Integration of AEGIS™ & Figure of Merit Evaluations of Calculated Efficiencies on the Mobile ISOCS™ Large Container Counter at TA-54 Los Alamos, NM - 24285

Kevin. Haar[1], Joe Harvill[1], Robert Semon[1], M. Collins[2], M. Garcia[2], Taylor Kurtz[2], W. Mussman[2], S. Price, T. Roupp[2], S. Stanfield[2], and Jenna Lente[1]
[1] Salado Isolation Mining Contractors
[2]Mirion Technologies (CANBERRA) Inc.

ABSTRACT

The classification of transuranic (TRU) waste can be challenging depending upon the type of waste matrix. At Los Alamos National Laboratory in NM, legacy TRU waste from the nuclear weapons program is still located at TA-54. Cleanup of this waste is managed by Newport News Nuclear BWXT Los Alamos (N3B), the Management and Operating (M&O) contractor selected by the Department of Energy (DOE). As part of the closure mission, several objects requiring disposal are non-standard waste items. These non-standard waste items include the Bolas Grande from the Confinement Vessel Disposition (CVD) project and Standard Large Boxes (SLB-2s) containing gloveboxes. New analysis techniques needed to be implemented and validated to measure these types of containers.

To measure these difficult matrices, calculated efficiencies applying gamma spectroscopy were required. To apply the calculated efficiencies, a new technique was required to validate the efficiencies modeled for these objects. An approach based on an In-Situ Object Counting Software™ (ISOCS™) Figure of Merit (FOM), which describes the validity of the efficiency curve used to quantify gamma spectroscopy data, was used to validate the efficiencies and measurements. The FOM approach was validated and approved at the Idaho National Laboratory (INL) Site previously and a similar process was adapted at LANL.

During the process, the system was also upgraded to Mirion AEGIS™ detectors as part of the plan to upgrade equipment across the complex initiated by Salado Isolation Mining Contractors, LLC (SIMCO), the M&O contractor for the Waste Isolation Pilot Plant (WIPP). These units have several newly integrated technologies that will improve reliability and overall performance of the system. Due to the upgrade of the system to AEGIS™ units, the NDA 2000™ software currently used on the systems was upgraded as well during this process.

Celebrating 25 years of operations at the speed of safety, WIPP continues to be the cornerstone for DOE's nuclear waste cleanup efforts, removing legacy TRU waste at 22 sites while reducing risk for Americans living near these sites, now and into the future.

INTRODUCTION

A wide array of waste containers must be processed to support the efforts of Los Alamos National Laboratory (LANL) to dispose legacy and production waste streams. Traditionally, a source matrix is used to calibrate counting equipment for each container configuration. This works well for standardized, repeatable container configurations. However, as facility overhauling at TA-55 and cleanup efforts at TA-54 continue, more and more containers will be packaged in non-standard configurations. Making a source container for each configuration quickly becomes cost prohibitive and impractical. To assist in these efforts, the FOM approach was adapted to validate data obtained from these unique containers. In doing so, a case-by-case calibration of each container is obtained, eliminating the need for the unique sources by modeling the packing containers and internal waste configurations on an individual basis. This will allow for a larger variety of containers to be assayed while minimizing resources needed to process these waste streams.

The Mobile ISOCS™ Large Container Counter #1 (MILCC1) is the first unit to implement AEGIS™ detectors for use by the Central Characterization Program (CCP) to conduct non-destructive assay (NDA) of transuranic (TRU) waste. Several factors went into the decision to upgrade the unit to AEGIS™ detectors. Some of these benefits include having a built-in battery backup, use of a thermal cycle-free and liquid nitrogen-free cryostat, self-maintaining vacuum, and an IP-65 rating. The aged detectors the AEGIS™ units replaced were reaching the end of their useful life. Because of the advantages the AEGIS™ detectors presented and the typical environmental conditions of the MILCC1 dome, it was decided to upgrade the failing units to the advanced and ruggedized AEGIS™ detectors. The increased resiliency of the detectors should reduce environmental effects and promote continuous operations.

OVERVIEW OF NDA METHODS

The LANL MILCC1 acquires and analyzes data collected by the germanium detectors. The gamma detectors are mounted on hydraulic carts. There is a detector on either side of the waste item, and both the height and distance of the carts are adjusted as needed. Both detectors are collimated and have a tin-copper filter on each detector face.

