INTERNATIONAL TRAINING COURSE ON IMPLEMENTATION
OF STATE SYSTEMS OF ACCOUNTING FOR
AND CONTROL OF NUCLEAR MATERIALS

October 17-November 4, 1983

SESSION 37: INTRODUCTION TO MC&A SYSTEM DESIGN WORKSHOP

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I. INTRODUCTION

The purpose of the workshop which follows this session is to give the students an opportunity to design the main features of a safeguards material control and accounting system (MC&A) for a low enriched uranium fuel fabrication plant.

II. PREPARATION FOR WORKSHOP

To prepare the participants for the workshop on MC&A system design, the following items are covered in this session:

1. Description of the Reference or Model Plant;
2. Preparation of a FNMC Plan;
3. Preparation of a DIQ, and
4. Description of the objectives, tasks, and mode of operation of the workshop.

A. Reference or Model Plant

The basis for the safeguards system design is the Reference or Model Plant described in condensed form next in Session 37a and in more detail in the example DIQ which follows later in Session 37c. The information for the Model Plant is presented in Session 37a in eight sections. These are:

1. Process Assumptions;
2. Six-Month Material Balance Model;
3. Measurements;
4. Error Parameters, Measurements, and Sigma MUF Calculations;
5. Material Control Areas;

6. Accounting, Records, and Reports;

7. Tamper-Safing; and

8. Measurement Control Program.

B. Preparation of a FNMC Plan

The key elements of a safeguards MC&A system which need to be considered in designing a system to meet State systems requirements are illustrated in Session 37b which shows how a FNMC Plan is prepared. The key topics which need to be considered in the system design to meet U.S. requirements are:

- Organization;
- Material Control Areas;
- Measurements;
- Measurement Control Program;
- Physical Inventory;
- Material Accounting System;
- Internal Control, and
- Management.

C. Preparation of a DIQ

The key elements of the safeguards MC&A system which need to be considered for IAEA safeguards are illustrated in Session 37c where the preparation of a DIQ is described.

D. Objectives and Operation of Workshop

After completion of Session 37c, the function, mode of operation, and objectives of the workshop are described. The students are to be divided into four groups with each group independently developing the safeguards MC&A system which they believe is best. To aid the students in their design work, a workshop guide is provided (which is one of the texts for the workshop, Session 38). The guides suggest the various factors which should be considered for each of the 10 main design elemer which determine the safeguards MC&A system. Worksheets (also part of the text for Session 38) are provided upon which the participants may record their design choices.

Instructors will be available to serve on each team or to act as consultants when requested.

Each of the four groups is to select a rapporteur to present its results at the plenary session (Session 39) which follows the workshop. The rapporteurs present the safeguards system design features chosen by their group as representing the best MC&A system. Each group is also asked to complete a questionnaire. The questionnaire is to be completed and turned in at the end of the workshop session. The completed questionnaire which summarizes the main design features chosen by each group will be used by the course instructors to evaluate and compare the results of the four subgroups by the course instructors.

INTERNATIONAL TRAINING COURSE ON IMPLEMENTATION OF STATE SYSTEMS OF ACCOUNTING FOR AND CONTROL OF NUCLEAR MATERIALS

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SESSION 37a: DESCRIPTION OF REFERENCE (MODEL) PLANT

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I. INTRODUCTION

For the workshop on Safeguards System design for a fuel fabrication plant, we use a generic example of a LEU bulk-handling facility that is based on the Exxon LWR fuel fabrication plant. This reference (or "model") plant description is to be used in developing system design features during the workshop. The same basic information has also been incorporated into the Design Information Questionnaire given later in this session (Session 37c).

The model plant information is given in the following separate sections:

- II Process Assumptions;
- III Six-Month Material Balance Model;
- IV Measurements;
- V Error Parameters, Measurements, and Sigma MUF Calculations;
- VI Material Control Areas;
- VII Accounting, Records, and Reports;
- VIII Tamper-Safing; and
- IX Measurement Control Program.

For convenience, a brief summary of each section is given below.

Section II--Process Assumptions. A one tonne-a-day plant having two process lines for UF_6 conversion, pellet preparation, and rod loading is described. Plant feed is UF_6 and plant product is finished fuel bundles. All scrap is converted to U_3O_8 and processed to UO_2. Poison preparation is excluded. All enrichment blending is assumed to take place in scrap recovery as UNH. Liquid wastes are stored in solar evaporation ponds and all solid wastes (barrels and filters) are either stored on-site or sent to burial.

Section III--Six Month Material Balance Model. The plant material balance model is described in terms of the number of items, item quantities, and U-factors for all components of the model plant material balance.

Section IV--Measurements. The key measurements and measurement points for the model plant are described. Brief descriptions of the sampling, analytical, volume, and mass measurements are given.

Section V--Error Parameters, Measurements, and Sigma MUF Calculations. The measurement error parameter values, the number and kind of measurements made for the example six-month material and an exampl of the measurement uncertainty of MUF are given.

Section VI--Material Control Areas. A simplified material control area structure is given for the model plant. The material control area structure is described in terms of its purpose in the accounting structure.

Section VII--Accounting, Records and Reports. The concepts of accounting by project and enrichment, and by a combination of MBAs and ICAs are described. The concept of perpetual inventory is also included. The main accounting records and reports for satisfying U.S. national system requirements are also given.

Section VIII--Tamper-Safing. The use of seals and their purpose in materials accounting are described in terms of meeting U.S. national system requirements.

Section IX--Measurement Control Program. The measurement control program is described in terms of its basic elements and its relationship to U.S. national system requirements.

II. PROCESS ASSUMPTIONS

For purposes of illustrating accountability in a conversion-fabrication plant, the model or example process is assumed to have th characteristics listed below and shown in Figure 1.

A. Production Rate

One tonne U per day and 5 days per week of production. Nominal enrichment of 3.0 weight percent U-235.

B. UF_6 Conversion

UF_6 conversion to aqueous UO_2F_2, precipitation of ammonium diuranate (ADU) with NH_4OH, and conversion of ADU to UO_2 powder.

C. Powder Preparation

Calcined powder is processed through preparation steps and blended to yield homogeneous lots of green UO_2 powder.

D. Pelletizing

Green powder is pressed mechanically to produce green fuel pellets.

E. Sintering

Green pellets are sintered in high temperature furnaces under a reducing atmosphere to yield sintered fuel pellets.

