ENGINEERING CHANGE NOTICE

Page 1 of 2

1. ECN 655142

Proj. ECN

2. ECN Category (mark one)	3. Originator's Name, Organization, MSIN, and Telephone No.	4. USQ Required?	5. Date
Supplemental ○	CE Wills, WRAP Engineering,	◉ Yes ○ No	02/24/00
Direct Revision ◉	T4-52, 373-9844		
Change ECN ○	6. Project Title/No./Work Order No.	7. Bldg./Sys./Fac. No.	8. Approval Designator
Temporary ○	WRAP Facility/AJ60	2336-W	Q
Standby ○	9. Document Numbers Changed by this ECN (includes sheet no. and rev.)	10. Related ECN No(s).	11. Related PO No.
Supersedure ○	HNF-4050, Rev. 3 All	N/A	N/A
Cancel/Void ○			

12a. Modification Work	12b. Work Package No.	12c. Modification Work Completed	12d. Restored to Original Condition (Temp. or Standby ECNs only)
○ Yes (fill out Blk. 12b)	N/A	N/A	N/A
◉ 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 current method to comply with CAO comments and the WIPP audit.

14a. Justification (mark one)	14b. Justification Details
Criteria Change ○	Design verification not required
Design Improvement ○	
Environmental ○	Additions made in response to WIPP audit comments
Facility Deactivation ○	
As-Found ◉	USQ WRP-00-049
Facilitate Const. ○	
Const. Error/Omission ○	
Design Error/Omission ○	

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16. Design Verification Required	17. Cost Impact		18. Schedule Impact (days)
	ENGINEERING	CONSTRUCTION	
○ Yes	Additional ○ $ N/A	Additional ○ $ N/A	Improvement ○ N/A
◉ No	Savings ○ $ N/A	Savings ○ $ N/A	Delay ○ N/A

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

	Signature	Date		Signature	Date
Design Authority			Design Agent		
Cog. Eng. CE Wills	CE Wills	2/24/00	PE		
Cog. Mgr. JR Weidert	JR Weidert	2-24-00	QA		
QA WR Thackaberry	WR Thackaberry	02/24/00	Safety		
Safety			Design		
Environ.			Environ.		
Other			Other		
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ADDITIONAL

DISTRIBUTION SHEET

To	From	Page 1 of 1
Distribution	WRAP Engineering	Date 02/24/00
Project Title/Work Order		EDT No. N/A
TOTAL MEASUREMENT UNCERTAINTY FOR NDA OF TRU WASTE AT THE WRAP FACILITY HNF-4050, Rev. 4		ECN No. ECN-655142

Name	MSIN	Text With All Attach.	Text Only	Attach./ Appendix Only	EDT/ECN Only
WG Jasen	T4-05	X			
JK Kersten	T4-52	X			
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Total Measurement Uncertainty For Nondestructive Assay of Transuranic Waste At the WRAP Facility

HNF-4050, Rev. 4
ECN-655142
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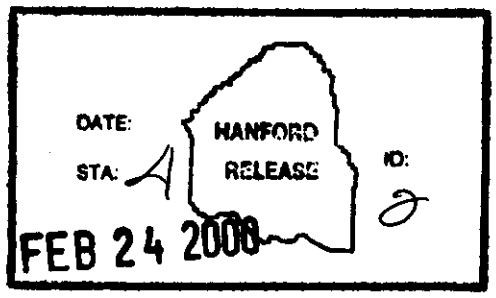
Date Published
February 24, 2000

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

Fluor Hanford, Inc.
P.O. Box 1000
Richland, Washington



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B. Document Number HNF-4050, Revision 4

C. Title

Total Measurement Uncertainty For Nondestructive Assay of Transuranic Wase At The WRAP Facility

D. Internet Address N/A

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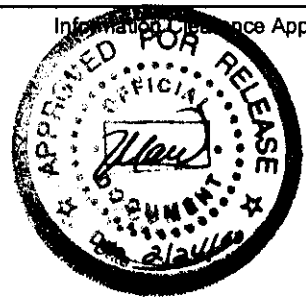

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HNF-4050
Revision 4
Volume N/A

Total Measurement Uncertainty 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
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Fluor Hanford, Inc.
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Richland, Washington

RECORD OF REVISION	(1) Document Number HNF-4050	Page 1

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Total Measurement Uncertainty For NDA of TRU Waste At the WRAP Facility

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3	Complete Revision to document per ECN-655111		
4 RS	Complete Revision to document per ECN-655142	CE Wills	JR Weidert 2-24-00

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

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

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) measurements of TRU waste containers is one of two required 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 uncertainty, associated with any measurements taken. 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 on the TMU is analyzed, and a final method is given for determining the TMU for NDA measurements at WRAP. As more data becomes available, and WRAP gains in operational experience, this report will be reviewed semi-annually and updated as necessary.

This report also includes the data flow paths for the analytical process in the radiometric determinations.

Table of Contents

Introduction

This document contains the limiting factors relating to the waste drum analysis for shipments destined to 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 Plants process lines, primarily combustible materials.
- Currently, only the GEA systems are used to characterize waste, therefore, only the GEA systems are addressed in this document.
- Plutonium analysis range is from MDC (Reference 2) to 160 grams (gms). However, analysis will be carried out on drums having sufficient activity in the 414 keV peak of ^{239}Pu. Those drums with lower levels of activity will be set aside for further instrumental evaluation.
- System calibration density ranges from 0.013 gms/cc to 1.6 gms/cc.
- PDP Plutonium drum densities were evaluated from 0.065 gm/cc to 0.305 gms/cc.
- PDP Plutonium source weights ranged from 0.030 gms to 318 gms, in both empty and combustible matrix drums.
- The system design density correction macroscopic absorption cross section table (MAC) is Lucite, a representative material of combustible waste.
- Drums with material not fitting the debris waste criterion are targeted for additional calculations, reviews, and potential re-analysis using a calibration suited for the material type.

System

At the WRAP facility, there are two identical imaging passive/active neutron (IPAN) assayers and two identical gamma energy (GEA) assayers. 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. Uncertainties are

minimized through the various correction factors applied to each of the segmented spectral scans, prior to developing the final summed spectrum for analysis.

The drum platform moves to three vertical positions during an assay, see Figures 1, 2, 3, thus dividing the drum into twelve segments for analysis. The uppermost and lowermost segments are discarded to eliminate end effects, leaving ten segments for analysis. This practice of not using the extreme positions for 208 liter drums is applied to PDP, QAO, calibration development, and waste stream analysis. Figure 1 displays the cone of gamma sensitivity for the upper discarded segment, it views the top drum lids and voids. Figure 3 displays the cone of gamma sensitivity for the lower discarded segment, i.e., 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 inhomogenieties.

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.

NDA analysis uses data from a variety of sources: Acceptable Knowledge (AK), WRAP scales, NDE, MGA, GEA; and, in the case of process drums, information is 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.

