*Delivery and Installation of PC/FRAM
at the PNC Tokai Works*

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*Edited by Jeff Skiby, Group CIC-1
Prepared by Celina Ortiz, Group NIS-5*

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Thomas E. Sampson

Thomas A. Kelley

Kenneth E. Kroncke

Howard O. Menlove

Jacobo Baca

*Takashi Asano**

*Shigeru Terakado**

*Yasushi Goto**

*Noboru Kogawa**

**Power Reactor and Nuclear Fuel Development Corporation, PFPP Tokai Works,
4-33 Mura Matsu, Tokai, Ibaraki, Japan.*

Los Alamos
NATIONAL LABORATORY

Los Alamos, New Mexico 87545

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DELIVERY AND INSTALLATION OF PC/FRAM AT THE PNC TOKAI WORKS

by

Thomas E. Sampson, Thomas A. Kelley, Kenneth E. Kroncke,
Howard O. Menlove, and Jacobo Baca,
Takashi Asano, Shigeru Terakado, Yasushi Goto, and Noboru Kogawa

ABSTRACT

We report on the assembly, testing, delivery, installation, and initial testing of three PC/FRAM plutonium isotopic analysis systems at the Power Reactor and Nuclear Fuel Development Corporation's Tokai Works. These systems are intended to measure the isotopic composition and ^{235}U /plutonium of mixed oxide (MOX) waste in 200-L waste drums. These systems provide capability for performing measurements on lead-lined drums.

INTRODUCTION

The Safeguards Science and Technology Group (NIS-5) at the Los Alamos National Laboratory has completed the assembly, testing, delivery, and on-site testing of three PC/FRAM* plutonium isotopic analysis systems¹⁻³ for the Power Reactor and Nuclear Fuel Development Corporation's (PNC) Tokai Works. These systems were designed to analyze the gamma-ray spectrum and determine the isotopic composition of plutonium and the ²³⁵U/plutonium ratio in lead-lined drums of mixed oxide (MOX) waste. These systems were intended to supplement three commercial isotopic analysis systems by providing the capability for making measurements of materials in lead-lined drums, a capability not available in PNC's existing commercial systems. The three Los Alamos isotopic analysis systems will provide ²⁴⁰Pu_{eff} results to three Los Alamos Waste Drum Assay Systems (WDAS) to yield total plutonium contents in the waste drums.

EQUIPMENT

Each of the three systems contained the following components.

- Coaxial high-purity germanium (HPGe) detector of approximately 25% relative efficiency
- Tungsten detector shield
- Manually operated lifting platform to position detector and shield for drum measurements
- Data acquisition electronics
 - Canberra 3106D Bias Supply
 - ORTEC 672 Spectroscopy Amplifier
 - Canberra 8706 ADC
 - Canberra 8233 Digital Stabilizer
 - Canberra 2071A Counter/Timer
 - ORTEC 4001D/4002D NIM Bin and Power Supply
 - Canberra S100 Multichannel Analyzer
- IBM model 65647H PC (90-MHz Pentium) personal computer
- NEC Multisync Monitor, model XE15
- Hewlett Packard Laser Jet 4L printer
- PC/FRAM isotopic analysis software, Version 2.1-TOKAI

The system interconnections are shown in Fig. 1.

* FRAM is a word of Scandinavian origin meaning "forward" or "onward." It is also an acronym meaning Fixed Energy, Response Function Aalysis, with Multiple Efficiencies.

Fig. 1. PC/FRAM System Interconnections.

Figure 2 shows one of the systems before delivery.

Fig. 2. A PC/FRAM system for the PNC Tokai Works.

