FOREWORD

The Dynamic Materials Control (DYMAC) program at the Los Alamos Scientific Laboratory (LASL) has as its task to install and evaluate a demonstration system that incorporates dynamic and real-time nuclear materials control principles into the newly constructed LASL plutonium facility. Preparatory to the installation of this demonstration system, the program underwent a test-and-evaluation phase (Phase I) at the DP Site LASL plutonium facility. From June 1976 to mid-February 1977 project personnel tested system components under realistic operating conditions at DP Site. They conducted the testing only to the point where enough information was collected to specify equipment and software requirements for the new facility. Processing began at the new facility in January 1978 at which time the DYMAC system went into operation (Phase II). Two years after startup the project will evaluate system components and operation of the system as a whole (Phase III), publishing its findings at that time. Other groups that are planning advanced nuclear-materials-control systems will find the reported information useful.

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GLOSSARY

ARHCO	Atlantic Richfield Hanford Company
ASCII	American standard code for information interchange
cusum	cumulative summation
DAT	Division of Applied Technology (ERDA)
DMA	Division of Military Application (ERDA)
DPMM	Division of Production and Materials Management (ERDA)
DRDT	Division of Reactor Development and Technology (ERDA)
DSNS	Division of Space Nuclear Systems (ERDA)
DYMAC	DYnamic MAterials Control
ITRAN	incomplete transaction (file)
IX	ion exchange
LAS	LASL accounting system (for nuclear materials)
LASL	Los Alamos Scientific Laboratory
LEMUF	limit of error of the MUF
LMFBR	liquid-metal fast-breeder reactor
MBA	material balance area
MIP	material in process
MUF	material unaccounted for
NDA	nondestructive assay
NMMSS	nuclear materials management and safeguards system
RA	receipt area
SAI	solution assay instrument
SGS	segmented gamma scanner
SNM	special nuclear material
TA-55	new LASL plutonium facility (at TA-55)
TNC	thermal-neutron coincidence counter
TRAN	transaction (activity file)

DYMAC DEMONSTRATION PROGRAM: PHASE I EXPERIENCE

by

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ABSTRACT

The DYMAC project tested a prototype system at the DP Site LASL plutonium facility, which consisted of a computerized accounting system based on material balancing by unit process. Transactions were written to describe the movement of material from one unit process to another. In the DYMAC prototype a specially designed computer program handled transactions that operators entered into the system via a terminal in the processing area. The transactions contained the same information that is used in the present LASL paper accounting system to create an inventory. During a 6-week period the DYMAC system operated in parallel with the paper system. At the end of the period results showed the DYMAC system was able to keep an accurate and timely inventory. Concurrent with testing the transaction-handling program, the project operated several nondestructive assay instruments in a glovebox environment, specifically the electronic balance, solution assay instrument, and thermal-neutron coincidence counter. From the instrument operation logs, project personnel were able to identify operational problems and incorporate design changes in the instrumentation for the new facility.

CHAPTER 1

INTRODUCTION

Demonstration that nuclear material in a facility can be safeguarded from diversion, theft, or loss is an essential component of full-scale use of nuclear power. To provide safeguards assurance at all levels of processing, nuclear facilities will have to incorporate an integrated safeguards system that can thwart a wide variety of threats. Optimally, such a system will combine physical security with in-plant materials control.^{1,2}

In-plant materials control reduces the probability that someone with authorized access will divert nuclear material. Associated with the control function, which lessens the opportunity for theft, is a second function--accountability--which provides early detection of a theft and assists in identifying the thief. The assurance that a facility can detect covert diversion allows it to counter nuclear blackmail threats with confidence. In case of a threat, the in-plant materials control system can quickly verify whether the physical protection system has been bypassed. If an overt theft occurs, the accountability system should be able to rapidly assess the quantity and form of the stolen material, thereby providing vital information to the recovery force.

