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Optimization and Verification of FRAM Version 6.1 Parameter Sets

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ABSTRACT

FRAM (Fixed-energy Response-function Analysis with Multiple efficiency) is a program developed at Los Alamos National Laboratory that determines actinide isotopic composition by analyzing gamma-ray spectra of special nuclear material. This report documents the creations of the parameter sets and the performance (bias and precision) of FRAM version 6.1, scheduled for release in late 2019 – early 2020.

A. INTRODUCTION

The Fixed-energy Response-function Analysis with Multiple efficiency (FRAM) software was developed and continues to be refined by Los Alamos National Laboratory. The code was developed for gamma-ray spectrometry measurements of the isotopic composition of plutonium, uranium, and other actinides [1–3]. FRAM version 6.1 can obtain a complete plutonium or uranium isotopic analysis using either a high-resolution high-purity germanium (HPGe) detector or a medium-resolution $LaBr_3$ or CZT detector.

For plutonium analysis when using a planar HPGe detector, FRAM has most often been used to collect and analyze data using an energy calibration of 0.075 keV/ch in the low-energy region 60–230 keV and in the medium-energy region 120–420 keV, although it is not limited to this energy calibration or these energy ranges. The most widely used mode of operation with the coaxial HPGe detector is to acquire the spectra in the 0–1024 keV energy range at 0.125 keV/ch energy calibration. If there exist sufficient counts in the region between 120 and 200 keV, then FRAM usually works best analyzing in the medium-energy range 120–420 keV. One setback of analysis employing this energy region is the summed peaks. When there are not enough filters to significantly suppress the 60-keV peak of ^{241}Am (the 60-keV peak height below the tallest peak in the 100-keV region), then the 60-keV peak may have a high probability to sum with the peaks in the 100-keV region to form the summed peaks near the only ^{240}Pu peak at 160.3 keV. These summed peaks would affect the determination of the 160.3-keV peak area and thus the ^{240}Pu activity.

When the gamma rays below 200 keV are not available, such as when measuring a sample inside a lead-lined container, FRAM can still obtain a complete isotopic analysis using only gamma rays in the high-energy region 180–1010 keV. Figure 1 shows a typical plutonium spectrum with these three overlapping analytical regions, which are depicted as three thick horizontal bars.

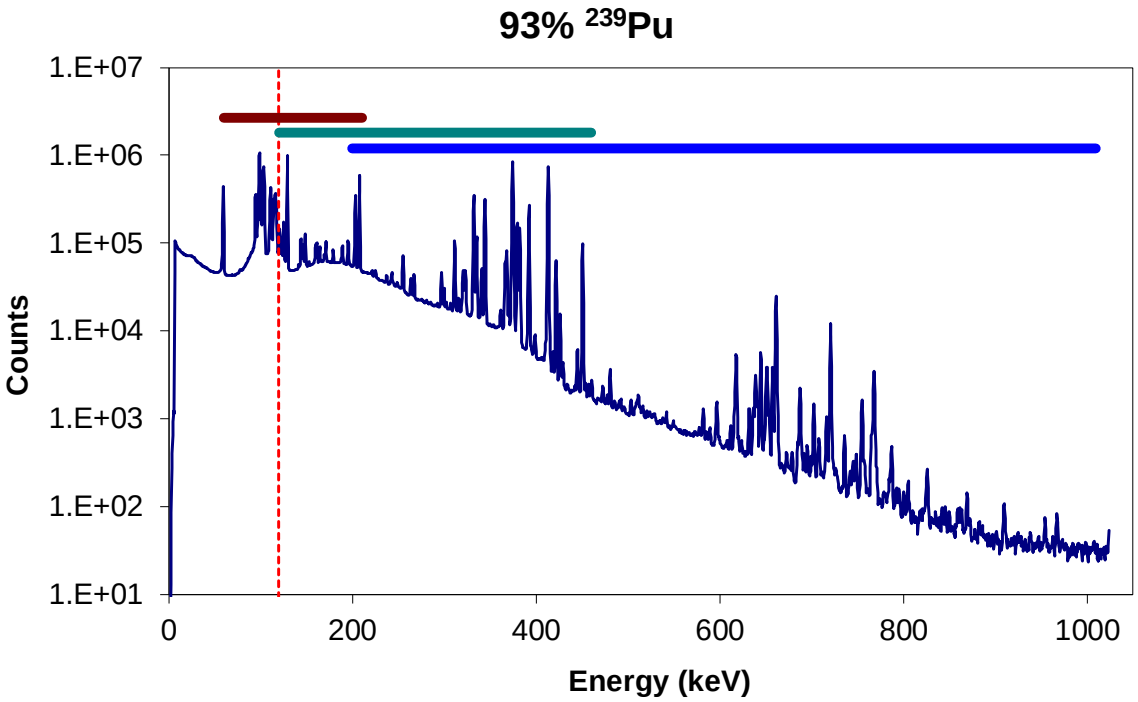

Figure 1. A low-burnup plutonium spectrum. The vertical dashed line denotes the plutonium K-edge. The three overlapping analytical regions that FRAM normally uses for the analysis are shown as three thick horizontal bars above the spectrum.

For uranium analysis when using a planar HPGe detector, FRAM is normally used to collect and analyze data in the low-energy region 60–250 keV at 0.075 keV/ch. The coaxial HPGe detector is normally used to acquire 8K channel spectra at 0.125 keV/ch covering the energy range of 0 to 1024 keV. The analytical region for such spectra is 120–1010 keV. Figure 2 shows an example of a uranium spectrum. The two thick horizontal bars above the spectrum represent the two overlapping analytical regions (low and high) that FRAM normally uses for the analysis. For more information concerning the historical use of FRAM, consult reference [2].

B. PARAMETER SET CREATION

New parameter sets for plutonium and uranium are created for FRAM v.6.1. The two parameter sets for low- and medium-energy planar plutonium analysis are GePlnr_Pu_060-230 and GePlnr_Pu_120-420, respectively. The two parameter sets for medium- and high-energy coaxial plutonium analysis are GeCoax_Pu_120-420 and GeCoax_Pu_180-1010, respectively. For uranium analysis, one low-enriched uranium (LEU) parameter set and one highly enriched uranium (HEU) parameter set are required for each analytical region. The GePlnr_ULEU_060-250 and GePlnr_UHEU_060-250 parameter sets are for the low-energy analytical region of the planar HPGe. For the high-energy analytical region of the coaxial HPGe detector, the parameter sets are GeCoax_ULEU_120-1010 and GeCoax_UHEU_120-1010.

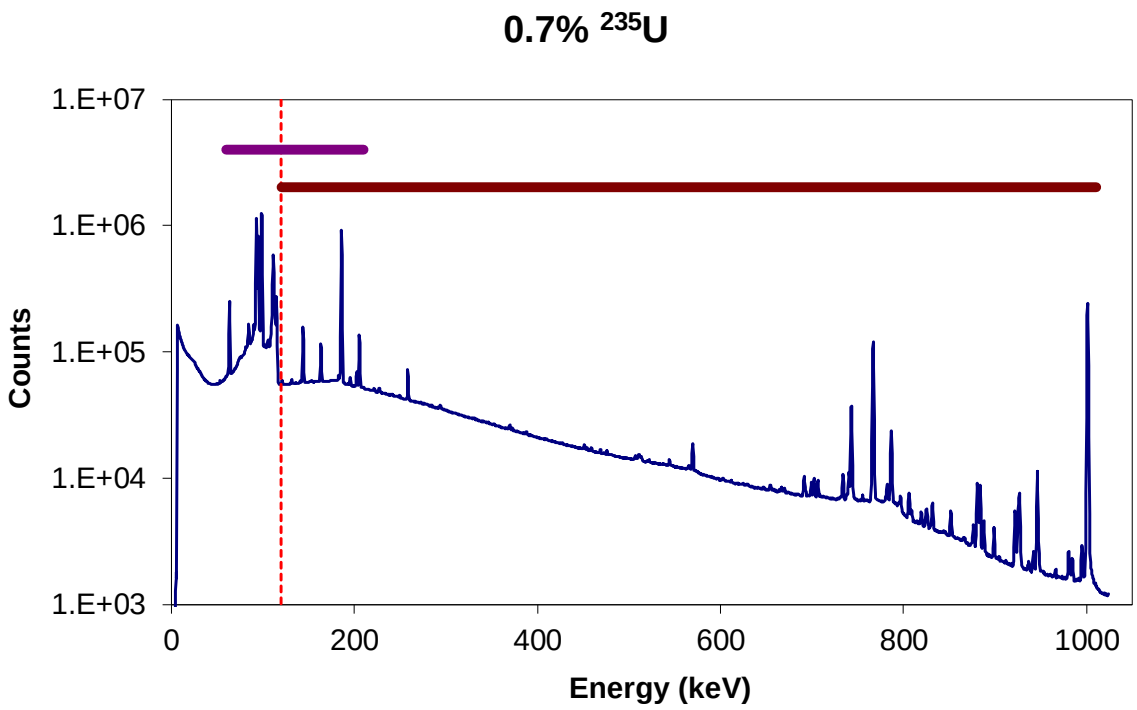

Figure 2. A natural uranium spectrum. The vertical dashed line denotes the uranium K-edge. The two overlapping analytical regions that FRAM normally uses for the analysis are shown as two thick horizontal bars above the spectrum.

These parameter sets are the basic parameter sets that FRAM uses to analyze plutonium and uranium isotopic compositions. All other parameter sets (such as those for non-equilibrium, heterogeneous samples; mixed uranium and plutonium oxide [MOX]; or samples with other interference isotopes) are derived from these basic ones, which are optimized for best results. The optimization process involves assigning the regions of interest, background regions and shapes, peaks for analysis, peak energies, and branching ratios (BRs).

For previous versions of FRAM, each parameter set was optimized individually. As a result, the BRs of many gamma rays from one parameter set are different from the gamma rays from the other sets. For the parameter sets of FRAM v.6.1, we optimized such that the BRs of the same peaks in different parameter sets are the same.

We wrote a code—FRAMBRO (FRAM Branching Ratio Optimization)—to optimize the BRs for best results. Traditionally, the FRAM model is given a set of inputs (a spectrum and nuclear data, such as BRs), and it outputs isotopic ratios. Here, we used FRAM to analyze thousands of archived plutonium and uranium spectra of certified and working reference materials with known isotopic compositions. The code employs the downhill simplex method to minimize the absolute differences between the calculated and certified isotopic ratios by changing the BRs. FRAM v.6.1 uses these optimized BRs in all the parameter sets.

The code reads in a list of the spectral files used for the optimization. It then runs FRAM in the command line mode, analyzing those spectra. From the results of these analyses, it then adjusts

the BRs of the parameter set using the downhill simplex method and then repeats the process until the minimum is reached. The physical efficiency model was used for these analyses.

For plutonium parameter sets, we started out with the medium-energy region (120–420 keV) parameter set for the planar HPGe detector. The initial BRs were from the National Nuclear Data Center (NNDC). The BRs of the 129- and 414-keV peaks of ^{239}Pu were fixed for this optimization. The data were 192 randomly selected planar spectra acquired from 1989 to 2002.

Both ^{237}U (daughter of ^{241}Pu) and ^{241}Am decay to the 267-keV energy level of the ^{237}Np nucleus. Three intense gamma rays (164, 208, and 267 keV) decay from this level. This leads to the same ratios of the ^{241}Pu BR to ^{241}Am BR for these three peaks. Due to this, we allowed the individual BRs of these gamma rays to vary in the optimization, with the condition that the ^{241}Pu to ^{241}Am BR ratios of the three peaks were the same.

After completing the optimization of the medium-energy region of the planar parameter set GePlnr_Pu_120-420, we optimized the low-energy region (60–230 keV) parameter set for the planar detector. The initial BRs for this parameter set from 60 to 120 keV were from the NNDC and from 120 to 230 keV were from the optimized GePlnr_Pu_120-420 parameter set. Only the peaks in the energy range 60–120 keV were adjusted for this optimization. The data were 192 randomly selected planar spectra acquired from 1989 to 2002. These spectra were not the same ones used in the optimization of the medium-energy region.

We did not optimize the medium-energy region of the coaxial detector with the FRAMBRO code. We instead modified the GePlnr_Pu_120-420 for the broader resolution of the coaxial detector. We verified the modified parameter set with the coaxial detector spectra. This parameter set is called GeCoax_Pu_120-420.

The parameter set for the high-energy region had initial BRs that were the same as those of the parameter sets for the medium-energy region in the energy region 180–420 keV and BRs from the NNDC for the energy region 420–1010 keV. Only the peaks in the energy range 420–1010 keV were adjusted for this optimization. The data were 201 randomly selected coaxial spectra acquired from 1993 to 2002.

For uranium parameter sets, we summed the planar and coaxial spectra for each set into one spectrum, and we analyzed the summed spectra instead of the randomly selected individual spectra as before. We started out with a parameter set for the low-energy region for all uranium from 60 to 250 keV. The initial BRs were from the NNDC. The BRs for the 144- and 186-keV peaks of ^{235}U were fixed for the optimization. The data were 82 summed spectra of the planar data acquired from 2001 to 2013. This parameter set was later manually modified slightly and separated into two parameter sets: GePlnr_ULEU_060-250 for LEU and GePlnr_UHEU_060-250 for HEU.

The optimization of the high-energy region of the coaxial detector was done separately for LEU and HEU. The parameter set for LEU was created with the initial BRs for the energy range 120–250 keV from the GePlnr_ULEU_060-250 parameter set and for the range 250–1010 keV from the NNDC. The BR of the 1001 keV peak of ^{234}Pa (^{238}U progeny) was fixed. The data were 82

summed LEU spectra of the coaxial detector acquired from 1996 to 2013. The result was the parameter set GeCoax_ULEU_120-1010.

The parameter set for HEU was created with initial uranium BRs that were the same as those of the GeCoax_ULEU_120-1010 parameter set and the ^{228}Th BRs from the NNDC. All the uranium BRs were fixed, and only the ^{228}Th BRs were adjusted for this optimization. The data were 43 summed HEU spectra of the coaxial detector acquired from 1996 to 2013. The optimized parameter set became GeCoax_UHEU_120-1010.

After all the parameter sets described above were created, they were manually tested with some data sets and the peak BRs, and analysis regions were slightly adjusted for optimal analysis.

The parameter sets for the CZT and $LaBr_3$ detectors were created from the parameter sets for the coaxial detector. The CZT500_Pu_120-500 parameter set was created by modifying the GeCoax_Pu_120-420 parameter set for the broader resolution and long tail of the CZT detector. The "Medium Resolution" flag is turned on to tell FRAM to fit the peaks of the CZT spectrum using the nonlinear least-squares fit instead of the linear least-squares fit used with the HPGe spectra. Similarly, the LaBr_Pu_200-750 parameter set was formed by modifying the GeCoax_Pu_180-1010 parameter set for the broader resolution of the $LaBr_3$ detector. The fits of the $LaBr_3$ peaks are also nonlinear. We created the CZT500_U_120-1010 and LaBr_U_120-1010 parameter sets by modifying the GeCoax_UHEU_120-1010 parameter set.

C. PERFORMANCE

We verified the performance of the parameter sets using the large archive of spectra we collected over many years using several different planar HPGe detectors, coaxial HPGe detectors, CZT detectors, and $LaBr_3$ detectors. The planar detectors were of various sizes, from 2.5 cm in diameter by 1.0 cm long to 5.1 cm in diameter by 1.5 cm long. The coaxial detectors also were of various sizes, with relative efficiencies ranging from about 25% to 50%. These HPGe detectors were made by either Canberra Industry or Ortec. One CZT detector was used to measure plutonium data, and another one was used to measure uranium data. They both had the same crystal size, 500 mm^3, although the one used to measure uranium had much worse resolution than the other. Three $LaBr_3$ detectors (one 2.5 cm in diameter by 3.8 cm long and two 5.1 cm in diameter by 1.25 cm long) were used to acquire both plutonium and uranium data. The electronics were either standalone multichannel analyzers from Canberra, Ortec, or GBS Elektronik or a mixture of Canberra and Ortec modules in the NIM bin racks. Note that some of the spectra used in this performance assessment were the same as those used in the optimizations of the parameter sets.

Tables 1 and 2 show the specifications of the plutonium and uranium data measured by the HPGe planar detectors, HPGe coaxial detectors, CZT500 detectors, and $LaBr_3$ detectors. Appendix A shows the accepted isotopic compositions of the measured plutonium and uranium samples.

Table 1. Specifications of the plutonium data.

Detector	Measurement Period	# sets	# spectra	Spectra per set	Meas. Real Time (min)	Ave. RT (sec)	Ave. LT (sec)
HPGe Planar	1988–2004	98	1628	5–29	15–180	1869	1604
HPGe Coaxial	1993–2002	68	1073	9–30	15–120	2935	2189
CZT500	2016	10	333	29–36	15	900	857
$LaBr_3$	2015–2016	21	530	16–35	15	900	729

Table 2. Specifications of the uranium data.

Detector	Measurement Period	# sets	# spectra	Spectra per set	Meas. Real Time (min)	Ave. RT (sec)	Ave. LT (sec)
HPGe Planar	2001–2013	96	1656	10–29	15–30	1039	932
HPGe Coaxial	1996–2013	101	1876	6–24	15–30	2175	1838
CZT500	2015	13	238	16–20	15	900	877
$LaBr_3$	2015	25	465	16–20	15	900	806

1. Isotopic analysis results

All the plutonium spectra of the planar detectors from all the sources mentioned in Table 1 and shown in Table A1 of Appendix A were analyzed with the parameter sets GePlnr_Pu_060-230 and GePlnr_Pu_120-420. The coaxial spectra from all the sources shown in Table A2 of Appendix A were analyzed with the parameter set GeCoax_Pu_180-1010. The spectra from the first 47 items in Table A2 were also analyzed with the parameter set GeCoax_Pu_120-420. The spectra of the 48th item (EuPu7Cx) to the 61st item (PuOc3Cx) were not included due to the very large 60-keV peak, which sums with the peaks in the 100-keV region to form the summed peaks around 160 keV. These summed peaks would interfere with the area determination of the only peak used for the calculation of the activity of ^{240}Pu at 160.3 keV. Thus, those spectra were not used in the analysis with the GeCoax_Pu_120-420 parameter set. The last 7 items in Table A2 were shielded by lead, and the peaks below 200 keV were not visible, so the spectra from those items were also not used.

The CZT spectra in Table A3 and $LaBr_3$ in Table A4 were analyzed with the parameter set CZT500_Pu_120-500 and LaBr_Pu_200-750, respectively.

For uranium analysis, the LEU spectra from the sources in Table A5 were analyzed with the parameter set GePlnr_ULEU_060-250, and the HEU spectra were analyzed with the parameter set GePlnr_UHEU_060-250. Similarly, the LEU spectra from the sources in Table A6 were analyzed with the parameter set GeCoax_ULEU_120-1010, and the HEU spectra were analyzed with the parameter set GeCoax_UHEU_120-1010. The CZT spectra in Table A7 and $LaBr_3$ in Table A8 were analyzed with the parameter set CZT500_U_120-1010 and LaBr_U_120-1010, respectively.

The physical efficiency model was used for all the analyses.

Each data set consists of multiple measurements taken without repositioning the sample. The individual results for each isotope were averaged over the multiple measurements. For any isotope, the relative bias x_{ij} for each spectrum j associated with each sample i is

$$x_{ij} = \frac{M_{ij} - D_i}{D_i} \ ,$$

where M_{ij} is the measured mass fraction and D_i is the declared mass fraction and is assumed to be the true mass fraction.

The average unweighted bias $\bar{x}_i$ associated with sample i is described by the equation below, where m_i is the number of individual measurements of sample i.

$$\bar{x}_i = \frac{1}{m_i} \sum_{j=1}^{m_i} x_{ij}$$

To utilize a single statistic to represent parameter set performance for a given isotope the $\bar{x}_i$ are further averaged to determine the global bias $\bar{x}$ represented by the equation below, where n denotes the number of samples measured.

$$\bar{x} = \frac{1}{n} \sum_{i=1}^{n} \bar{x}_i$$

The uncertainty of the unweighted global bias $u_{\bar{x}}$ is the standard deviation of the average unweighted biases $\sigma_{\bar{x}}$ divided by the square root of the number of data sets.

$$u_{\bar{x}} = \frac{\sigma_{\bar{x}}}{\sqrt{n}} = \sqrt{\frac{1}{n(n-1)} \sum_{i=1}^{n} (\bar{x}_i - \bar{x})^2}$$

If all the spectral acquisitions were of items with similar isotopic compositions, of similar counting times, and utilized similar counting geometries, then uncertainties of the reported isotopic fractions would be similar. Then the unweighted global bias should be a good indicator of overall parameter set performance. However, as in the case of this study, different isotopic compositions, counting times, and geometries have resulted in different uncertainties for each measurement. Therefore, this work also reports weighted global biases of weighted average biases. Weights are taken as the inverse of the isotopic fraction uncertainties reported by FRAM. Weighted global biases are calculated in a similar manner to the unweighted global biases.