INITIAL TESTING

A tight delivery schedule precluded extensive predelivery testing. However, we were able to complete fifteen 20-min measurements on each of four 6-g plutonium isotopic standards (CBNM NRM271) on each of the three systems. The average value of the ^{240}Pu bias [(average measured value for 15 measurements)/(certified value)] is plotted in Figs. 3-4 for the three standards in the burnup range most appropriate for the PNC application. The two plots show the results from analysis of the data in two different energy regions. The 120–460-keV analysis is appropriate for drums without a lead lining or with a lead thickness of ≤ 0.3 mm. The 200–800-keV analysis can be applied to all drums and was tested at PNC with lead thicknesses up to 1.2 mm. (In other applications the 200-800-keV analysis has been shown to work with lead up to 6 mm thick.)

Fig. 3. Low-energy analysis results at Los Alamos for 6-g PuO_2 standards. Measured value is the average of fifteen 20-min measurements.

Fig. 4. High-energy analysis results at Los Alamos for 6-g PuO_2 standards. Measured value is the average of fifteen 20-min measurements.

These results were thought to be acceptable with the exception of the 200–800-keV results from system 4311. The cause of the low bias on this system is not understood but may be related to the poorer resolution of the detector on this system, relative to the other systems.

The systems were delivered with parameter sets appropriate for analyzing MOX, these parameter sets having been adapted from the plutonium (only) parameters used for the analyses displayed in Figs. 3-4. We did not have appropriate MOX samples to test the delivered parameter sets. As will be seen later, our initial measurements with the MOX parameter sets at PNC showed some biases, which were subsequently corrected.

TESTING AT PNC

The three systems were tested on a variety of samples over a period of three days after delivery to PNC. The measurements were divided into two classes: (1) a shielding study and (2) measurements on mock waste drums.

Before we began the two measurement studies, we first scanned an empty drum with a point source in the center of the drum. The scans were performed to quantify the tradeoff between count rate and uniform response. The scan results for three detector-drum distances are shown in Fig. 5. We established a measurement protocol for the mock waste drums from this data. First we

positioned the detector 15 cm from the drum: a compromise position between uniform response and sensitivity. Then we positioned the detector at the upper quarter, middle, and lower quarter of the drum while looking for a count-rate maximum on the counter/timer. We left the detector at the position of the maximum count rate and completed the mock waste drum measurement while rotating the drum.

Fig. 5. Scan profiles of drum with point source in center. Parameters are the detector-drum distance in centimeters.

Shielding Study This study used a series of standards with nominal masses of 2, 10, and 30 g. These standards were placed in the center of an empty 208-L drum and measured with various thicknesses of lead sheet lining the inside wall of the drum. These measurement results were compared to the analytical values for the standards.

Mock Waste Drums One set of mock waste drums was lined with 0.3 mm of lead and contained known masses of plutonium (12–60 g) in matrices of paper, metal, and rubber. A second set of mock waste drums contained a high-density mineral matrix (a ceramic-like material formed from melted ash). The isotopic composition of the plutonium in the mock waste drums was not known. We compared our PC/FRAM measurements with previous measurements from PNC's commercial Canberra Multigroup Analysis (MGA) system.

AS-DELIVERED MEASUREMENT RESULTS

The measurement results obtained at PNC in the shielding study and for the mock waste drums are displayed below in Tables I—IV. For the measurements in the shielding study the known value of the ^{242}Pu isotopic fraction was operator-entered. The isotopic fraction of ^{242}Pu was not known for the Mock Waste Drum measurements, hence we used the ^{242}Pu correlation as delivered with the code. We later adjusted the parameters in this correlation for better agreement with known information.

TABLE I. Shielding Study. Baseline measurement results at PNC with As-Delivered system, Parameter Set: **mox_coax**—Analysis 120-460 keV.

