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|  | <b>ENGINEERING CHANGE NOTICE</b> | 1 ECN <span style="font-size: 1.5em; font-weight: bold;">655111</span><br><br>Proj<br>ECN |
| Page 1 of <u>2</u>  |                                  |   |

|   |   |  |   |
|---|---|--|---|
| 2 ECN Category (mark one)<br>Supplemental <input type="radio"/><br>Direct Revision <input checked="" type="radio"/><br>Change ECN <input type="radio"/><br>Temporary <input type="radio"/><br>Standby <input type="radio"/><br>Supersedure <input type="radio"/><br>Cancel/Void <input type="radio"/> | 3 Originator's Name Organization MSIN and Telephone No<br>CE Wills WRAP Engineering<br>T4-52 373-9844 | 4 USQ Required?<br><input checked="" type="radio"/> Yes <input type="radio"/> No         | 5 Date<br>01/05/00  |
|   | 6 Project Title/No /Work Order No<br>WRAP Facility/AJ60   | 7 Bldg /Sys /Fac No<br>2336-W  | 8 Approval Designator<br>Q  |
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| 12a Modification Work<br><input type="radio"/> Yes (fill out Blk 12b)<br><input checked="" type="radio"/> No (NA Blks 12b 12c 12d)  | 12b Work Package No<br>N/A  | 12c Modification Work Completed<br>N/A<br>Design Authority/Cog Engineer Signature & Date | 12d Restored to Original Condition (Temp or Standby ECNs only)<br>N/A<br>Design Authority/Cog Engineer Signature & Date |

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| 13a Description of Change<br><br>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 against previous revisions | 13b Design Baseline Document? <input type="radio"/> Yes <input checked="" type="radio"/> No |
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| 14a Justification (mark one)<br>Criteria Change <input type="radio"/><br>Design Improvement <input type="radio"/><br>Environmental <input type="radio"/><br>Facility Deactivation <input type="radio"/><br>As Found <input checked="" type="radio"/><br>Facilitate Const <input type="radio"/><br>Const Error/Omission <input type="radio"/><br>Design Error/Omission <input type="radio"/> | 14b Justification Details<br>Design verification not required<br><br>Additions made in response to WIPP audit comments<br><br>USQ WRP-00-002 |
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| 15 Distribution (include name MSIN and no of copies)<br><br>See attached distribution sheet | <div style="border: 2px solid black; padding: 10px; display: inline-block;"> RELEASE STAMP<br/> <div style="display: flex; justify-content: space-between; align-items: center;"> <div style="text-align: left;"> JAN 06 2000<br/> DATE<br/> STA 5 </div> <div style="text-align: center;"> <br/> HANFORD<br/>RELEASE </div> <div style="text-align: right;"> <div style="border: 1px solid black; border-radius: 50%; width: 40px; height: 40px; display: flex; align-items: center; justify-content: center; font-weight: bold; font-size: 1.2em;">12</div><br/> ID </div> </div> </div> |
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# ENGINEERING CHANGE NOTICE

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1 ECN (use no from pg 1)

655111  
ECN-65111-1 dp 1/6/00

## 16 Design Verification Required

☐ Yes  
☒ No

## 17 Cost Impact

### ENGINEERING

Additional ☐ \$ N/A  
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Additional ☐ \$ N/A  
Savings ☐ \$ N/A

## 18 Schedule Impact (days)

Improvement ☐ 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.

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## 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

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None

## 21 Approvals

Signature

Date

Signature

Date

Design Authority \_\_\_\_\_

Cog Eng CE Wills [Signature] 1-6-00

Cog Mgr JR Weidert [Signature] 1-6-00

QA WR Thackaberry [Signature] 1-06-00

Safety \_\_\_\_\_

Environ \_\_\_\_\_

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|   |                          | Date 01/05/00              |           |                              |                 |
| Project Title/Work Order<br>TOTAL MEASUREMENT UNCERTAINTY FOR NDA OF TRU WASTE AT THE WRAP FACILITY |                          | EDT No N/A                 |           |                              |                 |
|   |                          | ECN No ECN-655111          |           |                              |                 |
| Name  | MSIN                     | Text<br>With All<br>Attach | Text Only | Attach /<br>Appendix<br>Only | EDT/ECN<br>Only |

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# Total Measurement Uncertainty For Nondestructive Assay of Transuranic Waste At the WRAP Facility

CE Wills  
 Fluor Hanford Inc Richland WA 99352  
 U S Department of Energy Contract DE-AC06 96RL13200

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**Abstract** 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.

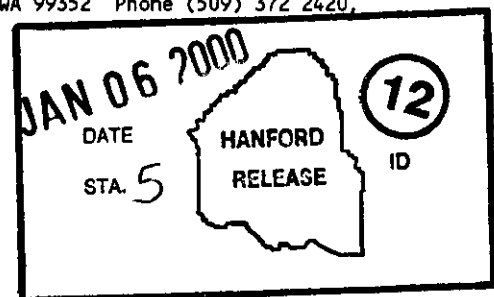
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# **Total Measurement Uncertainty for Nondestructive Assay of Transuranic Waste at the Waste Receiving and Processing Facility**

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Craig Wills, Fluor Hanford Inc

Michael Purcell, Fluor Hanford Inc

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.

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.

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## 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 1) 0.25 grams to 160 grams (gms). However, analysis will be carried out on drums having sufficient activity in the 414 keV peak of  $^{239}\text{Pu}$ . 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

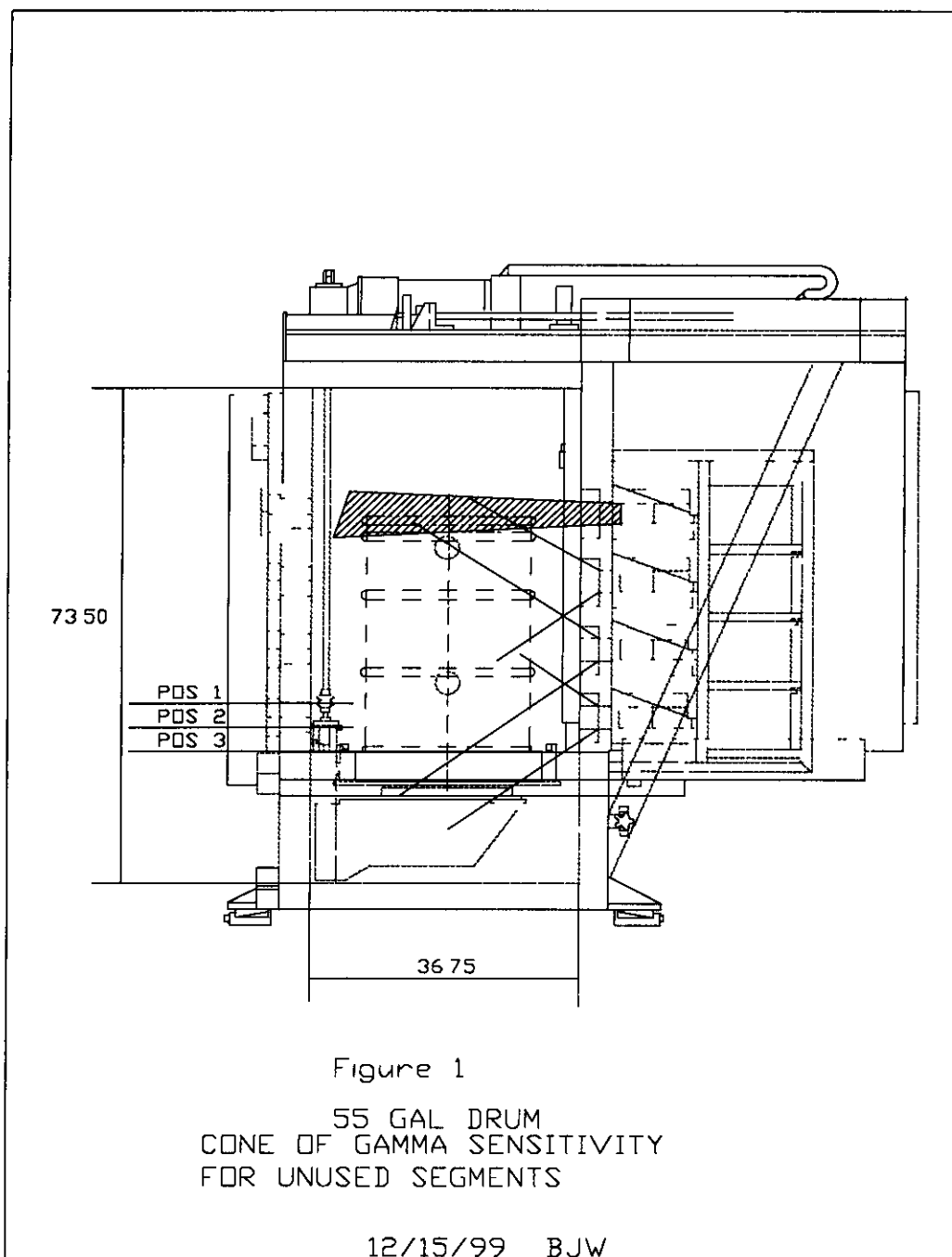
At the WRAP facility, there are two identical imaging passive/active neutron (IPAN) assayers and two identical gamma energy (GEA) assayers. The WRAP GEA systems were built by Canberra Industries and use current versions of their Genie-PC and Gamma Waste Assay Software (GWAS) packages. The algorithms are well documented in the Canberra literature (Reference 2). 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  $^{152}\text{Eu}$  transmission sources which provide a measure of the matrix attenuation effects in each segment, across selected  $^{152}\text{Eu}$  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 inhomogeneities.

