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Review of Selected Dynamic Material Control Functions for International Safeguards

USA
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PROGRAM FOR
TECHNICAL ASSISTANCE
TO IAEA SAFEGUARDS

Department of Energy
Safeguards & Security

University of California

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ACRONYMS AND ABBREVIATIONS

ADU	The ammonium diuranate process for converting UF_6 to UO_2.
AGENCY	The International Atomic Energy Agency.
CI	Current inventory, as used by G.E. Wilmington, is the sum of the inputs minus the sum of the outputs minus the RFB.
CODASYL	Conference on Data Systems Languages.
CUSUM	Cumulative sum. Here it refers to the cumulative sum of the instrument error variances.
DBMS	Data base management systems.
DoE	Department of Energy.
DU	Depleted uranium.
DYMAC	Dynamic Material Accounting System.
GECO	A General Electric Company proprietary process that converts UF_6 to UO_2.
H	Holdup. Material containing special nuclear material that is retained in machinery or sticking to the walls of equipment or glove boxes.
HEU	Highly enriched uranium ($\geq$ 20% ^{235}U).
IAEA	International Atomic Energy Agency.
INVB	Beginning inventory.
INVE	Ending inventory.
LASL	Los Alamos Scientific Laboratory.
LEU	Low enriched uranium ($<$ 20% ^{235}U).
MBA	Material balance area.
MICS	Manufacturing information control system at G.E. Wilmington.
MIP	Material in process. This is defined as the difference between the process input and output.
MUF	Material unaccounted for.
NBS	National Bureau of Standards.

NDA Nondestructive assay.

NMO Nuclear Material Officer.

NRC Nuclear Regulatory Commission.

NU Natural uranium.

NUMARS Nuclear material accounting and reporting system. This computer system serves certain report writing and other functions for a number of General Electric nuclear plants.

RA Receiving area.

RFB Reverse flow balance. This term is used by the G.E. Wilmington plant to indicate the estimated amount of scrap that will be generated by a process.

RPG Report program generator. Part of a data base management system.

S Scrap containing special nuclear material that will later be recovered.

SNM Special Nuclear Material. This is the material that can undergo nuclear fission.

TA-55 The plutonium facility at LASL.

UPA One or a short series of processing steps.

UPAA Unit process accounting area. This consists of one or a short series of process steps around which the material balance is closed.

W Waste. Expendables like rags, wiping papers, rubber gloves and other cleaning materials that contain special nuclear materials. This material is assayed to determine whether or not it should be processed. Normally, the amount is low and the material is disposed of.

safeguards. The operating plant acquires process information that fulfills the needs of Quality Control, Production Control, Nuclear Safety, Financial Control, and Department of Energy (DoE) and Nuclear Regulatory Commission (NRC) reporting requirements, as well as the needs of the IAEA. In this report we do not examine the system to see that it meets all of these needs. We have only been concerned with the needs of the IAEA.

In Section II, we define eleven fundamental functions of dynamic SNM accounting systems that seem essential to the IAEA. They provide the Agency with the information needed to do its job--which is, to have, on a timely basis, reasonable confidence in its judgement regarding the loss of specified levels of SNM. Section III examines certain systems to see the ways in which they have met these criteria.

In Section IV, we give our attention to finding ways to counter falsification techniques that are available to the dynamic system. The object here is to achieve an adequate level of confidence so that the Agency can make use of these powerful systems and benefit from them, possibly, to the same extent that the operator does.

The conclusions of the study are given in Section V. In order for the Agency to make full use of the dynamic SNM accounting system, it appears essential that hardware be developed to automatically counter four specific methods of information falsification, as described in Section IV.

Verification considerations also pointed out the desirability of replacing chemical methods with nondestructive assay methods (NDA). At this point, however, it is not obvious that NDA can provide, for all cases, the accuracy required to supplant the chemical methods. It should be kept in mind, however, that none of the systems in operation to date have had the benefit of a thorough systems analysis to establish safeguards performance requirements on system components. Such an analysis might provide an accuracy allocation scheme that would relieve certain demands so that NDA could replace more of the chemical methods.

Devising a functioning software system has been difficult in all cases. Some systems have collapsed because they became unmanageable. Others survived but operate clumsily, are expensive to operate, and resist accommodation to expanding needs because of the rigid structural concept in which they were originally cast. We make some recommendations that should improve future systems.

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II. FUNDAMENTAL FUNCTIONS OF A DYNAMIC SPECIAL NUCLEAR MATERIAL ACCOUNTING SYSTEM

The technical performance criteria that special nuclear material accounting systems should meet were suggested by G. Hough, et al., of the International Atomic Energy Agency (IAEA).[1] These criteria were specified as a "significant-quantity" of SNM whose diversion must be detected within a given period of time. The particular significant-quantity, detection-time pairs differ for different kinds of materials, enrichments, and processes (see Table I). Whether or not the plant's SNM accounting system can meet these objectives depends on quite a few things, such as plant throughput, instrument measurement accuracies, size of mass balance closures, frequency of measurement taking, ability to determine in-process inventories, time required to perform all SNM measurements, and the mathematical techniques used for loss analysis. Adjusting all these factors in a way that will let the system meet the performance goals is the essence of safeguards system design.

Ideally, a dynamic SNM accounting system is one that could be called upon at any time to give a quantitative statement of the material unaccounted for (MUF) in the entire plant together with an estimate of the error in the MUF and could print an inventory list for the entire plant, giving the location and isotopic mass of every item as well as all in-process material. In practice, it may not be possible for the system to respond at any arbitrary instant. In some plants a particular process may be going on that requires a certain amount of time for its completion. In that case, the best the system could do is to give the desired information at the time this process started. An example of this is the evaporation process in plutonium nitrate concentration. Since the concentration is continuously changing, it is difficult, though certainly not impossible, to estimate the amount of plutonium in the evaporator. When the product is emptied into an accounting vessel, it is then possible to take a measurement and respond to a request for MUF and inventory. So, except for process-imposed constraints, the dynamic feature of the system is timeliness. Its most critical implementation will be in facilities in which the SNM is undergoing frequent changes in location or in its chemical or physical form.

TABLE I

SIGNIFICANT QUANTITY/DETECTION-TIME PAIRS

Material	Quantity (kg)	Time
Pure Compounds		
Pu	8	1-3 weeks
HEU	25 (^{235}U)	1-3 weeks
Metal		
Pu	8	7-10 days
HEU	25 (^{235}U)	7-10 days
DU, NU, LEU	75 (^{235}U)	1 *year*

Note: DU = depleted uranium
NU = natural uranium
LEU = low enriched uranium ($< 20\%$ ^{235}U)
HEU = high enriched uranium ($\geq 20\%$ ^{235}U)

Our understanding of the functions that a dynamic special nuclear material accounting system should perform has been a developing one. Some of the functions are obvious; some have been seen from experience to add an important capability, so important that they are now considered basic and necessary; other functions have been incorporated that principally serve process control and it is not clear at all how or whether the safeguard functions should be separated from process control functions. But, at the present time, we regard the following functions as fundamental and essential.

1. Maintain a data base.
2. Maintain a record of transactions.
3. Provide an in-transit monitor.
4. Maintain an isotopic inventory by location.
5. Maintain an audit trail.
6. Close minibalances around unit processes.
7. Perform material loss analysis.
8. Use a measurement control program.
9. Incorporate an error prevention code.
10. Permit only authorized users.
11. Provide the opportunity for the IAEA to independently verify the presence and the disposition of the SNM inventory.

We will now discuss each of these function in a little more detail.

Function 1, the data base, provides computer storage for all the information needed to carry out the rest of the fundamental functions.

Function 2, the record of transactions, is the means of recording what is physically happening during processing as material changes its composition, amount, and location.

Function 3, in-transit monitor, is a means of limiting the time during which a batch of SNM can be in transit between material balance areas (MBA) before operator actions must be taken to locate it.

Function 4, isotopic inventory by location, is a printed report that gives the item identification, its location, and its isotopic mass. The location of this inventory should be precise. Locating it to an MBA, which could be a long process line or a large storage area, is not definite enough. The inspector must be able to go to a particular container or process vessel and perform whatever measurements he needs to verify the claimed inventory.

Function 5, audit trail, provides a printout of the sequence of events that happen to a container or item.