High-purity germanium detectors are sensitive to environmental conditions. Ideally, these detectors are operated in a climate-controlled environment to minimize the impacts of temperature and humidity changes. The IP-65 rating of AEGIS™ will limit this effect and help protect against adverse weather conditions. The detectors also have integrated hot-swappable lithium-iron-phosphate internal batteries. The batteries can be charged externally, allowing spares to be switched out with depleted batteries to continue operations if power is interrupted at the MILCC1 dome. The detectors that were replaced required liquid nitrogen to be refilled twice a week. The AEGIS™ detectors utilize a sterling motor cryo-cooler to achieve the crystal's rated operating temperature, eliminating the need for liquid nitrogen, and the logistics issues associated with supplying and maintaining dewars filled. The thermal-cycle free cryostat allows the detectors to be immediately cooled if an extended loss of power occurs. It is no longer required to fully warm up the detectors before beginning to cool down again—just start the cooler whenever it is desired, and the detector can be restored back to operation quickly. Another integrated technology allows field operators to maintain vacuum in the detector by operating an ion pump. The ion pump removes molecular impurities in the detector to maintain better vacuum longer and can be done locally within Genie 2000™.

Figure 1. MILCC1 at LANL, two AEGIS™ detectors on carts, with rotator in the middle.

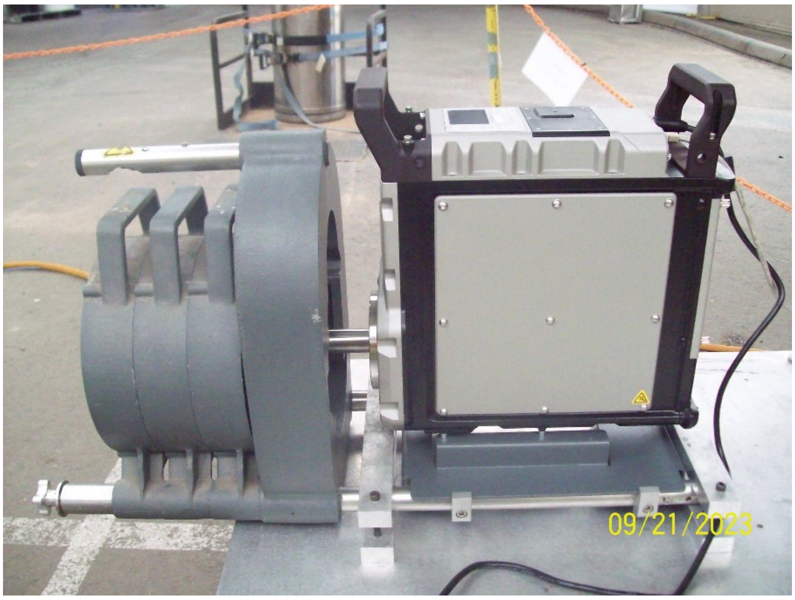

Figure 2. Close-up view of an AEGIS^{TM} unit in its ISOCS^{TM} enclosure.

ISOCS^{TM}/FOM LACE

Traditionally during analysis, the applied gamma efficiency is calculated by the multi-curve engine in the NDA 2000^{TM} software to produce assay results. This requires measurement of representative containers with waste matrices of varying densities to empirically determine efficiency curves spanning the expected waste stream. However, sometimes traditional density-based calibrations are not reasonable.

In such cases, gamma efficiency curves can be developed based on representative geometric modeling of the counting configuration utilizing Mirion's In-Situ Object Counting Software (ISOCS^{TM}). This takes into account many aspects of measurement geometry (detector-source configuration, collimators, filters, detector types, etc.) and is facilitated by the graphical user interface, Geometry Composer^{TM}. The generated efficiency curve is then applied to the acquired spectra to produce assay results. Because the measurement geometry can be adjusted in the ISOCS^{TM} model, users are afforded a high degree of configuration ability when measuring more complex waste items.

Validation of the ISOCS^{TM} modeling efficiency results can be achieved by utilizing a FOM check. The primary FOM utilized on the MILCC1 system is the Line Activity Consistency Evaluation (LACE). LACE functions based on the principal that for a given radionuclide with multiple energy lines, the activity at each energy line should be equal. Therefore, if this holds true when an ISOCS^{TM} based efficiency curve is applied to a spectrum, the ISOCS^{TM} model is a valid representation of the counting configuration used.

The LACE software aids in the evaluation of this criteria by calculating and plotting relative line activity vs. energy for each radionuclide with multiple energy lines. Pass/Fail criteria are based on the slope and linearity of the weighted best fit to the plotted data. Additionally, the fitting can be assessed to iteratively improve the ISOCS^{TM} model. Ideally, this evaluation should be done using the most prominent energy lines for selected radionuclides with good counting statistics.

When the efficiency curve is accurate the overall shape of the curve is flat and close to linear, indicating that the ISOCS^{TM} model is valid. The image below shows a valid LACE, in which the efficiencies vary by less than 15% [Figure 3].