Sample no. x mass (g)	No. Meas.	Pb (mm)	ct. rate (kHz)	ct. time (s)	Measured Value (wt%)				ug/gPu Am241
					238	239	240	241	
3 x 30	15	none	33	3600	1.159	63.59	23.14	7.863	16277
3 x 10	1	none	11	1800	1.179	64.87	21.76	7.942	16253
3 x 10	15	0.3	6.8	3600	1.173	63.92	22.78	7.878	17656
3 x 10	1	0.6	6.3	1800					
3 x 10	1	0.9	5	1800					
3 x 10	1	1.2	3.9	1800					
1 x 10	1	1.2	1.4	1800					
1 x 10	1	0.6	2.3	1800					
1 x 10	1	0.3	3.4	1800	1.241	63.24	23.36	7.916	15776
2 x 2	1	0.3	1.7	1800	1.15	63.71	22.99	7.911	17965
2 x 2	1	0.6	1.2	1800					
2 x 2	1	1.2	0.8	1800					
1 x 2	1	0.3	0.8	1800	1.034	66.03	21.91	6.773	25097
1 x 2	1	none	?	1800	1.084	65.66	21.62	7.384	17664
1 x 2	1	0.6	0.5	1800					
1 x 2	1	1.2	?	6000					
declared value					1.18	62.17	24.41	7.99	14558

The shielding study shown in Table I with the low-energy analysis established a range of lead thicknesses for this analysis of ≤ 0.3 mm. Above this thickness the peaks below 200 keV were too weak to analyze. We also note that the important ^{240}Pu measurement is biased low. This bias is seen to be about 6% if we consider the averages from the repeated 3 x 30-g and 3 x 10-g measurements.

TABLE II. Shielding Study. Baseline measurement results at PNC with As-Delivered system, Parameter Set: **shielded_MOX**—Analysis 200-800 keV.

Sample no. x mass (g)	No. Meas.	Pb (mm)	ct. rate (kHz)	ct. time (s)	Measured Value (wt%)				ug/gPu Am
					238	239	240	241	
3 x 30	15	none	33	3600	1.199	58.62	28.36	7.573	14998
3 x 10	1	none	11	1800	1.310	59.79	26.96	7.699	15535
3 x 10	15	0.3	6.8	3600	1.270	59.28	27.59	7.617	15342
3 x 10	1	0.6	6.3	1800	1.234	58.62	28.42	7.483	15202
3 x 10	1	0.9	5	1800	1.274	60.11	26.64	7.73	15647
3 x 10	1	1.2	3.9	1800	1.377	58.56	28.30	7.518	15967
1 x 10	1	1.2	1.4	1800	1.247	61.25	25.30	7.954	15800
1 x 10	1	0.6	2.3	1800	1.441	57.23	29.89	7.191	15622
1 x 10	1	0.3	3.4	1800	1.345	59.17	27.57	7.663	15441
2 x 2	1	0.3	1.7	1800	1.374	59.21	27.43	7.739	15388
2 x 2	1	0.6	1.2	1800	1.305	60.34	26.16	7.951	16073
2 x 2	1	1.2	0.8	1800	1.263	62.13	24.41	7.949	15756
1 x 2	1	0.3	0.8	1800	1.509	62.24	23.79	8.215	16495
1 x 2	1	none	?	1800	1.546	53.96	33.29	6.957	14763
1 x 2	1	0.6	0.5	1800	2.124	56.47	29.98	7.18	16223
1 x 2	1	1.2	?	6000	1.291	60.94	25.67	7.853	15542
declared value					1.18	62.17	24.41	7.99	14558

The shielding study analysis at high energies (200–800 keV) gave successful analyses for all tested combinations of mass and shielding thickness (see Table II). The 2-g sample measurements were very difficult because the counting statistics were very poor. The poor counting statistics resulted from the low plutonium mass, not from the lead shielding.

In contrast to the low-energy analysis we observed that the ^{240}Pu fraction was biased high for these measurements, by about 15% if we consider only the two 15-measurement data sets.

The as-delivered measurements on the mock waste drums are displayed below in two tables, one for analysis in the 120–460-keV range (see Table III) and the second for analysis in the 200–800-keV range (see Table IV). Here we are only able to compare the measurements with MGA results and we used the as-delivered ^{242}Pu correlation analysis to obtain ^{242}Pu values.

TABLE III. Mock Waste Drums. Baseline measurement results at PNC with As-Delivered system, Parameter Set: **mox_coax**—Analysis 120–460 keV.

