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EVALUATION OF LOW-LEVEL WASTE ANALYSIS USING THE MADAM SYSTEM

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ABSTRACT

Previously, the important hardware features and capabilities for the Multiple Assay Dual Analysis Measurement (MADAM) system were reported. MADAM is a combined low-level and transuranic waste assay system. The system integrated commercially available Segmented Gamma Scanner (SGS) capability together with multienergy x-ray and gamma-ray analysis to measure these two waste forms. In addition, the system incorporated a small neutron slab detector to satisfy safeguards concerns and high resolution gamma-ray isotopics analysis proficiency. Since delivery of the system to this facility, an evaluation of its low-level waste measurement performance has been conducted using a set of specially constructed NIST-traceable standards. The evaluation studied existing analysis algorithms, matrix and attenuation effects, source position as a function of detector response, instrument stability, and sensitivity. Based on these studies, several modifications to the existing analysis algorithms have been performed, new correction factors for matrix attenuation have been devised, and measurement error estimates have been calculated and incorporated into the software. This report discusses the results of the evaluation program and the software modifications that have been developed.

INTRODUCTION

The Plutonium Facility at Los Alamos National Laboratory (LANL) is a U.S. national defense facility involved in the recovery and processing of plutonium and other transuranic elements. Wastes are routinely generated from many stages of pyrochemical and aqueous processing of plutonium, and uranium and plutonium fuels fabrication. The processing steps generate a wide variety of leaner scrap and waste forms, such as plutonium oxide from burned residues, Pu-bearing salts from production/reduction and metal purification processes, impure plutonium metal, metal reduction slags, ash, ceramics, cleaning rags, plastics, HEPA filters, and other remnants and apparatus generated from processing and cleanup tasks. Solid wastes created from this processing are divided into two broad categories: transuranic waste (TRU) containing greater than 100 nCi/g and low-level waste (LLW) containing less than this amount. TRU waste

is obtained from various processing and cleanup steps within the processing gloveboxes and may be packaged in containers ranging from small cans up to 55 gal. drums. LLW is derived from locations outside the gloveboxes where contamination is expected to be light. Both solid waste categories receive nondestructive analysis (NDA) to determine radioactive content. For low bulk density materials (< 0.25 g/cc) such as paper, plastics, ash, powders, etc, the analyses are performed using x-ray or gamma-ray analytical methods. Denser materials, such as metals, leaded gloves, and some plutonium salts are measured with passive or active neutron counter analysis.

In general, measurements of low-density LLW utilize a combined L x-ray and gamma-ray analysis in which the contributions from ^{235}U , ^{238}Pu , ^{239}Pu , ^{241}Am , and fission products are collected, then added together to determine the total activity in the waste^{1,2}. Because this technique does not correct for matrix attenuation or self absorption effects, it is suitable only for low bulk density materials with diffuse contaminations of plutonium or uranium. The sample is rotated and vertically scanned before a single NaI detector to smooth the spatial response of the signal. Correlation factors for nongamma-ray emitting species may be incorporated into the software to account for radioactive species not directly detected by the instrument¹. This analytical method provides high sensitivity and reasonable accuracy for low-density materials. However, the method has several limitations. First, it is generally insensitive to unknown radioactive contaminants. That is, contaminants such as ^{237}Np , ^{243}Am , or ^{244}Cm , which are often associated with plutonium processing, may not be revealed with this method. Failure to detect their presence can lead to significant underestimation of the total activity in the waste. A second limitation in the method concerns its susceptibility to density variations in the waste. In the past, matrix attenuation of the gamma-ray and x-ray signals in low-density LLW has been discounted as a relatively minor constituent in the overall measurement uncertainty. Typically, a standard with the same density as the average LLW density has been used to calibrate the instrument. However, as the variability in waste matrix types has grown and come under increasingly stringent regulatory requirements for more accurate

