CONF-9007106--74

Paper presented at the Institute of Nuclear Material Management 31st Annual Meeting, Los Angeles, CA, July 15-18, 1990.

CONF-9007106--74

DE90 017835

SYSTEMS ANALYSIS FOR MATERIAL CONTROL AND ACCOUNTANCY TECHNOLOGY (SAMCAT)

by

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* Work supported by the U.S. Department of Energy.

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ABSTRACT

The Systems Analysis for Material Control and Accountancy Technology (SAMCAT) [1-4] is an interactive computer-based management system developed for the Department of Energy Office of Safeguards and Security, to assist in defining and prioritizing measurement upgrades programs for Material Control and Accountancy (MC&A). The SAMCAT system provides four functions: (1) materials accountancy database and analysis algorithms for evaluating the propagated variance in the inventory difference via user-definable material balance areas and user-selectable accountancy upgrades options; (2) quantification of the contributions of achievable upgrades to increase the capability of the Material Accountancy (MA) System for meeting, in part, the performance requirements of DOE Order 5633.3; (3) identification of key measurement locations and/or material types for MC&A upgrades to provide support for achieving DOE performance requirements and for validating the MA aspects of Master Safeguards and Security Agreements effectiveness; and (4) information on facility operations, processing technology, and material flows via a menu-oriented selection scheme that allows investigation at increasing depths of detail using integrated textual information sheets and graphic flow diagrams. The accountancy upgrades options evaluated by SAMCAT in this study are: (1) improvement of the uncertainties in the SNM measurement methods, (2) reduction of throughputs and/or inventories of SNM, and (3) reduction of the material balance accounting period. The goals of the MC&A upgrades program are reduced inventory differences and associated uncertainties, improved detection probabilities for theft/diversion, decreased operating costs, and enhanced material traceability.

INTRODUCTION

This paper is a summary of the results from the Systems Analyses for Materials Control and Accountancy Technology (SAMCAT) program applied to the analysis of the Example Facility described in the Guides to the DOE Order 5633.3, January 1989. The purpose of the study is to display the manner in which SAMCAT may support those Material Accountancy (MA) activities which contribute in part to the compliance of the overall MC&A performance requirements of the DOE Order 5633.3.

The SAMCAT program has been developed as an interactive computer-based management system for decision support in evaluating Materials Control and Accountancy (MC&A) upgrades that contribute to meeting the requirements of DOE Order 5633.3 and related guidelines for programmatic needs in the MC&A aspects of the Master Safeguards and Security Agreements (MSSA) effectiveness. The effort consists of the continued development of four integrated capabilities, namely:

(1) materials accountancy database and analysis algorithms for evaluating the propagated variance in the inventory difference via user-definable material balance areas and user-selectable accountancy upgrades options;

(2) quantification of the contributions of achievable upgrades to increase the capability of the Material Accountancy (MA) System for meeting, in part, the performance requirements of DOE Order 5633.3;

(3) identification of key measurement locations and/or material types for MC&A upgrades to provide support for achieving DOE performance requirements and for validating MA aspects of Master Safeguards and Security Agreements effectiveness; and

(4) information on facility operations, processing technology, and material flows via a menu-oriented selection scheme that allows investigation at increasing depths of detail using integrated textual information sheets and graphic flow diagrams.

The materials accountancy analyses illustrated in this summary describe the implementation of SAMCAT to the example facility. Details of the facility are given in "Guide to DOE Order 5633.3, Control and Accountability of Nuclear Materials: Facility Design and Evaluation Methods for the MC&A Performance Requirements, Draft Guidance," January 1989. A global representation of the special nuclear material (SNM) flows throughout the facility is given in Figure 1. Other supporting details necessary for the study which were not covered in the Guide description, such as the measurement methods uncertainties and nominal item size in a single measurement, for the specific "measurement locations/material types," are assigned representative values based on general information and experience attained in the development of the SAMCAT program.

VARIANCE PROPAGATION MODELING

Fundamental Considerations

The various DOE contractors and field offices have grouped materials accountability data according to either: (1) measurement location, (2) measurement-component method, or (3) material type. The first grouping has advantages in tracing the flow of SNM, while the other two groupings are favored for the analysis, management and display of the correlated variances originating from bias uncertainties in the individual measurement methods. Due to the variety of operations and physical and chemical nature of material types in the DOE production and product cycles, no set of measurement-component variances best represents all types of facilities in the DOE complex. It may be appropriate for a given contractor to propagate absolute, relative, or a combination of absolute and relative variances, depending upon the nature of the specific measurement components, in order to determine their contributions to the total variance of a particular MBA.

