S

ENGINEERING CHANGE NOTICE

Page 1 of 2

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Proj. ECN N/A

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◉ No (NA Blks. 12b, 12c, 12d)		Design Authority/Cog. Engineer Signature & Date	Design Authority/Cog. Engineer Signature & Date

13a. Description of Change

13b. Design Baseline Document? ○ Yes ◉ No

Completed analysis of the Total Measurement Uncertainty (TMU) for Nondestructive Assay of Transuranic Waste at the WRAP Facility, which revises the document to incorporate end affects into the TMU analysis and expands the range of TMU appliability.

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15. Distribution (include name, MSIN, and no. of copies)

See attached distribution sheet

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19. Change Impact Review: Indicate the related documents (other than the engineering documents identified on Side 1) that will be affected by the change described in Block 13. Enter the affected document number in Block 20.

SDD/DD	☐	Seismic/Stress Analysis	☐	Tank Calibration Manual	☐
Functional Design Criteria	☐	Stress/Design Report	☐	Health Physics Procedure	☐
Operating Specification	☐	Interface Control Drawing	☐	Spares Multiple Unit Listing	☐
Criticality Specification	☐	Calibration Procedure	☐	Test Procedures/Specification	☐
Conceptual Design Report	☐	Installation Procedure	☐	Component Index	☐
Equipment Spec.	☐	Maintenance Procedure	☐	ASME Coded Item	☐
Const. Spec.	☐	Engineering Procedure	☐	Human Factor Consideration	☐
Procurement Spec.	☐	Operating Instruction	☐	Computer Software	☐
Vendor Information	☐	Operating Procedure	☐	Electric Circuit Schedule	☐
OM Manual	☐	Operational Safety Requirement	☐	ICRS Procedure	☐
FSAR/SAR	☐	IEFD Drawing	☐	Process Control Manual/Plan	☐
Safety Equipment List	☐	Cell Arrangement Drawing	☐	Process Flow Chart	☐
Radiation Work Permit	☐	Essential Material Specification	☐	Purchase Requisition	☐
Environmental Impact Statement	☐	Fac. Proc. Samp. Schedule	☐	Tickler File	☐
Environmental Report	☐	Inspection Plan	☐	None	☒
Environmental Permit	☐	Inventory Adjustment Request	☐		☐

20. Other Affected Documents: (NOTE: Documents listed below will not be revised by this ECN.) Signatures below indicate that the signing organization has been notified of other affected documents listed below.

Document Number/Revision	Document Number/Revision	Document Number/Revision
None		

21. Approvals

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HNF-4050
Revision 5

Total Measurement Uncertainty (TMU) For Nondestructive Assay Of Transuranic Waste at the WRAP Facility

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

Project Hanford Management Contractor for the
U.S. Department of Energy under Contract DE-AC06-96RL13200

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Richland, Washington

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Total Measurement Uncertainty (TMU) For Nondestructive Assay Of Transuranic Waste at the WRAP Facility

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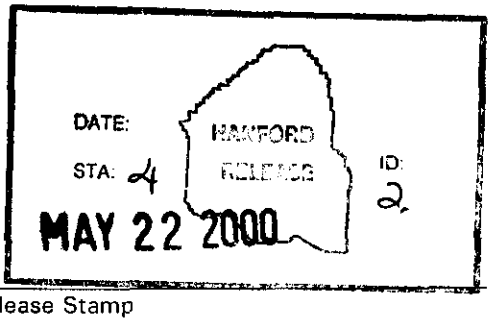

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Total Measurement Uncertainty for Nondestructive Assay of Transuranic Waste at the Waste Receiving and Processing Facility

Terri Welsh, Protection Technology Hanford
Michael Purcell, Fluor Daniel Hanford
Albert I. Davis, Waste Management Technical Services
Bruce Gillespie, Canberra Industries

Executive Summary

The Waste Receiving and Processing (WRAP) facility, located on the Hanford Site in southeast Washington, is a key link in the certification of Hanford's transuranic (TRU) waste for shipment to the Waste Isolation Pilot Plant (WIPP). Waste characterization is one of the vital functions performed at WRAP, and nondestructive assay (NDA) measurement of TRU waste containers is one of the methods used for waste characterization (Reference 1).

Various programs exist to ensure the validity of waste characterization data; all of these cite the need for clearly defined knowledge of the uncertainties associated with any measurements performed. All measurements have an inherent uncertainty associated with them. The combined effect of all uncertainties associated with a measurement is referred to as the Total Measurement Uncertainty (TMU).

The NDA measurement uncertainties can be numerous and complex. In addition to system-induced measurement uncertainty, other factors contribute to the TMU, each associated with a particular measurement. The NDA measurements at WRAP are based on processes (radioactive decay and induced fission) which are statistical in nature. As a result, the proper statistical summation of the various uncertainty components is essential.

This report examines the contributing factors to NDA measurement uncertainty at WRAP. The significance of each factor to the TMU is analyzed, and a final method is given for determining the TMU for NDA measurements at WRAP. A brief description of the data flow paths for the analytical process is also included in this report. As more data becomes available, and WRAP gains in operational experience, this report will be reviewed semi-annually and updated as necessary.

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APPENDIX A WRAP GEA-A gamma assay system Test Plan and Test Plan Results A1

1 Introduction

At the WRAP facility, there are two identical imaging passive/active neutron (IPAN) assay systems and two identical gamma energy assay (GEA) systems. Currently, only the GEA systems are used to characterize waste, therefore, only the GEA systems are addressed in this document.

This document contains the limiting factors relating to the waste drum analysis for shipments destined for WIPP. The TMU document provides the uncertainty basis in the NDA analysis of waste containers at the WRAP facility. The defined limitations for the current analysis scheme are as follows:

- The WRAP waste stream debris is from the Hanford Plutonium Finishing Plant's process lines, primarily combustible materials.
- Plutonium analysis range is from the minimum detectable concentration (MDC), Reference 6, to 160 grams (g).
- The GEA system calibration density ranges from 0.013 g/cc to 1.6 g/cc.
- PDP Plutonium drum densities were evaluated from 0.065 g/cc to 0.305 g/cc.
- PDP Plutonium source weights ranged from 0.030 g to 318 g, in both empty and combustibles matrix drums.
- The GEA system design density correction macroscopic absorption cross section table (MAC) is Lucite, a material representative of combustible waste.
- Drums with material not fitting the debris waste criteria are targeted for additional calculations, reviews, and potential re-analysis using a calibration suited for the waste type.

2 Systems

2.1 GEA

The WRAP GEA systems were built by Canberra Industries and use current versions of their Genie-PC and Gamma Waste Assay Software (GWAS) packages. The algorithms are well documented in the Canberra literature (Reference 3). The WRAP GEA is essentially what Canberra refers to as an IQ3 system, with a few unique features designed for the WRAP environment. The primary detectors are four vertically aligned, high-purity germanium detectors used for segmented gamma scanning. Directly opposite these detectors are four ^{152}Eu transmission sources which provide a measure of the matrix attenuation effects in each segment,

across selected ^{152}Eu gamma-ray energies. Transmission correction, density correction and gamma detection are performed on each segment, providing a well-defined picture of source distribution and matrix effects. Errors are minimized through the various correction factors, which are applied to each of the segmented spectral scans prior to developing the final summed spectrum for analysis. In this manner, the correction factors enhance system accuracy while propagating the counting statistics uncertainty in a proper statistical manner.

The drum platform moves to three vertical positions during an assay, thus dividing the drum into twelve segments for analysis (see Figures 1, 2, and 3). The uppermost and lowermost segments are discarded for 208-liter (55-gallon) drums, leaving ten segments for analysis. This practice of not using the extreme segments is implemented because these segments are not aligned with the waste matrix in 208-liter drums. This technique is applied to all 208-liter drum assays, including PDP and QAO measurements, calibration development, and waste stream analysis. Figure 1 shows the cone of gamma sensitivity for the upper discarded segment; it views the top drum lids and voids. Figure 3 shows the cone of gamma sensitivity for the lower discarded segment; its view is the drum rotational hardware. The drum also rotates at 10 rpm during the counting process in an attempt to average small radial inhomogeneities.

The GEA systems also have two low energy high-resolution germanium detectors designed for gamma-ray energy analysis up to 300 keV. These detectors collect the data used for the Multi-Group Analysis (MGA) software, which provides isotopic breakdown of plutonium and uranium waste. A variety of reports are available to allow a complete and very detailed analysis of the waste.

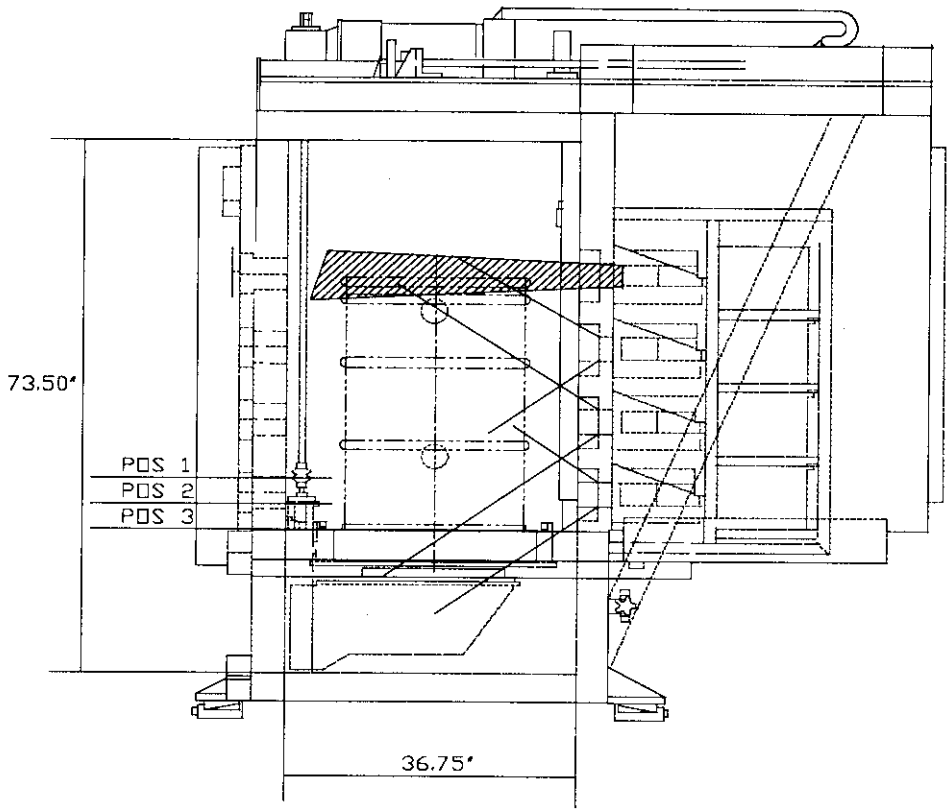


Figure 1

55 GAL DRUM
CONE OF GAMMA SENSITIVITY
FOR UNUSED SEGMENTS

12/15/99 BJW
(FILE) BJ55 NDA GEA-3

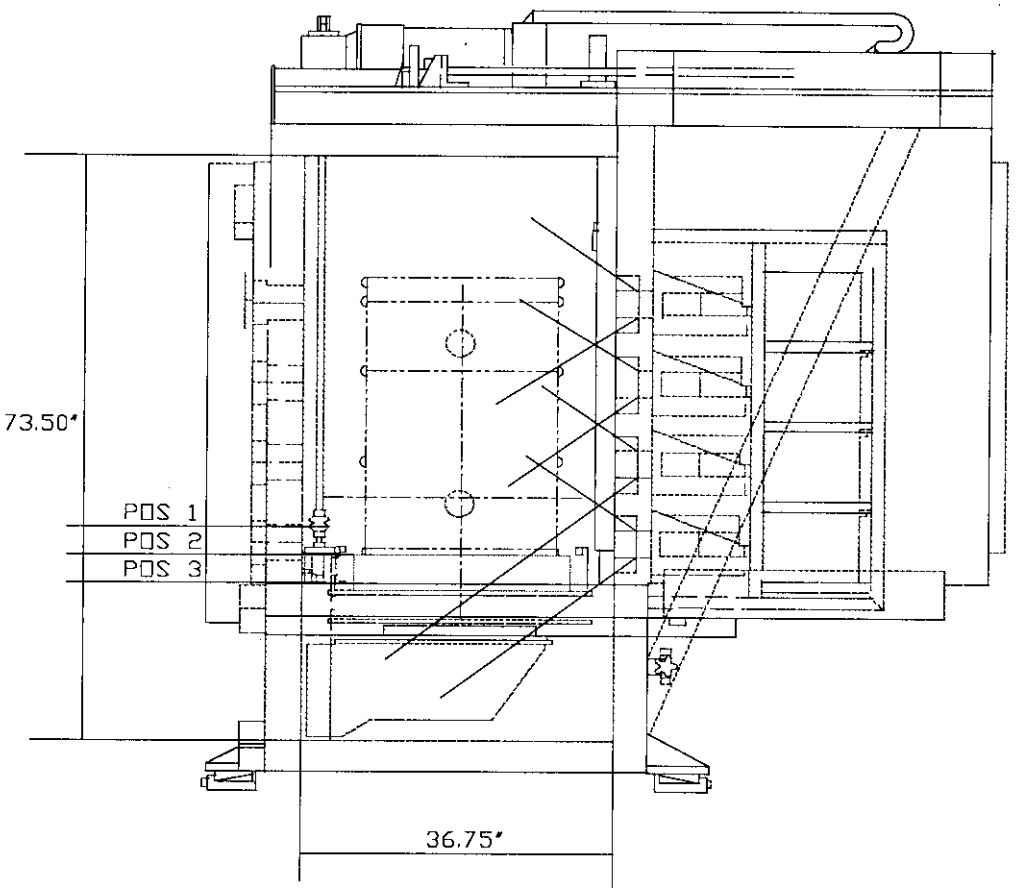


Figure 2
55 GAL DRUM
CONE OF GAMMA SENSITIVITY
FOR UNUSED SEGMENTS

12/15/99 BJW
(FILE) BJ55 NDA GEA-3

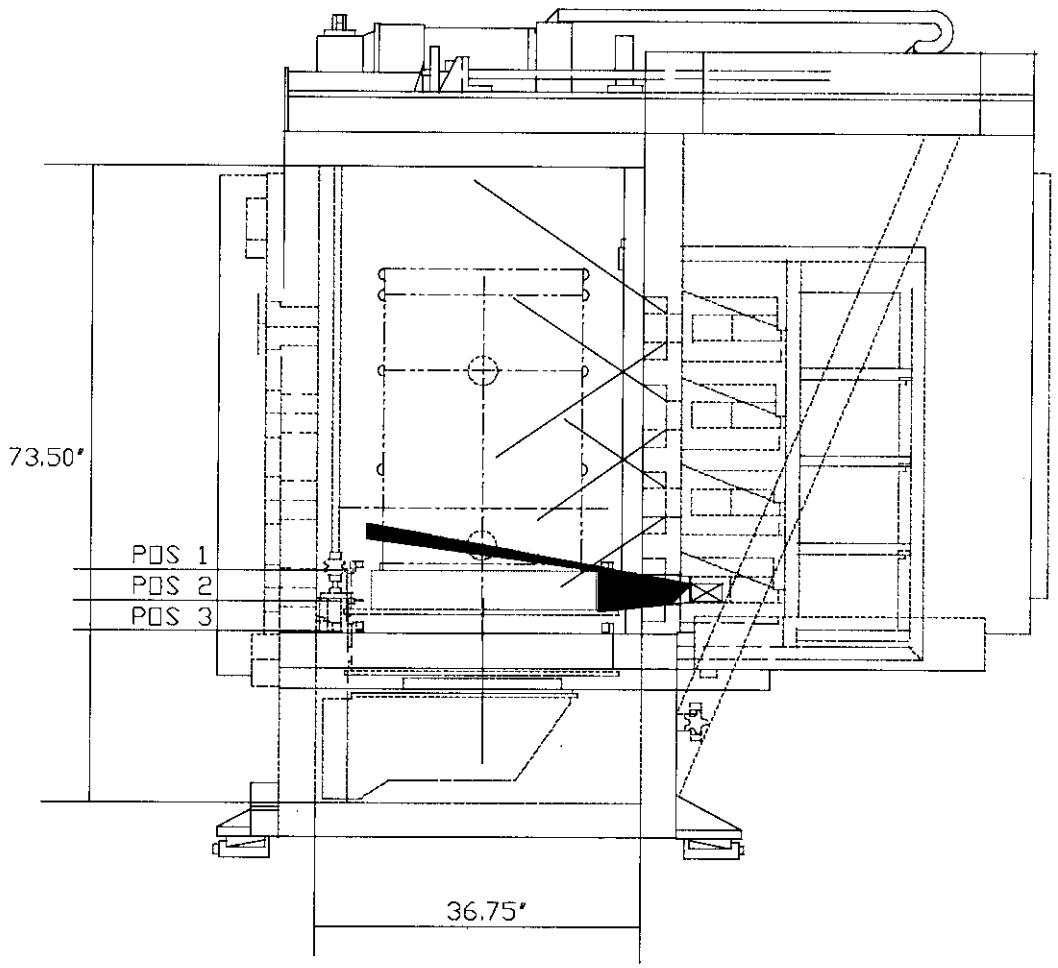


Figure 3
55 GAL DRUM
CONE OF GAMMA SENSITIVITY
FOR UNUSED SEGMENTS

12/15/99 BJW
(FILE) BJ55 NDA GEA-3

3 Overview of WRAP Drum Analysis

The procedure for performing expert NDA analysis is found in WMH-350, Section 2.2, "Calculation of Assay Results." The material below is a generalized overview of that procedure, to enable the reader to more easily understand the relationship between this document and overall analytical practice. This discussion is not to be interpreted as superceding or replacing WMH-350, Section 2.2. A flowchart of the drum analysis process is provided in Figures 4a, 4b, and 4c.

NDA analysis uses data from a variety of sources: acceptable knowledge (AK), WRAP scales, nondestructive examination (NDE), GEA, and, in the case of process drums, information gleaned from the sorting of the waste. Each data source has an associated uncertainty or set of uncertainties, which is the focus of this document. The TMU development follows the overview discussion and outline of the analytical methods analysis path.

3.1 Physical Measurements

Drums received at the WRAP facility are handled according to WRP1-OP-0503, "Move Drums Throughout WRAP Facility." This procedure describes in part how drums are weighed prior to NDE/NDA processing. The scale used and the gross weight of the drum is recorded in kilograms on a WIPP Waste Container Description Data Sheet found in the back of the procedure. This sheet becomes part of the WIPP data package, and the weight recorded is the gross weight used during expert analysis. Calculation of net weight and uncertainty handling will be discussed in the Expert Analysis section below.

WRP1-OP-0503 also describes the physical handling of the drums for NDE and NDA analyses. The procedures for the actual analyses of drums are WRP1-OP-0908, "Operation of the Drum Nondestructive Examination System," and WRP1-OP-0906, "Gamma Energy Assay Operations." Each drum having a potential to go to WIPP receives NDE and GEA analyses.

NDE results are recorded on a Radiography Data Sheet found within the NDE procedure. Copies of these sheets and a copy of the NDE image are provided to the NDA analyst for use in the expert analysis.

The GEA systems produce hard copy reports that become part of the WIPP data package. The NDA analyst has electronic copies of the data available for spreadsheet calculations as well. This reduces the possibility of transcription errors. The NDA analyst is also provided all of the NDA quality assurance data related to the batch to be analyzed to confirm that there are no quality issues.

3.2 Expert Analysis

Before beginning, the analyst ensures that all of the data necessary to complete an analysis of the data are at hand. Besides the materials listed above, the analyst checks for adequate AK data, and reports of any other NDA performed on the drum.

The quality control (QC) data (control charts and their associated raw data reports) are then reviewed. If there are issues that cannot be resolved, the drum (or drums) associated with the suspect QC data is removed from the batch.

AK data are decay corrected to the date of the WRAP NDA analyses to ensure comparability with measured data.

The NDE results and image are reviewed for an understanding of the drum contents and matrix distribution. This qualitative information is used to support the analyst's decision-making process as to which analytical data best represent the drum.

The GEA system filters the raw data through two algorithmic paths, yielding two sets of analytical results. The first, Sum Segments, uses drum density, (calculated from the weight and percent full volume data entered by the system operator), as its primary correction parameter, whereas the second, Combine All, uses transmission corrections.

The analyst is provided guidelines for making the choice of analytical result set forth in WMH-350 Section 2.2, and also in this document (see Tables 9 and 10). These guidelines are based on the quantity of ^{239}Pu measured. The analyst must, however, exercise judgement in this choice as well, taking into account the many factors discussed in this document and in WMH-350, Section 2.2. (These factors include NDE and GEA results; transmission adequacy; non-uniform matrix effects, as evidenced by inconsistent source transmission or segment activity; source lumping effects, as indicated by ratio of the 414 keV to 129 keV or 375 keV lines; etc.) The analyst selects the best algorithmic results or determines that the drum cannot be adequately analyzed and removes it from the analytical batch. A more complete discussion of variables, effects, and possible interferences is given in WMH-350, Section 2.2.

Uranium and other isotopes (e.g., ^{40}K, ^{94}Nb, ^{232}Th) are not expected to be routinely found in the current waste stream, and will not be discussed here.

In order to compare measured isotopics with AK Pu and Am values, the measured values must be converted from their reported units (μCi) to grams, and the reported measurement uncertainty (1σ) calculated. Specific activity values (Ci/g) for each isotope are found in Appendix A of WMH-350, Section 2.2.