Function 6, minibalances, are mass balance closures around short process steps. These are sometimes called unit process areas (UPA). This brings a greater versatility to the loss analysis by allowing closure around a single UPA for tight locational accuracy or around a combination of UPA's in the event of an instrument failure in one of them.

Function 7, diversion analysis, is a mathematical computation using material unaccounted for (MUF) values, measurement accuracies, and decision theory to obtain a probability of loss of SNM.[2,3]

Function 8, measurement control program, maintains a watch on instrument performance. It controls the frequency with which precision and accuracy are verified and performs a statistical analysis on each new measurement to see if it is within the range of values to be expected.

Function 9, error prevention, is concerned with the avoidance of human error by transmitting instrument readings automatically to the data base, thus avoiding transcription errors (or intentional misinformation); the program also provides a computer check on information before it enters the data base by verifying the logic and value conditions appropriate to the processing station.

Function 10, only authorized people have access. This access is given to the extent needed through correlation with a code number. Generally, three personnel levels suffice: process operator, process supervisor, and nuclear materials officer (NMO).

Function 11, IAEA verification depends on the Agency's ability to confirm the operator's measurements, computations, and claimed inventory.

III. SOME CURRENT SNM CONTROL SYSTEMS

We will now examine two automated SNM accounting systems to see how well they perform the fundamental functions. In cases where there is some deficiency, we will identify the cause and suggest remedies. The two systems we will examine are:

1. The General Electric Nuclear Facility, Wilmington, NC. This facility produces nuclear fuel enriched to a maximum of 4% for use in boiling water reactor (BWR) power plants and uranium oxide for shipment to other fuel fabricators. The general processes carried out are: (1) conversion of UF_6 to UO_2, (2) uranium purification, (3) blending, (4) pellet pressing, (5) pellet sintering, (6), pellet grinding, (7) rod loading, and (8) scrap and waste processing.
2. The Los Alamos Scientific Laboratory's (LASL) Plutonium Facility (TA-55), Los Alamos, NM. This is an experimental and small-production facility that has been designed to have some configurational versatility because it will be called upon to develop a variety of processes as well as produce limited quantities under selected processes.

<u>Function 1: Maintain a Data Base</u>

All SNM accounting systems depend, of course, on a computer for data storage and retrieval, and for computation and report generation. If the facility is large, or if several facilities are under a single corporate management, the computer system is often made up of different kinds of computers interconnected into a communications network. For smaller facilities, a single computer may be adequate. It appears, however, that the trend is toward computer systems that are large enough to do everything connected with the facility operation. This includes process control, production control, quality control and financial control as well as safeguards.

A. G. E. Wilmington

The data base is supported by two computer systems. One is the Manufacturing Information Control System (MICS) located at G. E. Wilmington. The other is the Nuclear Material Accounting and Reporting System (NUMARS) located at San Jose, California.

MICS is on-line at the manufacturing facility where it acquires information on process operations, makes analyses of the data and prints reports with the information sorted as indicated by the titles: (1) Selected MICS transaction by container identification, (2) Selected transaction by new station, (3) Selected transaction by old station, (4) Selected MICS transaction by date/time, (5) Selected MICS transaction by operator badge number, (6) Selected MICS transaction by transaction type, and (7) Transaction history for selected containers. These seven reports are similar in content since they all include container number, enrichment, operator badge number, date/time, transaction, and stations. An eighth report, Scan and Select Source and Disposition, scans selected discrete containers and generates a listing of transaction history for those containers from source through disposition.

MICS transmits data to NUMARS periodically. This information together with other kinds of information introduced by keypunch at San Jose provides a data base from which specialized reports can be generated. Most of these reports are prepared for plant management and some are prepared in response to government SNM control requirements.

MICS acquires its data base as follows: production control first defines the type and quality of material to be used and the way it is to be processed. From this information "travel cards" (punched cards) are prepared. They accompany the container through the process line until the container is dumped or until the uranium fraction is changed. When this happens, a new card is made.

Each travel card contains, as fixed information, the container number, the container type (can, boat, tray, rod, bundle), the U-235 enrichment and the uranium fraction. This information is used to allocate memory storage space in the MICS. All information that is picked up as the material moves through the process line will be stored in that space. At the work stations, weight or enrichment measurements may be taken. From these, isotopic weights and net weights are computed. These measurements as well as the computed values are stored in the data base corresponding to the container identification. Other information, such as station number, transaction, seal number, date/time container was filled, dumped container, inspection report, quality control release status, sample numbers of the samples taken from the container, and sample analysis results, is stored as well.

B. LASL - TA-55

The dynamic material accounting and control (DYMAC) system uses a Data General Eclipse C330 computer with file-oriented data base management. The system supplies more reports than an IAEA inspector would need, but they serve a useful purpose for various elements of the plant management.

Nine real-time reports are available to the user on his display screen and are useful for controlling production, tracing mistakes, and locating items. These reports are: (1) Inventory by Location, (2) Inventory by Account, (3) Single Item Activity Inside TA-55, (4) Single Item Activity Outside TA-55, (5) Item Status, (6) Items in Transit, (7) Transaction Look-up, (8) Inventory by Account with Remarks, and (9) Single Item Activity Inside TA-55 With Remarks.

Ten overnight reports are also available and contain more complete information about the inventory than the real-time reports. These reports are: (1) Inventory by Account, (2) Inventory by Location, (3) Inventory by Project, (4) Inventory by Special Designator, (5) Inventory Based on Item Description, (6) Condensed Inventory, (7) General Ledger, (8) Transaction Activity, (9) MIP (material-in-process) Activity, and (10) Transaction Activity Based on Item Description. The two most comprehensive ones are Inventory by Account (1) and Transaction Activity (8). The inventory reports can also be requested sorted on location, special designator, project, or item description.

In the DYMAC system, all data entered into the data base is associated with a DYMAC name. The DYMAC name is composed of the account number, the alphanumeric code designating the material type (based on fissionable isotope enrichment), and the alphanumeric code identifying the item. DYMAC names are created by the nuclear materials officer when he puts newly-received-on-site material into process. During the processing some portion of the name may change; when it does, a new name is created and further data acquired during subsequent processing is then associated with the new name.

At each UPAA, all the data needed to prepare the inventory file, the transaction file, and the in-transit file are provided. Some of it is entered by the process operator and some by the computer. Just what is entered by each depends on the kind of process being carried out. The things that must be entered by one or the other are the DYMAC name, receipt area, project, person, location, shelf, special designator, item description, date/ time, uranium or plutonium enrichment, uncertainty in enrichment (five isotopes can be recorded), impurities, condition of ending inventory, seal number, instrument code, bulk, units, verification amount, and verification instrument.

Other elements of the data base are generated in the computer and maintained in special files. The error prevention codes and the measurement control program are such files.

Function 2: Record of Transactions

If discrepancies are discovered either through data processing or through inspections, it is very helpful to have a record of transactions to locate the work station where the discrepancy occurred and identify the people who would most likely know what error had been made. A transaction is a statement of what was done with and/or to the material.

A. G. E. Wilmington

When a transaction occurs, a record is made of both the action and the location. In the processing line, which starts with low-enriched UF_6 and ends with reactor fuel bundles, fourteen different kinds of transactions can be made. They are: receipt, move, fill, dump, move after density check, move with weight verification, load tray and move, rod load, move rod lot, transfer rod, pull rods from storage cabinet, move bundle, and remove bundle from MICS on-line data base.

B. LASL - TA-55

The plutonium facility (TA-55) at LASL is organized into four major process areas: metal fabrication, advanced fuels, oxide reduction, and electrorefining. Each process area consists of a series of unit processes in which the chemical, physical, or isotopic form of the material is changed. Each unit process is identified with a receiving area (RA) number. As the process steps are completed, the operator enters transactions into DYMAC that record what was done in that step. As an example, part of the sequence of steps carried out in the metal fabrication operation is shown in Table II.