An example illustration is given below of such a combination of variance components, supplied to SAMCAT by the contractor for the Oak Ridge Y-12 plant, which describes the variance in the mass balance of U-235 for one of the material types in a particular MBA. For this purpose, the contractor uses:

a. a material mass measurement for the ith transfer or inventory storage, M_i, with an absolute random uncertainty in the measurement, σM, that is constant over the set of measurements for the material; and

b. a laboratory analytical measurement of U-235 concentration, C_i, which has an absolute random standard deviation, σC_i, and a constant relative bias, P, that is correlated over the set of measurements through a coefficient, α_i, which is +1 for beginning inventories and additions to the MBA and -1 for ending inventories and removals from the MBA.

The major contribution to the variance in the U-235 mass balance for a single material, is obtained by summing over all transactions and inventories within the MBA, as given by

$$\mathrm{Var}\ (\text{U-235}) = (\sigma M)^2 \sum_i F_i C_i^2 + \sum_i M_i^2 (\sigma C_i)^2 + \Big[\sum_i P\ (\alpha_i M_i C_i)\Big]^2 \qquad (1)$$

where F_i is a scale factor representing the number of weighings, such as weights of filled and empty container, necessary to determine the material weight for each accounting entry.

The preliminary Rocky Flats MBA analysis adopts a similar variance propagation model. A more complex example would be the case in which one (or more) of the measurement-component methods, with the same instrument calibration and relative bias uncertainty, may be used at different measurement locations throughout an MBA. Such is the case for the FB-Line MBA at the Savannah River plant (SRP), for which variances are propagated, through the SRP Errlim code, with the bias components correlated according to measurement method.

One of the functions of SAMCAT is to process the accountability data, as supplied by the contractors, at the appropriate level of detail necessary to provide representations of the measurement variances for either the contractors, the DOE headquarters or the field offices. Algorithms for propagating variances are being supplied to SAMCAT by the contractors. Guidance for propagation of variances at the measurement-component level has been prepared by Brookhaven National Laboratory [5]. In that guidance and related papers, bias uncertainties are correlated over a set of measurements for a particular calibration period. For the example study addressed in this report, as requested by the DOE/OSS, the total (rather than the measurement-component) variances were propagated for an MBA.

In order to define effective total variances from component level data supplied by a contractor, consideration must be given to the basic algorithms such as the one shown in Eq. 1. The term P in the expression gives a relative bias. If the material masses and U-235 concentrations do not change significantly, both an average mass for a single U-235 measurement and an effective (total relative) standard deviation for that measurement may be defined. The algorithms for variance propagation would then be identical to those used in this study. This set of circumstances would be more likely with solid product items of the same type and measurement location rather than with materials of less definite dimensions and SNM concentrations, such as volumes of solutions and collections of scrap. For MBA's like the FB-Line at Savannah River, in which the same analytical measurement may be used at locations with different volume and sampling measurement methods, the definition of total relative standard deviation for a given material type becomes even more complex.

Measurement Uncertainty Data for Example Facility

The description of the example facility listed the MBA total flow and inventory data according to material type. The measurement uncertainties derived from published information [6] and from experience attained in SAMCAT-contractor interactions were adjusted for the purpose of illustrating the SAMCAT approach to the analysis of potential measurement-improvement options for meeting the performance requirements of DOE Order 5633.3. Total relative (random and bias) variances for the current SAMCAT study of the example facility were obtained by addition of the individual (random and bias) component variances. The total relative bias uncertainties were assumed to be correlated over the entire accountancy interval of an MBA.

MATERIAL ACCOUNTANCY ANALYSIS

Design Basis Strategy for Protracted Theft or Diversion

The January 1989 Draft Guidance identifies specifications of the design basis strategies to be the responsibility of the facility contractor. However, a proposed strategy for the purposes of evaluation is given in the memorandum from E.Q. Ten Eyck, Director, Office of Safeguards and Security, to directors of safeguards-related divisions, DOE field offices, "Material Control and Accountability (MC&A) Guide," dated May 15, 1989. The design basis strategy used in the analysis of the example facility, consistent with this reference memorandum, is outlined as follows.

