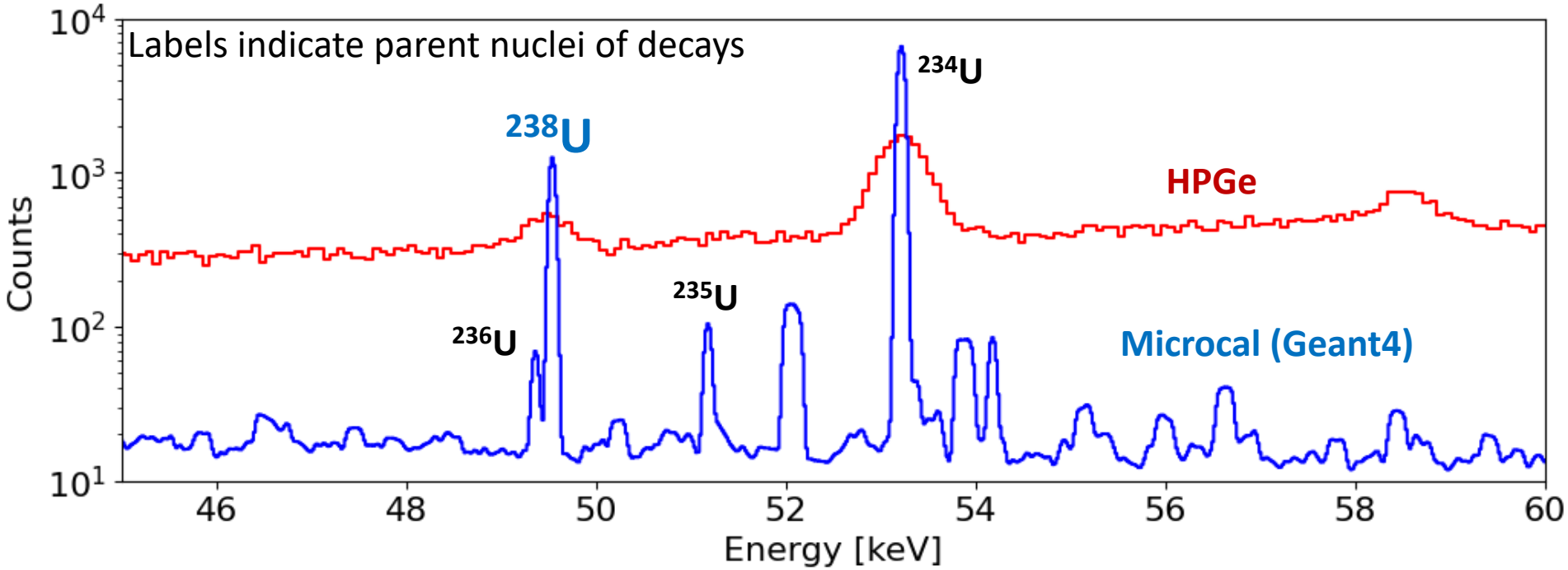
- Measure $^{235}U$ Enrichment level by $^{235}U/^{238}U$ ratio (one of the most important measurements)
- Currently there is no method for direct measurement of $^{238}U$
- Daughters are used instead, however this does not work for samples at non-equilibrium.




γ($^{234}$Th)

| Eγ | E(level) | Iγ†‡ | Mult. | α | Comments |
|---|---|---|---|---|---|
| 49.55 *6* | 49.55 | 0.064 *8* | E2 | 326.4 | Eγ: from 1973Ta25 (semi). Other: 1956Al30 ((α)(ce)).<br>Iγ=0.059% *2* was measured by 1990Ko40.<br>Total I(ce)=23 *3* per 100 α decays (1952Du12,1952Za01,1956Al30).<br>Mult.: α=359 *65* from Ice/Iγ and the measured half–life of 0.37 ns *3* for the 49.55–keV level rule out other multipolarities. |
| 113.5 *1* | 163.0 | 0.0102 *15* | [E2] | 6.63 | Eγ: from 1984Ro21. |