TABLE II

SAFEGUARDS TRANSACTIONS IN METAL FABRICATION

Location	RA	Operation
		<u>Machining</u>
D 304 or D 305 or D 306 or D 307	MA	Receive Cast Part, transfer to machining box.
	MA	During machining, place part of turnings (∿ 500 g) in slip top can, remove from box, weigh and transfer turnings into new item I.D.
	MA	Send above turnings to casting for remelt.
		Weigh individual finished part(s) and transfer into new item I.D.(s) i.e., JUØ 778901, 02, 03.
		Send finished parts to Inspection (one transaction per finished part)
		Weigh remainder of canned turnings and transfer into new item I.D.(s).
		Send turnings to casting for remelt.
D 301	MM	Package residues (separately) and move to TNC and measure.
D 304 D 307	MA	If turnings, are oxidized, weigh oxide.
D 301	MM	Transfer residues to Serna/Miley for shipping.
		Transfer oxide to Serna/Miley for shipping.
		When machining several parts from several individual pieces, i.e., JUØ 1359C1, C2, C3, C4, where total turnings weight is small, combine "book value" of turnings into one lot, i.e., JUØ 1359TR.
		Weigh canned turnings and transfer into a new item I.D.
		Send turnings to casting for remelt.
		<u>Casting</u>
D 302 or D 303	CA	Receive cast feed.
		Weigh and transfer cast feed into a casting.
		Add alloying material.
		Move casting to furnace.
		Move cast part to mold removal box.
		Remove cast part from mold, move cast part to DYMAC, balance and transfer cast part into new item I.D.
		Send cast part to machining.
		Move skull to metal burning box.
		Move graphite mold to TNC and measure.
		Move rags to TNC and measure.
		Weigh oxidized skull and transfer to new item I.D., MIP remainder.
		Transfer skull to Serna/Miley for shipping.
		Transfer graphite to Serna/Miley for shipping.
		Transfer rags to Serna/Miley for shipping.

There, the location number is the work station, the codes for the receiving stations are under RA, and the instructions under 'operation' are the transactions recorded in the transaction file of the data base. Since TA-55 carries out a large number of different processes, the number of transaction types is also large.

In practice, each of the four major process areas has a transaction list that the process operator can call up on the display of his computer terminal. After a transaction has been selected from the list, a sequence of questions will appear on the terminal screen. The operator answers them one by one. At the end of the questioning, a full display will appear on the screen to show the operator what he has entered. A sample display is shown in Table III. This is the operator's opportunity to check over the entries to be sure the data are correct before he notifies the computer to update the transactions files and the inventory file.

TABLE III

DISPLAY READY FOR OPERATOR APPROVAL

Number	Field	From	To
1,2	Lot ID	FS5301	SC5301
3,4	Account	711	711
5,6	Receipt area	OB	OB
7,8	Project	413	413
9,10	Special designator	S1	S1
11,12	Location	133	133
13,14	Shelf		
15,16	Item Description	CA1	DA9
17	"From" Remarks: Feed stock in oxide blending		
18	"To" Remarks: Scrap from oxide blending		
19	Destination:		
20,21	NM Amount: 4.00 g of Type 54	Bulk Amount	29.00 g
22	Enrichment: 11.74%	(Isotopic Weight:	4.00)
23,24	Impurity: .00% of	Measurement Code:	F10
25,26	Seal Number:	COEI Number	748
27	Isotopic A: .0006, B: .8651, C: .1174, D: .0149, E: .0020		

Results

711/54/FS5301	NM Value: 366.00 g,	Bulk Value: 2471.00 g
711/54/SC5301	NM Value: 4.00 g,	Bulk Value: 29.00 g

Transaction OK? (Y Yes, N No)

Function 3: In-Transit Monitor

When material goes from one MBA to another it may leave the confines of pipes or glove box lines. This loss of protection may occur for transfers other than between MBAs as well. When this happens it could be diverted by the custodian, who is frequently the last process operator, or by someone who takes the material from him. There is also a chance, of course, that the wrong destination was indicated so that the material is simply misrouted rather than diverted. Whichever happens, the material will not arrive at its destination at the expected time and the NMO will be alerted to begin enquiries at once.

Transfers of this kind should be recorded in the data base and the information necessary to identify the item transferred should be part of that record. The computer system, knowing the intended transfer points, would select the appropriate time interval for the transfer. Then, if the receiver fails to record the receipt of the material within this interval, the computer system automatically alerts the nuclear materials officer and the process operators at the sending and receiving stations.

A. G. E. Wilmington

Date, time, current location, and receiving station are standard data recorded in each transaction. If the material does not arrive within the appropriate time interval, MICS alerts the nuclear materials officer. His first action is to contact the sender and receiver by telephone to see if an error has been made in destination. If a destination error has been made, the actual destination is queried. If no error has been made, a physical search is instituted.

B. LASL - TA-55

In DYMAC, the in-transit monitor operates from a subclass of the send/receive transaction called the incomplete transaction file (ITRAN). This file flags the fact that the item is not at the location listed in the inventory file but is in the process of being measured at a measurement location or is in transit to another receiving location. ITRAN is used whenever an item enters the conveyor system, is sent to a measurement location, or is in-transit outside of the process system but still inside the facility.

The transaction sequence using the send/receive transaction is as follows: (a) the sender initializes the transaction and specifies the receiver by account number. If a measurement is to be made, a measurement code is entered to identify the measuring instrument; (b) if a measurement is made, the data along with the item's DYMAC name (account number, material type, item ID) are sent to the computer by the person making the measurement; (c) the receiver confirms receipt of the item by completing the transaction and the item is removed from the ITRAN file.

Time limits are set for the amount of time an item can remain in the ITRAN file. Any item overdue will be reported to the nuclear materials officer and it is his responsibility to investigate and assure completion of the transaction.

Function 4: Isotopic Inventory by Location

Facility record keeping should be such that an inventory by location report could be provided to the IAEA inspectors upon request.[4] It should give the container identification, its location, and its isotopic mass. This would allow the Agency to conduct an unscheduled inventory verification. It would also aid in resolving discrepancies in inventory balances at work stations.

A. G. E. Wilmington

The MICS provides a Selected Station by Location Report which lists items by location within a station and provides an item listing of each container, the location where the item can be found, and all other accounting data. The station referred to here is a process operation, a processing queue, or a storage area.

MICS provides two other reports that correlate location and SNM content. They are:

Material Type Detail Report. It lists each item by material type and other data elements including identity, location, and accounting data (gross weight, net weight, grams uranium and U-235).

Selected Station by Item Report. It lists items by enrichment within a given station.

At Wilmington, the MICS capability is used every two weeks to conduct an audit of material stored on-site in work stations and work station queues.

The quality control information stored in MICS gives quality status of each SNM container. This information is used for consistency checking when containers are moved into processing stations. MICS can provide production and quality control reports that give lists of quantities of material, by item, that have been released to designated work stations or queues. It also provides a daily production log for individual work stations.

B. LASL - TA-55

Dymac identifies material by its DYMAC name, which is the account number, the material type, and the item ID. These are the first three entries in the inventory record. There are twenty other entries. Among them are (1) receipt area, which is the unit process area or item control area; (2) physical location of the material, which is a station or glove box number; (3) shelf, if the material is in a vault; (4) item description, which is the physical form of the material; (5) SNM value; (6) enrichment; (7) seal number; (8) bulk value; and (9) date/time.

Two inventory by location reports can be produced, a real-time report and an overnight report. The real-time report lists all of the items at the requested location and gives its receipt area, SNM value, bulk value, shelf location, physical description, and seal number. This report can call for as many locations as desired.

The overnight report reads out all of the information in each record by location. In addition, it gives subtotals of SNM and isotopic weights by material type with a grand total of all SNM and isotopic weights at the end of the report.

The total plant inventory cannot be determined by these inventory reports alone because, when an item is in-transit, it is removed from the inventory file and entered in the in-transit file. The two files together do, however, provide a statement of the total inventory at the time the request is made.

Function 5: Audit Trail

Two kinds of audit trails are needed. One is the forward audit trail, which shows the sequence of events from the origin of the item to its final disposition. This is most helpful when an item cannot be physically located. The other is the backward audit trail. It is most helpful when a deficiency is discovered in an item. Backward tracing shows the sequence of events that actually produced the item and this sequence can be compared with the planned sequence. This should be useful in identifying the origin of the discrepancy.

A. G. E. Wilmington

MICS produces a report called Scan and Select Source Disposition which allows the generation of a listing of the transaction history for a selected item from its source through its disposition. This fulfills the need of a forward audit trail.

