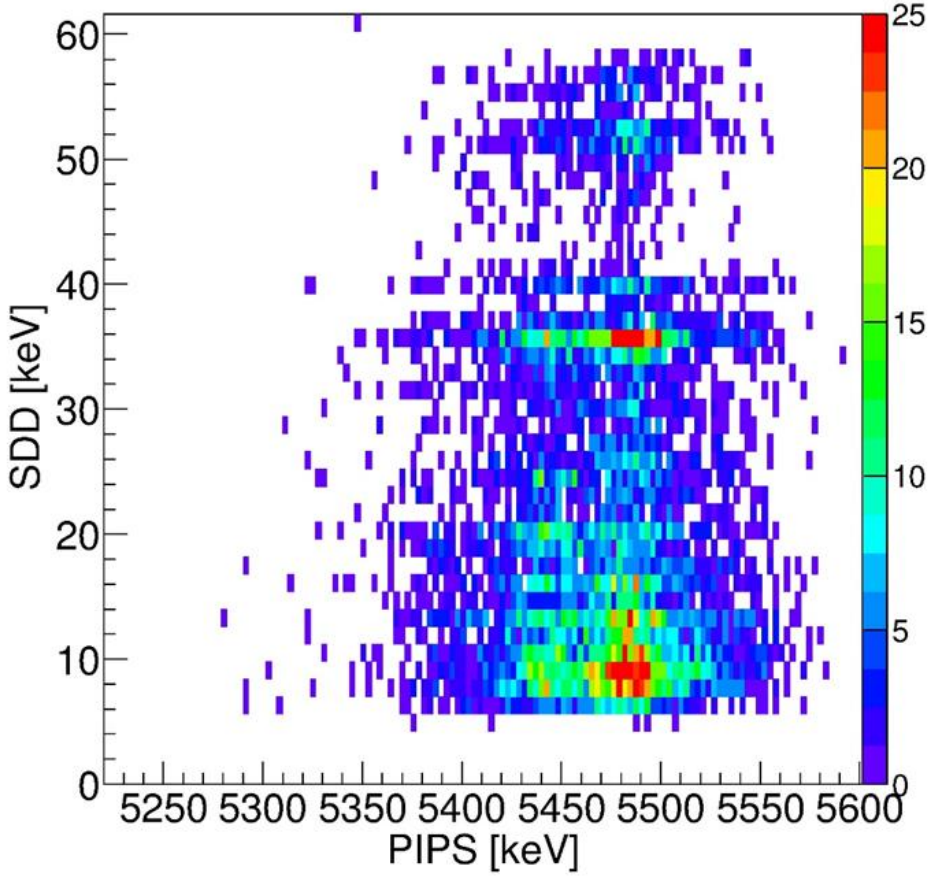
Applied Analysis Techniques and Detector Development



Michael Dion, PhD

March 16, 2023
Joint DOE/NIH Workshop - Advancing Medical Care Through Discovery in the Physics Sciences 2023

Jefferson Lab

U.S. DEPARTMENT OF ENERGY | Office of Science

JSA

Preface

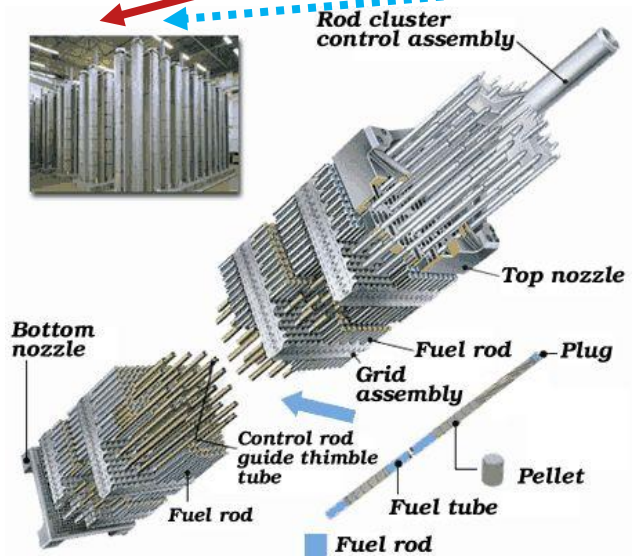
- A nuclear nonproliferation primer

- Challenge 1: Unresolvable Observables
  - Coincident detection of alpha-conversion electron coincidences

- Challenge 2: Difficult Measurement Conditions
  - High rates (~ 1 MHz)
  - High Rates and Elevated Temperatures
    - SBIR effort for neutron/gamma scintillator development

Primer in Nuclear Nonproliferation

- Apply radiation detection methods to identify weapons of mass destruction and terrorist activities, and in support of international treaties and agreements.
- Monitoring points in the nuclear fuel cycle, tracking and interdicting material, forensics, etc.