The acceptance and application of AK isotopic ratios to the measured ^{239}Pu value is a matter of some complexity. Originally, isotopic ratio values from drums leaving the Hanford Plutonium

Finishing Plant (PFP) were determined by high precision heavy atom mass spectroscopy. The uncertainties associated with the baseline measurements were insignificant, and the variation from batch to batch of product, small. Thus, any mixing of product batches in a glovebox waste stream would also have a small uncertainty. More recently, PFP has been using NDA methods to assign isotopics. These techniques are drum specific, but prone to greater uncertainty. Careful statistical analysis of PFP data has been performed to provide realistic uncertainties to apply to the AK isotopic data. The uncertainty related to these measurements is discussed in "Uncertainty Associated with Isotopic Analysis" later in this report.

The WRAP GEA systems have the capability to perform isotopic ratio measurements using low energy gamma detectors and specialized software (MGA). Although the complexity of peak analysis and limitations of the low energy detectors make MGA analysis unsuitable for some drums, measured isotopic ratios should be possible for a majority of the drums in the current waste stream. This provides a method for reviewing and confirming AK.

As there are two low energy detectors, two sets of isotopic ratios are produced for each drum that falls within measurement parameters. These data are evaluated as per WMH-350, Section 2-2, and a determination made as to which, if either, should be compared with AK data. WMH-350, Section 2-2 also delineates the criteria for determining whether to use MGA or AK data.

The isotopic values and their uncertainties are applied to the GEA measured values by a normalization process. The most reliably measured Pu isotope is ^{239}Pu. A normalizing factor relative to ^{239}Pu is calculated for each isotope, and the gram value of each Pu and ^{241}Am isotope is calculated by multiplying each isotope normalizing factor times the measured ^{239}Pu value. The uncertainty for each Pu and ^{241}Am isotope gram value is calculated by combining the relative isotope factor uncertainty and the relative measured ^{239}Pu measured uncertainty in quadrature.

The other components of TMU are factored in at this point. For GEA, self-absorption uncertainty, source non-uniformity uncertainty, matrix homogeneity uncertainty, and end effects uncertainty are combined in quadrature to produce an overall uncertainty for each isotope. An example of the combination of these uncertainties is given in the Propagation of Uncertainties section.

The total uncertainty (1σ) for FGE, alpha curies, specific activity, DE-Ci, PE-Ci, nCi/g, W, and W/m^3 must be calculated. For all but nCi/g, the same general scheme is followed: the gram value is calculated by dividing the measured activity by the specific activity.

For the total nCi/g calculation, the total alpha curie value, converted to nCi, must be divided by the waste net weight (converted from kilograms to grams). Likewise, the uncertainty terms must be converted and then summed in quadrature. The analyst then determines the waste category of the drum and creates a summary of the data for DMS entry. The final calculations convert all of the 1σ uncertainties into 1.96σ uncertainties for inclusion in the WRAP Radioassay Data Sheet, a summary compiled for WIPP.

WRAP DRUM ANALYSIS OVERVIEW

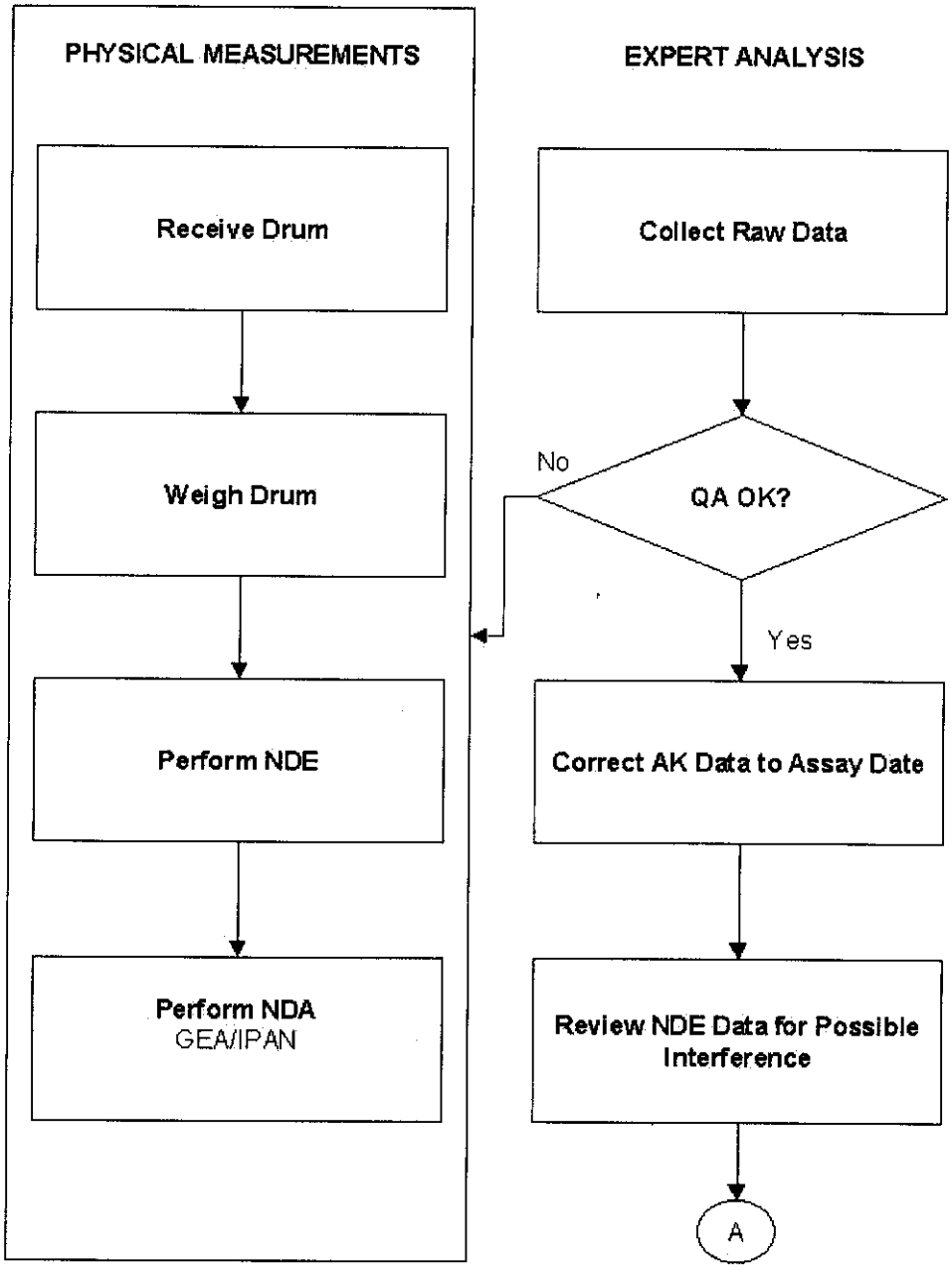


Figure 4a

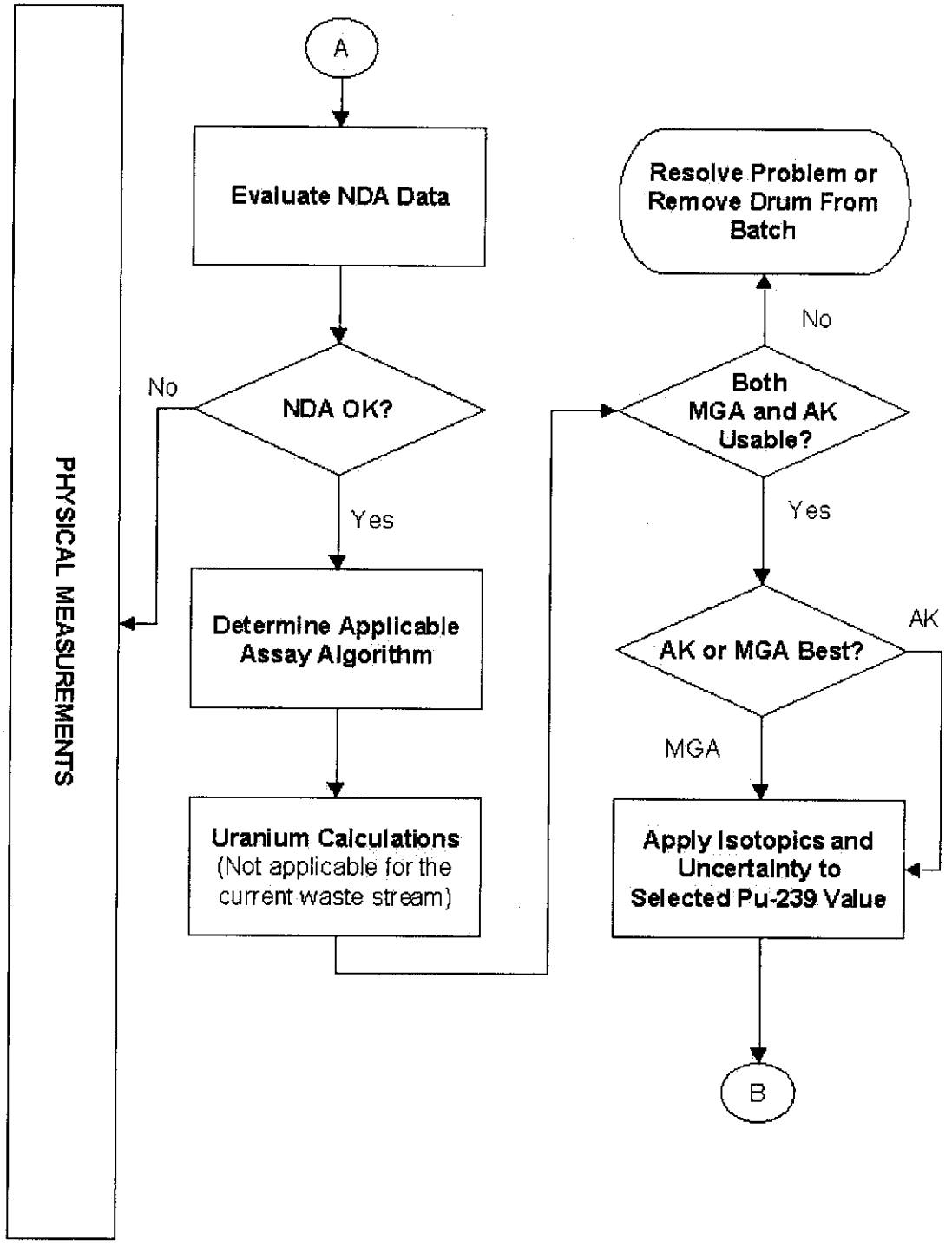

PHYSICAL MEASUREMENTS
A
Evaluate NDA Data
NDA OK?
No
Yes
Determine Applicable Assay Algorithm
Uranium Calculations (Not applicable for the current waste stream)
Resolve Problem or Remove Drum From Batch
No
Both MGA and AK Usable?
Yes
AK or MGA Best?
AK
MGA
Apply Isotopics and Uncertainty to Selected Pu-239 Value
B

Figure 4b

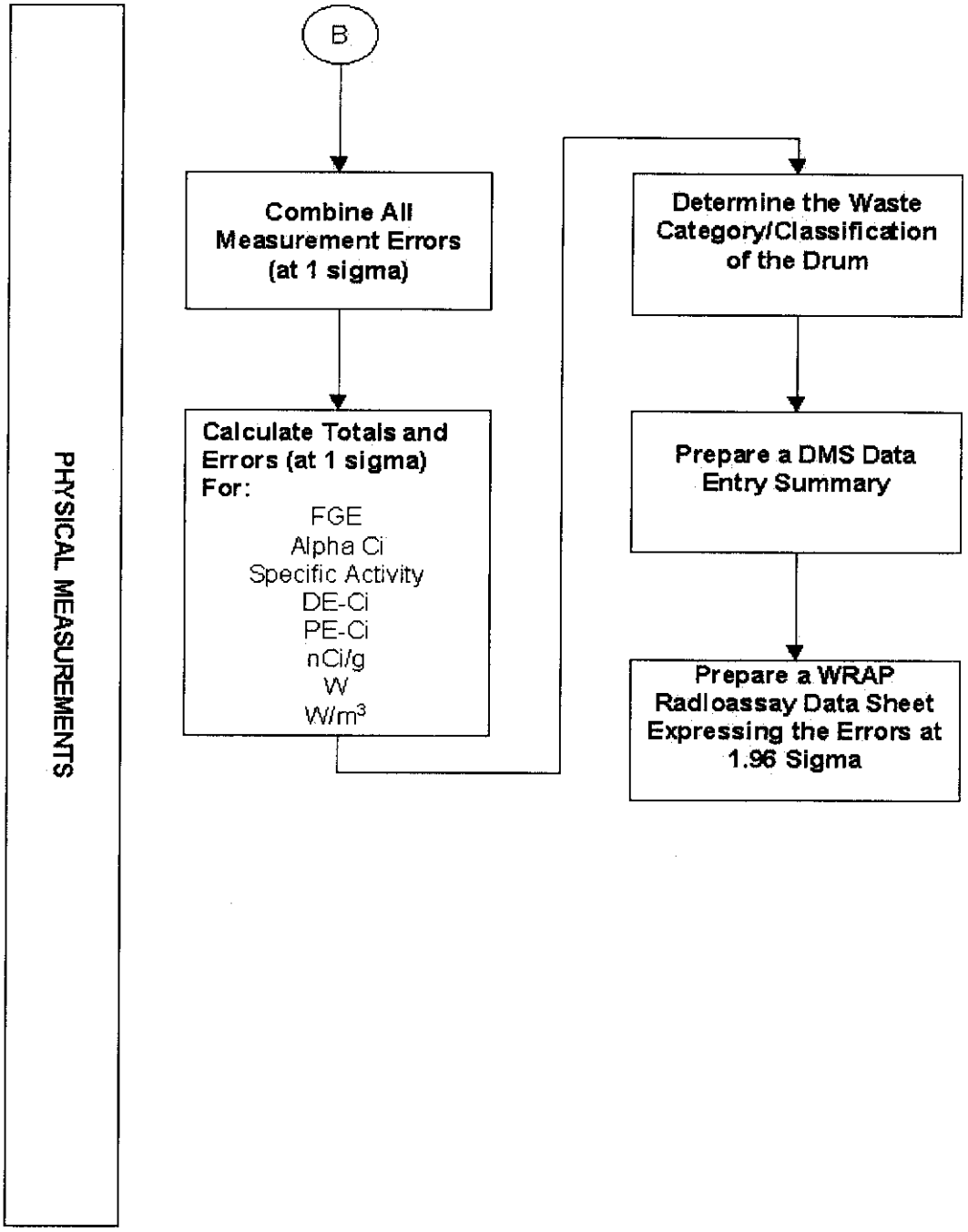

PHYSICAL MEASUREMENTS
B
Combine All Measurement Errors (at 1 sigma)
Calculate Totals and Errors (at 1 sigma) For:
FGE
Alpha Ci
Specific Activity
DE-Ci
PE-Ci
nCi/g
W
W/m3
Determine the Waste Category/Classification of the Drum
Prepare a DMS Data Entry Summary
Prepare a WRAP Radioassay Data Sheet Expressing the Errors at 1.96 Sigma

Figure 4c

4 Sources of Uncertainty

Measurement uncertainty generally results from sources that may be divided into two categories: those which can be statistically evaluated, and those which cannot be statistically evaluated. The values for both types of uncertainty are combined to produce a final uncertainty value, which we refer to as TMU. It is assumed that the statistical distribution of measurement uncertainties within the waste stream population follows a normal distribution. It is also assumed that the individual uncertainty components are statistically independent. This assumption is made because of the difficulty involved in distinguishing each source of potential uncertainty from the others for all possible measurement scenarios. The methodologies used in determining the uncertainty estimates isolate each uncertainty component as much as possible. For the TMU determination the uncertainty values for the different components will be combined using a "root sum of squares" method, as outlined in NIST Technical Note 1297.

Most sources of measurement uncertainty associated with NDA can be statistically evaluated. Such sources include scale readings and assay results. The statistical nature of radioactive decay or the interaction of a particle flux with a target matrix need not be belabored here, although these will be the dominant factors in analysis of NDA measurement uncertainty. A simpler example is the amount of random fluctuation in weight scale readings, which can be estimated using statistical methods. The standard deviation of a series of replicate measurements is used to evaluate this type of measurement uncertainty. By convention, uncertainty values for a given measurement are expressed as a range, at a given confidence level (e.g., "At the 95% confidence level, the object weighs 53 ± 2.7 kilograms").

Uncertainties from sources which cannot be statistically evaluated are estimated; the contribution of these sources to the TMU can be quite large. Such sources include AK data, system biases, if they exist, waste source self shielding, waste source heterogeneity and variations in the drum and packaging material tare weights. The uncertainties – both statistical and estimated – associated with each of these sources are discussed below.

5 GEA Measurement Uncertainty

The primary components of the TMU in the WRAP GEA assay are:

Calibration uncertainties
Counting statistics for sample analysis
Source self-absorption uncertainties (lumps)
Source non-uniformities
Matrix effects
End effects
MGA isotopics uncertainties

Quality control measurements are performed to ensure that the system is functioning properly, within a pre-determined set of criteria, and that there are no immediate or long-term slow changes to the system operation. This is accomplished by making two measurements; an assay of a known sample (control source), and a measurement of the background. The control source measurement serves to determine if the detection system (detectors, algorithms, and output files) is functioning properly. The background measurement serves as an indicator of potential contamination of the system and of changes in the radiological conditions in the area around the system. Additional details regarding QC measurements can be found in Reference 3.

5.1 Calibration Uncertainties

There are typically two components of the overall calibration uncertainty. The first component is the uncertainty associated with the calibration sources (typically 3 to 4%). The calibration source uncertainty is included in the source certificate files used to calibrate the instrument. The second component is the uncertainty associated with the calibration counting statistics and fit of the calibration data to the calibration curve. This uncertainty, like the first, is automatically calculated and propagated in the GEA software. Since the calibration uncertainty components are incorporated into the measurement uncertainty reported with the GEA assay value, the calibration uncertainties are not identified in this TMU document as a separate uncertainty term. Algorithms for propagation of the calibration source uncertainties are contained in Reference 3. For calibration of 208-liter drums, there is no additional calibration uncertainty beyond that generated by the GEA software.

5.2 Counting Statistics Uncertainties (Random Error)

Counting statistics uncertainties are very small when significant quantities of material are present but ultimately become the dominant source of uncertainty as the radioactive source strength decreases. The GEA software propagates this uncertainty term. The counting statistics tend to be the primary effect in the precision of the measurements. The algorithms for propagation of the counting statistics uncertainties are contained in Reference 3.

The random "error" for the GEA assay system can be estimated from repeated measurements of representative waste drums. Various masses of weapons grade plutonium in the form of NIST traceable standards were placed in PDP matrices 001 (empty) and 003 (combustibles) and multiple measurements obtained. All measurements were performed under normal operating conditions in the WRAP facility, so uncertainty arising from local background variability is included in the estimates. Measurement times were the same as those used under normal sample operating conditions.

The number of repeat measurements for each drum varied between 5 and 15. Since a large number (> 100 sets) of repeated measurements were carried out, only a representative sample of the results have been reported in this document. The assay data were evaluated for two computational methods (Sum Segments and Combine All) and three energy lines (375 keV, 129 keV, and 414 keV). For completeness the results from the six data classes for the combustibles drum are provided in Tables 1.A – 1.F. It should be noted that not all data are valid for all mass ranges. For each Pu mass listed in Tables 1.A – 1.F, the random uncertainty, as estimated by the relative standard deviation (RSD or standard deviation divided by the mean) calculated from the replicate measurements, is reported (see column 3).

For comparison purposes, the measurement uncertainty (calibration uncertainties and counting statistics) as reported by the GEA system and used in the TMU determinations at WRAP is also listed. The minimum, maximum, and average measurement uncertainties from the 5 to 15 repeated measurements are listed for each Pu mass (see columns 4, 5, and 6). As can be seen in Tables 1.A – 1.F, the two uncertainty estimates (% RSD from multiple measurements and % RSD from the instrument statistics) are close which validates the use of the uncertainty as generated by the software. In most cases, as expected, the uncertainty (%RSD) from the instrument statistics bounds the uncertainty (%RSD) from the multiple measurements as illustrated in Figure 5. For the majority of the cases where the opposite occurs, the hypothesis that the two variances are equal cannot be rejected.

For those special situations in QAO mass range II, where the preferred analytical result of Sum Segments is deemed not viable, the Combine All analytical result will be used. The random uncertainty as determined by the instrument statistics (414 keV) underestimates the GEA measurement uncertainty, illustrated in Table 1.F. (column 6 versus 3). Since replicate measurements are not routinely performed for waste drums, a factor was developed to increase the random uncertainty as determined from the GEA assay system. The ratio of the replicate %RSD to the Avg Inst Stat %RSD was calculated for QAOs between 0.33 g to 1.0 g total Plutonium. The average of the nine ratios was 1.8 with a standard deviation of 0.8. The 95% confidence interval for the mean value ranged from 1.1 to 2.6. Thus, to one significant digit, the GEA measurement uncertainty (414 keV) for the TMU calculation of waste drums evaluated under this condition will be two times the uncertainty generated in the GEA analysis report.

