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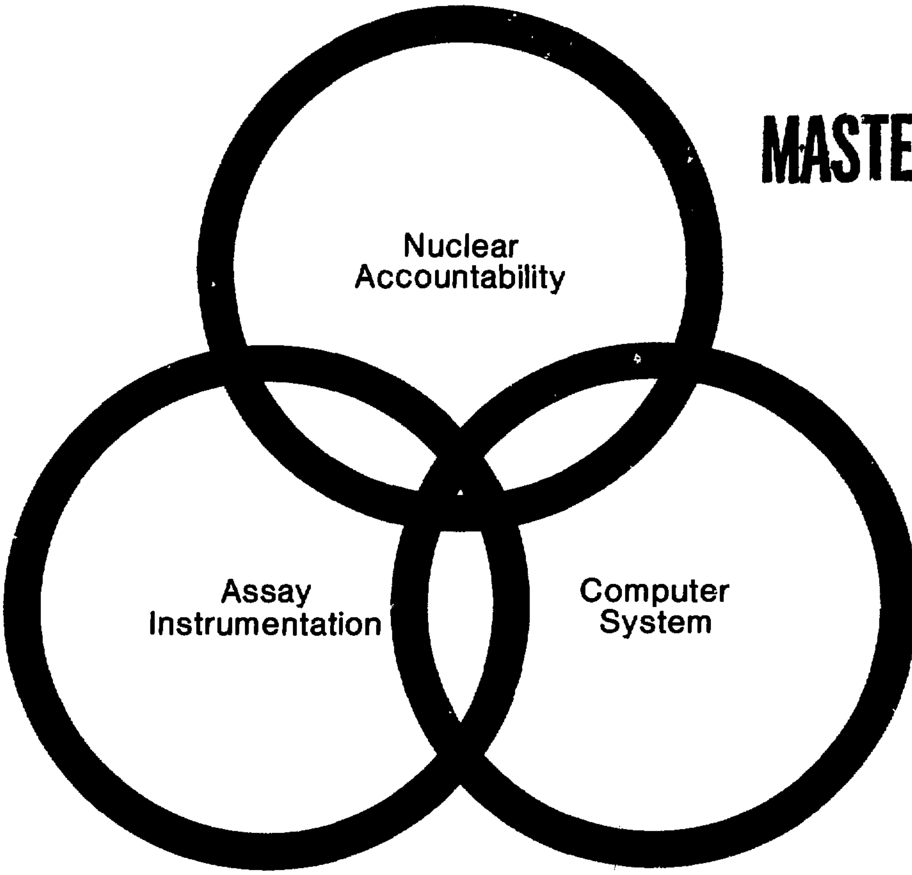

Implementation of the DYMAC System at the New Los Alamos Plutonium Processing Facility

Phase II Report

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ABSTRACT

The DYnamic Materials ACcountability System--called DYMAC--performs accountability functions at the new Los Alamos Plutonium Processing Facility where it began operation when the facility opened in January 1978. A demonstration program, DYMAC was designed to collect and assess inventory information for safeguards purposes. It accomplishes 75% of its design goals. DYMAC collects information about the physical inventory through deployment of nondestructive assay instrumentation and video terminals throughout the facility. The information resides in a minicomputer where it can be immediately sorted and displayed on the video terminals or produced in printed form. Although the capability now exists to assess the collected dat , this portion of the program is not yet implemented. DYMAC its present form is an excellent tool for process and quality control. The facility operator relies on it exclusively for keeping track of the inventory and for complying with accountability requirements of the U. S. Department of Energy.

BEFORE YOU READ THIS REPORT

Implementation of the DYMAC System at the Los Alamos Plutonium Processing Facility occurred in three phases over a period of 5 years. The first phase was a limited test-and-evaluation study conducted at the former Los Alamos plutonium facility.[1,2] It tested the basic principles of real-time accountability in a working environment.

The success of the initial phase led to the second phase, which is the subject of this report: the design, fabrication, and installation of the DYMAC System at the new plutonium facility; routine operation; and transfer of responsibility. Phase II extended from March 1977 to October 1980 when the operational version of the DYMAC System was turned over to the facility operator. The third phase of the project evaluated the performance of the system.[3,4]

This report is organized in two major parts. Chapters 1-6 present the background and underlying considerations of the DYMAC program, provide an overview of its operation, and discuss the results of the undertaking. Chapters 7-19 focus on more specific aspects of the program, such as deployment of the nondestructive assay instruments inside the plutonium facility, the measurement control plan that regulates the instruments' operation, the computer and communications systems, and the training that facility personnel received before using the DYMAC System. Descriptions of the unique facility in which DYMAC is installed appear in Chapters 7 and 8. These chapters highlight DYMAC's diverse processes and document its operation with particular attention to the role of the person responsible for all the nuclear material in the facility--the nuclear materials officer.

PART I

THE DYMAC SYSTEM IN GENERAL

4

CHAPTER I

INTRODUCTION

In 1975, the Nuclear Safeguards Program at the Los Alamos National Laboratory set out to demonstrate that real-time materials control and accountability could be implemented at a nuclear processing facility on a plant-wide basis. Program personnel contended that recent technological advances made it possible to measure nuclear material quickly, directly in the processing line, and that this development could be applied to maintaining, with negligible time lag, a computer-based record of every item in a facility's physical inventory.

Drawing on its expertise in nondestructive assay (NDA) technology, the Los Alamos Safeguards Research and Development (R&D) Program proposed[5] combining NDA instruments with an interactive computer system to keep an accurate and timely account of all nuclear material in a processing facility. The proposed accountability system, called DYMAC--for DYnamic Materials ACcountability, was approved in 1976 for installation at the new Los Alamos Plutonium Processing Facility (Fig. 1).

The DYMAC proposal responded to the heightened threat of nuclear terrorism. It was part of a stepped-up safeguards program, instigated and funded by the Office of Safeguards and Security of the U. S. Department of Energy (DOE), to improve physical security and materials control and accountability for nuclear facilities. Whereas physical security is concerned with preventing the theft of nuclear material, accountability has the role of detecting such thefts.[6] The two types of safeguards are mutually dependent. The purpose of nuclear accountability is to detect diversion of plutonium, uranium, and other strategic nuclear material in a single large theft or repeated small thefts. Accountability of a facility's nuclear holdings, if it is timely enough, can provide the vital information needed for informed decision-making in the face of a threat.

STATUS OF DYMAC

The DYMAC System went into operation in January 1978 when the first shipment of nuclear material entered the new plutonium facility (Fig. 2). As the facility's only method of accountability, it continues to provide reliable

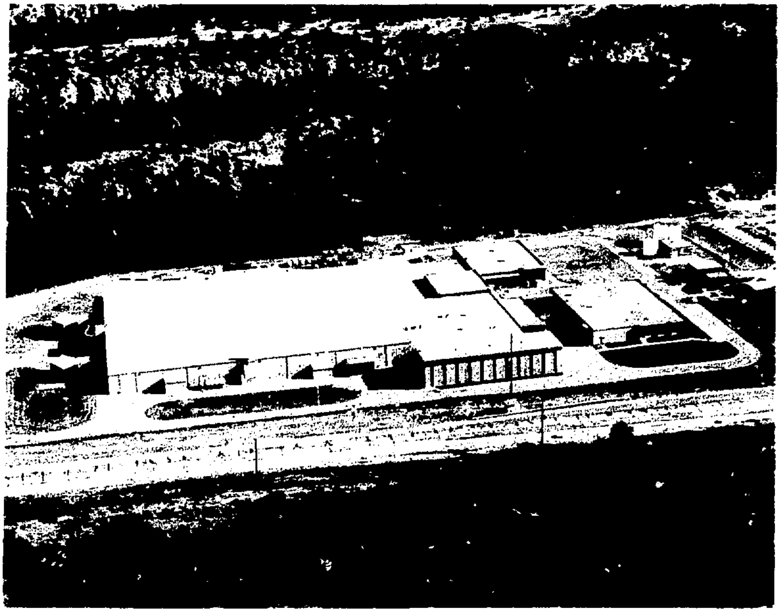


Fig. 1.
The new Los Alamos Plutonium Processing Facility is the concrete building in the left half of the photograph.

inventory information 4 years later. DYMAC records now exist for over 7500 items in the facility.

Two hundred process technicians and supervisors keep the computer inventory up to date at 30 video terminals located throughout the facility. During routine processing, they use NDA instruments located in the process line to measure the nuclear content of material for accountability purposes. The central computer maintains an accurate and timely account of all the nuclear material in the facility. To ensure that the computer inventory is kept up to date, the nuclear materials officer (NMO) oversees routine accountability procedures.

In its present state, the DYMAC System is a functioning but incomplete accountability system. It collects all the inventory data necessary to perform safeguards assessments but does not yet have the capability to assess the data on-line. By dividing the plutonium facility into material balance areas (MBAs) and locating NDA instruments and terminals in each area, DYMAC provides the basic criteria for performing on-line material balancing. Some, but not all of the instruments are connected on-line to the central computer to transmit measurements directly. Thus, DYMAC accomplishes 75% of the Safeguards Program's goal of providing near-real-time accountability. Because extensive groundwork has been established for implementing a full-fledged accountability system, the data assessment component of the DYMAC System can readily be implemented in the future.

Fig. 2.
The nuclear materials officer is shown wheeling the first shipment of nuclear material into the vault with the help of an assistant. A guard and a health monitor were in attendance.

As a data collection system, DYMAC works particularly well. Process technicians regularly use NDA instruments located in the processing lines to measure inventory items. Eighteen electronic balances are connected to the central computer and can transmit measurement data directly, without operator intervention; eventually all the instruments will be connected on-line to the computer. The technicians use interactive video terminals to enter logistic and measurement information about inventory items into the central computer. The computer serves as a repository for this constantly updated information and, on request, issues reports on the status of any portion of the inventory, its physical location in the facility, and its past activity.

Inventory items in transit from one location to another in the facility are monitored in near-real-time. Other assessments are performed irregularly on an off-line basis. For instance, a trace routine locates all source materials that contributed to a particular batch; conversely, the routine can trace all the batches that contain a particular source material. Other off-line assessments chart individual and cumulative material buildup.

DYMAC CONCEPTS

Spared from the complexities of replacing an existing accountability system, DYMAC began operation with no items in the computer inventory, building up the inventory item by item as shipments came to the new facility and were entered into the computer.

To maintain a timely book inventory, processing information must be logged immediately after a change occurs in the physical inventory. To ensure timeliness, the information must be logged at a terminal connected to the central computer where the inventory file for the entire facility resides. We do not call this procedure real-time accountability because that term implies a simultaneous updating of the inventory with each processing step. Instead we call it near-real-time accountability, to acknowledge the time lag introduced by the processing step itself.

For near-real-time accountability, it is not practicable for supervisors to log all the information for the process technicians. Hence, the DYMAC concept confers responsibility on the process technicians for updating the computer inventory each time they change the status of an inventory item. The concept holds that technicians who work directly with an inventory item know best what changes are made. They are also less likely to introduce errors into the inventory file because they know the information firsthand and enter it immediately after a change.

IMPACT OF NEW DEVELOPMENTS ON TRADITIONAL ACCOUNTABILITY

DYMAC resulted from several technological developments that occurred about the same time.[7,8] Of primary importance was the development of NDA instrumentation that could be placed in the process line to assay items in only a few minutes. Another important development was that of the inexpensive minicomputer with extensive capabilities for data management. Adaptation of material balancing[9] to near-real-time data collection made it possible to draw material balances dynamically instead of having to stop processing. Another adaptation resulting from the new technology was a change from recording accountability transactions on paper to entering those transactions at interactive video terminals.

Traditionally, accountability of nuclear material lagged weeks behind the constantly changing physical inventory. The need to know exactly what is in the physical inventory and where it is located spawned R&D efforts to reduce the time lag between a change in the physical inventory and its recording in the book inventory. As a result, NDA measurement techniques were improved and coupled with an automated data collection capability that could maintain an up-to-date inventory file.

Traditional accountability methods at Los Alamos relied on process personnel to write paper transactions on a timely basis. The process personnel often fell behind in writing transactions and wrote them from memory at the end of the day. Their transaction sheets were submitted daily for keypunching. The book inventory became available only twice a month; it lagged 5 days behind the physical inventory. This time lag was due to difficulties in keeping up with the movement of material (less stringent accounting practices and larger MBAs prevailed than are currently permitted), as well as difficulties with the mechanics of keypunching, data processing, printing, duplicating, and distributing the book inventory. Printouts allowed process personnel to identify mistakes in the book inventory and to correlate the book inventory with the physical inventory.

INITIAL DYMAC OPERATION

To shake down the DYMAC System at the new facility before processing began, Safeguards R&D personnel undertook an exhaustive test of the computer system: Project Sandbag (Ref. 10, pp. 75-77). Participants transported cans of sand into the facility, logged them into the computer inventory at interactive terminals, and took them to the vault. They then took a few cans at a time from the vault to a processing area, making sure to update the computer inventory every time they changed the location or amount of an item. In the processing area they placed small amounts of sand from each can into other cans and weighed them on DYMAC electronic balances. Thus, they created new inventory items and logged them into the computer system.

Using the video terminals to exercise every aspect of the computer code, Project Sandbag participants detected several errors. Some of the errors were bugs in the program; others were flaws in the system design. Another facet of the exercise revealed the need for improved system messages to the user. The benefits of Project Sandbag were threefold: errors were corrected, system messages were improved, and the experience gained by the participants proved invaluable for formal training sessions (see Chap. 19) that taught process supervisors and technicians use of the system.

Because DYMAC was designed to be the facility's only means of accountability, the facility operator (this term includes both the Plutonium Processing and Operational Accountability organizations) was initially unsure of how well the computerized system would keep track of the inventory. The operator planned to keep concurrent records of the physical inventory by the older paper method used at the former plutonium facility. This effort was never carried out; the tremendous volume of paperwork was more than personnel could keep up with while having to enter the same information into the DYMAC computer. The operator quickly came to depend exclusively on the computer inventory.

COOPERATIVE EFFORT

Throughout the design and implementation of the DYMAC System, three autonomous Los Alamos organizations cooperated to bring it about: Safeguards R&D, Plutonium Processing, and Operational Accountability. This combined design effort was necessary to ensure that the proposed system met all requirements. Safeguards R&D proposed and coordinated the plan for integrating NDA instruments with computerized accountability and dividing the facility into MBAs. Plutonium Processing offered its new building as a place where DYMAC could be tested and agreed to appoint an NMO. Plutonium Processing closely coordinated equipment placement with processing requirements. Operational Accountability, which regulates all accountability of nuclear material at Los Alamos, participated to ensure that accountability at the new facility met DOE standards. The interaction of these three organizations transformed the DYMAC concept into a functioning system.[11]

Members of the design team were among the first persons to receive formal training in use of the DYMAC System, shortly before it began official operation. During training, they detected some unforeseen design errors, which were corrected during preliminary and early operation.

When the facility operator assumed responsibility for DYMAC in October 1980 it renamed the accountability system PF/LASS, for Plutonium Facility/Los Alamos Safeguards System. Although PF/LASS serves only one of many Los Alamos facilities that handle nuclear material and report to Operational Accountability, it contributes 80% of all transactions made at Los Alamos.

CHAPTER 2

DYMAC SYSTEM OVERVIEW

DYMAC gathers information about the physical inventory and makes it immediately available to answer questions such as where a particular item is located, how many grams of plutonium it contains, what items went into its composition, and who handled it last.[12] The system is available for use on a 23-hour basis.

DYMAC depends on near-real-time NDA measurements and data entry to maintain a constantly updated computer file of all the nuclear material in the facility. The inventory file, or any part of it, is readily available to certify system users in the form of displays on video terminals or more extensive printed reports. This always-current inventory information is the basis for performing safeguards assessments. At present, only a few safeguards functions draw on the information, but it is there for additional safeguards use in the future. The inventory information has had many unanticipated benefits for the facility manager in improved production and quality control.

DYMAC FEATURES

The DYMAC System provides the user with many features. Initially, these features were designed for safeguards accountability; however, a surprising number of them are also useful to facility management.

- DYMAC provides near-real-time inventory information. This information is essential for drawing material balances around accountability areas and for subsequent diversion analysis, the basis of nuclear safeguards. It is also extremely useful for process control and quality control and can even be used for criticality control.

- DYMAC monitors items in transit within the facility. It notifies the NMO if an item takes longer than a predetermined time to arrive at its destination.

- DYMAC maintains a record of all transactions performed at the plutonium facility. From a file of these transactions, accountability personnel can perform off-line computation of audit trails and draw material balances for each unit process.

- DYMAC significantly shortens the time needed to reconcile the physical and book inventories. This makes it possible to determine whether anything is missing from the physical inventory at any time.

- DYMAC makes all inventory information immediately available to the requester in a variety of on-line displays and off-line printed reports.

- DYMAC reduces syntactical input errors to maintain an accurate database. It checks entry data for correct format and notifies the user to reenter incorrect information.

- DYMAC makes annual inventory a fast and uncomplicated procedure by furnishing accurate inventory listings to compare with the physical inventory.

- DYMAC regulates the performance of NDA instruments through the measurement control plan. It spots malfunctioning instruments and prohibits their use in making accountability measurements. It provides a basis for calculating measurement uncertainty.

- DYMAC NDA instruments are able to measure about 90% of all nuclear material in the plutonium facility. This makes it possible to maintain a near-real-time database for safeguards purposes.

- DYMAC NDA instruments have microprocessors that convert raw count data into usable assay values and their uncertainties. This makes it possible for technicians to operate the instruments.

- DYMAC places NDA instruments inside gloveboxes to measure nuclear material in the process line. It is not necessary to bag the material out to measure it.

- DYMAC label printers automatically produce labels for containers. The information printed on the labels comes directly from the database and reduces the possibility of mistakes that occur in handwritten labels.

- DYMAC restricts access to the accountability system to authorized users.

- DYMAC is easy to use. Technicians use DYMAC instruments and make transactions with little difficulty.

- DYMAC transactions require relatively little input from the user, who only has to supply pertinent information.

- DYMAC uses a prompt/response format for obtaining updates to the database. This leads users step by step through all the information that is necessary to complete the transaction.

- DYMAC reduces measurement input errors by direct transmission of measurement values from some of the NDA instruments to the computer. At present, 18 electronic balances transmit data directly to the computer.

- DYMAC provides daily accountability listings (such as isotopic inventory by location), that are useful to both operation and accountability personnel.

- DYMAC provides off-line audit trails. Using these programs, one can trace the components that made up an item or trace items that received part of a particular component.

In enumerating DYMAC's features, it is important to note what it does not do. DYMAC is basically an administrative system and does not provide direct control over the nuclear material in the facility. DYMAC furnishes the information to security personnel who use it to control nuclear material. DYMAC is not yet sufficiently reliable or timely to permit integration with the systems and procedures of physical security safeguards. DYMAC does not yet establish control limits that trigger alarms when material buildup exceeds the limits.

SYSTEM FUNCTIONS

The DYMAC System consists of four subsystems: nondestructive assay, data communications, database management, and accountability (Fig. 3). Nondestructive assay provides the in-line measurements that are the basis for drawing material balances around defined accountability areas. These measurements are transmitted in near-real-time to a central computer by

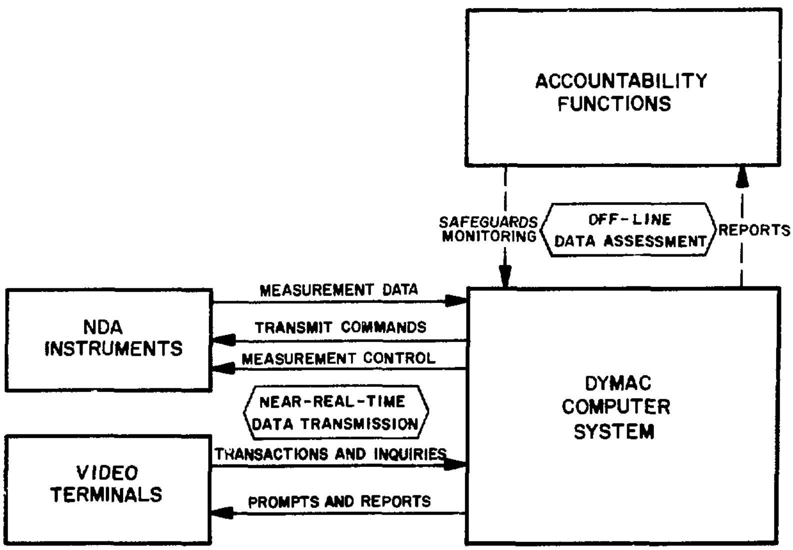


Fig. 3.
DYMAC System configuration showing on-line and off-line functions.

means of the communications subsystem. The computer's database management subsystem gathers and stores the inventory information and makes it readily available as on-line displays and off-line printouts. At the beginning of the DYMAC project, accountability personnel established MBAs in the facility, specified when and where measurements had to be made, and determined which inventory information should be kept in the database. The accountability subsystem assesses the database inventory information to determine whether a diversion has occurred. At present this assessment capability is in a rudimentary stage and is performed in an off-line mode.

The nondestructive assay subsystem has profited from many years of research and development at Los Alamos.[13] Evolution of the multienergy gamma assay system (MEGAS), the segmented gamma scanner (SGS), the fast-neutron coincidence counter (FNC), and the thermal-neutron coincidence counter (TNC) covered a span of approximately 15 years. During the course of the DYMAC project, new instruments were developed to meet certain needs at the plutonium facility: the solution assay instrument (SAI) and the filter holdup monitor. Table I enumerates the DYMAC NDA instruments installed in the facility. Each instrument is presented in more detail in Chaps. 11-17. (See Chap. 4 for general principles of nondestructive assay.) Figure 4 shows the location of the instruments on the main floor of the facility.

The data communications subsystem was the first DYMAC subsystem designed specifically for the plutonium facility. The type of communications lines originally specified influenced the development of the database management subsystem and dictated how the NDA instruments and video terminals would interface with the computer. The video terminal selected for data entry and retrieval was an inexpensive model that had no local processing capability and hence put the burden on the central computer to handle all data processing. Video terminals are located throughout the facility (Fig. 4).

TABLE I

DYMAC INSTRUMENTATION INSTALLED AT THE PLUTONIUM PROCESSING FACILITY

DYMAC Instrument	Number Installed by DYMAC Personnel	Number in Operation	Number On-line
Video terminal	37	30	30
Supervisory hard-copy terminal	6	6	6
Special-forms printer	5	5	5
5.5-kg balance	38	35	17
15-kg balance	3	3	1
Other balances	0	16	0
Thermal-neutron coincidence counter	20	18	0
Solution assay instrument	3	3	0
Segmented gamma scanner	2	2	0

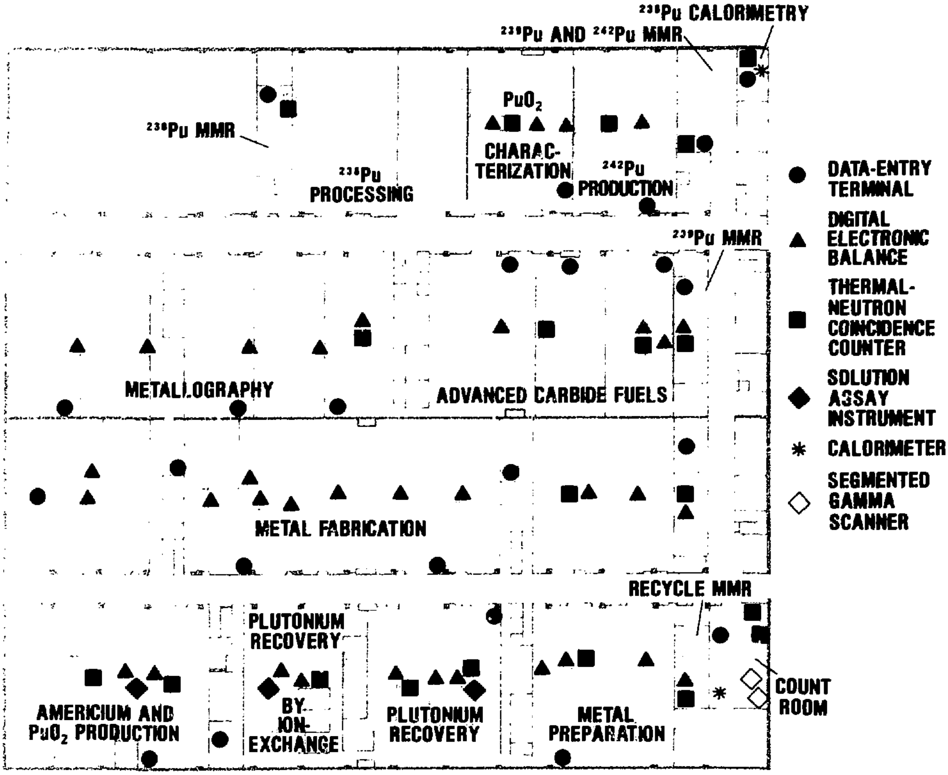


Fig. 4.
Location of NDA instruments and video terminals on the main floor of the facility. (Material management room is abbreviated as MMR.)

Ultimately, the communications subsystem became the limiting factor in expanding DYMAC's capabilities through lack of available computer ports (see Chap. 9).

The database management subsystem resides in a dedicated computer with an operating system that handles interactive traffic. It gathers inventory information from the processing areas of the facility, stores it in easily retrievable records, and makes it available on request. Transactions are the vehicles by which process personnel update the inventory information in the database. Inquiries allow them to display the always-current inventory information on the screen of their video terminals. In addition to these reports, they can request printed copies of the more comprehensive DYMAC reports, which are produced on the line printer in the DYMAC computer room.

The accountability subsystem specifies how all four DYMAC subsystems function together to produce a finely tuned safeguards system at the plutonium facility. It defines boundaries for MBAs and specifies at which points measurements and transactions must be made. It establishes a measurement control plan for the NDA instruments and creates the role of the NMO, who is responsible for all the nuclear material in the facility. The primary purpose of accountability is to determine whether a diversion of nuclear material has occurred and, if so, pinpoint where the material was when it disappeared and specify the amount and type of missing material. This primary role is not yet implemented in full. See Chap. 3 for more information.

REPORTS

The DYMAC user can request information from the database either on-line for short reports or off-line for longer reports. On-line reports appear on the screen of the user's terminal or can be produced in printed form at supervisory stations that have tandem hard-copy terminals. Off-line reports are usually printed on an overnight basis on the line printer in the DYMAC computer room. Appendix A provides a brief discussion and sample of each on-line and off-line report.

Ten on-line reports are available to the user on the display screen.

- Inventory by location
- Inventory by MBA
- Internal activity of item
- External activity of item
- Item status
- Items in transit
- Transaction look-up
- Inventory by MBA with remarks
- Internal activity of item with remarks
- Inventory by location with remarks

These reports are useful for controlling production, tracing mistakes, and locating items.

Certain reports, such as item activity reports and transaction look-up reports, contain <u>to</u> and <u>from</u> information about transactions. This is because a transaction effectively moves an item or changes some attribute from one status to another. The transaction is the bridge between the two statuses; hence, it is possible to have differing <u>from</u> and <u>to</u> information for item ID, MBA, unit process, project, special designator, location, shelf, item description, and remarks.

Ten line-printer-generated reports are available off-line on an overnight basis.

- Inventory by MBA
- Inventory by location
- Inventory by project
- Inventory by special designator
- Inventory based on item description
- Condensed inventory
- General ledger
- Transaction activity

- Material in process (MIP) transaction activity
- Transaction activity based on item description

Off-line reports contain more complete information about the inventory than on-line reports because there is sufficient room and time to present it. The two most comprehensive types of off-line reports are inventory by MBA reports and transaction activity reports. All others give subsets of the information contained in these two reports.

Off-line reports fall into two categories: activity and inventory. Activity reports describe the transaction activity that occurs during plant processing. Requesters may specify activity reports for a certain time span and selected MBAs. These reports help technicians and supervisors reconstruct and trace the path of items being processed and moved through the plant. Inventory reports describe the nuclear material holdings in the facility. They can be sorted by MBA (the standard type of report), by location (useful for taking a physical inventory), or by another parameter.

Note that inventory reports list items in the current inventory with their present status and attributes, sorted as the requester specifies. Activity reports do not include the status of items in the current inventory; rather, they give the history of how items arrived at their current status.

CHAPTER 3

ACCOUNTABILITY

The purpose of a nuclear materials accountability system is to monitor the storage, measurement, processing, and transfer of nuclear materials. An adequate accountability system ensures that no nuclear materials are inadvertently lost, that no unauthorized removals occur, and that materials are adequately measured.[14]

The goal of the DYMAC System as stated in the Phase I Report[1] was to be able to state the location and amount of all nuclear material in the facility at any time. DYMAC has met this goal. However, although DYMAC provides timely information for monitoring nuclear material in the facility, it is not yet able to draw on this information for near-real-time accountability of the material.

PRINCIPLES OF DYMAC MATERIAL BALANCING

Material balancing indicates the difference between the amount of material that goes into an accountability area and the amount that comes out. That difference, called MIP, contains the key to knowing whether diversion has occurred. Possible causes of MIP are (a) measurement uncertainties, (b) undetected measurement biases, (c) undetected or unmeasured process losses including equipment holdup, and (d) diversion. The primary objective of a nuclear materials accountability system is to reduce or eliminate (a), (b), and (c) so as to detect (d). The DYMAC System calculates MIP, but it does not yet assess its source.

DYMAC differs from a conventional accountability system in that it permits dynamic material balancing.[5,7,8] A dynamic material balance can be made without shutting down the process. DYMAC is not a real-time system that provides a book balance at any given instant. A time lapse of 5 to 30 minutes occurs between the material transfer and the transaction that updates the computer inventory.

The book balance (usually referred to as the computer inventory in this report) is the sum of (a) the beginning physical inventory and (b) the total receipts, diminished by (c) the total removals from the process (shipments, waste discards, and recycled or reprocessed scrap).

Book balance = BI + R - S - D,

where BI = beginning inventory, R = total receipts, S = total shipments (and recycle scrap), and D = total waste discards. The book balance does not indicate how much material is present, but how much should be present. A material balance is a reconciliation of the physical inventory with the book balance.

In a conventional accountability system, the determination of the material balance is a time-consuming operation that is performed only at inventory time. In the nuclear industry, inventories are conducted every 2 months or every 6 months, depending on the facility. The plant may be shut down from 1 to 3 days, after which 3 weeks or more can be spent calculating the ending inventory and the book balance and reconciling the two. Much of the time is spent collecting and shipping samples for wet chemistry assay; assaying the samples in-house and at outside laboratories; and, finally, calculating the inventory based upon bulk measurements (volumes and weights) made during the inventory and upon material concentrations and compositions determined in the laboratory.

The book balance and the ending inventory are seldom equal. This difference is called the inventory difference. (Inventory difference = book balance - physical inventory.) An inventory difference can be either positive or negative. A positive inventory difference indicates a loss of material (the physical inventory finds less nuclear material than should be there). A negative inventory difference indicates a gain of material (the physical inventory finds more nuclear material than should be there). Inventory differences may also occur due to such factors as transaction errors, rounding differences, and radioactive decay. The cleanup and measurement of process residues that are not directly related to the batch processing may also result in inventory differences.

DYMAC MATERIAL BALANCING

The Los Alamos plutonium facility is physically subdivided into MBAs, which facility personnel call accounts. An MBA can encompass one or more rooms, as shown in Fig. 5. There are 23 MBAs at the facility (16 on the main floor, 4 in the basement, and 3 that are nonphysical shipping/receiving or clearing accounts).

MBAs are further subdivided into unit processes, which facility personnel call receipt areas. The unit process is the smallest unit around which a material balance can be drawn (Appendix A of Ref. 2). For example, a typical unit process may be a glovebox or a series of contiguous gloveboxes. There are approximately 200 unit processes at the plutonium facility. The exact number varies, depending upon which specific products are in the processes. Figure 6 shows the Americium and PuO_2 Production MBA subdivided into unit processes.

A shutdown inventory is conducted every 6 months. However, reconciliation of the physical inventory with the book balance occurs weekly; this produces a book balance for every unit process. The supervisor for each unit process is responsible for making this physical reconciliation of the book

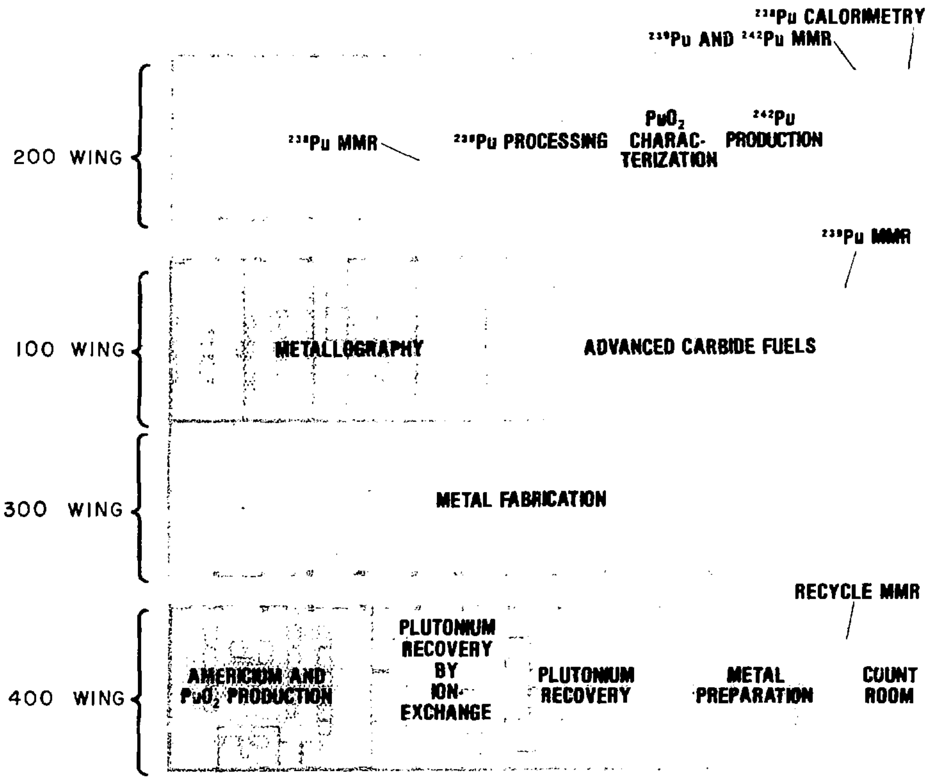


Fig. 5.
The main floor of the plutonium facility consists of four wings that are subdivided into 16 MBAs.

balance with the material actually present. The station balance, then, can be made by summing all unit-process material balances in addition to the receipts from and shipments to locations outside the facility.

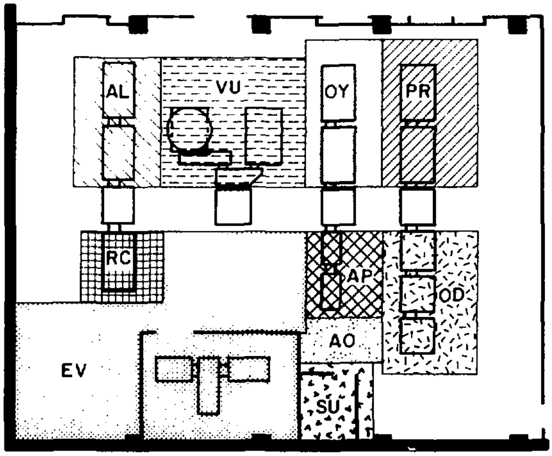
The station balance is determined routinely every day and can be determined at any time on request. The entire procedure takes approximately 2-1/2 hours. This is made possible through (a) subdividing the facility into unit processes, (b) basing all transfers between unit processes on measured nuclear material amounts, (c) determining the amounts by bulk measurement and/or assay, and (d) recording all transactions promptly on a quantitative, measured basis into the computer inventory via strategically located satellite terminals.

COMPUTER INVENTORY

In the DYMAC System, each inventory item has an associated inventory record. Each item is uniquely identified by a three-part name: MBA, material type, and item identification (ID). Each inventory record contains the DYMAC name of the item, the amount of nuclear material the item contains, the unit process in which it is located, and much more, as shown in Table II. The DYMAC designers wanted to assign unique one-part names to each inventory item, but they had to modify their ideas because the facility operator might assign the same ID to items in different MBAs or with different material types. The ideal situation would be to have single-name identifiers.

PROCESS DEFINITION

Processing in the plutonium facility varies widely, from research activities involving a few grams of plutonium on a monthly basis to full-scale production involving kilogram quantities every day. Each of the 20 or so processes in the facility has vastly differing accountability requirements.



AL ASH LEACHING
AO AMERICIUM OXALATE PRECIPITATION
AP AMERICIUM PROCESSING
EV EVAPORATOR
OD OXIDE DISSOLUTION
OY OXALATE PRECIPITATION
PR PEROXIDE PRECIPITATION
RC ROTARY CALCINER
SU SOLUTIONS UNLOADING
VU VESSEL UNLOADING

Fig. 6.
The Americium and PuO_2 Production MBA contains 10 unit processes. The dropboxes below the conveyor system are not included in a unit process because no material is processed or stored in them.

Before a process is brought into the DYMAC System, it must be carefully analyzed and a material flow diagram must be prepared, such as that shown in Fig. 7 for the Oxide Blending Process. The diagram in Fig. 7 delineates eight unit processes (not counting the vault), indicates all input and output points, specifies the succession of processing steps, and denotes the MBA and unit process in which each processing step occurs. For example, the diagram shows that the oxide dissolution step, unit process OD, takes place in MBA 745 and that two other steps take place in the same MBA but in different unit processes. From such information, measurement points can be established for material as it enters and leaves unit processes. NDA measurements made at these points make it possible to draw material balances around each unit process.