Challenges w/ Sample Triage and Overlapping Signatures

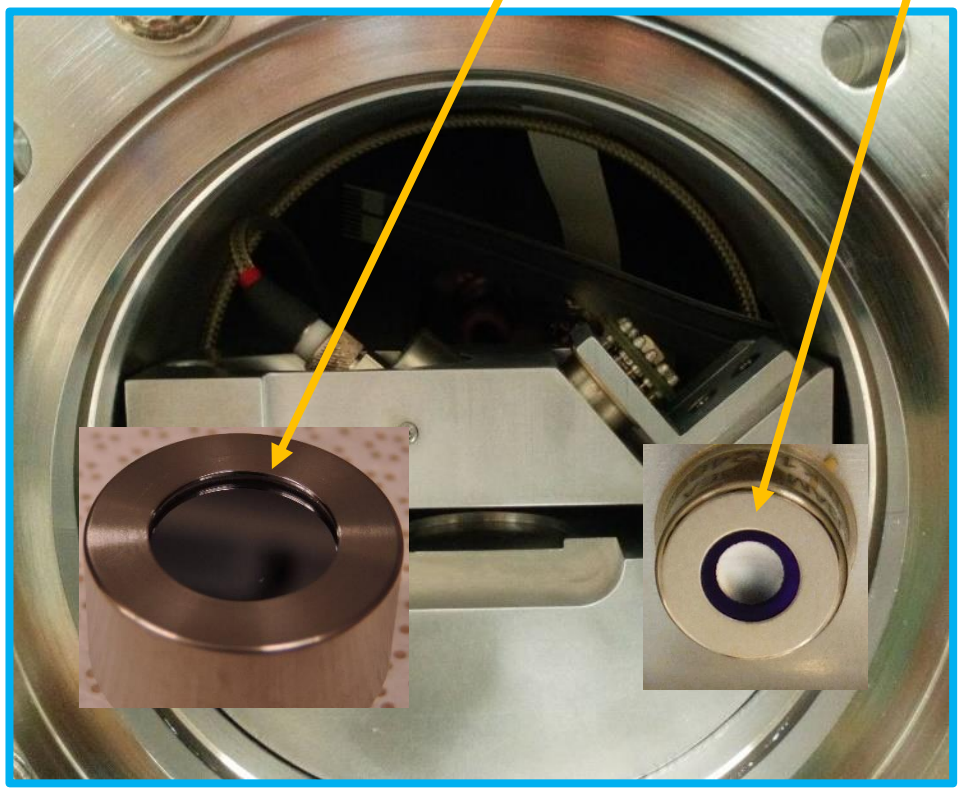
- Actinide radionuclides have high conversion electron emission[1] (2-30% coincidence)
  - BUT their alpha emission energy overlaps

Isotope	α [keV]	Intensity [%]
^{238}Pu	5499.0	71
^{241}Am	5485.6	85
^{239}Pu	5156.6	71
^{240}Pu	5168.2	73

[1]Warren, Dion, Miller, and Tatishvili, J Radioanal Nucl Chem (2015) 303:2113–2125 DOI 10.1007/s10967-014-3780-z

Challenges w/ Sample Triage and Overlapping Signatures

- Actinide radionuclides have high conversion electron emission[1] (2-30% coincidence)
  - BUT their alpha emission energy overlaps
- Detection system w/ COTS detectors
  - α detection w/ PIPS and γ/e- w/ SDD



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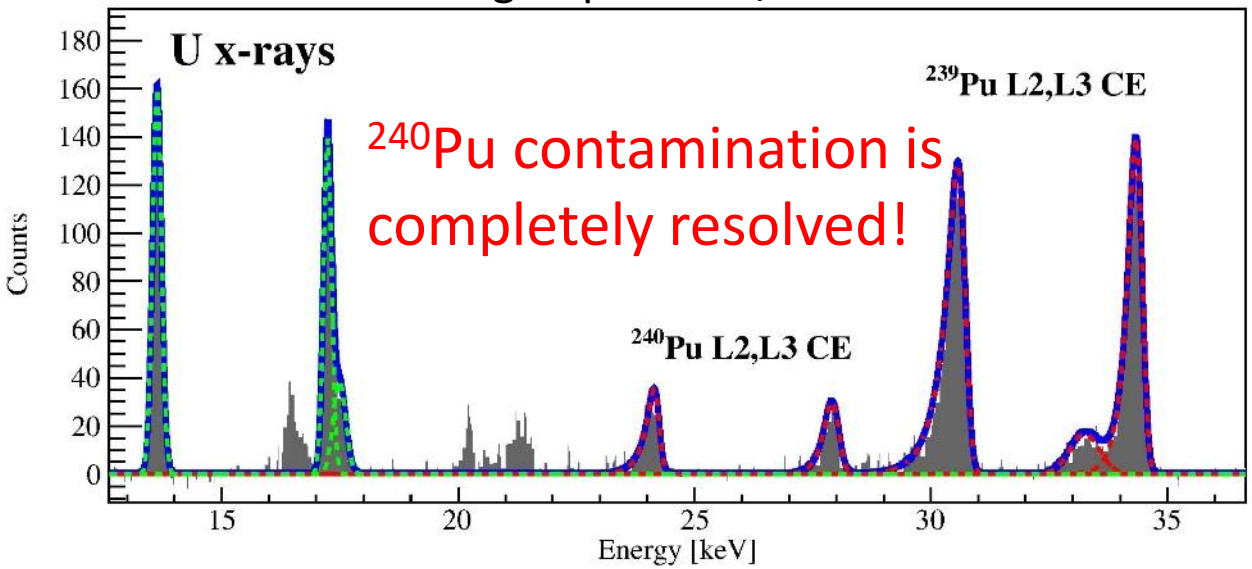
Single spectra w/ SDD