The average and uncertainty of the weighted global bias are calculated in accordance with reference [4]. The average weighted bias ${}_w\bar{x}_i$ associated with sample i is

$${}_w\bar{x}_i = \frac{\sum_{j=1}^{m_i} x_{ij} w_{ij}}{\sum_{j=1}^{m_i} w_{ij}} \ .$$

Here the weight w_{ij} is the inverse of the reported uncertainty for each spectrum j associated with each sample i.

The global bias ${}_w\bar{x}$ is represented by the equation

$$ {}_w\bar{x} = \frac{\sum_{i=1}^{n} \bar{x}_i w_i}{\sum_{i=1}^{n} w_i} \ . $$

Here, w_i is the weight of data set *i* and is set to be the inverse of the standard deviation of the results of data set *i*.

And finally, the uncertainty of the weighted global bias ${}_w u_{\bar{x}}$ is

$$ {}_w u_{\bar{x}} = \frac{{}_w\sigma_{\bar{x}}}{\sqrt{n}} = \sqrt{\frac{\sum_{i=1}^{n} ({}_w\bar{x}_i - {}_w\bar{x})^2 w_i}{n \sum_{i=1}^{n} w_i}} \ . $$

Tables 3 and 4 present the plutonium and uranium bias results of the analyses, respectively.

Table 3. Bias results of the plutonium analysis. Uncertainties represent 1-sigma or 68% confidence intervals.

Parameter	Global biases	^{238}Pu	^{239}Pu	^{240}Pu	^{241}Pu	^{241}Am
GePlnr_Pu _060-230	Unweighted bias	-0.0038	0.0003	-0.0001	0.0000	0.0000
	Unweighted bias uncertainty	0.0025	0.0001	0.0008	0.0004	0.0012
	Weighted bias	0.0033	0.0001	-0.0007	0.0000	-0.0013
	Weighted bias uncertainty	0.0015	0.0001	0.0007	0.0005	0.0010
GePlnr_Pu _120-420	Unweighted bias	-0.0050	0.0002	-0.0014	-0.0006	-0.0017
	Unweighted bias uncertainty	0.0024	0.0002	0.0010	0.0005	0.0017
	Weighted bias	0.0003	0.0001	-0.0005	-0.0002	-0.0011
	Weighted bias uncertainty	0.0016	0.0001	0.0008	0.0005	0.0012
GeCoax_Pu _120-420	Unweighted bias	-0.0039	0.0000	0.0015	-0.0001	-0.0037
	Unweighted bias uncertainty	0.0027	0.0002	0.0014	0.0006	0.0014
	Weighted bias	-0.0026	0.0000	0.0000	0.0000	-0.0016
	Weighted bias uncertainty	0.0016	0.0001	0.0012	0.0006	0.0011
GeCoax_Pu _180-1010	Unweighted bias	0.0187	0.0003	-0.0019	-0.0019	-0.0002
	Unweighted bias uncertainty	0.0096	0.0004	0.0022	0.0009	0.0011
	Weighted bias	-0.0023	0.0000	0.0007	-0.0016	-0.0001
	Weighted bias uncertainty	0.0058	0.0002	0.0019	0.0008	0.0010
CZT500_Pu _120-500	Unweighted bias	-0.1236	0.0019	0.0166	-0.0749	0.1501
	Unweighted bias uncertainty	0.1199	0.0029	0.0347	0.0426	0.0600
	Weighted bias	-0.2335	0.0012	-0.0123	-0.1060	0.0859
	Weighted bias uncertainty	0.1074	0.0027	0.0317	0.0238	0.0204
LaBr_Pu _200-750	Unweighted bias	0.3764	-0.0017	-0.0088	0.0609	-0.0048
	Unweighted bias uncertainty	0.1904	0.0034	0.0291	0.0681	0.0070
	Weighted bias	-0.0845	0.0005	-0.0044	-0.1046	-0.0168
	Weighted bias uncertainty	0.2731	0.0024	0.0225	0.0655	0.0058

Table 4. Bias results of the uranium analysis. Uncertainties represent 1-sigma or 68% confidence intervals.

Parameter	Global biases	^{234}U	^{235}U	^{238}U
GePlnr_ULEU_060-250 GePlnr_UHEU_060-250	Unweighted bias	-0.0072	0.0018	-0.0167
	Unweighted bias uncertainty	0.0039	0.0009	0.0068
	Weighted bias	-0.0016	-0.0004	-0.0001
	Weighted bias uncertainty	0.0016	0.0008	0.0003
GeCoax_ULEU_120-1010 GeCoax_UHEU_120-1010	Unweighted bias	-0.0029	-0.0027	-0.0046
	Unweighted bias uncertainty	0.0043	0.0011	0.0012
	Weighted bias	0.0020	0.0004	-0.0001
	Weighted bias uncertainty	0.0024	0.0008	0.0002
CZT500_U_120-1010	Unweighted bias	-0.0456	-0.0456	-0.0672
	Unweighted bias uncertainty	0.0372	0.0279	0.0655
	Weighted bias	0.0998	0.0239	-0.0035
	Weighted bias uncertainty	0.0314	0.0158	0.0184
LaBr_U_120-1010	Unweighted bias	-0.0160	0.0054	0.0746
	Unweighted bias uncertainty	0.0369	0.0185	0.0982
	Weighted bias	-0.0477	-0.0100	0.0006
	Weighted bias uncertainty	0.0305	0.0161	0.0130

For most isotopes and parameter sets, global biases agree with zero within uncertainty (typically within two sigma, or 95% confidence intervals). Also, for each parameter set, the weighted bias uncertainties are almost always less than the unweighted bias uncertainties.

For both the plutonium and uranium analyses, the bias uncertainties of the CZT500 and $LaBr_3$ detectors are more than an order of magnitude worse than the uncertainties of the coaxial detector's analyses. That is also expected since the resolution of these two detectors and the tail of the CZT500 detector are much worse than those of the coaxial detector.

2. ANOVA analysis

The isotopic results are also analyzed by the analysis of variance (ANOVA) to estimate the repeatability standard deviation and the standard deviation of the item-specific bias in each data set.

The FRAM measurement error model can be expressed as

$$M_{ij} = D_i\left(1 + G + S_i + R_{ij}\right) \ ,$$

where M_{ij} and D_i are the measured and declared mass fraction (defined in the previous section), G is the group-specific bias, S_i is the item-specific systematic uncertainty, and R_{ij} is the random uncertainty.

The error variance can be partitioned into within-group variance and between-group variance [5].

$$\sum_{i=1}^{n}\sum_{j=1}^{m_i}\left(x_{ij} - \bar{x}\right)^2 = \sum_{i=1}^{n}\sum_{j=1}^{m_i}\left(x_{ij} - \bar{x}_i\right)^2 + \sum_{i=1}^{n} m_i\,(\bar{x}_i - \bar{x})^2 = SSW + SSB$$

Here, *SSW* is the sum of squares for within-group variability, and *SSB* is the sum of squares for between-group variability.

The within-group replicate variance δ_R^2 is the mean square for within-group variability (*MSW*), which is the sum of squares for within-group variability *SSW* divided by the degrees of freedom:

$$\delta_R^2 = MSW = \frac{SSW}{N-n} = \frac{\sum_{i=1}^{n}\sum_{j=1}^{m_i}\left(x_{ij}-\bar{x}_i\right)^2}{N-n} \ ,$$

where $N = (\sum_{i=1}^{n} m_i)$ is the total of the measurements of all samples, and *n* is the number of samples (defined in previous section).

Reference [5] also shows that the variance of the estimated item-specific biases δ_S^2 can be estimated as

$$\delta_S^2 = \frac{N(n-1)(MSB-MSW)}{N^2-\sum_{i=1}^{n} m_i^2} \ ,$$

where $MSB = SSB/(n-1)$ is the mean square for between-group variability, which is the sum of squares for between-group variability divided by the degrees of freedom.

Tables 5 and 6 present the plutonium and uranium ANOVA analysis results, respectively. For the analysis of each parameter set, three different sets of results are shown: the random uncertainty δ_R, the item-specific systematic uncertainty δ_S, and the standard deviation of the average biases.

The estimate of δ_R represents a global random or statistical uncertainty for FRAM drawn from the specific data sets used in the analysis. The random uncertainty from a measurement can be larger or smaller than this, depending on the statistics of the data when compared with those represented in the data sets.

The estimate of δ_S represents the item-specific systematic uncertainty for an isotopic analysis of a spectrum measured with a detector system similar to those used to acquire the data sets in this work and good measurement techniques.

The standard deviation of the average biases is a rough estimate of δ_S that does not account for the impact of random error in the biases and is expressed as

$$\sigma_{\bar{x}} = \sqrt{\frac{1}{(n-1)}\sum_{i=1}^{n}(\bar{x}_i-\bar{x})^2} \ .$$

Table 5. Estimates of the relative standard deviations (%RSD) for the random uncertainties δ_R, the item-specific systematic uncertainties δ_S, and the standard deviation (STDEV) of the relative biases for the plutonium isotopes and ^{241}Am.

Parameter	Global biases	^{238}Pu	^{239}Pu	^{240}Pu	^{241}Pu	^{241}Am
GePlnr_Pu_060-230	Estimate of δ_R	6.0	0.2	0.8	0.5	0.7
	Estimate of δ_S	2.0	0.1	0.7	0.4	1.2
	STDEV of Relative Bias	2.4	0.1	0.8	0.4	1.2
GePlnr_Pu _120-420	Estimate of δ_R	6.0	0.4	2.1	0.8	1.4
	Estimate of δ_S	1.9	0.2	0.8	0.4	1.6
	STDEV of Relative Bias	2.4	0.1	0.8	0.4	1.2
GeCoax_Pu _120-420	Estimate of δ_R	6.1	0.3	2.1	0.4	0.8
	Estimate of δ_S	0.8*	0.1	0.7	0.4	1.0
	STDEV of Relative Bias	1.8	0.1	0.9	0.4	0.9
GeCoax_Pu_180-1010	Estimate of δ_R	10.9	0.6	3.3	0.7	1.0
	Estimate of δ_S	7.7	0.4	1.7	0.8	0.9
	STDEV of Relative Bias	7.9	0.4	1.8	0.8	0.9
CZT500_Pu _120-500	Estimate of δ_R	59.8	2.0	26.2	20.8	48.2
	Estimate of δ_S	35.1	0.9	10.2	13.1	17.2
	STDEV of Relative Bias	37.9	0.9	11.0	13.5	25.8
LaBr_Pu _200-750	Estimate of δ_R	83.7	3.7	34.0	11.4	5.3
	Estimate of δ_S	95.2	1.5	12.7	38.1	3.4
	STDEV of Relative Bias	106.0	1.9	16.2	37.9	3.9

* The ^{238}Pu results for the PID6_1 sample were not used.

Table 6. Estimates of the relative standard deviations (%RSD) for the random uncertainties δ_R, the item-specific systematic uncertainties δ_S, and the STDEV of the relative biases for the uranium isotopes.

Parameter	Global biases	^{234}U	^{235}U	^{238}U
GePlnr_ULEU_060-250 GePlnr_UHEU_060-250	Estimate of δ_R	9.0	2.1	8.4
	Estimate of δ_S	1.4*	0.9	5.8
	STDEV of Relative Bias	3.8	0.9	6.7
GeCoax_ULEU_120-1010 GeCoax_UHEU_120-1010	Estimate of δ_R	16.0	2.8	2.6
	Estimate of δ_S	1.2	0.7	0.9
	STDEV of Relative Bias	4.3	1.1	1.2
CZT500_U_120-1010	Estimate of δ_R	33.3	32.4	13.6
	Estimate of δ_S	11.3	6.7	23.6
	STDEV of Relative Bias	13.4	10.1	23.6
LaBr_U_120-1010	Estimate of δ_R	9.1	8.8	10.1
	Estimate of δ_S	18.8	9.1	50.9
	STDEV of Relative Bias	18.4	9.3	49.1

* The ^{234}U results for the 0.31% ^{235}U sample were not used.

This rough estimate is usually slightly larger than the item-specific systematic uncertainties δ_S, depending on the absolute and relative sample sizes for each sample.

For the plutonium analysis with the parameter set GeCoax_Pu_120-420, the intensities of sample PID6_1's spectra are weak, and the ^{238}Pu results have very large relative uncertainties and scatter wildly. This would significantly increase the mean square for within-group variability *MSW*, making it larger than the mean square for between-group variability *MSB*. As a result of this, the

variance of the estimated item-specific biases δ_S^2 becomes negative, which is unphysical. Excluding the ^{238}Pu results of that sample from the analysis would give a physical and realistic item-specific systematic uncertainties δ_S.

Similarly, for the uranium analysis with the parameter set GePlnr_ULEU_060-250, the ^{234}U fraction in the 0.31% ^{235}U sample is very small, and the ^{234}U results have very large relative uncertainties and are not reliable. So the ^{234}U results of the 0.31% ^{235}U sample are excluded from this analysis.

Examining the results of the CZT and $LaBr_3$ detectors in detail, we see that the random uncertainties δ_R, the item-specific systematic uncertainties δ_S, and the STDEV of the relative biases of these medium resolution detectors are about a factor of 10 larger than those of the coaxial HPGe detector in their respected analysis energy ranges. This factor of 10 worse is similar to the factor of 10 worse of the global biases in the previous section and is expected.

3. Comparison of observed precision and reported statistical uncertainties

FRAM analyzes and reports both the isotopic results and the corresponding statistical uncertainties (only propagating uncertainty due to Poisson counting statistics). It is of interest to see how the average reported statistical uncertainty of an isotopic fraction compares with the observed precision (standard deviation of reported isotopic fractions) for many runs. Table 7 shows the ratios of the observed precision to that of the average statistical uncertainty predicted by FRAM for plutonium data.

Table 7. Ratios of the observed precision to that of the average statistical uncertainty reported by FRAM.

Parameter set	^{238}Pu	^{239}Pu	^{240}Pu	^{241}Pu	^{241}Am
GePlnr_Pu_060-230	1.07	0.77	0.77	0.71	0.73
GePlnr_Pu_120-420	1.12	1.08	1.05	1.17	0.97
GeCoax_Pu_120-420	1.14	1.06	1.05	1.01	0.67
GeCoax_Pu_180-1010	0.97	0.93	0.92	1.03	1.02
CZT500_Pu_120-500	1.21	1.57	1.48	2.18	0.80
LaBr_Pu_200-750	0.18	0.26	0.24	0.93	0.43

The ratios are about unity for most of the isotopes for the HPGe detectors. This means that the FRAM reported statistical uncertainties for the HPGe detector are reasonably close to representing the precisions of the analysis. For the CZT detector, FRAM underestimates the uncertainty component from radiation-counting statistics somewhat. For the $LaBr_3$ detector, the ratios for ^{238}Pu, ^{239}Pu, ^{240}Pu, and ^{241}Am are much less than unity. This is due to the many bounds we employ in the $LaBr_3$ analysis. These bounds constrain the results in some specific directions, making the analysis appear to be more repeatable.

Table 8 shows the ratios of the observed uncertainty to that of the average uncertainty predicted by FRAM for uranium data.

Table 8. Ratios of the observed uncertainty from multiple runs to that of the average uncertainty predicted by FRAM.

Parameter set	^{234}U	^{235}U	^{236}U
GePlnr_ULEU_060-250 GePlnr_UHEU_060-250	0.87	0.89	0.86
GeCoax_ULEU_120-1010 GeCoax_UHEU_120-1010	0.88	1.62	1.63
CZT500_U_120-1010	3.53	3.65	4.06
LaBr_U_120-1010	2.98	3.20	3.25

The ratios of the CZT and $LaBr_3$ detectors are much greater than unity for all isotopes. This means that FRAM underestimates the uncertainties of the CZT and $LaBr_3$ analysis. So for CZT and $LaBr_3$ analysis of uranium data, it is better to use the reported total uncertainties in the medium results output than to use the reported random uncertainties in the short results output. The reported total uncertainty includes the systematic uncertainty in addition to the statistical uncertainty. Reference [6] describes the FRAM systematic uncertainties in detail.

D. CONCLUSIONS

We created new parameter sets for the upcoming FRAM v.6.1. The parameter sets were optimized such that the BRs of the same peaks in different parameter sets are the same. These parameter sets were tested with thousands of spectra to determine their accuracy at predicting the isotopic composition of plutonium and uranium. Their performances were reasonable and expected.

They were also tested for their accuracy on reporting the uncertainties of the results. The reported uncertainties for the HPGe detector are about right for both plutonium and uranium analyses. For plutonium analysis, the reported uncertainties for the CZT detector are somewhat underestimated and for the $LaBr_3$ detector appears to be very much overestimated. The appearance of overestimation was due to the observed uncertainties, which were too small. The too-small observed uncertainties were in turn the result of the way the analysis was done. For uranium analysis, the reported uncertainties for both the CZT and $LaBr_3$ detectors are significantly underestimated. It is suggested that for uranium analysis with CZT and $LaBr_3$ data, the reported total uncertainties be used instead of the statistical uncertainties in reporting the uncertainties.

E. REFERENCES

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4. P.R. Bevington, “Data Reduction and Error Analysis for the Physical Sciences,” (McGraw-Hill Book Company, 1969).

5. T. Burr, T. Sampson, and D. Vo, “Measurement Error Variance Estimation in Gamma-Spectroscopy Data using FRAM,” Los Alamos National Laboratory document LA-UR-19-25748 (2019).
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APPENDIX A

Tables A1–A8 show the accepted isotopic compositions of the plutonium and uranium samples. All these samples cover a very wide range of plutonium and uranium composition, from very low to very high burn-up plutonium and depleted to very high enriched uranium. The isotopic units are weight percent (wt%). Many of these sets are measurements of the same samples but at different times and different measurement conditions and/or with different detector systems.

Table A1. Accepted isotopic compositions of the plutonium samples taken with several planar detectors. The data were acquired from 1988 to 2004. The number of spectra for each set varies from 5 to 29. A total of 98 sets and 1628 spectra were collected. The measurement real time for each spectrum ranges from 15 minutes to 3 hours. The average real time is 1869 seconds, and the average live time is 1604 seconds.