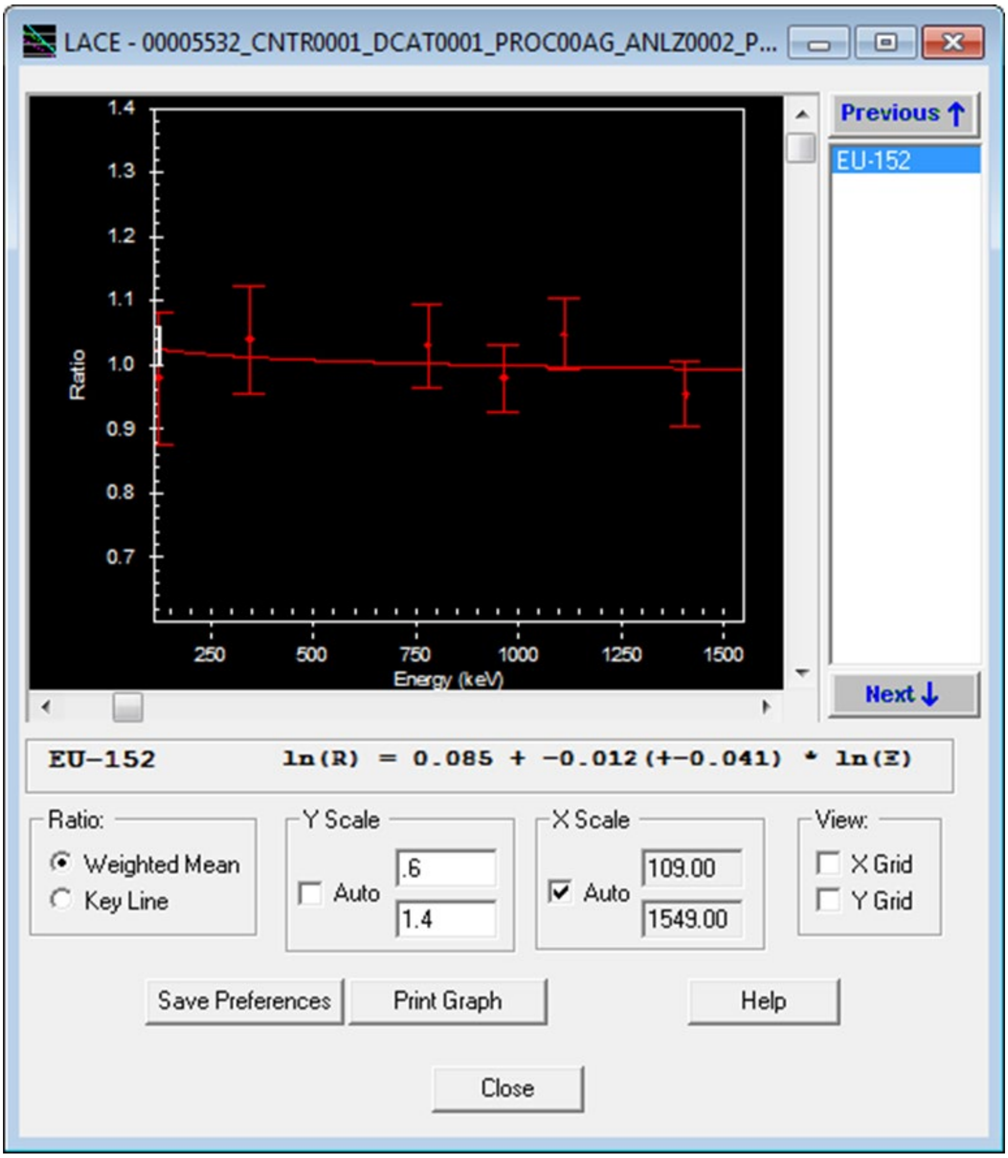

Figure 3. Example LACE curve for Eu-152 line sources in a Homasote matrix 55-gallon drum, with a matrix density of 0.55 g/cc.

When the efficiency curve is not accurate due to errors in the ISOCS™ model, the LACE curve will be affected. In Figure 4 the overall slope of the LACE curve is not flat, and the fit shows excessive curvature at the lower energies. This is a result of an incorrect efficiency calibration generated by ISOCS™ based on an incorrect matrix density.

