SEQUOYAH FUELS
CORPORATION

REPORT NO. 4

NONDESTRUCTIVE ASSAY (NDA) TECHNIQUES AND PROCEDURES

This report is prepared and submitted as a Task 2 requirement in accordance with contract DE-AC06-83RL10382.

U. S. Department of Energy
Richland Operations Office
P.O. Box 550
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INDEX

I. INTRODUCTION

Report No. 4 is precursory to Report No. 5 "Determination of the Quantity and Locations of the Pu Currently Retained in the Cimarron Fuel Plant Systems" which will be presented upon completion of the decontamination of the Cimarron Plutonium Fuel Fabrication Facility.

This report presents the Non-Destructive Assay (NDA) procedures which were developed and used by Sequoyah Fuels Corporation (successor to Kerr-McGee Nuclear Corporation) to measure equipment hold-up of plutonium materials for inventory purposes during operation of the plant. These procedures are also used to measure plutonium contamination on the equipment removed from the Material Balance Areas (MBA's) during final decontamination.

Report No. 5 will compare the measurements taken during this final decontamination period to previous inventory hold-up measurements, the data will be statistically analyzed, and a long-term assessment of the performance of the NDA equipment will be described.

II. BACKGROUND

The Cimarron Plutonium Fuel Fabrication Facility began operations in 1969 to produce mixed oxide (uranium-plutonium) fuels in support of various test and demonstration reactor programs. In 1972 new and significantly more stringent plutonium safeguards and accountability requirements were imposed by the Nuclear Regulatory Commission (NRC) requiring more frequent measurement of plutonium inventories to provide early detection of possible diversions of plutonium materials. These new regulations required complete plant physical inventories be taken at sixty (60) day intervals and imposed a complex statistical evaluation program with pre-established criteria for determining the significance of any book-physical inventory difference (BPID).

The Facility received plutonium nitrate solution as feed material which was blended with uranyl nitrate solution and subsequently co-precipitated and reduced to mixed oxide powder. The mixed oxide was then pressed into pellets, sintered, and loaded into fuel pins for delivery to the various customers. In addition, a complete scrap recovery operation was utilized to recycle off-specification and other scrap material for reuse which employed a number of steps to dissolve the plutonium scrap, purify the plutonium by ion exchange, the reblending of purified nitrate solution, and storage. These operations involved thousands of feet of piping to transport and store plutonium solutions and thousands of square feet of surface areas in gloveboxes, equipment in gloveboxes, tanks, etc., which were used continuously to process various forms of plutonium.

During the early periods it became obvious that as a result of the amount of surface area exposed continuously to plutonium and the difficutly of cleaning the equipment sufficiently to meet the statistical significance criteria, it would be extremely difficult to maintain production of plutonium fuel if all plutonium materials had to be removed from each pipe and each glovebox at sixty day intervals.

Consequently, Sequoyah Fuels Corporation developed an insitu measurement program using NDA techniques to measure residual hold-up in pipes, tanks, gloveboxes, filters, etc., after flushing the pipes and sweeping-up the loose

contamination from gloveboxes. This inventory method reduced the scheduled down time for each Material Balance Area during each sixty (60) day inventory period to only two to four days per area.

This program began in 1974 and has been continuously refined as experience has been gained working with the NDA equipment.

In 1975 the plant was placed on stand-by status and all readily removable plutonium materials were shipped off-site. Each glovebox and piping system was acid washed or flushed and measured for plutonium hold-up in accordance with the procedures contained in this report and residual hold-up values were assigned to each Material Balance Area.

Kerr-McGee requested the N.R.C. to commission a team of NDA Specialists to independently measure the plutonium hold-up in the plant. This work was completed in early 1976 and is reported in a report prepared by E. L. Tape, et al, dated April 1976, entitled "Measurement of Plutonium Processing Equipment at Kerr-McGee Plutonium Fuels Fabrication Facility". The Tape report compares the independent report submitted to the N.R.C. with the (KM) Sequoyah Fuels report. This report summarizies methods and comparative data of the measurements obtained by the commission audit team and Sequoyah Fuels' measurements.

The results of the independent measurements supported the measurements taken by Sequoyah Fuels. Final verification will, however, result from the carefully documented measurements taken during dismantling and removal of the equipment from the Material Balance Areas. The ability to measure much smaller surface areas without the influence of background radiation in production areas enhances the quality and precision of the final measurement.

This final comparison will be the subject of Report No. 5 which will be provided upon final removal of all plutonium from the Facility.

III. PROCEDURES

A. KM-NP-15-48 - Plutonium Plant Inventory

This procedure describes the techniques and methodology used to measure plutonium in-place for inventory purposes during the initial stand-by inventory as well as the techniques presently being used to measure the plutonium removed from the MBAs during decontamination activities. The procedure identifies the methods used to measure gloveboxes, tanks, pipes, filters, etc., as well as NDA equipment calibration procedures, summing and bias corrections, calculations for determining random and systematic error, and the forms and records used. A glossary of terms used in the procedure is also provided.

B. KM-NC-15-56 - Limit of Error

This procedure contains two sections. The first section describes the methods used to calculate the limit of error associated with inventory differences and waste shipments. The second section describes the methods used to reduce the raw data to inventory records and to reconcile the entries.

C. KM-NC-10-83 - Plutonium Plant LSA Waste Drum Counter

During decontamination and decommissioning activities a whole drum counter was constructed to measure 55 gallon drums of low-level plutonium contaminated wastes in order to segregate the less than 100 nanocurie per gram (nCi/gram) wastes from the greater than 100 nCi/gram wastes. This system evolved from a Nuclear Regulatory Commission decision to classify <100 nCi/gm wastes as Low Specific Activity (LSA) wastes as opposed to Transuranic (TRU) wastes. The use of this counter has resulted in a significant decrease in disposal costs throughout the project. A description of the equipment, calibration methods, and documentation is provided.

1.0 INTRODUCTION

This procedure describes the methods to be used for a physical inventory of Special Nuclear Materials. A physical inventory will be taken every other month (every 60 days). A physical inventory is the witnessing, measuring and listing of all materials on hand at some given time or duration. The data from this static inventory are compared to the sum total of the balance; i.e., material transfers since the last physical inventory. A record of material transfers are made on forms that are called "Waste Tickets" and "Internal Transfer/Drum Load Records". These forms must accompany a transfer of SNM between Material Balance Areas (MBA). Instructions for the completion of the forms can be found in Procedure KM-NP-15-17. A glossary of terms used is attached to this procedure.

For the Standby Operations, the Plutonium Plant is divided into three Material Balance Areas:

MBA-12	Vault - Waste Packaging and Storage
MBA-50	Glovebox Holdup Plutonium
MBA-121	Waste Shipment Storage (Rooms 121 & 123)

Section 2.0 of this procedure describes the inventory of the storage areas and Section 3.0 describes the NDA inventory procedure. All of the glovebox systems in the process areas have been blanked off and tamper safed. Since there is no "Material in Process" except for glovebox holdup, the inventory in the process areas consist of inspection of the tamper safing. Remeasurement for verification of the glovebox holdup is conducted only when tamper-safing does not pass inspection.

Inventory of a glovebox being decommissioned will consist of subtraction of the quantity of Pu in individual packages removed for burial from the quantity assigned by NDA to the glovebox prior to the decommissioning activity. The ID will be the difference between the sum of the individual packages and the original quantity assigned to the glovebox. NDA of the whole glovebox will be required only if the tamper safing specified for the decommissioning activity is compromised (see Tamper Safing Procedure KM-NP-15-61).

2.0 INVENTORY OF STORAGE AREAS

A. Vault Storage and Packaging

Since this area is for packaging and storage, the physical inventory should be accurate and require little time to perform, as all items are listed package by package as an inventory item. All material within the vault shall have undergone NDA prior to transfer to this area or exist in a form for NDA counting and properly labeled.

The following actions are to be completed in preparation for the vault inventory:

1. All items stored on transfer carts waiting for a NDA count must be counted, labeled properly and stored before starting inventory.
2. All line generated items of material shall have waste tickets attached with all required data entered.
3. All empty material containers stored in the vault shall have empty labels attached.
4. Bring vault log books up-to-date.
5. All partially full waste shipment drums must have an "Internal Transfer/Drum Load Record" sheet attached with all required data entered.

After preparations are completed, the actual inventory consists of obtaining a complete listing of all material stored in the vault item by item, material description, storage location, Pu content, etc.

The Safeguards Representative (Health & Safety Supervisor) will compare the inventory values with previous inventory listing and subsequent transfer records.

B. Waste Shipment Storage (Rooms 121 & 123)

Since this area is for storage of items packaged for shipment to burial, no preparation for inventory will be required. All items will already be tamper safed and will be tagged with an Internal Transfer/Drum Load Record sheet.

The actual inventory will consist of:

1. Checking the tamper safe seals and making a listing of each item. The listing shall show tamper seal number, Internal Transfer/Drum Load Record number, material descrption, plutonium content, weight, etc.

2. Check the listing against the storage record log to assure that there is no discrepancy.

The Safeguards Representative (Health & Safety Supervisor) will compare the inventory values with previous history inventory listings and subsequent transfer records.

3.0 NDA INVENTORY PROCEDURE

I. Calibration; Data Collection

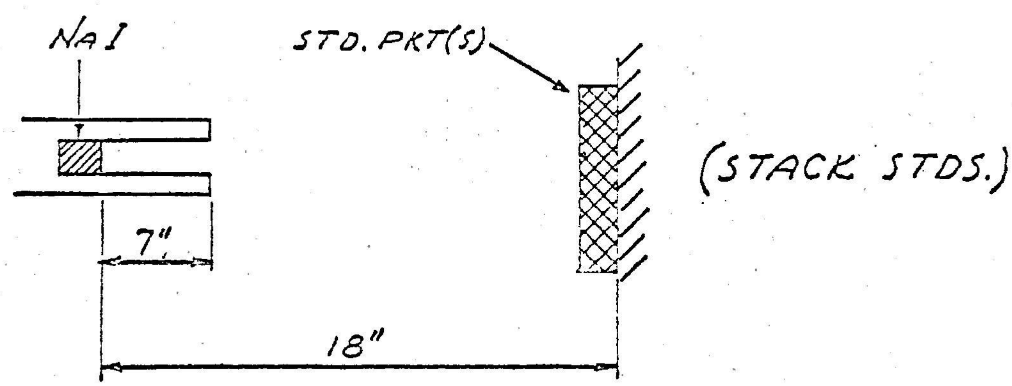
All calibrations are made using the flat sheet Pu, U oxide standards. There are a total of 13 with an average value of 1.936 g Pu. Basic calibration methods for assay of holdup follow:

A. Glovebox Sampling (S-7)

1. Equipment

a) Pu Standard Packets
b) Ludlum 2500
c) 2 x 2 NaI; 7" Recess; 1/2" Lead Plug

2. Setup



3. Operation

a) Complete Series of Measurements

(i) Gross count 1/2 min. twice each loading
(ii) Bkg. count 1/2 min. twice each loading.
(iii) Load Pu Standard Packets at increments of approximately 0, 2, 4, 6 and 8 grams, by using appropriate packets.

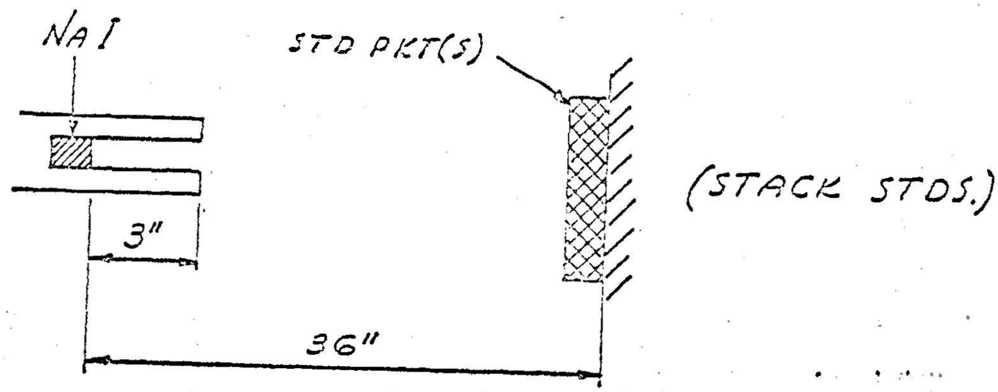
b) Make four complete sets

B. Glovebox Summing (S-3-36)

1. Equipment

a) Pu Standard Packets
b) Ludlum 2500
c) 2 x 2 NaI; 3" Recess; 1/2" Lead Plug

2. Setup



3. Operation

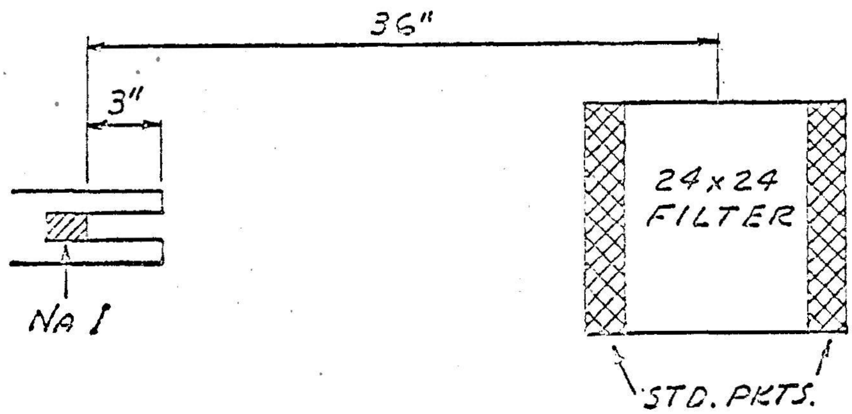
a) See IA3a
b) Make two complete sets

C. Intermediate Filter (S-3-36 Filt)

1. Equipment

   a) Eight Pu Standard Packets
   b) Ludlum 2500
   c) 2 x 2 NaI; 3" Recess; 1/2" Lead Plug
   d) Intermediate Filter

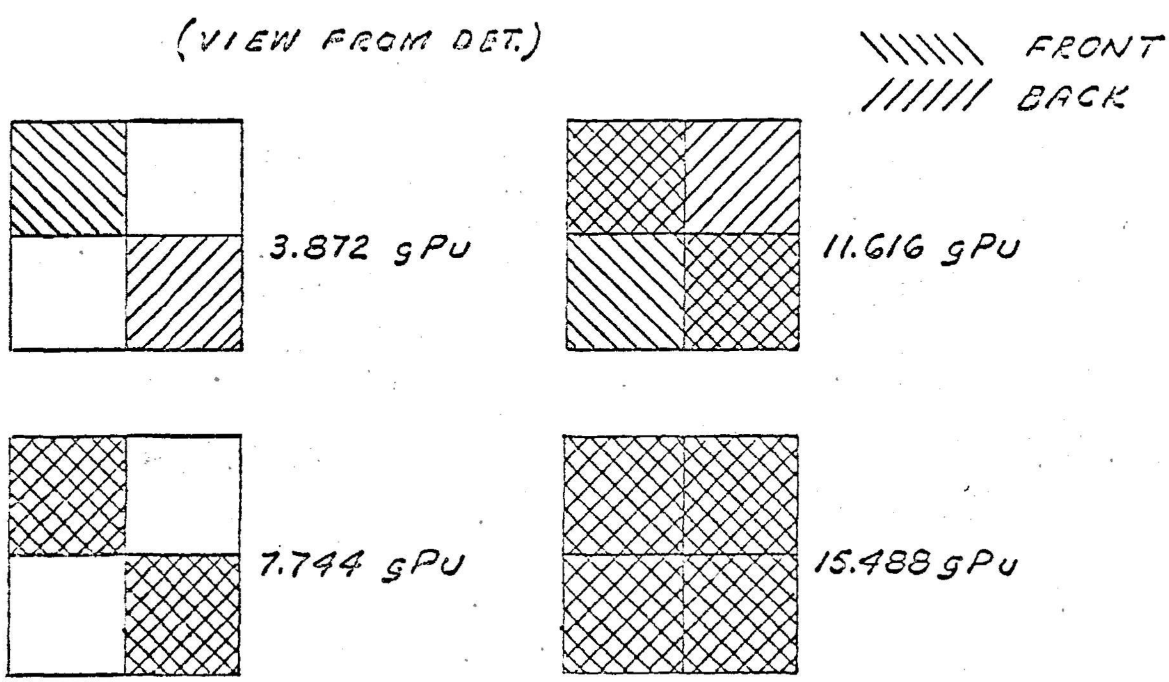
2. Setup



3. Operation

   a) Complete Series of Measurements

      (i) Gross count 1/2 min. twice each loading.
      (ii) Bkg. count 1/2 min. twice each loading.
      (iii) Load 0, ≈4, ≈8, ≈12 and ≈15 g Pu as shown below:



b) Make Final Series

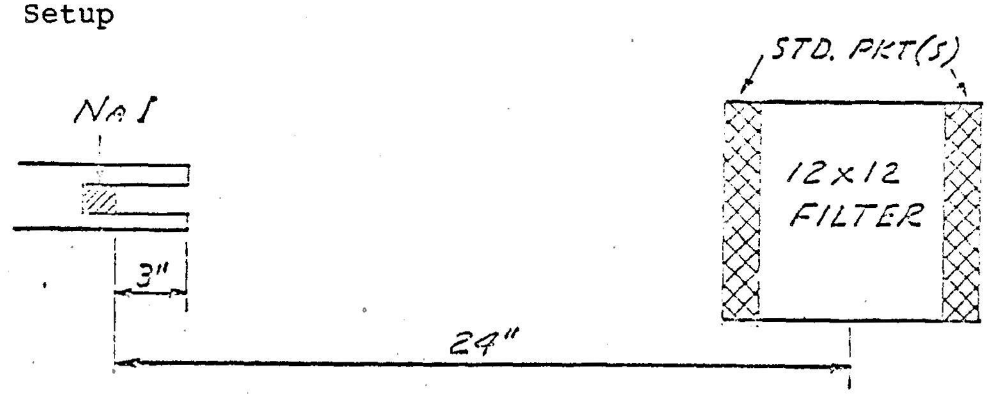
(i) Rotate Filter with Packets 180°.
(ii) See IC3aI and ii.
(iii) Remove packets in reverse order applied to load ≈15, ≈12, ≈ 8, ≈ 4 and 0 g Pu.

