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High Purity Germanium γ-PHA Assay of Uranium Storage Pigs For 321-M Facility

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ABSTRACT

The Analytical Development Section of SRTC was requested by the Facilities Disposition Division (FDD) to determine the holdup of enriched uranium in the 321-M facility as part of an overall deactivation project of the facility. The 321-M facility was used to fabricate enriched uranium fuel assemblies, lithium-aluminum target tubes, neptunium assemblies, and miscellaneous components for the production reactors. The facility also includes the 324-M storage building and the passageway connecting it to 321-M. The results of the holdup assays are essential for determining compliance with the Solid Waste's Waste Acceptance Criteria, Material Control & Accountability, and to meet criticality safety controls. This report describes and documents the use of a portable HPGe detector and EG&G Dart system that contains a high voltage power supply, signal processing electronics, a personal computer with Gamma-Vision software, and space to store and manipulate multiple 4096-channel γ-ray spectra to assay for ^{235}U content in 268 uranium shipping and storage pigs. This report includes a description of three efficiency calibration configurations and also the results of the assay. A description of the quality control checks is included as well.

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1. INTRODUCTION

The 321-M facility was used to fabricate highly enriched uranium (HEU) fuel assemblies, lithium-aluminum target tubes, neptunium assemblies, and miscellaneous components for the production reactors. The facility also includes the 324-M storage building and the passageway connecting it to 321-M. The facility operated for 25 years. During this time thousands of uranium-aluminum-alloy (U-Al) fuel tubes were produced. After the facility ceased operations in 1995 all of the easily accessible U-Al was removed from the building, and only residual amounts remained. The bulk of this residue is located in the equipment that generated and handled small U-Al particles and the exhaust systems for this equipment (e.g., Chip compactor, casting furnaces, log saw, lathes A & B, cyclone separator, Freon™ cart, riser crusher, …etc). [1] In addition to these examples there are 268 pigs that were used for storage and shipping of HEU.

Facilities Disposition Division (FDD) has requested technical assistance from the Analytical Development Section (ADS) of the Savannah River Technology Center to determine the holdup of enriched uranium in the 321-M facility as part of an overall deactivation project of the facility.[2] This project includes the dismantling and removal of all HEU to the extent practical. ADS was tasked to conduct holdup assays and waste residue assays of all components removed from the facility. The 268 uranium storage pigs were known to be nominally empty of HEU material. Each was expected to assay at or near our lower limit of detection. Since the assays are for material control and accountability as well as criticality purposes, it was important to obtain the best limit of detection possible. Determination of HEU content in each pig by a nondestructive assay (NDA) was required.

The 324-M assay station was especially suited to obtain a transmission-corrected assay of each of these fixed geometry pigs. The 324-M station was assembled for assay of HEU residue in waste scrap cans. The storage pigs are items very similar in shape and size to the scrap cans. Extension of the system to assay the pigs was an excellent use of the station's NDA capabilities. This report discusses the detector efficiency calibration and use of the portable HpGe detection system[3] to obtain an assay or limit of detection of U-235 content in each pig.

2. EXPERIMENTAL

The uranium pigs are cylindrical storage containers 15 ½ inches in depth and with an inner diameter of 6 1/4 inches. Since our portable HpGe detector is fixed on a snout of 9 9/16 inches in length with an outer diameter of 3 1/4 inches, this made for an ideal arrangement to insert the detector into the pig and to calibrate in a uniform cylinder configuration. The situation was made even more ideal by use of a flexible planar source of ^{152}Eu activity for the calibration. We have used this source (50384-147) frequently for efficiency calibration for the ^{235}U γ-ray at 185.74 KeV[4,5] because it has two intense γ-rays at 121.78 KeV and 244.69 KeV. These two γ-rays are nearly equally far in energy from 185.74 KeV and are on opposite energy sides of it. Therefore the efficiency for the ^{235}U transition can be easily interpolated from the measured efficiency of those two.

The flexible planar source had uniform total activity of 7.163×10^5 dps ^{152}Eu (dated 13 June 1995) and dimensions of 9.75 inches x 19.75 inches. This source also contained ^{137}Cs and ^{241}Am at known levels of activity near that of ^{152}Eu. By sliding it into a standard uranium pig, it made almost exactly one complete wrap around the inner circumference of the pig and very closely represented a uniform right cylinder of activity with finite height. It was not practical to release each pig by a radiation control organization (RCO) smear and count technique, but RCO was able to smear and release one item for ADS's use in the system calibration. For the calibration measurement, the detector was inserted into the pig (blue shading) to a depth of 6 13/16 inches as shown in Figure 1. As shown in Figure 1, the boundary h_1 of the planar source is 3 15/16 inches from the detector face, and the boundary h_2 is 5 13/16 inches from the opposite detector face.

