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ENGINEERING CHANGE NOTICE

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1. ECN 651741

Proj. ECN —

2. ECN Category (mark one)	3. Originator's Name, Organization, MSIN, and Telephone No.	4. USQ Required?	5. Date
Supplemental ○ Direct Revision ◉ Change ECN ○ Temporary ○ Standby ○ Supersedure ○ Cancel/Void ○	CE Wills, WRAP Engineering, T4-52, 373-9844	◉ Yes ○ No	09-16-99
	6. Project Title/No./Work Order No. WRAP Facility/AJ60	7. Bldg./Sys./Fac. No. 2336-W	8. Approval Designator Q
	9. Document Numbers Changed by this ECN (includes sheet no. and rev.) HNF-4050, Rev. 0, All	10. Related ECN No(s). N/A	11. Related PO No. N/A

12a. Modification Work	12b. Work Package No.	12c. Modification Work Completed	12d. Restored to Original Condition (Temp. or Standby ECNs only)
○ Yes (fill out Blk. 12b) ◉ No (NA Blks. 12b, 12c, 12d)	N/A	N/A Design Authority/Cog. Engineer Signature & Date	N/A Design Authority/Cog. Engineer Signature & Date

13a. Description of Change

13b. Design Baseline Document? ○ Yes ◉ No

Completed analysis of the Total Measurement Uncertainty (TMU) for Nondestructive Assay of Transuranic Waste at the WRAP Facility, which revises the current method.

14a. Justification (mark one)	14b. Justification Details
Criteria Change ○ Design Improvement ○ Environmental ○ Facility Deactivation ○ As-Found ◉ Facilitate Const. ○ Const. Error/Omission ○ Design Error/Omission ○	Design verification not required Additions made in response to WIPP audit comments USQ WRP-99- 203

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

See attached distribution sheet

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1. ECN (use no. from pg. 1): ECN-651741

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

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

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

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

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

21. Approvals

	Signature	Date		Signature	Date
Design Authority			Design Agent		
Cog. Eng. CE Wills	CE Wills	9/16/99	PE		
Cog. Mgr. JR Weidert	JR Weidert	9-16-99	QA		
QA WR Thackaberry	WR Thackaberry	9-16-99	Safety		
Safety			Design		
Environ.			Environ.		
Other			Other		
SQAO JL Maupin	JL Maupin	9/16/99			

DEPARTMENT OF ENERGY

Signature or a Control Number that tracks the Approval Signature

ADDITIONAL

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

CE Wills
Waste Management Federal Services of 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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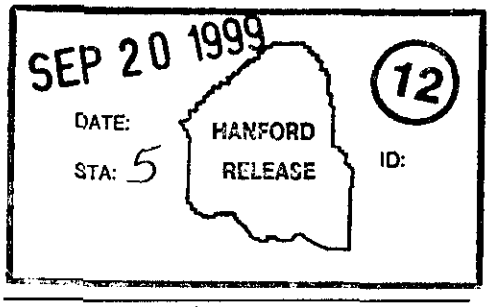

Release Approval 9/20/99 Date

Release Stamp

Approved for Public Release

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

(2) Title
TOTAL MEASURE UNCERTAINTY FOR NDA OF TRU WASTE AT THE WRAP FACILITY

CHANGE CONTROL RECORD

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		(5) Cog. Engr.	(6) Cog. Mgr. Date
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RS 1	Complete Revision to Document per ECN-651741	CE Wills	JR Weidert 9-16-99

HNF-4050, Revision 1

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

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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 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 the error, or uncertainty, associated with any measurements taken.

All measurements have an inherent uncertainty associated with them. The combined effect of all errors associated with a measurement is referred to as the total measurement uncertainty (TMU). NDA measurement uncertainties can be numerous and complex. In addition to system-induced measurement errors, there are other factors which contribute to the TMU associated with a particular measurement. NDA measurements at WRAP are based upon processes (radioactive decay and induced fission) which are statistical in nature. As a result, the proper statistical summation of the various error 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.

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Introduction

The process of performing NDA analysis on a waste container at WRAP invokes a number of other systems and processes. For purposes of this report, only waste drums shall be considered. All TRU or potentially TRU waste drums which enter the WRAP facility undergo the following process:

Acceptable knowledge (AK) data review and drum physical integrity check
Entry into the facility database for tracking
Temporary storage, as needed
Weight taken on facility scales and recorded for later use
Nondestructive examination (NDE)
NDA using Imaging Passive/Active Neutron (IPAN) system and Gamma Energy Assay (GEA) system
NDA analysis

Upon completion of this sequence, each drum is assigned a waste class (TRU or low level). If the drum is TRU and contains no prohibited items for disposal at WIPP (determined through NDE), then all processing which could impact TMU is complete and final calculations are performed. 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. 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.

As mentioned above, NDA is performed at WRAP using both neutron and gamma assay techniques. There are two identical neutron (IPAN) assayers and two identical gamma (GEA) assayers.

The WRAP IPAN systems were built by Pajarito Scientific Corporation (now BNFL Instruments Inc, or BII) and use their (proprietary) algorithms for active and passive neutron assay. As with typical PAN systems, the WRAP IPANs feature a shielded vault surrounded by packages of He-3 tubes for neutron detection. One side of the vault contains a neutron generator (average energy = 14.7 MeV) with a layer of moderating material designed to thermalize the neutrons before they reach the drum, thus providing a thermal neutron flux. Roughly opposite the neutron generator is a flux monitor package which quantifies the attenuation of the flux by the waste matrix. This is used to enhance corrections for matrix effects. A significant upgrade from the old, familiar PAN systems allows the IPANs to provide a graphical representation of source distribution within the drum. This "imaging" function (thus the new name) aids analysis of assay results, since source

distribution factors such as lumping and other inhomogeneities can be identified and taken into consideration. The IPANs have an array of reports available to allow as complete an analysis as is required. These are especially helpful when confronted with unusual matrix characteristics or source distributions.