Sample name	^{238}Pu	^{239}Pu	^{240}Pu	^{241}Pu	^{242}Pu	^{241}Am
256C10	0.058	82.289	16.288	1.026	0.340	0.353
A186	0.009*	94.228	5.605	0.138	0.018	0.187
A192	0.008*	94.606	5.262	0.110	0.014	0.176
CALEX23K	0.010	93.860	5.860	0.241	0.029	0.135
CBNM61B	1.168	63.460	25.776	5.339	4.256	2.890
CBNM70B	0.823	74.209	18.509	4.356	2.103	2.345
CBNM84B	0.068	84.529	14.234	0.811	0.358	0.434
CBNM93B	0.011	93.459	6.314	0.176	0.040	0.151
JOO1325	0.011	93.876	5.903	0.182	0.028	0.121
LAO225BS	0.059	82.122	16.614	0.952	0.354	0.643
PE0382C3	0.026	89.690	9.693	0.478	0.112	0.423
PUEU7	0.014	93.782	5.862	0.276	0.066	0.023
SRPISO12	0.057	87.087	11.821	0.814	0.222	0.265
SRPISO12	0.057	87.087	11.821	0.814	0.222	0.265
SRPISO15	0.166	82.295	15.437	1.390	0.712	0.285
SRPISO15	0.166	82.295	15.437	1.390	0.712	0.285
SRPISO3	0.006	96.317	3.562	0.096	0.018	0.032
SRPISO3	0.006	96.317	3.562	0.096	0.018	0.032
SRPISO6	0.014	93.540	6.130	0.259	0.057	0.063
SRPISO6	0.014	93.540	6.130	0.259	0.057	0.063
SRPISO9	0.021	92.660	6.891	0.356	0.073	0.076
SRPISO9	0.021	92.660	6.891	0.356	0.073	0.076
STD11612	0.364	79.804	15.455	3.327	1.050	1.846
STD1174K	0.015	93.579	6.154	0.213	0.039	0.121
STD11834	0.026	90.385	9.000	0.485	0.104	0.273
STD12018	0.364	79.806	15.455	3.326	1.050	2.574
STD1217K	0.060	81.899	16.491	1.106	0.353	0.489
STD3	0.023	91.930	7.615	0.354	0.077	0.311
STD4040K	0.065	87.139	11.768	0.828	0.200	0.433
STD627K	0.010	93.476	6.328	0.161	0.025	0.134
STD832K	0.010	93.476	6.328	0.161	0.025	0.134
STDR3	0.010	94.041	5.766	0.162	0.021	0.188
cbnm6175	1.103	64.876	26.330	3.340	4.352	5.010
cbnm7075	0.774	75.544	18.828	2.713	2.141	4.057
cbnm8475	0.063	84.810	14.270	0.498	0.360	0.742
cbnm9375	0.010	93.529	6.314	0.108	0.040	0.217
eupu775	0.013	93.906	5.864	0.151	0.066	0.147
iso0375	0.006	96.362	3.560	0.054	0.018	0.074
iso0675	0.013	93.654	6.131	0.145	0.057	0.175

iso0975	0.019	92.813	6.896	0.199	0.073	0.230
iso1275	0.052	87.416	11.854	0.455	0.223	0.619
iso1575	0.152	82.829	15.523	0.780	0.717	0.894
pidie175	0.010	93.862	5.990	0.103	0.035	0.318
pidie375	0.043	85.003	14.200	0.519	0.235	1.087
pidie575	0.119	76.674	21.415	1.082	0.710	2.704
pidie775	1.164	64.084	26.433	3.482	4.836	6.808
pufa175	0.012	93.952	5.852	0.139	0.044	0.066
EuPu7PlO	0.013	93.914	5.864	0.143	0.066	0.155
Iso03PlO	0.006	96.365	3.560	0.051	0.018	0.076
Iso06PlO	0.012	93.662	6.131	0.137	0.057	0.183
Iso09PlO	0.019	92.824	6.896	0.188	0.073	0.241
Iso12PlO	0.052	87.439	11.856	0.430	0.223	0.643
Iso15PlO	0.150	82.867	15.528	0.737	0.718	0.937
Pid1PlO	0.010	93.868	5.990	0.098	0.035	0.323
Pid3PlO	0.042	85.029	14.203	0.490	0.235	1.115
Pid5PlO	0.118	76.723	21.427	1.021	0.710	2.761
Pid7PlO	1.155	64.218	26.486	3.293	4.847	7.005
Pu61PlO	1.094	65.008	26.381	3.155	4.361	5.203
Pu70PlO	0.768	75.669	18.857	2.562	2.145	4.212
Pu84PlO	0.062	84.836	14.273	0.470	0.360	0.769
Pu93PlO	0.010	93.535	6.313	0.102	0.040	0.223
PuOc3PlO	0.012	93.985	5.830	0.132	0.041	0.023
pid1pl_r02	0.010	93.877	5.990	0.089	0.035	0.331
pid1pl_r04	0.010	93.877	5.990	0.089	0.035	0.331
pid1pl_r06	0.010	93.877	5.990	0.089	0.035	0.331
pid1pl_r10	0.010	93.877	5.990	0.089	0.035	0.331
pid1pl_r14	0.010	93.877	5.990	0.089	0.035	0.331
pid1pl_r20	0.010	93.877	5.990	0.089	0.035	0.331
pid1pl_r28	0.010	93.877	5.990	0.089	0.035	0.331
pid1pl_r40	0.010	93.877	5.990	0.089	0.035	0.331
pid1pl_r80	0.010	93.877	5.990	0.089	0.035	0.331
pid3pl_r02	0.042	85.071	14.208	0.444	0.235	1.157
pid3pl_r04	0.042	85.071	14.208	0.444	0.235	1.157
pid3pl_r06	0.042	85.071	14.208	0.444	0.235	1.157
pid3pl_r10	0.042	85.071	14.208	0.444	0.235	1.157
pid3pl_r14	0.042	85.071	14.208	0.444	0.235	1.157
pid3pl_r20	0.042	85.071	14.208	0.444	0.235	1.157
pid3pl_r28	0.042	85.071	14.208	0.444	0.235	1.157
pid3pl_r40	0.042	85.071	14.208	0.444	0.235	1.157
pid3pl_r80	0.042	85.071	14.208	0.444	0.235	1.157
pid5pl_r02	0.116	76.800	21.445	0.927	0.711	2.850
pid5pl_r04	0.116	76.800	21.445	0.927	0.711	2.850
pid5pl_r06	0.116	76.800	21.445	0.927	0.711	2.850
pid5pl_r10	0.116	76.800	21.445	0.927	0.711	2.850
pid5pl_r14	0.116	76.800	21.445	0.927	0.711	2.850
pid5pl_r20	0.116	76.800	21.445	0.927	0.711	2.850
pid5pl_r28	0.116	76.800	21.445	0.927	0.711	2.850
pid5pl_r40	0.116	76.800	21.445	0.927	0.711	2.850
pid5pl_r80	0.116	76.800	21.445	0.927	0.711	2.850
pid7pl_r02	1.141	64.430	26.569	2.997	4.863	7.313
pid7pl_r04	1.141	64.430	26.569	2.997	4.863	7.313
pid7pl_r06	1.141	64.430	26.569	2.997	4.863	7.313

pid7pl_r10	1.141	64.430	26.569	2.997	4.863	7.313
pid7pl_r14	1.141	64.430	26.569	2.997	4.863	7.313
pid7pl_r20	1.141	64.430	26.569	2.997	4.863	7.313
pid7pl_r28	1.141	64.430	26.569	2.997	4.863	7.313
pid7pl_r40	1.141	64.430	26.569	2.997	4.863	7.313
pid7pl_r80	1.141	64.430	26.569	2.997	4.863	7.313

* These were adjusted slightly from mass spectrometry values.

Table A2. Accepted isotopic compositions of the plutonium samples taken with several coaxial detectors. The data were acquired from 1993 to 2002. The number of spectra for each set varies from 9 to 30. A total of 68 sets and 1073 spectra were collected. The measurement real time for each spectrum ranges from 15 minutes to 2 hours. The average real time is 2935 seconds, and the average live time is 2189 seconds.

Sample name	^{238}Pu	^{239}Pu	^{240}Pu	^{241}Pu	^{242}Pu	^{241}Am
2G118CX8	0.025	90.490	9.007	0.374	0.104	0.382
2G119CX8	0.036	87.417	11.801	0.578	0.168	0.592
2G120CX8	0.352	80.437	15.571	2.583	1.058	3.339
2G121CX8	0.058	82.207	16.528	0.853	0.354	0.740
61COAX8K	1.154	63.845	25.928	4.791	4.282	3.478
70COAX8K	0.812	74.573	18.597	3.904	2.113	2.820
84COAX8K	0.067	84.606	14.244	0.724	0.359	0.520
86COAX8K	0.008*	94.261	5.605	0.106	0.018	0.219
92COAX8K	0.007*	94.633	5.261	0.084	0.014	0.200
93COAX8K	0.011	93.478	6.314	0.157	0.040	0.170
CALX30	0.009	93.924	5.861	0.176	0.029	0.199
EUPU7CX8	0.014	93.837	5.863	0.220	0.066	0.079
ISO12C8K	0.055	87.240	11.837	0.645	0.222	0.433
ISO15C8K	0.160	82.544	15.478	1.103	0.715	0.573
ISO3CX8K	0.006	96.338	3.561	0.076	0.018	0.052
ISO6CX8K	0.013	93.593	6.131	0.206	0.057	0.116
ISO9CX8K	0.020	92.731	6.893	0.282	0.073	0.149
JOO1325	0.011	93.925	5.904	0.132	0.028	0.169
LAO22530	0.057	82.246	16.534	0.809	0.354	0.785
PUEU730	0.014	93.847	5.863	0.209	0.066	0.090
SD4030	0.062	87.342	11.789	0.606	0.201	0.653
SGCOAX8K	0.006	96.336	3.562	0.078	0.018	0.050
STD830	0.009	93.546	6.303	0.116	0.025	0.176
PID6_1	0.010	93.834	5.991	0.131	0.035	0.293
PID6_2	0.021	89.483	10.109	0.293	0.094	0.415
PID6_3	0.044	84.881	14.185	0.655	0.235	0.957
PID6_4	0.102	78.238	19.886	1.204	0.571	2.198
PIDIE65	0.123	76.455	21.361	1.352	0.708	2.441
PIDIE66	0.884	67.646	24.342	3.502	3.627	5.652
PIDIE67	1.196	63.490	26.198	4.324	4.791	5.916
cbnm61	1.105	64.834	26.314	3.398	4.349	4.950
cbnm70	0.776	75.506	18.819	2.759	2.140	4.010
cbnm84	0.063	84.802	14.269	0.507	0.360	0.733
cbnm93	0.010	93.527	6.314	0.110	0.040	0.215
eupu7cx	0.013	93.907	5.864	0.150	0.066	0.148
iso03cx	0.006	96.361	3.560	0.055	0.018	0.073
iso06cx	0.013	93.654	6.131	0.145	0.057	0.176
iso09cx	0.019	92.813	6.896	0.199	0.073	0.230
iso12cx	0.052	87.416	11.854	0.455	0.223	0.619

iso15cx	0.152	82.829	15.523	0.780	0.717	0.894
pidie1cx	0.010	93.862	5.990	0.103	0.035	0.318
pidie3cx	0.043	85.003	14.200	0.519	0.235	1.087
pidie5cx	0.119	76.674	21.415	1.081	0.710	2.704
pidie7cx	1.164	64.084	26.433	3.482	4.836	6.808
stdiso03	0.006	96.361	3.560	0.055	0.018	0.073
stdiso09	0.019	92.810	6.895	0.202	0.073	0.227
stdiso15	0.152	82.816	15.521	0.794	0.717	0.881
EuPu7Cx	0.013	93.914	5.864	0.143	0.066	0.155
Iso03Cx	0.006	96.365	3.560	0.051	0.018	0.076
Iso09Cx	0.019	92.824	6.896	0.188	0.073	0.241
Iso12Cx	0.052	87.439	11.856	0.430	0.223	0.643
Iso15Cx	0.150	82.867	15.528	0.737	0.718	0.936
Pid1Cx	0.010	93.868	5.990	0.098	0.035	0.323
Pid3Cx	0.042	85.029	14.203	0.490	0.235	1.115
Pid5Cx	0.118	76.723	21.427	1.022	0.710	2.761
Pid7Cx	1.155	64.218	26.486	3.293	4.847	7.005
Pu61Cx	1.094	65.008	26.381	3.155	4.361	5.203
Pu70Cx	0.768	75.668	18.857	2.563	2.145	4.211
Pu84Cx	0.062	84.835	14.273	0.471	0.360	0.768
Pu93Cx	0.010	93.535	6.313	0.102	0.040	0.222
PuOc3Cx	0.012	93.985	5.830	0.133	0.041	0.022
CALX30PB	0.009	93.925	5.861	0.176	0.029	0.199
J1325PB1	0.011	93.925	5.904	0.132	0.028	0.169
J1325PB2	0.011	93.925	5.904	0.132	0.028	0.169
LAO225PB	0.058	82.245	16.534	0.809	0.354	0.784
PUEU7PB	0.014	93.848	5.863	0.209	0.066	0.090
SD4030PB	0.062	87.343	11.789	0.605	0.201	0.654
STD8PB	0.009	93.546	6.303	0.117	0.025	0.175

* These were adjusted slightly from mass spectrometry values.

Table A3. Accepted isotopic compositions of the plutonium samples taken with the CZT500 detector. The data were acquired in 2016. The number of spectra for each set varies from 29 to 36. A total of 10 sets and 333 spectra were collected. The measurement time for each spectrum is 15 minutes real time. The average live time is 857 seconds. The average FWHM at 662 keV is 7.7 keV.

Sample name	^{238}Pu	^{239}Pu	^{240}Pu	^{241}Pu	^{242}Pu	^{241}Am
czt500_eupu7_d0_c0p8	0.012	93.986	5.862	0.074	0.066	0.220
czt500_eupu7_d8_c0p8_s8	0.012	93.986	5.862	0.074	0.066	0.220
czt500_iso03_d0_c0p8	0.005	96.393	3.557	0.026	0.018	0.099
czt500_iso03_d8_c0p8_s8	0.005	96.393	3.557	0.026	0.018	0.099
czt500_iso09_d0_c0p8	0.017	92.917	6.895	0.097	0.074	0.326
czt500_iso09_d8_c0p8_s8	0.017	92.917	6.895	0.097	0.074	0.326
czt500_iso12_d12_c1_a1p5	0.046	87.637	11.871	0.223	0.223	0.837
czt500_iso12_d8_c1_s8	0.046	87.637	11.871	0.223	0.223	0.837
czt500_iso15_d10_c1_a1p5_s8	0.135	83.191	15.573	0.381	0.721	1.275
czt500_iso15_d34_c1_a1p5	0.135	83.191	15.573	0.381	0.721	1.275

Table A4. Accepted isotopic compositions of the plutonium samples taken with two different $LaBr_3$ detectors. The data were acquired from 2015 to 2016. The number of spectra for each set varies from 16 to 35. A total of 21 sets and 530 spectra were collected. The measurement time for each spectrum is 15 minutes real time. The average live time is 729 seconds. The average FWHM at 662 keV is 18.5 keV.

Sample name	^{238}Pu	^{239}Pu	^{240}Pu	^{241}Pu	^{242}Pu	^{241}Am
labr_eupu7_d23_c0p9_a0p8	0.012	93.987	5.862	0.074	0.066	0.221
labr_eupu7_d8_c0p9_s8	0.012	93.987	5.862	0.074	0.066	0.221
labr_iso03_d36_c0p7_a0p8	0.005	96.393	3.557	0.026	0.018	0.099
labr_iso03_d8_c0p7_a0p8_s8	0.005	96.393	3.557	0.026	0.018	0.099
labr_iso09_d23_c0p9_a0p8_s8	0.017	92.917	6.895	0.097	0.074	0.326
labr_iso09_d36_c0p9_a0p8	0.017	92.917	6.895	0.097	0.074	0.326
labr_iso12_d36_c1_a0p8_s8	0.046	87.637	11.871	0.223	0.223	0.837
labr_iso12_d74_c1_a0p8	0.046	87.637	11.871	0.223	0.223	0.837
labr_iso15_d36_c1_a0p8_s8	0.135	83.190	15.573	0.381	0.721	1.275
labr_iso15_d74_c1_a0p8	0.135	83.190	15.573	0.381	0.721	1.275
cbnm61000	1.003	66.076	26.788	1.699	4.434	6.670
cbnm70000	0.701	76.660	19.085	1.380	2.174	5.383
eupu7000	0.012	93.984	5.862	0.076	0.066	0.218
lao250c10pb1p64000	0.046	83.028	16.314	0.275	0.338	1.089
lao251c10pb1p64000	0.051	82.830	16.487	0.283	0.348	1.130
pidie1000	0.009	93.918	5.987	0.052	0.035	0.362
sga30000	0.005	96.392	3.558	0.027	0.018	0.099
stdiso12000	0.047	87.631	11.871	0.228	0.223	0.832
stdiso15000	0.136	83.179	15.571	0.393	0.721	1.264
stdiso3000	0.005	96.392	3.558	0.027	0.018	0.098
stdiso9000	0.017	92.915	6.895	0.100	0.074	0.324

Table A5. Accepted isotopic compositions of the uranium samples taken with several planar detectors. The data were acquired from 2001 to 2013. The number of spectra for each set varies from 10 to 29. A total of 96 sets (59 LEU sets and 37 HEU sets) and 1656 spectra were collected. The measurement time for each spectrum ranges from 15 minutes to 30 minutes. The average real time is 1039 seconds, and the average live time is 932 seconds.

Sample name	^{234}U	^{235}U	^{236}U	^{238}U
U0031PlO	0.002	0.317	0.015	99.667
u0031pl_r02	0.002	0.317	0.015	99.667
u0031pl_r04	0.002	0.317	0.015	99.667
u0031pl_r06	0.002	0.317	0.015	99.667
u0031pl_r10	0.002	0.317	0.015	99.667
u0031pl_r14	0.002	0.317	0.015	99.667
u0031pl_r20	0.002	0.317	0.015	99.667
u0031pl_r28	0.002	0.317	0.015	99.667
u0031pl_r40	0.002	0.317	0.015	99.667
u0031pl_r80	0.002	0.317	0.015	99.667
u031pl	0.002	0.317	0.015	99.667
U0071PlO	0.005	0.712	0.000	99.283
u0071pl_r02	0.005	0.712	0.000	99.283
u0071pl_r04	0.005	0.712	0.000	99.283
u0071pl_r06	0.005	0.712	0.000	99.283
u0071pl_r14	0.005	0.712	0.000	99.283
u0071pl_r20	0.005	0.712	0.000	99.283
u0071pl_r28	0.005	0.712	0.000	99.283
u0071pl_r40	0.005	0.712	0.000	99.283
u0071pl_r80	0.005	0.712	0.000	99.283

u071pl	0.005	0.712	0.000	99.283
A1-408-2pl000	0.005	0.714	0.001	99.281
U0194PlO	0.017	1.942	0.000	98.041
u0194pl_r02	0.017	1.942	0.000	98.041
u0194pl_r04	0.017	1.942	0.000	98.041
u0194pl_r06	0.017	1.942	0.000	98.041
u0194pl_r10	0.017	1.942	0.000	98.041
u0194pl_r14	0.017	1.942	0.000	98.041
u0194pl_r20	0.017	1.942	0.000	98.041
u0194pl_r28	0.017	1.942	0.000	98.041
u0194pl_r40	0.017	1.942	0.000	98.041
u0194pl_r80	0.017	1.942	0.000	98.041
u194pl	0.017	1.942	0.000	98.041
U0295PlO	0.028	2.949	0.003	97.020
u0295pl_r02	0.028	2.949	0.003	97.020
u0295pl_r04	0.028	2.949	0.003	97.020
u0295pl_r06	0.028	2.949	0.003	97.020
u0295pl_r10	0.028	2.949	0.003	97.020
u0295pl_r14	0.028	2.949	0.003	97.020
u0295pl_r20	0.028	2.949	0.003	97.020
u0295pl_r28	0.028	2.949	0.003	97.020
u0295pl_r40	0.028	2.949	0.003	97.020
u0295pl_r80	0.028	2.949	0.003	97.020
u295pl	0.028	2.949	0.003	97.020
A1-1126-1bpl000	0.025	3.026	0.016	96.934
A1-1126-1pl000	0.025	3.026	0.016	96.934
U0446PlO	0.036	4.462	0.007	95.495
u0446pl_r02	0.036	4.462	0.007	95.495
u0446pl_r04	0.036	4.462	0.007	95.495
u0446pl_r06	0.036	4.462	0.007	95.495
u0446pl_r10	0.036	4.462	0.007	95.495
u0446pl_r14	0.036	4.462	0.007	95.495
u0446pl_r20	0.036	4.462	0.007	95.495
u0446pl_r28	0.036	4.462	0.007	95.495
u0446pl_r40	0.036	4.462	0.007	95.495
u0446pl_r80	0.036	4.462	0.007	95.495
u446pl	0.036	4.462	0.007	95.495
A13241pl000	0.051	10.086	0.090	89.772
UISO13pl000	0.083	12.954	0.101	86.862
u2006pl_r02	0.149	20.107	0.197	79.547
u2006pl_r04	0.149	20.107	0.197	79.547
u2006pl_r06	0.149	20.107	0.197	79.547
u2006pl_r10	0.149	20.107	0.197	79.547
u2006pl_r14	0.149	20.107	0.197	79.547
u2006pl_r20	0.149	20.107	0.197	79.547
u2006pl_r28	0.149	20.107	0.197	79.547
u2006pl_r40	0.149	20.107	0.197	79.547
u2006pl_r80	0.149	20.107	0.197	79.547
U2011PlO	0.149	20.107	0.197	79.547
u20pl	0.149	20.107	0.197	79.547
UISO27pl000	0.234	26.752	0.270	72.745
UISO38pl000	0.260	37.552	0.217	61.971
U5249PlO	0.372	52.488	0.265	46.876

u5256pl_r02	0.372	52.488	0.265	46.876
u5256pl_r04	0.372	52.488	0.265	46.876
u5256pl_r06	0.372	52.488	0.265	46.876
u5256pl_r10	0.372	52.488	0.265	46.876
u5256pl_r14	0.372	52.488	0.265	46.876
u5256pl_r20	0.372	52.488	0.265	46.876
u5256pl_r28	0.372	52.488	0.265	46.876
u5256pl_r40	0.372	52.488	0.265	46.876
u5256pl_r80	0.372	52.488	0.265	46.876
u53pl	0.372	52.488	0.265	46.876
UISO66pl000	0.578	66.040	0.259	33.122
UISO91pl000	0.910	91.336	0.335	7.419
U9317PlO	0.980	93.170	0.294	5.556
u9318pl_r02	0.980	93.170	0.294	5.556
u9318pl_r04	0.980	93.170	0.294	5.556
u9318pl_r06	0.980	93.170	0.294	5.556
u9318pl_r10	0.980	93.170	0.294	5.556
u9318pl_r14	0.980	93.170	0.294	5.556
u9318pl_r20	0.980	93.170	0.294	5.556
u9318pl_r28	0.980	93.170	0.294	5.556
u9318pl_r40	0.980	93.170	0.294	5.556
u9318pl_r80	0.980	93.170	0.294	5.556
u93pl	0.980	93.170	0.294	5.556

Table A6. Accepted isotopic compositions of the uranium samples taken with several coaxial detectors. The data were acquired from 1996 to 2013. The number of spectra for each set varies from 6 to 24. A total of 101 sets (64 LEU sets and 37 HEU sets) and 1876 spectra were collected. The measurement time for each spectrum ranges from 15 minutes to 1 hour. The average real time is 2175 seconds, and the average live time is 1838 seconds.

