High-Energy, Beta-Delayed Gamma-Ray Spectroscopy Experiments

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Workshop on Nuclear Data Needs and Capabilities for Applications

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Delayed Gamma-Ray Spectroscopy for Non-Destructive Assay of Nuclear Materials

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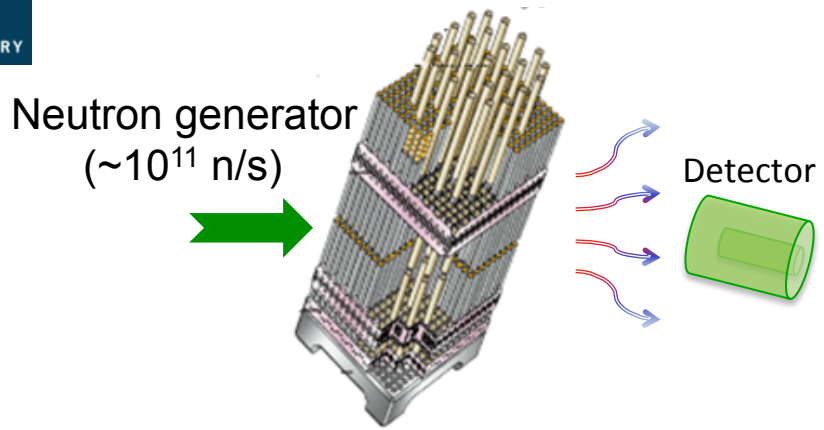


Delayed gamma-ray spectra are analyzed as superposition of U-235, Pu-239, Pu-241, U-238 contributions.

Delayed Gamma-Ray Experiments

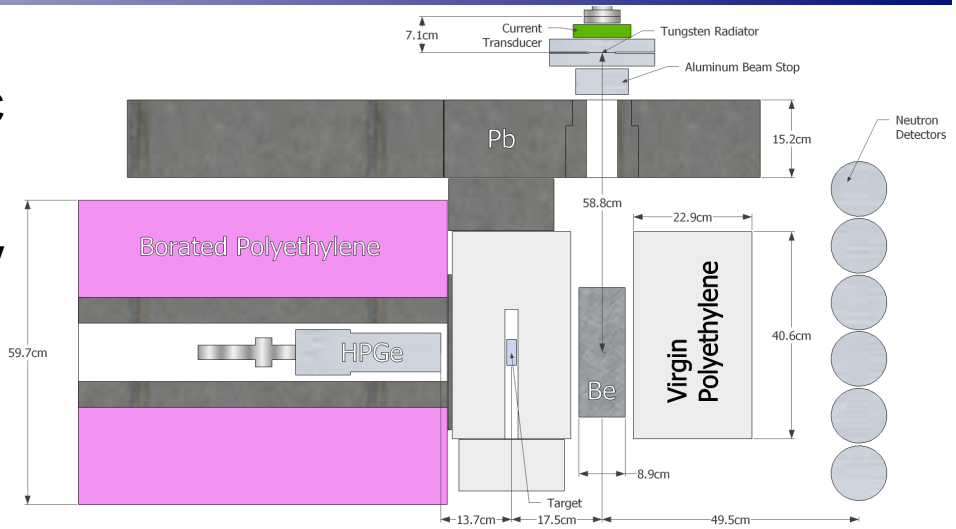
At IAC

Photo-neutron source, 15 MeV Electron LINAC

Targets: U-235, Pu-239, Pu-241, DU, Combined

Data sets for several irradiation/spectroscopy cycles:

- 15 min/30 min (multiple passes to increase statistics)
- Many cycles: 5 min/5 min, 90 sec/90 sec, 60 sec/60 sec, 10 sec/10 sec