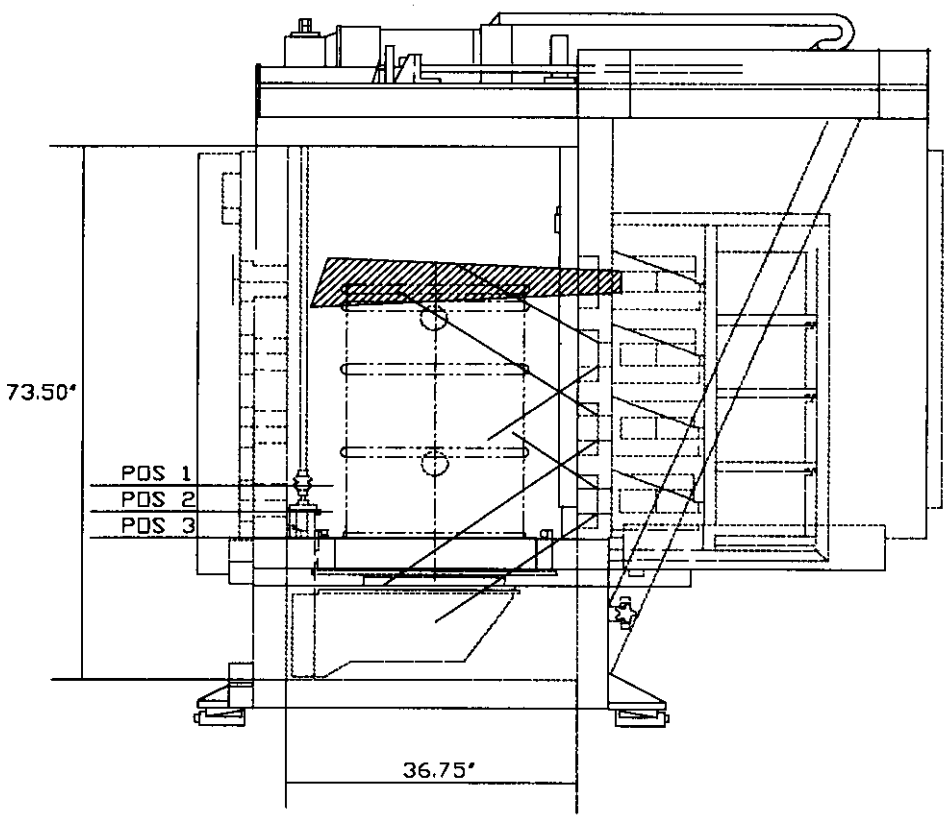

Figure 1

55 GAL DRUM
CONE OF GAMMA SENSITIVITY
FOR UNUSED SEGMENTS

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

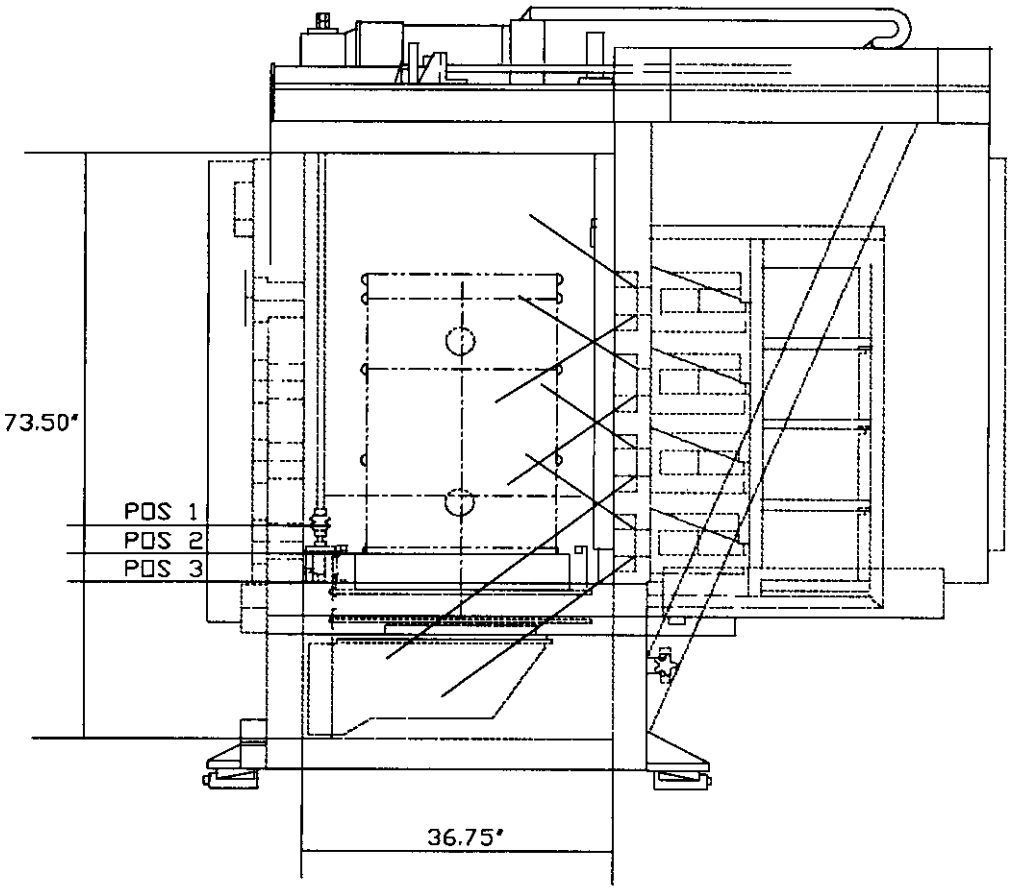

Figure 2
55 GAL DRUM
CONE OF GAMMA SENSITIVITY
FOR UNUSED SEGMENTS

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

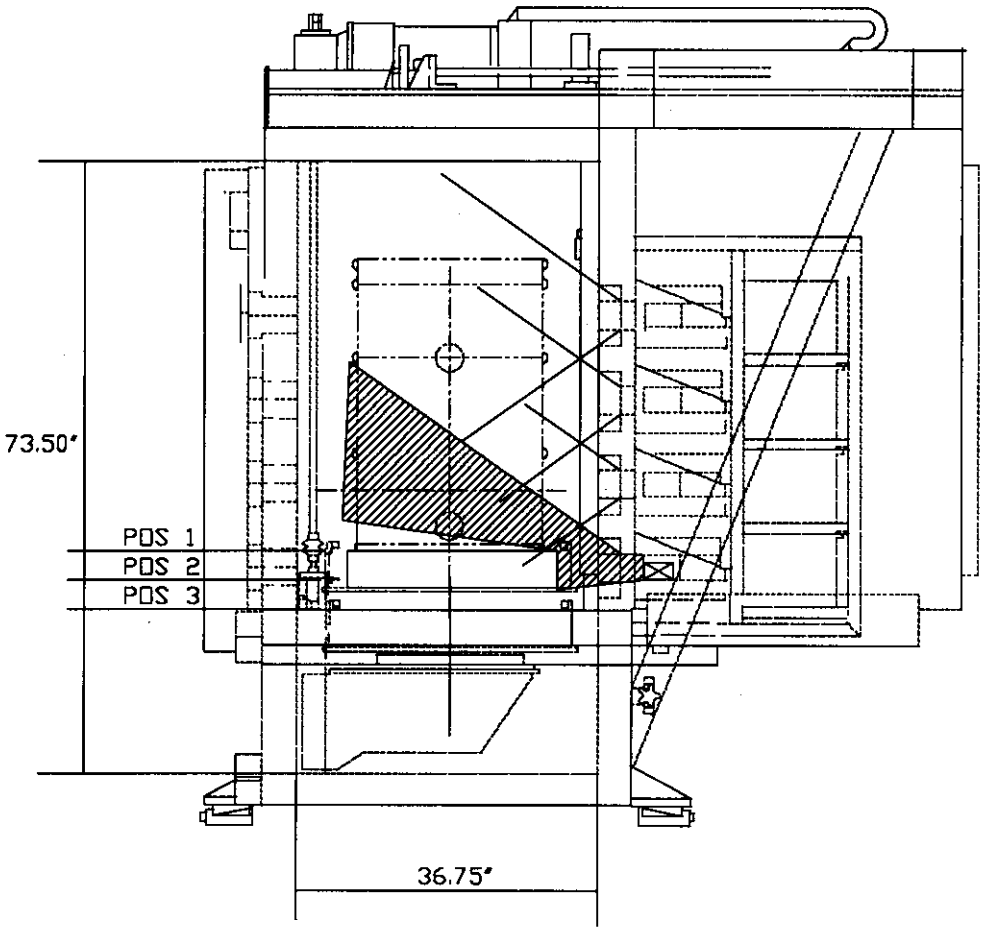

Figure 3
55 GAL DRUM
CONE OF GAMMA SENSITIVITY
FOR UNUSED SEGMENTS

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

Overview of WRAP Drum Analysis

The procedure for performing an expert 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 Figure 4.

Physical Measurements

Drums received at the WRAP facility are handled according to WRP1-OP-503, "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-503 also describes the physical handling of the drums for NDE and NDA analyses. The procedures for the actual analyses of drums are WRP1-OP-908, "Operation of the Drum Nondestructive Examination System", WRP1-OP-905, "Imaging Passive/Active Neutron Assay Operation", and WRP1-OP-906, "Gamma Energy Assay Operations". Each drum having a potential to go to WIPP receives an NDE, IPAN and GEA analyses. For this revision of the TMU document, only GEA and NDE analysis will be considered.

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.

Both the IPAN and 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.

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 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 QA 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 picture 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, from the inputted weight and percent full volume, 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 in WMH-350 Section 2.2, and also in this document (see Table 3). These guidelines are based on the quantity of ^{239}Pu measured. Factors such as: NDE and GEA results, transmission adequacy, non-uniform matrix effects, as evidenced by inconsistent source transmission or segment activity; and/or source lumping effects (determined by ratio of the 414 keV to 129 keV or 375 keV lines) are taken into account. The analyst selects the appropriate algorithmic results or determines that the drum cannot be adequately analyzed. A more complete discussion of possible interferences is given in WMH-350 Section 2.2.

Uranium is not 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 format, μCi, to grams, and the reported measurement uncertainty at one sigma calculated. Specific activity values, (Ci/gm), 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, all 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 NDA 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 lays out 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 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 total measurement uncertainty are factored in at this point. Self-absorption uncertainty, Non-uniformity uncertainty, Matrix 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 Uncertainty section.

The total and one sigma uncertainty 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: an isotopic value is calculated by dividing by isotopic gram value and the isotopic gram value uncertainty by the appropriate conversion factor.

The calculation of the sum of the individual isotopic uncertainties into an overall uncertainty is defined in the Propagation of Uncertainty section.

For the total nCi/g calculation, the total alpha curie value, converted to nCi must be divided by the net grams waste (converted from kilograms). Likewise, the error 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 one sigma uncertainties into 1.96 sigma errors for inclusion in the WRAP Radioassay Data Sheet, a summary compiled for WIPP.

Upon completion of the analysis, each drum is assigned a waste class (TRU or Low Level {LLW}). If the drum is TRU and contains no prohibited items for disposal at WIPP (determined through NDE), such drums are referred to as verification drums. If the drum is TRU and does contain prohibited items, it is dispositioned for processing in the WRAP TRU glovebox line, where it is opened for sorting and removal of the prohibited items. The contents are repackaged into a new drum, referred to as a process drum, which is considered newly generated waste.

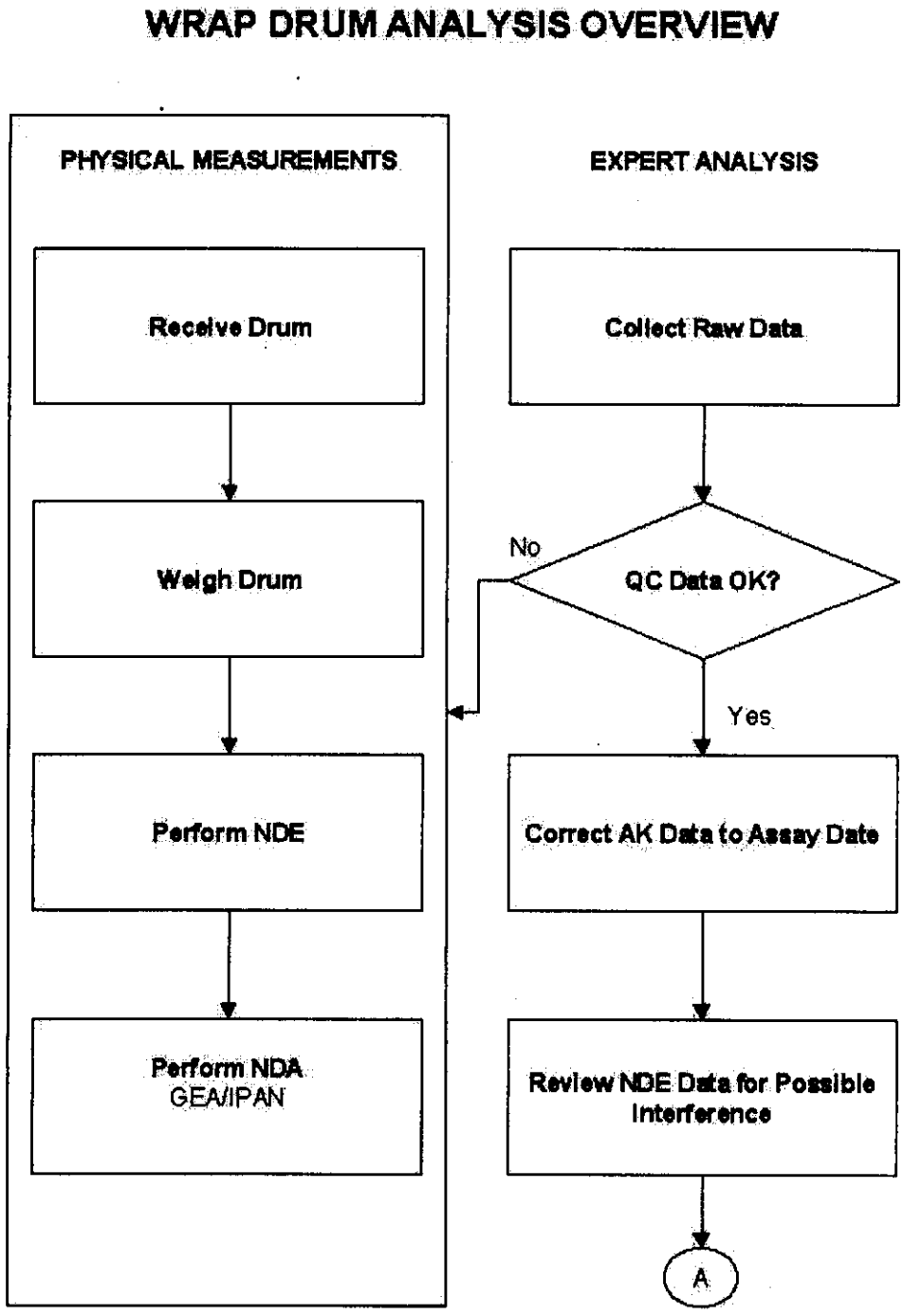
WRAP DRUM ANALYSIS OVERVIEW
PHYSICAL MEASUREMENTS
EXPERT ANALYSIS
Receive Drum
Collect Raw Data
Weigh Drum
No
QC Data OK?
Yes
Perform NDE
Correct AK Data to Assay Date
Perform NDA
GEA/IPAN
Review NDE Data for Possible Interference
A