measurements of LLW, corrections for matrix attenuation effects have become necessary. A third limitation on existing x-ray and gamma-ray analysis of LLW relates to the inability of these instruments to detect plutonium concealed within photon shielding materials. Here, the concern is not that the radioactive content in the waste will be underestimated as discussed above; but rather that comparatively large quantities of plutonium (10s of grams) may be concealed within gamma-ray shielding materials such that they are invisible to the detector. For example, significant amounts of plutonium could be contained within relatively thin lead shielding, thereby presenting a diversion scenario of significant proportions to safeguards analysts. At present, this vulnerability must be addressed by additional safeguards measurements before the waste items leave the facility.

To surmount these limitations on x-ray and gamma-ray measurements of waste, a new instrument has been developed jointly by personnel at the LANL Plutonium Facility and Canberra Industries, Inc. From the same measurement platform, the instrument can operate in either an SGS mode to analyze TRU waste and leaner residues or can be used in a multienergy analysis mode to measure LLW. In the multienergy analysis mode, the software inspects the ^{235}U , ^{238}Pu , ^{239}Pu , ^{241}Am , and fission product gamma-ray and x-ray spectral regions with the NaI detector as indicated above, and additionally performs gamma-ray isotopics analysis using a high resolution detector. In addition, a neutron counter measurement simultaneously examines the waste for the presence of radioactive materials that may be shielded from the gamma-ray analyses. A capability for high-resolution gamma-ray isotopic analysis for detection of contaminants has also been included with the system. A series of test measurements has been performed to determine instrument sensitivity, matrix and geometry effects, stability, and a more realistic assessment of the measurement uncertainty.

This paper will first describe the hardware and software components of the waste analysis system in more detail. The description includes all major revisions to current commercially available LLW measurement system counterparts. Then the software changes and test results will be discussed. Lastly, a brief review of future studies that are planned to test additional system parameters will be presented.

SYSTEM DESCRIPTION

The frame for the new instrument was taken from an old SGS unit that was decommissioned and retrofitted to accommodate both low-level and

transuranic waste containers. Its footprint is approximately 5 ft by 5 ft, although the dewar for the HPGe detector protrudes an additional 18 in. on one side. All power supplies, amplifiers, counter/timers, motion controllers, and other electronic modules are housed in one standard 180 cm high by 56 cm wide by 76 cm deep NIM cabinet. The computer, printer, and keyboard are separately mounted on an adjacent 24 in. by 24 in. desk.

At this facility, low level waste is normally packaged in 1 ft by 1 ft by 2 ft cardboard boxes. The new instrument is capable of measuring waste packaged in these containers; and, in addition, can accommodate LLW contained in 30-gal. and 55-gal. drums. The measurement time for the cardboard boxes is 2 min. The instrument is programmed to directly measure ^{235}U , ^{238}Pu , ^{239}Pu , ^{241}Am , and fission products using a single 5 in. diam by 2 in. long NaI detector optically coupled to a photomultiplier tube. Shielding around the detector consists of a specially fitted 1.75 in.-thick lead cover surrounding the sides, head, and back of the NaI crystal, except where the 2.0 in.-wide vertical collimator allows x-ray and gamma-ray access from the sample. The collimator permits the entire length of the LLW container to be viewed throughout the measurement. This collimator arrangement, plus rotational and vertical scanning, permits smoothing of the detector's spatial response to the waste package. The LLW measurement electronics, consisting of a preamplifier/discriminator, amplifier, high voltage power supply, scaler, and Canberra System 100 MCA board, form an independent, stand-alone unit that controls only the LLW measurements. Periodic measurements of a shuttered ^{133}Ba source mounted to the platform provide gain and intensity control for the detector. Table 1 contains a summary of the major components in the LLW measurement system.