In addition, two satellite-computer routines, CANTRACS and QATRACS, provide both forward and backward tracking with audit trails. These routines are historical data-base managers fed from the MICS transaction data base. The CANTRACS routine handles activities from UF_6 to UO_2 pressing while QATRACS handles activities from UO_2 pressing through rod load. They track each unit process in time sequence of item identity and material quantities. This scheme provides a knowledge of "Parent-Child/Child-Parent" relationships as well as "Brother-Sister" relationships with correlations to equipment, process parameters, and laboratory measurements. The system can be queried to provide this relational information. This system fulfills the need for forward and backward audit trails.

B. LASL - TA-55

To follow a forward and backward audit trail the 'from' and 'to' information must be recorded in each transaction record. DYMAC does this. At the current stage of development, however, DYMAC does not contain the computer program that can generate the audit trail.

Function 6: Minibalances Around Unit Processes

Some distinct advantages accrue to the safeguards system if the chemical or manufacturing process can be divided into units that contain a relatively small amount of SNM. Usually, the absolute error in a measurement is proportional to the quantity of material being handled (the relative standard deviation being constant). So handling small quantities results in smaller absolute errors and, therefore, in better loss sensitivity. Moreover, relatively small processing operations provide good locational accuracy so that, if loss is indicated, the search for the material has a well defined starting place.

Small unit processes also provide a backup capability. In the event of an instrument failure that prevents the measurement of input or output in one unit process area, two unit process areas can be combined to form a new one. Although it is larger than a single one, it is still small compared to the total process line and still has the advantages of a smaller unit. But, more important is the fact that the ability to close a balance around the crippled process is retained.

The IAEA guideline specified for a particular kind of plant as a significant-quantity, detection-time pair refers not only to a unit process but also to the entire plant. The total measurement error for the plant will be reduced when measurements are made at unit processes. The variances combine as the square root of the number of unit processes when the processes are in parallel. The same is true for series processes if each process measures its own inputs and outputs rather than sharing a measurement with its neighboring process. If the measurement is shared, the reduction in the total variance is reduced by something less than the square root of the number of unit processes but it is still an improvement over the accuracy achievable by measuring total plant input and total plant output.

A. G. E. Wilmington

At Wilmington, the material balance is closed around the entire plant, around each MBA, and around the work station. But, except for into-plant receipts and out-of-plant shipments, the data that goes into the computer data base is entered at the work stations.

The process line is composed of "work stations" which are unit process areas. In these stations batches of material enter the process and batches of product are removed. While this is going on, the work station inventory may or may not be zero, but it is never measured. After the process run is finished, the inventory is zero and the sum of inputs and outputs should be zero within the measurement errors. This consititues a "minibalance" around the work station or unit process.

Because of this work station philosophy of material accounting, the benefits of small absolute errors, better loss sensitivity for the total plant, backup benefits, and good locational accuracy of loss or error is available at Wilmington.

B. LASL - TA-55

At LASL's TA-55, a balance is also drawn around the facility as a whole, around each MBA (also called an account number), and around each unit process area (UPA).

A material balance is maintained around each account by measuring the material entering and leaving it. If, however, the material is in a sealed can, the recorded value is accepted.

DYMAC has embraced the concept of a minibalance and maintains the material balance around the unit process by measured values. The unit process area (UPA) may be a glovebox or part of a glovebox or two or more adjoining gloveboxes. This approach provides good information on the location of the material. Furthermore, some UPAs may be able to complete their batches and have time to perform a cleanout. This allows the removal of scrap and holdup to reduce the material in process (MIP) in that area to a known value, zero, thereby improving the balance accuracy. These cleanouts can be performed for a localized area without having to wait for a total plant shutdown.

Function 7: Loss Analysis

In a dynamic SNM accounting system, the definition of Material Unaccounted For (MUF) is fundamental to the loss analysis. We may arrive at the definition of MUF as follows: Consider an enclosure (a UPA, a work station, an MBA, or the entire plant) that contains some beginning inventory of material (INVB). The ending inventory (INVE) will be INVB plus the material put in (IN) minus the material taken out (OUT) minus the scrap (S) minus the waste (W) minus the holdup in the equipment (H). This can be written as

$$\mathrm{INVE} = \mathrm{INVB} + \mathrm{IN} - \mathrm{OUT} - S - W - H. \qquad (1)$$

This equation is true if there has been no loss. To verify this, all the terms of the equation must be measured. It isn't good enough to measure the quantities on the right side and calculate the quantity on the left.

If the measured left side is not equal to the measured right side, we have a nonzero MUF. Of course, using measured values, it is unlikely that MUF will be exactly zero because of measurement errors. We can then only state that MUF is or is not zero at some level of confidence. This determination of MUF is described as "closing the balance around the process."

The loss detection sensitivity can be improved, that is, smaller losses can be detected, if frequent balance closures are made. This provides a greater number of measurement samples and makes it possible to use more sensitive decision making analyses such as CUSUM and Kalman filtering.[2,3]

In some processes, it is not possible to measure the ending inventory in the enclosure. In that case, it must be estimated using an empirical relationship or a mathematical model. In either case, an estimate of error should also be made.

A. G. E. Wilmington

The work station is the unit in which the basic SNM accounting is done. It is a physical process operation, a process queue, or a storage area. In a few instances, a work station may consist of a series of unit operations in an enclosed process, for example, UF_6 to UO_2 conversion.

The following accounts are kept at the station: receipts, shipments, current inventory, reverse flow balance (RFB, see below), and difference. The current inventory is calculated as a running algebraic sum of receipts, shipments, and RFB.

$$CI = \text{SUM receipts} - \text{SUM shipments} - \text{RFB}. \tag{2}$$

This would be the same as the final inventory we discussed above, since the running sum is started when the beginning inventory is zero. The scrap and waste are temporarily accounted for by the Reverse Flow Balance Account. Process experience has shown, for each work station, the fraction of the receipts that typically goes to scrap and waste. To improve the estimate of the current inventory, this fraction is subtracted from each receipt. At monthly intervals, the scrap and waste accumulated from the work stations is measured and, using an allocation table stored in the computer, a fraction of the measured number replaces the standard estimate from the Reverse Flow Balance Account. At this point the entire right side of the INVE equation consists of measured numbers.

Generally, the current inventory (CI) is not measured during a process operation, so the two sides of Eq. 2 cannot be compared on a measurement basis at intermediate times. The only time CI is known directly is when all of the product has been shipped out of the work station. At this time the left side of the equation is known to be zero so the measured sum on the right side should be zero. This comparison really constitutes an estimate of MUF. It is only an estimate, however, because at this point the reverse flow balance account estimate has not been replaced by the measured value and the material held up on process equipment has not been cleaned out and measured. It should be remembered that many of these processes are essentially continuous. The completion point in a process may be the closing of one valve and the turning on of another, as would be the case with the starting of a new UF_6 cylinder. Nevertheless, it provides a point in time when the CI value is known.

Cleanouts occur less frequently than process completions so several MUF estimates are available during these intervals between cleanouts. The cleanout provides a real MUF and, in addition, provides the opportunity to correct the preceding MUF estimates by allocating a portion of the holdup. Table II shows the cleanout intervals for the various types of equipment.

Although current inventory is not measured during a process operation and a material balance cannot, therefore, be struck, the MICS does provide a method of monitoring the inventory during this period. This is done by establishing alarm limits. The limits are chosen on the basis of a knowledge of the variability of the process. It operates as follows: the weight of the material received is not verified at the receiving work station. Rather, the value attached by the shipping work station is accepted. As the processing work station finishes some of its processing, it weighs its output and sends it on. Under these circumstances, if a series of receipts were actually underweight and the series of shipments were of the correct weight, the MICS would observe a numerical growth in the current inventory since, presumably, more is going in than is going out. If this number got large enough to exceed the

TABLE IV

CLEANOUT FREQUENCY

Days Between Cleanouts	Equipment
90	ADU conversion
90	GECO conversion
15	Mill-slug-granulator
60	Uranium purification system
3	UO_2 powder blender
11	UO_2 pellet press
6	Pellet sintering furnace
10	Pellet grinder
2	Fuel rod loading
90	Scrap drying furnace

alarm limit, MICS would notify the operator and the nuclear material officer. This loss detection method operates between balance closures around the process station, which occur at the end of a process run. It might be argued that such a disagreement would not occur if each receipt were measured to verify the preceding process station's claim. But that introduces extra steps into the process and it has been shown that the operation is significantly more efficient using the alarm limits technique.

