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Generalization of the FRAM's Bias

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The World's Greatest Science Protecting America

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ABSTRACT

The Fixed-Energy Response-Function Analysis with Multiple Efficiency (FRAM) code was developed at Los Alamos National Laboratory to measure the gamma-ray spectrometry of the isotopic composition of plutonium, uranium, and other actinides. Its reported uncertainties of the results come from the propagation of the statistics in the peak areas only. No systematic error components are included in the reported uncertainties. We have done several studies and found that the FRAM's statistical precision can be reasonably represented by its reported uncertainties. The FRAM's biases or systematic uncertainties can come from a variety of sources and can be difficult to determine.

We carefully examined the FRAM analytical results of the archival plutonium data and of the data specifically acquired for this isotopic uncertainty analysis project and found the relationship between the bias and other parameters. We worked out the equations representing the biases of the measured isotopes from each measurement using the internal parameters in the spectrum such as peak resolution and shape, region of analysis, and burnup (for plutonium) or enrichment (for uranium).

A. INTRODUCTION

The Fixed-Energy Response-Function Analysis with Multiple Efficiency (FRAM) software has been developed and is continuing to be refined at the Los Alamos National Laboratory for the gamma-ray spectrometry measurement of the isotopic composition of plutonium, uranium, and other actinides [1–3]. It is capable of analyzing gamma-ray peaks obtained with the germanium detectors in the energy range from 30 keV to greater than 1 MeV, including the x-ray region. It is a code based on a self-calibration using several gamma-ray peaks for determining the isotopic ratios. The versatile-parameter database structure governs all facets of the data analysis. User editing of the parameter sets allows great flexibility in handling data with different isotopic distributions, interfering isotopes, and different acquisition parameters, such as energy calibration and detector type.

FRAM can obtain a complete plutonium or uranium isotopic analysis using either a single planar or coaxial germanium detector or a CdTe detector. The actual detector type is not really important; what matter most are the resolution and the shape of the peaks in the spectrum. The current version of FRAM (v4) can analyze a plutonium or uranium spectrum with a maximum peak resolution of 1.8 keV FWHM (full width at half maximum) at 122 keV for analysis of the 100-keV region, 2.2 keV at 122 keV for analysis of the low-energy region above 120 keV, and 3 keV at 1.3 MeV for analysis of the energy region above 500 keV. As for the peak shape, FRAM requires that the fraction of the peak area that is present in the low-energy tail of the peak must

be less than 0.2 for all the peaks in the spectrum. Note that FRAM can analyze a peak with a large tail on the low-energy side of the peak. However, it cannot determine the tail on the high-energy side of a peak. Therefore, in spectra with peaks that have large high-energy tails, FRAM will not be able to accurately determine the isotopic compositions of the plutonium or uranium.

Although FRAM can analyze spectra with very broad peaks and with large-tail peaks, such as those near the limits just mentioned, common sense would tell us that the results from those spectra may not be very good or they may have large errors. In our previous study, we found this is very true [4]. In general, a spectrum with good resolution and peak shape would give results with a smaller bias and better precision than a spectrum with bad resolution and peak shape.

Also, from that study [4], we identified two different kinds of errors from FRAM analysis, random and systematic. The random errors come mainly from statistics and are easily determined. We have done several studies and found that the FRAM's statistical precision can be reasonably represented by its reported uncertainties. The biases or systematic errors can come from varieties of sources and can be determined using the internal parameters of a spectrum such as peak resolution and shape, region of analysis, and burnup (for plutonium) or enrichment (for uranium). All other parameters such as weight, matrix material, shape, size, container, electronics, detector, input rate, etc., contribute little to the systematic error, or they contribute to the peak resolution and shape and then their contributions can be determined from the peak resolution and shape.

For this study, we set up experiments to obtain the relationships of the biases with the internal parameters (peak resolution and shape, region of analysis, plutonium burnup or uranium enrichment) of the spectra.

B. PLUTONIUM

When using the planar detector, FRAM is normally used to collect and analyze plutonium data in the 30–210-keV (only for freshly separated plutonium), 60–210-keV, and 120–420-keV ranges, although it is not limited to these ranges. For the coaxial detector, the normal mode of operation is to acquire the spectra in the range from 0 to 1,024 keV. If the region between 120 and 200 keV is available, FRAM usually works best analyzing in an energy range from 120 to 460 keV. When gamma rays below 200 keV are weak or not available, such as in the case of a sample inside a thin lead-lined container, FRAM can analyze data using the gamma rays in the energy range from 200 to 1,010 keV. When the plutonium is shielded by thick and dense absorber such as 0.125 inches of lead or thicker and no gamma ray below 300 keV may be visible, then FRAM can still obtain a complete isotopic analysis using only gamma rays above 300 keV from a single coaxial detector spectrum.

Basically, the FRAM's plutonium analytical regions can be classified into four separate regions: 30–60 keV, 60–120 keV, 120–500 keV, and 500–1,010 keV. All these four analytical regions have one thing in common; that is, each region has one and only one measurable gamma ray from ^{240}Pu decay.

For the freshly separated samples such as those spent-fuel dissolver solutions, all the peaks above 30 keV can be used for analysis. The peaks in the 30–60-keV range represent the most

intense gamma rays for most of the plutonium isotopes, except ^{241}Pu. It, therefore, is not sufficient to use this region alone for complete plutonium isotopic analysis. This region will need to be used together with another region that has a ^{241}Pu peak.

For aged material, the 60-keV peak of ^{241}Am is very intense, and its corresponding Compton distribution would overwhelm all other peaks below it, making the region below 60 keV useless for isotopic measurements. Therefore, for aged plutonium, we can only use the gamma rays in the region at and above 60 keV.

The 60–120-keV region contains intense peaks from all the plutonium isotopes except ^{239}Pu. Plutonium-239 actually has one fairly intense peak at 98.8 keV. However, it is sitting on the shoulder of a much more intense uranium x-ray peak, and its area cannot be accurately extracted, so it is not used. As in the 30–60-keV region, we cannot use this region alone in obtaining all the isotopic information and have to combine it with another region.

The 120–500-keV region contains peaks from all the plutonium isotopes, so by this region alone we can determine the isotopic ratios of all the plutonium isotopes. However, the gamma rays in this region are about two and one orders of magnitude less intense than the peaks in the 30–60-keV and 60–120-keV regions, respectively.

The 500–1,010-keV region does not have peaks from ^{241}Pu, so it will need to include some gamma rays from the immediate lower energy region for complete analysis. The gamma rays in this region are about one order of magnitude weaker than those in the 120–500-keV region. It is best to use this region with heavily shielded plutonium where the low-energy gamma rays from other regions are only weakly or not at all visible.

Figure 1 shows an example of a plutonium spectrum with four regions separated by three vertical dashed lines. Each of these four regions has one, and only one, measurable gamma ray from ^{240}Pu decay. The four overlapping analytical regions that FRAM normally uses for the analysis are shown as four thick, horizontal bars above the spectrum. The top bar corresponds to the analytical region for freshly separated plutonium. The other three are for aged plutonium.

1. Data acquisition

We set up the data acquisition system to obtain spectra with various resolutions and tails. We used two detector systems for the experiments, one planar germanium detector system and one coaxial germanium detector system. The planar detector system consists of a 16-mm-diameter × 13-mm-long planar detector from Canberra and the DSPEC Plus multichannel analyzer (MCA) from Ortec. The coaxial detector system consists of a 58-mm-diameter × 53-mm-long coaxial detector (32% relative efficiency) and the DSPEC Plus MCA, both from Ortec.

The samples for these measurements included four of the seven samples from the PIDIE (plutonium isotopic determination intercomparison exercise) set: PIDIE-1, PIDIE-3, PIDIE-5, and PIDIE-7. These samples are small, only 0.4 g each. In the planar detector system, the input rates for the four samples were 3, 5, 8, and 10 kHz, respectively, from low to high burnup. For

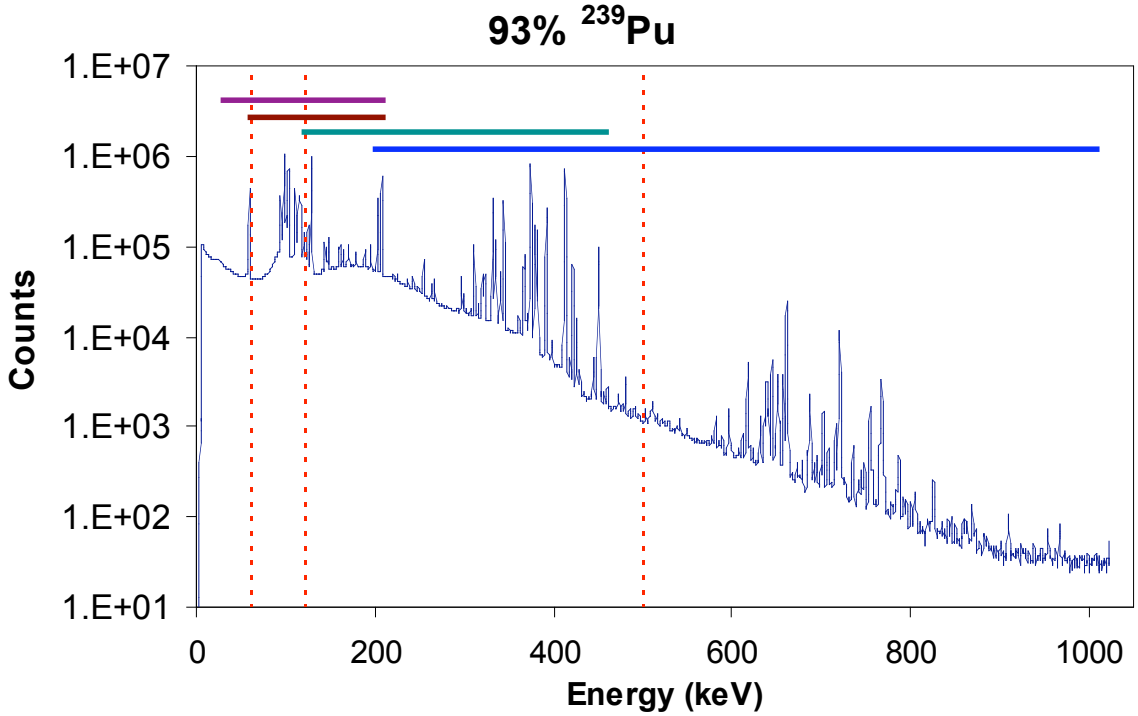

Figure 1. A low-burnup plutonium spectrum. The three vertical, dashed lines separate the four regions. The four overlapping analytical regions that FRAM normally uses for the analysis are shown as four thick horizontal bars above the spectrum.

the coaxial detector system, the input rates were 16 kHz for the PIDIE-1 sample and 20 kHz for the other three samples.

The data for the planar detector were acquired in 8K channels at 0.075 keV/ch (keV per channel) up to more than 600 keV so that the data could be analyzed in two different energy ranges: 60 to 210 keV and 120 to 500 keV. For the coaxial detector, the spectra were acquired in 8K channels at 0.125 keV/ch, covering the entire 0- to 1,024-keV energy range. These spectra can be analyzed using three separate parameter sets employing the 60–210-keV, 120–500-keV, and 200–1,010-keV regions.

In both detector systems, we varied the rise time of the DSPEC Plus to obtain spectra with various resolutions. The rise times used were 0.2, 0.4, 0.6, 1.0, 1.4, 2.0, 2.8, 4.0, and 8.0 µs. The flattop was 1.0 µs, and the cusp value was 0.8. The acquisition time for each spectrum was 15 minutes of live time. The reason live time was chosen over true time was so the statistics would be the same for all the spectra and they could be directly compared. Sixteen spectra were obtained for each data set.

Table 1 shows the average resolutions and tails of the 129-keV and 208-keV peaks of the spectra for each rise time setting for both detectors and of the 662-keV peak for the coaxial detector. The variations of the FWHMs and tails for different samples with the same rise time are small for both the planar and coaxial detectors, and the average values shown would represent the FWHMs and tails of the peaks of a measurement.

Table 1. Average resolution and tails of the 129-keV, 208-keV, and 662-keV peaks as a function of the rise time.

Rise time (μs)	Planar FWHM (eV)		Planar Tail %		Coaxial FWHM (eV)			Coaxial Tail %		
	129-keV	208-keV	129-keV	208-keV	129-keV	208-keV	662-keV	129-keV	208-keV	662-keV
0.2	703	820	0.91	1.80	2180	2281	2633	0.03	0.04	0.10
0.4	653	762	0.99	1.75	1880	1954	2234	0.05	0.06	0.16
0.6	673	777	0.94	1.80	1711	1783	2092	0.06	0.08	0.19
1.0	605	716	0.98	1.76	1477	1542	1847	0.09	0.11	0.26
1.4	572	691	1.01	1.75	1337	1401	1715	0.12	0.14	0.31
2.0	554	673	1.25	1.97	1212	1278	1599	0.15	0.17	0.37
2.8	541	662	1.11	1.85	1119	1185	1518	0.18	0.20	0.43
4.0	531	654	1.20	1.93	1052	1122	1472	2.29	2.31	2.69
8.0	521	644	1.31	1.99	960	1036	1408	3.51	3.33	2.94

In general, the resolution becomes better as the rise time increases from 0.2 μs to 8.0 μs. The only exception is at 0.6 μs rise time for the planar detector. For all four samples, the measurements at 0.6 μs rise time always give worse resolution than those at 0.4 μs (and also worse throughput).

To obtain spectra with various shapes, we used a rise time of 4.0 μs and manually adjusted the pole zero (PZ) to produce peaks with low-energy tails of various sizes. For each sample, six sets of data, with 16 spectra (15 minutes true time) in each set, were obtained, with the peak tail percentages varying from approximately zero to about 17%.

Table 2 shows the average resolutions and tails of the peaks of the spectra for each PZ setting for both detectors. The variations of the FWHMs and tails for different samples with the same PZ are small for the coaxial detector. However, for the planar detector, the FWHMs and tails are similar for different samples at only the first two PZ adjustments, and they start to deviate from one another as the PZ adjustment is gradually changed to positions 2, 3, 4, and 5. At PZ#5, the FWHMs and tails of the peaks for the PIDIE-1 sample are about 8% and 46% below the average values in Table 2, respectively. For the PIDIE-7 sample, the FWHMs of the peaks are about 8% larger than the average value and the tails are 46% larger. The diversion of the resolution and tail for different samples is due to different input rates for the four samples, ranging from 3 kHz to 10 kHz. That divergence effect is not seen with the coaxial detector because the input rates for the four samples measured with the coaxial detector are about the same.

Table 2. Average resolutions and tails of the 129-keV, 208-keV, and 662-keV peaks as a function of the pole zero.

PZ	Planar FWHM (eV)		Planar Tail %		Coaxial FWHM (eV)			Coaxial Tail %		
	129-keV	208-keV	129-keV	208-keV	129-keV	208-keV	662-keV	129-keV	208-keV	662-keV
PZ#0	530	652	0.94	1.84	1033	1104	1448	0.71	0.80	2.50
PZ#1	538	662	2.32	2.84	1061	1133	1481	2.84	2.75	2.83
PZ#2	562	684	5.33	5.31	1117	1188	1532	6.10	5.83	4.81
PZ#3	588	709	8.33	7.84	1175	1249	1596	9.29	9.01	7.46
PZ#4	617	736	10.38	9.89	1239	1315	1669	11.11	11.24	11.31
PZ#5	649	768	11.94	11.43	1304	1381	1738	11.90	12.71	16.11

We see from Tables 1 and 2 that, in general, the FWHM will be larger for higher energy peaks and vice versa. As for the tail, it can be either larger or smaller at different energy. On average, the tail is about the same at all different energies.

2. Analysis

a. Correlation

In Reference 5, we worked out two separate correlations, one for the bias and the FWHM of the ^{240}Pu peak and the other for the bias and the tail of the ^{240}Pu peak. They were expressed as

$$^{240}\text{Pu bias} = 1 - \exp(a\boldsymbol{W}^2) , \quad \text{(Eq. 1)}$$

and

$$^{240}\text{Pu bias} = 1 - \exp(b\boldsymbol{T}) , \quad \text{(Eq. 2)}$$

where bias = |Measured/Accepted – 1|, a and b are some constants, $\boldsymbol{W}$ is the FWHM of the ^{240}Pu peak, $\boldsymbol{T}$ is the tail percent of the ^{240}Pu peak, and the ^{240}Pu peak is the 104-keV peak for the 60–210-keV region analysis, the 160-kev peak for the 120–500-keV region analysis, and the 642-keV peak for the 200-1,010-keV region analysis. Note that each parameter set uses only one gamma ray to determine ^{240}Pu: 104-keV for the 60–210-keV region, 160-keV for the 120–500-keV region, and 642-keV for the 200–1,010-keV region.

For this paper, we are going to determine the bias for all the plutonium isotopes and ^{241}Am, except for ^{242}Pu where its fraction cannot be directly measured. We worked out a general equation that can reasonably relate the resolution and tail of a gamma ray peak to the bias. The equation is

$$\text{Bias} = a\boldsymbol{W}^b + c\boldsymbol{T}^d , \quad \text{(Eq. 3)}$$

where bias = |Measured/Accepted – 1|, a, b, c, and d are nonnegative variables, $\boldsymbol{W}$ is the FWHM of the selected peak, and $\boldsymbol{T}$ is the tail percent of that selected peak. The reason for the non-negative variables a, b, c, and d is to prevent the occurrence of the situation where the bias would become better as the resolution or the tail increases. The selected peaks are chosen to be the 129-keV peak of ^{239}Pu for the 60–210-keV region analysis, the 208-kev peak of ^{241}Pu and ^{241}Am for

the 120–500-keV region analysis, and the 662-keV peak of ^{241}Am for the 200–1,010-keV region analysis. The performances of the detectors at those energies were shown in Tables 1 and 2. The reason for choosing those peaks is as follows:

In Reference 5, it was easy to select the reference peak for the ^{240}Pu bias because each parameter set uses only one gamma ray to determine ^{240}Pu. For that work, the reference ^{240}Pu peaks were at 104 keV for the 60–210-keV region analysis, 160 keV for the 120–500-keV region analysis, and 642 keV for the 200–1,010-keV region analysis. For this general correlation in this work, we can also select those same ^{240}Pu peaks for the ^{240}Pu bias correlations. However, the selections of the reference peaks for the other isotopes such as ^{239}Pu, ^{241}Pu, or ^{241}Am would become much more difficult because each of those isotopes uses many peaks to determine their activity. Also, if different peaks were used for different isotopes, then it would become complicated to keep track of, to present the correlations, and to program the software code. So we decided to select a single reference peak that best represents each region analysis. These selected peaks are in general the most intense and clean peaks in a spectrum so the users can easily obtain their resolution using whatever methods beside FRAM.

b. Bias fitting

References 2–3 use a simple method to obtain the bias for a measurement. In those references, the results for the multiple runs for each sample were averaged. The relative standard deviation (RSD) of the large set (of many samples) of the ratios of those average measured values divided by the accepted values represents the minimum bias for an arbitrary measurement. That simple method does not work here. In this work, we have many data points, but each point is the average result of the measurements at a specific condition; the simple method used in References 2–3 will only give an average bias value but would not be able to give the bias at a specific measurement. To obtain the bias for any measurement, we would need to fit the data points to a model, which is described by Eq. 3.

