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Autonomous Enrichment with GADRAS-DRF for any Gamma Detector

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Objectives

- Create new uranium enrichment / plutonium isotopics algorithm for Safeguards
  - Automated
  - Robust
- Leverage capabilities in SNL's Gamma Detector Response and Analysis Software (GADRAS-DRF)
  - Gamma detector response function
  - Analysis/fitting routines
- Enhance GADRAS-DRF with new algorithm
  - Publicly available
  - Work with any (characterized) detector

Approach

- Multiple analysis methodologies
  - Full-Spectrum Analysis (FSA)
  - Differential Attenuation Analysis (DAA)
  - Hybrid FSA-DAA
  - Relative Efficiency (RE)
- Experience has shown some work better than others in certain regimes
- Can we combine the output from all?

Full-Spectrum Analysis (FSA)

Utilizes all counts in the spectrum, not just photopeaks

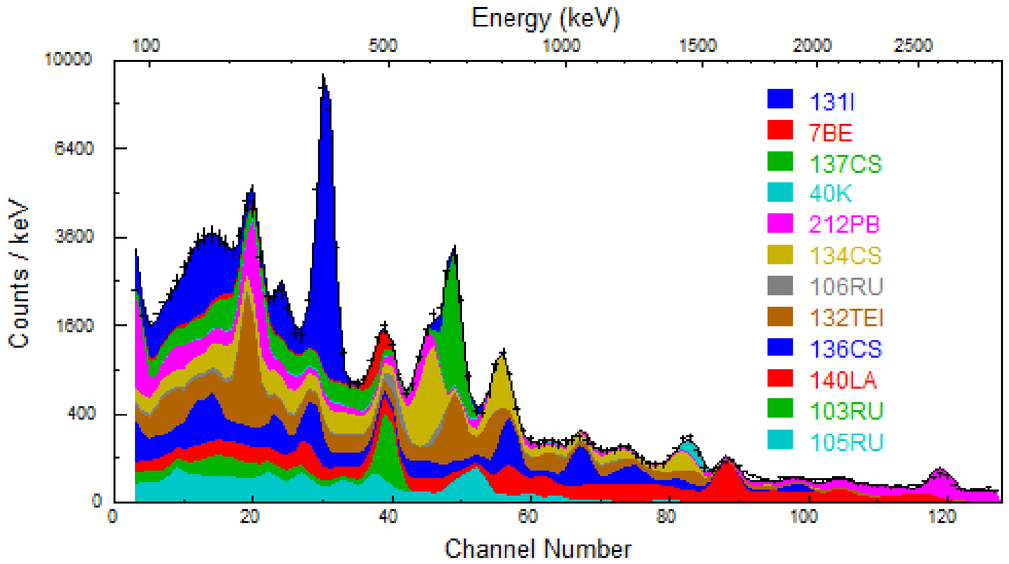
Requires high-fidelity Detector Response Function (DRF)

GADRAS & GADRAS-DRF rely upon characterization to create this high-fidelity model

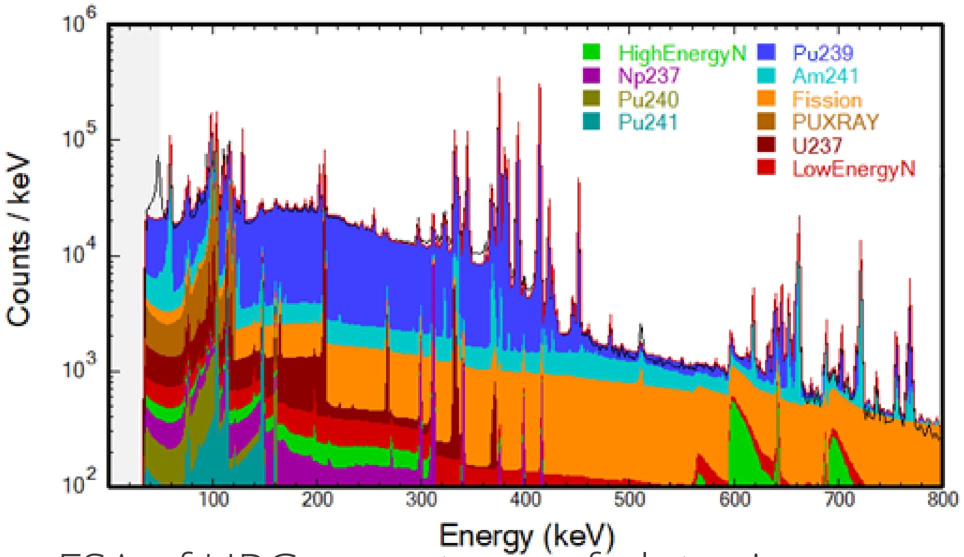
- Measure a few common calibration sources in a lab