Drum ID	Matrix/Shield	Pu mass Ct. Time		Code	238	239	wt% 240	241	Correlation	
		(g)	(s)						242	Am241
GFA-16	paper, .3mmPb	24.1	1800	PC/FRAM	1.137	63.40	23.35	6.968	5.136	1.930
			1000	MGA	1.200	64.60	23.96	7.000	3.240	2.430
			3000	MGA	1.180	67.04	21.87	7.050	2.860	2.390
			5000	MGA	1.190	66.63	22.17	7.090	2.930	2.400
GFC-34	metal, .3mmPb	61.6	1800	PC/FRAM	1.124	67.49	20.55	6.612	4.222	2.800
			1000	MGA	1.170	66.36	22.92	6.580	2.980	2.740
			3000	MGA	1.190	63.92	24.66	6.830	3.400	2.880
			5000	MGA	0.950	73.82	17.66	5.760	1.810	2.170
GFN-10	rubber, .3mmPb	18.9	1800	PC/FRAM	1.165	66.70	20.57	7.196	4.368	2.308
			1000	MGA	0.890	75.89	16.54	5.190	1.490	1.360
			3000	MGA	1.210	66.24	22.35	7.230	2.970	2.090
			5000	MGA	1.620	55.05	28.63	9.020	5.690	2.650
GFN-11	rubber, .3mmPb	12.1	1800	PC/FRAM	1.031	62.62	24.68	6.246	5.423	2.420
			1800	PC/FRAM	1.068	66.58	21.63	6.274	4.449	2.900
			1800	PC/FRAM	1.109	65.26	22.35	6.573	4.706	2.450
			1000	MGA	1.250	70.64	18.67	7.040	2.410	2.780
			3000	MGA	1.310	65.68	22.48	7.290	3.240	2.880
			5000	MGA	1.190	69.32	20.19	6.730	2.560	2.710
P-J-69	Hi Den Mineral		1800	PC/FRAM	0.518	72.61	21.28	3.266	2.326	2.530
			1000	MGA	0.390	82.03	14.48	2.380	0.720	2.360
			3000	MGA	0.400	79.72	16.63	2.410	0.850	2.230
			5000	MGA	0.410	78.86	17.20	2.600	0.920	2.420
P-J-70	Hi Den Mineral		1800	PC/FRAM	0.410	76.93	18.15	2.804	1.702	2.780
P-J-71	Hi Den Mineral		1800	PC/FRAM	0.489	81.45	14.15	2.613	1.298	3.510
			1000	MGA	0.370	82.67	14.19	2.100	0.670	2.500
			3000	MGA	0.320	81.15	15.92	1.910	0.700	2.450
			5000	MGA	0.330	81.04	16.01	1.910	0.720	2.470
P-J-72	Hi Den Mineral		1800	PC/FRAM	0.365	85.30	11.08	2.479	0.772	2.620
			1800	PC/FRAM	0.260	83.69	13.17	1.957	0.919	2.960
			1000	MGA	0.070	87.35	11.59	0.870	0.120	1.550
			3000	MGA	0.120	82.64	15.80	1.040	0.400	1.750
			5000	MGA	0.120	83.21	15.26	1.040	0.380	1.750

These data are difficult to analyze because the true isotopic values are not known and the MGA values, themselves, show great variability. It appears, as would be expected, that 0.3 mm of lead is more of an impediment for MGA than it is for the low-energy analysis (120–460 keV) of PC/FRAM. Nevertheless, we see general agreement between FRAM and MGA in most areas. The ^{242}Pu correlation is an exception.

All of the mock waste drums were also analyzed with the high-energy (200–800 keV) analysis, which is shown in Table IV.

TABLE IV. Mock Waste Drums. Baseline measurement results at PNC with As-Delivered system, Parameter Set: **shield_coax**—Analysis 200–800 keV.