Figure 4a

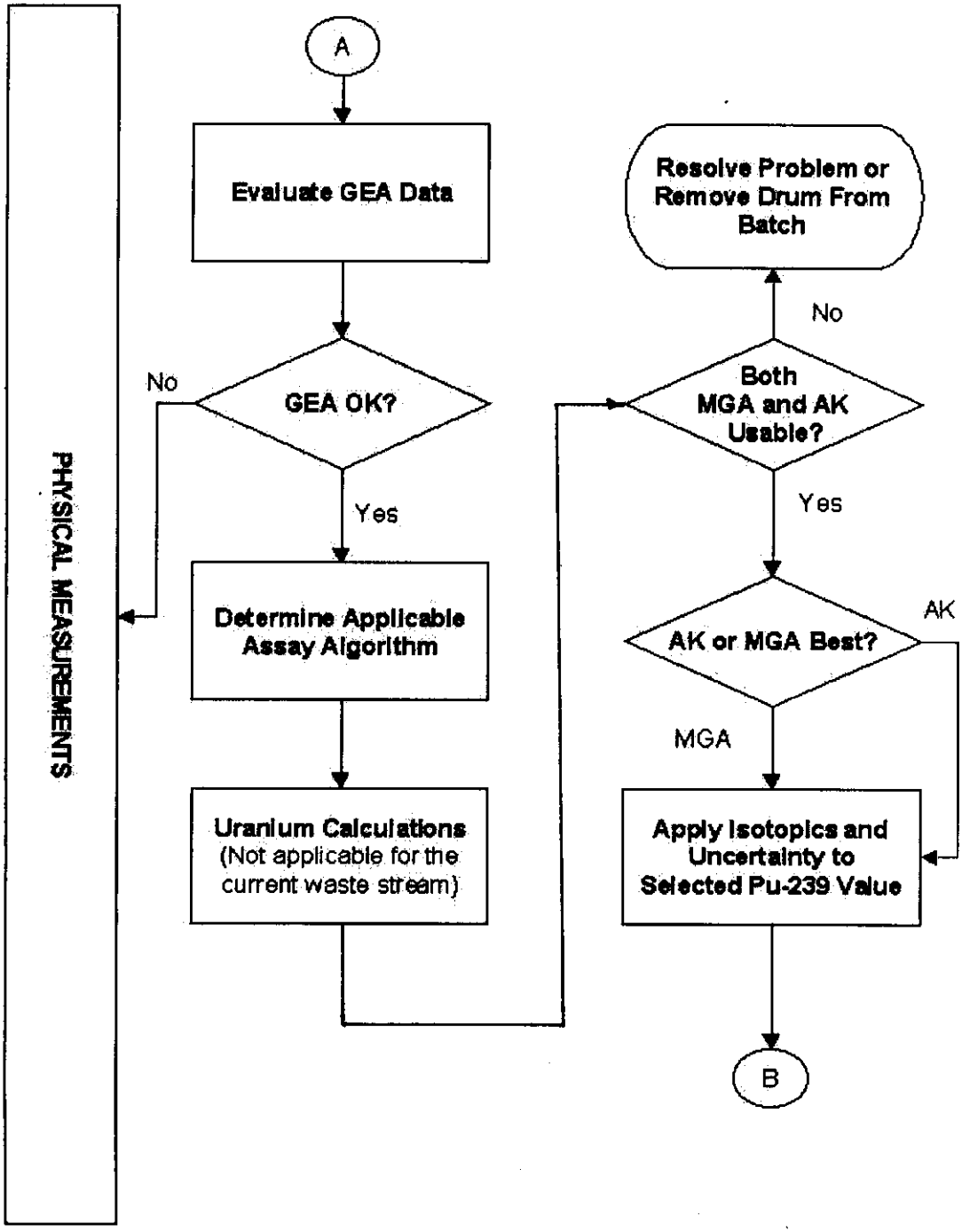
PHYSICAL MEASUREMENTS
A
Evaluate GEA Data
GEA OK?
No
Yes
Determine Applicable Assay Algorithm
Uranium Calculations (Not applicable for the current waste stream)
Resolve Problem or Remove Drum From Batch
No
Both MGA and AK Usable?
Yes
AK or MGA Best?
AK
MGA
Apply Isotopics and Uncertainty to Selected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

Figure 4b

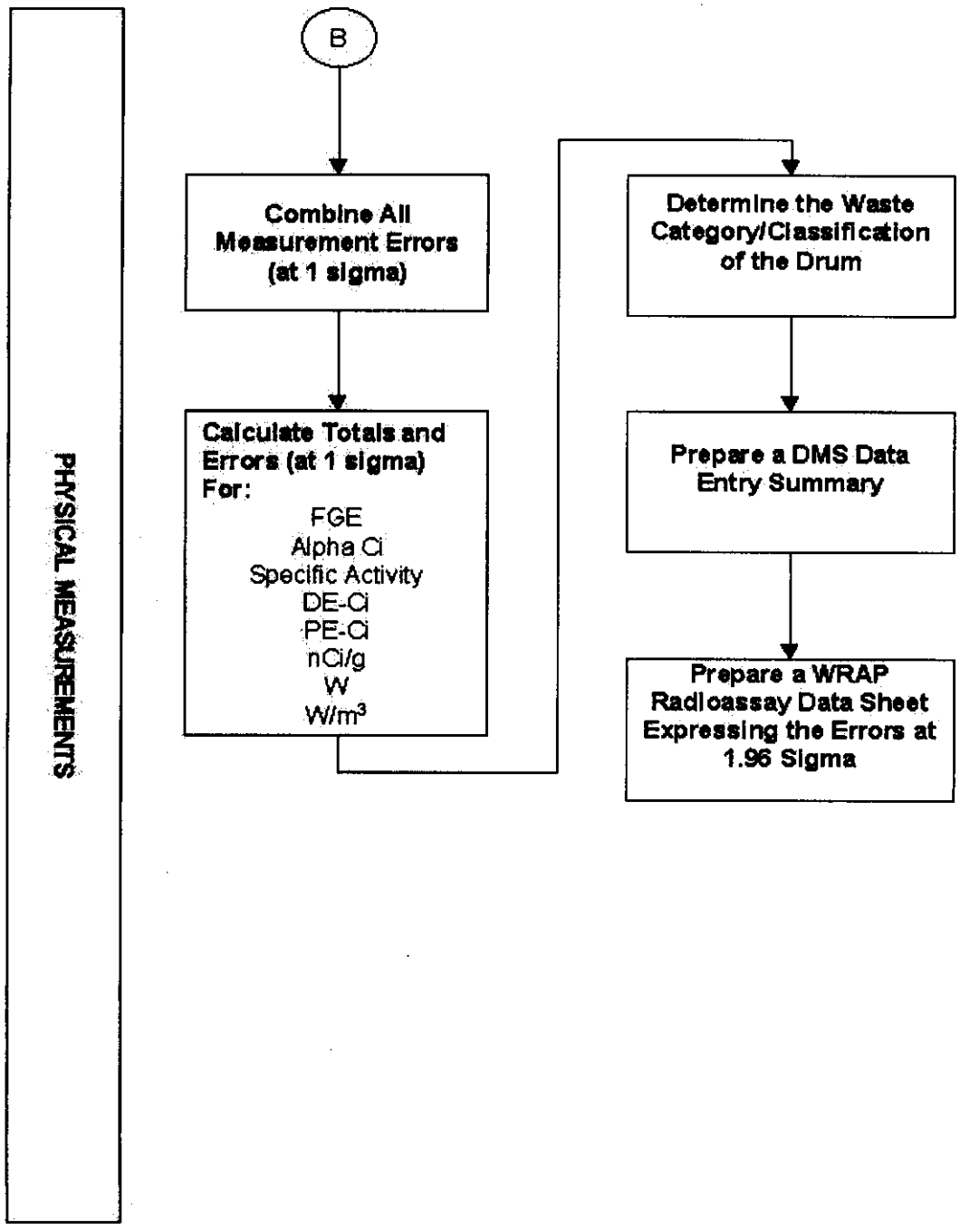
PHYSICAL MEASUREMENTS
B
Combine All Measurement Errors (at 1 sigma)
Calculate Totals and Errors (at 1 sigma) For:
FGE
Alpha Ci
Specific Activity
DE-Ci
PE-Ci
nCi/g
W
W/m3
Determine the Waste Category/Classification of the Drum
Prepare a DMS Data Entry Summary
Prepare a WRAP Radioassay Data Sheet Expressing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

Figure 4c

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, or TMU. It is assumed that the statistical distribution of measurement errors within the waste stream population follows a normal distribution. It is also assumed that the individual uncertainty components are statistically independent. 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 the mean of a series of replicate measurements is used to evaluate this kind 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 inhomogeniety 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.

GEA MEASUREMENT UNCERTAINTY

The primary components of the total measurement uncertainty 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 data uncertainties

Quality control measurements are obtained to ensure that the system is performing 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 first measurement serves to determine if all of the detectors are functioning properly, while the second serves as a measure of whether there has been contamination of the system or changes in the area around the system. Additional details regarding QC measurements can be found in Reference 3.

Calibration Uncertainties

There are typically two components of the overall calibration uncertainty. The first is the uncertainty associated with the calibration sources; this is included in the source certificate files used to calibrate the instrument. The second 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 so that measurement uncertainties will reflect the calibration uncertainty. Algorithms for propagation of the calibration source uncertainties are contained in Reference 3. For calibration of 208 liter (55 gallon) drums, there is no additional calibration uncertainty beyond that generated by the GEA software.

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 computation methodologies (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 Combustible drum are provided in Tables 1.A – 1.F. It should be noted that not all data are valid for all mass ranges. For this revision of the TMU, all analysis will be done using the 414 keV line. The 129 and 375 lines can be used for reference and to indicate severe lumping. For each Pu mass listed in Tables 1.A – 1.F the random uncertainty as estimated by the relative standard deviation (RSD), standard deviation divided by the mean, 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 uncertainty 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 statistic 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 underestimates the GEA measurement uncertainty, illustrated in Table 1.F. (columns 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 gm to 1.0 gm total Plutonium. The average of the nine ratios was 1.8 with a standard deviation of 0.7. The 95% confidence interval for the mean value ranged from 1.2 to 2.3. Thus, to one significant digit, the GEA measurement uncertainty for the TMU calculation of waste drums evaluated under this condition will be two times the uncertainty generated in the GEA analysis report.