Underlying the transaction-making capability of each process is a preprogrammed set of transaction forms designed to suit the requirements of the process. A process definition sheet is created for each particular process from information given on a material flow diagram. The process definition sheet specifies all the information that programmers need to know to code the transaction forms. (Transaction forms appear on the video terminal screen for the user to fill out when making a transaction to update the computer

TABLE II

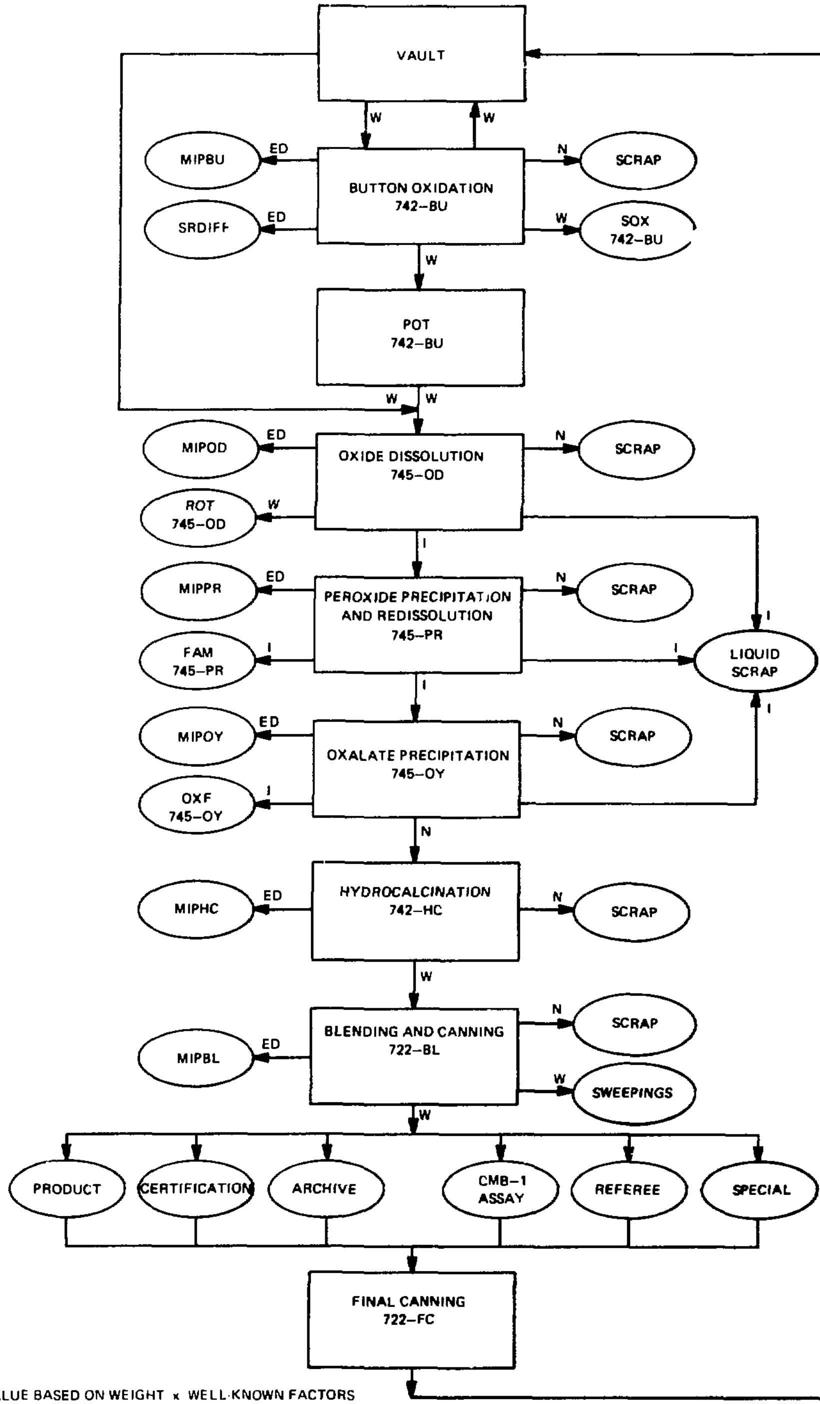
INFORMATION IN A DYMAC INVENTORY RECORD

Item Information	Explanation
MBA number[a]	identifies MBA where inventory item is located
material type[a]	indicates kind of material and its enrichment
item identification[a]	lot number assigned to this item
unit process	identifies unit process where item is located
project	identifies project that item is associated with
person	name of person who created this record
location	identifies physical location of item
shelf	sublocation identifier, used in vault and 300 Wing
special designator	(user defined)
item description	defines chemical or physical form of item
remarks	convey information pertaining to this record
date	date this record was first created (computer supplied)
time	time this record was first created (computer supplied)
nuclear material value	total element weight in this record
uncertainty of value	uncertainty of total element weight in this record
enrichment	required to calculate weight of principal isotope
uncertainty of enrichment	uncertainty of enrichment calculation
isotopes A-E	amount of each isotope contained in item
uncertainty of isotopes	uncertainty associated with value of each isotope
isotope weight	weight of principal isotope (computer supplied)
impurities	defines kind and amount of major impurity in this item
COEI	identifies composition of ending inventory for this item
seal number	identifies seal on item container
measurement code	identifies NDA instrument that determined the value
bulk	bulk value or total weight of item
bulk units	units of bulk value (e.g., grams, liters)

[a]Element of three-part DYMAC name.

inventory.) Appendix B contains the DYMAC worksheets used by process personnel to define and describe a new process for inclusion in the operational DYMAC System.

A design team, which consists of accountability personnel, computer programmers, and the process supervisor, determines at which points during processing the measurements and transactions must be made. The team identifies information to be precoded into the transaction and specifies the type of information that the process technician must supply.



W - SNM VALUE BASED ON WEIGHT x WELL-KNOWN FACTORS
ED ESTIMATED VALUE BASED ON BY-DIFFERENCE MEASUREMENT
N - SNM VALUE MEASURED WITH THERMAL-NEUTRON COINCIDENCE COUNTER
I SOLUTION ASSAY INSTRUMENT

Fig. 7.
Material flow diagram for the Oxide Blending Process.

TRANSACTIONS

DYMAC accountability depends on NDA measurements made in the process lines and the ensuing transactions that log them into the central computer inventory. A transaction notifies the computer that material has been changed from its previous status (amount-location-composition) to a new status. Thus, the transaction is the vehicle for changing the information in the computer inventory. Transactions can also be made to correct mistakes introduced into the inventory.

DYMAC only allows authorized users to make transactions. These users have been certified to make transactions for a particular process. DYMAC prevents users from making transactions for any process in the facility other than those for which they have certification.

The process technician uses a reference sheet to know when to make a transaction during processing. This set of instructions is supplied by the process supervisor and explains how to do the processing and at which points during processing to make a transaction.

We emphasize here that the DYMAC System designers geared transaction-making to the process technician. Transaction forms are designed so that persons unfamiliar with accountability can make transactions by answering prompts that appear on the terminal screen.

Some transaction-making rules were modified for expediency. For example, the original intent was to measure nuclear material whenever it entered or left a unit process. This would have required numerous back-to-back transactions as an item left one area and entered the next. As a compromise, one measurement serves as the exit value of one unit process and the entry value of the next. Another example of a modified rule allows an item to remain in contiguous unit processes without a transaction having to be made until the material is placed in the conveyor system to go to another row of gloveboxes.

When a batch of material has been completed, the process supervisor makes a MIP transaction. This transaction transfers the batch MIP to a separate MIP item that is specific for that unit process. MIP records are kept in the computer inventory for every unit process in the facility. MIP exists because the input and output values for a batch are not equal. Monthly MIP summaries by item are printed by the DYMAC System. Daily MIP transactions can also be printed. Figures 8-10 were generated using information obtained from the DYMAC System database. Figure 8 is a sample printed summary of the MIP by item for the Lean Residue (LR) Process from September 28, 1978, through November 15, 1978. Figure 9, a plot of the individual MIPs shown in Fig. 8, illustrates the erratic behavior of this process. Although a single large diversion or process anomaly would be detectable from such a data display, slow trends would not be apparent. Figure 10, the cumulative MIP plot, shows that this process experienced a continuing holdup problem. The process required cleanout and measurement to ensure that protracted diversion had not occurred.

MATERIAL IN PROCESS SUMMARY LOTS REPORT				1/22/80	PAGE 1	
FROM ACCT/MT/LOTID		TO ACCT/MT/LOTID	SNM	DATE	THRUPUT	STATUS
744/54/FAM	1004	744/54/MIPLR	-3. G	9/28/78	3. G	
744/54/FAM	1005	744/54/MIPLR	-3. G	9/28/78	3. G	
744/54/OXF	1003	744/54/MIPLR	-2. G	9/29/78	2. G	
744/54/FAM	1007	744/54/MIPLR	-3. G	10/ 2/78	3. G	
744/54/LAO	1002	744/54/MIPLR	3. G	10/ 2/78	951. G	
744/54/OXF	1004	744/54/MIPLR	-6.G	10/ 2/78	6. G	
744/54/OXF	1005	744/54/MIPLR	-2. G	10/ 2/78	2. G	
744/54/LAO	1003	744/54/MIPLR	84. G	10/ 3/78	952. G	
744/54/FAM	1008	744/54/MIPLR	-3. G	10/ 4/78	3. G	
744/54/LAO	1004	744/54/MIPLR	116. G	10/ 4/78	976. G	
744/54/LAO	1005	744/54/MIPLR	151. G	10/ 4/78	966. G	
744/54/JNK	1001	744/54/MIPLR	-2. G	10/ 5/78	2. G	
744/54/LAO	1007	744/54/MIPLR	27. G	10/ 5/78	995. G	
744/54/OXF	1007	744/54/MIPLR	-3. G	10/ 5/78	3. G	
744/54/PT	208	744/54/MIPLR	28. G	10/ 5/78	28. G	
744/54/FAM	1006	744/54/MIPLR	-1. G	10/ 6/78	1. G	
744/54/LAO	1008	744/54/MIPLR	44. G	10/ 6/78	974. G	
755/54/FAM	1009	744/54/MIPLR	-1. G	10/10/78	1. G	
744/54/OXF	1011	744/54/MIPLR	-7. G	10/10/78	7. G	
744/54/FAM	1010	744/54/MIPLR	-1. G	10/11/78	1. G	
744/54/FLT	100	744/54/MIPLR	-4. G	10/12/78	4. G	
744/54/JNK	1002	744/54/MIPLR	-1. G	10/12/78	1. G	
744/54/OXF	1006	744/54/MIPLR	-4. G	10/12/78	4. G	
744/54/OXF	1008	744/54/MIPLR	-4. G	10/12/78	4. G	
744/54/OXF	1009	744/54/MIPLR	-3. G	10/12/78	3. G	
744/54/OXF	1010	744/54/MIPLR	-5. G	10/12/78	5. G	
744/54/FAM	1012	744/54/MIPLR	-1. G	10/16/78	1. G	
744/54/LAO	1006	744/54/MIPLR	-19. G	10/16/78	924. G	
744/54/LAO	1009	744/54/MIPLR	13. G	10/16/78	969. G	
744/54/LAO	1010	744/54/MIPLR	82. G	10/16/78	1026. G	
744/54/LAO	1011	744/54/MIPLR	80. G	10/16/78	1021. G	
744/54/FAM	1013	744/54/MIPLR	-1. G	10/18/78	1. G	
744/54/FAM	1017	744/54/MIPLR	-1. G	10/18/78	1. G	
744/54/FFTF	PLS	744/54/MIPLR	-17. G	10/19/78	17. G	
744/54/TIN	10198	744/54/MIPLR	-1. G	10/19/78	0. G	*
744/54/FAM	1016	744/54/MIPLR	-4. G	10/23/78	4. G	
744/54/FAM	1018	744/54/MIPLR	-1. G	10/23/78	1. G	
744/54/LAO	1012	744/54/MIPLR	33. G	10/23/78	920. G	
744/54/LAO	1013	744/54/MIPLR	98. G	10/23/78	964. G	
744/54/LAO	1014	744/54/MIPLR	-12. G	10/23/78	939. G	
744/54/LAO	1017	744/54/MIPLR	-21. G	10/23/78	883. G	
744/54/FAM	1011	744/54/MIPLR	-2. G	10/24/78	2. G	
744/54/FAM	1015	744/54/MIPLR	-1. G	10/24/78	1. G	
744/54/FAM	1019	744/54/MIPLR	-1. G	10/24/78	1. G	
744/54/JNK	1003	744/54/MIPLR	-22. G	10/24/78	22. G	
744/54/JNK	1004	744/54/MIPLR	-2. G	10/24/78	2. G	
744/54/OXF	1012	744/54/MIPLR	-4. G	10/24/78	4. G	
744/54/OXF	1013	744/54/MIPLR	-3. G	10/24/78	3. G	
744/54/OXF	1014	744/54/MIPLR	-13. G	10/24/78	13. G	
744/54/OXF	1015	744/54/MIPLR	-8. G	10/24/78	8. G	

Fig. 8.
Contributions to MIP in the Lean Residue Process. The DYMAC name of each item is under the column headings ACCT/MT/LOTID for MBA/material type/item ID.

MATERIAL IN PROCESS SUMMARY LOTS REPORT 1/22/80 PAGE 2

FROM ACCT/MT/LOTID		TO ACCT/MT/LOTID	SNM	DATE	THRUPUT	STATUS
744/54/OXF	1016	744/54/MIPLR	-3. G	10/24/78	3. G	
744/54/OXF	1017	744/54/MIPLR	-6. G	10/24/78	6. G	
744/54/IXE	2	744/54/MIPLR	-3. G	10/25/78	9. G	
744/54/LAO	1016	744/54/MIPLR	16. G	10/25/78	935. G	
744/54/LAO	1018	744/54/MIPLR	37. G	10/25/78	971. G	
744/54/FAM	1020	744/54/MIPLR	-2. G	10/26/78	2. G	
744/54/OXF	1018	744/54/MIPLR	-2. G	10/26/78	2. G	I
743/54/MIPVP		744/54/MIPLR	11. G	10/27/78	0. G	*
745/54/MIPOY		744/54/MIPLR	15. G	10/27/78	0. G	*
745/54/MIPPR		744/54/MIPLR	54. G	10/27/78	0. G	*
744/54/FAM	1023	744/54/MIPLR	-1. G	10/30/78	1. G	
744/54/OXF	1019	744/54/MIPLR	-7. G	10/30/78	7. G	I
744/54/OXF	1020	744/54/MIPLR	-6. G	10/30/78	6. G	I
744/54/OXF	1021	744/54/MIPLR	-12. G	10/30/78	12. G	I
744/54/FAM	1022	744/54/MIPLR	-2. G	10/31/78	2. G	
744/54/LAO	1015	744/54/MIPLR	-37. G	10/31/78	701. G	
744/54/LAO	1019	744/54/MIPLR	51. G	10/31/78	962. G	
744/54/LAO	1020	744/54/MIPLR	28. G	10/31/78	824. G	
744/54/LAO	1021	744/54/MIPLR	14. G	10/31/78	785. G	
744/54/OXF	1023	744/54/MIPLR	-6. G	10/31/78	6. G	I
744/54/FAM	1025	744/54/MIPLR	-1. G	11/ 2/78	1. G	
744/54/LAO	1001	744/54/MIPLR	99. G	11/ 3/78	1881. G	
744/54/LAO	1022	744/54/MIPLR	45. G	11/ 3/78	0. G	I
744/54/LAO	1023	744/54/MIPLR	40. G	11/ 3/78	890. G	I
744/54/FAM	1027	744/54/MIPLR	-1. G	11/ 6/78	1. G	
744/54/FAM	1028	744/54/MIPLR	-1. G	11/ 6/78	1. G	
744/54/LAO	1024	744/54/MIPLR	44. G	11/ 7/78	813. G	
744/54/LAO	1025	744/54/MIPLR	47. G	11/ 7/78	1008. G	
744/54/LAO	1026	744/54/MIPLR	-44. G	11/ 7/78	915. G	
744/54/OXF	1022	744/54/MIPLR	-7. G	11/ 8/78	7. G	
744/54/OXF	1025	744/54/MIPLR	-6. G	11/ 8/78	6. G	
744/54/OXF	1026	744/54/MIPLR	-4. G	11/ 8/78	4. G	
744/54/FAM	1029	744/54/MIPLR	-1. G	11/ 9/78	1. G	
744/54/RAG	101	744/54/MIPLR	-18. G	11/ 9/78	31. G	
744/54/FAM	1030	744/54/MIPLR	-1. G	11/10/78	1. G	
744/54/FAM	1031	744/54/MIPLR	-1. G	11/10/78	1. G	
744/54/LAO	1027	744/54/MIPLR	70. G	11/10/78	955. G	
744/54/LAO	1028	744/54/MIPLR	37. G	11/10/78	936. G	
744/54/OXF	1024	744/54/MIPLR	-3. G	11/10/78	3. G	
744/54/OXF	1027	744/54/MIPLR	-4. G	11/10/78	4. G	
744/54/OXF	1028	744/54/MIPLR	-5. G	11/10/78	5. G	
744/54/OXF	1029	744/54/MIPLR	-9. G	11/10/78	9. G	
744/54/LAO	1029	744/54/MIPLR	69. G	11/14/78	864. G	
744/54/LAO	1030	744/54/MIPLR	-21. G	11/14/78	903. G	
744/54/MIPLRB		744/54/MIPLR	-13. G	11/14/78	-13. G	
744/54/JNK	6	744/54/MIPLR	-20. G	11/15/78	20. G	
744/54/LAO	1031	744/54/MIPLR	10. G	11/15/78	959. G	
744/54/OXF	1030	744/54/MIPLR	-9. G	11/15/78	9. G	
744/54/OXF	1031	744/54/MIPLR	-7. G	11/15/78	7. G	

Fig. 8.
(continued)

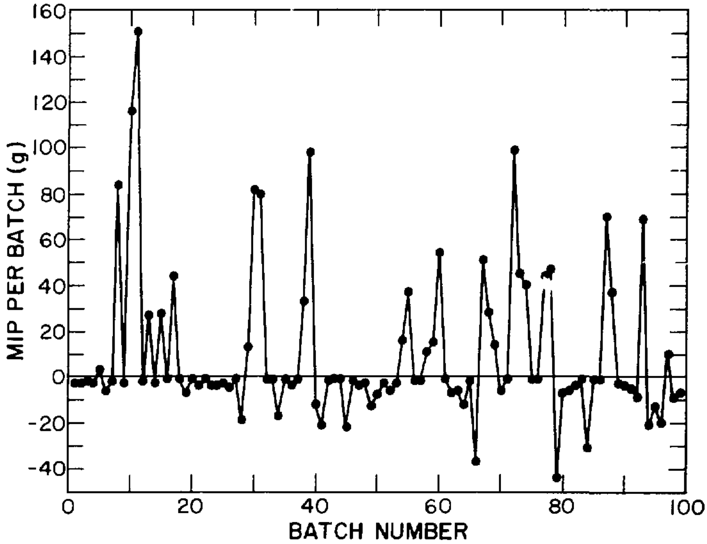


Fig. 9.
Individual MIPs for the Lean Residue Process.

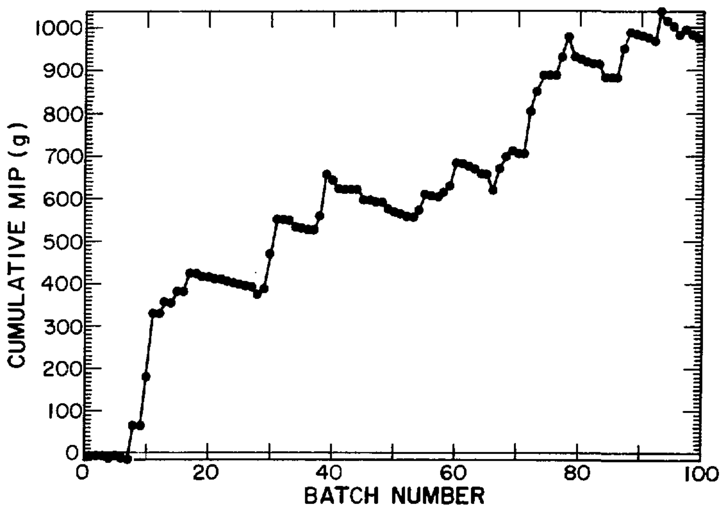


Fig. 10.
Cumulative MIP for the Lean Residue Process.

DYMAC ACCOUNTABILITY

A near-real-time accountability function of the DYMAC System is the monitoring of the IN TRANSIT file, which keeps track of all items moving to a new destination in the facility. The NMO monitors the file during the processing day to make sure that all items arrive at their destinations on time. No items are allowed to remain in transit for more than 90 minutes.

The Phase I Report[1] anticipated a real-time accountability subsystem that could monitor MIP charts for deviations that fall outside control limits and notify the NMO via the terminal. This has not yet been implemented. The intent was to compare the unit-process control parameters with alarm levels based on limits of errors. Two of the intended control parameters were the unit-process batch balance and the cumulative sum (cusum) of these balances.

A unique off-line accountability feature of DYMAC is the TRACE routine.[15] This routine can provide an audit trail of an item either backward through the process to its parent batches or forward to its diverse offspring through the labyrinth of transactions that may have taken place.

COMPATIBILITY WITH A PREVIOUSLY EXISTING SYSTEM

DYMAC replaced an older accountability system at a favorable moment, before material was transferred from the former plutonium facility to the new facility. Starting at a new facility allowed the DYMAC System to begin with no items in its inventory. Shipments that arrived at the new facility were logged into the DYMAC computer inventory in the proper new format.

DYMAC was not a radical departure from the older way of doing accountability. It began by automating the transaction-writing process used in the old system: no longer would transactions be written on 80-column sheets of coding paper for subsequent keypunching; instead, those transactions would be entered at a video terminal directly into a central computer. With the computer-based system established, other changes ensued, such as records lengthened from 80 characters to 200 characters (input punch cards were no longer a limiting factor). These records still contained the same information required by the older system, but they now had room for additional information.

Although DYMAC is an autonomous accountability system designed for one facility, it had to be compatible with the Los Alamos Safeguards System (LASS) that collects nuclear accountability information from all Los Alamos facilities that handle nuclear material. On a daily basis, DYMAC prepares tapes of all transaction activity in the plutonium facility to send to LASS.

The DYMAC System had to purposely restrict itself to remain compatible with LASS. A concession that the designers of DYMAC made was to round off nuclear material values (for example, to the nearest gram for ^{239}Pu) to arrive at the same calculation that LASS would make, even though DYMAC records had the capability of carrying more digits. The problem was that the two methods of calculating the amount of nuclear material would produce different results and that the DYMAC results had to agree with the LASS results. Another concession was made because even though DYMAC had the capability of carrying information for subaccountable quantities of nuclear material, LASS did not, and DYMAC had to emulate LASS. This resulted in subaccountable quantities of nuclear material not being kept track of until they were combined in amounts that exceeded the accountable threshold.

LASS is currently being revised to a computer-based system that will tie in closely with DYMAC. One of the main reasons for the LASS upgrading is that DYMAC handles about 80% of all the transactions made for nuclear material accountability at Los Alamos.

CHAPTER 4

NONDESTRUCTIVE ASSAY TECHNIQUES

Strategic nuclear material does not come in convenient denominations that can be counted. The quantity and type of nuclear material is different in every sample. To determine the quantity of nuclear material in a given sample, a variety of techniques have had to be developed.[16] Chemical analysis is one of the most highly developed and accurate techniques. However, chemical analysis may take a week or more to perform because samples must be sent to a remote laboratory. More rapid analyses can be performed using nondestructive assay.

NDA techniques have evolved for varied applications;[17] some of them apply to material control and accountability. They are more rapid than chemical analysis and can measure items directly in the production stream. Their use also avoids the problem of producing additional analytical samples that need control.

Nondestructive assay determines the desired properties of a sample without significantly affecting the sample itself. The desired property might be the weight, or the chemical or isotopic composition. Usually, and particularly in the present context, nondestructive assay is used to determine the chemical or isotopic composition of an item containing nuclear material.

As a simple example of an NDA technique, consider weighing a sample of pure plutonium metal to determine its plutonium content. The plutonium content is equal to the weight. Weighing does not alter the material in any observable way. If the sample is not pure, but its percentage of plutonium content is known, as for instance in a stoichiometric sample of PuO_2, then weighing still provides the necessary information to derive the plutonium content. This approach requires, however, that the ratio of nuclear material to the whole be known. This ratio can be in error; it is also open to manipulation. Other techniques are needed that can verify the presence of a particular isotope and its amount.

To assay a sample is, in essence, to determine the number of atoms of interest in that sample. Naturally occurring radioactivity provides us with a method of counting atoms: we count the radiations emitted by the radioactive atoms. Nondestructive assay using nuclear radiations can be categorized as passive or active.

Passive assay determines nuclear material content by detecting the radiations emitted spontaneously by a sample. For instance, the various plutonium isotopes continually emit both neutrons and gamma rays. Passive assay detects and analyzes these radiations. Choosing which type of radiation to measure in a particular context is complicated. The choice can only be made by considering the details of a particular assay: the isotopic distribution of the sample, the radioactive contaminants present, the chemical form of the nuclear material, and the geometry of the sample.

Active assay determines nuclear material content by detecting the radiations emitted by a sample in response to some other radiation impressed upon the sample. For instance, the sample can be irradiated with thermal neutrons to produce fissions that are in turn detected and related to nuclear material content.

The following discussion emphasizes passive assay techniques because they predominate at the Los Alamos plutonium facility. These techniques measure the heat generated by spontaneously fissioning nuclei and count neutron and gamma-ray emissions. Active assay is discussed only briefly.

CALORIMETRY

Radioactivity, in its simplest sense, is the emission of energy by nuclei as neutrons, alpha particles, gamma rays, beta rays, or fission fragments. The amount of energy released in the decay of a nucleus is a signature of that nucleus. Table III lists the decay energies of the plutonium isotopes. If the radiations emitted by a sample are captured within a certain volume, then conservation of energy requires that this entire energy appear as heat in that volume. Thus, the heat is proportional to the energy, which, in turn, is characteristic of the decaying nucleus. (The neutron energy will only be partially captured because neutrons may suffer several collisions and still

TABLE III

HEAT LIBERATED IN RADIOACTIVE DECAY OF NUCLEAR MATERIAL[a]

Isotope	Specific Power (W/g)
^{238}Pu	5.6716×10^{-1}
^{239}Pu	1.9293×10^{-3}
^{240}Pu	7.098×10^{-3}
^{241}Pu	3.390×10^{-3}
^{242}Pu	1.146×10^{-4}
^{241}Am	1.1423×10^{-1}

[a]Excerpted from Ref. 24.

escape the capturing volume. The energy carried by each of these radiations, however, is in fixed proportion to the total and so this loss can be accounted for.) This approach is used at the plutonium facility to measure ^{238}Pu in the calorimeter. However, as pointed out in Chap. 17, calorimetry results may take as long as 10 hours to obtain.

PASSIVE GAMMA-RAY ASSAY OF PLUTONIUM

Plutonium isotopes spontaneously emit gamma rays that have energies characteristic of each isotope.[18] Therefore, determination of the energy of the gamma rays is tantamount to determination of the plutonium isotope that produced them. The most important of these gamma rays are listed in Table IV.

Gamma rays can be detected by several techniques depending on the need for energy resolution and counting efficiency. If good energy discrimination is necessary, then a GeLi detector should be used. This type of detector, used in both the SAI and the SGS, is a solid state device with excellent energy resolution (typically 2 keV for a 1.3-MeV gamma ray) but relatively small efficiency because of its small size.

TABLE IV

MAJOR GAMMA-RAY SIGNATURES FOR THE FISSIONABLE ISOTOPES[a]

Isotope	Energy (keV)	Intensity $(g\text{-}s)^{-1}$
^{235}U	185.72	4.3×10^4
^{238}U	1001.10	1.0×10^2
	766.40	3.9×10^1
^{238}Pu	766.40	1.5×10^5
	152.77	6.5×10^6
^{239}Pu	413.69	3.4×10^4
	129.28	1.4×10^5
^{240}Pu	---	---
^{241}Pu	207.98	2.0×10^7
	164.59	1.8×10^6
	148.60	7.5×10^6
^{241}Am	59.54	4.6×10^{10}
^{242}Pu	---	---

[a]Excerpted from Ref. 25.

If high counting efficiency is required, the best choice is the NaI(Tℓ) detector. This detector can be made in sizes ranging up to a few cubic feet and can be tailored to almost any geometry. Unfortunately, the resolution of such detectors is relatively poor, usually less than 80 keV for a 1.3-MeV gamma ray. This type of detector is used in the MEGAS (see Chap. 17) for measuring low-density waste.

Once a technique is available to detect and analyze the gamma rays, plutonium assay becomes conceptually simple, although difficult in practice. The characteristic gamma rays from a standard sample can be counted using the detector. Dividing this number by the amount of material in the standard determines the calibration constant, which is the number of gamma rays detected by the system per gram of isotope. The assay of a sample of unknown plutonium content then is a matter of counting the characteristic gamma rays and dividing the number obtained by the calibration constant.

Although this approach appears straightforward and universally applicable, it is not. It neglects self-absorption by the sample. The number of gamma rays emitted per second by each gram of an isotope is unvarying in the absence of external radiation. The emission of these gamma rays, however, does not guarantee that they will escape the sample and its surrounding matrix unscathed. Matter absorbs gamma rays, and the amount of absorption depends on the amount and elemental content of the matter. Thus, unless all the samples of interest are identical, the calibration constant will vary from sample to sample because of matrix effects.

It is the genius of passive gamma-ray assay instruments that they correct for such matrix effects. The most frequently used correction technique employs transmission measurements. Gamma rays from a source are passed through the entire sample and the attenuation of this beam of gamma rays is determined. The attenuation of this beam can be related to the attenuation suffered by the characteristic gamma ray from the sample if certain assumptions about geometry are made and if the energy of the gamma ray is closely related to the energy of the characteristic gamma ray being analyzed. In this way the analysis can be corrected to obtain a more accurate assay of nuclear material content.

PASSIVE NEUTRON ASSAY OF PLUTONIUM

Passive neutron assay and gamma-ray assay are quite similar except for the type of emission detected. The neutron detection method is preferable to gamma-ray detection for large, thick samples of varying matrixes.[19]

Nuclear material emits neutrons through two quite different mechanisms: (α,n) reactions and spontaneous fission. Plutonium spontaneously emits alpha particles that can induce neutrons by bombardment of various light elements, particularly oxygen and fluorine. These neutrons, which can be quite prevalent from samples of PuO_2, PuF_3, and PuF_4, can themselves be used for assay, or they can be a hindrance to assays that use other radiations.

Some nuclear materials, particularly the even isotopes of plutonium, fission spontaneously. Selected isotopes of nuclear material are listed in Table V with the average number of neutrons emitted per fission. An assay

TABLE V

SPONTANEOUS FISSION OF FISSIONABLE ISOTOPES[a]

Isotope	Spontaneous Fission Half-Life (years)	Neutrons per Spontaneous Fission	Spontaneous Fissions per g-s
^{232}Th	1.4×10^{18}	---	4.1×10^{-5}
^{234}U	2.0×10^{16}	about 2	2.8×10^{-3}
^{235}U	1.9×10^{17}	about 2	2.96×10^{-4}
^{236}U	2×10^{16}	about 2	2.8×10^{-3}
^{238}U	9.86×10^{15}	1.95	5.64×10^{-3}
^{238}Pu	4.9×10^{10}	2.26	1.1×10^{3}
^{239}Pu	5.5×10^{15}	2.2	1.0×10^{-2}
^{240}Pu	1.17×10^{11}	2.17	4.71×10^{2}
^{241}Pu	5.0×10^{15}	2.2	1.1×10^{-2}
^{242}Pu	6.8×10^{10}	2.16	8.0×10^{2}
^{241}Am	2×10^{14}	2.3	0.27
^{252}Cf	86	3.8	6.14×10^{11}

[a]Excerpted from Ref. 25.

can be performed by counting these neutrons either individually or in coincident pairs. The latter approach ensures that only fission neutrons are detected rather than neutrons from some other event, such as an (α,n) event. The TNC is an example of a passive coincidence neutron assay device.

A number of devices can detect neutrons, but none provide an energy resolution approaching that available in gamma-ray spectroscopy. Thus, such devices are not usually used for energy measurements because they do not convey useful information. An exception is the application of the TNC to the assay of wet oxalate cake. Here a crude determination of energy is sufficient to correct the assay for the effects caused by the large and variable water content of the cake.[20,21]

The most commonly used neutron detector is the ^{3}He proportional counter. The ^{3}He detector produces a voltage pulse that signals a neutron's presence. The detector provides sufficient energy resolution to separate thermal neutrons from MeV neutrons. Because the detector has an efficiency for thermal neutron capture that is several orders of magnitude higher than its efficiency for MeV neutron capture, the detection geometries are normally designed to thermalize (that is, moderate) the neutrons.

Neutrons are thermalized most readily by hydrogenous (hydrogen-containing) material. One convenient and inexpensive hydrogenous material is water. Polyethylene is used in most Los Alamos applications, however, because it is relatively inexpensive, can be easily shaped, and does not change form. The amount of moderator is tailored to a particular application and can serve as a personnel shield or as a shield to prevent background neutrons in the room from reaching the detector. The incorporation of ^3He detectors in a moderator produces a neutron-detection system (see Chap. 12).

Metallic cadmium is also often used in neutron-detection systems because of its high affinity for thermal neutrons. Most neutron-detection systems have two layers of moderator separated by about 1 mm of cadmium. The outer moderator thermalizes background neutrons, which are then captured by the cadmium before they can reach the detector and give a false count. The inner layer moderates the neutrons so the ^3He tubes can detect them. Those neutrons that try to escape the detector system after thermalization are stopped by the cadmium before they can become a hazard to the detector operator.

An alternative detection technique uses plastic scintillators made of a hydrogenous material that emits light when ionizing radiation passes through it. A photomultiplier (a device that detects and amplifies light pulses) views the scintillator and can record, with some energy information, the passage of radiation. A neutron entering the scintillator may strike a hydrogen nucleus and cause a proton recoil. Because the proton ionizes the plastic as it passes, light (scintillation) is emitted and detected by the photomultiplier.

Because only fission can produce neutrons in sets of two, three, or more, simultaneous detection of a pair of neutrons is a relatively unambiguous test of whether a fission has occurred. Both ^3He and scintillation detectors lend themselves to the simultaneous detection of neutrons. Electronic circuits such as the shift register[22,23] have been built that determine when two detection events have occurred simultaneously. These are used in the TNC.

The passive neutron assay proceeds in the same manner as the gamma-ray assay. The neutron count rate from an unknown sample is compared to that from a standard of known composition. The assay is inferred from this comparison. Either neutrons or neutron coincidences may be counted as circumstances warrant.

Again, the conceptual scheme seems unassailable, but reality is more difficult. Neutrons can be absorbed and scattered by the sample matrix, which affects the calibration constant and, hence, the assay. Because this effect is much smaller for neutrons than for gamma rays, neutron detection is used when the matrix is massive and variable.

A more serious problem for the neutron technique is self-multiplication. Neutrons induce fissions in other fissionable nuclei, which in turn produce more neutrons and more fissions. The magnitude of this effect depends not only on the amount of spontaneously fissioning material present but on the amount of moderating material and its proximity to the fissioning material. This sensitivity occurs because thermal neutrons are more likely (by many factors of 10) to cause fission than are MeV neutrons.

It is, therefore, imperative to impose certain restrictions on neutron assay. The calibration sources used must be representative of the samples to be measured. It is of paramount importance that no assay be performed on a sample whose nuclear material content is greater than that of the largest calibration source. That situation would require extrapolation of the calibration constant and, as is generally known, extrapolation can be wildly at variance with fact.

ACTIVE ASSAY

Neutrons and gamma rays emitted spontaneously by nuclear material do not always provide a method of adequate assay. This might be true, for instance, in the neutron assay of odd isotopes of plutonium in the presence of even isotopes (the spontaneous fission rates are 10^4 to 10^5 higher for the even isotopes). Because the neutrons from odd isotopes are swamped by neutrons from even isotopes, it may be useful to induce fissions preferentially in the isotope of interest and record the resulting fissions.

Such active assays can be made using accelerator-produced neutrons or radioactive source neutrons. For routine production use, the reliability of source-based neutrons is preferable. Neutron-producing sources can be made from californium, or they can be made by combining an alpha emitter with material that produces neutrons by the (α,n) reaction.

An active assay is normally performed in several steps. First one counts the neutrons (or coincidence neutrons) emitted by a sample when the external neutron source is absent. This determines the background from spontaneous fission and from (α,n) reactions. The external source then irradiates the sample and the neutrons are counted again. The difference between the two counts determines the induced fission rate and is related to the amount of material in the sample through the thermal-neutron cross section. The fast-neutron coincidence counter described in Chap. 17 uses the active neutron assay principle.

SELECTION OF ASSAY TECHNIQUE

As we have seen, there is no universal NDA technique for measuring nuclear material. Each technique must be specifically tailored to the application at hand. This tailoring can be determined only after a careful study has identified the characteristics of the sample to be analyzed. Not only must this characterization be done, but it must be adhered to. The ability of an instrument to make an accurate assay deteriorates rapidly as the samples being analyzed depart from the characteristics assumed in the design of that instrument.

A sample is usually characterized by several factors: the amount and isotopic distribution of nuclear material, the amount and distribution of other radioactive species that could contribute gamma rays or neutrons to the emissions, the amount of hydrogenous material that could moderate the emitted neutron spectrum, and the amount and density of the other matrix materials that could particularly affect the gamma-ray spectrum. After characterization, the decision can be made whether to detect neutrons or gamma rays. Then a particular NDA system with its choice of detectors, auxiliary sources, and shielding can be tailored to the sample to be analyzed.

EFFECTIVENESS OF NDA TECHNIQUES

The ability of an assay system to do the job for which it was designed is determined by its precision and accuracy. These terms can be approximately defined as follows.

- Accuracy measures the ability of an instrument to determine the correct answer. Accuracy is usually expressed as an uncertainty such that the true assay has a 95% chance (2σ) of lying within the limits implied by this uncertainty.

- Precision measures the ability of an instrument to obtain the same answer (even the wrong one!) over again. Precision is also expressed as an uncertainty such that there is a 95% chance (2σ) that if the measurement is repeated the new answer will lie within the limits implied by the uncertainty.

A general rule of thumb is that an accuracy test checks the calibration factors, background, and other similar programmable features, whereas a precision test checks for problems with the hardware, electronics, and detector.

Measurement uncertainties based on the accuracy and precision of each NDA instrument in use at the plutonium facility are discussed in subsequent chapters. In general, it is possible with reasonably well-characterized samples to achieve accuracies and precisions of about 1%. This capability is not as good as that provided by chemical analysis, but timeliness gives nondestructive assay an edge. Instead of taking a week or more in a remote laboratory, NDA analysis can be performed in the production environment in an hour or less. Furthermore, the NDA measurement can often be applied to the bulk material as a whole instead of to a sample that may not always be representative of the whole. In most cases, the NDA method is adequate for safeguards purposes and has the additional advantage of providing analysis quickly.

CHAPTER 5

USING THE DYMAC SYSTEM

DYMAC System users participate in a training course (Chap. 19) before they use the NDA instruments and video terminals. In the course they learn the importance of making a transaction immediately after completing a measurement or processing step. Their supervisors acquaint them with the procedures followed in the processes where they work, often providing them with instruction sheets that detail the processing steps and their associated transactions.

Most system users are technicians who work in one process for an extended period of time. They become familiar with their processing tasks and the transactions that go with them. They are able to handle most measurement procedures and transactions with assurance and only occasionally have to ask their supervisors for help.

USING DYMAC INSTRUMENTS

DYMAC NDA instruments are located in all of the MBAs on the main floor (Fig. 5) of the plutonium facility.* The instruments are placed directly in the process lines to facilitate measurement taking. Because most of the instruments are installed inside gloveboxes, there is no need to bag out the material to be measured. The types of instruments selected for the different process areas correspond to the needs of the individual processes. Many of the instruments are in dropboxes beneath the conveyor system where contamination is at a minimum and access to other locations is optimal (Fig. 11).

The most commonly used measuring device in the DYMAC System is the digital electronic balance, which weighs items of known composition (see Chap. 11). A balance registers the mass of the item being weighed for the user to read. Of the 38 balances in operation, 18 transmit measured values

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*There is one exception. The TNC and terminal that service the ^{238}Pu Processing MBA are purposely located in the adjacent material management room to lessen the amount of radiation exposure that processing personnel receive while making transactions.

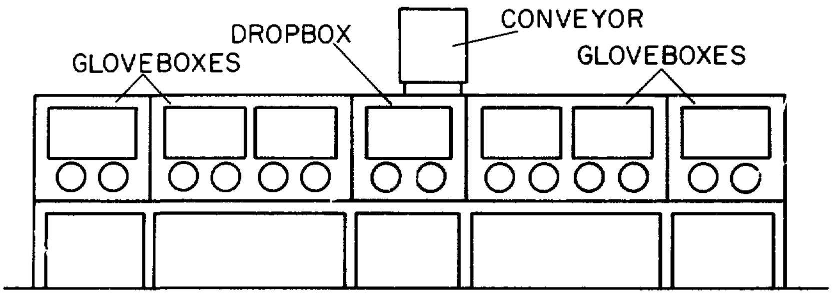

Fig. 11.
Most DYMAC NDA instruments are located in dropboxes beneath the conveyor system, which runs perpendicular to the glovebox line.

directly to the central computer by means of an electronic interface. After completing a measurement, the user makes a transaction at a nearby terminal to update the database. If the balance used is on-line to the computer, the user enters its identifying number during the course of the transaction and the computer reads the mass directly from the balance. If the balance is off-line, the user enters the mass into the transaction.

The more complex NDA instruments--the SAIs, TNCs, and SGSs--are equipped with microprocessors or minicomputers. These processors guide the assay and, from the raw data, calculate the final value and its uncertainty, which the technician enters into the database during the course of making a transaction. Eventually, when these instruments are brought on-line to the computer, the microprocessors will be capable of transmitting assay values directly to the computer without user intervention.

Using DYMAC instruments involves more than making measurements. There are certain measurement control functions that the user must perform on a regular basis before the instrument can be used. These procedures guarantee that the instrument is functioning properly. For example, before using a balance, the technician must perform accuracy and precision checks; these are performed daily. This allows the computer system to maintain a history of the balance's performance and to certify that it is fit for use. If a balance fails the checks, the computer system will not accept transactions that refer to that balance's ID number. (The computer system does not prevent someone from using the balance for off-line measurements. However, those measurements cannot be used for accountability purposes.) The TNCs, SAIs, and SGSs also undergo similar accuracy and precision checks.