The fit for the bias is done in several ways that differ from the usual.

i) In a normal fitting of a curve through some data points, there will be on the average half of the points above the curve and half will be below. Here we are trying to obtain a curve that would represent the standard deviation or the bias of the data. For a Gaussian distribution, it would be that about 32% of the points will be outside one standard deviation (STD) or sigma and 68% will be inside. So in fitting the Eq. 3, we gave the points above the curve a weight of 0.68 and the points below the curve a weight of 0.32. Then the bias curve will be obtained such that roughly 32% of the points will be above it and 68% will be below it.

ii) Instead of the normal minimizing the residual sum of squares of the differences, the fit employs minimizing the residual sum of the absolute of the differences. The reason behind this fit is to distribute the weight of the data points above and below the fitted curve somewhat equally, besides the 32/68 weight distribution in bullet **a**. In general, some of the data points above the fitted curve will have some probability of being very far away, several sigmas, from the curve, while none of the data points below the curve will be more than one standard deviation away. If the residual sum of squares

of the differences were used, then those far-away data points above the curve would have too much weight and would unfairly pull the curve upward.

iii) The data points include both the uncertainties of the biases and the random errors from statistics. The statistical error component would need to be subtracted out for proper determination of the bias. However, we know of no known method that can subtract out the random error component from a total error of an individual data point. So we have to somehow take into account both the uncertainties of the biases and the statistical errors in the calculations. A proper way would be a weighted fit with the bias and statistics appropriately contributing to the weight. We, however, do not know the uncertainty of the bias component relative to the statistical component. So, in this work, we employ a somewhat unconventional method to account for both components of the uncertainty. Instead of assuming each data point has a weight equal to the inverse of the "square" of the statistical error of that data point as in a pure statistical distribution (besides the weights described in the bullets **a** and **b**), we give each data point a weight equal to the inverse of the "square root" of the statistical error of that data point. This weighting method is somewhere between that of pure statistical distribution and no weighting (pure bias uncertainty) and would account for both the uncertainty of the bias and statistical error of that data point.

The data of the planar detector were analyzed using the two appropriate parameter sets for the data, employing the 60–210-keV and 120–500-keV regions. These parameter sets were modified slightly from the existing parameter sets included with the distribution of the current FRAM v4, Pu100keV2 and Planar_Widerange3. The 60–210-keV region parameter set had some minor changes of the branching ratios (BR) of several peaks in the 100-keV region to improve the accuracy of the results. These two parameter sets also include the ^{235}U isotope so that they can analyze spectra of Mix-Oxide (MOX) material. These parameter sets are listed in the appendix.

The data of the coaxial detector were also analyzed using the two appropriate parameter sets for the coaxial detector, employing the 120–500-keV and 200–1,010-keV regions. As with the planar detector, we took the two basic parameter sets for coaxial detector included with the FRAM distribution, Coax_Widerange3 and ShCoax_Widerange3, and modified them for much broader peaks in this work. These modified parameter sets are also included in the appendix. In addition, we modified the 60–210-keV parameter set for the planar detector to work with the much worse resolution of the coaxial detector. Note that this 60–210-keV region analysis for the coaxial detector is done only for this study and is not normally used in any true measurements in the field or in the lab.

For the 60–210-keV region analysis, we analyzed the data using both the current FRAM v4 version and an upgraded FRAM employing the bias correction algorithm [6]. This upgraded FRAM is supposed to improve the accuracy of the results in the analysis of plutonium and uranium in the x-ray regions somewhat.

We grouped the average results (of 16 runs at each setup) based on the energy region used in the analysis, regardless of the detector type: 60–210-keV region analysis, 120–500-keV region analysis, 200–1,010-keV region analysis, and 60–210-keV region analysis with the upgraded FRAM. We fitted the data from each group to the Eq. 3 to obtain the values for a, b, c, and d.

The data were fitted to a two-dimensional model with the FWHM and tail as the independent variables, so it is difficult to show how the data were fitted on a one-dimensional graph. We, however, can still see some of the approximated fits to most of the data. From Table 1, we see that the tails of most of the peaks are small, about 2% or less. Also, the tails of the peaks at PZ positions 0 and 1 in Table 2 are small as well. So, we may assume that the tails of those peaks are about the same and put the isotopic bias data for those sets on the same bias vs. FWHM one-dimensional plots. Then we can view the approximately fitted functions involving with the FWHMs of the peaks.

Figures 2–6 shows the one-dimensional plots of the data points at different FWHMs (for data involving with different rise times and the first two sets of data with different PZs) and the fitted curves. The curves (solid lines) are the fitted bias curves calculated with the tail values fixed at 2%. These curves may be thought as the sigma curves of the data points, with about 68% of the points are between the curves and 32% outside the curves. The figures are shown in the order of the plutonium isotopes. Note that the different reference peaks are used for different plots and that the 200–1,010-keV region analysis plot has different FWHM scale than the other three plots. The "Pu60-210" plots are for the 60–210-keV region analysis with the current FRAM and the "Pu60-210Xon" plots are for the 60–210-keV region analysis with the upgraded FRAM [6].

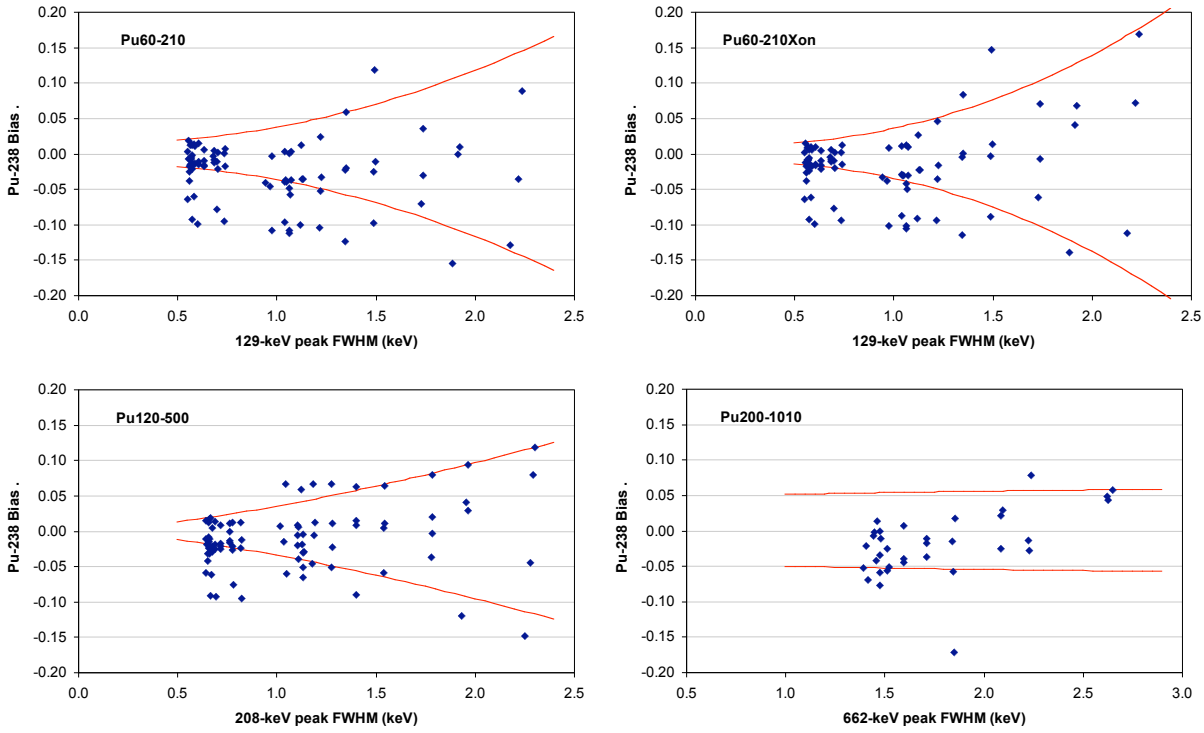

Figure 2. Bias data and fitted curves (at 2% tail) for ^{238}Pu.

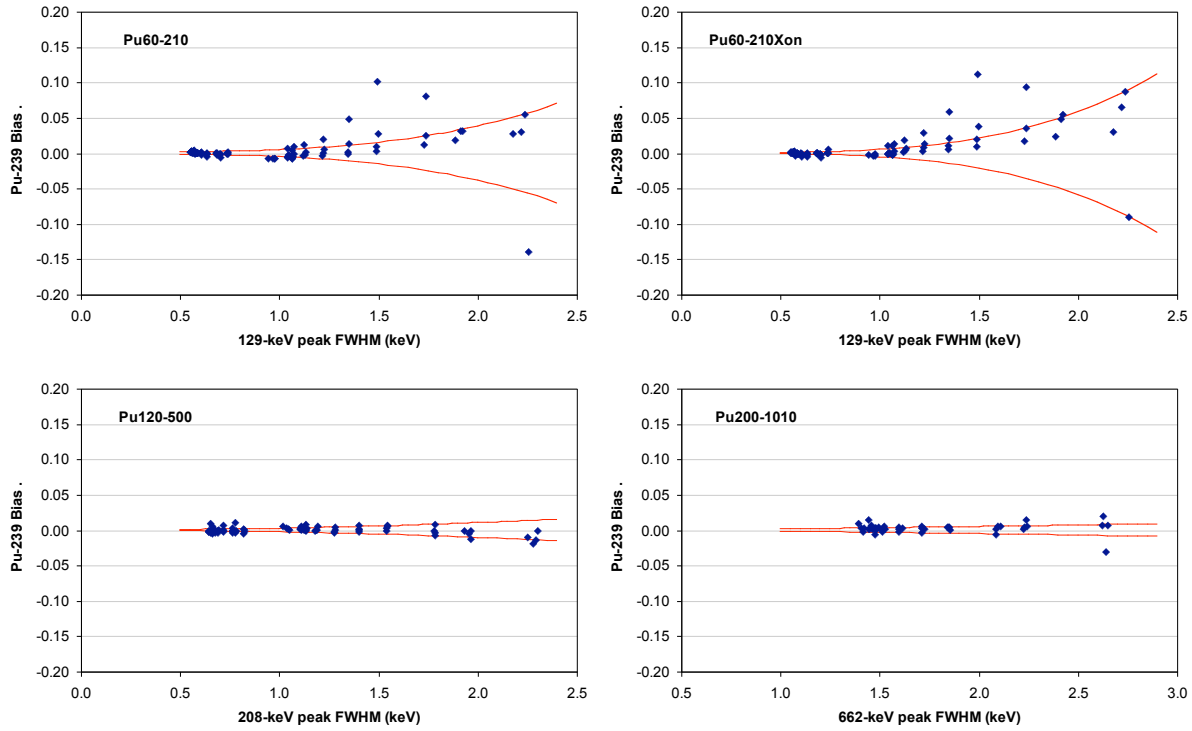

Figure 3. Bias data and fitted curves (at 2% tail) for ^{239}Pu.

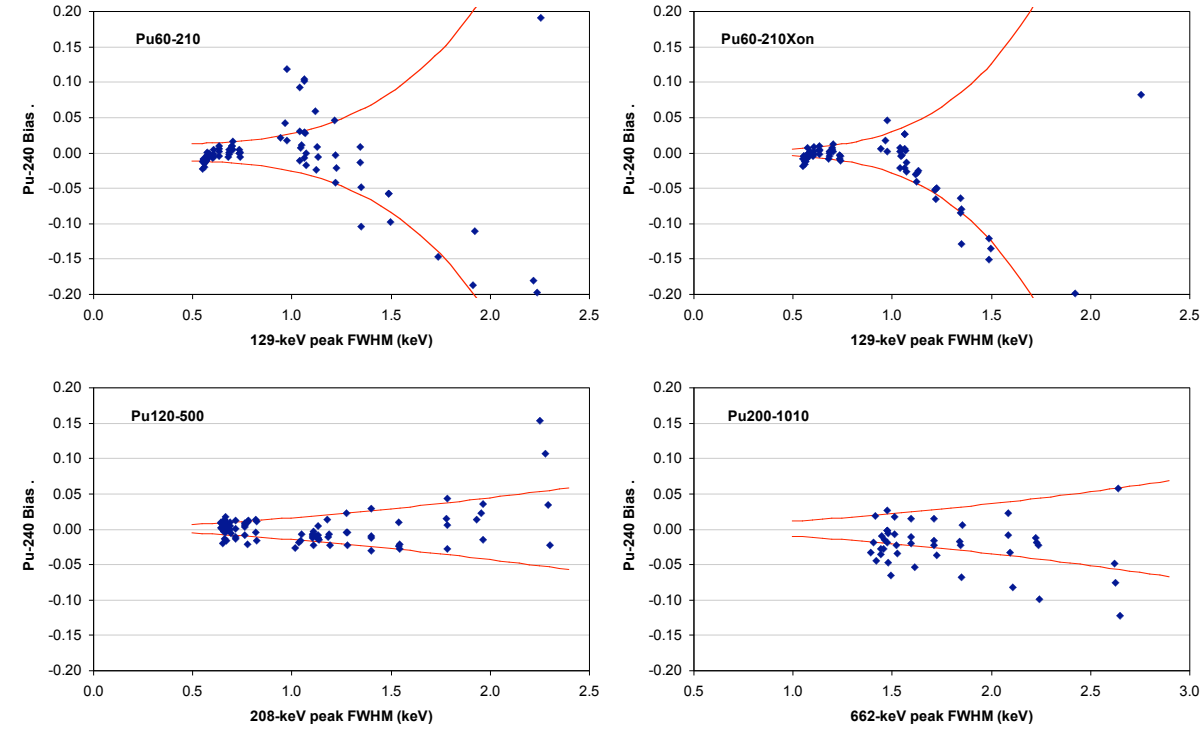

Figure 4. Bias data and fitted curves (at 2% tail) for ^{240}Pu.

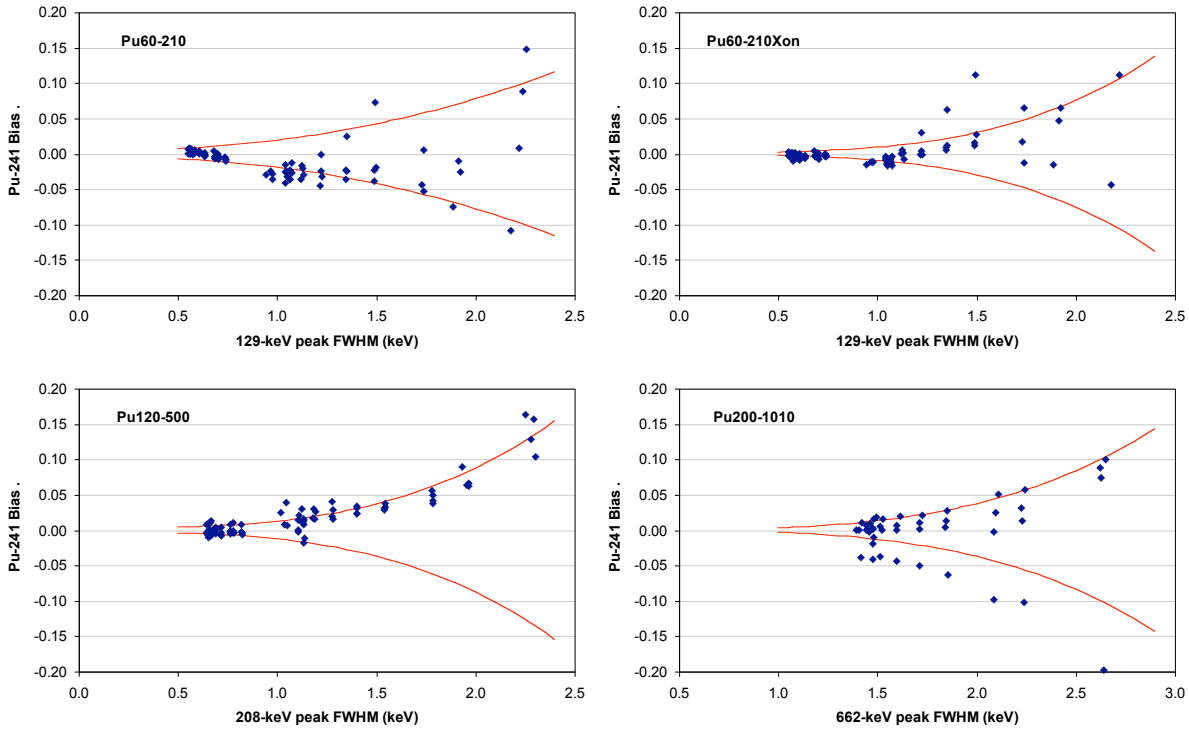

Figure 5. Bias data and fitted curves (at 2% tail) for ^{241}Pu.

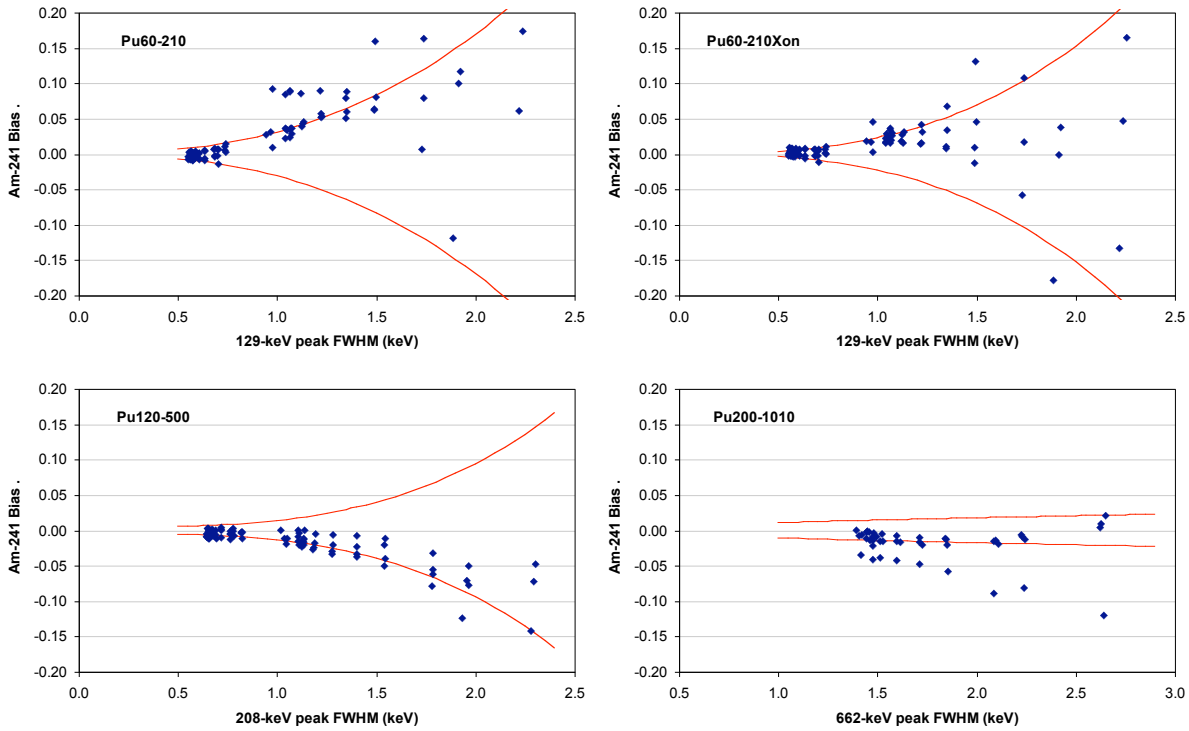

Figure 6. Bias data and fitted curves (at 2% tail) for ^{241}Am.

In Figure 2, we see several unusual things. At first, it appears that the data points for the top two plots are very similar. They are because the upgraded FRAM version does not change the ^{238}Pu results by much.

Secondly, the data points for the third plot at small FWHM (from the planar detector) are very similar to those of the top two plots. Even the data at higher energy (from the coaxial detector) are also somewhat similar. These similarities occur because the same and only peak at 152.7 keV are used for determining the activity of ^{238}Pu.

Thirdly, many points in the first three plots appear to be many sigmas away from the curves. All those bad data points are from the PIDIE-1 sample measurements. For that sample, the isotopic fraction of ^{238}Pu is very small, less than 0.01%. Therefore, its result has a very large error because of very weak statistics. The apparently large bias for those points seen in Figure 2 is due largely to the statistical errors of those points and not the bad fits of the curves.