Sample name	^{234}U	^{235}U	^{236}U	^{238}U
031_D00	0.002	0.317	0.015	99.667
031_D15	0.002	0.317	0.015	99.667
031_S05	0.002	0.317	0.015	99.667
NBS03112	0.002	0.317	0.015	99.667
U0031Cx	0.002	0.317	0.015	99.667
u0031cx_r14	0.002	0.317	0.015	99.667
u0031cx_r20	0.002	0.317	0.015	99.667
u0031cx_r28	0.002	0.317	0.015	99.667
u0031cx_r40	0.002	0.317	0.015	99.667
u0031cx_r80	0.002	0.317	0.015	99.667
071_00	0.005	0.712	0.000	99.283
071_00B	0.005	0.712	0.000	99.283
071_01	0.005	0.712	0.000	99.283
071_01B	0.005	0.712	0.000	99.283
071_03	0.005	0.712	0.000	99.283
071_03B	0.005	0.712	0.000	99.283
071_05	0.005	0.712	0.000	99.283
071_05B	0.005	0.712	0.000	99.283
071_10	0.005	0.712	0.000	99.283
071_10B	0.005	0.712	0.000	99.283
071_15	0.005	0.712	0.000	99.283
071_15B	0.005	0.712	0.000	99.283

NBS07112	0.005	0.712	0.000	99.283
U0071Cx	0.005	0.712	0.000	99.283
u0071cx_r14	0.005	0.712	0.000	99.283
u0071cx_r20	0.005	0.712	0.000	99.283
u0071cx_r28	0.005	0.712	0.000	99.283
u0071cx_r40	0.005	0.712	0.000	99.283
u0071cx_r80	0.005	0.712	0.000	99.283
NBS19412	0.017	1.942	0.000	98.041
U0194Cx	0.017	1.942	0.000	98.041
u0194cx_r14	0.017	1.942	0.000	98.041
u0194cx_r20	0.017	1.942	0.000	98.041
u0194cx_r28	0.017	1.942	0.000	98.041
u0194cx_r40	0.017	1.942	0.000	98.041
u0194cx_r80	0.017	1.942	0.000	98.041
NBS29512	0.028	2.949	0.003	97.020
U0295Cx	0.028	2.949	0.003	97.020
u0295cx_r14	0.028	2.949	0.003	97.020
u0295cx_r20	0.028	2.949	0.003	97.020
u0295cx_r28	0.028	2.949	0.003	97.020
u0295cx_r40	0.028	2.949	0.003	97.020
u0295cx_r80	0.028	2.949	0.003	97.020
446_D_00	0.036	4.462	0.007	95.495
446_D_01	0.036	4.462	0.007	95.495
446_D_02	0.036	4.462	0.007	95.495
446_D_05	0.036	4.462	0.007	95.495
446_D_10	0.036	4.462	0.007	95.495
446_D_15	0.036	4.462	0.007	95.495
446_S_00	0.036	4.462	0.007	95.495
446_S_01	0.036	4.462	0.007	95.495
446_S_02	0.036	4.462	0.007	95.495
446_S_05	0.036	4.462	0.007	95.495
446_S_10	0.036	4.462	0.007	95.495
446_S_15	0.036	4.462	0.007	95.495
NBS44612	0.036	4.462	0.007	95.495
U0446Cx	0.036	4.462	0.007	95.495
u0446cx_r14	0.036	4.462	0.007	95.495
u0446cx_r20	0.036	4.462	0.007	95.495
u0446cx_r28	0.036	4.462	0.007	95.495
u0446cx_r40	0.036	4.462	0.007	95.495
u0446cx_r80	0.036	4.462	0.007	95.495
UISO1212	0.072	11.797	0.115	88.016
U17C2T10	0.138	17.239	0.168	82.456
u2006cx_r14	0.149	20.107	0.197	79.547
u2006cx_r20	0.149	20.107	0.197	79.547
u2006cx_r28	0.149	20.107	0.197	79.547
u2006cx_r40	0.149	20.107	0.197	79.547
u2006cx_r80	0.149	20.107	0.197	79.547
U2011Cx	0.149	20.107	0.197	79.547
UISO27PS	0.234	26.752	0.270	72.745
U38C2G15	0.260	37.552	0.217	61.971
U52C2G20	0.531	52.117	0.868	46.484
nbl53_00	0.372	52.488	0.265	46.876
nbl53_00A	0.372	52.488	0.265	46.876

nbl53_03	0.372	52.488	0.265	46.876
nbl53_03a	0.372	52.488	0.265	46.876
nbl53_10	0.372	52.488	0.265	46.876
nbl53_10A	0.372	52.488	0.265	46.876
U5249Cx	0.372	52.488	0.265	46.876
u5256cx_r14	0.372	52.488	0.265	46.876
u5256cx_r20	0.372	52.488	0.265	46.876
u5256cx_r28	0.372	52.488	0.265	46.876
u5256cx_r40	0.372	52.488	0.265	46.876
u5256cx_r80	0.372	52.488	0.265	46.876
66_S01	0.578	66.040	0.259	33.122
U66C2G20	0.578	66.040	0.259	33.122
U91C2G20	0.910	91.336	0.335	7.419
U91C2T30	0.910	91.336	0.335	7.419
nbl93_00	0.980	93.170	0.294	5.556
nbl93_00a	0.980	93.170	0.294	5.556
nbl93_03	0.980	93.170	0.294	5.556
nbl93_03a	0.980	93.170	0.294	5.556
nbl93_10	0.980	93.170	0.294	5.556
nbl93_10a	0.980	93.170	0.294	5.556
U9317Cx	0.980	93.170	0.294	5.556
u9318cx_r14	0.980	93.170	0.294	5.556
u9318cx_r20	0.980	93.170	0.294	5.556
u9318cx_r28	0.980	93.170	0.294	5.556
u9318cx_r40	0.980	93.170	0.294	5.556
u9318cx_r80	0.980	93.170	0.294	5.556

Table A7. Accepted isotopic compositions of the uranium samples taken with the CZT500 detector. The data were acquired in 2015. The number of spectra for each set varies from 16 to 20. A total of 13 sets and 238 spectra were collected. The measurement time for each spectrum is 15 minutes real time. The average live time is 877 seconds. This detector is not the same one used to acquire data in Table A3 and is not very good. Its average FWHM at 662 keV is 19.0 keV.

Sample name	^{234}U	^{235}U	^{236}U	^{238}U
lgczt-a1-1126000.Chn	0.025	3.026	0.016	96.934
lgczt-a1-324000.Chn	0.051	10.086	0.090	89.772
lgczt-eupu1000.Chn	1.018	93.111	0.436	5.435
lgczt-u0031000.Chn	0.002	0.317	0.015	99.667
lgczt-u0071000.Chn	0.005	0.712	0.000	99.283
lgczt-u0194000.Chn	0.017	1.942	0.000	98.041
lgczt-u0295000.Chn	0.028	2.949	0.003	97.020
lgczt-u0446000.Chn	0.036	4.462	0.007	95.495
lgczt-u2006000.Chn	0.149	20.107	0.197	79.547
lgczt-u5256000.Chn	0.372	52.488	0.265	46.876
lgczt-u9318000.Chn	0.980	93.170	0.294	5.556
lgczt-uiso12000.Chn	0.072	11.797	0.115	88.016
lgczt-uiso13000.Chn	0.083	12.954	0.101	86.862

Table A8. Accepted isotopic compositions of the uranium samples taken with two $LaBr_3$ detectors. The data were acquired in 2015. The number of spectra for each set varies from 16 to 20. A total of 25 sets and 465 spectra were collected. The measurement time for each spectrum is 15 minutes real time. The average live time is 806 seconds. The average FWHM at 662 keV is 21.1 keV.

Sample name	^{234}U	^{235}U	^{236}U	^{238}U
a1-1126000	0.025	3.026	0.016	96.934
a1-324000	0.051	10.086	0.090	89.772
a1-409000	0.005	0.710	0.001	99.284
eupu1000	1.018	93.111	0.436	5.435
u0031000	0.002	0.317	0.015	99.667
u0071000	0.005	0.712	0.000	99.283
u0194000	0.017	1.942	0.000	98.041
u0295000	0.028	2.949	0.003	97.020
u0446000	0.036	4.462	0.007	95.495
u2006000	0.149	20.107	0.197	79.547
u5256000	0.372	52.488	0.265	46.876
u9318000	0.980	93.170	0.294	5.556
uiso12000	0.072	11.797	0.115	88.016
uiso13000	0.083	12.954	0.101	86.862
smlabr-eupu1000	1.018	93.111	0.436	5.435
smlabr-u0031000	0.002	0.317	0.015	99.667
smlabr-u0071000	0.005	0.712	0.000	99.283
smlabr-u0194000	0.017	1.942	0.000	98.041
smlabr-u0295000	0.028	2.949	0.003	97.020
smlabr-u0446000	0.036	4.462	0.007	95.495
smlabr-u2006000	0.149	20.107	0.197	79.547
smlabr-u5256000	0.372	52.488	0.265	46.876
smlabr-u9318000	0.980	93.170	0.294	5.556
smlabr-uiso12000	0.072	11.797	0.115	88.016
smlabr-uiso13000	0.083	12.954	0.101	86.862

APPENDIX B

The tables in this section show the bias results for individual data sets. Each result is the average of many runs. The number of runs for these data sets is shown in Tables 1–2 and in the titles of Tables A1–A8. The bias for each isotope for each data set is the difference of the average value and the accepted value divided by the accepted value.

We use two different ways of calculating the averages and their uncertainties: unweighted and weighted.

The average unweighted bias $\bar{x}_i$ associated with sample i is described by the equation

$\bar{x}_i = \frac{1}{m_i}\sum_{j=1}^{m_i} x_{ij}$, where x_{ij} is the bias for spectrum j associated with sample i and m is the number of individual measurements of sample i.

The global bias $\bar{x}$ is represented by the equation

$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} \bar{x}_i$, where n denotes the number of samples measured.

The uncertainty of the unweighted global bias $u_{\bar{x}}$ is

$u_{\bar{x}} = \frac{\sigma_{\bar{x}}}{\sqrt{n}} = \sqrt{\frac{1}{n(n-1)}\sum_{i=1}^{n}(\bar{x}_i - \bar{x})^2}$, where $\sigma_{\bar{x}}$ is the standard deviation of the average unweighted biases.

For the weighted average and uncertainty calculation, the average weighted bias ${}_w\bar{x}_i$ associated with sample i is

${}_w\bar{x}_i = \left.\sum_{j=1}^{m_i} x_{ij}w_{ij}\right/\sum_{j=1}^{m_i} w_{ij}$, where the weight w_{ij} is the inverse of the reported uncertainty for each spectrum j associated with each sample i.

The global bias ${}_w\bar{x}$ is represented by the equation

${}_w\bar{x} = \left.\sum_{i=1}^{n} \bar{x}_i w_i\right/\sum_{i=1}^{n} w_i$, where w_i is the weight of data set i and is set to be the inverse of the standard deviation of the results of data set i.

The uncertainty of the weighted global bias ${}_wu_{\bar{x}}$ is

$$ {}_wu_{\bar{x}} = \frac{{}_w\sigma_{\bar{x}}}{\sqrt{n}} = \sqrt{\frac{\sum_{i=1}^{n}({}_w\bar{x}_i - {}_w\bar{x})^2 w_i}{n\sum_{i=1}^{n} w_i}} \, . $$

Tables B1–B10 show the bias results of the data sets.

Table B1. Bias results of the data sets obtained with the planar detectors and analyzed using the GePlnr_Pu_060-230 parameter set. Each result is the average result from the multiple runs for a sample. The bottom rows (in bold) show the "averages of the averages" and uncertainties using both the unweighted and weighted average methods.

Sample name	^{238}Pu	^{239}Pu	^{240}Pu	^{241}Pu	^{241}Am
256C10	-0.0254	-0.0001	0.0003	0.0029	0.0026
A186	0.0024	-0.0002	0.0032	0.0006	0.0350
A192	0.0147	-0.0002	0.0032	-0.0008	-0.0045
CALEX23K	0.0472	-0.0010	0.0155	0.0031	-0.0079
CBNM61B	0.0035	-0.0033	0.0087	-0.0035	-0.0163
CBNM70B	0.0030	-0.0034	0.0146	-0.0046	-0.0198
CBNM84B	-0.0025	0.0001	-0.0005	-0.0003	-0.0080
CBNM93B	0.0011	-0.0008	0.0117	-0.0020	-0.0063
JOO1325	0.0212	-0.0009	0.0141	0.0026	0.0035
LAO225BS	0.0018	0.0009	-0.0102	-0.0034	-0.0098
PE0382C3	-0.0596	0.0006	-0.0059	0.0162	-0.0030
PUEU7	-0.0052	0.0006	-0.0098	-0.0005	0.0271
SRPISO12	-0.0022	0.0006	-0.0044	0.0010	-0.0139
SRPISO12	-0.0012	0.0002	-0.0015	-0.0006	-0.0140
SRPISO15	0.0070	0.0003	-0.0019	0.0006	-0.0109
SRPISO15	0.0049	0.0008	-0.0039	-0.0028	-0.0143
SRPISO3	0.0099	-0.0011	0.0293	0.0080	0.0397
SRPISO3	0.0097	-0.0009	0.0241	0.0072	0.0352
SRPISO6	0.0130	-0.0005	0.0082	0.0030	0.0129
SRPISO6	0.0065	-0.0004	0.0063	0.0011	0.0013
SRPISO9	0.0040	-0.0004	0.0050	0.0011	-0.0004
SRPISO9	-0.0049	-0.0002	0.0028	-0.0015	-0.0043
STD11612	-0.0103	-0.0018	0.0111	-0.0078	-0.0111
STD1174K	-0.0565	-0.0004	0.0062	-0.0038	-0.0084
STD11834	0.0061	-0.0002	0.0024	-0.0055	-0.0098
STD12018	-0.0021	-0.0015	0.0085	-0.0037	-0.0176
STD1217K	0.0038	0.0008	0.0015	0.0010	-0.0077
STD3	0.0104	-0.0002	0.0015	0.0074	0.0011
STD4040K	-0.0046	-0.0001	0.0008	0.0027	-0.0062
STD627K	-0.0109	-0.0003	0.0051	-0.0066	-0.0060
STD832K	-0.0117	-0.0008	0.0126	-0.0074	-0.0002
STDR3	-0.0035	0.0002	-0.0036	0.0047	-0.0132
cbnm6175	0.0059	0.0048	-0.0118	-0.0014	-0.0007
cbnm7075	0.0032	0.0021	-0.0077	-0.0049	-0.0066
cbnm8475	-0.0069	0.0013	-0.0078	-0.0011	0.0000
cbnm9375	0.0013	0.0000	-0.0004	-0.0038	-0.0031
eupu775	-0.0054	0.0004	-0.0073	0.0048	-0.0026
iso0375	0.0230	-0.0002	0.0043	0.0101	0.0190
iso0675	-0.0015	0.0004	-0.0060	0.0022	-0.0035
iso0975	-0.0002	0.0002	-0.0028	-0.0004	-0.0032
iso1275	0.0006	0.0022	-0.0163	0.0028	-0.0020
iso1575	0.0050	0.0022	-0.0116	-0.0006	-0.0017
pidie175	-0.0386	-0.0001	0.0019	-0.0024	0.0039
pidie375	0.0088	0.0002	-0.0014	0.0013	-0.0018
pidie575	-0.0042	0.0010	-0.0036	0.0001	0.0079
pidie775	0.0116	0.0029	-0.0072	-0.0034	-0.0015

pufa175	0.0295	0.0003	-0.0051	0.0075	-0.0035
EuPu7PlO	-0.0026	0.0000	-0.0003	0.0020	-0.0027
Iso03PlO	-0.0204	-0.0011	0.0305	0.0097	0.0335
Iso06PlO	-0.0082	-0.0003	0.0042	-0.0013	-0.0029
Iso09PlO	-0.1236	0.0001	-0.0006	-0.0034	-0.0035
Iso12PlO	0.0122	0.0015	-0.0107	-0.0017	-0.0017
Iso15PlO	0.0031	0.0009	-0.0046	-0.0022	-0.0004
Pid1PlO	-0.0397	-0.0004	0.0065	0.0010	0.0097
Pid3PlO	0.0085	0.0005	-0.0030	0.0048	-0.0019
Pid5PlO	-0.0052	0.0022	-0.0079	-0.0002	0.0062
Pid7PlO	0.0125	0.0026	-0.0065	-0.0032	-0.0014
Pu61PlO	0.0022	0.0024	-0.0054	-0.0062	-0.0089
Pu70PlO	0.0027	0.0006	-0.0017	-0.0078	-0.0144
Pu84PlO	-0.0131	0.0013	-0.0076	-0.0056	-0.0071
Pu93PlO	-0.0283	-0.0001	0.0016	-0.0049	-0.0045
PuOc3PlO	-0.0148	0.0000	0.0003	0.0015	0.0560
pid1pl_r02	-0.0534	0.0000	0.0000	-0.0093	-0.0033
pid1pl_r04	0.0062	0.0000	0.0002	-0.0014	0.0018
pid1pl_r06	-0.0634	0.0003	-0.0046	-0.0081	0.0036
pid1pl_r10	-0.0215	0.0002	-0.0029	-0.0014	0.0088
pid1pl_r14	-0.0446	0.0001	-0.0014	-0.0015	0.0003
pid1pl_r20	-0.0494	-0.0004	0.0059	0.0019	0.0070
pid1pl_r28	-0.0891	-0.0004	0.0069	-0.0019	0.0052
pid1pl_r40	0.0007	-0.0003	0.0046	-0.0039	0.0066
pid1pl_r80	-0.0258	0.0002	-0.0038	-0.0030	0.0013
pid3pl_r02	0.0082	-0.0002	0.0016	-0.0052	-0.0059
pid3pl_r04	0.0156	0.0001	-0.0008	-0.0027	-0.0051
pid3pl_r06	-0.0083	0.0005	-0.0029	-0.0001	-0.0070
pid3pl_r10	-0.0024	0.0009	-0.0055	0.0006	-0.0049
pid3pl_r14	-0.0011	0.0005	-0.0029	0.0018	-0.0051
pid3pl_r20	-0.0041	0.0009	-0.0056	0.0023	-0.0042
pid3pl_r28	-0.0063	0.0005	-0.0030	0.0054	-0.0046
pid3pl_r40	-0.0119	0.0005	-0.0032	0.0047	-0.0024
pid3pl_r80	0.0287	0.0007	-0.0044	0.0052	-0.0017
pid5pl_r02	-0.0132	-0.0001	0.0007	-0.0072	0.0022
pid5pl_r04	-0.0002	0.0008	-0.0026	-0.0048	0.0017
pid5pl_r06	-0.0051	0.0016	-0.0057	-0.0017	0.0028
pid5pl_r10	-0.0023	0.0004	-0.0015	-0.0022	0.0062
pid5pl_r14	-0.0007	0.0011	-0.0040	-0.0006	0.0042
pid5pl_r20	-0.0057	0.0013	-0.0048	0.0032	0.0071
pid5pl_r28	0.0091	0.0010	-0.0039	0.0024	0.0069
pid5pl_r40	0.0034	0.0015	-0.0056	0.0008	0.0064
pid5pl_r80	0.0076	0.0007	-0.0027	0.0018	0.0085
pid7pl_r02	0.0128	0.0002	-0.0007	-0.0033	-0.0130
pid7pl_r04	0.0153	-0.0002	-0.0003	0.0007	-0.0052
pid7pl_r06	0.0115	0.0011	-0.0030	-0.0013	-0.0068
pid7pl_r10	0.0211	0.0011	-0.0039	0.0036	-0.0043
pid7pl_r14	0.0241	-0.0006	0.0000	0.0030	-0.0031
pid7pl_r20	0.0196	0.0012	-0.0042	0.0043	-0.0031
pid7pl_r28	0.0199	0.0001	-0.0014	0.0033	-0.0027
pid7pl_r40	0.0191	0.0008	-0.0032	0.0030	-0.0036
pid7pl_r80	0.0254	0.0009	-0.0040	0.0067	-0.0009
Unweighted average	**-0.0038**	**0.0003**	**-0.0001**	**0.0000**	**0.0000**

Unweighted uncertainty	**0.0025**	**0.0001**	**0.0008**	**0.0004**	**0.0012**
Weighted average	**0.0033**	**0.0001**	**-0.0007**	**0.0000**	**-0.0013**
Weighted uncertainty	**0.0015**	**0.0001**	**0.0007**	**0.0005**	**0.0010**

Table B2. Bias results of the data sets obtained with the planar detectors and analyzed using the GePlnr_Pu_120-420 parameter set. Each result is the average result from the multiple runs for a sample. The bottom rows (in bold) show the "averages of the averages" and uncertainties using both the unweighted and weighted average methods.