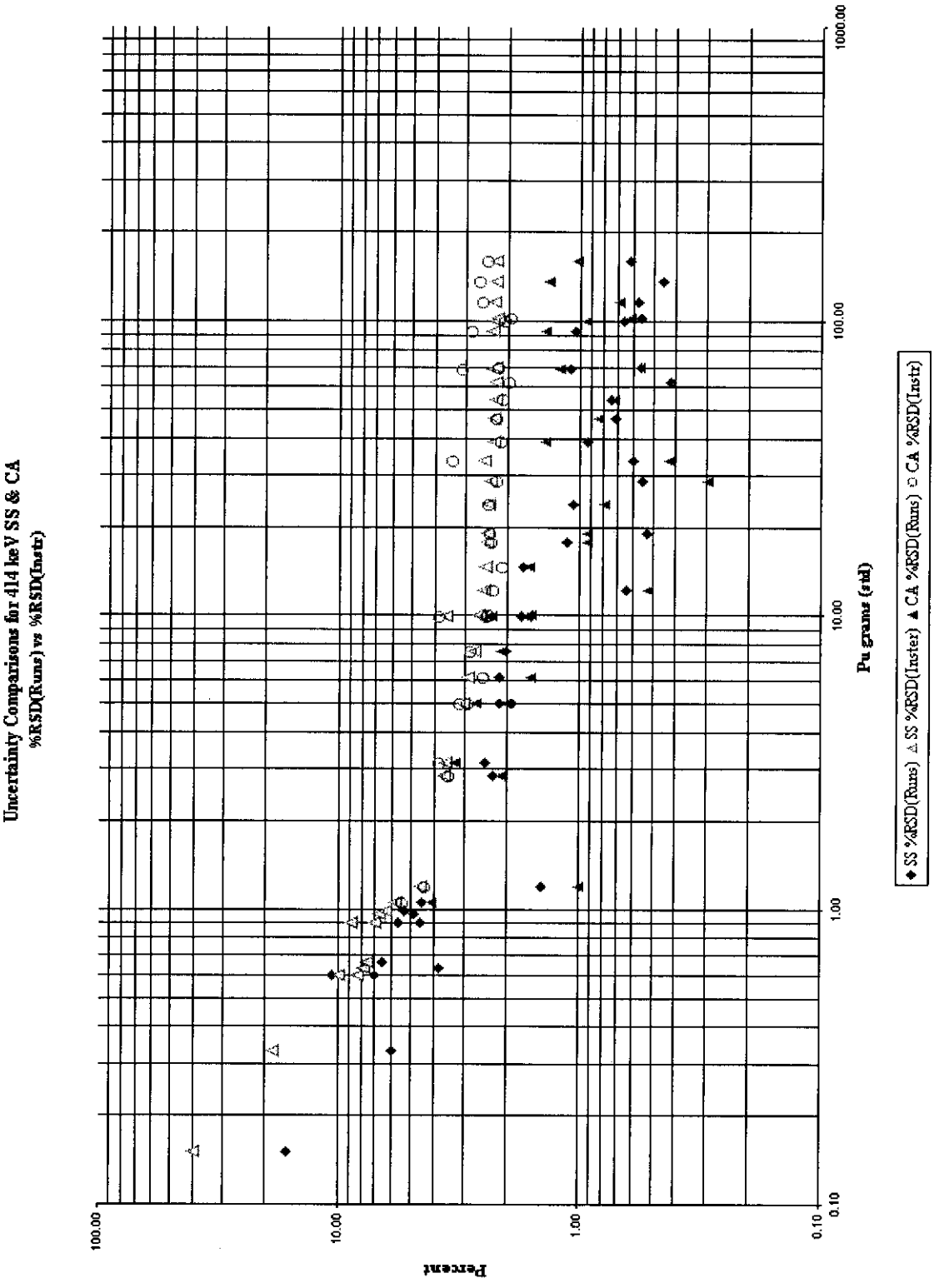

Uncertainty Comparisons for 414 keV SS & CA
%RSD(Runs) vs %RSD(Instr)
Percent
100.00
10.00
1.00
0.10
Pu grams (std)
1000.00
100.00
10.00
1.00
0.10
◆ SS %RSD(Runs) △ SS %RSD(Instr) ▲ CA %RSD(Runs) ○ CA %RSD(Instr)

Figure 5

Table 1.A. GEA A Combustibles Drum Test Results, Sum Segments (375 keV)

SUM SEGMENTS -- "Pu-239" (375 keV)							
Item ID	WG Pu Mass (gm)	Gross %RSD (Replicates)	Min Inst Stat (%RSD)	Max Inst Stat (%RSD)	Avg Inst Stat (%RSD)	%R	%R Adj
QAO-009	0.06	<MDC	<MDC	<MDC	<MDC	<MDC	
QAO-21	0.09	<MDC	<MDC	<MDC	<MDC	<MDC	
QAO-23	0.10	<MDC	<MDC	<MDC	<MDC	<MDC	N/A
QAO-11	0.15	21.57	14.76	29.46	22.52	72.81	
QAO-003	0.33	13.33	10.30	19.11	12.95	65.08	
QAO-011	0.60	5.35	6.12	8.69	6.72	79.47	
QAO-013	0.63	5.78	5.62	7.97	6.50	78.63	
QAO-001	0.66	9.00	5.79	8.43	6.62	74.28	
QAO-02	0.90	9.51	5.74	7.57	6.32	71.44	N/A
QAO-04	0.96	7.24	4.42	6.10	4.94	74.53	
QAO-20	0.99	4.95	4.20	5.27	4.82	75.16	
QAO-14	1.05	2.75	4.27	5.60	4.78	74.33	
QAO-08	1.20	3.84	3.38	4.06	3.58	85.59	
QAO-W20	2.85	4.97	2.63	3.00	2.78	75.23	89.14
QAO-18	3.15	3.84	2.72	3.11	2.89	62.86	74.49
QAO-W13	5.00	4.48	1.96	2.59	2.31	70.90	84.02
QAO-16	6.15	7.50	2.05	2.64	2.30	65.04	77.07
QAO-W17	7.53	2.49	1.88	2.16	1.97	74.77	88.59
QAO-19	9.90	5.18	1.62	2.00	1.76	76.41	92.24
QAO-W08	10.00	3.07	1.64	1.96	1.79	72.66	86.09
QAO-W41	12.20	1.75	1.61	1.77	1.69	76.20	90.29
QAO-W53	14.68	1.67	1.48	1.61	1.55	75.12	89.02
QAO-W37	17.70	3.78	1.47	1.69	1.54	72.36	85.74
QAO-W63	19.13	3.16	1.40	1.67	1.52	72.44	85.84
QAO-58	23.88	1.01	1.31	1.43	1.38	68.44	81.10
QAO-W36	28.60	2.68	1.25	1.44	1.34	67.95	92.24
QAO-W64	33.55	1.30	1.67	1.79	1.74	86.30	93.79
QAO-W40	39.00	1.33	1.14	1.27	1.23	70.62	95.86
QAO-W27	47.00	1.67	1.13	1.25	1.19	64.45	87.49
QAO-W46	54.30	2.29	1.09	1.23	1.16	71.84	97.52
QAO-W45	62.00	1.50	1.05	1.15	1.10	68.66	93.20
QAO-W51	68.67	3.35	1.34	1.55	1.47	82.40	89.54
QAO-W25	70.00	2.98	1.08	1.22	1.13	63.55	86.27
QAO-W60	92.25	2.09	1.25	1.39	1.32	79.10	85.96
QAO-W33	100.00	1.55	1.01	1.10	1.04	60.19	81.71
QAO-W48	102.70	1.89	0.99	1.05	1.03	63.04	85.58
QAO-W54	116.71	0.35	1.22	1.30	1.26	78.35	85.15
QAO-W57	135.70	2.59	1.18	1.37	1.27	77.04	83.73
QAO-W21	160.00	1.28	1.05	1.23	1.17	79.65	86.56

Sum segments methodology is used for masses below 5g and Combine All is used for masses above 5g.
For masses in the 0-2.5 g range, the 129 keV line is preferred.

Table 1.B. GEA A Combustibles Drum Test Results, Sum Segments (129 keV)

SUM SEGMENTS -- "Pu-239A" (129 keV)							
Item ID	**WG Pu Mass (gm)**	**Gross %RSD (Replicates)**	**Min Inst Stat (%RSD)**	**Max Inst Stat (%RSD)**	**Avg Inst Stat (%RSD)**	**%R**	**%R Adj**
QAO-009	0.06	18.46	13.28	33.14	20.76	113.26	118.59
QAO-21	0.09	9.69	11.44	18.05	14.19	108.70	113.82
QAO-23	0.10	19.22	13.05	22.01	17.22	88.08	92.23
QAO-11	0.15	6.11	9.86	11.06	10.43	103.60	108.48
QAO-003	0.33	5.95	5.62	8.61	6.75	99.47	101.69
QAO-011	0.60	3.96	4.20	5.22	4.62	115.76	118.35
QAO-013	0.63	4.56	4.30	4.79	4.55	118.21	120.86
QAO-001	0.66	3.84	4.23	5.05	4.68	108.49	110.92
QAO-02	0.90	2.34	4.11	4.85	4.55	102.95	105.25
QAO-04	0.96	4.82	3.79	4.67	4.31	103.75	106.07
QAO-20	0.99	4.56	3.82	4.71	4.23	103.85	106.17
QAO-14	1.05	6.32	3.82	4.59	4.16	105.30	107.65
QAO-08	1.20	5.49	3.54	3.67	3.60	95.08	97.21
QAO-W20	2.85	4.43	3.43	3.52	3.47	98.03	119.01
QAO-18	3.15	4.47	3.36	3.67	3.52	79.10	96.02
QAO-W13	5.00	4.10	3.12	3.38	3.33	82.49	100.14
QAO-16	6.15	1.29	3.19	3.30	3.24	82.77	100.49
QAO-W17	7.53	3.43	3.13	3.18	3.16	93.30	113.27
QAO-19	9.90	2.34	3.06	3.11	3.09	96.42	116.81
QAO-W08	10.00	4.02	3.11	3.15	3.13	86.50	105.01
QAO-W41	12.20	5.14	3.13	3.13	3.13	93.80	113.88
QAO-W53	14.68	4.06	3.07	3.13	3.10	88.09	106.95
QAO-W37	17.70	2.82	3.04	3.06	3.05	80.69	97.96
QAO-W63	19.13	3.43	3.08	3.10	3.09	82.31	99.93
QAO-58	23.88	3.64	3.09	3.11	3.10	63.54	77.13
QAO-W36	28.60	3.21	3.02	3.04	3.03	67.76	
QAO-W64	33.55	12.70	245.41	246.23	245.68	11.47	
QAO-W40	39.00	3.02	3.03	3.05	3.04	70.98	
QAO-W27	47.00	3.19	3.01	3.04	3.02	47.36	
QAO-W46	54.30	3.10	3.02	3.04	3.03	67.84	
QAO-W45	62.00	3.66	3.03	3.04	3.04	53.90	
QAO-W51	68.67	7.96	245.15	246.48	245.63	9.40	N/A
QAO-W25	70.00	2.62	2.98	2.99	2.99	56.64	
QAO-W60	92.25	9.81	244.71	246.49	245.62	7.84	
QAO-W33	100.00	2.28	2.98	2.99	2.98	45.91	
QAO-W48	102.70	0.45	3.01	3.02	3.02	49.15	
QAO-W54	116.71	8.83	244.90	246.24	245.55	8.16	
QAO-W57	135.70	8.74	245.06	245.79	245.54	7.37	
QAO-W21	160.00	8.26	251.66	252.84	252.22	8.13	

Sum segments methodology is used for masses below 5g and Combine All is used for masses above 5g.
For masses in the 0-2.5 g range, the 129 keV line is preferred.

Table 1.C. GEA A Combustibles Drum Test Results, Sum Segments (414 keV)

SUM SEGMENTS -- "Pu-239B" (414 keV)							
Item ID	**WG Pu Mass (gm)**	**Gross %RSD (Replicates)**	**Min Inst Stat (%RSD)**	**Max Inst Stat (%RSD)**	**Avg Inst Stat (%RSD)**	**%R**	**%R Adj**
QAO-009	0.06	<MDC	<MDC	<MDC	<MDC	<MDC	
QAO-21	0.09	<MDC	<MDC	<MDC	<MDC	<MDC	
QAO-23	0.10	<MDC	<MDC	<MDC	<MDC	<MDC	N/A
QAO-11	0.15	16.35	16.64	39.89	25.41	81.39	
QAO-003	0.33	6.02	10.51	18.60	13.45	71.53	80.69
QAO-011	0.60	7.00	6.44	9.88	7.74	80.38	90.67
QAO-013	0.63	3.82	6.19	7.81	7.06	85.28	96.21
QAO-001	0.66	6.53	6.25	7.58	6.88	81.97	92.47
QAO-02	0.90	4.55	6.23	8.80	7.53	77.93	87.92
QAO-04	0.96	4.86	5.51	6.74	6.20	76.15	85.91
QAO-20	0.99	5.33	5.14	6.39	5.62	78.31	88.35
QAO-14	1.05	4.50	4.77	5.83	5.47	78.32	88.35
QAO-08	1.20	1.44	4.17	4.53	4.36	91.03	102.69
QAO-W20	2.85	2.31	3.44	3.62	3.53	77.21	91.18
QAO-18	3.15	2.47	3.49	3.62	3.57	65.46	77.31
QAO-W13	5.00	2.17	2.82	3.02	2.98	72.26	85.33
QAO-16	6.15	2.15	2.82	2.90	2.86	70.05	82.72
QAO-W17	7.53	2.02	2.67	2.74	2.69	76.19	89.97
QAO-19	9.90	1.74	2.53	2.59	2.57	76.87	90.13
QAO-W08	10.00	1.58	2.57	2.62	2.59	72.51	85.62
QAO-W41	12.20	0.64	2.48	2.52	2.50	77.04	90.97
QAO-W53	14.68	1.72	2.45	2.48	2.47	74.07	87.46
QAO-W37	17.70	1.14	2.41	2.44	2.42	71.98	85.00
QAO-W63	19.13	0.53	2.38	2.42	2.40	72.56	85.69
QAO-58	23.88	1.07	2.35	2.39	2.37	67.31	79.48
QAO-W36	28.60	0.55	2.34	2.35	2.35	67.56	93.88
QAO-W64	33.55	0.60	2.45	2.49	2.47	87.65	97.72
QAO-W40	39.00	0.93	2.29	2.31	2.30	68.74	95.51
QAO-W27	47.00	0.71	2.28	2.30	2.29	62.87	87.36
QAO-W46	54.30	0.74	2.27	2.27	2.27	70.23	97.59
QAO-W45	62.00	0.42	2.26	2.26	2.26	66.89	92.94
QAO-W51	68.67	1.10	2.31	2.34	2.33	83.51	93.11
QAO-W25	70.00	0.56	2.25	2.27	2.26	62.00	86.15
QAO-W60	92.25	1.05	2.29	2.31	2.30	77.87	86.82
QAO-W33	100.00	0.66	2.24	2.25	2.24	57.66	80.12
QAO-W48	102.70	0.56	2.23	2.24	2.23	61.15	84.96
QAO-W54	116.71	0.58	2.25	2.28	2.27	77.09	85.95
QAO-W57	135.70	0.45	2.26	2.27	2.26	76.71	85.53
QAO-W21	160.00	0.62	2.25	2.27	2.26	77.75	86.69

Sum segments methodology is used for masses below 5g and Combine All is used for masses above 5g.
For masses in the 0-2.5 g range, the 129 keV line is preferred.

Table 1.D. GEA A Combustibles Drum Test Results, Combine All (375 keV)

COMBINE ALL -- "Pu-239" (375 keV)							
Item ID	**WG Pu Mass (gm)**	**Gross %RSD (Replicates)**	**Min Inst Stat (%RSD)**	**Max Inst Stat (%RSD)**	**Avg Inst Stat (%RSD)**	**%R**	**%R Adj**
QAO-009	0.06	<MDC	<MDC	<MDC	<MDC	<MDC	
QAO-21	0.09	<MDC	<MDC	<MDC	<MDC	<MDC	
QAO-23	0.10	<MDC	<MDC	<MDC	<MDC	<MDC	N/A
QAO-11	0.15	71.25	14.76	36.72	27.75	50.35	
QAO-003	0.33	29.45	10.15	27.10	14.51	47.60	
QAO-011	0.60	11.03	6.91	9.27	7.64	66.23	
QAO-013	0.63	7.64	5.83	8.41	6.66	74.86	
QAO-001	0.66	12.12	6.05	9.21	7.15	73.87	
QAO-02	0.90	27.32	6.42	9.48	7.66	58.82	N/A
QAO-04	0.96	7.42	4.88	5.75	5.47	75.77	
QAO-20	0.99	16.27	5.15	7.95	5.67	73.80	
QAO-14	1.05	5.10	4.75	5.41	5.06	73.82	
QAO-08	1.20	4.78	3.47	4.25	3.79	84.67	
QAO-W20	2.85	2.96	2.75	3.06	2.88	80.29	87.73
QAO-18	3.15	2.77	2.83	3.05	2.95	72.37	79.08
QAO-W13	5.00	2.38	2.32	2.45	2.39	75.99	83.03
QAO-16	6.15	1.29	1.99	2.15	2.07	79.05	86.38
QAO-W17	7.53	1.33	2.04	2.17	2.10	78.18	85.43
QAO-19	9.90	2.54	1.76	1.91	1.81	86.64	94.00
QAO-W08	10.00	3.62	1.76	1.95	1.84	79.74	87.13
QAO-W41	12.20	3.06	1.67	1.75	1.72	82.22	89.84
QAO-W53	14.68	1.90	1.52	1.62	1.57	81.11	88.63
QAO-W37	17.70	1.90	1.60	1.69	1.63	82.08	89.69
QAO-W63	19.13	1.90	1.63	1.73	1.67	80.67	88.15
QAO-58	23.88	2.32	1.61	1.68	1.64	74.05	80.92
QAO-W36	28.60	1.99	1.48	1.56	1.52	77.63	88.67
QAO-W64	33.55	3.78	2.14	2.23	2.19	84.87	93.21
QAO-W40	39.00	1.69	1.38	1.42	1.40	78.59	89.76
QAO-W27	47.00	3.07	1.40	1.50	1.43	75.80	86.58
QAO-W46	54.30	1.46	1.35	1.40	1.37	77.25	88.24
QAO-W45	62.00	2.34	1.25	1.31	1.28	71.40	81.55
QAO-W51	68.67	2.62	1.86	1.96	1.90	81.49	89.50
QAO-W25	70.00	3.69	1.35	1.44	1.39	74.80	85.44
QAO-W60	92.25	1.80	1.72	1.79	1.74	74.75	82.09
QAO-W33	100.00	2.10	1.27	1.32	1.30	72.98	83.36
QAO-W48	102.70	1.27	1.21	1.25	1.23	77.24	88.22
QAO-W54	116.71	1.57	1.57	1.62	1.59	75.06	82.43
QAO-W57	135.70	3.29	1.55	1.74	1.63	73.25	80.45
QAO-W21	160.00	1.82	1.44	1.50	1.47	75.90	83.35

Sum segments methodology is used for masses below 5g and Combine All is used for masses above 5g.
For masses in the 0-2.5 g range, the 129 keV line is preferred.

Table 1.E. GEA A Combustibles Drum Test Results, Combine All (129 keV)

COMBINE ALL -- "Pu-239A" (129 keV)							
Item ID	**WG Pu Mass (gm)**	**Gross %RSD (Replicates)**	**Min Inst Stat (%RSD)**	**Max Inst Stat (%RSD)**	**Avg Inst Stat (%RSD)**	**%R**	**%R Adj**
QAO-009	0.06	92.15	13.28	47.58	28.75	38.91	
QAO-21	0.09	134.74	13.15	54.20	31.32	23.97	
QAO-23	0.10	33.41	12.51	26.93	17.40	37.70	N/A
QAO-11	0.15	23.34	10.10	14.32	11.68	57.02	
QAO-003	0.33	5.57	7.28	8.38	7.73	60.09	71.30
QAO-011	0.60	3.27	5.18	5.49	5.35	69.00	81.87
QAO-013	0.63	3.83	5.39	5.68	5.53	73.68	87.42
QAO-001	0.66	3.76	5.03	5.39	5.18	77.90	92.42
QAO-02	0.90	8.67	4.68	5.40	4.99	68.46	81.22
QAO-04	0.96	3.01	4.86	5.01	4.92	76.06	90.25
QAO-20	0.99	6.49	4.70	5.45	4.86	76.40	90.65
QAO-14	1.05	2.10	5.14	5.36	5.24	84.77	100.58
QAO-08	1.20	2.70	4.72	4.82	4.75	97.72	115.94
QAO-W20	2.85	1.81	4.70	4.82	4.76	76.02	87.80
QAO-18	3.15	2.18	5.38	5.53	5.45	67.53	77.99
QAO-W13	5.00	1.55	4.98	5.12	5.05	60.96	70.40
QAO-16	6.15	0.93	3.70	3.72	3.71	72.11	83.28
QAO-W17	7.53	2.52	4.75	4.80	4.78	64.34	74.30
QAO-19	9.90	2.03	4.16	4.23	4.19	81.37	95.53
QAO-W08	10.00	2.25	4.04	4.13	4.08	69.82	80.63
QAO-W41	12.20	1.40	4.03	4.05	4.04	69.37	80.12
QAO-W53	14.68	1.44	3.63	3.66	3.64	69.49	80.25
QAO-W37	17.70	1.88	4.22	4.34	4.27	67.30	77.73
QAO-W63	19.13	2.90	4.27	4.41	4.32	69.21	79.93
QAO-58	23.88	3.39	4.43	4.53	4.49	54.81	63.29
QAO-W36	28.60	1.00	4.22	4.25	4.23	61.24	
QAO-W64	33.55	9.19	70.50	77.07	74.47	20.19	
QAO-W40	39.00	4.24	4.08	4.15	4.12	64.25	
QAO-W27	47.00	2.39	4.12	4.21	4.17	46.93	
QAO-W46	54.30	2.84	4.03	4.10	4.07	63.36	
QAO-W45	62.00	1.72	3.88	3.97	3.93	41.14	
QAO-W51	68.67	3.22	65.42	70.09	68.79	16.71	N/A
QAO-W25	70.00	2.67	4.32	4.40	4.36	55.29	
QAO-W60	92.25	7.66	46.66	55.50	50.80	15.46	
QAO-W33	100.00	5.96	3.80	4.07	3.88	47.40	
QAO-W48	102.70	2.84	3.77	3.83	3.80	55.37	
QAO-W54	116.71	3.47	45.03	51.57	47.37	15.48	
QAO-W57	135.70	4.43	41.78	47.24	44.25	14.45	
QAO-W21	160.00	6.13	45.74	52.82	49.62	14.89	

Sum segments methodology is used for masses below 5g and Combine All is used for masses above 5g.
For masses in the 0-2.5 g range, the 129 keV line is preferred.