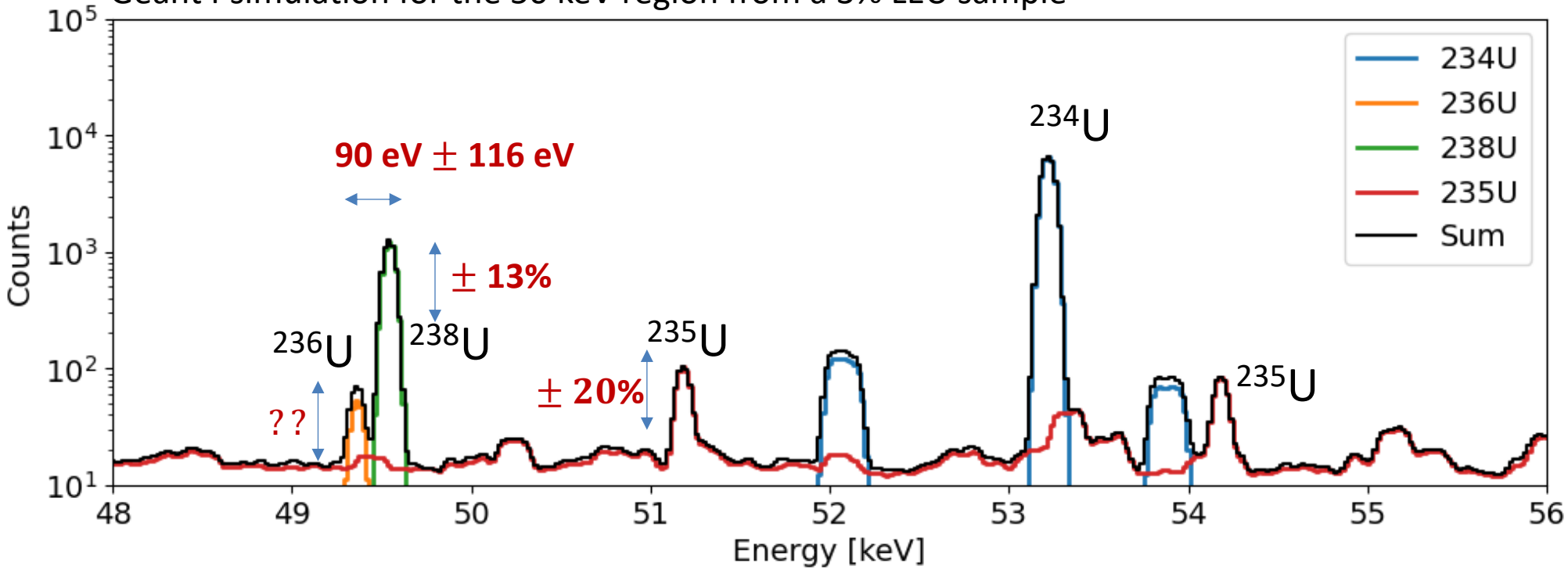
# New Capability with Microcalorimeters – Direct $^{238}$U Measurement




- Gamma-rays from U decays are populated in the 50 keV region, where can be precisely measured by microcal.
- 50 keV region will provide direct U enrichment analysis as well as minor U isotope compositions.