Sample name	^{238}Pu	^{239}Pu	^{240}Pu	^{241}Pu	^{241}Am
256C10	-0.0258	-0.0010	0.0050	0.0024	-0.0281
A186	-0.0063	0.0007	-0.0119	-0.0020	0.1736
A192	0.0035	0.0003	-0.0046	-0.0039	0.2513
CALEX23K	0.0530	-0.0003	0.0044	0.0036	-0.1268
CBNM61B	0.0059	-0.0009	0.0022	-0.0009	0.0642
CBNM70B	0.0068	0.0001	-0.0007	-0.0008	0.0715
CBNM84B	-0.0032	-0.0010	0.0063	-0.0013	-0.1562
CBNM93B	0.0031	-0.0001	0.0011	-0.0024	-0.2507
JOO1325	0.0209	-0.0002	0.0032	0.0004	-0.0335
LAO225BS	0.0085	-0.0007	-0.0028	0.0002	-0.0071
PE0382C3	-0.0536	-0.0006	0.0047	0.0190	-0.1500
PUEU7	0.0050	-0.0002	0.0032	0.0026	-0.5328
SRPISO12	-0.0016	0.0006	-0.0044	0.0010	-0.0732
SRPISO12	0.0015	0.0002	-0.0014	0.0003	-0.0678
SRPISO15	0.0016	0.0000	0.0009	-0.0091	-0.1729
SRPISO15	0.0056	-0.0008	0.0044	-0.0027	-0.1669
SRPISO3	0.0135	0.0002	-0.0067	0.0081	-0.5285
SRPISO3	0.0162	0.0001	-0.0021	0.0083	-0.5248
SRPISO6	0.0124	-0.0003	0.0048	0.0026	-0.4320
SRPISO6	0.0090	-0.0004	0.0066	0.0024	-0.4318
SRPISO9	0.0055	0.0004	-0.0054	0.0017	-0.3313
SRPISO9	-0.0017	0.0003	-0.0038	-0.0003	-0.3326
STD11612	-0.0108	0.0012	-0.0040	-0.0078	-0.0134
STD1174K	-0.0397	-0.0013	0.0205	-0.0037	-0.1347
STD11834	0.0118	-0.0012	0.0109	-0.0073	-0.0754
STD12018	-0.0060	0.0012	-0.0047	-0.0059	0.0013
STD1217K	0.0033	0.0008	0.0014	-0.0009	0.0004
STD3	0.0068	-0.0002	0.0018	0.0050	-0.1879
STD4040K	-0.0054	-0.0006	0.0043	0.0012	0.1315
STD627K	-0.0100	0.0002	-0.0025	-0.0059	0.0619
STD832K	-0.0034	0.0003	-0.0049	-0.0051	0.0626
STDR3	0.0036	-0.0005	0.0074	0.0016	0.2135
cbnm6175	0.0022	0.0004	-0.0002	-0.0063	0.0369
cbnm7075	-0.0007	-0.0003	0.0029	-0.0101	0.0435
cbnm8475	-0.0058	0.0004	-0.0020	-0.0026	-0.2037
cbnm9375	0.0091	-0.0002	0.0034	-0.0049	-0.2818
eupu775	-0.0124	0.0003	-0.0047	0.0039	-0.5691
iso0375	0.0256	0.0002	-0.0068	0.0077	-0.5534
iso0675	-0.0049	0.0001	-0.0012	0.0021	-0.4741
iso0975	0.0000	0.0003	-0.0046	-0.0009	-0.3694
iso1275	-0.0011	-0.0013	0.0095	-0.0008	-0.1047
iso1575	0.0034	-0.0006	0.0035	-0.0038	-0.2099
pidie175	-0.0407	0.0003	-0.0041	-0.0027	-0.2696

pidie375	0.0028	-0.0006	0.0038	-0.0032	0.0002
pidie575	-0.0100	0.0004	-0.0011	-0.0049	0.1504
pidie775	0.0067	0.0026	-0.0055	-0.0078	-0.0110
pufa175	0.0202	-0.0001	0.0020	0.0050	-0.3972
EuPu7PlO	-0.0099	0.0007	-0.0110	0.0040	-0.5748
Iso03PlO	-0.0113	0.0006	-0.0161	0.0104	-0.5722
Iso06PlO	-0.0028	0.0006	-0.0085	0.0023	-0.4815
Iso09PlO	-0.1118	0.0039	-0.0524	0.0076	-0.4544
Iso12PlO	0.0129	-0.0013	0.0092	-0.0016	-0.1030
Iso15PlO	0.0051	-0.0015	0.0082	-0.0018	-0.2083
Pid1PlO	-0.0434	-0.0006	0.0101	0.0017	-0.2606
Pid3PlO	-0.0011	0.0009	-0.0055	-0.0007	-0.0202
Pid5PlO	-0.0121	-0.0021	0.0077	-0.0053	0.1561
Pid7PlO	0.0182	-0.0059	0.0130	0.0031	0.0165
Pu61PlO	0.0170	0.0006	-0.0032	0.0092	0.0381
Pu70PlO	0.0177	0.0028	-0.0130	0.0083	0.0283
Pu84PlO	-0.0039	0.0000	-0.0001	0.0019	-0.2057
Pu93PlO	-0.0197	0.0002	-0.0033	0.0001	-0.3052
PuOc3PlO	-0.0097	0.0015	-0.0245	0.0049	-0.4196
pid1pl_r02	-0.0513	0.0007	-0.0107	0.0006	-0.2951
pid1pl_r04	0.0016	0.0000	0.0000	0.0040	-0.2592
pid1pl_r06	-0.0658	0.0006	-0.0090	-0.0013	-0.3004
pid1pl_r10	-0.0269	0.0009	-0.0139	-0.0022	-0.2871
pid1pl_r14	-0.0488	0.0013	-0.0198	0.0016	-0.3023
pid1pl_r20	-0.0521	0.0013	-0.0203	0.0026	-0.3015
pid1pl_r28	-0.0972	-0.0002	0.0029	-0.0028	-0.2998
pid1pl_r40	-0.0073	-0.0004	0.0062	-0.0030	-0.2571
pid1pl_r80	-0.0352	-0.0001	0.0023	-0.0033	-0.2732
pid3pl_r02	0.0051	-0.0011	0.0066	-0.0034	-0.0101
pid3pl_r04	0.0133	0.0003	-0.0021	0.0003	-0.0172
pid3pl_r06	-0.0113	-0.0011	0.0067	0.0022	-0.0197
pid3pl_r10	-0.0117	-0.0012	0.0072	-0.0038	-0.0191
pid3pl_r14	-0.0054	-0.0002	0.0015	-0.0005	-0.0231
pid3pl_r20	-0.0123	0.0011	-0.0063	-0.0028	-0.0372
pid3pl_r28	-0.0122	0.0000	-0.0002	0.0018	-0.0286
pid3pl_r40	-0.0219	0.0001	-0.0005	-0.0021	-0.0343
pid3pl_r80	0.0189	-0.0007	0.0042	-0.0016	-0.0047
pid5pl_r02	-0.0094	-0.0031	0.0113	-0.0007	0.1532
pid5pl_r04	0.0000	0.0004	-0.0014	-0.0010	0.1401
pid5pl_r06	-0.0086	-0.0010	0.0036	-0.0019	0.1423
pid5pl_r10	-0.0119	0.0024	-0.0080	-0.0088	0.1232
pid5pl_r14	-0.0082	-0.0017	0.0065	-0.0065	0.1471
pid5pl_r20	-0.0162	-0.0009	0.0035	-0.0063	0.1372
pid5pl_r28	-0.0063	-0.0028	0.0104	-0.0110	0.1547
pid5pl_r40	-0.0019	0.0007	-0.0024	-0.0030	0.1379
pid5pl_r80	-0.0058	0.0007	-0.0020	-0.0097	0.1364
pid7pl_r02	0.0153	-0.0028	0.0060	0.0019	-0.0008
pid7pl_r04	0.0146	0.0037	-0.0098	0.0024	-0.0207
pid7pl_r06	0.0146	0.0134	-0.0336	0.0041	-0.0514
pid7pl_r10	0.0119	0.0027	-0.0066	-0.0044	-0.0181
pid7pl_r14	0.0175	-0.0014	0.0030	-0.0028	-0.0022
pid7pl_r20	0.0103	0.0005	-0.0011	-0.0053	-0.0117
pid7pl_r28	0.0122	0.0029	-0.0070	-0.0040	-0.0184

pid7pl_r40	0.0131	0.0027	-0.0069	-0.0023	-0.0178
pid7pl_r80	0.0180	0.0000	-0.0008	-0.0004	-0.0067
Unweighted average	**-0.0050**	**0.0002**	**-0.0014**	**-0.0006**	**-0.0017**
Unweighted uncertainty	**0.0024**	**0.0002**	**0.0010**	**0.0005**	**0.0017**
Weighted average	**0.0003**	**0.0001**	**-0.0005**	**-0.0002**	**-0.0011**
Weighted uncertainty	**0.0016**	**0.0001**	**0.0008**	**0.0005**	**0.0012**

Table B3. Bias results of the data sets obtained with the coaxial detectors and analyzed using the GeCoax_Pu_120-420 parameter set. Each result is the average result from the multiple runs for a sample. The bottom rows (in bold) show the "averages of the averages" and uncertainties using both the unweighted and weighted average methods.

Sample name	^{238}Pu	^{239}Pu	^{240}Pu	^{241}Pu	^{241}Am
2G118CX8	-0.0226	-0.0003	0.0030	-0.0017	-0.0048
2G119CX8	-0.0010	-0.0006	0.0046	-0.0017	-0.0020
2G120CX8	-0.0181	0.0023	-0.0103	-0.0063	-0.0047
2G121CX8	-0.0052	-0.0012	0.0061	0.0006	0.0066
61COAX8K	0.0055	0.0003	-0.0010	0.0008	-0.0034
70COAX8K	0.0054	0.0011	-0.0045	-0.0002	-0.0054
84COAX8K	-0.0041	-0.0001	0.0006	-0.0015	-0.0003
86COAX8K	0.0302	0.0007	-0.0108	-0.0057	0.0201
92COAX8K	-0.0143	0.0010	-0.0175	-0.0035	-0.0072
93COAX8K	0.0070	0.0000	-0.0006	-0.0009	-0.0090
CALX30	-0.0028	-0.0012	0.0189	0.0001	-0.0098
EUPU7CX8	-0.0149	0.0003	-0.0046	0.0062	-0.0066
ISO12C8K	-0.0057	-0.0005	0.0035	-0.0025	0.0059
ISO15C8K	-0.0022	-0.0002	0.0014	-0.0046	0.0057
ISO3CX8K	0.0027	-0.0001	0.0017	0.0078	0.0015
ISO6CX8K	0.0372	-0.0001	0.0009	0.0029	0.0056
ISO9CX8K	0.0106	0.0001	-0.0012	-0.0013	0.0004
JOO1325	-0.0473	-0.0024	0.0389	-0.0034	-0.0039
LAO22530	0.0012	-0.0006	0.0032	-0.0018	-0.0015
PUEU730	0.0112	-0.0012	0.0194	0.0006	-0.0060
SD4030	-0.0025	-0.0011	0.0080	-0.0022	0.0019
SGCOAX8K	0.0148	0.0002	-0.0062	0.0040	0.0131
STD830	-0.0257	-0.0006	0.0082	0.0003	-0.0069
PID6_1	-0.0475	-0.0005	0.0077	-0.0010	-0.0247
PID6_2	0.0027	-0.0015	0.0128	0.0003	-0.0307
PID6_3	0.0421	-0.0003	0.0017	-0.0015	-0.0134
PID6_4	-0.0138	-0.0001	0.0007	-0.0026	0.0027
PIDIE65	-0.0119	-0.0001	0.0007	-0.0024	0.0054
PIDIE66	-0.0025	0.0016	-0.0038	-0.0034	0.0036
PIDIE67	-0.0020	0.0006	0.0001	-0.0091	0.0012
cbnm61	0.0069	0.0053	-0.0141	0.0058	0.0030
cbnm70	0.0038	0.0027	-0.0112	0.0023	-0.0035
cbnm84	-0.0107	-0.0008	0.0045	0.0012	-0.0044
cbnm93	0.0123	0.0004	-0.0061	-0.0016	-0.0141
eupu7cx	-0.0170	0.0004	-0.0069	0.0068	-0.0191
iso03cx	-0.0472	0.0002	-0.0047	-0.0099	-0.0098
iso06cx	0.0135	-0.0001	0.0010	0.0038	-0.0066
iso09cx	-0.0078	0.0002	-0.0028	0.0003	-0.0077
iso12cx	-0.0016	0.0004	-0.0032	0.0004	0.0006
iso15cx	-0.0028	-0.0003	0.0016	-0.0005	0.0029

pidie1cx	-0.0226	-0.0002	0.0023	0.0043	-0.0098
pidie3cx	-0.0133	-0.0005	0.0027	0.0059	-0.0101
pidie5cx	-0.0113	-0.0013	0.0045	0.0033	0.0029
pidie7cx	0.0092	0.0020	-0.0054	0.0014	0.0008
stdiso03	-0.0270	-0.0004	0.0107	0.0088	-0.0263
stdiso09	0.0023	-0.0008	0.0101	-0.0005	-0.0061
stdiso15	0.0016	-0.0014	0.0074	-0.0034	-0.0007
Unweighted average	**-0.0039**	**0.0000**	**0.0015**	**-0.0001**	**-0.0037**
Unweighted uncertainty	**0.0027**	**0.0002**	**0.0014**	**0.0006**	**0.0014**
Weighted average	**-0.0026**	**0.0000**	**0.0000**	**0.0000**	**-0.0016**
Weighted uncertainty	**0.0016**	**0.0001**	**0.0012**	**0.0006**	**0.0011**

Table B4. Bias results of the data sets obtained with the coaxial detectors and analyzed using the GeCoax_Pu_180-1010 parameter set. Each result is the average result from the multiple runs for a sample. The bottom rows (in bold) show the "averages of the averages" and uncertainties using both the unweighted and weighted average methods.

Sample name	^{238}Pu	^{239}Pu	^{240}Pu	^{241}Pu	^{241}Am
2G118CX8	-0.0526	-0.0018	0.0183	-0.0042	-0.0021
2G119CX8	-0.0203	-0.0006	0.0046	-0.0034	0.0009
2G120CX8	-0.0803	0.0086	-0.0421	-0.0015	-0.0026
2G121CX8	-0.0149	-0.0028	0.0142	-0.0034	0.0060
61COAX8K	-0.0245	-0.0004	0.0041	-0.0108	-0.0096
70COAX8K	-0.0262	-0.0007	0.0064	-0.0114	-0.0127
84COAX8K	0.0028	-0.0006	0.0038	-0.0056	0.0001
86COAX8K	0.1510	0.0016	-0.0273	-0.0053	0.0271
92COAX8K	0.1869	0.0019	-0.0341	-0.0031	-0.0008
93COAX8K	0.0899	0.0012	-0.0172	-0.0039	-0.0017
CALX30	0.0415	-0.0004	0.0071	0.0023	-0.0037
EUPU7CX8	0.0519	-0.0005	0.0071	0.0045	0.0080
ISO12C8K	-0.0229	-0.0013	0.0101	-0.0037	0.0022
ISO15C8K	-0.0189	-0.0021	0.0118	-0.0090	0.0013
ISO3CX8K	0.1393	0.0013	-0.0362	0.0090	0.0104
ISO6CX8K	0.0774	0.0006	-0.0097	0.0023	0.0069
ISO9CX8K	0.0311	0.0002	-0.0033	-0.0021	0.0048
JOO1325	-0.0089	-0.0007	0.0115	-0.0013	0.0166
LAO22530	0.0280	-0.0015	0.0076	-0.0016	-0.0008
PUEU730	-0.0025	-0.0007	0.0107	0.0015	0.0063
SD4030	0.0362	-0.0007	0.0048	-0.0005	0.0019
SGCOAX8K	0.1389	0.0010	-0.0284	0.0055	0.0219
STD830	0.0985	0.0000	-0.0002	-0.0015	0.0010
PID6_1	-0.2155	0.0021	-0.0318	-0.0016	-0.0076
PID6_2	-0.0652	0.0002	-0.0020	-0.0003	-0.0230
PID6_3	-0.0369	-0.0003	0.0023	-0.0020	-0.0120
PID6_4	-0.0012	-0.0003	0.0012	-0.0015	0.0012
PIDIE65	-0.0032	0.0029	-0.0105	0.0019	0.0067
PIDIE66	-0.0109	0.0150	-0.0430	0.0123	0.0130
PIDIE67	-0.0089	0.0140	-0.0350	0.0094	0.0080
cbnm61	-0.0266	0.0010	0.0000	-0.0095	-0.0065
cbnm70	-0.0322	-0.0033	0.0162	-0.0126	-0.0135
cbnm84	0.0171	-0.0045	0.0267	-0.0083	-0.0082
cbnm93	0.2410	0.0003	-0.0051	-0.0082	-0.0080
eupu7cx	0.0476	-0.0010	0.0158	0.0026	-0.0063

iso03cx	0.1973	0.0015	-0.0408	-0.0137	0.0069
iso06cx	0.0470	-0.0005	0.0081	-0.0006	-0.0045
iso09cx	0.0524	-0.0007	0.0099	-0.0054	-0.0035
iso12cx	-0.0048	-0.0026	0.0196	-0.0074	-0.0022
iso15cx	-0.0286	-0.0055	0.0299	-0.0096	-0.0017
pidie1cx	-0.1611	-0.0002	0.0040	0.0014	-0.0083
pidie3cx	-0.0225	-0.0005	0.0028	0.0028	-0.0122
pidie5cx	0.0130	0.0004	-0.0016	0.0036	0.0041
pidie7cx	-0.0303	0.0106	-0.0253	0.0067	0.0049
stdiso03	0.1246	0.0010	-0.0271	0.0068	-0.0004
stdiso09	0.0702	-0.0007	0.0091	-0.0036	-0.0073
stdiso15	-0.0146	-0.0010	0.0059	-0.0063	-0.0037
EuPu7Cx	-0.0071	-0.0020	0.0323	0.0062	0.0171
Iso03Cx	-0.0162	0.0015	-0.0409	0.0117	0.0133
Iso09Cx	0.0577	-0.0002	0.0029	-0.0035	0.0015
Iso12Cx	0.0181	-0.0004	0.0032	-0.0015	0.0066
Iso15Cx	-0.0033	-0.0025	0.0139	-0.0072	0.0035
Pid1Cx	-0.1302	0.0015	-0.0231	0.0189	-0.0022
Pid3Cx	0.0443	-0.0016	0.0092	0.0129	-0.0076
Pid5Cx	0.0546	-0.0025	0.0085	0.0033	-0.0005
Pid7Cx	-0.0389	-0.0063	0.0187	-0.0145	-0.0140
Pu61Cx	-0.0339	0.0040	-0.0072	-0.0098	0.0001
Pu70Cx	-0.0379	-0.0006	0.0060	-0.0145	-0.0086
Pu84Cx	0.0518	-0.0035	0.0206	-0.0075	0.0018
Pu93Cx	0.1842	0.0008	-0.0128	-0.0030	0.0046
PuOc3Cx	0.1351	-0.0001	0.0011	0.0013	0.0287
CALX30PB	-0.0010	-0.0004	0.0058	-0.0022	-0.0030
J1325PB1	-0.0134	-0.0002	0.0031	-0.0060	0.0013
J1325PB2	0.0061	-0.0018	0.0084	-0.0036	-0.0015
LAO225PB	-0.0171	-0.0004	0.0057	-0.0039	-0.0008
PUEU7PB	0.0509	0.0005	-0.0073	-0.0037	-0.0029
SD4030PB	0.0569	0.0006	-0.0080	-0.0036	-0.0027
STD8PB	0.0618	0.0006	-0.0085	-0.0037	-0.0023
Unweighted average	**0.0202**	**0.0002**	**-0.0017**	**-0.0018**	**0.0004**
Unweighted uncertainty	**0.0095**	**0.0004**	**0.0022**	**0.0008**	**0.0011**
Weighted average	**-0.0009**	**0.0000**	**0.0008**	**-0.0014**	**0.0000**
Weighted uncertainty	**0.0057**	**0.0002**	**0.0019**	**0.0007**	**0.0009**

Table B5. Bias results of the data sets obtained with the CZT detector and analyzed using the CZT500_Pu_120-500 parameter set. Each result is the average result from the multiple runs for a sample. The bottom rows (in bold) show the "averages of the averages" and uncertainties using both the unweighted and weighted average methods.

