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SAFEGUARDS CAPABILITIES
OF THE MATERIAL BALANCE
ACCOUNTING SYSTEMS OF THE PLUTONIUM
PROCESSING AND SCRAP RECOVERY
OPERATIONS AT HANFORD

L. F. Wirfs

June 1970

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by

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ABSTRACT

The measurement uncertainties in typical material balance systems of the plutonium processing and scrap recovery operations at Hanford are characterized in terms of general performance, intermediate improvement and general capability models. Both the random and the systematic components of error are identified for individual measurements. Material measurement errors inherently limit the control capabilities of material balance accounting systems.

The safeguards capabilities of material accounting are equated in terms of the probability of detecting a loss of material in MUF when material diversion actually occurs. An assessment is made of the detection capabilities of the material balance systems described in the study models.

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INTRODUCTION

The development of domestic and international safeguards programs to control the possession, use, and transfer of nuclear materials has aroused new interest in the control capabilities of material balance accounting systems. The protection of nuclear materials against diversions to unauthorized applications is a major objective of these safeguards programs. Material accounting systems indirectly detect diversion as losses of material when physical inventory quantities are periodically compared to accounting material balances. These differences are usually referred to as Material Unaccounted For (MUF). Capabilities for detecting losses of plutonium through MUF are analyzed in this report for the plutonium processing and the scrap recovery operations conducted by the Atlantic Richfield Hanford Company for the Atomic Energy Commission at Hanford. Although this study is oriented toward specific facilities and processes at Hanford, the findings of the study should have value to the design of safeguards systems for other plutonium processing plants.

THE BASIC PROBLEM

Material accounting records are subject to errors beyond the usual financial accounting experience because all material measurements are subject to some error. These measurement errors are an inherent cause of material imbalances in nuclear

materials accounting and a constant problem to the interpretation of the safeguards significance of MUF. The likelihood that a material balance will show a distinguishable loss of material when diversion occurs is directly related to the measurement uncertainties in the accounting source data. Because material accounting procedures cannot distinguish material losses from measurement errors, statistical procedures must be employed to assess objectively the significance of measurement errors and to test for material losses in MUF. A loss of material indicated by these tests must be carefully investigated for cause before the occurrence of diversion can be substantiated or disclaimed.

The characterization of the measurement uncertainties of MUF for the Plutonium Finishing plant was the first major objective of this study. An assessment of the material balance capabilities of the plant to detect diversion as material losses in MUF was the second objective of this investigation. The development of a quantitative background for, (1) conducting future safeguards studies and discussions, (2) for designing more sophisticated and definitive safeguards models, and (3) for planning future safeguards programs and activities was a secondary goal of this report.

A systems approach of analysis is used to show how the various elements of MUF relate to one another and to the final determination of the uncertainties of MUF. The basic measurement components of the material balance systems of the Plutonium Finishing plant are characterized and assembled into study models which are used to assess the safeguards capabilities of material balance accounting in the plant. General performance, intermediate improvement, and general capability models are presented for future program planning consideration. Based

upon the measurement uncertainties of MUF derived from the study models, statistical procedures are utilized to estimate thresholds and probabilities for detecting losses of plutonium at the plant. Although this study approach tends to oversimplify the general analysis problem, it does delineate the major subproblems of material balance measurement systems and promotes the optimization of systems regardless of the relative capabilities of their elements.

Reference to the absolute production rates and material throughput of the Plutonium Finishing plant is purposely omitted to permit the issuance of this report on an unclassified basis. No attempt is made to include nonmeasurement errors and operator mistakes in the considerations of this review. To do so would unduly inflate the measurement capability statistics of the material balance systems under study. All the statistical statements in this review are presented at the 95% confidence level unless otherwise noted.

SUMMARY AND CONCLUSIONS

Measurement errors inherently limit the safeguards capabilities of material balance accounting to detect diversion as losses of material in MUF. Material losses are difficult to detect through MF in the expected regions of measurement uncertainty. Both random and systematic errors contribute significantly to the measurement uncertainties of MUF for short material balance spans. The growth of measurement uncertainties in the material balance systems of the Plutonium Finishing plant is primarily the result of systematic errors in material transfer measurements. Hence, the long-term measurement uncertainties in MUF are dominated by systematic errors.

Plutonium nitrate measurements and the gamma-neutron counting of plutonium in scrap are the major sources of

measurement error in MF at the Plutonium Finishing plant. The accuracy of these measurements significantly affects the material balance capabilities of the plant to detect losses of plutonium. For material balance periods of small material throughput, the control of the size of the in-process inventories is also important to material balance performance.

The receipt of scrap from privately owned facilities without accurate verification of plutonium quantities at the Plutonium Finishing plant is a serious weakness in the safeguards control of privately processed material. If plutonium losses can be disguised as over-statements in scrap shipments, the usefulness of the material balance as a safeguards tool is greatly diminished, or even destroyed. At the present time, the accurate verification of scrap receipts is often impractical because of the physical form of the material or the limitations in existing measurement technology. Improvements in these areas would enhance the effectiveness of the safeguards program significantly.

MEASUREMENT CAPABILITIES

The current measurement capabilities of the Plutonium Finishing plant are summarized in Table 1 as typical uncertainties of MF under general performance conditions. These capabilities can be improved through better measurement quality control and the adoption of improved measurement methods and physical inventory practices. The expected results of a "best effort" approach are shown in the general capability cases. Under current operating conditions, the measurement uncertainties of MF at the Plutonium Reclamation facility are smaller than those of the Plutonium Processing facility in

TABLE 1. A Summary of Typical Measurement Uncertainties of MUF for the Plutonium Finishing Plant, 95% Confidence Level

<u>Material Throughput,</u> <u>kg</u>	<u>kg</u>	<u>Relative %</u>
<u>Plutonium Processing Facility</u>		
<u>General Performance</u>		
300	3.5	1.2
600	4.7	0.8
1,000	6.4	0.6
2,000	10.5	0.5
<u>General Capability</u>		
300	0.9	0.3
600	1.2	0.2
1,000	1.6	0.2
2,000	2.6	0.1
<u>Plutonium Reclamation Facility</u>		
<u>General Performance</u>		
50	1.7	3.4
100	2.9	2.9
170	4.3	2.5
330	7.6	2.3
<u>General Capability</u>		
50	0.8	1.6
100	1.2	1.2
170	1.9	1.1
330	3.4	1.0

NOTE: Relative percentages are related to material throughput. Equivalent time periods are shown for the two facilities.

terms of absolute quantities of plutonium for a given time period. This relationship is reversed under general capability conditions. For equal material throughput, the measurement capabilities of the Plutonium Processing facility

are superior. As illustrated in Table 1, the growth of measurement uncertainties in MUF is related to the increase of material throughput.

DETECTION CAPABILITIES

The safeguards capabilities of material balance accounting to detect diversion can be equated in terms of the probability of detecting a loss of material in MUF when diversion actually occurs. The probability of detecting material losses is dependent upon the size of the loss, the measurement uncertainty of MUF, and the risk assumed for mistaking measurement errors for material losses. Measurement uncertainties determine the minimum thresholds for detecting material losses under given test conditions. The current accounting detection capabilities of the Plutonium Finishing plant are summarized in Table 2 under general performance conditions. These capabilities can be improved under the "best effort" approach simulated in the general capability models. The differences in the measurement uncertainties of MUF outlined in Table 1 are responsible for these variations in detection capabilities. The probability of detecting the loss of a given quantity of plutonium decreases as material throughput increases.

The continuous growth of measurement uncertainties in time poses a serious safeguards problem because a series of small withdrawals of plutonium can be made over a period of time with little danger of detection through material accounting. Cumulatively, these removals can become a sizable diversion of material. Below the detection thresholds shown in Table 3, material may be withdrawn from the plant under the guise of measurement uncertainties with a sizable chance of success. The reduction of measurement uncertainties and a program of frequent physical inventories enhance the detection of material losses.

TABLE 2. The Probability of Detecting Plutonium Losses
Through MUF at the Plutonium Finishing Plant,
Type I Error of 5%

<u>Material Throughput, kg</u>	<u>Size of Loss, kg</u>			
	<u>2</u>	<u>4</u>	<u>6</u>	<u>10</u>
<u>Detection Probability, %</u>				
<u>Plutonium Processing Facility</u>				
<u>General Performance</u>				
300	30	73	96	100
600	21	52	82	100
1,000	15	34	59	93
2,000	10	19	31	61
<u>General Capability</u>				
300	100	100	100	100
600	96	100	100	100
1,000	80	100	100	100
2,000	46	92	100	100
<u>Plutonium Reclamation Facility</u>				
<u>General Performance</u>				
50	76	100	100	100
100	40	87	100	100
170	23	58	87	100
330	13	28	50	84
<u>General Capability</u>				
50	100	100	100	100
100	95	100	100	100
170	67	99	100	100
330	32	76	97	100

NOTE: Relative percentages are related to material throughput
Equivalent time periods are shown for the two facilities.

TABLE 3. Thresholds for Detecting Plutonium Losses
with a Probability of 80%*

<u>Material Throughput, kg</u>	<u>Minimum Loss Requirement</u>	
	<u>kg</u>	<u>Relative, %</u>
<u>Plutonium Processing Facility</u>		
<u>General Performance</u>		
300	4.4	1.5
600	5.8	1.0
1,000	8.0	0.8
2,000	13.0	0.7
<u>General Capability</u>		
300	1.1	0.4
600	1.5	0.3
1,000	2.0	0.2
2,000	3.2	0.2
<u>Plutonium Reclamation Facility</u>		
<u>General Performance</u>		
50	2.1	4.2
100	3.6	3.6
170	5.4	3.2
330	9.5	2.9
<u>General Capability</u>		
50	1.0	2.0
100	1.5	1.5
170	2.4	1.4
330	4.2	1.3

* A significance level of 5% is assumed for the test.
Equivalent time periods are shown for the two facilities.

SYSTEM DESCRIPTION

Seven material balance areas are utilized routinely to control the movement of plutonium in the Plutonium Finishing complex. Three are storage areas in which no plutonium

processing occurs so item accountability is used for material control. The plutonium processing operations are conducted in a single material balance area while the reclamation tasks are performed in three areas. Since two of the reclamation areas house pretreatment steps to the main solvent extraction process, all three of the areas are treated as a single material balance area for the purpose of this study. A simplified material flowsheet of the Plutonium Finishing accountability system is illustrated in Figure 1.

PLUTONIUM PROCESSING

A continuous flow process of oxalate precipitation, filtration, calcination, fluorination, and metal reduction is utilized to convert plutonium nitrate solution to plutonium metal of high purity. Product grade plutonium oxide is produced on demand from the calcination of plutonium oxalate. Other intermediate products are occasionally withdrawn on special order. Very little plutonium is discarded from these processes because nearly all of the scrap and waste materials are routed to the reclamation facility for plutonium recovery.

PLUTONIUM RECLAMATION

Most of the feed materials for the reclamation operation require some form of treatment prior to solvent extraction. Solid scrap and process residues are dissolved or leached for plutonium in pretreatment operations. Combustible materials are incinerated to place the material in a more desirable form for recovery. Process solutions are chemically treated to meet feed specifications for solvent extraction.

Plutonium is separated from most of its impurities in the solvent extraction process of the reclamation operation and concentrated as a nitrate solution scheduled for internal

FIGURE 1. A Simplified Material Balance Flowsheet of the Plutonium Finishing Operation

routing to the Plutonium Processing facility. Effluent streams are passed through an ion exchange system for plutonium removal prior to discharge to the environment.

MATERIAL TRANSFER MEASUREMENTS

The plutonium contents of material transfers are established in a number of different ways for material accounting purposes. The plutonium nitrate receipts of the Plutonium Processing facility are recorded at shippers' values and verified for plutonium composition prior to the start of processing operations. Many of these transfers originate from other facilities within the ARHCO complex at Hanford. Major shipper-receiver measurement differences are subject to investigation and accounting adjustment. The final products of the Plutonium Processing facility are weighed, sampled, and assayed for chemical and isotopic composition. Product batches of plutonium nitrate from the scrap recovery operations are measured for volume, sampled, and assayed for plutonium. Internally generated scrap and process wastes are regularly measured for plutonium prior to storage or disposal. Scrap shipments from other sites are provisionally entered into the accounting records at shippers' values after container identification because plutonium verification is frequently impossible or impractical. Shipping values can sometimes be substantiated by nondestructive measurements, or by process measurements performed after the dissolution or leaching steps of the reclamation operation. The regular transfer measurements in the Plutonium Finishing accountability system are described in greater detail in Table 4. Comprehensive quality control programs are maintained on a continuous schedule to monitor and control measurement performance.