To ensure that users perform the measurement control functions on a regular basis, the computer system rejects measurements made on unchecked instruments. In general, all DYMAC instruments must be checked by 1 p.m. on each workday. The system permits their use until that time, then refuses to accept the measured results until the instruments have passed the measurement control procedures. This allows technicians to select a convenient time during the morning to perform the procedures instead of at the beginning of the workday.

USING THE COMPUTER SYSTEM

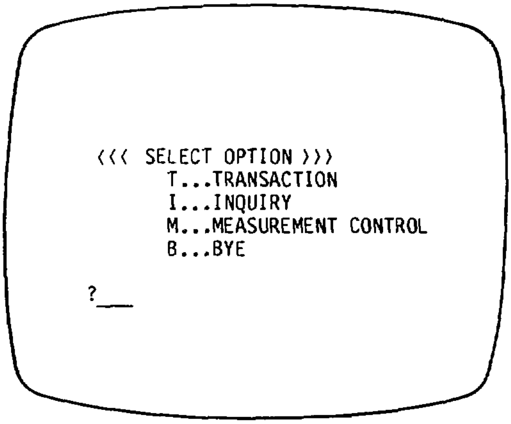

Fig. 12.
Startup menu.

Access to the DYMAC computer system is restricted to persons who successfully complete the introductory training course and have their supervisor's approval to use the system. Users' employee ID numbers are added to the computer access list and each person is assigned a password. Users can access the transaction forms for all four wings of the facility; however, only a supervisor can access supervisory transaction forms. Access to vault transaction forms and transaction forms that pertain to adjusting the station balance is restricted to the NMO. The computer system restricts user access to certain transaction forms by means of a priority list established by the NMO.

Messages and questions displayed on the video terminal are the primary contact that users have with the computer system. To make a transaction, inquiry, or measurement control function, a user signs on the system at a nearby terminal by typing his employee ID number and password. The system responds by displaying the startup menu (Fig. 12) on the terminal screen. The user selects one of the four options by typing the one-letter code associated with the option.

Transactions

If the user wishes to make a transaction, he responds by typing a T after the question mark that appears on the video screen. What follows is a selection process that enables the user to locate the proper transaction form to fill out. Filling out a transaction form on the video screen is referred to as making a transaction. To arrive at a particular transaction form, the user must first make selections through four levels of branching: startup menu, wing menu, menu of processes within a wing, and menu of transaction forms within a process.

Following the T response, a six-option menu (Fig. 13) appears on the screen for the user to select one of the four wings in the facility or one of the two restricted-access options. The user selects an option by typing the corresponding number after the question mark.

Selecting an option from the wing menu results in one of six displays (Table VI). If the user selects the NMO or standards option, a display of transaction forms results from which he can select the one he needs to fill out. If the user selects a wing option, an additional level of selection is necessary. Each wing option expands into a menu of processes within that wing.

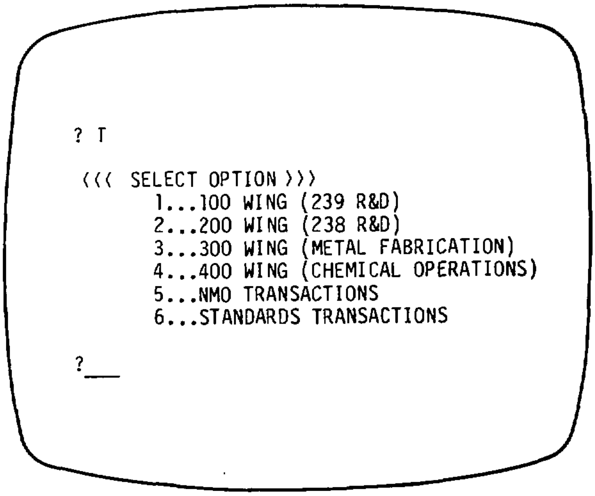

Fig. 13.
Wing menu.

Selecting an option from the process menu results in a display of the transaction forms associated with that particular process. For example, 16 transaction forms are associated with the Advanced Carbide Fuels Process (Fig. 14).

Selecting an option from the transaction form menu results in display of the particular transaction the user needs to fill out. The selection process is finished.

To help the user fill out the transaction form, the computer prompts the user one step at a time to supply the necessary information. When the user has provided all the required information the computer displays it for him to review (Fig. 15). If the information is correct, the user approves the transaction by typing Y (for YES) and the transaction updates the database.

For example, when a technician in the Advanced Carbide Fuels Process prepares a new batch from feed stock, he takes the proper amount of material from the feed stock to create a new batch and makes a transaction to update the computer inventory. He selects the T option (for transaction) on the startup menu, option 1 (for the 100 Wing) on the wing menu, option AF (for Advanced Carbide Fuels) on the process menu, and option 5 (for PREPARE NEW BATCH) on the transaction form menu. Then he fills in the transaction form.

An example follows of how a user makes transactions on the DYMAC System via short responses to the series of prompts that appear, one at a time, on the video screen. For the PREPARE NEW BATCH transaction (Fig. 15), the first two prompts ask for the from material type and from item ID to identify the feed stock from which the material has been taken. For the example shown in Fig. 15, the computer searches the database to locate item 711/54/35314; the MBA number has been precoded into the transaction form,

TABLE VI

MENU OF PROCESSES WITHIN EACH WING

General Area	Process or Restricted Transaction Form	User
100 Wing	MI...MANAGEMENT ROOM	All 100 Wing processes
	AF...ADVANCED CARBIDE FUELS	Advanced carbide fuel
	MA...MICROSTRUCTURAL ANALYSIS	Microstructural analysis
	EF...ELEMENT FABRICATION	Element fabrication
	SI...SUPERVISORY	All 100 Wing supervisors
200 Wing	M2...MANAGEMENT ROOM	All 200 Wing processes
	BC...FFTF BLENDING AND CANNING	FFTF blending and canning
	FC...FFTF CERTIFICATION	FFTF certification
	C1...CALORIMETRY	Calorimetry
	P1...PU238 PROCESSING	^{238}Pu processing
	G2...GENERAL 200 WING TRANSACTIONS	Rocky Flats metal sampling
		Plutonium-beryllium recovery
	S2...SUPERVISORY	All 200 Wing supervisors
300 Wing	FP...FABRICATION PROCESS	Metal fabrication
	S3...SUPERVISORY	All 300 Wing supervisors
400 Wing	M4...MANAGEMENT ROOM	All 400 Wing processes
	CR...COUNT ROOM	Count room personnel
	FO...FFTF OXIDE	FFTF oxide blending
	RR...RICH RESIDUE ION-EXCHANGE (FFTF)	FFTF rich residue ion-exchange
	OR...OXIDE REDUCTION	Oxide reduction
	ER...ELECTROREFINING	Electrorefining
	EV...EVAPORATOR	Evaporator
	LR...LEAN RESIDUE ION-EXCHANGE	Lean residue ion-exchange
	CL...CHLORIDE SOLUTIONS	Chloride solutions
	CM...CHLORIDE MELT	Chloride melt
	IS...INCINERATOR	Incinerator
	DS...DISSOLVER ION-EXCHANGE	Dissolver ion-exchange
	SD...SKULL DISSOLVER	Skull dissolver
	G4...GENERAL TRANSACTIONS	Polycube processing
		Noncombustible leaching
		Special recovery process
		Americium processing
		Ash-leaching
	S4...SUPERVISORY	All 400 Wing supervisors
NMO	RO...SHIP/REC ACCT 770	Nuclear materials officer
	R1...SHIP/REC ACCT 771	Nuclear materials officer
	VT...VAULT	Nuclear materials officer
	77...ACCOUNT 777 (NMO CLEARING)	Nuclear materials officer
	DB...DRUM AND BOX STORAGE	Nuclear materials officer
Standards	1...RECEIVE	Calibration personnel
	2...SEND TO NEW ACCOUNT	Calibration personnel
	3...MOVE TO NEW LOCATION AND/OR RECEIPT AREA (SAME ACCOUNT)	Calibration personnel

```
((( SELECT OPTION )))
      1...RECEIVE FROM MANAGEMENT ROOM
      2...TAKE SAMPLE
      3...RETURN FEED STOCK TO MANAGEMENT ROOM
      4...SEND SAMPLE OR SCRAP
      5...PREPARE NEW BATCH
      6...ADD CARBON AND UO2 TO PUO2 BATCH
      7...TRANSFER IN GLOVEBOX LINE (WITH MEASUREMENT)
      8...REDESCRIBE BATCH
      9...WEIGH SCRAP
     10...SEND BRIQUETTES TO REDUCTION FURNACE
     11...RECEIVE AND VERIFY BRIQUETTES
     12...REDUCE BRIQUETTES
     13...BLEND LOT
     14...SEND SINTERED PELLETS TO GRINDING
     15...RECEIVE SINTERED PELLETS
     16...WEIGH AND SEND FINISHED PELLETS

?__
```

Fig. 14.
Transaction forms associated with the Advanced Carbide Fuels Process.

so the user is not asked to supply it. When the computer finds the item (the search ensures that the item does indeed exist in the database), it asks the user to enter the to item ID, that is, the name of the new batch. Again the computer searches to see if the item already exists in the database (in this case, it should not previously exist because the intent is to create a new inventory item). Then the computer creates a new inventory item by the name specified. It asks for the to item description, by which the user can specify that it is a mixture of PuO_2 with unaccountable depleted uranium with the code C40. (The item description of the feed stock, CIP, denotes that it is high-fired PuO_2.) Then the user is asked to enter his name and to specify the weight per cent of the material, the ID number of the balance used to weigh the material, whether the measurement is of the net or gross weight, the weight value, and its associated error. At this point the computer displays the entire filled-in transaction form and asks if it is correct. The user inspects the information and approves or rejects the transaction. No record is kept of rejected transactions; approved transactions update the database and are recorded for historical purposes.

Inquiries and Measurement Control Functions

The I and M options on the startup menu require only one level of branching for the user to find the function he wishes to perform. To make an inquiry, the user types an I in response to the startup menu. The resulting display includes 10 types of on-line reports (Fig. 16) that the user can request to learn the inventory of a particular location, the status or activity of a

```
NUMBER ************ FIELD ************** FROM ********** TO *******************

1,2         ITEM ID                     35314         4529C10
3,4         ACCOUNT                     711               711
5,6         RECEIPT AREA                OB                 OB
7,8         PROJECT                     413               413
9,10        SPECIAL DESIGNATOR
11,12       LOCATION                    G133             G133
13,14       SHELF
15,16       ITEM DESCRIPTION            C1P               C40
17      "FROM" REMARKS:  FEED STOCK IN OXIDE BLENDING
18      "TO" REMARKS:  PREPARE NEW BATCH
19          DESTINATION:
20,21       SNM AMOUNT:     313.   G OF TYPE 54     BULK AMOUNT          358.74 G
22          ENRICHMENT:      11.75                  (ISOTOPIC WEIGHT:  276.   G)
23,24       IMPURITY:          .00  OF              MEASUREMENT CODE:     W50
25,26       SEAL NUMBER:                            COEI NUMBER:          748
27          ISOTOPIC A: .0006, B: .8567, C: .1174, D: .0133, E: .0019

RESULTS
     711/54/35314          SNM VALUE:     123.89 G, BULK VALUE:   141.26 G
     711/54/4529C10        SNM VALUE:     313.00 G, BULK VALUE:   358.74 G

     <<< TRANSACTION OK? >>>      (Y...YES, N...NO)

?
```

Fig. 15.
When the operator finishes entering information for the PREPARE NEW BATCH transaction, the system displays the entire transaction for final approval.

particular item, or which items are in transit inside the facility. The user selects the option that corresponds to the type of report he wishes to view. (Examples of all on-line reports appear in Appendix A.)

An M response to the startup menu displays the measurement control menu (Fig. 17), from which the user can check the current status of an instrument, perform an accuracy or precision check, or display current instrument performance data. To sign off the terminal after the session is finished, the operator types B for BYE.

TRANSACTION ACTIVITY

At present, 210 people are validated to use the DYMAC System. The number of transactions they make on a daily basis and over a month's time gives a good idea how busy the DYMAC System is. On the average, about 300 transactions are made daily (Fig. 18). The chart shows a steady growth from January 1978 when the system began accepting transactions. The high number of transactions made in July 1979 was due to consolidation of all previous vault MBAs into a single MBA.

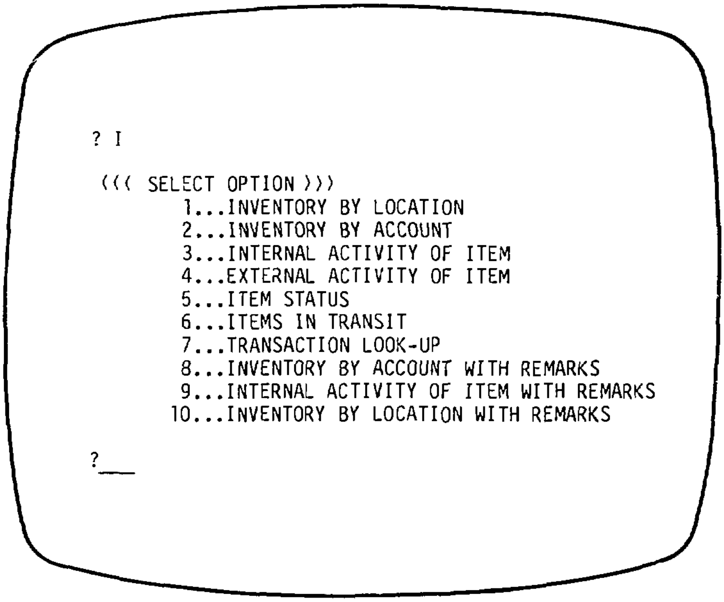

Fig. 16.
On-line reports available for display on video screen.

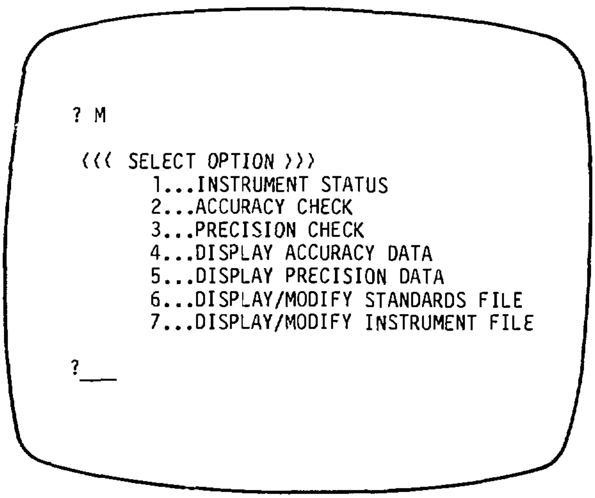

Fig. 17.
Measurement control menu.

Transactions are not the only demand made on the central computer. It also handles many inquiries, for which no accurate account is maintained. The programming staff estimates that two-thirds as many inquiries as transactions are made. Because inquiries have a lower priority than transactions, the system responds to them only when a transaction is not pending.

Specifications for the DYMAC System estimated that 6000 transactions per month would be the maximum load on the system, an amount already exceeded nine times in 1979 and 1980 (Fig. 19). Figures 18 and 19 demonstrate the heavy use made of the DYMAC System.

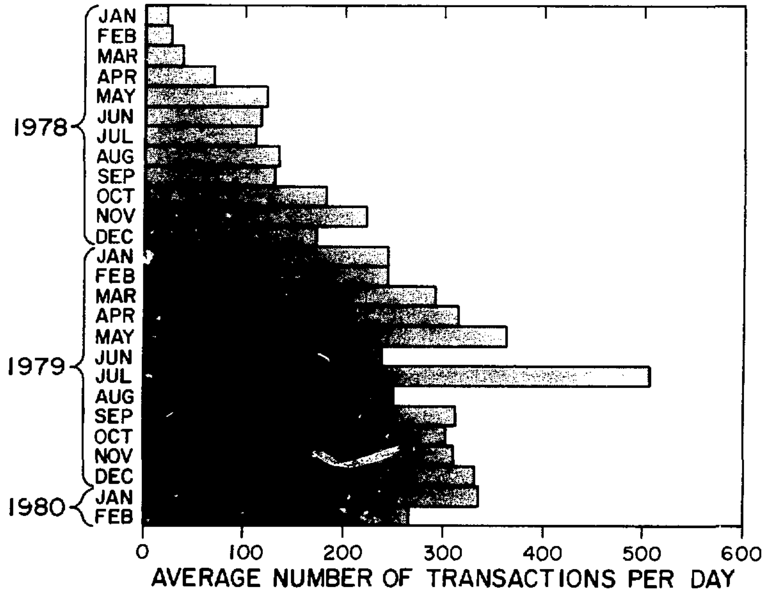

Fig. 18.
The DYMAC System handles about 300 transactions a day.

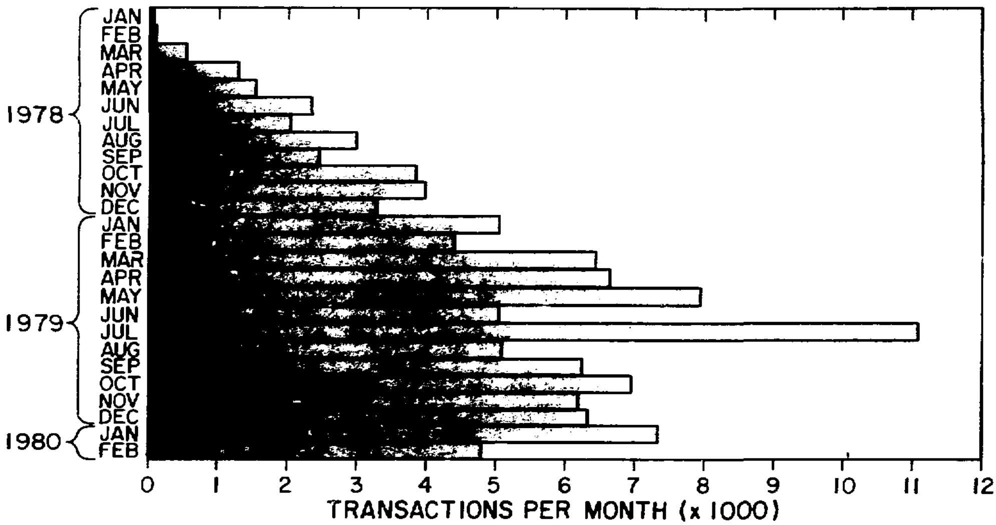

Fig. 19.
The DYMAC System often handles more than 6000 transactions a month.

CHAPTER 6

DISCUSSION OF RESULTS AND RECOMMENDATIONS

The DYMAC concept, as detailed in this report, is an accountability system, based on a computerized inventory file, for monitoring plutonium, uranium, and other strategic radioactive materials in nuclear facilities. DYMAC depends on near-real-time NDA measurements and data entry to maintain a constantly updated computer file of all inventory items in the facility. Instead of testing independent accountability components, the DYMAC System installed at the Los Alamos Plutonium Processing Facility tests and evaluates a complete facility-wide system.

A product of the Los Alamos Safeguards R&D program, DYMAC was designed to stimulate improved practices in nuclear material accountability. A more complete evaluation of the DYMAC System appears in the Phase III report.[3,4]

DISCUSSION OF RESULTS

The DYMAC System successfully brings nuclear accountability into the realm of near-real-time inventory-keeping. It is now possible to maintain a current computer inventory of every item in a facility, monitor all items in transit, and log all transactions. The transaction log permits such assessments (currently performed off-line) as audit trails and material balance determinations for each unit process. To ensure that measurements are within an acceptable error range, a measurement control plan monitors the performance of all NDA instruments in the process lines. The system limits access to authorized users and imposes logical constraints to reduce input errors.

DYMAC does not control nuclear material; it accounts for it. The system cannot prevent anyone from diverting material. It can, however, alert officials to a diversion by displaying current information that they must monitor to discover whether a diversion is taking place. Thus, we must consider DYMAC to be, essentially, a supporting information system for the NMO, the responsible custodian of all the nuclear material at the facility.

DYMAC routinely gathers information about the physical inventory and makes it readily available to answer accountability questions. The inventory is useful at any time, not just at the end of each reporting period. There is no need for a second, hardcopy set of books. All records are maintained accurately in the computer inventory.

Time lag is minimal between the physical inventory and the book inventory, usually less than an hour. The NMO sees that process technicians promptly update the computer inventory after processing steps that alter the physical inventory. The computerized transactions keep the book inventory a close reflection of the physical inventory.

Having an accurate and timely computer inventory provides many benefits for accountability and process control. For instance, operating personnel can generate current inventory listings of specified locations to take localized inventories. They can also draw on the database to produce labels for containers. The time spent in conducting physical inventories is reduced because the book inventory is always current and error-free. Processes are thus closed down only briefly during physical inventory. Accurate printouts of inventory items lessen the time that custodians must spend inventorying items in the vault, thus reducing their radiation exposure. The inventory information also helps supervisors plan work and make realistic schedules.

In addition to these benefits, DYMAC has other merits. Items can be measured in NDA instruments inside the gloveboxes, hence material does not have to be bagged out for transfer to the vault for temporary storage. Also, because transactions have to be made in a prescribed sequence, it is possible to detect when someone forgot to make one; a sequel cannot be entered until the preceding transaction is made. For example, it is not possible to make a RECEIVE transaction until a SEND transaction is entered.

From a user's viewpoint, the DYMAC System is easier to use than any other system that provides such complete and up-to-date information. One needs only to learn how and when to make NDA measurements, how to write transactions, and how to use the information that the DYMAC System provides. The process technician enters into the system only that information that is pertinent to the process step just completed.

Because DYMAC was designed for process technicians, a prompt/response type of query was selected as the best method for eliciting input. The prompt asks for pertinent information only; the technician responds in brief, concise statements. Another DYMAC feature that makes it possible for technicians to update the database is the incorporation of minicomputers or microprocessors with the NDA instruments; these convert raw data into assay measurements and measurement uncertainties that can be entered directly into the database.

The measurement control plan is a valuable control, particularly because it identifies malfunctioning NDA instruments before erroneous measurements enter the database. The history of instrument performance that it provides may soon be required by DOE regulations.

The DYMAC System works reliably, does not significantly impede processing, provides improved processing information, and adapts to changing process constraints and regulations. Facility personnel cooperated with the implementation of the system because they realized the long-term benefits from such improved accountability procedures.

Because the DYMAC concept was tailored to fit the needs of a particular plutonium research and development facility, many compromises were necessary. The major compromise was not being able to optimize the system for a single type of operation because of the variability of processing within the facility; the system had to remain general enough to handle large and small amounts of nuclear material. Another major compromise involved placement of NDA instruments. This placement was not always optimum because of the irregular flow of material through processes that have low throughput or highly variable conditions. In addition, the location of process equipment occasionally caused DYMAC terminals or instruments to be placed in inconvenient locations.

The DYMAC System had an operational impact on the facility operator. The system formalizes transaction writing--this often allows less freedom than the operator would prefer but has a tendency to minimize problems later, in particular with regulatory bodies. DYMAC is designed to encourage technicians to follow set procedures. Shortcuts are not possible. Transactions must be written promptly. Sometimes many transactions are necessary, which slows down processing. However, because the information is entered promptly, much less time is spent correcting mistakes.

The DYMAC development program cost slightly more than $9 million, with the computer and instrumentation hardware accounting for approximately $2 million. The large manpower investment (about 75 man-years over 4-1/2 years) was due to the unique, intensive, and extensive system implementation project. The effort was evenly distributed among five general areas:

- conceptual system design and evaluation;
- computer system support (including software development);
- NDA hardware development and fabrication;
- system hardware installation (including data communications), checkout, and maintenance; and
- system integration with facility process procedures.

Now that the DYMAC System is operating, the Los Alamos Operational Accountability organization is responsible for the continuing routine operation and maintenance of the system, renamed PF/LASS. This includes operation and maintenance of the computer system and maintenance of the NDA instruments. The process operators perform the NDA measurements and record the transaction data.

RECOMMENDATIONS

Although the DYMAC System does not embody all the features the designers would have liked to incorporate, it is a success. DYMAC significantly improves the reliability and timeliness of accountability data and enhances the reporting of process control information. Further development is necessary to utilize its full capability.

The Phase III report[3,4] evaluates the DYMAC System and explores more fully which aspects need further development. It emphasizes the need to complete work on three unfinished tasks defined in the original plan: (a) place all NDA instruments on-line to the central computer, (b) strengthen the effectiveness of the measurement control program, and (c) develop the accountability portion of the system for both rapid on-line assessment and off-line tracing.

Joint cooperation is necessary between the process operator of a facility, the operational accountability organization, and the safeguards R&D organization to create an accountability system such as DYMAC. If this experience were to be repeated, it would be important to establish clearly the responsibilities of each of the cooperating organizations. To the extent possible, it should be determined in advance who will resolve trade-off choices when they become necessary.

One reason that the NDA instruments were not always placed in the best locations is that the original design of the plutonium facility did not accommodate them. The DYMAC System did eventually become part of the plan as the building was being erected and equipped, but it was already too late to incorporate the accountability equipment as fully as one might have wished. Even though this imposes certain constraints on the operation of DYMAC, it is not a major obstacle to the effectiveness of the system.

The prompt/response approach to transaction-making proved to be an excellent training tool. However, when the technicians began making the same transactions over and over again, they became impatient with waiting for the next prompt. We think an approach that allows the technician to fill in the blanks on the terminal display without prompts might be better in the long run.

The database contains useful information that the current version of DYMAC leaves unexplored. To automate nuclear accountability further, control limits could be established for MIP buildup; if exceeded, these control limits could automatically provide alarms. It is the prerogative of the facility operator to implement criticality control based on information in the database.

Although DYMAC is still undergoing development, its successful implementation and continued routine operation at the Los Alamos plutonium facility justifies further improvement of the system. Implementation at the plutonium facility, with its diversity of processing, has provided a rigorous test of DYMAC's flexibility. The 3 years of operating experience gained at Los Alamos are especially valuable for adapting the DYMAC concept to other processing facilities.

PART II

SPECIFIC ASPECTS OF THE DYMAC SYSTEM

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CHAPTER 7

THE NEW LOS ALAMOS PLUTONIUM PROCESSING FACILITY

The new Los Alamos Plutonium Processing Facility is the most advanced of its kind. It incorporates safety and security at the basic level of its design to minimize personnel exposure to radiation and to inhibit diversion of strategic nuclear material.[6]

The facility is located on a 15-acre site (Fig. 20), which is surrounded by a chain link fence to prevent unauthorized persons from entering the protected area. A guard station limits access to the site to authorized pedestrians and vehicles. Private vehicles are parked outside the perimeter fence and personnel walk into the site through the guard station.

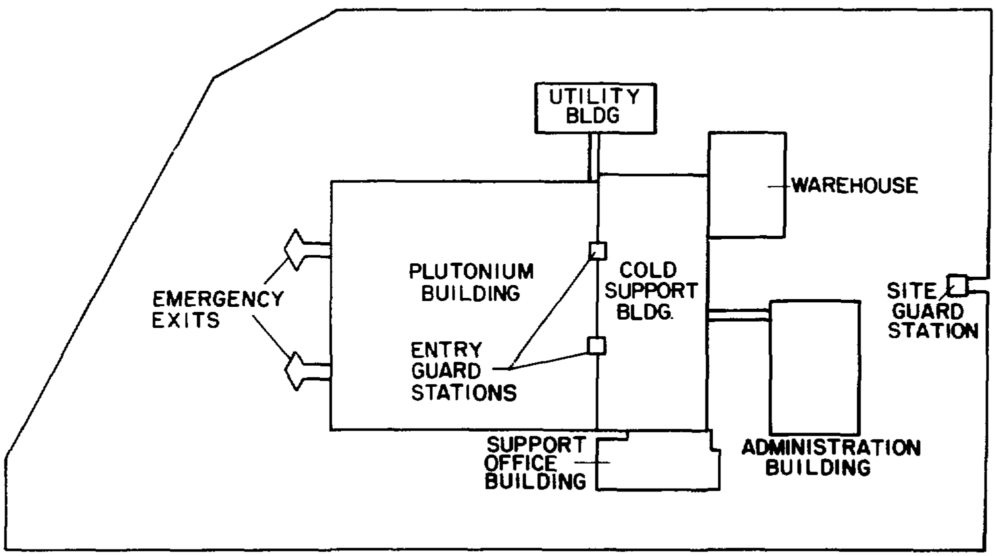

Fig. 20.
Site plan of the plutonium facility and support buildings.

The facility is built of reinforced concrete walls 0.36 m (14 in.) thick to withstand natural disasters, such as earthquakes and tornadoes. In addition, 0.36-m-thick reinforced concrete barriers protect all entrances to the facility. The processing area occupies the main floor. The basement contains a vault for storage of nuclear material, a ventilation system for the entire facility, support services, and distribution systems. Emergency power is supplied by a diesel generator as well as batteries.

Personnel enter the plutonium facility through two guard stations on the main level. Small shipments of nuclear material also enter through the guard station near the count room. Guards control access through an exchange badge procedure and personnel pass through a portal monitor that detects gamma radiation (Fig. 21). Two other exits on the main floor, at the opposite end of the building from the guard stations, permit heavy equipment to enter and also afford emergency evacuation. These exits are normally locked with vault doors. A basement entrance to the facility is used for most shipments of material and for emergency evacuation.

Fig. 21.
To enter the plutonium facility, personnel pass through a portal monitor and exchange badges with the guard on duty.

PHYSICAL LAYOUT

The plutonium facility is in reality four separate facilities under one roof (Fig. 22), each occupying a wing. In the original plan, each of the four wings was considered a separate entity; since then, there has been some overlapping of functions. One wing is for ^{239}Pu R&D, another for ^{238}Pu R&D, a third for metal fabrication, and the fourth for plutonium recovery and purification. The major change to the original plan resulted from changes in funding for some of the projects in the 200 Wing; due to program expansion, ^{239}Pu projects from the 400 Wing now occupy part of the 200 Wing.

The facility's ventilation systems are designed to withstand severe perturbations in pressure between the inside and outside of the building, as would occur, for example, in a tornado. They maintain three gradually reduced pressure areas inside the building. The lowest pressure area is maintained inside the gloveboxes to prevent contaminated air from escaping into the laboratory. The air must pass through a series of high-efficiency particulate air (HEPA) filters before it is released to the environment.

Material is processed inside gloveboxes, which are generally set up in rows (Fig. 23). All gloveboxes in a row interconnect but are normally closed off by means of movable doors. One of the boxes in each row--usually the middle

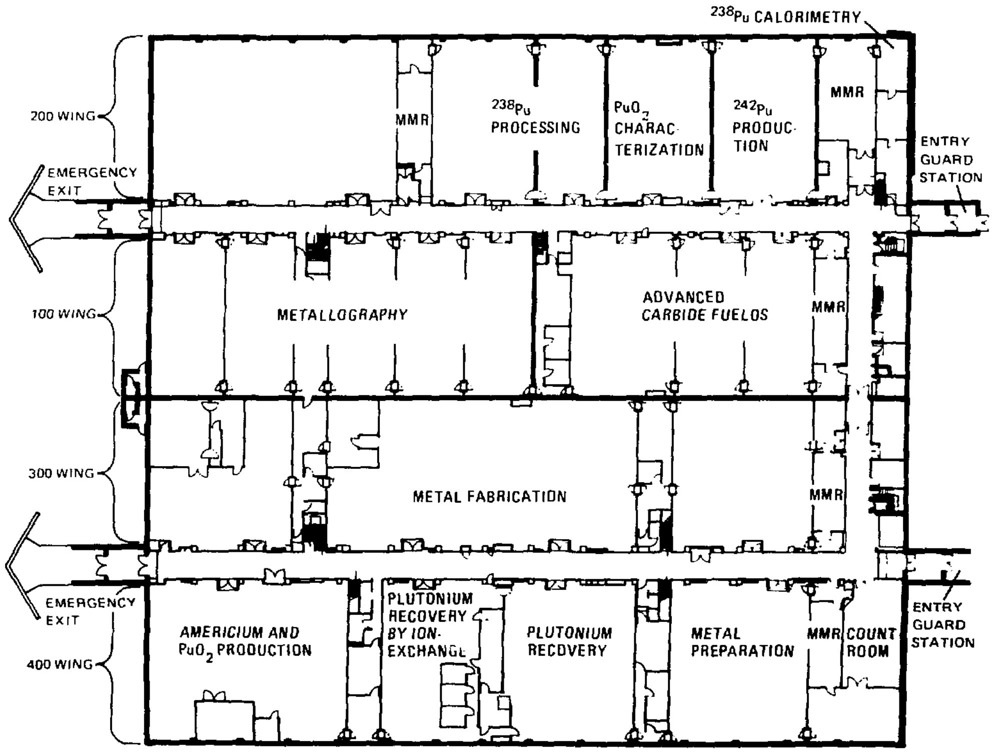

Fig. 22.
The plutonium facility consists of four separate wings.

Fig. 23.
Rows of gloveboxes are connected by an overhead conveyor.

one--is a dropbox, which gives access to an overhead conveyor system that runs perpendicular to the glovebox rows. Because material is not processed in dropboxes, many of the DYMAC NDA instruments are located there.

Most of the conveyors run the length of each wing (Fig. 24). By using the conveyor system, material never has to be taken out of the glovebox lines during processing (Fig. 25). In the 400 Wing, an additional parallel conveyor spans the width of one laboratory to absorb some of the heavy traffic in the wing. Two totally separate conveyor systems supply the 200 Wing: one carries ^{238}Pu items exclusively; the other handles ^{239}Pu and ^{242}Pu items. A cross conveyor system links the wing conveyors.

The conveyor system limits personnel exposure to radiation and decreases the opportunity for diversion of nuclear material. It enables transfer of material from one glovebox line to another without removal from the glovebox environment. (This eliminates the need to bag material out of a glovebox until processing is finished and reduces the amount of contaminated plastic that results from bagout procedures.) Conveyors reduce handling (and thus personnel radiation exposure) and minimize the generation of residues. Moreover, conveyors inhibit diversion of material.

Each wing has a material management room in which no processing takes place. In this room most material is entered into and removed from the conveyor system. Seals are checked on containers and verification measurements are made. There are two such rooms in the 200 Wing: one handles

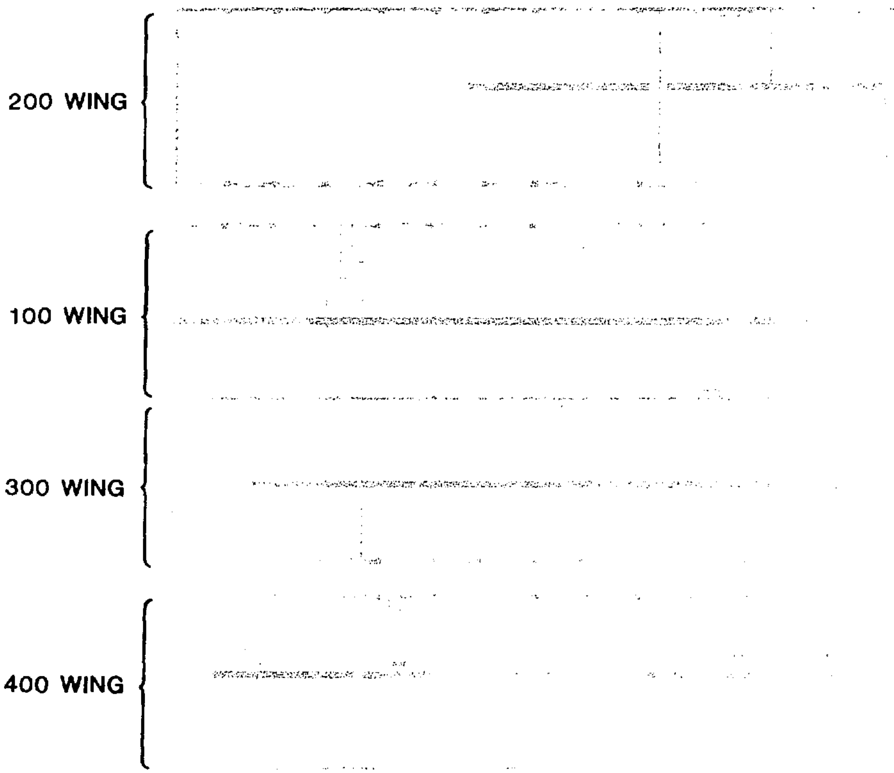

Fig. 24.
Overhead conveyors connect all the gloveboxes in a wing with the exception of the two short conveyors in the 200 Wing, which keep ^{238}Pu separate from other plutonium undergoing processing in the wing.

^{238}Pu exclusively, the other handles ^{239}Pu and ^{242}Pu. A cross conveyor links all material management rooms except the one for handling ^{238}Pu.

COUNT ROOM

Most incoming and outgoing shipments and all waste shipments pass through a count room where their nuclear material content is measured or verified by NDA instruments. For materials that do not lend themselves to rapid NDA measurement, other measurement methods (such as calorimetry or chemical assay) are used. The normal measurement procedure verifies the shipper's value for incoming shipments and ensures that outgoing shipments

Fig. 25.
A technician raises a can of nuclear material into the overhead conveyor.

indeed contain the amount of nuclear material stated on the accompanying transfer slip. Measurement may also be used to verify that a shipment does not contain nuclear material.

A secondary function of the count room is to measure certain materials undergoing processing that cannot be measured by NDA instruments in other locations in the facility. The NDA measurements performed in the count room are for contaminated equipment, large-volume cleanup residues, and HEPA filters, items that are either too large or too inhomogeneous to be measured by the instruments in the process lines. Shipper/receiver differences are also established in the count room and an ongoing program verifies previously assayed items in storage (randomly selected items in the vault are brought to the count room for verification measurements).

The count room contains a variety of NDA instruments to measure the varied material that passes through it (Fig. 26). Two TNCs measure solid scrap residues: one accommodates material in 55-gal. barrels; the other measures material in cans up to 15 cm in diameter. Two SGSs measure such materials as incinerator ash and leached crucibles: one accommodates large barrels; the other, small cans. Of the two types of instruments, the TNC is

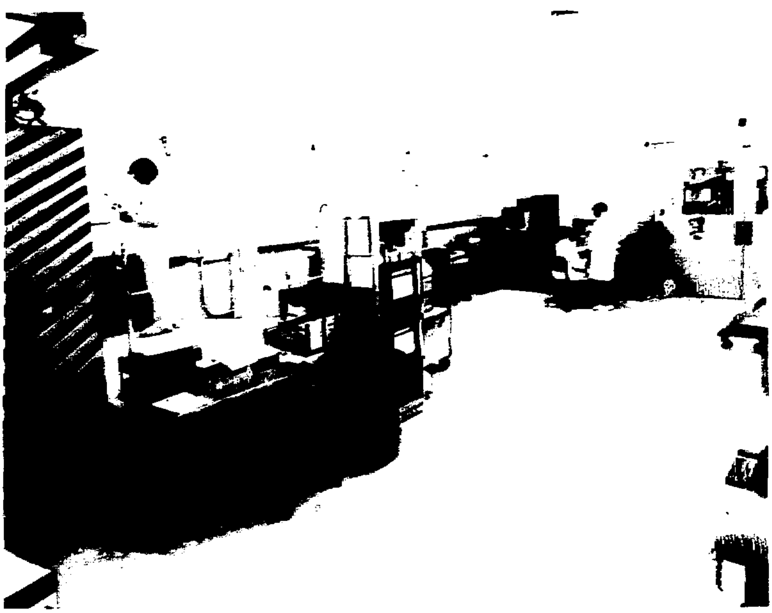

Fig. 26.
The NDA instruments in the count room measure most incoming and outgoing shipments. On the far left is part of the TNC for measuring barrels; the cylindrical instrument in the center is the TNC for measuring cans; to the right of center in the background are the two SGSs.

better for measuring heterogeneous waste that may contain plutonium metal, whereas the SGS is better for measuring low-density, lightweight matrixes that contain nonmetallic forms of plutonium. Also located in the count room is a calorimeter for measuring ^{239}Pu and ^{238}Pu in materials that are not amenable to other NDA measurement techniques.