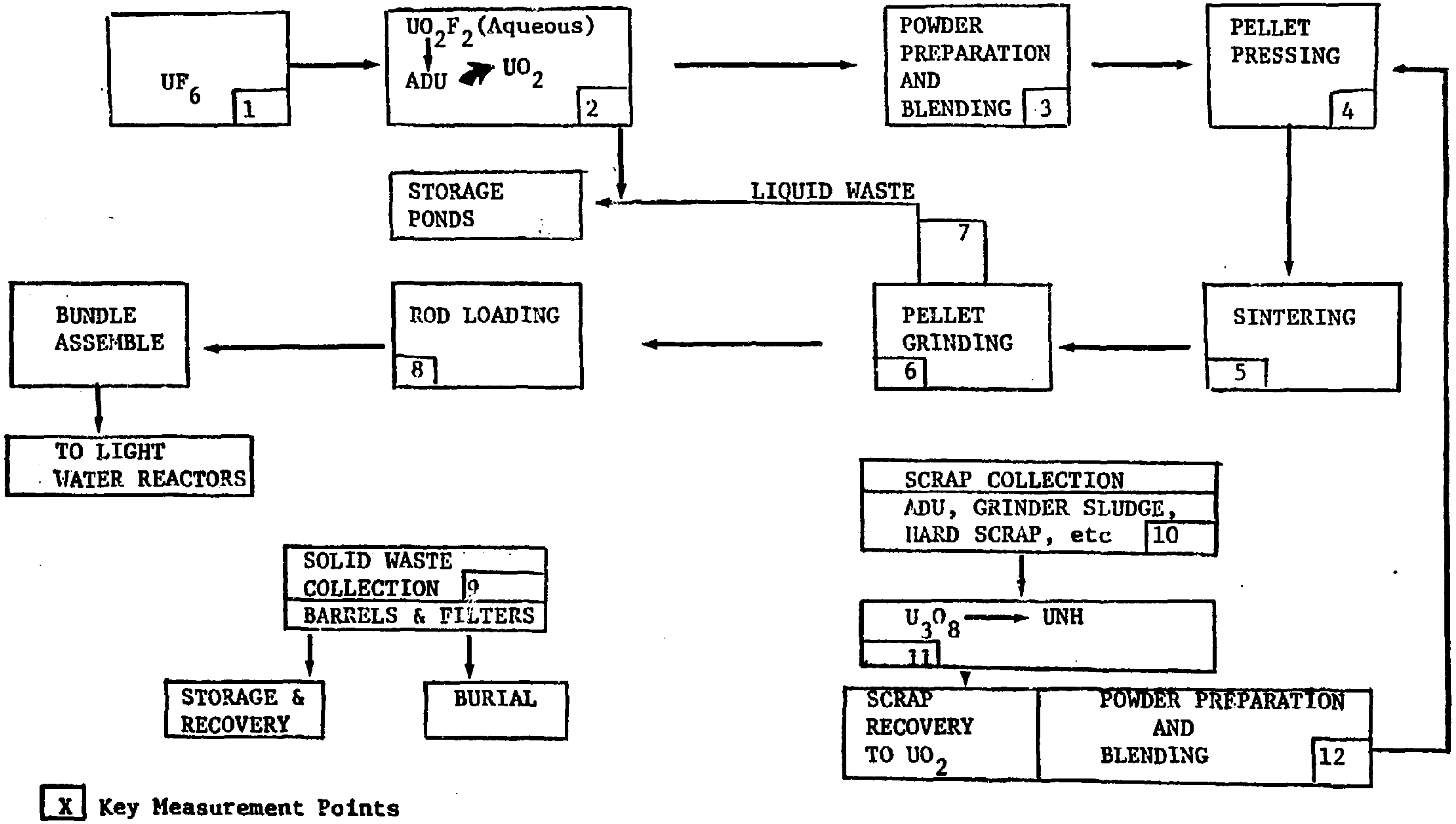

Figure 1. Process Flow Diagram for Model Plant

F. Grinding

Sintered pellets are ground by wet grinding to size specifications.

G. Rod Loading

Columns of finished sintered pellets are weighed and loaded into fuel rods.

H. Rod Finishing and Bundle Assembly

Loaded fuel rods are processed through rod finishing steps and assembled into fuel bundles.

I. Product Shipments

Finished fuel assemblies are packed in fuel assembly shipping containers and shipped via trucks to light water reactors.

J. Waste

The plant generates solid wastes of contaminated handling materials (gloves, paper, plastic) and process filters and liquid wastes from the ADU process and pellet grinding. The solid waste barrels and filters are either stored for recovery or shipped to burial. All liquid wastes are transferred to solar evaporation ponds for concentration and waste treatment. For the accountability model, the plant is assumed to generate solid waste at a rate of 0.2% of thruput and liquid waste at a rate of 0.3% of thruput or total waste of 0.5% of thruput. Note that the 0.5% value is selected as a typical industry value to give emphasis to waste measurements and the need for a measured material balance as opposed to by-difference accounting (zero MUF) practices which the IAEA is trying to eliminate.

K. Scrap Recovery and Enrichment Blending

Scrap materials--grinder sludge, ADU, hard scrap, and dirty powder--are converted to U_3O_8 dissolved to form UNH and processed through scrap recovery which produces prepared, blended green powder lots for pressing. All enrichment blending is assumed to take place in scrap recovery. For U-235 LEMUF calculation, a scrap recycle rate of 15% of thruput is assumed to illustrate the effect of booking 15% of thruput as measured U-235, and 85% of thruput as verified virgin (no enrichment change between input and output) material.

III. SIX-MONTH MATERIAL BALANCE MODEL

The six-month material balance model for the example plant assumed for the IAEA course is shown in Table I. The plant is assumed to operate at a one-tonne-U-per-day rate, 5 days a week and 20 days per month. The recycle of scrap is assumed to be 15% input with all scrap oxidized to U_3O_8 and then either going to storage or processed through scrap recovery and returned to the product stream during the current accounting period. Inventory holdings, which contribute to MUF and LEMUF are assumed to consist of ADU generated from inventory and enrichment cleanouts, green powder,

TABLE I. Six Month Uranium Material Balance Model for Example Plant

Material Balance Component	Percent Uranium	Number of Items	Kgs. U per Item	Total U per Type
Additions				
UF_6	67.60	84	1,400	117,600
Removals				
Rods (UO_2 pellets)	88.10	46,800	2.5	117,000
Waste Barrels	--	470	0.4	188
Filters	--	240	0.2	48
Liquid Wastes	50 ppm	176 (21)	2.0	352
UF_6 Heels	67.60	84	2.0	168
Inventory[a]				
Green Powder	87.6	300	17	5,100
Green Pellets	87.6	20	18	360
Sintered Pellets (on trays)	88.10	1,000	6	6,000
Sintered Pellets (in boats)	88.10	20	18	360
U_3O_8 Powder	84.5	250	17	4,250
Hard Scrap	88.10	40	21	840
ADU	60.0	40	10	400
Grinder Sludge	80.0	20	12	240
Dirty Powder	86.0	20	17	340

(a) Quantities present for both beginning and ending inventory.

green pellets, grinder sludge, U_3O_8, hard scrap, dirty powder, and sintered pellets. Wastes transferred to storage or sent to burial are treated as removals from the MBA (going to burial or retained waste).

IV. MEASUREMENTS

The key measurement points for the model plan were shown previously in Figure 1. The corresponding measurements for each measurement point are given in Table II. A summary of the uranium element and isotopic measurements are given in Table III and described briefly below. Sampling methods are given in Table IV.

The gravimetric method is used to determine the weight percents of uranium in UF_6 (outside laboratory), in UO_2 powders and pellets, and in scrap. For the powders and pellets, five to ten grams of sample is loaded into an ignited, tared crucible, weighed, and the UO_2 ignited to U_3O_8 in a muffle furnance at 900° ± 25°C. The weight percent uranium calculation depends on the sample weights before and after ignition, the impurity content as determined from the spectrographic analysis, the calculated U_3O_8 to U gravimetric factor.