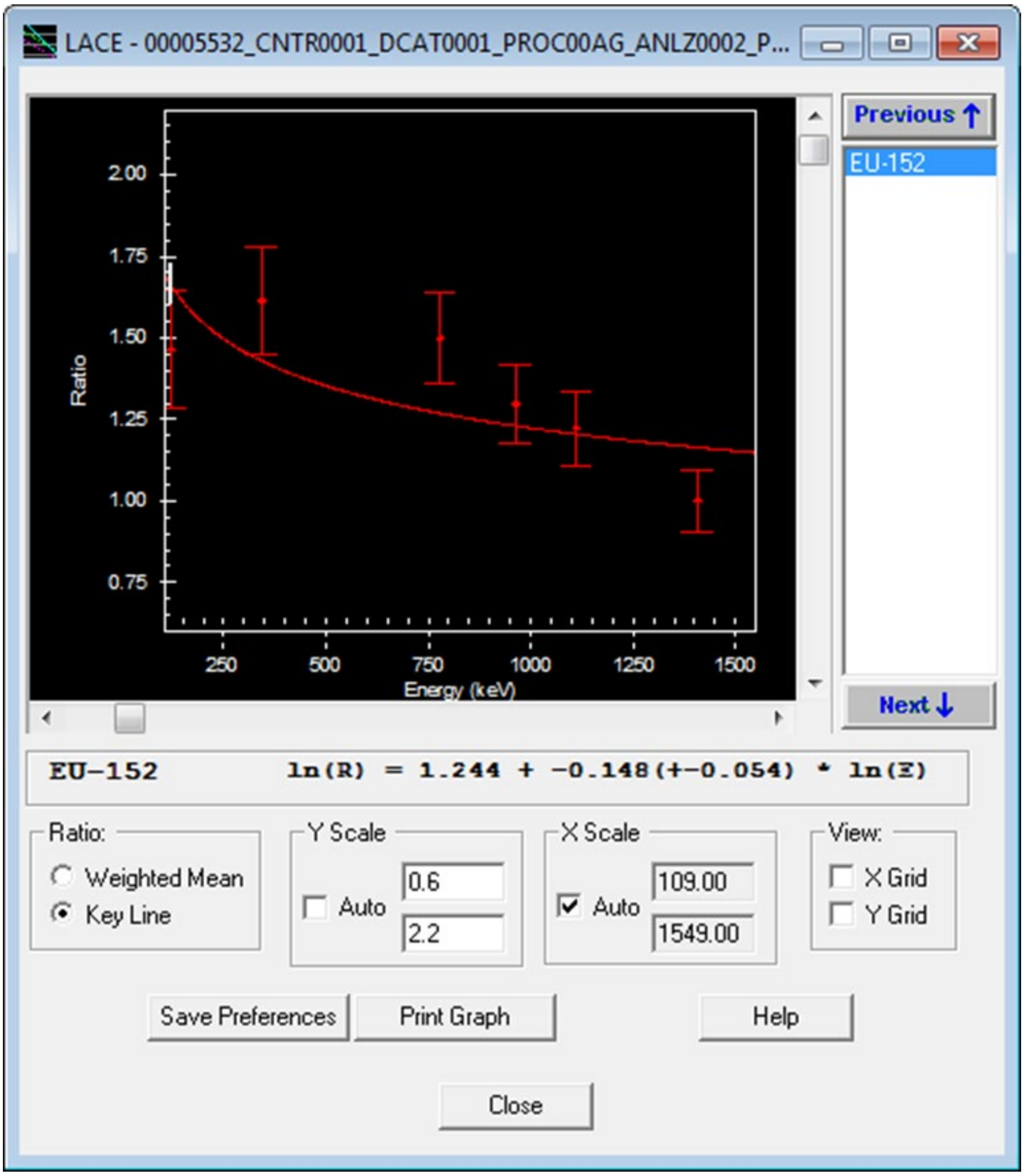

Figure 4. Example LACE curve for Eu-152 line sources in a Homasote matrix 55-gallon drum, with an incorrect matrix density of 0.65 g/cc.

VALIDATION OF FOM AND AEGIS™

In order to verify if FOM can consistently validate the generated ISOCS™ calibrations, measurements using known sources are required. Tests conducted adhering to program standards were performed for this validation.

FOM EVALUATIONS

Testing containers loaded with various National Institute of Standards and Technology (NIST) traceable sources were assayed to confirm the implementation of the ISOCS™ Calibration Software via the generated efficiencies. The Figure of Merit used to determine performance effectiveness was slope variation of the LACE curve. If the slope variation was less than 15% then this would be a success criterion of the ISOCS™ implementation [2]. Other success criteria are defined through accuracy and precision. Each emission line used to quantify activity must obey a recovery of 100% ± 10% for accuracy. Precision results for three replicate scans must not exceed 6.6% relative standard deviation, %RSD [1]. Each test adhered to a standard operating practice: 42" detector standoff from surface of container for each detector, both detectors aimed at the center of the container, 180° collimator used on each detector, three replicate measurements, each detector 37" from the ground in height, and the assay time being a total of 1800 seconds [3].