Non-linear regression can estimate multiple radionuclides' activity and shielding

FSA will be a new tool for the Safeguards community



FSA of NaI(Tl) spectrum of Chernobyl fallout



FSA of HPGe spectrum of plutonium source

Differential Attenuation Analysis (DAA)

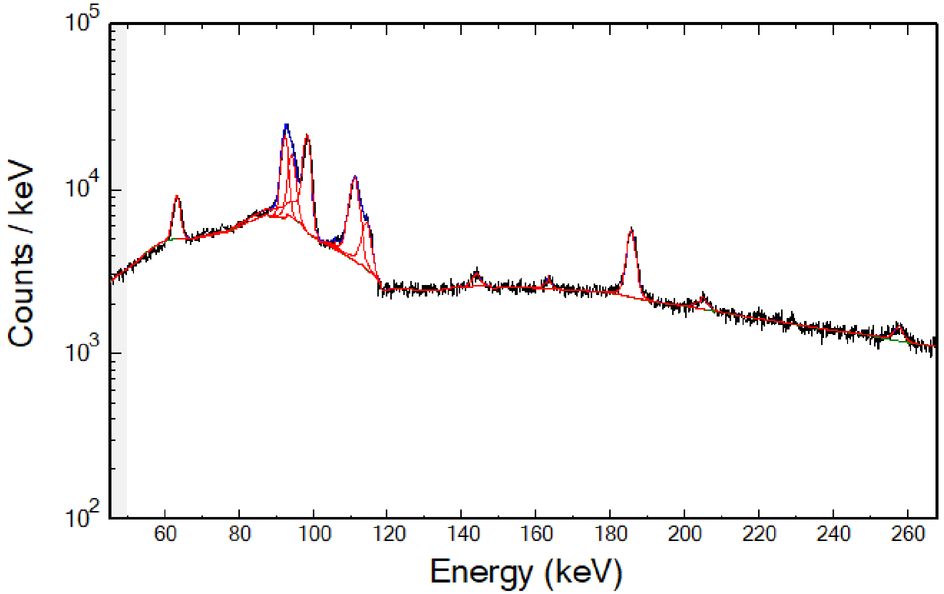
Fit discrete photon rate (leakage or incident)

Requires photopeak efficiency curve, usually created with one or more calibration sources

Similar to FSA, non-linear fitting can estimate activity & shielding

Not as sensitive to response function, simpler, but less robust

Requires advanced peak fitting for detectors with tailing such as CZT



Peak fit of CZT spectrum of 0.31% enriched uranium sample

Hybrid FSA-DAA

Can imagine FSA & DAA as extremes on a spectrum of assumptions

Fit every channel in spectrum
No empirical continuum

Fit subset of channels (ROIs)
Allow some empirical continuum (constrained)