PIPS - Passivated Implanted Planar Silicon, SDD – Silicon Drift Detector

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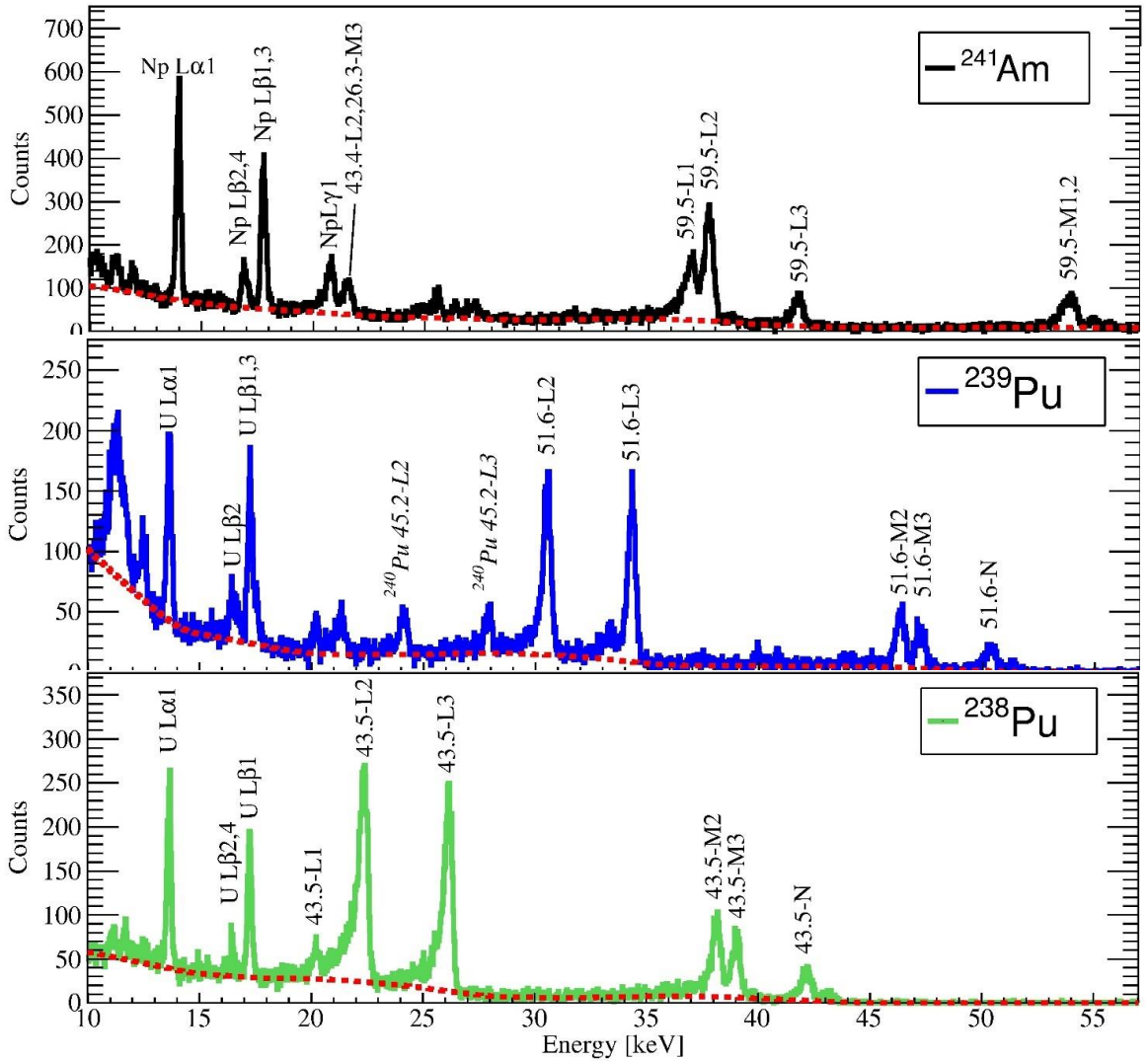
Internal Conversion Coefficient (ICC) Measurements

Measure emission subshell ratios[2]



Shell	Energy [keV]	Subshell Ratio	Exp. this work
^{241}Am			
59.5-L1	37.118 ± 0.009	L1/$\sum$ all	0.284 ± 0.012
59.5-L2	37.892 ± 0.010	L2/$\sum$ all	0.436 ± 0.013
59.5-L3	41.886 ± 0.011	L3/$\sum$ all	0.114 ± 0.004
59.5-M1,2	54.064 ± 0.018	M1,2/$\sum$ all	0.0287 ± 0.0047
^{239}Pu			
38.7-L2	17.490 ± 0.029	L2/L3	1.30 ± 0.01
38.7-L3	21.520 ± 0.012	–	–
51.6-L2	30.700 ± 0.006	L2/$\sum$ all	0.407 ± 0.010
51.6-L3	34.437 ± 0.009	L3/$\sum$ all	0.333 ± 0.009
51.6-M2	46.426 ± 0.017	M2/$\sum$ all	0.115 ± 0.006
51.6-M3	47.643 ± 0.037	M3/$\sum$ all	0.0873 ± 0.0051
51.6-Ntot	50.460 ± 0.027	Ntot/$\sum$ all	0.0544 ± 0.0032
^{238}Pu			
43.5-L1	20.282 ± 0.032	L1/L2	0.0739 ± 0.0057
43.5-L2	22.549 ± 0.004	L1/L3	0.0935 ± 0.0058
43.5-L3	26.327 ± 0.004	L2/L3	1.27 ± 0.03
43.5-M2	38.354 ± 0.010	M2/M3	1.37 ± 0.07
43.5-M3	39.167 ± 0.016	M3/$\sum$ all	0.0871 ± 0.0035
43.5-Ntot	42.266 ± 0.020	Ntot/$\sum$ all	0.0458 ± 0.0018