TABLE 4 Typical Measurements in the Material Balance Systems
of the Plutonium Finishing Operation

Material Balance Component	Plutonium Measurement Methods		Single Measurement Uncertainty (95% CL), %
	Volume or Weight	Pu Assay	
<u>Pu (NO₃)₄ Input</u>			
1. Purex Plant Shipments	Solution Weight Specific Gravity	X-ray Absorption	2.4
2. Reclamation Recycle	Pneumatic Dip Tube and Recorder Specific Gravity	Differential Spectrophotometry	2.7
<u>Product</u>			
1. Plutonium Metal	Weight	By-Difference (Impurities) Spectrograph & Wet Chemical	0.06
2. Plutonium Oxide	Weight	Potentiometric Titration	0.26
<u>Scrap</u>			
1. Oxalate Supernate Miscellaneous Liquids	Pneumatic Dip Tube and Recorder Specific Gravity	Radioassay	8.7
2. Scrap Metal	Weight	By-Difference (Impurities)	2
3. Scrap Powder	Weight	Potentiometric Titration	11
4. Slag and Crucible		Neutron Count	35
5. Sweeping	---	Neutron Count	27
<u>Waste</u>			
1. Liquid	Pneumatic Dip Tube and Recorder Specific Gravity	Radioassay	120
2. Unrecoverable Solids and Residues	---	Neutron Count	35
3. Waste Cartons	---	Neutron Count	200

PHYSICAL INVENTORIES

Physical inventories are performed at regular time intervals under process-shutdown conditions. Processing vessels, equipment, and hoods are emptied and cleaned as physical conditions and time permit. A typical in-process inventory of the Plutonium Processing facility contains approximately 18 kg of plutonium which is measured with an uncertainty of 10%. The average in-process inventory of the Plutonium Reclamation facility contains 10 kg of plutonium measured with an uncertainty of 0.3%. Wide variations can occur under unusual circumstances.

THE STUDY MODELS

Representative material balance models were developed for the processing areas of the Plutonium Finishing plant from the composite selection of material flow, physical inventory, and material measurement data from the accountability and operating records of the plant. Hence, the study models are not designed to simulate the material activities or measurement systems of any particular production period or process campaign. Instead, they are provided as working models to study material balance relationships and safeguards capabilities.

General Performance Models

The general performance models were constructed to represent the existing material balance systems of the processing areas of the plant. Quality control data from the first half of calendar year 1969 were used extensively in the design of these models. Material balance data were collected primarily from the accounting records of fiscal year 1969. In all the study models, standard statistical procedures were utilized for the propagation of measurement errors. Detailed summaries of these models are presented in Appendix A.

General Capability Models

The general capability models were developed to represent the best performance that might be expected from highly developed material control and plutonium measurement systems operated in a manufacturing environment. Improvements were postulated within the bounds of available technology. Particular emphasis was placed on the upgrading of plutonium nitrate measurements, the reduction of errors in scrap measurements, and the control of physical inventory quantities.

Intermediate Improvement Models

The preliminary results of the safeguards study suggested that significant improvement in accountability performance might be achieved through a limited program of change that would not entail a complete overhaul of present practices. To study the relative merits of this approach, a series of models was developed to reflect the capabilities of a selective program of improvement. Foremost in this plan was the improvement of the plutonium nitrate measurements to an intermediate level of control which would be readily achievable under available technology. As a second innovation, the physical inventory uncertainties at the Plutonium Processing facility were lowered approximately 40% solely through the reduction of inventory quantities, as is indicated in Appendix B.

MEASUREMENT ERRORS

Estimates of the systematic and random errors associated with the sampling, weight, volume, and analytical components of material balance measurements were developed from quality control reports and technical documents. Conventional Gaussian propagation techniques were used to combine the

errors of individual material balance measurements into statements of measurement uncertainty for MUF. Complete independence of measurement errors was assumed for all the material accounting entries except those which were based upon item counts and prior measurements. In the latter instances, perfect correlation was assumed.

THE MEASUREMENT UNCERTAINTIES OF MUF

The sensitivity of a material balance system to detect material losses is directly related to the measurement uncertainties of MUF. A knowledge of the relative importance of the individual measurement points which contribute to the total uncertainty of MUF and an understanding of the interrelationships of the components of measurement errors in MUF are essential to the development of a "total systems" concept of control. A detailed analysis is presented of the major causes of measurement uncertainties in MUF for the processing areas previously described.

OVERALL SYSTEM UNCERTAINTIES

The measurement uncertainties in the current material balance system of the Plutonium Finishing plant can grow in time to quantities of significant safeguards significance, as illustrated in Tables 5 and 6. During comparable time periods, the measurement uncertainties of the Plutonium Processing facility are larger than those of the Plutonium Reclamation facility because material flows are greater. For equal material throughputs, the measurement capabilities of the Plutonium Processing facility are superior.

Current levels of uncertainty can be reduced approximately 40% under intermediate improvement conditions and 75% under general capability conditions at the Plutonium Processing

**TABLE 5. Typical Measurement Uncertainties of MUF
for the Plutonium Processing Operation,
95% Confidence Level**

<u>General Performance</u>	<u>kg</u>	<u>Relative, % (a)</u>
Throughput - 300 kg	3.5	1.2
600	4.7	0.8
1,000	6.4	0.6
2,000	10.5	0.5
<u>Intermediate Improvement</u>		
Throughput - 300 kg	2.0	0.7
600	2.8	0.5
1,000	3.8	0.4
2,000	6.7	0.3
<u>General Capability</u>		
Throughput - 300 kg	0.9	0.3
600	1.2	0.2
1,000	1.6	0.2
2,000	2.6	0.1

(a) Relative percentages are related to material throughput.

TABLE 6. Typical Measurement Uncertainties of MUF
for the Plutonium Reclamation Operator,,
95% Confidence Level

<u>General Performance</u>	kg	<u>Relative %</u> ^(a)
Throughput - 50 kg	1.7	3.4
100	2.9	2.9
170	4.3	2.5
330	7.6	2.3
<u>Intermediate Improvement</u>		
Throughput - 50 kg	1.2	2.4
100	1.9	1.9
170	2.9	1.7
330	5.4	1.6
<u>General Capability</u>		
Throughput - 50 kg	0.8	1.6
100	1.2	1.2
170	1.9	1.1
330	3.4	1.0

(a) Relative percentages are related to material throughput.

facility. Error reductions of approximately 30% and 55%, respectively, can be achieved at the Plutonium Reclamation facility through similar programs. Under general capability conditions, the measurement uncertainties of the two facilities can be individually maintained below 3.5 kg of plutonium for relatively long production spans. In these advanced systems, the measurement uncertainties of the Plutonium Processing facility actually fall below those of the Plutonium Reclamation facility for the longer material balance spans.

SYSTEMATIC AND RANDOM ERROR COMPARISONS

A better understanding of the error relationships in MF can be acquired through a comparative study of the random and systematic errors in material measurements. Random errors are usually larger than systematic errors for a single measurement. In a series of like measurements, systematic errors tend to be directional in nature and additive in time, while random errors tend to fluctuate in an unbiased manner about a sample mean. Consequently, the growth of systematic errors in time is usually much greater than that of random errors. At the Plutonium Finishing plant, the growth of systematic errors is four to seven times greater than that of random errors at the Plutonium Processing facility and two to five times greater at the Plutonium Reclamation facility.

The measurement uncertainties of MF at the Plutonium Finishing plant closely follow the classical pattern of error distribution, as shown in Tables 7 and 8. Initially, both systematic and random errors are important factors in the uncertainties of MUF. As the total system uncertainties grow with increased material throughput, the relative significance of random errors decreases and systematic errors become the controlling factor in the long-term accumulation of MF uncertainties.

TABLE 7. A Comparison of the Systematic and Random Components of Measurement Error in MUF at the Plutonium Processing Facility, 95% Confidence Level

	<u>Systematic, kg</u>	<u>Random, kg,</u>	<u>Total, kg</u>
<u>General Performance</u>			
Throughput - 300 kg	2.4	2.5	3.5
600	3.7	2.8	4.7
1,000	5.5	3.3	6.4
2,000	9.7	4.1	10.5
<u>Intermediate Improvement</u>			
Throughput - 300 kg	1.4	1.5	2.0
600	2.3	1.7	2.8
1,000	3.4	1.9	3.8
2,000	6.2	2.4	6.7
<u>General Capability</u>			
Throughput - 300 kg	0.5	0.8	0.9
600	0.9	0.8	1.2
1,000	1.3	0.9	1.6
2,000	2.3	1.1	2.6

TABLE 8. A Comparison of the Systematic and Random Components of Measurement Error in MUF at the Plutonium Reclamation Facility, 95% Confidence Level

	<u>Systematic, kg</u>	<u>Random, kg</u>	<u>Total, kg</u>
<u>General Performance</u>			
Throughput - 50 kg	1.1	1.3	1.7
100	2.1	2.0	2.9
170	3.5	2.6	4.3
330	6.7	3.6	7.6
<u>Intermediate Improvement</u>			
Throughput - 50 kg	0.8	0.9	1.2
100	1.5	1.2	1.9
170	2.6	1.4	2.9
330	5.0	2.0	5.4
<u>General Capability</u>			
Throughput - 50 kg	0.6	0.5	0.8
100	1.1	0.6	1.2
170	1.7	0.8	1.9
330	3.3	1.1	3.4

PHYSICAL INVENTORY AND MATERIAL TRANSFER COMPARISONS

The physical inventory uncertainties of MUF remain relatively static in time because each material balance contains solely a beginning and an ending inventory, regardless of the time span of the control period. Only small variations in the measurement uncertainties of physical inventories are encountered in a material balance area as long as the inventories are conducted under controlled conditions. When physical inventories are performed in an uncontrolled environment, wide variations in uncertainties are possible.

The cumulative measurement uncertainties of material transfers naturally increase with time as the number of transactions and physical measurements multiply. When physical inventory uncertainties are held relatively stable in time by material control procedures, the growth of measurement uncertainties in MUF must necessarily be related to material transfers. The relative importance of inventory uncertainties naturally decreases with time, as illustrated in Table 9.

The measurement uncertainties of MUF at the Plutonium Finishing plant are dominated by measurement errors in material transfers except for short production spans at the Plutonium Processing facility. In the latter cases, both material transfer and physical inventory errors contribute significantly to the total uncertainty of MUF.

SYSTEMATIC ERRORS

A comprehensive study of the systematic errors in material balance measurements shows clearly that material transfers are the major source of systematic errors in MUF at the Plutonium Finishing plant, as demonstrated in Table 10. In turn, systematic errors are the primary cause of measurement uncertainties in material transfers during a material balance period.

TABLE 9. The Comparative Material Balance Significance of Measurement Errors in Physical Inventories and Material Transfers, Relative Percent

	<u>Plutonium Processing</u>		<u>Plutonium Reclamation</u>	
	<u>Inventory</u>	<u>Transfer</u>	<u>Inventory</u>	<u>Transfer</u>
	%	%	%	%
<u>General Performance</u>				
Period A	54	46	8	92
B	30	70	4	96
C	16	84	2	98
D	6	94	<1	>99
<u>Intermediate Improvement</u>				
Period A	50	50	12	88
B	26	74	4	96
C	16	84	2	98
D	4	96	<1	>99
<u>General Capability</u>				
Period A	64	36	12	88
B	38	62	6	94
C	22	78	2	98
D	8	92	<1	>99

NOTE:

<u>Time Period</u>	<u>Material Throughput, kg</u>	
	<u>Processing</u>	<u>Reclamation</u>
A	300	50
B	600	100
C	1,000	170
D	2,000	330

TABLE 10. The Relative Contribution of Material Transfers and Physical Inventories to the Systematic Errors of MUF, Relative Percent

	<u>Plutonium Processing</u>		<u>Plutonium Reclamation</u>	
	<u>Inventory</u>	<u>Transfer</u>	<u>Inventory</u>	<u>Transfer</u>
	%	%	%	%
<u>General Performance</u>				
Period A	35	65	7	93
B	15	85	2	98
C	7	93	1	99
D	2	98	<1	>99
<u>Intermediate Improvement</u>				
Period A	37	63	13	87
B	14	86	4	96
C	6	94	1	99
D	2	98	<1	>99
<u>General Capability</u>				
Period A	32	68	6	94
B	10	90	2	98
C	5	95	1	99
D	2	98	<1	>99

NOTE:

<u>Time Period</u>	<u>Material Throughput, kg</u>	
	<u>Processine</u>	<u>Reclamation</u>
A	300	50
B	600	100
C	1,000	170
D	2,000	330

A further characterization of these errors is desirable to identify the specific location and the relative significance of each major component.

Plutonium Nitrate Measurements

Measurement errors in the plutonium nitrate shipped from the Purex chemical reprocesssing plant currently form the major source of systematic errors in material transfers at the Plutonium Processing facility, as illustrated in Table 11. Of secondary significance is the measurement of plutonium recycled from the Plutonium Reclamation facility. The analytical determination of the concentrations of plutonium in these process solutions is the greatest cause of error in these measurements. Better analytical accuracy can be acquired through the adoption of titrimetric methods of plutonium analysis. Improvements in sampling and weighing capabilities are also feasible. The attainment of the measurement accuracies postulated in Table 12 would reduce the measurement uncertainties of MUF at the Plutonium Processing facility approximately **35%** for the intermediate improvement case and 50% for the general capability case.

Scrap Measurements

Systematic errors in the measurement of slag and crucible scrap and hood sweepings are controlling factors in the accumulation of MUF uncertainties at the Plutonium Reclamation facility. Some improvement can be achieved through the upgrading of measurement quality control programs for gamma-neutron counting and through the use of advanced counting equipment and procedures. New technology may be required to reduce these measurement errors to desired levels of control.