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

NDA analysis uses data from a variety of sources. Acceptable Knowledge (AK), WRAP scales, NDE, 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.



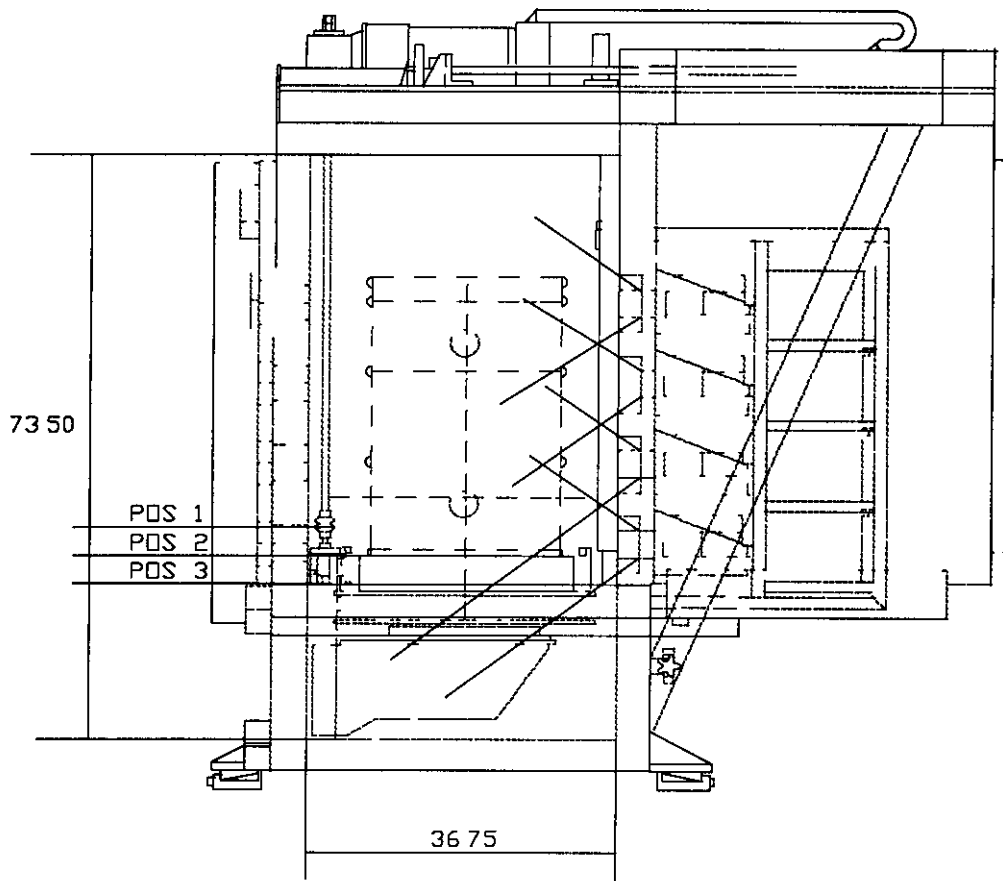


Figure 2  
55 GAL DRUM  
CONE OF GAMMA SENSITIVITY  
FOR UNUSED SEGMENTS

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(FILE) BJ55 NDA GEA-3

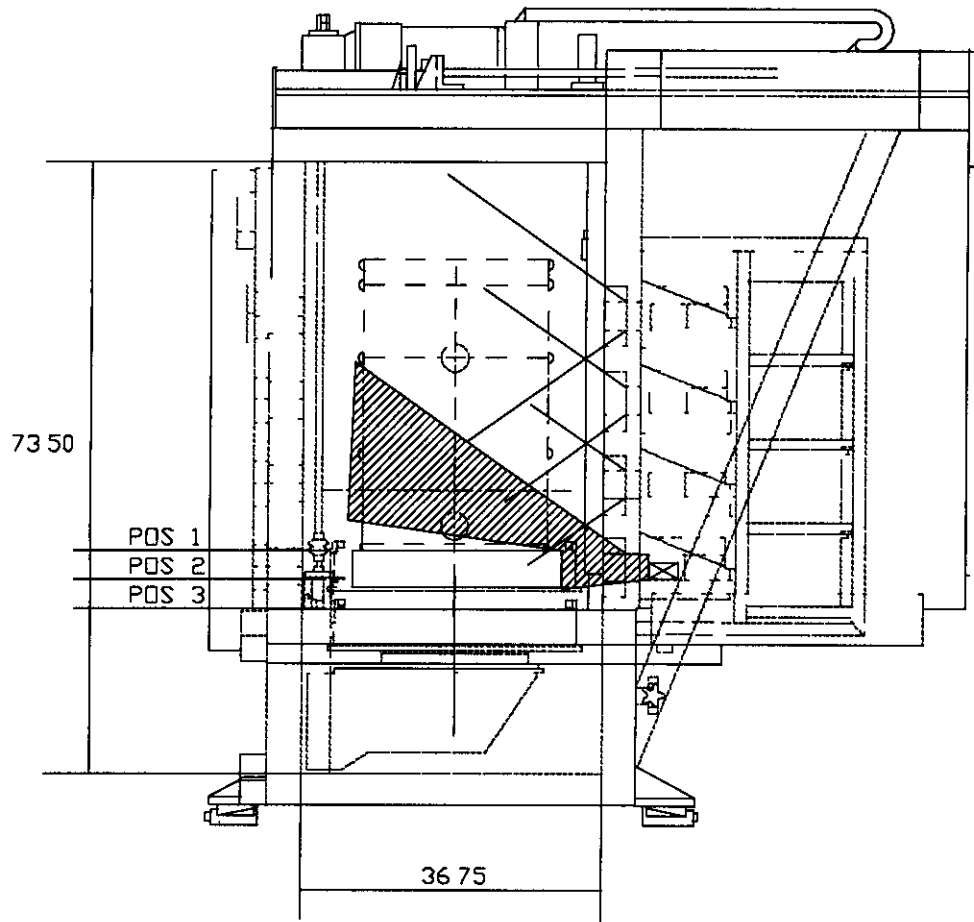


Figure 3  
55 GAL DRUM  
CONE OF GAMMA SENSITIVITY  
FOR UNUSED SEGMENTS

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 assurance 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 equation used for each isotope is

$$\text{Amount after Decay} = \text{Initial Amount} \left[ e^{-\ln(2) * \text{Decay Time} / \text{Half life}} \right]$$

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 input weight and 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  $^{239}\text{Pu}$  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.