B. LASL - TA-55

At TA-55 the material balance is closed at three levels. The station or entire facility balance is monitored by the nuclear materials officer (NMO), the account or MBA balance is monitored by the account supervisor, and all of the process data are input and the balance is closed at the unit process area (UPA).

Most of the processes at TA-55 are carried out on a batch basis so there are periodic occasions when the UPA is empty except for scrap, waste, and holdup (see Eq. 1). On these occasions, a material-in-process (MIP) calculation is made by subtracting the sum of the shipment out of the UPA from the sum of the receipts into the UPA, that is

$$\text{MIP} = \text{SUM receipts} - \text{SUM shipments} \ . \tag{3}$$

This equation is similar to Eq. (2) used at G. E. Wilmington except that TA-55 does not attempt to estimate the scrap and waste (Wilmington's RFB) that will be generated at the UPA. As standard practice, however, the scrap, which is usually more massive than the waste, is frequently weighed and sent out of the UPA as a shipment. Waste is accumulated from many UPAs and is finally measured to get the SNM content, but there is no attempt to allocate this material back to the individual UPAs. This, of course, leaves an unmeasured component in the MUF. Another unmeasured component is the holdup in equipment. Because of these unmeasured components, a MUF cannot be generated at the UPA level. At the MBA level, however, a MUF could be generated--but only when all of the UPAs in the MBA are cleaned out at once. More often, certain UPAs are cleaned out at times convenient to their own processing sequences. And although this does not provide a MUF at the MBA level, it does improve the accuracy of the MBA MIP.

Most of the processes at TA-55 are experimental ones and, therefore, there is little experience on which to establish an estimate of the "normal process variation". Consequently, no alarm limits are defined for these processes.

Function 8: Measurement Control Program

The reason for having a measurement control program is to assure accurate measurements, since accurate knowledge of SNM quantities lies at the heart of an accountability system. It can help us avoid mistakes that could arise from using an unvalidated instrument or one that is out-of-control because of either spontaneous changes or tampering.

The instrument control program assures accuracy by following a strict schedule of calibration and reference-checking. Calibration must be done with standards traceable to a national system of standards and measurements, where that is possible. For some measurements, such as those in which the material is in a nonstandard form or has an impurity component, secondary standards or artifacts are fabricated from material quantities that are traceable to national standards.

The measurement control program specifies the time or conditions when calibrations and reference-checks are to be made and it maintains a record of the results. The computer uses this record for a variety of things, such as verifying that the calibration or reference-check has been made, accumulating data from which estimates of systematic error can be made, and making a statistical check on individual measurements to verify that they are within expected limits.

The frequency with which the instrument performance should be verified in an SNM accountability system is, perhaps, greater than would be required on the basis of instrument stability alone because, in this system, we are on our guard against not only spontaneous deviations but also intentionally induced ones.

A. G. E. Wilmington

Data from reference standards are used to establish the systematic error, including bias, of the measurement systems used to determine the bulk, uranium content, and uranium-235 content. Only those reference standards are used whose assigned values and their uncertainties are known relative to (1) physical constants, (2) national standards such as standard reference materials supplied by NBS, or (3) for those cases where no national standards are available, use company fabricated standards whose preparation is well documented and has traceability to NBS or other nationally accepted laboratory. The company maintains records which document standards' certification, recertifications, and traceability for at least five years.

Platform scales are recalibrated when they are serviced or when calibration check exceeds two scale divisions. These calibration checks are made at least once each shift. For electronic balances, at least two calibration checks are made each week.

Process tanks are calibrated by repeated additions of weighed volumes of well-characterized liquids. They are recalibrated every five years or whenever changes are made that could affect the calibration.

Analytical chemistry methods used to analyze SNM are calibrated by analyzing traceable reference standards. At least two calibration checks are made each week. The method is recalibrated whenever an out-of-control condition at the 0.001 level of significance is indicated. The mass spectrometer is one-point-calibrated by analyzing a standard at least three times. Calibration is checked at least twice a week by analyzing traceable standards.

NDA equipment is calibrated using prepared standards that are representative of the process material in their bulk loading and isotopic values. The rod scanners[5] are recalibrated when the rod enrichment or design is changed. Calibration checks are made at four to five hour intervals.

The "elephant gun" waste counter[6] is recalibrated each month using four standards. Calibration checks are performed each week. The enrichment analyzer[7] is calibrated with traceable standards and checked daily with traceable reference standards.

Instrument measurement precision is maintained through a program of measurements on replicated samples. This program provides a minimum of 15 replicates or 100% replication, whichever is less, for each measurement type/material category during each material balance period. These measurements are conducted uniformly throughout the period with about equal numbers of unknown samples and replicates being measured.

The MICS monitors the instruments when standards are measured. If the measurements are outside the confidence levels, the computer indicates to the operator that the instrument is out of control.

B. LASL - TA-55

The DYMAC measurement control program uses two kinds of checks to assure proper instrument performance. An accuracy check is made at least four times per week to verify that no changes have occurred in instrument response to working standards. Precision checks are made weekly for changes in reproducibility and to detect nonrandom fluctuations in counting instruments that might indicate electronic problems. The data generated by these checks are transmitted directly to the computer for checks against control limits. The data are stored in instrument history files for additional use such as limit-of-error calculations. The control limits used are a 95% confidence level warning limit and a 99% confidence level as an action limit. If an instrument check exceeds the action limit, or exceeds the warning limit twice sequentially, the computer does not allow the instrument to be used for accounting measurements until the instrument's performance has been brought back within the limits.

The type of performance check used depends on the instrument being tested. DYMAC currently treats balances and counting instruments somewhat differently. The accuracy check for balances requires the measurement of three standard weights that cover the normal operating range of the balance. A t-test compares the difference between the measured and standard values to ensure that the response is consistent with previous observations and to determine possible bias terms. Precision checks consist of replicate measurements of each standard weight to estimate standard deviations for each level. These new standard deviations are then compared with the past 15 weeks' pooled standard deviations, using an F-test to monitor changes in balance reproducibility.

Counting instruments also use a t-test to check accuracy. In this case a plutonium sample is used and the instrument's actual response is compared with its expected response. Precision checks consist of two different tests that use the same set of 15 replicate measurements. The reduced chi-square test compares the counting variance estimate with a variance estimate based on replication. The replicate data are then tested for randomness using a mean square successive difference test that can detect long-term trends or rapid oscillations that might otherwise go unnoticed.

Function 9: Error Prevention

A computer controlled SNM accounting system can make automatic checks to assure that the actions being taken conform to the intended operation. Authorized users, logical moves of material, reasonableness of measured values, compliance with specified limits are among the actions that can be automatically checked.

A. G. E. Wilmington

The error prevention program derives its effectiveness from three basic functions: (1) using standardized, fixed information where possible; (2) allowing the computer to calculate needed information from the data stored in it; and (3) allowing the computer to verify the acceptability of newly-input data.

Examples of fixed information are container ID, container type, material type, uranium factor, and enrichment factor. These do not change as the container progresses through the process line.

The variable data inserted into the MICS include current location, gross and tare weights, release status from quality control, sample analysis results, sample analysis identification, current seal number, boat number. From these data and other data stored in it, the computer calculates and stores in the container record, current station, net weight, uranium weight, isotopic weight, date/time filled, filling station, inspection report, sequence - next/prior, dumped container. Computer generation of these numbers is far more reliable than operator generation of them.

The MICS is also able to verify or validate information it receives. If the information does not pass the test, the computer refuses to store the information and signals the operator, or the nuclear materials officer, that the data is in error.

There are basically five types of consistency checks made automatically by the MICS. These are:

(1) Data input checks such as validity of user's badge, validity of container ID, legitimacy of the transaction being performed, legitimacy of the computer terminal at which the transaction is being performed, measuring instrument being used has been calibrated or checked by a reference standard within the measurement control schedule. In all, MICS handles 68 kinds of data input checks.