[1]Dion, et al., NIMA (2016) 830:6-12 DOI https://doi.org/10.1016/j.nima.2016.05.041

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Internal Conversion Coefficient (ICC) Measurements

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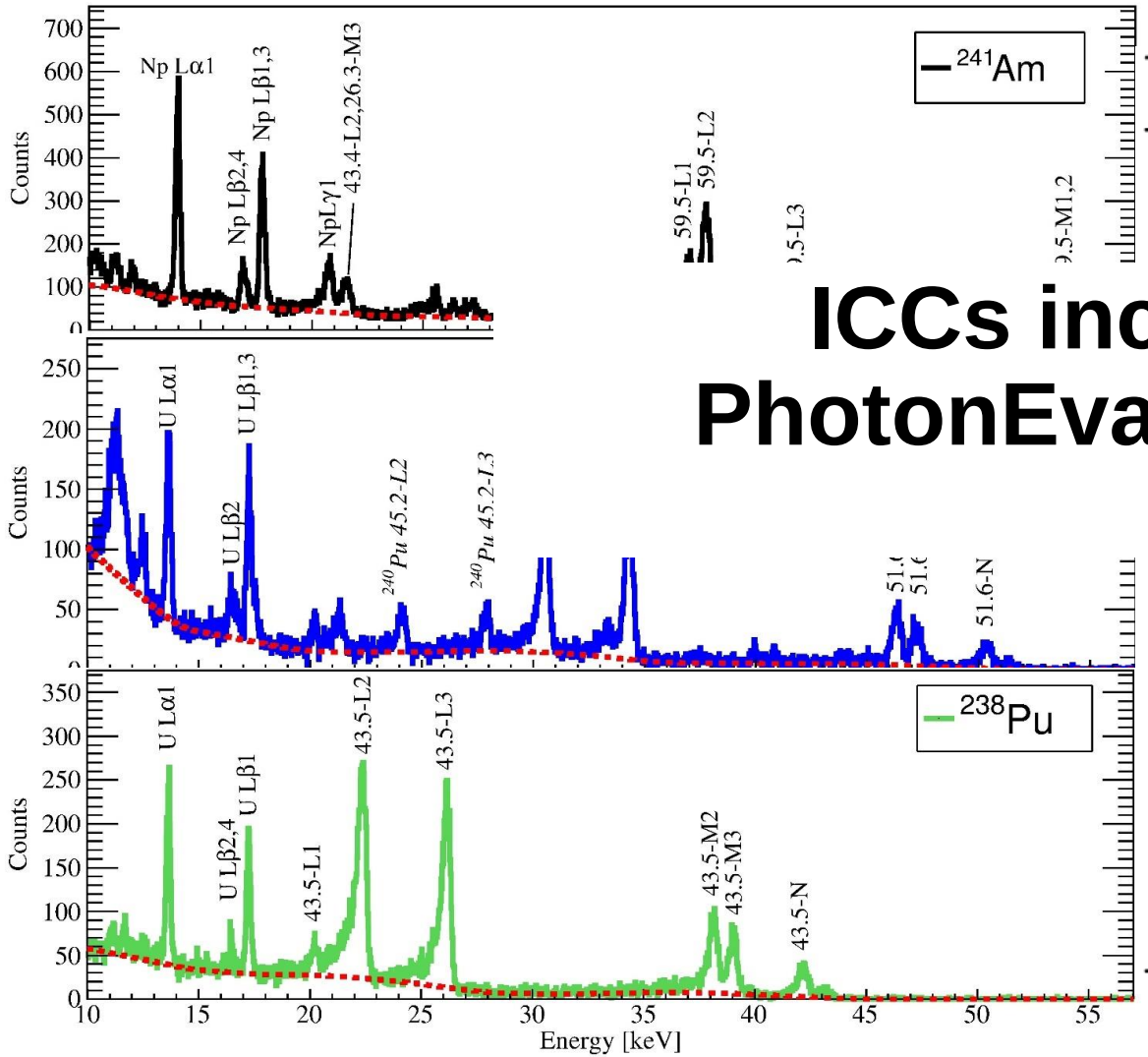