The following initial experiments were completed for LACE FOM verification with data tables and figures shown below:

- Q^2 55-gallon container filled with Homasote loaded with Am-241/Eu-152 sources [Table 1] in positions 2, 3, 4, 5, 6, and 9 [Figure 5], respectively.
- Q^2 55-gallon container filled with particle board loaded with Am-241/Eu-152 sources [Table 1] in positions 2, 3, 4, 5, 6, and 9 [Figure 5], respectively.
- Test SWB filled with cardboard loaded with Am-241/Eu-152 sources [Table 4] in positions O, P, I, J, N, and K [Figure 6], respectively.

Table 1. Line Sources Used in Q^2 Calibration Drum Measurements

Source ID (S/N)	Nuclide	Half Life (y)	Activity (□Ci)	Activity Ref. Date
M5-160	^{241}Am ^{152}Eu	432.7 □ 0.5 13.33 □ 0.04	10.95 □ 3.0% 10.97 □ 3.0%	6/1/2015
M5-161	^{241}Am ^{152}Eu	432.7 □ 0.5 13.33 □ 0.04	11.02 □ 3.0% 11.04 □ 3.0%	6/1/2015
M5-162	^{241}Am ^{152}Eu	432.7 □ 0.5 13.33 □ 0.04	11.03 □ 3.0% 11.04 □ 3.0%	6/1/2015
M5-163	^{241}Am ^{152}Eu	432.7 □ 0.5 13.33 □ 0.04	11.05 □ 3.0% 11.07 □ 3.0%	6/1/2015
M5-164	^{241}Am ^{152}Eu	432.7 □ 0.5 13.33 □ 0.04	11.07 □ 3.0% 11.09 □ 3.0%	6/1/2015
M5-165	^{241}Am ^{152}Eu	432.7 □ 0.5 13.33 □ 0.04	11.08 □ 3.0% 11.10 □ 3.0%	6/1/2015

Note: From Reference [2]

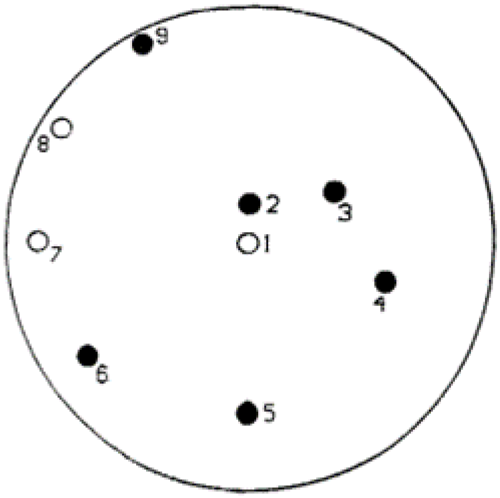

Figure 5. Top view of a Q^2 Calibration Drum depicting the positions of the line sources for the Homasote and particle board matrix drums.

Table 2. Q^2 Homasote Drum Assay Results

Nominal 66 µCi Eu-152 Reference Source								
Sequence #	**Activities at Each Energy Line (µCi)**						**Wt Mean (µCi)**	**LACE FOM (<15%)**
	121.8 keV	**344.3 keV**	**778.9 keV**	**964.1 keV**	**1112.1 keV**	**1408.0 keV**		
5532	61.89	67.55	66.20	62.78	67.02	60.87	63.94	1.88%
5533	62.00	67.41	66.58	64.00	66.83	59.53	63.59	3.02%
5534	62.50	68.13	64.73	64.52	63.37	61.06	63.30	3.84%
Average:	62.13	67.70	65.84	63.77	65.74	60.49	63.61	2.91%
Std Dev:	0.33	0.38	0.98	0.89	2.05	0.83	0.32	0.98%
%R:	93.70%	102.09%	99.29%	96.16%	99.14%	91.22%	95.93%	n/a
%RSD:	0.52%	0.56%	1.49%	1.40%	3.12%	1.38%	0.50%	n/a
Z-Test:	1.12	0.34	0.06	0.34	0.03	0.82	0.73	n/a

Note: From Reference [2]