D. Primary Filter (S-3-24 Filt)

1. Equipment

a) Four Pu Standard Packets
b) Ludlum 2500
c) 2 x 2 NaI; 3" Recess; 1/2" Lead Plug
d) Primary Filter (New)

2. Setup



3. Operation

a) Complete Series of Measurements

(i) Gross count 1/2 min. twice each loading.
(ii) Bkg. count 1/2 min. twice each loading.
(iii) Load 0, ≈2, ≈4, ≈6, ≈8, rotate filter 180°, ≈ 8, ≈ 6, ≈4, ≈2 and 0 g Pu (add packets to alternate sides of filter beginning with front, remove in reverse order applied).

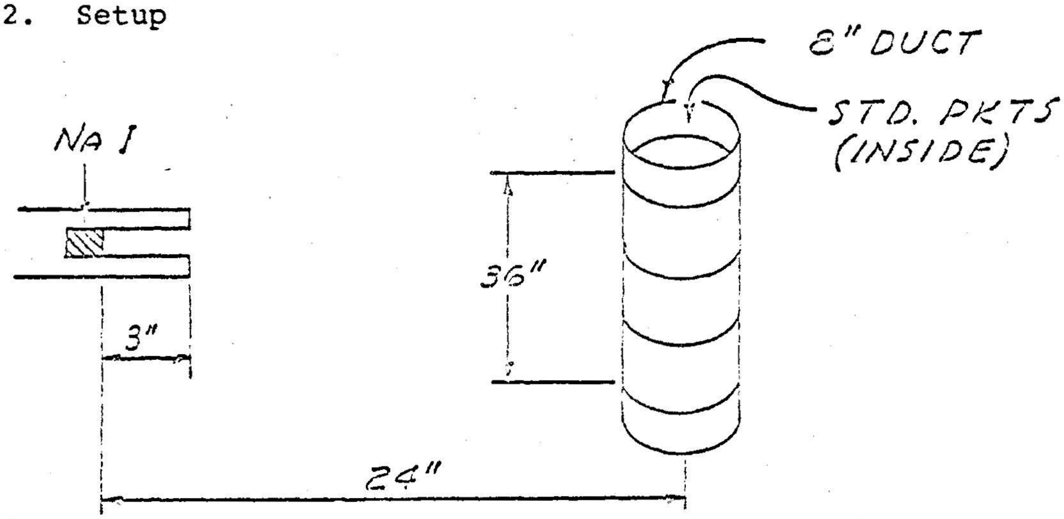
b) Repeat Complete Series above

E. Ducts (S-3-24 Duct)

1. Equipment

a) Twelve Pu Standard Packets
b) Ludlum 2500
c) 2 x 2 NaI; 3" Recess; 1/2" Lead Plug
d) 8" Duct ~ 4' length

2. Setup



3. Operation

a) Complete Series of Measurements

(i) Gross count 1/2 min. twice.
(ii) Bkg. Count 1/2 min. twice.
(iii) Rotate Duct 180°.
(iv) Repeat (i) and (ii) above.

b) Load 0, ≈ 2, ≈ 4, ≈ 6 and ≈ 8 g Pu/ft

(i) Each load (except 0) comprised of three packets taped end to end; total length 3' of Pu bearing surface.
(ii) Tape each load to inside of duct (alternate sides with each loading).

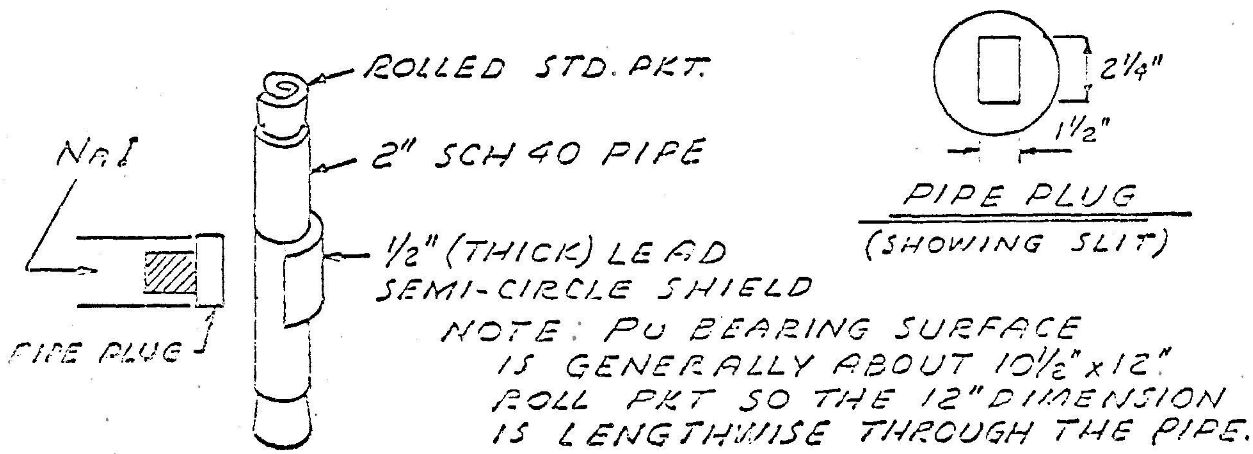
c) Complete 3a above with each loading 3b above

F. Pipe

1. Equipment

a) Two Pu Standard Packets
b) Ludlum 2500
c) 2 x 2 NaI; "Pipe Plug"; Tape Plug to collimator face and position NaI against "Pipe Plug"; 1/2" Lead Plug; 1/2" Lead semi-circle shield
d) 2" Schedule 40 pipe; at least 10' length

2. Setup



3. Operation

a) With tape measure and marking pen, divide the pipe into 4, 2" sections leaving at least 1" margin from either end of the pipe.
b) Load at 0 and ≈ 2 g Pu (carefully insert the rolled standard packet).
c) Complete series of measurements

(i) Gross count 1/2 min. twice @ each 2" section.
(ii) Bkg. Count 1/2 min. twice @ each 2" section.

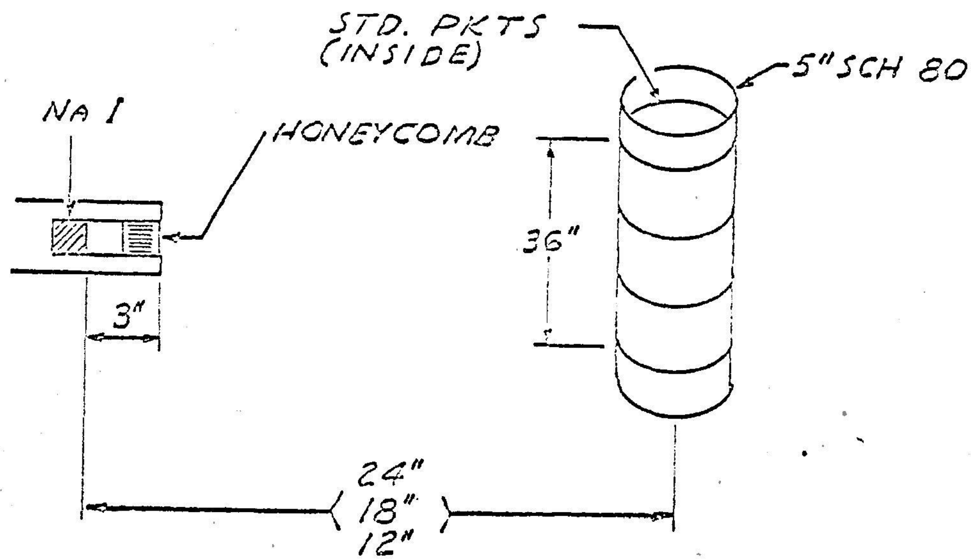
d) Make one complete series (3c above) at each loading for each of the two standard packets (16 total sets of gross and bkg. counts).

G. Tank, "Honeycomb" (S-3-HC-12, 18, 24)

1. Equipment

a) Nine Pu Standard Packets
b) Ludlum 2500
c) 2 x 2 NaI; 3" Recess; "Honeycomb"; 1/2" Lead Plug
d) 5" Schedule 80 pipe; 4' length

2. Setup



3. Operation

a) Complete Series of Measurements (See IE3a)
b) Load 0, ≈ 2, ≈ 4 and ≈ 6 g Pu/ft

(i) Each load (except 0 comprised of three packets taped end to end; total length 3' of Pu bearing surface.
(ii) Tape each load to inside of pipe.

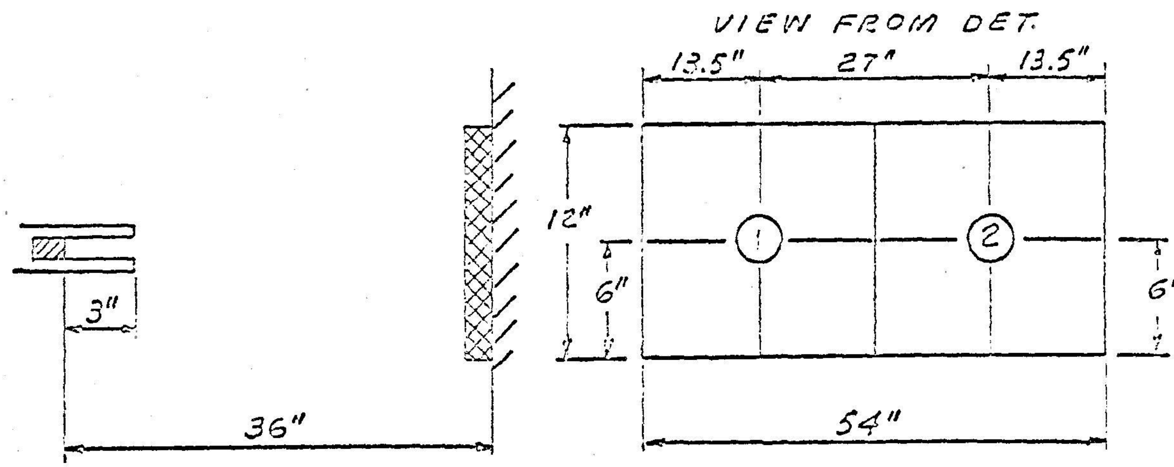
c) Complete 3a above with each loading 3b above at 12", 18" and 24" (detector to center of pipe distance).

H. Glovebox Summing Bias Correction

1. Equipment

a) Five Pu Standard Packets
b) Ludlum 2500
c) 2 x 2 NaI; 3" Recess; 1/2 Lead Plug

2. Setup



(Detector should be mounted on cart to allow easy movement).

3. Operation

a) Arrange five packets as shown to obtain 12" x 54" array of Pu bearing surface.
b) Complete Series of Measurements

(i) Aim detector at spot ① 6" from bottom and 13.5" from end of array.
(ii) Gross Count 1/2 min. twice.
(iii) Bkg. count 1/2 min. twice.
(iv) Aim detector at spot ② 6" from bottom and 13.5" from opposite end of array.
(v) Repeat steps (ii) and (iii) above.

c) Make four complete series of measurements.

I. Solid Waste Packages

1. Equipment

   a) Five Pu Standard Packets of ≈2 g Pu each
   b) Ludlum 2500
   c) 2 x 2 NaI detector and shield
   d) Cs^{137} sealed source (100 μci)
   e) Laboratory jackstands, fiber pak drum (14" dia. x 13 3/4" high)

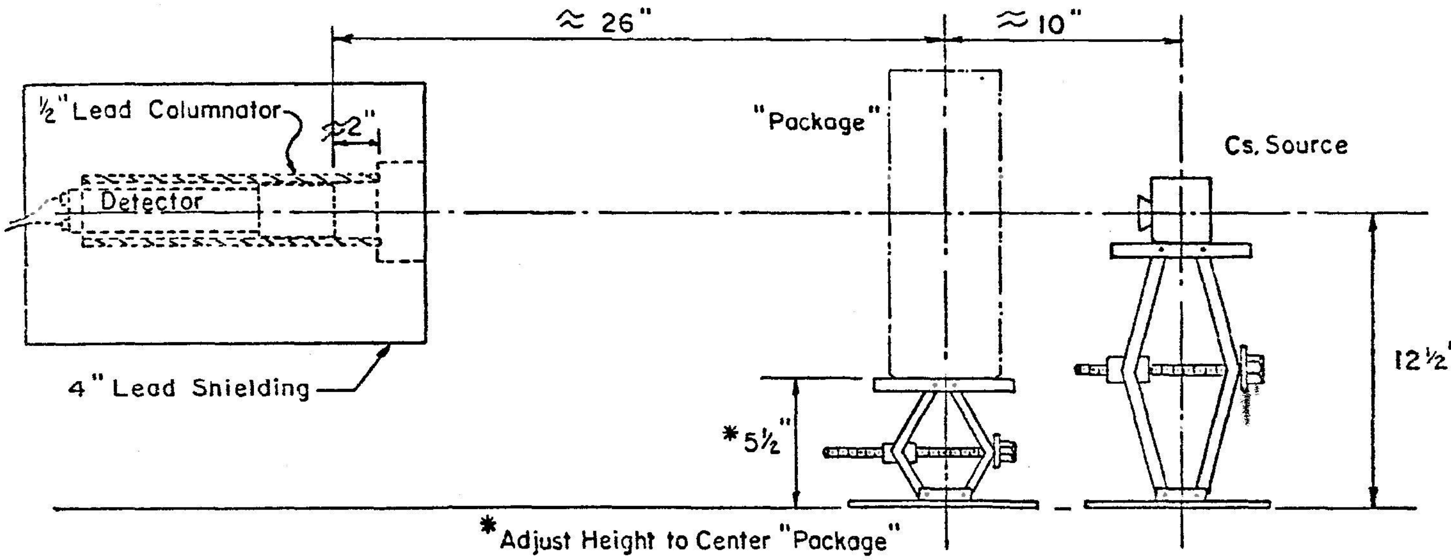
2. Set up as illustrated in Figure 1, Page 12.

3. Adjust the H.V. energy threshold and window width to count:

   a) The photon energy range from 320 Kev to 450 Kev.
   b) Find the threshold setting to count the Cs^{137} (662) Kev energy photon with the same window width.
   c) Record data obtained in steps d thru f on Pu Scrap Counter Form - Daily Check Sheet. See Figure 2, Page 13.
   d) With the threshold setting for Pu (320-450 Kev) make a series of ten 0.5 min. background counts and record in "Background Pu channel" column. Average the ten counts.
   e) With the threshold setting for the Cs^{137} (662 Kev), make a series of ten 0.5 min. background counts and record in "Background Cs^{137} channel" column. Average the ten counts.
   f) With the threshold setting as in (e) and the Cs^{137} source in place (the spot should be marked so it can be duplicated in other counts), make a series of ten, 0.5 min. counts and record "100 μCi Cs^{137} source channel" column. Average the counts.
   g) Record data obtained in steps h thru k on Pu Scrap Counting Worksheets. Use a seperate sheet for each loading. See Figure 3, Page 14.
   h) Load Pu Standard Packets (≈2 g Pu each) in the fiber pak and make two 0.5 min. counts with the threshold setting for Pu (320-450 Kev.) and two 0.5 min. counts with the threshold setting for Cs^{137} (662 Kev), and two, 0.5 min. counts with the Cs^{137} source in place.
   Rotate the fiber pak 180° and repeat above.

FIGURE 1

N.D.A.-1
PACKAGE SET-UP



Cs. THRESHOLD ________ **Pu. THRESHOLD** ________
WINDOW ________ **WINDOW** ________

HIGH VOLTAGE ________

CALIBRATION FACTOR ________
MINIMUM DETECTABLE LEVEL ________

ASSIGN ______ TO ALL PACKAGES LESS THAN
OR EQUAL TO ______ G. Pu.

MAXIMUM VALUE THAT CAN BE COUNTED ________ G. Pu.

FIGURE 2

Pu SCRAP COUNTER FORM

DAILY CHECK SHEET

SERIES # 1-85 DATE: ____________

OPERATOR: ____________

H.V. 2.30 Pu T. 3.2 Cs^{137} T. 5.8 Window 1.3

Multiplier 100KEV Recess 1.75 Distance 26" Count Time 0.5 min.

	Background Pu Channel	Background Cs Channel	100 uCi Cs^{137} Cs Channel
1.			
2.			
3.			
4.			
5.			
6.			
7.			
8.			
9.			
10.			
SUM			
AVG			

Avg. 100 uCi Cs^{137} - Avg. Cs Channel Bkgd = Cs I_o

Cs I_o = ____________

Avg. Pu Channel Bkgd.= ____________

FIGURE 3

SCRAP COUNTING WORKSHEET KM-4949

DATE	PU PKGD/ 0.5 MIN.	SERIES NO.
OPERATOR	$I_0 C_s$ 137	ITEM NO.

MR/HR

Calibration Factor (GPu/ 0.5 Min. Ct.)

TYPE OF MATERIAL (PIPE, PLASTIC, FLANGE, ETC.) AND BOX REMOVED FROM

IF CYLINDER SHAPE, LENGTH ______ Ft. IF PLANE SHAPE, LENGTH ______ Inches x ______ Inches Width ÷ 144 = ______ Sq. Ft.

Cs^{137} 0.5 MIN. CTS.

0 DEGREES			180 DEGREES		
BACKGROUND	GROSS	NET	BACKGROUND	GROSS	NET

Average Net ______ Average Net ______

$\frac{\text{Average Net}}{I_0}$ = (T_1) ______ $\frac{\text{Average Net}}{I_0}$ = (T_1) ______

Correction Factor = ______ Correction Factor = ______

Pu 0.5 MIN. CTS.

0 DEGREES			180 DEGREES		
BACKGROUND	GROSS	NET	BACKGROUND	GROSS	NET

1 Average Net ______ # 2 Average Net ______

$\frac{\text{\# 1 Avg. Net x Calib. Factor}}{\text{Correction Factor}}$ = (#1 GPu) ______ $\frac{\text{\# 2 Avg. Net x Calib. Factor}}{\text{Correction Factor}}$ = (#2 GPu) ______

$\frac{\text{\#1 GPu + \#2 GPu}}{2}$ = Avg. GPu ______

______ Avg. GPu x ______ b = ______ GPu in Package

Package: b = 1
Cylinder: b = # of Ft.
Plane: b = # of Sq. Ft.
24 x 24 x 12 Filter: b = 1

i. Load a second Pu Standard Packet (≈4 g Pu total) and repeat (f).
j. Continue as in (h) and (i) loading with Pu Standard Packets up to ~8 g Pu total.
k. To calibrate for bags of waste or items that may have more than 7.5 g Pu proceed as in (h), (j) and (k) adding additional packets until all 13 packets are used.