VAULT

The vault is a secure repository for all inventory items not in active processing (Fig. 27). Access is through a reinforced door with a double combination lock. Rooms that open into the main corridor store canned nuclear material on shelves behind latched grates. Water pools are available for storing encapsulated ^{238}Pu. Two rooms provide refrigerated storage for plutonium metal. Another room provides floor storage for drums of nuclear material. The vault has a storage capacity for about 1500 kg of nuclear material.

Members of two NMO teams must be present to open the vault door. Because each team knows only one of the two combinations to the vault, it takes members from both teams to open the combination locks. While the vault is open, two persons from the Plutonium Processing organization must always be present; one must be on the NMO staff.

Fig. 27.
The vault contains many small storage rooms on both sides of the main corridor.

All items in the vault are labeled and affixed with tamper-indicating seals. Labels are automatically generated from the DYMAC database on a label printer located near the vault entrance. The seals are affixed when items are to be sent to the vault frcm process areas or when off-site shipments are stored in the vault.

Material is transported, usually on handcarts, between the vault and the main processing floor via an elevator near the vault entrance.

INCOMING AND OUTGOING SHIPMENTS

Small shipments enter and leave the facility on the main floor through the guard station near the count room. Large shipments enter and leave through the basement entrance. Incoming shipments that are amenable to NDA measurement go immediately to the count room where they are measured and entered as new items into DYMAC before being stored in the vault. Outgoing scrap and waste shipments are measured for the last time in the count room and deleted from the accountability system. Product shipments leave the vault after chemical analysis determines their plutonium content and impurities.

The NMO (or a member of the NMO staff) escorts all shipments into and out of the facility. The NMO enters each incoming shipment into the DYMAC computer inventory, reconciles any shipper/receiver difference when the plutonium content has been determined by an acceptable method, and places the shipment in the vault for storage. The reverse procedure applies to outgoing shipments, which are removed from the inventory.

TYPES OF PROCESSES AND MATERIALS IN FACILITY

The Plutonium Processing organization operates the facility with the approval of Operational Accountability. It conducts R&D programs for plutonium and plutonium-containing materials. It is responsible for the production and fabrication of plutonium metal, alloys, and compounds. It also recovers and purifies plutonium in scrap residues.

Facility personnel work with plutonium in all its many forms: oxide and other compounds, metal, solution, and in combination with uranium and other elements. Some processes create fuel pellets and insert them into pins for tests of advanced mixed carbide fuels. Other processes cast and machine metal parts. Others create heat sources for the space program. Processes in the 400 Wing and part of the 200 Wing reclaim plutonium from scrap generated from other processes in the facility as well as from other installations. Table VII shows some of the processes currently in operation at the facility.

Because of the R&D nature of the plutonium facility's mission, some processing is subject to change. In this respect the Los Alamos facility differs from a production facility that does the same kind of work over a long period of time. Some of the processes in the Los Alamos facility work with large amounts of plutonium on a production basis, such as oxide production for the

TABLE VII

PROCESSES AT THE PLUTONIUM FACILITY

Process	Input Material	Product
Plutonium scrap recovery	Miscellaneous scrap	Plutonium oxide or metal
FFTF PuO_2 production	Impure plutonium metal	Pure PuO_2, FFTF grade
Plutonium metal preparation	Impure metal or plutonium nitrate	Pure plutonium metal
Metal fabrication	Plutonium metal	Finished plutonium metal parts
Advanced reactor fuels	Plutonium, uranium, and carbon	Fuel pins for FFTF reactor tests
^{238}Pu heat sources	$^{238}PuO_2$	Pressed $^{238}PuO_2$ spheres

Fast Flux Test Facility (FFTF). Other processes, such as metallography, work with subgram quantities of plutonium for research purposes.

The plutonium facility has a throughput of over a thousand kilograms of plutonium annually. At any given moment it has some 7500 inventory items to keep track of. About 85% of the items are in the vault during normal operation. One-half of the facility's inventory consists of product-grade oxide or metal; the other half is scrap to be recovered.

FACILITY OPERATIONS

The Los Alamos Plutonium Processing Facility is controlled by the DOE Albuquerque Operations Office, which enforces DOE regulations at the facility. These regulations differ from those of the Nuclear Regulatory Commission (NRC), which govern commercial facilities, mainly in safeguards requirements but also in containment requirements. The facility manager, head of the Plutonium Processing organization, is responsible for operation of the entire facility, including processing, safety, and safeguards. Section leaders head each of the four semiautonomous wings and decide what to process, determine schedules, and define what is important to their line of work in the way of accountability. The section leaders have schedules to meet and quality to maintain.

The NMO reports directly to the facility manager. Because the NMO is responsible for seeing that all the nuclear material in the facility is properly accounted for, his task is basically at cross-purposes to that of the section leaders. The NMO is responsible for keeping the book inventory as a true reflection of the physical inventory. He and his staff handle all shipments to and from the facility and are in charge of the vault. Other NMO duties are given in more detail in Chap. 8.

The control room for the plutonium facility is staffed on a 24-hour basis to make sure that all building systems function properly. Personnel who have no connection with safeguards are trained to handle emergency situations. The control room staff monitors heating, ventilation, alpha alarms, gamma alarms, and fire alarms. They can monitor the heat and ventilation systems from a computer console. The computer controls all these systems and displays messages to the control room staff. For example, if gamma radiation is detected in a laboratory outside the glovebox environment, the control room staff knows exactly where the radiation is occurring and notifies personnel to evacuate the building.

To help processing in the facility run smoothly with accountability tasks, the facility manager established a Process Coordination Office. Its staff assists the NMO in assigning codes to new shipments to the facility and in entering the information into the computer system. The staff compiles and issues monthly reports on the status of product and scrap processing at the facility. Other duties include monitoring every process in the plant to ensure that process transactions are being made correctly; when mistakes occur in transactions, members of the staff are authorized to make corrective transactions. Before a new process begins operation, the Process Coordination Office helps specify its requirements before they are coded into transaction forms in the computer system. All process changes that affect the computer system are channeled through the Process Coordination Office.

The NDA instrument supervisor is responsible for all measurement instrumentation at the facility. The supervisor has a staff of 13 to ensure that instruments are properly maintained. The staff performs daily accuracy checks and weekly precision checks for all the instruments. The staff is responsible for all the standards used in calibrating the instruments and for maintaining the video and hard-copy terminals and label printers. The supervisor is in charge of holdup measurements, changing filters and dewars, and calibrating pipettes for the SAIs.

Measurement problems in the facility come to the NDA supervisor's attention. He checks out discrepancies in measurements that lead to MIPs. Whenever a technician has a problem making a measurement, the supervisor assists. Some problems are caused by power surges in the facility; others can be caused by operator misunderstanding of how to use an instrument properly. About 50% of the problems that come to the supervisor's attention are caused by operator error and not by instrument malfunction.

FACILITY INVENTORY

The plutonium facility undergoes formal inventory procedures twice each year. January is the major inventory-taking time when the entire facility must stop all processing and gloveboxes are cleaned out. This inspection is conducted by DOE personnel who have access to all plant locations. Generally, they perform a 10% random reassay sampling in the vault, which can take as long as 2 weeks. Because of DYMAC, a recent book inventory took only 1 day for physical verification of the entire facility's inventory. The July semiannual inventory is less rigorous, conducted by the Operational Accountability organization with DOE observers. Reassay of vault items is normally not performed for this inventory and, thus far, a facility shutdown has not been required. In the future it is conceivable that dynamic material balancing will replace a total shutdown.

About 2 weeks preceding each inventory, Plutonium Processing begins shutting down operations in the vault and process areas. This preinventory period is for closing down processes and moving items to the vault for storage. During this time, a DYMAC report of the entire inventory sorted by location (see Fig. A-12 in Appendix A) is run every day to help supervisors clear inventory items from their areas. By the time the inventory is conducted, all items can be easily accounted for.

CHAPTER 8

NUCLEAR MATERIALS OFFICER

The Nuclear Materials Officer[8] and his staff, collectively referred to as the NMO, represent plant management with regard to nuclear materials accountability. They are responsible for all the nuclear material in the plutonium facility. The NMO oversees routine accountability procedures and participates in all decisions regarding changes to accountability procedures. In addition, the NMO manages the nuclear materials storage vault and the shipping/receiving office.

RESPONSIBILITIES

The NMO is responsible for the maintenance of accountability liaison with organizations external to the plutonium facility, including Operational Accountability at Los Alamos, other Los Alamos organizations, other DOE contractors, and DOE inspection agencies.

The NMO participates in the evaluation of modifications to DYMAC, including program modifications, the establishment of priorities for computer usage, and the designation of new accountability codes such as those defining MBAs, unit processes, and item descriptions.

To carry out these responsibilities, the NMO must ensure that (a) all external transactions have been properly documented; (b) all shipments and receipts are properly documented and verified by physical measurement; and (c) all shipper/receiver differences are properly documented, evaluated, monitored, and controlled. The NMO is also responsible for external accounting reports and for coordinating DOE inspections with Operational Accountability.

The DYMAC System is of great help in carrying out these responsibilities. A video terminal installed in the NMO office, along with a hard-copy terminal (Fig. 28), provides the NMO staff with the information necessary to maintain constant watch over all accountability activity in the facility.

Fig. 28.
A video terminal coupled with a hard-copy terminal constitute a supervisory station. This one is situated in the NMO office.

SAFEGUARDS DUTIES

During the workday, the NMO regularly checks the IN TRANSIT file, looking for overdue inventory items that have been sent from one location to another within the facility and are thus in transit. Items have an allotted time, usually 90 minutes, to arrive at their destination and be removed from the IN TRANSIT file. If an item is still in the IN TRANSIT file after the allotted time elapses, the NMO must immediately determine the location of the material and ensure that a RECEIVE transaction is made to remove the material from the IN TRANSIT file and assign it to the correct location. Although overdue items have arrived safely at their destinations, occasionally a receiver has forgotten to make a RECEIVE transaction, or an item did not leave the dispatching area after a SEND transaction was entered that placed it in the IN TRANSIT file.

The NMO evaluates and declares all inventory adjustments to Operational Accountability. Inventory adjustments concern inventory differences, measurement uncertainties, shipper-receiver differences, ^{238}Pu decay, and discrepancies between DYMAC and LASS that arise because of inaccurate transcription of data from transaction documents.

Inventory differences are of particular concern to the NMO. They represent differences in the element weight of nuclear materials before and after processing. The differences may represent holdup in gloveboxes or process equipment, differences between nuclear materials measurements, rounding differences, or possibly the diversion of nuclear material. The NMO must evaluate monthly reports of all inventory differences to determine their causes.

The results of the NMO evaluation are submitted to Plutonium Processing for further review prior to submittal to the Los Alamos Inventory Difference Review Board. Only after inventory differences are determined to have causes other than diversion is the DYMAC inventory adjusted to reflect the differences. If diversion is suspected, the NMO must contact the facility operator immediately. The NMO participates in all investigations of inventory differences of an unusual nature.

COMPUTER OPERATIONS

The DYMAC computer is available 23 hours a day. For accountability purposes, the day begins at 1 p.m. and ends at noon on the next calendar day. At the beginning of each day's business, the NMO checks the facility nuclear material station balance to be certain that it agrees with the previous day's end-of-day balance. This ensures that the proper database has been loaded into the DYMAC accountability system. At the end of each day, the day's external transaction forms are compared to the DYMAC external transaction record for agreement. The DYMAC station balance must then be the beginning station balance plus receipts minus shipments.

VAULT CUSTODIAN

The NMO manages the storage of nuclear materials in the basement vault (Fig. 29). This function includes the safe storage of nuclear materials in accordance with established packaging criteria, criticality limits, the assignment of accountability codes (that is, MBA, unit process, item description, material type, and so forth), the generation of reports on the status of vault holdings, and compliance with security procedures.

SHIPMENTS/RECEIPTS

All movement of nuclear materials into and out of the plutonium facility is handled, documented, and coordinated by the NMO (Fig. 30). This includes shipments between various sites at Los Alamos as well as long-distance shipments to other non-Los Alamos facilities.

The shipment of nuclear materials to non-Los Alamos facilities requires contacting many parties: the facility operator; the Los Alamos Laboratory's health and safety, property management, and security organizations; and the laboratory to which the material is to be shipped. The NMO prepares all the necessary documents, oversees the packaging of the material, coordinates the loading of the shipment onto the shipping vehicle, and maintains a permanent file of documents pertaining to the shipment.

For incoming shipments, the NMO provides a shipment control number to the shipper in advance of shipment to aid in the identification of the incoming material. Upon arrival of the shipment, the NMO enters the data

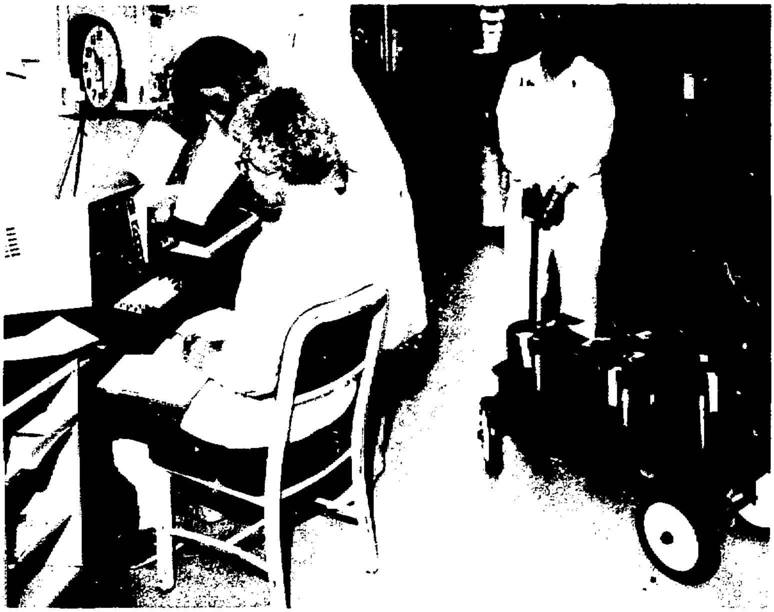

Fig. 29.
The NMO staff makes transactions to log items into and out of vault storage in the basement of the facility.

Fig. 30.
The NMO staff receives an incoming shipment in the basement.

that define the material plus the location of the material into the DYMAC database.

Shipments between sites at Los Alamos are delivered by Operational Accountability personnel. The NMO makes the shipping arrangements with the other Los Alamos site and with Operational Accountability, completes the necessary transaction documents, and performs the corresponding DYMAC transactions.

INVENTORY

Nuclear material holdings are audited by DOE twice annually. The NMO coordinates inventory preparations by performing a preinventory of the vault holdings, establishing deadlines for the movement of nuclear materials within and to and from the facility, performing all inventory adjustments, and distributing inventory printouts to the survey teams. In addition to the semiannual inventories, the NMO requires weekly physical inventories of all nuclear materials in the process lines. The NMO office aids this effort by providing weekly location printouts and maintaining a log of all completed inventories.

CHAPTER 9

DATA COMMUNICATIONS

The DYMAC communications system permits the transfer of data in near-real-time between the processing areas and the central computer.[26] Process technicians enter and retrieve data at video terminals located throughout the facility. The data flow through a network of trunk cables (one for each of the four wings) that connect the terminals and on-line NDA instruments to the computer (Fig. 31). The cables terminate in the computer room in a jackfield that permits some flexibility in port assignment at the computer.

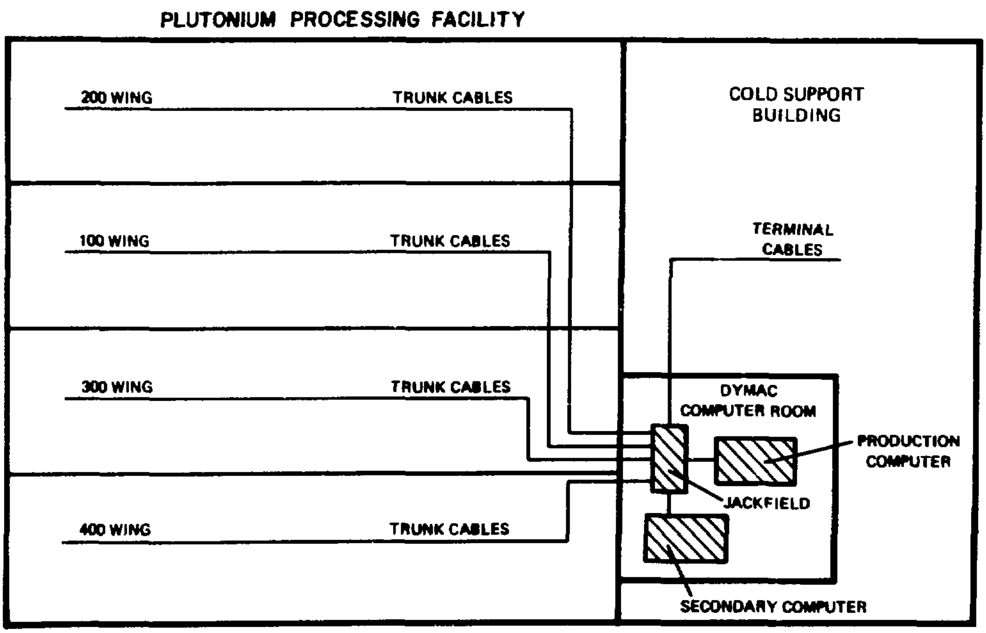

Fig. 31.
Trunk cables run through each wing to connect the NDA instruments and video terminals to the central computer.

What began as a simple matter of transmitting data became a limiting factor in the DYMAC System installed at the Los Alamos plutonium facility. During the early design stages of DYMAC, the availability of computer ports was not recognized as a problem. The original plan for the communications system called for 128 computer ports to which terminals and on-line NDA instruments could be connected. Software limitations in the DYMAC computer subsequently restricted the number of usable ports to 64 under the initial operating system, which was expanded to 80 under the present operating system.

The limited number of ports, coupled with heavy usage, slowed the response time that the computer could devote to terminal and instrument requests. Even with a few remaining ports available for instrument assignment, computer response time was too slow to connect all the NDA instruments that were originally planned to go on-line. Thus, the communications system and its associated software became a limiting factor in the number of instruments and terminals that could be connected to the computer, as well as in the speed with which the system could accept user requests.

INTERACTIVE TERMINALS

The DYMAC System at the plutonium facility deploys three types of interactive terminals for data entry and retrieval. One produces a video display for quick response and the other two produce slower, hardcopy printouts. All are relatively inexpensive commercial products available from Teleray* or Texas Instruments* (TI).

The principal device for making transactions is a Teleray 3741 terminal with a video display screen, shown in Fig. 32. Thirty-five Teleray terminals are installed at appropriate locations throughout the facility and the cold support building. The terminals operate at high speed (4800 bits/second) over the communication lines. They have standard keyboards and screens that can display 24 lines of 80-character information.

Some minor modifications were made to the Teleray terminals to adapt them to the DYMAC System. The CAPS LOCK key on the keyboard was permanently locked on all units to prevent transmission of lower-case characters, which the computer does not recognize. Modifications were made to several of the terminal circuits to improve the receive-current and transmit-current waveforms of the terminals and to eliminate communications problems on some longer lines.

Process supervisors and the NMO have TI-733 hardcopy terminals attached to their Teleray terminals (Fig. 28) for making permanent records. The six hardcopy terminals, which transmit at 300 bits/second, are much slower than the Teleray terminal. A hardcopy terminal can only be used in conjunction with an associated Teleray terminal, enabling the user to display report information on the Teleray screen or print it on the hardcopy terminal. Together, a Teleray and a TI-733 hardcopy terminal form a supervisory station.

*See Appendix C for manufacturers' addresses.

Fig. 32.
System users make transactions at video terminals, such as this one, which are located throughout the facility.

The TI-810 label printer is considerably faster than the TI-733 hardcopy terminal. The five label printers installed in the facility print information on continuous forms at the rate of 1200 bits/second. The label printers cannot be used independently of the Teleray terminals with which they are associated. Like the hardcopy terminals, the label printers enable the user to choose a display or printed form for report or label information. One label printer is located at the entrance to the vault; using information drawn directly from the database, it prints error-free labels for items entering the vault for storage. The other label printers are in the count room, NMO office, Process Coordination Office, and Metal Fabrication Process area.

COMPUTER PORTS

In the original plan for the DYMAC System, each terminal and NDA instrument was to be connected directly to the central computer. After implementing the system we learned that there are disadvantages in individual direct connections, which require many computer ports and the sacrifice of some flexibility. Although the communications system was designed to minimize such disadvantages, direct connections to the computer have built-in limitations that may best be overcome by a distributed processing system.

The DYMAC communications system uses an asynchronous line multiplexor (a manufacturer-supplied option for the central computer) to provide ports for the remote terminals and instruments in the plutonium facility and the Cold Support Building. The computer transmits data to and receives data from the remote devices via the multiplexor, which enables the computer to communicate with several devices simultaneously. The multiplexor gives higher priority to data coming from the remote devices than to data transmissions from the computer.

Obtaining an available port is not all that is required to place an NDA instrument on-line to the computer. The instrument must have an interface of its own that allows it to communicate with the computer. Interfaces exist for the Arbor electronic balances, the TNCs, and the SAIs. However, only 18 of 38 electronic balances operate with interfaces and are on-line. All of the TNCs and some of the SAIs have interfaces but none of these instruments has been placed on-line.

TRANSMISSION PROTOCOLS

Because the communications system was the first DYMAC component to be specified, it had to be flexible and able to adapt to the changing uses of the plutonium facility. During the design phase, existing data communications standards were chosen for all on-line devices. Commercial equipment that was completely compatible with these standards was readily available and interface devices were easily constructed to connect the NDA instruments. A reliable and flexible communications system resulted.

American Standard Code for Information Interchange (ASCII) upper-case characters are transmitted along a 20-mA current loop interface from the terminals and NDA instruments to the computer to reduce interference problems and allow longer transmission lines. The 4800-bits/second transmission rate is a compromise between speed of information transfer and the signal quality needed for error-free communication without expensive transmission lines or complicated equipment. The rate of 4800 bits/second is standard and is readily available on commercial equipment and communications components. The data formats for the terminals and the NDA instruments are identical; hence, the same signal processing considerations apply to both.

CABLING

The cabling is made of two twisted-pair lines (4 wires) terminated with standard 4-pin telephone outlets. One pair is for the transmit signal; the other pair is for the receive signal. Each twisted pair is individually shielded (to reduce crosstalk and noise pickup) and then combined with the other pair into trunk cables. Shielding integrity is maintained throughout.

Cables from each outlet (where terminals or NDA instruments plug into the network) lead to junction boxes in the basement where they are grouped into four trunk cables, each serving one wing of the building. All lines go to all junction boxes along a given trunk in order to increase flexibility. All trunk cables enter the computer room through a junction box to the jackfield and from there to the computer multiplexor board.

JACKFIELD

All lines coming into the computer are connected through an array of phone jacks assembled in a jackfield (Fig. 33). Three vertically positioned jacks are assigned to each incoming line: the top jack connects to the line, the middle jack connects to the multiplexor port, and the bottom jack is permanently wired for monitoring activity on that line. The line and multiplexor port jacks are connected to each other through plug-switchable contacts on each jack.

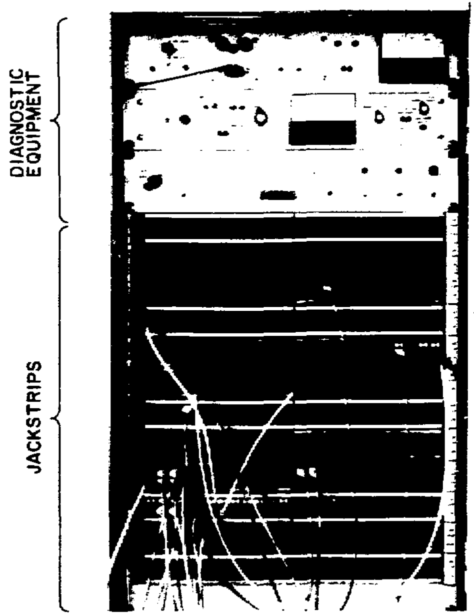

Fig. 33.
Jackfield and associated diagnostic equipment.

The junction boxes and jackfield provide flexibility to the network. Permanent changes can be made by connecting appropriate wires on the terminal strips in the junction boxes. Temporary changes can be made by patching at the jackfield. Any line can be patched to any multiplexor port or can be disconnected completely.

MAINTENANCE

A set of diagnostic procedures was developed for the communications system. Troubleshooting equipment is mounted in the rack that contains the jackfield. The equipment can be patched to perform tests for continuity, capacitance, loop-back, and transmission. The diagnostics equipment consists of a volt-ohm meter, a capacitance meter, and three diagnostic panels. One panel is a character generator that transmits, at selectable transmission rates, a character string containing every character available on the terminals. The transmit lines and receive lines can be completely exercised using this panel and the other panels.

CHAPTER 10

DYMAC COMPUTER SYSTEM

The initial design requirements for the DYMAC computer system specified a dedicated, stand-alone computer system that could handle a large amount of data.[27,28] The system had to have an interactive data-entry capability. Moreover, it had to be portable in the sense that it could be implemented on a similar computer at other installations at nonprohibitive cost, using standard hardware.

The operating system was required to provide some multiprogramming capability for handling more than one task at a time. It had to provide quick response time to facility personnel while they entered data into the system. In addition to the operating system, the computer system needed to support a database management system for the orderly storage and retrieval of accountability information.

HARDWARE

With these specifications in mind, DYMAC personnel selected the Data General Eclipse C330 minicomputer system (Fig. 34), the only minicomputer then on the market that offered both a multitasking operating system and a database management system. Since that time, the selection of minicomputers with similar capabilities has greatly increased.

Initially, the Eclipse C330 computer supported the Data General multiprogramming Real-Time, Disk-Oriented Operating System (RDOS) and a Data General database management system INFOS. The initial system had 131 072 words (16 bits per word) of core memory and peripherals that included two system consoles, two 5-million-word moving-head disk systems, two 9-track magnetic tape drives, one 600-lines/minute printer, and one 128-line asynchronous line multiplexer. Subsequent hardware upgrading resulted in the system configuration shown in Fig. 35.

A second Eclipse C330 was purchased as a back-up machine in case the primary machine failed. Normally the second computer is used for software development, training, off-line report generation, and accountability procedures. Both computers have since been upgraded to 256k 16-bit words of core memory with a total disk storage of 116 megabytes.

Fig. 34.
DYMAC computer room with Data General Eclipse C330 minicomputer.

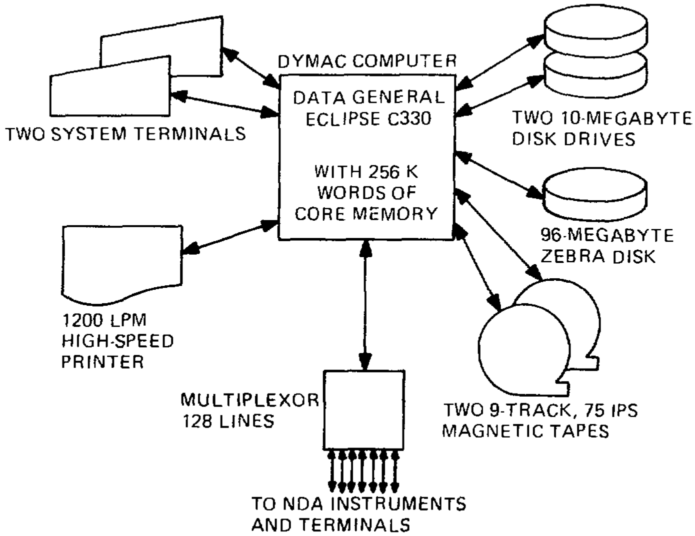

Fig. 35.
Hardware configuration of DYMAC computer system.

SOFTWARE

DYMAC software consists of an operating system, a database management system, and applications codes (Table VIII). A commercial vendor supplied the operating system and the database management system. The applications code was prepared by DYMAC programmers. The software description reflects the RDOS configuration that was in use until March 3, 1980. On that date, Data General's Advanced Operating System (AOS) replaced RDOS and a restructured applications code went into use. At that time, system availability changed from 8 hours a day to 23.

Commercial Software

The DYMAC Eclipse C330 initially operated under RDOS. Like all operating systems, RDOS was responsible for scheduling and allocating computer resources--such as disk space, memory, and peripherals--as well as for allocating these resources among its users. RDOS also supported multitasking, which allows more than one user to access the system at one time.

The Data General INFOS software was purchased to manage the DYMAC database (that is, computer inventory). Database management means the orderly handling and retrieval of large amounts of data in a file-oriented system. INFOS has the ability to create files, order them in special ways, search for and retrieve information from these files, insert and delete

TABLE VIII

DYMAC SOFTWARE[a]

Package	Name	Function
Operating system	RDOS[b]	Allocates and schedules computer resources (processor, disk, memory, line printer, tapes)
Database management	INFOS[b]	Manages files through an index structure
DYMAC software	DYSS	Interacts with system users and NDA instruments to provide updated accountability information to INFOS
Utility library	DYUTIL	Maintains and updates tables, generates reports, has recovery routines for system crash

[a]RDOS configuration.
[b]Purchased from Data General.

information, and change existing information. INFOS can lock a record that is in use to prevent information from being deleted or changed.

Files in the DYMAC database are structured so that INFOS can access them. Records in each file are accessed via different branches of an INFOS key structure. For example, the applications software can access a record by keying on the item's unique name or its location. INFOS maintains the file structure that links the key with the database records.

It became apparent in the spring of 1979 that the DYMAC System was nearing saturation, both in computing power and in the availability of port communication channels (see Chap. 9). A decision was made to convert the DYMAC System from RDOS to AOS. AOS provided many advantages over RDOS: the ability to handle more users on the system at one time, a more secure sign-on procedure, and the availability of additional ports for communication with terminals and NDA instruments in the plutonium facility.

AOS is a multiprogramming, disk-based operating system that controls and monitors user-program processing in both a time-sharing and real-time interactive mode. AOS supports INFOS; therefore the database structure and processing that was implemented under RDOS could be preserved under AOS. Conversion from RDOS to AOS was completed in January 1980 and went into operation on March 3, 1980.

User-Prepared Software

In addition to the commercially available operating system and database management system, applications software had to be written to embody the principles of the DYMAC concept. Project programmers wrote two main packages to operate under RDOS: the DYMAC software system (DYSS) and the DYMAC utility library (DYUTIL). They wrote the software in FORTRAN, a high-level computer language, for flexibility and ease of modification.

The applications code DYSS is a collection of on-line, real-time, multitasking programs and off-line programs that maintain and manipulate four databases. DYSS is structured as shown in Fig. 36. The executive program EXEC handles multitasking for DYSS, such as the interaction between the computer system and remote devices. DYSS processes all transactions, inquiries, and measurement control procedures. Using INFOS to maintain the database, DYSS interacts with facility personnel to record process information, update the database in near-real-time, and read data from NDA instrumentation.

The utility library DYUTIL maintains and updates various tables containing information about MBAs, material types, enrichments, instrument locations, and line speeds. The NMO staff uses utility routines to account for and verify the nuclear material totals at the facility. The report-generating routines give the DYMAC System an off-line reporting capability that describes transaction activity and current inventory plant holdings. In case of a system failure, other utility routines recover all the transaction activity entered after the last end-of-day procedure.

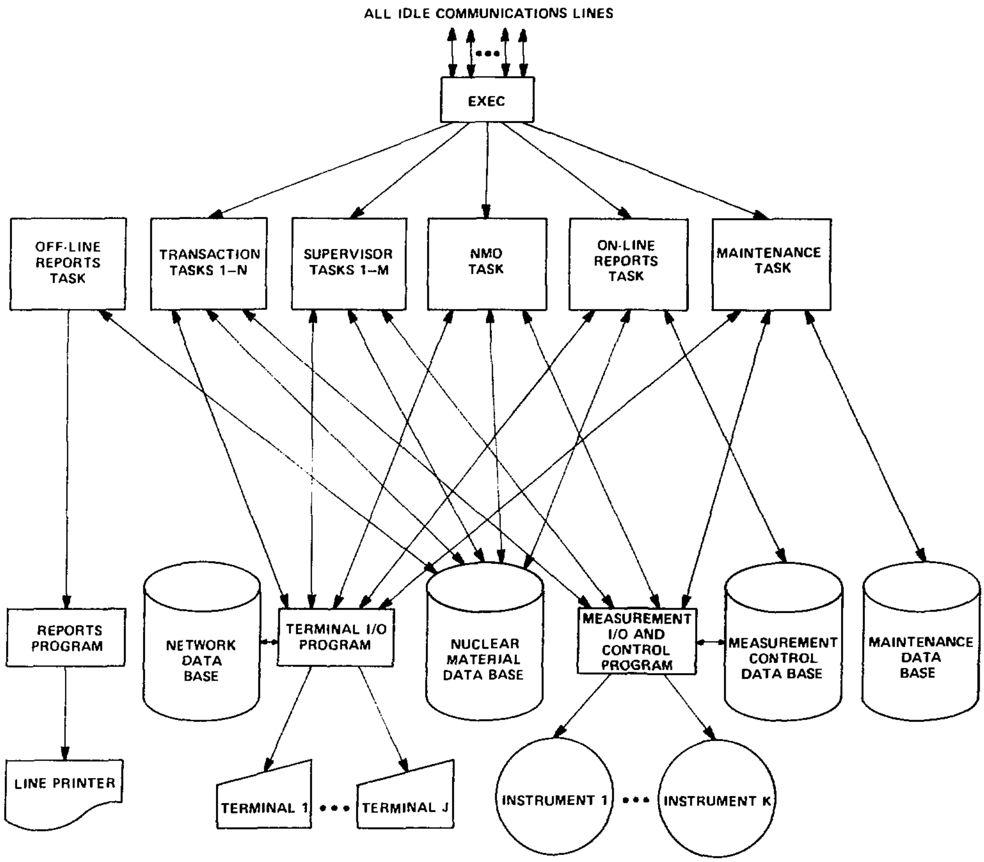

Fig. 36.
Structure of the DYMAC software under RDOS.

A Packet-and-Image Approach to Transaction Handling

Some approaches to handling transactions provide limited system diagnostics and require the user to supply considerable information. DYMAC programmers decided to adopt another approach by defining unique transactions for each process in the facility. Such transactions reduce operator input (and errors) and provide improved diagnostics. Another consideration was the ease of altering transaction forms as changes occur in the processing. The programmers decided not to put the transaction information into tables because that would require recompiling the entire system for any minor change. Instead they adopted a table-driven approach, using packets and images, that accommodates changes rapidly and accurately.

One packet and a corresponding image exist for every transaction in a process. A packet is a group of messages and instructions that DYSS draws on to prompt the user and check his responses. It enables DYSS to display a series of messages and questions to the user that are unique to the particular transaction he is doing. For example, the packet designed for the RECEIVE

FROM VAULT transaction tells DYSS which messages to display to prompt the user through the transaction. The corresponding image for the RECEIVE FROM VAULT transaction contains certain fields of information that remain unchanged every time this transaction is done. Figure 37 shows the image for the transaction form RECEIVE FROM VAULT. In this transaction, material always goes to account (MBA) 712, receipt area (unit process) M1, project 413, and location 150. These fields have been coded into the image, as one might place them on a preprinted form.

To create a packet and an image for each process, the programmers work from a process definition sheet, which defines the material balance areas and identifies the transaction and measurement points within each area (Chap. 3). For each transaction point they fill out a DYMAC process information sheet (Appendix B). From the information on the sheet, they can create the packet and image. The information sheet becomes the specification for each transaction form. Any changes to a transaction form start with a modification to the current sheet.

DATABASE MANAGEMENT AND STRUCTURE

The DYSS collection of on-line, real-time, multitasking programs and off-line programs maintain and manipulate four databases, as shown in Fig. 36. These databases contain information about nuclear material, measurement control, system maintenance, and the system network.

Nuclear Material Database

The nuclear material database consists of 15 files that contain inventory, transaction activity, operator interaction, and validation information for data

```
NUMBER ************ FIELD ************** FROM ********** TO *********************
 1,2        LOT ID
 3,4        ACCOUNT                                        712
 5,6        RECEIPT AREA                                   M1
 7,8        PROJECT                                        413
 9,10       SPECIAL DESIGNATOR
 11,12      LOCATION                                       150
 13,14      SHELF
 15,16      ITEM DESCRIPTION
 17         "FROM" REMARKS:
 18         "TO" REMARKS:
 19         DESTINATION:
 20,21      NM AMOUNT:        .00 G OF TYPE       BULK AMOUNT:                  .00 G
 22         ENRICHMENT:       .00%                {ISOTOPIC WEIGHT:             .00}
 23,24      IMPURITY:         .00% OF             MEASUREMENT CODE:
 25,26      SEAL NUMBER:                          COEI NUMBER:
 27         ISOTOPIC A:  .0000, B:  .0000, C:  .0000, D:  .0000, E:  .0000

                          NM VALUE:       .00 G,  BULK VALUE OF       .00 G
```

Fig. 37.
Software image of precoded information for the transaction form RECEIVE FROM VAULT.

entries. DYSS accesses the files and updates them in real-time. An off-line report program generates printouts of most portions of the database.

To the user, the four most important files in the nuclear material database are the inventory file, the in-transit file, the transaction history file, and the external transaction file. Together, the inventory and in-transit files contain records for every item in the facility, one record for each item.

Records are accessed by the three-part DYMAC name key: MBA number, material type, and item ID. The MBA number is the material balance area in which the item is located. Material type is a two-character code that defines the type of nuclear material in the item and its enrichment range. Item ID is the identifying code assigned to an individual inventory item.

The inventory file contains records of all the inventory items within the facility except those temporarily in transit. When an item is moved within the plant, a transaction places its record in the in-transit file and deletes it from the inventory file. A record cannot exist in both those files at the same time; it must reside in one or the other. An inventory record (Table II) contains complete information for a particular item in the physical inventory.

The in-transit file contains a record of each item that is in transit within the facility. We define items that are in transit as those moving to or from the vault and count room and those moving in the conveyor system. An in-transit record contains the same information as an inventory record, with the addition of the item's destination and instrument verification data. Records are accessed by the DYMAC name key. The amount of nuclear material in all the inventory and in-transit records constitutes the station balance for the facility.

The transaction history file contains records of all transactions that occur within the facility. Each transaction history record has information describing the origin and destination of every item and the amount of the transfer. Transaction history records contain the same information as inventory records with the addition of destination and instrument verification data and a transaction ID number. Transaction history records differ from inventory records in that they contain to and from information for the first 12 items in the record. Transaction history records are accessed using the to or from DYMAC name as the INFOS index key.

The external transaction file contains records of all transactions that involve a transfer of material into or out of the facility. These records have a format identical to the transaction history record format; however, they are accessed using their unique transaction number as the index key.

Measurement Control Database

The measurement control database contains information that the measurement control plan (Chap. 18) draws on to validate and monitor the performance of all instruments in the DYMAC network. It contains an instrument file, an instrument history file, and a standards file.

The instrument file contains measurement information for all NDA instruments in the DYMAC System. The information is referenced via INFOS and is accessed using the instrument ID number as the index key. The data are stored in two parts. The operating parameters (the information required to interface with the instrument and calculate the measured value) are stored in a partial record in the INFOS index structure. Information describing the instrument performance is stored in the actual database record. If a measurement is involved, transactions reference the instrument file.

The standards file contains information pertaining to standards, such as weights and containers, that is used for calibrating or checking the instruments. The information is referenced using the standard ID number as the INFOS index key and is stored only in INFOS partial records.

The instrument history file keeps measurement information concerning previous calibrations of each instrument. The information is in an INFOS file indexed by instrument ID numbers.

DYMAC System Maintenance Database

The maintenance database contains the diagnostic files required to maintain the network components. These files provide housekeeping information for the system. Another file consists of information concerning the material type, enrichment, isotopic ranges, and accountable units for every item in the facility. Project and item description information as well as MBA and unit process data are also kept in INFOS database records.

Network Database

The network database includes the information necessary to recognize and identify active terminals and to validate users. It includes a line-definition table and user validation information. The line-definition table specifies all the cable connections to remote devices in the DYMAC System. The user validation file contains information about every person authorized to use the DYMAC System, in the form of user ID and system privileges.