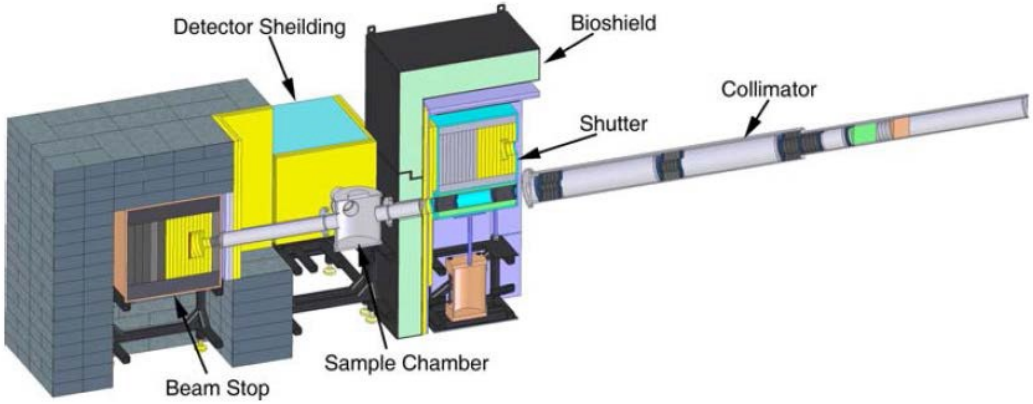


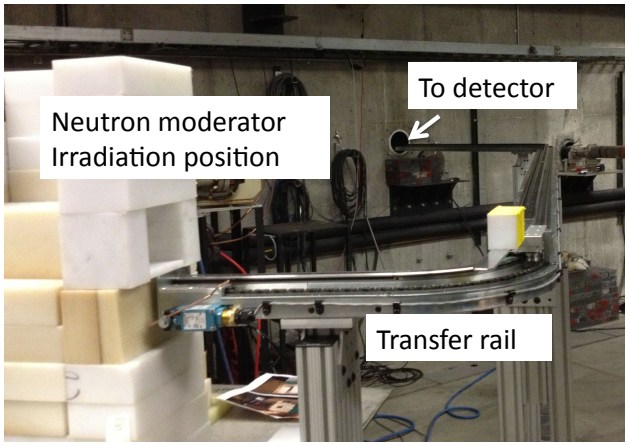
At OSU

TRIGA reactor, pure thermal neutron beam

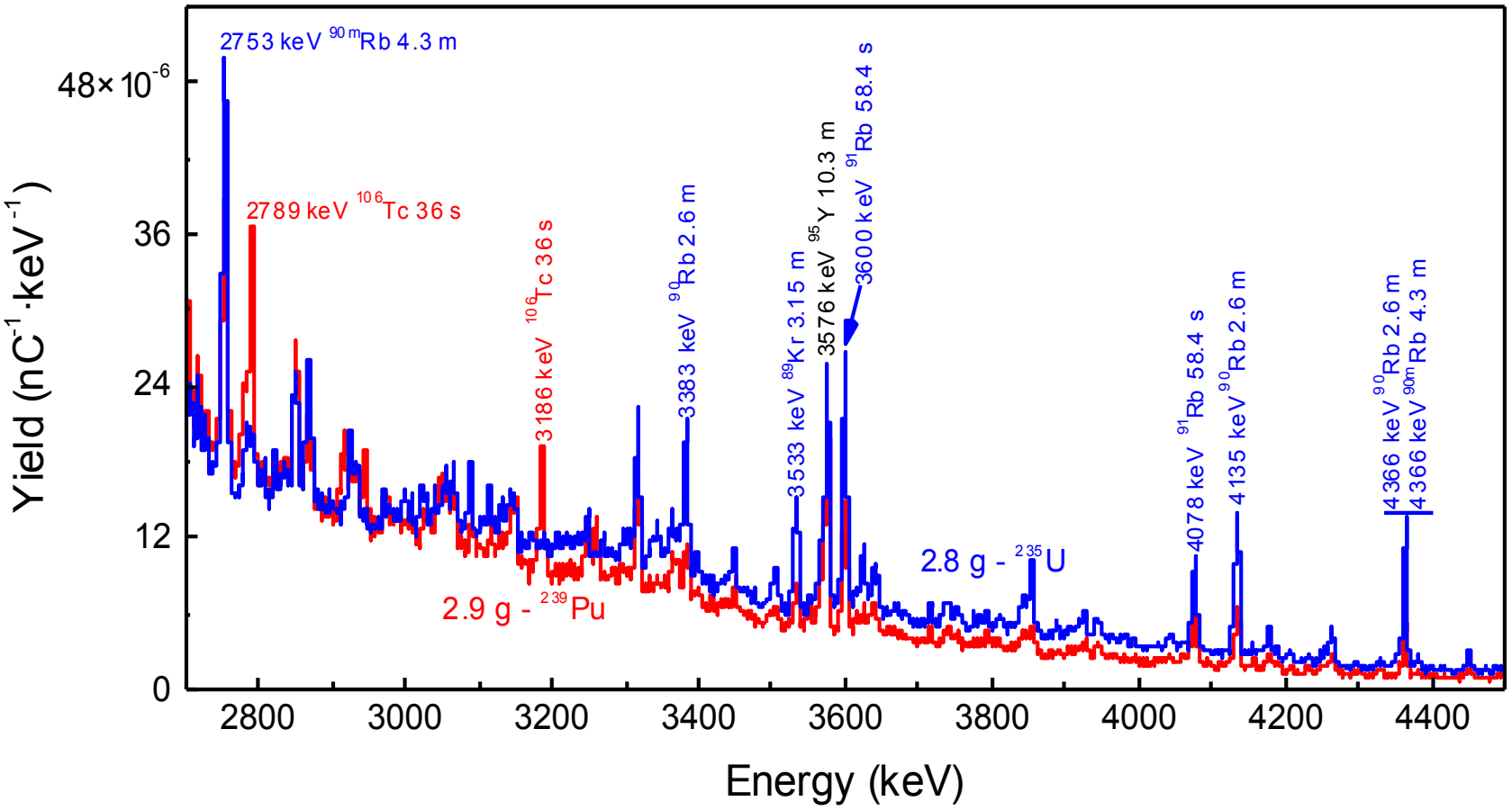
Targets: U-235, Pu-239, DU

Irradiation/spectroscopy cycles: 10/10 sec, 1/1 min, 10/10 min