4. Items of geometry other than fiber pak drum 14" x 13 3/4" high:

a) This method may be used for containers and items of different geometry and densities by varying one or more of the following and making the appropriate calibration.

(i) Detector to item distance
(ii) Detector recess distance
(iii) Simulating the geometry of the item to be assayed.

5. Data Preparation

a) Daily Check Sheet

(i) Subtract the average Cs^{137} background count (3, e) from the average Cs^{137} source count (3, f). This will be referred to as the CsI_o.

b) Pu Scrap Counting Worksheet

(i) Subtract the average Cs^{137} background count from the average Cs^{137} source count for each loading (3, h).
(ii) Divide the results of (5,b,i) by 5,a,i). The results are the Cs^{137} transmission factor for that loading.
(iii) Use the table attached (Figure 4, Page 18) and obtain the Pu correction factor for this loading.
(iiii) Subtract the average Pu background (3,e) from each Pu source count (3,h). This will give four Pu net counts for each loading.

(iiiii) Divide the net Pu counts (5,b,iiii) by the Pu correction factor. This will give four corrected Pu counts for each loading. (corrected for density, self absorption, and shielding).

(iiiiii) Treat the results of 5,b as in II B, page 19. The results will give the factors for grams of Pu per count for the type of calibration done.

6. Measurement of Solid Waste Packages

a) Complete the Pu Scrap Counter Form - Daily Check Sheet, as in I,3,c thru f and 5,a,i.
b) Position package as in Figure 1, Page 12, without the Cs source in place. With the threshold setting for Pu (320-450 Kev), make two 0.5 min. counts. Record in the Gross column of the 0 degrees, Pu 0.5 min. counts section of the Pu Scrap Counting Worksheet (Figure 3, Page 14). Subtract the Avg. Pu channel background obtained in Step 1 from each count. Record in the Net Count column. Average the two net counts to obtain #1 average net.
c) With the threshold setting for Cs^{137} (662 Kev.), make two 0.5 min. counts. Record in the background column of the 0 degrees, Cs^{137} 0.5 min. counts section.
d) Position the 100 μCi Cs^{137} source in place. Make two 0.5 min. counts. Record in the Gross column of the 0 degrees, Cs^{137} 0.5 min. counts section.
e) Subtract the backgrounds from the gross counts to obtain net counts. Average the two net counts and record. Divide this average net by the I_o obtained in Step 1. This is (T_1), or Cs^{137} fraction. Find this fraction on the Pu correction factor for self absorption and package density table, Figure 4, Page 17. Record the corresponding Pu correction factor.
f) Turn the package 180°. Make two 0.5 min. counts. Record in the Gross column of the 180 degrees, Cs^{137} 0.5 min. counts section.

g) Remove the Cs source. Make two 0.5 min. counts and record in the background column of the 180 degrees Cs section.

h) Repeat Step (e).

i) With the threshold setting for Pu (320-450 Kev.), repeat Step (b) for the 180 degree, Pu 0.5 min. counts section.

j) Multiply the #1 average net found in Step (b) by the calibration factor determined in E,2,f, and divide this product by the correction factor determined in Step (e). This is the #1 G Pu.

k) Repeat Step (j) for the #1 Average Net found in Step (i), to obtain #1 G Pu.

l) Average #1 g Pu and #2 g Pu. This is the grams Pu value to be assigned to the package. (NOTE: Packages that do not exhibit sufficient counts above background will be assigned a minimum value. See Page 21,D,1,d).

FIGURE 4

Pu WASTE COUNTING

Pu Correction Factor for Self Absorption and Package Density

$$\text{Pu(Corrected counts)} = \frac{\text{Pu Counts}}{\text{Correction Factor}}$$

Cs^{137} Fraction	Pu Correction Factor	Cs^{137} Fraction	Pu Correction Factor
.05	.21	.53	.72
.06	.23	.54	.73
.07	.26	.55	.73
.08	.27	.56	.74
.09	.29	.57	.75
.10	.30	.58	.75
.11	.31	.59	.76
.12	.33	.60	.77
.13	.35	.61	.77
.14	.36	.62	.78
.15	.37	.63	.79
.16	.39	.64	.79
.17	.40	.65	.80
.18	.41	.66	.81
.19	.42	.67	.81
.20	.43	.68	.82
.21	.44	.69	.82
.22	.45	.70	.83
.23	.47	.71	.84
.24	.48	.72	.84
.25	.49	.73	.85
.26	.49	.74	.85
.27	.51	.75	.86
.28	.52	.76	.87
.29	.52	.77	.87
.30	.53	.78	.88
.31	.54	.79	.88
.32	.55	.80	.89
.33	.56	.81	.90
.34	.57	.82	.90
.35	.58	.83	.91
.36	.59	.84	.91
.37	.59	.85	.92
.38	.60	.86	.92
.39	.61	.87	.93
.40	.62	.88	.93
.41	.63	.89	.94
.42	.64	.90	.95
.43	.64	.91	.95
.44	.65	.92	.96
.45	.66	.93	.96
.46	.67	.94	.97
.47	.67	.95	.97
.48	.68	.96	.98
.49	.69	.97	.98
.50	.70	.98	.99
.51	.70	.99	.99
.52	.71	1.00	1.00

NOTE: For all Cs^{137} fractions less than .05, use .21 as the Pu Corr. Factor.

II. Calibration; Data Reduction

A. Initial calculation involves finding net counts, which is simply gross-background. Also one must determine the units that net counts are to be correlated against. Individual methods follow:

1. Glovebox Sampling (S-7)

a) Units; g Pu/ft^2
b) Computation

Packet size is 10.5" x 12" Pu bearing surface or 0.88 ft^2. This is equal to 2.213 g Pu/ft^2 per packet. Net counts will be correlated with number of stacked packets times 2.213 g Pu/ft^2.

2. Glovebox Summing (S-3-36)

a) Units; g Pu
b) Computation

Net counts will be correlated with number of stacked packets times 1.936 g Pu.

3. Intermediate Filter (S-3-36 Filt)

a) Units; g Pu
b) Computation

Net counts will be correlated with number of packets times 1.936 g Pu.

4. Primary Filter (S-3-24 Filt)

a) Units; g Pu
b) Computation

Net counts will be correlated with number of packets times 1.936 g Pu.

5. Ducts (S-3-24 Duct)

a) Units; g Pu/ft
b) Computation

Although three packets are included in each loading, (except 0), the distribution within the duct corresponds to 1.936 g Pu/ft (ft of duct) therefore correlate net counts with number of packets divided by three times 1.936 g Pu/ft.

6. Pipe

a) Units; g Pu/ft
b) Computation

Net counts will be correlated with number of packets times 1.936 g Pu/ft (12" dimension lengthwise in pipe).

7. Tank, "Honeycomb" (S-3-HC-12, 18, 24)

a) Units; g Pu/ft
b) S-3-HC-12, S-3-HC-18 and S-3-HC-24 are three separate calibrations
c) For each calibration, net counts will be correlated with number of packets divided by three times 1.936 g Pu/ft.

B. Calibration Equation

All calibration data is correlated by linear regression to the form $y = a + bx$ where

y = estimated g Pu (or g Pu/unit)
a = constant (intercept)
b = constant (slope)
x = net counts

(NOTE: The calibration for (S-7-45°) is calculated from the (s-7), (T-7). Multiply slope and intercept by 0.75. Calibration error is same as (S-7, T-7).

The constants a and b are calculated by the following method:

If x and y satisfy the relation $y = bx$; i.e., they lie on a straight line that is known to pass through the origin and you have n measurements with uncertainties in x negligible and those in y all equal, then

$$b = \Sigma x_i y_i / \Sigma x_i^2$$

This will usually be the case for solid waste packages.

Otherwise:

$$b = \frac{n\Sigma x_i y_i - \Sigma x_i \Sigma y_i}{n\Sigma x_i^2 \quad (\Sigma x_i)^2}$$

$$a = \frac{\Sigma y_i}{n} - \frac{b\Sigma x_i}{n}$$

where n = number of data pairs
y_i = g Pu or g Pu/unit of the i^{th} data pair
x_i = net counts of the i^{th} data pair

Calculate a and b for each calibration.

C. Error calculation; systematic calibration error. The object of this exercise is to determine the contribution of calibration uncertainties to total measurement error.

$$S_c = \left[\left(\frac{\Sigma y_i^2 - a\Sigma y_i - b\Sigma x_i y_i}{(n-2) \quad (\bar{y})^2} \right) \left(\frac{1}{n} + \frac{\bar{x}^2}{\Sigma x_i^2 - \frac{(\Sigma x_i)^2}{n}}\right) + (0.00577)^2 \right]^{1/2}$$

where S_c = Systematic Calibration Error
calculate S_c for each calibration.

$$\bar{y} = \frac{\Sigma y_i}{n}$$

$$\bar{x} = \frac{\Sigma x_i}{n}$$

D. Quality Control

1. After calibration factors have been determined by utilizing methods prescribed in this procedure, reliability and stability of the system will be audited as follows:

a) Two control charts will be constructed at the first of each month. One chart will be for a plutonium standard at the lower end of the calibration range ($\sim$1.9 grams), and the other for a plutonium standard at the upper end ($\sim$9.7 grams). These charts will reflect a 95% confidence level by showing an average count rate ($\bar{x}$) for the standard and an upper and lower limit derived by extracting the square root of the average count rate and multiplying it by 1.96. This yields a $\pm$ value for the average ($\bar{x}$).

b) Each day that the count system is used, five counts of each standard will be taken. The counts will be plotted on their respective control chart. No more than one of each five counts should vary from the $\bar{x} \pm 1.96\ \bar{x}$ range. Should more than one count vary from this limit, a second set of counts will be taken to verify the deviation. If the deviation is verified, the system must be investigated for proper calibration.

c) No value greater than the upper end standard will be assigned to any item. Calibration must be extended to include the higher value, or the item must be split into two or more packages.

d) Minimum value assigned will be determined by the following calculation:

$$\frac{1.96 \dfrac{\text{Background}}{\text{Time of Background Count}} \text{ X } b + a}{2} \text{ grams Pu}$$

(See page 23 for determination of a and b)

This is a 95% confidence level of background. Plus "zero" divided by two which yields a gram value of one-half of the minimum detectable activity.

This value will be assigned to items that do not produce a count above the 95% confidence level of background.

EXAMPLE I

The following data was obtained from a glovebox sampling calibration:

	0	2.213	4.425	6.638	8.85 (g Pu Loading)
Net Count min.	<15>	317	679	1017	1360
	36	338	686	944	1450
	<23>	451	752	1171	1516
	98	368	800	1202	1532
	<44>	286	751	1133	1480
	5	357	814	1117	1379
	1	306	710	1068	1480
	<11>	362	794	1054	1376

Compute the following sums:

$\Sigma x_i = 29097$

$\Sigma y_i = 177.008$

$\Sigma x_i y_i = 192862.733$

$\Sigma x_i^2 = 31797079$

$\Sigma y_i^2 = 1174.9083$

and calculate

$\bar{x} = 727.425$

$\bar{y} = 4.4252$

Then find

$$b = \frac{(40)\,(192862.733) - (27097)\,(177.008)}{(40)\,(31797079) - (29097)^2} = 0.00603$$

$$a = \frac{177.008}{40} - \frac{(0.00603)\,(29097)}{40} = 0.03883$$

The derived equation for glovebox sampling is:

$g\ Pu/ft^2 = 0.03883\ g\ Pu/ft^2 + (X\ cp\ {}^{1}\!/_{2}m)(0.00603\ g\ Pu/ft^2/cp\ {}^{1}\!/_{2}m)$

Now collect the data necessary to calculate systematic error.

$$\delta^2_{y.x} = \frac{\Sigma y_i^2 - a\Sigma y_i - b\Sigma x_i y_i}{(n-2)\ \bar{y}^2}$$

$$\delta^2_{y.x} = \frac{(1174.9083) - (0.03883)\ (177.008) - (0.00603)\ (192862.733)}{(40-2)\ (4.4252)^2}$$

$$\delta^2_{y.x} = 0.006817$$

$$S(x^2) = \Sigma(x_i - \bar{x})^2 = \Sigma x_i^2 - \frac{(\Sigma x_i)^2}{n}$$

$$S(x^2) = (3179709) - \frac{(29097)^2}{40}$$

$$S(x^2) = 10631193.77$$

S_c may be written:

$$S_c = \left[\delta^2_{y.x}\ \left(\frac{1}{n} + \frac{\bar{x}^2}{S(x^2)}\right) + (0.00577)^2\right]^{\frac{1}{2}}$$

$$S_c = \left[(0.006817)\ \left(\frac{1}{40} + \frac{(727.425)^2}{10631193.77}\right) + (0.00577)^2\right]^{\frac{1}{2}}$$

$$S_c = 0.023303$$

NOTE: that rounding error may be significant. Therefore, it is best to avoid all rounding if possible. The exact result for S_C is $S_C = 0.023348$.

III. Measurements of Plant Holdup

A. Data Sheet Preparation

1. Obtain complete set of data sheets from previous inventory for the area to be measured.

2. With the exception of counting and g Pu data copy the information from the previous sheet on the new data sheet.

EXAMPLE II

Date ______________
Room No.______________
Instrument Ludlum 2500
Technician Initials__________

Calibration Constants

S-7 0.00603X + 0.03906

Item & Position		Trans-mission	Gross Count	Bkg. Count	Net Count	Corrected Count	g Pu	Yi
Box 2C S-7	1	A	675	701	<26>	<27>	<0.12>	<0.04>
			685	659	26	27	0.20	
Wall Area Box 2C = 84 ft^2	2	A	538	587	<49>	<51>	<0.27>	<0.05>
			567	547	20	21	0.16	
(84)(0.01) = 0.84	3	A	586	541	45	47	0.32	0.09
			519	549	<30>	<31>	<0.15>	
1 g Pu	4	A	558	557	1	1	0.05	<0.04>
			518	544	<26>	<27>	<0.12>	

$x = 0.01$

$\delta = 6.68$

EXAMPLE III

NEW DATA SHEET

Date ______________
Room No. ______________
Instrument Ludlum 2500
Technician Initials ________

Calibration Constants
____
S.7 0.00603X + 0.03906

Item & Position		Transmission	Gross Count	Bkg. Count	Net Count	Corrected Count	g Pu
Box 2C S07	1	A					
	2	A					
	3	A					
	4	A					

B. Measurement

1. Equipment

a) Ludlum 2500, 2 x 2 NaI Detector and 1/2" Lead Plug
b) Other equipment as required by measurements to be made (Consult Calibration, Section I, concerning additional equipment).

2. Data Collection

a) Proceed to measurement location.
b) Consult data sheet to determine type of measurement to be made, and set up equipment accordingly.
c) Measurement positions are labeled with "NDA Stickers" set up at position number indicated by Data Sheet.
d) Gross count, twice (time as indicated by calibration). Record under gross count column opposite position number on Data Sheet.
e) Bkg. count, twice (time as indicated by calibration). Record under Bkg. count column opposite position number on data sheet.
f) Move equipment to next measurement position and repeat d) and e) above until all positions have been counted.

IV. G Pu Determination

A. Obtain g Pu for each position measured.

1. Gross Count - Bkg. Count = Net Count
   Enter net counts under net count column opposite position on data sheet.

2. Net Counts - Transmission = Corrected Count
   Enter Corrected Counts under Corrected Count column opposite position on Data Sheet.

   A list of coded transmission values follows:

CODE	ITEM	TRANSMISSION		
A	Window	0.96	@45°	0.93
B	S.S. Glovebox	0.71	@45°	0.56
C	S.S. Glovebox + 1/8" PB	0.39	@45°	0.21
D	Window + PB Glass	0.57	@45°	0.41
E	Gloveport Cover	0.60		
F	Glove	0.97	@45°	0.94
E + F	Glove + Cover	0.58		
	IX Column, Loaded	0.67		
	Intermediate Filter Across 12" Dimension	0.77		
	Intermediate Filter Across 24" Dimension	0.59		
	Inlet Filter Across 12" Dimension	0.69		
	Calciner Tube	0.385		

NOTE: Record all values, even if they are negative.

3. Determine g Pu (or g Pu/unit)

$\hat{y} = a + bx$

where y = estimated g Pu (or g Pu/unit)
a = calibration constant
b = calibration constant (refer to Section II B)
x = corrected count

enter determination (y) on Data Sheet.

EXAMPLE IV

Gross Count = 414
Bkg. Count = 373

Measurement Method Glovebox Sampling

a = 0.039
b = 0.00603
Transmission A = 0.96
Net Count = Gross - Bkg.
Net = 414 - 373 = 41

$$\text{Corrected Count} = \frac{\text{NET}}{\text{Transmission}}$$

$$\text{Corrected} = \frac{41}{0.96} = 42.7$$

$$\hat{y} = a + b\,(\text{corrected count})$$

$$\hat{y} = 0.039 + 0.00603\,(42.7)$$

$$\hat{y} = 0.30 \text{ g Pu/ft}^2$$

B. Calculations

There are basically two types of measurements made, g Pu and g Pu/unit. When making these calculations, it is an advantage to also generate and record data that will later be used in the error calculation. I would suggest that the following tables be prepared prior to beginning calculation.

TABLE I

1	2	3	4	5	6	7	8	Note:
Item I.D.	n_i	Σ_i	$\frac{\Sigma_i^2 \delta_i^2}{2n}$	$(n_i-1)\delta_i^2$	n_j	E_j	E_j^2	Column 4 assumes two measurements per site which is normal.

One such table should be prepared for each measurement method (A measurement method corresponds to measurements based on a single calibration).

1. G Pu Calculation

a) If only one position (site) is measured, average the set of g Pu values.

(i) Record g Pu on Data Sheet.
(ii) Enter 1 under column #6, Table I, along with Item I.D. in column #1.
(iii) Record g Pu in column #7, Table I, and (g Pu)^2 in column #8.

b) Multiple positions for (S-3-24 Filt.) and (S-3-36 Filt.)