COMPUTER OPERATING PROCEDURES

For the first 2 years of operation, a staff of one full-time operator, one part-time data analyst, and three programmers developed the DYMAC System and ran it on a daily basis. On a normal working day the system was available from 8 a.m. to 4:30 p.m. for making transactions, inquiries, and doing maintenance procedures. Occasionally the programmers shut down the system at noon to make adjustments to the database or to add new codes. When processing continued until late at night, the DYMAC System was shut down as usual at 4:30 for end-of-day procedures and then restarted for the rest of the evening. Transactions made at that time were considered to be part of the next calendar day's processing. Under AOS, the DYMAC System operates 23 hours a day. It is shut down for an hour at noon for end-of-day procedures.

Computer Startup

Each new process period begins with a normal system shutdown and then a restart that resets the system and reinitializes system files. At this time the transaction log files, the instrument log files, and the error log files contain no entries. Then the NMO checks the database to ensure that the station balance is correct. If the station balance is correct, the video terminals in the facility are enabled and users can begin making transactions and inquiries.

When it is necessary to notify system users in the facility about events that will affect them, the computer operator can display a message along with the start-up menu. Users see the message after they sign on the system and are recognized as valid users.

End-of-Day Processing

Before any end-of-day checks or reports are performed, all the DYMAC video terminals in the plant must be disabled from the system so that no further transactions can be processed. The computer operator checks to see if there are any items in transit. The end-of-day procedure pauses until all items in the in-transit file have been properly removed by a RECEIVE transaction at their stated destination.

Using the line printer, the computer operator lists all external transactions processed during the day for the NMO. Then the NMO runs a database check to verify that the station balance is correct. The operator updates the general ledger to reflect the day's activity.

The plutonium facility is required to prepare a daily report of DYMAC activity for LASS. This is done by writing a tape that records the transaction activity for the day. Then the computer inventory is written on two different tapes: one for storage in the DYMAC computer room, the other for the NMO to store for back-up purposes.

At this point, normal end-of-day tasks are completed, unless it is time for mid-month or end-of-month reporting. Requested off-line reports are then printed.

During the monthly reporting period two tapes are written that record the period's transaction activity, which is then sent to LASS. These mid-month and end-of-month inventory tapes provide information about every item in the DYMAC inventory database.

Recovery from System Failure

When the system fails, the cause may be a hardware or software failure. If it is a hardware failure, such as a central processing unit or disk malfunction, the operator must decide if the failure will prevent a recovery. If recovery is not possible in a reasonable amount of time, the operator switches to the back-up Eclipse computer to handle essential transactions. Under this limited operation, no inquiries can be handled.

For software failures, the computer room staff tries to detect the error and correct it before restarting the system. The Data General utility program FIXUP is run to clean up any files left open when a failure occurs. A clean copy of the database (that is, a copy that has not been altered by transactions since the last general ledger update) is loaded. This database copy is the same as the database used at the beginning of the processing period before the failure. A database check is run to verify that the nuclear material balance is correct.

Then the recovery program is executed. The program reads the transactions (one at a time) that were written to the disk file. It reads a record, then modifies the database in exactly the same manner as had been done interactively when the transaction was initially entered at the user's console. When all the transactions in the file have been read, the database is current to the point when the failure occurred. The video terminals are enabled and facility personnel can resume using the accountability system.

CHAPTER 11

DIGITAL ELECTRONIC BALANCE

Two-thirds of the DYMAC NDA instruments at the plutonium facility are digital electronic balances, such as the one shown in Fig. 38. Compared to the other NDA instruments, the balances are inexpensive, rugged, and require little maintenance.[29] Weight measurements made on the balances are precise, accurate, easy to perform, and require little operator training. This chapter discusses only those digital electronic balances that were planned as part of the DYMAC System. Other balances not part of the original DYMAC plan are also used for accountability measurements (see Chap. 17).

Processing facilities commonly use balances to measure materials for their nuclear content. What makes the balances in the DYMAC System unique is that 18 (out of 38) are directly connected to a central computer and can transmit the measured values without operator intervention.

The weight of plutonium metal items can be used directly for accountability records. However, if an item is not pure plutonium--as is the case with plutonium alloys, compounds, solutions, or mixtures--its weight must be multiplied by a chemical factor to determine the amount of plutonium. Table IX provides examples of some materials handled at the facility and their associated chemical factors.

HISTORY OF DEVELOPMENT

Most of the DYMAC balances in use at the plutonium facility are installed in gloveboxes and have to withstand abrasive dust, corrosive fumes, vibration, and mechanical shock. Preliminary testing[1] showed that, under these conditions, balances using the knife-edge principle are unsuitable. Hence, DYMAC personnel decided to evaluate electronic balances and purchased three commercial models.

Arbor Laboratories, Inc., supplied two 5.5-kg-capacity balances, one with 0.1-kg sensitivity and the other with 0.01-g sensitivity; Mettler Instrument Corporation supplied one 15-kg-capacity balance with 0.1-g sensitivity. The three test balances spanned the ranges and sensitivities needed in processing lines to satisfy accountability requirements.

Fig. 38.
DYMAC digital electronic balance. Only the load-sensing head needs to be inside the glovebox; the readout unit is mounted outside.

The three balances were evaluated under laboratory conditions. The 15-kg Mettler balances had a precision of 0.15 g and an accuracy of 0.2 g. Both of the Arbor balances exhibited a precision of 0.08 g and an accuracy of 0.15 g. Although the evaluation showed that the balances did not meet all of the manufacturer's claims, it was determined that all three types were satisfactory for DYMAC application with certain modifications. Fourteen more Arbor balances were ordered from the manufacturer with modifications.

PRINCIPLES OF OPERATION

The DYMAC electronic balance is based on an electromagnetic force-restoring technique. The balance weighing pan is attached to a wire-wound bobbin located inside a motor housing. When an item is placed on the weighing pan, the bobbin momentarily moves downward. A current then returns the bobbin to its original (null) position and this current provides a signal that indicates the mass of the item on the weighing pan.

TABLE IX

MATERIALS AND THEIR TYPICAL CHEMICAL FACTORS

Material Description	Typical Chemical Factor	Determination of Chemical Factor
Plutonium alloy	0.970	Weighed quantities of plutonium and metal alloy combined to form specific alloy.
Plutonium oxide	0.878	Controlled chemical preparation and calcine conditions. Occasional chemical assay for confirmation.
Plutonium-uranium carbide	0.2	PuO_2, UO_2, and C are vacuum-calcined under controlled conditions. Occasional chemical assay for confirmation.
Plutonium nitrate solution	0.250	Sample analyzed by SAI.

FUNCTIONAL DESCRIPTION

As manufactured, Arbor balances consist of one unit that incorporates the load-sensing head and the readout unit. For glovebox installation, the two functions are remoted so that the sensitive electronic units are not subject to the harsh environmental conditions of the gloveboxes. That is, the balances are physically separated into two units connected by a cable (Fig. 39). The load-sensing head remains inside the glovebox protected from corrosion by a stainless steel housing. The readout unit, whose electronic components are more vulnerable to chemical and radiological damage, is mounted outside the glovebox. A six-conductor cable carries the electrical signals from the load-sensing head through the glovebox wall via a hermetically sealed bulkhead connector to the readout unit.

The three balances initially purchased for evaluation were remoted by Los Alamos personnel, as were two additional balances purchased from Mettler. All subsequent balances purchased from Arbor were remoted by the manufacturer. During normal use, the Arbor-supplied connectors that linked the load-sensing heads to the readout units suffered from contact resistance problems. Los Alamos personnel replaced them with hardwired connectors that are strain-relieved.

For locations where corrosion was not a significant problem, an alternate method of remoting was used to improve stability and accuracy. The transducer printed-circuit board was placed inside the load-sensing device and the null-detection signal was sent back to the readout unit via a single conductor cable. This removed all cable capacitance changes that affected balance calibration. It is now possible to move the balance and remoting cable inside the glovebox without affecting balance calibration.

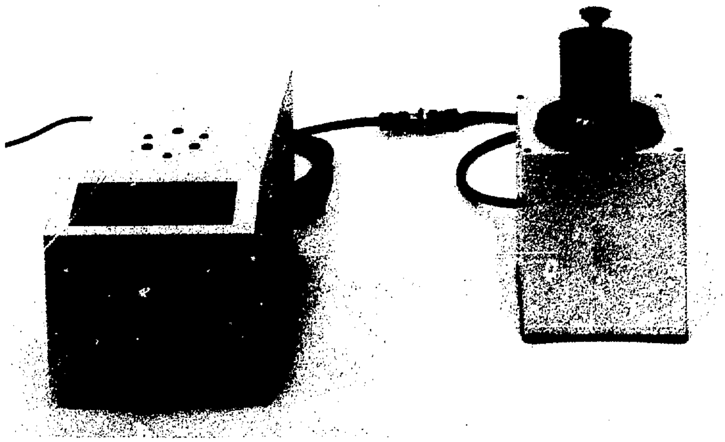

Fig. 39.
For glovebox use, the balance--normally housed in one unit--was separated into two units connected by a cable.

Each balance is connected to a Los Alamos-designed interface, which permits direct transmission of the balance output signal to the DYMAC computer. RESET and HOLD pushbuttons, mounted on the readout unit (Fig. 40), enable transmissions from the readout unit through the interface to the DYMAC computer and reverse transmissions. The HOLD pushbutton locks the measured weight in the readout unit. The computer then issues a command that directs the interface to assemble the data from the balance, convert it to serial computer-readable format, and transmit it to the computer. The RESET pushbutton unlocks the balance from the computer and allows the balance to be operated as an off-line, stand-alone instrument.

Another balance modification resulted from an unanticipated failure during routine usage in the plutonium facility. A 727.0-g item erroneously exhibited a weight of 707.0 g on the readout unit. We traced the readout failure to a faulty latch in the digital output for the second-place digit. The daily balance check did not detect the failure because both checkweights used for the check had zeroes for the second-place digit. Subsequently, a checking device was added to each Arbor balance to check the digital portion of the readout unit before use.

The digital checking device consists of a locking switch, select switch, and thumbwheel, as shown in Fig. 40. It operates as follows: the operator tares (zeroes) the balance, then selects the number 7 on the thumbwheel, places the locking switch in a TEST position, and presses a START pushbutton. All digit positions on the readout should then display the number 7. Then the operator repeats the procedure with the number 8.

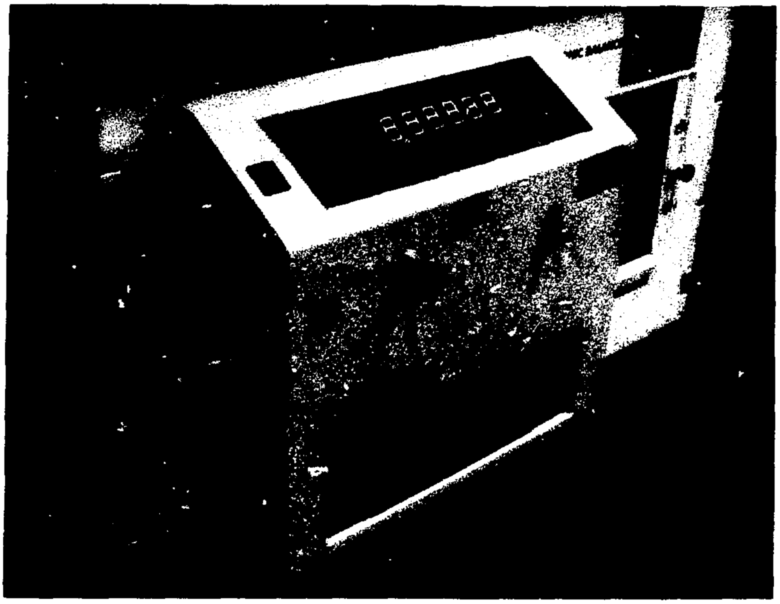

Fig. 40.
Balance readout unit with controls for operating the instrument and for checking its digital circuitry.

Successful displays of the numbers 7 and 8 in all positions indicate that the digital readout is operating properly.

INSTALLATION

Almost all the balances in the plutonium facility were installed in dropboxes located directly beneath the conveyor system (Fig. 11). A dropbox is typically the center-most glovebox in a parallel line of process gloveboxes. The overhead conveyor interconnects the parallel glovebox lines via the dropboxes.

The few balances not installed in dropboxes are located in special gloveboxes or on balance tables in the process rooms. A 15-kg Mettler balance is located outside the storage vault in the basement of the facility. As of March 1980, 41 DYMAC balances had been installed, of which 38 are in operation. The following table provides a breakdown by type.

Balance Type	Capacity (kg)	Sensitivity (g)	Number in Operation
Arbor	5.5	0.1	25
Arbor	5.5	0.01	10
Mettler	15	0.1	3

The locations of the DYMAC balances on the main floor of the facility are shown in Fig. 4.

PERFORMANCE CHARACTERISTICS

After modification, 17 balances were installed in gloveboxes and tested over a 6-week period. Two daily measurements were made for each balance using 1-kg and 4-kg test weights. The data were pooled on a weekly basis for the 6-week period. These performance data were then used to set measurement control limits for the existing electronic balances and all subsequent installations.[30]

Performance statistics over a 1-year period show that the 35 operating Arbor balances have an average accuracy of 0.060 g (1σ) and an average precision of 0.170 g (1σ) as determined with a 1-kg standard. This is adequate for use at the plutonium facility because DOE regulations allow nuclear material weights to be rounded to the nearest gram for accountability purposes.

CHAPTER 12

THERMAL-NEUTRON COINCIDENCE COUNTER

For high-purity plutonium metal and oxides, weight provides an accurate measurement. However, after such material is sealed in containers, weight is no longer reliable, especially because of the possibility of diversion and/or mislabeling. To verify that the correct material and amount are inside the container without opening it, one can use a TNC, such as the one in Fig. 41, to count the neutron emissions. Thermal-neutron counting is the best NDA method for measuring plutonium in dense and heterogeneous material.

PRINCIPLES OF OPERATION

In a fission, usually more than one neutron is produced. These neutrons from the same fission are strongly correlated in time and reach the ^{3}He detector (Fig. 42) within a short time interval of each other. Neutrons from (α,n) reactions are produced randomly; that is, they have no time correlation. By counting neutrons in time-correlated pairs one can obtain a reliable measure of plutonium content.

The TNCs[19] in the DYMAC System use a passive method of counting neutron emissions from a plutonium sample. They are able to detect coincident neutrons in the presence of a random neutron background, mostly from the (α,n) reactions in the sample.[31] The total mass of the plutonium can be determined from the known isotopic composition of the sample.

The TNC is highly efficient in detecting neutrons, is insensitive to gamma rays, has a flexible geometry, and is extremely reliable. It cannot, however, determine the isotopic composition of the plutonium in the sample.

The TNC counts coincident spontaneous fission neutrons from the even-mass plutonium isotopes. The measurement is expressed as the effective mass of ^{240}Pu that would give the same response as the actual ^{238}Pu, ^{240}Pu, and ^{242}Pu content of the sample; it is given by

$$\text{Eff}\ {}^{240}m = (2.49 \times {}^{238}m) + {}^{240}m + (1.57 \times {}^{242}m)\ ,$$

where ^{A}m denotes the mass of plutonium isotope A.

Fig. 41.
A technician directs the assay in the TNC on top of the glovebox line from a keyboard/display terminal.

Samples with large amounts of (α,n) emitters (such as beryllium, boron, or fluorine) present special measurement problems due to high singles counting rates. The effects due to bias, uncertainty in the deadtime correction, and induced multiplication limit useful measurements for these samples.

Neutron multiplication occurs when a spontaneous fission or a random neutron induces one or more fissions in the sample. The induced fission neutrons are counted like the spontaneous fission neutrons and, consequently, yield artificially high assays. Ensslin et al.[32] have developed a technique that corrects multiplication to a few per cent for plutonium metal and PuO_2 samples that weigh no more than several kilograms.

FUNCTIONAL DESCRIPTION

The TNC basically consists of five modules (Fig. 43): a neutron well counter and preamplifiers; an amplifier, discriminator, high-voltage module; a shift register; a control module called the THENCS controller (see Chap. 13); and a hand-held keyboard/display terminal. The sample to be counted is

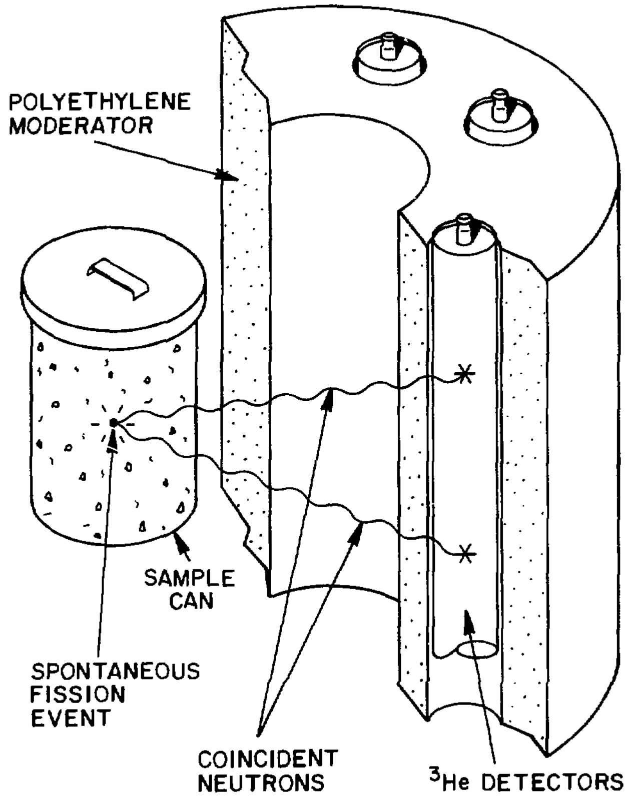

Fig. 42.
The TNC counts neutrons in time-correlated pairs to measure the plutonium content in the can.

placed in the middle of the well where the surrounding ^{3}He detectors count its neutron emissions for 500 seconds. The shift register counts coincident neutrons and passes the raw data to the THENCS controller, which converts the data to the sample's effective mass of ^{240}Pu. An operator directs the entire counting procedure from the hand-held terminal (Fig. 41).

The central sample counting well is surrounded by one or two concentric rings of ^{3}He proportional counters (Fig. 44), depending on the application. The ^{3}He tubes are embedded in polyethylene cylinders lined with cadmium. A neutron emitted from a sample will experience one of several fates: it may be captured by the polyethylene or the cadmium liner; it can leak out of the detector; or it may be thermalized by the polyethylene and captured by the ^{3}He counters, thus producing a pulse through the ^{3}He(n,p)^{3}H reaction.

The purpose of thermalizing the neutrons is to increase the detection efficiency. The 0.4-mm-thick cadmium liner on the well prevents low-energy neutrons from scattering back into the sample and inducing fissions (neutron multiplication). The outer shield, consisting of 10-cm-thick polyethylene lined with a 0.4-mm-thick cadmium sheet, provides neutron moderation and shielding from background neutrons. The cadmium liners also provide a reduced system die-away time, which is relatively independent of the sample. The double-ring design is sensitive to the average energy of the neutrons that leave the sample and is useful for variable moderation and multiplication effects.[33] Sensitivity to multiplication effects is particularly important in application to hydrogenous samples such as wet oxalate cake.

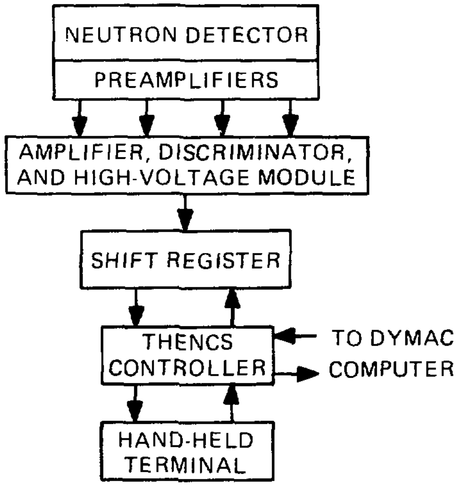

Fig. 43.
The TNC consists of five modules.

The TNC electronics, shown in Fig. 45, converts the signal from the ^{3}He counters for input to the shift register. As installed, the high-voltage junction boxes and four preamplifiers are placed underneath the TNC counting well, whereas the other electronic components are housed separately. The signals from the charge-sensitive preamplifiers are processed by four linear bipolar pulse-shaping amplifiers and four discriminators. The discrimination level and high voltage are set by front controls on the amplifier module. The four discriminator outputs are ORed together to provide a single standard logic signal to the shift-register coincidence logic.

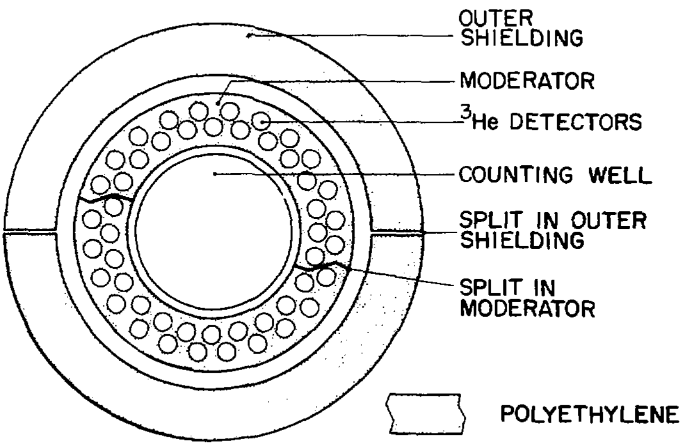

Fig. 44.
TNC counting well with a double ring of ^{3}He detectors.

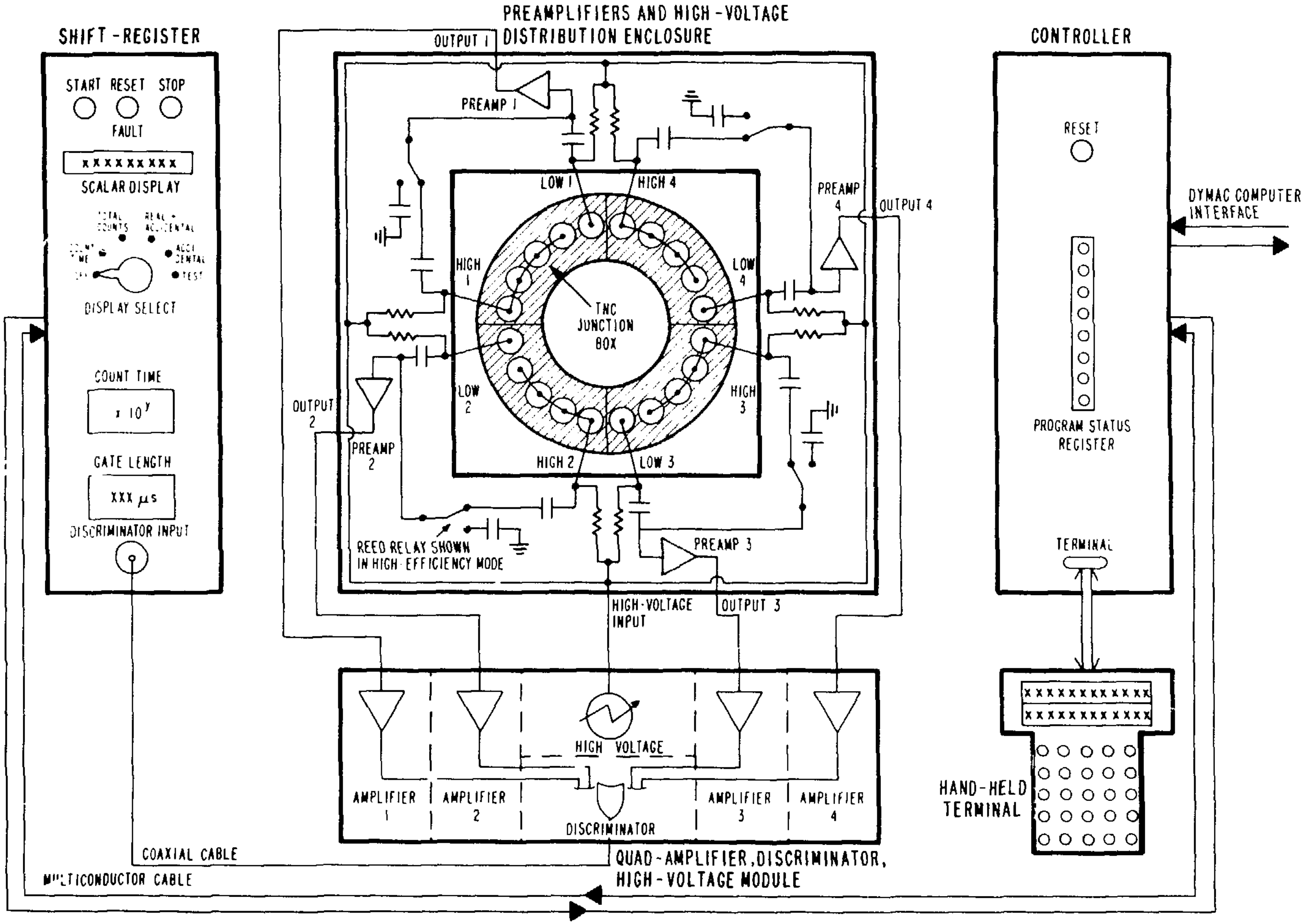

Fig. 45.
TNC electronics.

The shift register[22,23] separates random neutron activity from the coincident neutron activity that accompanies the spontaneous fission of radioactive material. The shift register enables useful operation of the counter and the electronics, up to several hundred thousand counts per second.

The THENCS controller communicates with the shift register. It provides data reduction and displays the corrected true coincidence count rates and the effective ^{240}Pu mass of the sample on the hand-held terminal after a measurment is completed. All operations, including interaction with the central accounting computer, are initiated through the terminal.[34]

INSTALLATION

Of the 20 TNCs called for in the DYMAC plan, all are installed and 19 are in operation (see Fig. 4 for their locations in the plutonium facility). Two configurations of ^{3}He tubes were used: 11 TNCs have a single ring and 9 have a double ring. Although all of the TNCs are capable of transmitting data on-line to the central computer through the THENCS controller, none have been connected on-line because of the constraints imposed by the communications system (see Chap. 9).

With a few exceptions (such as in the calorimetry and count rooms), the DYMAC TNCs are located in dropboxes that access the conveyor system. The electronics package (visible in the lower left corner of Fig. 41) is mounted underneath the glovebox that adjoins the dropbox.

Three physical orientations were used for installing the TNC well counters: vertical below the glovebox (Fig. 46), vertical on top of the glovebox (Fig. 41), and horizontal on the side of the glovebox (Fig. 47). Placement of the well counters was dictated by the activity in the gloveboxes and by nearby process apparatus.

For a TNC mounted below a glovebox, a shaft from the 16-cm-diameter counting well is bolted to the outside surface of the glovebox and opens into the glovebox. Plutonium samples are loaded into an elevator assembly that lowers them into the counting well by a direct-current motor-driven Teleflex control unit. The drive motor and controller are located outside the glovebox and provide forward, reverse, torque and speed controls. Part of the elevator assembly consists of a polyethylene and aluminum plug at the top that reduces the variation of efficiency across the sample cavity. A stationary plug remains in the bottom of the well. The other two TNC installation configurations are constructed similarly. Some TNCs have a 31-cm-diameter by 41-cm-deep central well that can be used for measuring bulky items.

PERFORMANCE CHARACTERISTICS

Routine measurements with the TNCs normally take 500 seconds, which provides a reasonable compromise between accuracy and timeliness for assaying plutonium. The TNCs can measure items of different shapes and sizes that vary in plutonium content from 0.1 g to more than 1 kg. They can also accommodate differences in the plutonium isotopic makeup of the material. For instance, samples assayed include ^{238}Pu heat sources, ^{240}Pu in

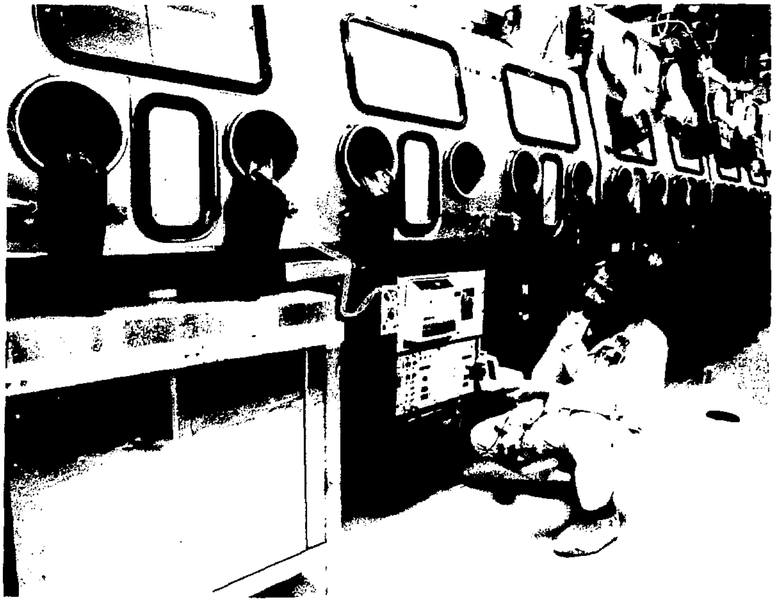

Fig. 46.
TNC installed underneath the glovebox line.

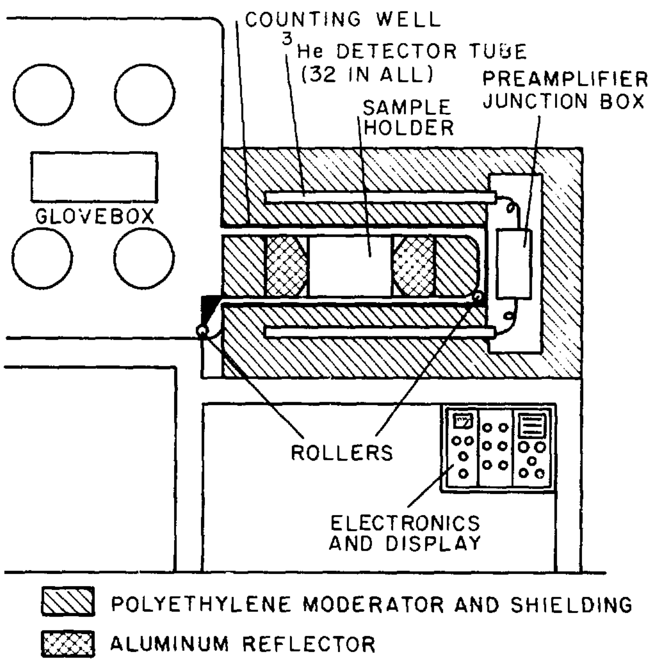

Fig. 47.
TNC installed horizontally to glovebox line for accommodating heavy samples.

weapons-grade material, FFTF fuel, advanced carbide fuel, and ^{242}Pu recovery materials.

The versatility of the TNCs enables them to measure glovebox trash whose plutonium content varies from subgram to gram quantities. Such trash may consist of rags, gloves, plastics, glass, rubber, sweepings, paper, and mantles. The Recovery Process uses the TNC to assay solids that have had most of their plutonium leached by nitric acid washings. The Recovery Process also uses the TNC on a routine basis to measure filter residues. The Casting and Fabrication Process assays graphite casting molds and crucibles that contain about 1 g of plutonium. The Casting and Fabrication Process also assays the burnt casting skull that contains up to hundreds of grams of PuO_2. The Oxide-to-Metal Reduction Process uses the TNC to assay reduction salts and crucible components, which contain a few grams of plutonium and about 1 kg of plutonium oxalate.

Although the TNC has proved extremely useful for assaying plutonium in a variety of samples of different shapes and sizes, there are limitations to its range and accuracy. The variations in assay due to geometric effects and matrix material are generally small, except when large quantities of hydrogenous material are present. This problem was reduced for measuring wet oxalate[20,21] by using data from the double-ring TNC, which yield a measure of the average neutron energy and hence the amount of moderation caused by the sample. For large plutonium samples, multiplication effects become important; it is imperative not to report assays beyond the range of the calibration standards.

CHAPTER 13

THENCS CONTROLLER

Originally, use of the TNC was awkward and slow because of the complicated procedures involved, such as manual data analysis.[33] The DYMAC project decided to automate the TNC with a microprocessor-based module called a THENCS[35] controller (Fig. 48) to simplify the operational procedures and increase the TNC's use and acceptance by process technicians. The controller reduces calculational errors and saves time by automating the operation of the instrument. By providing an effective interface between the instrument and the operator, the controller makes the TNC more useful for near-real-time accountability.

PRINCIPLES OF OPERATION

The THENCS controller is a microprocessor that enables the TNC to perform as a stand-alone system. Following an assay, the microprocessor, which is simply a small computer, calculates a sample's effective mass of ^{240}Pu from the raw count data. The microprocessor software automatically turns on the counting electronics, collects the data, stops the counting, transfers the data into the memory core, and performs the appropriate calculations to determine the result. Because the operation of the unit is controlled by software programming rather than hardwired logic, the program can be altered to satisfy particular requirements of the user. The software includes a step-by-step prompting routine that guides the operator through the required steps of each measurement via messages on the hand-held keyboard/display terminal.

FUNCTIONAL DESCRIPTION

A THENCS controller has been installed for each of the 20 TNCs in the facility.[34] The controller consists of a Motorola 6800 microprocessor, 16 programmable read-only memory (PROM) units that contain the software, and 8k of magnetic core memory. The hand-held terminal connects to the rear of the controller. The controller is housed together with the shift register and the electronics for the preamplifiers, amplifiers, and high-voltage discriminators (Fig. 49). Figure 50 shows the complete system in block diagram form.

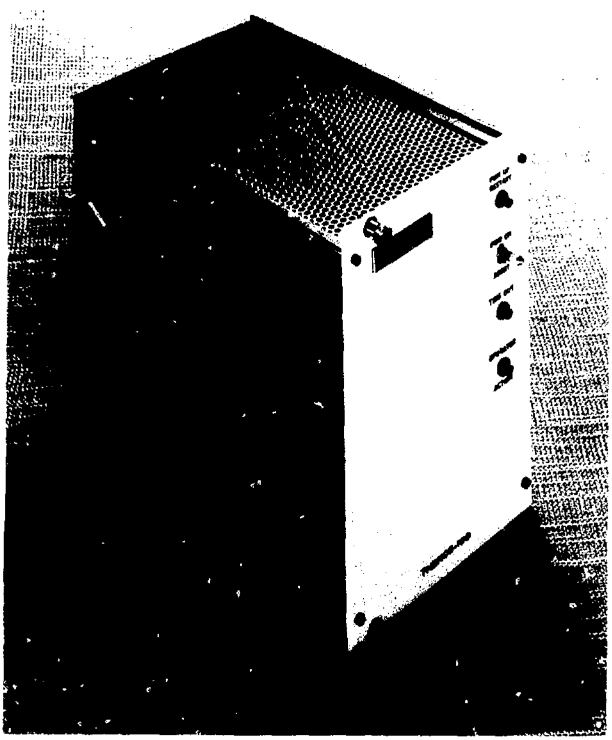

Fig. 48.
THENCS controller.

Before an actual assay can be made, several parameters must be determined: the TNC deadtime, the room background, and the TNC calibration. After an assay has been made, it is important to know its precision and accuracy. Each parameter is programmed as a separate function of the THENCS.

The operator uses the hand-held terminal to perform six functions: deadtime, background, calibration, assay, accuracy, and precision.[36] The operator requests a particular function by pressing a key on the terminal and the controller software guides him through the necessary steps. The following paragraphs describe each function separately.

Deadtime is the amount of time during which the TNC cannot accept additional information. It is the basic parameter upon which all other controller functions depend. The program measures each coincidence count rate and singles count rate that it needs to calculate the deadtime.

Background is the count rate caused by neutrons in the room. If the deadtime parameter has not been calculated before a background count rate is requested, the controller software automatically guides the operator through that measurement before performing the background measurement. After the

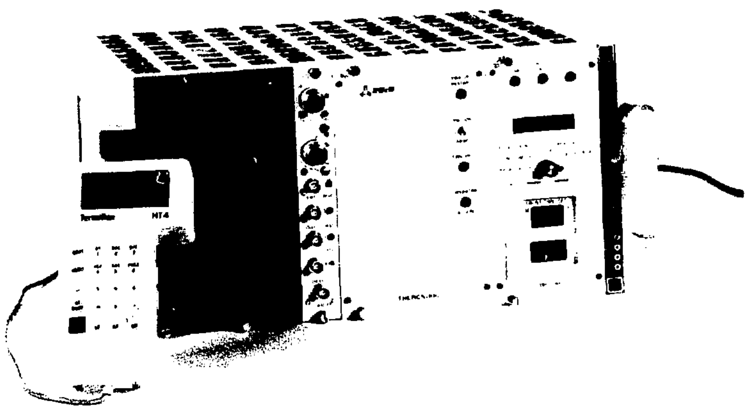

Fig. 49.
Complete electronics package, including THENCS controller, for the TNC.

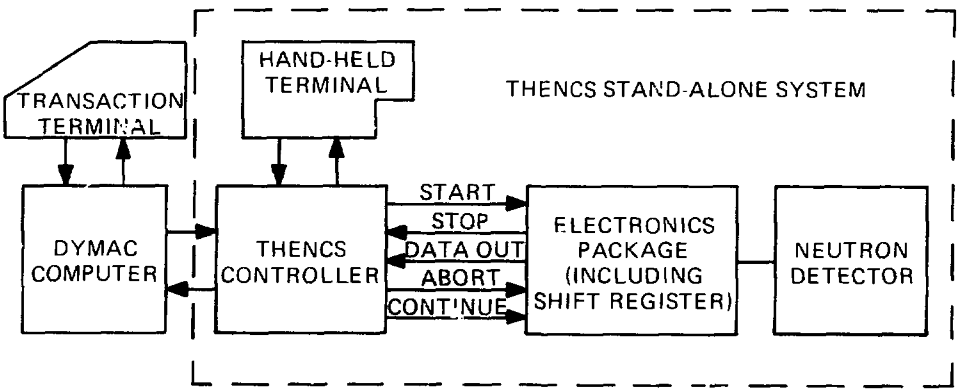

Fig. 50.
The THENCS controller is the interface between the TNC and the DYMAC computer.

operator measures the background, the software calculates the background count rate. Both the deadtime parameter and the background results are stored in the controller memory for later use. These values remain unchanged until a new value is stored.

Before an assay can be performed, the TNC must be calibrated with three or more calibration standards. The controller software guides the operator through the measurement of the standards one at a time, then determines the calibration constants for the assay and stores them in the controller memory.

After performing the deadtime, background, and calibration functions, the controller software guides the operator through an assay. When the assay is complete, the software calculates and displays the effective mass of ^{240}Pu and the uncertainty in the mass. These values are entered into the computer inventory.

Accuracy is the ability of the instrument to obtain the correct answer. Before an accuracy measurement can be made, the controller software makes sure that all the prerequisite measurements of deadtime, background, and calibration have been performed. The operator places a known mass of ^{240}Pu in the counter and measures it. The instrument compares the measured value of the mass with the known value and informs the operator of the result. If the instrument fails the accuracy measurement, the operator must take appropriate action before performing an assay measurement.

Precision is the ability of the instrument to repeat a measurement. The cycle operation checks the precision of the TNC. The operator places a standard in the counting chamber and the instrument automatically performs 15 replicate measurements. Then it calculates a statistical parameter that it compares to prescribed limits. The terminal informs the operator of the instrument's precision status. If the instrument fails the precision measurement, the operator must take appropriate action before performing an assay measurement.

The deadtime, background, and calibration process can be done in about 1 hour. Material can be assayed in about 10 minutes. The common failure rate for the THENCS controller is about one unit per month.

CHAPTER 14

SEGMENTED GAMMA SCANNER

Many waste and scrap shipments arrive at the plutonium facility for processing. Typically the shipments consist of incinerator ash, filters, gloves, coveralls, plastic, and paper that vary widely in nuclear material concentration. The SGS,[37] shown in Fig. 51, analyzes these low-density, nonhomogeneous materials. A computer associated with the SGS directs the automatic data acquisition and data analysis and operates the assay hardware. The assay procedures are simple and do not require a skilled operator. The instrument exhibits a typical accuracy of 2 to 5%, depending on the density of the material and its geometry, for a 10-minute assay time.[38,39]

Fig. 51.
Side-by-side SGSs in the count room.