The bias plots for ^{239}Pu in Figure 3 are the reduced images of those for ^{240}Pu in Figure 4. Some data points at large resolution for the first two plots in Figure 4 are outside the plotted bias ranges. The bias for both analysis methods employing the x-ray regions is very large at large FWHM. This result is expected because the x-ray regions are very complicated with many gamma rays and x-rays closely packed into a small region. To properly resolve those peaks, good resolution such as that from a good planar detector is required. The resolution of greater than 1-keV FWHM at 129 keV, such as that of these measurements of the coaxial detector, is just not good enough for good results.

The biases of the 120–500-keV region analysis in Figures 5 and 6 clearly show the trends of the biases as the function of the resolution. As the resolution increases, the ^{241}Pu bias increases in the positive direction while the bias of ^{241}Am also increases with about the same intensity but in the negative direction. These opposite trends of the biases are likely the results of obtaining the correct peak areas of the co-energetic peaks that contain contributions from both ^{241}Pu-^{237}U and ^{241}Am. When the peak areas of one isotope are positively biased for whatever reason, then the peak areas of the other isotope will be negatively biased. This finding may be one of the reasons, but may not be the only one, for the trends in the bias seen in the 120–500-keV analysis plots in Figures 5 and 6.

When the bias shows trends like those just mentioned, we know that we can make adjustment to the parameter set or to the FRAM code to reduce or eliminate the trend and thus reduce the overall bias. That modification task belongs to another project and is outside the scope of this work.

c. Results

Table 3 shows the results of the fits.

Table 3. Results of the fits of the equation Bias = |Measured/Accepted – 1| = $aW^b + cT^d$, where W and T are the FWHM and tail of the reference peak. The reference peak is the 129-keV peak for the 60–210-keV region analysis, 208-kev peak for the 120–500-keV region analysis, and 662-keV peak for the 200–1,010-keV region analysis.

Isotope	60–210-keV Region Analysis				60–210-keV Region Analysis Upgraded			
	a	b	c	d	a	b	c	d
^{238}Pu	0.02409	2.108	0.00774	0.745	0.02627	2.300	0.00609	0.551
^{239}Pu	0.00349	3.403	0.00076	0.862	0.00479	3.602	0.00038	0.151
^{240}Pu	0.01543	3.846	0.00595	0.860	0.02599	3.815	0.00275	0.169
^{241}Pu	0.01506	2.288	0.00152	1.433	0.00718	3.356	0.00076	1.314
^{241}Am	0.02975	2.495	0.00036	1.860	0.02232	2.768	0.00019	1.430
Isotope	120–500-keV Region Analysis				200–1010-keV Region Analysis			
	a	b	c	d	a	b	c	d
^{238}Pu	0.03458	1.471	0.00000	0.999	0.05049	0.131	0.00000	0.000
^{239}Pu	0.00202	2.285	0.00024	1.153	0.00170	1.562	0.00000	0.000
^{240}Pu	0.01408	1.588	0.00039	1.776	0.01050	1.749	0.00000	0.000
^{241}Pu	0.00943	3.170	0.00169	0.768	0.00302	3.625	0.00001	2.953
^{241}Am	0.00944	3.247	0.00443	0.000	0.01088	0.693	0.00000	0.000

To better visualize the results, we also display them as separate functions of the resolution and tail in the plots in Figure 7. The plots as a function of the resolution are shown on the left and as a function of the tail on the right. The plots are arranged from top to bottom as 60–210-keV region analysis, 60–210-keV region analysis with upgraded FRAM, 120–500-keV region analysis, and 200–1,010-keV region analysis.

The top two sets of plots, 60–210-keV region analysis with the current FRAM and with the upgraded FRAM, have the same X-axis and use the same 129-keV peak for the X-axis values so we can directly compare the biases. We see that the bias as the function of the tail is much smaller for the upgraded FRAM than the current FRAM. It is because this upgraded FRAM version [6] corrects for the large bias of the isotopic fractional results that is due to mainly the large tails of the peaks. However, the plots of the bias as the function of the resolution show the opposite: the upgraded FRAM has worse bias than the current FRAM. The reason for the poor performance of the upgraded FRAM is this: the correction for the large bias employed in the upgraded FRAM was developed using the data obtained with a planar detector that has good resolution and was intended for use with spectra with good peak resolution. For the analysis of spectra with broad resolution, such as those acquired with the coaxial detector, the correction would worsen the results instead of improving it. Note that the correction of the upgraded FRAM still improves the results for spectra with peaks with large tails.

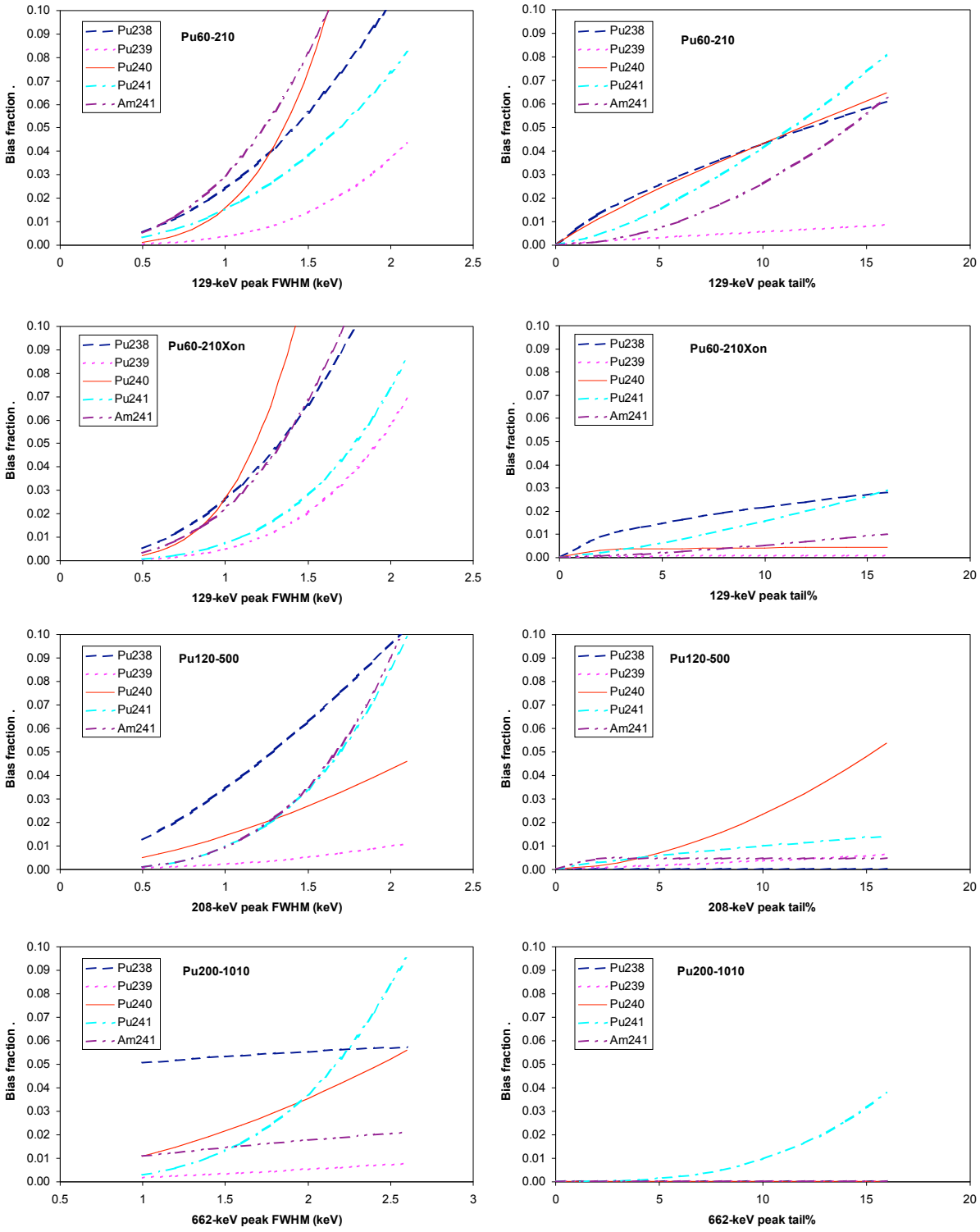

Figure 7. Biases as the functions of the FWHMs and of the tails of the peaks. The reference peak is the 129-keV peak for the 60–210-keV region analysis, 208-kev peak for the 120–500-keV region analysis, and 662-keV peak for the 200–1,010-keV region analysis.

This worsening of the results for spectra with broad peaks by the upgraded FRAM is not a concern because a) one can always turn on or off the correction feature in the upgraded FRAM and b) the 60–210-keV region analysis of spectra of the coaxial detector has very large bias and is not used in any real analysis. The only exception for the use of the 60–210-keV region analysis with broad peak spectra is for the CdTe spectrum analysis. The CdTe detector is very small, and its efficiency is very small, especially at high energy. To be able to make measurements with a CdTe detector in a reasonable time, the 60–210-keV region analysis is the only choice. One can always analyze the CdTe spectra using the 120–500-keV region analysis, but the measurements will have to be very long (at least an hour), and the statistical errors are very large.

The 120–500-keV region analysis shows small bias as the function of the tail for most of the isotopes except ^{240}Pu. For ^{240}Pu, the bias starts out small for small tails, but it quickly increases as the tail magnitude becomes larger. We believe that this result was due to the proximity of the peaks in the 160-keV region where three other peaks are overlapping with the 160-keV peak of ^{240}Pu. When the tails become larger, then it becomes more difficult to accurately determine the 160-keV peak area, and the bias increases.

It is interesting to note that the results of the 200–1,010-keV region analysis are independent of the tail for most of the isotopes. The only exception is the ^{241}Pu, which has peaks only at the low end of the 200–1,010-keV region.

From Table 3 and Figure 7, we see that as long as the widths of the peaks are not zero, some bias will always be associated with the finite resolutions. (The tail can be made zero or very near zero with a good detector system and careful measurements.) A quick scan of the plots in Figure 7 reveals that the 60–210-keV region analysis (with either the current of upgraded FRAM) can give the smallest bias if we can minimize the size of the tails of the peaks.

d. Comparison with other methods

The Safeguards Science and Technology (N-1) Group at LANL has a large set of archival spectra of plutonium acquired through the years since 1988. These spectra were of both lab and field measurements of small (less than 1 g) up to large (several kg) samples, and they were acquired with various detectors and electronics. These spectra were analyzed using the three standard parameter sets included in the distribution of FRAM v4, Planar_Widerange3, Coax_Widerange3, and ShCoax_Widerange3 for the 120–500-keV region analysis of both the planar and coaxial detector and the 200–1,010-keV region analysis of the coaxial detector. The isotopic results of these analyses were then analyzed by two different methods to obtain the biases for different isotopes.

The first method was simple [2–3]. The results of multiple runs for each sample were averaged. The RSD of the large set of the ratios of those average measured values divided by the accepted values represents the minimum bias for an arbitrary measurement. The second method was the Analysis of Variance (ANOVA) [7], considered to be more standard for estimating measurement bias from existing data sets.

To validate the method and results of this work, we need to compare the results at the appropriate resolution and tail with the results from the other two methods. Experts in the gamma-ray field obtained the archival data throughout many years using what was state-of-the-art equipment at the time, so the data all have excellent resolution and peak shape. On average, the resolution of the planar detector was about 0.55 keV at 129 keV and 0.69 keV at 208 keV and for the coaxial detector was about 0.89 keV at 129 keV, 0.96 keV at 208 keV, and 1.45 keV at 662 keV. The tails were about 1% for the 129- and 208-keV peaks and 2% for the 662-keV peak. We calculated the corresponding biases using Eq. 3, the information in Table 3, and the average resolution and tail values of the 208- and 662-keV peaks just mentioned. The resolution and tail values for the 129-keV peak given above were informative only and were not used in the calculation of the biases. Table 4 shows the comparison of the biases. The % bias for the "simple" method is the % RSD of the average bias [2–3] and is the relative systematic error for the ANOVA method [7].

Table 4. Comparison with other methods.

Analysis	Bias Method	^{238}Pu	^{239}Pu	^{240}Pu	^{241}Pu	^{241}Am
Planar 120–500 keV	Simple	1.91	0.12	0.77	0.61	1.30
	ANOVA	1.6	0.1	.07	0.6	1.3
	This work	2.00	0.11	0.82	0.46	0.73
Coaxial 120–500 keV	Simple	1.81	0.12	0.82	0.59	0.93
	ANOVA	2.3	0.1	0.8	0.6	0.9
	This work	3.26	0.21	1.36	1.00	1.27
Coaxial 200–1,010 keV	Simple	5.83	0.37	1.58	0.76	0.81
	ANOVA	7.6	0.4	1.6	0.7	0.8
	This work	5.30	0.30	2.01	1.17	1.41

The biases for the "simple" and ANOVA methods appear to be very similar. It is because they both use the same data set. The biases from this work are slightly different from those of the other two methods, but that is expected because this work uses a completely different data set and method for analysis. For the coaxial detector, the biases of most isotopes from this work are slightly larger than those of the other two methods. The reason for it is probably due to the performances of the parameter sets for coaxial detector used in this work. Note that even though these parameter sets were derived from the Coax_Widerange3 and ShCoax_Widerange3 parameter sets, due to the one-size-fits-all characteristics (regarding the peak resolution) of these parameter sets, their performances with a good detector are probably a bit worse than those of the original parameter sets. They are better than the original parameter sets only for spectra with very broad peak resolutions.

Overall, despite those differences, the biases in this work appear to agree with the biases from the other two methods reasonably well. No differences between these methods exceed a factor of two for all these comparisons.

C. URANIUM

FRAM can also obtain a complete isotopic analysis for uranium. If a planar detector is used, FRAM normally analyzes data from 80 to 210 keV. In low-enriched uranium (LEU), where the 63.3-keV peak from the ^{238}U decay-chain may be visible, FRAM may also use that peak. In

some measurement situations with the planar detector where the uranium is shielded by a somewhat thick absorber (such as the UF_6 cylinders) and the low-energy gamma rays and x-rays may not be visible, then FRAM may use the peaks in the range from 120 to 1,010 keV for analysis. If a coaxial detector is used, the analytical energy range is normally from 120 to 1,010 keV. Figure 8 shows an example of a uranium spectrum with two regions, one below the K-edge and one above the K-edge, separated by the dashed line. The two thick horizontal bars above the spectrum represent the two overlapping analytical regions that FRAM normally uses for the analysis.

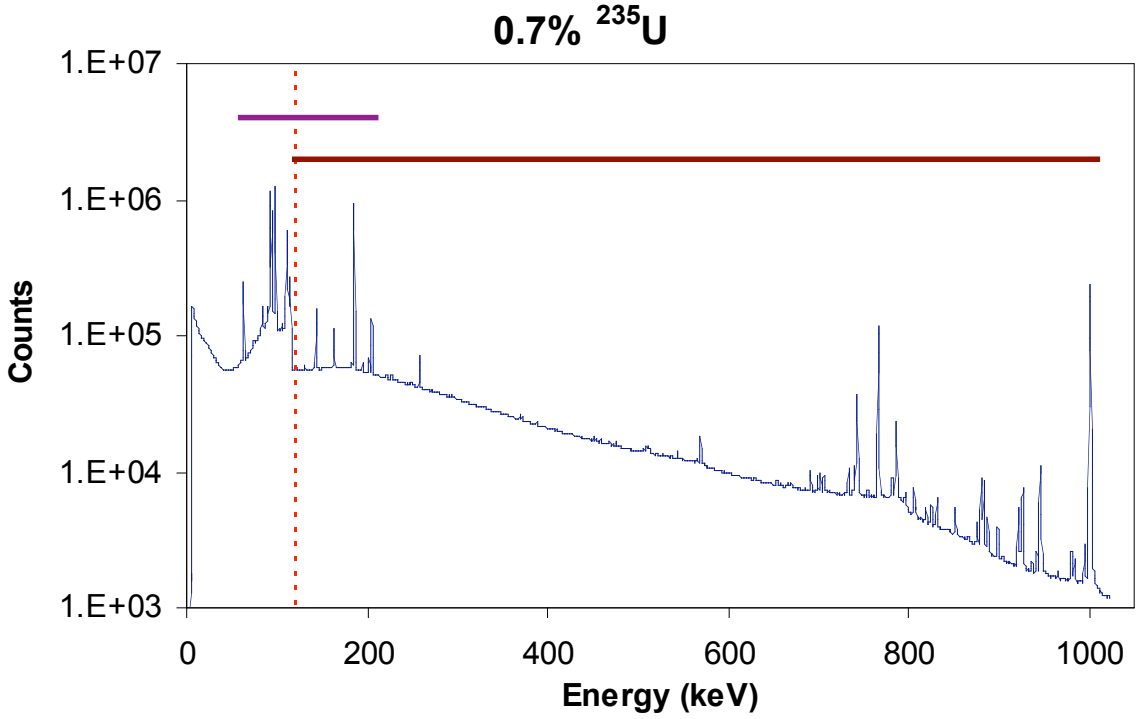

Figure 8. A natural-uranium spectrum. The vertical dash line separates the two regions: one below the K-edge and one above the K-edge. The two overlapping analytical regions that FRAM normally uses for the analysis are shown as two thick horizontal bars above the spectrum.

1. Data acquisition

The data acquisition system was set up the same way as it was for the plutonium bias determination (Section B). For these measurements, five LEU samples of the NBS-SRM* 969 set and three highly enriched uranium (HEU) samples of the NBL-CRM† 146 set, ranging from 0.3 to 93.2% ^{235}U enrichment, were used. These samples weight about 200 g each. For the planar detector system, the input rates for the five LEU samples were small, ranging from 1.8 kHz for the 0.3% ^{235}U sample to 3.5 kHz for the 4.5% ^{235}U sample. For the three HEU samples, input rates were at 10 kHz. For the coaxial detector system, the input rates were about 20 kHz for all eight samples.

* NBS-SRM - National Bureau of Standards - Standard Reference Materials.
† NBL-CRM - New Brunswick Laboratory - Certified Reference Materials.

The data for the planar detector were acquired in 4-K channels at 0.075 keV/ch and analyzed using the peaks in the 60–210-keV energy range. For the coaxial detector, the spectra were acquired in 8-K channels at 0.125 keV/ch and analyzed using the parameter set employing the 120–1,010-keV region.

Just as we did for plutonium (Section B), we varied the rise time of the DSPEC Plus to obtain spectra with various resolutions for both detector systems. The rise times used were 0.2, 0.4, 0.6, 1.0, 1.4, 2.0, 2.8, 4.0, and 8.0 μs. The flattop was 1.0 μs, and the cusp value was 0.8. The acquisition time for each spectrum was 15 minutes of live time.

In order to obtain spectra with various shapes, we used a rise time of 4.0 μs and manually adjusted the PZ to produce peaks with low-energy tails of various sizes. For each sample, six sets of data, with 16 spectra (15 minute true time) for each set, were obtained, with the 186-keV peak-tail percents varying from approximately zero to about 15%.

Table 5 shows the average resolutions of the 186-keV peak of the spectra for each rise time setting and PZ setting for both detectors. The variations of the FWHMs and tails for different samples with the same rise time are small for both the planar and coaxial detectors. In general, the resolution becomes better while the tail remains about constant as the rise time increases from 0.2 μs to 8.0 μs.

Table 5. Average resolution and tail of the 186-keV peak.

Rise time (μs) / PZ	Planar		Coaxial	
	FWHM (eV)	%Tail	FWHM (eV)	%Tail
0.2	766	1.08	2324	1.71
0.4	731	1.10	1975	0.98
0.6	707	1.01	1782	0.71
1.0	670	1.18	1537	0.86
1.4	652	1.15	1393	0.81
2.0	637	1.08	1271	1.00
2.8	629	1.06	1187	1.57
4.0	618	1.61	1098	2.21
8.0	610	1.41	999	2.10
PZ#0	617	1.17	1093	1.20
PZ#1	627	2.32	1128	3.89
PZ#2	647	4.60	1195	7.40
PZ#3	669	6.91	1281	10.34
PZ#4	694	8.86	1372	12.87
PZ#5	721	10.42	1472	14.57

2. Analysis

a. LEU and HEU

We analyzed the data using the appropriate parameter sets for the data: parameter sets using the 60–210-keV region for both the planar and coaxial detectors and the 120–1,010-keV region for the coaxial detector. These parameter sets were modified slightly to account for the much wider peak resolution from the existing parameter sets included with the distribution of the current FRAM v4, U100keVLEU, U100keVHEU, and U121_1001Coax. In the 60–210-keV region analysis, we analyzed the data using the current FRAM v4 version and the upgraded FRAM, as we did with the plutonium analysis in Section B.