(i) Average each set (one set per site) of g Pu values and record on Data Sheet.
(ii) Find the mean and standard deviation.

$$\text{Mean} = \bar{y} = \Sigma \frac{y_i}{n}$$

$$\text{Standard Deviation} = S = \left(\frac{n\Sigma y_i^2 - (\Sigma y_i)^2}{n(n-1)}\right)^{\frac{1}{2}}$$

(iii) Calculate Relative Standard Deviation

$$\text{Relative Standard Deviation} = \delta = \frac{S}{\bar{y}}$$

(iv) Enter Item I.D. column #1 and y g Pu, column #3 on Data Sheet.
(v) Enter number of sites column #2.
(vi) Calculate

$$\frac{E_i^2 \delta_i^2}{2n_i} = \frac{\bar{y}^2 \delta^2}{2n_i}$$

Enter column #4

(vii) Calulate

$$(n_i-1)\delta_i^2$$

Enter column #5

c) Multiple positions using (S-3-36) glovebox summing

(i) Average each set of g Pu values and record on Data Sheet.
(ii) Find mean ($\bar{y}$) and relative standard deviation (δ).
(iii) Find sum of the sets of average g Pu values. Record on Data Sheet and in column #3, Table I.
(iv) Record also in Table I the Item I.D. in column #1 and the number of sites in column #2.
(v) Calculate

$$\frac{E_i^2 \delta_i^2}{2n_i}$$

Enter column #4

(vi) Calculate

$$(n_i-1)\delta_i^2$$

Enter column #5

2. G Pu/Unit Calculation

a) One position measured

(i) Average set of g Pu/unit values
(ii) Multiply g Pu/unit times units

(EXAMPLE: (3.02 g Pu/ft)(6 ft) = 18.12 g Pu)

Record this value on Data Sheet and column #7.

(iii) Also record in Table I Item I.D. in column #1, 1 in column #6 and $(g\ Pu)^2$ in column #8 (g Pu is the result of (ii) above)

b) Multiple positions measured

(i) Average each set of g Pu/unit values
(ii) Find mean, $\bar{y}$, and relative standard deviation, δ, of the average values.
(iii) Multiply $\bar{y}$ g Pu/unit times units. This result is g Pu for the item. Enter result on Data Sheet and Table I, column #3.
(iv) Also record in Table I, Item I.D. in column #1 and number of sites in column #2.
(v) Calculate

$$\frac{E_i^2 \delta_i^2}{2n_i}$$

Enter column #4.

(vi) Calculate

$$(n_i - 1)\delta_i^2$$

Enter column #5.

V. Random Error

A. Data Collection

Random errors are calculated and accumulated by groups corresponding to the measurement techniques used. All data necessary for these calculations is listed in the tables prepared to the Form Table I.

Note that the following instructions should be applied for each measurement method individually. The tables prepared in Section IV shall be called "Table I" for simplicity of reference.

1. Compute the sum of columns #2 through #8 in "Table I".

2. Calculate an additional value K, where K is the number of multiple measurement items.

3. The random error for each method has two components, a multiple measurement component and a single measurement component (column numbers refer to "Table I").

   a) Multiple measurement variance, S_m^2

   $$S_m^2 = \Sigma \frac{E_i^2 \;\; {}_i^2}{2n_i} \qquad \text{(Sum of column \#4)}$$

   b) Single measurement variance,

   $$S_s^2 = \tfrac{1}{2} S_p^2 \Sigma E_j^2$$

   where

   $$S_p^2 = \frac{(n_i - 1) \;\; {}_i^2}{(n_j) - k} = \frac{\text{(Sum of column \#5)}}{\text{(Sum of column \#2)} - K}$$

   $$\Sigma E_j^2 = \text{(Sum of column \#8)}$$

   c) Write the random variance term,

   $$S_r^2 = S_m^2 + S_s^2 = \Sigma \frac{E_i^2 \;\; {}_i^2}{2n_i} + \tfrac{1}{2} S_p \Sigma E_j^2$$

4. Remember that a random variance is calculated for each measurement technique.

EXAMPLE IV

Consider the following set of data. Columns 6, 7, and 8 have been listed separately. The sums are $\Sigma n_j = 9$, $\Sigma E_j = 39$ and $\Sigma E_j^2 = 219$.

I.D.	n_i	E_i	$\frac{E_i^2 \delta_i^2}{2n_i}$	$(n_i-1)\delta_i^2$
45	3	6	1	0.2312
48	3	4	0	0.0288
49	3	1	0	0.4608
51	2	0	0	.0
52	3	8	6	1.0368
53	2	8	4	0.2401
55	2	7	0	0.0169
56	2	7	12	0.9409
109	2	10	2	0.0961
112	2	6	3	0.3364
113	4	7	1	0.4107
121	2	11	50	1.6384
157	2	3	3	1.2321
156	3	2	1	2.1218
158	2	4	5	1.3225
159	2	1	0	0.1764
39-14-40 DRAIN	3	4	1	0.4050
116	2	4	2	0.5476
	44	93	91	11.2425

K = 18

Use this data to calculate the random variance.

$$S_r^2 = S_m^2 + S_s^2$$

$$S_m^2 = \frac{\Sigma E_i^2 \delta_i^2}{{}^2 n_i} = 91$$

$$S_p^2 = \frac{\Sigma (n_i - 1) \delta_i^2}{(\Sigma n_i) - K} = \frac{11.2425}{(44) - 18} = 0.4324$$

$$S_s^2 = 1/2 S_p \Sigma E_j^2 = (1/2)\ (0.4324)\ (219)$$

$$S_s^2 = 47$$

$$S_r^2 = 91 + 47 = 138$$

The results of the random variance calculations should be recorded in a table for reference in error propagation. I might add that there is often some value in further breaking down of the data by room and MBA as well as by measurement method. However, $S_p 2$ should be based on the results of an entire method.

VI. Systematic Error

Systematic errors apply to all members of a measurement group. It is therefore necessary to determine the error contribution for each measurement method. Also keep in mind that in order to calculate LEID, the measurement errors must be related by the ID Equation.

I.D. = Beginning Inventory + Receipts - Shipments - Ending Inventory

A. Construct Table II in the following manner:

TABLE II

	1 Category	2 S_g	3 S_c	4 ΣE This Inv.	5 ΣE Last Inv.	6 ΣE Inv. Prior to last inv.
1	G.B. Samp.					
2	G.B. Sum.					
3	Filters					
4	Tank					
5	Pipe					
6	Duct					

	7 SP (5-4)	8 BP (6-4)	9 SP $\sigma^2\beta$ $(3x7)^2$	10 BP $\sigma^2\beta$ $(3x8)^2$	11 SP σ_Θ^2 $(2x7)^2$	12 BP σ_Θ^2 $(2x8)^2$
1						
2						
3						
4						
5						
6						

1. Column #1, list measurement categories.

2. Column #2, list geometry errors, this will be discussed in Section VII.

3. Column #3, list calibration errors determined by IIC (S_C).

4. Columns #4, #5 and #6 list g Pu measured (by method column #1) in the last three consecutive inventories.

   a) Column #4, g Pu this inventory
   b) Column #5, g Pu last inventory
   c) Column #6, g Pu inventory prior to last inventory

5. Column #7, column #5 - column #4.

6. Column #8, column #6 - column #4. (columns #7 and #8 are actually I.D. by measurement method, make sure the signs are correct).

7. Column #9 list single period (S.P.) calibration variances. This is calculated by multiplying column #3 times column #7 and squaring the result.

8. Column #10 list Bi-period (B.P.) calibration variances. This is calculated by multiplying column #3 times column #10 and squaring the result.

9. Columns #11 and #12 will be discussed in Section VII.

B. Systematic Error Applied to I.D.

1. The sum of column #9 is the systematic calibration variance for the single period I.D.

2. The sum of column #10 is the systematic calibration variance for the Bi-period I.D.

EXAMPLE 5

Consider a single category as an example.

For glovebox sampling, $S_C = 0.02335$

Using this method 3625 g Pu were measured in March 1976, 5495 g Pu in January 1976, and 10,232 g Pu in November, 1975 (These are three consecutive inventories).

Enter glovebox sampling column #1.

Enter 0.02335 column #3.

Enter 3625 column #4.

Enter 5495 column #5.

Enter 10,232 column #5.

5495 - 3625 = 1870, enter column #7.

10,232 - 3625 - 6607, enter column #8.

$[(1870)(0.02335)]^2 = 1907$, enter column #9.

$[(6607)(0.02335)]^2 = 23800$, enter column #10.

	1 Category	2 S_g	3 S_c	4 ΣE Mar. '76	5 ΣE Jan. '76	6 ΣE Nov. '75
1	G. B. Samp.		0.02335	3625	5495	10232
2						
3						
4						
5						
6						

	7 SP (5-4)	8 BP (6-4)	9 SP $\sigma^2\beta$	10 BP $\sigma^2\beta$	11 SP $\sigma^2\theta$	12 BP $\sigma^2\theta$
1	1870	6607	1907	23800		
2						
3						
4						
5						
6						

VII. Bias Correction

A. Calculation

1. See data obtained by 3.0, I.H.

2. Find the average number of net counts for positions 1 and 2 for each series of measurement.

3. Calculate g Pu for each of the above determined averages (use the (S-3-36) glovebox summing calibration).

4. Sum g Pu at positions 1 and 2 for each series.

5. Determine the mean, $\bar{y}$, and relative standard deviation, δ for the sums obtained in 4) above.

6. Calculate $S_g 2$

$$S_g 2 = \frac{\delta 2}{n} + (0.00577)^2$$

where n - number of series

7. Enter S_g in column #2, Table II, next to G. B. Summing.

8. Multiply column #2 times column #7 and square the result. This is the single period variance due to glovebox summing bias. Enter final result in column #11.

9. Multiply column #2 times column #7 and square the result. This is the Bi-period variance due to glovebox summing bias. Enter final result in column #12.

10. Determine B

$$B = \frac{9.68}{\bar{y}} = \text{Bias Ratio.}$$

B. Bias Correction to I.D.

Multiply g Pu measured by glovebox summing this inventory (listed in column #4) times (1-B). The result is the bias correction to I. D.

EXAMPLE 6

1 Category	2 S_g	4 Mar. '76	7 SP (5-4)	8 BP (6-4)	11 SP $\sigma\theta^2$ $(2x7)^2$	12 BP $\sigma\theta^2$ $(2x8)^2$
G.B. Summing	0.00898	60	49	515	0	21

B = 1.18049
(60)(1-B) = (60)(-0.18049) =<11>
Bias correction to I. D. = <11> g Pu

VIII. Error Propagation

This discussion of error propagation is confined to the calculations necessary to determine the limit of error for plant holdup.

A. Random Error

1. Find the sum of the random error variance for all methods for this inventory.

2. Find the sum of the random error variance for all methods last inventory.

3. Find the sum of the random error variance for all methods for the inventory prior to the last inventory.

4. The sum of 1) + 2) above is the single period random error variance. Record this sum as such.

5. The sum of 1) + 3) above is the Bi-period random error variance. Record this sum as such.

EXAMPLE 7

Sum of random error variance this inventory

$\sigma^2_{\omega 1} = 292,147$

sum of random error variance last inventory

$\sigma^2_{\omega 2} = 152,919$

Sum of random error variance inventory period to last inventory

$\sigma^2_{\omega 3} = 342,178$

Single period random error variance, $\sigma^2_{\omega 12}$

$\sigma^2_{\omega SP} = \sigma^2_{\omega 1} + \sigma^2_{\omega 2} = 292,147 + 152,919 = 445,066$

Bi-period random error variance, $\sigma^2_{\omega 13}$

$\sigma^2_{\omega BP} = \sigma^2_{\omega 1} + \sigma^2_{\omega 3} = 292,147 + 342,178 = 634,325$

B. Systematic Errors

1. The single period systematic calibration error, $\sigma^{2\bullet}_{\beta_{SP}}$, was found in VI B 1).
2. The Bi-period systematic calibration error, $\sigma^2_{\beta_{BP}}$, was found in VI B 2).
3. The single period variance due to glovebox summing bias, $\sigma^2_{\theta SP}$, was found in VII A 8).
4. The Bi-period variance due to glovebox summing bias, $\sigma^2_{\theta BP}$, was found in VII A 9).

C. Write LEID for the single period inventory.

$$\sigma^2_{SP} = \sigma^2_{\omega_{SP}} + \sigma^2_{\beta_{SP}} + \sigma^2_{\theta_{SP}}$$

LEID = 1.96 (σ_{SP}) Single Period

D. Write LEID for the Bi-period inventory.

$$\sigma^2_{BP} = \sigma^2_{\omega BP} + \sigma^2_{\beta BP} + \sigma^2_{\theta BP}$$

LEID = 1.96 (σ_{BP}) Bi-period

IX. Covariance

An item that has not been physically changed or remeasured that appears on beginning and ending inventory is considered to be "covariant". An example would be a tamper-safed glovebox. Since the g Pu value and measurement method is the same on both beginning and ending inventory, this item will not have an error component that applied to I.D. Care should be taken to assure that covariant items are not included in the LEID calculation.

I would suggest that covariant items, along with their measurement data, be listed separately to avoid confusion.

X. Inventory Statement

A. Separate summaries are written for the single period inventory and the Bi-period inventory.

B. Each summary should contain:

1. Beginning and ending inventory

2. LEID

3. Bias corrections (single period only)

C. Inventory Report

It is customary to report holdup in terms of room, box (item), and MBA.

NOTE: Each box may have several components such as wall values, floor values and tank values. In order to make the report more understandable sum these values and report the total g Pu for an individual box.

GLOSSARY

TERMS:

Background Count:	Count taken with front of collimator covered.
Background Plug:	Pb disk, 1/2" thick, used to cover front of collimator.
Gross Count:	Count taken with collimator uncovered.
Honeycomb:	Used to provide narrow viewing angle. 2 1/2" diameter Pb disk 1" thick with a concentric arrangement of 1/8" diameter holes spaced on 1/4" centers to be inserted in the end of the collimator.
LEID:	Limit of Error applied to I.D.
Loading:	Amount of Pu used in a particular calibration step.
I.D.:	Material unaccounted for. I.D. = Beginning Inventory + Receipts - Shipments - Ending Inventory.
Net Count:	Gross Count - Background Count = Net Count
Pipe Plug:	Pb disk made to fit over the end of the collimator. 1/2" thick with a centered 1 1/2" x 2 1/4" rectangular slit.
Pipe Shield:	1/2" thick piece of Pb used to help isolate a particular pipe for measurement.
Recess:	The distance that the face of the NaI crystal is recessed from the face of the collimator.
Transmission:	The fraction of radiation penetrating an absorber without interaction.

GLOSSARY

SYMBOLS:

a	Calibration Constant
b	Calibration Constant
B	Bias Ratio
E_i	Element Weight(g Pu), multiple measurement sites
E_j	Element Weight(g Pu), single measurement sites
S	Standard Deviation
S_c	Calibration Error
S_g	Geometry Error
$\mathcal{S}_i$	Relative Standard Deviation
S_m	Multiple Measurement Component, Random Error
S_p	Pooled Error
S_r	Random Error
S_s	Single Measurement Component, Random Error
$S(x^2)$	$(X - X)^2$
$\mathcal{S}\ y \cdot x$	Relative Variance of y about x
$\sigma\beta$	Short Term Systematic Error
$\sigma\theta$	Long Term Systematic Error
$\hat{y}$	Estimate g Pu (Based on Calibration)

This procedure describes the methods used to calculate the limit of error associated with inventory differences and waste shipments. The procedure is presented in two sections, the first of which describes how a limit of error is calculated for tasks encountered during the Facility's decommissioniong, i.e. waste shipments and Uranium Plant inventories.

The second section was adopted in its entirety (with changes to up-date terminology) as it was in revision 2 as the "Limit of Error Manual". This section was created to retain the limit of error manual, should the need for it arise before the Facility is completely dismantled. The section describes short term and long term errors.

SECTION I

I. Limit of Error Calculations

A. Groups of Assayed Items (Counted waste, counted solids, TRU waste drums).

1. N = Number of units (packages, drums, etc.)
ΣX_i = Sum of values of all items (grams Pu or U)
ΣX_i^2 = Sum of squares of values of items
$\overline{X}$ = Mean
$\Sigma (X_i)^2$ = Square of sum of values of items

$$s\text{(Standard deviation)} = \sqrt{\frac{N\Sigma X_i^2 - (\Sigma X_i)^2}{N(N-1)}}$$

$$\text{R.S.D.(Relative Standard deviation)} = s/\overline{X}$$

$$\text{Sp(Pooled Error)} = \sqrt{\frac{\Sigma (N-1) S_i^2}{\Sigma N_i - k}}$$

where: N = No. of objects counted
S_i = R.S.D. of grams of isotope or element
E_i = Total grams of isotope
K = Multi-measured objects

$$\text{Random Error} = S_R = \sqrt{\frac{\Sigma(\Sigma E_i)^2 S_i^2}{2N_i} + (\Sigma E_i)^2 \frac{S_p}{2}}$$

σ data = ± Random Error

Limit of Error @ 95% Confidence Level = 1.96 x σ data

a. If grams element was entered, then the above is L. E. Element, and L. E. Isotope is calculated:

L. E. Isotope = 1.96(σ data X % enrichment)

b. If grams isotope was entered, then the above is L. E. Isotope, and L. E. Element is calculated:

$$\text{L. E. Element} = \frac{(\sigma\text{ data})}{(\%\text{ enrichment})}$$

2. These calculations can be performed using a programable calculator (Hewlett-Packard model 97) in the following manner:

   a. Programs for the HP 97 are recorded on cards called Smart Cards. Select the card with the Limit of Error program. With the calculator ON, RUN position, print mode in NORM position, insert side 1 of the card, face up, into the front slot provided on the left side of the calculator, and press it into the slot until the reading mechanism picks it up and propels it out the rear slot. (Let go of the card as soon as you feel it begin to be propelled by the reading mechanism). Do this also for side 2 of the card.

   b. Press the F key and the A key to clear the calculator.

   c. Enter data (package value in grams, drum value in grams, etc.) by pushing the appropriate numerical keys, and either the A key or the Σ+ key. If, after depressing the Σ+ key or the A key, it is discovered the wrong value has been entered, press the F key and then the Σ+ key, and then enter the correct value.

   d. After all the data has been entered, press the B key. The calculator will print out a series of values. (See Example 1)

```
                 GSBa
       3.0000    Σ+
       2.0000    Σ+
       6.0000    Σ+
       5.0000    Σ+
       4.0000    Σ+
                 GSBB
```

N	5.0000	***
Σx_i	20.0000	***
$\Sigma x_i 2$	90.0000	***
$(\Sigma x_i)^2$	400.0000	***
$\bar{x}$	4.0000	***
s	1.5811	***
RSD	0.3953	***
RSD^2	0.1563	***
Sp^2	0.1250	***
Sp	0.3536	***
S_R^2	11.8750	***
S_R	3.4460	***

e. The last number printed (Sr) is the sigma (σ) for the data entered. Multiplying this number by 1.96 gives the limit of error at the 95% confidence level for this particular group of data; however, the more important number at this point is SR^2, the next-to-last number on the print out, because it will be used in finding the overall limit of error. (Limits of errors can not be summed for a total limit of error; the squares of their sigmas must be added, the square root extracted, and that root used to calculate the overall limit of error.) Now calculate either L. E. Isotope or L. E. Error as in I.A.1.a.or b.

f. NOTE - Items of different enrichments can not be mixed. A separate limit of error must be calculated for each enrichment.