Uranium is not found in the current waste stream, and will not be discussed here.

In order to compare measured isotopes with AK Pu and Am values, the measured values must be converted from their reported format,  $\mu\text{Ci}$ , to grams. This is done for each isotope using the equation

$$\text{Gram value} = (\mu\text{Ci value} / \text{specific activity}) / 1000000$$

Similarly, the reported measurement uncertainty at one sigma is calculated

$$\text{Gram value uncertainty} = (\mu\text{Ci value uncertainty} / \text{specific activity}) / 1000000$$

Specific activity values, ( $\text{Ci/gm}$ ), 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  $^{239}\text{Pu}$  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. Since the method used to assign isotopic ratios to a specific drum is unknown, and no uncertainty on the reported AK values given, WRAP NDA analysts are assigning a 2% uncertainty to AK Pu and  $^{241}\text{Am}$  isotopic values.

It should be noted that WRAP GEA systems have the capability to perform isotopic measurements using the system's Canberra's MGA software module. These measurements have not, however, received the quality assurance scrutiny necessary to use them in WIPP calculations. However, when these measurements do indicate a clear problem with isotopics, the discrepancy is either resolved or the drum removed from its analytical batch.

The decay corrected AK values are applied to the GEA measured values by a normalization process. As discussed above, a 2 % uncertainty ( $f_{AKU}$ ) is assigned to each Pu and  $^{241}\text{Am}$  isotope. The most reliably measured Pu isotope is  $^{239}\text{Pu}$ . A normalizing factor relative to  $^{239}\text{Pu}$  is calculated for each isotope, and the gram value of each Pu and  $^{241}\text{Am}$  isotope calculated by multiplying each isotope normalizing factor times the measured  $^{239}\text{Pu}$  value.

$$\text{Isotope Normalizing Factor} = \text{Isotope Weighting Factor} / ^{239}\text{Pu Weighting Factor}$$

$$\text{Pu and } ^{241}\text{Am Isotope Grams} = \text{Isotope Normalizing Factor} * \text{Measured } ^{239}\text{Pu Grams}$$

The uncertainty for each Pu and  $^{241}\text{Am}$  isotope gram value is calculated by combining the relative isotope factor uncertainty and the relative measured  $^{239}\text{Pu}$  measured uncertainty in quadrature. This represents the measurement uncertainty.

$$\text{Pu and Am } ^{241} \text{ Isotope Grams Uncertainty} = \text{Pu and Am } ^{241} \text{ Isotope Grams} * \sqrt{f_{AKU}^2 + (\text{Measured Pu } ^{239} \text{ Grams Uncertainty} / \text{Measured Pu } ^{239} \text{ Grams})^2}$$

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, and will not be repeated here.

The total and one sigma uncertainty for FGE, alpha curies, specific activity, DE-C1, PE-C1, nCi/g, W, and W/m<sup>3</sup> 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

$$\text{Isotopic FGE} = \text{Measured Isotopic Grams} / \text{Isotope FGE Conversion Factor}$$

$$\text{Isotopic FGE Uncertainty} = \text{Measured Isotopic Grams Uncertainty} / \text{Isotopic FGE Conversion Factor}$$

$$\text{Total FGE} = \text{Sum}(\text{All Isotopic FGE values})$$

The calculation of the sum of the individual isotopic uncertainties into an overall uncertainty is given in the Propagation of Uncertainty section and will not be repeated here

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 These equations are

$$\text{Total Alpha nCi} = \text{Total Alpha Ci} * 1\text{E}9$$

$$\text{Net g Waste} = \text{net Kg Waste} * 1000$$

$$\text{Total nCi/g} = \text{Total Alpha nCi} / \text{Net g Waste}$$

$$\text{Total Alpha nCi Error} = \text{Total Alpha Ci Error} * 1\text{E}9$$

$$\text{Net g waste Error} = \text{net Kg waste Error} * 1000$$

$$\text{Total nCi/g Error} = \text{Total nCi/g} * \text{Square root}[(\text{Total Alpha nCi Error} / \text{Total Alpha nCi})^2 + (\text{Net g Waste error} / \text{Net g Waste})^2]$$