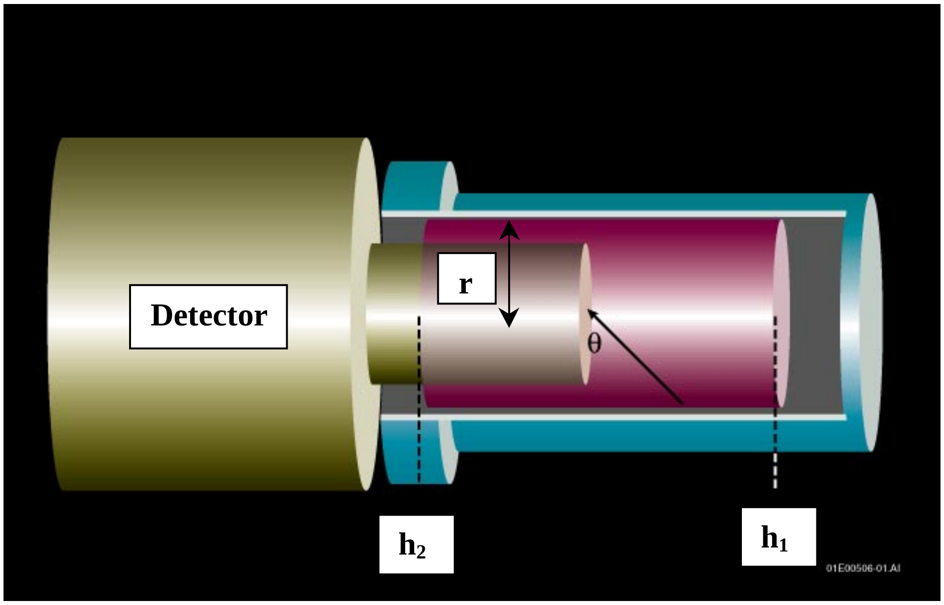

Figure 1. Drawing of the cylindrical shell acquisition as described in text.

With the detector inserted into the clean, standard pig as shown in Figure 1, we acquired a 9000-sec background spectrum without the planar source and a 200-sec active spectrum with the source. These two spectra are shown in Figures 2 and 3. The active spectrum had 60% dead-time because of the huge detection efficiency, which is exactly what we sought in this close-coupled cylindrical configuration. The data acquired for the ^{152}Eu peaks at 121.40-, 244.48-, and 344.07-KeV as well as the ^{137}Cs peak at 661.25 KeV are listed in Table 1. Table 1 includes the fitted peak areas and the decay corrected detection efficiencies for each of the four peaks. These data are recorded in reference 6.

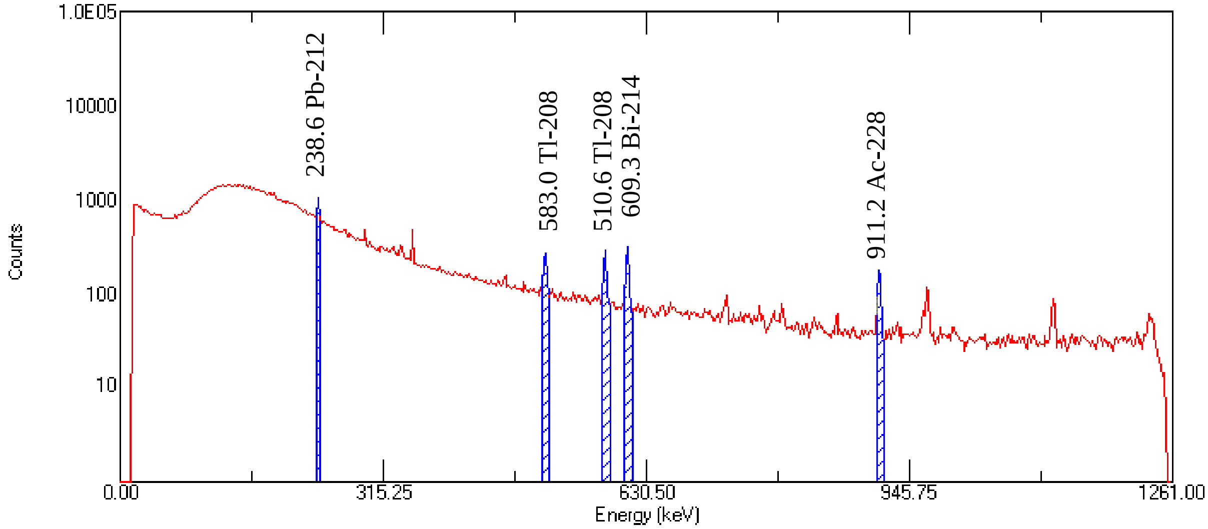

Figure 2. 313-M Background Spectrum.