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. 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 Eu-152 transmission sources which provide a measure of the matrix attenuation effects in each segment, across a wide range of energies. The drum platform moves to three vertical positions during an assay, thus dividing the drum into twelve segments for analysis. Transmission correction and "passive" gamma detection are performed on each segment, providing a well-defined picture of source distribution and matrix effects, while minimizing errors induced by same. A variety of reports are available to allow a complete and very detailed analysis of the waste. The GEAs also have two germanium detectors designed for low energy (up to 300 keV) gamma detection. These detectors collect the data used for the Multi-Group Analysis (MGA) software, which provides isotopic breakdown of plutonium and uranium waste.

NDA analysis uses data from a variety of sources: AK, WRAP scales, NDE, IPAN, GEA, and, in the case of process drums, information gleaned from the sorting of the waste. Each data source has an associated uncertainty or set of uncertainties, which is the focus of this document. A detailed discussion of the analytical method used to synthesize these data is beyond the scope of this report. The general procedure can be found in WMH-350-2.2, Calculation of Assay Results. Expert knowledge (NDA experience, system knowledge, etc) on the part of the NDA analyst is an invaluable component of the process. Briefly, to assist the discussion of combining errors later, it should be noted that any combination of the three radiological data sources – AK, NDE, and NDA – may be used to determine TRU isotopic and mass results. There are many NDA systems which use PAN assay for plutonium mass and GEA assay for plutonium isotopics, but the WRAP system is much more flexible.

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 error components are statistically independent. Another assumption is that the total bias is well approximated by a linear function (Reference 7). 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, IPAN results, and GEA results. The statistical nature of radioactive decay or the interaction of a particle flux with a target matrix need not be belabored here, although these will be the dominant factors in analysis of NDA measurement uncertainty. A simpler example is the amount of random fluctuation in weight scale readings, which can be estimated using statistical methods. The standard deviation of the mean of a series of replicate measurements is used to evaluate this kind of measurement uncertainty. By convention, uncertainty values for a given measurement are expressed as a range, at a given confidence level (e.g., "At the 95% confidence level, the object weighs 53 ± 2.7 kilograms"). Uncertainties from sources which cannot be statistically evaluated are estimated; the contribution of these sources to the TMU can be quite large. Such sources include AK data, NDE results, and variations in drum and packaging material tare weights. The uncertainties – both statistical and estimated – associated with each of these sources are discussed below.

IPAN MEASUREMENT UNCERTAINTY

The primary components of the total measurement uncertainty in the WRAP IPAN assay are:

Calibration uncertainty
Counting statistics (Random Error)
Matrix Effects
Source Distribution
Presence of Gamma-ray, Neutron, and (α,n) Interferents
Multiplication Effects
Self-Shielding

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 carried out by making two measurements, an assay of a

known sample 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.

Calibration Uncertainty

Uncertainties in calibration parameters are associated with (1) the use of appropriate reference materials, (2) measured statistical uncertainties, and (3) matching of calibration standards to the materials (matrix and source position) that affect assay accuracy. The IPAN software accounts for the calibration counting statistics. The matrix effects and source position uncertainties are accounted for in other sections of this document. Cf-252 and Depleted Uranium (DU) sources are used to calibrate the passive and active neutron components of the WRAP Drum IPAN systems, respectively. These standards are traceable to NIST and NBS standard reference material. The uncertainty for the Cf-252 source (passive mode) is approximately 3% and the uncertainty of the DU sources (active mode) is less than 1%.

The uncertainty due to the use of Cf-252 or DU reference sources can be evaluated using IPAN measurements of plutonium reference standards. The plutonium masses ranged from 0.010g to 160.00g. Multiple measurements using plutonium reference standards were performed using the performance demonstration program (PDP) matrices 003 (Combustibles) and 001 (Empty). These same measurements are used in the assessment of other IPAN uncertainties. The average recovered ratio (%Rec), defined as measured divided by known values times 100, for the active neutron measurements was 97%, with a standard deviation of 15%, (Combustibles matrix) and 77%, with a standard deviation of 13%, (Empty matrix). The average %Rec for the passive neutron measurements was 43%, with a standard deviation of 18%, (Combustibles matrix) and 83%, with a standard deviation of 36%, (Empty matrix). The observed uncertainty can largely be attributed to matrix and source effects and does not indicate a significant calibration bias (Reference 4).

For the purposes of TMU determination, it is assumed that the effect of the statistical uncertainty in the calibration data is (1) small compared to the other uncertainty components and (2) contained in the uncertainty estimate associated with matrix and source effects. Thus, only the uncertainty (in terms of 1 RSD) associated with the calibration source (~3% for the passive mode and ~1% for the active mode) needs to be included in the TMU determination.

Counting statistics (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 counting statistics tend to be the primary effect in the precision of the

measurements. The counting statistics (based on Poisson counting fluctuations) are propagated by the IPAN software. The algorithms for propagation of the counting statistics uncertainties are contained in the algorithms manual (Reference 3).

The random error for the IPAN assay system can be estimated from repeated measurements of representative waste drums. Various masses of weapons grade (WG) 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 error arising from local background variability is included in the estimates. Measurement times were the same as those used under normal operating conditions. The number of repeat measurements for each drum varied between 5 and 15 replicate measurements. Since a large number (> 100 sets) of repeated measurements were carried out, only a representative sample of the results have been reported in Table 1. For comparison purposes the counting statistics uncertainty, as reported by the IPAN system and used in the TMU determinations at WRAP, for similar gram quantities in actual waste drums is also listed. As can be seen in Table 1, the two uncertainty estimates (%RSD and instrument statistics) are close which validates the use of the uncertainty as generated by the software.