In addition to the NaI detector platform, the system is also capable of performing gamma-ray isotopic analysis of LLW containers using a coaxial HPGe detector. For LLW measurements, this detector has a specially fitted, 2.0 in.-wide vertical collimator, which allows the entire length and width of the container to be viewed by the detector. The purpose of the high-resolution measurement is to detect unexpected contaminants in the waste. An analytical balance, calibrated from 0 to 30 kg, is also connected to the system computer in order to calculate the activity per unit gram of waste. Finally, a small 1 ft by 1 ft by 4 in.-wide neutron slab counter, containing four 8 in.-long ^3He detectors surrounded by polyethylene, operates during LLW measurements. The amplifier for this counter is internally mounted. The amplifier converts the output of the ^3He tubes to a TTL pulse

train directed to the counter/timer which, in turn, is interfaced to the computer.

The neutron counter is attached to the side of the measurement platform, and its purpose is to detect the presence of relatively large amounts of plutonium that may be transparent to the NaI detector. Because this detector measures only total neutron counts, not coincidences, the neutron counter is not intended to accurately assay the plutonium content in the waste. Rather, it is meant only to detect the presence of relatively large quantities of fissioning nuclei. Motor controllers for rotational and vertical positioning of the sample and shutter regulation for the gain source support the detection apparatus. Figure 1 diagrams the system and indicates the positions of the three detectors.

Table 1. Equipment used with each of the major components of the LLW analysis system.

<p>LLW Assay System</p> <ul style="list-style-type: none"> - 5" diam x 2" long NaI(Tl) Detector with thin Be window. - Circular grid type, 10 stage photomultiplier tube. - Supporting electronic modules. - Gain control using shuttered ^{137}Ba - 4096 data channel MCA integrated within computer. - Stepping motor controllers for vertical and rotational scanning.
<p>Gamma-Ray Isotopic Analysis</p> <ul style="list-style-type: none"> - 20% efficient pure Ge coaxial detector with thin Be window. - Supporting electronic modules. - 4096 data channel MCA integrated within computer.
<p>Neutron Measurement</p> <ul style="list-style-type: none"> - 1' x 1' x 4" polyethylene slab housing four 8" long ^3He detector tubes. - Internal amplifier/discriminator - High voltage power supply. - 100 MHz Counter/Timer

MEASUREMENT ALGORITHMS

Until recently, the measurement methods used to assay LLW leaving the LANL Plutonium Facility were identical to the methods originally developed by Umbarger and Cowder^{1,2} in the original MEGAS box counter. In the latest revision of the MEGAS counter, the MADAM system, a number of changes have been made to the measurement algorithms in order to better satisfy changing regulatory requirements. The original MEGAS concept was intended to make a simple "go/no go" decision regarding the specific activity of a waste package. The new changes have been implemented in an effort to provide more quantitative

measurements and to apply an error estimate to the measurement result.

The changes to the measurement algorithms include: a background subtraction routine, a calibration as a function of box weight (density) to correct for matrix attenuation effects, and an error estimate that is provided with the final measurement result. The analysis has also been rewritten so that the activities of all regions of interest (ROIs) are calculated and the reported activity is the highest calculated activity. Previous versions of the MEGAS software halted execution of the analysis routine as soon as any activity above a specified cut off was detected. In addition, a spectrum integral of the areas outside of all analysis ROIs has been added to detect any unexpected isotopes that may not fall into the analysis ROIs.

Figure 1. Schematic of the MADAM measurement system showing the measurement platform and the three detectors.

The current MADAM system is configured to measure ^{238}Pu , ^{239}Pu , ^{241}Am , ^{235}U , and fission products. The analysis isotopes and the energy of the analysis ROI for each isotope are listed in Table 2. A brief description of the analysis algorithm, including the recent modifications, is given below. Detailed descriptions of the original MEGAS analysis method are available in the literature^{1,3}.