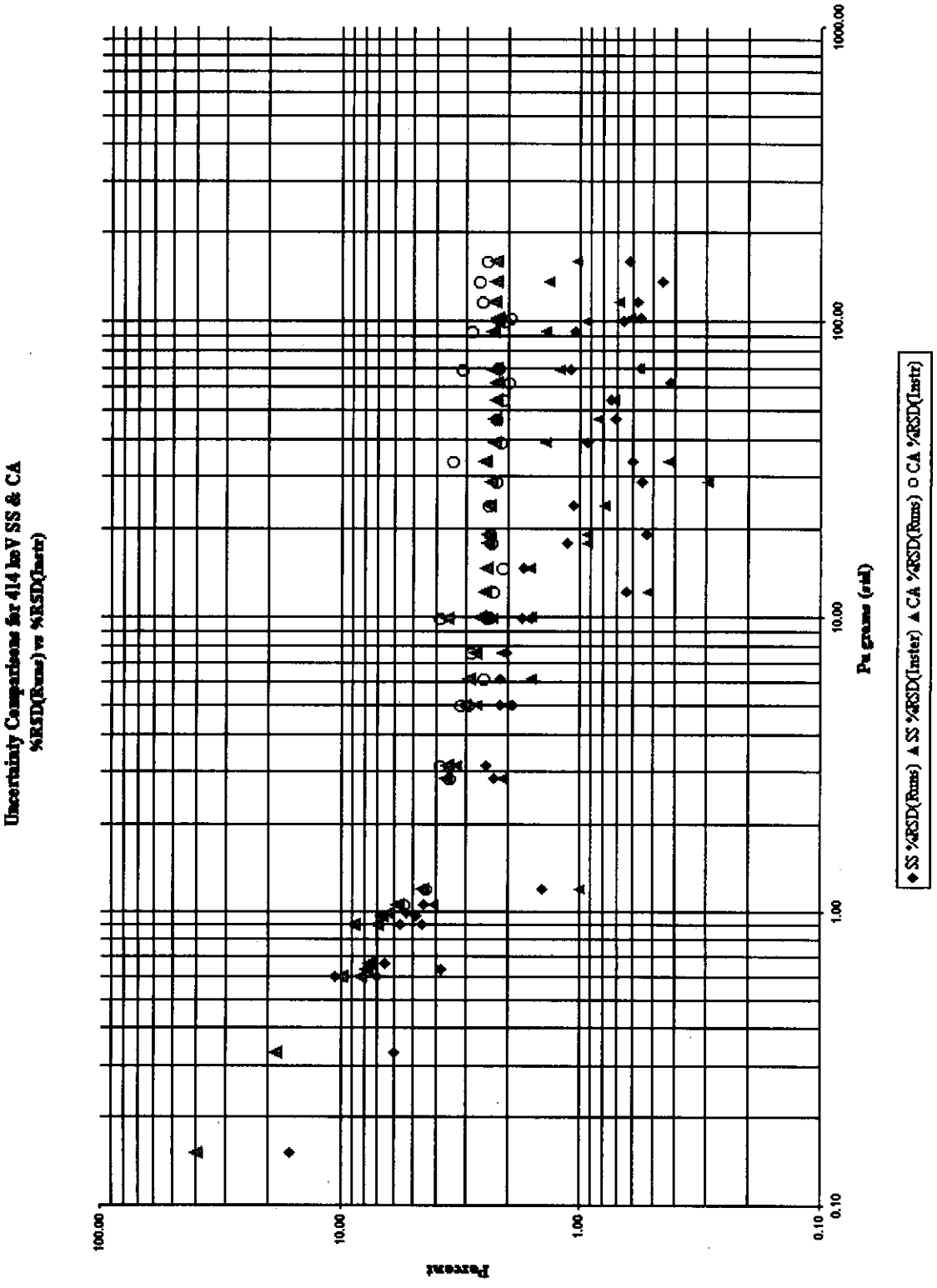
Uncertainty Comparisons for 414 keV SS & CA
%RSD(Rms) vs %RSD(Instr)
Percent
100.00
10.00
1.00
0.10
1000.00
100.00
10.00
1.00
0.10
Pu grams (mg)
◆ SS %RSD(Rms) ▲ SS %RSD(Instr) ▲ CA %RSD(Rms) ○ CA %RSD(Instr)

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
QAO009	0.06	<MDC	<MDC	<MDC	<MDC	<MDC	
QAO21	0.09	<MDC	<MDC	<MDC	<MDC	<MDC	
QAO24	0.09	<MDC	<MDC	<MDC	<MDC	<MDC	N/A
QAO23	0.10	<MDC	<MDC	<MDC	<MDC	<MDC	
QAO11	0.15	21.57	14.76	29.46	22.52	72.81	
QAO003	0.33	13.33	10.30	19.11	12.95	65.08	
QAO011	0.60	5.35	6.12	8.69	6.72	79.47	
QAO10	0.60	4.73	5.79	6.56	6.12	82.72	
QAO013	0.63	5.78	5.62	7.97	6.50	78.63	
QAO001	0.66	9.00	5.79	8.43	6.62	74.28	
QAO2	0.90	9.51	5.74	7.57	6.32	71.44	N/A
QAO6	0.90	6.65	4.54	6.31	5.47	68.86	
QAO4	0.96	7.24	4.42	6.10	4.94	74.53	
QAO20	0.99	4.95	4.20	5.27	4.82	75.16	
QAO14	1.05	2.75	4.27	5.60	4.78	74.33	
QAO8	1.20	3.84	3.38	4.06	3.58	85.59	
QAOW20	2.85	4.97	2.63	3.00	2.78	75.23	89.14
QAO18	3.15	3.84	2.72	3.11	2.89	62.86	74.49
QAOW13	5.00	4.48	1.96	2.59	2.31	70.90	84.02
QAOW16	5.00	5.63	2.09	2.54	2.21	77.40	91.71
QAO16	6.15	7.50	2.05	2.64	2.30	65.04	77.07
QAOW17	7.53	2.49	1.88	2.16	1.97	74.77	88.59
QAO19	9.90	5.18	1.62	2.00	1.76	76.41	92.24
QAO19	9.90	0.86	1.68	3.11	1.72	77.84	90.54
QAOW08	10.00	3.07	1.64	1.96	1.79	72.66	86.09
QAOW41	12.20	1.75	1.61	1.77	1.69	76.20	90.29
QAOW53	14.68	1.67	1.48	1.61	1.55	75.12	89.02
QAOW37	17.70	3.78	1.47	1.69	1.54	72.36	85.74
QAOW63	19.13	3.16	1.40	1.67	1.52	72.44	85.84
QAO58	23.88	1.01	1.31	1.43	1.38	68.44	81.10
QAOW36	28.60	2.68	1.25	1.44	1.34	67.95	92.24
QAOW64	33.55	1.30	1.67	1.79	1.74	86.30	93.79
QAOW40	39.00	1.33	1.14	1.27	1.23	70.62	95.86
QAOW27	47.00	1.67	1.13	1.25	1.19	64.45	87.49
QAOW46	54.30	2.29	1.09	1.23	1.16	71.84	97.52
QAOW45	62.00	1.50	1.05	1.15	1.10	68.66	93.20
QAOW51	68.67	3.35	1.34	1.55	1.47	82.40	89.54
QAOW25	70.00	2.98	1.08	1.22	1.13	63.55	86.27
QAOW60	92.25	2.09	1.25	1.39	1.32	79.10	85.96
QAOW33	100.00	1.55	1.01	1.10	1.04	60.19	81.71
QAOW48	102.70	1.89	0.99	1.05	1.03	63.04	85.58
QAOW54	116.71	0.35	1.22	1.30	1.26	78.35	85.15
QAOW57	135.70	2.59	1.18	1.37	1.27	77.04	83.73
QAOW21	160.00	1.28	1.05	1.23	1.17	79.65	86.56

Sum segments methodology is used for masses below 5gm and Combine All is used for masses above 5gm. For masses in the 0-2.5 gm range, the 129 keV line is preferred. However, the current TMU is not defined for 129 keV measurements, drums in mass range I (<MDC) will be set aside. For masses above 0.25 gm, the 414 keV line will be used.

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
QAO009	0.06	18.46	13.28	33.14	20.76	113.26	118.59
QAO21	0.09	9.69	11.44	18.05	14.19	108.70	113.82
QAO24	0.09	10.50	13.72	22.80	16.51	94.44	98.89
QAO23	0.10	19.22	13.05	22.01	17.22	88.08	92.23
QAO11	0.15	6.11	9.86	11.06	10.43	103.60	108.48
QAO003	0.33	5.95	5.62	8.61	6.75	99.47	101.69
QAO011	0.60	3.96	4.20	5.22	4.62	115.76	118.35
QAO10	0.60	2.87	4.41	5.04	4.80	113.56	116.10
QAO013	0.63	4.56	4.30	4.79	4.55	118.21	120.86
QAO001	0.66	3.84	4.23	5.05	4.68	108.49	110.92
QAO2	0.90	2.34	4.11	4.85	4.55	102.95	105.25
QAO6	0.90	2.40	4.30	4.96	4.64	91.46	93.51
QAO4	0.96	4.82	3.79	4.67	4.31	103.75	106.07
QAO20	0.99	4.56	3.82	4.71	4.23	103.85	106.17
QAO14	1.05	6.32	3.82	4.59	4.16	105.30	107.65
QAO8	1.20	5.49	3.54	3.67	3.60	95.08	97.21
QAOW20	2.85	4.43	3.43	3.52	3.47	98.03	119.01
QAO18	3.15	4.47	3.36	3.67	3.52	79.10	96.02
QAOW13	5.00	4.10	3.12	3.38	3.33	82.49	100.14
QAOW16	5.00	4.99	3.24	3.38	3.26	99.27	120.51
QAO16	6.15	1.29	3.19	3.30	3.24	82.77	100.49
QAOW17	7.53	3.43	3.13	3.18	3.16	93.30	113.27
QAO19	9.90	2.34	3.06	3.11	3.09	96.42	116.81
QAO19	9.90	0.75	3.07	3.67	3.09	96.22	117.06
QAOW08	10.00	4.02	3.11	3.15	3.13	86.50	105.01
QAOW41	12.20	5.14	3.13	3.13	3.13	93.80	113.88
QAOW53	14.68	4.06	3.07	3.13	3.10	88.09	106.95
QAOW37	17.70	2.82	3.04	3.06	3.05	80.69	97.96
QAOW63	19.13	3.43	3.08	3.10	3.09	82.31	99.93
QAO58	23.88	3.64	3.09	3.11	3.10	63.54	77.13
QAOW36	28.60	3.21	3.02	3.04	3.03	67.76	
QAOW64	33.55	12.70	245.41	246.23	245.68	11.47	
QAOW40	39.00	3.02	3.03	3.05	3.04	70.98	
QAOW27	47.00	3.19	3.01	3.04	3.02	47.36	
QAOW46	54.30	3.10	3.02	3.04	3.03	67.84	
QAOW45	62.00	3.66	3.03	3.04	3.04	53.90	
QAOW51	68.67	7.96	245.15	246.48	245.63	9.40	N/A
QAOW25	70.00	2.62	2.98	2.99	2.99	56.64	
QAOW60	92.25	9.81	244.71	246.49	245.62	7.84	
QAOW33	100.00	2.28	2.98	2.99	2.98	45.91	
QAOW48	102.70	0.45	3.01	3.02	3.02	49.15	
QAOW54	116.71	8.83	244.90	246.24	245.55	8.16	
QAOW57	135.70	8.74	245.06	245.79	245.54	7.37	
QAOW21	160.00	8.26	251.66	252.84	252.22	8.13	

Sum segments methodology is used for masses below 5gm and Combine All is used for masses above 5gm. For masses in the 0-2.5 gm range, the 129 keV line is preferred. However, the current TMU is not defined for 129 keV measurements, drums in mass range I (<MDC) will be set aside. For masses above 0.25 gm, the 414 keV line will be used.