Matrix Effects

Uncertainty due to matrix effects refers to the potential for random or systematic error to arise in passive and active neutron analyses due to neutron absorbing or moderating properties in the drum matrix material. The WRAP Drum IPAN systems use a calculated ABSMOD index to select the active and passive calibration matrices with properties which most closely match those of the waste drum (Reference 3).

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 radial (center, 6" from center, outside edge) and vertical positions (various inches as measured from the bottom of the drum) in the drum. The ratio of the measured to the known activity for each run was calculated for each measurement. This ratio, multiplied by 100, will be referred to as percent recovery (%Rec). A representative sample of these runs (combustible matrix) are listed in Table 1 and plotted in Figure 1. The average %Rec over all reported data (< 25g) in Table 1 for the active mode is 97% with a standard deviation of 15%. The average %Rec over all reported data (< 25g) in Table 1 for the passive mode is 43% with a standard deviation of 18%. Using a similar representative sample of the empty matrix drum runs (see Figure 2), the average %Rec is 77% (standard deviation of 13%) for the active mode and 83% (standard deviation of 36%) for the passive mode. This indicates that an uncertainty of approximately 15% exists for the active mode results and 57% for the passive mode. This uncertainty can be attributed to both matrix and source nonuniformity effects.

Source Distribution Uncertainty

Source heterogeneity can be an important source of bias in passive and active neutron measurements. Bias arises because instrument calibration may not fully reflect all the variability in plutonium source location and strength encountered in real waste forms. This variability can be compounded by matrix differences from sample to sample. The WRAP Drum IPAN systems image the active and passive source distribution so as to minimize the uncertainty arising from source heterogeneity. This uncertainty has been included with the matrix effects uncertainty.

Uncertainty Resulting from the Presence of Gamma-ray, Neutron, and (α,n) Interferents

For both passive and active neutron analyses, gamma-ray emissions do not cause pileup in the He detectors because of the nature of the Contact-Handled TRU waste. That is, all Contact-Handled TRU waste drums have dose rates below 200 mRem/hour. At these dose rates, pileup of gamma-ray pulses within the resolving time of the electronics will be negligible and no bias will be introduced into neutron analyses due to this effect.

The presence of spontaneous fission neutron emitters in the waste will not affect active neutron assay accuracy because background subtraction of all neutrons that do not result from induced fission by the neutrons from the neutron generator is performed real time, i.e. during the active mode measurement process. However, the presence of a large spontaneous fission background would increase the random error on the active neutron measurement. Repeated measurements were performed on a "test" drum containing a DU standard and a Cf-252 source, which simulated an active measurement under high background conditions (Reference 4). The random uncertainty (% RSD) from the repeated measurements was ~9% while the counting statistics uncertainty was ~3%.

For the active mode neutron analysis, there is a potential for systematic error due to the presence of U-233, U-235, Cm-243, and Cf-249. For passive neutron measurements, the presence of U-238, Cm-244, and Cf-252 can lead to measurement bias (Reference 4). At WRAP, these nuclides are accounted for through detection by the GEA system or from AK. The effect of these nuclides on IPAN measurements is calculated and corrected for (WMH-350, 2.2). Therefore, no significant additional uncertainty or bias is introduced.

Uncertainty Due to Neutron Multiplication

Neutron multiplication is the process by which neutrons from one nuclear decay process lead to additional fissions in other isotopes. Significant neutron multiplication is not expected in WRAP

TRU waste drums because plutonium is anticipated to be distributed over the waste drum volume rather than abiding in a concentrated form. Also, no neutron multiplication effects were apparent in measurements of the largest plutonium standards containing 50g of moderately concentrated WG plutonium (Reference 6). However, if large plutonium masses in concentrated form do occur, there is a potential for neutron multiplication effects to bias the passive measurement result. The IPAN system is currently not certified by WIPP for quantities above 25g, therefore, no significant uncertainty is anticipated.

Self-Shielding Uncertainty

For active assay a potential exists for bias created by self-shielding. Although unlikely in Hanford waste streams, imaging data and comparisons with GEA results would identify the effect. While the GEA result would probably be used in this case, an uncertainty of 22% would be assigned if the IPAN value were utilized. This value comes from Monte Carlo analysis performed by the manufacturer (Reference 4).

Self-shielding effects for the passive neutron assays are negligible due to the high energy of the fission neutrons.

Table 1. IPAN A Combustibles Drum Test Results

Pu(g)	Active Neutron Data			Passive Neutron Data	
	%Rec	%RSD	Instrument Statistics from Actual Waste	%Rec	%RSD
0.03	48.35	29.45	20.5		
0.06	93.02	18.75	12.1		
0.09	101.80	12.23	11.8		
0.15	108.10	5.21	10.1		
0.30	111.24	5.82	10.9		
0.33	104.03	6.46	10.6		
0.60	108.13	3.76	9.0	11.17	118.91
0.66	109.25	2.75	N/A	22.85	62.66
0.90	105.23	5.03	8.5	26.02	43.44
0.96	109.47	4.76	10.3	19.46	27.40
0.99	103.56	6.26	N/A	31.46	21.10
1.05	111.74	1.51	11.7	26.83	35.09
1.20	79.81	0.26	9.3	71.28	8.43
2.14	105.46	5.42	9.8	38.05	6.12
3.15	85.54	2.68	10.4	45.38	7.65
6.15	97.68	2.09	11.5	54.47	6.31
9.90	111.59	0.61	11.0	59.71	3.84
12.20	98.82	2.57	N/A	55.97	4.59
14.68	90.55	0.89	N/A	58.71	1.44
17.70	91.83	0.86	N/A	58.24	2.45
19.13	92.56	0.63	N/A	59.39	2.01
23.88	74.17	0.78	10.7	56.23	4.25