For the coaxial analysis in the 120–1,010-keV region, instead of using the one-size-fits-all parameter set such as the U121_1001Coax set that is used for all the uranium enrichment, we made different parameter sets for LEU and HEU. The difference between the two sets is the use of the 766-keV peak of the ^{238}U decay chain for the energy, FWHM, and shape calibrations in the LEU parameter set and not in the HEU set. The reason is that for HEU, especially the very

high HEU, the 766-keV peak is very weak, and the (interference) peaks at 763 keV and 768 keV can interfere with it and ruin the analysis if it is used for calibration.

We further divided the HEU analysis into two: one that used the gamma rays of ^{235}U, ^{238}U, and ^{228}Th for the relative efficiency curve, and one that used only the peaks of ^{235}U and ^{238}U decay for the relative efficiency curve. There is normally some ^{228}Th in uranium if the uranium is enriched from recycled uranium. Therefore, we may be able to use the gamma rays from ^{228}Th decay to determine the relative efficiency curve. However, in LEU or HEU enriched from natural uranium where the gamma rays from the ^{228}Th decay chain may be weak or absent, only the peaks of ^{235}U and ^{238}U decay can be used to determine the relative efficiency curve. This division based on ^{228}Th is not necessary for LEU analysis since the ^{228}Th is normally very weak in LEU and its presence or absence would not significantly alter the results. For the LEU measurements done in this work, the results are about the same regardless of the use of ^{228}Th in the parameter set or not. However, for actual measurements in the field where the detector is not adequately shielded and the uranium quantity is tiny, then the gamma rays from ^{228}Th decay chain from the background (soil, concrete, etc.) entering the detector may become significant relative to the uranium peaks and the ^{228}Th peaks from the sample. Then those unwanted ^{228}Th peaks from the background may affect the efficiency curve of LEU somewhat and may bias the results if the ^{228}Th peaks are used for the determination of the efficiency curve. So we suggest that, for LEU, no ^{228}Th peaks be used for relative efficiency determination.

b. Correlation

The correlation equation relating the resolutions and tails of the peaks to the bias of ^{234}U and ^{235}U is the same as that of plutonium. It is

$$\text{Bias} = a\boldsymbol{W}^b + c\boldsymbol{T}^d , \qquad \text{(Eq. 3)}$$

where bias = |Measured/Accepted – 1|, a, b, c, and d are nonnegative variables, $\boldsymbol{W}$ is the FWHM of the selected peak, and $\boldsymbol{T}$ is the tail percent of that selected peak. The selected peak is chosen to be the 185.7 keV peak of ^{235}U for all different region analyses.

As for ^{238}U, this correlation (Eq. 3) does not work well. A good correlation for ^{238}U bias would be

$$\text{Bias} = (^{235}\text{U}/^{238}\text{U})^* (a\boldsymbol{W}^b + c\boldsymbol{T}^d) \qquad \text{(Eq. 4)}$$

It turns out that this ^{238}U bias is closely related to the bias of ^{235}U. The ^{238}U bias can be calculated from the ^{235}U bias through the relationship (^{238}U bias) = (^{235}U bias) * (^{235}U/^{238}U).

The bias fittings of Equation 3 for ^{234}U and ^{235}U are done the same way as for plutonium described in section B.2.b. Figures 9 and 10 show the one-dimensional plots of the data points at different FWHMs (for data involving with different rise times and the first two sets of data with different PZs) and the fitted curves. The curves (solid lines) are the fitted bias curves calculated with the tail values fixed at 2%. The "U120_1010 no Th" plots are for the HEU analysis with no ^{228}Th peaks for relative efficiency determination. Those plots do not include LEU data.

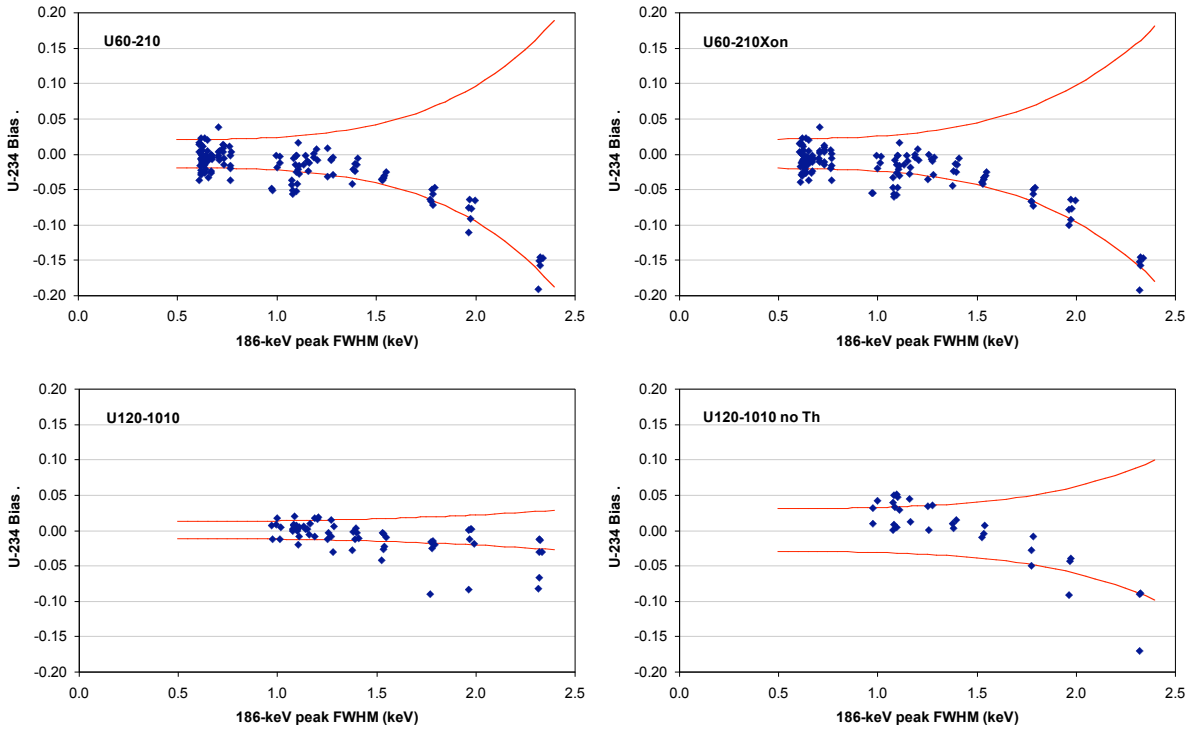

Figure 9. Bias data and fitted curves (at 2% tail) for ^{234}U.

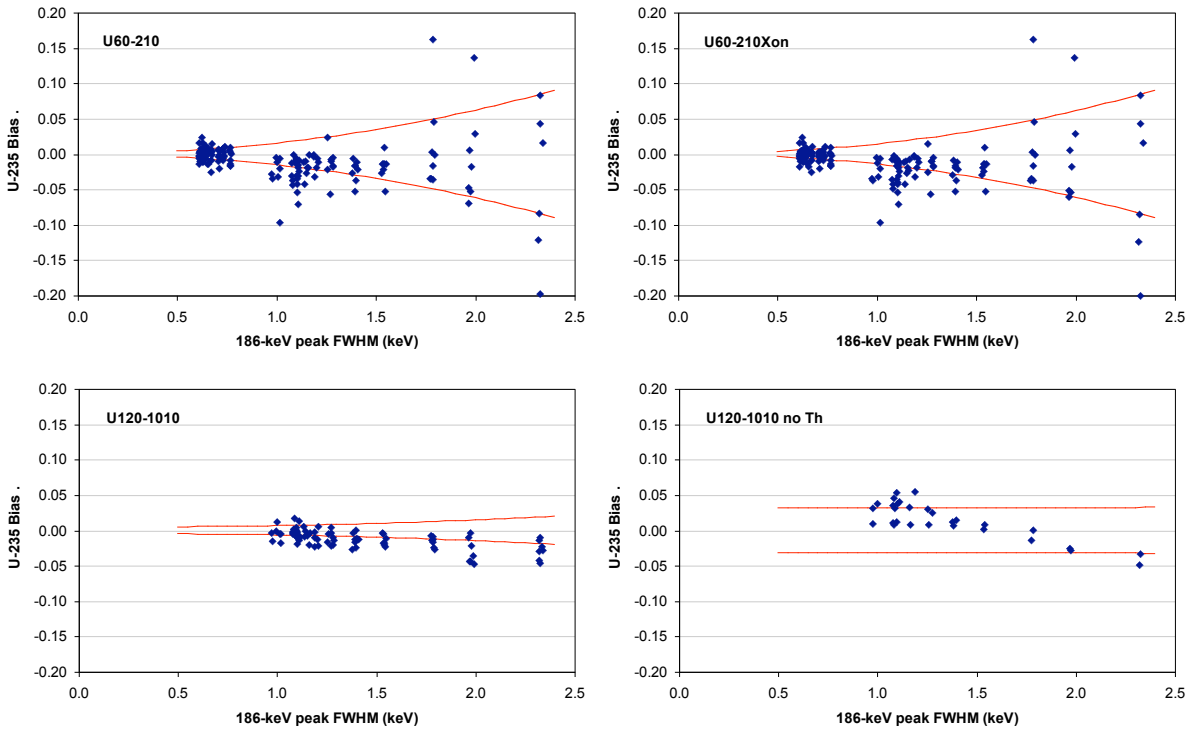

Figure 10. Bias data and fitted curves (at 2% tail) for ^{235}U.

The ^{234}U fraction results of the depleted (0.3% ^{235}U) and natural uranium (0.7% ^{235}U) have very large statistical errors. Those results were used in the fits for the ^{234}U bias, but they were not plotted in the plots in Figure 9; if they were, their widely scattered positions would dilute the significances of other data points in the plots.

We see from the "U60_210" and "U60_210Xon" plots for ^{234}U and ^{235}U that they both are very much the same. It is because the upgraded FRAM corrects for the large bias of the 60–210-keV region analysis caused by the large tails of the peaks only. The data points and curves in these plots are for small tails only so the corrections from the upgraded FRAM are minimal in these plots.

Similar to the plutonium bias of the 60–210-keV region analysis, we see that the 60–210-keV region analysis for uranium also depends very much on the resolution of the peaks. The bias is small at small resolution but quickly increases as the resolution increases. The reason for the quick increase of the bias as a function of the resolution is the closely packing of the peaks in the region about the peak pair of ^{238}U decay chain at about 92 keV.

For the analyses in the 120–1,010-keV region, the biases of both ^{234}U and ^{235}U are much less dependent on the peak resolution or tail. It is because most of the gamma rays in this region are widely separated, so they are not very affected by the change in resolution and peak shape.

c. Results

Table 6 shows the results of the fits.

Table 6. Results of the fits of the equation Bias = |Measured/Accepted – 1| = $aW^b + cT^d$, where W and T are the FWHM and tail of the 186-keV reference peak.

Isotope	60–210-keV				60–210-keV upgraded			
	a	b	c	d	a	b	c	d
^{234}U	0.00366	4.377	0.01955	0.000	0.00444	4.091	0.02037	0.000
^{235}U	0.01443	2.081	0.00033	1.526	0.01330	2.178	0.00038	1.312
Isotope	**120–1,010-keV**				**120–1,010-keV no ^{228}Th**			
	a	b	c	d	a	b	c	d
^{234}U	0.00142	2.787	0.01145	0.000	0.00154	4.334	0.03028	0.000
^{235}U	0.00211	2.250	0.00265	0.769	0.00011	2.006	0.03179	0.000

Figure 11 displays the results as separate functions of the resolution and tail. The plots as function of the resolution are shown on the left and as function of the tail on the right. The plots are arranged from top to bottom as 60–210-keV region analysis, 60–210-keV region analysis with upgraded FRAM, 120–1,010-keV region analysis, and 120–1,010-keV region analysis without the ^{228}Th peaks for efficiency calculation.

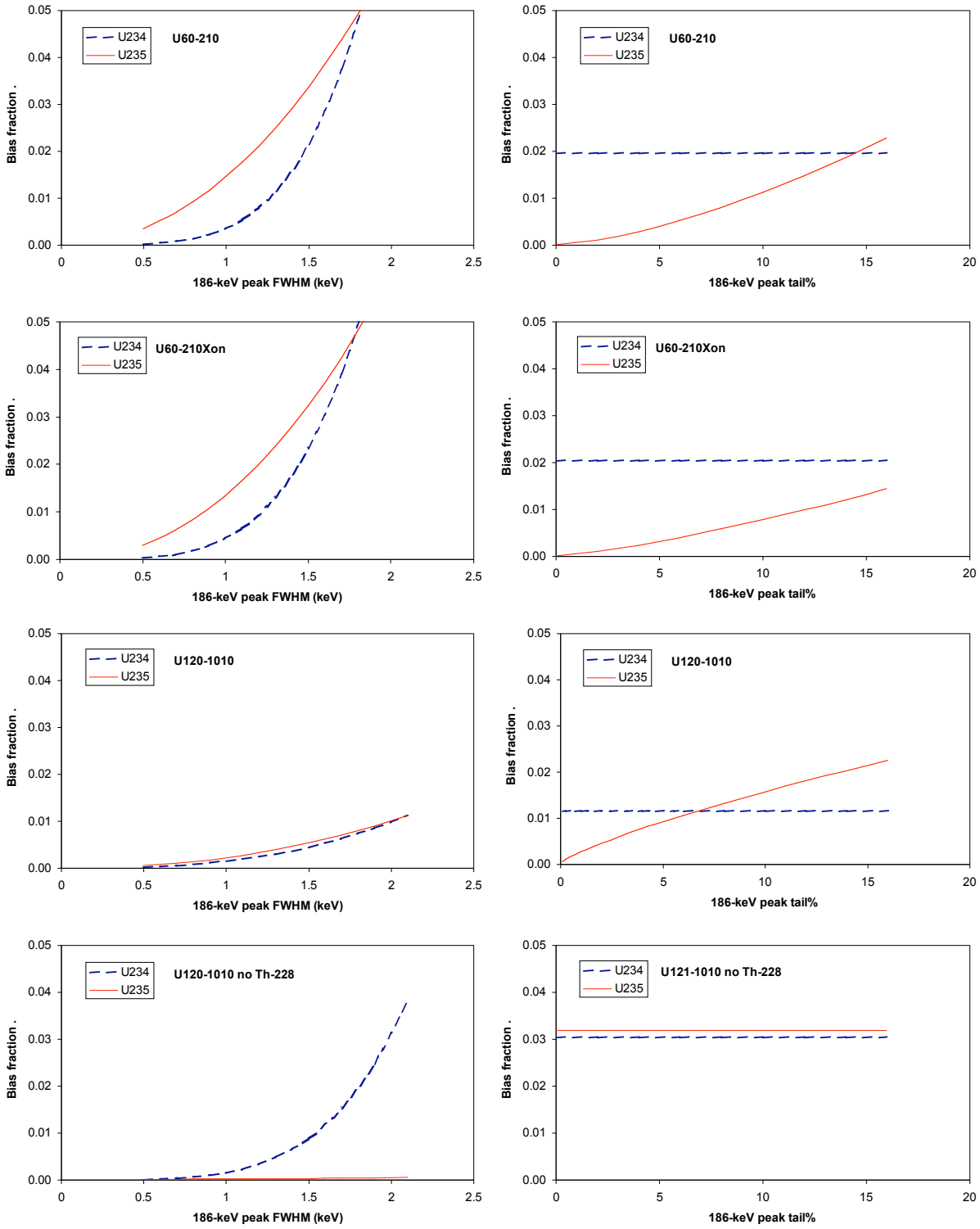

Figure 11. Biases as the functions of the FWHMs and of the tails of the peaks. The reference peak is the 186-keV peak for all different region analyses.

All the ^{234}U biases for all the region analyses appear to be at some constant values. This appearance is somewhat misleading. It just means that the ^{234}U bias is independent of the tails of the peaks. For these biases, we cannot think of them as separate functions of the separate resolution and tail but as the combined results of both the resolution and tail.

We see that the biases for both the 60–210-keV region analyses with the current FRAM and the upgraded FRAM are very similar, with the ^{235}U bias at the large tail of the upgraded FRAM a bit better. For the analyses at the 120–1,010-keV region, the bias for the HEU analysis without the ^{228}Th peaks is much worse than the analysis with the ^{228}Th peaks for efficiency calculations. It is expected because the lack of the ^{228}Th peaks reduces the accuracy of the relative efficiency curve and thus worsens the biases.

Note that the 60–210-keV region analysis does not depend on the ^{228}Th peaks, so it should be used with a planar detector or even with a good coaxial detector, for analysis of HEU in thin containers that do not have much ^{228}Th concentration. From the plots in Figure 11, we see that the bias of the 120–1,010-keV region analysis without the ^{228}Th peaks is about constant at 3.2%. For a good coaxial detector, the 186-keV peak resolution is about 1 keV or less, which would result in bias of less than 2% if analyzed by the 60–210-keV region analyses (with either the current FRAM or the upgraded FRAM).

d. Comparison with other methods

Group N-1 at LANL also has a large set of archival spectra of uranium, similar to the archival plutonium spectra mentioned in section B.2.d, acquired through the years with various coaxial detectors. These spectra were analyzed using the standard parameter set for uranium included in the distribution of FRAM v4, U120_1001Coax. The isotopic results of these analyses were then analyzed by the "simple" method [2–3]. There is no ANOVA analysis of these results. Table 7 shows the comparison of the biases determined by the "simple" method and the method in this work. For this work, the biases are calculated using the variables of the 120–1,010-keV region analysis with ^{228}Th peaks in Table 6 and the FWHM and tail of 0.94 keV and 1% respectively at 186 keV. Refs. 2–3 also determined the ^{238}U bias, but we cannot compare it here because the ^{238}U bias in this work also depends on the ^{235}U/^{238}U ratio and cannot be expressed as a number in the table for easy comparison.

We see that the bias in this work is about half of those determined by the "simple" method. We do not currently know for sure the reason for these differences. It could be that the separate parameter sets used for LEU and HEU in this work can give better results than the one-size-fits-all parameter set used in the analysis in Refs. 2–3.

Table 7. Comparison with the "simple" method.

Analysis	Bias method	^{234}U	^{235}U
Coaxial	Simple	2.20	0.90
120–1,010 keV	This work	1.26	0.45

D. CONCLUSION

We have studied the bias of FRAM analysis by employing various parameter sets using gamma and x-rays in various energy regions of data taken with the planar and coaxial detectors. We determined the biases as functions of the resolutions and the tails of the peaks. This method takes the specific measurement conditions into account for every measurement and estimates the bias based on those measurement conditions.

The upgraded FRAM (to be released hopefully by sometime in 2006) will include the systematic uncertainties in addition to the random uncertainties in its results. These systematic uncertainties will be based on the biases shown in this paper. In the meantime, the users of the current FRAM can estimate the biases or systematic uncertainties of the results using Eq. 3 and the variables in Tables 3 and 6.

This paper shows only the results of the work done using the physical-efficiency curve. The biases that occur with the empirical-efficiency model of FRAM are believed to be similar for plutonium analysis in the regions above 120 keV and somewhat larger for uranium analysis in the region above 120 keV. Note that the empirical-efficiency analysis cannot analyze the x-ray regions because of the inability to cross the plutonium or uranium K-edge.