Spectra are recorded by the NaI and HPGe detectors while the LLW box is rotated and vertically translated in front of the detectors. Typical measurement times range from 2 to 4 min. The HPGe spectrum is used only if the box contains greater than

100 nCi/g, unexpected isotopes, or fission products. The background is removed from the spectrum by performing a channel-by-channel subtraction with a smoothed background spectrum. The background spectrum is stored on disk and is updated frequently through a menu option using strict administrative controls. Then integrals of the analysis peaks and the spectral sum for unexpected isotopes are determined.

Table 2. ROI locations used in MADAM LLW analysis.

Isotope	Energy (keV)
Am - Pu	17
Pu-238	17 & 43
Am-241	60
U-235	185
Pu-239 gamma	414
Fission Products	~200 - 300

If fission products or unexpected isotopes are found, or the deadtime is greater than 60%, the analysis is aborted with the appropriate error message. The contribution from Am to the 17 keV ROI is determined from a fraction of the area in the 60 keV ROI. The contribution to the 17 keV ROI from ^{241}Am must be subtracted before the Pu calibration constant is applied. The procedure for calibrating and determining the appropriate fraction is discussed in the following section. The calibration constants for each isotope are determined from a quadratic fit to the box weight. The ^{238}Pu peak at 43 keV is used only as a flag to determine whether the calibration constant for ^{238}Pu or ^{239}Pu should be applied to the 17 keV ROI. The area of the 43 keV peak is compared to the area of the ^{241}Am peak at 60 keV. It is assumed that ^{239}Pu material types will always contain measurable amounts of Am. If the 43 keV ROI is greater than twice the 60 keV ROI, indicating the absence of Am, it is assumed that the box contains ^{238}Pu . If twice the 60 keV ROI is larger than the 43 keV ROI, it is assumed the box contains ^{239}Pu . This procedure is necessary because the intensity of the 43 keV gamma from ^{238}Pu is not sufficient to allow a good ^{238}Pu measurement with reasonable statistics. An inherent limitation of this method is the inability to measure both ^{239}Pu and ^{238}Pu in the same LLW waste box. This limitation is not a concern at the Plutonium Facility since ^{238}Pu and ^{239}Pu processing are performed in separate areas and the waste streams are not mixed in the same LLW box. The activities corresponding to each analysis ROI are then calculated. The highest activity is then reported

as the box activity. In addition, if the highest activity is ^{239}Pu , the ^{241}Am activity is also reported.

EXPERIMENTAL METHODS AND RESULTS

Low-level waste standards were prepared for calibration and characterization of the MADAM instrument by Robert Marshall of group CST-1 at LANL. The standards were prepared by pipetting a known amount of a standard solution (2 molar nitric) of ^{239}Pu or ^{241}Am onto filter paper. The solution was allowed to air dry for 1 to 3 hours in an open-face hood. The filters were then placed between two strips of adhesive-backed polyester film (FasCal PX 1071 Bright Chrome 1 Mil Polyester, Fasson Co., Painesville, Ohio) with seven evenly spaced filter papers for each assembly. The strips were then heat-sealed in two envelopes of 4.5 mil polyethylene. The final dimensions of each standard are approximately 4.5 in. by 23 in. The end product consists of a set of six ^{239}Pu standards ranging from 0.26 to 22 mg total Pu and a set of six ^{241}Am standards ranging from 5.7 to 434 μg Am. The Pu stock used to produce the standards had a nominal ^{240}Pu enrichment of 6%. Each set of standards is sufficient to span the specific activity range from 5 to 100 nCi/g in boxes ranging from 5 to 15 kg.

Figure 2. Box configuration used for calibration of the MADAM LLW measurement system.

Standard boxes were prepared by placing five 2 in.-thick, 1 ft by 2 ft slabs of a variable-density

polyurethane foam (Last-A-Foam FR-3700, General Plastics Manufacturing Co., Tacoma, Washington) into the normal waste boxes used at LANL. The variable-density foam was chosen for the box matrix rather than simulated waste, such as clean plastics and paper, since it is a very controllable and reproducible matrix. The slabs are held apart by 7/16-in. spacers to allow the standards to be slipped into the boxes in many different positions. A top view of a typical standard box is shown in Figure 2. Boxes with weights of 3, 4.5, 9, and 14 kg were constructed for the calibration measurements. The specific activities and box weights reported in this paper do not include the carton weight in accordance with DOE LLW regulations. The LLW boxes add an additional 700 g to the total weight of the package.