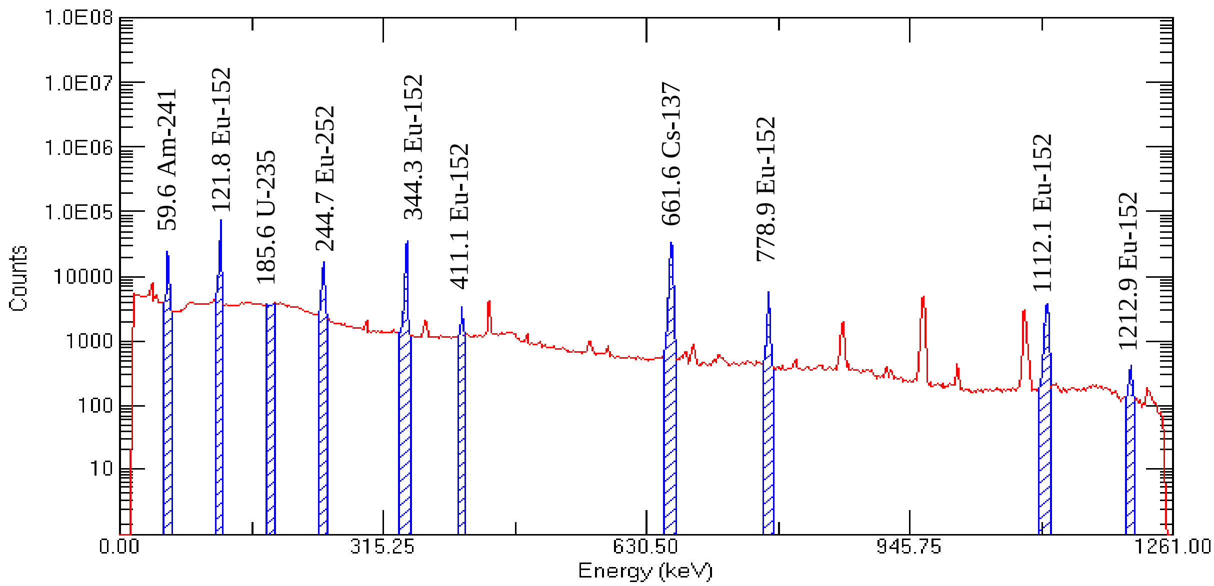

Figure 3. 313-M Efficiency Calibration Spectrum.

Note in Table 1 that we obtained very high efficiencies, near 1% for all of the γ-rays acquired. The efficiency data can be fit or interpolated with any of log-log, semi-log, or linear functions to determine the efficiency for the 186 KeV transition for ^{235}U. This yields six determinations of that efficiency which yield for us an average adopted efficiency of 0.01139±0.00022.

Table 1. Peak energies and detected areas for the cylindrical shell configuration.

Energy	Area	Cps	Branch	eff
58.89	117306±628	587±3	0.357	0.00283±1
121.40	422838±1076	2114±5	0.284	0.01339±3
244.48	83674±628	418±3	0.0751	0.01001±7
344.07	227124±689	1136±3	0.266	0.00768±2
661.25	287435±746	1437±4	0.8521	0.00434±1

From this calculated efficiency we can calculate a lower limit of detection for a uniform distribution of ^{235}U in a standard pig. We use five times the standard deviation of the background at 186 KeV. The background spectrum has a fit peak area of 873 with an uncertainty of 568, for a detection rate and uncertainty of 0.097±0.063 cps. Including efficiency and the 0.53 branching ratio, we obtain a detection limit of

$$\begin{aligned} LLD &= (5)(0.063)/(0.01139)(0.53) = 52 \text{ dps}, \\ &= 1.4\text{x}10^{-9} \text{ Ci}, \\ &= 0.0007 \text{ g } ^{235}\text{U}. \qquad (1) \end{aligned}$$

2.1 Deming Calibration and Measurement

In the event of assaying the uranium pigs, the facility RCO inspectors were unable to provide the support necessary to acquire data in the cylindrical configuration. To assay each pig by inserting the detector into it required opening the pig. Since each could not be certified free of transferable contamination, assay in the cylindrical configuration would require full and constant RCO coverage. FDD management opted to perform the assays with a reduced but best achievable efficiency.

Our previous experience with the 321-M scrap cans was to use the portable HpGe detector in the transmission-corrected far-field point source configuration and in a constant geometry-constant transmission configuration with an empirical fit to the standards' data.[3] The latter configuration required no assumptions regarding geometry. We attempted to adopt a similar approach for the uranium storage pigs.

The uranium storage pigs are 15.5 inches tall and only 6.25 inches in diameter. Each is tall and thin, appearing as much like a line as like a point. This made our point source calibration a poor approximation, and so we determined to set up another configuration in which we acquired standards' data that could be fit empirically. Each of the pigs that we intended to assay was known to be empty of material and assumed to contain very little or no ^{235}U residue. Therefore it was reasonable to assume a constant transmission correction throughout the measurements.

To obtain a constant geometry-constant transmission empirical curve we counted eight standards in the range of 0.69 g to 38.84 g of ^{235}U by successively placing each source inside the standard clean pig. It was our intention in the assays to obtain as good a sensitivity as possible yet still be able to observe the entire length of the pig in each acquisition. We determined the optimum source-to-detector distance by placing a 4.85 g standard on top of the standard pig and incremented the source-to-detector distance to obtain the highest count rate. It was our reasoning that the rate would increase with decreasing distance until the source was close enough to begin to go out of view of the detector. At the maximum count rate we assumed the optimum distance was attained. This optimum distance would also approximately yield a good line source of activity. The acquisition configuration is shown in the photograph of Figure 4.

Figure 4. Photograph of the assay configuration.

Without presenting the data for this optimization, we fixed the source-to-detector distance for counting the pigs at 25.5 inches or 64.77 cm. The data acquired for the empirical constant geometry-constant transmission curve are shown in Table 2 and are plotted in Figure 5. The measured counts per second versus standard mass are fit with the empirical quadratic curve

$$cps = 2.996\ m - 0.01992\ m^2, \qquad (2)$$

where m is the mass in grams of the standard. For each unknown pig assayed, the ^{235}U content can be obtained with an interactive fit of the measured cps onto the empirical curve. No correction of any kind is required. Our limit of detection was determined by an interactive fit of five times the standard deviation of the background count rate onto the curve. In this manner we determined an LLD of 0.055 g. For all limit of detection samples we conservatively reported < 0.1 g ^{235}U content. This limit was suitable for the customer's purpose even though a factor of 80 poorer than the best we could achieve.

Table 2. Deming pig calibration data.