Protracted theft or diversion is defined in the Order as resulting from occurrences over an extended period of time. This definition applies to the removal of material from one or several MBA's. The extended period of time is taken to be one material balance period, provided that the balance period is not less than one month; if it is, the extended period of time is taken to be one month. Because the theft or diversion could occur in two different material balance periods (potentially reducing detection capability), it is suggested that for the purposes of evaluation, the removals of material be assumed to start 3/4 of the way into a material balance period, and continue uniformly for one balance period. Thus 1/4 of the target quantity is removed in the first balance period, and 3/4 of the target quantity is removed in the second.

Based upon ANL's interpretations of the Draft Guidances and considerations of MA system functions, it was assumed that, given an alarm of the materials accountancy system, the probability for resolution of that alarm was very close to unity. The system is generally taken as the best system for resolving the alarms of other, perhaps more timely, safeguards system elements. For this investigation the probability of resolution of an MA alarm was assigned a value of 0.7 for each case studied. The probability curve, relating the probability of detection of an MA alarm with the uncertainty in the inventory difference, is plotted in Figure 2.

Analysis of Some Potential Upgrades Options

The SAMCAT output for the analysis of the reference data for Machining and Inspection MBA is presented in Table I; the output for the analysis of a program of potential MA upgrades is in Table II. These tables present quantitatively the improvements in the MA analysis. Figure 3 graphically displays the improvements in the variance for each material type which has upgraded accountancy procedure methods, the total uncertainty in the inventory difference of the MBA, and the probability of detection based upon the protracted diversion strategy for each scenario period and for the total. In the pair of bars, the left bar represents the reference analysis (Table I), and the right represents the upgraded analysis (Table II).

Three upgrade options were examined:

(1) reduction in the random uncertainty of the Segmented Gamma Scan for the measurement of sediment and fines from 9.2% to 4.6%;

(2) reduction in the beginning and ending inventories of sediment and fines from 20 kg. to 10 kg.; and

(3) reduction in the length of the accountancy period from 2 months to 1 month.

The upgrades are applied in sequence: first, upgrade #1; then, upgrades #1 and #2; and finally, all three upgrades (Table II and Figure 3).

RESULTS OF ANALYSIS

Discussion of Results

Referring to the reference analysis in Table I, the major contribution to the variance of the inventory difference for the Machining and Inspection MBA was found to be the Segmented Gamma Scan random error in the measurements of the sediment and fines. The variance contribution to the MBA inventory difference for this measurement procedure considering both inventories and waste shipments is about 87%.

The first potential upgrade, halving the random uncertainty from 9.2% to 4.6% for this measurement procedure, reduced the standard deviation of the inventory difference from 3.425 kg to 2.028 kg, and increased the total probability of detection from about 15% to a detection probability of 54%.

Applying the second potential upgrade of reducing the beginning and ending inventories of the sediment and fines from 20 kg to 10 kg resulted in a further reduction of the standard deviation for the MBA inventory difference to a level of 1.687 kg and further increased the detection probability to about 66%.

The two combined upgrades for the category II B material contribute, in part, to meeting the performance requirements for the "very high" detection probability of 87% for the target value of 10 fkg for protracted diversion. However, the timeliness aspect of the performance requirements are not satisfied in the final period of the diversion strategy. To attain a materials accountancy timeliness aspect for meeting the performance requirements, the analysis investigated the effect of increasing the frequency of the accountancy period from 2 months to 1 month. The combined upgrades to the measurement accountancy procedure resulted in reducing the standard deviation for the MBA to a value of 1.042 kg, and increasing the total probability of detection to about 76%. For the timeliness aspect of the performance requirements, the probability of detection was increased from a negligible level of less than 1% to the significant level of 19% in the first period of the diversion strategy.

The above accumulated upgrades in the measurement procedures suggest that increasing the frequency of the accountancy period by an additional factor of two could significantly enhance the importance of materials accountancy in contributing, in part, to meeting the timely detection aspect of the performance requirements in the given protracted diversion strategy.

SUMMARY

Based on the three upgrade options and related assumptions, the resulting analysis demonstrates the usefulness of the SAMCAT approach. The approach provides technology support for performance compliance/guidance identified in DOE Orders 5633.3 and/or related guides. The system is flexible, user friendly, and designed to be readily modified to accommodate administrative changes in the definitions of performance requirements for the characteristic and facility-specific needs of the field/contractor operations in MC&A. The SAMCAT program can develop a set of options as defined by the field/contractor in the broader context of MC&A improvements on what upgrades may be expected to be included in a cost/benefit analysis.