Physical Inventories

Systematic errors in physical inventories have significance to the uncertainties of MUF only at the Plutonium Processing

TABLE 11. The Major Components of Systematic Errors
in Material Transfers, Relative Percent

<u>Plutonium Processing</u>	<u>General Performance</u>	<u>Intermediate Improvement</u>	<u>General Capability</u>
	%	%	%
External Plutonium Nitrate Receipts	85	65	21
Reclamation Plutonium Nitrate Recycle	4	8	15
Metal Button Shipments	1	2	14
Hood Sweepings	3	10	17
Oxalate Filtrate	2	3	10
Slag and Crucibles	1	2	6
Miscellaneous	4	10	17
<u>Plutonium Reclamation</u>			
Hood Sweepings	30	30	31
Slag and Crucibles	27	27	27
Waste Cartons	12	12	12
Product Nitrate	11	11	9
Skulls/Oxide	4	4	4
Oxalate Filtrate	4	4	4
Incinerator Ash	5	5	5
Miscellaneous	7	7	8

TABLE 12. Measurement Capabilities for Plutonium Nitrate Shipped from Chemical Reprocessing Plants

	<u>Relative Measurement Errors, 95% CL</u>		
	<u>Systematic, %</u>	<u>Random, %</u>	<u>Total, %</u>
<u>General Performance Model</u>			
Net Solution Weight	0.20	0.17	0.26
Sampling	0.41	0.95	1.03
Specific Gravity	0.06	0.26	0.27
Plutonium Concentration (g/liter)	0.61	2.00	2.09
Total Measurement	0.76	2.24	2.36
<u>Intermediate Improvement Model</u>			
Net Solution Weight	0.10	0.10	0.14
Sampling	0.25	0.50	0.56
Specific Gravity	0.04	0.15	0.16
Plutonium Concentration (g/liter)	0.30	1.00	1.04
Total Measurement	0.41	1.13	1.20
<u>General Capability Model</u>			
Net Solution Weight	0.01	0.06	0.06
Sampling	0.05	0.10	0.11
Plutonium Concentration (g/g)	0.10	0.30	0.32
Total Measurement	0.11	0.32	0.34

facility for short production spans. These errors occur primarily in the engineering estimates made of the plutonium holdup in operating hoods and processing equipment. The measurement of scrap powder is next in importance, as illustrated in the inventory models displayed in Appendix B. A reduction of inventory size is the best avenue of improvement because these heterogeneous materials are not amenable to good sampling.

RANDOM ERRORS

Random errors are particularly important to the determination of MUF for short production spans. This type of error is a major cause of fluctuations among individual material balance results.

Material Transfers

Material transfer measurements are the greatest source of random errors in MUF at the Plutonium Reclamation facility, as illustrated in Table 13. The neutron counting of waste cartons is the major contributor to this type of error. Overall improvement must come primarily through the development of reliable nondestructive measurement methods for determining the plutonium composition of scrap. New procedures for segregating and packaging scrap may be beneficial to this effort. A summary of the major components of random errors in material transfers at the Plutonium Finishing plant is presented in Table 14.

The measurement of plutonium nitrate shipped from the Purex plant is the major source of random errors in material transfers at the Plutonium Processing facility. Of secondary importance is the measurement of plutonium recycled from scrap recovery operations. These measurements control the long-term

TABLE 13. The Relative Contribution of Material Transfers and Physical Inventories to the Random Errors of MUF, Relative Percent

<u>General Performance</u>	<u>Plutonium Processing</u>		<u>Plutonium Reclamation</u>	
	<u>Inventory</u>	<u>Transfer</u>	<u>Inventory</u>	<u>Transfer</u>
	%	%	%	%
Period A	72	28	11	89
B	57	43	5	95
C	41	59	3	97
D	27	73	1	99
<u>Intermediate Capability</u>				
Period A	72	28	22	78
B	56	44	13	87
C	45	55	9	91
D	28	72	5	95
<u>General Capability</u>				
Period A	82	18	23	77
B	71	29	16	84
C	57	43	9	91
D	41	59	5	95

NOTE:

<u>Time Period</u>	<u>Material Throughput, kg</u>	
	<u>Processing</u>	<u>Reclamation</u>
A	300	500
B	600	100
C	1,000	170
D	2,000	330

**TABLE 14. The Major Components of Random Errors
in Material Transfers, Relative Percent**

<u>Plutonium Processing</u>	<u>General Performance</u>	<u>Intermediate Improvement</u>	<u>General Capability</u>
	%	%	%
External Plutonium Receipts	68	51	25
Internal Reclamation Recycle	15	12	14
Hood Sweepings	4	11	14
Oxalate Filtrate	1	2	6
Slag and Crucibles	1	2	3
Miscellaneous Scrap	11	22	38
<u>Plutonium Reclamation</u>			
Waste Cartons	70	60	51
Plutonium Nitrate Product	16	13	10
Hood Sweepings	6	13	15
Miscellaneous	8	14	24

accumulation of random errors in MUF under current programs. Once the plutonium nitrate measurements are improved, the measurement of scrap will become a significant factor in the control of random errors at the Plutonium Processing facility.

Physical Inventories

The short-term measurement uncertainties of MUF at the Plutonium Processing facility are dominated by random errors in the determination of physical inventory quantities. The relative significance of this type of error is lessened as the length of the control period is increased. Under existing

practices, physical inventory uncertainties have little impact on the results of MF at the Plutonium Reclamation facility.

The physical inventories of the Plutonium Processing facility are primarily estimated inventories because sizable quantities of material are held in inaccessible locations and in undesirable measurement forms. Kilograms of plutonium are usually left inside processing equipment of the calcination and fluorination operations. Every inventory contains some plutonium deposited on the sides of hoods and the walls of equipment. Engineering estimates are made of the quantities of plutonium held under these conditions. The regulation of inventory size is the main avenue of control for these uncertainties.

DIVERSION DETECTION CAPABILITIES

Measurement uncertainties complicate the interpretation of MF and limit the capabilities of material balance systems to detect diversion as losses of material. In an ideal error-free system, each underage of material in MUF would be positive evidence of a loss of material. Since nuclear materials accounting records inherently contain measurement errors, statistical tests must be employed to distinguish objectively material losses from measurement uncertainties. The effectiveness of these tests can be equated in terms of detection thresholds and probabilities.

DECISION RISKS

Two types of errors are encountered in making decisions regarding the significance of MUF. In one case, the occurrence of MUF may be interpreted as a loss of material when in reality, no loss occurs and the MUF is caused solely by

measurement uncertainties in the system (Type I error). In the other instance, the occurrence of MUF may be judged to be the sole result of measurement errors when in reality, a material loss actually occurs (Type II error). It is impossible to choose between the two alternatives without the risk of error. The suitability of a given level of risk depends on the consequences which may arise as the result of making a wrong decision.

ALARM CRITERIA

Decision rules pertaining to the detection of material losses are frequently related to the cumulative normal distribution function of the measurement errors in MUF. Alarm criteria are selected so that there is little chance of mistaking measurement errors for material losses. The risk of making such an error is often called the level of significance of the test. A choice of a 5% level of risk, for example, simply means that the alarm will place under suspicion all the MUF values which normally fall in the lower five percentile region of the cumulative normal distribution curve. Risk levels of 1, 5 and 10% are often used for material control purposes.

DETECTION PROBABILITIES

Standard statistical procedures for deriving the power of the test of a hypothesis can be utilized to determine probability functions for detecting material losses. Probability curves for the study models are graphically presented in Appendix C to provide the reader the capability of determining probability values for cases not covered in this report. A limited number of study tables are presented in Appendix D to supplement the examples provided in the following discussion.

Quantity of Diversion

The probability of detecting a real diversion as a loss of material in MF is dependent upon the quantity of material diverted, the measurement uncertainty of MUF, and the level of significance of the test employed. Large losses of material are naturally easier to detect than small losses under the same test conditions. The probability of detecting the loss of a fixed quantity of material in a given system decreases with time as material throughput increases, as illustrated in Tables 15 and 16. A plutonium loss of 6 kg at the Plutonium Processing facility, for example, can currently be detected with a probability of 96% for a production span of 300 kg but only 31% for a production period of 2,000 kg. Plutonium losses below 2 kg are, at present, very difficult to detect in the processing material balance areas of the Plutonium Finishing complex; losses of 15 kg have a high probability of detection. A better understanding of these relationships can be acquired from a study of the effects of measurement uncertainties on detection probabilities.

Measurement Uncertainties

The most important factor in the determination of detection capabilities is the measurement uncertainty of a material balance. The probability of detecting the loss of an absolute quantity of material increases as measurement uncertainties decrease. It is for this reason that the detection capabilities of the general capability cases are better than those of the other models. In a like sense, the probability of detecting a given loss of material decreases with time because measurement uncertainties grow with new additions of throughput. The current detection capabilities of the Plutonium Processing facility, for example, are greater

TABLE 15. The Probability of Detecting Material Losses
in the Plutonium Processing Operation,
Type I Error of 5%

<u>Process Throughput, kg</u>	<u>Size of Loss, kg</u>					
	<u>2</u>	<u>4</u>	<u>6</u>	<u>10</u>	<u>15</u>	<u>20</u>
	<u>Detection Probability, %</u>					
<u>General Performance</u>						
300	30	73	96	100	100	100
600	21	52	82	100	100	100
1,000	15	34	59	93	99	100
2,000	10	19	31	61	89	98
<u>Intermediate Improvement</u>						
300	63	99	100	100	100	100
600	42	89	100	100	100	100
1,000	27	67	93	100	100	100
2,000	15	33	56	91	100	100
<u>General Capability</u>						
300	100	100	100	100	100	100
600	96	100	100	100	100	100
1,000	80	100	100	100	100	100
2,000	46	92	100	100	100	100

All probability values are rounded to the nearest percent.

TABLE 16. The Probability of Detecting Material Losses
in the Plutonium Reclamation Operation,
Type I Error of 5%

<u>Process Throughput, kg</u>	<u>Size of Loss, kg</u>				
	2	4	6	10	15
	<u>Detection Probability, %</u>				
<u>General Performance</u>					
50	76	100	100	100	100
100	40	87	100	100	100
170	23	58	87	100	100
330	13	28	50	84	99
<u>Intermediate Improvement</u>					
50	95	100	100	100	100
100	68	100	100	100	100
170	39	87	99	100	100
330	19	44	72	98	100
<u>General Capability</u>					
50	100	100	100	100	100
100	95	100	100	100	100
170	67	99	100	100	100
330	32	76	97	100	100

All probability values are rounded to the nearest percent.

for a production span of 300 kg than for 2,000 kg because the measurement uncertainties of the shorter period are 3.5 kg as compared to 10.5 kg for the longer period. The continuous growth of measurement uncertainties in time poses a serious safeguards problem for material accounting because a series of small withdrawals can cumulatively grow into a sizable diversion of material with little danger of detection through MUF. The reduction of measurement uncertainties to minimal levels and frequent physical inventories are the best protection material balance accounting can offer against such activities.

Significance Level of the Test

The probability of detecting a material loss is significantly enhanced as higher risks are accepted for making Type I errors. The final size of the critical region for testing the significance of a loss of material in MUF is actually determined by the level of significance selected for the test. In the example cited in Table 17, it can be seen that significant improvements in detection capability can frequently be achieved by raising the level of significance of the test from 1% to 5%. Additional gains can be obtained by accepting a risk level of 10%. There are, of course, practical limitations to the false alarm levels which an organization can effectively assume. Levels above 10% are seldom found acceptable for material balance control.

DETECTION THRESHOLDS

The sensitivity of a material balance system to detect material losses is an important measure of safeguards effectiveness because statistical tests cannot completely distinguish material losses from measurement errors. Below detection thresholds, material can be diverted with little danger of detection through material accounting. In this regard,

TABLE 17. The Effects of Varying Type I Error Levels
on the Probability of Detecting Plutonium Losses
at the Plutonium Processing Facility^(a)

<u>Risk Level</u>	<u>Type I Errors</u>	<u>Amount of Plutonium Loss</u>				
		<u>2 kg</u>	<u>4 kg</u>	<u>6 kg</u>	<u>10 kg</u>	<u>15 kg</u>
		<u>Probability of Detection, %</u>				
<u>General Performance, %</u>						
	1	3	6	12	33	70
	5	10	19	31	61	89
	10	18	30	44	73	94
<u>Intermediate Improvement, %</u>						
	1	4	13	29	74	98
	5	15	33	56	91	100
	10	24	46	69	96	100
<u>General Capability, %</u>						
	1	21	77	99	100	100
	5	46	92	100	100	100
	10	59	96	100	100	100

^(a) A production span of 2,000 kg is assumed.
All probability values are rounded to the
nearest percent.

detection sensitivities are sometimes equated in terms of the alarm levels of MUF which are used to signal the presence of material losses. When detection probabilities are utilized as safeguards criteria, detection thresholds are often equated in terms of the smallest loss of material that can be detected at a given probability level. These two evaluation approaches are used to describe detection thresholds for the material balance systems in this study.