# Uranium Gamma Data Needs Improvement

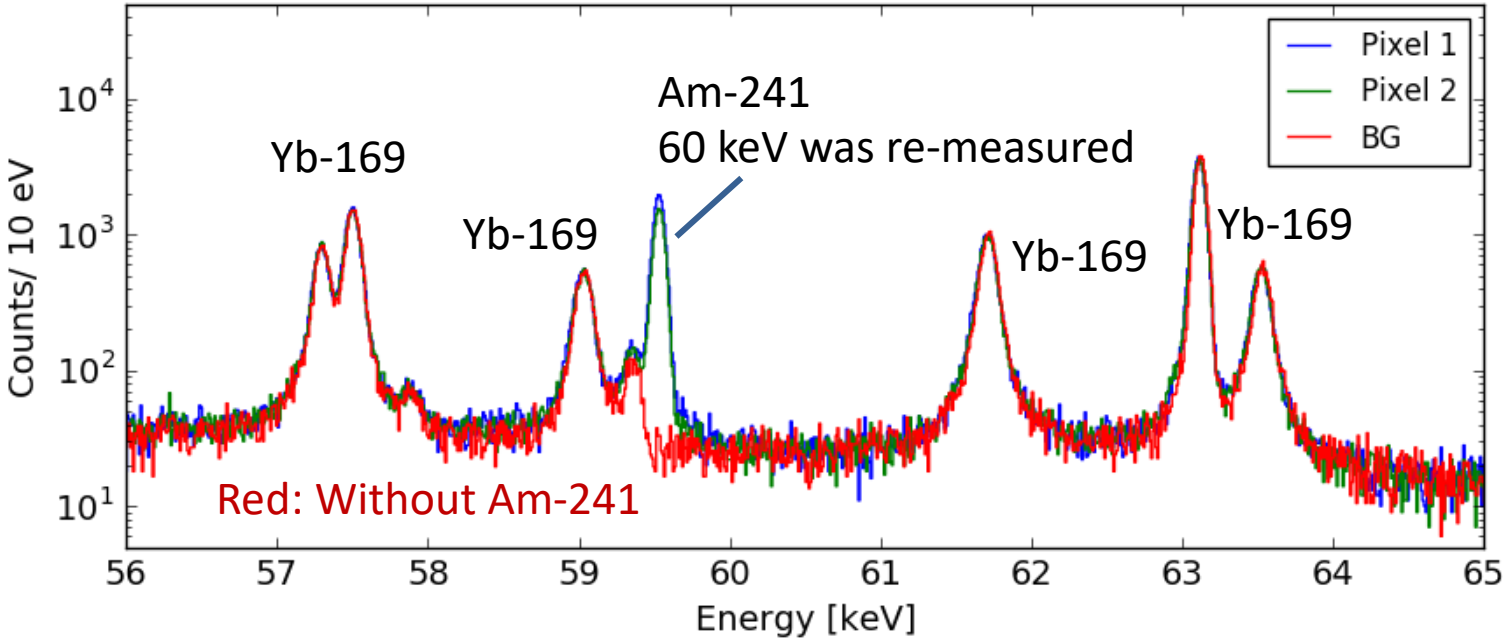
Geant4 simulation for the 50 keV region from a 3% LEU sample

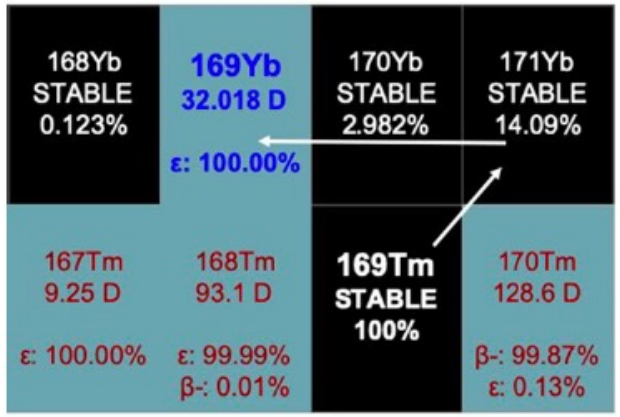



- 50 keV from $^{238}$U can be used for direct measurement of U enrichment.
- $^{236}$U interference need to be understood.
- Simple measurement series can significantly improve this decay data

# Gamma Data Improvement with Yb-169 Calibration Source

**Yb-169 is the most accurate** calibration source for low energy gamma.




$^{169}Tm(d,2n)^{169}Yb$

Yb-169 was produced at the LBNL 88” Cyclotron
Journal of Low Temperature Physics (2020) 199:1055–1061