U-235 Mass (g)	Cps	Uncertainty	Pig only C_f
1.01	3.50	0.13	2.89±0.14
38.84	87.33	1.36	2.97±0.15
4.85	13.71	0.31	3.55±0.14
0.92	2.56	0.11	3.60±0.19
5.91	19.30	0.46	3.07±0.12
3.24	9.12	0.19	3.56±0.14
0.69	2.30	0.10	3.01±0.16
15.66	39.26	0.81	3.48±0.18

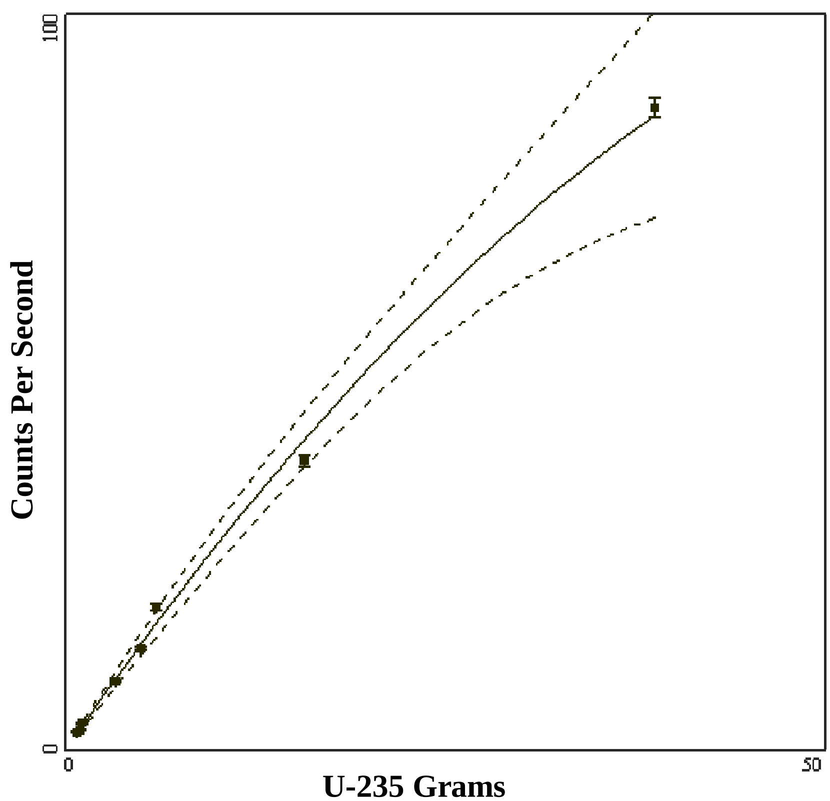

Figure 5. Deming calibration curve.

2.2 Line Source Calibration and Measurement

We were also able to calculate ^{235}U content for each measurement using the line source calibration constant derived in reference 3. As described above in the Deming calibration section, the source to detector distance was determined so that each pig would be in full view by the detector yet would be as close as possible to the detector. Thus the detector was approximately viewing the pig as if it were infinitely long. This made the counting configuration approximately representative of an infinite line source.

From the line source calibration data of reference 3 we obtained a line source constant of $1.72 \pm 0.10 \times 10^{-5}$ g-sec/cm^2. At a distance of r=25.5 inches, the effective length of view of the detector is 89.30 cm[3,6], yielding a line source calibration constant of 0.00154 ± 0.00009 g-sec/cm. From this constant the ^{235}U content in grams of each pig viewed in the approximate line source configuration described above is

$$[^{235}U] = (r)(K_l)(cps)Cf$$

$$= (25.5 \times 2.54)(0.00154)(cps)Cf \qquad (3)$$

$$= 0.0997(cps)Cf.$$

For a 1g source counted in this configuration at 25.5 inches, this corresponds to a detection rate of

$$cps = 1/(0.0997)Cf$$

$$= (10.03/Cf) = 602/Cf \text{ in units of cpm.}$$

From the QC data acquired and from the Deming data acquired we have derived a transmission correction factor of 3.27 ± 0.31 for an empty pig.[6] The transmission correction factors for the standard empty pig are listed in the last column of Table 2. Our detection efficiency is then

$$Eff = (602)/(Cf)(1.922 \times 10^{-6})(2.22 \times 10^{12})(0.53)$$

$$= 0.000081,$$

where 1.922×10^{-6} is the specific activity of U-235 in units of Ci/gram. Here the calculated efficiency is a factor of 100 less than that of the cylindrical configuration above.

Using the first background spectrum acquired (67PegBG), we are able to determine a limit of detection for ^{235}U content using the line source configuration. As above, the LLD is calculated from equation (3) using five times the uncertainty of the background detection rate.

$$\text{LLD} = (5)(\text{cps})(0.0997)\text{Cf} = (5)(0.056)(0.0997)(3.27)$$

$$= 0.092 \text{ g.} \qquad (4)$$

The fit uncertainty in background spectrum 67PegBG obtained from the MCA of the detection system is (17/300) cps. The overall sensitivity using the line source configuration is a factor of 130 poorer than the sensitivity using the cylindrical source configuration.

3. RESULTS AND DISCUSSION

Using the geometry described in the experimental section above, we have assayed 268 uranium storage pigs that were previously known to be empty of anything but residual HEU. In each acquisition the detector face of the portable detection system was fixed 25.5 inches from and approximately centered on the vertical length of the pigs. Each pig was counted for 300 seconds, and the ^{235}U content was determined using the line source calibration configuration and using the interactive fit of the empirical constant geometry-constant transmission curve of equation (2). For the line source configuration we used a constant transmission correction factor of 3.27. This factor was determined from the empirical data of Table 2.