Fit discrete leakage
Entirely empirical continuum

Channel subset

- Grows to full spectrum ⇒ FSA
- Shrinks to peaks ⇒ DAA

Empirical continuum

- Tightly constrained to zero ⇒ FSA
- Unconstrained ⇒ DAA

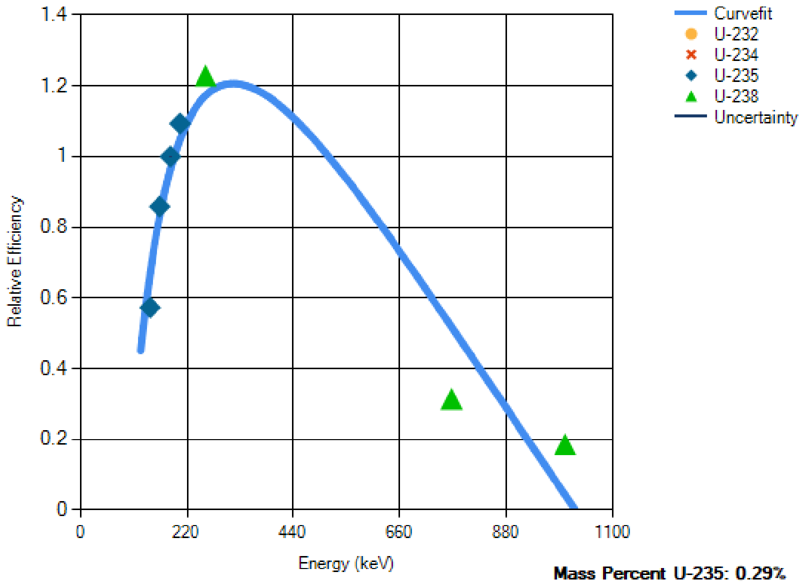
Relative Efficiency (RE)

Similar to DAA, extract photopeak areas

Assume a simple functional form for the absolute efficiency curve

material attenuation × geometric attenuation × detector efficiency

Above the K-edge for plutonium (121.8 keV), curve is smooth and fittable with multiple peaks



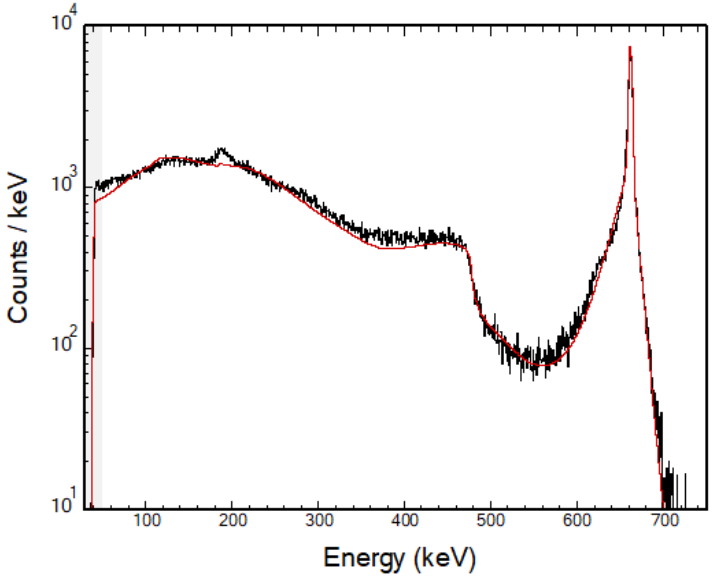
RE curve fit to peaks from 0.31% enriched uranium sample