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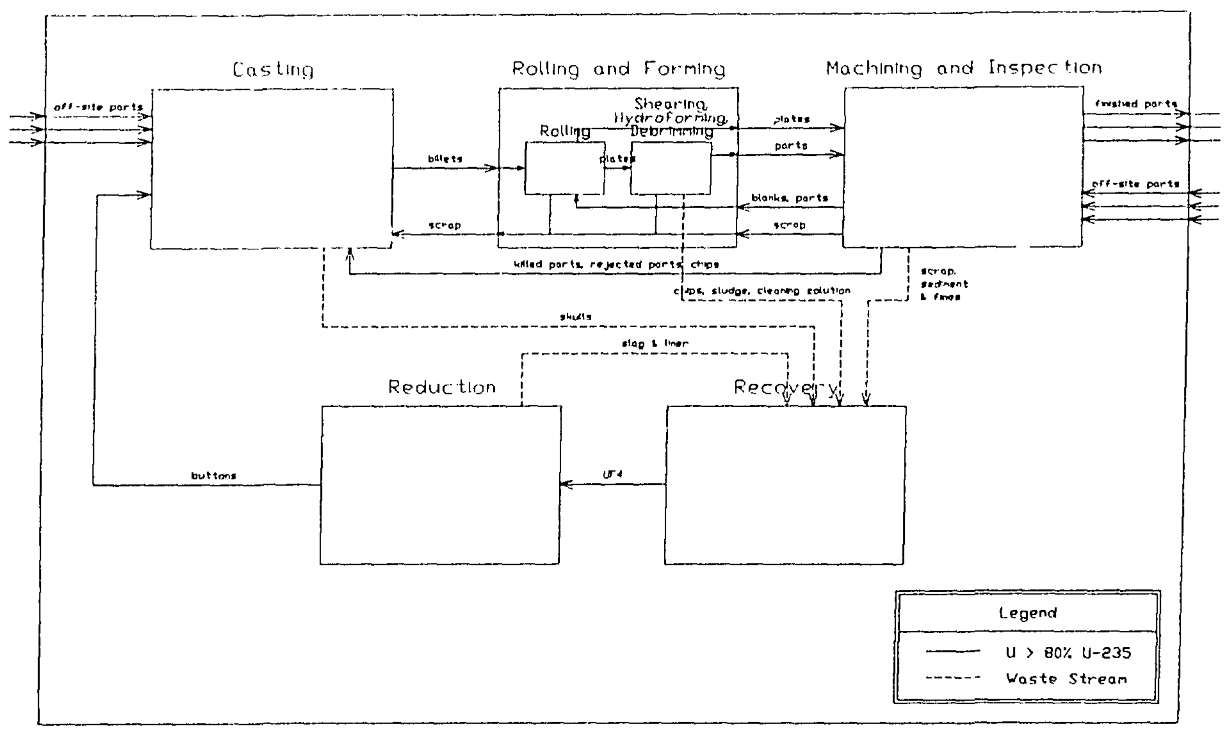