Alarm Levels

The growth of measurement uncertainties in time naturally increases the alarm levels of MUF which may be utilized to detect plutonium losses. Sizable quantities of MUF may be required to actuate alarm systems covering lengthy material balance periods. Under general performance conditions at the Plutonium Finishing plant, the alarm levels of short production spans are frequently less than 3.0 kg of plutonium for the 5 and 10% test levels, as illustrated in Tables 18 and 19. For a material throughput of 2,000 kg at the Plutonium Processing facility, the alarm limit becomes 8.6 kg of plutonium at the 5% test level. For an equivalent period of time at the Plutonium Reclamation facility, a MUF of 6.2 kg is required as an alarm limit. These values of MUF are of considerable safeguards significance. The higher rates of growth in the alarm levels of the Plutonium Reclamation facility are attributable to the random errors in the material transfers of that operation.

The alarm levels for the general performance cases can be reduced approximately 75% at the Plutonium Processing facility and 57% at the Plutonium Reclamation facility under conditions postulated for the general capability models. Reductions of approximately 40% and 30%, respectively, can be

**TABLE 18. Alarm Levels for Detecting Plutonium Losses
at the Plutonium Processing Facility**

<u>Process Throughput, kg</u>	<u>Level of Significance of the Test</u>		
	<u>1%</u>	<u>5%</u>	<u>10%</u>
	<u>Alarm Values, kg</u>		
<u>General Performance</u>			
300	4.1	2.9	2.2
600	5.5	3.9	3.0
1,000	7.4	5.3	4.1
2,000	12.2	8.6	6.7
<u>Intermediate Improvement</u>			
300	2.3	1.6	1.3
600	3.3	2.3	1.8
1,000	4.4	3.1	2.4
2,000	7.8	5.5	4.3
<u>General Capability</u>			
300	1.0	0.7	0.6
600	1.4	1.0	0.8
1,000	1.9	1.3	1.0
2,000	3.0	2.1	1.7

**TABLE 19. Alarm Levels for Detecting Plutonium Losses
at the Plutonium Reclamation Facility**

	Level of Significance of the Test		
<u>Process Throughput, kg</u>	1%	5%	10%
	<u>Alarm Values, kg</u>		
<u>General Performance</u>			
50	2.0	1.4	1.1
100	3.4	2.4	1.9
170	5.0	3.5	2.8
330	8.8	6.2	4.9
<u>Intermediate Improvement</u>			
50	1.4	1.0	0.8
100	2.2	1.6	1.2
170	3.4	2.4	1.9
330	6.3	4.4	3.5
<u>General Capability</u>			
50	0.9	0.7	0.5
100	1.4	1.0	0.8
170	2.2	1.6	1.2
330	4.0	2.8	2.2

obtained under intermediate improvement conditions. Alarm limits of 2 kg are feasible under general capability conditions for production runs as long as 2,000 kg at the Plutonium Processing facility. Limits in the vicinity of 2.5 kg are possible for scrap recovery throughputs of 330 kg. At the 5% test level under general capability conditions, it is estimated that alarm limits below 5 kg are attainable for material balance spans up to 5,000 kg of plutonium for the nitrate conversion process and 600 kg for the scrap recovery operation.

Probability Levels

In using detection probabilities as safeguards criteria, it is important to consider the capabilities of systems to detect small losses of material. The measurement uncertainties in a system may be too large to permit the detection of small, but strategically significant, losses of material with the desired level of protection. As an example of existing safeguards capabilities, threshold quantities for the 80% probability level are listed in Table 20 for the study cases. Threshold values for the 50, 70, 80, and 90% probability levels are summarized in Appendix E. Losses of material smaller than the threshold values cannot be detected with the desired level of probability unless the measurement uncertainties in MUF are reduced or the risk of making Type I errors is increased. The reduction of measurement uncertainties is the most effective procedure for lowering threshold levels.

Detection thresholds are adversely affected by increases in material throughput. For the longer production spans, sizable losses of material must occur before high degrees of detection probability are attainable under general performance conditions. At the Plutonium Processing facility, for example,

**TABLE 20. Thresholds for Detecting Plutonium Losses
with a Probability of 80%**

	<u>Minimum Loss Requirement</u>	
	<u>Plutonium Processing</u>	<u>Plutonium Reclamation</u>
<u>General Performance</u>	kg (%)	kg (%)
Period A	4.4 (1.5)	2.1 (4.2)
B	5.8 (1.0)	3.6 (3.6)
C	8.0 (0.8)	5.4 (3.2)
D	13.0 (0.7)	9.5 (2.9)
<u>Intermediate Improvement</u>		
Period A	2.5 (0.8)	1.5 (3.0)
B	3.5 (0.6)	2.4 (2.4)
C	4.9 (0.5)	3.6 (2.1)
D	8.3 (0.4)	6.7 (2.0)
<u>General Capability</u>		
Period A	1.1 (0.4)	1.0 (2.0)
B	1.5 (0.3)	1.5 (1.5)
C	2.0 (0.2)	2.4 (1.4)
D	3.2 (0.2)	4.2 (1.3)

NOTE:

A significance level of 5% is assumed for the test.

<u>Process Period</u>	<u>Material Throughput, kg</u>	
	<u>Processing</u>	<u>Reclamation</u>
A	300	50
B	600	100
C	1,000	170
D	2,000	330

plutonium losses must total at least 13 kg for a production span of 2,000 kg before a detection probability of 80% can be acquired. Kilogram quantities of plutonium can be withdrawn or lost from the system with little chance of detection by material accounting for even short periods of time. Under general performance conditions, detection thresholds of the Plutonium Reclamation facility fall in the general range of 3 to 4% of material throughput.

The detection thresholds of the Plutonium Finishing plant can be reduced several fold through the adoption of improved measurement methods and inventory practices. Under general capability conditions, the detection threshold of the Plutonium Processing facility can be reduced from 13.0 to 3.2 kg at a detection probability of 80% for a production span of 2,000 kg. Long-term detection thresholds in the vicinity of 0.15% of throughput are attainable at the Plutonium Processing facility. For a production span of 5,000 kg, it is estimated that material losses as small as 7 kg can be detected with a probability of 80%. Under general capability conditions for a given period of time, the detection capabilities of the Plutonium Processing facility are equivalent or better than those of the Plutonium Reclamation facility, in absolute quantities of plutonium. It is doubtful whether the long-term detection thresholds can be reduced below 1.0 percent of throughput for the scrap recovery operations in the near future.

SCRAP STORAGE

The storage of scrap for extended periods of time at the Plutonium Finishing complex has other diversion detection implications aside from the measurement uncertainties of MUF. The size of the scrap inventory often exceeds the total

plutonium throughput of an entire material balance period. The measurement uncertainty of the scrap inventory is usually several times greater than the measurement uncertainty of MUF. Because these materials are physically inventoried on an item identification - prior measurement basis, no new measurements are performed for physical inventory purposes and no measurement uncertainties are added to the MUF equation. In fact, no MUF is generated unless an item is lost or miscounted on inventory. Nevertheless, the uncertainty of the material contents of the inventory is sizable and of extensive safeguards significance.

Limitations in the verification of scrap receipts at the Plutonium Finishing plant may provide the shippers of scrap, and others, opportunities to hide material losses and diversion with little danger of detection through their material accounting systems. At the Plutonium Finishing plant, scrap materials are usually received, stored, and eventually moved to processing areas on the basis of shippers' measurements or estimates. Accurate verification of the plutonium contents of scrap at the time of receipt is often impossible or impractical because of the physical form of the material or limitations in existing measurement technology. Consequently, errors in the shippers' values may go undetected for long periods of time. Under the guise of overstated transfer quantities for scrap, plutonium losses and diversion at the site of scrap generation may be hidden with little fear of detection through MUF. In-transit diversion may also go undetected because of verification limitations.

A control system of containment, surveillance, and accountability has been successfully used within the nuclear complexes of the government to protect nuclear materials

against diversion. For many years, most of the collected scrap at the Plutonium Finishing plant was generated internally and stored under direct government supervision. External scrap was received primarily from government owned and contractor operated facilities which were under the direct security and operating control of the Atomic Energy Commission. Movements of material between sites were directly guarded or carefully controlled by government personnel. Consequently, there was little opportunity for the physical diversion of material without detection.

The receipt of scrap from privately owned and operated facilities poses new problems to the control of nuclear materials. No longer does the government have primary control over the security, production, and management of nuclear materials in the facilities from which scrap is generated. Instead, great reliance must be placed on the periodic reporting of material balance status to detect unusual losses of material. If material losses and diversion can be disguised in the transfer of scrap to the government or a third party, the usefulness of the material balance as a safeguards tool in the private sector of the industry is greatly diminished, or destroyed. Although greater attention is now being directed to the verification of scrap receipts at the Plutonium Finishing plant, verification capabilities are still severely limited. This lack of verification capability for scrap must be considered a serious weakness in the safeguards control of nuclear materials. Many suggestions, including the placement of scrap in measurable forms for shipment and storage, the limitation of the size of scrap accumulations, the rapid recovery of scrap, the selective processing of scrap to acquire feedback recovery data, and the development of improved nondestructive testing methods merit consideration in the planning of future programs.

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APPENDIX A

MODELS

MATERIAL BALANCE MEASUREMENT UNCERTAINTIES

TABLE A-1. General Performance Model of Measurement Uncertainties
In Plutonium Processing Material Balance, (a)
300 kg Throughput

	Quantity, kg	Measurement Errors ^(b)			Fraction of Total Variance, %
		Systematic, kg	Random, kg	Total, kg	
A. Beginning Inventory	18	1.0	1.5	1.8	27
B. Receipts:					
External Nitrate	255	1.9	1.1	2.2	40
Internal Nitrate	45	0.3	0.5	0.6	3
C. Removals:					
Metal Buttons	255	0.1	<0.1	0.1	<1
Oxide Powder	26	<0.1	<0.1	<0.1	<1
Oxalate Filtrate	6	0.2	0.1	0.2	<1
Metal Scrap	3	<0.1	<0.1	<0.1	<1
Slag and Crucibles	3	0.2	0.1	0.2	<1
Sweepings	3	0.3	0.3	0.4	1
Misc. Scrap	3	0.3	0.4	0.5	2
Measured Waste	<0.1	<0.1	<0.1	<0.1	<1
D. Book Inventory (A+B+C)	19	2.2	2.0	3.0	73
E. Physical Inventory	18	1.0	1.5	1.8	27
F. Material Unaccounted For	1	2.4	2.5	3.5	
(Throughput, %)	0.3%	0.8%	0.8%	1.2%	

a. Includes only the processing areas.

b. Confidence Level, 95%.

TABLE A-2. General Performance Model of Measurement Uncertainties
In Plutonium Processing Material Balance, (a)

600 kg Throughput

	Quantity, kg	Measurement Errors ^(b)			Fraction of Total Variance, %
		Systematic, kg	Random, kg	Total, kg	
A. Beginning Inventory	18	1.0	1.5	1.8	15
B. Receipts:					
External Nitrate	510	3.2	1.6	3.6	59
Internal Nitrate	90	0.7	0.7	1.0	5
C. Removals:					
Metal Buttons	510	0.3	<0.1	0.3	<1
Oxide Powder	52	0.1	<0.1	0.1	<1
Oxalate Filtrate	12	0.4	0.2	0.5	1
Metal Scrap	6	<0.1	<0.1	<0.1	<1
Slag and Crucibles	6	0.3	0.1	0.3	<1
Sweepings	6	0.6	0.4	0.7	2
Misc. Scrap	6	0.6	0.5	0.8	3
Measured Waste	<0.1	<0.1	<0.1	<0.1	<1
D. Book Inventory (A+B+C)	20	3.6	2.4	4.3	85
E. Physical Inventory	18	1.0	1.5	1.8	15
F. Material Unaccounted For	2	3.7	2.8	4.7	
(Throughput, %)	0.3%	0.6%	0.5%	0.8%	

a. Includes only the processing areas.

b. Confidence Level, 95%.

TABLE A-3. General Performance Model of Measurement uncertainties
In Plutonium Processing Material Balance, (a)
1000 kg Throughput

	Quantity, kg	Measurement Errors ^(b)			Fraction of Total Variance, %
		Systematic, kg	Random, kg	Total, kg	
A. Beginning Inventory	18	1.0	1.5	1.8	8
B. Receipts:					
External Nitrate	850	4.9	2.1	5.3	70
Internal Nitrate	150	1.1	1.0	1.5	6
C. Removals:					
Metal Buttons	850	0.4	<0.1	0.4	<1
Oxide Powder	87	0.1	<0.1	0.1	<1
Oxalate Filtrate	20	0.7	0.2	0.7	1
Metal Scrap	10	0.1	<0.1	0.1	<1
Slag and Crucibles	10	0.5	0.2	0.5	1
Sweepings	10	1.0	0.5	1.1	3
Misc. Scrap	10	1.0	0.7	1.2	3
Measured Waste	<0.1	<0.1	<0.1	<0.1	<1
D. Book Inventory (A+B+C)	21	5.4	2.9	6.1	92
E. Physical Inventory	18	1.0	1.5	1.8	8
F. Material Unaccounted For	3	5.5	3.3	6.4	
(Throughput, %)	0.3%	0.6%	0.3%	0.6%	

a. Includes only the processing areas.

b. Confidence Level, 95%.