TABLE II. Description of Key Measurements for Model Plant

Key Measurement Points (see Figure 1)	Measurement Description
1	Each cylinder of UF_6 is weighed upon receipt and the cylinder tare weight is used to determine the net weight of UF_6.
(1)	Percent of uranium and U-235 are determined for each cylinder or for each group of cylinders with the same nominal composition using sealed samples taken at the diffusion plant and witnessed by an Exxon Nuclear employee or authorized agent.
(1)	After UF_6 removal, the cylinder is weighed to determine the net weight of any residual heel using the cylinder tare weight.
2	The uranium concentration in liquid wastes is measured when the material is discharged to the lagoon on a batch basis. The batch volumes are also determined.
3	After powder preparation, each bucket of UO_2 is weighed and buckets are tared individually. The cans of UO_2 powder are randomly selected on a sample basis for measurement of percent uranium and U-235.
4	Each boat is weighed with the boats tared individually for green pellet inventory.
5	The loaded boats containing the sample pellets, as at measurement point 4, are weighed for inventory of sintered pellets.
6	The loaded pellet trays are weighed; each tray is individually tared for sintered UO_2 inventory.
7	Centrifuged grinder water is sampled for uranium concentration and a volume measurement is made of each batch transferred to the storage ponds.
8	Pellet samples sent to the analytical laboratory are weighed. Percents of uranium and U-235 are determined. The weight of the UO_2 in each rod is determined by weighing the fuel column stack before inserting into the rod. Accountability is maintained thereafter on a piece count basis.

TABLE II. (Continued)

Key Measurement Points	Measurement Description
9	Low grade wastes (filters, solid wastes in barrels) are contained as a heterogeneous mass and measured for total U-235 by NDA.
10	All containers of dirty powder, ADU scrap, and grinder sludge are individually weighed, sampled, and assayed. The percent of uranium factor for hard scrap is the same as for sintered pellets.
11	Blended lots of U_3O_8 are sampled for percent U and U-235. Each bucket of U_3O_8 is weighed and buckets are tared individually.
12	Same as measurement point 3.

TABLE III. Summary of Uranium Methods

Measurement Point		Analytical Method	
		Element	Isotope
(see Figure 1)			
1	UF_6	Gravimetric	Mass Spectrometer
2	Liquid Waste	Fluorimetric, Titration	Factor
3,12	UO_2 Powder	Gravimetric	Mass Spectrometer
8	UO_2 Pellets	Gravimetric	Mass Spectrometer
10	Dirty Powder, ADU	Gravimetric or Titration	Factor
11	U_3O_8	Gravimetric	Factor
10	Grinder Sludge	Gravimetric or Titration	Factor
9	Solid Waste	Factor	NDA

TABLE IV. Model Plant Sampling Method

Key Measurement Point (see Figure 1)		Materials	Description
1	UF_6 Receipts	UF_6	Sampled at diffusion plants. See UF_6 sampling procedures, TID-7029, "Selected Measurement Methods for Plutonium and Uranium in the Nuclear Fuel Cycle," USAEC, 1963.
2,7	Liquid Waste Lagoon Inventory	Centrifuged Grinder Water	Line sample from transfer line.
		Filtrate (Centrate Hold Tank)	Tank solution mixed by circulating pump and sampled through built-in circulating sampling lines.
3,12	UO_2 Green Powder	UO_2 Powder	Thief or scoop sampled after blending. Three buckets from each lot are sampled and each sample assayed.
11	U_3O_8	U_3O_8 Powder	
8	Sintered Pellets UO_2 Product	UO_2 Pellets	Random samples of whole pellets are taken for U assay and U-235 verification. Five pellets per lot are taken for U assay and two for percent U-235 verification.
10	Scrap Inventory	Grinder Sludge, ADU, Dirty Powder, U_3O_8	All scrap is sampled by scoop after mixing of container (5-gallon cans) contents by mechanical stirring or by tumbling the container.

The titration method may be used to determine the percents of uranium in scrap and liquid waste. An excess of ferrous sulfate is used to reduce U(VI) to U(IV) in a phosphoric acid medium containing sulfuric acid. Excess ferrous ion is destroyed with nitric acid using Mo(VI) as a catalyst. The titration is made potentiometrically with standard potassium dichromate in a sulfuric acid solution. The primary variables used in the calculation include the weight and normality of $K_2Cr_2O_7$, the volume of the titrant, the equivalent weight of U, the sample weight, and the effective oxidation of NBS $K_2Cr_2O_7$.

The mass spectrometer is used to determine isotopic composition (percent U-235). A solid sample deposited on a filament is thermally ionized. The ions travel through electrical and magnetic fields that accelerate and separate the ions into beams, each beam consisting of ions having the same mass-to-charge ratio. Separation of the ions is explained by an equation expressing the mass-to-charge ratio as a function of the magnetic field strength, the radius of curvature of the ion path, and the accelerating voltage. The magnetic field is varied to focus a specific ion on the detector. The detector output is recorded on a strip chart and isotopic content is calculated from the voltages of the ion beams.

Analysis of liquid wastes for uranium concentration is performed using the fluorometric technique. Samples are fused with NaF-LiF and the amount of uranium determined by measuring the amount of fluorescense when activated with ultraviolet radiation. Samples are purified via solvent extraction where interfering materials are present.

Nondestructive Assay Measurements: Uranium in 55-gallon drums of solid wastes is measured by an NDA system consisting of four sodium iodide (NaI) detectors and associated electronics and a barrel rotating fixture. The barrel is rotated at about five rpm to provide an average count from the barrel independent of the radial location of the uranium. Lead shields around the detectors provide vertical and horizontal columnation to flatten out the system response due to variations in source location in the vertical direction.

Uranium retained in HEPA filters after they have been shaken to remove loosely adhered particles is measured by the same NDA system as described above. The filters are packaged in boxes about one foot by two feet by two feet in size during the measurement operation.

Volume Measurements: The volumes of liquid wastes transferred to the storage ponds are measured as follows:

1. Filtrate (Centrate Waste from Conversion and Scrap Recovery): Volumes are measured by a liquid level (full) sensor for each batch transfer to the lagoon system. A typical batch transfer is about 500 gallons.

2. Centrifuge Grinder Water: Small volumes of clean grinder water ($\sim$15 gallons) are measured by the liquid level (sight markings) change of each discharge to the lagoon. The liquid level markings are calibrated for the small volume horizontal tanks by adding known volumes of water.

Mass Measurements--UF_6 cylinders are weighed on a UF_6 cylinder scale of 4000 kg capacity. All other weighings except fuel pellet columns are done on load cell digital read-out scales of 50 kg capacity. Fuel pellet columns are weighed on load-cell digital readout scales of 5 kg capacity.

V. ERROR PARAMETERS, MEASUREMENTS, AND SIGMA MUF CALCULATIONS

The measurement errors for illustrating uranium sigma MUF (LEMUF) calculations are given in Table V. The table also gives the measurement methods by name. The number of measurements made by each measurement instrument or method, the measurement batch sizes, and the number of items or quantities affected by short-term and long-term systematic errors are given in Table VI.