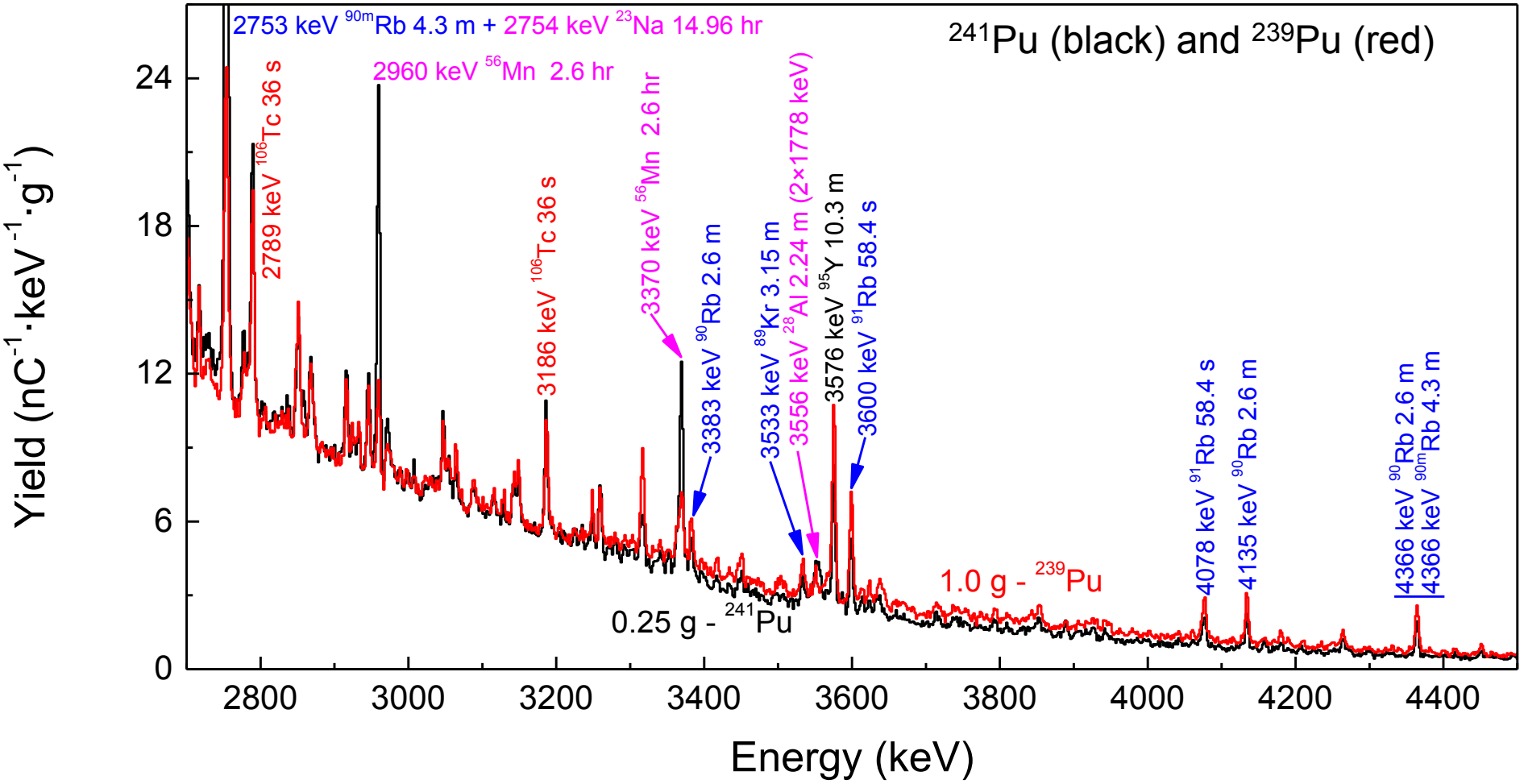


Comparison of ^{239}Pu, ^{235}U spectra collected for 90s/90s irradiation/spectroscopy cycle.



Significant differences between ^{235}U and ^{239}Pu for a number of lines:
Strong ^{235}U indicators include ^{90}Rb + ^{90m}Rb with half-lives of 2.6 and 4.3 min, ^{91}Rb, t½ = 58.4 s.