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

$$\text{Uncertainty at 1.96 sigma} = \text{Uncertainty at 1 sigma} * 1.96$$

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

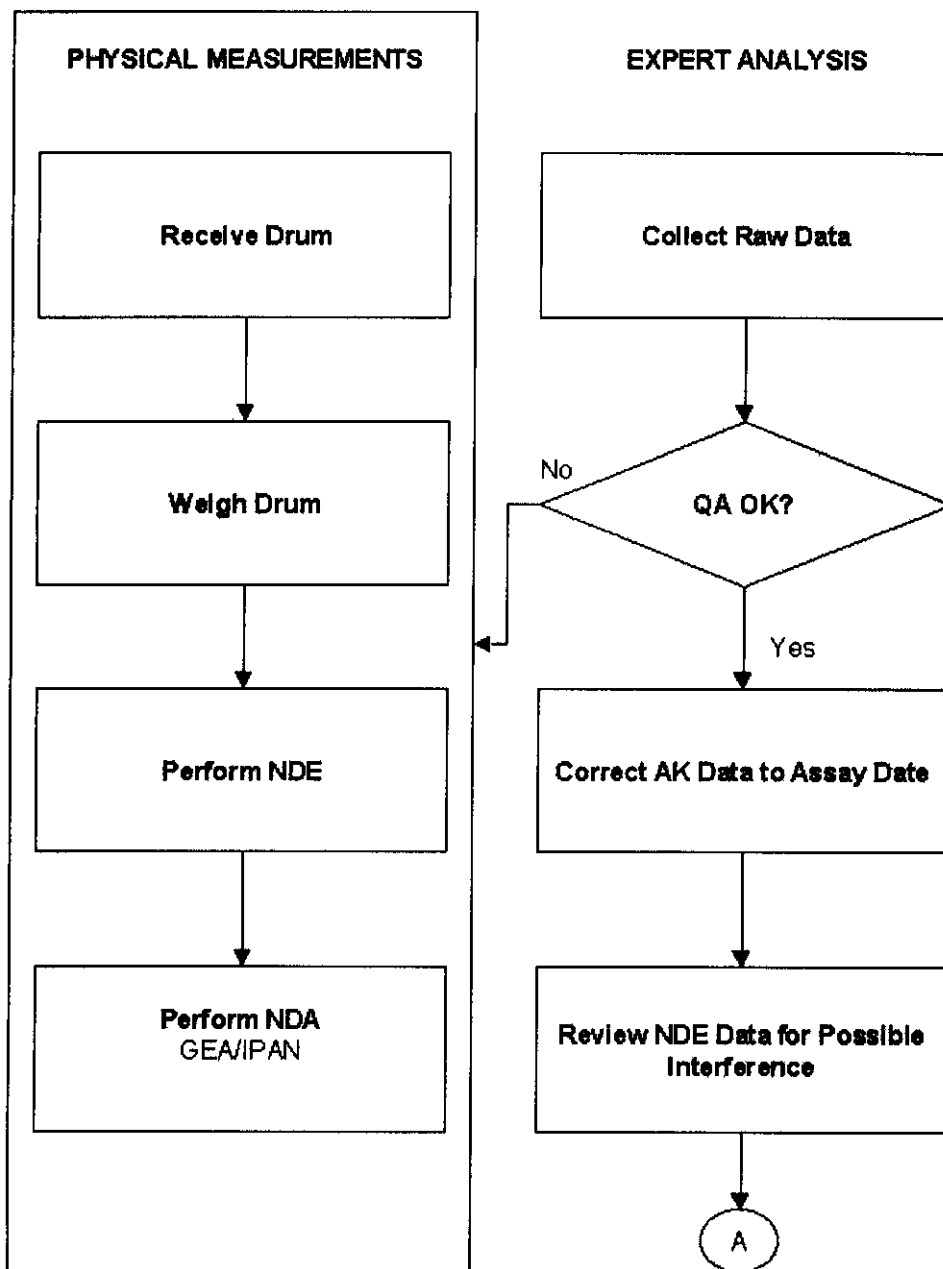


Figure 4a

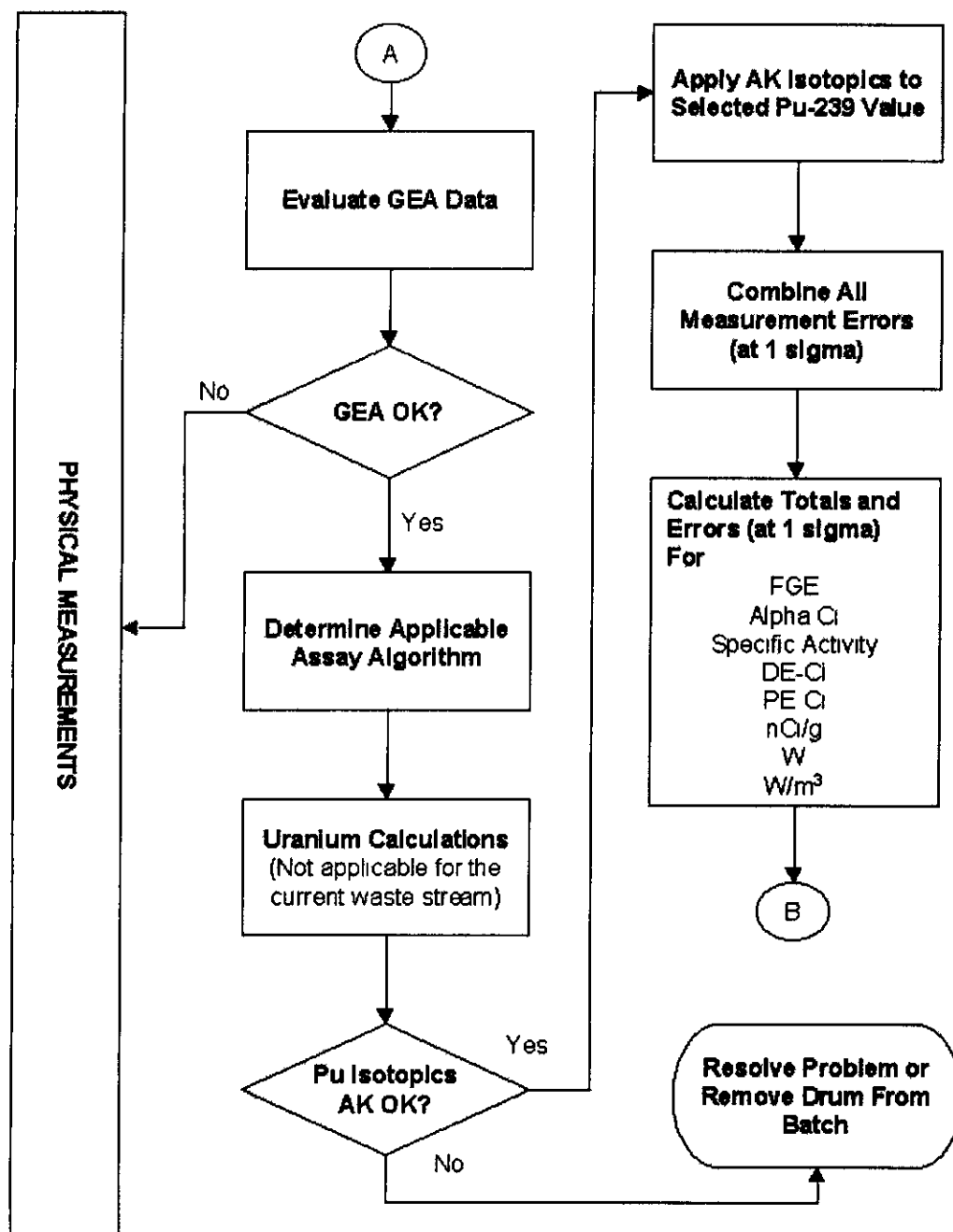


Figure 4b

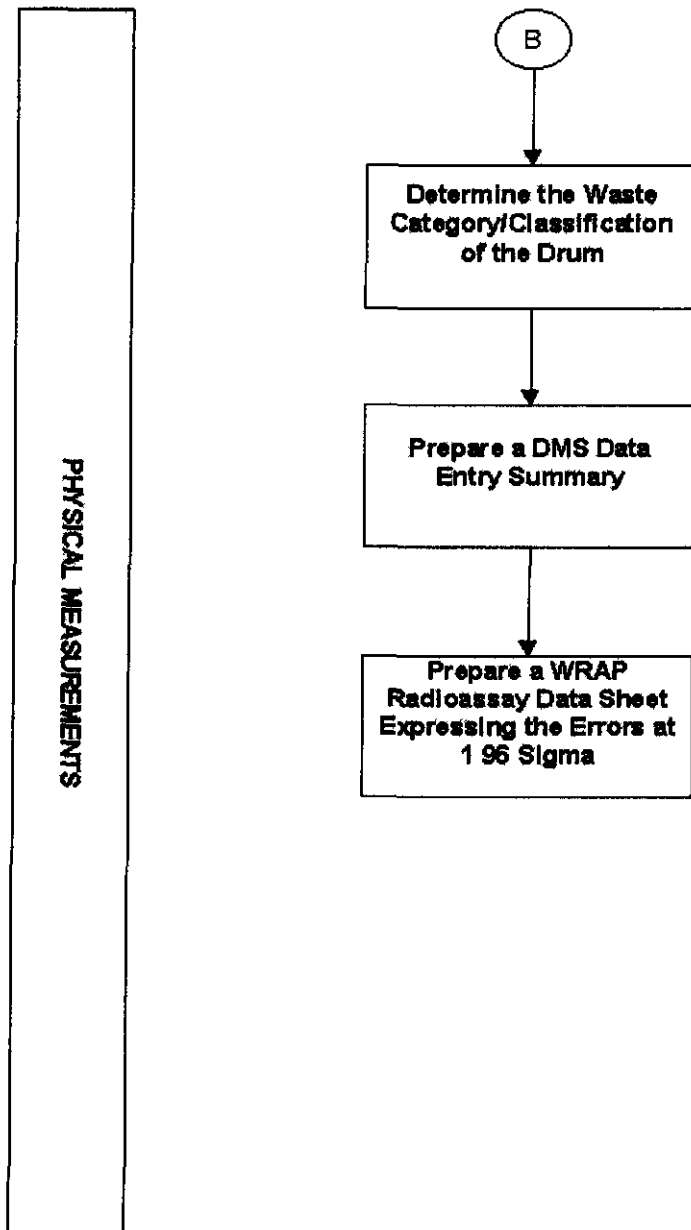


Figure 4c

Upon release from the glovebox process area, each process drum is weighed and then subjected to NDE and NDA. All AK data associated with the contents of the original drum are maintained with the process drum. The TMU analysis within this document applies to verification and process drums equally.

## 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  $53 \pm 2.7$  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 inhomogeneity 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

Quality assurance 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 QA measurements can be found in Reference 2.

### **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 2. For calibration of 208 liter 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 2.