Table 3. Q^2 Particle Board Drum Assay Results

Nominal 66 µCi Eu-152 Reference Source								
Sequence #	**Activities at Each Energy Line (µCi)**						**Wt Mean (µCi)**	**LACE FOM (<15%)**
	121.8 keV	**344.3 keV**	**778.9 keV**	**964.1 keV**	**1112.1 keV**	**1408.0 keV**		
5535	66.42	65.44	63.95	62.42	64.61	60.95	63.15	5.32%
5536	66.08	65.64	64.67	65.04	62.52	61.50	63.51	5.16%
5537	65.29	65.51	65.77	63.44	65.49	61.60	63.98	3.51%
Average:	65.93	65.53	64.79	63.63	64.21	61.35	63.55	4.66%
Std Dev:	0.58	0.10	0.92	1.32	1.52	0.35	0.42	1.00%
%R:	99.42%	98.83%	97.71%	95.96%	96.83%	92.52%	95.83%	n/a
%RSD:	0.88%	0.16%	1.42%	2.07%	2.37%	0.57%	0.66%	n/a
Z-Test:	0.07	0.27	0.20	0.25	0.17	1.29	0.65	n/a

Note: From Reference [2]

Table 4. Line Sources Used in Cardboard SWB Measurements

Source ID (S/N)	**Nuclide**	**Half Life (y)**	**Activity (µCi)**	**Activity Ref. Date**
R4-395	^{241}Am ^{152}Eu	432.7 ± 0.5 13.33 ± 0.04	9.509 ± 3.0% 9.499 ± 3.0%	5/1/2019
R4-396	^{241}Am ^{152}Eu	432.7 ± 0.5 13.33 ± 0.04	9.826 ± 3.0% 9.817 ± 3.0%	5/1/2019
R4-397	^{241}Am ^{152}Eu	432.7 ± 0.5 13.33 ± 0.04	9.972 ± 3.0% 9.962 ± 3.0%	5/1/2019
R4-398	^{241}Am ^{152}Eu	432.7 ± 0.5 13.33 ± 0.04	9.972 ± 3.0% 9.962 ± 3.0%	5/1/2019
R4-399	^{241}Am ^{152}Eu	432.7 ± 0.5 13.33 ± 0.04	9.936 ± 3.0% 9.926 ± 3.0%	5/1/2019
R4-400	^{241}Am ^{152}Eu	432.7 ± 0.5 13.33 ± 0.04	10.18 ± 3.0% 10.17 ± 3.0%	5/1/2019

Note: From Reference [2]

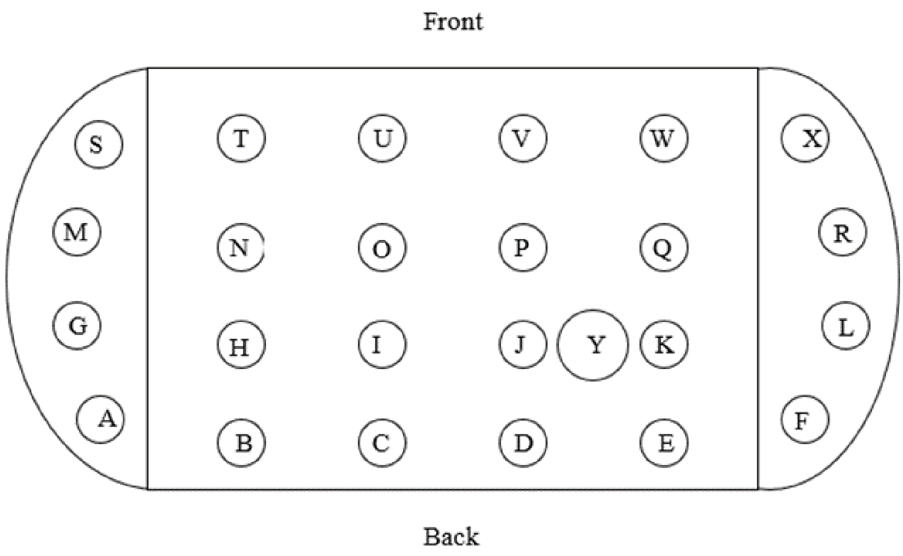

Figure 6. Top view of the Cardboard SWB with source loading positions labeled.

Table 5. Carboard SWB Assay Results

Nominal 59 µCi Eu-152 Reference Source								
Sequence #	Activities at Each Energy Line (µCi)						Wt Mean (µCi)	LACE FOM (<15%)
	121.8 keV	344.3 keV	778.9 keV	964.1 keV	1112.1 keV	1408.0 keV		
5544	57.14	63.60	62.89	58.43	58.77	56.00	58.56	4.33%
5545	56.19	63.67	60.99	60.80	57.58	55.04	57.93	4.54%
5546	57.01	63.43	62.72	59.40	57.16	56.35	58.33	4.44%
Average:	56.78	63.57	62.20	59.55	57.83	55.79	58.27	4.44%
Std Dev:	0.51	0.12	1.05	1.19	0.84	0.68	0.32	0.11%
%R:	95.69%	107.13%	104.83%	100.35%	97.47%	94.03%	98.21%	n/a
%RSD:	0.90%	0.19%	1.69%	2.00%	1.44%	1.21%	0.55%	n/a
Z-Test:	0.54	1.52	0.33	0.02	0.21	0.60	1.66	n/a

Note: From Reference [2]

Testing with plutonium sources was conducted for further verification of the LACE FOM values. The sources used are similar to masses we see in the field from TRU waste containers. The following experiments using plutonium sources were conducted:

- 55-gallon PDP drum filled with combustibles loaded with plutonium sources RANT 50-1 and RANT 50-2 [Table 6] both in position 3 at heights 4” and 15” [Figure 7], respectively.