Figure 3. Ratio of the response of the 17 keV ROI to the response of the 60 keV ROI for a pure ^{241}Am standard.

Because there is a significant contribution from ^{241}Am in the 17 keV region, it is necessary to subtract the Am contribution from the 17 keV ROI before applying any Pu calibration constants. The ratio of the areas of the 17 keV ROI to the 60 keV ROI was measured in each standard box using one of the Am standards. The ratio was then fit using an empirical function with the box weight as the independent variable. The results are shown in Figure 3. It is obvious from the figure that the Am fraction is strongly dependent on the box weight. Previous versions of the MEGAS analysis algorithms used a constant fraction of 0.62 to subtract the Am contribution. The error bars in Figure 3 indicate one standard deviation of the measured ratio as a function of source position within the box. To perform an assay on the 17 keV region, the proper Am fraction is determined from the box weight. The product of the Am fraction and the area of the 60 keV ROI is subtracted from the 17 keV ROI to remove the Am

contribution.

All calibration measurements were performed with the standards located in an approximate volume averaged location in the box. In the square waste boxes, this position is located at a distance of approximately 4.5 in. from the center of the box. The location used for the calibration measurements is indicated in Figure 2. The standards necessary to span the range of 5 to 100 nCi/g were measured in each box at least five times each for the ^{239}Pu standards and three times each for the ^{241}Am standards. A linear least squares line was then fit to the data for each box. The results for the ^{239}Pu calibration for the 4.5 kg box are shown in Figure 4. The results for this box are typical of all measurements.

Figure 4. ^{239}Pu calibration measurements for the 4.5 kg box. The line shown is a linear least squares fit to the data.

Figure 5. Calibration curve for ^{239}Pu as a function of box weight. The line shown is a quadratic least squares fit to the data.

A least squares fit quadratic in box weight was then made to the inverse of the slope of the fit line for each individual box for both the ^{239}Pu and ^{241}Am data. The results are shown in Figures 5 and 6. The resulting

quadratic function gives the appropriate calibration constant as a function of box weight. This calibration procedure provides the matrix attenuation correction based on the weight of the LLW box.

The calibration functions were entered into the system and high and low standards were measured in each box. These measurements provide an estimate of the calibration error for each box. The standard deviation of the measured to nominal activity values are shown as the error bars in Figures 5 and 6. The results are the basis for the calibration error presented in a later section. It should be noted that all Pu measurements reported in this paper were made using the 17 keV x-ray region. With the MADAM system in the present configuration, the 414 keV ^{239}Pu gamma region does not contain statistically significant count rates for specific activity levels at or below the 100 nCi/g LLW fiducial.

Figure 6. Calibration curve for ^{241}Am as a function of box weight. The line shown is a quadratic least squares fit to the data.

The efficiency and geometric variation in the response of the neutron counter were measured using a certified ^{252}Cf neutron source. The measured efficiency of the neutron counter with a neutron source located on the center of the platform is 0.34%. Monte Carlo calculations using MCNP indicate the efficiency for a ^{240}Pu neutron distribution should be approximately 5% higher. Also, calculations indicate the slab is slightly undermoderated. The response could be increased by about 50% by adding additional poly to the face of the slab. The geometric variation in the neutron detector response has a maximum deviation of -45% within the volume of a LLW box. The response of the neutron detector to Pu was measured using cans of Pu oxide placed in the position with the lowest sensitivity. The results of these measurements are shown in Figure 7 as the totals rate as a function of the ^{240}Pu effective mass.