Acknowledgement

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APPENDIX

This section lists the parameter sets used in this work except the parameter sets analyzing the 60–210-keV regions of the coaxial detectors. All these parameter sets were slightly modified from the standard parameter sets distributed with FRAM v4 to account for much wider measurement conditions of this work.

UPu100keVSolidX

This parameter set is derived from the Pu100keV2 parameter set. It should give somewhat better precision than the Pu100keV2 parameter set for low-burnup plutonium. It also includes ^{235}U and ^{238}U for the analysis of MOX material. This parameter set can give good results for MOX samples with the ^{235}U/Pu ratio of up to 1. For higher ^{235}U/Pu ratio, the user should make modification to the parameter set to account for the more intense peaks of ^{235}U. This parameter set is good for a detector with the 129-keV peak resolution of up to 0.9 keV.

In the "Application constants" part of the parameter set, the statement "fix_100kev_plutonium" is applicable for only the upgraded FRAM [6]. "TRUE" would turn on the bias correction algorithm correction, and "FALSE" would turn it off; the code would then work just like the current FRAM. This "fix_100kev_plutonium"statement has no effect when used with the current FRAM.

```
// fit information
name: UPu60_210SolidX
desc: "Planar .075 kev/ch, Equ. w U,  U235/Pu <1, 60-210keV"
date: "2005.05.19 08:48"
ecal: 7.500000e-002 0.000000e+000
fix-ecal: N
fcal: 2.900000e+000 3.900000e-001 0.000000e+000
fix-fcal: N
scal: -3.000000e+000 1.000000e-002 4.000000e-001 0.000000e+000
fix-scal: N
// peak information
num_peaks: 72
  1 "Pu241" 59.536    0.000 8.487000e-006 0.000000e+000  71   0 N N N N N 9
  2 "Am241" 59.536    0.000 3.590000e-001 0.000000e+000   0   0 Y N Y Y Y 9
  3 "U238"  92.370    0.000 2.467000e-002 0.000000e+000   4   0 N N N N N 10
  4 "U238"  92.792    0.000 2.552000e-002 0.000000e+000   0   0 N Y N N N 10
  5 "U235"  93.358   80.400 5.136000e-002 0.000000e+000  66   0 N N N N N 10
  6 "UXray" 93.848   87.600 1.470000e-007 0.000000e+000   7   0 N N N N N 10
  7 "UXray" 94.658   87.600 4.220000e-005 0.000000e+000   0   0 Y Y Y N N 10
  8 "Pu239" 96.130    0.000 2.300000e-007 0.000000e+000  52   0 N N N N N 12
  9 "Pu241" 96.245   91.300 1.477000e-008 0.000000e+000  10   0 N N N N N 12
 10 "Pu241" 97.072   91.300 3.735000e-006 0.000000e+000   0   0 N N N N N 12
 11 "UXray" 98.441   87.600 6.760000e-005 0.000000e+000   0   0 N Y N N N 12
 12 "PuXray"98.703   95.000 1.660000e-007 0.000000e+000  15   0 N N N N N 12
 13 "Pu239" 98.780    0.000 1.230000e-005 0.000000e+000  52   0 N N N N N 12
 14 "Am241" 98.951    0.000 1.970000e-004 0.000000e+000   0   0 N N N N N 12
 15 "PuXray"99.541   95.000 4.130000e-005 0.000000e+000   0   0 N N N N N 12
 16 "Pu238" 99.866    0.000 6.954000e-005 0.000000e+000  61   0 N N N N N 12
 17 "Pu241" 101.066  91.300 6.129000e-006 0.000000e+000   0   0 Y Y N N N 12
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 18 "Am241" 101.066   91.300 1.912000e-005 0.000000e+000  21   0 N N N N N 12
 19 "Am241" 102.040   99.000 7.059000e-007 0.000000e+000  26   0 N N N N N 12
 20 "Pu241" 102.961    0.000 1.568000e-009 0.000000e+000  17   0 N N N N N 12
 21 "Am241" 102.961    0.000 1.911000e-004 0.000000e+000   0   0 Y Y N N N 12
 22 "Pu239" 103.064    0.000 2.250000e-006 0.000000e+000  52   0 N N N N N 12
 23 "Pu241" 103.672    0.000 9.600000e-007 0.000000e+000  17   0 N N N N N 12
 24 "PuXray"103.748   95.000 6.900000e-005 0.000000e+000   0   0 N N N N N 12
 25 "Pu240" 104.242    0.000 6.880000e-005 0.000000e+000   0   0 N Y N N N 12
 26 "Am241" 106.481   99.000 1.117000e-006 0.000000e+000   0   0 N N N N N 11
 27 "UXray" 110.426   87.600 8.470000e-006 0.000000e+000   0   0 Y N N N N 13
 28 "UXray" 111.304   87.600 1.620000e-005 0.000000e+000   0   0 Y N N N N 13
 29 "UXray" 111.970   87.600 5.950000e-007 0.000000e+000  28   0 N N N N N 13
 30 "Pu241" 113.316   91.300 7.470000e-007 0.000000e+000   0   0 N N N N N 13
 31 "Pu241" 114.249   91.300 1.415000e-006 0.000000e+000   0   0 N N N N N 13
 32 "UXray" 114.551   87.600 6.246000e-006 0.000000e+000   0   0 N N N N N 13
 33 "UXray" 114.859   87.600 1.800000e-007 0.000000e+000  32   0 N N N N N 13
 34 "Pu241" 114.927   91.300 5.450000e-008 0.000000e+000  10   0 N N N N N 13
 35 "UXray" 115.394   87.600 1.406000e-006 0.000000e+000  32   0 N N N N N 13
 36 "Pu239" 115.395    0.000 4.956000e-006 0.000000e+000   0   0 N N N N N 13
 37 "UXray" 115.597   87.600 2.380000e-007 0.000000e+000  32   0 N N N N N 13
 38 "PuXray"116.250   95.000 8.209000e-006 0.000000e+000  40   0 N N N N N 13
 39 "Pu239" 116.270    0.000 5.860000e-006 0.000000e+000   0   0 N N N N N 13
 40 "PuXray"117.238   95.000 1.640000e-005 0.000000e+000   0   0 N N N N N 13
 41 "Pu241" 117.554   91.300 5.667000e-007 0.000000e+000   0   0 N N N N N 13
 42 "PuXray"117.925   95.000 6.320000e-007 0.000000e+000  40   0 N N N N N 13
 43 "Pu241" 117.967   91.300 1.630000e-008 0.000000e+000  41   0 N N N N N 13
 44 "Pu241" 118.430   91.300 1.318000e-007 0.000000e+000   0   0 N N N N N 13
 45 "Pu241" 118.650   91.300 2.200000e-008 0.000000e+000  10   0 N N N N N 13
 46 ""      118.900    0.000 0.000000e+000 0.000000e+000   0   0 N N N N N 13
 47 "Am241" 123.003    0.000 1.010000e-005 0.000000e+000   0   0 N N N N N 2
 48 "Pu239" 123.620    0.000 1.900000e-007 0.000000e+000  52   0 N N N N N 2
 49 "Pu239" 124.530    0.000 6.270000e-007 0.000000e+000   0   0 N N N N N 2
 50 "Pu239" 125.222    0.000 5.350000e-007 0.000000e+000  52   0 N N N N N 2
 51 "Am241" 125.292    0.000 4.078000e-005 0.000000e+000   0   0 Y Y N N N 2
 52 "Pu239" 129.294    0.000 6.260000e-005 0.000000e+000   0   0 Y Y Y Y Y 1
 53 "Pu239" 141.657    0.000 3.341000e-007 0.000000e+000  56   0 N N N N N 0
 54 "Pu239" 143.350    0.000 1.806000e-007 0.000000e+000  56   0 N N N N N 0
 55 "U235"  143.760    0.000 1.095000e-001 0.000000e+000  66   0 N N N N N 4
 56 "Pu239" 144.211    0.000 2.888000e-006 0.000000e+000   0   0 N N N N N 4
 57 "Pu239" 146.077    0.000 1.224000e-006 0.000000e+000  56   0 N N N N N 4
 58 "Am241" 146.557    0.000 4.750000e-006 0.000000e+000   0   0 N N N N N 4
 59 "Pu241" 148.567    0.000 1.885000e-006 0.000000e+000   0   0 Y Y Y Y N 4
 60 "Am241" 150.113    0.000 7.570000e-007 0.000000e+000  58   0 N N N N N 4
 61 "Pu238" 152.720    0.000 9.310000e-006 0.000000e+000   0   0 N Y N N N 5
 62 "U235"  163.354    0.000 5.089000e-002 0.000000e+000  66   0 N N N N N 6
 63 "Pu241" 164.597    0.000 4.614000e-007 0.000000e+000   0   0 Y Y N N N 6
 64 "Am241" 164.597    0.000 6.807000e-007 0.000000e+000  51   0 N N N N N 6
 65 "Am241" 165.930    0.000 2.300000e-007 0.000000e+000   0   0 N N N N N 6
 66 "U235"  185.715    0.000 5.739000e-001 0.000000e+000   0   0 N Y N N N 3
 67 "U235"  202.110    0.000 1.100000e-002 0.000000e+000  66   0 N N N N N 7
 68 "Pu239" 203.545    0.000 5.560000e-006 0.000000e+000   0   0 Y Y N N N 7
 69 "Am241" 203.870    0.000 3.500000e-008 0.000000e+000  51   0 N N N N N 7
 70 "U235"  205.311    0.000 4.993000e-002 0.000000e+000  66   0 N N N N N 7
 71 "Pu241" 208.000    0.000 5.250000e-006 0.000000e+000   0   0 Y Y Y Y Y 8
 72 "Am241" 208.000    0.000 7.745000e-006 0.000000e+000  51   0 N N N N N 8
// region information
num_regions: 13
```

```
 1  128.00 130.30 127.30 127.90 130.40 131.00 131.20 131.80   0.00   0.000 6 "linear step"
 2  122.60 126.20 123.70 124.10 126.20 127.00 127.00 127.80   0.00   0.000 6 "linear step"
 3  184.60 186.60 183.70 184.40 186.80 187.50   0.00   0.00   0.00   0.000 5 "flat step"
 4  143.50 150.80 145.00 145.40 150.90 151.40   0.00   0.00   0.00   0.000 5 "flat step"
 5  151.80 153.60 151.20 151.70 153.80 154.30   0.00   0.00   0.00   0.000 2 "linear"
 6  163.00 166.60 162.40 162.80 166.60 167.00 167.00 167.40   0.00   0.000 6 "linear step"
 7  202.00 205.40 201.80 202.20 204.30 204.70 200.60 201.00   0.00   0.000 2 "linear"
 8  205.20 209.30 206.20 207.00 209.30 209.90 211.00 211.50   0.00   0.000 6 "linear step"
 9   58.70  60.30  57.50  58.00  58.10  58.60  60.40  60.90  61.10  61.600 7 "bilinear step"
10   91.90  95.40  91.40  91.80  93.00  93.60  95.40  95.80   0.00   0.000 6 "linear step"
11  105.60 107.20 105.20 105.70 107.20 107.80   0.00   0.00   0.00   0.000 2 "linear"
12   95.80 105.20  95.60  96.20 101.80 102.10 105.10 105.70 107.20 107.800 7 "bilinear step"
13  109.20 119.00 107.60 108.30 108.30 109.00 111.90 112.30 118.90 119.200 7 "bilinear step"
// isotope information
num_isotopes: 9
 1 "Pu239”  2.411900e+004 years  239.05220    1.92880  0.0000 1
 2 "Pu241”  1.434800e+001 years  241.05690    3.41120  0.0000 1
 3 "Am241”  4.336000e+002 years  241.05679  114.20000  0.0000 1
 4 "Pu238”  8.774000e+001 years  238.04961  567.57000  2.5200 1
 5 "Pu240”  6.564000e+003 years  240.05380    7.08240  1.0000 1
 6 "Pu242”  3.763000e+005 years  242.05874    0.11590  1.6800 1
 7 "UXray”  2.411900e+004 years  239.05220    0.00000  0.0000 1
 8 "U235”   7.038100e+008 years  235.04393    0.00006  0.0000 1
 9 "U238”   4.468300e+009 years  238.05078    0.00001  0.0000 1
// appcon information
num_appcons: 47
 1 "pu242_correlation”  “1.1174"
 2 "pu238_exponent”     “.5"
 3 "pu239_exponent”     “-1.5"
 4 "pu240_exponent”     “.75"
 5 "pu241_exponent”     “.25"
 6 "FRAM_SUMMARY_TYPE”  “PLUTONIUM"
 7 "num_ecal”           “2"
 8 "ecal_energy[1]”     “59.536"
 9 "ecal_channel[1]”    “793.8"
10 "ecal_limit[1]”      “2"
11 "ecal_energy[2]”     “208"
12 "ecal_channel[2]”    “2773.3"
13 "ecal_limit[2]”      “5"
14 "num_fwhmcal”        “2"
15 "fcal_energy[1]”     “129.3"
16 "fcal_limit[1]”      “700"
17 "fcal_energy[2]”     “208"
18 "fcal_limit[2]”      “800"
19 "num_tailfract”      “2"
20 "scal_energy[1]”     “129.3"
21 "scal_limit[1]”      “5"
22 "scal_energy[2]”     “208"
23 "scal_limit[2]”      “5"
24 "num_intf”           “1"
25 "intf_1st_energy[1]” “228.140"
26 "intf_2nd_energy[1]” “203.545"
27 "intf_limit[1]”      “.1"
28 "intf_msg[1]”        “** possible presence of Np239 **"
29 "num_samptype”       “1"
30 "type_1st_peak[1]”   “59"
31 "type_2nd_peak[1]”   “63"
32 "type_lower_limit[1]”“.9"
33 "type_upper_limit[1]”“1.1"
```

```
34 "type_msg[1]”        “Possible non-equilibrium or heterogeneous sample."
35 "fix_bad_bkg”        “TRUE"
36 "restrict_fwhm_model”“TRUE"
37 "fix_100kev_plutonium”“TRUE"
38 "eff_use_dflts”      “yes"
39 "eff_det_type”       “0"
40 "eff_upu_min”        “0.001"
41 "eff_upu_max”        “10."
42 "eff_abs_name[1]”    “Cd"
43 "eff_abs_min[1]”     “.0"
44 "eff_abs_max[1]”     “3.0"
45 "eff_abs_name[2]”    “"
46 "eff_abs_min[2]”     “.0"
47 "eff_abs_max[2]”     “3."
// end
```

Planar_WR

This parameter set is derived from the Planar_Widerange3 parameter set. It can analyze spectra with the 129-keV peak resolution of up to 1 keV. This parameter set can analyze MOX samples with the ^{235}U/Pu ratio of up to 5. The listed parameter set has the energy calibration of 0.075 keV/ch. The user can change it to the normal 0.105 keV/ch to use with 4K spectra. Normally, when the energy calibration of a spectrum is changed, then the FWHM parameters should also be changed to

$A_{new} = (G_{old}/G_{new})^2 * A_{old,}$ where G_{old} is the old energy calibration, G_{new} is the new energy calibration, and A is A_1, A_2, and A_3 of the FWHM parameter equation in FRAM.