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**
QAO009	0.06	<MDC	<MDC	<MDC	<MDC	<MDC	
QAO21	0.09	<MDC	<MDC	<MDC	<MDC	<MDC	
QAO24	0.09	<MDC	<MDC	<MDC	<MDC	<MDC	N/A
QAO23	0.10	<MDC	<MDC	<MDC	<MDC	<MDC	
QAO11	0.15	16.35	16.64	39.89	25.41	81.39	
QAO003	0.33	6.02	10.51	18.60	13.45	71.53	80.69
QAO011	0.60	7.00	6.44	9.88	7.74	80.38	90.67
QAO10	0.60	10.62	6.28	8.36	7.60	81.69	92.15
QAO013	0.63	3.82	6.19	7.81	7.06	85.28	96.21
QAO001	0.66	6.53	6.25	7.58	6.88	81.97	92.47
QAO2	0.90	4.55	6.23	8.80	7.53	77.93	87.92
QAO6	0.90	5.63	5.63	7.01	6.34	72.79	82.11
QAO4	0.96	4.86	5.51	6.74	6.20	76.15	85.91
QAO20	0.99	5.33	5.14	6.39	5.62	78.31	88.35
QAO14	1.05	4.50	4.77	5.83	5.47	78.32	88.35
QAO8	1.20	1.44	4.17	4.53	4.36	91.03	102.69
QAOW20	2.85	2.31	3.44	3.62	3.53	77.21	91.18
QAO18	3.15	2.47	3.49	3.62	3.57	65.46	77.31
QAOW13	5.00	2.17	2.82	3.02	2.98	72.26	85.33
QAOW16	5.00	1.91	2.89	3.02	2.93	77.46	91.47
QAO16	6.15	2.15	2.82	2.90	2.86	70.05	82.72
QAOW17	7.53	2.02	2.67	2.74	2.69	76.19	89.97
QAO19	9.90	1.74	2.53	2.59	2.57	76.87	90.13
QAO19	9.90	2.31	2.56	3.62	2.58	76.33	90.77
QAOW08	10.00	1.58	2.57	2.62	2.59	72.51	85.62
QAOW41	12.20	0.64	2.48	2.52	2.50	77.04	90.97
QAOW53	14.68	1.72	2.45	2.48	2.47	74.07	87.46
QAOW37	17.70	1.14	2.41	2.44	2.42	71.98	85.00
QAOW63	19.13	0.53	2.38	2.42	2.40	72.56	85.69
QAO58	23.88	1.07	2.35	2.39	2.37	67.31	79.48
QAOW36	28.60	0.55	2.34	2.35	2.35	67.56	93.88
QAOW64	33.55	0.60	2.45	2.49	2.47	87.65	97.72
QAOW40	39.00	0.93	2.29	2.31	2.30	68.74	95.51
QAOW27	47.00	0.71	2.28	2.30	2.29	62.87	87.36
QAOW46	54.30	0.74	2.27	2.27	2.27	70.23	97.59
QAOW45	62.00	0.42	2.26	2.26	2.26	66.89	92.94
QAOW51	68.67	1.10	2.31	2.34	2.33	83.51	93.11
QAOW25	70.00	0.56	2.25	2.27	2.26	62.00	86.15
QAOW60	92.25	1.05	2.29	2.31	2.30	77.87	86.82
QAOW33	100.00	0.66	2.24	2.25	2.24	57.66	80.12
QAOW48	102.70	0.56	2.23	2.24	2.23	61.15	84.96
QAOW54	116.71	0.58	2.25	2.28	2.27	77.09	85.95
QAOW57	135.70	0.45	2.26	2.27	2.26	76.71	85.53
QAOW21	160.00	0.62	2.25	2.27	2.26	77.75	86.69

Sum segments methodology is used for masses below 5gm and Combine All is used for masses above 5gm. For masses in the 0-2.5 gm range, the 129 keV line is preferred. However, the current TMU is not defined for 129 keV measurements, drums in mass range I (<MDC) will be set aside. For masses above 0.25 gm, the 414 keV line will be used.

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
QAO009	0.06	<MDC	<MDC	<MDC	<MDC	<MDC	
QAO21	0.09	<MDC	<MDC	<MDC	<MDC	<MDC	
QAO24	0.09	<MDC	<MDC	<MDC	<MDC	<MDC	
QAO23	0.10	<MDC	<MDC	<MDC	<MDC	<MDC	
QAO11	0.15	71.25	14.76	36.72	27.75	50.35	
QAO003	0.33	29.45	10.15	27.10	14.51	47.60	
QAO011	0.60	11.03	6.91	9.27	7.64	66.23	
QAO10	0.60	14.09	5.79	7.55	6.56	71.23	
QAO013	0.63	7.64	5.83	8.41	6.66	74.86	
QAO001	0.66	12.12	6.05	9.21	7.15	73.87	
QAO2	0.90	27.32	6.42	9.48	7.66	58.82	
QAO6	0.90	17.49	6.04	8.44	6.59	69.24	
QAO4	0.96	7.42	4.88	5.75	5.47	75.77	
QAO20	0.99	16.27	5.15	7.95	5.67	73.80	
QAO14	1.05	5.10	4.75	5.41	5.06	73.82	
QAO8	1.20	4.78	3.47	4.25	3.79	84.67	
QAOW20	2.85	2.96	2.75	3.06	2.88	80.29	87.73
QAO18	3.15	2.77	2.83	3.05	2.95	72.37	79.08
QAOW13	5.00	2.38	2.32	2.45	2.39	75.99	83.03
QAOW16	5.00	3.12	2.20	2.34	2.26	81.41	88.96
QAO16	6.15	1.29	1.99	2.15	2.07	79.05	86.38
QAOW17	7.53	1.33	2.04	2.17	2.10	78.18	85.43
QAO19	9.90	2.54	1.76	1.91	1.81	86.64	94.00
QAO19	9.90	3.08	1.76	3.05	1.81	86.03	94.67
QAOW08	10.00	3.62	1.76	1.95	1.84	79.74	87.13
QAOW41	12.20	3.06	1.67	1.75	1.72	82.22	89.84
QAOW53	14.68	1.90	1.52	1.62	1.57	81.11	88.63
QAOW37	17.70	1.90	1.60	1.69	1.63	82.08	89.69
QAOW63	19.13	1.90	1.63	1.73	1.67	80.67	88.15
QAO58	23.88	2.32	1.61	1.68	1.64	74.05	80.92
QAOW36	28.60	1.99	1.48	1.56	1.52	77.63	88.67
QAOW64	33.55	3.78	2.14	2.23	2.19	84.87	93.21
QAOW40	39.00	1.69	1.38	1.42	1.40	78.59	89.76
QAOW27	47.00	3.07	1.40	1.50	1.43	75.80	86.58
QAOW46	54.30	1.46	1.35	1.40	1.37	77.25	88.24
QAOW45	62.00	2.34	1.25	1.31	1.28	71.40	81.55
QAOW51	68.67	2.62	1.86	1.96	1.90	81.49	89.50
QAOW25	70.00	3.69	1.35	1.44	1.39	74.80	85.44
QAOW60	92.25	1.80	1.72	1.79	1.74	74.75	82.09
QAOW33	100.00	2.10	1.27	1.32	1.30	72.98	83.36
QAOW48	102.70	1.27	1.21	1.25	1.23	77.24	88.22
QAOW54	116.71	1.57	1.57	1.62	1.59	75.06	82.43
QAOW57	135.70	3.29	1.55	1.74	1.63	73.25	80.45
QAOW21	160.00	1.82	1.44	1.50	1.47	75.90	83.35

Sum segments methodology is used for masses below 5gm and Combine All is used for masses above 5gm. For masses in the 0-2.5 gm range, the 129 keV line is preferred. However, the current TMU is not defined for 129 keV measurements, drums in mass range I (<MDC) will be set aside. For masses above 0.25 gm, the 414 keV line will be used.

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
QAO009	0.06	92.15	13.28	47.58	28.75	38.91	
QAO21	0.09	134.74	13.15	54.20	31.32	23.97	
QAO24	0.09	95.95	15.68	59.58	28.31	40.04	N/A
QAO23	0.10	33.41	12.51	26.93	17.40	37.70	
QAO11	0.15	23.34	10.10	14.32	11.68	57.02	
QAO003	0.33	5.57	7.28	8.38	7.73	60.09	71.30
QAO011	0.60	3.27	5.18	5.49	5.35	69.00	81.87
QAO10	0.60	2.76	5.96	6.26	6.09	66.85	79.32
QAO013	0.63	3.83	5.39	5.68	5.53	73.68	87.42
QAO001	0.66	3.76	5.03	5.39	5.18	77.90	92.42
QAO2	0.90	8.67	4.68	5.40	4.99	68.46	81.22
QAO6	0.90	1.64	4.77	4.90	4.85	72.54	86.06
QAO4	0.96	3.01	4.86	5.01	4.92	76.06	90.25
QAO20	0.99	6.49	4.70	5.45	4.86	76.40	90.65
QAO14	1.05	2.10	5.14	5.36	5.24	84.77	100.58
QAO8	1.20	2.70	4.72	4.82	4.75	97.72	115.94
QAOW20	2.85	1.81	4.70	4.82	4.76	76.02	87.80
QAO18	3.15	2.18	5.38	5.53	5.45	67.53	77.99
QAOW13	5.00	1.55	4.98	5.12	5.05	60.96	70.40
QAOW16	5.00	1.54	4.55	4.60	4.58	71.58	82.67
QAO16	6.15	0.93	3.70	3.72	3.71	72.11	83.28
QAOW17	7.53	2.52	4.75	4.80	4.78	64.34	74.30
QAO19	9.90	2.03	4.16	4.23	4.19	81.37	95.53
QAO19	9.90	3.06	4.18	5.53	4.20	82.72	93.97
QAOW08	10.00	2.25	4.04	4.13	4.08	69.82	80.63
QAOW41	12.20	1.40	4.03	4.05	4.04	69.37	80.12
QAOW53	14.68	1.44	3.63	3.66	3.64	69.49	80.25
QAOW37	17.70	1.88	4.22	4.34	4.27	67.30	77.73
QAOW63	19.13	2.90	4.27	4.41	4.32	69.21	79.93
QAO58	23.88	3.39	4.43	4.53	4.49	54.81	63.29
QAOW36	28.60	1.00	4.22	4.25	4.23	61.24	
QAOW64	33.55	9.19	70.50	77.07	74.47	20.19	
QAOW40	39.00	4.24	4.08	4.15	4.12	64.25	
QAOW27	47.00	2.39	4.12	4.21	4.17	46.93	
QAOW46	54.30	2.84	4.03	4.10	4.07	63.36	
QAOW45	62.00	1.72	3.88	3.97	3.93	41.14	
QAOW51	68.67	3.22	65.42	70.09	68.79	16.71	N/A
QAOW25	70.00	2.67	4.32	4.40	4.36	55.29	
QAOW60	92.25	7.66	46.66	55.50	50.80	15.46	
QAOW33	100.00	5.96	3.80	4.07	3.88	47.40	
QAOW48	102.70	2.84	3.77	3.83	3.80	55.37	
QAOW54	116.71	3.47	45.03	51.57	47.37	15.48	
QAOW57	135.70	4.43	41.78	47.24	44.25	14.45	
QAOW21	160.00	6.13	45.74	52.82	49.62	14.89	