Table 1.F. GEA A Combustibles Drum Test Results, Combine All (414 keV)

COMBINE ALL -- "Pu-239B" (414 keV)							
Item ID	**WG Pu Mass (gm)**	**Gross %RSD (Replicates)**	**Min Inst Stat (%RSD)**	**Max Inst Stat (%RSD)**	**Avg Inst Stat (%RSD)**	**%R**	**%R Adj**
QAO-009	0.06	<MDC	<MDC	<MDC	<MDC	<MDC	
QAO-21	0.09	<MDC	<MDC	<MDC	<MDC	<MDC	
QAO-23	0.10	<MDC	<MDC	<MDC	<MDC	<MDC	N/A
QAO-11	0.15	84.47	19.71	40.68	30.58	44.05	
QAO-003	0.33	30.71	9.86	20.38	13.13	54.36	67.17
QAO-011	0.60	11.66	6.59	8.32	7.48	69.45	85.82
QAO-013	0.63	6.89	6.06	7.09	6.69	78.92	97.51
QAO-001	0.66	8.81	6.35	8.09	7.03	78.27	96.72
QAO-02	0.90	25.83	6.49	9.21	7.66	58.16	71.86
QAO-04	0.96	8.49	5.15	6.02	5.62	80.42	99.37
QAO-20	0.99	9.27	5.03	5.99	5.39	81.09	100.20
QAO-14	1.05	4.10	5.04	5.39	5.26	83.64	103.35
QAO-08	1.20	1.00	4.03	4.36	4.16	95.41	117.89
QAO-W20	2.85	2.12	3.40	3.50	3.44	85.74	89.56
QAO-18	3.15	3.28	3.61	3.82	3.67	76.50	79.91
QAO-W13	5.00	2.02	3.06	3.14	3.09	79.83	83.39
QAO-16	6.15	1.59	2.46	2.49	2.48	86.17	90.01
QAO-W17	7.53	2.12	2.76	2.81	2.78	83.66	87.39
QAO-19	9.90	1.67	2.39	2.44	2.41	92.22	95.74
QAO-W08	10.00	1.60	2.36	2.41	2.38	85.55	89.36
QAO-W41	12.20	0.52	2.28	2.31	2.29	88.20	92.13
QAO-W53	14.68	1.61	2.07	2.11	2.09	86.98	90.86
QAO-W37	17.70	0.93	2.30	2.33	2.32	85.89	89.73
QAO-W63	19.13	0.93	2.34	2.36	2.36	85.87	89.70
QAO-58	23.88	0.79	2.38	2.41	2.39	80.20	83.78
QAO-W36	28.60	0.29	2.21	2.23	2.22	82.87	89.71
QAO-W64	33.55	0.43	3.33	3.40	3.37	89.33	93.60
QAO-W40	39.00	1.39	2.12	2.13	2.12	82.50	89.31
QAO-W27	47.00	0.84	2.19	2.21	2.20	81.60	88.34
QAO-W46	54.30	0.72	2.06	2.09	2.08	83.60	90.51
QAO-W45	62.00	0.42	1.97	1.98	1.98	76.04	82.32
QAO-W51	68.67	1.21	3.05	3.11	3.07	86.96	91.11
QAO-W25	70.00	0.57	2.17	2.19	2.18	81.73	88.48
QAO-W60	92.25	1.40	2.78	2.82	2.79	80.11	83.93
QAO-W33	100.00	0.94	2.04	2.06	2.05	78.18	84.64
QAO-W48	102.70	0.62	1.94	1.95	1.95	82.82	89.66
QAO-W54	116.71	0.69	2.52	2.54	2.53	81.49	85.39
QAO-W57	135.70	1.35	2.58	2.62	2.61	79.98	83.80
QAO-W21	160.00	1.03	2.41	2.44	2.42	81.22	85.10

Sum segments methodology is used for masses below 5g and Combine All is used for masses above 5g.
For masses in the 0-2.5 g range, the 129 keV line is preferred.

5.3 Self-Absorption Uncertainties

Self-absorption uncertainties depend on the quantity of plutonium as a "lump," the "lump" density, and the waste material type. Self-absorption uncertainties are difficult to calculate except for the worst case measurement potentials. Reference 4 provides guidance for the following discussion.

The worst case for a lump causing self-absorption is represented by a spherical metallic source. Reference 2 reports a signal underestimation of 25 % for a Segmented Gamma Scan (SGS) assay of a single 1 gram spherical lump of pure plutonium metal using the ^{239}Pu gamma ray peak at 414 keV, assuming no differential peak correction is applied. The probability of having a single spherical lump of metal waste is highly unlikely. Therefore a more realistic assumption would be a single 1 gram lump of PuO_2 which might be plated onto a pipe, crucible or other matrix form. It can be shown that changing from a metal to an oxide and changing the geometry to a less spherical shape reduces the self-absorption underestimation to less than 5%. Going through the same exercise for a larger single 10-gram spherical lump, the attenuation would be approximately 70%, again assuming no differential peak correction. Reconsidering this as PuO_2 rather than a metal and considering the material in a more plated form greatly reduces the self-absorption effects. Furthermore, the probability of a single 10-gram lump is very low compared to that of a number of smaller lumps summing to 10 grams.

Since it is not possible to directly quantify the extent of any self-absorption in the drums being assayed, the following are assumptions that will be used to determine the self-absorption effect in the TMU analysis. Results are reported as percentages of the assay value.

- For Pu assays < 1 gram: 0%
- For gram loads between 1g < Pu < 10g: 5%
- For gram loads greater than 10 g Pu: 10%

The above discussion, from Reference 4, dictates how uncertainties will be included by the analyst. Lumping effects will be evident through evaluation of the ratio of the 129/414 keV gamma peaks of ^{239}Pu.

5.4 Non-uniform Source Distribution Uncertainties

The most significant source of total measurement uncertainty is the effect of non-uniform source distribution. This effect is dependent on gamma energy and matrix density. The magnitude of this uncertainty was evaluated by performing a series of tests on the WRAP GEA-A gamma assay system.

5.4.1 WRAP GEA Testing (uniform matrix drums - foam, homosote, pressboard)

Measurements were made using a point source (Eu-152) placed in various positions in three uniform matrix drums (foam drum, homosote drum, and pressboard drum). Long count times were used to minimize the random error (counting statistics). Replicate measurements were performed on a routine basis to ensure that the system was functioning within its calculated measurement uncertainties. The densities (g/cc) of the three drums were 0.01 (foam), 0.43 (homosote), and 0.63 (pressboard). The WRAP GEA test plan is included in Appendix A.

The point source was placed at multiple radial and azimuthal positions in the drums and their signals (122 and 344 keV) were measured at each position. The source was moved in 2" vertical increments starting at 1" above the bottom of the drum and ending at 9" above the bottom of the drums (a few measurements were also performed at 15" above the bottom of the drum to ensure that there could be no end effects) in three different radial locations. The three radial locations consisted of Tube 1 (center of the drum), Tube 6 (a position which approximates a uniform distribution response), and Tube 9 (a position next to the drum wall). A point source in Tube 1 typically represents the worst case underestimate for the source positioning error. A point source in Tube 9 typically represents the worst case overestimate for the source positioning error.

Since it is known that the uncertainty caused by the source non-uniformity is a function of both the matrix density and the gamma energy, the source non-uniformity was evaluated for two energies. The 122 keV line from the Eu-152 source represents the response which would be expected for the 129 keV Pu-239 line. The 344 keV line represents the response which would be expected for the 414 keV Pu-239 line. All of the Sum Segments data obtained from this testing is provided in Appendix A.

To determine the source non-uniformity uncertainty for the Sum Segments assay, the data which exhibited variations due to end effects was excluded. The data results indicate that the measurements for the two highest source positions (9" and 15") from the bottom of the drum are not affected by the end effects. Therefore, to evaluate the source non-uniformity, the data from each tube position (9" and 15") was averaged. As discussed in previous TMU analyses (Reference 5), data taken from the center and the outside edge of the drum were considered to be the minimum and maximum extremes and these extremes are considered to be 3 sigma limits.

An exception to the above criteria was the data for the lowest matrix density 0.01 where the center tube (Tube 1) represented an extreme overestimate and the outermost tube (Tube 9) represented the worst case underestimate. The logical explanation for this is that there are two separate effects that relate to the source positioning non-uniformity. These are the absorption of the gamma radiation in the matrix and the pseudo-fan shaped vertical field of view for the detector as the source moves away from the collimator. These effects are opposite effects, i.e., the matrix effect causes the source in the center to be underestimated, and the field of view causes the source in the center to be overestimated. In most cases the matrix effect is the dominant effect, however the 0.01 g/cc matrix provides almost no absorption of the gamma

radiation. Therefore, for this matrix density, the field of view becomes the dominant effect. This was not seen in published Canberra data (Reference 5) because the detection system used for that analysis used uncollimated detectors which allows all detectors to see the full volume of the drum. Since these are opposing effects, it is expected that the source non-uniformity uncertainty for the GEA system will be smaller. This was demonstrated in the testing results.

From the Sum Segments measurements, the range of variation in the signal was plotted as a function of matrix density. In addition, the corresponding maximum and minimum signals were determined as a function of density. In equation form, these maximum and minimum values are given below and are used as a basis for the Sum Segments uncertainty source non-uniformity.

$$EXTREME_{SS}(129keV)_{Max} = 2.1258*Density^2 - 0.4754*Density + 1.2086 \quad \text{(Equation 1)}$$
$$EXTREME_{SS}(129keV)_{Min} = 1.0617*Density^2 - 1.9974*Density + 1.0883 \quad \text{(Equation 2)}$$

$$EXTREME_{SS}(414keV)_{Max} = 1.4743*Density^2 - 0.2773*Density + 0.9534 \quad \text{(Equation 3)}$$
$$EXTREME_{SS}(414keV)_{Min} = 0.1108*Density^2 - 0.8545*Density + 0.8482 \quad \text{(Equation 4)}$$

The data from which these equations were generated are provided in Table 2.

Table 2

Density	129 keV Extremes		414 keV Extremes	
g/cc	Minimum	Maximum	Minimum	Maximum
0.01	1.07	1.20	0.84	0.95
0.43	0.43	1.40	0.50	1.11
0.63	0.26	1.75	0.35	1.36

The minimum and maximum extremes (assuming normality) represent the 3σ lower and 3σ upper limits. The estimated uncertainty (1 RSD) due to non-uniform source distribution is then determined using Equation 5 (thus the factor of 6 in this equation).

$$\text{Non-uniform uncertainty} = (EXTREME_{Max} - EXTREME_{Min})/6 \quad \text{(Equation 5)}$$

Reference 5 (Canberra data) provided the following equations. These equations will be used to estimate the non-uniformity uncertainty for the Combine All measurements. Reference 5 provides the discussion and analysis of the Canberra testing.

$$EXTREME_{CAN}(414keV)_{Max} = -0.238*Density^2 + 1.5131*Density + 1.2189 \quad \text{(Equation 6)}$$
$$EXTREME_{CAN}(414keV)_{Min} = 0.2439*Density^2 - 0.8645*Density + 0.8092 \quad \text{(Equation 7)}$$

The estimated uncertainty (1 RSD) due to non-uniform source distribution is then determined using Equation 5.

5.4.2 WRAP GEA Testing (PDP Combustible drum)

To characterize the source non-uniformity uncertainties, tests were performed on the WRAP GEA system. These tests consisted of performing a number of measurements using the PDP combustibles drum with various source distributions and gram loads. The source positions and total Pu gram loads for each test are listed in Table 3. As can be seen in Table 3, the QAO mass range III and IV configurations represent somewhat distributed sources; therefore, the effects of source non-uniformity should be lessened for these configurations (Reference 6).

The standard deviation listed in Table 4 encompasses several sources of uncertainty (instrument statistics and non-uniformity in particular). If it is assumed that these are the only significant terms, then the effect of the non-uniformity can be calculated.

> For Sum Segments mass range II (129 keV) the standard deviation is 7.51%; if the instrument statistics RSD is 4.60%, then the estimate of the non-uniformity is 5.94% ($0.0594^2 = 0.0751^2 - 0.0460^2$). In comparison, the 129 keV equations (equations 1,2, and 5) calculate an uncertainty of ~10% for a drum with a density ~0.27 g/cc (combustible PDP drum). For Sum Segments mass range II (414 keV) the standard deviation is 6.31%; if the instrument statistics RSD is 6.36%, then the estimate of the non-uniformity is negative or 0.0%. In comparison, the 414 keV equations (equations 3,4, and 5) calculate an uncertainty of ~6% for a drum with a density of ~0.27 g/cc (combustible PDP drum). Equations 1, 2, and 5 (129 keV) or equations 3, 4, and 5 (414 keV) will be used to determine the non-uniformity uncertainty for Sum Segments assay results.
>
> For Combine All mass range II (129 keV) the standard deviation is 12.70%; if the instrument statistics RSD is 5.40%, then the estimate of the non-uniformity is 11.49%. For Combine All mass range II (414 keV) the standard deviation is 15.88%; if the instrument statistics RSD is 6.93%, then the estimate of the non-uniformity is 14.29%. In comparison, if equations 5, 6, and 7 (Canberra testing for the 414 keV peak) are used for the PDP combustibles test drums (density ranged from 0.26 to 0.29g/cc), then the estimate of the non-uniformity would range from 16.6% to 18.0% (1 RSD). To be conservative, equations 5, 6, and 7 (Canberra, 414 keV) will be used to determine the non-uniformity uncertainty for the Combine All assay results.

Figure 6 illustrates the observed densities for 100 PFP waste drums. The majority of the waste drum densities range from 0.08 to 0.34 with a median density of ~0.20 kg/l. The corresponding non-uniformity uncertainties range from 5.0% to 15% (Sum Segments 129 keV equation), 3% to 9% (Sum Segments 414 keV equation), and 10% to 19% (Combine All 414 keV equation).

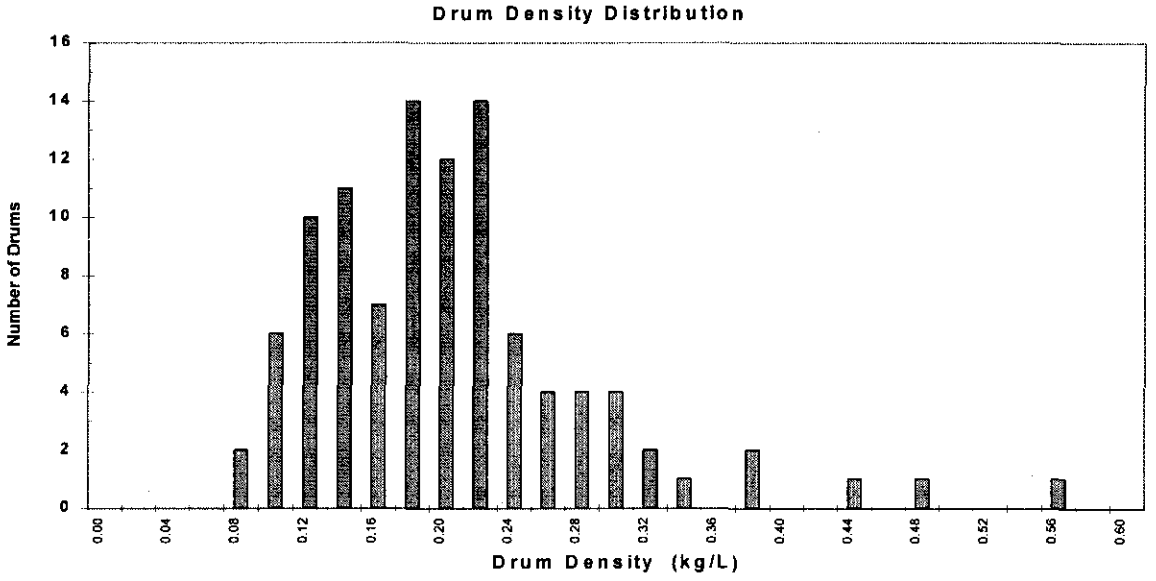


Figure 6. PFP drum density distribution for 100 drums.

5.4.3 Geometry Comparison (Canberra versus WRAP GEA Systems)

Both systems use a shielded assay chamber to minimize background radiation levels. Both systems have multiple vertical detectors along the side of the drum.

The primary difference between the systems is that the WRAP system uses collimation of the detectors which more closely approximates an SGS system, while the Canberra Q2/IQ3 geometry uses uncollimated detectors in a near field geometry.

It would be expected that the WRAP geometry would provide a somewhat lower uncertainty due to source non-uniformity for the following reasons:

1. With the detectors at a greater distance from the side of the drum, there are smaller $1/r^2$ effects particularly for sources near the outside of the drum.

2. Because the detectors are collimated and there are more vertical detector measurements (10 vs 3) for a 55 gallon drum, absorption effects are limited to mostly the radial distance to the center of the drum versus a combination of a radial and vertical term on the Q2/IQ3 systems.

Table 3. QAO Test Configurations

Pu (g)	Item ID	Source Loading T# = Tube #, P# = bottom position of 9" source								
0.03	QAO005	T1,P6 0.03g								
0.06	QAO009	T1,P12 0.03g	T3,P4 0.03g							
0.09	QAO21	T1,P0 0.03g	T2,P10 0.03g	T3,P19 0.03g						
0.09	QAO24	T1,P0 0.03g	T1,P9 0.03g	T1,P18 0.03g						
0.10	QAO23	T1,P12 0.10g								
0.15	QAO11	T1,P6 0.03g	T1,P18 0.03g	T2,P0 0.03g	T2,P12 0.03g	T3,P9 0.03g				
0.33	QAO003	T1,P18 0.03g	T2,P0 0.30g							
0.60	QAO011	T2,P3 0.30g	T3,P12 0.30g							
0.60	QAO10	T2,P9 0.30g	T3,P9 0.30g							
0.63	QAO013	T1,P5 0.03g	T2,P18 0.30g	T3,P12 0.30g						
0.66	QAO001	T1,P3 0.30g	T1,P12 0.03g	T2,P6 0.03g	T3,P15 0.30g					
0.90	QAO2	T1,P9 0.30g	T2,P0 0.30g	T3,P18 0.30g						
0.90	QAO6	T1,P0 0.30g	T1,P9 0.30g	T1,P18 0.30g						
0.96	QAO4	T1,P3 0.30g	T1,P15 0.30g	T2,P0 0.03g	T2,P12 0.03g	T3,P12 0.30g				
0.99	QAO20	T1,P3 0.03g	T1,P15 0.30g	T2,P3 0.30g	T2,P15 0.03g	T3,P0 0.30g	T3,P18 0.03g			
1.05	QAO14	T1,P0 0.03g	T1,P9 0.30g	T1,P18 0.03g	T2,P0 0.03g	T2,P9 0.30g	T2,P18 0.03g	T3,P0 0.03g	T3,P9 0.30g	
1.20	QAO8	T1,P6 0.30g	T1,P15 0.30g	T2,P9 0.30g	T3,P9 0.30g					
2.85	QAOW20	T1,P0 0.05g	T1,P9 1.0g	T1,P18 0.20g	T2,P6 1.0g	T2,P15 0.10g	T3,P9 0.50g			
3.15	QAO18	T1,P0 3.0g	T1,P12 0.03g	T2,P3 0.03g	T2,P15 0.03g	T3,P3 0.03g	T3,P15 0.03g			
5.00	QAOW13	T1,P9 5.0g								
5.00	QAOW16	T1,P8 2.0g	T2,P6 1.0g	T2,P15 0.50g	T3,P3 1.0g	T3,P12 0.50g				
6.15	QAO16	T1,P0 3.0g	T1,P9 0.03g	T1,P18 3.0g	T2,P6 0.03g	T2,P15 0.03g	T3,P6 0.03g	T3,P15 0.03g		

Table 3. QAO Test Configurations (cont.)