Sample name	^{238}Pu	^{239}Pu	^{240}Pu	^{241}Pu	^{241}Am
czt500_eupu7_d0_c0p8	-0.5724	0.0060	-0.0927	-0.2075	0.0504
czt500_eupu7_d8_c0p8_s8	-0.2897	0.0030	-0.0447	-0.1987	0.1194
czt500_iso03_d0_c0p8	-0.4807	-0.0078	0.2127	-0.1004	0.0259
czt500_iso03_d8_c0p8_s8	-0.3128	-0.0063	0.1686	0.2743	0.6730
czt500_iso09_d0_c0p8	-0.3394	0.0014	-0.0157	-0.1311	0.1699
czt500_iso09_d8_c0p8_s8	0.0788	-0.0063	0.0867	-0.1253	0.1637
czt500_iso12_d12_c1_a1p5	0.1114	0.0082	-0.0598	-0.0509	0.0635
czt500_iso12_d8_c1_s8	0.7455	-0.0090	0.0641	-0.0476	0.0610
czt500_iso15_d10_c1_a1p5_s8	-0.0659	0.0150	-0.0777	-0.0651	0.0942

czt500_iso15_d34_c1_a1p5	-0.1105	0.0147	-0.0751	-0.0965	0.0798
Unweighted average	**-0.1236**	**0.0019**	**0.0166**	**-0.0749**	**0.1501**
Unweighted uncertainty	**0.1199**	**0.0029**	**0.0347**	**0.0426**	**0.0600**
Weighted average	**-0.2335**	**0.0012**	**-0.0123**	**-0.1060**	**0.0859**
Weighted uncertainty	**0.1074**	**0.0027**	**0.0317**	**0.0238**	**0.0204**

Table B6. Bias results of the data sets obtained with the $LaBr_3$ detectors and analyzed using the LaBr_Pu_200-750 parameter set. Each result is the average result from the multiple runs for a sample. The bottom rows (in bold) show the "averages of the averages" and uncertainties using both the unweighted and weighted average methods.

Sample name	^{238}Pu	^{239}Pu	^{240}Pu	^{241}Pu	^{241}Am
labr_eupu7_d23_c0p9_a0p8	-0.2666	0.0018	-0.0282	-0.0686	-0.0507
labr_eupu7_d8_c0p9_s8	0.0074	-0.0064	0.1018	0.0356	0.0143
labr_iso03_d36_c0p7_a0p8	-0.6342	0.0023	-0.0641	0.5373	0.0066
labr_iso03_d8_c0p7_a0p8_s8	-0.5513	-0.0004	0.0072	0.7136	-0.0189
labr_iso09_d23_c0p9_a0p8_s8	-0.1967	0.0065	-0.0965	0.6558	-0.0016
labr_iso09_d36_c0p9_a0p8	0.0506	-0.0019	0.0168	0.6141	-0.0414
labr_iso12_d36_c1_a0p8_s8	0.6231	0.0103	-0.0844	0.3232	0.0094
labr_iso12_d74_c1_a0p8	1.0250	-0.0039	0.0188	0.3250	-0.0093
labr_iso15_d36_c1_a0p8_s8	0.4450	-0.0034	0.0115	0.1227	-0.0106
labr_iso15_d74_c1_a0p8	0.4704	-0.0041	0.0150	0.1207	-0.0354
cbnm61000	-0.2211	0.0530	-0.1297	0.1161	0.0458
cbnm70000	-0.0061	-0.0327	0.1318	-0.0039	-0.0395
eupu7000	-0.4892	0.0100	-0.1529	-0.4995	0.0497
lao250c10pb1p64000	3.0722	-0.0048	0.0207	-0.2782	-0.0094
lao251c10pb1p64000	2.4904	-0.0002	-0.0008	-0.3404	-0.0614
pidie1000	0.9728	-0.0140	0.2226	-0.5910	-0.0279
sga30000	-0.9638	0.0177	-0.4742	-0.5369	0.1132
stdiso12000	1.9252	-0.0392	0.2817	-0.0022	-0.0030
stdiso15000	0.7772	-0.0263	0.1352	-0.0501	-0.0151
stdiso3000	-0.7926	0.0084	-0.2266	0.0235	-0.0178
stdiso9000	0.1656	-0.0083	0.1101	0.0612	0.0013
Unweighted average	**0.3764**	**-0.0017**	**-0.0088**	**0.0609**	**-0.0048**
Unweighted uncertainty	**0.1904**	**0.0034**	**0.0291**	**0.0681**	**0.0070**
Weighted average	**-0.0845**	**0.0005**	**-0.0044**	**-0.1046**	**-0.0168**
Weighted uncertainty	**0.2731**	**0.0024**	**0.0225**	**0.0655**	**0.0058**

Table B7. Bias results of the data sets obtained with the planar detectors and analyzed using the GePlnr_ULEU_060-250 and GePlnr_UHEU_060-250 parameter sets. Each result is the average result from the multiple runs for a sample. The bottom rows (in bold) show the "averages of the averages" and uncertainties using both the unweighted and weighted average methods.

Sample name	^{234}U	^{235}U	^{238}U
U0031PlO	-0.0956	-0.0070	0.0001
u0031pl_r02	-0.0790	0.0205	0.0000
u0031pl_r04	0.0149	0.0114	0.0000
u0031pl_r06	-0.0958	0.0058	0.0001
u0031pl_r10	-0.0291	-0.0202	0.0001
u0031pl_r14	-0.1202	0.0147	0.0000
u0031pl_r20	-0.0403	0.0028	0.0001
u0031pl_r28	-0.1834	0.0078	0.0001

u0031pl_r40	-0.0589	0.0083	0.0001
u0031pl_r80	-0.1424	-0.0086	0.0001
u031pl	0.0211	0.0105	0.0000
U0071PlO	-0.0140	-0.0019	-0.0001
u0071pl_r02	0.0781	0.0132	-0.0002
u0071pl_r04	0.0103	0.0096	-0.0002
u0071pl_r06	-0.0823	0.0086	-0.0002
u0071pl_r14	0.0471	-0.0032	-0.0001
u0071pl_r20	-0.0535	0.0120	-0.0002
u0071pl_r28	-0.0031	0.0161	-0.0002
u0071pl_r40	0.0443	0.0102	-0.0002
u0071pl_r80	0.0495	-0.0090	-0.0001
u071pl	-0.0125	0.0030	-0.0001
A1-408-2pl000	0.0048	-0.0392	0.0002
U0194PlO	0.0341	-0.0090	-0.0001
u0194pl_r02	-0.0170	-0.0016	-0.0002
u0194pl_r04	-0.0119	0.0053	-0.0004
u0194pl_r06	0.0634	0.0084	-0.0004
u0194pl_r10	-0.0300	0.0001	-0.0003
u0194pl_r14	0.0001	0.0078	-0.0004
u0194pl_r20	-0.0142	0.0038	-0.0003
u0194pl_r28	0.0184	0.0006	-0.0003
u0194pl_r40	0.0217	0.0001	-0.0003
u0194pl_r80	0.0055	-0.0034	-0.0002
u194pl	0.0104	0.0012	-0.0003
U0295PlO	0.0074	-0.0037	-0.0002
u0295pl_r02	-0.0305	0.0024	-0.0004
u0295pl_r04	0.0006	0.0055	-0.0005
u0295pl_r06	0.0043	0.0022	-0.0004
u0295pl_r10	-0.0142	0.0030	-0.0004
u0295pl_r14	-0.0029	0.0067	-0.0005
u0295pl_r20	-0.0076	-0.0018	-0.0003
u0295pl_r28	-0.0007	0.0081	-0.0006
u0295pl_r40	-0.0136	0.0061	-0.0005
u0295pl_r80	-0.0013	0.0061	-0.0005
u295pl	0.0011	0.0026	-0.0004
A1-1126-1bpl000	-0.0354	-0.0093	0.0001
A1-1126-1pl000	-0.0292	-0.0077	0.0000
U0446PlO	0.0158	-0.0040	-0.0003
u0446pl_r02	-0.0234	-0.0026	-0.0003
u0446pl_r04	0.0082	0.0012	-0.0005
u0446pl_r06	0.0245	0.0041	-0.0007
u0446pl_r10	0.0098	-0.0006	-0.0004
u0446pl_r14	0.0256	0.0021	-0.0006
u0446pl_r20	0.0320	-0.0042	-0.0003
u0446pl_r28	-0.0031	-0.0003	-0.0004
u0446pl_r40	0.0088	-0.0029	-0.0003
u0446pl_r80	0.0228	-0.0010	-0.0004
u446pl	0.0024	-0.0010	-0.0004
A13241pl000	-0.0146	-0.0041	0.0005
UISO13pl000	-0.0007	-0.0013	0.0001
u2006pl_r02	0.0024	-0.0027	0.0013
u2006pl_r04	-0.0011	-0.0007	0.0008

u2006pl_r06	-0.0079	0.0003	0.0005
u2006pl_r10	-0.0021	-0.0010	0.0008
u2006pl_r14	-0.0050	0.0028	-0.0001
u2006pl_r20	0.0068	0.0049	-0.0007
u2006pl_r28	-0.0077	0.0024	0.0000
u2006pl_r40	-0.0032	-0.0027	0.0013
u2006pl_r80	-0.0086	-0.0027	0.0013
U2011PlO	-0.0067	-0.0051	0.0019
u20pl	-0.0109	-0.0061	0.0022
UISO27pl000	-0.0052	-0.0123	0.0057
UISO38pl000	-0.0026	-0.0011	0.0004
U5249PlO	-0.0138	-0.0170	0.0188
u5256pl_r02	0.0054	0.0079	-0.0094
u5256pl_r04	0.0153	0.0085	-0.0100
u5256pl_r06	0.0049	0.0071	-0.0084
u5256pl_r10	0.0097	0.0100	-0.0118
u5256pl_r14	0.0058	0.0099	-0.0116
u5256pl_r20	0.0037	0.0040	-0.0050
u5256pl_r28	-0.0054	0.0031	-0.0039
u5256pl_r40	0.0121	0.0029	-0.0038
u5256pl_r80	0.0021	0.0039	-0.0048
u53pl	-0.0135	-0.0098	0.0107
UISO66pl000	-0.0173	-0.0168	0.0321
UISO91pl000	-0.0070	0.0000	0.0046
U9317PlO	0.0153	0.0139	-0.2341
u9318pl_r02	0.0127	0.0141	-0.2368
u9318pl_r04	0.0066	0.0122	-0.2034
u9318pl_r06	0.0072	0.0136	-0.2274
u9318pl_r10	0.0109	0.0230	-0.3838
u9318pl_r14	-0.0021	0.0094	-0.1549
u9318pl_r20	0.0016	0.0071	-0.1176
u9318pl_r28	0.0045	0.0106	-0.1765
u9318pl_r40	-0.0089	0.0010	-0.0149
u9318pl_r80	-0.0073	0.0017	-0.0265
u93pl	-0.0127	-0.0102	0.1723
Unweighted average	**-0.0072**	**0.0018**	**-0.0167**
Unweighted uncertainty	**0.0039**	**0.0009**	**0.0068**
Weighted average	**-0.0016**	**-0.0004**	**-0.0001**
Weighted uncertainty	**0.0016**	**0.0008**	**0.0003**

Table B8. Bias results of the data sets obtained with the coaxial detectors and analyzed using the GeCoax_ULEU_120-1010 and GeCoax_UHEU_120-1010 parameter sets. Each result is the average result from the multiple runs for a sample. The bottom rows (in bold) show the "averages of the averages" and uncertainties using both the unweighted and weighted average methods.

Sample name	^{234}U	^{235}U	^{238}U
031_D00	-0.0638	0.0101	0.0000
031_D15	-0.1713	-0.0010	0.0001
031_S05	0.0783	0.0432	-0.0001
NBS03112	-0.0003	0.0036	0.0001
U0031Cx	-0.1106	-0.0164	0.0001
u0031cx_r14	-0.0260	0.0001	0.0001
u0031cx_r20	-0.1231	0.0008	0.0001

u0031cx_r28	-0.1907	-0.0151	0.0001
u0031cx_r40	-0.0384	0.0057	0.0001
u0031cx_r80	-0.0939	-0.0096	0.0001
071_00	-0.0096	0.0001	-0.0001
071_00B	-0.0493	-0.0172	0.0000
071_01	0.0397	-0.0095	-0.0001
071_01B	0.0048	-0.0051	-0.0001
071_03	-0.0430	-0.0028	-0.0001
071_03B	0.0112	-0.0109	0.0000
071_05	0.0494	-0.0071	-0.0001
071_05B	-0.0074	-0.0019	-0.0001
071_10	0.0458	0.0044	-0.0002
071_10B	0.0373	0.0033	-0.0001
071_15	0.0535	-0.0040	-0.0001
071_15B	0.0262	-0.0225	0.0000
NBS07112	0.1053	0.0033	-0.0002
U0071Cx	-0.0295	-0.0056	-0.0001
u0071cx_r14	-0.0372	-0.0124	0.0000
u0071cx_r20	-0.0182	0.0016	-0.0001
u0071cx_r28	-0.0367	-0.0049	-0.0001
u0071cx_r40	-0.0334	-0.0122	0.0000
u0071cx_r80	-0.0079	-0.0132	0.0000
NBS19412	0.0625	0.0008	-0.0003
U0194Cx	-0.0071	-0.0098	-0.0001
u0194cx_r14	-0.0178	-0.0114	0.0000
u0194cx_r20	-0.0181	-0.0129	0.0000
u0194cx_r28	0.0058	-0.0114	0.0000
u0194cx_r40	-0.0070	-0.0065	-0.0001
u0194cx_r80	0.0060	-0.0049	-0.0002
NBS29512	0.0217	-0.0094	-0.0001
U0295Cx	-0.0005	-0.0113	0.0000
u0295cx_r14	0.0074	-0.0083	-0.0001
u0295cx_r20	0.0011	-0.0033	-0.0002
u0295cx_r28	-0.0086	-0.0146	0.0001
u0295cx_r40	-0.0110	-0.0142	0.0001
u0295cx_r80	-0.0042	-0.0060	-0.0002
446_d_00	0.0226	-0.0005	-0.0004
446_D_01	0.0129	-0.0104	0.0000
446_D_02	0.0131	-0.0083	-0.0001
446_D_05	0.0165	-0.0044	-0.0002
446_D_10	0.0121	-0.0144	0.0002
446_D_15	0.0187	-0.0285	0.0009
446_S_00	0.0522	0.0003	-0.0005
446_S_01	0.0503	-0.0011	-0.0004
446_S_02	0.0620	0.0043	-0.0007
446_S_05	0.0538	0.0011	-0.0005
446_S_10	0.0542	-0.0048	-0.0002
446_S_15	0.0178	0.0003	-0.0005
NBS44612	0.0200	0.0023	-0.0006
U0446Cx	-0.0197	-0.0096	0.0000
u0446cx_r14	-0.0134	-0.0184	0.0004
u0446cx_r20	-0.0074	-0.0230	0.0006
u0446cx_r28	0.0032	-0.0015	-0.0004

u0446cx_r40	0.0019	-0.0044	-0.0002
u0446cx_r80	0.0019	-0.0105	0.0000
UISO1212	-0.0501	-0.0113	0.0017
U17C2T10	-0.0279	-0.0216	0.0050
u2006cx_r14	-0.0129	-0.0108	0.0039
u2006cx_r20	-0.0045	-0.0065	0.0028
u2006cx_r28	-0.0090	-0.0082	0.0032
u2006cx_r40	-0.0076	-0.0028	0.0019
u2006cx_r80	0.0012	0.0033	0.0003
U2011Cx	-0.0362	-0.0187	0.0060
UISO27PS	0.0032	-0.0058	0.0039
U38C2G15	-0.0307	-0.0130	0.0085
U52C2G20	-0.0121	0.0123	-0.0003
nbl53_00	0.0272	0.0093	-0.0104
nbl53_00A	0.0272	0.0093	-0.0104
nbl53_03	0.0374	0.0310	-0.0348
nbl53_03a	0.0374	0.0310	-0.0348
nbl53_10	0.0210	0.0069	-0.0076
nbl53_10A	0.0210	0.0069	-0.0076
U5249Cx	-0.0203	0.0032	-0.0031
u5256cx_r14	-0.0256	-0.0012	0.0019
u5256cx_r20	-0.0117	0.0082	-0.0088
u5256cx_r28	-0.0145	-0.0019	0.0026
u5256cx_r40	0.0023	0.0172	-0.0190
u5256cx_r80	-0.0042	0.0099	-0.0107
66_S01	0.0149	0.0067	-0.0145
U66C2G20	-0.0166	-0.0015	0.0024
U91C2G20	-0.0193	0.0028	-0.0276
U91C2T30	-0.0256	0.0017	-0.0134
nbl93_00	0.0397	0.0019	-0.0385
nbl93_00a	0.0397	0.0019	-0.0385
nbl93_03	0.0007	0.0002	-0.0025
nbl93_03a	0.0007	0.0002	-0.0025
nbl93_10	0.0105	0.0009	-0.0163
nbl93_10a	0.0105	0.0009	-0.0163
U9317Cx	-0.0184	-0.0004	0.0107
u9318cx_r14	-0.0017	0.0038	-0.0627
u9318cx_r20	-0.0074	0.0007	-0.0094
u9318cx_r28	0.0013	0.0019	-0.0319
u9318cx_r40	0.0017	0.0020	-0.0325
u9318cx_r80	0.0039	0.0034	-0.0564
Unweighted average	**-0.0029**	**-0.0027**	**-0.0046**
Unweighted uncertainty	**0.0043**	**0.0011**	**0.0012**
Weighted average	**0.0020**	**0.0004**	**-0.0001**
Weighted uncertainty	**0.0024**	**0.0008**	**0.0002**

Table B9. Bias results of the data sets obtained with the CZT detector and analyzed using the CZT500_U_120-1010 parameter set. Each result is the average result from the multiple runs for a sample. The bottom rows (in bold) show the "averages of the averages" and uncertainties using both the unweighted and weighted average methods.

Sample name	^{234}U	^{235}U	^{238}U
lgczt-a1-1126000.Chn	-0.2233	-0.0991	0.0031

lgczt-a1-324000.Chn	-0.0072	-0.2824	0.0323
lgczt-eupu1000.Chn	0.1513	0.0488	-0.8421
lgczt-u0031000.Chn	0.1708	0.0405	0.0000
lgczt-u0071000.Chn	-0.1118	-0.0717	0.0005
lgczt-u0194000.Chn	-0.2476	-0.0537	0.0010
lgczt-u0295000.Chn	-0.1698	0.1217	-0.0038
lgczt-u0446000.Chn	-0.1407	-0.0138	0.0005
lgczt-u2006000.Chn	-0.0768	-0.0350	0.0102
lgczt-u5256000.Chn	0.0098	-0.0186	0.0213
lgczt-u9318000.Chn	0.0608	0.0066	-0.1322
lgczt-uiso12000.Chn	0.0609	-0.0813	0.0115
lgczt-uiso13000.Chn	-0.0686	-0.1544	0.0236
Unweighted average	**-0.0456**	**-0.0456**	**-0.0672**
Unweighted uncertainty	**0.0372**	**0.0279**	**0.0655**
Weighted average	**0.0998**	**0.0239**	**-0.0035**
Weighted uncertainty	**0.0314**	**0.0158**	**0.0184**

Table B10. Bias results of the data sets obtained with the $LaBr_3$ detectors and analyzed using the LaBr_U_120-1010 parameter set. Each result is the average result from the multiple runs for a sample. The bottom rows (in bold) show the "averages of the averages" and uncertainties using both the unweighted and weighted average methods.