For the tail, T_1 and T_2 remain the same. $T_{3new} = T_{3old} * \text{sqrt}(G_{new}/G_{old})$ where T_i are the tail parameters of the tail equation in FRAM.

```
// fit information
name: Planar_WR.075
desc: "Planar .075 kev/ch, Homo. Am/Pu, Equ. w U, U235/Pu <5, <414 keV"
date: "2005.09.12 12:07"
ecal: 7.500000e-002 0.000000e+000
fix-ecal: N
fcal: 3.910000e+000 3.850000e-001 3.370000e+002
fix-fcal: N
scal: -1.220000e+000 1.920000e-003 2.640000e-001 0.000000e+000
fix-scal: N
// peak information
num_peaks: 69
  1 "Pu239″ 124.490    0.000 6.000000e-007 0.000000e+000   0   0 N N N N N 2
  2 "Pu239″ 125.190    0.000 6.040000e-007 0.000000e+000   4   0 N N N N N 2
  3 "Am241″ 125.292    0.000 4.136000e-005 0.000000e+000   0   0 N Y N N N 2
  4 "Pu239″ 129.294    0.000 6.290000e-005 0.000000e+000   0   0 Y Y Y Y Y 1
  5 "Pu239″ 141.657    0.000 3.341000e-007 0.000000e+000   8   0 N N N N N 0
  6 "Pu239″ 143.350    0.000 1.806000e-007 0.000000e+000   8   0 N N N N N 0
  7 "U235″  143.780    0.000 1.070000e-001 0.000000e+000  30   0 N N N N N 4
  8 "Pu239″ 144.211    0.000 2.888000e-006 0.000000e+000   0   0 N N N N N 4
  9 "Pu239″ 146.077    0.000 1.224000e-006 0.000000e+000   8   0 N N N N N 4
 10 "Am241″ 146.557    0.000 4.750000e-006 0.000000e+000   0   0 N N N N N 4
 11 "Pu241″ 148.567    0.000 1.894000e-006 0.000000e+000   0   0 Y Y Y Y N 4
 12 "Am241″ 150.113    0.000 7.570000e-007 0.000000e+000   0   0 N N N N N 4
 13 "Pu238″ 152.720    0.000 9.504000e-006 0.000000e+000   0   0 N Y N N N 5
 14 "Am241″ 158.400    0.000 1.970000e-004 0.000000e+000   0   0 N N N N N 6
 15 "Pu238″ 159.350    0.000 5.950000e-005 0.000000e+000  23   0 N N N N N 6
 16 "Pu241″ 159.970    0.000 7.023000e-008 0.000000e+000  11   0 N N N N N 6
 17 "Pu239″ 160.180    0.000 4.924000e-008 0.000000e+000  21   0 N N N N N 6
 18 "Pu240″ 160.308    0.000 3.997000e-006 0.000000e+000   0   0 N Y N N N 6
 19 "Pu241″ 160.550    0.000 6.130000e-006 0.000000e+000  23   0 N N N N N 6
 20 "Am241″ 160.550    0.000 1.910000e-005 0.000000e+000  23   0 N N N N N 6
 21 "Pu239″ 161.482    0.000 1.229000e-006 0.000000e+000   0   0 N Y N N N 6
 22 "Am241″ 161.540    0.000 1.900000e-008 0.000000e+000   3   0 N N N N N 6
 23 "Am241″ 162.450    0.000 1.910000e-004 0.000000e+000   0   0 N N N N N 6
 24 "U235″  163.363    0.000 4.970000e-002 0.000000e+000  30   0 N N N N N 6
 25 "Pu241″ 164.597    0.000 4.690000e-007 0.000000e+000   0   0 Y Y N N N 6
 26 "Am241″ 164.597    0.000 6.919000e-007 0.000000e+000   3   0 N N N N N 6
 27 "Am241″ 165.930    0.000 2.300000e-007 0.000000e+000   0   0 N N N N N 6
 28 "Am241″ 169.567    0.000 1.739000e-006 0.000000e+000   0   0 N Y N N N 7
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 29 "Pu239″ 171.372    0.000 1.130000e-006 0.000000e+000   0   0 N Y N N N 7
 30 "U235″  185.718    0.000 5.730000e-001 0.000000e+000   0   0 N Y N N N 3
 31 "U235″  202.130    0.000 1.080000e-002 0.000000e+000  30   0 N N N N N 8
 32 "Pu239″ 203.545    0.000 5.727000e-006 0.000000e+000   0   0 Y Y N N N 8
 33 "Am241″ 203.870    0.000 3.500000e-008 0.000000e+000   3   0 N N N N N 8
 34 "U235″  205.311    0.000 5.050000e-002 0.000000e+000  30   0 N N N N N 8
 35 "Am241″ 208.000    0.000 7.954000e-006 0.000000e+000   3   0 N N N N N 8
 36 "Pu241″ 208.000    0.000 5.392000e-006 0.000000e+000   0   0 Y Y Y Y Y 8
 37 "Pu239″ 255.380    0.000 7.987000e-007 0.000000e+000   0   0 Y Y N N N 9
 38 "Pu239″ 263.930    0.000 2.498000e-007 0.000000e+000   0   0 N N N N N 10
 39 " "     264.850    0.000 0.000000e+000 0.000000e+000   0   0 N N N N N 10
 40 "Pu239″ 265.700    0.000 1.507000e-008 0.000000e+000  38   0 N N N N N 10
 41 "Am241″ 267.540    0.000 2.635000e-007 0.000000e+000   3   0 N N N N N 10
 42 "Pu241″ 267.540    0.000 1.786000e-007 0.000000e+000   0   0 Y Y N N N 10
 43 "Pu239″ 311.700    0.000 2.617000e-007 0.000000e+000  54   0 N N N N N 11
 44 "Np237″ 311.900    0.000 3.860000e-001 0.000000e+000   0   0 N Y N N N 11
 45 "Am241″ 332.387    0.000 1.480000e-006 0.000000e+000  48   0 N N N N N 13
 46 "Pu241″ 332.387    0.000 2.982000e-007 0.000000e+000   0   0 N Y N N N 13
 47 "Pu239″ 332.850    0.000 4.930000e-006 0.000000e+000  54   0 N N N N N 13
 48 "Am241″ 335.432    0.000 4.826000e-006 0.000000e+000   0   0 N Y N N N 13
 49 "Pu241″ 335.432    0.000 2.370000e-008 0.000000e+000  36   0 N N N N N 13
 50 "Pu239″ 336.112    0.000 1.144000e-006 0.000000e+000  54   0 N N N N N 13
 51 " "     337.720    0.000 0.000000e+000 0.000000e+000   0   0 N N N N N 13
 52 " "     340.450    0.000 0.000000e+000 0.000000e+000   0   0 N N N N N 12
 53 "Pu239″ 341.495    0.000 6.603000e-007 0.000000e+000  54   0 N N N N N 12
 54 "Pu239″ 345.011    0.000 5.533000e-006 0.000000e+000   0   0 Y Y Y Y Y 12
 55 "Pu239″ 367.054    0.000 8.470000e-007 0.000000e+000   0   0 N N N N N 15
 56 "Pu239″ 368.534    0.000 8.800000e-007 0.000000e+000  62   0 N N N N N 15
 57 "Am241″ 368.605    0.000 2.110000e-006 0.000000e+000   0   0 N Y N N N 15
 58 "Pu241″ 368.605    0.000 1.036000e-008 0.000000e+000  36   0 N N N N N 15
 59 "Am241″ 370.934    0.000 4.989000e-007 0.000000e+000  48   0 N N N N N 15
 60 "Pu241″ 370.934    0.000 2.677000e-008 0.000000e+000   0   0 N N N N N 15
 61 " "     372.450    0.000 0.000000e+000 0.000000e+000   0   0 N N N N N 14
 62 "Pu239″ 375.042    0.000 1.554000e-005 0.000000e+000   0   0 Y Y Y N N 14
 63 "Np237″ 375.300    0.000 6.790000e-003 0.000000e+000  44   0 N N N N N 14
 64 "Am241″ 376.610    0.000 1.374000e-006 0.000000e+000   0   0 N N N N N 14
 65 "Pu239″ 410.994    0.000 3.933000e-008 0.000000e+000   0   0 N N N N N 16
 66 "Pu239″ 413.712    0.000 1.469000e-005 0.000000e+000   0   0 Y Y Y Y Y 16
 67 ""      414.800    0.000 0.000000e+000 0.000000e+000   0   0 N N N N N 16
 68 "Np237″ 415.731    0.000 1.745000e-002 0.000000e+000  44   0 N N N N N 16
 69 ""      415.930    0.000 0.000000e+000 0.000000e+000   0   0 N N N N N 16
// region information
num_regions: 16
 1  128.00 130.30 127.30 127.90 130.40 131.00 131.20 131.80   0.00   0.00 6 "linear step"
 2  124.20 126.20 126.20 127.00 127.00 127.80   0.00   0.00   0.00   0.00 2 "linear"
 3  184.10 186.80 183.40 184.10 186.70 187.20   0.00   0.00   0.00   0.00 2 "linear"
 4  143.50 150.80 145.00 145.40 150.90 151.40   0.00   0.00   0.00   0.00 5 "flat step"
 5  151.80 153.60 151.20 151.70 153.80 154.30   0.00   0.00   0.00   0.00 2 "linear"
 6  157.90 166.60 158.70 159.20 162.90 163.40 157.10 157.70 166.60 167.40 7 "bilinear step"
 7  168.80 172.20 168.20 168.70 172.30 172.80   0.00   0.00   0.00   0.00 2 "linear"
 8  201.80 209.30  20.80 201.40 204.80 205.50 209.90 210.60 211.60 212.30 7 "bilinear step"
 9  254.20 256.50 252.70 253.10 253.70 254.10 256.70 257.10   0.00   0.00 6 "linear step"
10  262.70 269.00 261.50 262.50 265.80 266.20 269.10 269.70 270.00 270.60 6 "linear step"
11  310.40 313.10 309.30 309.80 313.80 314.30   0.00   0.00   0.00   0.00 2 "linear"
12  339.50 347.30 338.90 339.40 342.90 343.30 347.40 348.00 348.20 348.80 7 "bilinear step"
13  330.50 338.60 329.50 330.50 338.70 339.20   0.00   0.00   0.00   0.00 5 "flat step"
14  372.10 377.80 363.20 363.70 364.00 364.50 385.20 385.70 385.90 386.40 5 "flat step"
15  365.60 372.00 363.20 363.70 364.00 364.50 385.20 385.70 385.90 386.40 5 "flat step"
16  409.90 417.50 408.10 408.80 409.00 409.70 417.30 417.70   0.00   0.00 5 "flat step"
// isotope information
```

```
num_isotopes: 8
 1 "Pu239" 2.411900e+004 years  239.05220    1.92880  0.0000 1
 2 "Pu241" 1.434800e+001 years  241.05690    3.41120  0.0000 1
 3 "Am241" 4.336000e+002 years  241.05679  114.20000  0.0000 1
 4 "Pu238" 8.774000e+001 years  238.04961  567.57000  2.5200 1
 5 "Pu240" 6.564000e+003 years  240.05380    7.08240  1.0000 1
 6 "Pu242" 3.763000e+005 years  242.05874    0.11590  1.6800 1
 7 "Np237" 2.140000e+006 years  237.04817    0.00000  0.0000 1
 8 "U235"  7.038100e+008 years  235.04390    0.00000  0.0000 1
// appcon information
num_appcons: 55
 1 "pu242_correlation”  " 1.1174"
 2 "pu238_exponent”     " .5"
 3 "pu239_exponent”     " -1.5"
 4 "pu240_exponent”     " .75"
 5 "pu241_exponent”     " .25"
 6 "FRAM_SUMMARY_TYPE”  " PLUTONIUM"
 7 "num_ecal”           " 2"
 8 "ecal_energy[1]”     " 208.00"
 9 "ecal_channel[1]”    " 2773.33"
10 "ecal_limit[1]”      " 1.0"
11 "ecal_energy[2]”     " 413.712"
12 "ecal_channel[2]”    " 5516.16"
13 "ecal_limit[2]”      " 2.0"
14 "num_fwhmcal”        " 2"
15 "fcal_energy[1]”     " 129.3"
16 "fcal_limit[1]”      " 700"
17 "fcal_energy[2]”     " 413.714"
18 "fcal_limit[2]”      " 1100"
19 "num_tailfract”      " 2"
20 "scal_energy[1]”     " 129.3"
21 "scal_limit[1]”      " 5"
22 "scal_energy[2]”     " 413.714"
23 "scal_limit[2]”      " 5"
24 "num_intf”           " 2"
25 "intf_1st_energy[1]” " 185.720"
26 "intf_2nd_energy[1]” " 203.545"
27 "intf_limit[1]”      " .1"
28 "intf_msg[1]”        " ** possible presence of U235 **"
29 "intf_1st_energy[2]” " 228.140"
30 "intf_2nd_energy[2]” " 203.545"
31 "intf_limit[2]”      " .1"
32 "intf_msg[2]”        " ** possible presence of Np239 **"
33 "num_samptype”       " 2"
34 "type_1st_peak[1]”   " 11"
35 "type_2nd_peak[1]”   " 25"
36 "type_lower_limit[1]”" .9"
37 "type_upper_limit[1]”" 1.1"
38 "type_msg[1]”        " Possible non-equilibrium or heterogeneous sample."
39 "type_1st_peak[2]”   " 3"
40 "type_2nd_peak[2]”   " 48"
41 "type_lower_limit[2]”" .90"
42 "type_upper_limit[2]”" 1.1"
43 "type_msg[2]”        " Possible heterogeneous (Am/Pu) sample."
44 "fix_bad_bkg”        " TRUE"
45 "restrict_fwhm_model”" TRUE"
46 "eff_use_dflts”      " yes"
```

```
47 "eff_det_type”       “ 0"
48 "eff_upu_min”        “ 0.001"
49 "eff_upu_max”        “ 20."
50 "eff_abs_name[1]”    “ Cd"
51 "eff_abs_min[1]”     “ 0"
52 "eff_abs_max[1]”     “ 5.0"
53 "eff_abs_name[2]”    “ 0"
54 "eff_abs_min[2]”     “ 0"
55 "eff_abs_max[2]”     “ 5.0"
// end
```

Coax_WR

This parameter set is derived from the Coax_Widerange3 parameter set for spectra with broad peaks. It can analyze spectra with the 129-keV peak resolution of up to 2 keV. This parameter set can analyze MOX samples with the ^{235}U/Pu ratio of up to 1.

Even though this parameter set is derived from the Coax_Widerange3 parameter set, its performance with a good detector may not be better than that of the original Coax_Widerange3 parameter set. It is better than the Coax_Widerange3 parameter set only for spectra with very broad peak resolutions (129-keV peak FWHM > 1.5 keV).

```
// fit information
name: Coax_WR
desc: "Coax .125 kev/ch, HomoAm/Pu, Equ. w U,  U235/Pu <1, <450 keV "
date: "2005.09.12 14:31"
ecal: 1.250000e-001 5.000000e-003
fix-ecal: N
fcal: 1.500000e+001 1.800000e-001 2.000000e+003
fix-fcal: N
scal: -4.200000e+000 3.000000e-003 2.700000e-001 0.000000e+000
fix-scal: N
// peak information
num_peaks: 81
  1 "Pu239”  124.490    0.000 6.000000e-007 0.000000e+000   0   0 N N N N N 1
  2 "Pu239”  125.200    0.000 6.560000e-007 0.000000e+000   4   0 N N N N N 1
  3 "Am241”  125.292    0.000 4.136000e-005 0.000000e+000   0   0 N Y N N N 1
  4 "Pu239”  129.294    0.000 6.290000e-005 0.000000e+000   0   0 Y Y Y Y Y 1
  5 "Pu239”  141.657    0.000 3.341000e-007 0.000000e+000   8   0 N N N N N 0
  6 "Pu239”  143.350    0.000 1.806000e-007 0.000000e+000   8   0 N N N N N 3
  7 "U235”   143.780    0.000 1.070000e-001 0.000000e+000  30   0 N N N N N 3
  8 "Pu239”  144.211    0.000 2.888000e-006 0.000000e+000   0   0 N N N N N 3
  9 "Pu239”  146.077    0.000 1.224000e-006 0.000000e+000   8   0 N N N N N 3
 10 "Am241”  146.557    0.000 5.150000e-006 0.000000e+000   0   0 N N N N N 3
 11 "Pu241”  148.567    0.000 1.894000e-006 0.000000e+000   0   0 Y Y N N N 3
 12 "Am241”  150.113    0.000 7.570000e-007 0.000000e+000   0   0 N N N N N 3
 13 "Pu238”  152.720    0.000 9.411000e-006 0.000000e+000   0   0 N Y N N N 3
 14 "Am241”  158.400    0.000 1.970000e-004 0.000000e+000   0   0 N N N N N 4
 15 "Pu238”  159.350    0.000 5.950000e-005 0.000000e+000  23   0 N N N N N 4
 16 "Pu241”  159.970    0.000 6.588000e-008 0.000000e+000  11   0 N N N N N 4
 17 "Pu239”  160.180    0.000 7.616000e-008 0.000000e+000  21   0 N N N N N 4
 18 "Pu240”  160.308    0.000 4.074000e-006 0.000000e+000   0   0 N Y N N N 4
 19 "Pu241”  160.550    0.000 6.130000e-006 0.000000e+000  23   0 N N N N N 4
 20 "Am241”  160.550    0.000 1.910000e-005 0.000000e+000  23   0 N N N N N 4
 21 "Pu239”  161.482    0.000 1.229000e-006 0.000000e+000   0   0 N Y N N N 4
 22 "Am241”  161.540    0.000 1.900000e-008 0.000000e+000   3   0 N N N N N 4
 23 "Am241”  162.450    0.000 1.910000e-004 0.000000e+000   0   0 N N N N N 4
 24 "U235”   163.363    0.000 4.970000e-002 0.000000e+000  30   0 N N N N N 4
 25 "Am241”  164.597    0.000 6.919000e-007 0.000000e+000   3   0 N N N N N 4
 26 "Pu241”  164.597    0.000 4.690000e-007 0.000000e+000   0   0 Y Y N N N 4
 27 "Am241”  165.930    0.000 2.300000e-007 0.000000e+000   0   0 N N N N N 4
 28 "Am241”  169.567    0.000 1.739000e-006 0.000000e+000   0   0 N Y N N N 4
 29 "Pu239”  171.372    0.000 1.130000e-006 0.000000e+000   0   0 N Y N N N 4
 30 "U235”   185.718    0.000 5.730000e-001 0.000000e+000   0   0 N Y N N N 2
```

```
 31 "U235"  202.130    0.000 1.080000e-002 0.000000e+000  30   0 N N N N N 5
 32 "Pu239" 203.545    0.000 5.727000e-006 0.000000e+000   0   0 Y Y N N N 5
 33 "U235"  205.311    0.000 5.050000e-002 0.000000e+000  30   0 N N N N N 5
 34 "Am241" 208.000    0.000 7.954000e-006 0.000000e+000   3   0 N N N N N 5
 35 "Pu241" 208.000    0.000 5.392000e-006 0.000000e+000   0   0 Y Y Y Y Y 5
 36 "Am243" 209.750    0.000 3.420000e-002 0.000000e+000  39   0 N N N N N 5
 37 "Am243" 226.360    0.000 2.800000e-003 0.000000e+000  39   0 N N N N N 6
 38 "Am243" 227.810    0.000 5.100000e-003 0.000000e+000  39   0 N N N N N 6
 39 "Am243" 228.160    0.000 1.076000e-001 0.000000e+000   0   0 N Y N N N 6
 40 "Am243" 254.400    0.000 1.100000e-003 0.000000e+000  39   0 N N N N N 7
 41 "Pu239" 255.380    0.000 7.987000e-007 0.000000e+000   0   0 Y Y N N N 7
 42 "Pu239" 263.930    0.000 2.498000e-007 0.000000e+000   0   0 N N N N N 8
 43 " "     264.850    0.000 0.000000e+000 0.000000e+000   0   0 N N N N N 8
 44 "Pu239" 265.700    0.000 1.507000e-008 0.000000e+000  42   0 N N N N N 8
 45 "Am241" 267.540    0.000 2.635000e-007 0.000000e+000   3   0 N N N N N 8
 46 "Pu241" 267.540    0.000 1.786000e-007 0.000000e+000   0   0 Y Y N N N 8
 47 "Pu239" 311.700    0.000 2.617000e-007 0.000000e+000  63   0 N N N N N 9
 48 "Np237" 311.900    0.000 3.860000e-001 0.000000e+000   0   0 N Y N N N 9
 49 "Pu239" 319.828    0.000 4.545000e-008 0.000000e+000   0   0 N N N N N 10
 50 "Pu239" 320.868    0.000 5.026000e-007 0.000000e+000   0   0 N N N N N 10
 51 "Am241" 322.526    0.000 1.498000e-006 0.000000e+000   0   0 N N N N N 10
 52 "Pu239" 323.828    0.000 5.377000e-007 0.000000e+000   0   0 N N N N N 10
 53 "Am241" 332.387    0.000 1.476000e-006 0.000000e+000  57   0 N N N N N 11
 54 "Pu241" 332.387    0.000 2.974000e-007 0.000000e+000   0   0 N Y N N N 11
 55 "Pu239" 332.850    0.000 4.940000e-006 0.000000e+000  63   0 N N N N N 11
 56 "Am243" 334.310    0.000 2.070000e-002 0.000000e+000  39   0 N N N N N 11
 57 "Am241" 335.432    0.000 4.872000e-006 0.000000e+000   0   0 N Y N N N 11
 58 "Pu241" 335.432    0.000 2.392000e-008 0.000000e+000  35   0 N N N N N 11
 59 "Pu239" 336.112    0.000 1.144000e-006 0.000000e+000  63   0 N N N N N 11
 60 " "     337.720    0.000 0.000000e+000 0.000000e+000   0   0 N N N N N 11
 61 " "     340.450    0.000 0.000000e+000 0.000000e+000   0   0 N N N N N 11
 62 "Pu239" 341.495    0.000 6.603000e-007 0.000000e+000  63   0 N N N N N 11
 63 "Pu239" 345.011    0.000 5.533000e-006 0.000000e+000   0   0 Y Y Y Y Y 11
 64 "Pu239" 367.054    0.000 8.590000e-007 0.000000e+000   0   0 N N N N N 12
 65 "Pu239" 368.534    0.000 8.992000e-007 0.000000e+000  71   0 N N N N N 12
 66 "Am241" 368.605    0.000 2.115000e-006 0.000000e+000   0   0 N Y N N N 12
 67 "Pu241" 368.605    0.000 1.039000e-008 0.000000e+000  35   0 N N N N N 12
 68 "Am241" 370.934    0.000 5.119000e-007 0.000000e+000  57   0 N N N N N 12
 69 "Pu241" 370.934    0.000 2.747000e-008 0.000000e+000   0   0 N N N N N 12
 70 " "     372.450    0.000 0.000000e+000 0.000000e+000   0   0 N N N N N 12
 71 "Pu239" 375.042    0.000 1.554000e-005 0.000000e+000   0   0 Y Y Y N N 12
 72 "Np237" 375.300    0.000 6.790000e-003 0.000000e+000  48   0 N N N N N 12
 73 "Am241" 376.610    0.000 1.520000e-006 0.000000e+000   0   0 N N N N N 12
 74 "Pu239" 410.994    0.000 3.933000e-008 0.000000e+000   0   0 N N N N N 13
 75 "Pu239" 413.712    0.000 1.469000e-005 0.000000e+000   0   0 Y Y Y Y N 13
 76 ""      414.800    0.000 0.000000e+000 0.000000e+000   0   0 N N N N N 13
 77 "Np237" 415.731    0.000 1.745000e-002 0.000000e+000  48   0 N N N N N 13
 78 ""      415.930    0.000 0.000000e+000 0.000000e+000   0   0 N N N N N 13
 79 "Am241" 419.270    0.000 2.874000e-007 0.000000e+000   0   0 N N N N N 0
 80 "Pu239" 451.474    0.000 1.898000e-006 0.000000e+000   0   0 Y Y Y Y Y 14
 81 "Am241" 452.450    0.000 2.400000e-008 0.000000e+000  57   0 N N N N N 14
// region information
num_regions: 14
 1  124.20 131.00 126.70 127.40 131.50 132.00 132.20 133.00   0.00   0.006 "linear step"
 2  184.10 186.80 183.40 184.10 186.70 187.20   0.00   0.00   0.00   0.002 "linear"
 3  142.70 153.90 138.10 139.20 151.00 151.40 154.60 155.20   0.00   0.006 "linear step"
 4  157.90 172.90 156.20 157.20 162.50 163.00 167.00 168.00 173.20 173.807 "bilinear step"
 5  201.60 211.50 200.60 201.40 204.80 205.50 211.70 212.40 212.70 213.407 "bilinear step"
```

```
 6  226.30 229.30 223.10 223.90 229.60 230.40   0.00   0.00   0.00   0.002 "linear"
 7  253.70 257.10 252.50 253.00 253.10 253.60 257.30 258.00   0.00   0.002 "linear"
 8  262.40 269.70 261.70 262.40 269.80 270.40 270.50 271.10   0.00   0.006 "linear step"
 9  309.90 313.90 309.00 309.60 314.00 314.60   0.00   0.00   0.00   0.002 "linear"
10  318.70 325.20 317.50 318.00 318.00 318.50 325.40 325.90 326.10 326.605 "flat step"
11  330.00 347.30 328.60 329.30 338.70 339.20 348.30 348.80 348.80 349.405 "flat step"
12  365.30 378.00 363.80 364.40 364.50 365.10 385.80 386.20 386.30 386.805 "flat step"
13  409.20 417.20 404.00 404.60 404.90 405.50 432.20 432.80 433.00 433.605 "flat step"
14  449.00 453.50 448.00 448.80 456.10 456.70   0.00   0.00   0.00   0.005 "flat step"
// isotope information
num_isotopes: 9
 1 "Pu239" 2.411900e+004 years  239.05220    1.92880  0.0000 1
 2 "Pu241" 1.434800e+001 years  241.05690    3.41120  0.0000 1
 3 "Am241" 4.336000e+002 years  241.05679  114.20000  0.0000 1
 4 "Pu238" 8.774000e+001 years  238.04961  567.57000  2.5200 1
 5 "Pu240" 6.564000e+003 years  240.05380    7.08240  1.0000 1
 6 "Pu242" 3.763000e+005 years  242.05874    0.11590  1.6800 1
 7 "Np237" 2.140000e+006 years  237.04817    0.00000  0.0000 1
 8 "U235"  7.038100e+008 years  235.04390    0.00000  0.0000 1
 9 "Am243" 7.370000e+003 years  243.06140    0.00000  0.0000 1
// appcon information
num_appcons: 70
 1 "pu242_correlation”  “1.1174"
 2 "pu238_exponent”     “.5"
 3 "pu239_exponent”     “-1.5"
 4 "pu240_exponent”     “.75"
 5 "pu241_exponent”     “.25"
 6 "FRAM_SUMMARY_TYPE”  “PLUTONIUM"
 7 "num_ecal”           “2"
 8 "ecal_energy[1]”     “208.00"
 9 "ecal_channel[1]”    “1664.00"
10 "ecal_limit[1]”      “2.0"
11 "ecal_energy[2]”     “662.456"
12 "ecal_channel[2]”    “5299.40"
13 "ecal_limit[2]”      “4.0"
14 "num_fwhmcal”        “2"
15 "fcal_energy[1]”     “129.3"
16 "fcal_limit[1]”      “1300"
17 "fcal_energy[2]”     “413.7"
18 "fcal_limit[2]”      “1600"
19 "num_tailfract”      “2"
20 "scal_energy[1]”     “129.3"
21 "scal_limit[1]”      “5"
22 "scal_energy[2]”     “413.7"
23 "scal_limit[2]”      “5"
24 "num_intf”           “3"
25 "intf_1st_energy[1]” “185.720"
26 "intf_2nd_energy[1]” “203.545"
27 "intf_limit[1]”      “4"
28 "intf_msg[1]”        “** U235 TOO HIGH, USE MOX PARAMETER FILE **"
29 "intf_1st_energy[2]” “228.140"
30 "intf_2nd_energy[2]” “208.000"
31 "intf_limit[2]”      “.05"
32 "intf_msg[2]”        “** possible presence of Np239 **"
33 "intf_1st_energy[3]” “311.887"
34 "intf_2nd_energy[3]” “345.011"
35 "intf_limit[3]”      “5."
36 "intf_msg[3]”        “** possible presence of Np237 **"
37 "num_samptype”       “2"
```

```
38 "type_1st_peak[1]”   “11"
39 "type_2nd_peak[1]”   “26"
40 "type_lower_limit[1]”“.9"
41 "type_upper_limit[1]”“1.1"
42 "type_msg[1]”        “Possible non-equilibrium or heterogeneous sample."
43 "type_1st_peak[2]”   “3"
44 "type_2nd_peak[2]”   “57"
45 "type_lower_limit[2]”“.9"
46 "type_upper_limit[2]”“1.1"
47 "type_msg[2]”        “Possible heterogeneous (Am/Pu) sample."
48 "fix_bad_bkg”        “TRUE"
49 "restrict_fwhm_model”“TRUE"
50 "AutoShieldTest”     “no"
51 "AutoShieldPass”     “ShCoax_Widerange3"
52 "Shield_LowEnergy”   “129.294"
53 "Shield_HighEnergy”  “413.712"
54 "Shield_HighToLowLimit”“20"
55 "AutoHeteroTest”     “no"
56 "AutoHeteroPass”     “Coax_HeteroAmPu3"
57 "Hetero_Energy[1]”   “125.292"
58 "Hetero_Energy[2]”   “335.422"
59 "Hetero_LowerLimit”  “.9"
60 "Hetero_UpperLimit”  “1.05"
61 "eff_use_dflts”      “yes"
62 "eff_det_type”       “1"
63 "eff_upu_min”        “0.001"
64 "eff_upu_max”        “20."
65 "eff_abs_name[1]”    “Cd"
66 "eff_abs_min[1]”     “0"
67 "eff_abs_max[1]”     “5.0"
68 "eff_abs_name[2]”    “"
69 "eff_abs_min[2]”     “0"
70 "eff_abs_max[2]”     “5.0"
// end
```