B. Surveyed Items (Non-line drums, unique items)

1. The base number used in determining the value of the item in question must be known. This is usually, the average counts per minute/area from the survey meter. To determine the sigma for the base number:

$$\sigma n = \sqrt{\frac{\sigma \text{ cpm}}{\text{cpm}}} \text{ (error in base number)}$$

2. To calculate sigma for the item, multiply the determined value of the item by σ n.

$$\sigma \text{ items} = \sigma n \times \text{determined value}$$

3. Now, for a group of like items:

$$\sqrt{(\#\text{ of items})\ (\sigma \text{ item})} = \sigma \text{ isotope}$$

4. Divide σ isotope by the appropriate enrichment to find the σ element:

$$\frac{\sigma \text{ Isotope}}{\%\text{ enrichment}} = \sigma \text{ element}$$

5. The limit of error at the 95% confidence level for this item (group of items) would be:

L. E. Isotope = 1.96 x σ isotope
L. E. Element = 1.96 x σ element

But, remember, the square of the sigma must be used in calculating the overall limit of error.

6. NOTES: a) One exception to this category is a group of concrete donuts. Use the method in I.A..
b) Items of different enrichments can not be mixed. A separate limit of error must be calculated for each enrichment.

C. Scales Errors (Uranium)

1. Review the check-weight sheets for the appropriate scales (dirt, dried solids, ash), and pick the weight nearest the average net weight of item(drum, packages, solution), and calculate the mean of the check weights for that weight. Convert from pounds to grams.

2. N = Number of check weighings
ΣX_i = Sum of Scales Values for the check weight
ΣX_i^2 = Sum of squares of Scales Values for the check weight

$$X(\text{Mean}) = \frac{\Sigma X_i}{N} \times 453.59 \text{ grams/lb.}$$

$$\text{Std. Dev.} = \sqrt{\frac{\Sigma X_i^2 - (\Sigma X_i)^2}{N(N-1)}}$$

$$\text{Random Weight Error} = \text{Std. Dev.} \times \sqrt{2}$$

Systematic Weight Error

a. Dirt and ash

$$\left[(\text{Std.Wt.} - \text{Mean Std.Meas.})^2 + \frac{(\text{Std. Dev.})^2}{\#\text{ Times of Ck. Wt.}} + (\text{R.W.E.})^2 \times \#\text{ drums} + \frac{(453.59)^2}{\#\text{ drums}}\right]^{\frac{1}{2}}$$

b. Dried solids

$$\left[(\text{Std.Wt.} - \text{Mean Std.Meas.})^2 + \frac{(\text{Std. Dev.})^2}{\#\text{ Times of Ck. Wt.}} + (\text{R.W.E.})^2 \times \#\text{ pkgs}\right]^{\frac{1}{2}}$$

c. Soda Ash

$$\left[(\text{Std.Wt.} - \text{Mean Std.Meas.})^2 + \frac{(\text{Std. Dev.})^2}{\#\text{ Times of Ck. Wt.}} + (\text{R.W.E.})^2 \times \#\text{ Sol.} + \frac{(453.59)^2}{\#\text{ Ck.Wts.}}\right]^{\frac{1}{2}}$$

σ Isotope = Systematic Weight Error (grams) x Assigned Value of Item

$$\text{Element} = \frac{\sigma\text{ Isotope}}{\%\text{ Enrichment}}$$

3. Limit of Error at 95% confidence level = 1.96σ

4. Calculate σ^2 for use in overall Limit of Error.

5. See Figures 1, 2, 3 and 4 for forms used for Scales Errors.

FIGURE 1

Dried Solids

Weight Limit of Error

Weight Error

Use check weight nearest to average weight of packages and calculate mean of the check weights.

$$\text{Mean} = \frac{\Sigma X_i}{N} = \underline{\hspace{3cm}}\text{ grams}$$

$$\text{Std. Dev.} = \sqrt{\frac{N\Sigma X_i^2 - (\Sigma X_i)^2}{N(N-1)}} = \sqrt{\frac{(\underline{\quad} \times \underline{\hspace{2cm}}) - \underline{\hspace{2cm}}}{\underline{\hspace{1.5cm}}}} = \underline{\hspace{2cm}}\text{ g}$$

$$\text{Random Wt. Error} = \text{Std.Dev.} \times \sqrt{2} = \underline{\quad} \times 1.41 = \underline{\hspace{1.5cm}}\text{ g}$$

$$\text{Sys.Wt.Error} = \left[(\text{Std.Wt.} - \text{Mean Std.Meas.})^2 + \frac{(\text{Std.Dev.})^2}{\#\text{ Times of Ck. Wt.}} + (\text{R.W.E.})^2 \times \#\text{ Pkgs.}\right]^{\frac{1}{2}}$$

$$= \left[(\underline{\hspace{1.5cm}} - \underline{\hspace{2cm}})^2 + (\underline{\hspace{1.5cm}})^2 + (\underline{\hspace{1.5cm}})^2 \times \underline{\hspace{1.5cm}}\right]^{\frac{1}{2}}$$

$$= \left[\underline{\hspace{1.5cm}} + \underline{\hspace{1.5cm}} + \underline{\hspace{1.5cm}}\right]^{\frac{1}{2}} = \underset{\sigma}{\underline{\hspace{1.5cm}}}\text{ g}$$

$$\underline{\hspace{1.5cm}}\text{ g} \times \underset{\text{Lab. Ana.}}{\underline{\hspace{2.5cm}}}\text{ g U/g} = \underset{\sigma}{\underline{\hspace{1.5cm}}}\text{ g U}$$

$$\underline{\hspace{1.5cm}}\text{ g U} \times \underset{\%\text{ Enrichment}}{\underline{\hspace{3cm}}} = \underset{\sigma}{\underline{\hspace{2cm}}}\text{ g } U^{235}$$

$$\sigma^2\ U = \underline{\hspace{3cm}}$$

$$\sigma^2\ U^{235} = \underline{\hspace{3cm}}$$

FIGURE 2

Soda Ash

Weight Limit of Error

Weight Error

Use check weight nearest to average net weight of solutions and calculate mean of the check weights.

$$\text{Mean} = \frac{\Sigma X_i}{N} = \_\_\_\_\_\_ \times 453.59 = \_\_\_\_\_\_\_\_\text{grams}$$

$$\text{Std.Dev.} = \sqrt{\frac{N\Sigma X_i^2 - (\Sigma X_i)^2}{N(N-1)}} = \sqrt{\frac{(\_\_\_ \times \_\_\_\_\_\_\_\_) - \_\_\_\_\_\_\_\_}{\_\_\_\_}} = \_\_\_\_\_\text{g}$$

$$\text{Random Wt. Error} = \text{Std.Dev.} \times \sqrt{2} = \_\_\_ \times 1.41 = \_\_\_\_\text{g}$$

$$\text{Sys.Wt.Error} = \left[(\text{Std.Wt.} - \text{Mean Std.Meas.})^2 + \left(\frac{\text{Std.Dev.}}{\text{\# Times of Ck. Wt.}}\right)^2 + (\text{R.W.E.})^2 \times \text{\# Sol.} + \left(\frac{453.59}{\text{\# Ck.Wt.}}\right)^2\right]^{\frac{1}{2}}$$

$$= \left[(\_\_\_\_ - \_\_\_\_\_\_)^2 + \left(\frac{\_\_\_\_}{\_\_\_}\right)^2 + (\_\_\_\_ \times \_\_\_\_\_)^2 + \left(\frac{453.59}{\_\_\_\_}\right)\right]^{\frac{1}{2}}$$

$$= \left[\_\_\_\_ + \_\_\_\_ + \_\_\_\_ + \_\_\_\_\right]^{\frac{1}{2}} = \_\_\_\_\_\text{g}$$

$$\_\_\_\_\_\text{g} \times \underset{\text{Lab.Ana.}}{\_\_\_\_\_\_\_}\text{g U/g} = \underset{\sigma}{\_\_\_\_\_}\text{g U}$$

$$\_\_\_\_\_\text{g U} \times \underset{\text{\% Enrichment}}{\_\_\_\_\_\_\_\_\_} = \underset{\sigma}{\_\_\_\_\_\_}\text{g } U^{235}$$

σ 2U = __________

σ $2U^{235}$ = __________

FIGURE 3

Ash

Weight Limit of Error

Weight Error

Use check weight nearest to average net weight of drums and calculate mean of the check weights.

$$\text{Mean} = \frac{\Sigma X_i}{N} = \_\_\_\_\_\_ \times 453.59 = \_\_\_\_\_\_\_\_ \text{grams}$$

$$\text{Std.Dev.} = \sqrt{\frac{N\Sigma X_i^2 - (\Sigma X_i)^2}{N(N-1)}} = \sqrt{\left(\_\_\_ \times \frac{\_\_\_\_\_\_\_\_}{\_\_\_\_}\right) - \_\_\_\_\_\_\_\_} = \_\_\_\_\_\_ \text{g}$$

$$\text{Random Wt.Error} = \text{Std.Dev.} \times \sqrt{2} = \_\_\_ \times 1.41 = \_\_\_\_\_\_ \text{g}$$

$$\text{Sys.Wt.Error} = \left[(\text{Std.Wt.} - \text{Mean Std.Meas.})^2 + \left(\frac{\text{Std.Dev.}}{\text{\# Times of Ck. Wt.}}\right)^2 + (\text{R.W.E.})^2 \times \text{\# drum} + \left(\frac{453.59}{\text{\# drums}}\right)^2\right]^{\frac{1}{2}}$$

$$= \left[(\_\_\_\_ - \_\_\_\_\_\_)^2 + \left(\frac{\_\_\_\_}{\_\_\_}\right)^2 + (\_\_\_\_)^2 \times \_\_\_\_\_ + \left(\frac{453.59}{\_\_\_\_}\right)^2\right]^{\frac{1}{2}}$$

$$= \left[\_\_\_\_\_ + \_\_\_\_\_ + \_\_\_\_\_ + \_\_\_\_\_\right]^{\frac{1}{2}} = \_\_\_\_\_ \text{g}$$

$$\frac{\_\_\_\_\_\_\_\_ \text{g}}{453.59 \text{g/lb.}} = \_\_\_\_\_\_\_ \text{lb.} \times \frac{\_\_\_\_\_\_\_\_ \text{g } U^{235}\text{/lb.}}{\text{Lab.Ana.}} = \frac{\_\_\_\_\_ \text{g } U^{235}}{\sigma}$$

$$\frac{\_\_\_\_\_ \text{g } U^{235}}{.03} = \frac{\_\_\_\_\_ \text{g U}}{\sigma}$$

$\sigma^2 U$ = __________

$\sigma^2 U^{235}$ = __________

FIGURE 4

Dirt

Weight Limit of Error

Weight Error

Use check weight nearest to average net weight of drums and calculate mean of the check weights.

$$\text{Mean} = \frac{\Sigma X_i}{N} = \_\_\_\_\_ \times 453.59 = \_\_\_\_\_\_\text{grams}$$

$$\text{Std.Dev.} = \sqrt{\frac{N\Sigma X_i^2 - (\Sigma X_i)^2}{N(N-1)}} = \sqrt{\frac{(\_\_\_ \times \_\_\_\_\_\_) - \_\_\_\_\_\_}{\_\_\_}} = \_\_\_\_\text{g}$$

$$\text{Random Wt.Error} = \text{Std.Dev.} \times \sqrt{2} = \_\_\_ \times 1.41 = \_\_\_\text{g}$$

$$\text{Sys.Wt.Error} = \left[(\text{Std.Wt.} - \text{Mean Std.Meas.})^2 + \left(\frac{\text{Std.Dev.}}{\text{\# Times of Ck. Wt.}}\right)^2 + (\text{R.W.E.})^2 \times \text{\# drum} + \left(\frac{453.59}{\text{\# drums}}\right)^2\right]$$

$$= \left[(\_\_\_ - \_\_\_\_)^2 + \left(\frac{\_\_\_}{\_\_\_}\right)^2 + (\_\_\_)^2 \times \_\_\_\_ + \left(\frac{453.59}{\_\_\_}\right)^2\right]^{\frac{1}{2}}$$

$$= \left[\_\_\_ + \_\_\_ + \_\_\_ + \_\_\_\right]^{\frac{1}{2}} = \_\_\_\_\text{g}$$

$$\frac{\_\_\_\_\_\text{g}}{453.59\text{g/lb.}} = \_\_\_\_\text{lb.} \times \frac{\_\_\_\_\_\text{g } U^{235}\text{/lb.}}{\text{Lab.Ana.}} = \_\_\_\_\text{g } U^{235}_{\sigma}$$

$$\frac{\_\_\_\text{g } U^{235}}{.03} = \_\_\_\_\text{g } U_{\sigma}$$

$$\sigma^2 U = \_\_\_\_\_\_$$

$$\sigma^2 U^{235} = \_\_\_\_\_\_$$

D. Overall Limit of Error (Totals)

1. Totals for limit of error for materials of each enrichment must be determined, by adding all the σ^2 for each σ isotope at all the σ^2 for each σ element for that enrichment. The square root of that total is extracted, and multiplied by 1.96; if this is L. E. Element, multiply by % enrichment to get L. E. Isotope. If this is L. E. Isotope, divide by % enrichment to get L. E. Element.

2. Overall limit of error is found by adding all σ^2 isotope and all σ^2 element, extracting the square root for each, and multiplying them by 1.96:

$$\text{L. E. Isotope} = 1.96\sqrt{\Sigma\sigma^2 \text{ isotope}}$$

$$\text{L. E. Element} = 1.96\sqrt{\Sigma\sigma^2 \text{ element}}$$

II. Examples

A. Suppose a Pu TRU waste shipment of three drums, and the drums had packages of the following values(grams Pu):

Drum #1 - 1.380, 1.878, 1.917, 1.752, 1.576

Drum #2 - 0.010, 0.042, 0.045, 0.010, 0.052

Drum #3 - 1.723, 1.689, 0.010, 0.010, 0.010

1. Calculate the limit of error for each drum as in I.A.1. using I.A.2..

Drum #1			Drum #2			Drum #3		
		GSBa			GSBa			GSBa
	1.3800	Σ+		1.7230	Σ+		.0100	Σ+
	1.8780	Σ+		1.6890	Σ+		.0420	Σ+
	1.9170	Σ+		.0100	Σ+		.0450	Σ+
	1.7520	Σ+		.0100	Σ+		.0100	Σ+
	1.5760	Σ+		.0100	Σ+		.0520	Σ+
		GSBB			GSBB			GSBB
	5.0000	***		5.0000	***		5.0000	***
	8.5030	***		3.4420	***		0.1590	***
	14.6595	***		5.8218	***		0.0067	***
	72.3010	***		11.8474	***		0.0253	***
	1.7006	***		0.6884	***		0.0318	***
	0.2232	***		0.9290	***		0.0202	***
	0.1312	***		1.3495	***		0.6361	***
	0.0172	***		1.8212	***		0.4047	***
	0.0138	***		1.4570	***		0.3237	***
	0.1174	***		1.2071	***		0.5690	***
element σ^2	0.2255	***	element σ^2	6.3988	***	element σ^2	0.0021	***
σ	0.4749	***	σ	2.5296	***	σ	0.0459	***

For TRU waste, the values entered are grams of the element. The enrichmnent (actually, percent fissile) is 87.35%, so the σ-isotope can be determined:

	.4749	ENT↑		2.5296	ENT↑		.0459	ENT↑
	.8735	x		.8735	x		.8735	x
σ-isotope	0.4148	***	σ-isotope	2.2096	***	σ-isotope	0.0401	***
		X^2			X^2			X^2
σ^2	0.1721	***	σ^2	4.8824	***	σ^2	0.0016	***

Then, the limit of error for each individual drum can be calculated:

	.4749 ENT↑		2.5296 ENT↑		.0459 ENT↑
L.E.	1.9600 x	L.E.	1.9600 x	L.E.	1.9600 x
element	0.9308 ***	element	4.9580 ***	element	0.0900 ***
	.4100 ENT↑		2.2100 ENT↑		.0400 ENT↑
	1.9600 x		1.9600 x		1.9600 x
isotope	0.8036 ***	isotope	4.3316 ***	isotope	0.0784 ***

The limit of error would be as follows:

Drum #1 Element 8.503 ± 0.93 grams
Isotope 7.427 ± 0.80 grams

Drum #2 Element 3.442 ± 4.96 grams
Isotope 3.007 ± 4.33 grams

Drum #3 Element 0.159 ± 0.09 grams
Isotope 0.139 ± 0.08 grams

But would be rounded and reported as follows:

Drum #1 Element 9 ± 1 grams
Isotope 7 ± 1 grams

Drum #2 Element 3 ± 5 grams
Isotope 3 ± 4 grams

Drum #3 Element)Limit of Error not
Isotope)required for values ≤ 1.0 gram

2. Calculate the total limit of error for the shipment. This can be done using the H. P. 97 programmable calculator:

   Push the F key, and the C key. Then enter the σ^2 element for each drum with the C key. After entering all the σ^2's, push the D key. This prints the following:

```
                2           GSBc
                     .2255  GSBC
                    6.3988  GSBC
                     .0021  GSBC
                            GSBD

      Σσ²           6.6264  ***
       σ            2.5742  ***

      L.E.element   5.0454  ***
```

   Multiply the L. E. Element by .8735 to get L. E. Isotope:

```
                    5.0454  ENT↑
                     .8735  x
      L.E.isotope   4.4072  ***
```

Shipment totals, then are:

L. E. Element	12.104	± 5.0454 grams
L. E. Isotope	10.5730	± 4.4074 grams

Report:

L. E. Element	12	± 5 grams
L. E. Isotope	11	± 4 grams

B. Suppose a Uranium Plant inventory or shipment with the following items:

Counted trash (packages) 3, 2, 1, 5, 4, grams ^{235}U (3%).
2.83% ^{235}U enriched solids (packages) 4, 2, 1, 6, 5 grams ^{235}U.
3 drums non-line trash.
Assume 2.83 % packages weigh 2000 grams.
Assume .0636 g ^{235}U/gram.