(2) Logical moves of material that correlate with the physical manufacturing flow. Examples of these are: (a) press feed can only be dumped into a work station designated as a press and from a press feed queuing work station, (b) a boat of pellets can only be filled from a press process work station and filled to the green pellet storage work station. MICS monitors 25 such logical moves.

(3) A material container cannot be released to the next processing step until the quality of the material has been ascertained. If it meets the quality criteria, quality control personnel insert a release code into the container record. Without this release, MICS puts a hold on the container. Material release status is established at 20 locations.

(4) Enrichment matching is carried out at 41 stations. This action aids in preventing unintentional enrichment mixing. Process stations are assigned specific enrichments. Only material identified on the MICS as containing the same enrichment as that assigned to the processing station can be processed at that station.

(5) Weight matching is done at 50 locations. This prevents the generation of containers reflecting weights outside the expected range. This serves as a secondary check on weights and quantities to assist in the control of inventories and material flows.

To complete a transaction all of these consistency and data integrity checks must be met. If any are not, the process aborts.

B. LASL - TA-55

To help assure the quality of the data it collects, DYMAC does two things: (1) it performs extensive diagnostics on user inputs, and (2) minimizes the input required of user personnel by using on-line instruments and drawing on standardized information precoded into the computer data files.

Diagnostic checks are performed on all input data. Each response typed in at the terminal is checked syntactically, that is, for the correct number of characters and for proper alphanumeric format. Many entries are then compared with valid contents of corresponding files. For example, a technician may respond with "G253" for glovebox 253 when asked for an item's new location. After checking the syntax of the response, the computer checks its validity by searching a file of the facility's location designators.

The computer next searches the inventory file to see if an inventory record for that DYMAC name exists. If it does not, the operator is not allowed to continue. This check will detect a typing error, a mislabeling or an improper transaction that has previously been made.

Searches are also made of the instrument file to confirm the identity of the instrument used in the transaction and searches the standards file to validate the standards used in the daily precision and accuracy checks of the NDA instrument used. If any of these diagnostic errors are found, the result is displayed on the process operator's terminal so that he can take corrective action.

In addition to detecting errors, DYMAC tries to minimize the opportunities to make them. Whenever it is possible to let the instrument provide the input or when the computer can generate or transfer data, this is done in preference to allowing human input. Instrument measurement results are automatically read by the system and diagnostics are performed on the data to ensure its integrity and to guarantee that the transmission has been error-free.

To provide the computer with the precoded information, each process in the facility has been analyzed to determine material flow and measurement points. For each step in the process, the computer has been precoded to know whether an item's name is changing, whether it is to be divided to form new items, or combined with another item. It also knows what type of material is involved, what verification is needed, what calculations to perform with the measured data, and whether completion of a process step indicates that a material balance can be drawn.

All this standardized information is stored in computer data files. When a technician identifies the process step he has just completed, the system accesses the appropriate files to furnish a large part of the transaction data. It only asks for human intervention when the information cannot be precoded.

Function 10: Authorized Users

The dynamic SNM accounting system normally performs many more functions than keeping track of SNM. The system is more properly described as a Dynamic Accounting and Operating system with SNM accounting and control as only a part of it. And like all company records, the information is restricted in its dissemination. The information needed by various sections of the company to help them carry out their duties is made available to them - but to them only.

The dynamic accounting and operating system provides real-time information to process operators, to quality control, to production control, to the radiological and environmental protection office, and to the nuclear safety office. Periodic reports are prepared for the above offices as well as for safeguards accounting for NRC licensing, and for the finance department.

Only designated individuals are given access, usually by means of a machine-readable coded badge, to real-time information, and periodic or special reports are prepared in response to written requests from designated individuals.

There are occasions when erroneous data get into the data base or data is not entered. When these conditions are discovered, the needed changes should be recommended with justifications to a single individual who is the only one authorized to make changes in the data base. The changes with justification should be documented.

A. G. E. Wilmington

Operators involved in processing or measuring material containing SNM need to enter the results into the data base. They are identified by a punch-coded badge. They are also able to call to their terminals certain data relating to their processing tasks. Designated individuals can call up on-line reports or request periodic reports. Only the Manager of Nuclear Materials Management can authorize the modificiation, deletion, or addition of data in the data bank.

B. LASL - TA-55

In DYMAC there are three levels of responsibility for seeing that safeguards procedures are followed. They are the unit process level, the MBA or account level, and the station level. The unit process operator is, of course, the heart of the system since he controls the entry of data. But there are only certain entries he can make or change and these are controlled by the computer program. A supervisor at the MBA level monitors the material balance of his area and periodically takes a physical inventory to verify the balance (this is done each six months). The supervisor cannot make changes in the data. If a discrepancy is found at any level, a change has to be requested of the nuclear materials officer, who is the custodian of the station level. He is the only person authorized to make corrective changes at any place in the data base.

Function 11: Opportunity for IAEA Verification

It is of considerable help to the IAEA inspector to have a complete inventory listing by location. This is easy to do with a dynamic SNM accounting system because this information is continuously on file. Stored inventory is of special importance because it is usually in a concentrated form, and, therefore, most attractive to diverters. Furthermore, it often constitutes the major portion of the plant inventory. Stored material, as compared with in-process material, is also easier to inspect or verify. Generally, the integrity of the tamper-indicating seals, whose identities correspond to the accounting system inventory record, aids in the verification for most of the individual items. Verification of the isotopic contents of all the containers is often not practical so a statistical sampling is made sufficient to generate an adequate confidence level.

IAEA verification of in-process material is very difficult. Throughputs can be high and processing can require a very large number of transactions. The transactions should be supported by quantitative measurements as the material moves through the processing line. But verifying quantitative measurements means that the inspector has to make the measurements himself or he has to convince himself that the operator's measurements are correct. Currently, inspector-made measurements occur at infrequent intervals and can be made at only a few points in the process line.

A. G. E. Wilmington

A record of stored inventory by location is always available to aid in the verification of stored items. But the number of items can be so large, running into the tens of thousands, that verification can only be achieved by statistical sampling to reach some desired level of confidence.

The plant's standard procedure of conducting a biweekly item audit for material going into and out of process equipment would, if Agency inspectors were present, provide an opportunity to verify the presence of the material in a piece-wise-continuous fashion. This is not a partial sampling. 100% of the material in the process line is verified. If the Agency could make use of this opportunity, its level of confidence in its ability to detect loss would be very greatly increased.

With its current capabilities, the Agency is restricted to spot verification of in-process-material concentrations. And this would have to be done with the Agency's own instruments. There is no way for them to verify plant-measured values on a real-time basis, particularly when the majority of the measurements involve chemical analyses (virtually all of the uranium determinations and over half of the ^{235}U determinations involve chemical processes). On a delayed-time basis, it is possible, in principle, for the Agency to collect duplicate samples and have them analyzed in IAEA facilities. In practice, this approach is probably not feasible because of the large number of samples and because of the transportation restrictions on radioactive material.

B. LASL - TA-55

The SNM inventory at TA-55 is monitored and controlled by the Dept. of Energy. DYMAC provides an up-to-the-minute record of items in storage, items in process queues, and material in process. The material in storage and in queues is inspectable and its presence can be verified. The material in process is calculated from the difference in weighed values of material into the process minus the material out of the process.

A truly dynamic SNM accounting system that was fully verifiable by the IAEA would allow the Agency to verify each measurement, the instrument accuracies, and all the calculations. DYMAC's philosophical intent is to make most material measurements by NDA which will allow easier independent verification than if the SNM determinations were made by checmical processes. DYMAC's initial measurement of the amount of SNM in received material is done chemically and the material is stored in the vault. Subsequent SNM measurements are usually done by NDA. Quality control requires chemical and physical analysis of samples done throughout the process line and this information is also available to the safeguards function.

IV. IMPACT OF DYNAMIC SNM ACCOUNTING SYSTEMS ON IAEA VERIFICATIONS

The safeguards task facing the plant operator is that of guarding against diversion by a comparatively small number of people who have some degree of access to the material. Though the conspirators may be very knowledgeable and may have cooperation within their group, they do not have the cooperation of plant management.