- Test SWB filled with cardboard loaded with plutonium source PDP1-10 [Table 6] in position P at a height of 15” [Figure 6]

- Test SWB filled with cardboard loaded with plutonium sources RANT 50-1 and RANT 50-2 [Table 6] in positions N and K [Figure 6], respectively, and both at a height of 15”

Table 6. Plutonium Sources Used in Validation Measurements

Pu Standard	Source Type	Pu Mass (g)	Ref. Date
RANT 50-1	PuO_2	50.03132 □ 0.04652	6/25/1998
RANT 50-2	PuO_2	50.01032 □ 0.04667	6/25/1998
PDP1-10	PuO_2	10.0056 □□0.0083	7/15/1995

Note: From Reference [2]

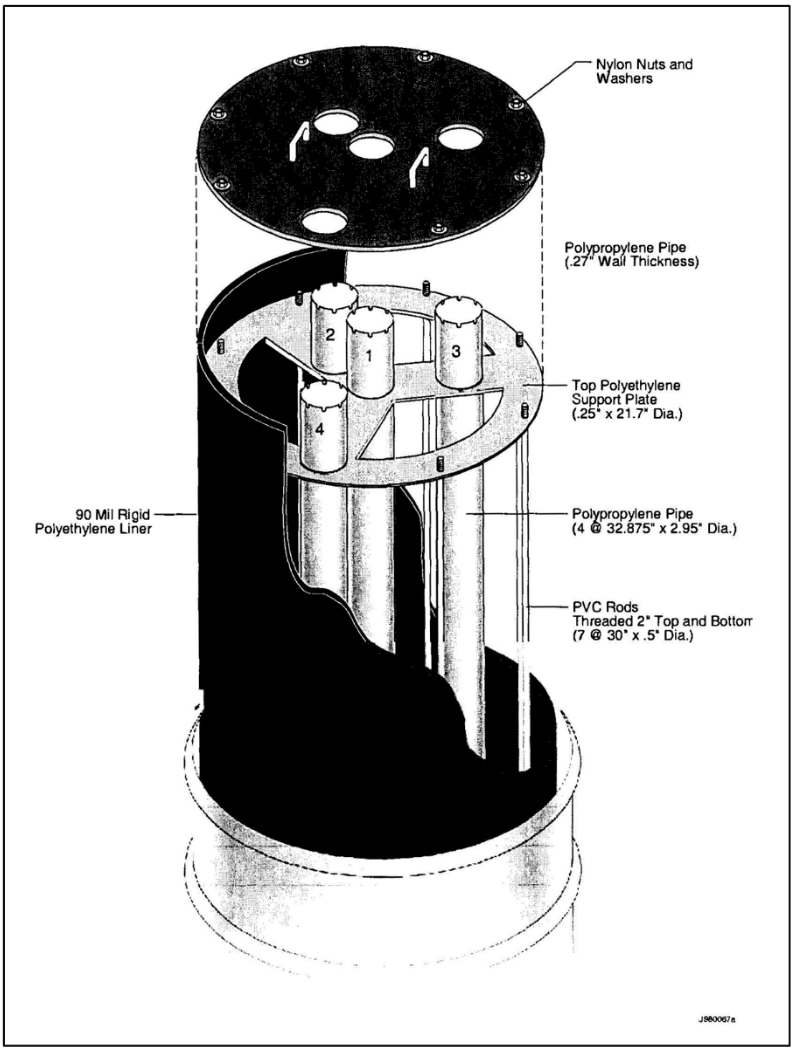

Figure 7. Exploded view of a PDP style drum.