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 the blocked data regions 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, (as explained in Reference 8) 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(Runs) vs %RSD(Instr)

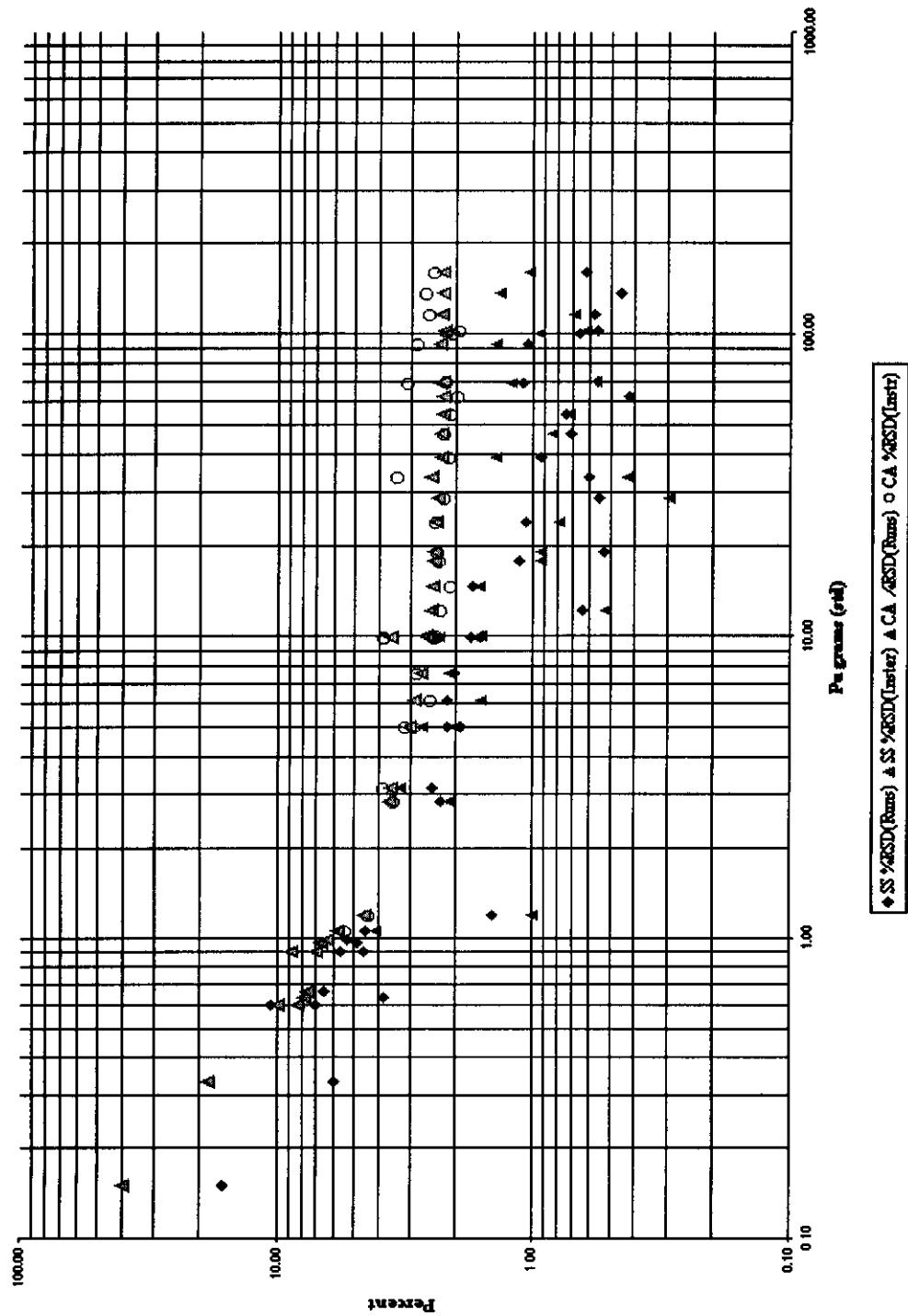


Figure 5



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  |        |
| 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 |        |
| 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 preferred for masses below 5gm and Combine All is preferred 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   |        |
| 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 preferred for masses below 5gm and Combine All is preferred for masses above 5gm. For masses in the 0-2.5 gm range (boxed) 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  |        |
| 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 preferred for masses below 5gm and Combine All is preferred 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 The boxed region is the activity area of preference

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 preferred for masses below 5gm and Combine All is preferred 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 |        |
| 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 |        |
| 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 preferred for masses below 5gm and Combine All is preferred 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  |        |
| 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 preferred for masses below 5gm and Combine All is preferred 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 The boxed region is area of activities for preferred application

## 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 3 provides guidance for the following discussion.

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  $^{239}\text{Pu}$  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  $\text{PuO}_2$  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  $\text{PuO}_2$  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.

If during the expert analysis, there is an indication of self absorption, then the following uncertainties will be applied as specified in Reference 8.

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

## 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 3, 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 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

$$ERR_{Max} = (-238 * AverageDens^2) + 15131 * AverageDens + 12189$$

$$ERR_{Min} = (2439 * AverageDens^2) - 08645 * AverageDens + 08092$$

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 3), 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.

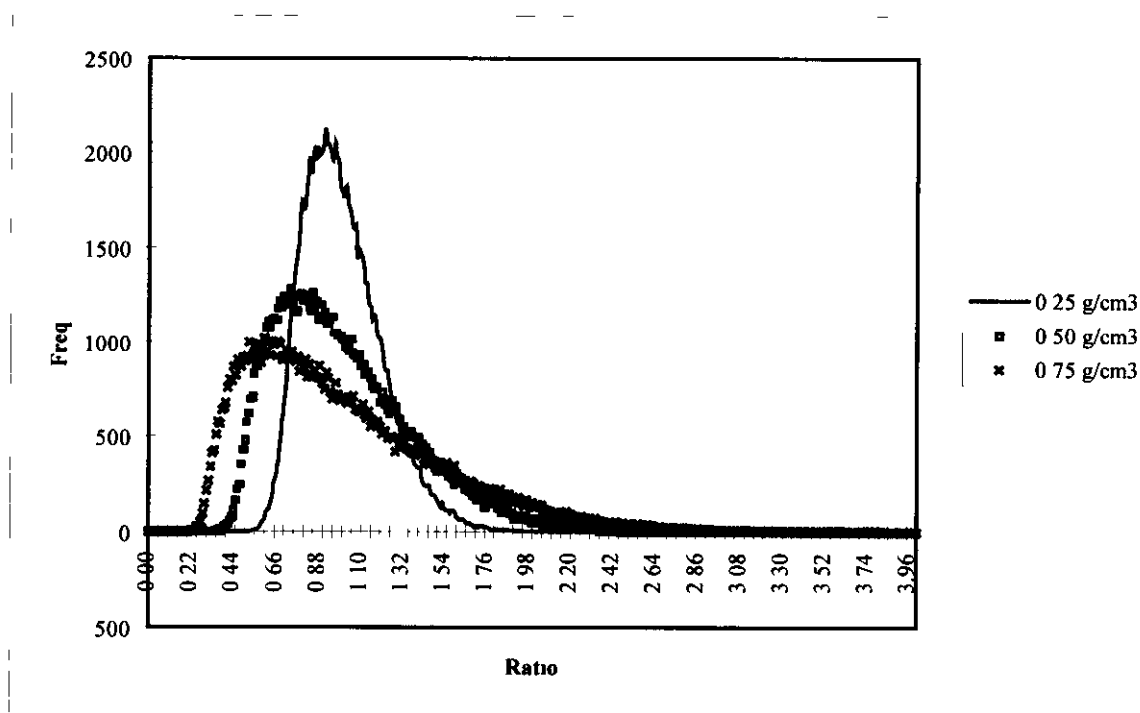


Figure 6 {Calculated response / Calculated input} versus matrix density



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).

## 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.

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 0.29 g/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%.