The SGS has a long history at Los Alamos,[40] where it was originally designed and implemented. Subsequently, it was turned over to commercial interests for large-scale fabrication. Instruments similar to the SGS in use at the plutonium facility are now commercially available. Safeguards personnel at Los Alamos custom designed and fabricated the computers affiliated with the assay units.

PRINCIPLES OF OPERATION

Using gamma-ray techniques for nondestructive assay of nuclear material is always complicated to some degree by the attenuation and inhomogeneities in both sample and matrix material. The key to minimizing the problems is to combine a careful transmission correction with a rotation-collimation method,[41] as illustrated in Fig. 52.

This combination translates into three general principles that are involved in performing an SGS assay. First, the container must be considered as a series of horizontal segments that are equal in height. The SGS scans one segment at a time; then it sums the results for all segments to arrive at a total assay result. This compensates for vertical inhomogeneities. Second, the sample must rotate during each scan to reduce the effects of radial inhomogeneities. Third, the gamma-ray assay technique must be corrected for transmission losses.

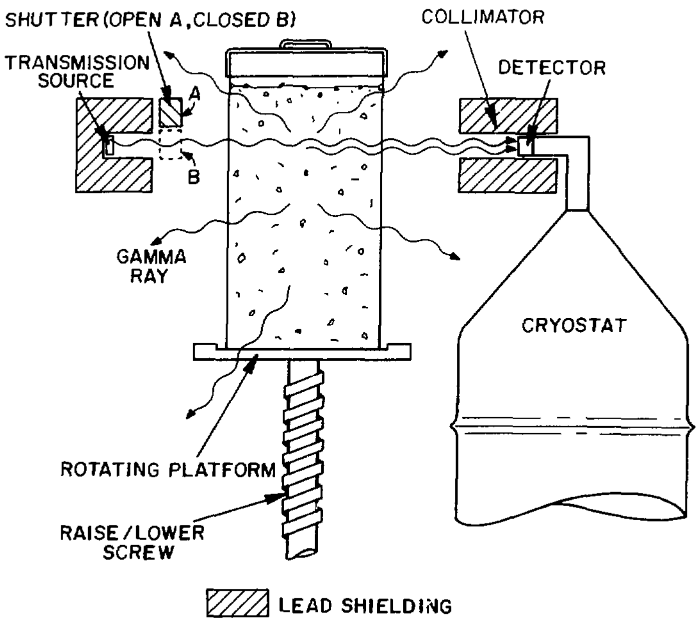

Fig. 52.
SGS configuration for scanning a rotating sample one segment at a time.

The technique for correcting transmission errors employs an external source. The SGS uses a Ge(Li) detector that measures gamma rays emitted from the plutonium isotopes to assay the material. Because these gamma rays are absorbed in the plutonium itself, as well as in the other materials in which the plutonium may be embedded, a transmission correction must be made for these so-called matrix effects. This correction can be made by placing the sample between the detector and an external transmission source. The energies of the source gamma rays are chosen as a close approximation to the energy of the plutonium gamma rays used for plutonium assay. By comparing the intensity of the attenuated source gamma rays with the intensity of the unattenuated source gamma rays, a correction factor can be obtained for the attenuation of the plutonium gamma rays in the sample.

FUNCTIONAL DESCRIPTION

Two SGSs were installed in the count room to measure scrap and waste. One measures barrel-size containers of the material and the other measures much smaller cans. The SGS measurements aid in determining shipper/receiver differences and in verifying the nuclear content of product and waste materials that have been previously measured elsewhere in the facility.

Each SGS consists of a high-resolution Ge(Li) gamma-ray detector and its associated electronics, a display scope, a minicomputer with terminal, and a sample-positioning mechanism and its control (Fig. 51). The complete electronics racks--including the electronics, minicomputer, control panels, and scope for the two independent SGSs--are visible in the center of the photograph. The terminals, which are used for hardcopy output and program input for the two SGS units, are shown on opposite sides. Next to the terminal on the left side is the scanning table for cans, which rotates and moves vertically. A transmission source is mounted to the left of the sample holder. The Ge(Li) gamma-ray detector for the can table is located to the right of the sample holder, behind the lead collimator and shielding. The barrel table (which is similar to the can table) and its respective Ge(Li) detector do not appear in Fig. 51.

The SGS is computer controlled for automatic data acquisition, data analysis, and hardware control. The assay codes, written in Data General-compatible assembly language, occupy minimal core space and permit fast computer operation. The codes fit into 8k words of 16-bit core memory and consist of four relocatable routines to handle interrupt, display, calculation, and floating-point operations.

The two SGSs in the count room are routinely used to assay the ^{238}Pu or ^{239}Pu content of inventory items. The calibration routine enables the system to assay either ^{238}Pu or ^{239}Pu by selecting the appropriate gamma-ray peaks emitted from the respective isotopes. The calibration standards used with the SGS are representative of the samples to be measured in geometry and range of transmission, but they do not necessarily correspond to the matrix material or chemical form. The system calibration must be rechecked before switching to a different kind of assay, such as ^{239}Pu or ^{238}Pu. The result of the recheck indicates whether systematic errors occurred in the SGS.

INSTALLATION

In July 1978, DYMAC personnel moved the SGS in use at the former plutonium facility to the count room at the new facility. At that time, the instrument consisted of one set of electronics that drove two scan tables, but not concurrently. To permit a greater volume of throughput in the count room, DYMAC personnel fabricated a second electronics unit in July 1979 that allowed the scan tables to operate independently as two separate SGSs. The electronics units are interchangeable; they can be switched to operate either scan table if one unit fails.

CHAPTER 15

SOLUTION ASSAY INSTRUMENT

The Plutonium Recovery Process generates copious amounts of plutonium-bearing solutions whose concentrations vary from a few mg/ℓ to about 500 g/ℓ. High-concentration solutions result from the dissolution of plutonium oxide or metal; low-concentration solutions result from filtration steps.

The DYMAC project installed three SAIs,[18] one of which appears in Fig. 53, in the 400 Wing to assay plutonium-bearing solutions in the process lines where they are generated. The SAIs are used for assaying solutions generated by the Americium and PuO_2 Production Process, the Plutonium Recovery by Ion-Exchange Process, and the Plutonium Recovery Process. The Americium and PuO_2 Production Process produces solutions with a high concentration of plutonium; the other two processes generally produce low-concentration solutions. An SAI can assay a high-concentration solution (greater than 10 g/ℓ) in about 17 minutes and a low-concentration solution (less than 1 g/ℓ) in about twice that time.

The SAI operational data[42,43] indicate that, using standards ranging from 0.5 to 300 g/ℓ, the calibration constant can be determined to within 0.2%. Precision for a concentration range of 0.5 to 10 g/ℓ is 5% for a 2000-second assay. For plutonium concentrations greater than 40 g/ℓ the uncertainty is about 1% for a 1000-second assay. Measurement control data taken over a period of several months indicate an observed standard deviation of 0.7%. These results are consistent with the expected instrument performance.

The intensity of the gamma rays emitted by a sample is proportional to the amount of the emitting isotope present; however, the number that reach the detector are affected by self-absorption in the sample. To correct for self-absorption, an external transmission source is situated so that its gamma rays must pass through the entire sample to reach the detector. The corrected count rate is then linearly related to the ^{239}Pu concentration of the sample over the calibration range of the instrument.

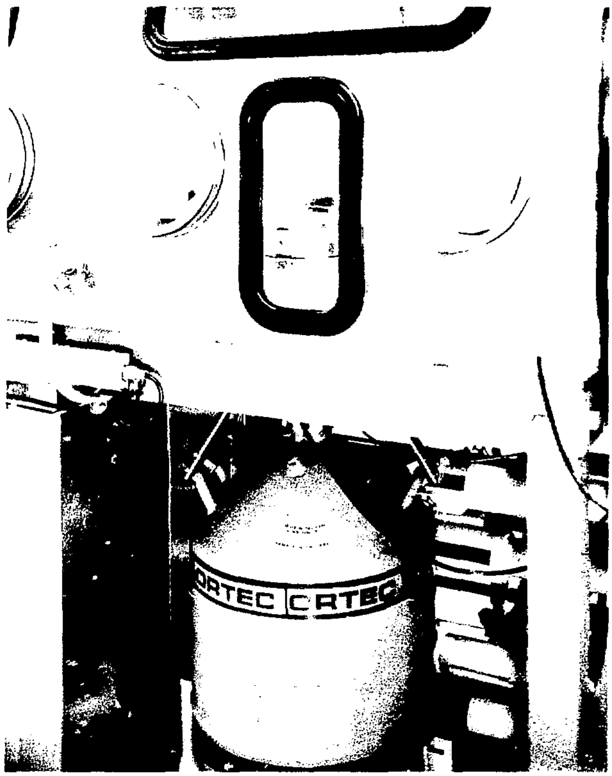

Fig. 53.
The SAI measures samples of plutonium-bearing solutions in the process lines where they are generated.

PRINCIPLES OF OPERATION

To measure the concentration of a solution, an operator places the solution in a holding tank and initiates the measurement sequence by pressing the appropriate key on the operator console. The SAI then leads the operator through the assay steps by a series of prompts that appear on the console: (a) draw a 25-mℓ aliquot of the solution, (b) assay it in the SAI sample chamber to determine the amount of ^{239}Pu, (c) weigh it on the affiliated electronic balance, and (d) weigh the contents of the holding tank. Eventually, a pressure-transducer system (Chap. 16) will be used to weigh the tank automatically; however, the system is not yet operational. When the assay is complete, the results are printed on the console, expressed as grams of ^{239}Pu per gram of sample or grams of $^{239}Pu/\ell$, depending on whether the operator requested a mass or a volume assay. The operator can then determine the plutonium content of the tank by multiplying the plutonium assay value for the aliquot by the ratio of the two masses or volumes.

Determination of the ^{239}Pu concentration in the aliquot is quite straightforward. Measurements are required of (a) the transmission source,

(b) the background, (c) the sample, and (d) the transmission source and sample together. The operator performs the first two measurements once or twice a day depending on glovebox conditions. The SAI performs the last two measurements for each sample without operator intervention.

Because the SAI depends on the bulk measurement of solutions, assay results can be expressed either volumetrically (as grams of plutonium per liter) or by mass (as grams of plutonium per gram of sample). In the first case, the volume of the solution must be well known; in the second case, an accurate mass determination of the solution must be made.

FUNCTIONAL DESCRIPTION

The solution assay system consists of seven components (Fig. 54): germanium detector and sample chamber, digital electronic balance, operator console, minicomputer, electronics, pressure-transducer weighing system, and mobile graphics cart.

The germanium detector and sample chamber are mechanically aligned during installation. The sample chamber (Fig. 55), located inside the glovebox, positions the 25-mℓ sample vial directly over the detector, which is located underneath the glovebox. When the sample chamber is closed, the vial is surrounded by 5 cm of lead shielding. The transmission source, a plutonium metal disk, is fixed onto a rotating tungsten shutter in the sample chamber lid, which is positioned immediately above the sample vial. The shutter operates pneumatically under computer control. The detector views gamma rays from the transmission source and from the sample vial through a 0.75-cm tungsten filter and through the glovebox floor.

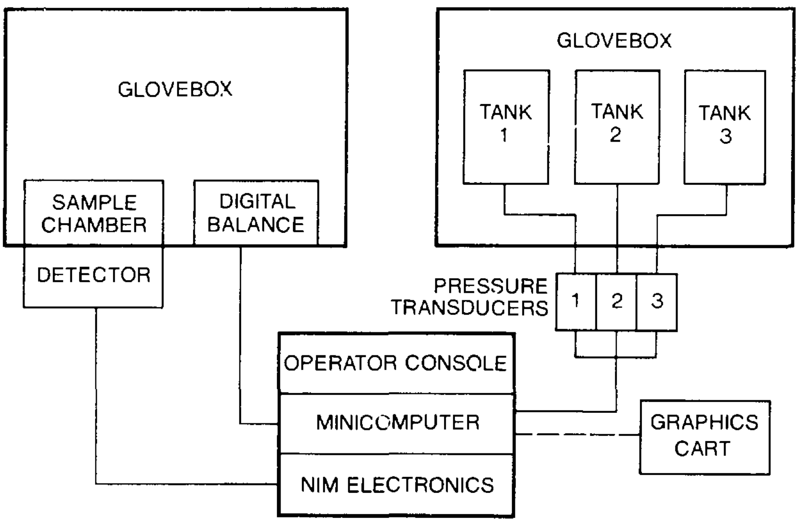

Fig. 54.
The entire solution assay system involves other components in addition to the sample chamber and detector.

Fig. 55.
An operator places an aliquot of solution into an open SAI sample chamber.

Pulses from the detector are processed by standard, high-resolution, gamma-ray spectroscopy nuclear instrument module (NIM) electronics. The electronics package includes an amplifier with an internal pulse-pileup rejector and a dual-point, energy-stabilized, analog-to-digital converter.

A Data General-compatible 16-bit minicomputer is the computational control tool for the SAI. The computer chassis contains the central processing unit, 32k words of core memory, and the serial communications board. Control functions and measurements carried out by the computer are initiated from the operator console. The operator uses a 16-key pushpad to direct the SAI and its peripheral devices during an assay.

The mobile cart serves two functions: maintenance and graphics. The cart has a paper-tape reader to load the instrument code or diagnostic programs. The graphics display, similar to a standard multichannel-analyzer display, allows the user to view the pulse-height distribution and to enter specified regions of interest around the gamma peaks required by the analysis software. The cart is attached to the SAI only during the set-up and maintenance periods.

To give the SAI the capability of reporting assay results in terms of mass, the load-sensing head of a dedicated electronic balance is located inside the glovebox. The sample mass is automatically transmitted to the SAI minicomputer when the operator presses a key on the operator console.

INSTALLATION

Two SAI components are installed inside the glovebox: the sample chamber/shutter assembly and the balance load-sensing head. The sample chamber is secured to the glovebox floor with a Silastic™ rubber compound; no welding or mechanical alteration to the glovebox is necessary. Alignment of the detector underneath the glovebox with the sample chamber is accomplished using a well-collimated 3-mm-diameter gamma-ray beam from a ^{57}Co source. The detector is aligned so that its axis is coincident with the axis of the sample chamber. After a full year of operation, two of the SAIs needed realignment. In one case, the detector had been inadvertently moved; in the other case, the sample chamber had been moved from its previous location.

Three glovebox penetrations are necessary to install an SAI: two accommodate the air lines that operate the pneumatic shutter and the third accommodates cables that connect the balance load-sensing head to the readout unit. These penetrations are hermetically sealed.

CHAPTER 16

SOLUTION MASS MEASUREMENTS

Determining the mass of moderate volumes of solution by automatic means is not easy. As part of their efforts to automate the operation of the SAI (Chap. 15), DYMAC personnel needed to determine the mass of plutonium-bearing solutions that range in volume from 10 to 50 ℓ. The solutions to be measured are kept in tanks and are maintained in homogeneous form by a stirrer. There is no known method for accurately assaying the plutonium content of the entire tank. Instead, a small sample is drawn for assay in the SAI. Then, an accurate mass or volume determination is necessary to calculate the amount of plutonium in the tank from the sample's concentration.

During DYMAC implementation, two approaches were attempted for determining the mass of solutions in tanks: a load cell method and a bubbler method. The first method used a load cell to measure the force produced by the mass of the tank and its contents. A double suspension system using a single load cell was fabricated so that tanks could be weighed without interfering with the stirring mechanism (Ref. 44, pp. 31-34; Ref. 45, pp. 68-69). The stir motor created side forces on the load cell, however, that caused inaccuracies in the weighings when test weights were used. Unfortunately, we found no simple design to decouple the stirrer shaft from the tank. The load cell approach was abandoned.

The second method couples differential pressure transducers (Fig. 56) to a bubbler system. The bubbler approach promises to be reliable and accurate. However, it requires selecting the correct pressure transducer for the application.

PRINCIPLES OF OPERATION

Plutonium-bearing solutions that must be measured for their nuclear content are processed or stored in cylindrical tanks that are interconnected by plumbing. The solutions vary widely in characteristics. They are almost always nitric acid solutions, ranging from weak to strong concentrations, whose color varies from clear to opaque dark brown.

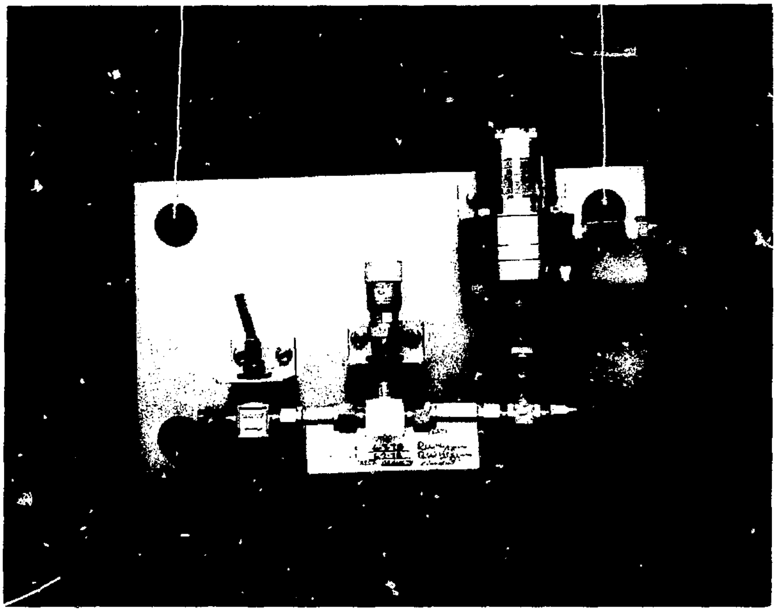

Fig. 56.
Differential pressure transducer.

The storage tanks are much greater in length than in diameter. Generally the tanks outside the gloveboxes are stainless steel, mounted either horizontally or vertically. The tanks inside the gloveboxes are Pyrex glass and are mounted vertically.

Solution mass measurements are made only in the glass tanks, which are approximately 15-cm in diameter by 83-cm high and hold 30 ℓ. Each tank contains a stirring mechanism for maintaining homogeneous solutions. The drive motor is mounted outside the glovebox and is coupled to the stirrer by a shaft that penetrates the glovebox and the tank. The shaft penetrations are hermetically sealed.

At present, the mass measurement method uses a technique based on the hydrostatic pressure in a tank (Fig. 57). One end of a tube is inserted into the tank until it is within a few millimeters of the tank bottom. Air is forced down the tube and a measurement is made of the pressure required to create a bubble stream. This pressure is equal to the hydrostatic pressure at the end of the tube. The hydrostatic pressure is, in turn, determined by the depth of the fluid and the mass density of that fluid. Hence, the pressure times the cross-sectional area of the tank (assumed to be uniform) equals the mass of the fluid in the tank. A differential strain gage is used to measure the air pressure. The reference port of the transducer is vented into the glovebox, which is maintained at a slight negative pressure with respect to the air in the room.

To determine the plutonium content in a tank of solution, a sample is drawn, weighed on an electronic balance, and analyzed in an SAI. The SAI yields the plutonium concentration in grams per gram of solution. If the mass of the tank contents is known, the total plutonium content of the tank can be determined by multiplying the mass times the concentration. The bubbler system is used to determine the mass of the solution in the tank.

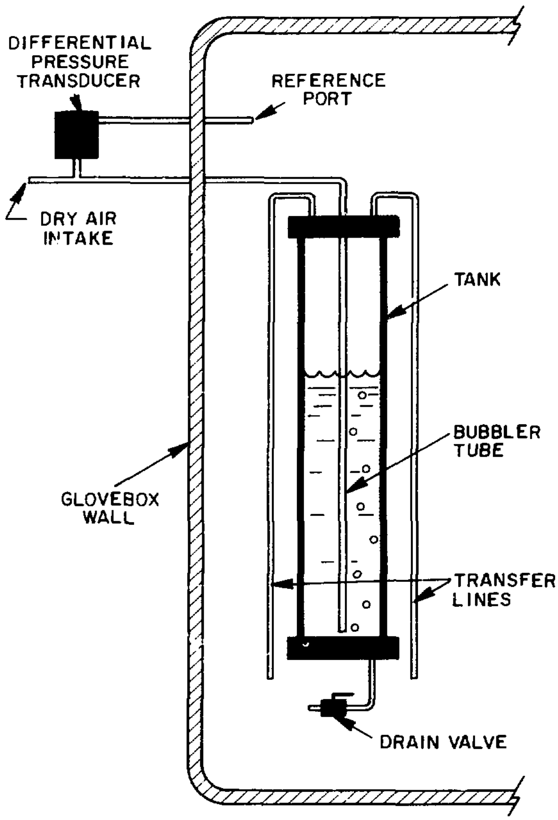

Fig. 57.
A pressure transducer measures the hydrostatic pressure in a tank of solution.

To transfer solution from a tank, an operator can apply air pressure at the top of the tank. However, this procedure can result in back pressure on the transducer, causing solution to back up the bubbler tube into the transducer. To overcome this problem, several approaches have been tested. The most promising approach is to replace the present type of transducers with a sturdier unit. Laboratory tests using the replacement unit produced good results. Changes of 30 mℓ (0.1% of the 30-ℓ full-scale volume of the tank) can be detected easily. Resolution of the readout (which is calibrated in kilograms) is 10 g.

Los Alamos personnel also designed an electronics package that reads the transducer and produces an output signal. The output is the mass of the solution in kilograms, which is displayed on a continuous readout and sent to the SAI minicomputer upon request. Each electronics package has a unique ID number. This identifier is sent as part of the data message to the SAI minicomputer so that it can differentiate among the pressure transducers connected to it.

CHAPTER 17

OTHER NDA INSTRUMENTS

The NDA instruments discussed in this chapter play a secondary and supportive role to DYMAC accountability. A brief description of each instrument gives its purpose, measurement technique, system components, performance capability, sensitivity, and application. The references provide more complete information.

FAST-NEUTRON COINCIDENCE COUNTER FOR PLUTONIUM

Certain types of plutonium samples with very high (α,n) neutron backgrounds (such as PuO_2, PuF_3, PuF_4) and kilogram quantities of plutonium metal cannot be measured accurately by thermal-neutron coincidence counting.[1] The FNC (Fig. 58), also known as the random driver, utilizes an active/passive fast-neutron coincidence counting technique that may provide a more suitable assay for these types of plutonium (see Ref. 45, pp. 23-27).

The three principal features of the FNC are its count rate (one million counts per second), which is 20 times faster than the TNC; its ability to function in both passive and active modes; and its capacity for multiplication correction.

The FNC is an active neutron interrogation system that uses an ^{241}AmLi neutron interrogation source. With the source absent in the passive mode, the measured response is proportional to the spontaneous fission caused by ^{240}Pu and other less-abundant, even-mass isotopes. With the source present in the active mode, the reponse is proportional to the ever-present ^{240}Pu response and the stimulated response caused by ^{239}Pu. The difference between the active and passive measurements is then proportional to ^{239}Pu.

One FNC was installed in the new plutonium facility for evaluation as a DYMAC verification instrument. Positioned below a glovebox, the device surrounds a long cylindrical well into which samples are lowered (Fig. 59). The interrogation source is movable under computer control (a Digital Equipment Corp. PDP-11/05). The detector, a U-shaped assembly consisting of three plastic scintillators, enables measurements of double and triple coincidences that are used to correct for multiplication.

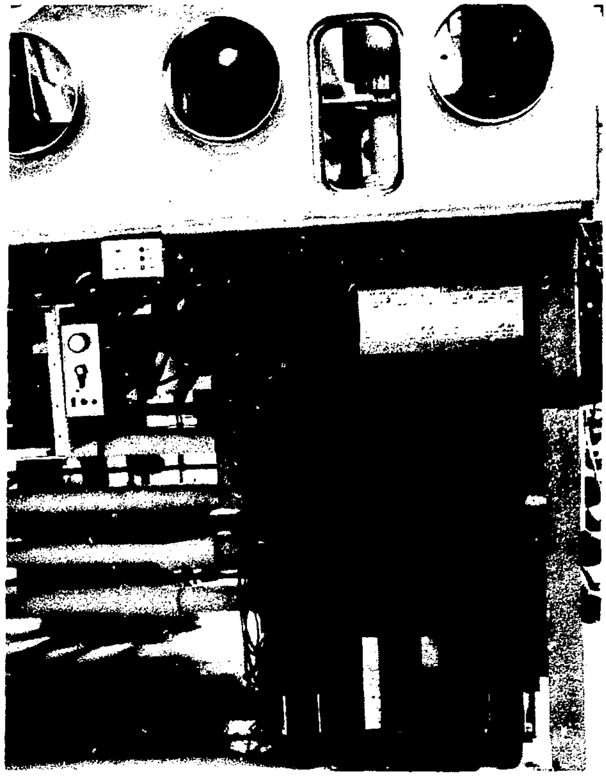

Fig. 58.
FNC installed beneath a glovebox.

The FNC is potentially a useful instrument for materials that cannot be measured by other NDA techniques. Tests have been performed on plutonium metal, both with and without impurities; 1 to 3% precision and 5 to 10% accuracy can be achieved. The FNC has also been used to assay electrorefining salts and residues.

GAMMA ASSAY SYSTEM FOR LOW-LEVEL SOLID WASTE

A box counter, MEGAS, was designed and fabricated at Los Alamos in 1975 and has been in use ever since.[46,47] It assays low-density, solid alpha waste (such as paper, rags, rubber, and plastic) in bulk packages at and below the 10-nCi/g level (the currently recommended[48] maximum activity level for alpha waste that is to be disposed of in nonretrievable storage or buried). MEGAS can measure boxes up to 0.06 m^3 that contain approximately 4 kg of low-density waste.

MEGAS detects x rays for samples below the 10-nCi/g level and automatically shifts to detection of gamma rays as the activity level increases. The detector is a 127-mm-diameter by 50-mm-thick NaI(Tℓ) crystal with a 0.25-mm-thick beryllium window.

The MEGAS shown in Fig. 60 is located in the basement of the plutonium facility, an area reasonably free from background radiation. The NaI detector is housed in a cylindrical iron shield. The system also includes a computerized multichannel analyzer for data handling and a box-handling mechanism equipped with an automatic weighing transducer.

The system provides detectability at the 0.1-nCi/g level (equivalent to 6.6 μg of plutonium) for a 100-second count time. Assay accuracy is ±50% at 10 nCi/g. Above 70 nCi/g (4 mg of plutonium/4 kg of waste), accuracy is ±30%.

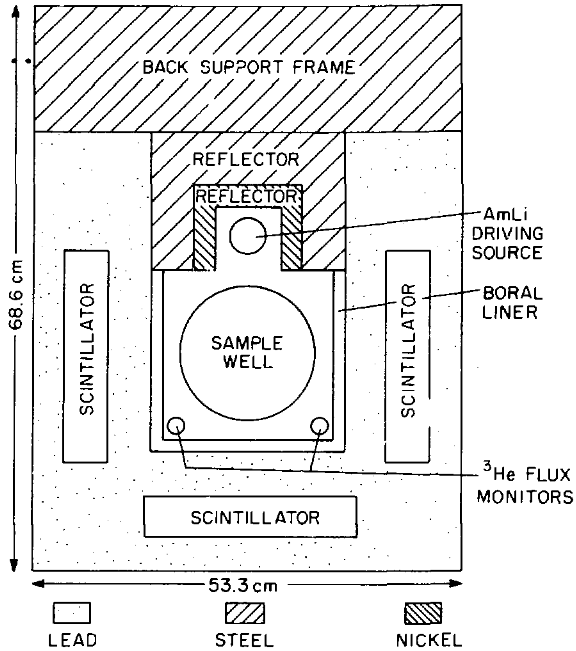

Fig. 59.
Simplified top view of FNC for plutonium (drawn roughly to scale).

MEGAS is used routinely to assay all of the low-density, room-generated wastes that are produced at the plutonium facility. The monthly throughput for MEGAS is 350 boxes (0.06 m^3 each) that contain a total of 1400 kg of waste material. The count time for a routine assay is only 200 seconds. MEGAS not only provides a timely, reliable assay for waste material but aids immensely in sorting the material for effective waste management control.

CALORIMETER FOR PLUTONIUM

Plutonium calorimetry[49,24] allows materials in sealed containers (such as oxide powder or fuel pellets that have high plutonium concentration) to be assayed without subsampling or aliquoting. Calorimetry is relatively insensitive to the geometry and matrix effects that are a major concern in many other NDA methods. Calorimeters, such as the one in Fig. 61, are useful for measuring the PuO_2 products in the plutonium facility and also for characterizing the calibration standards used in other NDA methods.[24,50] Portable[51] and transportable[52] calorimeters have been described in the literature and are commercially available.

Plutonium calorimetry measures the heat generated by radioactive decay of plutonium and americium. All the decay energy is transferred into heat when the decay particles are absorbed by the sample and the calorimeter walls. The energy from ^{238}Pu, which has the highest specific heat, is dominant. Calorimetry yields precise and accurate determinations of plutonium content if the plutonium isotopic composition and ^{241}Am content

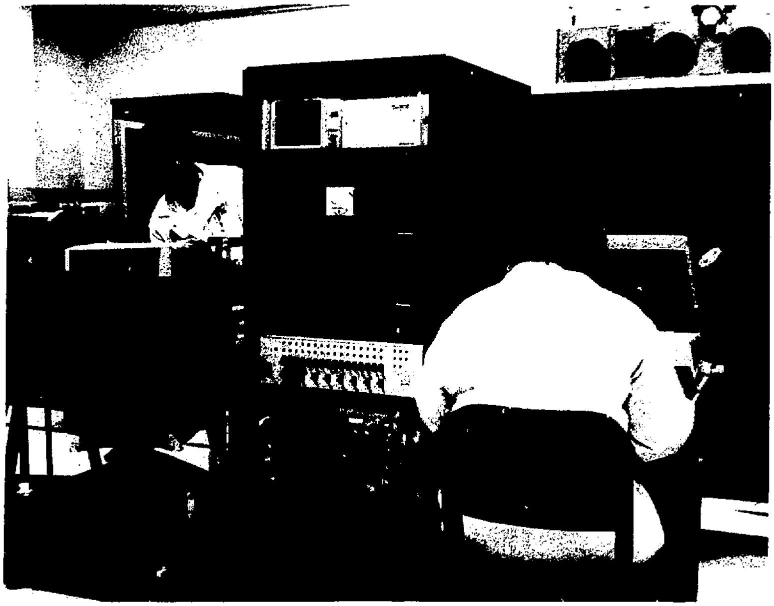

Fig. 60.
The MEGAS box counter assays low-density, solid alpha waste.

are known. Errors in the isotope determination are usually the largest uncertainties in the plutonium measurement. Because the sample and the calorimeter must come to thermal equilibrium before heat determination can be made, an assay may take as long as 10 hours. The typical accuracy of a plutonium assay by calorimetry is 0.5% with a precision of better than 0.2%.

The two calorimeters installed at the plutonium facility are used extensively as off-line DYMAC verification instruments. The calorimeter located in the count room is used routinely to verify the shipper/receiver values of PuO_2 samples and periodically to monitor the accuracy of other NDA measurement techniques. The other calorimeter is located in the 200 Wing to assay ^{238}Pu inventory items.

FILTER HOLDUP MONITOR

During processing, plutonium deposits occur on glovebox walls and equipment. These deposits constitute a major source of holdup. The capability to measure holdup in the gloveboxes or other main process streams in a plutonium facility is essential for obtaining timely and accurate material balances.

An in-line filter holdup monitoring system[53] (Fig. 62), designed by project personnel, was installed in the plutonium facility to determine the rate of plutonium buildup on filters as a function of the amount of plutonium processed. An exhaust filter was placed on top of a glovebox in which PuO_2, UO_2, and carbon are blended, milled, and prepared for making carbide fuel

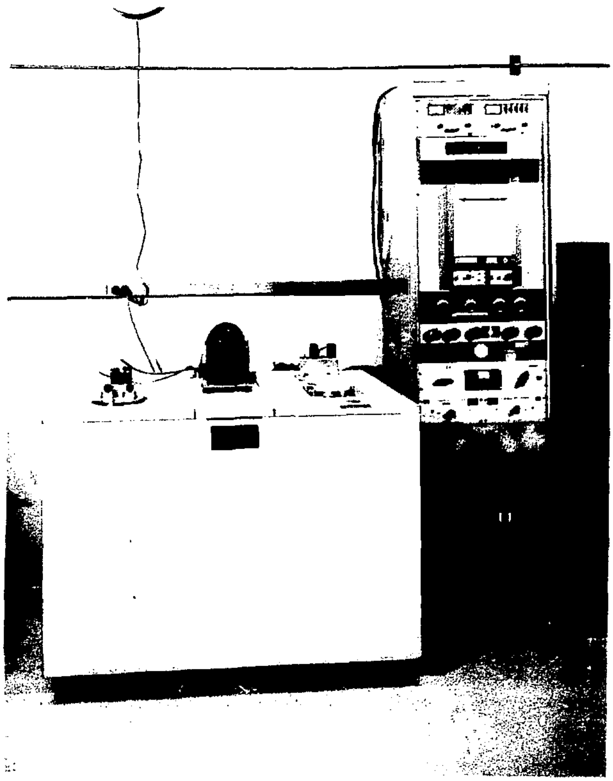

Fig. 61.
The calorimeter assays plutonium in sealed containers.

pellets. The monitoring system automatically and continuously collects data on plutonium buildup in the filter and prints it out on paper tape.

The monitoring system uses a NaI detector to measure gamma rays from ^{239}Pu. The detector (Fig. 63) is installed 18 cm from the active filter. Lead shields the detector and filter areas to eliminate gamma rays from the glovebox and conveyor system. The electronics system consists of three single-channel analyzers, an automatic gain-control amplifier, and a printer unit with an automatic paper-tape advance.

The system was calibrated with three plutonium filter standards. The standards were prepared by sprinkling known quantities of PuO_2 powder evenly over the surface of the filters while drawing air through them. The system was used to measure the plutonium buildup during the processing of 16 batches of advanced carbide fuel. The results, plotted as a function of the number of batches in Fig. 64, indicate a sensitivity to plutonium buildup of less than 0.1 g.

The automated filter holdup monitoring system is inexpensive and easy to operate. It can be moved to different locations to establish the plutonium buildup rate in filters throughout the facility. Deployment of the filter

Fig. 62.
Filter holdup monitor being installed on top of a glovebox.

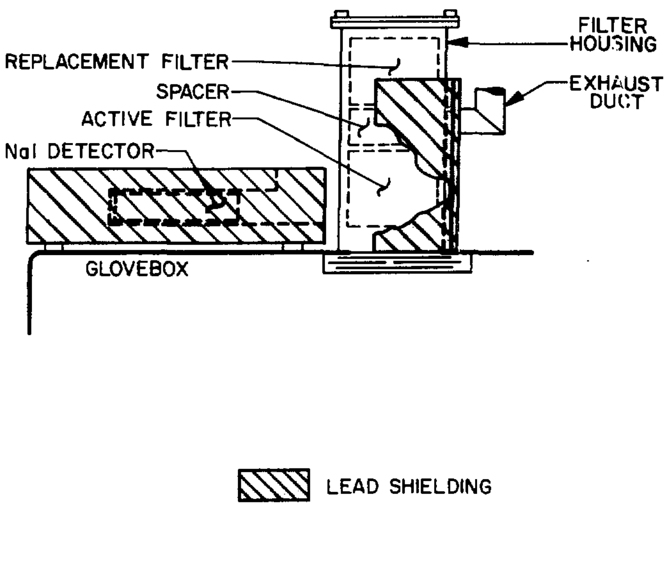

Fig. 63.
Arrangement of the glovebox, filters, and detector, including shielding and collimation.

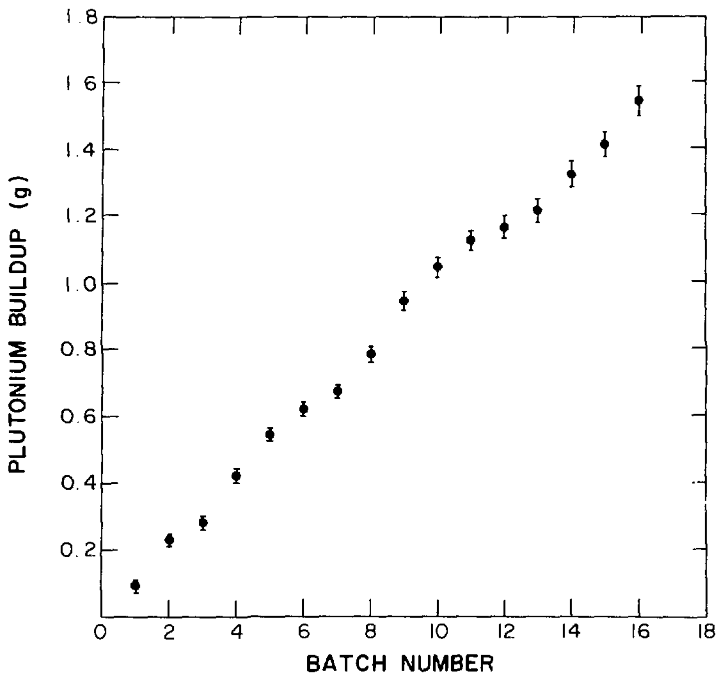

Fig. 64.
Plutonium buildup in the glovebox exhaust filter as a function of the batch.

holdup monitor can improve the measurement of nuclear material holdup in process gloveboxes.

HAND-CARRIED SODIUM IODIDE DETECTOR FOR PLUTONIUM HOLDUP

Another type of holdup measurement system, mounted on a mobile cart (Fig. 65), was designed and built at Los Alamos to measure plutonium holdup in gloveboxes. The system measures passive gamma rays with a 5-cm-diameter by 5-cm-thick NaI(Tℓ) detector collimated with a lead shield. Stabilized electronics, coupled to a small multichannel analyzer, are mounted on a mobile cart.

To measure plutonium holdup in a glovebox, the detector's counting windows are set to the ^{239}Pu 400-keV peak, which essentially excludes contributions from other isotopes. The attenuation correction is measured using a ^{137}Cs source, which has a 662-keV peak. Calibration is based on well-characterized PuO_2 as a point source and appropriate geometric efficiency functions.[25] For cylinders such as ion-exchange columns and for line sources such as small-diameter pipes, more extensive calculations and calibration are required. The system is sensitive to about 1 g of plutonium.

A number of holdup measurements were performed at the new plutonium facility after it began operation. In many cases the measurements included

Fig. 65.
Mobile system for measuring plutonium holdup in a glovebox.

floors and walls, furnace walls, and equipment in gloveboxes. Twenty-six contaminated gloveboxes from the former Los Alamos plutonium facility were cleaned and measured at the new facility. The plutonium holdup from each of these gloveboxes was found to be 45 ± 20 g of plutonium at one standard deviation. After the new facility began processing, the glovebox holdup for a 6-month period varied between 10 and 130 g of plutonium, depending on the types of processing in the glovebox.

Typical holdup in calciners ranged from 13 to 230 g of plutonium for a 6-month period, depending on calciner throughput. The uncertainty of holdup measurements is between 30 to 50% but may be much higher in cases where the geometry is unfavorable. The holdup detector has proven useful and reliable and provides an important tool for process holdup measurements.

OTHER BALANCES

In addition to the DYMAC electronic digital balances, other types of balances are used for accountability measurements. Table X lists these balances and shows their capacities, standard deviations, and primary uses.

For well-characterized materials, the balances are used to verify shippers' values and to assay PuO_2 end products. For plutonium metal, they can also provide a direct analysis. These commercially available balances are usually simple to use and, if properly cared for, are relatively dependable.