Figure 1

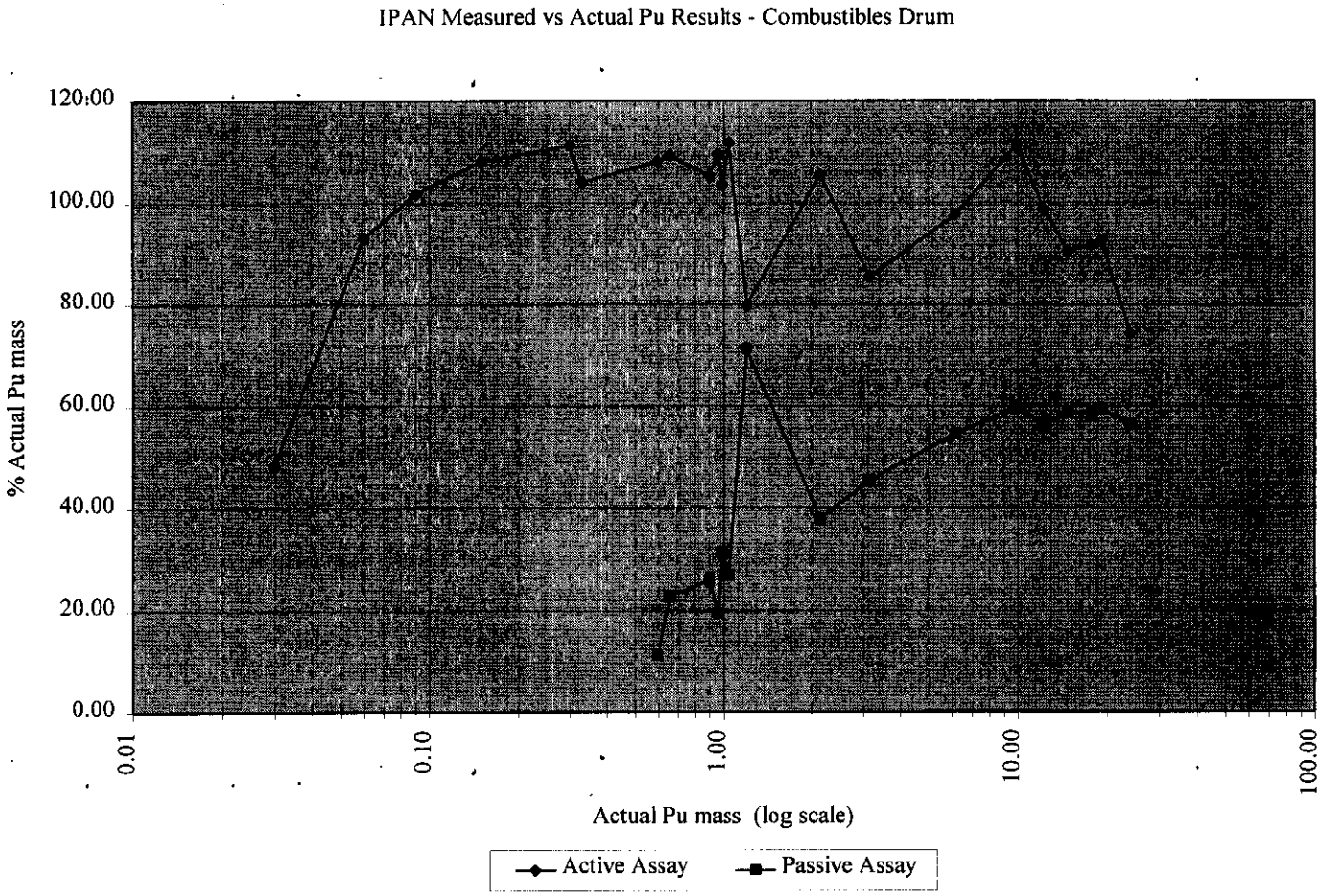
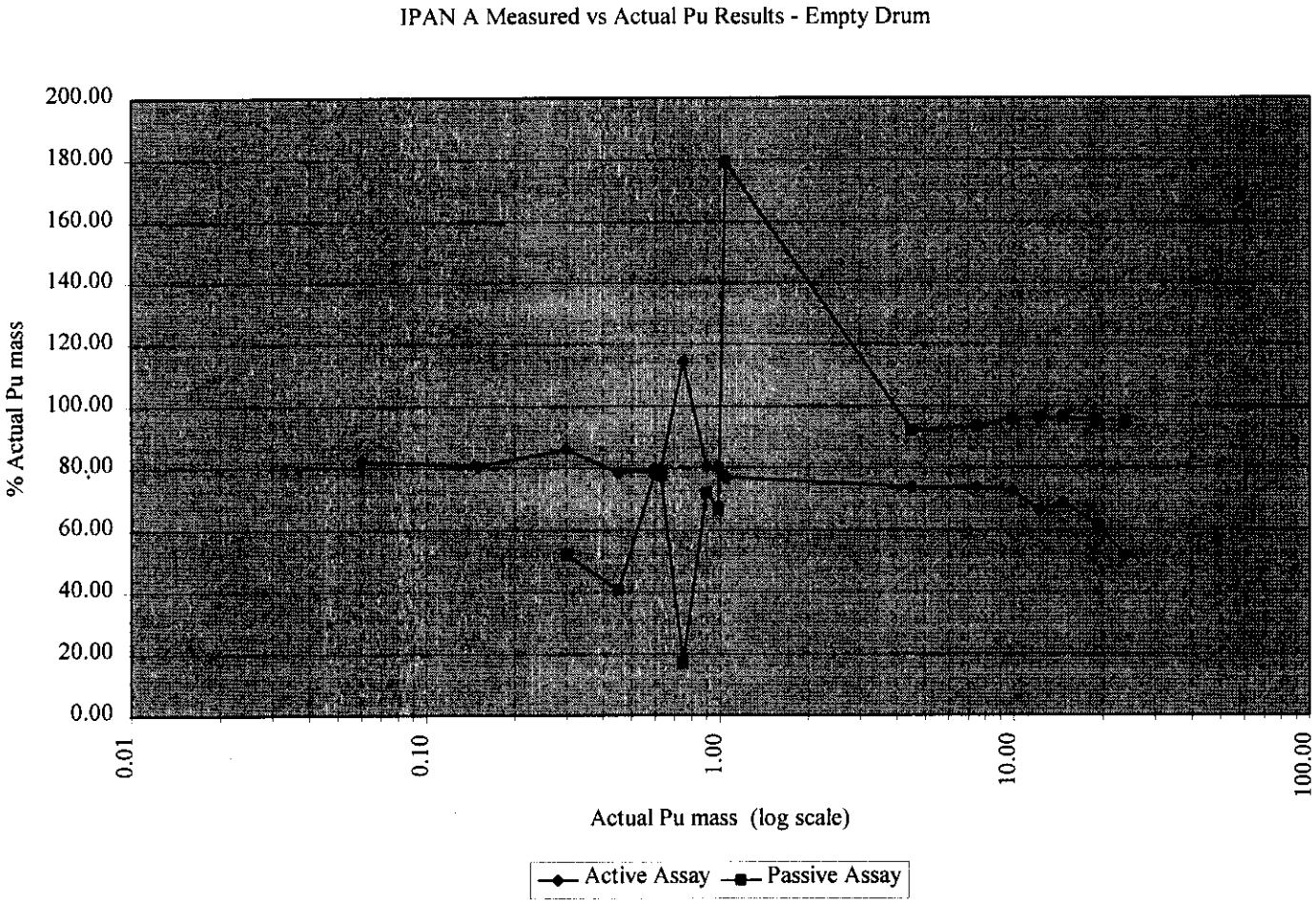