Figure 1. Special Nuclear Material Flows Throughout Example Facility

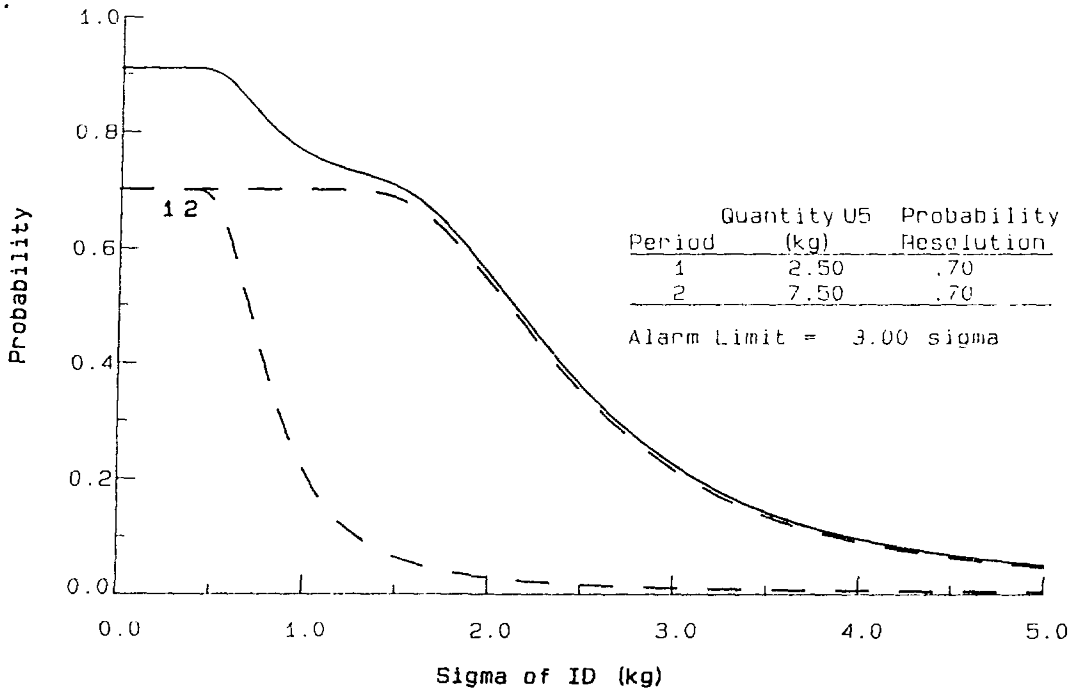

Figure 2. SAMCAT Plot of Probability of Detection for Protracted Theft of U-235

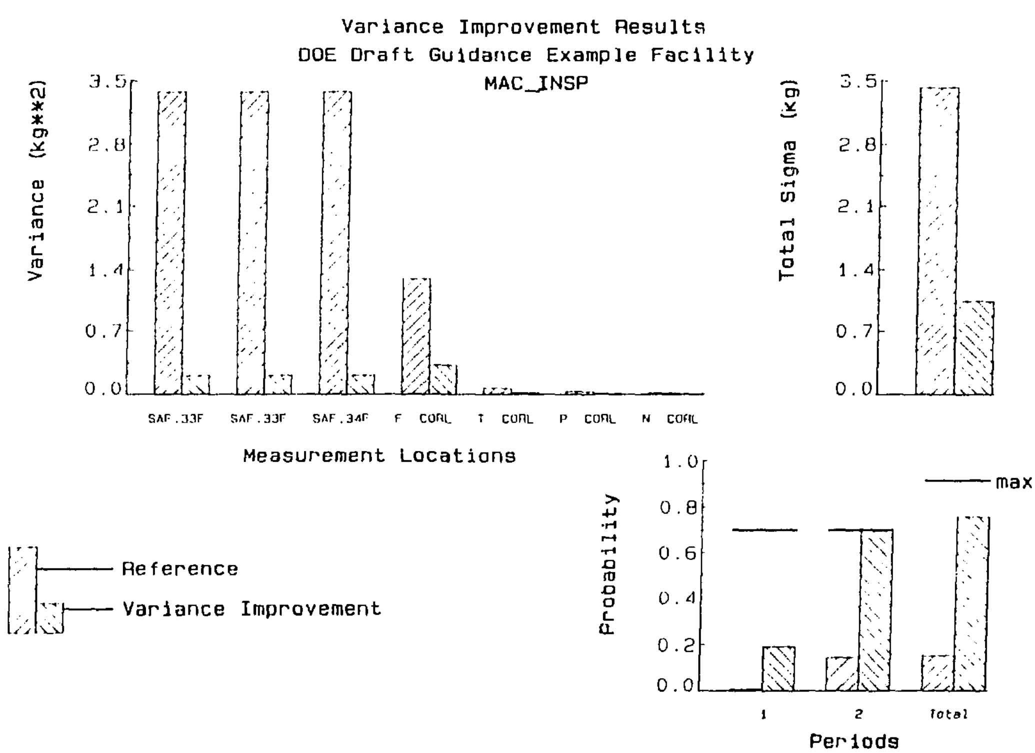

Figure 3. SAMCAT Summary of Material Accountancy Upgrades in Table II

Table I. SAMCAT Output for Accountancy of Machining and Inspection MBA

Material Balance Accountancy Output for
Facility: DOE Draft Guidance Example Facility
MBA: MAC_INSP, MBA #3 SNM: U5 Period: 08/31/88