1. Calculate the overall limit of error:

a. Counted trash - follow I.A.1. and I.A.2.. (NOTE - If the material is 3% ^{235}U enriched, the σ U and σ^2U can be found by pushing the F key and the D key.

		GSBc
	3.0000	Σ+
	2.0000	Σ+
	1.0000	Σ+
	5.0000	Σ+
	4.0000	Σ+
		GSBB
	5.0000	***
	15.0000	***
	55.0000	***
	225.0000	***
	3.0000	***
	1.5811	***
	0.5270	***
	0.2778	***
	0.2222	***
	0.4714	***
$\sigma^2\ ^{235}U$	12.3611	***
$\sigma\ ^{235}U$	3.5158	***
		GSBd
σ U	117.1946	***
σ^2 U	13734.5679	***

b. 2.83% ^{235}U enriched solids - follow I.A.1 and I.A.2..

		GSBa
	4.0000	Σ+
	2.0000	Σ+
	6.0000	Σ+
	1.0000	Σ+
	5.0000	Σ+
		GSBB
	5.0000	***
	18.0000	***
	82.0000	***
	324.0000	***
	3.6000	***
	2.0736	***
	0.5760	***
	0.3318	***
	0.2654	***
	0.5152	***
$\sigma^2\ {}^{235}U$	21.6327	***
$\sigma\ U$	4.6511	***
		ENT↑
	.0283	÷
$\sigma\ U$	164.3498	***
		X^2
$\sigma^2\ U$	27010.8455	***

NOTE: dividing $\sigma\ {}^{235}U$ by 2.83% to get $\sigma\ U$.

C. Non-Line Trash

The value assigned to non-line trash drums is 0.25 grams ^{235}U. This is based on some assumptions, one being that there is an average of 7500 dpm/100 cm^2 on all surfaces. This is (assuming a 50% counter efficiency) 3750 cpm.

Following I.B.:

i) $\sigma n = \frac{\sqrt{3750}}{3750}$

$= 0.0.0163$

ii) $0.28 \times .0163$
$= .0046$

iii) $\sqrt{3 \text{ drums} \times .0046}$

$= 0.117 \sigma\ ^{235}U$
$= 0.014 \sigma\ ^{235}U$

$0.117/.03$ (3% ^{235}U enriched)
$= 3.90 \sigma\ U$
$15.213 \sigma\ U$

d. Scales

See attached sheet

Dried Solids 2.83%

Weight Limit of Error

Weight Error

Use check weight nearest to average net weight of packages and calculate mean of the check weights.

Mean $= \frac{\Sigma X_i}{n} = \underline{1899.9}$ grams (Assume 10 check weighings and X = 18999 grams)

Std.Dev. $= \sqrt{\frac{N\Sigma X_i^2 - (\Sigma X_i)^2}{N(N-1)}} = \sqrt{\frac{(\underline{10})\text{x}\ \underline{3609620.01}) - \underline{360962001}}{90}} = \underline{.1000}$g

Random Wt. Error = Std. Dev. $\times\sqrt{2} = \underline{.1} \times 1.41 = \underline{.141}$ g

Sys.Wt.Error $= \left[(\text{Std.Wt.} - \text{Mean Std.Meas.})^2 + \frac{(\text{Std.Dev.})^2}{\text{\# Times of Ck. Wt.}} + (\text{R.W.E.})^2 \times \text{\# Pkgs.}\right]^{1/2}$

$= \left[(\underline{1900} - \underline{1899.9})^2 + (\frac{\underline{.100}}{10})^2 + (\underline{.141})^2 \times \underline{5}\right]^{1/2}$

$= \left[\underline{0.01} + \underline{.001} + \underline{.099}\right]^{1/2} = \underline{0.332}$ g

$\underline{0.332}$ g x $\underline{.0636}$ g U/g (Lab. Ana.) = $\underline{.0211}$ g U (σ)

$\underline{.0211}$ g U x $\underline{.0283}$ (% Enrichment) = $\underline{.000598}$ g U^{235} (σ)

$\sigma^2 U = \underline{.000445}$

Scales Error Negligible

$\sigma^2 U^{235} = \underline{.00000035}$

e. Totals

For the 2.83%

Element = 1.96 x σU = 1.96 x 164.3498 = + 322 grams
Isotope = 1.96 x $\sigma^{235}U$ = 1.96 x 4.6511 = + 9 grams

For the 3%

	$\sigma^2 U$	$\sigma^2\ {}^{235}U$
Counted Trash	13734.5679	12.3611
Non-Line Trash	15.213	0.014
$\Sigma\sigma^2$ =	13749.7809	12.375
σ =	117.25946	3.517

Element = 1.96 x 117.25946 = ± 230 grams
Isotope = 1.96 x 3.517 = ± 7 grams

Shipment Totals

	$\sigma^2 U$	$\sigma^2\ {}^{235}U$
2.83%	27010.8455	21.6327
3%	13749.7809	12.375
$\Sigma\sigma^2$ =	40760.62640	34.0077
σ =	201.89	5.83

Limit of Error, Element = 1.96 x 201.89 = ± 396
Limit of Error, Isotope = 1.96 x 5.83 = ± 11

SECTION II

II. Limit of Error Manual

Introduction

This manual describes the methods for reducing raw source data to measurement random and systematic errors about these data. Also presented is the means to propagate these errors for obtaining a term called LE(ID) This term is the limit of error of the inventory differences for I.D. The limit of error, LE, represents a 95% confidence level where the ID represents the difference between a period's ending book balance and the period's ending physical inventory. A period's book balance is that period's beginning physical inventory plus succeeding receipts minus shipments.

The source data for generating the errors arises from three types of measurements.

1. Standards: This refers to materials made up of certified weights. This collected data supplies information for calculating short term systematic errors and their corresponding biases. Certified weights also supply data for random errors and long term systematic errors (KM-NP-15-46).

2. Waste Samples: Mutiple sampling of waste materials furnishes data for evaluating random error contributions arising from waste material variabilities. (KM-NP-15-46).

A. Scale and Balance LE

This section describes the manner in which to calculate random and systematic errors for those scales and balances used for weighing special nuclear materials when making transfers between material balance areas or for inventory purposes.

1. Random Errors

The data for the calculations comes from making many weighings of reference weights on each scale or balance. Reference weight magnitudes represents typical values seen by that scale or balance. Each scale or balance may have one or more reference weight. These calculations apply to each reference weight value for each scale. The reference weight values are traceable to certified or standard weights.

a. Error

Let W_o represent a given reference weight's value. For period $_j$ we have $_k$ measurements of values $W_1, W_2, \ldots, W_k$ giving an average weight of:

$$\overline{W_j} = \frac{1}{k} \Sigma W_i, \quad i = 1, 2, \ldots, k \qquad (1)$$

These data will have a standard deviation of:

$$s\,(W_j) = \left[\frac{k\Sigma W_i^{\,2} - (\Sigma W_i)^2}{K\,(k-1)}\right]^{\frac{1}{2}} \qquad (2)$$

In order to obtain the total random error for a weight, use the assumptions:

i) Tare and gross weights are rounded to the same place.

ii) Tare and gross weights have the same random error.

iii) No co-variance condition exists between the tare and the gross weights.

From these conditions the net random standard deviation is:

$$s(R) = \sqrt{2}\ s(w) \qquad (3)$$

where . . .

$$s(w) = \left[\frac{\Sigma(n_j - i)s^2(W_j)}{\Sigma(n_j) - \ell}\right]^{\frac{1}{2}} \qquad (4)$$

where ℓ represents the number of periods under consideration, $\ell \leq 30$.

2. Systematic Error

a. Short Term

The short term systematic error is:

$$s(S_k) = \left|\bar{W}_j = W_o\right| \qquad (8)$$

This error applies to those weights represented by period k.

b. Long Term

The average of averages is . . .

$$\bar{\bar{W}} = \frac{1}{\ell}\Sigma\bar{W}_j, \quad j = 1, 2, \ldots, \ell \qquad (9)$$

$$s(\bar{W}) = \left[\frac{\ell\Sigma\ \bar{W}^2 - (\Sigma\bar{W})^2}{\ell(\ell - 1)}\right]^{\frac{1}{2}} \qquad (10)$$

The long term systematic error is . . .

$$a(T) = \left[(\bar{\bar{W}} - W_o)^2 + s_o^{\ 2} + \frac{s^2(\bar{W})}{\ell} + \frac{\Delta^2}{12}\right]^{\frac{1}{2}} \qquad (11)$$

where s_o represents the error of the check weight, and Δ the units rounded to.

B. Assay I.D.

During Standby Operations, only low level waste material will be produced as a result of decontamination work. Should any material sampling become necessary the assay work would be done by an outside Laboratory and an I. D. for that assay would be requested as part of the assay report.

1. Fissile Analysis

Fissile assays, g fissile per g element, are treated in the same fashion as for assays.

When more than one fissile isotope exists it is assumed they are independent measurements and the combined fissile standard deviation for each error term is . . .

$$s(F) = \left[s^2(F_{239}) + s^2(F_{241}) \right]^{\frac{1}{2}} \tag{40}$$

C. Errors For Algebraic Sums

This section describes the methods for calculating errors for plantwide receipts or shipments, receipts or shipments occurring during an inventory period and for inventoried items. In the expressions below a term, a_i, is used which can only have values of +1, 0 or -1. The rules to determine which values to use is covered in C.3.

1. For Element Conditions

For those conditions for obtaining errors for the total element.

a. Random Weight Variance

For each scale, i, there exists a random variant $s^2(R_i)$, see equation 3. Each item will have an assay of $A_{j(i)}$. Here j(1) implies a set of j assays for scale i. The net random weight variance is . . .

$$s^2(Rn) = \Sigma_i \left[(\Sigma_{j(i)} a_{j(i)}{}^2 A_{j(i)}{}^2)_i \; s^2(R_i) \right] \tag{42}$$

Form the sums over j(i) first then those over i.

b. Short Term Systematic Weight Variance

Similarly for each scale i, period k for scale i, $k(i)$, and item j for scale i period k, $j(ik)$ we have the net variance.

$$s^2(Sn) = \Sigma_i \left\{ \Sigma_{k(i)} \left[\Sigma_{j(ik)} a_{j(ik)} A_{j(ik)} \right]^2_{k(i)} s^2(S_{k(i)}) \right\}_i \tag{43}$$

See equation 8 for $s(S_{k(i)})$

c. Net Element Limit of Error

The net element standard deviation is . . .

$$s(En) = \left[s^2(Rn) + s^2(Sn) \right]^{\frac{1}{2}} \quad (54)$$

The limit of error . . .

$$LE(en) = 1.96\ s(En) \quad (55)$$

2. For Fissile Conditions

For those conditions where fissile errors are needed. If only one fissile isotope exists, U-235, the isotopic value for that isotope is the fissile assay.

$$F + I\ (U\text{-}235) \quad (56)$$

If two isotope fissile exist then . . .

$$F + I(Pu\text{-}239) + I(Pu\text{-}241) \quad (57)$$

The first two items are similary to those for element errors. The prime serves to identify isotopic data.

a. Random Weight Variance

$$s^2(R'_n) = \Sigma_i \left[(\Sigma_{j(i)} a_i{}^2 F_{j(i)}{}^2 A_{j(i)} \right]^2)_i\ s^2(R_i) \Big] \quad (58)$$

b. Short Term Systematic Weight Variance

$$s^2(S'_n) = \Sigma_i \left\{ \Sigma_{k(i)} \left[\Sigma_{j(ik)} a_{j(ik)} F_{j(ik)} A_{j(ik)} \right]^2_{k(i)} s^2(S_{k(i)}) \right\}_i \quad (59)$$

c. Net Fissile Limit of Error

The net standard deviation for the fissile mass is . . .

$$s(F_n) = \left[s^2(R'_n) + s^2(S'_n) \right]^{\frac{1}{2}} \quad (72)$$

The limit of error is . . .

$$LE(F_n) = 1.96\ s(F_n) \quad (73)$$

3. Evaluation of a_r

The values used for a_r depend on whether it represents a plantwise receipts or shipments, receipts or shipments during an inventory period or inventory items.

a. Plantwise Shipments

This data furnished the data needed for such items as ACE-741 forms.

$a_r = 1$, for all items.

b. Shipments During Inventory Period

$a_r = 1$, for all items received.

$a_r = -1$, for all items shipped.

c. Inventory Items

a = o Items present on the previous inventory or items on inventory unchanged from what was received by that process area.

a = 1 All other items.

Each inventory is considered as independent of all others.

D. Inventory Differences - I.D.

Whether in terms of element or fissile the ID is . . .

$$ID = BI + (R - S) - EI \quad (74)$$

Where . . .

Bi Beginning Physical Inventory
R Material Received
S Material Shipped
EI Ending Physical Inventory

For element conditions use equation 54; equation 72 for a fissile condition. Then . . .

$$LE(ID)\ element = \left[LE^2(E_n)_{BI} + LE^2(E_n)_{S-R} + LE^2(E_n)_{EI}\right]^{1/2} \quad (75)$$

or . . .

$$LE(ID)\ fissile = \left[LE^2(F_n)_{BI} + LE^2(F_n)_{S-R} + LE^2(F_n)_{EI}\right]^{1/2} \quad (76)$$

Where S-R represents combined limit of error for shipments and receipts.

APPENDIX I

ERROR PROPAGATION MODELS

This appendix summarizes the methodology for propagating errors for shipments, inventories and the inventory differences. Each error type is propagated individually then all the error types are added together as variances.

a: Covariant Condition,

= 0 When item present on previous inventory, being unchanged on present inventory,

or

when present in a process area in same form as received,

or

item represents a shipment in or out of a storage area, this prevents counting the error twice.

= 1 When an inventory is not present on the previous inventory and unchanged,

or

when item represents a receipt into a process area.

= -1 when item represents a shipment from a process area.

The plant as a whole will represent a process area.

E ( ): Expected value of variable in ( ).

i : Individual item weighed for a given scale.

j : Scale used.

k : Scale short term period.

ℓ	:	Measure assay.
L	:	Long term systematic error.
m	:	Assay material type.
n	:	Assay method short term period.
P	:	Process variability.
R	:	Random error.
S	:	Short term systematic error.
var()	:	Variance of the variable in ().
x	:	Weight variable.
y	:	Assay variable.
σ ( )	:	Standard deviation of variable in (). If the test s^2 is considered as the best unbiased estimate of the variance σ^2.

A. Random Weight Varance

$$var(\Sigma x_R) = \Sigma_j (\Sigma_i a_i^2 E^2(y)_i)_j \sigma_x^2(R)_j$$

B. Long Term Systematic Weight Variance

$$var\ (\Sigma x_L) = \Sigma_j (\Sigma_i a_i E(y)_i)^2_j \sigma_x^2(L)_j$$

C. Short Term Systematic Weight Variance

$$var\ (\Sigma x_s) = \Sigma_j \left[\Sigma_k (\Sigma_i a_i E(y)_i)^2_k \sigma_x^2(S)_k\right]_j$$

D. ID Variance

var(ID) = var(Σxy) beginning inventory.
+ var(Σxy) shipments-receipts.
+ var(Σxy) ending inventory.

GLOSSARY

a_i	:	Covariant Condition: Distinguishes between items received and inventoried unchanged, those present on the previous inventory or between those shipped or received. All these have random variable contributions:
$a_{j(i)}$	:	Convariant Condition: Same as A_i except applies to long term variences for measurement type j item i.
$a_{j(ik)}$	:	Convariant Condition: Same as $A_{j(i)}$ except applies also to the short term period$_k$.
a_r	:	Covariant Condition: General expression for A_i, $A_{j(i)}$ and $A_{j(ik)}$.
b	:	Bias: Difference between the average of a set of measurement and the true value for an assay method.
B	:	Bias: Difference between the means of means and the mean of a set of assays measured from reference samples.
B_o	:	Factor: Value used when not using an actual measured quantity.
BI	:	Beginning Inventory: A period's beginning physical inventory mass balance.
$E_{j(i)}$	:	Element Mass: Calculated mass present as determined by assay method type i, j items exist all having the same assay.
$E_{j(ik)}$	:	Element Mass: Same as $E_{j(i)}$ except it represents the kth short term period.
EI	:	Ending Inventory: A period's ending physical inventory mass balance.
F	:	Fissile Assay: Gram fissile isotopes present per gram element.

F_{239} : Fissile Assay: Same as F except for Pu-239 isotope only.

F_{241} : Fissile Assay: Same as F except for Pu-241 isotope only.

$F_{j(i)}$: Fissile Assay: $_j$th fissile assay represented by scale $_i$.

$F_{j(ik)}$: Fissile Assay: Same as $F_{j(i)}$ except it represents the scale $_k$th short term period.

I : Integer: For indexing say a single item.

ID : Inventory Difference: The book balance and inventory time minus the physical inventory.

$I_{j(i)}$: Fissile Mass: Calculated mass present as determined by assay method type $_i$, $_j$ items exist all having the same assay.

$I_{j(ik)}$: Fissile Mass: Same as $I_{j(i)}$ except it represents the $_k$th short term period.

I(Pu-239) : Fissile Assay: Gram fissile isotope Pu-239 only per gram plutonium.

I(Pu-241) : Fissile Assay: Gram fissile isotope Pu-241 only per gram plutonium.

I(U-235) : Fissile Assay: Gram U-235 isotope per gram uranium.

j : Integer: For indexing say a single set of data.

k : Integer: For indexing say a specific period, or describing the number of results being treated.

ℓ : Integer: For defining the number of periods of items being considered.

ℓ_i : Integer: Number of measurements represented by the $_i$th measurement.