The assays of the 268 pigs were performed at the 324-M assay station and ran over a two-month period. Quality control (QC) spectra acquired with a 4.85 g source placed inside of the standard calibration pig were acquired at the beginning and end of each assay shift. For no single pig did we observe 186 KeV γ-ray events from ^{235}U above our detection limit of 0.1 cps. In the actual acquisitions it was never necessary to perform the spreadsheet transmission corrected line source calculations to determine ^{235}U content. For every one of the 268 pigs we were able to report <0.1 g ^{235}U content from the interactive fit of equation (2).

The data and results for each acquisition are listed in the spreadsheet of Table 3. The first five columns of Table 3 contain sample identification, acquisition parameters, and measured counts. The last few columns contain the assay results from the Deming interactive fit of equation (5). Note that even for the pig with the largest count rate observed (number 2036 assayed on 15 June) the interactive yields an assay value of 0.081 g ^{235}U. Inserting the detection rate of 73 counts/300 second into equation (3) yields an assay value of 0.079 grams. We have conservatively set our limit of detection as 0.1 gram, which is the value we have reported for each pig in Table 3.

Note that throughout Table 3 we have included several QC runs that are identified with the notation *mddqc2021x* where mdd denote the month and day, and x denotes a daily run number (a,b,c). Each of these acquisitions was obtained by placing the 4.85 g calibration standard of ^{235}U (standard number 2021A) inside the standard clean pig. A QC spectrum is shown in Figure 6. The QC data acquired were evaluated with the interactive curve of equation (2) to determine ^{235}U content. While we did not make a rigorous quality control chart, these QC runs were used to demonstrate to our satisfaction that the assay system was performing properly. Note that throughout Table 3, the QC runs gave ^{235}U results in very good agreement with the required 4.85 g.

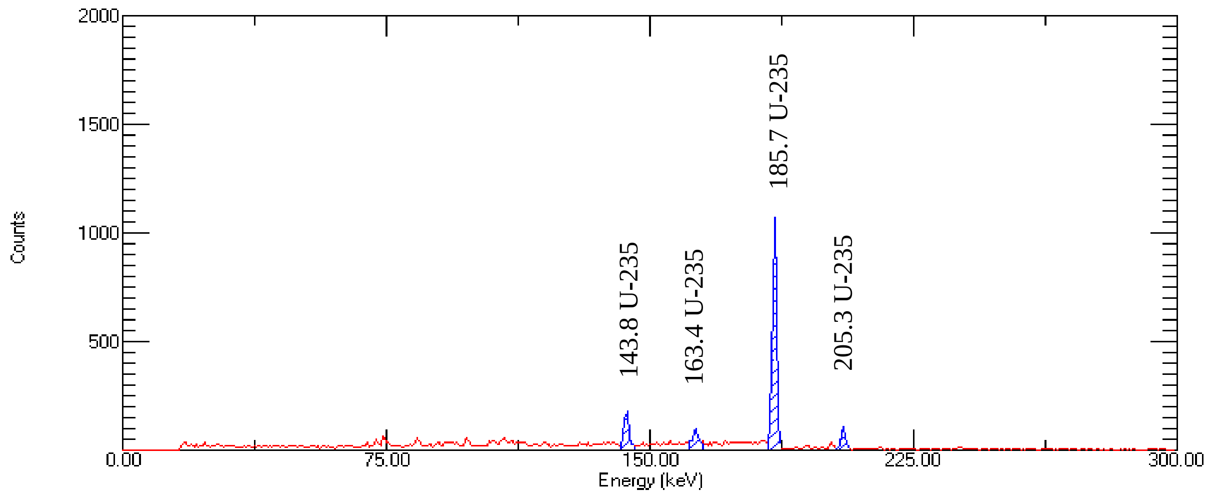

Figure 6. A spectrum showing γ-ray transitions from ^{235}U.

Note also in Table 3 that we have tabulated a detected area for the 238.6 KeV peak from ^{212}Pb. This is a naturally occurring γ-ray that appears in all of our spectra including the QC spectra. Since all of our pig sample spectra were very clean of sample γ-ray transitions, it was difficult to gain confidence during the course of a day of acquisitions that the system was running properly. To avoid very frequent QC runs, we determined that monitoring the naturally occurring ^{212}Pb transition would be a good way to monitor the performance of our detection system. In the last two columns of Table 3 we began to record the measured area and uncertainty in the 238.6 KeV γ-ray. Note this peak appears with an intensity of about 0.09 cps and is completely independent of sample activity. Using this technique we obtained additional QC data with every acquisition. Blank elements in this column of Table 3 represent points where these data were not recorded.

4. CONCLUSION

Using a portable HpGe detector with an EG&G Dart electronics package and an Ortec Gamma-Vision acquisition system, we have performed an efficiency calibration in a uniform cylinder configuration in order to assay cylindrical uranium storage pigs for the 321-M deactivation and decontamination project. With this configuration we were able to obtain a sensitivity of 0.0007 g ^{235}U in the storage pigs. This capability exceeded the customer's requirements by over two orders of magnitude and provided a third method of determination of ^{235}U content for each item counted. We have also used a line source calibration constant determined previously with 3% precision to assay the pigs. The line source constant used was $1.72\pm0.06 \times 10^{-5}$ g-sec/cm^2. In these assays we have performed a traditional transmission correction using a 4.85 g source of ^{235}U placed behind the samples with respect to the detector field of view.