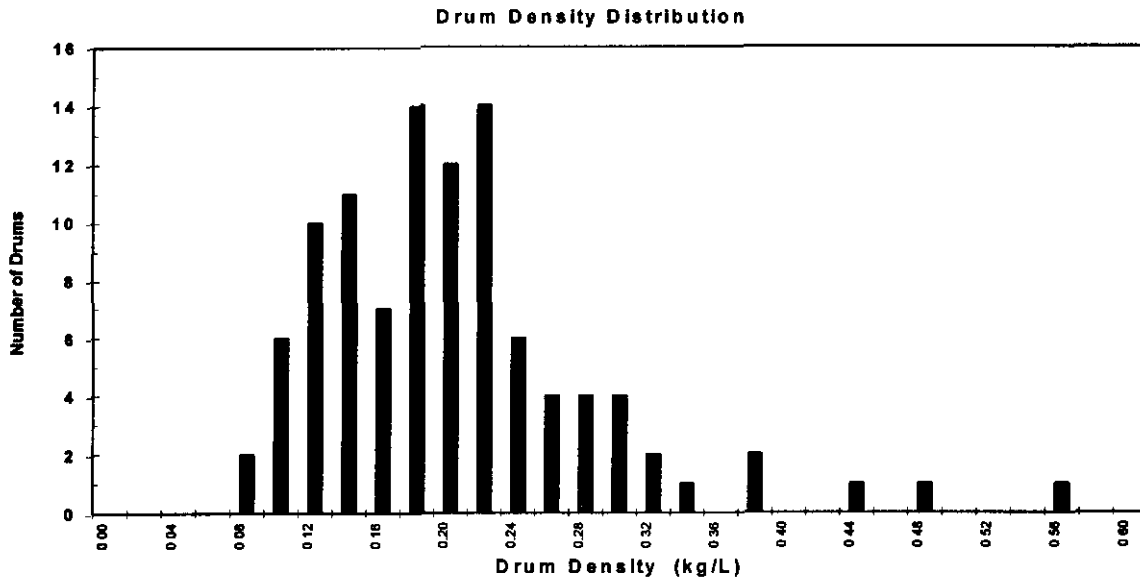


Figure 7 PFP drum density distribution for 100 drums

### **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<br>gms | Item ID | Source Loading                                |               |               |               |               |               |               |              |  |
|-----------|---------|---|---------------|---------------|---------------|---------------|---------------|---------------|--------------|--|
|           |         | T# = Tube # P# = bottom position of 9' source |               |               |               |               |               |               |              |  |
| 0 03      | QAO005  | T1P6<br>0 03                                  |               |               |               |               |               |               |              |  |
| 0 06      | QAO009  | T1P12<br>0 03                                 | T3P4<br>0 03  |               |               |               |               |               |              |  |
| 0 09      | QAO21   | T1P0<br>0 03                                  | T2P10<br>0 03 | T3P19<br>0 03 |               |               |               |               |              |  |
| 0 09      | QAO24   | T1P0<br>0 03                                  | T1P9<br>0 03  | T1P18<br>0 03 |               |               |               |               |              |  |
| 0 10      | QAO23   | T1P12<br>0 10                                 |               |               |               |               |               |               |              |  |
| 0 15      | QAO11   | T1P6<br>0 03                                  | T1P18<br>0 03 | T2P0<br>0 03  | T2P12<br>0 03 | T3P9<br>0 03  |               |               |              |  |
| 0 33      | QAO003  | T1P18<br>0 03                                 | T2P0<br>0 30  |               |               |               |               |               |              |  |
| 0 60      | QAO011  | T2P3<br>0 30                                  | T3P12<br>0 30 |               |               |               |               |               |              |  |
| 0 60      | QAO10   | T2P9<br>0 30                                  | T3P9<br>0 30  |               |               |               |               |               |              |  |
| 0 63      | QAO013  | T1P5<br>0 03                                  | T2P18<br>0 30 | T3P12<br>0 30 |               |               |               |               |              |  |
| 0 66      | QAO001  | T1P3<br>0 30                                  | T1P12<br>0 03 | T2P6<br>0 03  | T3P15<br>0 30 |               |               |               |              |  |
| 0 90      | QAO2    | T1P9<br>0 30                                  | T2P0<br>0 30  | T3P18<br>0 30 |               |               |               |               |              |  |
| 0 90      | QAO6    | T1P0<br>0 30                                  | T1P9<br>0 30  | T1P18<br>0 30 |               |               |               |               |              |  |
| 0 96      | QAO4    | T1P3<br>0 30                                  | T1P15<br>0 30 | T2P0<br>0 03  | T2P12<br>0 03 | T3P12<br>0 30 |               |               |              |  |
| 0 99      | QAO20   | T1P3<br>0 03                                  | T1P15<br>0 30 | T2P3<br>0 30  | T2P15<br>0 03 | T3P0<br>0 30  | T3P18<br>0 03 |               |              |  |
| 1 05      | QAO14   | T1P0<br>0 03                                  | T1P9<br>0 30  | T1P18<br>0 03 | T2P0<br>0 03  | T2P9<br>0 30  | T2P18<br>0 03 | T3P0<br>0 03  | T3P9<br>0 30 |  |
| 1 20      | QAO8    | T1P6<br>0 30                                  | T1P15<br>0 30 | T2P9<br>0 30  | T3P9<br>0 30  |               |               |               |              |  |
| 2 85      | QAOW20  | T1P0<br>0 05                                  | T1P9<br>1 0   | T1P18<br>0 20 | T2P6<br>1 0   | T2P15<br>0 10 | T3P9<br>0 50  |               |              |  |
| 3 15      | QAO18   | T1P0<br>3 0                                   | T1P12<br>0 03 | T2P3<br>0 03  | T2P15<br>0 03 | T3P3<br>0 03  | T3P15<br>0 03 |               |              |  |
| 5 00      | QAOW13  | T1P9<br>5 0                                   |               |               |               |               |               |               |              |  |
| 5 00      | QAOW16  | T1P8<br>2 0                                   | T2P6<br>1 0   | T2P15<br>0 50 | T3P3<br>1 0   | T3P12<br>0 50 |               |               |              |  |
| 6 15      | QAO16   | T1P0<br>3 0                                   | T1P9<br>0 03  | T1P18<br>3 0  | T2P6<br>0 03  | T2P15<br>0 03 | T3P6<br>0 03  | T3P15<br>0 03 |              |  |