IPAN Measured vs Actual Pu Results - Combustibles Drum
120.00
100.00
80.00
60.00
40.00
20.00
0.00
% Actual Pu mass
0.01
0.10
1.00
10.00
100.00
Actual Pu mass (log scale)
Active Assay
Passive Assay

Figure 2


IPAN A Measured vs Actual Pu Results - Empty Drum
% Actual Pu mass
200.00
180.00
160.00
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
0.01
0.10
1.00
10.00
100.00
Actual Pu mass (log scale)
Active Assay
Passive Assay

GEA MEASUREMENT UNCERTAINTY

The primary components of the total measurement uncertainty in the WRAP GEA assay are:

Calibration source uncertainties
Counting statistics
Matrix absorption
Source self-absorption uncertainties (lumps)
Source nonuniformities

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 carried out by making two measurements, an assay of a known sample 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 5.

Calibration Source Uncertainties

There are typically two components of the overall calibration uncertainty. The first is the uncertainty associated with the calibration sources, which typically have a maximum uncertainty of 3 - 5%. The second is the uncertainty associated with the calibration counting statistics and fit of the calibration data to the calibration curve. This uncertainty 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 5. For calibration of 208 liter drums, the combination of the source, geometrical, and statistical uncertainties typically cause the overall calibration uncertainty to be in the range of 5% (Reference 6).

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 5

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 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 Table 2. For comparison purposes the counting statistics uncertainty, as reported by the GEA system and used in the TMU determinations at WRAP, for similar gram quantities in actual waste drums is also listed. As can be seen in Table 2, the two uncertainty estimates (% RSD and instrument statistics) are close which validates the use of the uncertainty as generated by the software.

Self Absorption Uncertainties

Self absorption uncertainties depend on the quantity of plutonium in a "lump", lump density, and the waste material type. Self absorption errors are difficult to calculate except for the worst case measurement potentials. This would be represented by a spherical metallic source. Reference 1 reports a worst case underestimate for a Segmented Gamma Scan (SGS) assay of a single 1 gram spherical lump of pure plutonium metal using the Pu-239 gamma-ray peak at 413 keV at 25% assuming no differential peak correction is applied. The probability of having a single spherical lump of metal waste is highly unlikely. Therefore a more realistic assumption would be a single 1 gram lump of PuO_2 which might be plated onto a pipe, crucible or other matrix form. It can be calculated that changing from a metal to an oxide and changing the geometry to a less spherical shape would reduce the self absorption underestimation to less than 5%. Going through the same exercise for a larger single 10-gram spherical lump, the attenuation would be approximately 70%, again assuming no differential peak correction. Reconsidering this as a PuO_2 rather than a metal and considering the material in a more plated form would greatly reduce the self absorption effects. Furthermore the probability of a single 10-gram lump is much less probable than a number of smaller lumps summing to 10 grams (Reference 6).

The differential peak absorption correction, which is performed by the GEA software, applies a correction for the Pu result based on the increased absorption of the 129 keV line over the 414 keV line. The mass absorption coefficient ratios, which are used in the differential peak correction equation, may tend to overestimate the result by 5% for small lumps of Pu, depending on where the lump is located. For large single lumps of Pu (> 10g) the correction may underestimate the effect of the lump depending on the location and distribution with other distributed plutonium.

In order to minimize the potential error from plutonium lump self absorption, drums above the 10-gram level will be carefully reviewed to ensure that the plutonium is distributed throughout the drum and therefore cannot be considered as a single significant lump of Pu. In addition NDE measurements and expert review are performed on all drums. The NDE data assist in selecting the appropriate differential peak correction. Since it is not possible to directly quantify the extent of any self absorption in the drums being assayed, the following assumptions will be used to determine the self absorption effect in the TMU analysis. Results are reported as RSDs.

If expert review determines that "lumps" are present, through comparison of segment data and IPAN image data (WMH-350, 2.2), the effect of the self absorption in the TMU analysis will be considered to be 5% for gram loadings of greater than 1 gram and less than 10 grams. For drums above 10 grams it will be assumed to be 10%.