ShCoax_WR

This parameter set is derived from the ShCoax_Widerange3 parameter set for spectra with broad peaks. It can analyze spectra with the 662-keV peak resolution of up to 2.5 keV. This parameter set can analyze MOX samples with the ^{235}U/Pu ratio of up to 1.

Similar to the Coax_WR parameter set, even though this ShCoax_WR parameter set is derived from the ShCoax_Widerange3 parameter set, its performance with a good detector may not be better than that of the original ShCoax_Widerange3 parameter set. It is better than the ShCoax_Widerange3 parameter set only for spectra with very broad peak resolutions (662-keV peak FWHM > 2.0 keV).

```
// fit information
name: ShCoax_WR
desc: "ShCoax .125 kev/ch, Homo. Am/Pu, Equ. w U,  U235/Pu <1, <800 keV"
date: "2005.09.12 15:23"
ecal: 1.251000e-001 5.000000e-003
fix-ecal: N
fcal: 1.500000e+001 1.800000e-001 2.000000e+003
fix-fcal: N
scal: -4.200000e+000 3.000000e-003 2.700000e-001 0.000000e+000
fix-scal: N
// peak information
num_peaks: 81
  1 "U235”  185.718    0.000 5.730000e-001 0.000000e+000   0   0 N Y N N N 1
  2 "U235”  202.130    0.000 1.080000e-002 0.000000e+000   1   0 N N N N N 2
  3 "Pu239” 203.545    0.000 5.727000e-006 0.000000e+000   0   0 Y Y N N N 2
  4 "U235”  205.311    0.000 5.050000e-002 0.000000e+000   1   0 N N N N N 2
  5 "Pu241” 208.000    0.000 5.392000e-006 0.000000e+000   0   0 Y Y Y Y Y 2
  6 "Am241” 208.000    0.000 7.954000e-006 0.000000e+000  29   0 N N N N N 2
  7 "Am243” 209.750    0.000 3.420000e-002 0.000000e+000  10   0 N N N N N 2
  8 "Am243” 226.360    0.000 2.800000e-003 0.000000e+000  10   0 N N N N N 3
  9 "Am243” 227.810    0.000 5.100000e-003 0.000000e+000  10   0 N N N N N 3
 10 "Am243” 228.160    0.000 1.076000e-001 0.000000e+000   0   0 N Y N N N 3
 11 "Am243” 254.400    0.000 1.100000e-003 0.000000e+000  10   0 N N N N N 4
 12 "Pu239” 255.380    0.000 7.987000e-007 0.000000e+000   0   0 Y Y N N N 4
 13 "Pu239” 263.930    0.000 2.498000e-007 0.000000e+000   0   0 N N N N N 5
 14 ” ”     264.850    0.000 0.000000e+000 0.000000e+000   0   0 N N N N N 5
 15 "Pu239” 265.700    0.000 1.507000e-008 0.000000e+000  13   0 N N N N N 5
 16 "Pu241” 267.540    0.000 1.786000e-007 0.000000e+000   0   0 Y Y Y N N 5
 17 "Am241” 267.540    0.000 2.635000e-007 0.000000e+000  29   0 N N N N N 5
 18 "Pu239” 311.700    0.000 2.617000e-007 0.000000e+000  34   0 N N N N N 6
 19 "Np237” 311.900    0.000 3.860000e-001 0.000000e+000   0   0 N Y N N N 6
 20 "Pu239” 319.828    0.000 4.545000e-008 0.000000e+000   0   0 N N N N N 7
 21 "Pu239” 320.868    0.000 5.026000e-007 0.000000e+000   0   0 N N N N N 7
 22 "Am241” 322.526    0.000 1.498000e-006 0.000000e+000   0   0 N Y N N N 7
 23 "Pu239” 323.828    0.000 5.377000e-007 0.000000e+000   0   0 N N N N N 7
 24 "Pu241” 332.387    0.000 2.974000e-007 0.000000e+000   0   0 Y Y N N N 9
 25 "Am241” 332.387    0.000 1.476000e-006 0.000000e+000  29   0 N N N N N 9
 26 "Pu239” 332.850    0.000 4.940000e-006 0.000000e+000  34   0 N N N N N 9
 27 "Am243” 334.310    0.000 2.070000e-002 0.000000e+000  10   0 N N N N N 9
 28 "Pu241” 335.432    0.000 2.392000e-008 0.000000e+000   5   0 N N N N N 9
 29 "Am241” 335.432    0.000 4.872000e-006 0.000000e+000   0   0 N Y N N N 9
 30 "Pu239” 336.112    0.000 1.144000e-006 0.000000e+000  34   0 N N N N N 9
```

```
 31 " "      337.720    0.000 0.000000e+000 0.000000e+000   0   0 N N N N N 9
 32 " "      340.450    0.000 0.000000e+000 0.000000e+000   0   0 N N N N N 8
 33 "Pu239" 341.495    0.000 6.603000e-007 0.000000e+000  34   0 N N N N N 8
 34 "Pu239" 345.011    0.000 5.533000e-006 0.000000e+000   0   0 Y Y Y Y Y 8
 35 "Pu239" 367.054    0.000 8.590000e-007 0.000000e+000   0   0 N N N N N 11
 36 "Pu239" 368.534    0.000 8.992000e-007 0.000000e+000  42   0 N N N N N 11
 37 "Pu241" 368.605    0.000 1.039000e-008 0.000000e+000   5   0 N N N N N 11
 38 "Am241" 368.605    0.000 2.115000e-006 0.000000e+000   0   0 N Y N N N 11
 39 "Pu241" 370.934    0.000 2.747000e-008 0.000000e+000   0   0 N Y N N N 11
 40 "Am241" 370.934    0.000 5.119000e-007 0.000000e+000  29   0 N N N N N 11
 41 " "      372.450    0.000 0.000000e+000 0.000000e+000   0   0 N N N N N 11
 42 "Pu239" 375.042    0.000 1.554000e-005 0.000000e+000   0   0 Y Y Y N N 10
 43 "Np237" 375.300    0.000 6.790000e-003 0.000000e+000  19   0 N N N N N 10
 44 "Am241" 376.610    0.000 1.520000e-006 0.000000e+000   0   0 N N N N N 10
 45 "Pu239" 410.994    0.000 3.933000e-008 0.000000e+000   0   0 N N N N N 12
 46 "Pu239" 413.712    0.000 1.469000e-005 0.000000e+000   0   0 Y Y Y Y N 12
 47 ""       414.800    0.000 0.000000e+000 0.000000e+000   0   0 N N N N N 12
 48 "Np237" 415.731    0.000 1.745000e-002 0.000000e+000  19   0 N N N N N 12
 49 ""       415.930    0.000 0.000000e+000 0.000000e+000   0   0 N N N N N 12
 50 "Am241" 419.270    0.000 2.874000e-007 0.000000e+000   0   0 N N N N N 0
 51 "Pu239" 451.474    0.000 1.898000e-006 0.000000e+000   0   0 Y Y Y Y Y 13
 52 "Am241" 452.450    0.000 2.400000e-008 0.000000e+000  29   0 N N N N N 13
 53 "Pu239" 637.820    0.000 2.458000e-008 0.000000e+000   0   0 N N N N N 15
 54 "Pu239" 640.040    0.000 8.123000e-008 0.000000e+000   0   0 N N N N N 15
 55 "Am241" 641.450    0.000 7.273000e-008 0.000000e+000  64   0 N N N N N 15
 56 "Pu240" 642.500    0.000 1.254000e-007 0.000000e+000   0   0 N Y N N N 15
 57 "Pu239" 645.940    0.000 1.491000e-007 0.000000e+000   0   0 Y Y N N N 15
 58 "Pu239" 649.321    0.000 6.903000e-009 0.000000e+000  60   0 N N N N N 0
 59 "Pu239" 650.529    0.000 2.662000e-009 0.000000e+000  60   0 N N N N N 0
 60 "Pu239" 652.052    0.000 6.509000e-008 0.000000e+000   0   0 N N N N N 0
 61 "Am241" 652.990    0.000 3.828000e-007 0.000000e+000  64   0 N N N N N 0
 62 "Pu239" 654.890    0.000 2.270000e-008 0.000000e+000   0   0 N N N N N 0
 63 "Pu239" 658.919    0.000 9.990000e-008 0.000000e+000   0   0 N N N N N 14
 64 "Am241" 662.456    0.000 3.619000e-006 0.000000e+000   0   0 Y Y Y Y N 14
 65 "Pu239" 664.587    0.000 2.651000e-008 0.000000e+000   0   0 N N N N N 14
 66 "Pu239" 717.650    0.000 2.800000e-008 0.000000e+000   0   0 N N N N N 16
 67 "Pu239" 720.000    0.000 3.700000e-009 0.000000e+000   0   0 N N N N N 16
 68 "Am241" 721.990    0.000 1.889000e-006 0.000000e+000   0   0 Y Y Y Y Y 16
 69 "Am241" 723.500    0.000 5.678000e-008 0.000000e+000  68   0 N N N N N 16
 70 "Am241" 763.300    0.000 1.434000e-008 0.000000e+000   0   0 N N N N N 17
 71 ""       764.600    0.000 0.000000e+000 0.000000e+000   0   0 N N N N N 17
 72 "Pu238" 766.410    0.000 2.177000e-007 0.000000e+000   0   0 N Y N N N 17
 73 "U238"  766.410    0.000 3.074000e-003 0.000000e+000  81   0 N N N N N 17
 74 "Pu239" 766.450    0.000 3.387000e-009 0.000000e+000  77   0 N N N N N 17
 75 "Am241" 766.920    0.000 4.984000e-008 0.000000e+000  68   0 N N N N N 17
 76 "Pu239" 767.700    0.000 4.000000e-009 0.000000e+000  77   0 N N N N N 17
 77 "Pu239" 769.250    0.000 1.129000e-007 0.000000e+000   0   0 Y Y N N N 17
 78 "Am241" 770.590    0.000 4.642000e-008 0.000000e+000  68   0 N N N N N 17
 79 "Am241" 772.130    0.000 2.697000e-008 0.000000e+000   0   0 N N N N N 17
 80 "Pu238"1001.030    0.000 9.900000e-009 0.000000e+000  72   0 N N N N N 18
 81 "U238" 1001.030    0.000 8.371000e-003 0.000000e+000   0   0 N Y N N N 18
// region information
num_regions: 18
 1  184.10 186.80 183.40 184.10 186.70 187.20   0.00   0.00   0.00   0.002 "linear"
 2  201.80 211.50 200.60 201.40 204.90 205.50 211.70 212.40 212.70 213.407 "bilinear step"
 3  226.30 229.30 223.10 223.90 229.60 230.40   0.00   0.00   0.00   0.002 "linear"
 4  253.90 256.90 252.70 253.20 253.30 253.80 257.10 257.80   0.00   0.002 "linear"
 5  262.60 269.50 261.90 262.60 269.60 270.20 270.40 270.90   0.00   0.006 "linear step"
```

```
 6  310.10 313.70 309.20 309.70 313.90 314.40   0.00   0.00   0.00   0.002 "linear"
 7  318.70 325.20 317.50 318.00 318.00 318.50 325.40 325.90 326.10 326.605 "flat step"
 8  339.50 347.30 328.80 329.40 329.50 330.10 347.80 348.40 348.80 349.405 "flat step"
 9  330.00 339.00 328.80 329.40 329.50 330.10 347.80 348.40 348.80 349.405 "flat step"
10  373.00 378.00 363.80 364.40 364.50 365.10 385.50 386.10 386.20 386.805 "flat step"
11  365.30 372.90 363.80 364.40 364.50 365.10 385.50 386.10 386.20 386.805 "flat step"
12  409.20 417.20 404.00 404.60 404.90 405.50 432.20 432.80 433.00 433.605 "flat step"
13  449.00 453.50 448.20 448.80 455.90 456.50   0.00   0.00   0.00   0.005 "flat step"
14  656.60 665.90 628.50 629.20 635.20 636.20 671.00 672.40 682.40 683.606 "linear step"
15  635.90 647.80 628.50 629.20 635.20 636.20 671.00 672.40 682.40 683.606 "linear step"
16  715.80 724.20 711.60 712.20 713.60 714.20 733.20 733.80 734.00 734.605 "flat step"
17  762.20 774.20 761.10 761.70 764.10 764.60 777.60 778.20   0.00   0.005 "flat step"
18  997.801003.60 996.10 997.601004.501006.00   0.00   0.00   0.00   0.002 "linear"
// isotope information
num_isotopes: 10
 1 "Pu239" 2.411900e+004 years  239.05220    1.92880  0.0000 1
 2 "Pu241" 1.434800e+001 years  241.05690    3.41120  0.0000 1
 3 "Am241" 4.336000e+002 years  241.05679  114.20000  0.0000 1
 4 "Pu238" 8.774000e+001 years  238.04961  567.57000  2.5200 1
 5 "Pu240" 6.564000e+003 years  240.05380    7.08240  1.0000 1
 6 "Pu242" 3.763000e+005 years  242.05874    0.11590  1.6800 1
 7 "Np237" 2.140000e+006 years  237.04817    0.00000  0.0000 1
 8 "Am243" 7.370000e+003 years  243.06140    0.00000  0.0000 1
 9 "U235"  7.038100e+008 years  235.04390    0.00000  0.0000 1
10 "U238"  4.468300e+009 years  238.05080    0.00000  0.0000 1
// appcon information
num_appcons: 62
 1 "pu242_correlation”  “1.1174"
 2 "pu238_exponent”     “.5"
 3 "pu239_exponent”     “-1.5"
 4 "pu240_exponent”     “.75"
 5 "pu241_exponent”     “.25"
 6 "FRAM_SUMMARY_TYPE”  “PLUTONIUM"
 7 "num_ecal”           “2"
 8 "ecal_energy[1]”     “208.00"
 9 "ecal_channel[1]”    “1664.00"
10 "ecal_limit[1]”      “2"
11 "ecal_energy[2]”     “662.456"
12 "ecal_channel[2]”    “5299.40"
13 "ecal_limit[2]”      “4.0"
14 "num_fwhmcal”        “2"
15 "fcal_energy[1]”     “208.0"
16 "fcal_limit[1]”      “1300"
17 "fcal_energy[2]”     “662.456"
18 "fcal_limit[2]”      “1800"
19 "num_tailfract”      “2"
20 "scal_energy[1]”     “208"
21 "scal_limit[1]”      “5"
22 "scal_energy[2]”     “662.456"
23 "scal_limit[2]”      “5"
24 "num_intf”           “2"
25 "intf_1st_energy[1]” “185.720"
26 "intf_2nd_energy[1]” “203.545"
27 "intf_limit[1]”      “4"
28 "intf_msg[1]”        “** U235 TOO HIGH, USE MOX PARAMETER FILE **"
29 "intf_1st_energy[2]” “228.140"
30 "intf_2nd_energy[2]” “203.545"
31 "intf_limit[2]”      “.05"
32 "intf_msg[2]”        “** possible presence of Np239 **"
```

```
33 "intf_1st_energy[3]” “311.887"
34 "intf_2nd_energy[3]” “345.011"
35 "intf_limit[3]”      “5."
36 "intf_msg[3]”       “** possible presence of Np237 **"
37 "num_samptype”      “1"
38 "type_1st_peak[1]”  “29"
39 "type_2nd_peak[1]”  “68"
40 "type_lower_limit[1]”“.9"
41 "type_upper_limit[1]”“1.1"
42 "type_msg[1]”       “Possible heterogeneous (Am/Pu) sample."
43 "fix_bad_bkg”       “TRUE"
44 "AutoHeteroTest”    “no"
45 "AutoHeteroPass”    “ShCoax_HeteroAmPu3"
46 "Hetero_Energy[1]”  “335.23"
47 "Hetero_Energy[2]”  “721.99"
48 "Hetero_LowerLimit” “.9"
49 "Hetero_UpperLimit” “1.05"
50 "eff_use_dflts”     “yes"
51 "eff_det_type”      “1"
52 "eff_upu_min”       “.001"
53 "eff_upu_max”       “20"
54 "eff_abs_name[1]”   “Cd"
55 "eff_abs_min[1]”    “.2"
56 "eff_abs_max[1]”    “3.0"
57 "eff_abs_name[2]”   “Pb"
58 "eff_abs_min[2]”    “0"
59 "eff_abs_max[2]”    “6"
60 "eff_abs_name[3]”   “"
61 "eff_abs_min[3]”    “0"
62 "eff_abs_max[3]”    “6"
// end
```

U100keVLEUX and U100keVHEUX

These two parameter sets are derived from the U100keVLEU and U100keVHEU parameter sets. These parameter sets are good for detectors with the 186-keV peak resolution of up to 1.0 keV for LEU and moderately high enriched uranium up to about 80% ^{235}U enrichment. For higher enriched uranium, then the resolution limit is 0.8 keV for the 186-keV peak.