# Summary: Microcalorimeter and Nuclear Data

1) Nuclear Data needs for Microcalorimeter Operations (IAEA NML, very high impact)
   - U/Pu Decay Gamma Intensities & Energies. **Significant impacts** to international nuclear safeguards.
   - U/Pu Half-lives (also needed for chronology)
   - $^{235}$U Alpha Branching Ratios

2) Microcalorimeter for Nuclear Data Improvements
   - Decay data (half-life, αβγ energies and BRs)
   - Fission yield
   - Reaction cross-section

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# Gamma Data Needs for Microcal at the IAEA NML

$^{235}U \rightarrow {}^{231}Th \rightarrow {}^{231}Pa$

| Energy [keV] | Intensity [%] |
|---|---|
| 51.21(5) | 0.034(7) |
| 54.25(5) | 0.015(15) |
| $^{231}Th$ | |
| 53.2(8) | 0.48(?) |

$^{238}U \rightarrow {}^{234}Th \rightarrow {}^{234}Pa \rightarrow 234U$

| Energy [keV] | Intensity [%] |
|---|---|
| 49.55(6) | 0.064(8) |
| 113.5(1) | 0.0102(15) |
| $^{234}Th$ | |
| 92.38(1) | 2.13(20) |
| 92.80(2) | 2.10(20) |

$^{232}U$

| Energy [keV] | Intensity [%] |
|---|---|
| 57.78(5) | 0.1999(18) |

$^{234}U$

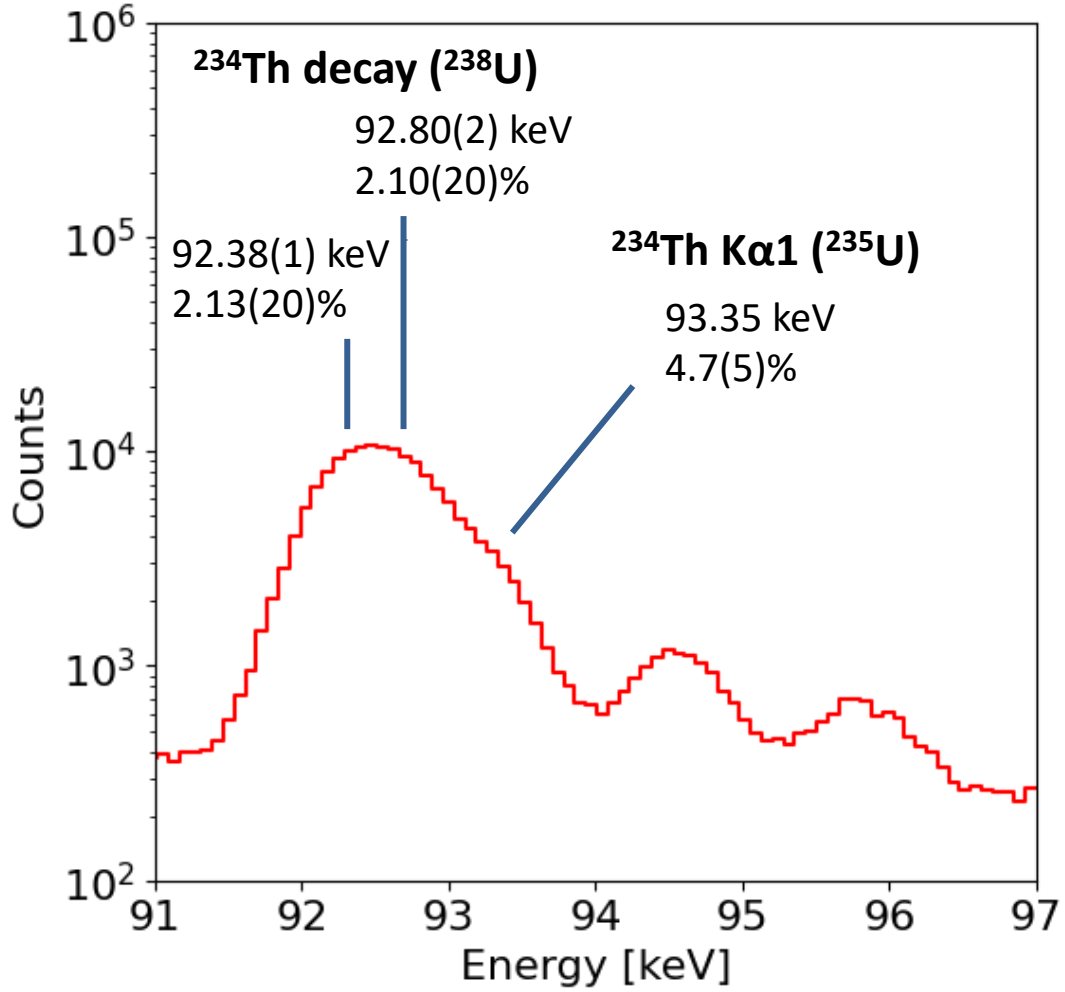
| Energy [keV] | Intensity [%] |
|---|---|
| 53.20(2) | 0.1230(20) |