ICCs included in the G4 PhotonEvaporation database

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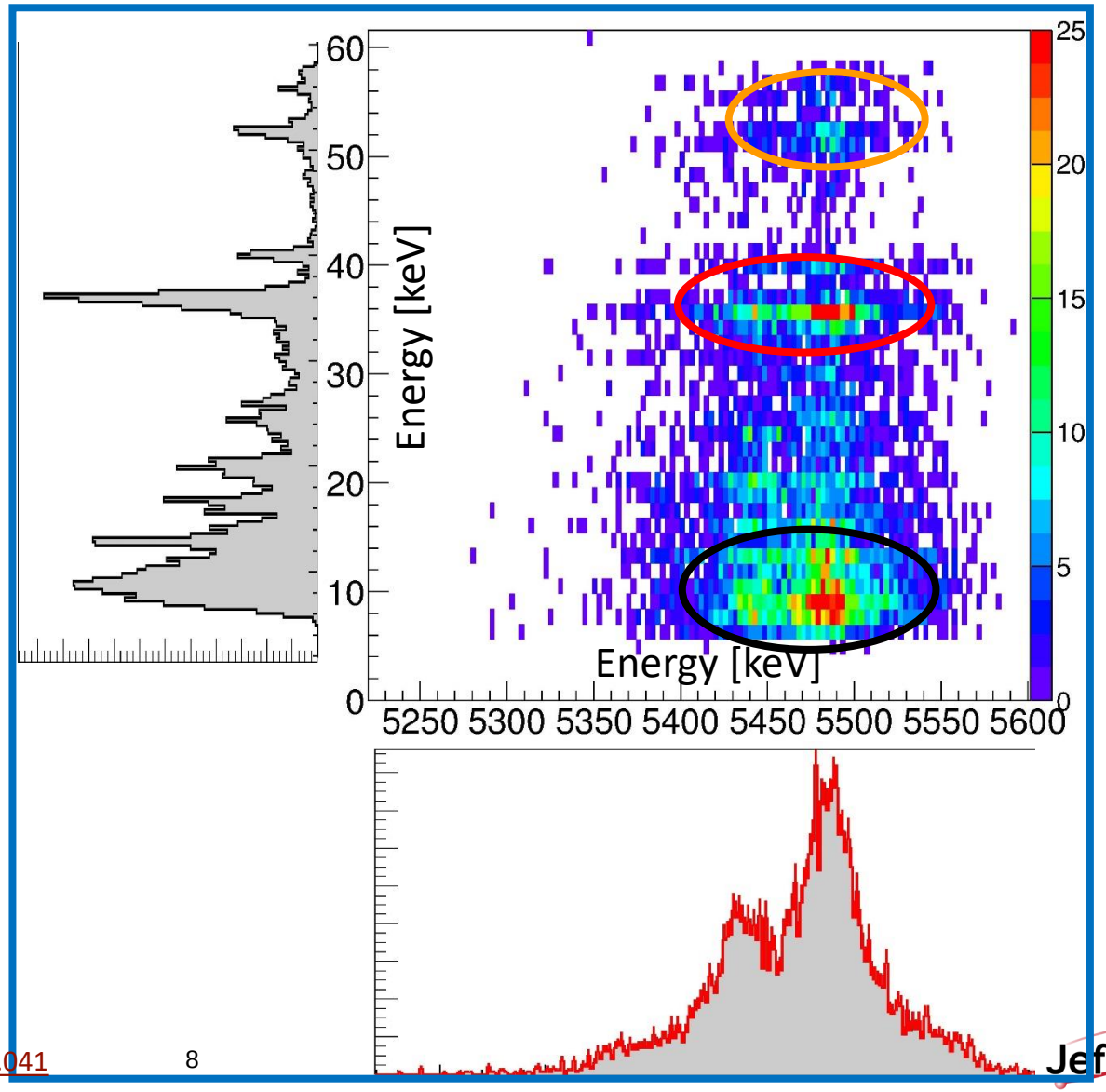
Coincident Measurement Demonstrates the Utility for Actinides

- Singles and coincident data can be used together for signature discrimination
- Provides a method to quantify these actinides in a mixed sample
- Line width exaggerated due to geometry



M shell CE

37 keV 59.5
L1,L2

X-rays &
Auger

Dion, et al., NIMA (2016) 830:6-12 DOI https://doi.org/10.1016/j.nima.2016.05.041

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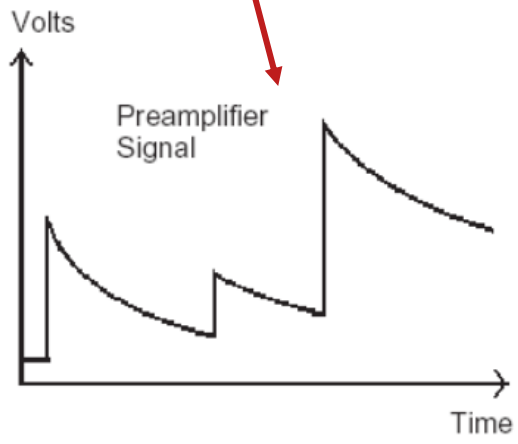
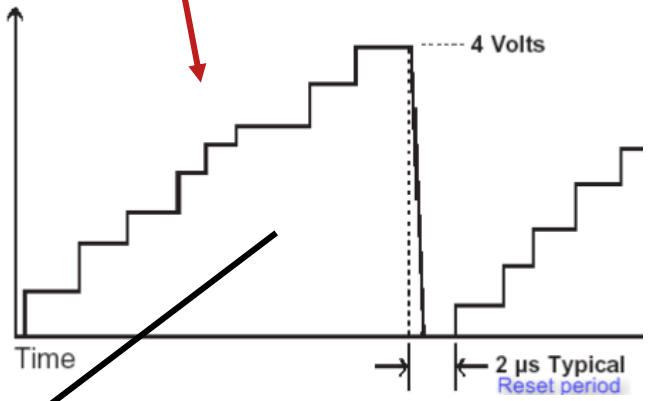
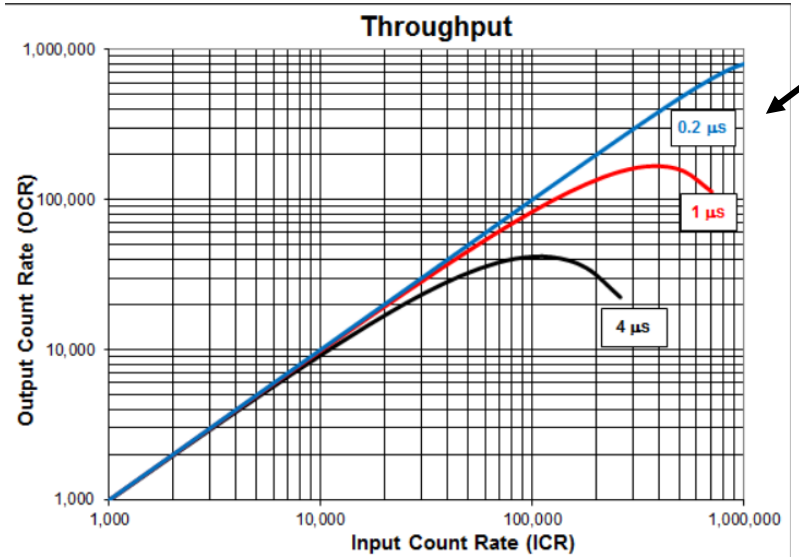
Challenging Environmental Conditions