From this series of measurements, the minimum sensitivity of the neutron counter is estimated to be approximately 5 g total plutonium (6% ^{240}Pu) for a 120-sec. measurement. The minimum detectable quantity will be somewhat higher for plutonium metal. This value is more than sufficient for the safeguards function that this slab counter is intended to perform. These measurements were made in the relatively high background, approximately 33 totals/sec, of the basement of the Plutonium Facility. In the lower neutron background of the LANL CMR building where the second MADAM unit is located, the minimum sensitivity is reduced to approximately 1 g total plutonium.

Figure 7. Neutron counter response from plutonium oxide measured in the position of least sensitivity. Background rate is 33 counts/sec.

The HPGe detector will be used in combination with Canberra's Spectran AT for isotope identification purposes. The isotope identification feature will not be used routinely, but will be used for boxes that have activities above the 100 nCi/g limit and for boxes that are found to contain fission products or unexpected isotopes. When a box is flagged for one of the above reasons, a Spectran AT compatible file is created from the HPGe spectrum taken during the LLW analysis and saved to the disk. These files can be analyzed later by the NDA lab supervisor. If the count rates are not high enough to produce a useable HPGe spectrum in the short LLW assay time, the boxes are set aside for counting at a later time. Measurements have shown that an overnight count of 10 hours is more than sufficient to measure ^{239}Pu gamma rays in a waste box with an activity level of 90 nCi/g to better than 5%.

The errors that contribute to a LLW measurement were broken down into four major categories: background, calibration, statistical, and geometric variation. The geometric variation includes both the change in detector response as a function of source

location and the effects of matrix attenuation. The one sigma estimates for each of these error components for ^{239}Pu LLW analysis are shown in Table 3.

The background error was determined by calculating the standard deviation in the integral counts in the 17 keV ROI over 10 repeated runs. The bias in the calibration was measured by remeasuring a set of standards in each box after all the calibration functions had been entered into the system. The bias averaged over the entire calibration range is very small. However, it is clear from Figures 5 and 6 that some bias is built into the calibration curve, since the individual calibration constants determined for each box do not lie directly on the calibration curve. The maximum calibration bias for any source-box weight combination was 12%. The one sigma uncertainties in the calibration constants due to random variations in the calibration measurements range from 0.5 to 1.5%. The statistical error was determined from the standard deviation of repeat measurements over the entire calibration range.

Table 3. Estimated error contributions for a Pu LLW measurement.

Source	Estimated Error	
Background	5.82 %RSD	
Calibration	Ave. Bias <1%, Max. Bias 12%	
Statistics	10% at 1 nCi/g, <1% at 100 nCi/g	
Geometric Response	3.0 kg	9.3 %RSD
	4.5 kg	16.2 %RSD
	9.0 kg	39.7 %RSD
	14.0 kg	82.8 %RSD

Finally, the geometric error was estimated by measuring a source in various locations in each box, including folded lengthwise and placed in the top and bottom of the box. The %RSD reported in Table 3 was determined by assuming the measured range in the response to be ± 2 standard deviations. Thus 95% of all measurements fall within the measured range. For example, in the 14 kg box, the measurements ranged from 12 nCi/g in the center of the box to 110 nCi/g at the extreme edge of the box with no matrix material between the source and the side of the box. The box had a nominal activity of 29.7 nCi/g. If the

measurement at the edge of the box is not included, the next largest measurement is 30.2 nCi/g, reducing the standard deviation to 15%. Because the 2 in. foam slabs constrain the position measurements, it is not possible to get a uniform volume sampling of the box. It is not clear whether the 110 nCi/g measurement should be allowed to drive the error statement. Further work is needed to resolve this question.