Pu (g)	Item ID	Source Loading T# = Tube #, P# = bottom position of 9" source								
7.53	QAOW17	T1,P12 2.0g	T2,P0 0.01	T2,P9 5.0g	T3,P3 0.50g	T3,P12 0.02g				
9.90	QAO19	T1,P6 3.0g	T1,P15 0.30g	T2,P6 0.30g	T2,P15 3.0g	T3,P6 0.30g	T3,P15 3.0g			
9.90	QAO19	T1,P6 3.0g	T1,P15 0.30g	T2,P6 0.30g	T2,P15 3.0g	T3,P6 0.30g	T3,P15 3.0g			
10.00	QAOW08	T1,P0 1.0g	T1,P9 5.0g	T1,P18 2.0g	T2,P9 1.0g	T3,P9 1.0g				
12.20	QAOW41	T1,P6 5.0g	T1,P15 0.50g	T2,P6 0.50g	T2,P15 5.0g	T3,P6 1.0g	T3,P15 0.20g			
14.68	QAOW53	T1,P0 2.0g	T1,P9 5.0g	T1,P18 5.0g	T2,P0 0.50g	T2,P9 0.02	T2,P18 0.05g	T3,P0 0.10g	T3,P9 1.0g	T3,P18 1.0g
17.70	QAOW37	T1,P6 5.0g	T1,P15 0.20g	T2,P9 10.0g	T2,P18 0.50g	T3,P0 1.0g	T3,P18 1.0g			
19.13	QAOW63	T1,P1 1.0g	T1,P12 10.0g	T1,P21 0.10g	T2,P0 0.50g	T2,P12 5.0g	T2,P21 0.02g	T3,P0 0.50g	T3,P12 2.0g	T3,P21 0.01
23.88	QAOW58	T1,P3 0.50g	T1,P12 20.0g	T1,P21 0.20g	T2,P3 1.0g	T2,P12 2.0g	T2,P21 0.10g	T3,P3 0.05g	T3,P12 0.02	T3,P21 0.01
28.60	QAOW36	T1,P9 20.0g	T1,P18 0.10g	T2,P0 0.50g	T2,P15 5.0g	T3,P3 2.0g	T3,P18 1.0g			
33.55	QAOW64	T1,P5 1.0g	T1,P14 10.0g	T2,P6 0.50g	T2,P15 0.05g	T3,P9 2.0g	T3,P18 20.0g			
39.00	QAOW40	T1,P5 20.0g	T1,P14 2.0g	T2,P3 1.0g	T2,P12 10.0g	T3,P6 1.0g	T3,P15 5.0g			
47.00	QAOW27	T1,P6 2.0g	T1,P15 40.0g	T3,P5 5.0g						
54.30	QAOW46	T1,P0 5.0g	T1,P9 10.0g	T1,P18 5.0g	T2,P0 0.10g	T2,P9 1.0g	T2,P18 2.0g	T3,P0 30.0g	T3,P9 1.0g	T3,P18 0.20g
62.00	QAOW45	T1,P3 40.0g	T2,P0 0.50g	T2,P9 1.0g	T2,P18 0.50g	T3,P15 20.0g				
68.67	QAOW51	T1,P0 0.10g	T1,P9 20.0g	T1,P18 5.0g	T2,P0 0.05g	T2,P9 0.50g	T2,P18 2.0g	T3,P0 0.02g	T3,P9 1.0g	T3,P18 40.0g
70.00	QAOW25	T1,P13 30.0g	T2,P3 5.0g	T2,P12 10.0g	T3,P0 5.0g	T3,P16 20.0g				
92.25	QAOW60	T1,P2 30.0g	T1,P11 20.0g	T1,P20 1.0g	T2,P2 40.0g	T2,P11 1.0g	T2,P20 0.005g	T3,P2 0.20g	T3,P11 0.05g	
100.00	QAOW33	T1,P0 5.0g	T1,P9 20.0g	T2,P6 30.0g	T2,P15 5.0g	T3,P9 40.0g				
102.70	QAOW48	T1,P2 1.0g	T1,P11 50.0g	T1,P20 1.0g	T2,P2 30.0g	T2,P11 0.20g	T2,P20 5.0g	T3,P2 10.0g	T3,P11 5.0g	T3,P20 0.50g
116.71	QAOW54	T1,P2 50.0g	T1,P11 20.0g	T1,P20 10.0g	T2,P2 5.0g	T2,P11 30.0g	T2,P20 1.0g	T3,P2 0.50g	T3,P11 0.20g	T3,P20 0.01g
135.70	QAOW57	T1,P2 50.0g	T1,P11 30.0g	T1,P20 5.0g	T2,P0 40.0g	T2,P9 10.0g	T2,P18 1.0g	T3,P3 1.0g	T3,P12 0.50g	
160.00	QAOW21	T1,P10 50.0g	T1,P19 20.0g	T2,P10 5.0g	T2,P19 30.0g	T3,P1 40.0g	T3,P10 10.0g	T3,P19 5.0g		

5.5 Matrix Effects

Uncertainties due to matrix absorption are small for low density matrices. The GEA software corrects for the absorption by calculating the matrix density using the transmission correction technique. This technique measures the absorption of the gamma radiation for the matrix by beaming an external source through the drum with a gamma energy close to the energy of the primary assay peak. This directly accounts for both the density and the Z effects of the matrix. Therefore the effects of the elemental composition of the matrix are directly accounted for in the correction technique. The algorithms and propagation of uncertainties are found in Reference 3.

Since the GEA assays the drum in small vertical segments, each of which receives a transmission correction, the vertical component of waste matrix inhomogeneity is adequately corrected. This minimizes the potential uncertainty associated with stratified matrices of differing densities.

Document WMH-350 Section 2.2 limits the potential matrix effects which can be considered by requiring special reviews when the transmission ratio is less than 5%.

The uncertainty associated with a heterogeneous matrix distribution can be estimated using test drums. Various masses of weapons grade plutonium in the form of NIST traceable standards were placed in PDP matrices 001 (empty) and 003 (combustibles). The sources were placed at multiple radials (center, 6" from center, outside edge) and vertical positions (various inches as measured from the bottom of the drum) in the drum.

The GEA data generated from the measurements of the empty test drums containing the NIST traceable standards and the PDP empty drums indicate that a bias exists in the measurements. The bias is associated with the configuration of the standards and the construction of the test drum. For each QAO range (listed as I, II, III, or IV in Tables 4 and 10), data from the PDP empty test drum measurements were used to determine the applicable bias correction factor. All combustibles test drum results (see the "%R" columns) were then adjusted (dividing by the correction factor) to determine the matrix effect. The adjusted combustibles test drum measurements are listed in Tables 1.A – 1.F (see the "%R Adj" column). The summary statistics for each QAO range are listed in Table 4. The data in Table 4 indicate that the matrix uncertainty (estimated from the PDP combustibles drum results) ranges from 4% to 21% with an average of 11.3% (n=15). It should be noted that this uncertainty represents a single data point with respect to the overall matrix uncertainty. The use of "bias" (absolute value of the difference of the mean from 100%) as the uncertainty is discussed in Reference 7.

As discussed in Reference 4, the measurement uncertainty associated with a heterogeneous matrix distribution was evaluated by modeling the response of a measurement segment. The results of the modeling indicated a matrix uncertainty of 12%. To be conservative, the WRAP TMU calculations will use 12% as the matrix uncertainty instead of 11.3% (as determined from the PDP combustible drum data).

Table 4

Combustibles Drum – Summary Statistics (Values in %)							
Mass Range		Sum Segments			Combine All		
		375 keV	129 keV	414 keV	375 keV	129 keV	414 keV
I	N		4				
	Mean		108.28				
	StdDev		11.47				
	Sxbar		5.74				
	Bias		8.28				
II	N		9	9		9	9
	Mean		108.24	90.36		90.18	93.32
	StdDev		7.51	6.31		12.70	15.88
	Sxbar		2.50	2.10		4.23	5.29
	Bias		8.24	9.64		9.82	6.68
III	N	12	12	12	12	12	12
	Mean	85.30	103.88	85.91	86.67	79.27	88.46
	StdDev	5.37	11.47	4.44	4.11	8.09	4.28
	Sxbar	1.55	3.31	1.28	1.19	2.34	1.24
	Bias	14.70	3.88	14.09	13.33	20.73	11.54
IV	N	14		14	14		14
	Mean	88.90		89.60	85.92		87.56
	StdDev	4.83		5.41	3.81		3.34
	Sxbar	1.29		1.45	1.02		0.89
	Bias	11.10		10.40	14.08		12.44

notes

I, II, III, & IV refer to the QAO mass ranges, where I is less than 0.25g WG Pu, etc.

The 375 keV, 129 keV, and 414 keV headings refer to Pu-239 energy peaks; these correspond to "Pu-239," "Pu-239A," and "Pu-239B," respectively, on the GEA report.

A dark shaded area indicates that the energy line in question is not used in that particular mass range.

Bias: the absolute value of the difference between the mean value and 100 %.

StdDev = Standard deviation.

Sxbar = StdDev/Sqrt(N)

5.6 End Effects

The following section evaluates the potential problems related to end effects for the GEA system.

5.6.1 Measurement Geometry

As noted from the previous documentation the drum is assayed in 10 vertical segments with a segment separation of 8.9 cm.

The bottom segment is measured with the bottom of the collimator physically lined up with the bottom of the drum. This is labeled as segment 2 in the assay report.

There is a traditional technique in SGS measurements which is used to minimize bottom end effect problems. In this technique the drum is placed on a low Z pedestal, and the segmented measurements begin one segment below the bottom of the drum. This technique is known as underscanning. The capability exists to have a segment that would underscan the drum by 8.9 cm, but this segment was dropped from both the calibration and analysis since the transmission source would be passing through the mechanical structure and therefore would always have a minimum transmission (see Figure 3).

The top segment encompasses the top of the drum and includes void space and lid (see Figure 1).

5.6.2 Acceptable Knowledge Related to Drum Packing

Drums being assayed under this classification are packaged to a procedure which requires at least 1 inch of absorbing material placed at the bottom of the drum prior to loading. From an end effect concern this ensures that the waste materials are at least 1 inch above the bottom of the drum.

A review of NDE data shows that most drums are only filled to 60% - 80% of the drum height. Therefore end effects at the top of the drum are not expected to be a problem.

5.6.3 Discussion of the Causes of End Effects

In a traditional SGS calibration, the corrected net area counts are added for each segment and a response calibration is performed on the final sum of the corrected counts. Therefore the count rate from each segment is assigned an equal weight.

The end effect hypothesis raises an issue with this type of calibration because the detector collimation allows the detector to view a larger non-drum volume with only a fraction of the

drum included. A normal segment views a cylindrical volume of an assayed drum. Therefore, material which is not near to the bottom or top of the drum is actually counted and added into the total corrected net area counts over the adjacent segments above and below the segment where the source material is located. Material located only at the bottom of the drum receives counts from the measurement segment and an adjacent segment above the bottom of the drum. Thus the analytical results for that segment are potentially underestimated because of not receiving count contributions from the adjacent segment below the source material.

5.6.4 WRAP GEA Calibration Technique

On the WRAP GEA system an efficiency (response) calibration is performed for each vertical segment of the system. During an assay the actual quantified results for each segment are added to provide a final summed value for the drum.

A review of the calibration curves for the segments (Reference 8) shows that the efficiency response for the bottom segment is significantly lower than the segments in the center of the drum. (See Reference 8 page E-3 for the bottom segment as compared to Reference 8 page E-12 for a segment near the middle of the drum.)

A lower efficiency curve will produce a higher activity result for the same net area counts. Therefore material which is in the bottom segment of the drum is given a heavier weight based on the efficiency curve, to offset the losses which occur in not under-scanning the drum.

5.6.5 End Effect Uncertainty for this TMU Analysis

5.6.5.1 Sum Segments

A series of tests was performed on the WRAP GEA-A gamma assay system to more accurately quantify source non-uniformity and end effects for calculating the total measurement uncertainty (TMU). The testing was previously described in the non-uniformity uncertainty section. In order to analyze the end effects as an individual uncertainty term, the source non-uniformity uncertainty must be removed from the data. A normalizing factor was created for each of the three tube positions from the data results from the 9" and 15" positions (data used to estimate non-uniformity uncertainty). The ratio of the averaged result from the non end effect data (9" and 15") to the known value was calculated for each tube position to eliminate the radial non-uniformity effects.

The following graphs (Figures 7 and 8) illustrate the data results using the normalized data for the Sum Segment results. Multiple measurements at a specified position and density were averaged. The data show that with the source 1" from the bottom of the drum there is approximately a 23% underestimate in the assay result. The average percent recovery was 77.22% (9 measurements) with a standard deviation of 13.71% and a standard error of 4.57%. The small variations in the curve shapes are most probably due to the combination of counting

statistics, normalization uncertainties, and matrix correction uncertainties.

When the source is in the 1" height position for any of the tube positions and drum densities, at least 50% of the activity is measured in the first segment. Therefore the criteria for applying an end effects correction will be that at least 50% of the activity is in the first segment. If the end effect error is known to exist, a correction of 23% will be applied to the assay result (i.e., assay result * 1.23). A 5% (1 RSD) uncertainty is associated with the end effect correction.

Figure 7

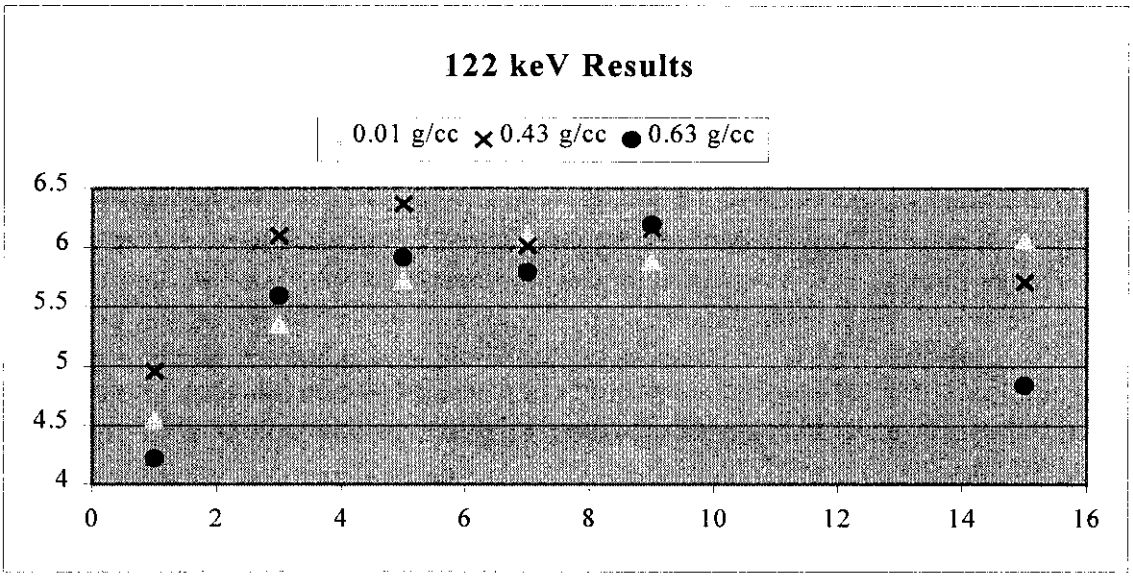
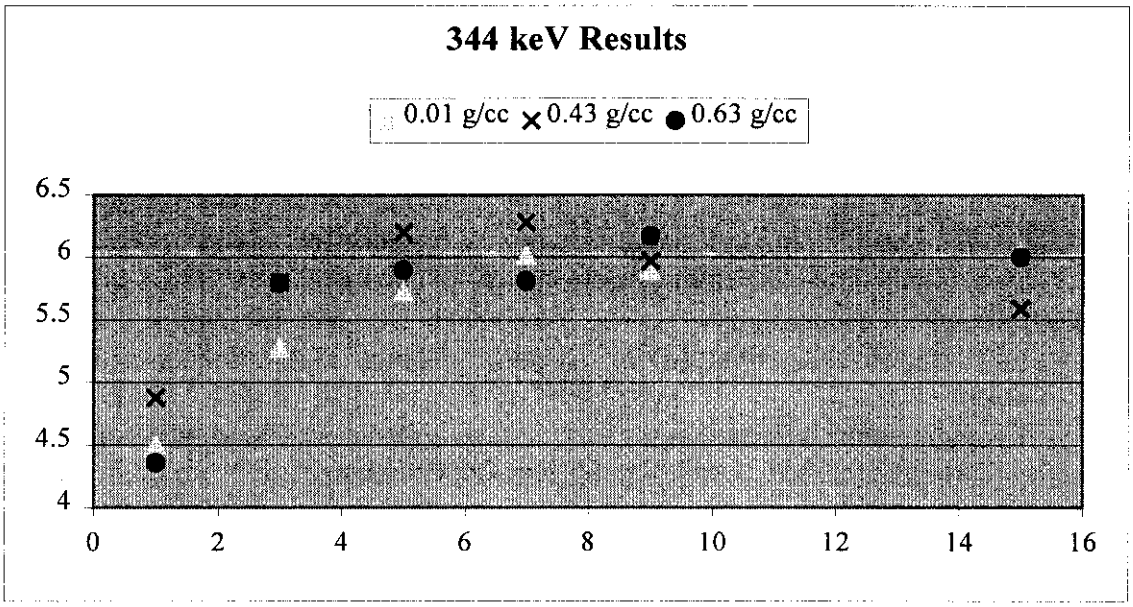


Figure 8



5.6.5.2 Combine All

The end effect data analysis for the Combine All measurements (obtained during the WRAP testing, discussed previously) has not been completed. The data review process will use a conservative approach of setting aside any drum with a Combine All assay result where 50% or more of the total drum activity is located in the bottom 2 segments, as having a potential problem with end effects. These drums will be reanalyzed with the GEA system after a more definitive end effect uncertainty for the Combine All assay measurement is established.

The choice of 50% is based on the fact that the end effect problem in traditional SGS measurements is typically in the range of 30% for the adjacent segment and 15% for the second segment. Therefore, assuming the activity distribution in the bottom two segments as divided equally, the overall uncertainty for the total measurement would be approximately 11.5% (Reference 9).

5.7 Uncertainty Associated With Isotopic Analyses

All waste drums received from PFP have isotopic data (AK). The WRAP GEA system has two low energy high-resolution germanium detectors used to measure the isotopic breakdown (MGA software). The following sections address how the uncertainties associated with isotopics from either the AK or the MGA data have been developed. In general the MGA results and uncertainties will be used for assay results except when the MGA results are questionable. Acceptability criteria for the MGA results are defined in the data analysis procedure WMH-350 section 2.2.

5.7.1 AK Data

AK data, although an essential part of waste characterization, can easily be the source of the largest uncertainty associated with NDA analysis. This is due to the nature of AK, which is often gathered through a compilation of decades-old records, "process knowledge," and interviews with workers. Process knowledge and interviews are entirely subjective in nature, and past records are often suspect since the regulatory scrutiny encountered today did not exist when the records were generated.

At the Plutonium Finishing Plant at Hanford, which is projected to be the source of WRAP's initial TRU waste stream, process knowledge of one (or more) data component is based on analytical measurements.

5.7.1.1 SGSAS Analyzed Drums (at PFP)

At PFP all drums that the Sodium Iodide (NaI) package counter measures at greater than 10g Pu are assayed using a segmented gamma scan assay system (SGSAS). Since January 1996, a germanium detector has obtained plutonium isotopic data at the same time as the SGSAS analysis. Multi-Group Analysis (MGA) software, a code originally developed by Dr. R. Gunnink, is used to evaluate the isotopic data. The MGA software code provides an estimate of the random uncertainty based on the counting statistics. The PFP MGA generated uncertainties based on the counting statistics are not available.

At PFP, two isotopic standards (one with a ^{240}Pu weight percent of approximately 6% and the other with a ^{240}Pu weight percent of approximately 18%) are analyzed at a frequency of once per week. The standards data provide both random and systematic uncertainty estimates. These uncertainty estimates, by isotopic content, are listed in Table 5. The uncertainty estimates for material consisting of 12% ^{240}Pu, should be bounded by the uncertainty estimates provided for the 18% ^{240}Pu standard and the 6% ^{240}Pu standard. Therefore, the uncertainty estimates based on the 6% ^{240}Pu standard will be used for material identified as containing up to12% ^{240}Pu; the uncertainty estimates based on the 18% ^{240}Pu standard will be used for material containing more than 12% ^{240}Pu.

The total uncertainty for the isotopic measurements for SGSAS analyzed drums is also listed in Table 5. The total uncertainty is calculated using the following formula:

$$\sigma_{total}^2 = \sigma_{ran}^2 + \sigma_{sys}^2 + \sigma_{source}^2 \qquad \text{(Equation 8)}$$

where the random uncertainty is estimated from the replicate measurements of the standards (data generated between 2/27/96 and 10/8/99) and not from the MGA counting statistics. The use of this equation to calculate the estimate of the total uncertainty is discussed in Reference 7.

5.7.1.2 NaI Analyzed Drums (at PFP)

The PFP drums that measure less than 10g Pu on the NaI package counter are given isotopic values based on 1990 process data. Production data from 67 items (generated during the campaign prior to October 1990) were compiled and decay corrected to a common date. The average isotopic composition was then calculated from the 67 isotopic measurements. The average isotopic composition is decayed to the 15th of the current month and the resulting isotopic composition is assigned to all waste drums that are measured using the NaI package counter during that month. This assumes that the isotopic content of the material contained in current waste drums is the same as the material processed in the campaign prior to October 1990.

The analysis of standards at PFP has not significantly changed since 1990; standards are still analyzed approximately once a week. Standards data provide both random and systematic uncertainty estimates. Data generated using the 6% ^{240}Pu standard prior to October 1990 were used to estimate the random and systematic uncertainty associated with the 1990 isotopic measurements. In addition, the uncertainty (representing the heterogeneity of the process material) in the average isotopic composition was calculated from the 67 historic isotopic measurements. The individual uncertainty components and the total uncertainty for the isotopic measurements for the NaI analyzed drums are listed in Table 6. The total uncertainty is calculated using a formula similar to that provided previously, but with an extra term for the process uncertainty.