An example calculation of the uranium element sigma MUF (σMUF) for a six-month material balance is given in Table VII. The example calculation for σ MUF includes several simplifying assumptions. Long term systematic weighing errors for the UF_6 scale are assumed to be of the same magnitude and direction for both full cylinders and heels, e.g., they cancel. For scales used to establish inventory weights, the long-term systematic weighing errors of beginning inventory and ending inventory items are assumed to be of the same magnitude but a different and unknown direction, e.g., independent. Long-term systematic errors for sampling and analytical measurements are assumed to be constant throughout the accounting period. Since the model material balance has identical quantities in the beginning and ending inventory, those errors are self-cancelling in the example. The example errors and subsequent σ_{MUF} give high emphasis to the potential systematic errors associated with sampling liquid waste and in assaying solid waste. It should be noted that the combination of an equilibrium inventory model and the conversion of difficult-to-measure material such as ADU to U_3O_8, results in a very low σMUF. For example, if the inventory quantity of U_3O_8 shown in the model were a quantity of ADU and grinder sludge accumulated during the accounting period, the sigma MUF would be about 2 times larger due to the systematic sampling errors for those materials.

TABLE V. Error Parameter Values for Model Plant Uranium Material Balance

Method	Description	Number	Component and Class[a]	σ, % RSD U (or as noted)[b]		
				Random	S.T. System	L.T. System
Weighing	Scale 1 UF_6 Scale	W_1	Additions--UF_6 Full Cylinders, Class I Removals--UF_6 Heels, Class 2e	0.40 kg	0.60 kg	0.15 kg
Weighing	Scales 2-13	W_2-W_{13}	Inventory--Class 3a, 3b, 3c, 3d, 3e, 3f, 3g, 3h, 3i	8 gm	---	6 gm
Weighing	Scales 14,15	W_{14},W_{15}	Removals--Rods Class 3a	0.30 gm	---	0.20 gm
Sampling	Sampling by Sooop or by Thief	S_1	Inventory--Scrap, Class 3g, ADU	6.0	---	3.0
Sampling	Sampling by Scoop or by Thief	S_2	Inventory--Scrap, Class 3h, Grinder Sludge	3.0	---	2.0
Sampling	Sampling by Scoop or by Thief	S_3	Inventory--Scrap, Class 3i, Dirty Powder	3.0	---	0.5
Sampling	Circulating Sample	S_4	Removals--Liquid Waste, Class 2d	5.0	---	15.0
Volume	Liquid Level Constant Volume Discharge	V_1,V_2 V_3	Removals--Liquid Waste Class 2d	5.0	---	3.0[c]

TABLE V. (contd)

Method	Description	Number	Component and Class[a]	σ, % RSD U (or as noted)[b] Random	S.T. System	L.T. System
U-Factor	Gravimetric	U_1	Receipts--UF_6 Input, Class 1 Removals--UF_6 Heels, Class 2e	0.013	---	0.005
U-Assay	Gravimetric	U_2	Removals--Class 2a	0.02	---	0.015
U-Factor	Gravimetric	U_3	Inventory--Class 3a,3b	---	0.30	0.015
U-Factor	Gravimetric	U_4	Inventory--Class 3c, 3d,3f	---	0.030	0.10
U-Factor	Gravimetric	U_5	Inventory--Class 3e--U_3O_8	---	0.10	0.10
U-Assay	Gravimetric	U_6-U_8	Inventory--Scrap Class 3g,3h,3i	0.04	---	0.10
U-235 Assay	Passive NDA	U-235_1	Removals--Waste, Class 2b, 2c, Barrels and Filters	15.0	---	20.0[d]
U-Assay	Fluorimetric	U_9	Removals--Liquid Waste, Class 2d	10	---	8

(a) RSD denoted relative standard deviation. S.T. System and L.T. System denote short-term and long-term systematic errors. Weighing errors for UF_6 cylinders are given as absolute standard deviations for gross weights of uranium. The tare is assumed to be constant. The other weighing errors are given as absolute standard deviations for net uranium weight.
(b) The material classes correspond to those given in Table 1.
(c) Combined systematic error for 2 banks of identical tanks for each discharge point, e.g., line 1, Line 2, and Scrap Recovery.
(d) Illustrative composite value. Actual NDAs are calculated for each Class 2b and 2c from calibration error equations.

TABLE VI. Measurements for Model Plant Six-Month Uranium Material Balance

Measurement	Material	Class	Method Number	Batch Size Kgs U	Total Kgs U by Method	Measurements by Method: Random	Measurements by Method: S.T. System	Total Affected by L.T. System Error
Weighing	UF_6	1	W_1	1,400	117,600	84	17[a]	84 Items
Weighing	UF_6 Heels	2e	W_1	2.0	164	84	17	84 Items
Weighing	Pellet Columns (rods)	2a	W_{14}	2.5	58,500	23,400	--	23,400 Items
Weighing	Pellet Columns (rods)	2a	W_{15}	2.5	58,500	23,400	--	23,400 Items
Weighing	Green Powder	3a	W_2	17	4,590	270	--	135 Items (2)
Weighing	Hard Scrap	3f	W_2	21	420	20	--	10 Items (2)
Weighing	ADU	3g	W_2	10	400	40	--	20 Items (2)
Weighing	Dirty Powder	3i	W_2	17	340	20	--	10 Items (2)
								W_2 = 175 Items (2)
Weighing	Green Powder	3a	W_3	17	4,590	270		135 Items (2)
Weighing	Hard Scrap	3f	W_3	21	420	20	--	10 Items (2)
Weighing	ADU	3g	W_3	10	400	40	--	20 Items (2)
Weighing	Dirty Powder	3i	W_3	17	340	20		10 Items (2)
								W_3 = 175 Items (2)
Weighing	Green Powder (scrap recovery)	3a	W_{10}	17	1,020	60	--	30 Items (2)
Weighing	Green Pellets	3b	W_4	18	360	20	--	10 Items (2)

TABLE VI. (contd)

Measurement	Material	Class	Method Number	Batch Size kgs U	Total kgs U by Method	Measurements by Method Random	S.T. System	Total Affected by L.T. System Error
Weighing	Green Pellets	3b	W_5	18	360	20	--	10 Items (2)
Weighing	Sintered Pellets (on trays)	3c	W_6	6	6,000	1,000	--	500 Items (2)
Weighing	Sintered Pellets (on trays)	3c	W_7	6	6,000	1,000	--	500 Items (2)
Weighing	Sintered Pellets (in boats)	3d	W_8	18	360	20	--	10 Items (2)
Weighing	Sintered Pellets (in boats)	3d	W_9	18	360	20	--	10 Items (2)
Weighing	Grinder Sludge	3h	W_{11}	12	240	20	--	10 Items (2)
Weighing	Grinder Sludge	3h	W_{12}	12	240	20	--	10 Items (2)
Weighing	U_3O_8	3e	W_{13}	17	8,500	500	--	250 Items (2)
Sampling	ADU	3g	S_1	10	800	80	--	--
Sampling	Grinder Sludge	3h	S_2	12	480	40	--	--
Sampling	Dirty Powder	3i	S_3	17	680	40	--	--
Sampling	Liquid Waste	2d	S_4	2.0	352	176	--	352 Kgs
Volume	Liquid Waste (line 1)	2d	V_1	2.0	158	1,659	--	158 Kgs