Using the same detection system, we have derived a constant-geometry, constant-transmission calibration curve for assay of the 321-M storage pigs. The calibration curve obtained from eight standards assayed from a distance of 25.5" yielded an empirical least-squares-curve that we fit with a two-parameter quadratic function using Deming software. Thus for every pig assayed we were able to obtain two assay values. The measured values along with the transmission correction factor were obtained with an Excel spreadsheet calculation and with an interactive fit of the measured count rate of the 185-KeV γ-ray onto the empirical quadratic function. For each data acquisition we were able to produce an on-the-spot assay by two techniques and an on-the-spot calculation of the observed transmission correction value for each of the 268 pigs.

5. REFERENCES

1. D. L. Honkonen, "Nuclear Criticality Safety Evaluation (NCSE): Enriched Uranium Removal From Building 321-M N-NCS-G-00051, February 2000.

2. Deactivation Project Plan 321-M Fuel Fabrication Facility, V-PMP-M-00004, January 2000.

3. S. R. Salaymeh and R. A. Dewberry, "HPGe Detector Efficiency Calibration Using HEU Standards," WSRC-TR-2000-00317, September 2000.

4. R. A. Dewberry, S. R. Salaymeh, and F. S. Moore "Confirmatory Gamma-PHA Assays of SRS Uranium Production Facility High Density Solid Waste", WSRC-MS-99-00320, 4th Annual Conference on Industrial Radiation and Radioisotope Measurement Applications, Raleigh, NC, October 1999.

5. R. A. Dewberry and S. R. Salaymeh, "U-235 Holdup Measurements of Mixed Waste at SRS," WSRC-TR-99-00396, October 1999.

6. R. A. Dewberry, Laboratory Notebook WSRC-NB-2000-00086, pg 10 – 24.

Table 3. Assay results for 268 pigs and for multiple quality control acquisitions.

Date	Pig Number	t_C = CT (sec) Peg	C_C = counts	σ_C = count error Peg	Deming ^{235}U (grams)	Deming σ	238.6 KeV Area	σ
5/3/00	peg1840	600	12	10	0.06	0.01		
6/6/00	2461	300	30	16				
6/6/00	2073	300	3	17				
6/6/00	1798	300	25	14				
6/6/00	1700	300	45	16				
6/6/00	2081	300	4	16				
6/6/00	2322	300	-15	18				
6/6/00	1625	300	46	16				
6/6/00	2248	300	16	16				
6/7/00	67QC2021	300	4280	71	4.87	0.55	49	17
6/7/00	67PegBG	300	43	17				
6/7/00	2589	300	56	16				
6/7/00	2469	300	20	18				
6/7/00	2099	300	43	16			52	17
6/8/00	Peg68BG	300	38	16				
6/8/00	68QC2021	300	4128	71	4.74	0.54	61	16
6/8/00	1840	300	57	17				
6/8/00	1649	300	38	19				
6/8/00	1759	300	37	17				
6/8/00	1850	300	43	18				
6/8/00	1795	300	38	17				
6/8/00	2495	300	11	16				
6/8/00	1525	300	21	17				
6/8/00	2064	300	49	16				
6/8/00	2250	300	29	16				
6/8/00	2038	300	11	17				
6/8/00	1855	300	14	19				
6/8/00	68QC2021a	300	4223	72	4.86	0.55	44	16
6/8/00	1833	300	47	19				
6/8/00	1695	7200	1610	93	0.07	0.01		
6/8/00	2229	300	14	17				
6/8/00	1695a	300	2	18				
6/8/00	2293	300	19	18				
6/8/00	1818	300	40	16				
6/8/00	1909	300	17	16				
6/8/00	2175	300	0	17				
6/8/00	1791	300	34	17				
6/8/00	2301	300	40	17				
6/8/00	2359	300	17	17				
6/8/00	1921	300	22	16				

Table 3. (Continued)

Date	Pig Number	t_C = CT (sec) Peg	C_C = counts	σ_C = count error Peg	Deming ^{235}U (grams)	Deming σ	238.6 KeV Area	σ
6/8/00	2278	300	5	16				
6/8/00	2522	300	-20	17				
6/8/00	2039	300	12	15				
6/8/00	1872	300	18	16				
6/8/00	68QC2021b	300	4304	72	4.95	0.56	60	17
6/8/00	Peg68BGa	300	-17	19				
6/13/00	613pegBG	300	18	29				
6/13/00	613qc2021	300	4308	71	4.96	0.56	53	15
6/13/00	Peg1851	300	37	14				
6/13/00	peg2056	300	24	17				
6/13/00	peg1879	300	4	18				
6/13/00	peg2260	300	18	17				
6/13/00	peg2354	300	17	17				
6/13/00	peg2369	300	16	16				
6/13/00	peg1858	300	9	18				
6/13/00	peg2276	300	-2	14				
6/13/00	peg1800	300	44	15				
6/13/00	peg2194	300	18	15				
6/13/00	peg1794	300	45	15				
6/13/00	peg2220	300	20	17				
6/13/00	peg1771	300	22	16				
6/13/00	peg1722	300	10	16				
6/13/00	613qc2021b	300	4161	71	4.78	0.54	59	16
6/13/00	peg1680	300	19	17				
6/13/00	peg1560	300	-2	17				
6/13/00	peg1823	300	23	16				
6/13/00	peg2311	300	32	16				
6/13/00	peg2207	300	24	15				
6/13/00	peg2340	300	32	11				
6/13/00	peg1871	300	27	16				
6/13/00	peg1654	300	30	15				
6/13/00	peg2234	300	34	15				
6/13/00	peg2040	300	26	15				
6/13/00	peg1799	300	-8	17				
6/13/00	peg1618	300	12	16				
6/13/00	peg1725	300	-25	17				
6/13/00	peg1878	300	28	15				
6/13/00	613qc2021c	300	4265	73	4.91	0.56	42	17
6/14/00	614QC2021	1200	15728	139	4.51	0.51	140	34
6/14/00	614pegBG	300	53	15			55	16
6/14/00	peg2449	300	22	17			31	16