Strong ^{239}Pu indicator: ^{106}Tc, t½ = 36 s
^{95}Y, t½ = 10.3 min, is strong in both spectra and important.

Measured Delayed Gammas from ^{241}Pu

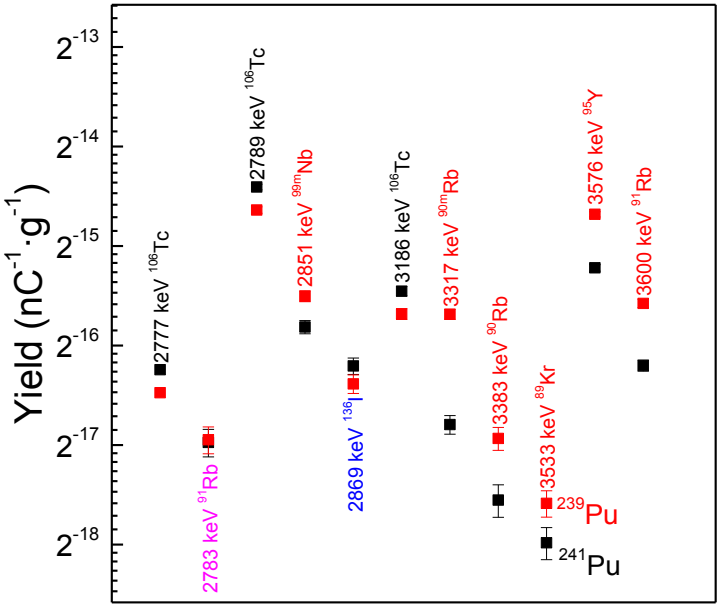


The ^{241}Pu/^{239}Pu ratios of prominent peaks vary between 1.2 and 0.5.