Matrix Uncertainties

Uncertainties due to matrix absorption are small for uniform matrices and source distributions. The GEA software corrects for this 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 is directly accounted for in the correction technique. The algorithms and propagation of uncertainties are found in Reference 5.

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

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 ratio of the measured to the known activity for each run was calculated for each measurement. This ratio, multiplied by 100, will be referred to as percent recovery (%Rec). A representative sample of these runs (combustible matrix) are listed in Table 2 and plotted in Figure 3. The average %Rec over all reported data in Table 2 is 79% (with a standard deviation 11%) for the Sum Segments Data technique and 85% (with a standard deviation 7%) for the Combine All Results Data technique. Using a similar representative sample of the empty matrix drum runs (see Figure 4), the average %Rec is 87% (with a standard deviation 4%) for the Sum Segments Data technique and 93% (with a standard deviation 7%) for the Combine All technique. This indicates that a "bias" of approximately 22%

(Sum Segments) and 15% (Combine All) may exist in the GEA measurements. This uncertainty can be attributed to both matrix and source non-uniformity effects.

The results listed in Table 2 also indicate that a bias exists for the combustible matrix between the GEA Sum Segments technique and the Combine All technique (the majority of the %Rec for the GEA Combine All are higher than the %Rec for the GEA Sum Segments). However, this effect is not seen in the analysis of actual waste drums. This is illustrated in Figure 5. Thus, 15% uncertainty should be used for both Sum Segments and Combine All GEA techniques to account for matrix and source effects.

Nonuniform Source Distribution Uncertainties

The GEA software contains a non-uniformity algorithm, which calculates nonuniformities in both the absorption of a transmission energy and from a nuclide in the sample. The algorithm is described in Reference 5. The algorithm calculates a non-uniformity index for each segment for the transmission source energy and nuclide specified. The software provides corrections to the activities measured for the cases of non-uniformity. Any uncertainty associated with source nonuniformity is incorporated in the matrix uncertainty correction above.

Table 2. GEA A Combustibles Drum Test Results

Pu(g)	Sum Segments Data			Combine All Results Data		
	%Rec	%RSD	Instrument Statistics from Actual Waste	%Rec	%RSD	Instrument Statistics
0.03	103.45	36.89	31.99			
0.06	108.40	20.37	28.21			
0.09	77.58	17.79	22.55			
0.10	67.30	31.42	25.90			
0.15	81.39	16.35	20.10			
0.33	71.38	6.02	12.25	67.65	9.43	5.37
0.60	79.11	8.59	NA	79.06	6.69	7.21
0.63	85.28	3.82	9.87	88.57	4.37	7.11
0.66	81.97	6.53	NA	85.69	5.63	6.85
0.90	106.27	4.55	9.43	100.71	11.66	N/A
0.96	76.15	2.91	9.24	83.54	3.96	N/A
0.99	76.14	12.25	NA	85.07	7.80	6.37
1.05	78.32	4.50	9.28	87.76	2.55	5.95
1.20	91.03	1.44	NA	98.12	0.76	5.79
2.85	77.21	2.31	8.41	86.73	2.27	5.86
3.15	65.46	2.47	8.27	77.66	3.38	5.44
5.00	77.46	1.91	NA	85.88	1.91	5.11
6.15	70.05	4.73	NA	86.17	3.55	7.01
7.53	76.19	2.02	8.30	83.92	2.10	5.31
9.90	76.87	1.76	8.23	92.61	1.65	NA
10.00	72.51	1.58	8.25	85.55	1.60	4.27
12.20	77.04	0.64	NA	88.64	0.60	NA
14.68	74.07	1.72	8.16	86.98	1.61	5.25
17.70	71.98	1.14	8.16	85.89	0.93	5.05
19.13	72.56	0.53	8.12	85.90	0.95	NA
23.88	67.31	1.07	8.14	80.44	1.21	4.59
28.60	67.56	0.55	NA	82.87	0.29	NA
39.00	68.74	0.93	NA	82.57	1.25	3.43
62.00	66.89	0.42	8.06	76.04	0.42	4.09
68.67	83.51	1.10	NA	76.39	1.18	NA
87.70	90.09	0.46	NA	99.21	0.60	NA
116.71	77.09	0.58	NA	80.62	1.24	NA
137.50	75.71	0.45	NA	78.54	1.55	NA
160.00	77.75	0.62	NA	81.22	1.03	NA