Table 7. 55-Gallon PDP Drum Assay Results Using RANT 50-1 and RANT 50-2 Sources

Nominal 100 g Pu Reference Source		
Sequence #	**Measured Pu Mass (g)**	**LACE FOM for Pu-239 (<15%)**
5557	100.00	11.44%
5558	97.90	14.78%
5559	101.00	11.84%
Average:	99.59	12.69%
Std Dev:	1.58	1.82%
%R:	99.59%	n/a
%RSD:	1.59%	n/a

Note: From Reference [2]

Table 8. Combustibles SWB Assay Results Using PDP1-10 Source

Nominal 10 g Pu Reference Source		
Sequence #	**Measured Pu Mass (g)**	**LACE FOM for Pu-239 (<15%)**
5561	10.30	2.38%
5562	10.50	11.62%
5563	10.50	7.20%
Average:	10.43	7.07%
Std Dev:	0.12	4.62%
%R:	104.27	n/a
%RSD:	1.11%	n/a

Note: From Reference [2]

Table 9. Combustibles SWB Assay Results Using RANT 50-1 and RANT 50-2 Sources

Nominal 100 g Pu Reference Source		
Sequence #	**Measured Pu Mass (g)**	**LACE FOM for Pu-239 (<15%)**
5564	95.20	9.35%
5565	95.40	8.59%
5566	94.50	8.47%
Average:	95.03	8.80%
Std Dev:	0.47	0.48%
%R:	94.99%	n/a
%RSD:	0.50%	n/a

Note: From Reference [2]

INTEGRATION OF AEGIS™ UNITS FOR MILCC1

After the AEGIS™ units were physically installed into the MILCC1 system, data affirming compliance with regard to WIPP was necessary. The same requirements for accuracy and precision needed to be met via testing [1].

A mock calibration verification was performed using the sources from Table 1 in positions 2, 3, 4, 5, 6, and 9 [Figure 5], respectively. Similarly, followed the same standard operating practices: 42” detector standoff from surface of container for each detector, both detectors aimed at the center of the container, 180º collimator used on each detector, three replicate measurements, each detector 37” from the ground in height, and the assay time being a total of 1800 seconds [3].

Table 10. Mock Calibration Verification for AEGIS™ Units

66.31 uCi Eu-152 Reference Source							
Sequence #	**Activities at Each Energy Line (uCi)**						**Wt Mean (uCi)**
	121.8 keV	**344.3 keV**	**778.9 keV**	**964.1 keV**	**1112.1 keV**	**1408.0 keV**	
6048	69.57	72.80	67.44	67.77	67.64	69.55	69.62
6049	71.46	71.84	69.90	68.70	66.24	69.60	70.09
6050	71.29	72.97	69.64	69.70	69.81	70.10	70.91
Average:	70.77	72.53	69.00	68.72	67.90	69.75	70.21
Std Dev:	1.04	0.61	1.35	0.97	1.80	0.30	0.65
%R:	106.73%	109.39%	104.05%	103.64%	102.40%	105.19%	105.87%
%RSD:	1.47%	0.84%	1.96%	1.41%	2.65%	0.43%	0.93%

Note: Adapted from in-field data post AEGIS™ installation.

DISCUSSION/CONCLUSION

The MILCC1 was successfully upgraded to improve operational consistency. The implementation of AEGIS™ detectors brought with it an upgrade to Windows 10. This allows the software to be directly ran on a PC removing the need to use a virtual machine to run NDA 2000™. The newer versions of NDA 2000™ and Genie 2000™ provide the ability to work with newer versions of Windows. The newer version of Genie 2000 was required to use the AEGIS™ detectors. The addition of the ISOCS™ FOM expanded LANL's waste characterization capabilities. These upgrades directly support the CCP's drive to modernize counting equipment and take advantage of new technologies.

The MILCC1 was reviewed by both the Department of Energy and the U.S. Environmental Protection Agency in 2011. The certification letter for the MILCC1 was issued on November 16, 2011. With the certification letter issued to the CCP the MILCC1 can perform waste measurements on multiple container types at LANL for shipment to the WIPP.

Celebrating 25 years of operations at the speed of safety, WIPP continues to be the cornerstone for DOE's nuclear waste cleanup efforts, removing legacy TRU waste at 22 sites while reducing risk for Americans living near these sites, now and into the future.

Footnotes:

REFERENCES

[1] Transuranic Waste Acceptance Criteria for the Waste Isolation Pilot Plant, DOE/WIPP-02-3122, Revision 11, November 4th, 2022.
[2] Addendum to Calibration Report for the Mobile ISOCS™ Large Container Counter #1 (MILCC1) at Los Alamos National Laboratory For ISOCS™ Figure of Merit Methodology, CCP Document CI-MILCC-NDA-1006-ADD, Revision 0, February 13th 2023.
[3] Calibration Report for the Mobile ISOCS™ Large Container Counter (MILCC) at Los Alamos National Laboratory Including Gamma Spectrometer Calibration and Confirmation, CCP Document CI-MILCC-NDA-1006, Revision 0, April 4th 2013.