Drum ID	Pu mass (g)									
	Matrix/Shield		Ct. Time (s)	Code	238	239	wt% 240	241	correlation 242	Am241
GFA-16	paper, .3mmPb	24.1	1800	PC/FRAM	1.202	58.23	27.40	6.416	6.75	1.99
			1000	MGA	1.20	64.60	23.96	7	3.24	2.43
			3000	MGA	1.18	67.04	21.87	7.05	2.86	2.39
			5000	MGA	1.19	66.63	22.17	7.09	2.93	2.4
GFC-34	metal, .3mmPb	61.6	1800	PC/FRAM	1.252	57.21	28.47	5.841	7.22	2.54
			1000	MGA	1.17	66.36	22.92	6.58	2.98	2.74
			3000	MGA	1.19	63.92	24.66	6.83	3.4	2.88
			5000	MGA	0.95	73.82	17.66	5.76	1.81	2.17
GFN-10	rubber, .3mmPb	18.9	1800	PC/FRAM	1.235	59.74	25.95	6.737	6.34	2.04
			1000	MGA	0.89	75.89	16.54	5.19	1.49	1.36
			3000	MGA	1.21	66.24	22.35	7.23	2.97	2.09
			5000	MGA	1.62	55.05	28.63	9.02	5.69	2.65
GFN-11	rubber, .3mmPb	12.1	1800	PC/FRAM	1.169	58.25	27.75	5.941	6.88	2.53
			1800	PC/FRAM	1.239	59.68	26.62	6.043	6.42	2.59
			1800	PC/FRAM	1.244	59.77	26.50	6.089	6.40	2.60
			1000	MGA	1.25	70.64	18.67	7.04	2.41	2.78
			3000	MGA	1.31	65.68	22.48	7.29	3.24	2.88
			5000	MGA	1.19	69.32	20.19	6.73	2.56	2.71

Here the MGA results are the same as previously displayed. The PC/FRAM high-energy analysis results are not shown for the high-density mineral samples. These results were very poor and the PC/FRAM low-energy analysis is to be preferred for these samples. The PC/FRAM high-energy results, when compared to MGA, seem to show the same high bias for ^{240}Pu as found in the high-energy results for the shielding study. The differences in the ^{242}Pu correlation are also present, as would be expected.

RESULTS FROM RE-ANALYSIS OF DATA

Subsequent to the installation and initial measurements at PNC we re-analyzed the data and made some adjustments in the parameters to improve results when compared with the standard sample measurements. We also made a simple adjustment in one of the constants governing the ^{242}Pu correlation.

The re-analyzed data from the shielding study are shown below for the low-energy (120–460 keV) (see Table V) and high-energy (200–800 keV) analysis (see Table VI). As before, in the shielding study we used operator-declared values for ^{242}Pu , hence the ^{242}Pu results are not shown below. The adjustments made were directed mainly toward improving the ^{240}Pu measurement and focused on the data from the 15 measurements on the 3 x 30-g and 3 x 10-g samples. We were also able to successfully analyze the 3 x 10-g and 1 x 10-g samples with 0.6 mm of lead in the low-energy range (120–460 keV). The results are not shown below because the analysis failed for the smaller samples and thus would not be generally applicable to the complete range of unknown items.

TABLE V. Shielding Study. PNC Data reanalyzed with **mox_coax_PNC2** parameters—Analysis 120–460 keV.

Sample no. x mass (g)	No. Meas.	Pb (mm)	ct. rate (kHz)	ct. time (s)	Measured Value (wt%)				ug/gPu Am
					238	239	240	241	
3 x 30	15	none	33	3600	1.192	62.08	24.43	8.058	15801
3 x 10	1	none	11	1800	1.199	63.24	23.29	8.028	15934
3 x 10	15	0.3	6.8	3600	1.178	62.12	24.57	7.887	17919
3 x 10	1	0.6	6.3	1800					
3 x 10	1	0.9	5	1800					
3 x 10	1	1.2	3.9	1800					
1 x 10	1	1.2	1.4	1800					
1 x 10	1	0.6	2.3	1800					
1 x 10	1	0.3	3.4	1800	1.248	62.04	24.57	7.888	16748
2 x 2	1	0.3	1.7	1800	1.148	62.35	24.41	7.851	19012
2 x 2	1	0.6	1.2	1800					
2 x 2	1	1.2	0.8	1800					
1 x 2	1	0.3	0.8	1800	1.259	65.46	20.68	8.356	18635
1 x 2	1	none	?	1800	1.109	62.15	24.92	7.574	16216
1 x 2	1	0.6	0.5	1800					
1 x 2	1	1.2	?	6000					
declared value					1.18	62.17	24.41	7.99	14558