Figure 3

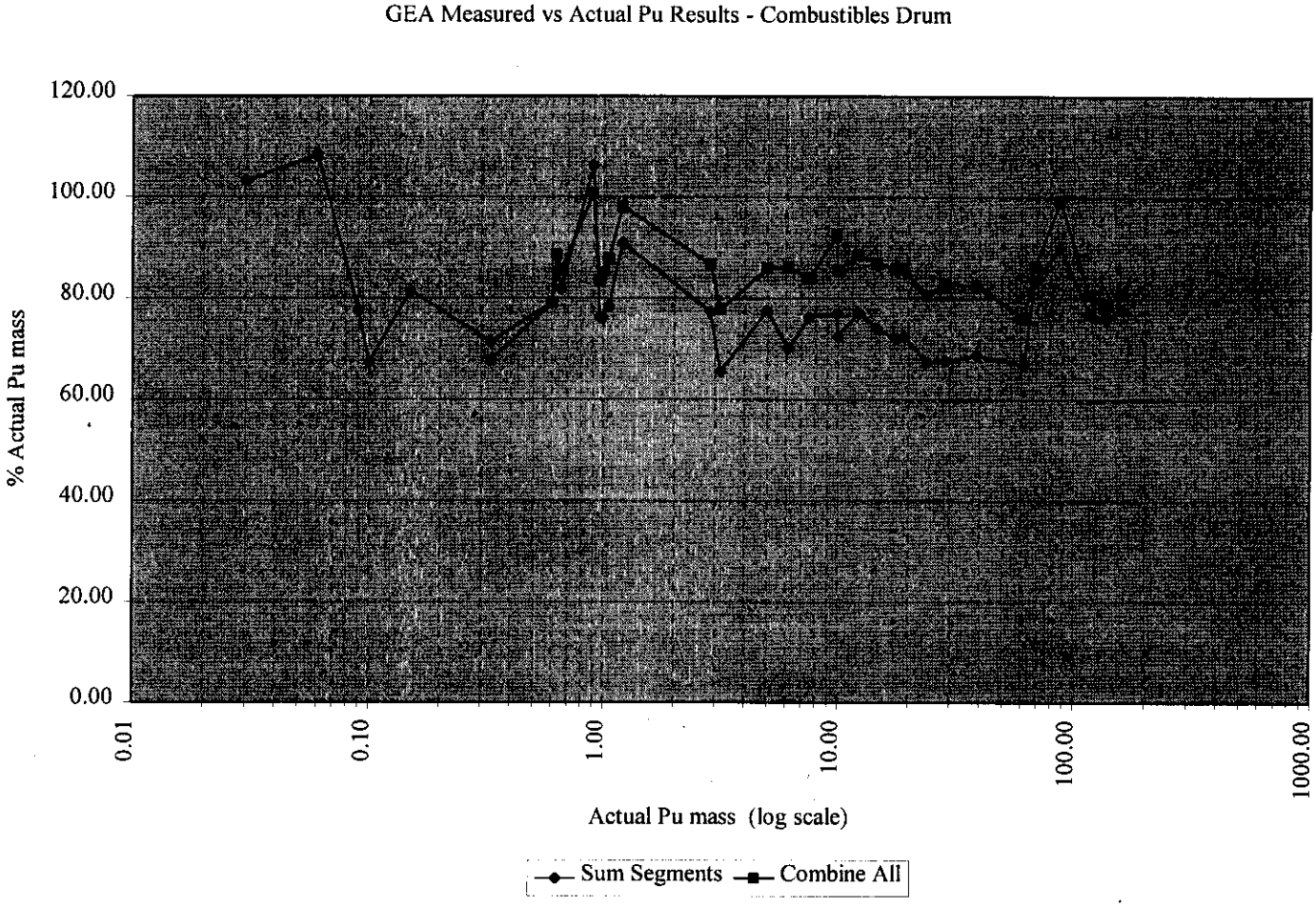
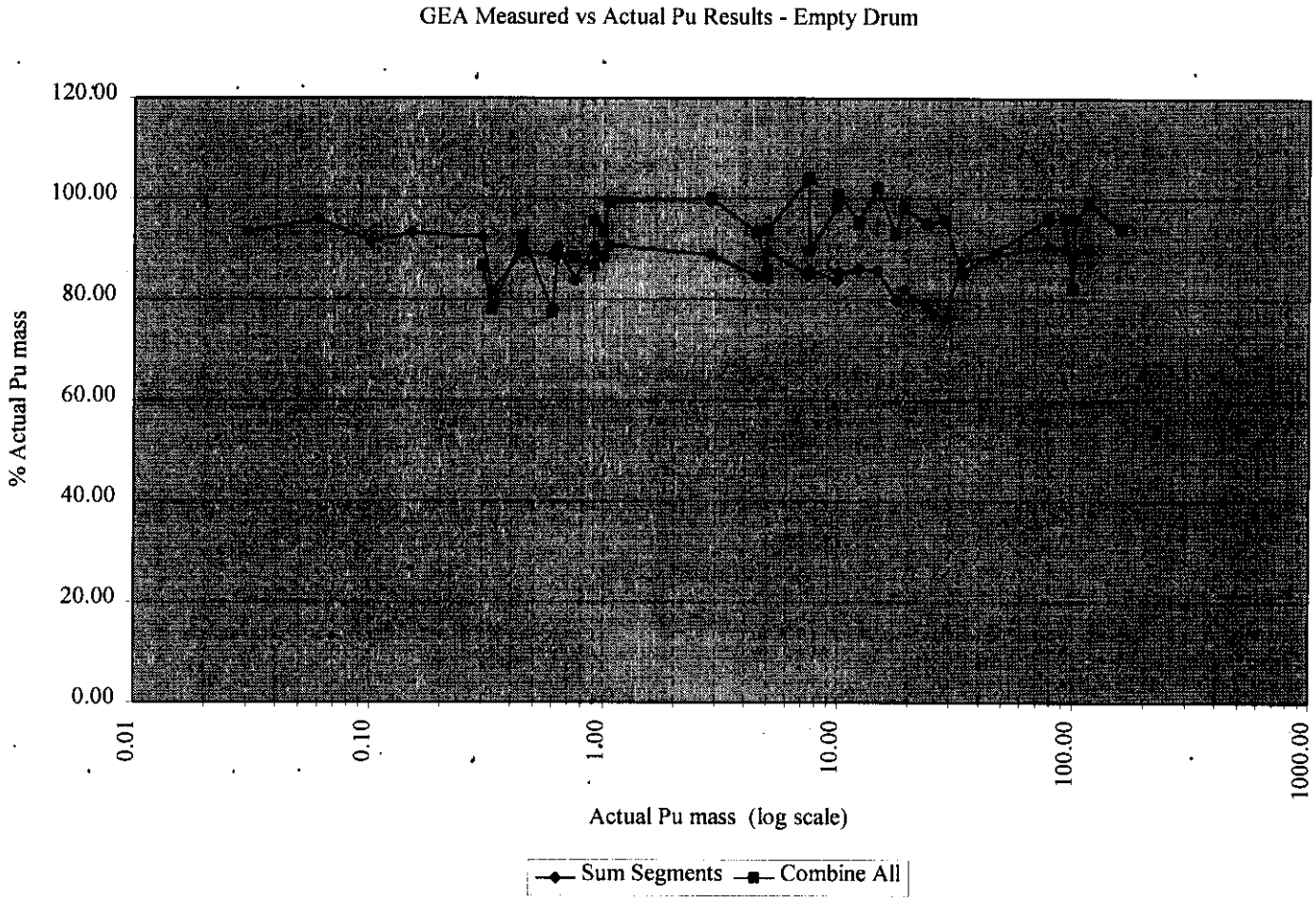