Table 3. (Continued)

Date	Pig Number	t_C = CT (sec) Peg	C_C = counts	σ_C = count error Peg	Deming ^{235}U (grams)	Deming σ	238.6 KeV Area	σ
6/14/00	peg2522	300	33	15			52	16
6/14/00	peg1826	300	24	16			27	15
6/14/00	peg1658	300	27	16			60	15
6/14/00	peg1616	300	43	14			9	16
6/14/00	peg2224	300	19	16				
6/14/00	peg1506	300	13	16				
6/14/00	peg2080	300	-15	18				
6/14/00	peg1835	300	22	15				
6/14/00	peg1924	300	53	16				
6/14/00	peg1845	300	25	18				
6/14/00	peg1619	300	15	17				
6/14/00	peg2204	300	17	17				
6/14/00	peg2258	300	14	15				
6/14/00	peg1861	300	50	17				
6/14/00	peg1874	300	46	14				
6/14/00	peg1507	300	18	17				
6/14/00	peg2035	300	16	18				
6/14/00	peg1765	300	42	15				
6/14/00	peg2255	300	5	18				
6/14/00	peg2072	300	16	18				
6/14/00	peg1710	300	31	17				
6/14/00	peg1535	300	8	16				
6/14/00	614QC2021b	300	4203	72	4.83	0.55	53	16
6/15/00	615pegBG	300	60	15				
6/15/00	615QC2021a	300	4206	71	4.84	0.55	41	17
6/15/00	peg2036	300	73	14				
6/15/00	peg1514	300	41	16				
6/15/00	peg1667	300	35	16				
6/15/00	peg1664	300	41	16				
6/15/00	peg2002	300	59	14				
6/15/00	peg1804	300	22	17				
6/15/00	peg1873	300	-16	18				
6/15/00	peg2093	300	17	17				
6/15/00	peg1830	300	12	17				
6/15/00	peg1808	300	33	18				
6/15/00	peg1740	300	12	17				
6/15/00	peg2163	300	40	16				
6/15/00	peg2086	300	43	17				
6/15/00	peg2401	300	11	15				
6/15/00	peg1783	300	15	16				
6/15/00	peg2518	300	32	17				

Table 3. (Continued)

Date	Pig Number	t_C = CT (sec) Peg	C_C = counts	σ_C = count error Peg	Deming ^{235}U (grams)	Deming σ	238.6 KeV Area	σ
6/15/00	peg2029	300	13	16				
6/15/00	peg2052	300	23	17				
6/15/00	peg2519	300	19	17				
6/15/00	peg2112	300	42	15				
6/15/00	peg1831	300	-12	17				
6/15/00	peg1645	300	7	16				
6/15/00	peg2096	300	19	17				
6/15/00	615qc2021b	300	3955	70	4.51	0.51		
6/21/00	621pegBG	300	6	16			28	14
6/21/00	621qc2021	300	4247	71	4.88	0.55	46	18
6/21/00	peg2109	300	11	16			50	16
6/21/00	peg2367	300	52	16			29	17
6/21/00	peg2186	300	14	16			42	16
6/21/00	peg2235	300	13	15			12	17
6/21/00	peg2235A	300	13	17			64	15
6/21/00	peg1699	300	16	16			50	16
6/21/00	peg1712	300	35	16			48	15
6/21/00	peg2213	300	18	16			58	16
6/21/00	peg1954	300	20	28			29	15
6/21/00	peg1796	300	32	15			27	16
6/21/00	peg1524	300	38	15			58	16
6/21/00	peg1715	300	23	16			33	17
6/21/00	peg2585	300	27	16			41	16
6/21/00	peg1526	300	1	17			31	17
6/21/00	peg2078	300	12	16			-8	18
6/21/00	621qc2021a	300	4331	72	4.97	0.56	18	17
6/21/00	peg1917	300	13	17			12	17
6/21/00	peg2212	300	2	17			43	15
6/21/00	peg2583	300	46	17			52	14
6/21/00	peg2076	300	40	15			52	16
6/21/00	peg12-2426	300	-9	17			41	15
6/21/00	peg2605	300	11	15			61	13
6/21/00	peg2453	300	64	14			25	14
6/21/00	621qc2021b	300	4203	71	4.83	0.56	19	16
6/21/00	621pegBG1	3600	287	56			532	55
6/21/00	peg2006	300	18	16			38	15
6/21/00	peg1814	300	17	17			36	16
6/21/00	peg1741	300	31	16			38	16
6/21/00	peg2292	300	23	17			51	18
6/21/00	peg2270	300	10	16			36	15
6/21/00	peg1757	300	8	17			44	15
6/21/00	peg1545	300	-39	17			27	16

Table 3. (Continued)