TABLE VI. Shielding Study. PNC Data reanalyzed with **shield_mox_PNC4** parameters—Analysis 200-800 keV.

Sample no. x mass (g)	No. Meas.	Pb (mm)	ct. rate (kHz)	ct. time (s)	Measured Value (wt%)				ug/gPu Am241
					238	239	240	241	
3 x 30	15	none	33	3600	1.202	61.51	24.94	8.102	14891
3 x 10	1	none	11	1800	1.291	62.76	23.48	8.227	16064
3 x 10	15	0.3	6.8	3600	1.301	61.88	24.47	8.100	16052
3 x 10	1	0.6	6.3	1800	1.295	61.03	25.49	7.94	15943
3 x 10	1	0.9	5	1800	1.308	62.58	23.65	8.215	16203
3 x 10	1	1.2	3.9	1800	1.400	61.40	24.91	8.041	16931
1 x 10	1	1.2	1.4	1800	1.265	63.84	22.13	8.515	15899
1 x 10	1	0.6	2.3	1800	1.390	60.62	26.00	7.738	16906
1 x 10	1	0.3	3.4	1800	1.299	62.13	24.16	8.166	16310
2 x 2	1	0.3	1.7	1800	1.416	61.73	24.44	8.165	17187
2 x 2	1	0.6	1.2	1800	1.166	64.29	21.62	8.672	15545
2 x 2	1	1.2	0.8	1800	1.553	62.58	23.43	8.188	17927
1 x 2	1	0.3	0.8	1800	1.494	64.90	20.63	8.730	17134
1 x 2	1	none	?	1800	1.422	58.07	28.69	7.571	17241
1 x 2	1	0.6	0.5	1800	1.738	60.84	25.42	7.759	18288
1 x 2	1	1.2	?	6000	1.269	63.51	22.65	8.331	15822
declared value					1.18	62.17	24.41	7.99	14558

The data from the mock waste drums were also re-analyzed and is shown in Tables VII–VIII. The re-analyzed mock waste drum results from the 120–460-keV analysis are displayed in Table VII.

The re-analyzed ^{240}Pu values generally seem to fall within the range of the variable MGA results for the waste matrices. The adjustment in the ^{242}Pu correlation has produced better agreement with the MGA correlation, although there is no indication of the accuracy of either one. However, the agreement on the high-density mineral drums is less satisfactory although, again, there is no indication of which result (FRAM or MGA) is better. The re-analysis using the high-energy parameter (200-800 keV) again did not produce satisfactory results for the high-density mineral samples and the results are not shown in Table VIII.

TABLE VII. Mock Waste Drums. PNC Data reanalyzed with `mox_coax_PNC2` parameters—Analysis 120-460 keV.