GEA Measured vs Actual Pu Results - Combustibles Drum
120.00
100.00
80.00
60.00
40.00
20.00
0.00
% Actual Pu mass
0.01
0.10
1.00
10.00
100.00
1000.00
Actual Pu mass (log scale)
Sum Segments
Combine All

Figure 4


GEA Measured vs Actual Pu Results - Empty Drum
120.00
100.00
80.00
60.00
40.00
20.00
0.00
% Actual Pu mass
0.01
0.10
1.00
10.00
100.00
1000.00
Actual Pu mass (log scale)
Sum Segments
Combine All

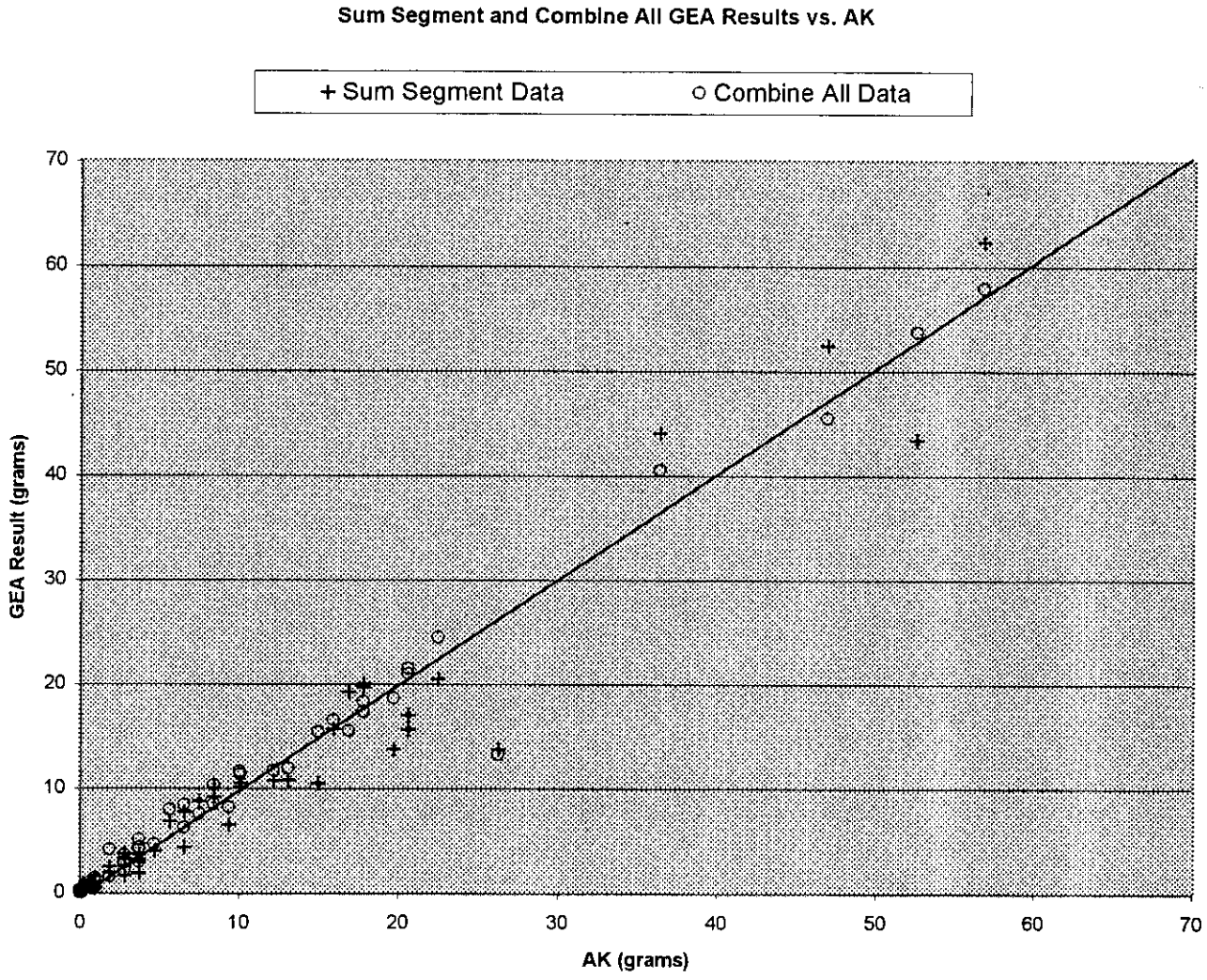

Sum Segment and Combine All GEA Results vs. AK
+ Sum Segment Data
o Combine All Data
GEA Result (grams)
AK (grams)
0
10
20
30
40
50
60
70

Figure 5

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 8). 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 errors are introduced and propagated at 1 sigma, and corrected to the 95% confidence level after all errors are accounted for, this error 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 error 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 error factor of 2% to PFP plutonium isotopics data, although it is known that this is a gross overstatement of the true error. 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.

NDE Uncertainty

The primary component of any uncertainty associated with NDE is in the estimation of weight and volume for each type of material found in a drum. This activity is validated through a system of checks and via the Visual Examination program. Until enough data has been collected on this activity it shall be assumed to have no uncertainty.

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 Errors

Each source of error analyzed above is statistically independent of the others. Propagation of errors 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.

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

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