TABLE A-4. General Performance Model of Measurement ^{unc}ertainties
In Plutonium Processing Material Balance, (a)
2000 kg Throughput

	Quantity, kg	Measurement Errors (b)			Fraction of Total Variance, %
		Systematic, kg	Random, kg	Total, kg	
A. Beginning Inventory	18	1.0	1.5	1.8	3
B. Receipts:					
External Nitrate	1700	8.7	2.9	9.2	76
Internal Nitrate	300	2.2	1.4	2.6	6
C. Removals:					
Metal Buttons	1700	0.9	<0.1	0.9	1
Oxide Powder	174	0.2	<0.1	0.2	<1
Oxalate Filtrate	40	1.4	0.3	1.4	2
Metal Scrap	20	0.1	0.1	0.1	<1
Slag and Crucibles	20	1.0	0.2	1.0	1
Sweepings	20	2.0	0.6	2.1	4
Misc. Scrap	20	2.0	1.0	2.2	4
Measured Waste	0.1	<0.1	<0.1	<0.1	<1
D. Book Inventory (A+B+C)	23.9	9.7	3.8	10.4	97
E. Physical Inventory	18	1.0	1.5	1.8	3
F. Material Unaccounted For	5.9	9.7	4.1	10.5	
(Throughput, %)	0.3%	0.5%	0.2%	0.5%	

a. Includes only the processing areas.

b. Confidence Level, 95%.

TABLE A-5. Intermediate Improvement Model of Measurement Uncertainties
In Plutonium Processing Material Balance, (a)

300 kg Throughput

	Quantity, kg	Measurement Errors (b)			Fraction of Total Variance, %
		Systematic, kg	Random, kg	Total, kg	
A. Beginning Inventory	10	0.6	0.9	1.0	25
B. Receipts:					
External Nitrate	255	1.0	0.6	1.2	34
Internal Nitrate	45	0.3	0.3	0.4	4
C. Removals:					
Metal Buttons	255	0.1	<0.1	0.1	<1
Oxide Powder	26	<0.1	<0.1	<0.1	<1
Oxalate Filtrate	6	0.2	0.1	0.2	1
Metal Scrap	3	<0.1	<0.1	<0.1	<1
Slag and Crucibles	3	0.2	0.1	0.2	1
Sweepings	3	0.3	0.3	0.4	4
Misc. Scrap	3	0.3	0.4	0.5	6
Measured Waste	<0.1	<0.1	<0.1	<0.1	<1
D. Book Inventory (A+B+C)	11	1.3	1.2	1.8	75
E. Physical Inventory	10	0.6	0.9	1.0	25
F. Material Unaccounted For	1	1.4	1.5	2.0	
(Throughput, %)	0.3%	0.5%	0.5%	0.7%	

a. Includes only the processing areas.

b. Confidence Level, 95%.

**TABLE A-6. Intermediate Improvement Model of Measurement Uncertainties
In Plutonium Processing Material Balance^(a)**

600 kg Throughput

	Quantity, kg	Measurement Errors ^(b)			Fraction of Total Variance, %
		Systematic, kg	Random, kg	Total, kg	
A. Beginning Inventory	10	0.6	0.9	1.0	13
B. Receipts:					
External Nitrate	510	1.7	0.8	1.9	47
Internal Nitrate	90	0.5	0.4	0.7	7
C. Removals:					
Metal Buttons	510	0.3	<0.1	0.3	1
Oxide Powder	52	0.1	<0.1	0.1	<1
Oxalate Filtrate	12	0.3	0.2	0.4	3
Metal Scrap	6	<0.1	<0.1	<0.1	<1
Slag and Crucibles	6	0.3	0.1	0.3	1
Sweepings	6	0.6	0.4	0.7	7
Misc. Scrap	6	0.6	0.5	0.8	8
Measured Waste	<0.1	<0.1	<0.1	<0.1	<1
D. Book Inventory (A+B+C)	12	2.2	1.4	2.6	87
E. Physical Inventory	10	0.6	0.9	1.0	13
F. Material Unaccounted For	2	2.3	1.7	2.8	
(Throughput, %)	0.3%	0.4%	0.3%	0.5%	

a. Includes only the processing areas.

b. Confidence Level, 95%.

TABLE A-7. Intermediate Improvement Model of Measurement Uncertainties
In Plutonium Processing Material Balance ^(a)

1000 kg Throughput

	Quantity, kg	Measurement Errors ^(b)			Fraction of Total Variance, %
		Systematic, kg	Random, kg	Total, kg	
A. Beginning Inventory	10	0.6	0.9	1.0	8
B. Receipts:					
External Nitrate	850	2.6	1.0	2.8	52
Internal Nitrate	150	0.9	0.5	1.0	8
C. Removals:					
Metal Buttons	850	0.4	<0.1	0.4	1
Oxide Powder	87	0.1	<0.1	0.1	<1
Oxalate Filtrate	70	0.8	0.7	0.5	2
Metal Scrap	10	0.1	<0.1	0.1	<1
Slag and Crucibles	10	0.8	0.2	0.5	2
Sweepings	10	1.0	0.5	1.1	9
Misc. Scrap	10	1.0	0.7	1.2	10
Measured Waste	<0.1	<0.1	<0.1	<0.1	<1
D. Book Inventory (A+B+C)	13	3.3	1.7	3.7	93
E. Physical Inventory	10	0.6	0.9	1.0	8
F. Material Unaccounted For	3	3.4	1.9	3.8	
(Throughput, %)	0.3%	0.3%	0.2%	0.4%	

a. Includes only the processing areas.

b. Confidence Level, 95%.

TABLE A-8. Intermediate Improvement Model of Measurement Uncertainties
In Plutonium Processing Material Balance, (a)

2000 kg Throughput

	Quantity, kg	Measurement Errors ^(b)			Fraction of Total Variance, %
		Systematic, kg	Random, kg	Total, kg	
A. Beginning Inventory	10	0.6	0.9	1.0	2
B. Receipts:					
External Nitrate	1700	4.9	1.5	5.1	59
Internal Nitrate	300	1.7	0.7	1.8	7
C. Removals:					
Metal Buttons	1700	0.9	<0.1	0.9	2
Oxide Powder	174	0.2	<0.1	0.2	<1
Oxalate Filtrate	40	1.1	0.2	1.4	5
Metal Scrap	20	0.1	0.1	0.1	<1
Slag and Crucibles	20	1.0	0.2	1.0	2
Sweepings	20	2.0	0.6	2.1	10
Misc. Scrap	20	2.0	1.0	2.2	11
Measured Waste	0.1	<0.1	<0.1	<0.1	<1
D. Book Inventory (A+B+C)	15.9	6.2	2.2	6.6	98
E. Physical Inventory	10	0.6	0.9	1.0	2
F. Material Unaccounted For	5.9	6.2	2.4	6.7	
(Throughput, %)	0.3%	0.3%	0.1%	0.3%	

a. Includes only the processing areas.

b. Confidence Level, 95%.

TABLE A-9. General Capability Model of Measurement Uncertainties
In Plutonium Processing Material Balance, (a)

300 kg Throughput

	Quantity, kg	Measurement Errors (b)			Fraction of Total Variance, %
		Systematic, kg	Random, kg	Total, kg	
A. Beginning Inventory	4	0.2	0.5	0.5	32
B. Receipts:					
External Nitrate	255	0.3	0.2	0.3	11
Internal Nitrate	45	0.1	0.1	0.2	5
C. Removals:					
Metal Buttons	255	0.1	<0.1	0.1	1
Oxide Powder	26	<0.1	<0.1	<0.1	1
Oxalate Filtrate	6	0.1	0.1	0.1	1
Metal Scrap	3	<0.1	<0.1	<0.1	<1
Slag and Crucibles	3	0.1	<0.1	0.1	1
Sweepings	3	0.2	0.1	0.2	5
Misc. Scrap	3	0.2	0.2	0.3	11
Measured Waste	<0.1	<0.1	<0.1	<0.1	<1
D. Book Inventory (A+B+C)	5	0.5	0.6	0.7	68
E. Physical Inventory	4	0.2	0.5	0.5	32
F. Material Unaccounted For	1	0.5	0.8	0.9	
(Throughput, %)	0.3%	0.2%	0.3%	0.3%	

a. Includes only the processing areas.

b. Confidence Level, 95%.

TABLE A-10. General Capability Model of Measurement Uncertainties
In Plutonium Processing Material Balance, (a)
600 kg Throughput

	Quantity, kg	Measurement Errors ^(b)			Fraction of Total Variance, %
		Systematic, kg	Random, kg	Total, kg	
A. Beginning Inventory	4	0.2	0.5	0.5	19
B. Receipts:					
External Nitrate	510	0.5	0.2	0.5	19
Internal Nitrate	90	0.3	0.1	0.3	6
C. Removals:					
Metal Buttons	510	0.3	<0.1	0.3	6
Oxide Powder	52	0.1	<0.1	0.1	1
Oxalate Filtrate	12	0.2	0.1	0.2	3
Metal Scrap	6	<0.1	<0.1	<0.1	<1
Slag and Crucibles	6	0.2	0.1	0.2	3
Sweepings	6	0.3	0.2	0.4	12
Misc. Scrap	6	0.3	0.3	0.4	12
Measured Waste	<0.1	<0.1	<0.1	<0.1	<1
D. Book Inventory (A+B+C)	6	0.9	0.7	1.1	81
E. Physical Inventory	4	0.2	0.5	0.5	19
F. Material Unaccounted For	2	0.9	0.8	1.2	
(Throughput, %)	0.3%	0.2%	0.1%	0.2%	

a. Includes only the processing areas.

b. Confidence Level, 95%.

TABLE A-11. General Capability Model of Measurement Uncertainties
In Plutonium Processing Material Balance, (a)

1000 kg Throughput

	Quantity, kg	Measurement Errors ^(b)			Fraction of Total Variance, %
		Systematic, kg	Random, kg	Total, kg	
A. Beginning Inventory	4	0.2	0.5	0.5	11
B. Receipts:					
External Nitrate	850	0.6	0.3	0.7	22
Internal Nitrate	150	0.5	0.2	0.5	11
C. Removals:					
Metal Buttons	850	0.4	<0.1	0.4	7
Oxide Powder	87	0.1	<0.1	0.1	<1
Oxalate Filtrate	20	0.4	0.1	0.4	7
Metal Scrap	10	<0.1	<0.1	<0.1	<1
Slag and Crucibles	10	0.3	0.1	0.3	4
Sweepings	10	0.5	0.2	0.5	11
Misc. Scrap	10	0.5	0.4	0.6	16
Measured Waste	<0.1	<0.1	<0.1	<0.1	<1
D. Book Inventory (A+B+C)	7	1.3	0.8	1.5	89
E. Physical Inventory	4	0.2	0.5	0.5	11
F. Material Unaccounted For	3	1.3	0.9	1.6	
(Throughput, %)	0.3%	0.1%	0.1%	0.2%	

a. Includes only the processing areas.

b. Confidence Level, 95%.

TABLE A-12. General Capability Model of Measurement Uncertainties
In Plutonium Processing Material Balance, (a)

2000 kg Throughput

	Quantity, kg	Measurement Errors (b)			Fraction of Total Variance, %
		Systematic, kg	Random, kg	Total, kg	
A. Beginning Inventory	4	0.2	0.5	0.5	4
B. Receipts:					
External Nitrate	1700	1.0	0.4	1.1	19
Internal Nitrate	300	0.9	0.3	0.9	12
C. Removals:					
Metal Buttons	1700	0.9	<0.1	0.9	12
Oxide Powder	174	0.2	<0.1	0.2	<1
Oxalate Filtrate	40	0.7	0.2	0.7	7
Metal Scrap	20	0.1	<0.1	0.1	<1
Slag and Crucibles	20	0.5	0.1	0.5	4
Sweepings	20	1.0	0.3	1.1	19
Misc. Scrap	20	1.0	0.5	1.1	19
Measured Waste	0.1	<0.1	<0.1	<0.1	<1
D. Book Inventory (A+B+C)	9.9	2.3	1.0	2.5	96
E. Physical Inventory	4	0.2	0.5	0.5	4
F. Material Unaccounted For	5.9	2.3	1.1	2.6	
(Throughput, %)	0.3%	0.1%	0.1%	0.1%	

a. Includes only the processing areas.

b. Confidence Level, 95%.

TABLE A-13. General Performance Model of Measurement Uncertainties
In Plutonium Reclamation Material Balance, (a)

50 kg Throughput					
	Quantity, kg	Measurement Errors (b)			Fraction of Total Variance, %
		Systematic, kg	Random, kg	Total, kg	
A. Beginning Inventory	10	0.2	0.3	0.3	4
B. Receipts:					
Skulls/Oxide	14	0.2	0.1	0.2	2
Slag and Crucibles	10	0.5	0.2	0.5	10
Oxalate Filtrate	6	0.2	0.1	0.2	2
Sweepings/Compounds	5	0.6	0.3	0.6	14
Scrap Metal	4	<0.1	<0.1	<0.1	<1
Incinerator Ash	4	0.2	0.2	0.2	2
Waste Cartons	4	0.4	1.0	1.1	40
Misc. Scrap	3	0.3	0.2	0.3	4
C. Removals:					
Product Nitrate	45	0.3	0.5	0.6	13
Incinerator Ash	3	0.1	0.1	0.2	2
Misc. Scrap	2	0.2	0.1	0.2	2
Measured Discards	1	0.1	0.1	0.1	1
D. Book Inventory (A+B+C)	9	1.1	1.3	1.7	96
E. Physical Inventory	10	0.2	0.3	0.3	4
F. Material Unaccounted For	(1)	1.1	1.3	1.7	
(Throughput, %)	2.0%	2.2%	2.7%	3.4%	

a. Includes only the processing areas.

b. Confidence Level, 95%.