TABLE VI. (contd)

Measurement	Material	Class	Method Number	Batch Size kgs U	Total kgs U by Method	Measurements by Method: Random	Measurements by Method: S.T. System	Total Affected by L.T. System Error
Volume	Liquid Waste (line 2)	2d	V_2	2.0	158	1,659	--	158 Kgs
Volume	Liquid Waste	2d	V_3	2.0	36	378	--	36 Kgs
U-Assay	UF_6	1	U_1	1,400	117,600	17	(full-heels)	117,432 Kgs
U-Assay	UF_6 Heels	2e	U_1	2.0	164	17		
U-Assay	UO_2 in Rods	2a	U_2	1,200	117,000	488	--	117,000 Kgs
U-Factor	UO_2 Unsintered	3a,3b	U_3	1,200	10,920	--	9 (lot-to-lot) (variation)	--
U-Factor	UO_2 Sintered on Inventory	3c,3d	U_4	1,200	14,400	--	12 (lot-to lot) (variation)	--
U-Factor	U_3O_8	3e	U_5	500	8,500	--	17 (lot-to-lot) (variation)	--
U-Assay	ADU	3g	U_6	10	800	80	--	--
U-Assay	Grinder Sludge	3h	U_7	12	480	40	--	--
U-Assay	Dirty Powder	3i	U_8	17	680	40	--	--

TABLE VI. (contd)

Measurement	Material	Class	Method Number	Batch Size kgs U	Total kgs U by Method	Measurements by Method Random	S.T. System	Total Affected by L.T. System Error
U-235 Assay	Waste Barrels	2b	U-235_1	0.4	188	470	--	288 Kgs
U-235 Assay	Filters	2c	U-235_1	0.2	48	240	--	48 Kgs
U-Assay	Liquid Waste	2d	U_9	2.0	352	176	--	352 Kgs

(a) The short-term systematic error for UF_6 cylinder weighing is assumed to affect all cylinders weighed on a given day. For the 84 cylinders and heels, 5 cylinders are weighed per day for 16 days and 4 cylinders weighed during one day.

TABLE VII. Example Calculation of Uranium Sigma MUF for a Six-Month Material Balance

				Items or Quantities Affected[a] by Types of Error			σ[b]			σ^2 Kgs^2 U by Method		
Measurement	Material	Class	Method Number	Random	S.T. System	L.T. System	Random	S.T. System	L.T. System	Random	S.T. System	L.T. System
Weighing	UF_6	1	W_1	84	17	84	0.40 Kg	0.60 Kg	0.15 Kg	13.44	149.76	158.76
Weighing	UF_6 Heels	2e	W_1	84	17	84	0.40 Kg	0.60 Kg	0.15 Kg	13.44	149.76	158.76
Weighing	Sintered Pellets (rods)	2a	W_{14}	23,400	—	23,400	0.30 gm	—	0.20 gm	0.002	—	21.90
Weighing	Sintered Pellets (rods)	2a	W_{15}	23,400	—	23,400	0.30	—	0.20 gm	0.002	—	21.90
Weighing	Green Powder	3a	W_2	270	—	135 (2)	8 gm	—	6 gm	Variance Computed for Total Weighing on Scale 2		
Weighing	Hard Scrap	3c	W_2	20	—	10 (2)	8 gm	—	6 gm			
Weighing	ADU	3g	W_2	40	—	20 (2)	8 gm	—	6 gm			
Weighing	Dirty Powder	3i	W_2	20	—	10 (2)						
				350		175 (2)				0.023		2.21
Weighing	Green Powder (scrap recovery)	3a	W_3	270	—	135 (2)	8 gm	—	6 gm			
Weighing	Green Pellets	3b	W_4	20	—	10 (2)	8 gm	—	6 gm	0.004	—	0.065
Weighing	Green Pellets	3b	W_5	20	—	10 (2)	8 gm	—	6 gm	0.001	—	0.007
Weighing	Green Pellets Pellets (on trays)	3b	W_6	1,000	—	500 (2)	8 gm	—	6 gm	0.064	—	18.00
Weighing	Sintered Pellets (on trays)	3c	W_7	1,000	—	500 (2)	8 gm	—	6 gm	0.064	—	18.00
Weighing	Sintered Pellets (in boats)	3d	W_8	20	—	10 (2)	8 gm	—	6 gm	0.001	—	0.004
Weighing	Sintered Pellets (in boats)	3d	W_9	20	—	10 (2)	8 gm	—	6 gm	0.001	—	0.004
Weighing	Grinder Sludge	3h	W_{11}	20	—	10 (2)	8 gm	—	6 gm	0.001	—	0.004
Weighing	Grinder sludge	3h	W_{12}	20	—	10 (2)	8 gm	—	6 gm	0.001	—	0.004
Weighing	U_3O_8	3c	W_{13}	500	—	250 (2)	8 gm	—	6 gm	0.032		4.815
									Total Weighing	27.100	299.52	116.815
Sampling	ADU	3g	S_1	80	—	—	6%	—	(3.0%)[c]	28.80	—	—
Sampling	Grinder Sludge	3h	S_2	40	—	—	3%	—	(2.0%)[c]	5.184	—	—
Sampling	Dirty Powder	3i	S_3	40	—	—	3%	—	(0.5)[c]	10.404	—	—
Sampling	Liquid	2d	S_4	176	—	—	5%	—	15%	1.76	—	2,787.84
									Total Sampling	46.148		2,787.84

TABLE VII. (contd)

Measurement	Material	Class	Method Number	Items or Quantities Affected[a] by Types of Error: Random	S.T. System	L.T. System	σ[b]: Random	S.T. System	L.T. System	σ^2 Kgs^2 U by Method: Random	S.T. System	L.T. System
Volume	Liquid Waste (line 1)	2d	V_1	1,659	—	158	5%	—	3.0%	0.0376	—	22,468
Volume	Liquid Waste (line 2)	2d	V_2	1,659	—	158	5%	—	3.0%	0.0376	—	22,468
Volume	Liquid Waste (scrap recovery)	2d	V_3	378	—	36	5%	—	3.0%	0.009	—	1,166
U-Assay	UF_6	1	U_1	17	—	117,432 Kgs (full-heels)	0.013%	—	0.005%	13.74	—	34,475
U-Assay	UF_6 Heels	2c	U_1	17	—	—	0.013%	—	0.005%	—	—	—
U-Assay	Sintered UO_2 (in rods)	2a	U_2	488	—	117,000	0.02%	0.02	0.015%	1.122	—	308.00
U-Factor	Unsintered UO_2	3a,3b	U_3	—	10,920 Kgs (9 lots)		—	0.30	—	—	119.246	—
U-Factor	Sintered UO_2 (in inventory)	3c,3d 3f	U_4	—	14,400 Kgs (12 lots)		—	0.030%	—	—	1.555	—
U-Factor	U_3O_8	3e	U_5	—	8,500 Kgs (17 lots)		—	0.10%	—	—	4.25	—
U-Assay	ADU	3g	U_6	80	—	—	0.04%	—	(0.10)[3]	0.001	—	—
U-Assay	Grinder Sudge	3h	U_7	40	—	—	0.04%	—	(0.10)[3]	0.001	—	—
U-Assay	Dirty Powder	3i	U_8	40	—	—	0.04%	—	(0.10)[3]	0.002	—	—
U-Assay	Waste Barrels	2b	$U\text{-}235_1$	470	—	188 Kgs	15%	—	20%	1.692	—	Total by Method
U-Assay	Filters	2c	$U\text{-}235_1$	240	—	48 Kgs	15%	—	20%	0.216	—	2,227.840
U-Assay	Liquid Waste	2d	U_9	176	—	352 Kgs	10%	—	8%	7.04	—	792