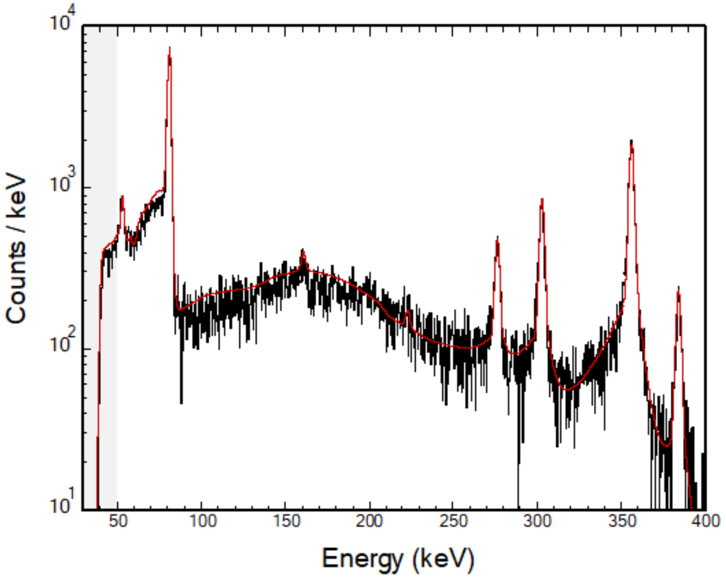
Preliminary Results

DOE/NNSA/NA-241 (Office of International Safeguards) funded Gamma Rodeo project measured multiple uranium oxide enrichment standards with an H3D M400 CZT

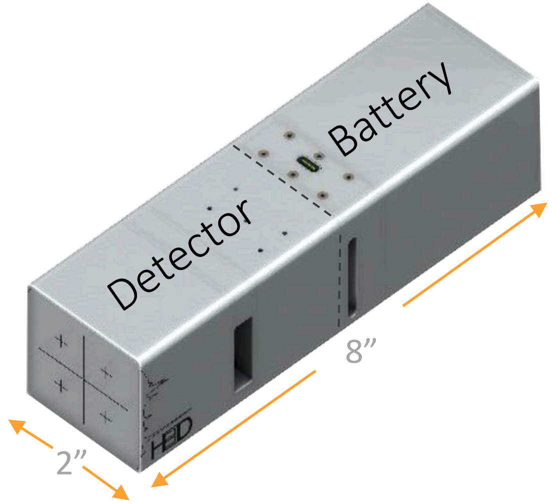
Four 2×2×1-cm CZT crystals, 0.65% FWHM @ 661 keV

Detector was characterized in GADRAS for analysis





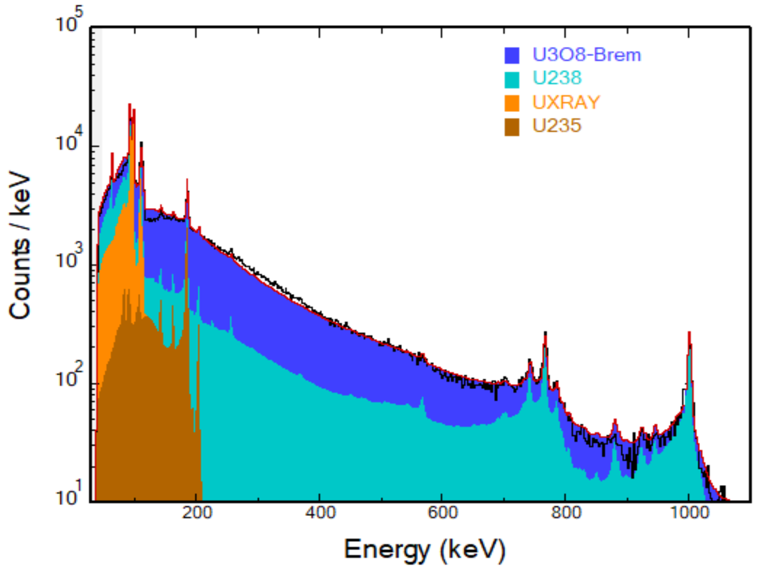
Comparison of measured spectra (black) to GADRAS simulated (red) for Cs-137 and Ba-133 calibration sources



M400 CZT detector with battery module

Preliminary Uranium Enrichment Results with CZT (long dwell)

Source	Mass Estimates (g)	U-235 Estimates (%)			
	FSA	FSA	Hybrid FSA-DAA	DAA	RE
200 g 0.31%	217 ± 0.86	0.39 ± 0.005	0.44 ± 0.02	-	0.32
200 g 0.71%	228 ± 1.06	0.89 ± 0.01	1.02 ± 0.04	-	0.62
200 g 1.94%	233 ± 1.31	2.54 ± 0.02	2.82 ± 0.10	-	2.40
200 g 2.95%	217 ± 1.23	3.96 ± 0.03	4.32 ± 0.15	-	4.39
200 g 4.46%	263 ± 1.67	6.42 ± 0.05	7.05 ± 0.23	-	4.64
230 g 20.11%	366 ± 1.98	26.4 ± 0.17	28.65 ± 0.85	-	24.20
230 g 52.49%	374 ± 1.77	64.0 ± 0.37	65.00 ± 1.42	-	-
230 g 93.17%	508 ± 1.77	98.6 ± 0.48	96.97 ± 1.43	-	-