Relative Delayed Gamma-Ray Yields from ^{241}Pu, ^{239}Pu

Integrated discrete delayed γ-ray yields from the ^{241}Pu and ^{239}Pu targets. (Prel. Data)

Discrete γ-ray energy (keV)	^{241}Pu Discrete γ-ray yield ($nC^{-1}\cdot g^{-1}$)	^{239}Pu Discrete γ-ray yield ($nC^{-1}\cdot g^{-1}$)	^{241}Pu/^{239}Pu
2783 – ^{91}Rb	$(7.8\pm0.7)\times10^{-6}$	$(7.9\pm0.7)\times10^{-6}$	1.0
2789 – ^{106}Tc	$(4.60\pm0.09)\times10^{-5}$	$(3.92\pm0.09)\times10^{-5}$	1.2
2851 – ^{99m}Nb	$(1.74\pm0.08)\times10^{-5}$	$(2.15\pm0.08)\times10^{-5}$	0.8
2869 – ^{136}I	$(1.32\pm0.07)\times10^{-5}$	$(1.17\pm0.07)\times10^{-5}$	1.1
3186 – ^{106}Tc	$(2.23\pm0.07)\times10^{-5}$	$(1.90\pm0.07)\times10^{-5}$	1.2
3317 – ^{90m}Rb	$(8.8\pm0.6)\times10^{-6}$	$(1.90\pm0.07)\times10^{-5}$	0.5
3383 – ^{90}Rb	$(5.2\pm0.6)\times10^{-6}$	$(8.0\pm0.6)\times10^{-6}$	0.65
3533 – ^{89}Kr	$(3.9\pm0.4)\times10^{-6}$	$(5.1\pm0.5)\times10^{-6}$	0.76
3576 – ^{95}Y	$(2.62\pm0.06)\times10^{-5}$	$(3.81\pm0.07)\times10^{-5}$	0.69
3600 – ^{91}Rb	$(1.33\pm0.05)\times10^{-5}$	$(2.05\pm0.06)\times10^{-5}$	0.65



Determination of Fission Yields from Time-dependent Delayed Gamma-ray Data

Physical model: Systems of decaying isotopes produce time-varying spectral peaks & background

Independent fission yields, parameters in the model, are found by fitting the experimental time-energy data using a maximum-likelihood estimation method.