TABLE A-14. General Performance Model of Measurement Uncertainties
In Plutonium Reclamation Material Balance, (a)

		100 kg Throughput				Fraction of Total Variance, %
		Measurement Errors (b)				
		Quantity, kg	Systematic, kg	Random, kg	Total, kg	
A.	Beginning Inventory	10	0.2	0.3	0.3	2
B.	Receipts:					
	Skulls/Oxide	28	0.4	0.2	0.5	2
	Slag and Crucibles	21	1.1	0.2	1.1	14
	Oxalate Filtrate	12	0.4	0.2	0.4	2
	Sweepings/Compounds	11	1.1	0.5	1.2	17
	Scrap Metal	8	0.1	<0.1	0.1	<1
	Incinerator Ash	7	0.4	0.2	0.4	2
	Waste Cartons	7	0.7	1.7	1.8	39
	Misc. Scrap	6	0.5	0.3	0.6	4
C.	Removals:					
	Product Nitrate	90	0.7	0.7	1.0	12
	Incinerator Ash	6	0.3	0.2	0.3	1
	Misc. Scrap	4	0.3	0.2	0.4	2
	Measured Discards	2	0.1	0.2	0.2	1
D.	Book Inventory (A+B+C)	8	2.1	2.0	2.9	98
E.	Physical Inventory	10	0.2	0.3	0.3	2
F.	Material Unaccounted For	(2)	2.1	2.0	2.9	
	(Throughput, %)	2%	2.1%	2.0%	2.9%	

a. Includes only the processing areas.

b. Confidence Level, 95%.

**TABLE A-15. General Performance Model of Measurement Uncertainties
In Plutonium Reclamation Material Balance, (a)**

	170 kg Throughput Measurement Errors ^(b)				Fraction of Total Variance, %
	Quantity, kg	Systematic, kg	Random, kg	T o T kg	
A. Beginning Inventory	10	0.2	0.3	0.3	1
B. Receipts:					
Skulls/Oxide	48	0.7	0.2	0.7	3
Slag and Crucibles	36	1.8	0.3	1.8	16
Oxalate Filtrate	20	0.7	0.2	0.7	3
Sweepings/Compounds	19	1.9	0.6	2.0	20
Scrap Metal	13	0.1	0.1	0.1	<1
Incinerator Ash	12	0.6	0.3	0.7	3
Waste Cartons	12	1.2	2.2	2.5	34
Misc. Scrap	10	0.8	0.3	0.8	4
C. Removals:					
Product Nitrate	150	1.1	1.0	1.5	11
Incinerator Ash	11	0.5	0.3	0.6	2
Misc. Scrap	8	0.6	0.3	0.6	2
Measured Discards	4	0.1	0.2	0.2	<1
D. Book Inventory (A+B+C)	7	3.5	2.6	4.3	99
E. Physical Inventory	10	0.2	0.3	0.3	1
F. Material Unaccounted For	(3)	3.5	2.6	4.3	
(Throughput, %)	1.8%	2.0%	1.5%	2.5%	

a. Includes only the processing areas.

b. Confidence Level, 95%.

TABLE A-16. General Performance Model of Measurement Uncertainties
In Plutonium Reclamation Material Balance, (a)

	330 kg Throughput Measurement Errors (b)				Fraction of Total Variance, %
	Quantity,	Systematic,	Random,	Total,	
	kg	kg	kg	kg	
A. Beginning Inventory	10	0.2	0.3	0.3	<1
B. Receipts:					
Skulls/Oxide	92	1.4	0.3	1.4	4
Slag and Crucibles	69	3.5	0.4	3.5	21
Oxalate Filtrate	40	1.4	0.3	1.4	3
Sweepings/Compounds	36	3.7	0.9	3.8	24
Scrap Metal	27	0.1	0.1	0.1	<1
Incinerator Ash	23	1.2	0.4	1.2	3
Waste Cartons	23	2.3	3.0	3.8	25
Misc. Scrap	20	1.5	0.4	1.6	4
C. Removals:					
Product Nitrate	300	2.2	1.4	2.6	12
Incinerator Ash	18	0.9	0.4	1.0	2
Misc. Scrap	12	1.1	0.4	1.1	2
Measured Discards	7	0.2	0.3	0.4	<1
D. Book Inventory (A+B+C)	3	6.7	3.6	7.6	100
E. Physical Inventory	10	0.2	0.3	0.3	<1
F. Material Unaccounted For	(7)	6.7	3.6	7.6	
(Throughput, %)	2.1%	2.0%	1.1%	2.3%	

a. Includes only the processing areas.

b. Confidence Level, 95%.

TABLE A-17. Intermediate Improvement Model of Measurement Uncertainties
In Plutonium Reclamation Material Balance, (a)

50 kg Throughput

	Quantity, kg	Measurement Errors (b)			Fraction of Total Variance, %
		Systematic, kg	Random, kg	Total, kg	
A. Beginning Inventory	10	0.2	0.3	0.3	6
B. Receipts:					
Skulls/Oxide	14	0.2	0.1	0.2	3
Slag and Crucibles	10	0.4	0.1	0.4	12
Oxalate Filtrate	6	0.2	0.1	0.2	3
Sweepings/Compounds	5	0.4	0.2	0.5	18
Scrap Metal	4	<0.1	<0.1	<0.1	<1
Incinerator Ash	4	0.1	0.1	0.2	3
Waste Cartons	4	0.3	0.5	0.6	26
Misc. Scrap	3	0.2	0.2	0.3	6
C. Removals:					
Product Nitrate	45	0.3	0.3	0.4	12
Incinerator Ash	3	0.1	0.1	0.1	1
Misc. Scrap	2	0.1	0.1	0.2	3
Measured Discards	1	0.1	0.1	0.1	1
D. Book Inventory (A+B+C)	9	0.8	0.8	1.1	94
E. Physical Inventory	10	0.2	0.3	0.3	6
F. Material Unaccounted For	(1)	0.8	0.9	1.2	
(Throughput, %)	2.0%	1.6%	1.8%	2.4%	

a. Includes only the processing areas.

b. Confidence Level, 95%.

TABLE A-18. Intermediate Improvement Model of Measurement uncertainties
In Plutonium Reclamation Material Balance, (a)

100 kg Throughput

		Measurement Errors(b)			Fraction of Total Variance, %
		Quantity, kg	Systematic, kg	Random, kg	
A.	Beginning Inventory	10	0.2	0.3	0.3
B.	Receipts:				
	Skulls/Oxide	28	0.3	0.1	0.3
	Slag and Crucibles	21	0.8	0.2	0.8
	Oxalate Filtrate	12	0.3	0.2	0.4
	Sweepings/Compounds	11	0.8	0.4	0.9
	Scrap Metal	8	<0.1	<0.1	<0.1
	Incinerator Ash	7	0.3	0.2	0.3
	Waste Cartons	7	0.5	0.8	0.9
	Misc. Scrap	6	0.4	0.2	0.5
C.	Removals:				
	Product Nitrate	90	0.5	0.4	0.7
	Incinerator Ash	6	0.2	0.2	0.3
	Misc. Scrap	4	0.2	0.2	0.3
	Measured Discards	2	0.1	0.1	0.1
D.	Book Inventory (A+B+C)	8	1.5	1.1	1.9
E.	Physical Inventory	10	0.2	0.3	0.3
F.	Material Unaccounted For	(2)	1.5	1.2	1.9
	(Throughput, %)	2.0%	1.5%	1.2%	1.9%

a. Includes only the processing areas.

b. Confidence Level, 95%.

**TABLE A-19. Intermediate Improvement Model of Measurement Uncertainties
In Plutonium Reclamation Material Balance, (a)**

170 kg Throughput					
	Quantity, kg	Measurement Errors ^(b)			Fraction of Total Variance, %
		Systematic, kg	Kandon, kg	Total, kg	
A. Beginning Inventory	10	0.2	0.3	0.3	1
B. Receipts:					
Skulls/Oxide	48	0.5	0.2	0.5	3
Slag and Crucibles	36	1.3	0.2	1.3	20
Oxalate Filtrate	20	0.5	0.2	0.5	3
Sweepings/Compounds	19	1.4	0.5	1.5	26
Scrap Metal	13	0.1	<0.1	0.1	<1
Incinerator Ash	12	0.5	0.2	0.5	3
Waste Cartons	12	0.9	1.1	1.4	23
Misc. Scrap	10	0.6	0.2	0.6	4
C. Removals:					
Product Nitrate	150	0.9	0.5	1.0	12
Incinerator Ash	11	0.4	0.2	0.4	2
Misc. Scrap	8	0.4	0.2	0.4	2
Measured Discards	4	0.1	0.1	0.2	<1
D. Book Inventory (A+B+C)	7	2.6	1.4	2.9	99
E. Physical Inventory	10	0.2	0.3	0.3	1
F. Material Unaccounted For	(3)	2.6	1.4	2.9	
(Throughput, %)	1.8%	1.5%	0.8%	1.7%	

a. Includes only the processing areas.

b. Confidence Level, 95%.

TABLE A-20. Intermediate Improvement Model of Measurement Uncertainties
In Plutonium Reclamation Material Balance, (a)

330 kg Throughput					
	Quantity, kg	Measurement Errors ^(b)			Fraction of Total Variance, %
		Systematic, kg	Random, kg	Total, kg	
A. Beginning Inventory	10	0.2	0.3	0.3	<1
B. Receipts:					
Skulls/Oxide	92	1.0	0.2	1.0	4
Slag and Crucibles	69	2.6	0.3	2.6	23
Oxalate Filtrate	40	1.1	0.2	1.1	4
Sweepings/Compounds	36	2.7	0.7	2.8	27
Scrap Metal	27	0.1	0.1	0.1	<1
Incinerator Ash	23	0.9	0.3	1.0	4
Waste Cartons	23	1.7	1.5	2.3	18
Misc. Scrap	20	1.1	0.3	1.1	4
C. Removals:					
Product Nitrate	300	1.7	0.7	1.8	11
Incinerator Ash	18	0.7	0.3	0.8	2
Misc. Scrap	12	0.8	0.3	0.9	3
Measured Discards	7	0.2	0.2	0.3	<1
D. Book Inventory (A+B+C)	3	5.0	2.0	5.4	100
E. Physical Inventory	10	0.2	0.3	0.3	<1
F. Material Unaccounted For	(7)	5.0	2.0	5.4	
(Throughput, %)	2.1%	1.5%	0.6%	1.6%	

a. Includes only the processing areas.

b. Confidence Level, 95%.

TABLE A-21. General Capability Model of Measurement Uncertainties
In Plutonium Reclamation Material Balance, (a)

50 kg Throughput

	Quantity, kg	Measurement Errors(b)			Fraction of Total Variance,
		Systematic, kg	Random, kg	Total, kg	
A. Beginning Inventory	7	0.1	0.2	0.2	6
B. Receipts:					
Skulls/Oxide	14	0.1	0.1	0.1	2
Slag and Crucibles	10	0.3	0.1	0.3	14
Oxalate Filtrate	6	0.1	0.1	0.1	2
Sweepings/Compounds	5	0.3	0.2	0.4	25
Scrap Metal	4	<0.1	<0.1	<0.1	<1
Incinerator Ash	4	0.1	0.1	0.1	2
Waste Cartons	4	0.2	0.3	0.4	25
Misc. Scrap	3	0.1	0.1	0.2	6
C. Removals:					
Product Nitrate	45	0.1	0.1	0.2	6
Incinerator Ash	3	0.1	0.1	0.1	2
Misc. Scrap	2	0.1	0.1	0.1	2
Measured Discards	1	0.1	0.1	0.1	2
D. Book Inventory (A+B+C)	6	0.6	0.5	0.8	94
E. Physical Inventory	7	0.1	0.2	0.2	6
F. Material Unaccounted For	(1)	0.6	0.5	0.8	
(Throughput, %)	2%	1.2%	1.0%	1.6%	

a. Includes only the processing areas.

b. Confidence Level, 95%.

TABLE A-22. General Capability Model of Measurement Uncertainties
In Plutonium Reclamation Material Balance, (a)

100 kg Throughput					
	Quantity, kg	Measurement Errors ^(b)			Fraction of Total Variance, %
		Systematic, kg	Random, kg	Total, kg	
A. Beginning Inventory	7	0.1	0.2	0.2	3
B. Receipts:					
Skulls/Oxide	28	0.2	0.1	0.2	3
Slag and Crucibles	21	0.5	0.1	0.5	16
Oxalate Filtrate	12	0.2	0.1	0.2	3
Sweepings/Compounds	11	0.6	0.2	0.6	25
Scrap Metal	8	<0.1	<0.1	<0.1	<1
Incinerator Ash	7	0.2	0.1	0.2	3
Waste Cartons	7	0.4	0.4	0.6	25
Misc. Scrap	6	0.3	0.1	0.3	6
C. Removals:					
Product Nitrate	90	0.3	0.1	0.3	6
Incinerator Ash	6	0.1	0.1	0.2	3
Misc. Scrap	4	0.2	0.1	0.2	3
Measured Discards	2	<0.1	0.1	0.1	1
D. Book Inventory (A+B+C)	5	1.1	0.6	1.2	97
E. Physical Inventory	7	0.1	0.2	0.2	3
F. Material Unaccounted For	(2)	1.1	0.6	1.2	
(Throughput, %)	2%	1.1%	0.6%	1.2%	

a. Includes only the processing areas.

b. Confidence Level, 95%.