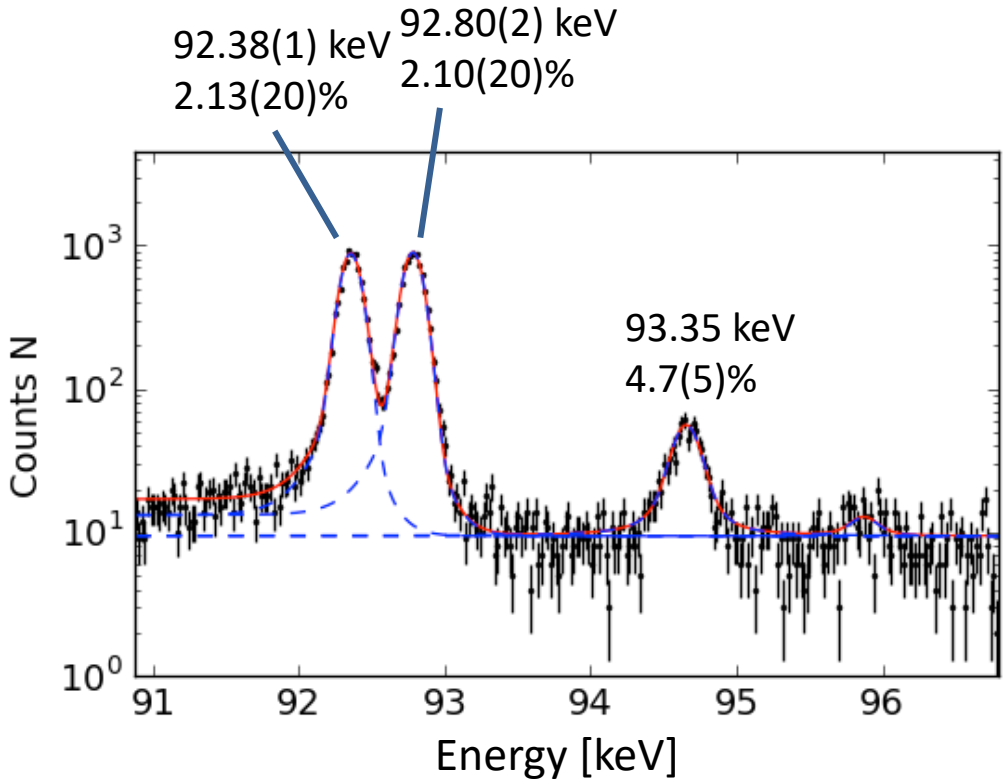
$^{236}U$

| Energy [keV] | Intensity [%] |
|---|---|
| 49.46(10) | 0.078(?) |

- Huge uncertainties on intensity (10% - 100%)

# Microcalorimeters for 92 keV Region




**U Enrichment measurements will be limited by gamma intensity data (~10% uncertainty)**