Sample name	^{234}U	^{235}U	^{238}U
a1-1126000	-0.1006	0.0431	-0.0014
a1-324000	0.4277	0.0312	-0.0034
a1-409000	0.0622	0.0512	-0.0004
eupu1000	0.1303	0.0493	-0.8405
u0031000	0.2713	0.1297	-0.0003
u0071000	0.0449	0.0921	-0.0007
u0194000	-0.0997	0.1323	-0.0027
u0295000	-0.1745	0.1155	-0.0036
u0446000	-0.0326	0.1102	-0.0054
u2006000	-0.0904	-0.0471	0.0133
u5256000	0.0014	-0.0214	0.0244
u9318000	-0.2222	-0.0642	1.1045
uiso12000	0.2576	0.0893	-0.0117
uiso13000	0.1527	0.0460	-0.0067
smlabr-eupu1000	0.1268	0.0304	-0.5257
smlabr-u0031000	0.1832	0.0515	0.0000
smlabr-u0071000	-0.1012	-0.0604	0.0004
smlabr-u0194000	-0.2440	-0.0492	0.0009
smlabr-u0295000	-0.2529	0.0097	-0.0004
smlabr-u0446000	-0.0626	0.0758	-0.0037
smlabr-u2006000	-0.2268	-0.1890	0.0496
smlabr-u5256000	-0.0816	-0.0984	0.1117
smlabr-u9318000	-0.3074	-0.1121	1.9254
smlabr-uiso12000	0.0012	-0.1319	0.0183
smlabr-uiso13000	-0.0639	-0.1496	0.0228
Unweighted average	**-0.0160**	**0.0054**	**0.0746**
Unweighted uncertainty	**0.0369**	**0.0185**	**0.0982**
Weighted average	**-0.0477**	**-0.0100**	**0.0006**
Weighted uncertainty	**0.0305**	**0.0161**	**0.0130**

APPENDIX C

FRAM analyzes and reports both the isotopic results and the corresponding uncertainties. For a data set containing an infinite number of runs, the standard deviation is the true uncertainty of a run. The average number of runs in all of our data sets was only about 15 or slightly more. Therefore, the standard deviations are not the true uncertainties of these data sets. However, they would be close. In this section, they are called the observed uncertainties. It is of interest to see how the observed uncertainty of an isotope compared with the FRAM reported uncertainty of the same isotope from many runs. The tables in this section show the ratios of the observed uncertainty from multiple runs to the average uncertainty predicted by FRAM for plutonium and uranium data.

Table C1. Comparison of the observed uncertainties with the average uncertainties predicted by FRAM. The data were acquired using the planar detectors and analyzed with the parameter set GePlnr_Pu_060-230.

Sample name	^{238}Pu	^{239}Pu	^{240}Pu	^{241}Pu	^{241}Am
256C10	1.28	0.98	0.96	0.76	0.77
A186	1.07	0.51	0.51	0.66	0.49
A192	1.23	0.61	0.62	0.46	0.79
CALEX23K	1.10	0.86	0.88	0.50	1.01
CBNM61B	0.98	0.78	0.77	0.97	0.72
CBNM70B	0.73	0.90	0.90	0.67	0.54
CBNM84B	0.95	1.39	1.39	0.80	0.88
CBNM93B	1.02	1.38	1.40	0.99	0.99
JOO1325	1.34	1.02	1.04	0.55	0.73
LAO225BS	1.04	1.14	1.16	0.43	0.67
PE0382C3	0.73	0.78	0.78	0.71	0.66
PUEU7	0.92	0.64	0.64	0.25	0.90
SRPISO12	1.12	1.40	1.40	0.68	1.14
SRPISO12	0.96	0.94	0.96	0.67	0.59
SRPISO15	1.04	0.83	0.82	0.87	0.60
SRPISO15	1.05	1.12	1.10	0.70	0.44
SRPISO3	1.20	1.14	1.18	0.48	1.59
SRPISO3	0.91	0.56	0.57	0.55	1.01
SRPISO6	0.78	0.90	0.91	0.70	0.82
SRPISO6	1.16	0.77	0.78	0.61	0.78
SRPISO9	1.18	1.00	1.00	0.87	0.98
SRPISO9	1.08	0.82	0.82	0.50	0.86
STD11612	0.74	0.57	0.55	0.65	0.61
STD1174K	0.90	0.42	0.43	0.79	0.51
STD11834	1.17	0.81	0.89	0.78	0.74
STD12018	1.15	0.41	0.40	0.71	0.69
STD1217K	0.83	0.72	0.70	0.81	0.74
STD3	0.85	0.77	0.76	0.73	0.67
STD4040K	1.12	0.60	0.60	0.62	0.54
STD627K	0.99	0.49	0.49	0.37	0.62
STD832K	1.16	0.80	0.82	0.52	0.47
STDR3	0.98	0.71	0.70	0.55	0.61
cbnm6175	0.66	0.69	0.66	0.79	0.66
cbnm7075	0.82	0.82	0.81	0.64	0.59
cbnm8475	1.52	0.85	0.84	0.66	0.58
cbnm9375	1.14	1.19	1.20	0.79	1.36
eupu775	0.81	0.71	0.71	0.59	0.68

iso0375	1.09	0.85	0.85	0.50	0.49
iso0675	1.51	0.87	0.87	0.68	0.72
iso0975	1.24	1.00	1.00	0.64	0.97
iso1275	1.13	0.74	0.74	0.49	0.74
iso1575	1.04	0.54	0.52	0.52	0.47
pidie175	1.18	1.01	1.02	0.96	1.12
pidie375	0.99	0.61	0.60	0.88	0.82
pidie575	1.30	0.46	0.44	0.84	0.50
pidie775	0.41	0.46	0.42	0.52	0.51
pufa175	1.12	0.72	0.72	0.41	0.34
EuPu7PlO	1.42	0.55	0.55	0.66	0.34
Iso03PlO	1.21	1.08	1.11	0.75	0.58
Iso06PlO	1.19	0.63	0.64	0.65	0.64
Iso09PlO	1.31	0.71	0.71	0.35	0.45
Iso12PlO	1.04	0.40	0.40	0.54	0.66
Iso15PlO	0.94	0.79	0.78	0.59	0.73
Pid1PlO	1.12	0.89	0.90	1.21	1.02
Pid3PlO	1.41	0.48	0.49	0.67	0.60
Pid5PlO	1.21	0.59	0.57	0.74	0.58
Pid7PlO	0.89	0.49	0.44	0.62	0.54
Pu61PlO	0.70	0.61	0.55	0.79	0.69
Pu70PlO	0.69	0.47	0.45	0.40	0.51
Pu84PlO	1.26	0.42	0.42	0.33	0.50
Pu93PlO	0.90	0.73	0.73	0.43	0.49
PuOc3PlO	1.39	0.41	0.41	0.50	0.18
pid1pl_r02	1.43	1.63	1.64	0.54	0.81
pid1pl_r04	1.17	1.12	1.13	0.90	1.28
pid1pl_r06	1.22	1.24	1.23	0.77	0.90
pid1pl_r10	1.44	1.19	1.20	0.81	0.78
pid1pl_r14	1.21	0.84	0.84	0.87	1.09
pid1pl_r20	1.08	0.63	0.63	1.02	1.06
pid1pl_r28	0.89	0.90	0.91	0.59	0.89
pid1pl_r40	0.73	0.90	0.91	0.97	0.82
pid1pl_r80	1.20	0.64	0.64	0.63	0.74
pid3pl_r02	1.11	0.85	0.84	0.91	0.92
pid3pl_r04	1.39	0.54	0.54	0.91	0.67
pid3pl_r06	1.10	0.78	0.78	1.13	0.75
pid3pl_r10	1.28	0.56	0.56	1.04	0.84
pid3pl_r14	1.17	0.93	0.94	1.15	0.93
pid3pl_r20	1.45	0.84	0.84	0.78	0.75
pid3pl_r28	1.14	0.73	0.72	0.97	0.81
pid3pl_r40	1.15	0.80	0.79	0.80	0.74
pid3pl_r80	0.82	0.56	0.56	0.69	0.75
pid5pl_r02	0.97	0.45	0.45	0.69	0.54
pid5pl_r04	1.46	0.60	0.61	0.71	0.93
pid5pl_r06	1.09	0.72	0.70	1.00	0.93
pid5pl_r10	1.07	0.71	0.71	0.58	0.60
pid5pl_r14	0.80	0.56	0.56	0.71	0.61
pid5pl_r20	1.11	0.63	0.63	0.61	0.36
pid5pl_r28	0.98	0.47	0.47	0.46	0.46
pid5pl_r40	1.08	0.57	0.56	0.38	0.73
pid5pl_r80	1.21	0.65	0.64	0.97	0.66
pid7pl_r02	1.09	0.60	0.61	0.72	0.64

pid7pl_r04	0.91	0.64	0.63	0.75	0.76
pid7pl_r06	0.90	0.52	0.51	0.62	0.56
pid7pl_r10	0.85	0.61	0.60	0.81	0.70
pid7pl_r14	0.89	0.64	0.62	0.74	0.71
pid7pl_r20	0.81	0.66	0.65	0.88	0.67
pid7pl_r28	0.65	0.60	0.62	0.73	0.83
pid7pl_r40	0.91	0.61	0.60	0.79	0.72
pid7pl_r80	1.30	2.06	2.17	1.46	1.49
Average	**1.07**	**0.77**	**0.77**	**0.71**	**0.73**

Table C2. Comparison of the observed uncertainties with the average uncertainties predicted by FRAM. The data were acquired using the planar detectors and analyzed with the parameter set GePlnr_Pu_120-420.

Sample name	^{238}Pu	^{239}Pu	^{240}Pu	^{241}Pu	^{241}Am
256C10	1.21	1.26	1.25	1.56	0.88
A186	1.08	0.95	0.94	1.01	0.76
A192	1.22	0.77	0.77	0.59	0.66
CALEX23K	1.12	0.93	0.93	0.82	0.87
CBNM61B	1.03	1.29	1.16	0.95	1.16
CBNM70B	1.02	1.16	1.11	1.39	1.02
CBNM84B	0.96	1.13	1.12	1.20	0.91
CBNM93B	1.02	1.06	1.06	1.38	0.68
JOO1325	1.35	0.94	0.94	0.79	1.18
LAO225BS	1.06	1.02	1.01	1.19	1.20
PE0382C3	0.73	1.11	1.11	1.53	1.06
PUEU7	0.98	1.05	1.05	0.73	0.66
SRPISO12	1.15	0.86	0.85	0.93	1.15
SRPISO12	1.05	0.76	0.76	1.40	0.77
SRPISO15	0.94	1.08	1.11	1.40	0.99
SRPISO15	1.19	1.25	1.24	1.16	0.96
SRPISO3	1.20	1.06	1.05	1.05	0.49
SRPISO3	0.93	1.36	1.36	1.11	0.68
SRPISO6	0.79	0.92	0.93	1.42	0.67
SRPISO6	1.16	0.86	0.87	0.85	0.99
SRPISO9	1.21	1.28	1.28	1.59	0.74
SRPISO9	1.11	1.12	1.11	1.03	1.04
STD11612	1.02	1.33	1.29	1.13	1.27
STD1174K	0.93	1.09	1.11	0.64	0.68
STD11834	1.09	0.74	0.71	0.64	0.84
STD12018	1.08	1.12	1.07	1.05	1.43
STD1217K	0.80	0.80	0.78	0.85	0.99
STD3	0.84	1.21	1.21	1.13	0.72
STD4040K	1.04	1.06	1.05	1.25	0.82
STD627K	0.98	0.71	0.71	0.59	0.63
STD832K	1.12	1.66	1.65	0.83	0.49
STDR3	1.01	0.65	0.65	0.42	0.45
cbnm6175	0.95	1.26	1.16	1.25	1.32
cbnm7075	1.17	0.92	0.89	1.42	0.83
cbnm8475	1.50	0.72	0.71	1.30	0.95
cbnm9375	1.14	1.08	1.08	1.26	1.08
eupu775	0.80	1.12	1.11	0.82	0.93
iso0375	1.08	0.91	0.90	0.84	0.75
iso0675	1.52	1.09	1.09	1.09	1.00

iso0975	1.28	1.06	1.05	1.14	1.06
iso1275	1.14	1.59	1.60	0.89	0.95
iso1575	1.31	1.39	1.38	1.18	1.12
pidie175	1.15	1.08	1.07	1.14	1.01
pidie375	1.00	1.09	1.09	1.22	0.79
pidie575	1.35	0.93	0.91	1.42	1.14
pidie775	0.86	1.21	1.14	1.00	1.17
pufa175	1.14	0.81	0.81	0.75	0.48
EuPu7PlO	1.39	1.52	1.50	1.05	0.79
Iso03PlO	1.22	1.07	1.05	1.22	1.01
Iso06PlO	1.18	1.00	0.99	1.02	1.29
Iso09PlO	1.30	1.25	1.17	0.66	0.86
Iso12PlO	1.00	1.00	1.00	1.18	1.16
Iso15PlO	0.98	1.03	1.04	1.34	0.92
Pid1PlO	1.14	1.19	1.20	1.61	0.98
Pid3PlO	1.40	0.94	0.93	0.92	0.86
Pid5PlO	1.40	1.17	1.14	1.51	1.19
Pid7PlO	1.09	1.05	0.99	1.23	0.99
Pu61PlO	0.97	1.15	1.10	1.18	0.85
Pu70PlO	1.19	0.92	0.85	1.37	0.83
Pu84PlO	1.54	0.90	0.88	1.35	1.29
Pu93PlO	0.93	0.99	0.98	0.86	0.62
PuOc3PlO	1.46	0.80	0.78	0.87	0.86
pid1pl_r02	1.43	0.88	0.86	1.03	1.02
pid1pl_r04	1.12	1.10	1.10	1.29	1.13
pid1pl_r06	1.22	1.04	1.03	0.96	1.37
pid1pl_r10	1.46	0.84	0.82	1.29	1.07
pid1pl_r14	1.25	0.77	0.76	1.25	1.22
pid1pl_r20	1.09	1.10	1.07	1.30	1.01
pid1pl_r28	0.88	1.27	1.27	0.72	1.08
pid1pl_r40	0.75	1.26	1.26	0.99	0.85
pid1pl_r80	1.20	1.17	1.17	0.95	1.01
pid3pl_r02	1.13	1.04	1.04	1.35	0.97
pid3pl_r04	1.41	0.75	0.74	2.01	1.29
pid3pl_r06	1.09	1.14	1.13	1.83	1.44
pid3pl_r10	1.27	1.06	1.06	1.71	1.00
pid3pl_r14	1.12	1.22	1.21	1.36	0.66
pid3pl_r20	1.40	0.93	0.92	1.29	0.96
pid3pl_r28	1.02	0.95	0.94	1.68	0.76
pid3pl_r40	1.20	0.98	0.97	1.17	1.08
pid3pl_r80	0.81	0.97	0.97	0.97	0.77
pid5pl_r02	0.98	1.39	1.38	1.31	1.26
pid5pl_r04	1.51	1.20	1.18	1.33	1.15
pid5pl_r06	1.15	1.51	1.48	1.68	1.29
pid5pl_r10	1.26	1.60	1.54	1.56	1.43
pid5pl_r14	0.80	1.31	1.30	1.25	0.99
pid5pl_r20	1.06	1.06	1.05	1.36	0.60
pid5pl_r28	0.97	1.02	1.01	1.24	1.35
pid5pl_r40	1.34	0.84	0.83	1.30	0.93
pid5pl_r80	1.30	1.15	1.11	1.85	0.94
pid7pl_r02	1.01	0.98	0.93	0.80	1.26
pid7pl_r04	1.04	1.16	1.04	1.25	1.31
pid7pl_r06	1.01	1.24	1.07	1.24	1.37

pid7pl_r10	1.18	1.07	0.97	1.45	1.03
pid7pl_r14	1.05	1.13	1.07	1.21	1.04
pid7pl_r20	1.06	1.00	0.91	1.44	0.92
pid7pl_r28	1.15	1.00	0.97	1.34	0.57
pid7pl_r40	1.10	1.22	1.12	1.34	1.17
pid7pl_r80	0.69	1.19	1.09	0.81	1.29
Average	**1.12**	**1.08**	**1.05**	**1.17**	**0.97**

Table C3. Comparison of the observed uncertainties with the average uncertainties predicted by FRAM. The data were acquired using the planar detectors and analyzed with the parameter set GeCoax_Pu_120-420.

Sample name	^{238}Pu	^{239}Pu	^{240}Pu	^{241}Pu	^{241}Am
2G118CX8	1.04	1.21	1.20	0.78	0.53
2G119CX8	1.04	0.71	0.71	0.81	0.52
2G120CX8	0.82	0.75	0.76	0.72	0.21
2G121CX8	0.80	1.16	1.16	0.58	0.49
61COAX8K	1.29	1.16	1.16	0.91	0.63
70COAX8K	1.37	1.31	1.29	0.99	0.44
84COAX8K	1.01	1.34	1.34	1.04	0.51
86COAX8K	1.00	1.14	1.12	0.54	0.98
92COAX8K	0.87	0.77	0.75	0.58	0.83
93COAX8K	1.08	1.36	1.36	0.82	0.68
CALX30	1.63	0.95	0.97	1.23	0.77
EUPU7CX8	1.36	1.07	1.07	0.61	0.52
ISO12C8K	0.74	0.80	0.81	1.07	0.79
ISO15C8K	1.07	1.16	1.15	1.09	0.48
ISO3CX8K	1.44	1.33	1.34	0.80	0.40
ISO6CX8K	1.58	0.75	0.75	1.06	0.72
ISO9CX8K	1.27	1.65	1.64	0.92	0.55
JOO1325	0.86	1.04	1.08	1.12	0.83
LAO22530	1.24	1.20	1.21	1.46	0.72
PUEU730	1.66	0.96	0.98	1.30	0.58
SD4030	1.25	0.87	0.88	1.12	1.38
SGCOAX8K	1.47	0.87	0.86	0.45	0.28
STD830	1.09	1.11	1.11	1.04	0.86
PID6_1	1.24	1.19	1.19	1.49	1.02
PID6_2	1.42	1.21	1.23	1.38	0.84
PID6_3	1.26	1.23	1.22	1.22	0.96
PID6_4	1.38	0.81	0.80	1.20	0.55
PIDIE65	1.06	0.92	0.91	0.86	0.43
PIDIE66	0.62	0.88	0.89	0.65	0.37
PIDIE67	0.62	0.81	0.85	0.59	0.38
cbnm61	0.94	0.89	0.84	0.90	0.72
cbnm70	1.29	1.38	1.33	1.12	0.98
cbnm84	1.21	1.31	1.31	1.12	0.66
cbnm93	1.13	1.11	1.10	1.62	0.76
eupu7cx	1.27	1.08	1.08	0.75	0.81
iso03cx	0.93	0.87	0.87	1.16	1.08
iso06cx	1.25	1.04	1.04	1.14	0.58
iso09cx	1.30	0.82	0.81	1.17	0.66
iso12cx	1.06	1.24	1.23	1.60	1.04
iso15cx	1.45	1.02	1.01	1.26	0.84
pidie1cx	1.09	0.83	0.83	1.08	0.73

pidie3cx	1.22	1.09	1.09	1.10	0.57
pidie5cx	1.28	0.99	0.98	1.18	0.51
pidie7cx	0.74	0.81	0.77	0.59	0.54
stdiso03	1.04	1.15	1.16	0.98	0.43
stdiso09	1.08	1.06	1.07	1.25	0.74
stdiso15	0.88	1.20	1.19	1.06	0.75
Average	**1.14**	**1.06**	**1.05**	**1.01**	**0.67**

Table C4. Comparison of the observed uncertainties with the average uncertainties predicted by FRAM. The data were acquired using the coaxial detectors and analyzed with the parameter set GeCoax_Pu_180-1010.