Drum ID	Matrix/Shield	Pu mass (g)	Ct. Time (s)	Code	Measured Value (wt%)					
					238	239	240	241	correlation 242	Am
GFA-16	paper, .3mmPb	24.1	1800	PC/FRAM	1.184	62.58	25.82	7.283	3.139	1.870
			1000	MGA	1.200	64.60	23.96	7.000	3.240	2.430
			3000	MGA	1.180	67.04	21.87	7.050	2.860	2.390
			5000	MGA	1.190	66.63	22.17	7.090	2.930	2.400
GFC-34	metal, .3mmPb	61.6	1800	PC/FRAM	1.179	66.58	22.74	6.911	2.589	2.794
			1000	MGA	1.170	66.36	22.92	6.580	2.980	2.740
			3000	MGA	1.190	63.92	24.66	6.830	3.400	2.880
			5000	MGA	0.950	73.82	17.66	5.760	1.810	2.170
GFN-10	rubber, .3mmPb	18.9	1800	PC/FRAM	1.231	64.48	23.81	7.625	2.854	1.958
			1000	MGA	0.890	75.89	16.54	5.190	1.490	1.360
			3000	MGA	1.210	66.24	22.35	7.230	2.970	2.090
			5000	MGA	1.620	55.05	28.63	9.020	5.690	2.650
GFN-11	rubber, .3mmPb	12.1	1800	PC/FRAM	1.070	63.36	26.05	6.461	3.058	2.599
			1800	PC/FRAM	1.107	65.95	23.67	6.592	2.674	2.858
			1800	PC/FRAM	1.118	63.78	25.48	6.648	2.971	2.471
			1000	MGA	1.250	70.64	18.67	7.040	2.410	2.780
			3000	MGA	1.310	65.68	22.48	7.290	3.240	2.880
			5000	MGA	1.190	69.32	20.19	6.730	2.560	2.710
P-J-69	Hi Den Mineral		1800	PC/FRAM	0.486	72.62	22.45	3.161	1.279	2.620
			1000	MGA	0.390	82.03	14.48	2.380	0.720	2.360
			3000	MGA	0.400	79.72	16.63	2.410	0.850	2.230
			5000	MGA	0.410	78.86	17.20	2.600	0.920	2.420
P-J-70	Hi Den Mineral		1800	PC/FRAM	0.427	76.74	19.03	2.857	0.944	2.762
P-J-71	Hi Den Mineral		1800	PC/FRAM	0.554	74.21	20.99	3.061	1.192	2.954
			1000	MGA	0.370	82.67	14.19	2.100	0.670	2.500
			3000	MGA	0.320	81.15	15.92	1.910	0.700	2.450
			5000	MGA	0.330	81.04	16.01	1.910	0.720	2.470
P-J-72	Hi Den Mineral		1800	PC/FRAM	0.356	79.99	16.57	2.440	0.643	2.332
			1800	PC/FRAM	0.315	75.92	20.61	2.293	0.863	2.350
			1000	MGA	0.070	87.35	11.59	0.870	0.120	1.550
			3000	MGA	0.120	82.64	15.80	1.040	0.400	1.750
			5000	MGA	0.120	83.21	15.26	1.040	0.380	1.750

TABLE VIII. Mock Waste Drums. PNC Data reanalyzed with shield_mox_PNC4 parameters—Analysis 200–800 keV.

Drum ID	Matrix/Shield	Pu mass (g)	Ct. Time (s)	Code	Measured Value (wt%)					
					238	239	240	241	correlation 242	Am241
GFA-16	paper, 0.3mmPb	24.1	1800	PC/FRAM	1.20	64.81	24.03	7.21	2.75	2.03
			1000	MGA	1.20	64.6	23.96	7.00	3.24	2.43
			3000	MGA	1.18	67.04	21.87	7.05	2.86	2.39
			5000	MGA	1.19	66.63	22.17	7.09	2.93	2.40
GFC-34	metal, 0.3mmPb	61.6	1800	PC/FRAM	1.29	64.32	24.96	6.52	2.90	2.73
			1000	MGA	1.17	66.36	22.92	6.58	2.98	2.74
			3000	MGA	1.19	63.92	24.66	6.83	3.4	2.88
			5000	MGA	0.95	73.82	17.66	5.76	1.81	2.17
GFN-10	rubber, 0.3mmPb	18.9	1800	PC/FRAM	1.23	65.95	22.7	7.51	2.61	2.09
			1000	MGA	0.89	75.89	16.54	5.19	1.49	1.36
			3000	MGA	1.21	66.24	22.35	7.23	2.97	2.09
			5000	MGA	1.62	55.05	28.63	9.02	5.69	2.65
GFN-11	rubber, 0.3mmPb	12.1	1800	PC/FRAM	1.21	64.92	24.486	6.57	2.81	2.72
			1800	PC/FRAM	1.22	66.62	22.92	6.69	2.55	2.79
			1800	PC/FRAM	1.27	66.37	23.06	6.72	2.58	2.77
			1000	MGA	1.25	70.64	18.67	7.04	2.41	2.78
			3000	MGA	1.31	65.68	22.48	7.29	3.24	2.88
			5000	MGA	1.19	69.32	20.19	6.73	2.56	2.71