Example FSA fit to 0.31% standard

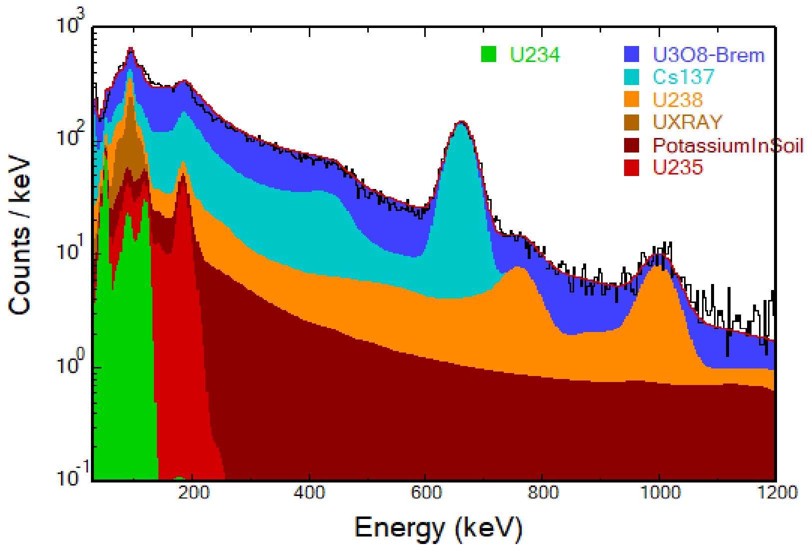
Preliminary Uranium Enrichment Results with NaI (short dwell)

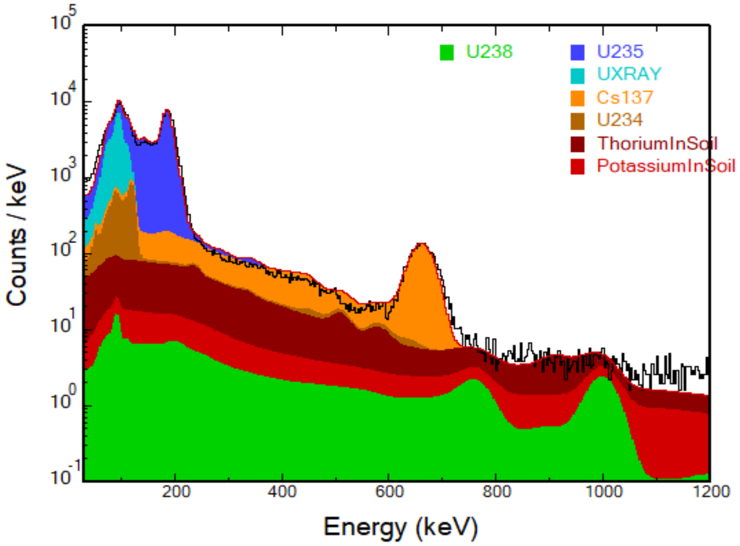
LANL collected data with handheld IdentiFINDER NGH (with Cs-137 seed source)

3.5×5.1-cm cylinder, 7.5% FWHM @ 661 keV

Sample	U-235 Estimates (%)			
	FSA	Hybrid FSA-DAA	DAA	RE
839 g 1.96%	0.84 ± 0.04	4.50 ± 0.37	-	-
989 g 17.5%	27.7 ± 0.29	16.4 ± 0.53	-	-
991 g 27.1%	41.6 ± 0.29	22.7 ± 0.64	-	-
989 g 52.5%	68.5 ± 0.50	34.6 ± 0.96	-	-
990 g 91.4%	90.0 ± 0.23	50.8 ± 1.16	-	-