TABLE X
OTHER BALANCES USED FOR ACCOUNTABILITY

Commercial Balance	Capacity (g)	Standard Deviation (g)	Primary Use
Mettler H80	160	0.0001	To weigh small samples for chemical analysis in FFTF program
Analytical	300-500	0.0001	To weigh small samples such as PuO_2 in ^{238}Pu production and AmO_2 in americium research
Sartorius	7000	0.1	To weigh metal buttons, PuO_2 end products, and scrap materials in FFTF program
Ohaus triple beam	2610	0.4	To weigh PuO_2 feeds and end-products, metals, residues, scraps, and chemicals in the special recovery process
Arbor digital electronic[a]	5500	0.01	(Same function as other Arbor balances adapted for the DYMAC System)

[a] This instrument is in one unit and has no interface to the DYMAC computer.

CHAPTER 18

MEASUREMENT CONTROL PLAN

The DYMAC measurement control plan has a threefold purpose. It ensures the accuracy and precision of NDA instruments used in measuring nuclear materials for accountability purposes. It maintains the database of instrument performance needed to estimate the systematic and random errors associated with measurements used in error-propagation calculations. It complies with the DOE regulations[54] governing the processing facilities under DOE control.

The DYMAC measurement control plan consists of an integrated program of certified standards, established practices, and administrative procedures designed to ensure the adequacy of the near-real-time NDA measurements.[55] The specific standards, practices, and procedures vary, depending upon the type of NDA instrument used.

Much work remains in implementing the DYMAC measurement control plan at the plutonium facility. Full implementation would involve placing all the NDA instruments on-line. At present, of the 77 instruments in the measurement control plan, only 18 (all digital electronic balances) are on-line. However, the measurement control plan does monitor the performance of all instruments that are used to make accountability measurements.

REGULATIONS

Compliance with DOE regulations requires that each facility establish and maintain a measurement control plan for all measurements of nuclear material. Such a plan includes periodic calibration with standards that are traceable to a national measurements and standards program for all scales and balances, volume measurements, and NDA instruments. The uncertainty associated with each sampling method must be determined, minimized, and maintained on a current basis. The DOE order requires precision and accuracy determinations of volume measurements and the establishment and monitoring of control limits for NDA instruments.

The NRC has similar requirements, which are of concern if the DYMAC concept is to be transferable to an NRC-licensed facility. The applicable

NRC regulation[56] specifies the frequency of calibrations, traceability, representativeness of and recertification of standards, propagation of errors, qualification and requalification of the operators who make accountability measurements, bias corrections, verification and monitoring of sampling accuracy, assurance of the integrity of samples during transport and storage, as well as routine measurement of sampling precision. The regulation also requires statistical control limits on all measurements of standards as well as control charts with specific action procedures and responses when control limits are exceeded. Other requirements include the calculation of biases and systematic and random error components.

The DYMAC concept is not incompatible with NRC regulations and could facilitate compliance with many of the above requirements. In particular, a computer-based measurement control plan could call to the attention of the system manager the standards and operators that are due for recertification or requalification. Such a computer program could expeditiously propagate uncertainties and do limit-of-error calculations, incorporate bias corrections, and calculate sampling precision. A DYMAC system with a plotting capability could keep current control charts for all instruments and promptly flag any out-of-control conditions.

BALANCES

All of the balances used for accountability purposes at the plutonium facility are check-weighed daily with standard weights certified and traceable to the National Bureau of Standards. These weights must be recertified every 2 years. The measurement control plan employs standard weights that cover the normal range of operations. At the plutonium facility, the measurement control plan has 1-, 2-, and 4-kg standard checkweights available for use with the 5.5-kg balances.

The daily accuracy check of the balances consists of a single weighing of the 1- and 4-kg standard weights. The observed result is compared with the known <u>true value</u>, or certified value, of the standard and a modified t-parameter is computed.

$$t = \frac{\bar{M} - M_0}{S_A} , \qquad (1)$$

where $\bar{M}$ = average mass measurement from five precision weighings or the single observation of a daily accuracy check,

M_0 = certified mass of the standard, and

S_A = estimated population standard deviation based upon testing and including both random and systematic uncertainty.

Control limits, corresponding to 95% and 99% confidence levels, are imposed upon the t-parameter.

A precision test, consisting of five successive weighings with the 1- and 4-kg standards, is performed at least once a week on each balance. An

F-parameter is computed based upon the result of these precision test weighings.

$$F = \frac{S^2}{S_p^2} , \qquad (2)$$

where S = standard deviation of the five precision weighings and

S_p^2 = estimated population variance based upon testing and including a random error component only.

$$S = \left[\sum_{i=1}^{n} \frac{(\bar{X} - X_i)^2}{n - 1} \right]^{1/2} = \left[\frac{\sum_{i=1}^{n} X_i^2 - \frac{1}{n} \left(\sum_{i=1}^{n} X_i \right)^2}{n - 1} \right]^{1/2} , \qquad (3)$$

where $\bar{X}$ = average observed result of the weighings,

X_i = a single weighing result, and

n = number of weighings (5).

Control limits corresponding to 95% and 99% confidence levels are also imposed upon the F-parameter. The control limits for the t and F statistics are presented in the following table.

Parameter	Warning Limit	Action Limit
t	$1.97 < \lvert t \rvert \leq 2.58$	$2.58 < \lvert t \rvert$
F	$2.37 < F \leq 3.32$	$3.32 < F$

The DYMAC measurement control plan calls for a second checkweighing of the standard if the warning limit is exceeded. If two successive checkweighings exceed the warning limit, or if a single weighing exceeds the action limit, the balance must be recalibrated. The program provides for routine recalibrations of all balances at least every 6 months.

The DYMAC System will not accept data from a balance (on-line or off-line) that exceeded a warning limit, unless a recheckweighing has been performed and the result was within limits. An accuracy check must be performed by noon on each working day before the system will accept accountability data; an acceptable precision test within the previous 7 calendar days is required before the system will accept the accuracy test.

An NDA instrument, such as a balance, may perform within the 95% confidence level control limits and still be out of control. Consider, for example, an early accuracy plot of one of the balances, presented in Fig. 66. From the first week through the nineteenth week, this balance exhibited a negative bias relative to the lower (1 kg) standard, although at no time did it exceed the warning limit. A plot of accuracy data can be helpful in identifying such biases. However, an effective measurement control plan

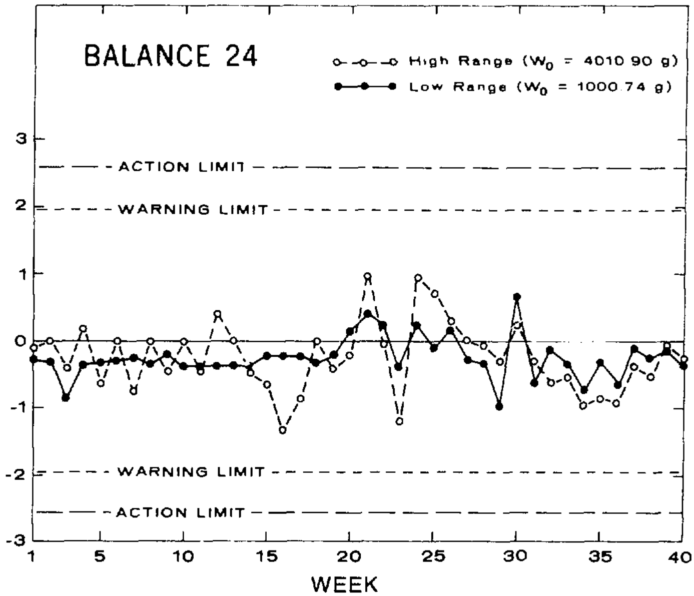

Fig. 66.
Accuracy plot for Balance 24.

requires procedures that can quantify, limit, and control relatively subtle and long-term biases.

To detect persistent and subtle biases, the DYMAC measurement control plan includes the computation of 5-day and 15-week moving averages and moving variances for each balance. Specific administrative procedures have not yet evolved for the timely identification, evaluation, and resolution of such biases and trends. Instrument histories are now being generated and will be helpful when these procedures are evolved. Data generated by instrument histories will be invaluable in the calculation of random and systematic error components and in the selection of methods and procedures to follow in performing these calculations. Accurate, representative, and realistic estimates of error components are essential for any effective improvement of diversion detection and for sensitivity and inventory difference analysis and evaluation.

GAMMA-RAY AND NEUTRON COUNTERS

Other NDA instruments covered by the DYMAC measurement control plan are the devices that count gamma-ray or neutron emissions: the TNCs, SGSs, and SAIs. Tests applied to these instruments include the modified t-test, reduced chi-square test (χ^2/n), and eta test (η).

The modified t-test is used to control the accuracy of the instrument and is based upon a single measurement.

$$t = \frac{M_i - M_0}{\sigma_M} \quad , \tag{4}$$

where M_0 = actual value of the standard,
M_i = observed measured value of the standard, and
σ_M = the square root of the Poisson variance based upon the counting statistics of the single observation.

The reduced chi-square precision test is used to detect deviation of counter performance from the expected statistical distribution. A reduced chi-square statistic is calculated because it simplifies computer monitoring of the parameter by eliminating variation with degrees of freedom. The reduced chi-square statistic for a series of n measurements is

$$\chi^2/n = S_n^2/\sigma_n^2 \quad , \tag{5}$$

where S_n^2 = is the observed variance and
σ_n^2 = is the Poisson variance based upon counting statistics.

$$S_n^2 = \sum_{i=1}^{n} \frac{(\bar{X} - X_i)^2}{n - 1} = \frac{\sum_{i=1}^{n} X_i^2 - \frac{1}{n}\left(\sum_{i=1}^{n} X_i\right)^2}{n - 1} \quad , \tag{6}$$

where $\bar{X}$ = is the average of the n measurements,
X_i = is the i^{th} result, and
n = is the number of measurements (15).

Both the chi-square and the eta test are based upon the same set of 15 replicated measurements. The eta test is used to detect nonrandom fluctuations in a counting instrument.

$$\eta = \delta_n^2 / S_n^2 \quad , \tag{7}$$

where δ_n^2 = is the mean square of successive differences and
S_n^2 = is the observed variance as defined in Eq. (6).

$$\delta_n^2 = \sum_{i=1}^{n-1} \frac{(X_{i+1} - X_i)^2}{n - 1} \quad ,$$

where X_i and n are as defined in Eq. (6) above. Upper and lower control limits for the reduced chi-scuare (χ^2/n) parameter and the eta statistic (η) for n = 15 appear in the following table.

Parameter	Warning Limit		Action Limit	
	Lower	Upper	Lower	Upper
χ^2/n	0.40	1.87	0.29	2.24
η	1.21	2.79	0.92	3.08

SAMPLING

Most NDA instruments determine the total amount of nuclear material by evaluating the contents of an entire container. Each container in the process stream passes through the counter and the nuclear material is quantified by the actual measurement of all material. At Los Alamos, the TNCs and SGSs are of this type.

Other NDA instruments depend on a representative sample, just as chemical assay systems. The composition of the sample is determined, and the total quantity of nuclear material is computed from the sample's composition and a bulk measurement of the entire item. The SAIs are of this type.

NDA determination of a container's nuclear material value by counting the entire contents has, essentially, one major source of error: the specific NDA measurement itself. Representative sampling has three major sources of error: (a) bulk determination, (b) sampling uncertainty and error, and (c) NDA measurement uncertainty.

One source of error, bulk determination, can be divided into two classes: volume determinations and mass determinations. At present, mass can be more accurately and precisely determined than volume, hence, a pressure-transducer system (Chap. 16) was selected as the bulk measurement method for the SAIs.

Sampling, another source of error, involves knowledge of the homogeneity of the material and the degree to which the sample is representative of the whole. For any measurement system, continuing assurance is needed that the samples are representative. A single demonstration can only prove that samples can be representative, not that they always are. An example of an inadequate sample would be a solution aliquot drawn from the upper strata of a process tank in which the lower strata consisted of a solid precipitate.

A quantitative knowledge of the homogeneity of the sampled material is essential to determine the number of aliquots to be drawn at random for assay or for the generation of composite samples to reduce this source of uncertainty. A quantitative knowledge of homogeneity and sampling uncertainty is also necessary in the determination of diversion detection limits and the evaluation of inventory differences.

FUTURE WORK

Considerable work remains to be done in the area of measurement control. DYMAC needs to be developed both as a concept and as a functioning system at the plutonium facility to evaluate sampling uncertainty and ensure that samples are representative.

Topics to be addressed are propagation of errors, bias corrections, control charts, calibration, and standards. Procedures need to be evolved that permit the propagation of measurement uncertainties concurrently with the dynamic determination of material balances. Specific procedures need to be evolved defining how biases in NDA systems will be identified and corrected. Up-to-date charts of instrument performance are necessary for the prompt and timely identification and resolution of small or subtle but persistent biases; this can best be done with an automatic plotting capability.

All NDA instruments are periodically recalibrated. They are recalibrated when they exceed the control limits, as evidenced by statistical tests. The time period for routine recalibration differs for each type of instrument; it can be determined by evaluating the instrument's history and performance.

Because some standards are subject to degeneration with time, they should periodically be recertified. Weight standards may wear and thus be subject to the corrosive atmosphere of a glovebox. Evaporation and precipitation may take place in process solution standards. Other standards may oxidize or pick up moisture.

The selection of standards also requires study. The two main criteria for the selection of standards--traceability to a national measurement system (as are the standard weights for balances at the plutonium facility) and representativeness (resemblance to the specific process material being measured)--often are incompatible. Representative standards, which are composed of process materials, are used with DYMAC NDA counting instruments. It may be possible to supplement process standards with synthetic standards made from traceable materials.

CHAPTER 19

TRAINING

During the 30-month installation phase of the DYMAC System at the plutonium facility, Safeguards R&D was responsible for training system users. The training took two different forms. First the trainees, both supervisors and technicians, were introduced to the concept of near-real-time accountability and how it would affect their normal processing tasks. They learned how to interact with the accountability system's central computer via video terminals.

The second type of training concerned operating the NDA instruments. Trainees learned how to use the DYMAC balances, TNCs, SAIs, and SGSs. Safeguards personnel also trained a few technicians to perform daily accuracy and weekly precision checks on all the NDA instruments. (Accuracy and precision checks must be performed before the DYMAC System will allow the instruments to be used for making transactions.) The technicians also learned to calibrate the balances by weighing checkweights and adjusting the balance to the correct calibration. When the DYMAC System entered the operational phase in March 1980, training became the responsibility of the Plutonium Processing organization that operates the facility.

INTRODUCTORY DYMAC TRAINING

Training began for DYMAC users in December 1977 before the plutonium facility went into operation. They attended a series of lectures to learn how the accountability system would function and what impact it would have on their work. The first trainees were supervisors who were already familiar with accountability as applied to a paper-transaction system. Many of the later trainees were newly hired technicians who had no experience with the former accountability system and consequently could adapt more quickly to DYMAC; however, they knew nothing about accountability and had to learn its concepts and rationale.

The need to instruct several hundred people over a period of years persuaded Safeguards personnel to videotape the introductory lectures. A set of three 45-minute tapes resulted, called "DYMAC--A Training Course." They were used to introduce over 300 technicians and supervisors to the system. Another videotape, "Introduction to DYMAC,"[57] replaced the early lectures to serve as the primary system overview.

To accompany the video training tapes, a draft of the DYMAC User's Manual, an unpublished document, was distributed. The manual covers essentially the same information as that given in the videotapes, provides additional examples, and serves as a readily available reference.

VIDEO TERMINAL

Supervisors and technicians who attended the videotaped lectures also received hands-on training at the video terminals, which are the user's access point to the DYMAC System. These training sessions, specific to each process, were held one week before each new process was due to begin.

A specially equipped training room was set up in the Cold Support Building located across the hall from the DYMAC computer room. The five video terminals installed in the room were connected to the backup DYMAC computer. Training exercises used a copy of the previous day's database to make the sessions realistic.

Small groups of no more than 10 trainees spent 3 hours in the training room learning to use the video terminals to make transactions and inquiries. The trainees learned the functions of the various keys on the terminal. Then they learned how to sign on and access the options displayed on the startup menu. They also learned to locate the transactions that pertain to their process and to select the appropriate transaction for each process step. Once the trainees realized how useful the inquiries are, they used them regularly to obtain current inventory information about a particular location or to locate a certain inventory item.

A comprehensive training exercise acquainted the users with the transactions designed for their particular processing area. A new exercise was written for each group of trainees because no two processes have the same material flow and, hence, cannot share the same set of transactions. One such training exercise appears in Fig. 67. The exercise taught the trainees to couple a processing step with a subsequent transaction to update the computer inventory. They learned to select the proper transaction forms when they divided or combined inventory items, to place items in an in-transit file and remove them, and to change an item's description or location to correspond to its new status.

Supervisors also attended special sessions to acquaint them with supervisory capabilities that only they could access. They learned to make sensitive transactions to correct mistakes and transfer inventory differences into special, nonphysical MIP accounts. They learned to use the inquiry option in an effective manner to locate misplaced items and trace mistakes. They were advised to give all their technicians instruction sheets that detailed the step-by-step operation of their process with the corresponding DYMAC transactions clearly indicated. Some of them followed the sample instruction sheets and others adapted them to their own needs.

DYMAC TRAINING EXERCISE
FOR THE ELEMENT FABRICATION PROCESS

You will work with fuel pellet batch 336905, material type 54. It is in transit to you from fuel preparation, location G134, receipt area IP, account 711.

1. Make a RECEIVE transaction to notify the DYMAC System that you have received the batch into the loading area, location G183, receipt area EL, account 711. Select option 1 on the EF menu for the 100 Wing. Tare weight of container = 54.4 g.

2. Place the fuel element container on the balance pan and tare it before loading the fuel pellets into it. Then load the fuel pellets. When the balance readout stabilizes, put the balance on HOLD, and make a LOAD ELEMENT transaction (option 2) to notify DYMAC. Name the fuel element 337405.

3. Place the archive container on the balance pan and tare it before loading. Then place the fuel pellet samples in it and weigh. As before, put balance on HOLD, and make a LOAD ARCHIVE SAMPLE transaction (option 3). Name the sample 336905R.

4. Relocate fuel element to bonding and inspection area using the CHANGE ELEMENT LOCATION transaction (option 4). It is going to location R124, receipt area EP.

5. Store the partly completed fuel element in a storage rack, again using option 4. The rack is in location S124, receipt area EP.

6. Relocate the fuel element to the packaging area (option 4), location R124, receipt area EP.

7. Make a SEND transaction to send the fuel element to the nuclear materials officer for shipping. The "to" account is 770.

8. Make a SEND transaction to send the fuel sample to the nuclear materials officer for storage. The "to" account is 750.

Fig. 67.
Short training exercise used on November 21, 1978, to teach personnel from the Element Fabrication Process how to use the transaction forms designed for their process. The instructor filled in the blanks with different numbers for each trainee. The flowchart shows the sequence of changes in location that each batch undergoes in the process.

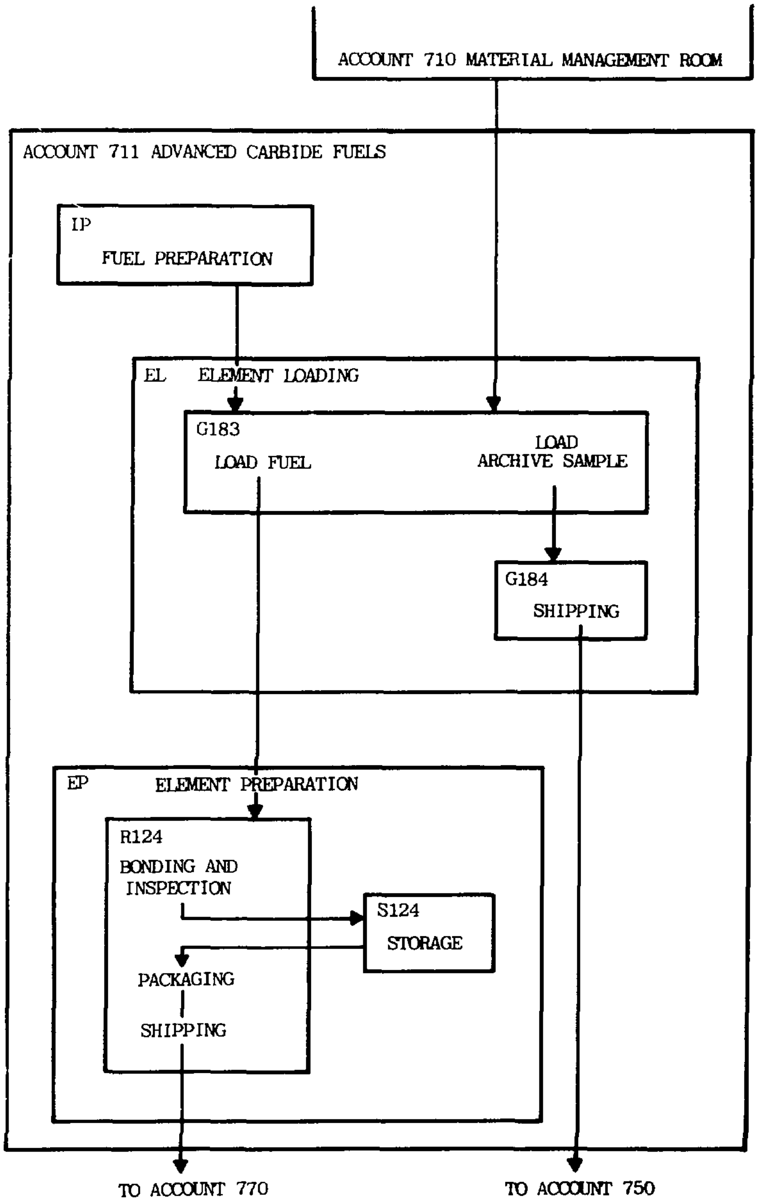

Fig. 67.
(continued)

After the training sessions, most of the technicians were able to make transactions without much difficulty during the course of processing. Those who still were uncomfortable using the terminals obtained help from their coworkers or from the Process Coordination Office (Chap. 7). A few technicians never learned to use the system properly and their supervisors removed their names from the terminal access list.

DIGITAL ELECTRONIC BALANCE

Safeguards personnel installed DYMAC balances in the facility processing areas during 1978 and 1979. When they installed a balance in a new area, they trained the technicians to use it. Training included a videotape presentation, demonstrations, hands-on usage, and discussion. Additional training was provided when some of the balances were connected on-line to the DYMAC computer.

In February 1980, Safeguards personnel gave 12 training sessions for 165 technicians to acquaint or reacquaint them with use of the balance. The course covered use of the load-sensing head, readout unit, digital display test, and checkweights. Each session required an hour of lecture and demonstration followed by further demonstrations, discussion, and actual balance usage at the operators' request. At the end of the 12 sessions, almost all the technicians in the facility had learned to use the balance.

Most of the technicians find the balances easy to use. Some technicians have trouble understanding the difference between net and gross weights. Others take a while to understand that they can tare an empty can before filling it to arrive at a net weighing. Apart from these few difficulties, technicians use the balances uneventfully as part of their work.

THERMAL-NEUTRON COINCIDENCE COUNTER

Safeguards personnel operated the TNCs until the latter half of 1979 when the THENCS units were installed. These microprocessor units replaced manual calculations of plutonium content from the raw count rate, thus greatly facilitating measurements with the TNCs. With the THENCS unit in operation, room supervisors and technicians were trained to operate the TNCs.

Training was conducted in three sessions for about 175 supervisors and technicians. It consisted of lecture sessions and in-plant exercises. The trainees attended a 3-hour lecture session on neutron counting and on operation of the TNC using the THENCS unit. Following the lecture, they had 2 hours of hands-on experience operating the TNCs.

Hands-on training included making a TNC measurement and entering the results into the DYMAC System at a terminal. Trainees learned to make accuracy and precision checks for measurement control purposes. Then they assayed a sample using the appropriate calibration for the plutonium enrichment. The THENCS unit calculates the plutonium content and uncertainty as two parameters to be entered at a terminal. Although the DYMAC computer automatically calculates the amount of plutonium in the sample from the isotopic data already in the database, the trainees learned to do it manually. They also were taught to use the low efficiency mode of operation for high counting rates.

Limited training sessions were provided for special measurements. Only supervisors were trained to calibrate the TNCs. Selected operators learned to make plutonium oxalate measurements.

The training proved effective, as confirmed by plant personnel who routinely perform assays and measurement control tasks. Moreover, their ensuing discussions of neutron measurements and applications to different material forms demonstrate that they assimilated their training.

SOLUTION ASSAY INSTRUMENT

During 1979, Safeguards personnel installed, calibrated, and operated three SAIs in the Recycle Wing. Before turning calibration and operation of the instruments over to the facility operator, they undertook several comprehensive training sessions to teach the technicians, room supervisors, and the NDA instrument supervisor how to use the SAIs properly. Training sessions for the technicians and room supervisors consisted of two parts: (a) presentation of measurement principles, techniques, and problems; and (b) demonstration of the SAI with hands-on experience for every participant.

The first part of the training concerned the physical principles underlying the SAI. The instructors discussed the types of measurements that are possible with the instrument and the accuracy and precision that can be expected. They also discussed potential measurement problems and their effect on the assay results. Then they introduced the operating procedures for the instrument.

SAI operating procedures were reviewed in detail during the hands-on training. Using two of the SAIs in the plutonium facility, the trainees made sample assay measurements. They received individual instruction about the dialogue between the instrument and the user and learned to make the appropriate response to each query. They completed a minimum of two assays of plutonium-bearing solutions and performed measurement control functions, consisting of accuracy and precision checks, for at least one solution measurement.

A follow-up training session one week later identified potential problems and resolved questions that arose concerning operation of the instrumentation. After approximately a month of operation, assay measurements with the SAI became a routine matter.

The NDA instrument supervisor received additional SAI training in the following areas: gamma interaction with NaI and Ge(Li) detectors, pulse-shaping techniques, collection and analysis of digitized data, NDA techniques for correcting gamma-ray transmissions, and measurement problems and their effect on nondestructive assay of nuclear material. This training took place away from the plutonium facility in a Safeguards NDA instrument laboratory. As a result of this specialized training, the supervisor is equipped to handle most operating problems that arise with the DYMAC instrumentation at the plutonium facility.

SEGMENTED GAMMA SCANNER

Safeguards personnel trained several technicians to operate the SGS while it was still located at the former Los Alamos plutonium facility. They were taught to set up one scan table at a time. This procedure consisted of setting the minicomputer to the correct table, identifying assay peaks, calculating the calibration constants, and then measuring the unknown sample. A switch on the minicomputer indicated which scan table (large or small) to use, corresponding to a scan of 4-in. segments for barrels or 1/2-in. segments for cans. Every time a change was made from one table to the other, a recalibration was necessary. The recalibration accounted for the change in detector and the distance of the transmission source from the detector. The technicians were also taught procedures for measurement control, including collection of accuracy data twice daily and precision data once a week. Written operating instructions described detailed daily operating procedures, special procedures, and measurement control functions.

A second minicomputer was installed 2 years after the SGS was moved to the new facility. This addition allowed the SGS to be separated into two independent instruments, greatly reducing the need for recalibration. Now each SGS unit is recalibrated when it is changed to measure a different isotope. No additional training was necessary after separation of the two units.

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APPENDIX A

DYMAC ON-LINE AND OFF-LINE REPORTS

Figures A-1 through A-20 show examples of the DYMAC reports that are available on-line (on the video terminals) and off-line (printed on the line printer). Definitions of the abbreviations used in the reports are listed below.

ACCT	account; that is, material balance area
BULK WGT	bulk weight: number of total grams or liters in inventory item
COEI	composition of ending inventory; that is, its form, such as liquid
DESC	item description (for example, pellets, powder, etc.)
DEST	destination
DYMAC NAME	MBA/material type/item ID; for example, 721/54/PROD100-1
ENR	enrichment
FM	from
ISWT, ISO WEIGHT	isotopic weight
ITEM ID, ITM ID	item identity; that is, the name of the inventory item
LOC	location, usually refers to a glovebox number
MEAS	measurement code: ID of the instrument that performed the measurement
MT, MATL, MAT ID	material type
PROJ	project
RA	receipt area; that is, unit process
SD, SP DES	special designator
SHLF	shelf
SNM VALUE, SNM VAL	amount of nuclear material contained in inventory item
TRANID	transaction ID, assigned after transaction is made
UNCERT	uncertainty of measured value

INVENTORY IN LOCATION G201 1/ 4/79, 11:49

ACCT	MT	ITEM ID	RA	SNM VALUE	BULK VALUE	SHLF	DESC	SEAL
721	54	MIPBL	BL	6. G	10.00 G		M21	
721	54	PROD100-1	BL	348. G	400.00 G		CA6	
721	54	PROD100-2	BL	348. G	400.00 G		CA6	
721	54	SAMP 100R	BL	39. G	40.00 G		CA4	

TOTAL FISSILE ISOTOPE NOT IN USE AT LOCATION G201 = 705. GRAMS

Fig. A-1.
Inventory by location (on-line report). This report displays the current inventory of items for the requested location; in this case, glovebox G201. Nonphysical items, i.e., MIP, are not included in the total of fissile isotope available for use.

INVENTORY IN ACCOUNT 721 1/ 4/79, 12: 2

LOC	MT	ITEM ID	RA	SNM VALUE	BULK VALUE	SHLF	DESC
SEAL							
G201	54	MIPBL	BL	6. G	10.00 G		M21
G201	54	PROD100-1	BL	348. G	400.00 G		CA6
G201	54	PROD100-2	BL	348. G	400.00 G		CA6
G201	54	SAMP 100R	BL	39 G	40.00 G		CA4
G202	54	SAMP100-1	BL	87. G	100.00 G		CA4
G202	54	SAMP100-2	BL	44. G	50.00 G		CA4

Fig. A-2.
Inventory by MBA (on-line report). This report displays the current inventory of items for the requested MBA; in this case, MBA 721.

```
               INTERNAL ACTIVITY OF ITEM -- 721/54/LOT    100

TRANSFER INTO ITEM
    872.  G  FROM   770/54/LOT    100    RA: SR   LOC:433N  1/ 4  074Z2

TRANSFER FROM ITEM
     87.  G    TO   721/54/SAMP100-1     RA: SA   LOC:G202  1/ 4  018A0
  REMARKS: SAMPLE FROM LOT 100
     44.  G    TO   721/54/SAMP100-2     RA: SA   LOC:G202  1/ 4  018A1
  REMARKS: SAMPLE FROM LOT 100
    348.  G    TO   721/54/PROD100-1     RA: BL   LOC:G201  1/ 4  018A2
  REMARKS: CAN 1 OF PRODUCT...LOT 100
    348.  G    TO   721/54/PROD100-2     RA: BL   LOC:G201  1/ 4  018A3
  REMARKS: CAN 2 OF PRODUCT...LOT 100
     39.  G    TO   721/54/SAMP 100R     RA: BL   LOC:G201  1/ 4  018A4
  REMARKS:  REFEREE SAMPLE
      6.  G    TO   721/54/MIPBL         RA: BL   LOC:G201  1/ 4  018A5
  REMARKS:
```

Fig. A-3.
Internal activity of item (on-line report). This report displays all transactions that have affected an inventory item (in this case, item 721/54/LOT100) during the previous 6 to 10 weeks. It only displays transactions that occurred inside the plutonium facility. This report is extremely useful for tracing mistakes.

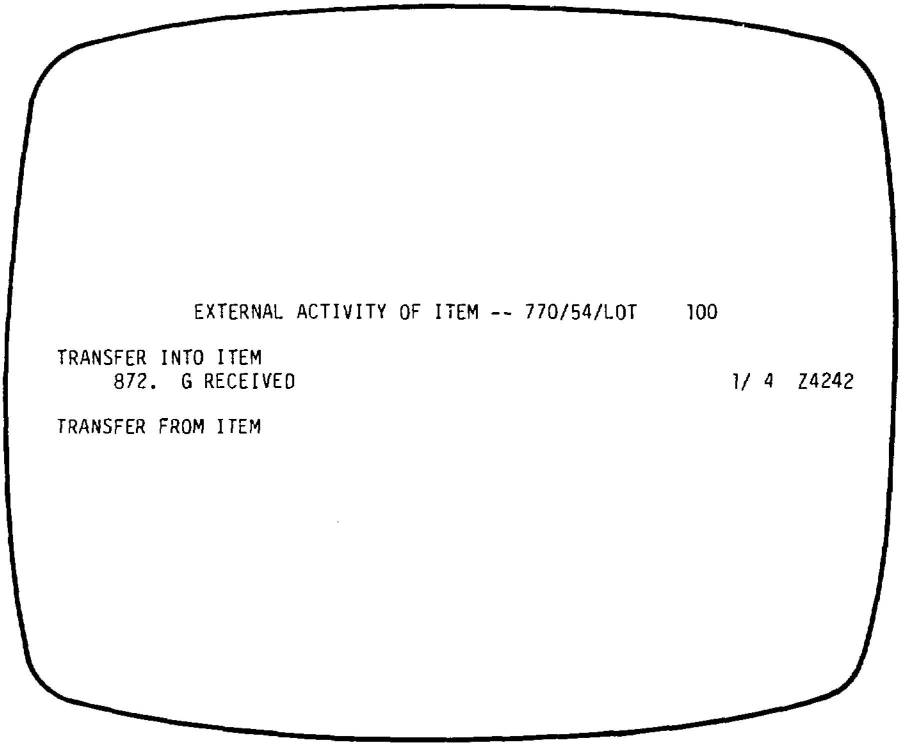


Fig. A-4.
External activity of item (on-line report). This report provides information similar to the internal activity report except that it pertains to external transactions (in this case, for item 770/54/LOT100); that is, transactions between shipping/receiving MBAs 770 or 771, or clearing MBA 777 and an account outside the facility. This report displays only transactions for items entering or leaving the facility or other special NMO transactions that also affect the station balance.

```
ACCOUNT                    721
MATERIAL TYPE               54
ITEM ID              S[illegible]100-1

CREATION DATE          1/ 4/79
LOCATION                  G202
SHELF
RECEIPT AREA                SA
PROJECT                    413
SPECIAL DESIGNATOR          S1
ITEM DESCRIPTION           CA4
SNM AMOUNT                 87.    G UNC       .80
ISOTOPIC WEIGHT            77.0
ENRICHMENT              11.50  %   UNC       .30
BULK AMOUNT            100.00  G
MEASUREMENT CODE           F15
IMPURITIES               1.00 %CA
COEI                       455
SEAL NUMBER
REMARKS: SAMPLE FROM LOT 100
```

Fig. A-5.
Item status (on-line report). This report displays detailed information about a single inventory item; in this case, item 721/54/SAMP100-1.

ITEMS IN TRANSIT

DATE	TIME	ACCT	MATL	ITEM ID	SNM VALUE	PERSON	DEST
1/ 5/79	9:53	722	54	LAO 108CS	9. G	TAYLOR	CMB1
1/ 5/79	8:54	731	52	JAM1139S1	9. G	JS	CMB1
1/ 5/79	9: 9	743	52	STD 1	5. G	RS	NO3
1/ 5/79	8: 8	743	53	STD 2	5. G	RS	N13

Fig. A-6.
Items in transit (on-line report). This report displays all items currently in transit in the facility, with the date and time sent, origin, and destination.

```
    TRANSACTION NUMBER 018A0
    TRANSACTION MADE ON    1/ 4/79  AT  11: 0
    FROM PERSON:                          TO PERSON:         JH
NUMBER ************ FIELD ************** FROM ********** TO *******************

1,2          ITEM ID                   LOT    100      SAMP100-1
3,4          ACCOUNT                        721             721
5,6          RECEIPT AREA                   BL               SA
7,8          PROJECT                        413             413
9,10         SPECIAL DESIGNATOR             S1               S1
11,12        LOCATION                       G201           G202
13,14        SHELF                            A
15,16        ITEM DESCRIPTION               CA1             CA4
17     "FROM" REMARKS: THIS LOT TO BE USED FOR SAMPLE REPORTS.
18     "TO" REMARKS: SAMPLE FROM LOT 100
19           DESTINATION:
20,21        SNM AMOUNT:     87.  G OF TYPE 54     BULK AMOUNT            100.0  G
22           ENRICHMENT:     11.50%                (ISOTOPIC WEIGHT:      77.  G)
23,24        IMPURITY:        1.00% OF CA          MEASUREMENT CODE:        F15
25,26        SEAL NUMBER:                          COEI NUMBER:             455
27           ISOTOPIC A: .0000, B: .0000, C: .0000, D: .0000, E: .0000
```

Fig. A-7.
Transaction look-up (on-line report). This report allows the requester to display any transaction made in the previous 6 to 10 weeks. Note: the requester can only view the transaction, not modify it.