Total All Methods	Random	S.T. System	L.T. System
Weighing	27,100	299.52	116.815
Sampling	46.148		2,787.84
Volume	0.0842		46.102
U-Assay	23.8113	125.051	3,363.301
Subtotal	97.145	424.571	6,314.058

Total σ^2_{MUF} = 6,835.774 Kgs^2 U
Total σ_{MUF} = 82.679 Kgs U

(a) Unless specified as kilogram quantities the numbers shown refer to the number of items affected by random or short-term systematic errors.
(b) Percent errors are in units of relative standard deviations.
(c) Long-term systematic sampling and analytical errors are assumed to cancel when the quantities in the beginning and ending are identical.

VI. MATERIAL CONTROL AREAS

For IAEA Safeguards the entire plant area is treated as a single material balance area. The concept of internal material control areas is not relevant to IAEA acounting requirements. For a single plant MBA, emphasis is given to the plant book inventory and the plant MUF. In this case, changes in the plant book inventory are reflected in the plant receipts and shipments. Those inventory changes are reported in the Nuclear Material Transaction Records (Form NRC-741) which are submitted to the U.S. NRC (or IAEA safeguards. A modified 741 form will be used which corresponds to the IAEA Inventory Change Report.

Using the plant ending physical inventory as a starting point, the submission of Inventory Change Reports for shipment and receipts will provide the IAEA with a plant book inventory which is essentially the same as the book inventory maintained by the plant. The plant accounting system for the plant material balance is the Nuclear Material Reporting System (NMRS) which maintains a historical record of all plant receipts, shipments, waste discards, MUF's and ending physical inventories. Internal material control areas are not identified in this system.

To meet U.S. national system requirements, a system of internal material control areas is established and maintained. These are established in order to localize possible MUF losses and to provide internal administrative and custodial control over the nuclear materials. The material control area structure for the model plant is shown in Figure 2. The various material control areas are shown in their approximate locations on the plant site.

For the material control area structure shown in Figure 2, all nuclear materials enter and leave the plant as discrete items through Item Control Area-1 (ICA-1). UF_6 cylinders received from off-site enter the plant accounting records as item receipts to ICA-1. Finished fuel bundles, waste barrels and filters which are to be shipped are transferred to ICA-1 as discrete items prior to shipment off-site.

UF_6 cylinders enter the process as a transfer from ICA-1 to MBA-1 (Conversion and Scrap Recovery). Prepared UO_2 powder is transferred from MBA-1 to ICA-3A (Powder Storage) and then to MBA-2 (Pellet Preparation). Finished pellets are transferred from MBA-2 to MBA-3 for rod loading. Loaded fuel rods are transferred as discrete items to ICA-2 (Rod Storage and Bundle Assembly) for rod finishing and bundle assembly. Analytical samples are transferred from MBA-1, -2, and -3 to MBA-4, the Analytical Laboratory. Fuel bundles ready for shipment are transferred from ICA-2 (Rod Storage and Bundle Assembly) to ICA-1 (Shipping and Receiving). Waste Barrels designated for on-site storage are transferred from MBA-1 to ICA-3K, the Waste Barrel Storage Area.

Containers of scrap and intermediate products are transferred from the originating MBA to the various storage ICAs for storage as discrete items. The letter designations for ICA-3 (3A-3K) specifies a particular location within ICA-3 such as the powder storage room, 3A, the radioactive materials warehouse 3B, or one of the storage trailers 3C-3H.

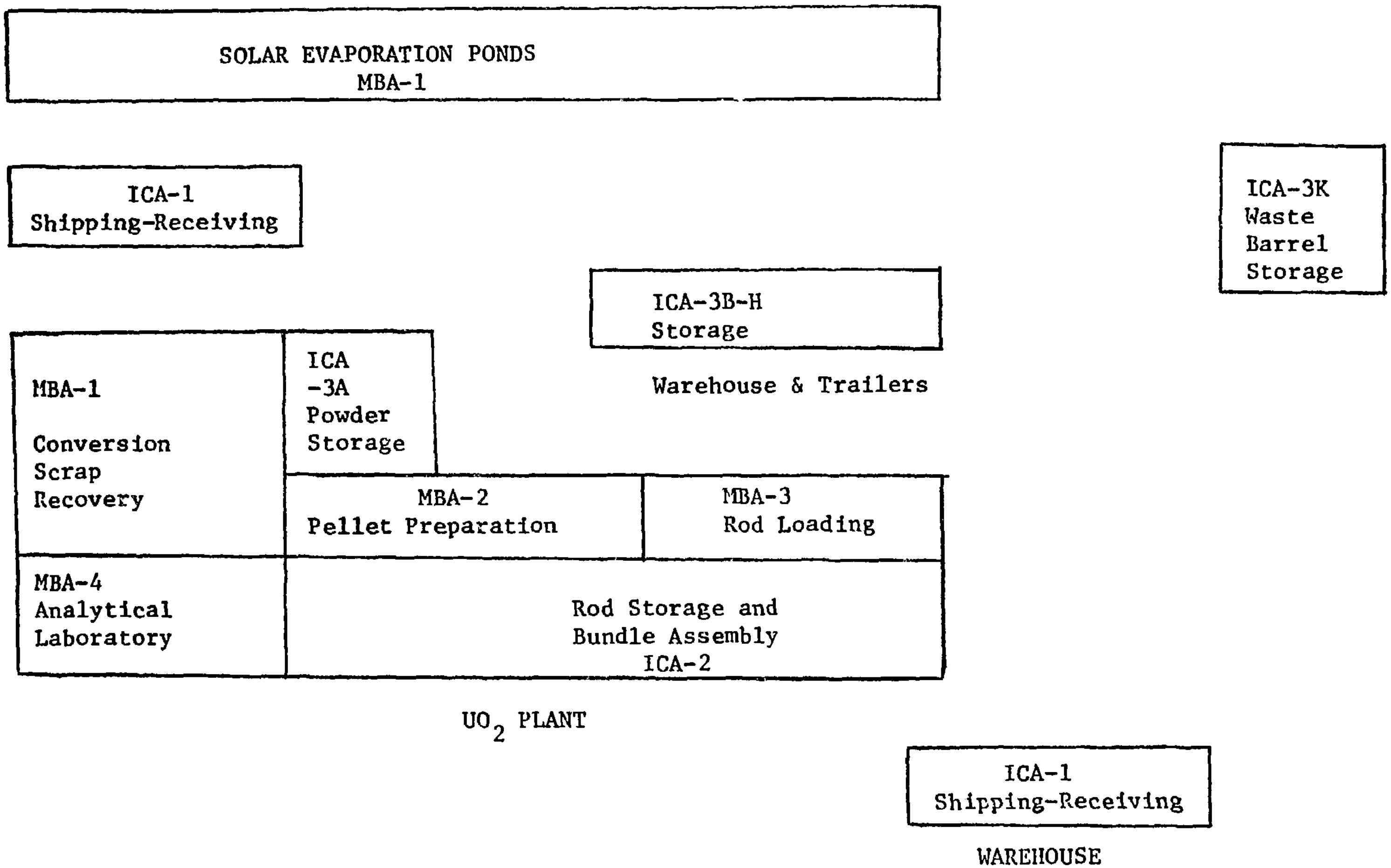

Figure 2. Model Plant Material Control Areas

A main purpose of the combination of item control areas and material balance areas within the plant is to maximize the amount of inventory present as previously measured discrete items and to minimize the amount of inventory present as bulk quantities. The plant accounting system for the internal material control areas is the Nuclear Inventory Control System (NICS) which maintains a continuous plant book balance by MBA and ICA.