Sample name	^{238}Pu	^{239}Pu	^{240}Pu	^{241}Pu	^{241}Am
2G118CX8	1.69	1.09	1.12	0.78	0.93
2G119CX8	1.49	0.53	0.54	0.87	0.59
2G120CX8	1.20	0.83	0.78	0.87	0.83
2G121CX8	0.88	1.26	1.27	1.21	1.01
61COAX8K	1.31	1.08	1.05	0.87	0.76
70COAX8K	0.58	0.81	0.80	0.77	0.54
84COAX8K	0.81	1.09	1.10	1.20	1.03
86COAX8K	1.19	0.94	0.91	0.94	1.62
92COAX8K	1.64	1.84	1.76	0.78	1.28
93COAX8K	1.32	0.97	0.95	0.55	1.43
CALX30	1.70	0.87	0.88	1.38	0.65
EUPU7CX8	1.15	0.89	0.89	0.46	1.17
ISO12C8K	1.03	0.99	1.00	1.25	1.24
ISO15C8K	0.73	0.91	0.93	1.52	0.86
ISO3CX8K	1.18	1.06	1.02	0.83	1.01
ISO6CX8K	1.29	0.91	0.90	0.68	0.80
ISO9CX8K	1.20	0.58	0.58	0.31	0.62
JOO1325	0.79	0.65	0.66	1.34	0.97
LAO22530	1.58	0.78	0.79	1.54	1.03
PUEU730	1.13	0.91	0.92	0.92	1.05
SD4030	2.81	1.17	1.18	1.38	2.14
SGCOAX8K	1.13	0.77	0.75	0.48	1.13
STD830	1.12	0.84	0.84	1.04	0.98
PID6_1	0.38	0.71	0.69	1.41	0.98
PID6_2	0.56	0.90	0.90	0.99	1.00
PID6_3	0.89	0.93	0.93	1.07	1.27
PID6_4	0.84	0.79	0.79	1.05	0.77
PIDIE65	0.90	0.83	0.82	1.07	0.81
PIDIE66	0.82	0.90	0.83	0.74	0.81
PIDIE67	0.88	0.91	0.84	0.90	0.80
cbnm61	0.84	1.15	1.10	1.18	1.11
cbnm70	0.66	0.86	0.86	0.79	0.79
cbnm84	0.82	0.98	1.01	0.91	0.93
cbnm93	0.78	0.85	0.85	1.10	1.32
eupu7cx	0.86	0.85	0.86	0.61	1.15
iso03cx	0.78	0.92	0.87	0.63	1.07
iso06cx	1.02	1.00	1.01	0.86	0.99
iso09cx	0.90	0.81	0.81	0.79	0.90
iso12cx	1.03	1.19	1.21	1.41	1.47
iso15cx	0.81	0.94	0.96	0.92	1.00
pidie1cx	0.65	0.80	0.80	1.00	0.78

pidie3cx	0.78	0.93	0.93	1.08	0.80
pidie5cx	0.98	1.21	1.19	1.14	1.25
pidie7cx	0.76	0.70	0.65	0.71	0.73
stdiso03	0.75	0.61	0.59	0.87	0.93
stdiso09	1.02	0.99	1.00	0.84	1.47
stdiso15	0.88	0.86	0.85	0.82	0.88
EuPu7Cx	0.48	0.83	0.85	0.59	0.94
Iso03Cx	0.50	0.89	0.85	0.86	0.69
Iso09Cx	0.69	0.79	0.79	0.95	1.19
Iso12Cx	0.93	1.14	1.14	1.44	1.14
Iso15Cx	0.73	1.13	1.13	1.17	1.28
Pid1Cx	0.48	0.88	0.85	0.99	1.41
Pid3Cx	0.73	0.87	0.88	0.70	1.00
Pid5Cx	0.64	0.59	0.59	0.67	0.62
Pid7Cx	0.74	0.87	0.85	0.83	0.85
Pu61Cx	0.81	0.90	0.85	0.88	0.85
Pu70Cx	1.12	1.11	1.11	1.29	1.21
Pu84Cx	0.93	1.01	1.03	1.13	1.23
Pu93Cx	0.59	0.93	0.91	0.81	1.25
PuOc3Cx	0.71	0.89	0.89	0.52	0.75
CALX30PB	1.06	0.63	0.64	1.86	1.22
J1325PB1	1.50	0.55	0.55	1.92	0.77
J1325PB2	1.70	1.58	1.42	2.82	1.51
LAO225PB	0.62	0.74	0.86	1.33	0.64
PUEU7PB	0.64	1.03	1.12	1.39	1.02
SD4030PB	0.19	1.07	1.12	1.41	1.03
STD8PB	1.72	1.14	1.13	1.42	0.98
Average	**0.97**	**0.93**	**0.92**	**1.03**	**1.02**

Table C5. Comparison of the observed uncertainties with the average uncertainties predicted by FRAM. The data were acquired using the CZT detector and analyzed with the parameter set CZT_Pu_120-500.

Sample name	^{238}Pu	^{239}Pu	^{240}Pu	^{241}Pu	^{241}Am
czt500_eupu7_d0_c0p8	0.49	1.23	1.11	0.90	1.01
czt500_eupu7_d8_c0p8_s8	0.66	1.38	1.16	1.42	1.13
czt500_iso03_d0_c0p8	0.49	0.97	1.14	1.01	0.79
czt500_iso03_d8_c0p8_s8	0.68	1.07	1.12	4.61	0.72
czt500_iso09_d0_c0p8	1.36	2.18	2.06	3.41	1.27
czt500_iso09_d8_c0p8_s8	1.08	1.46	1.41	1.64	1.15
czt500_iso12_d12_c1_a1p5	2.14	2.16	1.97	1.97	0.35
czt500_iso12_d8_c1_s8	2.18	1.52	1.54	1.80	0.66
czt500_iso15_d10_c1_a1p5_s8	1.68	2.04	1.75	2.82	0.52
czt500_iso15_d34_c1_a1p5	1.35	1.74	1.54	2.28	0.39
Average	**1.21**	**1.57**	**1.48**	**2.18**	**0.80**

Table C6. Comparison of the observed uncertainties with the average uncertainties predicted by FRAM. The data were acquired using the $LaBr_3$ detectors and analyzed with the parameter set LaBr_Pu_200-750.

Sample name	^{238}Pu	^{239}Pu	^{240}Pu	^{241}Pu	^{241}Am
labr_eupu7_d23_c0p9_a0p8	0.17	0.35	0.32	1.53	0.36
labr_eupu7_d8_c0p9_s8	0.17	0.27	0.28	1.08	0.33
labr_iso03_d36_c0p7_a0p8	0.10	0.31	0.28	1.96	0.34

labr_iso03_d8_c0p7_a0p8_s8	0.11	0.28	0.29	1.88	0.39
labr_iso09_d23_c0p9_a0p8_s8	0.22	0.39	0.32	1.03	0.34
labr_iso09_d36_c0p9_a0p8	0.28	0.43	0.40	1.33	0.23
labr_iso12_d36_c1_a0p8_s8	0.41	0.44	0.36	0.74	0.30
labr_iso12_d74_c1_a0p8	0.37	0.38	0.33	0.61	0.27
labr_iso15_d36_c1_a0p8_s8	0.22	0.30	0.27	0.36	0.26
labr_iso15_d74_c1_a0p8	0.25	0.34	0.32	0.41	0.27
cbnm61000	0.12	0.21	0.14	0.28	0.21
cbnm70000	0.22	0.28	0.26	0.30	0.27
eupu7000	0.13	0.34	0.27	1.13	0.54
lao250c10pb1p64000	0.03	0.01	0.01	0.35	0.09
lao251c10pb1p64000	0.02	0.01	0.01	0.32	0.08
pidie1000	0.24	0.19	0.22	0.42	0.36
sga30000	0.00	0.04	0.02	0.72	2.87
stdiso12000	0.10	0.04	0.05	0.48	0.14
stdiso15000	0.17	0.18	0.20	0.30	0.15
stdiso3000	0.07	0.31	0.25	3.15	0.93
stdiso9000	0.29	0.41	0.39	1.22	0.26
Average	**0.18**	**0.26**	**0.24**	**0.93**	**0.43**

Table C7. Comparison of the observed uncertainties with the average uncertainties predicted by FRAM. The data were acquired using the planar detectors and analyzed with the parameter sets GePlnr_ULEU_060-250 and GePlnr_UHEU_060-250.

Sample name	^{234}U	^{235}U	^{238}U
U0031PlO	0.83	1.72	1.69
u0031pl_r02	0.53	1.37	1.32
u0031pl_r04	0.46	1.32	1.30
u0031pl_r06	0.40	1.05	1.05
u0031pl_r10	0.43	0.99	0.97
u0031pl_r14	0.38	1.09	1.08
u0031pl_r20	0.66	1.18	1.15
u0031pl_r28	0.40	1.17	1.12
u0031pl_r40	0.49	1.13	1.11
u0031pl_r80	0.41	0.78	0.80
u031pl	0.94	1.45	1.41
U0071PlO	0.88	1.32	1.29
u0071pl_r02	1.13	0.90	0.85
u0071pl_r04	0.89	1.43	1.40
u0071pl_r06	1.02	1.14	1.12
u0071pl_r14	0.82	0.84	0.84
u0071pl_r20	1.02	1.25	1.22
u0071pl_r28	0.84	1.03	1.00
u0071pl_r40	0.78	1.50	1.45
u0071pl_r80	0.79	1.29	1.30
u071pl	0.98	1.19	1.18
A1-408-2pl000	1.03	1.12	1.15
U0194PlO	1.25	0.88	0.87
u0194pl_r02	0.97	0.93	0.91
u0194pl_r04	0.75	1.26	1.25
u0194pl_r06	1.20	0.72	0.69
u0194pl_r10	1.05	0.75	0.74
u0194pl_r14	1.13	0.98	0.95

u0194pl_r20	0.89	1.10	1.11
u0194pl_r28	0.97	1.08	1.07
u0194pl_r40	1.07	0.96	0.97
u0194pl_r80	0.79	0.47	0.46
u194pl	0.93	1.16	1.16
U0295PlO	1.22	0.87	0.88
u0295pl_r02	0.90	1.69	1.67
u0295pl_r04	1.02	1.24	1.21
u0295pl_r06	1.03	0.90	0.89
u0295pl_r10	0.66	1.21	1.19
u0295pl_r14	1.23	1.18	1.16
u0295pl_r20	0.66	0.75	0.74
u0295pl_r28	1.27	1.10	1.10
u0295pl_r40	0.85	0.72	0.71
u0295pl_r80	0.82	0.88	0.85
u295pl	1.04	1.26	1.26
A1-1126-1bpl000	0.82	0.69	0.71
A1-1126-1pl000	1.22	0.48	0.48
U0446PlO	0.85	0.90	0.91
u0446pl_r02	0.96	0.98	0.98
u0446pl_r04	0.93	1.11	1.11
u0446pl_r06	0.94	0.75	0.74
u0446pl_r10	1.18	0.89	0.91
u0446pl_r14	0.92	1.28	1.28
u0446pl_r20	0.82	1.30	1.30
u0446pl_r28	0.81	0.78	0.79
u0446pl_r40	1.07	0.96	0.94
u0446pl_r80	0.75	0.77	0.77
u446pl	0.89	0.80	0.80
A13241pl000	0.80	0.49	0.49
UISO13pl000	0.84	0.57	0.57
u2006pl_r02	0.83	0.65	0.64
u2006pl_r04	1.14	0.53	0.52
u2006pl_r06	1.02	0.66	0.66
u2006pl_r10	1.05	0.92	0.93
u2006pl_r14	1.00	0.57	0.57
u2006pl_r20	0.93	0.64	0.64
u2006pl_r28	0.92	0.72	0.71
u2006pl_r40	0.79	0.57	0.56
u2006pl_r80	1.21	0.79	0.79
U2011PlO	0.82	0.52	0.52
u20pl	0.88	0.58	0.58
UISO27pl000	0.64	0.63	0.64
UISO38pl000	0.76	0.46	0.46
U5249PlO	0.62	0.52	0.54
u5256pl_r02	0.77	0.67	0.66
u5256pl_r04	0.97	0.91	0.89
u5256pl_r06	0.90	0.91	0.90
u5256pl_r10	0.78	0.79	0.77
u5256pl_r14	0.79	0.82	0.80
u5256pl_r20	0.93	0.65	0.64
u5256pl_r28	0.90	0.58	0.58
u5256pl_r40	0.94	0.70	0.69

u5256pl_r80	0.99	0.57	0.56
u53pl	0.54	0.32	0.32
UISO66pl000	0.62	0.36	0.38
UISO91pl000	0.58	0.55	0.54
U9317PlO	0.89	0.96	0.64
u9318pl_r02	0.67	0.83	0.47
u9318pl_r04	0.99	0.60	0.44
u9318pl_r06	1.09	0.69	0.46
u9318pl_r10	0.91	0.61	0.32
u9318pl_r14	1.01	0.88	0.58
u9318pl_r20	0.87	0.86	0.66
u9318pl_r28	0.73	0.53	0.40
u9318pl_r40	0.75	0.74	0.63
u9318pl_r80	0.71	0.69	0.61
u93pl	0.90	0.73	0.83
Average	**0.87**	**0.89**	**0.86**

Table C8. Comparison of the observed uncertainties with the average uncertainties predicted by FRAM. The data were acquired using the coaxial detectors and analyzed with the parameter sets GeCoax_ULEU_120-1010 and GeCoax_UHEU_120-1010.

Sample name	^{234}U	^{235}U	^{238}U
031_D00	1.15	1.01	1.00
031_D15	0.32	1.15	1.23
031_S05	0.39	1.95	1.86
NBS03112	0.47	1.40	1.38
U0031Cx	0.85	1.23	1.28
u0031cx_r14	0.90	1.69	1.74
u0031cx_r20	0.69	1.86	1.90
u0031cx_r28	0.79	1.30	1.37
u0031cx_r40	0.76	1.24	1.27
u0031cx_r80	0.88	1.92	2.00
071_00	0.80	1.62	1.62
071_00B	0.80	1.14	1.18
071_01	0.97	1.43	1.44
071_01B	1.07	1.03	1.07
071_03	0.91	1.89	1.90
071_03B	1.04	2.02	2.07
071_05	0.82	2.22	2.24
071_05B	1.01	2.15	2.16
071_10	0.93	2.36	2.36
071_10B	1.16	2.21	2.18
071_15	0.63	2.62	2.63
071_15B	1.00	2.25	2.35
NBS07112	0.93	2.04	1.99
U0071Cx	0.85	1.13	1.13
u0071cx_r14	1.19	1.93	1.98
u0071cx_r20	1.12	1.35	1.37
u0071cx_r28	0.75	1.76	1.79
u0071cx_r40	0.95	1.97	2.01
u0071cx_r80	1.08	1.38	1.41
NBS19412	1.25	1.29	1.27
U0194Cx	1.15	1.63	1.67

u0194cx_r14	1.24	2.50	2.57
u0194cx_r20	0.85	1.84	1.89
u0194cx_r28	0.55	1.37	1.39
u0194cx_r40	0.69	1.45	1.47
u0194cx_r80	0.66	1.42	1.44
NBS29512	0.89	0.99	1.01
U0295Cx	1.03	1.88	1.92
u0295cx_r14	1.02	2.16	2.20
u0295cx_r20	0.77	2.18	2.21
u0295cx_r28	0.78	1.72	1.77
u0295cx_r40	0.96	1.77	1.82
u0295cx_r80	0.95	1.56	1.59
446_d_00	0.68	1.03	1.05
446_D_01	0.79	1.80	1.83
446_D_02	1.11	2.00	2.04
446_D_05	0.96	2.05	2.07
446_D_10	1.57	2.81	2.88
446_D_15	1.09	2.77	2.87
446_S_00	1.06	1.87	1.89
446_S_01	0.68	1.62	1.63
446_S_02	1.05	1.79	1.80
446_S_05	1.13	1.89	1.90
446_S_10	1.14	2.51	2.53
446_S_15	1.12	2.84	2.85
NBS44612	0.91	1.27	1.29
U0446Cx	0.92	1.64	1.67
u0446cx_r14	1.36	1.88	1.94
u0446cx_r20	1.01	1.79	1.85
u0446cx_r28	0.74	1.35	1.37
u0446cx_r40	0.86	1.78	1.80
u0446cx_r80	0.84	1.31	1.34
UISO1212	0.62	1.36	1.39
U17C2T10	0.74	1.85	1.90
u2006cx_r14	0.94	1.15	1.17
u2006cx_r20	1.08	1.97	2.00
u2006cx_r28	1.45	1.34	1.37
u2006cx_r40	1.15	1.86	1.87
u2006cx_r80	1.22	1.53	1.54
U2011Cx	1.01	1.03	1.06
UISO27PS	0.93	1.34	1.34
U38C2G15	0.92	1.00	1.03
U52C2G20	0.88	1.09	1.08
nbl53_00	0.80	1.47	1.47
nbl53_00A	0.80	1.47	1.47
nbl53_03	0.78	0.96	0.92
nbl53_03a	0.78	0.96	0.92
nbl53_10	0.41	1.27	1.25
nbl53_10A	0.41	1.27	1.25
U5249Cx	0.78	1.94	1.95
u5256cx_r14	0.98	2.02	2.05
u5256cx_r20	0.67	1.75	1.74
u5256cx_r28	0.97	2.19	2.22
u5256cx_r40	0.97	2.06	2.00

u5256cx_r80	0.99	2.12	2.10
66_S01	0.82	1.29	1.28
U66C2G20	0.60	0.74	0.74
U91C2G20	0.71	1.00	1.05
U91C2T30	0.73	0.94	0.96
nbl93_00	0.50	1.03	1.08
nbl93_00a	0.50	1.03	1.08
nbl93_03	0.44	0.91	0.93
nbl93_03a	0.44	0.91	0.93
nbl93_10	0.47	0.75	0.75
nbl93_10a	0.47	0.75	0.75
U9317Cx	0.26	1.27	1.28
u9318cx_r14	0.63	2.86	2.53
u9318cx_r20	0.30	0.75	0.74
u9318cx_r28	0.38	0.82	0.80
u9318cx_r40	0.45	1.04	0.98
u9318cx_r80	4.11	3.61	2.70
Average	**0.88**	**1.62**	**1.63**

Table C9. Comparison of the observed uncertainties with the average uncertainties predicted by FRAM. The data were acquired using the CZT detector and analyzed with the parameter set CZT500_U_120-1010.

Sample name	^{234}U	^{235}U	^{238}U
lgczt-a1-1126000.Chn	3.35	3.90	4.57
lgczt-a1-324000.Chn	5.20	3.80	5.98
lgczt-eupu1000.Chn	0.00	0.11	0.02
lgczt-u0031000.Chn	5.92	5.27	5.08
lgczt-u0071000.Chn	3.25	3.39	3.46
lgczt-u0194000.Chn	3.07	3.87	3.83
lgczt-u0295000.Chn	4.23	5.73	4.94
lgczt-u0446000.Chn	3.33	3.85	3.81
lgczt-u2006000.Chn	4.10	4.38	5.26
lgczt-u5256000.Chn	2.28	2.47	2.69
lgczt-u9318000.Chn	0.38	1.08	0.76
lgczt-uiso12000.Chn	6.29	5.52	7.11
lgczt-uiso13000.Chn	4.48	4.14	5.20
Average	**3.53**	**3.65**	**4.06**

Table C10. Comparison of the observed uncertainties with the average uncertainties predicted by FRAM. The data were acquired using the $LaBr_3$ detectors and analyzed with the parameter set LaBr_U_120-1010.

Sample name	^{234}U	^{235}U	^{238}U
a1-1126000	3.35	3.95	3.80
a1-324000	4.23	3.18	3.09
a1-409000	5.60	5.60	5.32
eupu1000	0.00	0.03	0.00
u0031000	5.31	5.71	5.06
u0071000	3.10	3.25	2.99
u0194000	2.33	2.95	2.59
u0295000	2.40	3.27	2.92
u0446000	4.15	4.84	4.31
u2006000	0.91	1.03	1.10
u5256000	0.43	0.46	0.49

u9318000	0.13	0.11	0.25
uiso12000	3.53	3.21	2.95
uiso13000	3.12	2.99	2.86
smlabr-eupu1000	0.01	0.19	0.01
smlabr-u0031000	2.35	2.67	2.58
smlabr-u0071000	2.84	3.10	3.31
smlabr-u0194000	2.98	3.78	4.03
smlabr-u0295000	4.20	5.76	5.79
smlabr-u0446000	3.84	4.49	4.17
smlabr-u2006000	5.00	5.46	6.64
smlabr-u5256000	3.63	3.74	4.40
smlabr-u9318000	0.20	0.18	0.59
smlabr-uiso12000	6.64	5.96	6.96
smlabr-uiso13000	4.35	4.08	4.94
Average	**2.98**	**3.20**	**3.25**