Sum segments methodology is used for masses below 5gm and Combine All is used for masses above 5gm. For masses in the 0-2.5 gm range, the 129 keV line is preferred. However, the current TMU is not defined for 129 keV measurements, drums in mass range I (<MDC) will be set aside. For masses above 0.25 gm, the 414 keV line will be used.

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**
QAO009	0.06	<MDC	<MDC	<MDC	<MDC	<MDC	
QAO21	0.09	<MDC	<MDC	<MDC	<MDC	<MDC	
QAO24	0.09	<MDC	<MDC	<MDC	<MDC	<MDC	NA
QAO23	0.10	<MDC	<MDC	<MDC	<MDC	<MDC	
QAO11	0.15	84.47	19.71	40.68	30.58	44.05	
QAO003	0.33	30.71	9.86	20.38	13.13	54.36	67.17
QAO011	0.60	11.66	6.59	8.32	7.48	69.45	85.82
QAO10	0.60	14.20	6.27	7.75	7.18	68.60	84.76
QAO013	0.63	6.89	6.06	7.09	6.69	78.92	97.51
QAO001	0.66	8.81	6.35	8.09	7.03	78.27	96.72
QAO2	0.90	25.83	6.49	9.21	7.66	58.16	71.86
QAO6	0.90	7.85	5.71	6.42	6.13	73.79	91.18
QAO4	0.96	8.49	5.15	6.02	5.62	80.42	99.37
QAO20	0.99	9.27	5.03	5.99	5.39	81.09	100.20
QAO14	1.05	4.10	5.04	5.39	5.26	83.64	103.35
QAO8	1.20	1.00	4.03	4.36	4.16	95.41	117.89
QAOW20	2.85	2.12	3.40	3.50	3.44	85.74	89.56
QAO18	3.15	3.28	3.61	3.82	3.67	76.50	79.91
QAOW13	5.00	2.02	3.06	3.14	3.09	79.83	83.39
QAOW16	5.00	2.69	2.83	2.91	2.87	85.71	89.53
QAO16	6.15	1.59	2.46	2.49	2.48	86.17	90.01
QAOW17	7.53	2.12	2.76	2.81	2.78	83.66	87.39
QAO19	9.90	1.67	2.39	2.44	2.41	92.22	95.74
QAO19	9.90	2.31	2.40	3.82	2.42	91.65	96.33
QAOW08	10.00	1.60	2.36	2.41	2.38	85.55	89.36
QAOW41	12.20	0.52	2.28	2.31	2.29	88.20	92.13
QAOW53	14.68	1.61	2.07	2.11	2.09	86.98	90.86
QAOW37	17.70	0.93	2.30	2.33	2.32	85.89	89.73
QAOW63	19.13	0.93	2.34	2.36	2.36	85.87	89.70
QAO58	23.88	0.79	2.38	2.41	2.39	80.20	83.78
QAOW36	28.60	0.29	2.21	2.23	2.22	82.87	89.71
QAOW64	33.55	0.43	3.33	3.40	3.37	89.33	93.60
QAOW40	39.00	1.39	2.12	2.13	2.12	82.50	89.31
QAOW27	47.00	0.84	2.19	2.21	2.20	81.60	88.34
QAOW46	54.30	0.72	2.06	2.09	2.08	83.60	90.51
QAOW45	62.00	0.42	1.97	1.98	1.98	76.04	82.32
QAOW51	68.67	1.21	3.05	3.11	3.07	86.96	91.11
QAOW25	70.00	0.57	2.17	2.19	2.18	81.73	88.48
QAOW60	92.25	1.40	2.78	2.82	2.79	80.11	83.93
QAOW33	100.00	0.94	2.04	2.06	2.05	78.18	84.64
QAOW48	102.70	0.62	1.94	1.95	1.95	82.82	89.66
QAOW54	116.71	0.69	2.52	2.54	2.53	81.49	85.39
QAOW57	135.70	1.35	2.58	2.62	2.61	79.98	83.80
QAOW21	160.00	1.03	2.41	2.44	2.42	81.22	85.10

Sum segments methodology is used for masses below 5gm and Combine All is used for masses above 5gm. For masses in the 0-2.5 gm range, the 129 keV line is preferred. However, the current TMU is not defined for 129 keV measurements, drums in mass range I (<MDC) will be set aside. For masses above 0.25 gm, the 414 keV line will be used.

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.

This would be represented by a spherical metallic source. Reference 1 reports a worst case underestimate 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 at 25% 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 calculated that changing from a metal to an oxide and changing the geometry to a less spherical shape would reduce 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 a PuO_2 rather than a metal and considering the material in a more plated form would greatly reduce the self absorption effects. Furthermore the probability of a single 10-gram lump is much less than 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, Uncertainties will be included by the analyst should lumping be detected. Lumping effects will be evident through evaluation of the ratios of the 129/414 and 375/414 keV gamma peaks of ^{239}Pu.

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 Canberra Industries for a multiple detector, un-collimated, shielded assay system (Q2 and IQ3) and is based on a combination of both measured and modeled data. As discussed in Reference 5, measurements were made using a point source in a number of equal volume elements of several uniform matrix drums. Four drums with (uniform) matrix densities ranging from 0.1 to 1.7 g/cc were prepared. Point sources were placed at

multiple radial and azimuthal positions in the drums and and their signals (414 keV) were measured at each position. From these measurements, the range of variation in the signal were 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 uncertainty source non-uniformity.

$$ERR_{Max} = (-.238*AverageDens^2) + 1.5131*AverageDens + 1.2189$$
$$ERR_{Min} = (.2439*AverageDens^2) - 0.8645*AverageDens + 0.8092$$

The estimated uncertainty (1 RSD) due to non-uniform source distribution is then determined as

$$ERR = (ERR_{Max} - ERR_{Min})/6$$

Additional modeled data was generated at Canberra (Reference 4), for the same configuration, to show the expected response distribution for three randomly distributed sources in a uniform matrix distribution. Five matrix densities were modeled (0.25, 0.5, 0.75, 1.0, and 1.25 g/cc.). For each density 1,000,000 random distributions were modeled. Figure 6 illustrates the ratio of the measured to the true activity for each run for three of the five densities in the study. The three densities plotted are closer to the densities of the PFP waste drums.

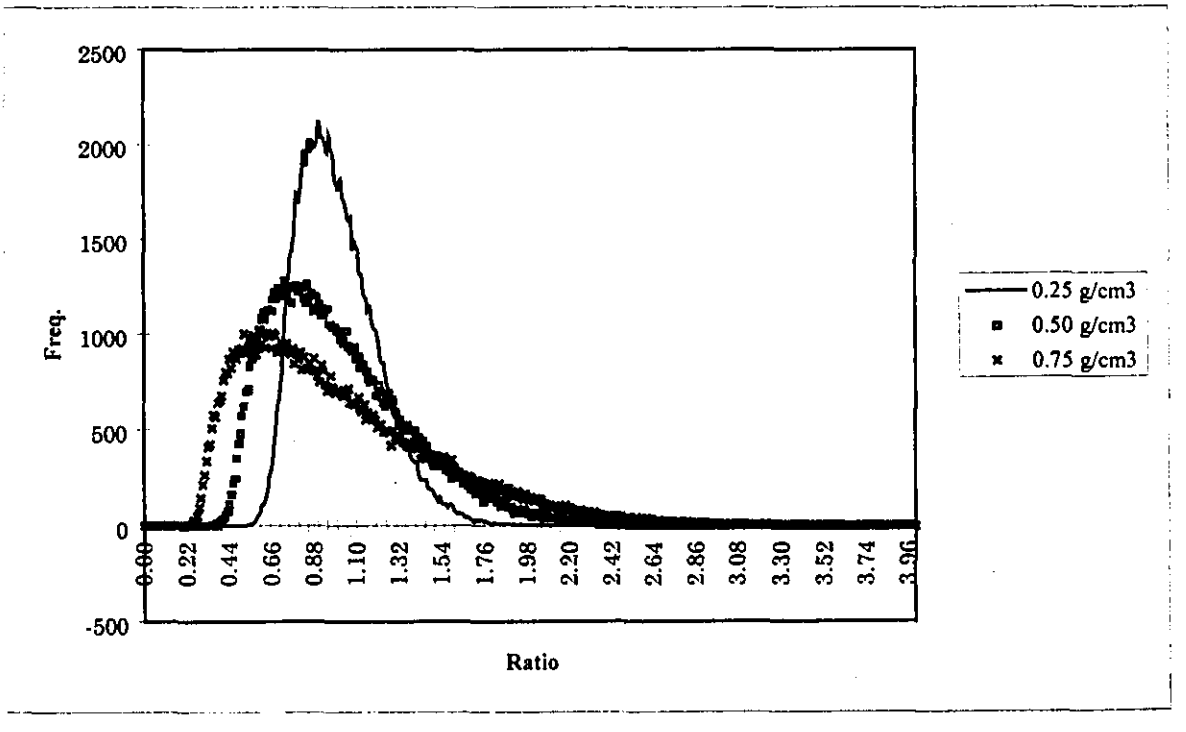

Figure 6. {Calculated response / Calculated input} versus matrix density.