VII. ACCOUNTING, RECORDS, AND REPORTS

A. General

This section describes the details of the Model Plant accounting and reporting system for special nuclear material. The accounting system employs double-entry bookkeeping and is established and maintained centrally.

The nuclear materials accounting records are maintained in two computer data bases:

1. The Nuclear Inventory Control System (NICA) maintains a continuous material balance for the plant by MBA and ICA. Additions, removals, and MUF transactions are processed in the time sequence in which they are recorded; and

2. The Nuclear Material Reporting System (NMRS) maintains a historical record of all plant receipts, shipments, discards, MUFs and ending physical inventories. MBAs and ICAs are not identified in this system.

B. Account Structure

The f llowing types of accounts are established and maintained:

Plant Location. MBA or ICA designation as identified in Figure 2.

Material Type. Currently, there are three accounts: 1) depleted uranium; 2) enriched uranium; and 3) natural uranium.

Enrichment. An account is set up for each nominal enrichment for enriched uranium.

Project. Each job or activity is assigned to an account, i.e., a reactor reload batch.

A chart of project and enrichment accounts is maintained in a separate manual.

A separate record is maintained of additions to and removals from the process, of the quantities of material in unopened receipts, and the ultimate product maintained under tamper-safing or in the form of sealed sources.

C. Accounting Forms

The following basic accounting forms used to record and transmit accounting data are shown in Table VIII. The various accounting forms and methods of preparation are to be illustrated in class-room workshops.

D. Operational Description

The operating mode of the internal accounting system is shown in Figure 3. The NICS systems maintains a continuous book inventory of each internal MBA by quantities of U element and U-235 and by project and by enrichments within each project. The computer-based system also maintains an item listing of each item by ICA designation along with the associated U-element, U-235, and project designation.

The internal accounting system operates via the movement of material from one control area to another. Each movement of material is recorded on a location transfer form which is processed into the computer-based system. That system then credits the receiving MBA with the quantities of element and isotope for that project and enrichment and removes those quantities from the project and enrichment account of the shipping MBA. A similar receipt and removal transaction is made in the case of transfers between ICA's or transfer between an ICA and an MBA.

Two basic data records are used in conjunction with the location transfer forms. As each item of material is generated, the applicable weight data, material composition, item identification number, project and nominal enrichment are recorded on a material record card. The material record card is attached to the container. When a container (or other similar item) is transferred, the data on the record card are entered on the location transfer form which is processed into the computer-based system via key punching of the data and submittal of key punch cards. The corresponding data (or U-factors are selected from the memory for each appropriate material composition such as green UO_2 or sintered UO_2. For items such as ADU and grinder sludge, which require a U-assay for each item, the laboratory result is entered into the system along with the location transfer form.

U-235 factors are determined for most materials as the weighted average enrichment of each nominal enrichment within each project. The computer-based system updates the (U-235 factors for all material within a given project and enrichment once isotopic measurements are complete. Some scrap items of mixed enrichment are assigned a specific isotopic factor based on measurement of the item.

Accounting Records

An example of the accounting records and their retention periods are shown in Table IX.

Accounting Reports

A number of accounting reports are generated from the master record accounting system data. An example listing is shown in

TABLE VIII. Model Plant Accounting Forms

Title	Descriptions
Receipt-Shipment	This form documents receipts and shipments between the Model Plant and other licensees of power locations. The data from this form are used to complete NRC/DOE 741 forms.
NRC/DOE Form 741	Procedures for completing this form are provided by NRC/DOE.
Location Transfer	This form is used to transfer material between internal MBA or ICA location accounts.
Project/Enrichment Transfer	Transfers between material type, enrichment, and/or project accounts are documented on this form.
Seal Number Replacement	This form is used to record a replaced tamper-indicating seal on a container in an ICA.
MBA Physical Inventory	All containers in a MBA are recorded on this form during a physical inventory.

Table X. Two reports are generated, specifically to meet U.S. national system requirements. These are: Material Balance Reports and Material Status Reports.

The Material Balance Report is prepared within 30 calendar days after the start of each six-month inventory. That report includes a listing of the quantities of element and isotope in shipments, receipts, discards, beginning and ending inventory, and in MUF. The Material Balance Report also includes the calculated LEMUF (2_{MUF}) and a comparison of MUF to LEMUF and applicable U.S. limits.

The Material Status Reports (742 Form Reports) are also prepared after the six-month inventories. An example 742 form (or the model plant will be prepared for the course.

Bias Adjustments

A separate measurement bias account is maintained in which bias adjustments based on standards measurements can be made to all components of the material balance. A bias adjusted MUF is computed for each physical inventory using all estimated biases (whether statistically sigificant or not). The bias adjusted MUF is used and reported to NRC as a separate index. However, bias adjustments to permanent components of the plant material balance (shipments and receipts) and to the corresponding permanent records and transfer documents are not made unless the measurement bias is statistically