- **High Rates**: (not exhaustive)
  - Electronics: Preamplifier feedback can be passive (resistor) or active (transistor), digital processing, etc.







https://www.amptek.com/products/x-ray-detectors/fastsdd-x-ray-detectors-for-xrf-eds/fastsdd-silicon-drift-detector

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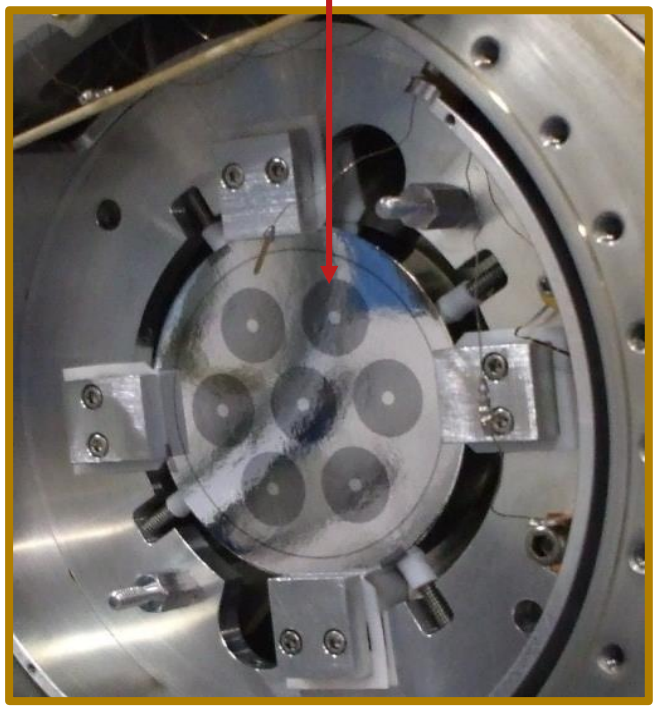
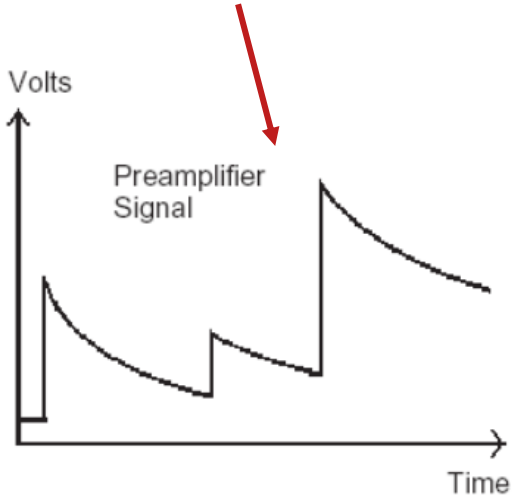
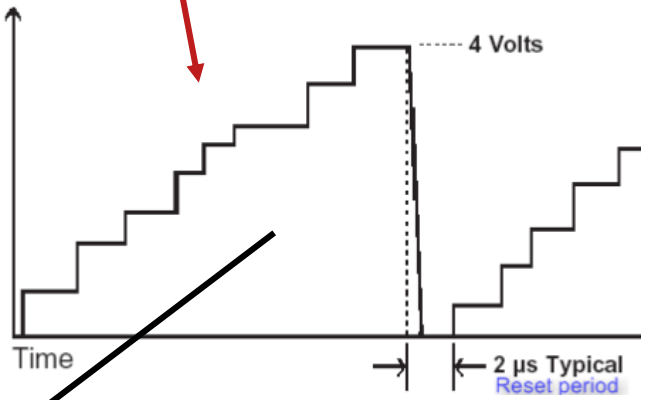
Challenging Environmental Conditions

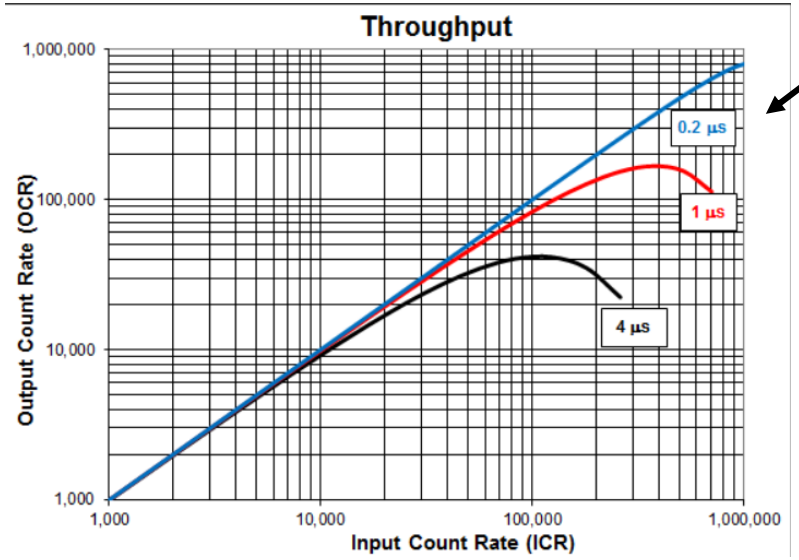
- **High Rates**: (not exhaustive)
  - Electronics: Preamplifier feedback can be passive (resistor) or active (transistor), digital processing, etc.
  - Hardware/Detector Options
    - Segment the detector allowing charge collection to be distributed