Table 5 Current PFP Isotopic Uncertainty Values

6% ^{240}Pu Isotopic Standard (as of 1/98)	Random Uncertainty 1σ (%)	Systematic Uncertainty 1σ (%)	Uncertainty in the Standard Value 1σ (%)	Total Uncertainty 1σ (%)
^{238}Pu (0.009)	13.08	9.87	0.6	16.4
^{239}Pu (93.950)	0.11	0.05	0.003	0.12
^{240}Pu (5.861)	1.70	0.93	0.06	1.94
^{241}Pu (0.152)	1.16	1.02	1.04	1.86
^{242}Pu (0.029)	NA	NA	5.0	NA
^{241}Am (0.223)	0.91	0.46	0.4	1.10
18% ^{240}Pu Isotopic Standard (as of 7/86)	Random Uncertainty 1σ (%)	Systematic Uncertainty 1σ (%)	Uncertainty in the Standard Value 1σ (%)	Total Uncertainty 1σ (%)
^{238}Pu (2.675)	3.50	5.50	2.03	6.83
^{239}Pu (77.531)	0.58	0.57	0.014	0.81
^{240}Pu (18.760)	2.19	0.16	0.044	2.20
^{241}Pu (2.232)	1.95	2.27	1.11	3.19
^{242}Pu (1.210)	NA	NA	0.624	NA
^{241}Am (3.576)	1.45	5.28	0.984	5.56

Table 6 Historical PFP Isotopic Uncertainty Values

6% ^{240}Pu Isotopic Standard	Random Uncertainty 1σ (%)	Systematic Uncertainty 1σ (%)	Process Uncertainty 1σ (%)	Uncertainty in the Standard Value 1σ (%)	Total Uncertainty 1σ (%)
^{238}Pu	13.11	7.45	1.12	0.6	15.13
^{239}Pu	0.26	0.16	0.06	0.003	0.31
^{240}Pu	4.19	2.61	0.59	0.06	4.97
^{241}Pu	0.67	0.15	0.99	1.04	1.59
^{242}Pu	NA	NA	NA	5.0	NA
^{241}Am	2.50	4.74	5.96	0.4	8.02

Other waste streams will be analyzed for AK reliability as they are identified.

5.7.2 WRAP MGA Data

The WRAP plutonium isotopics measurement system utilizes two low energy, high resolution, germanium detectors for the assay data collection. A version of the MGA software code, which has been optimized for waste measurements, is used to evaluate the data. MGA utilizes the low energy gamma and x-ray lines (primarily in the 100-300 keV energy range) from the plutonium isotopes to calculate the relative abundance for each of the plutonium isotopes, as well as a few other actinides (e.g., ^{241}Am) which are frequently found in the plutonium spectra.

Performance testing was completed to evaluate the precision and accuracy of the plutonium isotopic measurements on the WRAP GEA-A assay system. The performance testing utilized two PDP drums (empty and combustibles matrices) and several weapons grade plutonium sources. It should be noted that the configuration of the drums and sources used in the testing causes a significant absorption of the low energy lines used for the MGA analysis. Therefore, in actual waste drums the assay results may be better than the performance testing results. Summary statistics for the performance testing are listed in Tables 7A and 7B.

5.7.2.1 Pu ^{238}

Analysis of the MGA testing results shows that the measured and uncertainty values for ^{238}Pu can be quite volatile, especially in the case of low Pu mass. MGA relies primarily on the 99 keV peak for ^{238}Pu, but also analyzes the less abundant 152 keV peak since the area around 100 keV is often too cluttered with various gammas and x-rays to isolate the 99 keV peak (Reference 11). In cases of low Pu mass or high absorption in the 100-200 keV range, the ^{238}Pu peaks are often too small for the MGA software to discern their presence. Occasionally in such cases, the ^{238}Pu weight fraction and uncertainty algorithms break down, producing rather outlandish results. Table 8 shows examples taken from the MGA test runs which illustrate both extremes of this phenomenon, as well as more typical results.

The actual isotopic fraction for ^{238}Pu in the test sources, decayed to the date of testing, is 0.014. A quick look shows that the most accurate measured values have an uncertainty in the 50-70% range. As the measured value decreases in relation to the actual value, the associated uncertainty increases; when the measured value increases in relation to the actual value, the associated uncertainty value decreases. While the relationship between the measured and uncertainty values is clearly an inverse one, the MGA ^{238}Pu algorithms are not documented in sufficient detail to offer an explanation for the extreme results. The shaded areas indicate so-called extreme results. The lowest measured values have associated uncertainty values in the thousands of percent, which is clearly unrealistic. However, the uncertainty for relative abundance to ^{239}Pu for these counts is in the range of 200%, which is much more acceptable for analysis. The highest measured values are 400-500% of the actual value, and have associated uncertainty values in the 30-40% range, which is clearly not representative of the actual uncertainty but is more acceptable than thousands of percent.

In most cases where an extreme result is given, the other detector gives an acceptable result. In these instances, the better result will be used as long as the other isotopes pass the reliability tests

laid out in WMH-350, Section 2.2. There will be cases where the isotopes other than ^{238}Pu are acceptable, but neither detector gives a plausible ^{238}Pu uncertainty for measured weight percent. In cases where the measured weight percent uncertainty is greater then 200%, this uncertainty will be compared to the uncertainty for relative abundance to ^{239}Pu, and the smaller uncertainty will be selected. This effectively caps most uncertainty values at about 200%, with some uncertainty values potentially reaching 600% for ^{238}Pu. Again, this method only holds true if the other isotopes pass the reliability tests in WMH-350, Section 2.2.

This phenomenon is only present when there is a small amount of weapons grade Pu. At higher masses (above ~1 gram) or at other enrichments (i.e., 88% ^{239}Pu), the amount of ^{238}Pu is significant enough to be properly detected. It should also be noted that ^{238}Pu only affects thermal power at lower enrichments; it is not a significant contributor in weapons grade Pu.

5.7.2.2 Pu^{239}

5.7.2.2.1 Empty Drum

Analysis of the LeGe-5 and the LeGe-6 MGA testing results shows that the measured values for ^{239}Pu in the empty drum are not significantly different from 100% (two-sided test at the 0.05 significance level) for plutonium masses ranging from 0.5g to 80g. The counting statistics, which estimate the random uncertainty, are close to the uncertainty estimates generated from the replicate measurements except for the LeGe-6 measurements of the 0.5g Pu standard (a factor of three difference).

5.7.2.2.2 Combustible Drum

Analysis of the LeGe-5 and the LeGe-6 MGA results (5g source) for ^{239}Pu in the combustibles drum indicate that the random uncertainty estimated from the counting statistics is usually lower than the random uncertainty estimated from the replicate measurements. The ratio of the two random uncertainty values ranges from 1.4 to 2.4 for LeGe-5 and from 0.5 to 2.3 for LeGe-6. Therefore, to be conservative, the estimate of the random uncertainty, as generated from the counting statistics, will be multiplied by 2 for the TMU calculations.

The variability observed in the data is due to source position heterogeneity and random uncertainty. The average over the six source positions should minimize the effect of the source heterogeneity. The average percent recovery for the six averages (assumes equal weight for each different source position and does not take into account the number of replicates from each source position) is 100.59% for LeGe-5 and 100.66% for LeGe-6. Rounding to one significant digit, the estimate of the systematic uncertainty is 1%.

5.7.2.3 Pu^{240}

5.7.2.3.1 Empty Drum

Analysis of the LeGe-5 and the LeGe-6 MGA testing results shows that the measured values for ^{240}Pu in the empty drum are not significantly different from 100% (two-sided test at the 0.05 significance level) for plutonium masses ranging from 0.5g to 80g. The counting statistics, which estimate the random uncertainty, are close to the uncertainty estimates generated from the replicate measurements except for the LeGe-6 measurements of the 0.5g Pu standard (a factor of approximately 4 difference).

5.7.2.3.2 Combustible Drum

Analysis of the LeGe-5 and the LeGe-6 MGA results (5g source) for ^{240}Pu in the combustibles drum indicate that the random uncertainty estimated from the counting statistics is usually lower than the random uncertainty estimated from the replicate measurements. The ratio of the two random uncertainty values ranges from 1.0 to 2.5 for LeGe-5 and from 0.6 to 2.1 for LeGe-6. Therefore, to be conservative, the estimate of the random uncertainty, as generated from the counting statistics, will be multiplied by 2 for the TMU calculations.

The variability observed in the data is due to source position heterogeneity and random uncertainty. The average over the six source positions should minimize the effect of the source heterogeneity. The average percent recovery for the six averages (assumes equal weight for each different source position and does not take into account the number of replicates from each source position) is 91.88% for LeGe-5 and 90.53% for LeGe-6. Rounding to one significant digit, the estimate of the systematic uncertainty is 8% for LeGe-5 and 9% for LeGe-6.

5.7.2.4 Pu^{241}

5.7.2.4.1 Empty Drum

Analysis of the LeGe-5 and the LeGe-6 MGA testing results shows that the measured values for ^{241}Pu in the empty drum are not significantly different from 100% (two-sided test at the 0.05 significance level) for plutonium masses ranging from 0.5g to 80g, except for the LeGe-6 measurement of the 0.5g source (~90% recovery). The counting statistics, which estimate the random uncertainty, are close to the uncertainty estimates generated from the replicate measurements (ratio of the two uncertainty values range from 0.3 to 1.5).

5.7.2.4.2 Combustible Drum

Analysis of the LeGe-5 and the LeGe-6 MGA results (5g source) for ^{241}Pu in the combustibles drum indicate that the random uncertainty estimated from the counting statistics is usually lower than the random uncertainty estimated from the replicate measurements. The ratio of the two random uncertainty values ranges from 0.5 to 1.2 for LeGe-5 and from 0.4 to 1.2 for LeGe-6.

Therefore, to be conservative, the estimate of the random uncertainty, as generated from the counting statistics, will be multiplied by 2 for the TMU calculations.

The variability observed in the data is due to source position heterogeneity and random uncertainty. The average over the six source positions should minimize the effect of the source heterogeneity. The average percent recovery for the six averages (assumes equal weight for each different source position and does not take into account the number of replicates from each source position) is 80.69% (standard deviation of 7.68) for LeGe-5 and 88.94% (standard deviation of 7.55) for LeGe-6. The hypothesis that these two means are equal cannot be rejected at the 0.05 level of significance (two-sided hypothesis testing). Rounding to one significant digit, the estimate of the systematic uncertainty is 19% for LeGe-5 and 11% for LeGe-6. Since the hypothesis that two means are not equal was not rejected, the difference in the systematic uncertainty is not a cause for concern.

5.7.2.5 Am^{241}

5.7.2.5.1 Empty Drum

Analysis of the LeGe-5 and the LeGe-6 MGA testing results shows that the measured values for ^{241}Am in the empty drum are not significantly different from 100% (two-sided test at the 0.05 significance level) for plutonium masses ranging from 0.5g to 80g. The counting statistics, which estimate the random uncertainty, are close to the uncertainty estimates generated from the replicate measurements except for the LeGe-6 measurements of the 0.5g Pu standard (a factor of approximately two difference).

5.7.2.5.2 Combustible Drum

Analysis of the LeGe-5 and the LeGe-6 MGA results (5g source) for ^{241}Am in the combustibles drum indicate that the random uncertainty estimated from the counting statistics is usually lower than the random uncertainty estimated from the replicate measurements. The ratio of the two random uncertainty values ranges from 1.3 to 2.4 for LeGe-5 and from 0.6 to 2.1 for LeGe-6. Therefore, to be conservative, the estimate of the random uncertainty, as generated from the counting statistics, will be multiplied by 2 for the TMU calculations.

The variability observed in the data is due to source position heterogeneity and random uncertainty. The average over the six source positions should minimize the effect of the source heterogeneity. The average percent recovery for the six averages (assumes equal weight for each different source position and does not take into account the number of replicates from each source position) is 99.85% (standard deviation of 7.95) for LeGe-5 and 97.40% (standard deviation of 8.09) for LeGe-6. The hypothesis that these two means are equal cannot be rejected at the 0.05 level of significance (two-sided hypothesis testing). Rounding to one significant digit, the estimate of the systematic uncertainty is 0.2% for LeGe-5 and 3% for LeGe-6. Since the hypothesis that two means are not equal was not rejected, the difference in the systematic uncertainty is not a cause for concern.

5.7.3 Summary

The uncertainty components (random, systematic, and source) for all isotopes are listed in Table 9. The total uncertainty for isotopes (other than ^{238}Pu and ^{242}Pu) is a combination of the individual components, per Equation 8. For ^{238}Pu, total uncertainty is as described above. Since ^{242}Pu is reported by MGA based upon an algorithmic method, with no direct measurement, total uncertainty is twice the absolute value of the stated counting statistics error.

Table 7A. Detector LeGe-5 Test Data

g Pu	Drum	Position	Isotope	Detector	N	%REC mean	%REC std dev	CtStat% Mean	CtStat% Min	CtStat% Max
5	C	T1 P11	Pu-238	5	6	42.79	49.13	4081.91	52.11	10231.00
5	C	T3 P11	Pu-238	5	5	64.99	33.73	168.48	42.26	648.00
5	C	T1 P0	Pu-238	5	4	169.23	218.06	196.57	33.34	526.70
5	C	T3 P0	Pu-238	5	7	107.37	93.67	1489.01	33.74	9657.00
5	C	T1 P21	Pu-238	5	7	85.57	63.76	247.14	25.04	791.70
5	C	T3 P21	Pu-238	5	1	79.71	NA	36.10	36.10	36.10
0.5	E	T1 P11	Pu-238	5	3	4.38	4.83	7646.43	896.30	18573.00
20	E	T1 P11	Pu-238	5	2	113.68	20.35	14.71	12.66	16.75
50	E	T1 P11	Pu-238	5	3	109.57	5.69	12.67	12.29	13.26
80	E	T1 P6,15	Pu-238	5	2	103.68	12.07	10.88	10.16	11.60
5	C	T1 P11	Pu-239	5	6	100.66	1.45	0.67	0.47	0.95
5	C	T3 P11	Pu-239	5	5	99.83	1.23	0.50	0.40	0.72
5	C	T1 P0	Pu-239	5	4	100.74	1.96	1.10	0.72	1.83
5	C	T3 P0	Pu-239	5	7	101.56	1.07	0.79	0.54	1.17
5	C	T1 P21	Pu-239	5	7	100.87	0.98	0.51	0.41	0.61
5	C	T3 P21	Pu-239	5	1	99.87	NA	0.35	0.35	0.35
0.5	E	T1 P11	Pu-239	5	3	100.37	1.15	1.31	0.97	1.80
20	E	T1 P11	Pu-239	5	2	100.10	0.18	0.19	0.19	0.19
50	E	T1 P11	Pu-239	5	3	99.95	0.22	0.16	0.16	0.16
80	E	T1 P6,15	Pu-239	5	2	99.99	0.15	0.13	0.13	0.13
5	C	T1 P11	Pu-240	5	6	91.10	22.20	11.32	9.59	15.43
5	C	T3 P11	Pu-240	5	5	103.59	19.23	7.58	6.89	8.19
5	C	T1 P0	Pu-240	5	4	89.47	30.43	19.05	15.01	20.82
5	C	T3 P0	Pu-240	5	7	76.71	16.40	16.34	14.16	20.07
5	C	T1 P21	Pu-240	5	7	87.50	14.79	9.03	7.40	12.36
5	C	T3 P21	Pu-240	5	1	102.92	NA	5.34	5.34	5.34
0.5	E	T1 P11	Pu-240	5	3	95.14	17.43	22.16	15.54	32.22
20	E	T1 P11	Pu-240	5	2	98.89	2.76	3.03	3.03	3.03
50	E	T1 P11	Pu-240	5	3	101.18	3.47	2.46	2.37	2.51
80	E	T1 P6,15	Pu-240	5	2	100.63	2.34	2.04	1.98	2.09
5	C	T1 P11	Pu-241	5	6	73.35	24.78	47.34	8.88	184.00
5	C	T3 P11	Pu-241	5	5	91.72	12.77	10.26	6.25	15.25
5	C	T1 P0	Pu-241	5	4	76.44	17.20	23.90	15.92	37.57
5	C	T3 P0	Pu-241	5	7	74.90	15.66	17.62	14.42	21.38
5	C	T1 P21	Pu-241	5	7	79.00	24.81	33.46	5.55	91.44
5	C	T3 P21	Pu-241	5	1	88.74	NA	5.00	5.00	5.00

Table 7A. Detector LeGe-5 Test Data (cont.)

g Pu	Drum	Position	Isotope	Detector	N	%REC mean	%REC std dev	CtStat% Mean	CtStat% Min	CtStat% Max
0.5	E	T1 P11	Pu-241	5	3	91.32	23.15	21.15	14.46	28.78
20	E	T1 P11	Pu-241	5	2	102.64	3.09	2.42	2.40	2.44
50	E	T1 P11	Pu-241	5	3	101.58	4.41	2.96	1.93	3.63
80	E	T1 P6,15	Pu-241	5	2	100.08	0.51	1.66	1.63	1.69
5	C	T1 P11	Am-241	5	6	94.16	25.29	12.61	8.88	19.20
5	C	T3 P11	Am-241	5	5	111.00	18.56	7.72	6.45	8.83
5	C	T1 P0	Am-241	5	4	104.64	22.59	17.95	15.33	21.46
5	C	T3 P0	Am-241	5	7	89.03	33.41	16.95	12.34	20.23
5	C	T1 P21	Am-241	5	7	97.04	19.43	9.78	7.30	15.04
5	C	T3 P21	Am-241	5	1	103.23	NA	5.88	5.88	5.88
0.5	E	T1 P11	Am-241	5	3	91.51	6.73	24.17	18.68	34.78
20	E	T1 P11	Am-241	5	2	101.55	0.27	3.17	3.14	3.20
50	E	T1 P11	Am-241	5	3	101.02	2.23	2.59	2.50	2.65
80	E	T1 P6,15	Am-241	5	2	100.67	2.56	2.13	2.08	2.17

Table 7B. Detector LeGe-6 Test Data

G Pu	Drum	Position	Isotope	Detector	N	%REC mean	%REC std dev	CtStat% Mean	CtStat% Min	CtStat% Max
5	C	T1 P11	Pu-238	6	5	60.00	42.35	1583.37	57.73	9058.00
5	C	T3 P11	Pu-238	6	6	77.00	61.41	1005.80	24.93	5757.00
5	C	T1 P0	Pu-238	6	6	59.39	56.22	113.90	27.70	181.60
5	C	T3 P0	Pu-238	6	4	44.57	35.50	104.11	31.85	205.50
5	C	T1 P21	Pu-238	6	4	55.55	47.07	3655.60	108.50	14073.00
5	C	T3 P21	Pu-238	6	5	108.51	174.77	4074.83	17.07	12367.00
0.5	E	T1 P11	Pu-238	6	6	41.82	55.47	4870.61	65.09	15838.00
20	E	T1 P11	Pu-238	6	2	96.68	13.79	18.74	16.92	20.56
50	E	T1 P11	Pu-238	6	2	99.07	29.50	15.97	12.86	19.08
80	E	T1 P6,15	Pu-238	6	2	103.11	0.35	10.83	10.65	11.00
5	C	T1 P11	Pu-239	6	5	101.43	0.81	1.78	0.47	7.72
5	C	T3 P11	Pu-239	6	6	100.40	0.65	0.48	0.41	0.52
5	C	T1 P0	Pu-239	6	6	100.21	1.14	0.57	0.34	0.91
5	C	T3 P0	Pu-239	6	4	100.43	0.80	0.35	0.33	0.39
5	C	T1 P21	Pu-239	6	4	100.78	0.67	1.11	0.99	1.20
5	C	T3 P21	Pu-239	6	6	100.69	1.00	0.97	0.76	1.18
0.5	E	T1 P11	Pu-239	6	6	98.46	3.56	1.18	0.83	2.04
20	E	T1 P11	Pu-239	6	2	100.53	0.11	0.20	0.20	0.20
50	E	T1 P11	Pu-239	6	2	100.18	0.02	0.17	0.17	0.17
80	E	T1 P6,15	Pu-239	6	2	100.21	0.14	0.13	0.12	0.13
5	C	T1 P11	Pu-240	6	5	78.32	13.03	14.28	9.87	23.68
5	C	T3 P11	Pu-240	6	6	94.46	10.07	7.90	7.29	8.55
5	C	T1 P0	Pu-240	6	6	97.10	17.57	9.00	7.22	13.76
5	C	T3 P0	Pu-240	6	4	94.14	12.59	5.91	5.38	6.28
5	C	T1 P21	Pu-240	6	4	88.74	11.30	19.82	18.20	21.20
5	C	T3 P21	Pu-240	6	6	90.40	15.61	17.18	13.57	20.65
0.5	E	T1 P11	Pu-240	6	6	125.34	56.25	14.86	12.87	16.81
20	E	T1 P11	Pu-240	6	2	92.34	1.66	3.47	3.43	3.50
50	E	T1 P11	Pu-240	6	2	97.66	0.35	2.69	2.68	2.70
80	E	T1 P6,15	Pu-240	6	2	97.27	2.30	2.05	1.98	2.12
5	C	T1 P11	Pu-241	6	5	91.03	17.36	13.98	9.64	25.70
5	C	T3 P11	Pu-241	6	6	94.79	4.15	9.29	6.76	12.76
5	C	T1 P0	Pu-241	6	5	92.98	15.03	12.24	6.11	38.64
5	C	T3 P0	Pu-241	6	4	92.84	4.71	4.96	4.72	5.21
5	C	T1 P21	Pu-241	6	4	87.62	25.03	21.34	16.20	35.41
5	C	T3 P21	Pu-241	6	5	74.35	16.01	15.64	6.29	19.68

Table 7B. Detector LeGe-6 Test Data (cont.)