The sensitivity of the LLW measurement system was estimated based on the system response determined from the calibration and the geometric and background error statements. The sensitivity is reported as the activity where the detector response from a source is equal to three standard deviations of the background signal. In this report, the activity is defined as the total alpha activity. A significant contributor to the total activity of Pu is the beta decay of ^{241}Pu . Unfortunately, this decay mode does not produce any radiations that can be directly measured by the MADAM system. If the beta activity of ^{241}Pu is included, the stated activity levels would increase by approximately a factor of 5. Thus, the minimum detectable activity would increase significantly. However, the sensitivity stated in g of total Pu would not change. The estimated sensitivities are shown in Table 4. The error estimates shown in Table 4 are based on a 120-sec. measurement time. The nominal sensitivity is based on the detector response with the source located in the volume averaged position used for the calibration measurements. The minimum sensitivity is the estimated sensitivity for a source located in the box position with the lowest detector response. For the lightest two boxes, the lowest Pu response was with the source in the top of the box. For the two heaviest boxes, the minimum Pu response was observed with the source in the center of the box. For the Am measurements, in each case the minimum response was observed with the source in the top of the box. It is interesting to note that the maximum Am response always occurs with the source in the center of the box. At 60 keV, the radius squared dependence on the solid angle is stronger than the effect of the matrix attenuation. The minimum sensitivity in units of nCi/g is relatively independent of the box weight. The increase in the attenuation with increasing box weight is partially compensated for by the decrease in specific activity. The effect of the attenuation on the sensitivity is demonstrated in the columns where the sensitivity is given directly in grams rather than in units of specific activity.

Table 4. Sensitivities for plutonium and americium using the MADAM LLW measurement system.

Weight	Plutonium Sensitivity			Americium Sensitivity (nCi/g)		
	Nominal	Minimum*	Minimum**	Nominal	Minimum*	Minimum**
3.0 kg	0.20 nCi/g	0.25 nCi/g	10 µg	0.011 nCi/g	0.014 nCi/g	0.012 µg
4.5 kg	0.18 nCi/g	0.24 nCi/g	14 µg	0.007 nCi/g	0.009 nCi/g	0.012 µg
9.0 kg	0.16 nCi/g	0.24 nCi/g	28 µg	0.004 nCi/g	0.005 nCi/g	0.013 µg
14.0 kg	0.16 nCi/g	0.40 nCi/g	74 µg	0.003 nCi/g	0.003 nCi/g	0.014 µg
*Worst-case sensitivity estimated for box position with lowest response.						
**Minimum sensitivity in g of total Pu assuming material with 6% Pu-240 enrichment.						

CONCLUSION

A new NDA system has been developed to assay LLW and TRU waste generated from plutonium and uranium processing operations from the same measurement platform. The LLW waste measurements have been improved by the addition of algorithms for matrix correction, background subtraction, and error estimation. The results of this paper show that quantitative LLW measurements can be performed from this measurement platform with realistic error statements associated with the assay.

Several additional tests are planned in order to further characterize the LLW measurement performance of the instrument. Included are tests to quantify measurement error arising from source and matrix heterogeneities; evaluation of the existing ²³⁸Pu analysis algorithm for matrix effects, geometric response, and spectral identification capacity; determination of the sensitivity of the instrument for assaying ²³⁵U and ²³⁸Pu; and assessment of the effectiveness of the software for measuring mixed isotopes. On completion of the LLW tests, the SGS portion of the system will be examined in detail.

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Reference herein to any specific commercial product, process, or service by tradename, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation or favoring by the Regents of the University of California, the United States Government, or any agency thereof.

REFERENCES

1. C.J. Umbarger and L.R. Crowder, *Measurement of Transuranic Solid Wastes at the 10 nCi/g Activity Level*. Los Alamos National Laboratory Report LA-5904, March, 1975.
2. T.K. Li, et al, *A High Performance, Low Density Waste Assay System*, Proc. of 29th Annual Inst. of Nuclear Materials Management Meeting, Las Vegas, NV, June, 1988.
3. D.F. Jones, L.R. Cowder, and E.R. Martin, *Computerized Low-Level Waste Assay System Operation Manual*, Los Alamos National Laboratory Report LA-6202, February, 1976.

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