TABLE A-23. General Capability Model of Measurement Uncertainties
In Plutonium Reclamation Material Balance, ^(a)

170 kg Throughput

	Quantity, kg	Measurement Errors ^(b)			Fraction of Total Variance, %
		Systematic, kg	Random, kg	Total, kg	
A. Beginning Inventory	7	0.1	0.2	0.2	1
B. Receipts:					
Skulls/Oxide	48	0.4	0.1	0.4	5
Slag and Crucibles	36	0.9	0.2	0.9	23
Oxalate Filtrate	20	0.4	0.1	0.4	5
Sweepings/Compounds	19	0.9	0.3	1.0	27
Scrap Metal	13	<0.1	<0.1	<0.1	<1
Incinerator Ash	12	0.3	0.2	0.4	5
Waste Cartons	12	0.6	0.5	0.8	18
Misc. Scrap	10	0.4	0.2	0.4	5
C. Removals:					
Product Nitrate	150	0.5	0.2	0.5	7
Incinerator Ash	11	0.2	0.1	0.2	1
Misc. Scrap	8	0.3	0.1	0.3	2
Measured Discards	4	0.1	0.1	0.1	<1
D. Book Inventory (A+B+C)	4	1.7	0.8	1.9	99
E. Physical Inventory	7	0.1	0.2	0.2	1
F. Material Unaccounted For	(3)	1.7	0.8	1.9	
(Throughput, %)	2%	1.0%	0.5%	1.1%	

a. Includes only the processing areas.

b. Confidence Level, 95%.

**TABLE A-24. General Capability Model of Measurement Uncertainties
In Plutonium Reclamation Material Balance, (a)**

330 kg Throughput

	Quantity, kg	Measurement Errors ^(b)			Fraction of Total Variance, %
		Systematic, kg	Random, kg	Total, kg	
A. Beginning Inventory	7	0.1	0.2	0.2	<1
B. Receipts:					
Skulls/Oxide	92	0.7	0.1	0.7	4
Slag and Crucibles	69	1.7	0.2	1.7	24
Oxalate Filtrate	40	0.7	0.2	0.7	4
Sweepings/Compounds	36	1.8	0.4	1.9	30
Scrap Metal	27	0.1	<0.1	0.1	<1
Incinerator Ash	23	0.6	0.2	0.6	3
Waste Cartons	23	1.2	0.8	1.5	19
Misc. Scrap	20	0.7	0.2	0.7	4
C. Removals:					
Product Nitrate	300	0.9	0.3	1.0	8
Incinerator Ash	18	0.5	0.2	0.5	2
Misc. Scrap	12	0.5	0.2	0.5	2
Measured Discards	7	0.1	0.1	0.2	<1
D. Book Inventory (A+B+C)	0	3.3	1.1	3.5	100
E. Physical Inventory	7	0.1	0.2	0.2	<1
F. Material Unaccounted For (7)		3.3	1.1	3.4	
(Throughput, %)	2%	1.0%	0.3%	1.0%	

a. Includes only the processing areas.

b. Confidence Level, 95%.

APPENDIX B
PHYSICAL INVENTORY MODELS

TABLE B-1. General Performance Model of Physical Inventory
at Plutonium Processing Facility

Inventory ^(a) Location	Plutonium Quantity, g ^(b)	Measurement Errors (95% C L)		
		Systematic, g	Random, g	Total, g
Equipment Holdup	5,000	740	1,020	1,260
Powder Pans	4,700	470	200	510
Hood Holdup	3,900	440	870	970
Processing Tanks	1,600	100	170	200
Process Filters	600	100	200	220
Vacuum Traps	400	60	130	140
Miscellaneous	1,800	270	500	570
Total	18,000	1,030	1,480	1,800

a. Processing areas only.

b. g = grams.

TABLE B-2. Intermediate Improvement Model of Physical
Inventory at Plutonium Processing Facility

Inventory ^(a) Location	Plutonium Quantity, g ^(b)	Measurement Errors (95% C L)		
		Systematic, g	Random, g	Total, g
Equipment Holdup	2,600	420	640	770
Powder Pans	2,400	240	100	260
Hood Holdup	2,300	250	450	510
Processing Tanks	1,100	60	100	120
Process Filters	400	80	150	170
Vacuum Traps	200	30	80	90
Miscellaneous	1,000	150	300	340
Total	10,000	570	870	1,040

a. Processing areas only.

b. g = grams.

TABLE B-3. General Capability Model of Physical Inventory at Plutonium Processing Facility

Inventory ^(a) Location	Plutonium Quantity, g ^(b)	Measurement Errors (95% C L)		
		Systematic, g	Random, g	Total, g
Equipment Holdup	1,000	180	350	400
Powder Pans	500	50	60	80
Hood Holdup	1,000	90	180	200
Processing Tanks	600	40	70	80
Process Filters	300	60	120	140
Vacuum Traps	100	20	50	50
Miscellaneous	500	80	140	160
Total	4,000	230	450	510

a. Processing areas only.

b. g = grams.

TABLE B-4. General Performance and Intermediate Improvement Model of Physical Inventory at Plutonium Reclamation Facility

Inventory ^(a) Location	Plutonium Quantity, g ^(b)	Measurement Errors (95% C L)		
		Systematic, g	Random, g	Total, g
Product Concentration Tanks	7,710	150	140	200
Misc. Treatment Tanks	700	30	90	100
Canyon and Hood Floors	590	60	130	140
Solvent Extraction Tanks	360	50	100	110
Waste Treatment Tanks	200	20	50	50
Leaching and Inciner- ation Hoods	180	40	90	100
Slag and Crucible Dissolvers	160	15	40	40
Miscellaneous	100	25	50	60
Total	10,000	180	260	320

NOTE: A single physical inventory model is used for both the general performance and intermediate improvement cases.

a. Processing areas only.

b. g = grams.

TABLE B-5. General Capability Model of Physical Inventory at Plutonium Reclamation Facility

Inventory ^(a) Location	Plutonium Quantity, g ^(b)	Measurement Errors (95% C L)		
		Systematic, g	Random, g	Total, g
Product Concentration Tanks	5,200	20	39	40
Misc. Treatment Tanks	500	20	50	50
Canyon and Hood Floors	500	50	100	110
Solvent Extraction Tanks	300	50	80	90
Waste Treatment Tanks	200	20	40	40
Leaching and Incineration Hoods	100	30	50	60
Slag and Crucible Dissolvers	100	10	30	30
Miscellaneous	100	20	50	50
Total	7,000	90	170	190

a. Processing areas only.

b. g = grams

APPENDIX C

PROBABILITY CURVES FOR
DETECTING PLUTONIUM DIVERSION

FIGURE C-1. Probability Curves for Detecting Material Diversion in the Plutonium Processing Facility for a Material Throughput of 300 kg, General Performance Model

FIGURE C-2. Probability Curves for Detecting Material Diversion in the Plutonium Processing Facility for a Material Throughput of 600 kg, General Performance Model

FIGURE C-3. Probability Curves for Detecting Material Diversion in the Plutonium Processing Facility for a Material Throughput of 1000 kg, General Performance Model

FIGURE C-4. Probability Curves for Detecting Material Diversion in the Plutonium Processing Facility for a Material Throughput of 2000 kg, General Performance Model

FIGURE C-5. Probability Curves for Detecting Material Diversion in the Plutonium Processing Facility for a Material Throughput of 300 kg, Intermediate Improvement Model

FIGURE C-6. Probability Curves for Detecting Material Diversion in the Plutonium Processing Facility for a Material Throughput of 600 kg, Intermediate Improvement Model

FIGURE C-7. Probability Curves for Detecting Material Diversion in the Plutonium Processing Facility for a Material Throughput of 1000 kg, Intermediate Improvement Model

FIGURE C-8. Probability Curves for Detecting Material Diversion in the Plutonium Processing Facility for a Material Throughput of 2000 kg, Intermediate Improvement Model

FIGURE C-9. Probability Curves for Detecting Material Diversion in the Plutonium Processing Facility for a Material Throughput of 300 kg, General Capability Model

FIGURE C-10. Probability Curves for Detecting Material Diversion in the Plutonium Processing Facility for a Material Throughput of 600 kg, General Capability Model

FIGURE C-11. Probability Curves for Detecting Material Diversion in the Plutonium Processing Facility for a Material Throughput of 1000 kg, General Capability Model

FIGURE C-12. Probability Curves for Detecting Material Diversion in the Plutonium Processing Facility for a Material Throughput of 2000 kg, General Capability Model

FIGURE C-13. Probability Curves for Detecting Material Diversion in the Plutonium Reclamation Facility for a Material Throughput of 50 kg, General Performance Model

FIGURE C-14. Probability Curves for Detecting Material Diversion in the Plutonium Reclamation Facility for a Material Throughput of 100 kg, General Performance Model

FIGURE C-15. Probability Curves for Detecting Material Diversion in the Plutonium Reclamation Facility for a Material Throughput of 170 kg, General Performance Model

FIGURE C-16. Probability Curves for Detecting Material Diversion in the Plutonium Reclamation Facility for a Material Throughput of 330 kg, General Performance Model

FIGURE C-17. Probability Curves for Detecting Material Diversion in the Plutonium Reclamation Facility for a Material Throughput of 50 kg, Intermediate Improvement Model

FIGURE C-18. Probability Curves for Detecting Material Diversion in the Plutonium Reclamation Facility for a Material Throughput of 100 kg, Intermediate Improvement Model

FIGURE C-19. Probability Curves for Detecting Material Diversion in the Plutonium Reclamation Facility for a Material Throughput of 170 kg, Intermediate Improvement Model

FIGURE C-20. Probability Curves for Detecting Material Diversion in the Plutonium Reclamation Facility for a Material Throughput of 330 kg, Intermediate Improvement Model

FIGURE C-21. Probability Curves for Detecting Material Diversion in the Plutonium Reclamation Facility for a Material Throughput of 50 kg, General Capability Model

FIGURE C-22. Probability Curves for Detecting Material Diversion in the Plutonium Reclamation Facility for a Material Throughput of 100 kg, General Capability Model

FIGURE C-23. Probability Curves for Detecting Material Diversion in the Plutonium Reclamation Facility for a Material Throughput of 170 kg, General Capability Model

FIGURE C-24. Probability Curves for Detecting Material Diversion in the Plutonium Reclamation Facility for a Material Throughput of 330 kg, General Capability Model

APPENDIX D
SELECTED PROBABILITY TABLES
FOR DETECTING PLUTONIUM LOSSES

TABLE D-1. The Probability of Detecting Material Losses
in the Plutonium Processing Operation,
Type I Error of 10%

<u>Process Throughput, kg</u>	<u>Size of Loss, kg</u>					
	<u>2</u>	<u>4</u>	<u>6</u>	<u>10</u>	<u>15</u>	<u>20</u>
	<u>Detection Probability, %</u>					
<u>General Performance</u>						
300	43	83	98	100	100	100
600	33	66	90	100	100	100
1,000	25	48	72	96	100	100
2,000	18	30	44	73	94	99
<u>Intermediate Improvement</u>						
300	75	99	100	100	100	100
600	55	94	100	100	100	100
1,000	39	78	97	100	100	100
2,000	24	46	69	96	100	100
<u>General Capability</u>						
300	100	100	100	100	100	100
600	98	100	100	100	100	100
1,000	88	100	100	100	100	100
2,000	59	96	100	100	100	100

All probability values are rounded to the nearest percent.

TABLE D-2. The Probability of Detecting Material Losses
in the Plutonium Processing Operation,
Type I Error of 5%

<u>Process Throughput, kg</u>	<u>Size of Loss, kg</u>					
	<u>2</u>	<u>4</u>	<u>6</u>	<u>10</u>	<u>15</u>	<u>20</u>
	<u>Detection Probability, %</u>					
<u>General Performance</u>						
300	30	73	96	100	100	100
600	21	52	82	100	100	100
1,000	15	34	59	93	99	100
2,000	10	19	31	61	89	98
<u>Intermediate Improvement</u>						
300	63	99	100	100	100	100
600	42	89	100	100	100	100
1,000	27	67	93	100	100	100
2,000	15	33	56	91	100	100
<u>General Capability</u>						
300	100	100	100	100	100	100
600	96	100	100	100	100	100
1,000	80	100	100	100	100	100
2,000	46	92	100	100	100	100

All probability values are rounded to the nearest percent.