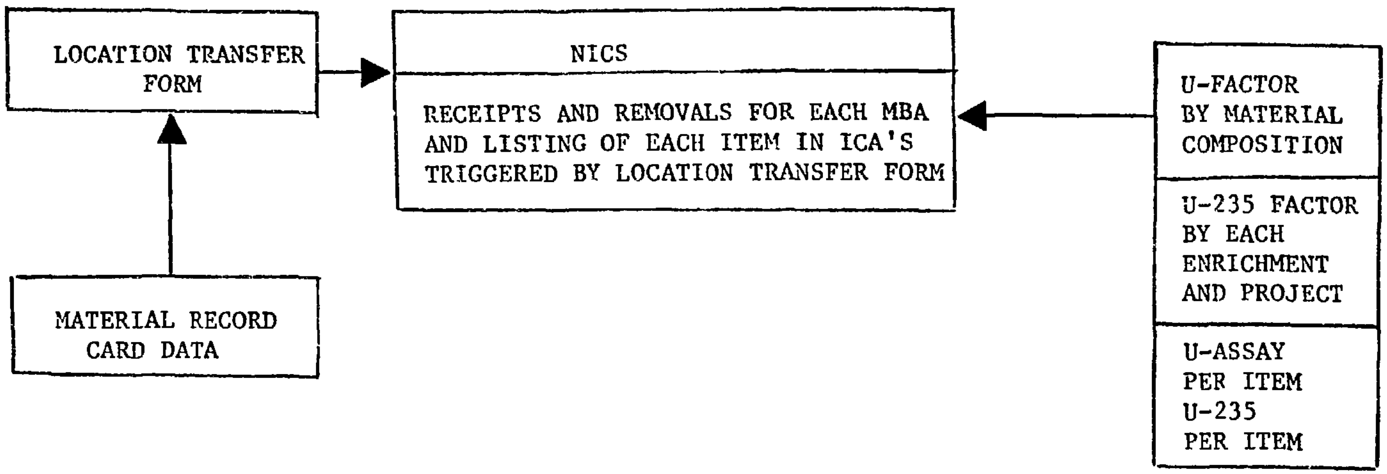

Figure 3. Operating Mode of Internal Accounting System

TABLE IX. Example of Accounting Records and Reports Retention

Document	Issued by	Maintained by	Retention Period
Source Documents			
NRC/DOE 741	NM Accounting	NM Accounting	Permanent
Receipt-Shipment	S/R ICA Custodian	NM Accounting	Five Years
Location Transfer	MBA/ICA Custodian	NM Accounting	Five Years
Project/Enrichment Transfer	MBA Custodian	NM Accounting	Five Years
Seal No. Replacement	ICA Custodian	NM Accounting	Five Years
MBA Physical Inventory	MBA Custodian/ NM Accounting	NM Accounting	Permanent
Internal Records			
Analytical Lab Results	Analytical Lab	Analytical Lab	Item Identity Retained While on Inventory plus Five Years
Physical Inventory Count Sheets	MBA/ICA Custodian	NM Accounting	Permanent
Error Control for Scales and Balances	MBA/ICA Custodian	Statistical Consultant	Five Years
Physical Inventoty Instructions and Results	NM Accounting	NM Accounting	Five Years
Packing Slips	S/R ICA Custodian	S/R ICA Custodian	Ten Years
Tamper-Indicating Seal Logs	MBA/ICA Custodian	MBA/ICA Custodian	Five Years
Perpetual Inventory Listing	NM Accounting	NM Accountinu	Five Years
Material Balance Ledger	NM Acounting	NM Accounting	Permanent
Ending Inventory Summary	NM Accounting	NM Accounting	Permanent

TABLE IX. (contd)

Document	Issued by	Maintained by	Retention Period
Detailed Transaction Listing	NM Accounting	NM Accounting	Five Years
MUF Calculations	NM Accounting	NM Accounting	Permanent
MUF and Measured Discard Summary	NM Accounting	NM Accounting	Permanent
Possession Limits	NM Accounting	NM Accounting	Five Years
NRC/DOE 742 Material in Process	NM Accounting Systems Analyst	NM Accounting Systems Analyst	Permanent Five years
MUF and LEMUF Analysis	Statistical Consultant	Statistical Consultant	Five Years
Inter-Lab Comparisons	Analytical Lab	Analytical Lab	Five Years
Shipper/Receiver Differences	Statistical Consultant	Statistical Consultant	Five Years

significant. Measurement control measures generally maintain measurement bias well below the level of statistical sigificance.

VIII. TAMPER-SAFING

Tamper-safing seals are used to protect the integrity of previously made measurements. Two kinds of seals are used. One is the Type E-seal consisting of two metallic parts that, when snapped together form a closed flat cylinder about the knot (wire crimped within a metal sleeve) on the seal wire passing through the two holes in the cylinder. This seal is used primarily for long-term storage items. The E-seal may also be used as a fingerprinted seal by photographing the random distribution of solder droplets adhering to the inside of the seal cap. A serial number is pre-stamped on each of the metal caps.

The second seal is a pressure-sensitive paper seal. It is a fully opague paper seal with an adhesive backing. The company name and serial number are pre-printed on the seal.

The U.S. national system requires that items in item control areas be tamper-safed to protect the integrity of prior measurements. Items present as inventory items with broken seals must be verified by re-measurement.

TABLE X. Example of Accounting Reports

Title	Data Base	Description
Perpetual Inventory Listing	NICA	Shows current MBA and ICA status. Element and isotope quantities are shown for each MBA by material type, project, and enrichment accounts. Individual containers are shown for each ICA inventory.
Material Balance Ledger	NMRS	Periodic summary of beginning inventory, receipts, shipments, discards, MUF, and ending inventory. Material type, project, and enrichment account detail is given.
Ending Inventory Summary	NICS	Periodic summary showing all containers on ending inventory.
Detailed Transaction Listing	NICS	Shows all transactions which modify the perpetual inventory.
MUF Calculation	NICS/ Physical Inventory	Matches MBA physical inventory and NICA book inventory by material type, project, and enrichment accounts.
MUF and Measured Discard Summary	NMRS	Summarizes MUF and measured discards by enrichment account.
Possession Limits	NMRS	A weekly report comparing inventory levels with license limits.
NRC/DOE Form 742	NMRS	Prepared in accordance with printed instructions.

The U.S. national system also requires that the seals be controlled. Unused seals are kept under lock and records are kept of all seals applied to items. Log books are maintained of the disposition of each seal issued for use. The log hook entry includes the container number, the seal type, the seal number, date of application, and signature of two witnesses to the measurements made (such as sampling and weighing) just prior to sealing.

IX. MEASUREMENT CONTROL PROGRAM

The measurement control program is carried out to meet three safeguards objectives. The first is to ensure the control and quality of accountability and verification measurements. The second is to provide an experimental basis for the estimation of the random and systematic errors of measurement in order to calculate the measurement uncertainty of the material accounting term, MUF. The third is to provide documented evidence that safeguards measurements have met quality criteria.

The measurement control program encompasses all elements of the measurement processes used to determine quantities of uranium element and U-235 isotope in plant receipts, shipments, waste discards, and inventory.

The program is directed at the individual elements of the measurement processes rather than the measurement components of the plant material balance. For each element of the measurement process, such as weighing, sampling, and analytical measurement, a program of standards, replicate measurement, calibrations, and statistical analysis are applied. In addition, the program includes special experiments to estimate weighing and sampling errors and the potential matrix bias arising from the passive gamma measurement of U-235 in solid wastes.

For mass measurements, the program includes a set of standard weights for each scale type, replica mass standards, routine check weighings, replicate standard weighings, and initial and periodic certifications.

A similar program of standards, replicate measurements and certification is carried out for analytical measurements. The high-quality features of the analytical measurements form the basis for the preparation, traceability, and certification of the NDA standards.

The control program for the passive gamma assay of U-235 in solid waste (barrels and filters) includes calibration standards, replicate measurements, daily control measurements, matrix control procedures, and special chemical leaching experiments.

The sampling program consists of two aspects. One part is aimed at homogeneous materials for which sampling error control is an inherent part of the production process. The other part is directed to non-homogeneous materials such as ADU and grinder sludge. For these types of materials, a special resampling program is carried out for estimating random error. Special oxidation experiments of entire items using the U_3O_8 process facility may be used to estimate systematic sampling errors.

All data generated in the program are documented and subject to routine review and statistical analysis. Control program results are used for taking immediate corrective actions in the case of an out-of-control measurement and also for the estimation of long-term trends and measurement error parameters for LEMUF calculations. A detailed measurement review is performed annually and error parameter estimates are updated at least every six months.