G Pu	Drum	Position	Isotope	Detector	N	%REC mean	%REC std dev	CtStat% Mean	CtStat% Min	CtStat% Max
0.5	E	T1 P11	Pu-241	6	6	89.75	5.33	16.13	12.92	18.81
20	E	T1 P11	Pu-241	6	2	97.48	1.99	2.76	2.76	2.76
50	E	T1 P11	Pu-241	6	2	99.83	1.91	2.39	2.25	2.52
80	E	T1 P6,15	Pu-241	6	2	99.82	1.98	1.64	1.61	1.66
5	C	T1 P11	Am-241	6	5	89.77	24.08	13.44	10.23	22.26
5	C	T3 P11	Am-241	6	6	101.79	5.76	8.23	7.51	8.78
5	C	T1 P0	Am-241	6	6	107.05	20.09	9.46	6.97	15.89
5	C	T3 P0	Am-241	6	4	103.08	6.30	5.99	5.70	6.24
5	C	T1 P21	Am-241	6	4	86.31	22.13	23.36	18.68	30.75
5	C	T3 P21	Am-241	6	6	96.39	10.62	17.30	15.05	20.97
0.5	E	T1 P11	Am-241	6	6	106.30	37.40	17.23	14.54	22.84
20	E	T1 P11	Am-241	6	2	93.86	0.91	3.68	3.67	3.68
50	E	T1 P11	Am-241	6	2	102.08	1.42	2.78	2.73	2.82
80	E	T1 P6,15	Am-241	6	2	97.14	1.05	2.17	2.13	2.20

Table 8. Comparison of ^{238}Pu Weight Fraction Results

	LeGe-5				LeGe-6			
	Measured	Uncertainty	Rel Abun to ^{239}Pu	Rel Abun Error	Measured	Uncertainty	Rel Abun to ^{239}Pu	Rel Abun Error
Ex. 1	0.00009	10231	0.000001	208	0.01546	63.98	0.000161	64.1
Ex. 2	0.01447	52.11	0.000154	52.2	0.00621	121.7	0.000066	121
Ex. 3	0.00758	98.82	0.000079	99.1	0.01248	57.73	0.000131	57.8
Ex. 4	0.00099	648	0.000011	648	0.0001	5757	0.000001	202
Ex. 5	0.06889	33.34	0.000751	33.7	0.00357	167.1	0.000038	167
Ex. 6	0.01595	70.61	0.000169	70.7	0.0001	5216	0.000001	204
Ex. 7	0.01865	54.89	0.000195	55	0.00358	113.5	0.000038	113
Ex. 8	0.0001	18573	0.000001	229	0.01934	65.09	0.000208	65.2

Note: All values are in %

Table 9. WRAP MGA Isotopic Uncertainty Values

LeGe-5	Random Uncertainty 1σ (%)	Systematic Uncertainty 1σ (%)	Uncertainty in the Standard Value 1σ (%)	Total Uncertainty 1σ (%)
^{238}Pu	N/A	N/A	1.8	See Note 1
^{239}Pu	$2\sigma_{CtStat}$	1	0.0008	Equation 8
^{240}Pu	$2\sigma_{CtStat}$	8	0.006	Equation 8
^{241}Pu	$2\sigma_{CtStat}$	19	0.24	Equation 8
^{242}Pu	N/A	N/A	0.28	$2\lvert\sigma_{CtStat}\rvert$
^{241}Am	$2\sigma_{CtStat}$	0.2	0.35	Equation 8

LeGe-6	Random Uncertainty 1σ (%)	Systematic Uncertainty 1σ (%)	Uncertainty in the Standard Value 1σ (%)	Total Uncertainty 1σ (%)
^{238}Pu	N/A	N/A	1.8	See Note 1
^{239}Pu	$2\sigma_{CtStat}$	1	0.0008	Equation 8
^{240}Pu	$2\sigma_{CtStat}$	9	0.006	Equation 8
^{241}Pu	$2\sigma_{CtStat}$	9	0.24	Equation 8
^{242}Pu	N/A	N/A	0.28	$2\lvert\sigma_{CtStat}\rvert$
^{241}Am	$2\sigma_{CtStat}$	3	0.35	Equation 8

Note 1 - ^{238}Pu uncertainty is calculated per discussion above.

Note 2 - Equation 8: $\sigma^2_{total} = \sigma^2_{ran} + \sigma^2_{sys} + \sigma^2_{source}$

5.8 Scale Measurement Uncertainty

For a complete discussion of the uncertainty associated with scale measurements at WRAP, refer to HNF-3954, *Drum Weight Measurement Uncertainty Review Findings* (Reference 10). Engineering notebook WHC-N-930-2, page 97, calculates that the scale "error" at WRAP, determined through a simple standard deviation model based on calibration measurements, is 1.1549 lbs (0.5239 kg) at the 95% confidence level (1.96σ). Since uncertainties are introduced and propagated at 1σ, and corrected to the 95% confidence level after all uncertainties are accounted for, this uncertainty is introduced to calculations at +/- 0.5892 lbs (0.2673 kg).

5.9 Tare Weight Uncertainty

WRAP assumes that there is no uncertainty associated with the tare weight of drums, drum liners, or packaging material, per internal memo 32B00-PJC-99-004, from the Hanford TRU Waste Project Office. This conclusion is based on discussions with representatives of the DOE Carlsbad Area Office. The following weights are assigned, with no uncertainty:

55 gallon (208 liter) drum --	29.0 kg
Rigid drum liner --	As determined by NDE results
Liner bag --	0.4 kg

5.10 Other Measurement Uncertainties

There are none of significance.

6 Propagation of Uncertainties

Each source of uncertainty previously described is assumed to be statistically independent of the others. Propagation of uncertainty becomes a simple matter of combining them in quadrature. In a case of direct addition or subtraction of measurements, this means simply taking the "root of the sum of the squares" of the uncertainties in question to provide the resultant uncertainty. In the case of multiplication or division of measured quantities with associated uncertainties, the root of the squares of the fractional uncertainties provides the final uncertainty.

All uncertainties are summed in quadrature after all data is gathered and as final calculations are performed. For GEA, self-absorption uncertainty, source non-uniformity uncertainty, matrix homogeneity uncertainty, and end effects uncertainty are combined in quadrature to produce an overall uncertainty for each isotope.

Table 10

Uncertainty Estimates (%) – GEA Assay System (g Pu239)							
Mass Range	Component	Sum Segments			*Combine All*		
		375 keV	129 keV	414 keV	375 keV	129 keV	414 keV
I	$\sigma_{InstStat}$		Inst Stat				
	σ_{SelfAb}		0				
	$\sigma_{NonUnif}$		Equation				
	σ_{Matrix}		12				
	σ_{End}		5#				
II	$\sigma_{InstStat}$		Inst Stat	Inst Stat		Inst Stat	2 × Inst Stat
	σ_{SelfAb}		0 if <1gm 5 if > 1gm	0 if <1gm 5 if > 1gm		0 if <1gm 5 if > 1gm	0 if <1gm 5 if > 1gm
	$\sigma_{NonUnif}$		Equations 1, 2, 5	Equations 3, 4, 5		NA	Equations 5, 6, 7
	σ_{Matrix}		12	12		12	12
	σ_{End}		5#	11.5		11.5	11.5
III	$\sigma_{InstStat}$	Inst Stat	Inst Stat	Inst Stat	Inst Stat	Inst Stat	Inst Stat
	σ_{SelfAb}	5 if <10gm 10 if >10gm	5 if <10gm 10 if > 10gm	5 if <10gm 10 if > 10gm	5 if <10gm 10 if > 10gm	5 if <10gm 10 if > 10gm	5 if <10gm 10 if > 10gm
	$\sigma_{NonUnif}$	Equations * 3, 4, 5	Equations 1, 2, 5	Equations 3, 4, 5	Equations * 5, 6, 7	NA	Equations 5, 6, 7
	σ_{Matrix}	12	12	12	12	12	12
	σ_{End}	11.5	5#	11.5	11.5	11.5	11.5
IV	$\sigma_{InstStat}$	Inst Stat		Inst Stat	Inst Stat		Inst Stat
	σ_{SelfAb}	10		10	10		10
	$\sigma_{NonUnif}$	Equation * 3, 4, 5		Equations 3, 4, 5	Equations * 5, 6, 7		Equations 5, 6, 7
	σ_{Matrix}	12		12	12		12
	σ_{End}	11.5		11.5	11.5		11.5

Sum Segments should be used for masses below 5 g. For masses in the 0 - 2.5 g range, the 129 keV line is preferred. The other peaks (light shaded areas) can be used for reference and to indicate severe lumping.

$\sigma_{Inst\ Stat}$ -- ***the system-reported measurement uncertainty (i.e., counting statistics, calibration)***

σ_{SelfAb} -- **the uncertainty associated with self-absorption (lumping effect), weight is total Pu.**

$\sigma_{NonUnif}$ -- **the uncertainty associated with source non-uniformity**

σ_{Matrix} -- **the uncertainty due to the matrix**

σ_{End} -- **the uncertainty related to end effects for the GEA system**

* -- **the Canberra equation was developed for the 414 energy line, however the WRAP data do not indicate major differences between the 375 and 414 keV energy lines**

\# -- **Only if end effect correction applied**

6.1 Example Calculations

The following examples illustrate the magnitude of the uncertainty associated with the GEA measurement. The drum density, the GEA gram quantity of ^{239}Pu, and the instrument uncertainty are stated, the other uncertainties are obtained from Table 10 or equations referenced by Table 10.

Example 1 – Mass Range II (414 keV)

Assay did not exhibit end effect problems, 129 keV assay value was used.

Density = 0.15 g/cc, Sum Segments (GEA) = 1.5 gm ^{239}Pu, $\sigma_{\text{Inst Stat}} = 7.5\%$

$\sigma_{\text{SelfAb}} = 5.0\%$, $\sigma_{\text{NonUnif}} = 6.2\%$, $\sigma_{\text{Matrix}} = 12.0\%$, $\sigma_{\text{End}} = 0\%$

σ_{GEA} = Square root of $(0.05^2 + 0.075^2 + 0.062^2 + 0.12^2) = 0.162$ or 16.2%

= 0.24 gm ^{239}Pu.

Example 2 - Mass Range III (414 keV)

Density = 0.25, Combine All (GEA) = 9.0 gm ^{239}Pu, $\sigma_{\text{Inst Stat}} = 2.75\%$

$\sigma_{\text{SelfAb}} = 5.0\%$, $\sigma_{\text{NonUnif}} = 16.2\%$, $\sigma_{\text{Matrix}} = 12.0\%$, $\sigma_{\text{End}} = 11.5\%$

σ_{GEA} = Square root of $(0.0275^2 + 0.05^2 + 0.162^2 + 0.12^2 + 0.115^2) = 0.239$ or 23.9%

= 2.15 gm ^{239}Pu.

Example 3 - Mass Range IV (414 keV)

Density = 0.28, Combine All (GEA) = 50.0 gm ^{239}Pu, $\sigma_{\text{Inst Stat}} = 2.05\%$

$\sigma_{\text{SelfAb}} = 10.0\%$, $\sigma_{\text{NonUnif}} = 17.3\%$, $\sigma_{\text{Matrix}} = 12.0\%$, $\sigma_{\text{End}} = 11.5\%$

σ_{GEA} = Square root of $(0.0205^2 + 0.10^2 + 0.173^2 + 0.12^2 + 0.115^2) = 0.261$ or 26.1%

= 13.04 gm ^{239}Pu.

6.2 Summary Calculations

The following calculations are performed utilizing the activity concentrations for the applicable isotopes. The conversion factors used are those found in WMH-350 2.2. MF = Mass fraction SpAct = Specific Activity.

FGE = GMS239 * (1/MF239) * [0.113*MF238 + MF239 + 0.0225*MF240 + 2.25*MF241 + 0.0075*MF242 + 0.0187*MFAM241]

ALPHACI = GMS239 * (1/MF239) * [17.1*MF238 + 0.062*MF239 + 0.227*MF240 + 0.00238*MF241 + 0.00393*MF242 + 3.43*MFAM241]

DOSEEQCI = GMS239 * (1/MF239) * [0.913*SpAct238*MF238 + SpAct239*MF239 + SpAct240*MF240 + 0.0192*SpAct241*MF241 + 0.956*SpAct242*MF242 + 1.03*SpActAm241*MFAM241]

PUEQCI = GMS239 * (1/MF239) * [0.909*SpAct238*MF238 + SpAct239*MF239 + SpAct240*MF240 + 0.0192*SpAct241*MF241 + 0.909*SpAct242*MF242 + SpActAm241*MFAM241]

WATTS = GMS239 * (1/MF239) * [0.573*MF238 + 0.00195*MF239 + 0.00716*MF240 + 0.00331*MF241 + 0.000117*MF242 + 0.116*MFAM241]

The uncertainty calculations for the above equations are similar, only one example will be demonstrated.

6.2.1 WATTS Uncertainty

The WATTS equation is of the form X*Y*Z, where X is the GMS239 from the GEA assay system, Y is the inverse of the MF239 from either the AK or WRAP MGA isotopics, and Z is a function of the decay corrected AK or WRAP MGA isotopics and the appropriate parameters.

Uncertainty associated with X

The uncertainty associated with X, the GMS239 from the GEA assay system, was previously described and three examples were provided. All uncertainties ($\sigma_{\text{Inst Stat}}$, σ_{SelfAb}, σ_{NonUnif}, σ_{Matrix}, σ_{End}) are summed in quadrature.

σ_{GEA} = Square root of ($\sigma^2_{\text{Inst Stat}} + \sigma^2_{\text{SelfAb}} + \sigma^2_{\text{NonUnif}} + \sigma^2_{\text{Matrix}} + \sigma^2_{\text{End}}$).

Uncertainty associated with Y

The uncertainty associated with Y, the inverse of the MF239 is approximated by the RSD of the MF239, i.e., $RSD^2(1/Y) \cong RSD^2(1) + RSD^2(Y) = RSD^2(Y)$.

The RSD(Y) and Var(Y) are defined as follows.

[RSD(MF239)] = Std(MF239)/MF239

$Var(Y) \cong [RSD(MF239)*MF239]^2$

Uncertainty associated with Z

Z = 0.573*MF238 + 0.00195*MF239 + 0.00716*MF240 + 0.00331*MF241 + 0.000117*MF242 + 0.116*MFAM241.

The uncertainty (as a variance) associated with Z is

$Var(Z) = 0.573^2 * Var(MF238) + 0.00195^2 * Var(MF239) + 0.00716^2 * Var(MF240) + 0.00331^2 * Var(MF241) + 0.116^2 * Var(MFAM241)$.

Since the uncertainty for each isotope is usually provided in terms of RSD, the variance for each term is calculated using the following formulas.

$Var(MF238)=[RSD(MF238)*MF238]^2$, $Var(MF239)=[RSD(MF239)*MF239]^2$, $Var(MF240)=[RSD(MF240)*MF240]^2$, $Var(MF241)=[RSD(MF241)*MF241]^2$, and $Var(MFAM241)=[RSD(MFAM241)*MFAM241]^2$

The uncertainty for Z in terms of RSD is calculated using the following formula

[RSD(Z)] = Std(Z)/Z where Std is the square root of the variance and Z is defined above.

Uncertainty associated with Watts

Watts = X * Y * Z

Assuming that X, Y, And Z are independent the uncertainty associated with Watts in terms of RSD is calculated using the following formula.

$[RSD(WATTS)]^2 \cong RSD^2(X) + RSD^2(Y) + RSD^2(Z)$

The uncertainty (in terms of variance and standard deviation) is then calculated using the following equations.

$Var(WATTS) = [RSD(WATTS)*WATTS]^2$

σ_{WATTS} = square root of Var(WATTS)

Example (Historical PFP Uncertainties)

MF238=0.000293, RSD=0.164
MF239=0.937, RSD=0.0012
MF240=0.0570, RSD=0.0194
MF241=0.00355, RSD=0.0186
MF242=0.0002, RSD=NA
MFAM241=0.00169, RSD=0.011

Density = 0.166 g/cc

Sum segements, 129 keV assay result, no end effects

GEA result = 2.02 gm ^{239}Pu, $\sigma_{Inst\ Stat} = 5.73\%$

$\sigma_{SelfAb} = 5.0\%$, $\sigma_{NonUnif} = 6.6\%$, $\sigma_{Matrix} = 12.0\%$, $\sigma_{End} = 0\%$

X = GEA result = 2.02 gm ^{239}Pu

$RSD(X)$ = Square root of $(0.05^2 + 0.0573^2 + 0.066^2 + 0.12^2) = 15.67\%$

Y = 1/MF239 = 1.07
RSD(Y) = 0.0012

Z = 0.00261
Var(Z) = 8.30E-10
RSD(Z) = 1.10%

Watts = 2.02 * 1.07 * 0.00261 = 5.64E-03
$RSD(Watts) \cong$ Square root of $(0.1567^2 + 0.0012^2 + 0.011^2) = 15.71\%$

7 References

1. *Waste Acceptance Criteria for the Waste Isolation Pilot Plant*, U.S. Department of Energy Carlsbad Area Office, DOE /WIPP-069, November 8, 1999.

2. *Passive Nondestructive Assay of Nuclear Materials*, Edited by Doug Reilly, Norbert Ensslin and Hastings Smith, Jr., Report NUREG/CR-5550, March 1991.

3. *Model S431 Genie-PC Gamma Waste Assay Software Technical Reference Manual*, Canberra Industries, 1999.

4. *Total Measurement Uncertainty for the Canberra Segmented Gamma Scanner System,* Canberra Industries, April 1999. PROPRIETARY

5. *Q2 – A Very Low Level Quantitative and Qualitative Waste Assay and Release Certification*; Proceedings of Waste Management '90; Tucson, Arizona; February 25-28, 1995.

6. *Quality Assurance Objectives for Nondestructive Assay at the Waste Receiving and Processing Facility*, HNF-4051, C. E. Wills, September, 1999.

7. *Statistical Methods in Nuclear Material Control,* John L. Jaech, TID-26-298, 1993.

8. *Calibration Report for the WRAP Facility Gamma Energy Analysis System*, HNF-5148, Craig Wills, March 2000.

9. *Communication on End Effect Uncertainties*, from B.Gillespie, Canberra Inc., to J. Weidert, Fluor Hanford Inc., e-mail, 6 January, 2000

10. *Drum Weight Measurement Uncertainty Review Findings,* HNF-3954, M.P. Lane, February, 1999

11. *MGA: A Gamma-Ray Spectrum Analysis Code for Determining Plutonium Isotopic Abundances*; Volume I: Methods & Algorithms, R. Gunnink, NTIS DE90013529, April 1990.

APPENDIX A WRAP GEA-A gamma assay system Test Plan and Test Plan Results

OPERATION TEST PROCEDURE
for
NONDESTRUCTIVE ANALYSIS
GAMMA ENERGY ASSAY

HNF - 6042

March 2000

GEA TEST PROCEDURE COVER SHEET

Test Procedure: HNF-####		Title: End, Matrix, Lumping Effects on the WRAP GWAs (NDA)
Revision: 0	Execution:	

Date/Time: Start: _____ - _____ End: _____ - _____

Test Exceptions Recorded? ☐ Yes ☐ No
COMMENTS:

TEST PROCEDURE COMPLETION APPROVAL:

☐ **Successful** ☐ **Unsuccessful**

_____ _____ _____

WMH NDA Engineer **Date** **QA** **Date**

This procedure is designed to test for End Effects of source materials at or near the bottom of a waste drum. The end effect suspected is the instrumentation will not properly calculate the activity of such materials. A second test associated with this is the source being radially displaced through the material at or near the bottom of the drum; this is the non-uniformity test. The final test in this series is to evaluate lumping due to the self absorption of the gamma rays from the source material, as the material particle increases in size (and mass). These results will be incorporated into the Total Measurements Uncertainty document, HNF-4050.

Test Procedure HNF-6042	Revision 0	**TITLE: End, Matrix, Lumping Effects on the WRAP GWAs (NDA)**

REVISION STATUS

None.

TEST OBJECTIVES

This test procedure is designed to provide the testing for specific effects of activity distributions in the bottom or near bottom of a waste drum,

BASIS FOR A SUCCESSFUL TEST

The basis of a successful test shall be the completion of the test cases listed below and analysis of the spectral data to resolve the system's response to activity at or near the bottom of a waste drum.

ITEMS TESTED

The GEA-A system response to sources in the bottom or near bottom of a drum.

RESOURCE REQUIREMENTS

GEA-A system

Canberra calibration drums

Foam filled drum 0.01346 gm/cc density

Homosote filled drum, 0.4303 gm/cc density

Pressboard filled drum, 0.6525 gm/cc density

North American Scientific reference source A6271:

Americium-241

Europium-152

Resource requirements met: _____, _____. Date: _____
Print Sign

REFERENCES

1. Letter, Bruce Gillespie to J. R. Weidert, 3/8/00, WRAP Engineering Manager.

2. Total Measurement Uncertainty for Nondestructive Assay of Transuranic Waste at the WRAP facility, HNF-4050

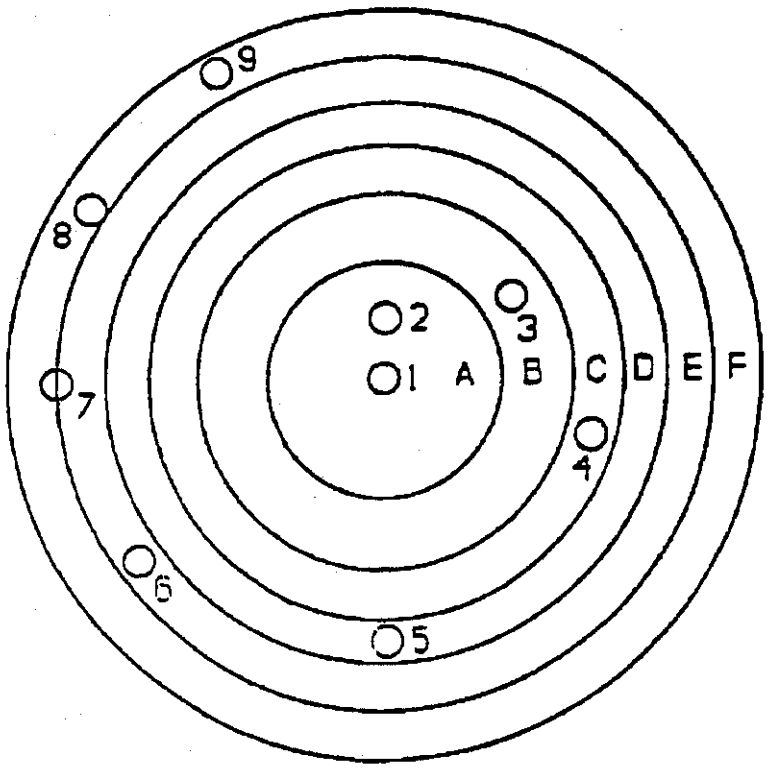
Qualifications

SAFETY PRECAUTIONS

1. Source handling, Use ALARA and established procedures.

TEST MEASUREMENTS:

The following test will have a count time specified to achieve the desired counting statistics at the 2% to 3% at one sigma level.