The SNM accounting system was designed to be of help to the plant operator in his safeguarding effort. The accuracy of the data base is strongly supported by the automatic features of the measurement control program and the error prevention code. Attempts to insert data that are too disparate or move material to illogical places are discovered and flagged, and the diverter, even if he knew how, does not have access to the computer program to disable it. The in-transit monitor would discover the diversion if it occurred during transit. Loss at the unit process level could be discovered on any of three occasions: (1) by exceeding alarm limits on the current inventory, (2) at closure of the minibalance around the process, and (3) at station cleanout. Periodic physical audits of material going into and out of process equipment provide a relatively frequent opportunity to discover a diversion (G. E. Wilmington conducts these audits biweekly).

The IAEA's position is quite different from that of the operator. First, the Agency is concerned with a diversion by the plant operator. Second, the Agency is in an adverse environment, dependent on its own capabilities, if the plant operator attempts to divert.

What use can the IAEA make of the dynamic SNM accounting system? Since the Agency has no capability to verify the plant's software and hardware, it would have to assume that the plant's system experts could provide a completely acceptable set of artificial data that could be introduced into the computer system so that the sequence of operations would appear normal. The only feature of the plant's SNM system that would be of use to the Agency is the inventory by location report.

This situation would be changed if the IAEA could verify the functioning of the dynamic SNM accounting system. If it could do that, the entire power of the system could be used by the Agency to detect operator-diversion with the same effectiveness that the operator has in detecting diversion by a group of conspirators. The question then becomes whether or not the dynamic SNM accounting system can be verified by the Agency.

Some preliminary examination of this question encourages us to believe that the system can be verified - but not without additional equipment and manpower and, perhaps, some tolerable interferences with plant measurement operations.

Keeping in mind that verification involves being able to cope with subversive actions that are intended to make false information appear to be correct information, we must examine the various parts of the system to see how they could be subverted. Then find ways to counter them.

The problem falls into three parts: (1) software verification, (2) subversion of instrument operations that can be countered automatically, and (3) subversions that can be countered only by human intervention, i.e., inspection.

To have the quantitative credibility inherent in the dynamic SNM accounting system, the Agency must be able to exploit all of the fundamental functions of the system: data base, record of transactions, in-transit monitor, inventory by location, audit trail, minibalances around unit processes, loss analysis, measurement control program, and error prevention code. This means that the Agency must have its own computer to verify that the output of these fundamental functions is the product of the proper algorithms and computer programs. Computers suitable for this purpose are not excessively expensive and a large part of the software needed would have been developed by the operator. Of course, the Agency would want to make sure that the software does what is claimed. The computer would also make it possible for the Agency to make any other comparisons or analyses it desires. With its own computer, the Agency could monitor and confirm by comparison every computation made by the plant operator. This comparison function could be automatic with only those that disagree being flagged for human resolution.

The next thing the Agency must do is validate the data coming into the computer from the instruments. To reduce cost and manpower, the instruments should belong to and be maintained by the operator. As we shall see, however, certain additional hardware would have to be supplied and maintained by the IAEA.

We have identified five ways in which the data might be subverted. Four of them can be countered automatically. One will require human countermeasures.

A. Automatic Countermeasures

Figure 1 will aid in the discussion of the instrument characteristics, the countermeasure mechanisms, and their functions.

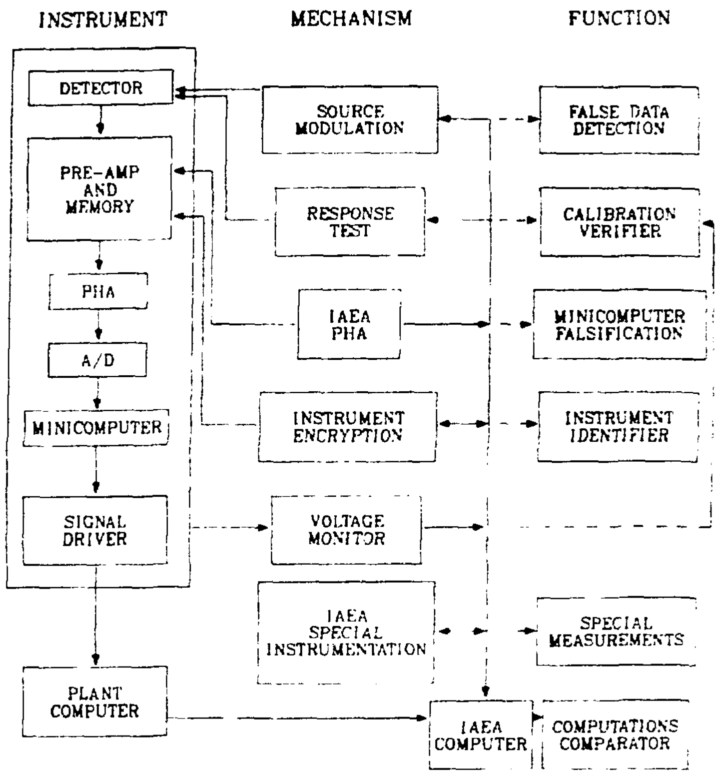

Fig. 1.
IAEA verification system.

1. Falsification at the Minicomputer. If SNM had been removed from the process material, a sample of it would have a lower concentration. To make the output of the instrument right so the plant computer would give the right answers, the instrument's minicomputer could adjust the low reading by multiplying it by the ratio of concentrations, which the diverter would know. On the other hand, there will be times when the Agency will run its own standards on this instrument. At such times, a normal software program would have to be in operation. To know which algorithm to use, the operator would have to be able to automatically distinguish between the Agency's sources and his own. But this could be done, for example, by concealing signatures in his source holders for ultrasonic, magnetic, or even optical recognition.

However, if we take the output of the instrument's detector preamp as the input to the Agency's own pulse height analyzer (as illustrated in Fig. 1), then it would not be possible for the operator to modify the signal, since it doesn't go through the operator's minicomputer. This means, of course, that the Agency would have to have additional electronic components on the operator's instrument. They would be sealed and the Agency would have to maintain them. In the illustration, the output of the Agency's pulse height analyzer goes to the Agency's computer, rather than to a minicomputer, for gamma-ray spectral analysis. In fact, there may be no advantage for the operator to use a minicomputer, for spectral analysis either. (Minicomputers for data reduction and analysis are useful for stand-alone instruments. For this case, a minicomputer would still be needed for instrument control.)

2. Biased Calibration. This may be done in two ways. (1) A set of false standards may be used to indicate a higher mass or (2) the instrument sensitivity may be increased by appropriate adjustment of voltages or discriminators so that the weaker source would give high count rates. The particular technique used would depend on the characteristics of the instrument. Indeed, since the sensitivity to voltage levels is different for different detectors, the feasibility of making adequate changes in the sensitivity will depend on the instrument.

However, the initial calibration of the instrument in its operational environment should be done jointly by the operator and the IAEA inspectors. The Agency should subject the operator's standards to a verification count in its own instrument designed and calibrated for this purpose. During the calibration, the Agency should monitor and record all instrument voltages (voltage monitor box in Fig. 1) that could have any influence on the instrument's sensitivity. Immediately after the calibration exercise, the Agency should run a response curve with its remotely variable source. Variability is achieved by either changing the distance between source and detector as in the Californium Shuffler, for example, or by the remote introduction of standard absorbers (these functions are indicated by the response test box in Fig. 1). With this information available, the Agency could run a response check coordinated with an instrument voltage verification any time it wanted to. Moreover, it would be good practice to monitor the instrument voltages each time a measurement is made.

3. False Data Insertion. In a TV surveillance system, for example, false data could be inserted by feeding the system from a video disc so that the scene would appear stationary. In a pulse system, electronically generated pulses could be used to bring the reading up to the desired level.

However, such tampering could be detected by exercising the detector. In the case of the TV system, the scene being viewed should be equipped with a modulatable light source. It could be as simple as a light that could be turned on or off from the Agency's computer. In the case of a gamma detector, remotely insertable absorbers should be available; for neutron detectors, arrangements should be made to remotely insert material that would change the neutron spectrum, such as polyethylene, boron, or cadmium. For either of these detectors, the count rate would not change in the proper way if some portion of the count were being generated electronically.

This interference with the gamma-ray and neutron detectors would have to be timed so that corrections could be made for counts collected during these periods.

4. Instrument Substitution. A multiplexing system would be used to cycle the computers through the instruments to be read. The Agency's computer may be switched to the wrong, or a substitute, instrument.