The above curves are supplied as additional supporting information; the modeling results are of a drum geometry for a large number (1,000,000) of random source distributions, which represents an 8 sigma distribution. The curves agree with the conclusions and evolved equations developed from the experimental data. The data (modeled using 3 randomly distributed sources in a uniform matrix) supports the assumptions above regarding the establishment of a 3 sigma error bound on the equations (based on the single point source data) See Reference 4.

WRAP GEA Testing

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 combustible drum with various source distributions and gram loads. At the present time this represents the only available measurement data for evaluating the source non-uniformity. The source positions and gram loads for each test are listed in Table 2. As can be seen in Table 2, the source positions for QAO mass ranges III and IV represent reasonable distributed source configuration, therefore, should adequately cover the overall source non-uniformity uncertainty (Reference 6).

The standard deviation listed in Table 3 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 8.52%; if the instrument statistics RSD is 4.63%, then the estimate of the non uniformity calculates to be 7.15% ($0.0715^2 = 0.0852^2 - 0.0463^2$). For Sum Segments mass range II (414 keV) the standard deviation is 6.21%; if the instrument statistics RSD is 6.48%, then the estimate of the non uniformity calculates to be negative or 0.0%. For Combine All mass range II (129 keV) the standard deviation is 11.85%; if the instrument statistics RSD is 5.41%, then the estimate of the non uniformity calculates to be 10.54%. For Combine All mass range II (414 keV) the standard deviation is 14.44%; if the instrument statistics RSD is 6.26%, then the estimate of the non uniformity calculates to be 13.01%.

If the Canberra equation (414 keV peak) is used for the PDP combustible 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) as compared to 13.01% (Combine all, mass range II). To be conservative, the Canberra equation will be used to determine the non-uniformity uncertainty. Since the Canberra equation was developed using the 414 keV peak, the non-uniformity uncertainty associated with the 129 keV peak is not known. Thus at the current time, WRAP GEA results will be reported only using the 414 keV peak. Any waste drums in mass range I will be set aside for later analysis.

Figure 7 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 10.0% to 19.4% with the median corresponding to 14.4%.

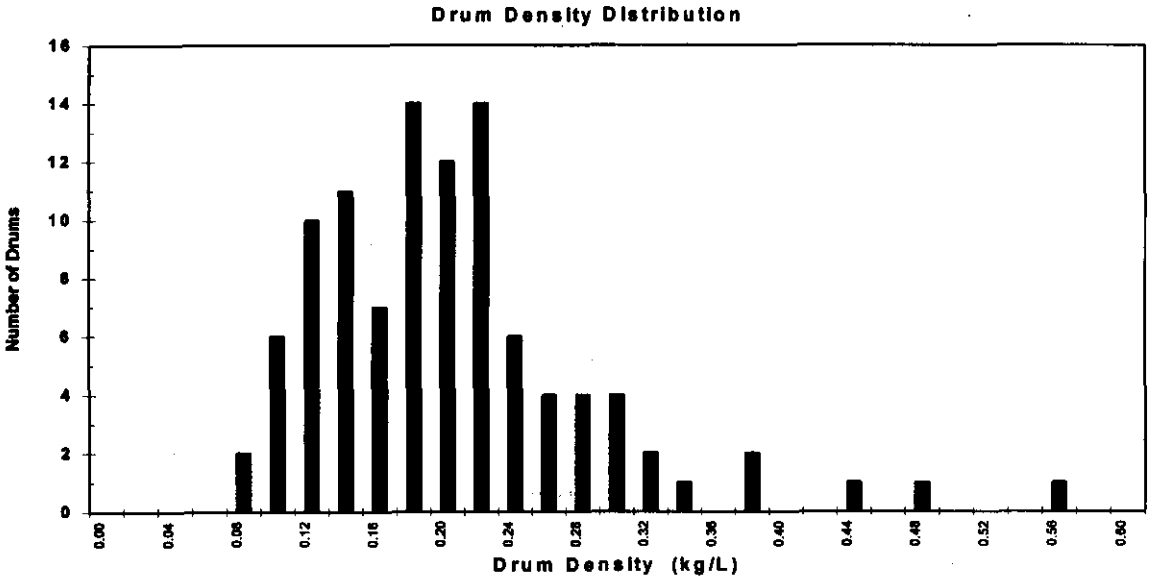

Figure 7. PFP drum density distribution for 100 drums.

Geometry Comparison
(Canberra Measurement Geometry to WRAP GEA)

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 2. QAO Test Configurations

Pu gms	Item ID	Source Loading T# = Tube #, P# = bottom position of 9" source								
0.03	QAO005	T1P6 0.03								
0.06	QAO009	T1P12 0.03	T3P4 0.03							
0.09	QAO21	T1P0 0.03	T2P10 0.03	T3P19 0.03						
0.09	QAO24	T1P0 0.03	T1P9 0.03	T1P18 0.03						
0.10	QAO23	T1P12 0.10								
0.15	QAO11	T1P6 0.03	T1P18 0.03	T2P0 0.03	T2P12 0.03	T3P9 0.03				
0.33	QAO003	T1P18 0.03	T2P0 0.30							
0.60	QAO011	T2P3 0.30	T3P12 0.30							
0.60	QAO10	T2P9 0.30	T3P9 0.30							
0.63	QAO013	T1P5 0.03	T2P18 0.30	T3P12 0.30						
0.66	QAO001	T1P3 0.30	T1P12 0.03	T2P6 0.03	T3P15 0.30					
0.90	QAO2	T1P9 0.30	T2P0 0.30	T3P18 0.30						
0.90	QAO6	T1P0 0.30	T1P9 0.30	T1P18 0.30						
0.96	QAO4	T1P3 0.30	T1P15 0.30	T2P0 0.03	T2P12 0.03	T3P12 0.30				
0.99	QAO20	T1P3 0.03	T1P15 0.30	T2P3 0.30	T2P15 0.03	T3P0 0.30	T3P18 0.03			
1.05	QAO14	T1P0 0.03	T1P9 0.30	T1P18 0.03	T2P0 0.03	T2P9 0.30	T2P18 0.03	T3P0 0.03	T3P9 0.30	
1.20	QAO8	T1P6 0.30	T1P15 0.30	T2P9 0.30	T3P9 0.30					
2.85	QAOW20	T1P0 0.05	T1P9 1.0	T1P18 0.20	T2P6 1.0	T2P15 0.10	T3P9 0.50			
3.15	QAO18	T1P0 3.0	T1P12 0.03	T2P3 0.03	T2P15 0.03	T3P3 0.03	T3P15 0.03			
5.00	QAOW13	T1P9 5.0								
5.00	QAOW16	T1P8 2.0	T2P6 1.0	T2P15 0.50	T3P3 1.0	T3P12 0.50				

6.15	QAO16	T1P0 3.0	T1P9 0.03	T1P18 3.0	T2P6 0.03	T2P15 0.03	T3P6 0.03	T3P15 0.03		
Pu gms	**Item ID**	**Source Loading** T# = Tube #, P# = bottom position of 9" source								
7.53	QAOW17	T1P12 2.0	T2P0 0.01	T2P9 5.0	T3P3 0.50	T3P12 0.02				
9.90	QAO19	T1P6 3.0	T1P15 0.30	T2P6 0.30	T2P15 3.0	T3P6 0.30	T3P15 3.0			
9.90	QAO19	T1P6 3.0	T1P15 0.30	T2P6 0.30	T2P15 3.0	T3P6 0.30	T3P15 3.0			
10.00	QAOW08	T1P0 1.0	T1P9 5.0	T1P18 2.0	T2P9 1.0	T3P9 1.0				
12.20	QAOW41	T1P6 5.0	T1P15 0.50	T2P6 0.50	T2P15 5.0	T3P6 1.0	T3P15 0.20			
14.68	QAOW53	T1P0 2.0	T1P9 5.0	T1P18 5.0	T2P0 0.50	T2P9 0.02	T2P18 0.05	T3P0 0.10	T3P9 1.0	T3P18 1.0
17.70	QAOW37	T1P6 5.0	T1P15 0.20	T2P9 10.0	T2P18 0.50	T3P0 1.0	T3P18 1.0			
19.13	QAOW63	T1P1 1.0	T1P12 10.0	T1P21 0.10	T2P0 0.50	T2P12 5.0	T2P21 0.02	T3P0 0.50	T3P12 2.0	T3P21 0.01
23.88	QAOW58	T1P3 0.50	T1P12 20.0	T1P21 0.20	T2P3 1.0	T2P12 2.0	T2P21 0.10	T3P3 0.05	T3P12 0.02	T3P21 0.01
28.60	QAOW36	T1P9 20.0	T1P18 0.10	T2P0 0.50	T2P15 5.0	T3P3 2.0	T3P18 1.0			
33.55	QAOW64	T1P5 1.0	T1P14 10.0	T2P6 0.50	T2P15 0.05	T3P9 2.0	T3P18 20.0			
39.00	QAOW40	T1P5 20.0	T1P14 2.0	T2P3 1.0	T2P12 10.0	T3P6 1.0	T3P15 5.0			
47.00	QAOW27	T1P6 2.0	T1P15 40.0	T3P5 5.0						
54.30	QAOW46	T1P0 5.0	T1P9 10.0	T1P18 5.0	T2P0 0.1	T2P9 1.0	T2P18 2.0	T3P0 30.0	T3P9 1.0	T3P18 0.20
62.00	QAOW45	T1P3 40.0	T2P0 0.50	T2P9 1.0	T2P18 0.50	T3P15 20.0				
68.67	QAOW51	T1P0 0.10	T1P9 20.0	T1P18 5.0	T2P0 0.05	T2P9 0.50	T2P18 2.0	T3P0 0.02	T3P9 1.0	T3P18 40.0
70.00	QAOW25	T1P13 30.0	T2P3 5.0	T2P12 10.0	T3P0 5.0	T3P16 20.0				
92.25	QAOW60	T1P2 30.0	T1P11 20.0	T1P20 1.0	T2P2 40.0	T2P11 1.0	T2P20 0.005	T3P2 0.20	T3P11 0.05	
100.00	QAOW33	T1P0 5.0	T1P9 20.0	T2P6 30.0	T2P15 5.0	T3P9 40.0				
102.70	QAOW48	T1P2 1.0	T1P11 50.0	T1P20 1.0	T2P2 30.0	T2P11 0.20	T2P20 5.0	T3P2 10.0	T3P11 5.0	T3P20 0.50
116.71	QAOW54	T1P2 50.0	T1P11 20.0	T1P20 10.0	T2P2 5.0	T2P11 30.0	T2P20 1.0	T3P2 0.50	T3P11 0.20	T3P20 0.01
135.70	QAOW57	T1P2 50.0	T1P11 30.0	T1P20 5.0	T2P0 40.0	T2P9 10.0	T2P18 1.0	T3P3 1.0	T3P12 0.50	
160.00	QAOW21	T1P10 50.0	T1P19 20.0	T2P10 5.0	T2P19 30.0	T3P1 40.0	T3P10 10.0	T3P19 5.0		

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 2 and 9), data from the PDP empty test drum measurements were used to determine the applicable bias correction factor. All combustible test drum results (see the "%R" columns) were then adjusted (dividing by the correction factor) to determine the matrix effect. The adjusted combustible 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 3. The data in Table 2 indicate that the matrix uncertainty (estimated from the PDP Combustible drum results) ranges from 6% to 20% with an average of 11.1% (n=15). It should be noted that this uncertainty represents a single data point with respect to the overall matrix uncertainty. The use of the "bias", absolute value of the difference of the mean from 100%, as the uncertainty is discussed in Reference 7.