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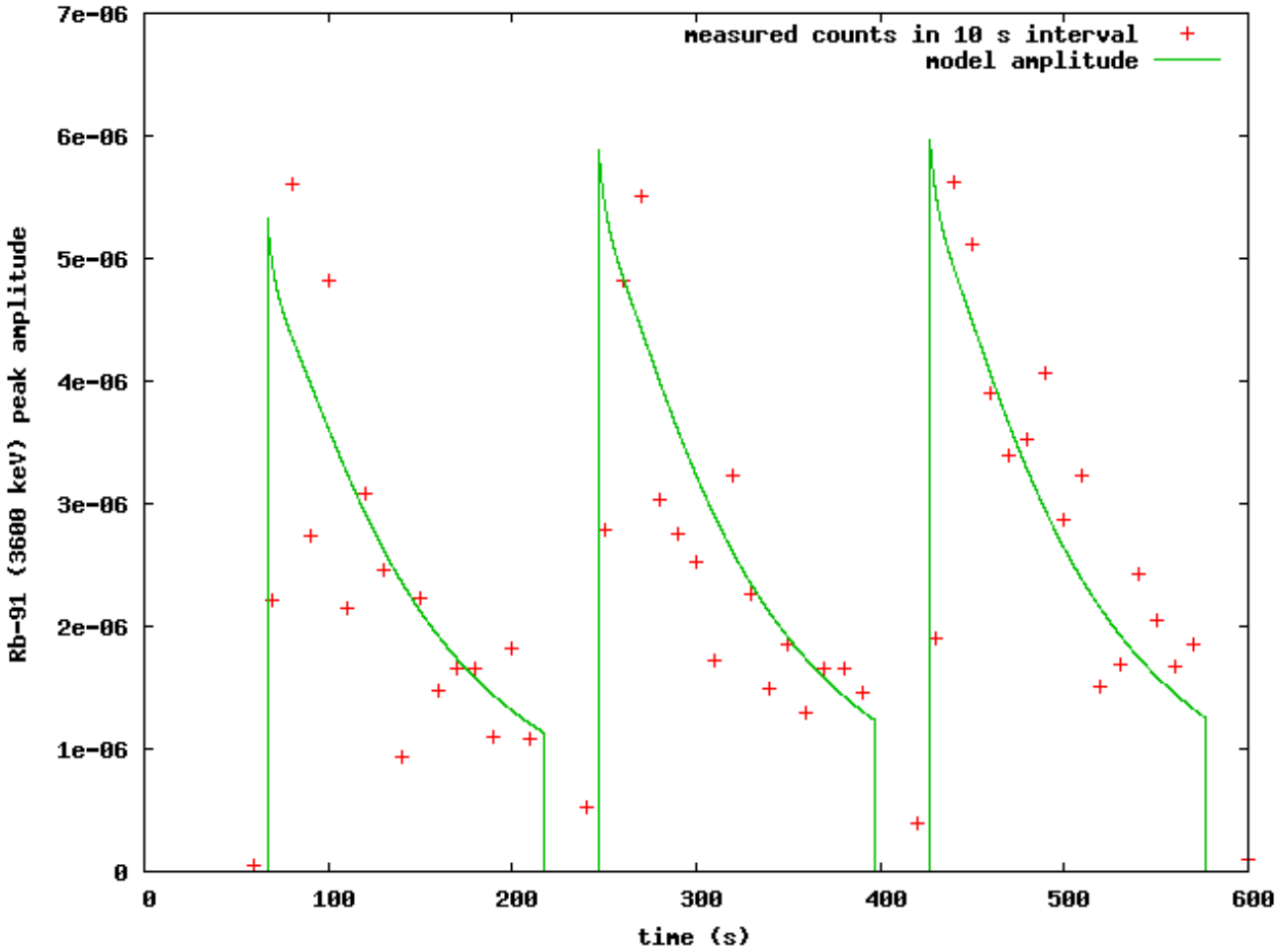
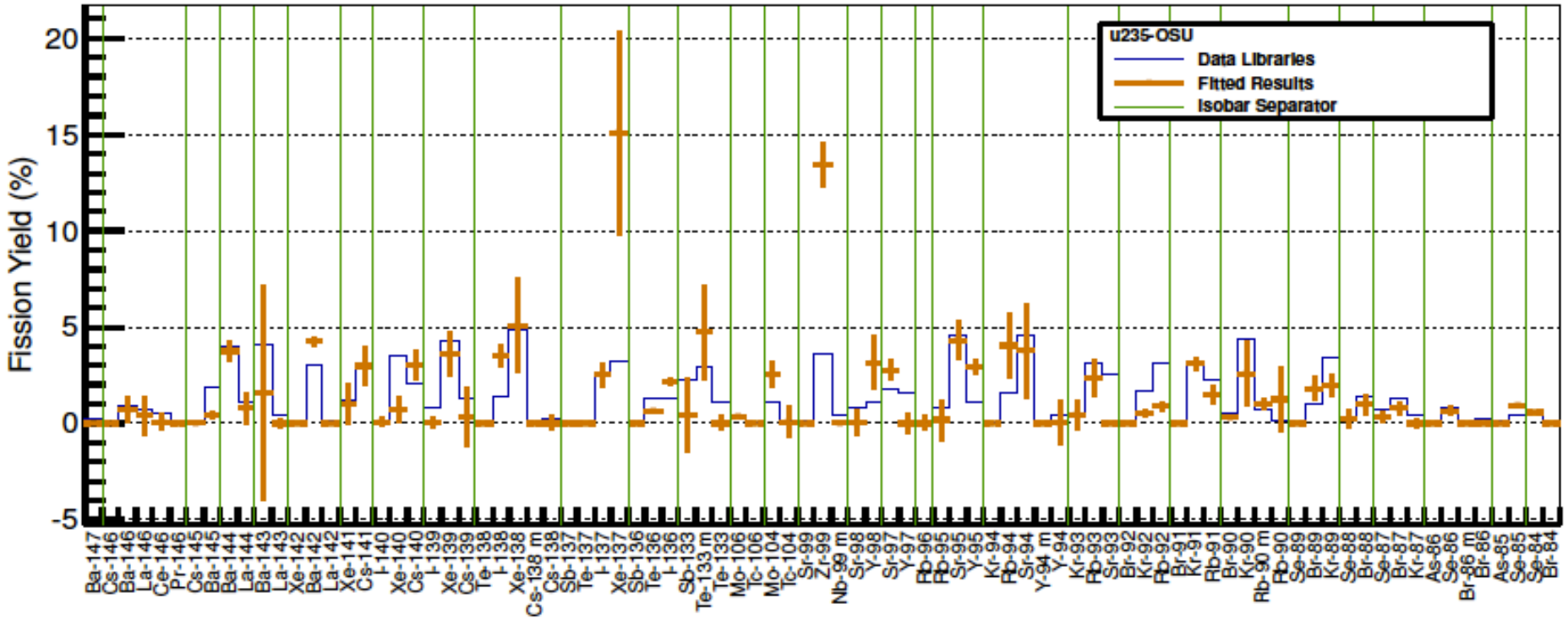