Meas Loc/ Mat Type	ID Term	Random: Bias:	Vol/Wgt Correlated	Analytic/Isotopic Material Types	# of Meas	Total SNM(kg)	RSD/BSD (%)	Variance (%)
OFF.03P	F	Random	Wgt	Optcl & Mass Spec	20	200.000	0.110	0.021
PRT.23P	F	Random	Wgt	Optcl & Mass Spec	157	1570.000	0.110	0.152
PLT.23T	F	Random	Wgt	Optcl & Mass Spec	16	250.000	0.180	0.108
FIN.30P	P	Random	Wgt	Optcl & Mass Spec	100	1000.000	0.110	0.103
BLN.32N	P	Random	Wgt	Optcl & Mass Spec	12	200.000	0.110	0.034
PRT.32P	P	Random	Wgt	Optcl & Mass Spec	20	200.000	0.110	0.021
SAF.34F	W	Random		Segmntd Gamma Scan	1	20.000	9.200	28.858
SCR.34S	W	Random	Wgt	Dav-Gr & Mass Spec	5	100.000	0.160	0.044
KIL.31P	S	Random	Wgt	Optcl & Mass Spec	20	200.000	0.110	0.021
REJ.31P	S	Random	Wgt	Optcl & Mass Spec	10	100.000	0.110	0.010
CHP.31C	S	Random	Wgt	Dav-Gr & Mass Spec	20	100.000	0.250	0.027
SCR.32S	S	Random	Wgt	Dav-Gr & Mass Spec	5	100.000	0.160	0.044
PRT.33P	BI	Random	Wgt	Optcl & Mass Spec	80	800.000	0.110	0.093
PRT.33P	EI	Random	Wgt	Optcl & Mass Spec	80	800.000	0.110	0.093
PLT.33T	BI	Random	Wgt	Optcl & Mass Spec	12	200.000	0.180	0.092
PLT.33T	EI	Random	Wgt	Optcl & Mass Spec	12	200.000	0.180	0.092
BLN.33N	BI	Random	Wgt	Optcl & Mass Spec	6	100.000	0.110	0.017
BLN.33N	EI	Random	Wgt	Optcl & Mass Spec	6	100.000	0.110	0.017
SCR.33S	BI	Random	Wgt	Dav-Gr & Mass Spec	2	50.000	0.160	0.027
SCR.33S	EI	Random	Wgt	Dav-Gr & Mass Spec	2	50.000	0.160	0.027
CHP.33C	BI	Random	Wgt	Dav-Gr & Mass Spec	5	25.000	0.250	0.007
CHP.33C	EI	Random	Wgt	Dav-Gr & Mass Spec	5	25.000	0.250	0.007
SAF.33F	BI	Random		Segmntd Gamma Scan	1	20.000	9.200	28.858
SAF.33F	EI	Random		Segmntd Gamma Scan	1	20.000	9.200	28.858
P CORL	-	Bias	FIN+KIL+OFF+PRT+REJ			270.000	0.070	0.304
T CORL	-	Bias	PLT			250.000	0.110	0.645
N CORL	-	Bias	BLN			-200.000	0.070	0.157
F CORL	-	Bias	SAF			-20.000	5.700	11.077
S CORL	-	Bias	SCR			-200.000	0.050	0.085
C CORL	-	Bias	CHP			-100.000	0.110	0.103

MBA Accountancy Summary: Total Variance 11.732 kg**2
Inventory Difference 0.000 kg Standard Deviation 3.425 kg

For the MBA,
ID = Sum (BI + F - P - S - W - HM - HNM - LGE - LLE - EI), where
the summation is over all measurement locations or material types, and
the balance terms are defined in the Table by ID Balance Components below.

At each measurement location or for each material type,
for Random components,
Meas Loc / Mat Type format is xxx.src, where
xxx is an identification of the measurement location or material type,
s is an MBA index to identify the shipper MBA in the SNM transfer,
r is an MBA index to identify the receiver MBA in the SNM transfer,
c is a correlation index to compute the correlated bias variances;
for s = r, the entry identifies the SNM inventory for the MBA index;
Total SNM = Quantity of SNM summed over all measurements,
Random Var = (Total SNM * Random Std Dev / 100%) squared / (# of Meas);
for Bias components,
Meas Loc / Mat Type format is c CORL, where
c is a correlation index as defined under the random components;
Total SNM = BI + Rcpt (F) - Ship (P, S, W, ...) - EI,
Correl Bias Var = (Total SNM * Bias Std Dev / 100%) squared;
for both components,
Variance Contribution = (Random or Bias Var / MBA Total Var) * 100%;

Table II. SAMCAT Output for Material Accountancy Upgrades for Machining and Inspection MBA.