Example FSA fit to 1.96% standard





Example FSA fit to 91.4% standard

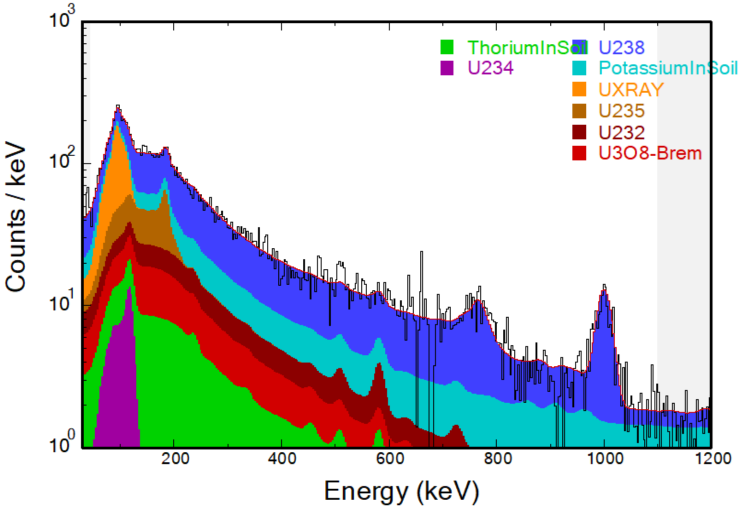
Preliminary Uranium Enrichment Results with LaBr (short dwell)

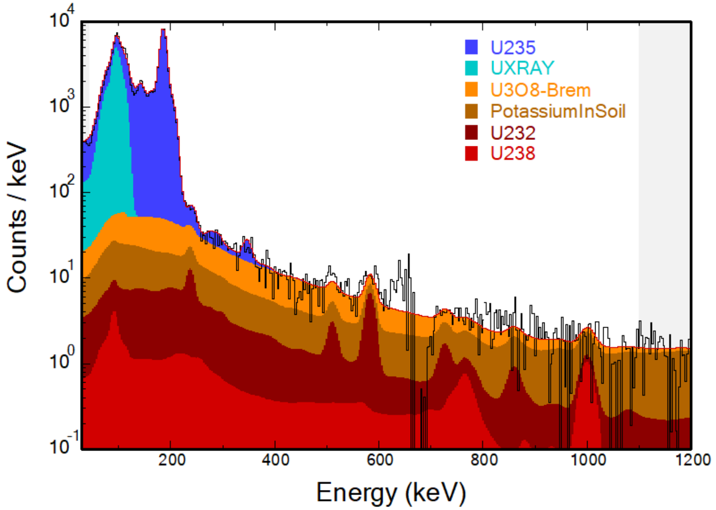
LANL collected data with handheld IdentiFINDER LGH

3×3-cm cylinder, 3.5% FWHM @ 661 keV

Standard	U-235 Estimates (%)			
	FSA	Hybrid FSA-DAA	DAA	RE
1041 g 0.7256%	2.07 ± 0.12	3.00 ± 0.62	-	-
984 g 3.065%	4.32 ± 0.12	5.85 ± 0.53	-	-
1120 g 10.22%	10.2 ± 0.20	11.38 ± 0.73	-	-
1169 g 17.42%	22.5 ± 0.48	23.60 ± 1.92	-	-
1172 g 37.848%	44.0 ± 0.91	67.37 ± 9.93	-	-
1171 g 66.317%	74.5 ± 1.19	79.38 ± 11.3	-	-
1178 g 91.419%	94.4 ± 2.36	98.03 ± 9.73	-	-

Example FSA fit to 0.73% standard





Example FSA fit to 91.4% standard

Summary

Ensemble of techniques can span detector types and counting statistics

Need to improve error estimates to build confidence

DAA algorithm is complete but not shown in these results

Additional testing to be done on Safeguards-relevant source standards

Acknowledgement

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