INVENTORY IN ACCOUNT 721 1/ 4/79, 12: 1

MT	ITEM ID	RA	SNM AMOUNT		REMARKS
54	MIPBL	BL	6.	G	
54	PROD100-1	BL	348.	G	CAN 1 OF PRODUCT...LOT 100
54	PROD100-2	BL	348.	G	CAN 2 OF PRODUCT...LOT 100
54	SAMP 100R	BL	39.	G	REFEREE SAMPLE
54	SAMP100-1	SA	87.	G	SAMPLE FROM LOT 100
54	SAMP100-2	SA	44.	G	SAMPLE FROM LOT 100

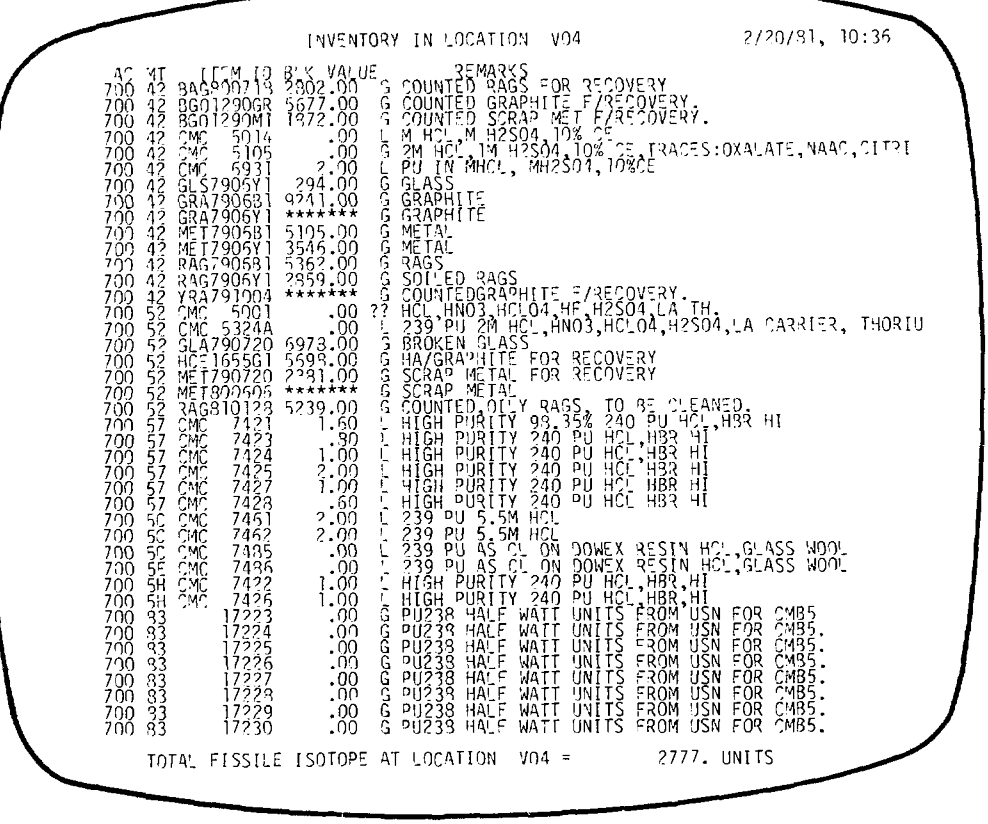
Fig. A-8.
Inventory by MBA with remarks (on-line report). This report supplements the Inventory by MBA report in that it allows the requester to see the REMARKS field, in this case, for MBA 721.

```
            INTERNAL ACTIVITY OF ITEM -- 721/54/LOT    100

TRANSFER INTO ITEM
     872.  G  FROM    770/54/LOT    100    RA: SR    LOC:433N   1/ 4   074Z2

TRANSFER FROM ITEM
      87.  G    TO    721/54/SAMP100-1    RA: SA    LOC:G202   1/ 4   018A0
      44.  G    TO    721/54/SAMP100-2    RA: SA    LOC:G202   1/ 4   018A1
     348.  G    TO    721/54/PROD100-1    RA: BL    LOC:G201   1/ 4   018A2
     348.  G    TO    721/54/PROD100-2    RA: BL    LOC:G201   1/ 4   018A3
      39.  G    TO    721/54/SAMP 100R    RA: BL    LOC:G201   1/ 4   018A4
       6.  G    TO    721/54/MIPBL        RA: BL    LOC:G201   1/ 4   018A5
```

Fig. A-9.
Internal activity of item with remarks (on-line report). This report supplements the Internal Activity of Item report in that it allows the requester to see the REMARKS field; in this case, for item 721/54/LOT100.



```
                    INVENTORY IN LOCATION  V04                 2/20/81, 10:36

 AC  MT   ITEM ID  BLK VALUE        REMARKS
700 42 BAG900713 2802.00   G COUNTED RAGS FOR RECOVERY
700 42 BG01290GR 5677.00   G COUNTED GRAPHITE F/RECOVERY.
700 42 BG01290MT 1872.00   G COUNTED SCRAP MET F/RECOVERY.
700 42 CMC  5014      .00  L M HCL,M H2SO4,10% CE
700 42 CMC  5105      .00  G 2M HCL,1M H2SO4,10% CE,TRACES:OXALATE,NAAC,CITRI
700 42 CMC  6931     2.00  L PU IN MHCL, MH2SO4,10%CE
700 42 GLS7906Y1  294.00   G GLASS
700 42 GRA7906B1 9241.00   G GRAPHITE
700 42 GRA7906Y1 *******   G GRAPHITE
700 42 MET7905B1 5105.00   G METAL
700 42 MET7906Y1 3546.00   G METAL
700 42 RAG7906B1 5362.00   G RAGS
700 42 RAG7906Y1 2859.00   G SOILED RAGS
700 42 YRA791004 *******   G COUNTEDGRAPHITE F/RECOVERY.
700 52 CMC  5001      .00 ?? HCL,HNO3,HCLO4,HF,H2SO4,LA TH.
700 52 CMC 5324A      .00  L 239 PU 2M HCL,HNO3,HCLO4,H2SO4,LA CARRIER, THORIU
700 52 GLA790720 6973.00   G BROKEN GLASS
700 52 HCE1655G1 5698.00   G HA/GRAPHITE FOR RECOVERY
700 52 MET790720 2281.00   G SCRAP METAL FOR RECOVERY
700 52 MET800606 *******   G SCRAP METAL
700 52 RAG810128 5239.00   G COUNTED,OILY RAGS, TO BE CLEANED.
700 57 CMC   7421    1.60  L HIGH PURITY 98.35% 240 PU HCL,HBR HI
700 57 CMC   7423     .80  L HIGH PURITY 240 PU HCL,HBR HI
700 57 CMC   7424    1.00  L HIGH PURITY 240 PU HCL,HBR HI
700 57 CMC   7425    2.00  L HIGH PURITY 240 PU HCL HBR HI
700 57 CMC   7427    1.00  L HIGH PURITY 240 PU HCL HBR HI
700 57 CMC   7428     .60  L HIGH PURITY 240 PU HCL HBR HI
700 5C CMC   7461    2.00  L 239 PU 5.5M HCL
700 5C CMC   7462    2.00  L 239 PU 5.5M HCL
700 5C CMC   7485     .00  L 239 PU AS CL ON DOWEX RESIN HCL,GLASS WOOL
700 5E CMC   7486     .00  L 239 PU AS CL ON DOWEX RESIN HCL,GLASS WOOL
700 5H CMC   7422    1.00  L HIGH PURITY 240 PU HCL,HBR,HI
700 5H CMC   7426    1.00  L HIGH PURITY 240 PU HCL,HBR,HI
700 83       17223    .00  G PU238 HALF WATT UNITS FROM USN FOR CMB5
700 83       17224    .00  G PU238 HALF WATT UNITS FROM USN FOR CMB5.
700 83       17225    .00  G PU238 HALF WATT UNITS FROM USN FOR CMB5.
700 83       17226    .00  G PU238 HALF WATT UNITS FROM USN FOR CMB5.
700 83       17227    .00  G PU238 HALF WATT UNITS FROM USN FOR CMB5.
700 83       17228    .00  G PU238 HALF WATT UNITS FROM USN FOR CMB5.
700 83       17229    .00  G PU238 HALF WATT UNITS FROM USN FOR CMB5.
700 83       17230    .00  G PU238 HALF WATT UNITS FROM USN FOR CMB5.

     TOTAL FISSILE ISOTOPE AT LOCATION  V04 =        2777. UNITS
```

Fig. A-10.

Inventory by location with remarks (on-line report). This report supplements the Inventory by Location report in that it allows the requester to see the REMARKS field; in this case, for location V04.

DYMAC CURRENT INVENTORY REPORT 1/ 4/79 PAGE NO. 6

DATE	ACCT	MT	ITM ID	RA	PROJ	PERSON	LOC	SHLF	SD	ITEM	SNM VAL	ENR	ISWT	IMPURITIES	COEI	SEAL	MEAS	BULK WGT
1/ 4/79	721	54	MIPBL	BL	413	JH	G201		S1	M21	6.	11.50	5.	1.00 CA	455		S00	10.0 G
1/ 4/79	721	54	PROD100-1	BL	413	JH	G201		S1	CA6	348.	11.50	308.	1.00 CA	455		F16	400.0 G
1/ 4/79	721	54	PROD100-2	BL	413	JH	G201		S1	CA6	348.	11.50	308.	1.00 CA	455		F16	400.0 G
1/ 4/79	721	54	SAMP 100R	BL	413	JH	G201		S1	CA4	39.	11.50	35.	1.00 CA	455		F15	40.0 G
1/ 4/79	721	54	SAMP100-1	SA	413	JH	G202		S1	CA4	87.	11.50	77.	1.00 CA	455		F15	100.0 G
1/ 4/79	721	54	SAMP100-2	SA	413	JH	G202		S1	CA4	44.	11.50	39.	1.00 CA	455		F15	50.0 G
TOTAL FOR	721	54	**								872.		772.					
ACCOUNTABLE TOTAL FOR	721		**								872.		772.					

Fig. A-11.

Inventory by MBA (off-line report). This is a current inventory report sorted by MBA, material type, and item ID. For each MBA it gives subtotals, by material type, of the amount of nuclear material and isotopic weight for all accountable and subaccountable items. The total for each MBA includes only accountable nuclear material and isotopic weight. A grand total of all accountable nuclear material and isotopic weight appears at the end of the report. The Inventory by MBA report is available for all MBAs or selected ones.

Fig. A-12.

Inventory by location (off-line report). This is a report of the DYMAC inventory sorted by location, shelf, and material type. It shows the total number of items within each location. For each location it gives subtotals, by material type, for accountable and subaccountable amounts of nuclear material and isotopic weights. The total for each location includes only accountable nuclear material and isotopic weight. A grand total of all accountable nuclear material and isotopic weight appears at the end of the report. The Inventory by Location report is available for all MBAs or selected ones.

DYMAC INVENTORY FOR LOCATION G201 1/ 4/79 PAGE NO. 1

DATE	ACCT	MT	ITM ID	RA	PROJ	PERSON	LOC	SHLF	SD	ITEM	SNM VAL	ENR	ISWT	IMPURITIES	[illegible]	SEAL	MEAS	BULK WGT
1/ 4/79	721	54	MIPBL	BL	413	JH	G201		S1	M21	6.0	11.50	5.0	1.0 CA	455		503	10.0 G
1/ 4/79	721	54	PROD100-1	BL	413	JH	G201		S1	CA6	348.0	11.50	303.0	1.0 CA	455		F16	400.0 G
1/ 4/79	721	54	PROD100-2	BL	413	JH	G201		S1	CA6	348.0	11.50	303.0	1.1 CA	455		F16	400.0 G
1/ 4/79	721	54	SAMP 100R	BL	413	JH	G201		S1	CA4	39.0	11.50	35.0	1.1 CA	455		F15	40.0 G

******ACCOUNTABLE AND SUBACCOUNTABLE SUMMATION FOR LOCATION G201******

MATERIAL TYPE	TOTAL SNM	TOTAL ISOTOPIC	NUMBER OF ITEMS
54	741.00	656.10	4.

ACCOUNTABLE TOTALS FOR THIS LOCATION	741.00	656.10	4.

DYMAC INVENTORY FOR LOCATION G202 1/ 4/79 PAGE NO. 1

DATE	ACCT	MT	ITM ID	RA	PROJ	PERSON	LOC	SHLF	SD	ITEM	SNM VAL	ENR	ISWT	IMPURITIES	[illegible]	SEAL	MEAS	BULK WGT
1/ 4/79	721	54	SAMP100-1	SA	413	JH	G202		S1	CA4	87.0	11.50	77.0	1.0 CA	455		F15	100. G
1/ 4/79	721	54	SAMP100-2	SA	413	JH	G202		S1	CA4	44.0	11.50	39.0	1.1 CA	455		F15	[illegible]

******ACCOUNTABLE AND SUBACCOUNTABLE SUMMATION FOR LOCATION G202******

MATERIAL TYPE	TOTAL SNM	TOTAL ISOTOPIC	NUMBER OF ITEMS
54	131.00	116.00	2.

ACCOUNTABLE TOTALS FOR THIS LOCATION	131.00	116.00	2.

******ACCOUNTABLE TOTALS FOR THIS REPORT******

TOTAL SNM	TOTAL ISOTOPIC	NUMBER OF ITEMS
872.00	772.00	6.

DYMAC INVENTORY FOR PROJECT 413 1/ 4/79 PAGE NO. 1

DATE	ACCT	MT	ITM ID	RA	PROJ	PERSON	LOC	SHLF	SD	ITEM	SNM VAL	ENR	ISWT	IMPURITIES	COEI	SEAL	MEAS	BULK WGT
1/ 4/79	721	54	MIPRL	BL	413	JH	G201		S1	M21	6.0	11.50	5.0	1.0 CA	455		S00	10.0 G
1/ 4/79	721	54	PROD100-1	BL	413	JH	G201		S1	CA6	348.0	11.50	308.0	1.0 CA	455		F16	400.0 G
1/ 4/79	721	54	PROD100-2	BL	413	JH	G201		S1	CA6	348.0	11.50	308.0	1.0 CA	455		F16	400.0 G
1/ 4/79	721	54	SAMP 100R	BL	413	JH	G201		S1	CA4	39.0	11.50	35.0	1.0 CA	455		F15	40.0 G
1/ 4/79	721	54	SAMP100-1	SA	413	JH	G202		S1	CA4	87.0	11.50	77.0	1.0 CA	455		F15	100.0 G
1/ 4/79	721	54	SAMP100-2	SA	413	JH	G202		S1	CA4	44.0	11.50	39.0	1.0 CA	455		F15	50.0 G

******ACCOUNTABLE AND SUBACCOUNTABLE SUMMATION FOR PROJECT 413******

	MATERIAL TYPE	TOTAL SNM	TOTAL ISOTOPIC	NUMBER OF ITEMS
	54	872.00	772.00	6.
ACCOUNTABLE TOTALS FOR THIS PROJECT		872.00	772.00	6.

******ACCOUNTABLE TOTALS FOR THIS REPORT******

TOTAL SNM	TOTAL ISOTOPIC	NUMBER OF ITEMS
872.00	772.00	6.

Fig. A-13.
Inventory by project (off-line report). This report provides a printout of the current inventory sorted by project (in this case, Project 413) and material type. For each project it gives subtotals, by material type, of accountable and subaccountable amounts of nuclear material, isotopic weights, and number of inventory items. The total for each project includes only accountable nuclear material and isotopic weight. A grand total of all accountable material for all projects included in the report appears at the end. The Inventory by Project report is available for all or selected projects.

DYMAC INVENTORY FOR SP DES S1 1/ 4/79 PAGE NO. 1

DATE	ACCT	MT	ITM ID	RA	PROJ	PERSON	LOC	SHLF	SD	ITEM	SNM VAL	ENR	ISWT	IMPURITIES	COEI	SEAL	MEAS	BULK WGT
1/ 4/79	721	54	MIPBL	BL	413	JH	G201		S1	M21	6.0	11.50	5.0	1.0 CA	455		S00	10.0 G
1/ 4/79	721	54	PROD100-1	BL	413	JH	G201		S1	CA6	348.0	11.50	308.0	1.0 CA	455		F16	400.0 G
1/ 4/79	721	54	PROD100-2	BL	413	JH	G201		S1	CA6	348.0	11.50	308.0	1.0 CA	455		F16	400.0 G
1/ 4/79	721	54	SAMP 100R	BL	413	JH	G201		S1	CA4	39.0	11.50	35.0	1.0 CA	455		F15	40.0 G
1/ 4/79	721	54	SAMP100-1	SA	413	JH	G202		S1	CA4	87.0	11.50	77.0	1.0 CA	455		F15	100.0 G
1/ 4/79	721	54	SAMP100-2	SA	413	JH	G202		S1	CA4	44.0	11.50	39.0	1.0 CA	455		F15	50.0 G

******ACCOUNTABLE AND SUBACCOUNTABLE SUMMATION FOR SD S1

54	872.00	772.00	6.
ACCOUNTABLE TOTALS FOR THIS SD	872.00	772.00	6.

******ACCOUNTABLE TOTALS FOR THIS REPORT******

TOTAL SNM	TOTAL ISOTOPIC	NUMBER OF ITEMS
872.00	772.00	6.

Fig. A-14.
Inventory by special designator (off-line report). This report provides a printout of the current inventory sorted by special designator (in this case, S1) and material type. For each special designator it gives subtotals, by material type, of accountable and subaccountable amounts of nuclear material, isotopic weights, and number of inventory items. The total for each special designator includes only accountable material. A grand total of all accountable material for all special designators included in the report appears at the end. The Inventory by Special Designator report is available for all or selected special designators.

DYMAC INVENTORY BY ITEM DESCRIPTION REPORT 1/ 4/79 PAGE NO. 1

DATE	ACCT	MT	ITM ID	RA	PROJ	PERSON	LOC	SHLF	SD	ITEM	SNM VAL	ENR	ISWT	IMPURITIES	COEI	SEAL	MEAS	BULK WGT
1/ 4/79	721	54	SAMP 100R	BL	413	JH	G201		S1	CA4	39.	11.50	35.	1.00 CA	455		F15	40.0 G
1/ 4/79	721	54	SAMP100-1	SA	413	JH	G202		S1	CA4	87.	11.50	77.	1.00 CA	455		F15	100.0 G
1/ 4/79	721	54	SAMP100-2	SA	413	JH	G202		S1	CA4	44.	11.50	39.	1.00 CA	455		F15	50.0 G
TOTAL FOR	721	54								CA4	170.		151.					
1/ 4/79	721	54	PROD100-1	BL	413	JH	G201		S1	CA6	348.	11.50	308.	1.00 CA	455		F16	400.0 G
1/ 4/79	721	54	PROD100-2	BL	413	JH	G201		S1	CA6	348.	11.50	308.	1.00 CA	455		F16	400.0 G
TOTAL FOR	721	54								CA6	696.		616.					
1/ 4/79	721	54	MIPBL	BL	413	JH	G201		S1	M21	6.	11.50	5.	1.00 CA	455		S00	10.0 G
TOTAL FOR	721	54								M21	6.		5.					
TOTAL FOR	721	54									872.		772.					
ACCOUNTABLE TOTAL FOR	721										872.		772.					

Fig. A-15.

Inventory based on item description (off-line report). This is a current inventory report sorted by MBA, material type, and item description; in this case, CA4, CA6, and M21. It gives the total amount of nuclear material and isotopic weight for each accountable and subaccountable material type in the account, as well as a total for all accountable material types in the account. The Inventory report based on item description is available for all or specific MBAs.

DYMAC CONDENSED INVENTORY REPORT 1/ 4/79 PAGE NO. 26

ACCT	MT	SNM VALUE	ISOTOPE WGT
761	12	14.	0.
761	38	5.	5.
761	3I	2.	2.
761	52	17879.	16815.
761	54	9.	8.
761	56	300.	251.
761	5C	3.	3.
761	8D	3.	3.
ACCOUNTABLE TOTAL FOR 761		18207.	17079.

DYMAC CONDENSED INVENTORY REPORT 1/ 4/79 PAGE NO. 27

ACCT	MT	SNM VALUE	ISOTOPE WGT
762	38	4376.	4078.
762	4C	1.	1.
762	51	6366.	6171.
762	52	37964.	35689.
762	56	17799.	14886.
762	82	95.	0.
ACCOUNTABLE TOTAL FOR 762		66600.	60824.

Fig. A-16.

Condensed inventory (off-line report). This is an inventory report that gives totals for the entire facility sorted by MBA (in this case, 761 and 762) and material type. It gives inventory totals of the amount of nuclear material and isotopic weight for each accountable and subaccountable material type within every MBA, in addition to an accountable total of amount of nuclear material and isotopic weight, for all material types within an MBA. The Condensed Inventory report is available for all accounts or specific ones.

****

-- MATERIAL TYPE 41 --

ACCT	MAT ID	SNM VALUE	ISO WEIGHT
731	41	152.0	65.0
756	41	141.0	39.0
759	41	200.0	55.0
760	41	204.0	58.0
763	41	11.0	3.0

	SNM VALUE	ISO WEIGHT
INTERNAL INVENTORY TOTALS	708.0	220.0
EXTERNAL BEGINNING BALANCE	708.0	221.0
EXTERNAL RECEIPTS	.0	.0
EXTERNAL SHIPMENTS	.0	.0
EXTERNAL ENDING BALANCE	708.0	221.0
INTERNAL INVENTORY	708.0	220.0
INTERNAL "IN-TRANSIT"	.0	.0
INTERNAL BALANCE (7XX)	708.0	220.0
DIFFERENCE (EXTERNAL-INTERNAL)	.0	1.0

****

-- MATERIAL TYPE 42 --

ACCT	MAT ID	SNM VALUE	ISO WEIGHT
753	42	3.0	3.0
756	42	36.0	36.0
759	42	109.0	98.0
761	42	1.0	1.0
763	42	14.0	13.0

	SNM VALUE	ISO WEIGHT
INTERNAL INVENTORY TOTALS	163.0	151.0
EXTERNAL BEGINNING BALANCE	163.0	151.0
EXTERNAL RECEIPTS	.0	.0
EXTERNAL SHIPMENTS	.0	.0
EXTERNAL ENDING BALANCE	163.0	151.0
INTERNAL INVENTORY	163.0	151.0
INTERNAL "IN-TRANSIT"	.0	.0
INTERNAL BALANCE (7XX)	163.0	151.0
DIFFERENCE (EXTERNAL-INTERNAL)	.0	.0

Fig. A-17.

General ledger (off-line report). This report is an extensive summation of all the nuclear material in the facility, sorted by material type (in this case, 41 and 42, for ^{242}Pu) and MBA. It lists the total amount of nuclear material and total isotopic weight for the facility, by material type, for each MBA. It is printed once each processing day for the facility's NMO. The General Ledger gives a beginning balance for each material type, totals for all material shipped and received in that material type, and an ending balance for that material type. It also compares the general ledger value for that material type with the inventory total for the same material type.

DYMAC ACTIVITY REPORT 1/19/79 PAGE NO. 7

TRANID	DATE	TO NAME ACCT	TO NAME MT	TO NAME ITM	TO NAME ID	FROM NAME ACCT	FROM NAME MT	FROM NAME ITM	FROM NAME ID	TO RA	FM RA	TO PROJ	FROM PROJ	TO LOC	FM LOC	TO SD	FM SD	TO ITEM	FROM ITEM	SNM VAL	ENR	ISO	MEAS CODE	BULK WGT
08574	1/18/79	**742**	**54**	**OFL**	**138**	745	54	OFL	138	BU	OY	208	208	G417	G459	FL	FO	C93	C90	-1032.	11.75	-911.	F03	-1180.0 G
TOTAL FOR		**742**	**54**	**OFL**	**138**															-1032.		-911.		
08575	1/18/79	**742**	**54**	**OFL**	**139**	745	54	OFL	139	BU	OY	208	208	G417	G459	FL	FO	C93	C90	-1031.	11.76	-910.	FC3	-1180 0 G
TOTAL FOR		**742**	**54**	**OFL**	**139**															-1031.		-910.		
085U5	1/16/79	**742**	**54**	**OFL**	**140**	742	54	NX	6LS	BU	BU	208	208	G417	G415	FL	FL	C91	A32	1032.	11.75	911.	F03	1180.0 G
096B4	1/18/79	**742**	**54**	**OFL**	**140**	758	54	OFL	140	BU	F1	208	208	G417	V06	FL	FL	C13	C90	-1032.	11.75	-911.	F03	-1180.0 G
TOTAL FOR		**742**	**54**	**OFL**	**140**															0.		0.		
085U6	1/16/79	**742**	**54**	**OFL**	**141**	742	54	NX	6LS	BU	BU	208	208	G417	G415	FL	FL	C91	A32	962.	11.75	849.	F03	1100.1 G
085U8	1/16/79	**742**	**54**	**OFL**	**141**	742	54	POT		BU	BU	208	208	G417	G417	FL	FK	C91	C92	70.	11.97	62.	F03	79.9 G
096B5	1/18/79	**742**	**54**	**OFL**	**141**	758	54	OFL	141	BU	F1	208	208	G417	V06	FL	FL	C93	C90	-1032.	11.76	-911.	F03	-1180.0 G
TOTAL FOR		**742**	**54**	**OFL**	**141**															0.		0.		
085X1	1/17/79	**742**	**54**	**OFL**	**142**	742	54	NX	7LS	BU	BU	208	208	G417	G415	FL	FL	C91	A32	1032.	11.75	911.	F03	1180.0 G
096B6	1/18/79	**742**	**54**	**OFL**	**142**	758	54	OFL	142	BU	F1	208	208	G417	V06	FL	FL	C93	C90	-1032.	11.75	-911.	F03	-1180.0 G
TOTAL FOR		**742**	**54**	**OFL**	**142**															0.		0.		
085X2	1/17/79	**742**	**54**	**OFL**	**143**	742	54	NX	7LS	BU	BU	208	208	G417	G415	FL	FL	C91	A32	995.	11.75	878.	F03	1137.7 G
085X4	1/17/79	**742**	**54**	**OFL**	**143**	742	54	POT		BU	BU	208	208	G417	G417	FL	FK	C91	C92	37.	11.97	33.	F03	42.3 G
096B7	1/18/79	**742**	**54**	**OFL**	**143**	758	54	OFL	143	BU	F1	208	208	G417	V06	FL	FL	C93	C90	-1032.	11.76	-911.	F03	-1190.0 G
TOTAL FOR		**742**	**54**	**OFL**	**143**															0.		0.		
085U8	1/16/79	**742**	**54**	**POT**		742	54	OFL	141	BU	BU	208	208	G417	G417	FK	FL	C92	C91	-70.	11.97	-62.	F03	-79.9 G
085X4	1/17/79	**742**	**54**	**POT**		742	54	OFL	143	BU	BU	208	208	G417	G417	FK	FL	C92	C91	-37.	11.97	-33.	F03	-42.3 G
096B8	1/18/79	**742**	**54**	**POT**		758	54	POT		BU	F1	208	208	G417	V06	FK	FK	C93	C90	-319.	11.97	-281.	F10	-364.4 G
TOTAL FOR		**742**	**54**	**POT**																-426.		-376.		
085V8	1/16/79	**742**	**54**	**PRP**	**105**	742	54	PRP	105S	BU	BU	208	208	G417	G417	RS		R22	C92	-9.	11.99	-8.	F03	-10.0 G
096B9	1/13/79	**742**	**54**	**PRP**	**105**	758	54	PRP	105	BU	F1	208	208	G417	V06	RS	RS	C93	C90	-1077.	11.99	-948.	W12	-1104.0 G
TOTAL FOR		**742**	**54**	**PRP**	**105**															-1086.		-956.		
085V8	1/16/79	**742**	**54**	**PRP**	**105S**	742	54	PRP	105	BU	BU	208	208	G417	G417		RS	C92	R22	9.	11.99	8.	F03	10.0 G
085W1	1/16/79	**742**	**54**	**PRP**	**105S**	770	54	PRP	105S	BU	BU	208	208	G417	433N			C92	C98	-9.	11.99	-8.	F03	-10.0 G
TOTAL FOR		**742**	**54**	**PRP**	**105S**															0.		0.		
085U3	1/16/79	**742**	**54**	**SOX**		742	54	NX	6L	BU	BU	208	208	G417	G417	FO	FL	C91	A32	7.	11.75	6.	F03	8.3 G
085W9	1/17/79	**742**	**54**	**SOX**		742	54	NX	7L	BU	BU	208	208	G417	G417	FO	FL	C91	A32	10.	11.75	9.	F03	11.0 G
096C9	1/18/79	**742**	**54**	**SOX**		758	54	SOX		BU	F1	208	208	G417	V06	FO	FO	C93	C90	-172.	11.90	-152.	F16	-197.7 G
TOTAL FOR		**742**	**54**	**SOX**																-155.		-137.		
TOTAL FOR		**742**	**54**																	-9832.		-8676.		
TOTAL FOR		**742**																		-16355.		-14817.		

Fig. A-18.

Transaction activity (off-line report). This report sorts activity, internal and external to the facility, by the "to" parameters for an inventory item; in this case, all items of material type 54 (for ^{240}Pu) in MBA 742. It gives subtotals for the net amount of nuclear material and isotopic weight transacted for each item whether it is accountable or subaccountable. It gives another subtotal for the net amount of nuclear material and isotopic weight transacted for each material type. It gives a total of the net amount transacted for each MBA. The Transaction Activity report is available for all or selected MBAs.

MIP ACTIVITY REPORT 12/19/78 PAGE # 3

		TO NAME		FROM NAME							MEAS	
TRANID	DATE	ACCT MT	ITM ID	ACCT MT	ITM ID	RA	SNM VAL	UNCERT	ENR	ISO	CODE	BULK WGT
05989	10/ 5/78	711 54	336003	711 54	MIPID	ID	0.	44936.12	11.99	0.	P41	.0 G
05988	10/ 5/78	711 54	336003	711 54	336003	ID	206.	44936.12	11.99	131.	F41	1463.3 G
05989	10/ 5/78	711 54	336003	711 54	MIPID	ID	0.	44936.12	11.99	0.	P41	.0 G
05900	10/ 5/78	711 54	336003	711 54	336003	ID	-206.	63549.25	11.99	-131.	F41	-1463.3 G
05909	10/24/78	711 54	3360A	711 54	MIPIN	IN	0.	5069.01	11.99	0.	P60	.0 G
05908	10/24/78	711 54	3360A	711 54	3360A	IN	1.	5069.01	11.99	1.	P60	5.2 G
05909	10/24/78	711 54	3360A	711 54	MIPIN	IN	0.	5069.01	11.99	0.	P60	.0 G
05980	10/24/78	711 54	3360A	711 54	336002	IN	-1.	7169.66	11.99	-1.	P60	-5.2 G
059P3	10/24/78	711 54	336003	711 54	MIPIN	IN	0.	110970.40	11.99	0.	P41	-.1 G
05906	10/10/78	711 54	336003	711 54	336003	IN	206.	89872.19	11.99	131.	F41	1463.0 G
059P2	10/24/78	711 54	336003	711 54	MIPRS	IN	1.	65095.50	11.99	1.	F50	5.2 G
059P3	10/24/78	711 54	336003	711 54	MIPIN	IN	0.	110970.40	11.99	0.	P41	-.1 G
045V8	10/ 2/78	711 54	336004	711 54	MIPOB	OB	2.	20.47	11.99	2.	P41	15.5 G
045V3	10/ 2/78	711 54	336004	711 54	3360041	OB	59.	5.20	11.99	52.	F50	525.0 G
045V4	10/ 2/78	711 54	336004	711 54	3360042	OB	60.	7.35	11.99	53.	F50	525.0 G
045V5	10/ 2/78	711 54	336004	711 54	3360043	OB	59.	10.72	11.99	52.	F50	525.0 G
045V6	10/ 2/78	711 54	336004	711 54	3360044	OB	60.	3.68	11.99	53.	F50	525.0 G
045V7	10/ 2/78	711 54	336004	711 54	SCP 133	OB	0.	14.43	11.99	0.	F50	-3.8 G
045V8	10/ 2/78	711 54	336004	711 54	MIPOB	OB	2.	20.47	11.99	2.	P41	15.5 G
045V9	10/ 2/78	711 54	336004	711 54	336004	OB	-240.	28.95	11.99	-211.	F41	-2111.7 G
045X7	10/ 3/78	711 54	336005	711 54	MIPOB	OB	-1.	29.48	11.99	-1.	P41	-4.8 G
045X2	10/ 3/78	711 54	336005	711 54	3360051	OB	59.	5.20	11.99	52.	F50	525.0 G
045X3	10/ 3/78	711 54	336005	711 54	3360052	OB	60.	7.35	11.99	53.	F50	525.0 G
045X4	10/ 3/78	711 54	336005	711 54	3360053	OB	59.	10.40	11.99	52.	F50	525.0 G
045X5	10/ 3/78	711 54	336005	711 54	3360054	OB	60.	14.71	11.99	53.	F50	525.0 G
045X6	10/ 3/78	711 54	336005	711 54	SCP 133	OB	0.	20.14	11.99	0.	F50	-3.2 G
045X7	10/ 3/78	711 54	336005	711 54	MIPOB	OB	-1.	28.48	11.99	-1.	P41	-4.8 G
045X8	10/ 3/78	711 54	336005	711 54	336005	OB	-237.	40.28	11.99	-209.	F41	[illegible]

Fig. A-19.

MIP transaction activity (off-line report). This is a report of 6-10 weeks activity that concerns MIP items; that is, those items that accumulate inventory differences for each unit process in every processing MBA, in this case, MBA 711. It lists transactions that directly contribute to the MIP items, as well as transactions that affect the items that contribute to the MIP items. The sort is by from MBA, from material type, from MIP item ID, from unit process, date and time. The MIP Transaction Activity report is available for all MBAs.

DYMAC ACTIVITY BY ITEM DESCRIPTION REPORT 1/ 4/79 PAGE NO. 1

TRANID	DATE	TO ACCT	TO MT	TO NAME	TO ITM ID	FROM ACCT	FROM MT	FROM NAME	FROM ITM ID	TO RA	FM RA	TO PROJ	FROM PROJ	TO LOC	FM LOC	TO SD	FM SD	TO ITEM	FROM ITEM	SNM VAL	ENR	ISO	MEAS CODE	BULK WGT
074Z2	1/ 4/79	721	54	LOT	100	770	54	LOT	100	BL	SR	413	413	G201	433N	S1	S1	CA1	CA1	872.	11.50	772.	S00	1000.0 G
018A0	1/ 4/79	721	54	LOT	100	721	54	SAMP	100-1	BL	SA	413	413	G201	G202	S1	S1	CA1	CA4	-87.	11.50	-77.	F15	-100.0 G
018A1	1/ 4/79	721	54	LOT	100	721	54	SAMP	100-2	BL	SA	413	413	G201	G202	S1	S1	CA1	CA4	-44.	11.50	-39.	F15	-50.0 G
018A3	1/ 4/79	721	54	LOT	100	721	54	PROD	100-2	BL	BL	413	413	G201	G201	S1	S1	CA1	CA6	-348.	11.50	-308.	F16	-400.0 G
018A4	1/ 4/79	721	54	LOT	100	721	54	SAMP	100R	BL	BL	413	413	G201	G201	S1	S1	CA1	CA4	-39.	11.50	-35.	F15	-40.0 G
018A5	1/ 4/79	721	54	LOT	100	721	54	MIPBL		BL	BL	413	413	G201	G201	S1	S1	CA1	M21	-6.	11.50	-5.	S00	-10.0 G
TOTAL FOR		721	54															CA1		348.		308.		
018A4	1/ 4/79	721	54	SAMP	100R	721	54	LOT	100	BL	BL	413	413	G201	G201	S1	S1	CA4	CA1	39.	11.50	35.	F15	40.0 G
018A0	1/ 4/79	721	54	SAMP	100-1	721	54	LOT	100	SA	BL	413	413	G202	G201	S1	S1	CA4	CA1	87.	11.50	77.	F15	100.0 G
018A1	1/ 4/79	721	54	SAMP	100-2	721	54	LOT	100	SA	BL	413	413	G202	G201	S1	S1	CA4	CA1	44.	11.50	39.	F15	50.0 G
TOTAL FOR		721	54															CA4		170.		151.		
018A2	1/ 4/79	721	54	PROD	100-1	721	54	LOT	100	BL	BL	413	413	G201	G201	S1	S1	CA6	CA6	348.	11.50	308.	F16	400.0 G
018A3	1/ 4/79	721	54	PROD	100-2	721	54	LOT	100	BL	BL	413	413	G201	G201	S1	S1	CA6	CA1	348.	11.50	308.	F16	400.0 G
018A2	1/ 4/79	721	54	LOT	100	721	54	PROD	100-1	BL	BL	413	413	G201	G201	S1	S1	CA6	CA6	-348.	11.50	-308.	F16	-400.0 G
TOTAL FOR		721	54															CA6		348.		308.		
018A5	1/ 4/79	721	54	MIPBL		721	54	LOT	100	BL	BL	413	413	G201	G201	S1	S1	M21	CA1	6.	11.50	5.	S00	10.0 G
TOTAL FOR		721	54															M21		6.		5.		
TOTAL FOR		721	54																	872.		772.		
TOTAL FOR		721																		872.		772.		

Fig. A-20.

Transaction activity based on item description (off-line report). This is a report of transaction activity during the last 6 to 10 week period. It is sorted by to MBA, to material type, and to item description. For each MBA, it gives the net amount of nuclear material and isotopic weight transacted for each material type by MBA, and then it gives a net total of the amount transacted for all material types in the MBA.

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APPENDIX B

DYMAC WORKSHEETS FOR TRANSACTION SEQUENCE DEFINITION

TRANSACTION SEQUENCE DEFINITION FOR A PRODUCTION PROCESS

DYMAC personnel need three categories of information to implement a transaction sequence for a production process: a map of the area, a verbal description of the process, and a diagram of the unit processes in the area.

Map of production process area

The map should show gloveboxes and the conveyor system and indicate account(s), receipt areas, and location.

Process description

Briefly describe the process in a paragraph. Include types of approximate amounts of material processed (e.g., are you dealing with blended plutonium and uranium, subaccountable quantities?)

Unit-process diagram

A production process may be internally divided into material balance areas called unit processes. For example, the Advanced Carbide Fuel Production Process includes blending, pellet pressing, sintering, and inspecting unit processes. The smaller a unit process is defined, the better our ability to control SNM and the better your ability to monitor production parameters such as efficiency, throughput, and hold-up.

The unit processes you define should be physical areas. Any item crossing a unit-process boundary must have a measured SNM value--no items with by-difference SNM values may cross the boundary. Each unit process will have an associated book-physical inventory difference (BPID, also called MIP).

Draw a unit-process diagram showing material flow and measurement points. Don't forget any samples or scrap. DYMAC uses the receipt area field in a transaction to denote the unit process(es) involved. Indicate on the unit-process diagram which location(s) are included in each unit process.

Production Process ____________
Wing ____________

TRANSACTION DEFINITION

1. Name of transaction: ____

   Transaction number ______________ of ________________ in the process.

   Briefly, the purpose of this transaction is __________________________

   ____

   ____

2. Type of material involved (e.g., 51, 52, 35) ________________________.

3. This is a: (check one)

   _____ SEND (destination ________________)

   _____ RECEIVE (from ________________)

   _____ TRANSFER

   If this is a TRANSFER, will you possibly be combining material?

   ( ) yes ( ) no

4. Does the transaction involve a measurement? ( ) yes ( ) no

   If you replied no, go immediately to Step 5.

   What kind of measurement is involved? (e.g., weight, SAI, TNC) __________

   If you answered weight, what formula is then used for calculating the SNM value? Example: bulk weight x 87.2% = SNM for PuO_2.

   ____

   ____.

   Does completion of this measurement indicate that a book-physical inventory difference (BPID, or MIP) may now be drawn? ( ) yes ( ) no

   Explain: ____

5. Does this transaction involve one or more verifications? ( ) yes ( ) no

   If you responded yes, check one or more fields below:

   _____Seal verification _____SGS verification

   _____Weight verification _____SAI verification

   _____TNC verification

   _____Other ____

   ____

6. Authorization level for performing this transaction:

   _____Nuclear materials officer and staff

   _____Supervisor

   _____Process coordinator

7. Fill out transaction fields below for an imaginary transaction. If this is a SEND, the to fields will be blank but the destination will be filled in. If this is a RECEIVE or TRANSFER, both from and to fields should be filled in and the destination will be blank.

	FROM	***TO***
Item ID	_ _ _ _ _ _ _ _ _	_ _ _ _ _ _ _ _ _
Account	_ _ _	_ _ _
Receipt area	_ _	_ _
Project	_ _ _	_ _ _
Special designator	_ _	_ _
Location	_ _ _	_ _ _
Shelf	_ _ _	_ _ _
Item description	_ _ _	_ _ _

Destination _ _ _

Material type _ _

8. To further define the transactions, we must determine which fields contain fixed information, which fields are unneeded, and so forth. Using the following definitions, circle one code for each field. If this is a SEND, ignore to fields. If this is a RECEIVE or TRANSFER, circle U for unneeded in the destination field.

- C Constant, never changes. Example in Step 7 should have correct field data.
- O Supplied by operator.
- U Unneeded.
- N Field contents remain the same as what is already carried in the inventory.

	FROM	***TO***
Item ID	(O)	(O, N, C)
Account	(O, C)	(O, N, C)
Receipt area	(C, N)	(O, N, C)
Project	(C, N)	(O, N, C)
Special designator	(C, N, U)	(O, N, C, U)
Location	(C, N)	(O, N, C)
Shelf	(N, U)	(O, N, C, U)
Item description	(C, N)	(O, N, C)
Destination	(C, O, U)	
Material type	(C, O)	

9. Comments ______________________________

____

____

Signature ______________________________

Date ______________________________

APPENDIX C
MANUFACTURERS' INDEX

Arbor Laboratories, Inc., 3784 Fabian Way, Palo Alto, CA 94303

Data General Corp., 4400 Computer Drive, Westboro, MA 01580

Digital Equipment Corp., 146 Main Street, Maynard, MA 01754

Mettler Instrument Corporation, 1 Princeton-Hightstown Road, Hightstown, NJ 08520

Motorola Semiconductor Group, P. O. Box 20912, Phoenix, AZ 85036

Ohaus Scale Corp., 35 Hanover Road, Florham Park, NJ 07932

Sartorius Werke, GMBH Göttingen, German Federal Republic; American distributor: Division of Brinkmann Instruments, Inc., Westbury, NY 11590

Research Inc., Teleray Division, P. O. Box 24054-T.R., Minneapolis, MN 55424

Texas Instruments, Inc., Digital Systems Division, P. O. Box 1444, Houston, TX 77001

GLOSSARY

AOS	Advanced Operating System
ASCII	American standard code for information interchange
cusum	cumulative sum
DOE	Department of Energy
DYMAC	DYnamic Materials ACcountability
DYSS	DYMAC Software System
DYUTIL	DYMAC utility library
FFTF	Fast Flux Test Facility (Richland, Washington)
FNC	fast-neutron coincidence counter
HEPA	high-efficiency particulate air
ID	identification
LASS	Los Alamos Safeguards System
LR	lean residue
MBA	material balance area (account)
MEGAS	multienergy gamma assay system
MIP	material in process
MMR	material management room
NDA	nondestructive assay
NIM	nuclear instrument module
NMO	nuclear materials officer
NRC	Nuclear Regulatory Commission
PF/LASS	Plutonium Facility/Los Alamos Safeguards System
PROM	programmable read-only memory
RDOS	Real-Time, Disk-Oriented Operating System
R&D	research and development
SAI	solution assay instrument
SGS	segmented gamma scanner
THENCS	thermal-neutron coincidence counting system
TI	Texas Instruments
TNC	thermal-neutron coincidence counter

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076-100	A05	226-250	A11	376-400	A17	526-550	A23
101-125	A06	251-275	A12	401-425	A18	551-575	A24
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