However, to provide instrument identification, the Agency could store a set of random numbers in each instrument. Then, when the Agency's computer is supposed to be connected to a certain instrument, the computer could call for a transmission of a stored number. If the proper number were received, connection to the proper instrument would be assured. Transmission of the random numbers to the instrument's memory could be encrypted so the operator could not learn what they were. The numbers transmitted in response to interrogation would not have to be encrypted since they would be used only once.

B. Human Countermeasures

Augmented Source. Here some of the SNM has been removed from the process material so that concentrations are too low. To achieve the proper instrument reading, an augmenting source of the same SNM is provided.

We assume that the augmenting source is of the proper isotopic composition. The combination, therefore, is indistinguishable from the correct source and, consequently, appears to the instrument as a valid source.

If the augmentation is through spiking to bring the sample up to strength, or if a sample is drawn from a previously prepared supply, there is no way to discover this at the instrument. To prevent this, IAEA inspection of the chemistry laboratory would be necessary to show that no material was available to allow either of these subterfuges to occur.

If augmentation is by addition of a separate source, such as a foil, to the sample of the real process material, the Agency may inhibit such practice by asking that two samples be made of the process material, or that the Agency be given custody of the measured sample. The Agency would tell the operator that the sample would be used at unannounced times as a secondary standard. There would be no way for the operator to know when to attempt an augmentation.

It appears that there is an approach to verifying the operation of the dynamic SNM accounting system. If it can be done, the IAEA would have a safeguards capability equal to that of the plant operator.

V. CONCLUSIONS

Current dynamic SNM accounting and control systems used by plant operators incorporate functions that would be of great help to the IAEA. These systems have a high loss detection sensitivity, complete and specific material inventory records, high measurement accuracies, and timeliness. And a permanent record of the material genesis which provides a means of tracing some discrepancies to their origins. Moreover, the system uses automatic measurement control and error prevention programs to enhance instrument and operator performance. If the Agency inspectors were able to use this system themselves, the availability of such detailed, simultaneous, and plant-wide information would tend to inhibit a plant operator's impulse to generate a floating or fictitious inventory.

The Agency's inspectors may be able to use the plant's safeguards equipment in a more continuous, more digestible way than having a mass of information dumped on them at intervals. This, however, would require solutions to the possible ways in which the plant operator could subvert the system. Such solutions seem possible for certain NDA instruments. Chemical analyses, on the other hand, present sample preparation problems that are difficult to solve automatically and it is for this reason that recommendations were made to find more suitable ways of making these measurements.

The performance of dynamic SNM accounting and control systems depends heavily on the data base management system used. These are functionally different than scientific data bases used for computational purposes but, unfortunately, current SNM accounting systems have been developed along the scientific line. Under IAEA guidance and initiative, a properly chosen working group could develop a set of features that a data base management system should have to best serve the purposes of IAEA safeguards.

VI. RECOMMENDATIONS

A. Equipment for Subversion Detection

Since making the operator's dynamic SNM accounting system available to the IAEA would increase the Agency's ability to cope with state diversion efforts, it is recommended that an experimental program be established to see if certain subversion methods can be effectively countered. Specifically, the experiments should be directed to learning how to mechanize the detections of the four subversion methods described in section IV-A and to running proof tests of the system.

B. Verifiable Measurements

To reduce the opportunity to surreptitiously modify samples before they are measured, it would be desirable to eliminate the need for sample treatment. This would require the development of measurement techniques or instruments that can determine the amount of SNM in a sample in whatever form the process produces--and the variety is large. In G.E.'s Wilmington and LASL's TA-55 plants, SNM is encountered in liquids (UF_6, $UO_2(NO_3)_2$, $(NH_4)_2U_2O_7$-H_2O), powders (UO_2, PuO_2), and solids (UO_2, PuO_2, UC, $UO_4 \cdot 2H_2O$). Moreover, in some of these forms, densities and concentrations vary.

From the safeguards point of view it would be best to have an on-line instrument at each station that could accept the material in the form normally produced there. Then the material would not have to be transported to an instrument room. Better still, the instrument's detector assembly should be integral with the process line, further relieving the need for material handling.

The importance of this problem is gauged by the fact that about 71% of the uranium determinations at G. E. Wilmington are totally chemical analyses or require a chemical processing step. And about 62% of the ^{235}U determinations involve chemical sample preparation.

C. Software and Computer System Design

Virtually all of the dynamic SNM accounting systems have had difficulties in the development of their software and in the selection of their computer. There are three causes of these difficulties: (1) changes or additions to things the system must do, (2) failure to select hardware capable of adequate expansion, and (3) computer programming in inappropriate file management concepts and languages.

The first dynamic SNM accounting systems designed had, of course, great difficulties in defining a complete set of functional specifications because no previous experience was available. This situation is considerably altered now since a number of systems have been designed and are in operation. Nevertheless, changes and additions are bound to be introduced into existing systems no matter when they are built and new systems may be quite different from the old. Because of these realities, one can never have a complete or firm set of functional specifications at the outset of the software design task. Neither will it be possible to firmly fix the size of the hardware system. After the best estimate of its size has been made, growth must be allowed.

The uncertainty in the size of the hardware system has little effect on the fundamental software problem, but the fact that changes and additions will be made to the system's functions is of tremendous importance. The software system simply must be able to accommodate them.

The inefficiencies and awkwardness of existing systems very likely stems from the fact that dynamic SNM accounting systems were conceived in an engineering and scientific environment. Consequently, the file structures and manipulation techniques used, as well as the programming language used, were those known to the "technology" programmer.

Outside the technological fields, in the business area, other file manipulation concepts and programming languages have developed, called data base management systems (DBMS). Their principal characteristics are flexibility and simple use. The flexibility of DBMS can accommodate changes and additions to system functions and the simplicity of use makes it operationally efficient and acceptable.

Looking forward to the development of future dynamic SNM accounting systems in installations around the world, it appears that the IAEA could perform an important service by laying the groundwork for improved software systems.

It is, therefore, recommended that the IAEA sponsor a working group whose objective would be to develop an expandable model of a dynamic SNM accounting system with software based on DBMS concepts. The functional specifications for this model would be provided by an existing system, say, a fuel fabrication facility. The kind of facility chosen for this purpose is not important except that its operational functions should be sufficiently complex and numerous to provide a challenge to the software design.

The working group should be composed of two categories of people. The first would consist of people who have been involved in devising the software for a dynamic SNM accounting system. The second, professionals who work in companies that design DBMS. This mix will provide (1) people who have an understanding of the practical difficulties and pitfalls involved in trying to actually implement a system, and (2) people who have done the research and development on DBMS.

Although the specific set of features the working group's model will contain must await the completion of their effort, it is quite likely to contain many of the following:

1. Automatically convert existing files into DBMS.
2. Minimum restrictions on structures.
3. Free form and highly adaptable retrieval or enquiry systems - individual records, subsets, and boolean retrieval.
4. On-line and batch modes simultaneously.
5. Efficient and automatic checkpoint restarts.
6. Multi-level security.
7. Expansion of individual fields or cancelling without restructuring the data base or recompiling programs.
8. Growth of data base without reorganization.
9. Random access capability for uniform retrieval speeds.
10. Sequential processing at high speeds.
11. Automatically handle the administration of data storage devices.
12. Re-entrant multiprogramming allowing simultaneous use of the system by many programs.
13. Use of data compression techniques for efficient storage.

14. Allow for the creation of temporary files in response to enquiry.
15. Allow data base enquiry through procedural languages.
16. Multithreading allowing several accesses to the same file in parallel.
17. Minimum DBMS overhead memory. Few or no overlays.
18. Maximum number of fields per record, records per file, and files per data base.
19. Allow inverted list processing.
20. Allow variable length records and files.
21. Allow many children for one parent and many parents for one child.
22. Be close in specifications to CODASYL.
23. Direct interface to report program generator (RPG) type systems.
24. Fast execution.

The final report should contain a list of safeguard functions as examples of modifications or additions that might be required and give explanations of how the software would be expanded to accommodate them.

The product of this working group would be of immense help to facilities that were going to develop a dynamic SNM accounting system. It would reduce the development time, provide a software system that could cope with changes that are certain to come, and reduce software development costs for the many facilities that will need such a system.

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