As discussed in Reference 4 (Canberra SGS TMU Document), the measurement uncertainty associated with a heterogeneous matrix distribution was evaluated by modeling the response of a measurement segment. As reported in Reference 2, the results of the modeling indicated a

matrix uncertainty of 12%. To be conservative, the WRAP TMU calculations will also use 12% as the matrix uncertainty.

Table 3

Combustible 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		5				
	Mean		106.40				
	StdDev		10.79				
	Sxbar		4.82				
	Bias		6.40				
II	N		11	11		11	11
	Mean		107.62	89.78		88.82	92.35
	StdDev		8.52	6.21		11.85	14.44
	Sxbar		2.57	1.87		3.57	4.35
	Bias		7.62	10.22		11.18	7.65
III	N	14	14	14	14	14	14
	Mean	86.14	106.01	86.65	87.40	80.56	89.10
	StdDev	5.38	11.88	4.50	4.36	8.43	4.46
	Sxbar	1.44	3.17	1.20	1.17	2.25	1.19
	Bias	13.86	6.01	13.35	12.60	19.44	10.90
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	1.9		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. The light shaded area is for energies not used in TMU calculations.

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

StdDev = Standard deviation.

Sxbar = StdDev/Sqrt(N)

End Effects

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

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 that 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)

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.

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 problem is 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 which is located at the bottom of the drum only receives counts which are from the measurement segment and an adjacent segments above the bottom of the drum. Thus the analytical results for that segment is potentially underestimated because of not receiving count contributions from the adjacent segment below the source material.

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 (see HNF-5148) shows that the efficiency response for the bottom segment is significantly lower than the segments in the center of the drum. (see page E-3 for the bottom segment as compared to 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.

End Effect Uncertainty for this TMU Analysis

Based on the above discussion it is not expected that there will be any significant end effects problems when using the WRAP GEA assay for the drum type and matrix limitations defined in this document.

However since the measurements required to confirm this evaluation will not be available until a later date, the data review process will use a conservative approach of setting aside any drums which have 50% of the activity in the bottom 2 segments, as having a potential problem with end effects. These drums will be assayed on the IPAN system or reanalyzed with the GEA system after a more definitive end effect uncertainty 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 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 9). 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 (1.96 sigma). Since uncertainties are introduced and propagated at 1 sigma, 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).

UNCERTAINTY ASSOCIATED WITH ISOTOPIC ANALYSES

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 (PFP) 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.

SGS Analyzed Drums, 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 SGS run. 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.

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 4. 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 SGS analyzed drums is also listed in Table 4. The total uncertainty is calculated using the following formula:

$$\sigma^2_{total} = \sigma^2_{ran} + \sigma^2_{sys} + \sigma^2_{source} \qquad \text{(Equation 1)}$$

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.

Table 4: Current PFP Isotopic Uncertainty Values

6% ^{240}Pu Isotopic Standard	Random Uncertainty 1σ (%)	Systematic Uncertainty 1σ (%)	Uncertainty in the Standard Value 1σ (%)	Total Uncertainty 1σ (%)
^{238}Pu	13.08	9.87	0.6	16.4
^{239}Pu	0.11	0.05	0.003	0.12
^{240}Pu	1.70	0.93	0.06	1.94
^{241}Pu	1.16	1.02	1.04	1.86
^{242}Pu	NA	NA	5.0	NA
^{241}Am	0.91	0.46	0.4	1.10
18% ^{240}Pu Isotopic Standard	Random Uncertainty 1σ (%)	Systematic Uncertainty 1σ (%)	Uncertainty in the Standard Value 1σ (%)	Total Uncertainty 1σ (%)
^{238}Pu	3.50	5.50	2.03	6.83
^{239}Pu	0.58	0.57	0.014	0.81
^{240}Pu	2.19	0.16	0.044	2.20
^{241}Pu	1.95	2.27	1.11	3.19
^{242}Pu	NA	NA	0.624	NA
^{241}Am	1.45	5.28	0.984	5.56

NaI Analyzed Drums

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 5. The total uncertainty is calculated using a formula similar to that provided previously, but with an extra term for the process uncertainty.

Table 5: 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.

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 (Reference 10), 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 combustible matrix) 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 6A and 6B.

Table 6A: 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 6A: 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 6B: 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 6B: 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

^{238}Pu

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. 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 7 shows examples taken from the MGA test runs which illustrate both extremes of this phenomenon, as well as more typical results.

Table 7. 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 %

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 error 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 uncertainties 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.

^{239}Pu

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). It should be noted that only 2 or 3 replicate measurements were performed for the majority of the test configurations.

Analysis of the LeGe-5 and the LeGe-6 MGA results (5g source) for ^{239}Pu in the combustible 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%.

^{240}Pu

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). It should be noted that only 2 or 3 replicate measurements were performed for the majority of the test configurations.

Analysis of the LeGe-5 and the LeGe-6 MGA results (5g source) for ^{240}Pu in the combustible 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 102.92% for LeGe-5 and 90.53% for LeGe-6. Rounding to one significant digit, the estimate of the systematic uncertainty is 3% for LeGe-5 and 9% for LeGe-6.

^{241}Pu

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).

Analysis of the LeGe-5 and the LeGe-6 MGA results (5g source) for ^{241}Pu in the combustible 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% for LeGe-5 and 88.94% for LeGe-6. Rounding to one significant digit, the estimate of the systematic uncertainty is 19% for LeGe-5 and 11% for LeGe-6.

^{241}Am

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). It should be noted that only 2 or 3 replicate measurements were performed for the majority of the test configurations.

Analysis of the LeGe-5 and the LeGe-6 MGA results (5g source) for ^{241}Am in the combustible 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% for LeGe-5 and 97.40% for LeGe-6. Rounding to one significant digit, the estimate of the systematic uncertainty is 0.2% for LeGe-5 and 3% for LeGe-6.

The uncertainty components (random, systematic, and source) for all isotopes are listed in Table 8. The total uncertainty for isotopes (other than ^{238}Pu and ^{242}Pu) is a combination of the individual components, per Equation 1. 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 8. 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 1
^{240}Pu	$2\sigma_{CtStat}$	3	0.006	Equation 1
^{241}Pu	$2\sigma_{CtStat}$	19	0.24	Equation 1
^{242}Pu	N/A	N/A	0.28	$2\lvert\sigma_{CtStat}\rvert$
^{241}Am	$2\sigma_{CtStat}$	0.2	0.35	Equation 1
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 1
^{240}Pu	$2\sigma_{CtStat}$	9	0.006	Equation 1
^{241}Pu	$2\sigma_{CtStat}$	9	0.24	Equation 1
^{242}Pu	N/A	N/A	0.28	$2\lvert\sigma_{CtStat}\rvert$
^{241}Am	$2\sigma_{CtStat}$	3	0.35	Equation 1

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

Note 2 - *Equation 1:* $\sigma^2_{total} = \sigma^2_{ran} + \sigma^2_{sys} + \sigma^2_{source}$

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

Other Measurement Uncertainties

There are none of significance.

Propagation of Uncertainty

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 ($\sigma_{\text{Inst Stat}}$, σ_{SelfAb}, σ_{NonUnif}, σ_{Matrix}, σ_{End}, weight uncertainty, isotopics/AK uncertainty) are summed in quadrature after all data is gathered and as final calculations are performed.

Table 9

Uncertainty Estimates (%) – GEA Assay System (gm 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				
	$\sigma_{NonUnif}$		TBD				
	σ_{Matrix}		12				
	σ_{End}		11.5				
II	$\sigma_{InstStat}$		Inst Stat	Inst Stat		Inst Stat	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
	$\sigma_{NonUnif}$		TBD	Equation		Equation	Equation
	σ_{Matrix}		12	12		12	12
	σ_{End}		11.5	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
	$\sigma_{NonUnif}$	Equation *	TBD	Equation	Equation *	Equation	Equation
	σ_{Matrix}	12	12	12	12	12	12
	σ_{End}	11.5	11.5	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 *		Equation	Equation *		Equation
	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. However, since the TMU is not currently defined for peaks other than 414 keV, waste drums not having a 414 keV peak will be set aside and not analyzed at the current time. For all masses above 2.5 g, the 414 keV line should be used. The other peaks (light shaded areas) can be used for reference and to indicate severe lumping.

σ 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.

σ 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

Equation * -- 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 lenergy lines

TBD -- to be determined in future testing

Example SGS Calculations

The following examples illustrate the magnitude of the uncertainty associated with the SGS measurement. The drum density, the SGS gram quantity of ^{239}Pu, and the instrument uncertainty are stated, the other uncertainties are obtained from Table 9 or equations referenced by Table 9.

Example 1 – Mass Range II (414 keV)

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

$\sigma_{\text{SelfAb}} = 5.0\%$, $\sigma_{\text{NonUnif}} = 12.6\%$, $\sigma_{\text{Matrix}} = 12.0\%$, $\sigma_{\text{End}} = 11.5\%$

σ_{SGS} = Square root of $(0.05^2 + 0.075^2 + 0.126^2 + 0.12^2 + 0.115^2) = 0.227$ or 22.7%

= 0.34 gm ^{239}Pu.

Example 2 - Mass Range III (414 keV)

Density = 0.25, Combine All (SGS) = 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_{SGS} = 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 (SGS) = 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_{SGS} = 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.

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.

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*MF238 + MF239 + MF240 + 0.0192*MF241 + 0.956*MF242 + 1.03*MFAM241]

PUEQCI = GMS239 * (1/MF239) * [0.909*MF238 + MF239 + MF240 + 0.0192*MF241 + 0.909*MF242 + 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.

WATTS Uncertainty

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

Uncertainty associated with X

The uncertainty associated with X, the GMS239 from the SGS 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, i.e.,
σ_{SGS} = 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 **N/A**
MFAM241=0.00169 RSD=0.011

Density = 0.166 g/cc

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

$\sigma_{\text{SelfAb}} = 5.0\%$, $\sigma_{\text{NonUnif}} = 13.2\%$, $\sigma_{\text{Matrix}} = 12.0\%$, $\sigma_{\text{End}} = 11.5\%$

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

RSD(X) = Square root of $(0.05^2 + 0.0573^2 + 0.132^2 + 0.12^2 + 0.115^2) = 22.55\%$

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) ≅ Square root of $(0.2255^2 + 0.0012^2 + 0.011^2) = 22.58\%$

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