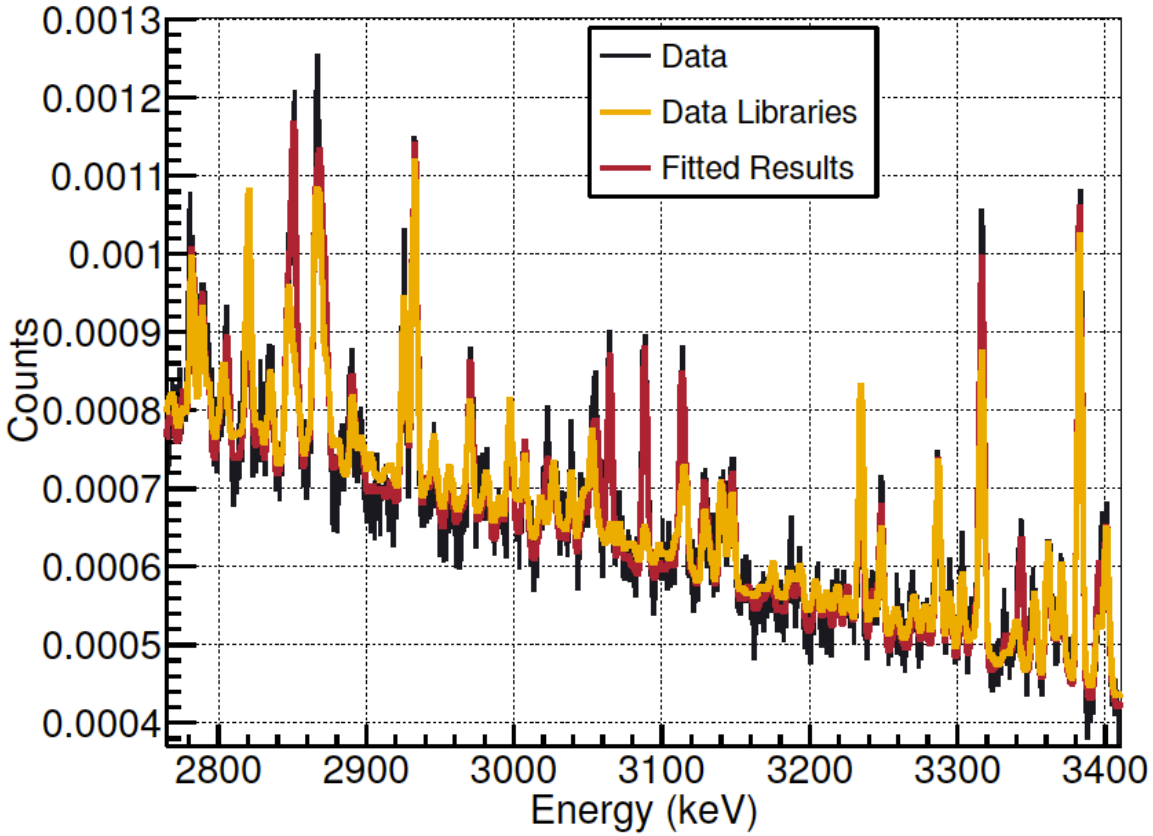
Fit of the time-dependence of the number of counts measured in 10 s intervals in the ^{91}Rb peak at 3600 keV.