Random Std Dev for SAF: 9.2 % -> 4.6 %
Beg/End Inventory for SAF: 20 kg -> 10 kg
Half Accountancy Period: 2 mo -> 1 mo
(output for first of two half-periods)

Material Balance Accountancy Upgrades Output for
Facility: DOE Draft Guidance Example Facility
MBA: MAC_INSP, MBA #3 SNM: U5 Period: 06/30/88-08/31/88 [1-2]

Meas Loc/ Mat Type	ID Term	Random: Bias:	Vol/Wgt Correlated	Analytic/Isotopic Material Types	# of Meas	Total SNM(kg)	RSD/BSD (%)	Varianc (%)
OFF.03P	F	Random	Wgt	Optcl & Mass Spec	10	100.000	0.110	0.112
PRT.23P	F	Random	Wgt	Optcl & Mass Spec	79	785.000	0.110	0.870
PLT.23T	F	Random	Wgt	Optcl & Mass Spec	8	125.000	0.180	0.583
FIN.30P	P	Random	Wgt	Optcl & Mass Spec	50	500.000	0.110	0.558
BLN.32N	P	Random	Wgt	Optcl & Mass Spec	6	100.000	0.110	0.186
PRT.32P	P	Random	Wgt	Optcl & Mass Spec	10	100.000	0.110	0.112
SAF.34F	W	Random		Segmntd Gamma Scan	1	10.000	4.600	19.506
SCR.34S	W	Random	Wgt	Dav-Gr & Mass Spec	3	50.000	0.160	0.197
KIL.31P	S	Random	Wgt	Optcl & Mass Spec	10	100.000	0.110	0.112
REJ.31P	S	Random	Wgt	Optcl & Mass Spec	5	50.000	0.110	0.056
CHP.31C	S	Random	Wgt	Dav-Gr & Mass Spec	10	50.000	0.250	0.144
SCR.32S	S	Random	Wgt	Dav-Gr & Mass Spec	3	50.000	0.160	0.197
PRT.33P	BI	Random	Wgt	Optcl & Mass Spec	80	800.000	0.110	0.892
PRT.33P	EI	Random	Wgt	Optcl & Mass Spec	80	800.000	0.110	0.892
PLT.33T	BI	Random	Wgt	Optcl & Mass Spec	12	200.000	0.180	0.996
PLT.33T	EI	Random	Wgt	Optcl & Mass Spec	12	200.000	0.180	0.996
BLN.33N	BI	Random	Wgt	Optcl & Mass Spec	6	100.000	0.110	0.186
BLN.33N	EI	Random	Wgt	Optcl & Mass Spec	6	100.000	0.110	0.186
SCR.33S	BI	Random	Wgt	Dav-Gr & Mass Spec	2	50.000	0.160	0.295
SCR.33S	EI	Random	Wgt	Dav-Gr & Mass Spec	2	50.000	0.160	0.295
CHP.33C	BI	Random	Wgt	Dav-Gr & Mass Spec	5	25.000	0.250	0.072
CHP.33C	EI	Random	Wgt	Dav-Gr & Mass Spec	5	25.000	0.250	0.072
SAF.33F	BI	Random		Segmntd Gamma Scan	1	10.000	4.600	19.506
SAF.33F	EI	Random		Segmntd Gamma Scan	1	10.000	4.600	19.506
P CORL	-	Bias	FIN+KIL+OFF+PRT+REJ			135.000	0.070	0.923
T CORL	-	Bias	PLT			125.000	0.110	1.743
N CORL	-	Bias	BLN			-100.000	0.070	0.452
F CORL	-	Bias	SAF			-10.000	5.700	29.950
S CORL	-	Bias	SCR			-100.000	0.050	0.230
C CORL	-	Bias	CHP			-50.000	0.110	0.279

MBA Accountancy Summary: Total Variance 1.085 kg**2
Inventory Difference 0.000 kg Standard Deviation 1.042 kg