$LE(E_n)$	:	Limit of Error: 95% confidence limit for the net element mass.
$LE(E_n)_{BI}$	:	Limit of Error: Same as $LE(E_n)$ except for the beginning inventory only.
$LE(E_n)_{EI}$	:	Limit of Error: Same as $LE(E_n)$ except for the ending inventory only.
$SE(E_n)_{S-R}$	:	Limit of Error: Same as $LE(E_n)$ except for shipment and receipts only.
$LE(F_n)$	:	Limit of Error: 95% confidence limit of error for the net fissile mass.
$LE(F_n)_{BI}$	:	Limit of Error: Same as $LE(F_n)$ except for the beginning inventory only.
$LE(F_n)_{EI}$	:	Limit of Error: Same as $LE(F_n)$ except for the ending inventory only.
$LE(F_n)_{S-R}$	:	Limit of Error: Same as $LE(F_n)$ except for shipments and receipts only.
LE(ID)	:	Element: Limit of Error: 95% confidence for the element mass inventory difference.
LE(ID)	:	Fissile: Limit of Error: Same as LE(ID) element except for fissile mass.
m_i	:	Integer: Number fissile samples represented by the $_i$th measurement.
n	:	Integer: Number of items.
n_i	:	Integer: Number of items for the $_i$th measurement.
n_j	:	Integer: Number of items for the $_j$th period.
R	:	Receipts: Mass of material received.

s_o	:	Standard Deviation: Represents that of the check weight.
$S(E_n)$	:	Standard Deviation: Net error for the net element mass.
s(F)	:	Standard Deviation: Net error for a fissile assay.
$s(F_{239})$	:	Standard Deviation: Error for plutonium 239 isotope.
$s(F_{241})$	:	Standard Deviation: Error for plutonium 241 isotope.
$s(F_n)$	:	Standard Deviation: Net error for the total fissile mass.
s(R)	:	Standard Deviation: Weight random error.
$s(R_i)$	:	Standard Deviation: Same as s(R) except for a specific scale.
$s(R_n)$	:	Standard Deviation: Net weight random error contribution.
s(R'n)	:	Standard Deviation: Same as $s(R_n)$ except in terms of fissile mass.
$s(S_{k(i)})$	:	Standard Deviation: Weight short term systematic error for period $_k$ and scale $_i$.
$s(S_k)$	:	Standard Deviation: A weight short term systematic error for period $_k$.
$s(S_n)$	:	Standard Deviation: Net weight short term systematic error contribution.
$s(S'_n)$	:	Standard Deviation: Same as $s(S_n)$ except in terms of fissile mass.
s(T)	:	Standard Deviation: A weight long term systematic error.

$s(T_i)$	:	Standard Deviation: Same as s(T) except for a specific scale.
$s(T_n)$	:	Standard Deviation: Net long term systematic error contribution.
$s(t'_n)$	:	Standard Deviation: Same as $s(T_n)$ except in terms of fissile mass.
$s(w)$	:	Standard Deviation: Pooled estimate of a set of weight standard deviations, $s(W_j)$.
$s(\bar{\bar{W}})$	:	Standard Deviation: Weight error for a mean of means.
$S(W_j)$	:	Standard Deviation: Error made from a set of check weights made during period j.
S	:	Shipped: Mass of material shipped.
$\bar{\bar{W}}$	:	Mean of Means: Mean of a set of mean weights, W_j.
W_o	:	Reference Weight: Certified value of a reference weight.
W_1, W_2	:	Weights: Individually made weights.
$\bar{W}_j$	:	Mean Weight: Mean of a set of reference weighings made during period j.
$W_{j(i)}$	:	Weight: Weight made on scale i during period j.
W_k	:	Weight: kth individually made weight.
Δ	:	Increment: Decimal increment value of a given weight made.

REFERENCE

ASTM Manual on Quality Control of Materials ASTM Special Technical Publication 15-C, January, 1951.

C. A. Bennet & N. L. Franklin, Statistical Analysis in Chemistry and the Chemistry Industry, John Wiley & Sons, 1954.

W. H. Beyer (Ed), Handbook of Tables for Probability and Statistics, The Chemical Rubber Co., 1968

John L. Jaech, New Approach to Calculating LE-MUF, J of the Institute of Nuclear Materials Management 1 (3) July, 1972, 14-17.

John L. Jaech, Statistical Methods in Nuclear Material Control, TID-26298 December, 1973.

Specific: These describe sampling frequencies, short periods, methods for obtaining MUF.

Plutonium Assay Sampling and Scale Checkweighing - KM-NP-15-46.

Material Safeguards Records and Data Systems Procedure - KM-NP-15-55.

Safeguard Reference Sample Procedure - Uranium Plant - KM-NU-15-60.

Material Safeguards Record and Data Systems Procedure - Uranium Plant KM-NU-15-63.

PURPOSE: To provide a conservative estimate of contamination levels in combustible LSA waste that cannot be easily surveyed with alpha detection instrumentation.

I. Equipment Used

A. Ludlum Model 2500 Scaler Ratemeter.
B. Two - 5 inch photomultiplier tubes.
C. Plastic scintillator - 5 inches in diameter and 36 inches long.
D. Drum turn table.
E. Lead lined pit.

II. Equipment Settings

A. Ludlum Model 2500

R_1 1. High voltage ≈ 7.30 ≈ 2000 volts.
2. Window - in - 0.70.
3. Threshold - 1.90.
4. Energy Multiplier - 100 KEV.
R_1 5. Timer - clock - 5.6 minutes - 13 revolutions of drum for each count.

III. Sources Used

A. 0.1 mCi Cs^{137} Source #1597 G. R.
B. 1 mCi Ra^{226} Source # None.
C. 0.4688g Pu Standard (FFTF pellet encased in brass).
D. 245 cpm 2pi Pu^{239} Source #P-1819 to document 95% confidence level of Hewlett-Packard Model #5560A automatic sample counter.
E. Source #P-1959, P-5983, P-5565, P-1819, P-3029, and 6896 to document Hewlett-Packard automatic sample counter effeciency from 3 dpm to 1,866,000 dpm.
F. ≈ 2,000,000,000 dpm collected on ≈ 4,000 air sample filters and counted with Hewlett-Packard automatic sample counter. These air samples were placed in packages of 100 or 50 samples and sealed in plastic using the bag sealer.

IV. Counter Response

R1 H.V. - 7.30 window in - 0.10 E.M. - 100 KEV count time 1.0 minute.

82.7 NCi/g in 125 lbs. standard drum.

R1 H.V. - 7.30 W - 0.1 E.M. - 100 KEV Count Time 1.0 Min.

Threshold	Bkg. CPM	82.7 NCi/g in 125 Lbs. std. drum	Ratio Net counts/bkg.
0.10	358235	494025	
0.20	120398	175314	
0.30	60735	98463	
0.40	40274	66494	
0.50	23300	39219	
0.60	10870	28292	
0.70	8338	20779	
0.80	6884	16470	
0.90	5632	13370	
1.00	4738	11318	1.39
1.10	4012	9708	1.42
1.20	3444	8650	1.51
1.30	2840	7928	1.79
1.40	2374	7472	2.14
1.50	1953	6798	2.48
1.60	1777	6064	2.41
1.70	1473	5725	2.88
1.80	1243	5213	3.19
1.90	1056	4651	3.40
2.00	926	4054	3.38
2.10	754	3735	3.95
2.20	672	3289	3.89
2.30	618	2904	3.70
2.40	534	2416	3.52
2.50	508	2163	3.26
2.60	464	1912	3.12
2.70	422	1568	2.72
2.80	335	1317	2.93
2.90	356	1178	2.31
3.00	342	956	1.79
3.10	345	883	
3.20	311	749	
3.30	282	644	
3.40	290	588	
3.50	272	542	

Threshold	Bkg. CPM	82.7 NCi/g in 125 lbs. std. drum	Ratio Net counts/bkg.
3.60	284	461	
3.70	282	413	
3.80	273	434	
3.90	280	373	
4.00	253	369	
4.10	244	306	
4.20	260	328	
4.30	280	313	
4.40	272	339	
4.50	247	315	
4.60	240	298	
4.70	236	315	
4.80	236	302	
4.90	226	270	
5.00	230	287	
5.10	272	322	
5.20	248	292	
5.30	291	310	
5.40	243	290	
5.50	269	292	
5.60	242	286	
5.70	268	311	
5.80	260	290	
5.90	279	348	
6.00	251	289	
6.10	306	392	
6.20	613	901	
6.30	1596	1892	
6.40	2922	3411	
6.50	4542	4936	
6.60	5979	6438	
6.70	7968	8092	
6.80	9409	9642	
6.90	11054	11203	
7.00	12584	12853	
7.10	13789	13987	
7.20	14380	14488	
7.30	14433	15008	
7.40	14677	14924	
7.50	14731	15126	
7.60	14782	15088	
7.70	14547	14998	
7.80	14488	14882	
7.90	14683	14828	
8.00	14655	14750	

Threshold	Bkg. CPM	82.7 NCi/g in 125 lbs. std. drum	Ratio Net counts/bkg.
8.10	14580	14698	
8.20	14632	14598	
8.30	14185	14444	
8.40	14115	14467	
8.50	14150	14228	
8.60	13820	14108	
8.70	13618	14052	
8.80	13567	13793	
8.90	13467	13631	
9.00	13461	13734	
9.10	13475	13600	
9.20	13355	13327	
9.30	13007	13302	
9.40	12900	13205	
9.50	12717	13002	
9.60	12851	12968	
9.70	12846	12783	
9.80	12455	12872	
9.90	12350	12629	

From this data a threshold setting of 1.90 and a window setting of 0.70 was selected.

V. Detector Linearity

R_1 H.V. - 7.30 window in - 0.70 threshold 1.90 Energy Multiplier - 100 KEV.

0.488g Pu standard - FFTF pellet encased in brass placed in 1/2" thick 9 inch long lead columniator. See Figure #1.

VI. Construction of Dummy Loads of Combustible Waste

A. Assume uniform distribution of radioactive material in each waste drum. To simulate this with our standards each drum was divided into six load zones. See Figure #2.

B. Four dummy loads were constructed using plastic, pvc pipe, cardboard, tape, and wipes to fill in between these load zones with a net weight of 75 lbs., 125 lbs., 175 lbs., and 225 lbs. Each of these drums was then loaded from 2 NCi/g of waste to 100 NCi/g of waste and calibration curves plotted. See Figures #3, #4, #5, and #6.

C. To document response from a point source in zone A, B, and C the 125 lbs. standard was loaded with ≈ 20 NCi/g of waste. Source #42 and #43 were used containing 238,575,384 dpm alpha.

Zone A - center of drum - 9,459 net counts
Zone B - center of drum - 18,094 net counts
Zone C - center of drum - 19,750 net counts

D. After considering this data all combustible drums of waste will be packaged to a minimum of 75 lbs. and a maximum of 225 lbs. To ensure that the value assigned to each drum is in fact less than 82.7 NCi/g we will use the most restrictive calibration factor which was obtained from the 75 lbs. standard drum.

VII. Instructions for Packaging LSA Waste

A. KM-NC-10-82.

B. All packaged trash will be sorted with an Eberline E-500B with an open window GM tube. All packages with 0.3 mr/hr or greater will be handled as TRU waste. All packages less then 0.3 mr/hr will be handled as LSA waste.

C. To prevent shielding problems, metal and combustible waste must be separated. All metal will be surveyed with an alpha survey meter and all combustible will be counted in the LSA drum counter.

VIII. Instruction for Use of LSA Waste Drum Counter

A. Each day that the LSA waste drum counter is to be used:

R_1 1. The drum turn table must be timed to ensure it making 13 complete revolutions in 5.6 minutes.

R_1 2. Five source counts must be taken using the 78.4 NCi/g - 75 lbs. standard to verify the count system is operating properly and within a 95% confidence level twice daily.

R1 3. Three 5.6 minute background counts with a 0.0 NCi/g - 75 lbs. standard on turn table and the turn table rotating will be taken and averaged. This background will be used for all drums counted that day.

4. Pu Plant waste drum counter count sheet will be used to record all drum counts. See Figure #7.

5. New counts times calibration factor will be equal to NCi/g of waste. This will be multiplied by actual grams of waste in drum and converted to total g Pu.

6. At the first of each month a new CHI^2 control chart will be made.

7. After repair and at least yearly, a calibration to obtain a new calibration factor for this counter shall be required.

R1 8. All drums will be counted before being compacted and the net counts above background will be added to arrive at a value for the compacted drum. See Figure #8.

DETECTOR LINEAVITY CHECK

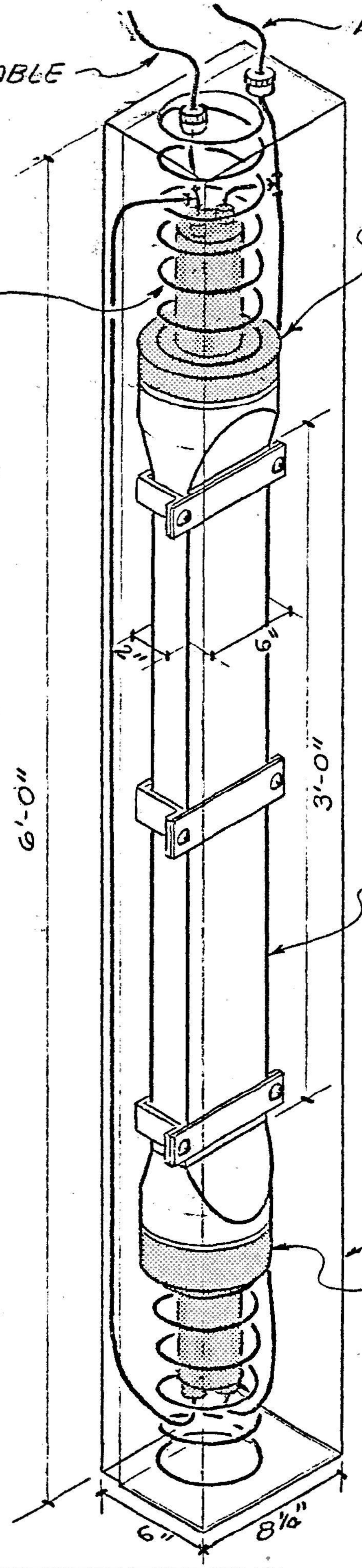
H.V. 7.45 Window in 0.70

Threshold 1.90 EM - 100 KEV

.4688g Pu standard

FFTF pellet encased in brass

Columinated in 1/2" lead columinator.



COUNTS/MINUTE

Top	9128 - 9065
Middle	10277 - 10094
Center	9196 - 9391
Middle	10323 - 10486
Bottom	9434 - 9359

L.S.A. DRUM COUNTER DETECTOR

Figure 1

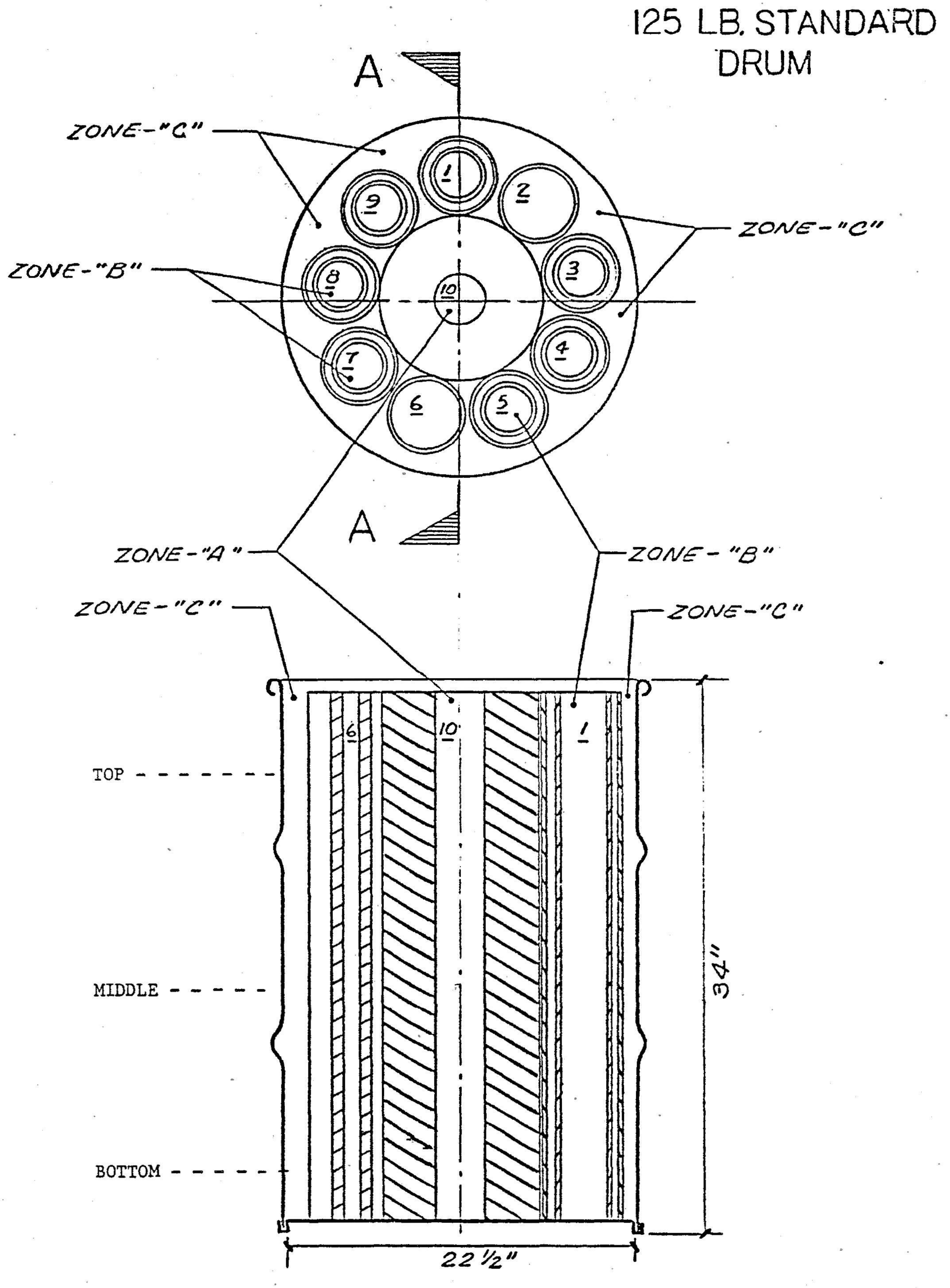
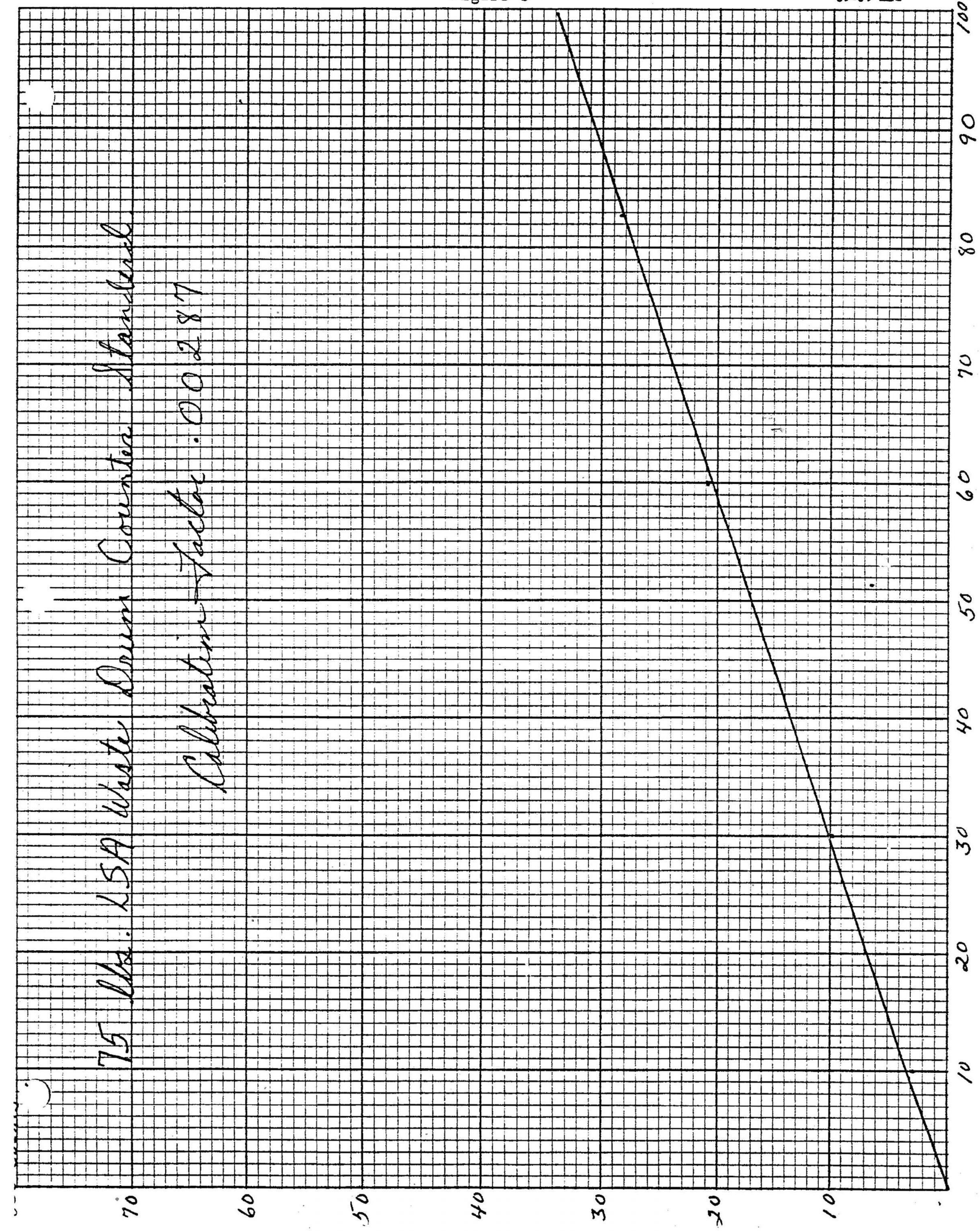