TABLE D-3. The Probability of Detecting Material Losses
in the Plutonium Processing Operation,
Type I Error of 1%

<u>Process Throughput, kg</u>	<u>Size of Loss, kg</u>					
	<u>2</u>	<u>4</u>	<u>6</u>	<u>10</u>	<u>15</u>	<u>20</u>
	<u>Detection Probability, %</u>					
<u>General Performance</u>						
300	11	46	86	100	100	100
600	7	26	58	97	100	100
1,000	4	14	32	78	99	100
2,000	3	6	12	33	70	93
<u>Intermediate Improvement</u>						
300	36	95	100	100	100	100
600	18	70	97	100	100	100
1,000	9	39	79	100	100	100
2,000	4	13	29	74	98	100
<u>General Capability</u>						
300	98	100	100	100	100	100
600	84	100	100	100	100	100
1,000	56	100	100	100	100	100
2,000	21	77	99	100	100	100

All probability values are rounded to the nearest percent.

**TABLE D-4. The Probability of Detecting Material Losses
in the Plutonium Reclamation Operation,
Type I Error of 10%**

<u>Process Throughput, kg</u>	<u>Size of Loss, kg</u>				
	<u>2</u>	<u>4</u>	<u>6</u>	<u>10</u>	<u>15</u>
	<u>Detection Probability, %</u>				
<u>General Performance</u>					
50	86	100	100	100	100
100	54	93	100	100	100
170	35	70	93	100	100
330	22	40	61	91	100
<u>Intermediate Improvement</u>					
50	98	100	100	100	100
100	79	100	100	100	100
170	53	93	100	100	100
330	39	58	82	99	100
<u>General Capability</u>					
50	100	100	100	100	100
100	98	100	100	100	100
170	78	100	100	100	100
330	46	86	99	100	100

All probability values are rounded to the nearest percent.

**TABLE D-5.. The Probability of Detecting Material Losses
in the Plutonium Reclamation Operation,
Type I Error of 5%**

<u>Process Throughput, kg</u>	<u>Size of Loss, kg</u>				
	<u>2</u>	<u>4</u>	<u>6</u>	<u>10</u>	<u>15</u>
	<u>Detection Probability, %</u>				
<u>General Performance</u>					
50	76	100	100	100	100
100	40	87	100	100	100
170	23	58	87	100	100
330	13	28	50	84	99
<u>Intermediate Improvement</u>					
50	95	100	100	100	100
100	68	100	100	100	100
170	39	87	99	100	100
330	19	44	72	98	100
<u>General Capability</u>					
50	100	100	100	100	100
100	95	100	100	100	100
170	67	99	100	100	100
330	32	76	97	100	100

All probability values are rounded to the nearest percent.

TABLE D-6. The Probability of Detecting Material Losses
in the Plutonium Reclamation Operation,
Type I Error of 1%

<u>Process Throughput, kg</u>	<u>Size of Loss, kg</u>				
	<u>2</u>	<u>4</u>	<u>6</u>	<u>10</u>	<u>15</u>
	<u>Detection Probability, %</u>				
<u>General Performance</u>					
50	51	99	100	100	100
100	17	66	97	100	100
170	8	30	66	99	100
330	4	10	23	62	95
<u>Intermediate Improvement</u>					
50	84	100	100	100	100
100	41	97	100	100	100
170	17	66	96	100	100
330	6	20	45	92	100
<u>General Capability</u>					
50	100	100	100	100	100
100	84	100	100	100	100
170	39	97	100	100	100
330	13	51	88	100	100

All probability values are rounded to the nearest percent.

APPENDIX E

TABLES

DETECTION THRESHOLDS FOR PLUTONIUM LOSSES

**TABLE E-1. Detection Thresholds for Plutonium Losses at the Plutonium Processing Operation, (a)
Type I Error of 10%**

Process Throughput, kg	Probability of Detection			
	50%	70%	80%	90%
Detection Threshold - kg, %				
<u>General Performance</u>				
300	2.3 (0.8)	3.2 (1.1)	3.8 (1.3)	4.6 (1.5)
600	3.0 (0.5)	4.3 (0.7)	5.0 (0.8)	6.0 (1.0)
1,000	4.2 (0.4)	5.8 (0.6)	6.9 (0.7)	8.3 (0.8)
2,000	6.8 (0.3)	9.6 (0.5)	11.2 (0.6)	13.7 (0.7)
<u>Intermediate Improvement</u>				
300	1.3 (0.4)	1.8 (0.6)	2.2 (0.7)	2.6 (0.9)
600	1.8 (0.3)	2.6 (0.4)	3.0 (0.5)	3.6 (0.6)
1,000	2.5 (0.3)	3.5 (0.4)	4.1 (0.4)	4.9 (0.5)
2,000	4.3 (0.2)	6.1 (0.3)	7.2 (0.4)	8.6 (0.5)
<u>General Capability</u>				
300	0.6 (0.2)	0.8 (0.3)	1.0 (0.3)	1.2 (0.4)
600	0.8 (0.1)	1.0 (0.2)	1.3 (0.2)	1.6 (0.3)
1,000	1.0 (0.1)	1.5 (0.2)	1.7 (0.2)	2.1 (0.2)
2,000	1.7 (0.1)	2.4 (0.1)	2.8 (0.1)	3.4 (0.2)

Threshold percentages are related to process throughput.

a. *Includes only the processing areas.*

TABLE E-2. Detection Thresholds for Plutonium Losses
at the Plutonium Processing Operation, ^(a)
Type I Error of 5%

Process Throughput, kg	Probability of Detection			
	50%	70%	80%	90%
	Eetection Threshold - kg, %			
General Performance				
300	2.9 (1.0)	3.8 (1.3)	4.4 (1.5)	5.2 (1.7)
600	3.8 (0.6)	5.1 (0.9)	5.8 (1.0)	6.8 (1.1)
1,000	5.3 (0.5)	7.0 (0.7)	8.0 (0.8)	9.4 (0.9)
2,000	8.7 (0.4)	11.2 (0.6)	13.0 (0.7)	15.2 (0.8)
Intermediate Improvement				
300	1.7 (0.6)	2.2 (0.7)	2.5 (0.8)	3.0 (1.0)
600	2.3 (0.4)	3.0 (0.5)	3.5 (0.6)	4.1 (0.7)
1,000	3.2 (0.3)	4.2 (0.4)	4.9 (0.5)	5.7 (0.6)
2,000	5.5 (0.3)	7.2 (0.4)	8.3 (0.4)	9.8 (0.5)
General Capability				
300	0.7 (0.2)	1.0 (0.3)	1 . (0.4)	1.3 (0.4)
600	1.0 (0.2)	1.3 (0.2)	1.5 (0.3)	1.8 (0.3)
1,000	1.3 (0.1)	1.7 (0.2)	2.0 (0.2)	2.4 (0.2)
2,000	2.1 (0.1)	2.8 (0.1)	3.2 (0.2)	3.8 (0.2)

Threshold percentages are related to process throughput.

a. *Includes only the processing areas.*

TABLE E-3. **Detection Thresholds for Plutonium Losses
at the Plutonium Processing Operation, (a)**
Type I Error of 1%

<u>Process Throughput, kg</u>	<u>Probability of Detection</u>			
	<u>50%</u>	<u>70%</u>	<u>80%</u>	<u>90%</u>
<u>Detection Threshold - kg, %</u>				
<u>General Performance</u>				
300	4.2 (1.4)	5.1 (1.7)	5.6 (1.9)	6.4 (2.1)
600	5.5 (0.9)	6.7 (1.1)	7.5 (1.3)	8.5 (1.4)
1,000	7.5 (0.8)	9.2 (0.9)	10.2 (1.0)	11.6 (1.2)
2,000	12.2 (0.6)	15.0 (0.8)	16.8 (0.8)	19.0 (1.0)
<u>Intermediate Improvement</u>				
300	2.4 (0.8)	2.9 (1.0)	3.2 (1.1)	3.6 (1.2)
600	3.3 (0.6)	4.0 (0.7)	4.5 (0.8)	5.1 (0.9)
1,000	4.5 (0.5)	5.5 (0.6)	6.1 (0.6)	6.9 (0.7)
2,000	7.8 (0.4)	9.6 (0.5)	10.7 (0.5)	12.1 (0.6)
<u>General Capability</u>				
300	1.1 (0.4)	1.3 (0.4)	1.4 (0.5)	1.6 (0.5)
600	1.4 (0.2)	1.7 (0.3)	1.9 (0.3)	2.2 (0.4)
1,000	1.9 (0.2)	2.3 (0.2)	2.6 (0.3)	2.9 (0.3)
2,000	3.0 (0.2)	3.7 (0.2)	4.1 (0.2)	4.7 (0.2)

Threshold percentages are related to process throughput.

a. Includes only the processing areas.

**TABLE E-4. Detection Thresholds for Plutonium Losses
at the Plutonium Reclamation Operation, (a)
Type I Error of 10%**

Process Throughput, kg	Probability of Detection			
	50%	70%	80%	90%
	Detection Threshold - kg, %			
General Performance				
50	1.1 (2.2)	1.6 (3.2)	1.8 (3.6)	2.2 (4.4)
100	1.8 (1.8)	2.6 (2.6)	3.1 (3.1)	3.7 (3.7)
170	2.8 (1.6)	4.0 (2.4)	4.6 (2.7)	5.5 (3.2)
330	4.9 (1.5)	6.8 (2.1)	8.0 (2.4)	9.7 (2.9)
Intermediate Improvement				
50	0.8 (1.6)	1.1 (2.2)	1.3 (2.6)	1.6 (3.2)
100	1.2 (1.2)	1.7 (1.7)	2.0 (2.0)	2.4 (2.4)
170	1.9 (1.1)	2.6 (1.5)	3.1 (1.8)	3.7 (2.2)
330	3.5 (1.1)	4.9 (1.5)	5.7 (1.7)	6.9 (2.1)
General Capability				
50	0.5 (1.0)	0.7 (1.4)	0.9 (1.8)	1.0 (2.0)
100	0.8 (0.8)	1.1 (1.1)	1.3 (1.3)	1.5 (1.5)
170	1.2 (0.7)	1.8 (1.0)	2.0 (1.2)	2.4 (1.4)
330	2.2 (0.7)	3.1 (0.9)	3.6 (1.1)	4.4 (1.3)

Threshold percentages are related to process throughput.

a. Includes only the processing areas.

**TABLE E-5. Detection Thresholds for Plutonium Losses
at the Plutonium Reclamation Operation, ^(a)
Type I Error of 5%**

Process Throughput, kg	probability of Detection							
	50%		70%		80%		90%	
	Detection Threshold - kg, %							
<u>General Performance</u>								
50	1.4	(2.8)	1.9	(3.8)	2.1	(4.2)	2.5	(5.0)
100	2.4	(2.4)	3.1	(3.1)	3.6	(3.6)	4.2	(4.2)
170	3.5	(2.1)	4.7	(2.8)	5.4	(3.2)	6.4	(3.8)
330	6.2	(1.9)	8.2	(2.5)	9.5	(2.9)	11.2	(3.4)
<u>Intermediate Improvement</u>								
50	1.0	(2.0)	1.3	(2.6)	1.5	(3.0)	1.8	(3.6)
100	1.6	(1.6)	2.0	(2.0)	2.4	(2.4)	2.8	(2.8)
170	2.4	(1.4)	3.2	(1.9)	3.6	(2.1)	4.3	(2.5)
330	4.4	(1.3)	5.8	(1.8)	6.7	(2.0)	7.8	(2.4)
<u>General Capability</u>								
50	0.7	(1.4)	0.9	(1.8)	1.0	(2.0)	1.2	(2.4)
100	1.0	(1.0)	1.3	(1.3)	1.5	(1.5)	1.7	(1.7)
170	1.6	(0.9)	2.1	(1.2)	2.4	(1.4)	2.8	(1.6)
330	2.8	(0.8)	3.7	(1.1)	4.2	(1.3)	5.0	(1.5)

Threshold percentages are related to process throughput.

a. Includes only the processing areas.

TABLE E-6. Detection Thresholds for Plutonium Losses
at the Plutonium Reclamation Operation, (a)
Type I Error of 1%

Process Throughput, kg	Probability of Detection			
	50%	70%	80%	90%
	Detection Threshold - kg, %			
General Performance				
50	2.0 (4.0)	2.4 (4.8)	2.7 (5.4)	3.1 (6.2)
100	3.4 (3.4)	4.1 (4.1)	4.6 (4.6)	5.2 (5.2)
170	5.1 (3.0)	6.2 (3.6)	6.9 (4.1)	7.8 (4.6)
330	8.8 (2.7)	10.8 (3.3)	12.0 (3.6)	13.7 (4.2)
Intermediate Improvement				
50	1.4 (2.8)	1.7 (3.4)	1.9 (3.8)	2.2 (4.4)
100	2.2 (2.2)	2.7 (2.7)	3.0 (3.0)	3.4 (3.4)
170	3.4 (2.0)	4.2 (2.5)	4.6 (2.7)	5.3 (3.1)
330	6.3 (1.9)	7.7 (2.3)	8.6 (2.6)	9.7 (2.9)
General Capability				
50	0.9 (1.8)	1.2 (2.4)	1.3 (2.6)	1.5 (3.0)
100	1.4 (1.4)	1.7 (1.7)	1.9 (1.9)	2.2 (2.2)
170	2.2 (1.3)	2.7 (1.6)	3.0 (1.8)	3.4 (2.0)
330	4.0 (1.2)	4.8 (1.5)	5.4 (1.6)	6.2 (1.9)

Threshold percentages are related to process throughput.

a. Includes only the processing areas.

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