70 mm diameter, 10 mm thick







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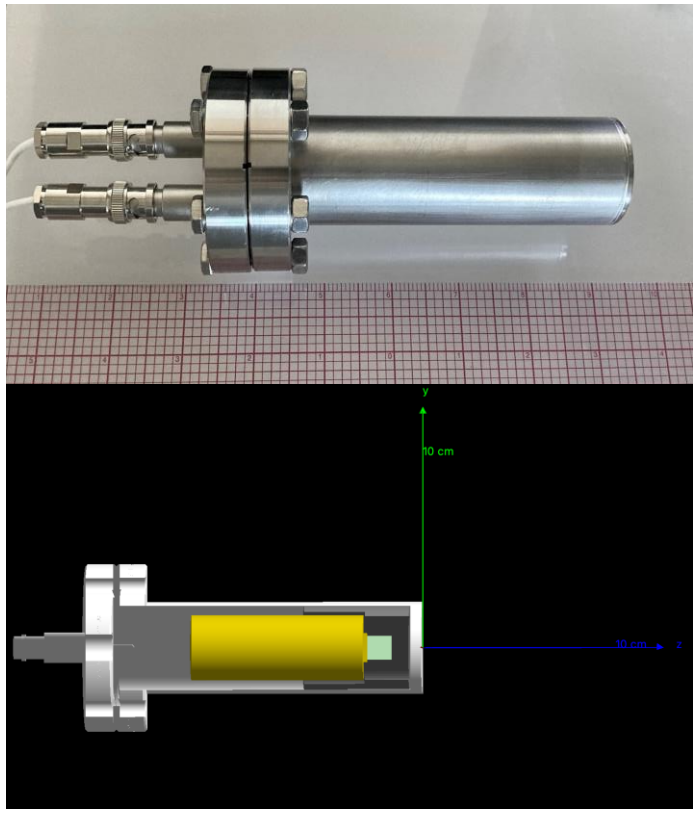
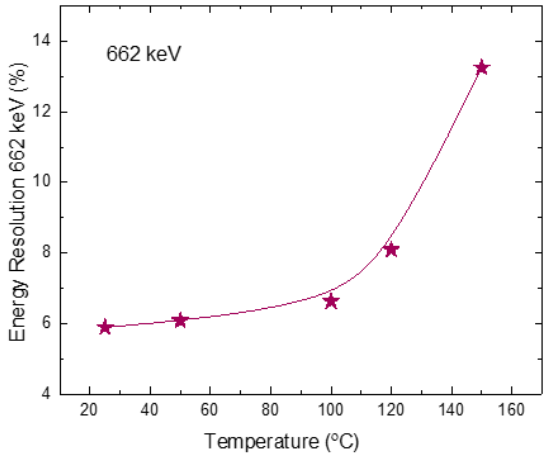
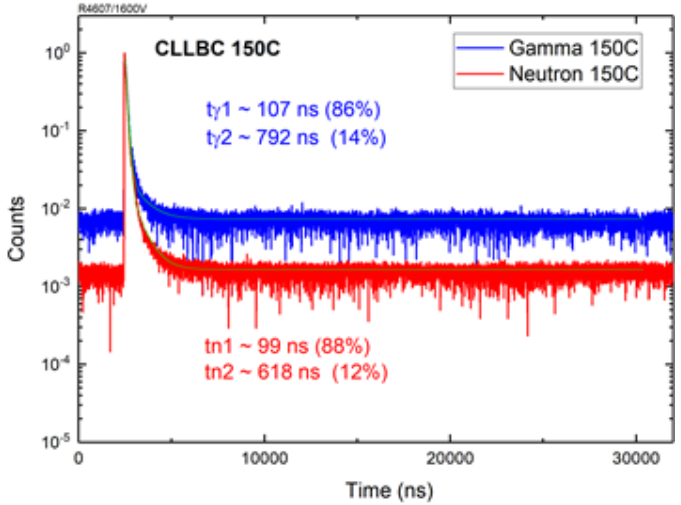
Challenging Environments: Elevated Temperatures + Rates

- SBIR effort with Radiation Monitoring Devices: Scintillator Development $Cs_2LiLa(Br,Cl)_6$ (CLLBC)
  - Pulse shape discrimination allowing neutron/gamma detection
- Measurements for a molten salt reactor = high temperature and highly radioactive