Fitted ^{235}U Fission Yields

Fitted ^{235}U fission yields (orange) extracted from delayed gamma-ray measurements between 2.8 and 3.4 MeV normalized to the cumulative ^{95}Y yield and ENDF/B-VII data library values (blue line).



^{235}U Delayed Gamma-ray Spectrum Calculated with Fitted Fission Yields



- Black: measured.
- Yellow: calculated based on ENDF/B-VII data libraries.
- Red: calculated based on the fitted fission yields.

- More data sets needed to be fitted to improve the accuracy of the extracted fission yields.
- Also ^{239}Pu and ^{241}Pu.
- Experimental data available – Prof. Alan Hunt, ISU

Physical model

- Systems of decaying isotopes produce time-varying spectral peaks & background

Determine set of fission yields that reproduces observed data

- Have preliminary fits for certain spectral regions.
- Single and double escape peaks included in analysis.

Preliminary best-fit relative fission yields for U-235 thermal fission
(normalized to cumulative yield of Y-95 = 0.064)

Se 85	0.007691	+/-	0.00049
Se 87	0.008732	+/-	0.002671
Br 87	0.006921	+/-	0.003191
Br 88	0.015212	+/-	0.001169
Kr 89	0.023941	+/-	0.001884
Rb 89	0.005172	+/-	0.002859
Rb 90 M	0.012803	+/-	0.001086
Rb 90	0.036539	+/-	0.000603
Rb 91	0.045594	+/-	0.000441
Rb 92	0.005367	+/-	0.007878
Rb 93	0.026013	+/-	0.000965
Sr 95	0.040862	+/-	0.001605
Y 95	0.022825	+/-	0.001804
Y 97	0.020542	+/-	0.002252
Tc 106	0.009858	+/-	0.002155
Te 135	2.85E-08	+/-	2.19E-05
I 136	1.84E-07	+/-	5.33E-05
I 137	0.019238	+/-	0.002389
I 138	0.028651	+/-	0.005515
Xe 139	0.086401	+/-	0.051444
Cs 139	0.051121	+/-	0.054131
Cs 140	0.059973	+/-	0.003645
La 142	0.050324	+/-	0.002785
La 144	1.31E-10	+/-	7.99E-07
Ba 145	1.29E-06	+/-	0.000161