The calibration drum source tubes, 1-9, start with 1 at the center and 9 at the outermost position. Tube 6 is the "mid" position, as a function of gamma path length and density, for a drum segment and best represents the uniform distribution simulation for the 300 keV to 600 keV energy range. *(Note: Image provided above is the reverse of actual drum.)*

The measurements will start at the bottom of the source tube, which is one inch above the bottom of the drum to simulate the presence of absorber material. The sources will be moved upward in four steps of 2 inches each, the final position representing 9 inches from the bottom of the drum.

TEST PLAN

1. The following table lists the drum matrix, tube utilized, insertion depth (position from the bottom of the drum) and the real time for transmission and source counting.
2. The daily QC and background checks must be run at the beginning and end of each day of counting.
3. The daily QC-57 check drum must also be used for the testing of the low density evaluations. It must have the daily test sources removed and later replaced. Always record the source's position (tube #) and serial number (tab #) when removing or replacing them. Use the attached daily source form for these actions; note, two signatures, time and date are required for QA purposes.
4. Configure the drum for the next scheduled test on the list. Initial and date the list for that test after drum closure prior to counting.
5. Follow procedure WRP1-OP-0906 for preparation to count:

   In step 6.5.10, set the transmission and the count time to those listed for the particular test or by direction of the cognizant engineer.

6. Note the completion of count in the GEA log book.
7. Repeat steps 3-6 for the next test, until testing is complete.
8. At the end of the day, ensure all printouts, signed and/or initialed lists, etc. are gathered for the NDA Cognizant Engineer and attached to the test document.

TEST DESCRIPTION

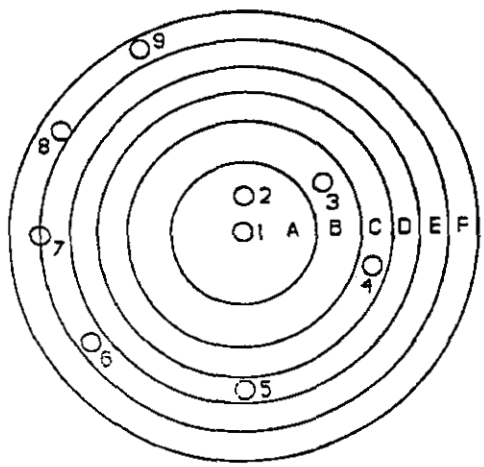
Date	Time	Initial	Test No.	Drum type	Tube Pos	Height from Bottom	Time (sec) Transmission	Count	Replicates
			1	**Foam**	Tube 1	15"	30	400	2
			2	Foam	Tube 1	1"	30	400	
			3	**Foam**	Tube 1	3"	30	400	3
			4	Foam	Tube 1	5"	30	400	
			5	Foam	Tube 1	7"	30	400	
			6	Foam	Tube 1	9"	30	400	
			7	Foam	Tube 9	1"	30	400	
			8	Foam	Tube 9	3"	30	400	
			9	Foam	Tube 9	5"	30	400	
			10	Foam	Tube 9	7"	30	400	
			11	Foam	Tube 9	9"	30	400	
			12	Foam	Tube 6	1"	30	400	
			13	Foam	Tube 6	3"	30	400	
			14	Foam	Tube 6	5"	30	400	
			15	Foam	Tube 6	7"	30	400	
			16	Foam	Tube 6	9"	30	400	
			17	**Foam**	Tube 1	3"	30	400	3
			18	**Homosote**	Tube 1	15"	30	400	2
			19	Homosote	Tube 1	1"	30	1000	
			20	Homosote	Tube 1	3"	30	400	
			21	Homosote	Tube 1	5"	30	400	
			22	Homosote	Tube 1	7"	30	400	
			23	Homosote	Tube 1	9"	30	400	
			24	Homosote	tube 9	1"	30	400	
			25	**Homosote**	tube 9	3"	30	400	3
			26	Homosote	tube 9	5"	30	400	
			27	Homosote	tube 9	7"	30	400	
			28	Homosote	tube 9	9"	30	400	
			29	Homosote	tube 6	1"	30	400	
			30	Homosote	tube 6	3"	30	400	
			31	Homosote	tube 6	5"	30	400	
			32	Homosote	tube 6	7"	30	400	
			33	Homosote	tube 6	9"	30	400	
			34	**Homosote**	Tube 9	3"	30	400	3

Date	Time	Initial	Test	Drum type	Tube Pos	Height	Time (sec)		
			No.			from	Transmission	Count	Replicates
						Bottom			
			35	**Pressboard**	Tube 1	15"	30	400	2
			36	Pressboard	Tube 1	1"	50	3000	
			37	Pressboard	tube 1	3"	50	3000	
			30	Pressboard	tube 1	5"	50	3000	
			31	Pressboard	tube 1	7"	50	3000	
			32	Pressboard	tube 1	9"	50	3000	
			33	Pressboard	tube 6	1"	50	1000	
			34	**Pressboard**	tube 6	3"	50	1000	3
			35	Pressboard	tube 6	5"	50	1000	
			36	Pressboard	tube 6	7"	50	1000	
			37	Pressboard	tube 6	9"	50	1000	
			38	Pressboard	tube 9	1"	50	1000	
			39	Pressboard	tube 9	3"	50	1000	
			40	Pressboard	tube 9	5"	50	1000	
			41	Pressboard	tube 9	7"	50	1000	
			42	Pressboard	tube 9	9"	50	1000	
			43	**Pressboard**	Tube 6	3"	30	400	3
			44	Combustible	Tube 3		std cnt	Large Particle	5
								sources	
			45	Combustible	tube 1		std cnt	Large Particle	5
								sources	
			46	Combustible	tube 2		std cnt	Large Particle	5
								sources	

Source Position and Orientation

This form is for the purpose of providing a record of source loading or unloading from the GWAS calibration and daily check source drum.

Drum Id. _____. Date: _____



Source Id. E-839 Tube No. 1 Install _____ Remove _____.

Source Id. E-840 Tube No. 3 Install _____ Remove _____.

Source Id. E-842 Tube No. 4 Install _____ Remove _____.

Source Id. E-843 Tube No. 5 Install _____ Remove _____.

Source Id. E-841 Tube No. 7 Install _____ Remove _____.

Source Id. E-838 Tube No. 9 Install _____ Remove _____.

Ensure the tube source's orientation is maintained.

(Note: Image provided above is the reverse of the actual drum.)

Sources are : Removed (date)_____ Installed (date)_____

Final drum configured with _____.

Signature: _____ Date/Time: _____

Signature:_____ Date/Time: _____

Table A.1 – Test Data

Sum Segments Data					
Description	Density	Eu-122 (μCi)	Eu-122 ±1σ (μCi)	Eu-344 (μCi)	Eu-344 ±1σ (μCi)
TEST 1 TUBE 1 15" RUN 1	0.01	7.410	0.281	5.750	0.115
TEST 1 TUBE 1 15" RUN 2	0.01	7.260	0.273	5.790	0.112
TEST 2, TUBE 1 1" RUN 1	0.01	5.010	0.195	3.770	0.082
TEST 2, TUBE 1 1" RUN 2	0.01	4.920	0.191	3.850	0.079
TEST 3 TUBE 1 3" RUN 1	0.01	5.980	0.228	4.660	0.091
TEST 3 TUBE 1 3" RUN 2	0.01	6.240	0.239	4.750	0.102
TEST 3 TUBE 1 3" RUN 3	0.01	6.020	0.232	4.810	0.097
TEST 4 TUBE 1 5" RUN 1	0.01	6.990	0.264	5.570	0.119
TEST 5 TUBE 1 7" RUN 1	0.01	7.410	0.278	5.620	0.113
TEST 6 TUBE 1 9" RUN 1	0.01	7.090	0.266	5.620	0.117
TEST 7 TUBE 9 1" RUN 1	0.01	5.120	0.198	4.140	0.087
TEST 7 TUBE 9 1" RUN 2	0.01	5.190	0.203	4.250	0.090
TEST 8 TUBE 9 3" RUN 1	0.01	5.810	0.225	4.800	0.109
TEST 8 TUBE 9 3" RUN 2	0.01	5.680	0.217	4.840	0.101
TEST 8 TUBE 9 3" RUN 3	0.01	5.710	0.218	4.790	0.097
TEST 9 TUBE 9 5" RUN 1	0.01	5.960	0.230	4.970	0.101
TEST 10 TUBE 9 7" RUN1	0.01	6.460	0.245	5.350	0.110
TEST 11 TUBE 9 9" RUN 1	0.01	6.400	0.245	5.030	0.105
TEST 12 TUBE 6 1" RUN 1	0.01	5.280	0.203	4.290	0.086
TEST 12 TUBE 6 1" RUN 2	0.01	5.260	0.206	4.270	0.092
TEST 13 TUBE 6 3" RUN 1	0.01	6.440	0.247	5.190	0.101
TEST 13 TUBE 6 3" RUN 2	0.01	6.430	0.247	5.160	0.100
TEST 13 TUBE 6 3" RUN 3	0.01	6.500	0.249	5.150	0.100
TEST 14 TUBE 6 5" RUN 1	0.01	6.490	0.248	5.150	0.099
TEST 15 TUBE 6 7" RUN 1	0.01	6.880	0.262	5.510	0.112
TEST 16 TUBE 6 9" RUN 1	0.01	6.470	0.246	5.510	0.112
TEST 17 TUBE 1 3" RUN 1	0.01	6.210	0.239	4.840	0.100
TEST 17 TUBE 1 3" RUN 2	0.01	5.990	0.224	4.890	0.095
TEST 17 TUBE 1 3" RUN 3	0.01	6.190	0.238	4.850	0.109
TEST 18 TUBE 1 15" RUN 1	0.43	2.200	0.213	2.370	0.091
TEST 18 TUBE 1 15" RUN 2	0.43	2.660	0.230	3.300	0.107
TEST 19 TUBE 1 1" RUN 1	0.43	2.090	0.199	2.290	0.087
TETS 19 TUBE 1 1" RUN 2	0.43	1.770	0.166	2.340	0.084
TEST 20 TUBE 1 3" RUN 1	0.43	2.890	0.246	2.880	0.094
TEST 20 TUBE 1 3" RUN 2	0.43	2.620	0.226	2.810	0.083
TEST 20 TUBE 1 3" RUN 3	0.43	2.430	0.197	2.970	0.097
TEST 21 TUBE 1 5" RUN 1	0.43	2.980	0.237	3.240	0.094
TEST 22 TUBE 1 7" RUN 1	0.43	2.670	0.229	3.310	0.098
TEST 23 TUBE 1 9" RUN 1	0.43	2.670	0.234	3.170	0.092
TEST 24 TUBE 9 1" RUN 1	0.43	7.770	0.585	6.210	0.120
TEST 25 TUBE 9 3" RUN 1	0.43	8.280	0.617	6.640	0.116
TEST 25 TUBE 9 3" RUN 2	0.43	8.300	0.624	6.580	0.121
TEST 26 TUBE 9 5" RUN 1	0.43	8.340	0.625	7.030	0.127
TEST 27 TUBE 9 7" RUN 1	0.43	8.630	0.645	7.290	0.135

Sum Segments Data					
Description	Density	**Eu-122**	**Eu-122**	**Eu-344**	**Eu-344**
		(μCi)	**±1σ (μCi)**	**(μCi)**	**±1σ (μCi)**
TEST 28 TUBE 9 9" RUN 1	0.43	8.370	0.622	6.630	0.133
TEST 29 TUBE 6 1" RUN 1	0.43	6.260	0.470	4.950	0.111
TEST 30 TUBE 6 3" RUN 1	0.43	7.600	0.574	5.960	0.114
TEST 30 TUBE 6 3" RUN 2	0.43	7.600	0.575	6.050	0.115
TEST 31 TUBE 6 5" RUN 1	0.43	7.390	0.555	6.050	0.119
TEST 32 TUBE 6 7" RUN 1	0.43	6.750	0.510	5.910	0.133
TEST 33 TUBE 6 9" RUN 1	0.43	7.470	0.568	5.830	0.112
TEST 34 TUBE 9 3" RUN 1	0.43	8.350	0.622	6.740	0.130
TEST 34 TUBE 9 3" RUN 2	0.43	8.330	0.620	6.660	0.128
TEST 35 TUBE 1 15" RUN 1	0.63	1.320	0.146	2.100	0.068
TEST 36 TUBE 1 1" RUN 1	0.63	0.850	0.087	1.300	0.038
TEST 37 TUBE 1 3" RUN 1	0.63	1.330	0.127	1.970	0.048
TEST 37 TUBE 1 3" RUN 2	0.63	1.430	0.137	2.090	0.049
TEST 38 TUBE 1 5" RUN 1	0.63	1.550	0.153	2.060	0.045
TEST 39 TUBE 1 7" RUN 1	0.63	1.580	0.156	2.050	0.048
TEST 40 TUBE 1 9" RUN 1	0.63	1.690	0.165	2.140	0.049
TEST 41 TUBE 6 1" RUN 1	0.63	4.860	0.428	4.060	0.064
TEST 42 TUBE 9 9" RUN 1	0.63	10.500	0.919	8.170	0.121
TEST 43 TUBE 6 3" RUN 1	0.63	6.930	0.608	5.620	0.084
TEST 43 TUBE 6 3" RUN 2	0.63	7.100	0.625	5.630	0.082
TEST 43 TUBE 6 5" RUN 1	0.63	8.350	0.732	6.820	0.096
TEST 45 TUBE 6 7" RUN 1	0.63	7.170	0.630	5.990	0.082
TEST 46 TUBE 6 9" RUN 1	0.63	8.210	0.720	6.790	0.096
TEST 47 TUBE 9 1" RUN 1	0.63	10.100	0.880	7.520	0.097
TEST 48 TUBE 9 5" RUN 1	0.63	11.000	0.957	8.450	0.107
TEST 48 TUBE 9 5" RUN 2	0.63	10.900	0.949	8.640	0.112
TEST 48 TUBE 9 3" RUN 1	0.63	9.730	0.851	7.330	0.102
TEST 50 TUBE 9 7" RUN 1	0.63	10.500	0.922	8.060	0.112
TEST 51 TUBE 6 3" RUN 1	0.63	7.200	0.633	5.680	0.087
TEST 51 TUBE 6 3" RUN 2	0.63	7.270	0.639	5.680	0.083

Table A.2. Test Data by Location

Sum Segments Data								
					Eu-122	Eu-122	Eu-344	Eu-344
Matrix	Tube	Depth	Description	Density	(µCi)	%REC	(µCi)	%REC
1	1	1	TEST 2 TUBE 1 1" AVG	0.01	4.965	82.89	3.810	63.61
1	1	3	TEST 3,17 TUBE 1 3" AVG	0.01	6.105	101.92	4.800	80.13
1	1	5	TEST 4 TUBE 1 5" RUN 1	0.01	6.990	116.69	5.570	92.99
1	1	7	TEST 5 TUBE 1 7" RUN 1	0.01	7.410	123.71	5.620	93.82
1	1	9	TEST 6 TUBE 1 9" RUN 1	0.01	7.090	118.36	5.620	93.82
1	1	15	TEST 1 TUBE 1 15" AVG	0.01	7.335	122.45	5.770	96.33
1	6	1	TEST 12 TUBE 6 1" AVG	0.01	5.270	87.98	4.280	71.45
1	6	3	TEST 13,TUBE 6 3" AVG	0.01	6.457	107.79	5.167	86.25
1	6	5	TEST 14 TUBE 6 5" RUN 1	0.01	6.490	108.35	5.150	85.98
1	6	7	TEST 15 TUBE 6 7" RUN 1	0.01	6.880	114.86	5.510	91.99
1	6	9	TEST 16 TUBE 6 9" RUN 1	0.01	6.470	108.01	5.510	91.99
1	9	1	TEST 7 TUBE 9 1" AVG	0.01	5.155	86.06	4.195	70.03
1	9	3	TEST 8 TUBE 9 3" AVG	0.01	5.733	95.72	4.810	80.30
1	9	5	TEST 9 TUBE 9 5" RUN 1	0.01	5.960	99.50	4.970	82.97
1	9	7	TEST 10 TUBE 9 7" RUN1	0.01	6.460	107.85	5.350	89.32
1	9	9	TEST 11 TUBE 9 9" RUN 1	0.01	6.400	106.84	5.030	83.97
2	1	1	TEST 19 TUBE 1 1" AVG	0.43	1.930	32.22	2.315	38.65
2	1	3	TEST 20 TUBE 1 3" AVG	0.43	2.647	44.18	2.887	48.19
2	1	5	TEST 21 TUBE 1 5" RUN 1	0.43	2.980	49.75	3.240	54.09
2	1	7	TEST 22 TUBE 1 7" RUN 1	0.43	2.670	44.57	3.310	55.26
2	1	9	TEST 23 TUBE 1 9" RUN 1	0.43	2.670	44.57	3.170	52.92
2	1	15	TEST 18 TUBE 1 15" AVG	0.43	2.430	40.57	2.835	47.33
2	6	1	TEST 29 TUBE 6 1" RUN1	0.43	6.260	104.51	4.950	82.64
2	6	3	TEST 30 TUBE 6 3" AVG	0.43	7.600	126.88	6.005	100.25
2	6	5	TEST 31 TUBE 6 5" RUN 1	0.43	7.390	123.37	6.050	101.00
2	6	7	TEST 32 TUBE 6 7" RUN 1	0.43	6.750	112.69	5.910	98.66
2	6	9	TEST 33 TUBE 6 9" RUN 1	0.43	7.470	124.71	5.830	97.33
2	9	1	TEST 24 TUBE 9 1" RUN 1	0.43	7.770	129.72	6.210	103.67
2	9	3	TEST 25,34 TUBE 9 3" AVG	0.43	8.315	138.81	6.655	111.10
2	9	5	TEST 26 TUBE 9 5" RUN 1	0.43	8.340	139.23	7.030	117.36
2	9	7	TEST 27 TUBE 9 7" RUN 1	0.43	8.630	144.07	7.290	121.70
2	9	9	TEST 28 TUBE 9 9" RUN 1	0.43	8.370	139.73	6.630	110.68

Sum Segments Data								
					Eu-122	Eu-122	Eu-344	Eu-344
Matrix	Tube	Depth	Description	Density	(µCi)	%REC	(µCi)	%REC
3	1	1	TEST 36 TUBE 1 1" RUN 1	0.63	0.850	14.19	1.300	21.70
3	1	3	TEST 37 TUBE 1 3" AVG	0.63	1.380	23.04	2.030	33.89
3	1	5	TEST 38 TUBE 1 5" RUN 1	0.63	1.550	25.88	2.060	34.39
3	1	7	TEST 39 TUBE 1 7" RUN 1	0.63	1.580	26.38	2.050	34.22
3	1	9	TEST 40 TUBE 1 9" RUN 1	0.63	1.690	28.21	2.140	35.73
3	1	15	TEST 35 TUBE 1 15" RUN 1	0.63	1.320	22.04	2.100	35.06
3	6	1	TEST 41 TUBE 6 1" RUN 1	0.63	4.860	81.14	4.060	67.78
3	6	3	TEST 43,51 TUBE 6 3" AVG	0.63	7.125	118.95	5.653	94.37
3	6	5	TEST 43 TUBE 6 5" RUN 1	0.63	8.350	139.40	6.820	113.86
3	6	7	TEST 45 TUBE 6 7" RUN 1	0.63	7.170	119.70	5.990	100.00
3	6	9	TEST 46 TUBE 6 9" RUN 1	0.63	8.210	137.06	6.790	113.36
3	9	1	TEST 47 TUBE 9 1" RUN 1	0.63	10.100	168.61	7.520	125.54
3	9	3	TEST 48 TUBE 9 3" RUN 1	0.63	9.730	162.44	7.330	122.37
3	9	5	TEST 48 TUBE 9 5" AVG	0.63	10.950	182.80	8.545	142.65
3	9	7	TEST 50 TUBE 9 7" RUN 1	0.63	10.500	175.29	8.060	134.56
3	9	9	TEST 42 TUBE 9 9" RUN 1	0.63	10.500	175.29	8.170	136.39

DISTRIBUTION SHEET

To	From	Page 1 of 1
Distribution	WRAP Engineering	Date 05/11/00
Project Title/Work Order		EDT No. N/A
HNF-4050, Rev. 5, Total Measurement Uncertainty (TMU) for NDA of TRU Waste at the WRAP Facility		ECN No. ECN-657509

Name	MSIN	Text With All Attach.	Text Only	Attach./ Appendix Only	EDT/ECN Only
MG Cantaloub	T4-52	X			
JK Kersten	T4-52	X			
JL Maupin	T4-06				X
WR Thackaberry	T4-52				X
CE Taylor	T4-52				X
JR Weidert	T4-52				X
DOE/RL Reading Room	H2-53	X			
Engineering Files	B1-07	X			