MEASUREMENT PRECISION

All data presented above have been listed without the statistical measurement uncertainties that often contribute significantly to the differences between the measured and accepted values. In Table IX, we display the statistical uncertainty expressed as percent relative standard deviation (% RSD) of a single measurement for the indicated time. This uncertainty is that calculated by the PC/FRAM software from the actual measurement data. Note that for drums lined with ≤ 0.3 mm lead, we can analyze the data in either the high-energy mode (200–800 keV) or the low-energy mode (120–460 keV). The statistical precision is better for the high-energy analysis in most cases where either high-energy or low-energy analysis can be performed. The high-density mineral is the principal exception.

The shaded area for the high density mineral indicates that this type of analysis (200–800 keV) is not recommended for these items.

TABLE IX. Measurement Precision. Plutonium 240 Precision Comparison between Low Energy (<460 keV analysis) and High Energy (200-800 keV) shielded analysis.

Shielding Study					% RSD Pu240	
					Low Energy < 460 keV)	High Energy 200-800 keV
					no Pb or light lead mox_coax_PNC2	both Pb or no Pb shield_MOX_PNC4
sample no. x mass (g)	No Meas.	Pb (mm)	ct. rate (kHz)	single meas ct. time (s)		
3 x 30	15	none	33	3600	1.7	1.5
3 x 10	1	none	11	1800	3.9	3.6
3 x 10	15	0.3	6.8	3600	4.1	2.4
3 x 10	1	0.6	6.3	1800		2.9
3 x 10	1	0.9	5	1800		3.4
3 x 10	1	1.2	3.9	1800		3.5
1 x 10	1	1.2	1.4	1800		5.8
1 x 10	1	0.6	2.3	1800		4.9
1 x 10	1	0.3	3.4	1800	7.3	4.8
2 x 2	1	0.3	1.7	1800	9.5	7.4
2 x 2	1	0.6	1.2	1800		8.3
2 x 2	1	1.2	0.8	1800		9.2
1 x 2	1	0.3	0.8	1800	19.6	13.5
1 x 2	1	none	?	1800	6.8	9.5
1 x 2	1	0.6	500	1800		12.7
1 x 2	1	1.2	?	6000		7.3
Mock Waste and High Density Mineral						
Drum ID	Matrix/Shield	Pu mass (g)	Ct. Time (s)	Code		
GFA-16	paper, .3mmPb	24.1	1800	PC/FRAM	3.7	3.7
GFC-34	metal, .3mmPb	61.6	1800	PC/FRAM	5.0	4.3
GFN-10	rubber, .3mmPb	18.9	1800	PC/FRAM	5.3	4.5
GFN-11	rubber, .3mmPb	12.1	1800	PC/FRAM	4.2	5.4
			1800	PC/FRAM	4.8	6.1
			1800	PC/FRAM	4.4	5.8
P-J-69	Hi Den Mineral		1800	PC/FRAM	14.6	63.6
P-J-70	Hi Den Mineral		1800	PC/FRAM	8.5	10.4
P-J-71	Hi Den Mineral		1800	PC/FRAM	11.6	26.5
P-J-72	Hi Den Mineral		1800	PC/FRAM	16.6	93.4
			1800	PC/FRAM	8.5	69.5

SUMMARY

We have successfully assembled, delivered, and tested three plutonium isotopic analysis systems to be used to measure lead-lined waste drums at the PNC Tokai Works. The PC/FRAM code has demonstrated its ability to analyze measurement data in situations of small sample masses, poor counting statistics and lead-lined drums.

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