| Pu<br>gms | Item ID | Source Loading                                 |               |               |               |               |                |              |               |               |
|-----------|---------|--|---------------|---------------|---------------|---------------|----------------|--------------|---------------|---------------|
|           |         | T# = Tube #, P# = bottom position of 9" source |               |               |               |               |                |              |               |               |
| 7 53      | QAOW17  | T1P12<br>2 0                                   | T2P0<br>0 01  | T2P9<br>5 0   | T3P3<br>0 50  | T3P12<br>0 02 |                |              |               |               |
| 9 90      | QAOW19  | T1P6<br>3 0                                    | T1P15<br>0 30 | T2P6<br>0 30  | T2P15<br>3 0  | T3P6<br>0 30  | T3P15<br>3 0   |              |               |               |
| 9 90      | QAOW19  | T1P6<br>3 0                                    | T1P15<br>0 30 | T2P6<br>0 30  | T2P15<br>3 0  | T3P6<br>0 30  | T3P15<br>3 0   |              |               |               |
| 10 00     | QAOW08  | T1P0<br>1 0                                    | T1P9<br>5 0   | T1P18<br>2 0  | T2P9<br>1 0   | T3P9<br>1 0   |                |              |               |               |
| 12 20     | QAOW41  | T1P6<br>5 0                                    | T1P15<br>0 50 | T2P6<br>0 50  | T2P15<br>5 0  | T3P6<br>1 0   | T3P15<br>0 20  |              |               |               |
| 14 68     | QAOW53  | T1P0<br>2 0                                    | T1P9<br>5 0   | T1P18<br>5 0  | T2P0<br>0 50  | T2P9<br>0 02  | T2P18<br>0 05  | T3P0<br>0 10 | T3P9<br>1 0   | T3P18<br>1 0  |
| 17 70     | QAOW37  | T1P6<br>5 0                                    | T1P15<br>0 20 | T2P9<br>10 0  | T2P18<br>0 50 | T3P0<br>1 0   | T3P18<br>1 0   |              |               |               |
| 19 13     | QAOW63  | T1P1<br>1 0                                    | T1P12<br>10 0 | T1P21<br>0 10 | T2P0<br>0 50  | T2P12<br>5 0  | T2P21<br>0 02  | T3P0<br>0 50 | T3P12<br>2 0  | T3P21<br>0 01 |
| 23 88     | QAOW58  | T1P3<br>0 50                                   | T1P12<br>20 0 | T1P21<br>0 20 | T2P3<br>1 0   | T2P12<br>2 0  | T2P21<br>0 10  | T3P3<br>0 05 | T3P12<br>0 02 | T3P21<br>0 01 |
| 28 60     | QAOW36  | T1P9<br>20 0                                   | T1P18<br>0 10 | T2P0<br>0 50  | T2P15<br>5 0  | T3P3<br>2 0   | T3P18<br>1 0   |              |               |               |
| 33 55     | QAOW64  | T1P5<br>1 0                                    | T1P14<br>10 0 | T2P6<br>0 50  | T2P15<br>0 05 | T3P9<br>2 0   | T3P18<br>20 0  |              |               |               |
| 39 00     | QAOW40  | T1P5<br>20 0                                   | T1P14<br>2 0  | T2P3<br>1 0   | T2P12<br>10 0 | T3P6<br>1 0   | T3P15<br>5 0   |              |               |               |
| 47 00     | QAOW27  | T1P6<br>2 0                                    | T1P15<br>40 0 | T3P5<br>5 0   |               |               |                |              |               |               |
| 54 30     | QAOW46  | T1P0<br>5 0                                    | T1P9<br>10 0  | T1P18<br>5 0  | T2P0<br>0 1   | T2P9<br>1 0   | T2P18<br>2 0   | T3P0<br>30 0 | T3P9<br>1 0   | T3P18<br>0 20 |
| 62 00     | QAOW45  | T1P3<br>40 0                                   | T2P0<br>0 50  | T2P9<br>1 0   | T2P18<br>0 50 | T3P15<br>20 0 |                |              |               |               |
| 68 67     | QAOW51  | T1P0<br>0 10                                   | T1P9<br>20 0  | T1P18<br>5 0  | T2P0<br>0 05  | T2P9<br>0 50  | T2P18<br>2 0   | T3P0<br>0 02 | T3P9<br>1 0   | T3P18<br>40 0 |
| 70 00     | QAOW25  | T1P13<br>30 0                                  | T2P3<br>5 0   | T2P12<br>10 0 | T3P0<br>5 0   | T3P16<br>20 0 |                |              |               |               |
| 92 25     | QAOW60  | T1P2<br>30 0                                   | T1P11<br>20 0 | T1P20<br>1 0  | T2P2<br>40 0  | T2P11<br>1 0  | T2P20<br>0 005 | T3P2<br>0 20 | T3P11<br>0 05 |               |
| 100 00    | QAOW33  | T1P0<br>5 0                                    | T1P9<br>20 0  | T2P6<br>30 0  | T2P15<br>5 0  | T3P9<br>40 0  |                |              |               |               |
| 102 70    | QAOW48  | T1P2<br>1 0                                    | T1P11<br>50 0 | T1P20<br>1 0  | T2P2<br>30 0  | T2P11<br>0 20 | T2P20<br>5 0   | T3P2<br>10 0 | T3P11<br>5 0  | T3P20<br>0 50 |
| 116 71    | QAOW54  | T1P2<br>50 0                                   | T1P11<br>20 0 | T1P20<br>10 0 | T2P2<br>5 0   | T2P11<br>30 0 | T2P20<br>1 0   | T3P2<br>0 50 | T3P11<br>0 20 | T3P20<br>0 01 |
| 135 70    | QAOW57  | T1P2<br>50 0                                   | T1P11<br>30 0 | T1P20<br>5 0  | T2P0<br>40 0  | T2P9<br>10 0  | T2P18<br>1 0   | T3P3<br>1 0  | T3P12<br>0 50 |               |
| 160 00    | QAOW21  | T1P10<br>50 0                                  | T1P19<br>20 0 | T2P10<br>5 0  | T2P19<br>30 0 | T3P1<br>40 0  | T3P10<br>10 0  | T3P19<br>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 2.

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 1.0 %.

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 4), 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 3 (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**

| <b>Combustible Drum – Summary Statistics (Values in %)</b> |        |              |         |         |             |         |         |
|--|--------|--------------|---------|---------|-------------|---------|---------|
| 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 9



## 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 5) 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)

## AK Data Uncertainty

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 In rare cases, such as the Plutonium Finishing Plant (PFP) at Hanford, process knowledge of one (or more) data component is so precise that the accompanying uncertainty is negligible At PFP, which is projected to be the source of WRAP’s initial TRU waste stream, the operational and criticality requirements have been so rigorous that plutonium isotopic knowledge is accurate to at least four significant digits This is far more accurate than the MGA software on the GEA, especially for small (less than 0 5 gram) quantities of plutonium For calculation of TMU, WRAP has assigned an uncertainty of 2% to PFP plutonium isotopics data, although it is known that this is a gross overstatement of the true uncertainty Plutonium mass data from PFP are subject to extra scrutiny In the past quantities known to be less than or equal to 1 gram were assigned a value of 1 gram and the known isotopic ratios were applied to render all plutonium mass values More recently outgoing waste has been assayed using a segmented gamma scan (SGS) system The resulting mass values are more accurate, but precedence is still given to WRAP assay values Other waste streams will be analyzed for AK reliability as they are identified

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

**Table 4**

| <b>Uncertainty Estimates (%) – SGS Assay System (gm Pu239)</b> |                            |                           |                            |                            |                            |                            |                            |
|--|----------------------------|---------------------------|----------------------------|----------------------------|----------------------------|----------------------------|----------------------------|
| <b>Mass Range</b>  | <b>Component</b>           | <b>Sum Segments</b>       |                            |                            | <b>Combine All</b>         |                            |                            |
|  |                            | <b>375 keV</b>            | <b>129 keV</b>             | <b>414 keV</b>             | <b>375 keV</b>             | <b>129 keV</b>             | <b>414 keV</b>             |
| <b>I</b>   | $\sigma_{\text{InstStat}}$ |                           | Inst Stat                  |                            |                            |                            |                            |
|  | $\sigma_{\text{SelfAb}}$   |                           | 0                          |                            |                            |                            |                            |
|  | $\sigma_{\text{NonUnif}}$  |                           | TBD                        |                            |                            |                            |                            |
|  | $\sigma_{\text{Matrix}}$   |                           | 12                         |                            |                            |                            |                            |
|  | $\sigma_{\text{End}}$      |                           | 11.5                       |                            |                            |                            |                            |
| <b>II</b>  | $\sigma_{\text{InstStat}}$ |                           | Inst Stat                  | Inst Stat                  |                            | Inst Stat                  | Inst Stat * 2              |
|  | $\sigma_{\text{SelfAb}}$   |                           | 0 if <1gm<br>5 if > 1gm    | 0 if <1gm<br>5 if > 1gm    |                            | 0 if <1gm<br>5 if > 1gm    | 0 if <1gm<br>5 if > 1gm    |
|  | $\sigma_{\text{NonUnif}}$  |                           | TBD                        | Equation                   |                            | TBD                        | Equation                   |
|  | $\sigma_{\text{Matrix}}$   |                           | 12                         | 12                         |                            | 12                         | 12                         |
|  | $\sigma_{\text{End}}$      |                           | 11.5                       | 11.5                       |                            | 11.5                       | 11.5                       |
| <b>III</b>   | $\sigma_{\text{InstStat}}$ | Inst Stat                 | Inst Stat                  | Inst Stat                  | Inst Stat                  | Inst Stat                  | Inst Stat                  |
|  | $\sigma_{\text{SelfAb}}$   | 5 if <10gm<br>10 if >10gm | 5 if <10gm<br>10 if > 10gm | 5 if <10gm<br>10 if > 10gm | 5 if <10gm<br>10 if > 10gm | 5 if <10gm<br>10 if > 10gm | 5 if <10gm<br>10 if > 10gm |
|  | $\sigma_{\text{NonUnif}}$  | Equation *                | TBD                        | Equation                   | Equation *                 | TBD                        | Equation                   |
|  | $\sigma_{\text{Matrix}}$   | 12                        | 12                         | 12                         | 12                         | 12                         | 12                         |
|  | $\sigma_{\text{End}}$      | 11.5                      | 11.5                       | 11.5                       | 11.5                       | 11.5                       | 11.5                       |
| <b>IV</b>  | $\sigma_{\text{InstStat}}$ | Inst Stat                 |                            | Inst Stat                  | Inst Stat                  |                            | Inst Stat                  |
|  | $\sigma_{\text{SelfAb}}$   | 10                        |                            | 10                         | 10                         |                            | 10                         |
|  | $\sigma_{\text{NonUnif}}$  | Equation *                |                            | Equation                   | Equation *                 |                            | Equation                   |
|  | $\sigma_{\text{Matrix}}$   | 12                        |                            | 12                         | 12                         |                            | 12                         |
|  | $\sigma_{\text{End}}$      | 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.