Date	Pig Number	t_C = CT (sec) Peg	C_C = counts	σ_C = count error Peg	Deming ^{235}U (grams)	Deming σ	238.6 KeV Area	σ
6/21/00	peg1598	300	-4	18			38	15
6/21/00	peg1671	300	4	16			87	15
6/21/00	621qc2021c	111	1623	44	5.05	0.57	18	9
6/21/00	peg1784	300	-5	18			29	16
6/21/00	peg2024	300	22	16			89	14
6/21/00	peg2373	300	3	18			46	14
6/21/00	peg1876	300	25	15			51	15
6/21/00	peg1949	300	2	16			58	16
6/21/00	621qc2021d	300	4324	72	4.97	0.56	35	17
6/27/00	621pegBG2	300	35	16			27	17
6/27/00	627qc2021a	300	4228	71	4.86	0.55		
6/27/00	627pegBG1	300	-9	17				
6/27/00	peg1558	300	-8	17				
6/27/00	peg1512	300	-10	17				
6/27/00	peg1834	300	30	15			53	15
6/27/00	peg1927	300	26	16			48	17
6/27/00	peg2287	300	16	17			39	17
6/27/00	peg2409	300	19	16			37	16
6/27/00	peg2245	300	-5	17			30	16
6/27/00	peg1519	300	18	15			58	16
6/27/00	peg1829	300	16	16			51	14
6/27/00	peg2157	300	-3	16			87	15
6/27/00	peg2438	300	-6	18			8	16
6/27/00	peg2587	300	30	15			56	15
6/27/00	peg1748	300	16	17			62	14
6/27/00	peg1910	300	-12	18			65	16
6/27/00	peg2216	300	25	16			38	15
6/27/00	peg2307	300	6	16			20	18
6/27/00	627qc2021b	300	4201	72			68	16
6/27/00	627pegBG2	300	4	16			58	15
6/28/00	628qc2021	300	4382	72	5.05	0.57	62	18
6/28/00	628bg1	300	34	16			27	17
6/28/00	peg2300	300	7	17			48	14
6/28/00	peg1737	300	27	15			39	15
6/28/00	peg2483	300	25	16			44	15
6/28/00	peg2198	300	1	18			61	15
6/28/00	peg2291	300	13	16			71	16
6/28/00	peg1738	300	0	15			41	16
6/28/00	peg2511	300	-19	19			31	16
6/28/00	peg1565	300	-6	16			29	16
6/28/00	peg2297	300	54	16			43	15
6/28/00	peg1756	300	12	16			51	16

Table 3. (Continued)

Date	Pig Number	t_C = CT (sec) Peg	C_C = counts	σ_C = count error Peg	Deming ^{235}U (grams)	Deming σ	238.6 KeV Area	σ
6/28/00	peg2059	300	26	17			59	16
6/28/00	peg1908	300	49	15			48	14
6/28/00	peg1711	300	-3	18			52	17
6/28/00	peg1717	300	10	16			12	17
6/28/00	peg1866	300	0	16			42	17
6/28/00	peg1706	300	38	16			11	16
6/28/00	peg2171	300	-19	18			55	16
6/28/00	peg2114	300	52	16			47	15
6/28/00	peg0440	300	0	17			74	15
6/28/00	peg2078	300	33	15			64	16
6/28/00	628qc2021a	300	4206	71	4.84	0.55	36	15
6/28/00	628bg2	7200	360	82			1019	80
6/28/00	628qc2021b	308	4215	71	4.72	0.54	44	17
6/28/00	peg2033	300	1	17			45	14
6/28/00	peg2072	300	14	16			36	16
6/28/00	peg1768	300	48	16			20	15
6/28/00	peg2386	300	6	18			26	15
6/28/00	peg1542	300	3	16			29	17
6/28/00	peg1753	300	23	15			29	18
6/28/00	peg2075	300	31	15			30	15
6/28/00	peg1651	300	2	17			38	16
6/28/00	peg2347	300	30	15			31	16
6/28/00	peg1633	300	53	14			33	16
6/28/00	peg1755	300	6	16			16	17
6/28/00	peg2032	300	32	16			39	15
6/28/00	peg1839	300	31	16			32	14
6/28/00	peg2722	300	9	17			56	15
6/28/00	peg1694	300	4	17			43	15
6/28/00	peg1950	300	9	16			29	16
6/28/00	628qc2021c	300	4034	71	4.63	0.52	72	16
6/29/00	629qc2021	300	4274	71	4.93	0.55	30	18
6/29/00	peg2023	300	20	17			46	15
6/29/00	peg1906	300	43	15			33	16
6/29/00	peg1721	300	13	16			38	17
6/29/00	peg2252	300	46	15			29	15
6/29/00	peg1843	300	44	17			22	16
6/29/00	peg2201	300	15	17			52	15
6/29/00	peg1847	300	5	17			36	17
6/29/00	peg2037	300	23	16			64	15
6/29/00	629qc2021a	300	4088	71	4.7	0.53	35	17
6/29/00	629bkg	2800	229	50			407	50
6/29/00	629qc2021b	300	3941	71	4.51	0.52	59	18

Table 3. (Continued)

Date	Pig Number	t_C = CT (sec) Peg	C_C = counts	σ_C = count error Peg	Deming ^{235}U (grams)	Deming σ	238.6 KeV Area	σ
6/29/00	peg1841	300	19	18			35	16
6/29/00	peg2417	300	22	15			27	17
6/29/00	peg1802	300	18	16			34	16
6/29/00	peg2404	300	31	15			40	15
6/29/00	peg2254	300	6	17			38	16
6/29/00	peg1578	300	24	16			30	16
6/29/00	peg1854	300	-3	17			26	15
6/29/00	peg1816	300	26	17			43	16
6/29/00	peg2254a	300	10	17			72	14
6/29/00	peg2187	300	25	16			36	16
6/29/00	peg1787	300	15	16			50	15
6/29/00	peg2514	300	40	16			33	17
6/29/00	peg2400	2800	229	50			407	55
6/29/00	629qc2021c	300	4320	73	4.97	0.56	36	17