Figure 2

SECTION - A A

SCALE: 1½" = 1'-0"

Figure 3



75 Lbs. LSA Waste Drum Counter Standard
Calibration Factor .00287
10
20
30
40
50
60
70
80
90

Figure 3-1

LSA WASTE DRUM COUNTER 7-30-85

75# Std.

```
             GSBb
   352.00    ENT↑
 1.973232    GSBA
   396.00    ENT↑
 1.973232    GSBA
  2617.00    ENT↑
 9.393963    GSBA
  2660.00    ENT↑
 9.393963    GSBA
 11292.00    ENT↑
32.734408    GSBA
 10922.00    ENT↑
32.734409    GSBA
 29411.00    ENT↑
77.672911    GSBA
 29318.00    ENT↑
77.672911    GSBA
 31288.00    ENT↑
94.900331    GSBA
 31747.00    ENT↑
94.900331    GSBA
             GSBC

         0.99    ***
         1.34    ***
2.79950813-03    ***


             DSP8
             GSBC

   0.99056507    ***
   1.34150725    ***
   0.00279951    ***
```

0.00280 NCi/g/Count

Figure 4

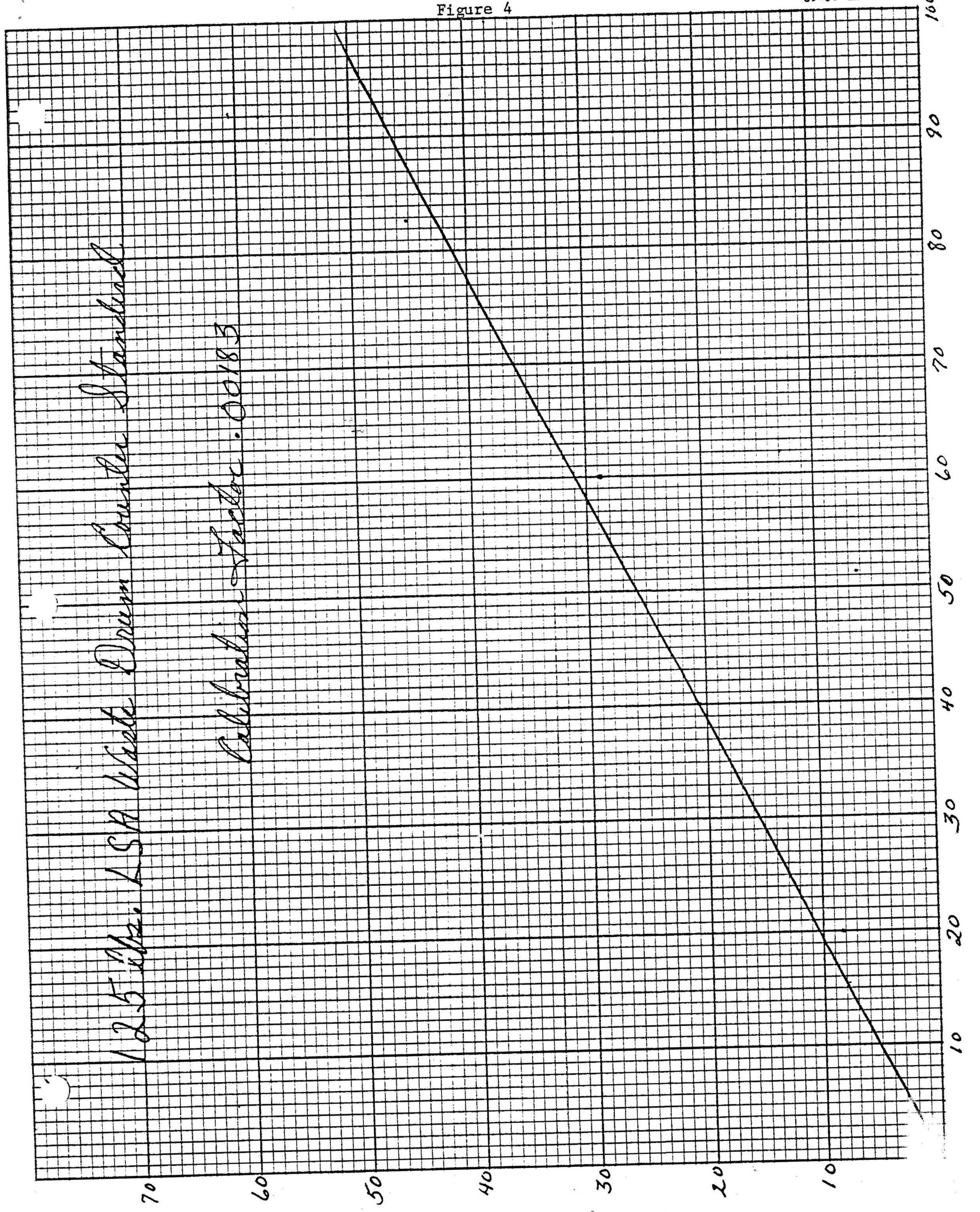

125 lbs LSA Waste Drum Counter Standard
Calibration Factor .00183
10
20
30
40
50
60
70
80
90
100 ml

Figure 5

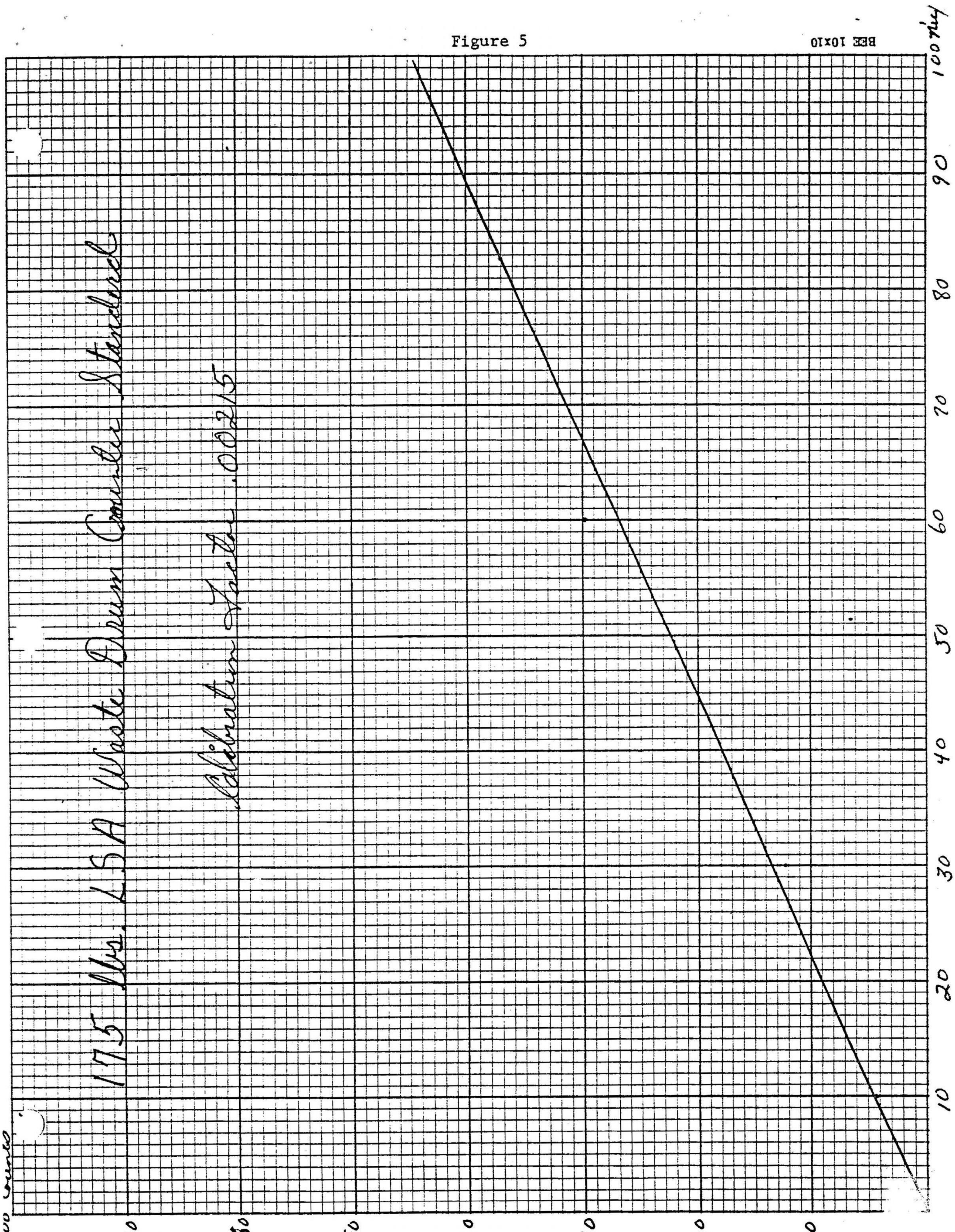
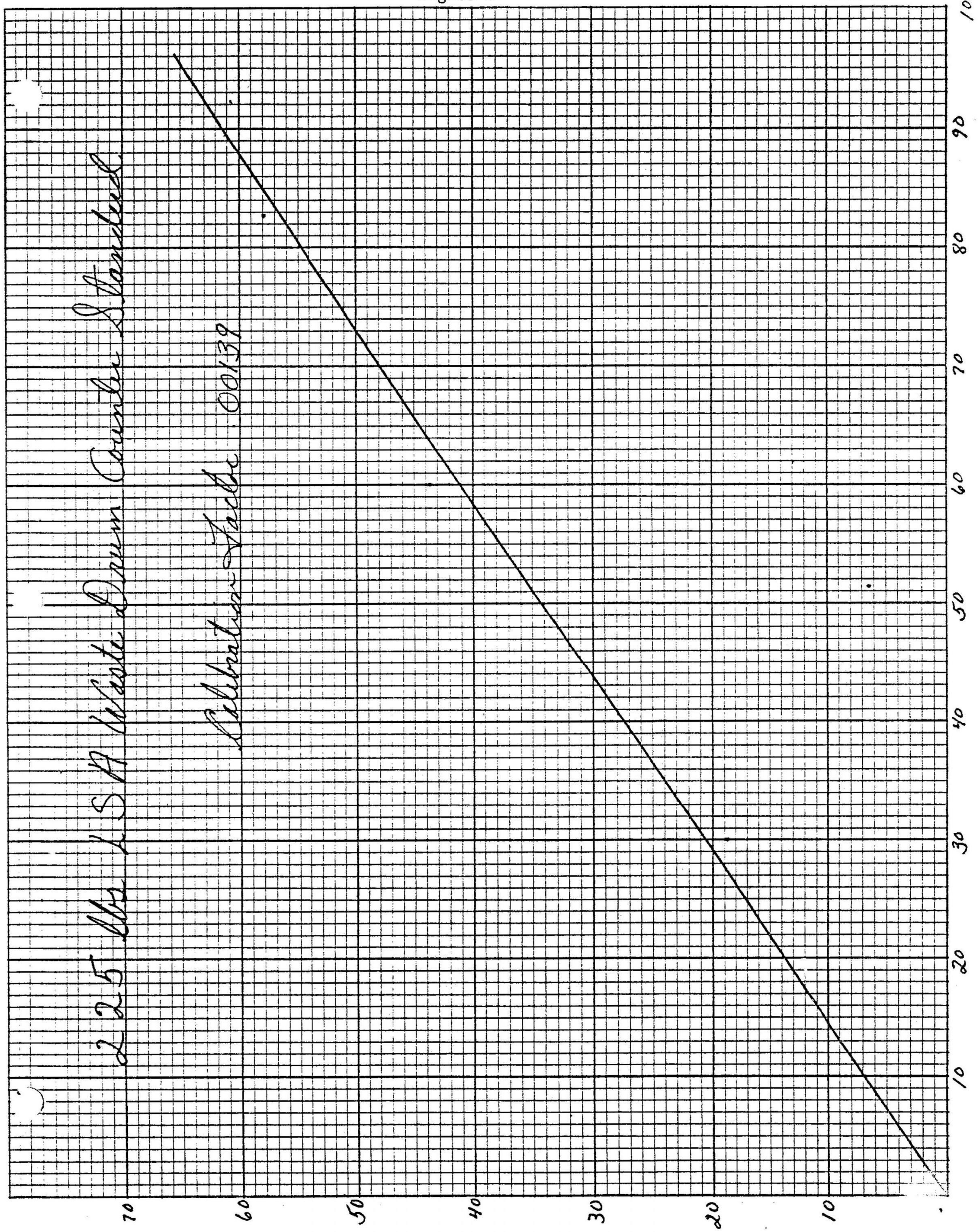

BEE 10x10
175 lbs. LSA Waste Drum Counter Standard
Calibration Factor .00215
1000 counts
70
60
50
40
30
20
10
90
80
70
60
50
40
30
20
10

Figure 6


225 lbs LSA Waste Drum Counter Standard
Calibration Factor .00139
10
20
30
40
50
60
70
80
90
100%
10
20
30
40
50
60
70

Pu PLANT LSA WASTE DRUM COUNTER COUNT SHEETS

DRUM NUMBER ____________ DATE ____________

DRUM GROSS WT. ______________ lbs. OPERATOR ________________

TARE WT. ______________ lbs.

NET WT. ______________ lbs. X 453.59 g/lbs = ________________ grams

H. V. 7.30 WINDOW 0.70 THRESHOLD 1.90

E. M. 100 KEV COUNT TIME 5.6 MINUTES

BKG. - 1 ______________

BKG. - 2 ______________

BKG. - 3 ______________

TOTAL ____________________ ÷ 3 = ______________ AVG. BKG.

GROSS COUNT - 1 ___________________

GROSS COUNT - 2 ___________________

TOTAL ___________________ ÷ 2 = ______________________ AVG. COUNT

\- __________________________ AVG. BKG.

_____________________ NET AVG. COUNT

.0028 CAL. FACTOR X NET AVG. COUNTS __________ = ____________ NCi/g
(78.4 Max.)

______________ GRAMS X ______________ NCi/g = ______________ NCi TOTAL

$$\frac{\text{NCi} \times 10^{-9}}{1.12 \text{ Ci/g}} = \_\_\_\_\_\_\_\_\_\_ \text{ g Pu}$$ or

__________________ g Pu

Figure 7

Pu PLANT LSA DRUM COUNTER COMPACTED DRUMS

DATE ______________ DRUM NUMBER ______________ OPERATOR ______________

COUNT #	NET AVG. COUNTS	
________	____________	GROSS WT. ______________
________	____________	TARE WT. ______________
________	____________	NET WT. ______________
________	____________	
________	____________	
________	____________	
________	____________	
________	____________	
TOTAL	____________	

TOTAL NET WT. ________ lbs. X 453.59 g/lb. = ______________ GRAMS

.0028 ________ CAL. FACTOR X TOTAL NET AVG. COUNTS ________ = __________NCI/g
(78.4 MAX.)

____________ GRAMS X ____________ NCi/g = ____________NCi TOTAL

$\frac{\text{NCi X } 10^{-9}}{1.12 \text{ Ci/g}}$ = __________ g Pu

or

______________ g Pu

Figure 8