In the "Application constants" part of the parameter set, the statement "fix_100kev_uranium" is applicable for only the upgraded FRAM [6]. Similar to the UPu100keVSolidX parameter set, "TRUE" would turn on the bias correction algorithm correction and "FALSE" would turn it off. This "fix_100kev_uranium"statement has no effect when used with the current FRAM.

The parameter set listed below is the U100keVHEUX. The U100keVLEUX parameter set is slightly different from the U100keVHEUX set. It will not be listed. Instead, its few differences with the U100keVHEUX parameter set are listed. Those differences are as follows:

a) It uses the ^{238}U 63-keV peak for energy, FWHM, and shape calibrations instead of the ^{235}U 84.2-keV peak.
b) It does not use the ^{235}U 90.0-keV and 143.8-keV peaks for efficiency.
c) One of the BG regions in the analytical region 7 is changed from 90.9–91.4 to 90.8–91.2.
d) The description would be for Enrichment <= 10% instead of >= 2%.

For this U100keVLEUX parameter set, if the 63-keV peak is not visible, then FRAM may not be able to determine the shapes of the peaks properly. The user should check the "fixed shape calibration" box to fix the shape calibration to the default values.

```
// fit information
name: U100keVHEUX
desc: " U Only, Enrichment >=2%, 0.075 keV/ch, Planar Detector"
date: "2005.09.12 16:58"
ecal: 7.500000e-002 0.000000e+000
fix-ecal: N
fcal: 3.910000e+000 3.850000e-001 3.370000e+002
fix-fcal: N
scal: -1.700000e+000 5.000000e-003 4.000000e-001 0.000000e+000
fix-scal: N
// peak information
num_peaks: 41
  1 "U238"  63.277    0.000 4.566000e-002 0.000000e+000   0   0 N N N N N 9
  2 "U235"  81.232    0.000 1.047000e-002 0.000000e+000   0   0 N N N N N 6
  3 "U235"  82.093    0.000 4.760000e-003 0.000000e+000   0   0 N N N N N 6
  4 "U238"  82.620    0.000 1.000000e-004 0.000000e+000   5   0 N N N N N 6
  5 "U238"  83.286    0.000 7.920000e-004 0.000000e+000   0   0 N N N N N 6
  6 "U235"  84.220    0.000 7.335000e-002 0.000000e+000   0   0 Y Y Y Y Y 6
  7 "~      84.450   68.000 5.580000e-002 0.000000e+000   8   0 N N N N N 6
  8 "~      84.953   68.000 1.101000e-001 0.000000e+000   0   0 N N N N N 6
  9 "~      87.398   68.000 4.780000e-002 0.000000e+000   0   0 N N N N N 7
 10 "U235"  88.550    0.000 6.130000e-004 0.000000e+000   0   0 N N N N N 7
 11 "U235"  89.957   80.400 3.197000e-002 0.000000e+000   0   0 Y N N N N 7
 12 "U235"  89.963    0.000 9.866000e-003 0.000000e+000  11   0 N N N N N 7
 13 "U235"  92.287   84.000 4.554000e-003 0.000000e+000  18   0 N N N N N 8
```

```
 14 "U238”  92.287   84.000 2.100000e-004 0.000000e+000  15   0 N N N N N 8
 15 "U238”  92.366    0.000 2.467000e-002 0.000000e+000   0   0 N Y N N N 8
 16 "U238”  92.788    0.000 2.552000e-002 0.000000e+000  15   0 N N N N N 8
 17 "U235”  93.030    0.000 5.000000e-004 0.000000e+000  18   0 N N N N N 8
 18 "U235”  93.354   80.400 5.136000e-002 0.000000e+000   0   0 N N N N N 8
 19 "UXray” 93.844   87.600 2.170000e-003 0.000000e+000  20   0 N N N N N 8
 20 "UXray” 94.652   87.600 6.142000e-001 0.000000e+000   0   0 Y Y N N N 8
 21 "U235”  95.881   84.000 7.344000e-003 0.000000e+000   0   0 N N N N N 8
 22 "U238”  95.881   84.000 3.400000e-004 0.000000e+000  21   0 N N N N N 8
 23 "U235”  96.350    0.000 1.900000e-004 0.000000e+000  18   0 N N N N N 8
 24 "UXray” 98.434   87.600 1.000000e+000 0.000000e+000   0   0 Y Y Y N N 8
 25 "U235”  99.278    0.000 1.120000e-003 0.000000e+000  18   0 N N N N N 8
 26 "U235”  102.270    0.000 4.446000e-003 0.000000e+000   0   0 N N N N N 0
 27 "U238”  103.600    0.000 4.490000e-005 0.000000e+000  15   0 N N N N N 10
 28 "U235”  104.819   80.400 5.956000e-003 0.000000e+000  29   0 N N N N N 10
 29 "U235”  105.604   80.400 1.153000e-002 0.000000e+000   0   0 Y Y N N N 10
 30 "U235”  105.810    0.000 7.360000e-005 0.000000e+000  29   0 N N N N N 10
 31 "U235”  106.239   80.400 4.086000e-004 0.000000e+000  29   0 N N N N N 10
 32 "U235”  106.610    0.000 1.764000e-004 0.000000e+000  29   0 N N N N N 10
 33 "U234”  120.905    0.000 3.330000e-004 0.000000e+000   0   0 N Y N N N 1
 34 "U235”  140.760    0.000 2.620000e-003 0.000000e+000   0   0 N N N N N 2
 35 "U235”  143.760    0.000 1.095000e-001 0.000000e+000   0   0 Y Y Y Y Y 2
 36 "“      145.940    0.000 0.000000e+000 0.000000e+000   0   0 N N N N N 2
 37 "U235”  163.330    0.000 5.127000e-002 0.000000e+000   0   0 Y Y Y Y N 3
 38 "U235”  182.610    0.000 4.024000e-003 0.000000e+000   0   0 N N N N N 4
 39 "U235”  185.715    0.000 5.739000e-001 0.000000e+000   0   0 Y Y Y Y Y 4
 40 "U235”  202.110    0.000 1.100000e-002 0.000000e+000   0   0 N N N N N 5
 41 "U235”  205.311    0.000 4.993000e-002 0.000000e+000   0   0 Y Y Y N N 5
// region information
num_regions: 10
 1  120.20 122.10 118.70 119.50 122.40 123.40   0.00   0.00   0.00   0.002 "linear"
 2  139.20 147.00 136.80 137.70 137.90 139.00 147.10 148.20 148.50 149.606 "linear step"
 3  160.80 165.00 158.40 159.70 159.80 161.00 166.30 167.40 167.80 169.006 "linear step"
 4  181.20 186.80 177.00 178.50 180.00 181.00 189.10 190.50 190.80 192.007 "bilinear step"
 5  198.10 207.00 197.50 198.00 200.00 200.50 207.00 208.00 211.00 212.006 "linear step"
 6   80.80  85.20  79.80  80.50  82.60  82.90  85.20  85.90   0.00   0.002 "linear"
 7   87.10  90.90  86.00  86.60  87.70  88.10  90.90  91.40   0.00   0.006 "linear step"
 8   91.60  99.90  91.10  91.60  96.60  96.90  99.60 100.10 100.90 101.407 "bilinear step"
 9   62.30  63.90  61.60  62.20  64.00  64.50   0.00   0.00   0.00   0.002 "linear"
10  103.10 106.70 103.00 103.40 106.60 107.00   0.00   0.00   0.00   0.002 "linear"
// isotope information
num_isotopes: 5
 1 "U235" 7.038100e+008 years  235.04393    0.00006  0.0000 1
 2 "U238" 4.468300e+009 years  238.05078    0.00001  0.0000 1
 3 "U234" 2.446000e+005 years  234.04090    0.18023  0.0000 1
 4 "U236" 2.341500e+007 years  236.04556    0.00175  0.0000 1
 5 "UXray" 4.468300e+009 years  238.05078    0.00000  0.0000 1
// appcon information
num_appcons: 34
 1 "u236_correlation”   “0.00472"
 2 "u235_exponent”      “0.925"
 3 "u238_exponent”      “0.075"
 4 "FRAM_SUMMARY_TYPE”  “URANIUM"
 5 "num_ecal”           “1"
 6 "ecal_energy[1](keV)”“185.715"
 7 "ecal_channel[1]”    “2476.2"
 8 "ecal_limit[1](channels)”“5.0"
 9 "ecal_energy[2](keV)”“84.22"
10 "ecal_channel[2]”    “1122.93"
```

```
11 "ecal_limit[2](channels)”“3.0"
12 "num_fwhmcal”        “2"
13 "fcal_energy[1](keV)”“185.715"
14 "fcal_limit[1](eV)”  “700"
15 "fcal_energy[2](keV)”“92.7"
16 "fcal_limit[2](eV)”  “600"
17 "num_tailfract”      “2"
18 "scal_energy[1](keV)”“185.718"
19 "scal_limit[1](percent)”“5"
20 "scal_energy[2](keV)”“92.7"
21 "scal_limit[2](percent)”“5"
22 "fix_bad_bkg”        “TRUE"
23 "restrict_fwhm_model”“TRUE"
24 "fix_100kev_uranium” “TRUE"
25 "eff_use_dflts”      “yes"
26 "eff_det_type”       “0"
27 "eff_upu_min”        “0.1"
28 "eff_upu_max”        “5"
29 "eff_abs_name[1]”    “Cd"
30 "eff_abs_min[1]”     “0"
31 "eff_abs_max[1]”     “3"
32 "eff_abs_name[2]”    “"
33 "eff_abs_min[2]”     “0"
34 "eff_abs_max[2]”     “2"
// end
```

UCoax_WR

The only difference between this UCoax_WR parameter set and the standard parameter set U121_1001Coax is that it has one extra peak at 768.3 keV to account for the BG peak at that position. We did not, however, use this exact parameter set for the analyses done with uranium in this work. Instead, we created three slightly different parameter sets, one for LEU, one for HEU, and one for HEU without the peaks from ^{228}Th decay. For the LEU analysis, we removed peaks from ^{228}Th decay from the efficiency calculations from the UCoax_WR parameter set. We remove the 766-keV peak from energy, FWHM, and shape calibration for HEU analysis. And finally, in addition to the removal of the 766-keV peak from calibrations, we removed all the peaks from ^{228}Th decay from the efficiency calculations for the HEU analysis without ^{228}Th.

```
// fit information
name: UCoax_WR
desc: " U Only, All Enrichments, 0.125 keV/ch, Coax Detector"
date: "2005.09.13 14:06"
ecal: 1.250000e-001 0.000000e+000
fix-ecal: N
fcal: 1.920000e+001 1.760000e-001 1.550000e+003
fix-fcal: N
scal: -2.400000e+000 1.600000e-003 2.500000e-001 0.000000e+000
fix-scal: N
// peak information
num_peaks: 28
  1 "U234″  120.905    0.003.390000e-004 0.000000e+00  0   0 N Y N N N 1
  2 "U235″  140.760    0.002.620000e-003 0.000000e+00  0   0 N N N N N 2
  3 "U235″  143.760    0.001.095000e-001 0.000000e+00  0   0 Y N Y Y Y 2
  4 ""      145.940    0.000.000000e+000 0.000000e+00  0   0 N N N N N 2
  5 "U235″  163.330    0.005.089000e-002 0.000000e+00  0   0 Y N N N N 3
  6 "U235″  182.610    0.004.024000e-003 0.000000e+00  0   0 N N N N N 4
  7 "U235″  185.715    0.005.739000e-001 0.000000e+00  0   0 Y Y Y Y Y 4
  8 "U235″  202.110    0.001.100000e-002 0.000000e+00  0   0 N N N N N 5
  9 "U235″  205.311    0.004.993000e-002 0.000000e+00  0   0 Y N N N N 5
 10 "Th228″ 238.630    0.004.494000e-001 0.000000e+00  0   0 Y Y N N N 6
 11 "U235″  240.870    0.006.984000e-004 0.000000e+00  0   0 N N N N N 6
 12 "U238″  258.260    0.007.330000e-004 0.000000e+00  0   0 Y N N N N 7
 13 "Th228″ 583.190    0.002.944000e-001 0.000000e+00  0   0 Y Y N N N 8
 14 "Th228″ 727.300    0.006.577000e-002 0.000000e+00  0   0 Y Y N N N 9
 15 "U238″  738.000    0.002.091000e-005 0.000000e+00  0   0 N N N N N 10
 16 "U238″  739.950    0.001.165000e-004 0.000000e+00  0   0 N N N N N 10
 17 "U238″  742.810    0.008.982000e-004 0.000000e+00  0   0 Y N N N N 10
 18 "Th228″ 763.300    0.006.380000e-003 0.000000e+00  0   0 N N N N N 11
 19 "U238″  766.360    0.003.074000e-003 0.000000e+00  0   0 Y N Y Y Y 11
 20 ""      768.300    0.000.000000e+000 0.000000e+00  0   0 N N N N N 11
 21 "Th228″ 860.500    0.004.596000e-002 0.000000e+00  0   0 Y Y N N N 12
 22 "U238″  880.450    0.002.119000e-004 0.000000e+00  0   0 Y N N N N 13
 23 "U238″  883.220    0.002.121000e-004 0.000000e+00  0   0 Y N N N N 13
 24 "U238″  941.940    0.002.851000e-005 0.000000e+00  0   0 N N N N N 14
 25 "U238″  945.950    0.003.462000e-004 0.000000e+00  0   0 Y N N N N 14
 26 "U238″  947.700    0.002.215000e-005 0.000000e+00  0   0 N N N N N 14
 27 "U238″  994.940    0.005.656000e-005 0.000000e+00  0   0 N N N N N 15
 28 "U238″  1001.03    0.008.371000e-003 0.000000e+00  0   0 Y Y Y Y Y 15
// region information
num_regions: 15
```

```
 1  119.70 122.10 118.70 119.50 122.40 123.40   0.00   0.00   0.00   0.002 "linear"
 2  139.20 147.00 136.80 137.70 137.90 139.00 147.10 148.20 148.50 149.606 "linear step"
 3  160.80 165.00 158.40 159.70 159.80 161.00 166.30 167.40 167.80 169.006 "linear step"
 4  181.20 187.50 177.00 178.50 180.00 181.00 189.10 190.50 190.80 192.007 "bilinear step"
 5  198.10 207.00 197.50 198.00 200.00 200.50 207.00 208.00 211.00 212.006 "linear step"
 6  237.50 242.00 231.00 232.00 243.00 244.00   0.00   0.00   0.00   0.002 "linear"
 7  256.70 260.00 252.50 254.50 260.50 262.50   0.00   0.00   0.00   0.002 "linear"
 8  581.00 585.00 579.00 580.00 586.00 587.00   0.00   0.00   0.00   0.002 "linear"
 9  725.00 729.80 718.10 719.60 734.80 735.80 745.70 746.80 749.30 750.706 "linear step"
10  736.40 745.40 718.10 719.60 734.80 735.80 745.70 746.80 749.30 750.706 "linear step"
11  762.00 768.60 752.70 754.20 758.60 760.20 770.20 771.60 772.00 773.506 "linear step"
12  857.75 862.50 855.75 857.00 862.75 864.00   0.00   0.00   0.00   0.002 "linear"
13  874.00 889.00 871.00 872.50 890.00 892.00   0.00   0.00   0.00   0.002 "linear"
14  940.00 949.00 938.00 939.50 954.00 956.00   0.00   0.00   0.00   0.002 "linear"
15  992.501006.00 987.00 988.50 990.00 991.501008.001010.001011.001013.006 "linear step"
// isotope information
num_isotopes: 5
 1 "U238"  4.468300e+009 years  238.05078    0.00001  0.0000 1
 2 "U235"  7.038100e+008 years  235.04393    0.00006  0.0000 1
 3 "U234"  2.446000e+005 years  234.04090    0.18023  0.0000 1
 4 "U236"  2.341500e+007 years  236.04556    0.00175  0.0000 1
 5 "Th228" 1.913100e+000 years  228.02873    0.00000  0.0000 1
// appcon information
num_appcons: 32
 1 "u236_correlation”   “0.00472"
 2 "u235_exponent”      “0.925"
 3 "u238_exponent”      “0.075"
 4 "u236_corr_err%”     “25."
 5 "FRAM_SUMMARY_TYPE”  “URANIUM"
 6 "num_ecal”           “2"
 7 "ecal_energy[1](keV)”“185.718"
 8 "ecal_channel[1]”    “1486."
 9 "ecal_limit[1](channels)”“3.0"
10 "ecal_energy[2](keV)”“1001.025"
11 "ecal_channel[2]”    “8008."
12 "ecal_limit[2](channels)”“5.0"
13 "num_fwhmcal”        “2"
14 "fcal_energy[1](keV)”“185.718"
15 "fcal_limit[1](eV)”  “1200"
16 "fcal_energy[2](keV)”“1001.025"
17 "fcal_limit[2] (eV)” “2000"
18 "num_tailfract”      “2"
19 "scal_energy[1](keV)”“185.718"
20 "scal_limit[1](percent)”“5"
21 "scal_energy[2](keV)”“1001.025"
22 "scal_limit[2](percent”“5"
23 "eff_use_dflts”      “yes"
24 "eff_det_type”       “1"
25 "eff_upu_min”        “0.01"
26 "eff_upu_max”        “30."
27 "eff_abs_name[1]”    “Cd"
28 "eff_abs_min[1]”     “0"
29 "eff_abs_max[1]”     “5.0"
30 "eff_abs_name[2]”    “"
31 "eff_abs_min[2]”     “0"
32 "eff_abs_max[2]”     “5.0"
// end
```

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