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

$\sigma_{\text{SelfAb}}$  – the uncertainty associated with self absorption (lumping effect), weight is total Pu

$\sigma_{\text{NonUnif}}$  – the uncertainty associated with source non uniformity

$\sigma_{\text{Matrix}}$  – the uncertainty due to the matrix

$\sigma_{\text{End}}$  – 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 energy 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  $^{239}\text{Pu}$ , and the instrument uncertainty are stated, the other uncertainties are obtained from Table 4 or equations referenced by Table 4.

#### Example 1 – Mass Range II (414 keV)

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

$\sigma_{\text{SelfAb}} = 0.0\%$ ,  $\sigma_{\text{NonUnif}} = 12.6\%$ ,  $\sigma_{\text{Matrix}} = 12.0\%$ ,  $\sigma_{\text{End}} = 11.5\%$

$\sigma_{\text{SGS}} = \text{Square root of } (0.075^2 + 0.126^2 + 0.12^2 + 0.115^2) = 0.222 \text{ or } 22.2\%$   
 $= 0.33 \text{ gm } ^{239}\text{Pu}$

#### Example 2 - Mass Range III (414 keV)

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

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

$\sigma_{\text{SGS}} = \text{Square root of } (0.0275^2 + 0.05^2 + 0.162^2 + 0.12^2 + 0.115^2) = 0.239 \text{ or } 23.9\%$   
 $= 2.15 \text{ gm } ^{239}\text{Pu}$

#### Example 3 - Mass Range IV (414 keV)

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

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

$\sigma_{\text{SGS}} = \text{Square root of } (0.0205^2 + 0.10^2 + 0.173^2 + 0.12^2 + 0.115^2) = 0.261 \text{ or } 26.1\%$   
 $= 13.04 \text{ gm } ^{239}\text{Pu}$

### 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

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

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

$$\text{DOSEEQCI} = \text{GMS239} * (1/\text{MF239}) * [0.913 * \text{MF238} + \text{MF239} + \text{MF240} + 0.0192 * \text{MF241} + 0.956 * \text{MF242} + 1.03 * \text{MFAM241}]$$

$$\text{PUEQCI} = \text{GMS239} * (1/\text{MF239}) * [0.909 * \text{MF238} + \text{MF239} + \text{MF240} + 0.0192 * \text{MF241} + 0.909 * \text{MF242} + \text{MFAM241}]$$

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

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 ( $\sigma_{\text{Inst Stat}}$ ,  $\sigma_{\text{SelfAb}}$ ,  $\sigma_{\text{NonUnif}}$ ,  $\sigma_{\text{Matrix}}$ ,  $\sigma_{\text{End}}$ ) are summed in quadrature, i.e.,

$$\sigma_{\text{SGS}} = \text{Square root of } (\sigma_{\text{Inst Stat}}^2 + \sigma_{\text{SelfAb}}^2 + \sigma_{\text{NonUnif}}^2 + \sigma_{\text{Matrix}}^2 + \sigma_{\text{End}}^2)$$

#### Uncertainty associated with Y

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

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

$$[\text{RSD}(\text{MF239})] = \text{Std}(\text{MF239})/\text{MF239}$$

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

Uncertainty associated with Z

$$Z = 0.573 \cdot \text{MF238} + 0.00195 \cdot \text{MF239} + 0.00716 \cdot \text{MF240} + 0.00331 \cdot \text{MF241} + 0.000117 \cdot \text{MF242} + 0.116 \cdot \text{MFAM241}$$

The uncertainty (as a variance) associated with Z is

$$\text{Var}(Z) = 0.573^2 \cdot \text{Var}(\text{MF238}) + 0.00195^2 \cdot \text{Var}(\text{MF239}) + 0.00716^2 \cdot \text{Var}(\text{MF240}) + 0.00331^2 \cdot \text{Var}(\text{MF241}) + 0.116^2 \cdot \text{Var}(\text{MFAM241})$$

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

$$\begin{aligned} \text{Var}(\text{MF238}) &= [\text{RSD}(\text{MF238}) \cdot \text{MF238}]^2, \text{Var}(\text{MF239}) = [\text{RSD}(\text{MF239}) \cdot \text{MF239}]^2, \\ \text{Var}(\text{MF240}) &= [\text{RSD}(\text{MF240}) \cdot \text{MF240}]^2, \text{Var}(\text{MF241}) = [\text{RSD}(\text{MF241}) \cdot \text{MF241}]^2, \text{ and} \\ \text{Var}(\text{MFAM241}) &= [\text{RSD}(\text{MFAM241}) \cdot \text{MFAM241}]^2 \end{aligned}$$

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

$$[\text{RSD}(Z)] = \text{Std}(Z)/Z$$

where Std is the square root of the variance and Z is defined above

Uncertainty associated with Watts

$$\text{Watts} = X \cdot Y \cdot Z$$

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

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

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

$$\text{Var}(\text{WATTS}) = [\text{RSD}(\text{WATTS}) \cdot \text{WATTS}]^2$$

$$\sigma_{\text{WATTS}} = \text{square root of Var}(\text{WATTS})$$

**Example**

MF238=0.000293, RSD=0.02

MF239=0.937, RSD=0.02

MF240=0.0570, RSD=0.02

MF241=0.00355, RSD=0.02

MF242=0.0002, RSD=0.02

MFAM241=0.00169, RSD=0.02

Density = 0.166 g/cc

SGS result = 2.02 gm  $^{239}\text{Pu}$ ,  $\sigma_{\text{Inst Stat}} = 5.73\%$  $\sigma_{\text{SelfAb}} = 0.0\%$ ,  $\sigma_{\text{NonUnif}} = 13.2\%$ ,  $\sigma_{\text{Matrix}} = 12.0\%$ ,  $\sigma_{\text{End}} = 11.5\%$  $X = \text{SGS result} = 2.02 \text{ gm } ^{239}\text{Pu}$  $\text{RSD}(X) = \text{Square root of } (0.0573^2 + 0.132^2 + 0.012^2 + 0.115^2) = 21.97\%$  $Y = 1/\text{MF239} = 1.07$  $\text{RSD}(Y) = 0.02$  $Z = 0.00261$  $\text{Var}(Z) = 1.43\text{E-}09$  $\text{RSD}(Z) = 1.45\%$  $\text{Watts} = 2.02 * 1.07 * 0.00261 = 5.63\text{E-}03$  $\text{RSD}(\text{Watts}) \cong \text{Square root of } (0.2197^2 + 0.02^2 + 0.0145^2) = 22.11\%$

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