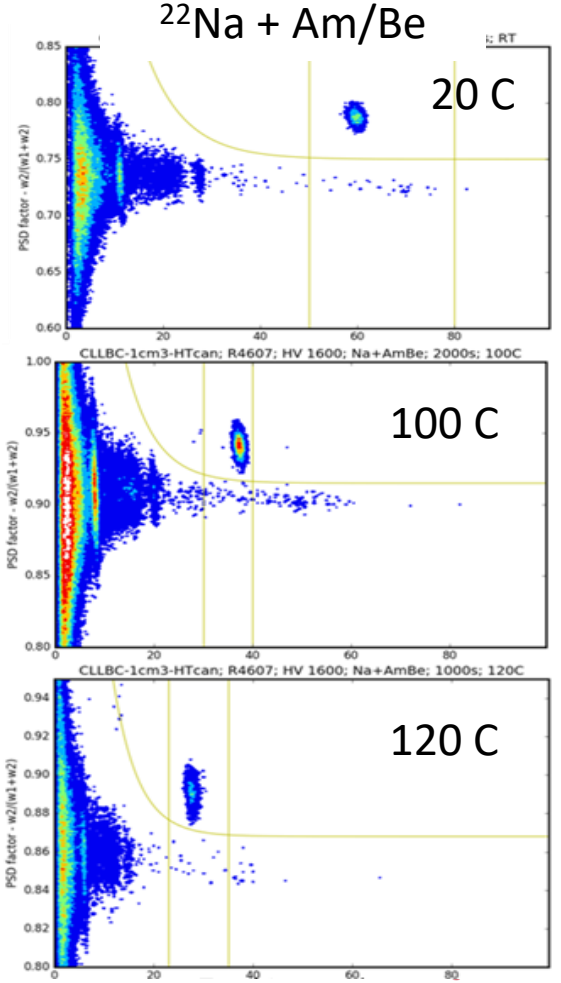
High temperature packaging,
1 cm^3 crystal





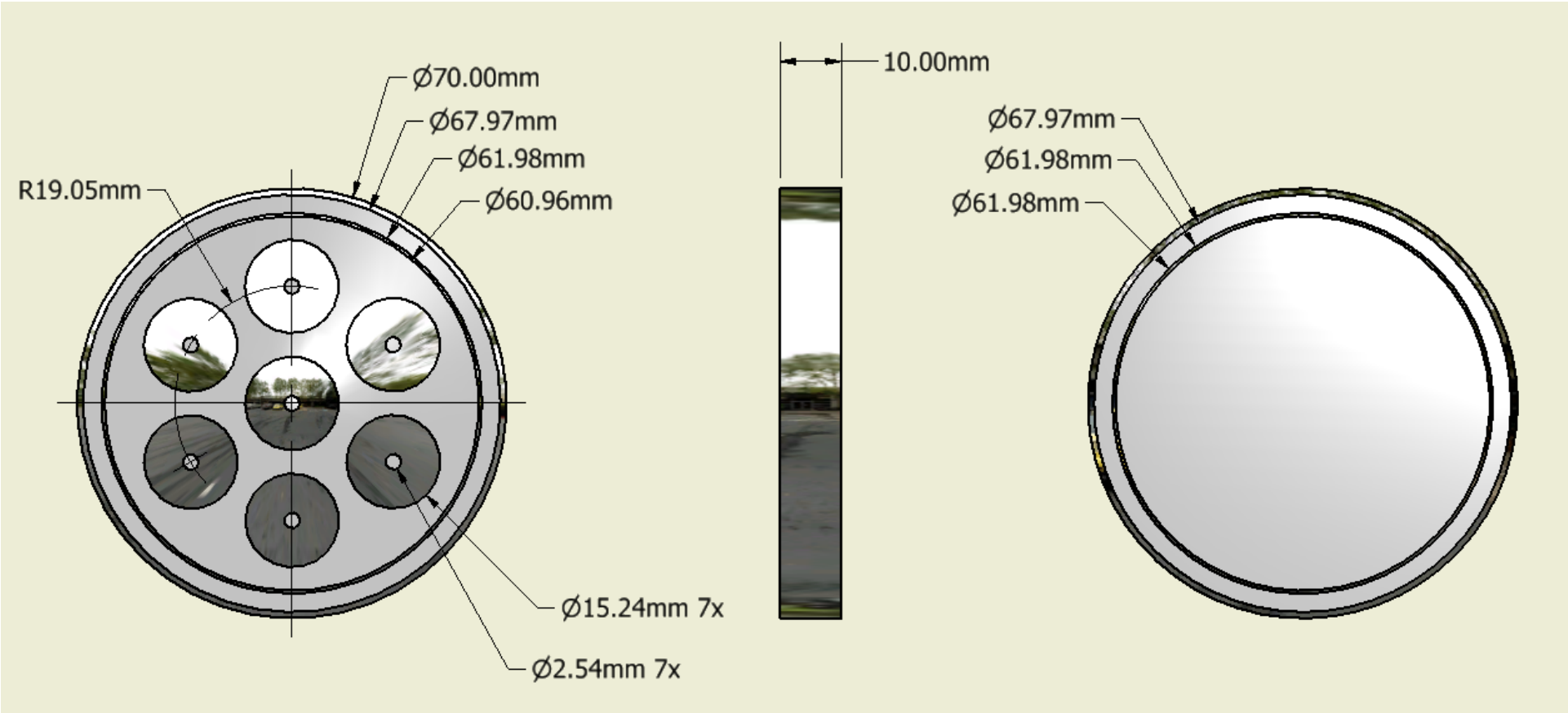


^{22}Na + Am/Be



Thanks For Your Attention

contact: dion@jlab.org


Ø70.00mm
Ø67.97mm
Ø61.98mm
Ø60.96mm
R19.05mm
Ø15.24mm 7x
Ø2.54mm 7x
10.00mm
Ø67.97mm
Ø61.98mm
Ø61.98mm

Passive, High-Rate Measurement Challenges

- Assay of spent fuel for determination of actinide content
  - Extremely radioactive → dead time, loss of spectral resolution, etc.
- Distribute charge collection on independently instrumented point contacts
  - Amorphous Ge contacts and electrically cooled

70 mm diameter, 10 mm thick