THE DYMAC PROGRAM

At present, safeguards considerations require plants to shut down periodically for cleanout, followed by physical inventory and calculation of material unaccounted for (MUF) and the limit of error of the MUF (called the LEMUF). This method of plant operation with periodic shutdowns has certain obvious shortcomings. Principal of these shortcomings is the lack of timeliness in assessing the material in the plant. Other shortcomings are the relative insensitivity of the accumulated figures that represent MUF, the practical difficulties in achieving a MUF less than 0.5% of throughput (or some small "trigger" quantity of fissile material), and the economic penalty levied by frequent shutdowns and cleanouts. Enforcement of safeguards requirements, given the current methods of processing, seriously threatens the viable utilization of reactor fuels in the commercial sector.

DYMAC proposes to obviate many of these cumbersome, inefficient, and sometimes ineffective safeguards procedures. Essentially, the DYMAC system controls and accounts for nuclear materials in real time on a unit-process basis. (Refer to Appendix A for a description of dynamic balancing within a unit process.) It is now feasible to install a detailed and timely materials control system such as DYMAC in an entire nuclear plant because of recently developed nondestructive assay (NDA) techniques and also because of advances in supportive computer technology, which provide expanded computing and storage capabilities at reasonable cost. Coupled with surveillance and verification instruments, DYMAC constitutes an in-plant safeguards system that is particularly responsive to covert diversion and inadvertent loss of nuclear materials. Furthermore, the measurements and control data that DYMAC generates also apply to process and quality control as well as to criticality safety, all three of which are essential factors in economic and safe production. Successful implementation of DYMAC may significantly offset its cost in terms of minimizing plant shutdowns and cleanouts.

The DYMAC Program at LASL draws together the experience and technology necessary to implement dynamic materials control. The program builds on the experience of others, adapts technology from a variety of disciplines, and develops new solutions to problems as needed.^{3,4} System development falls into four areas: nondestructive assay, data communications, data base management, and real-time materials control. To give direction to the development, a DYMAC system is being installed in the new LASL plutonium facility at TA-55, presently nearing completion. Successful operation of DYMAC/TA-55, as the system is designated, in a working facility will demonstrate its safeguards and production capabilities, namely

- reliable operation of in-line instruments in a production environment,
- accurate and efficient data collection,
- management of a common data base,
- sensitive and timely nuclear material accounting, and
- production control, quality assurance, and financial management.

Development of DYMAC/TA-55 is proceeding in three phases. Phase I, recently completed, was a pilot program of research and development carried on at the old LASL plutonium processing facility at DP Site. Phase II concerns the design, installation, and operation of a full-scale, plant-wide DYMAC system at the new plutonium facility. The test and evaluation program,

Phase III, will evaluate the operating data from Phase II to determine the degree of control achievable for special nuclear material (SNM) and the cost-effectiveness of the system.

This report describes Phase I activities at DP Site and the experience gained from them.

PHASE I: TEST AND EVALUATION AT DP SITE

LASL has been processing plutonium since Manhattan Project days. In 1943, the DP Site facility was constructed for fabrication and recycling of plutonium for weapons research and fuel development. That facility has been in continuous operation ever since. (See Appendix B for a summary of current activities carried on at DP Site by LASL Group CMB-11.) The DP Site facility is no longer adequate by today's standards. As part of a program to upgrade ERDA facilities to meet more stringent criteria for safeguards, fire, earthquakes, and tornadoes, the new facility at TA-55 will replace DP Site.

Preparatory to installing DYMAC at the new plutonium facility, its four component subsystems (nondestructive assay, data communications, data base management, and real-time material control) were tested at DP Site. The next chapter discusses the subsystem functions, and subsequent chapters detail the activities at DP Site that were undertaken to aid in the development or adaptation of each subsystem. We have integrated the experience gained from Phase I into the design of the DYMAC/TA-55 system.

CHAPTER 2

DYMAC FUNCTIONS

The DYMAC system monitors the flow of SNM in the facility and sounds the alert for abnormal situations. Figure 1 shows the basic system structure. Surveillance begins with input to the system from each unit-process area. Measurement instruments and interactive terminals in each area transmit the status of SNM, in various stages of production, to a central computer. In the computer, the incoming data is verified for accuracy and is organized into files in the data base. A measurement control program periodically checks instrument performance. Control parameters are calculated from information in the data base and are compared with predetermined alarm levels. If the parameters exceed the alarm levels, the system alerts the nuclear materials officer who is responsible for the integrity of the facility's safeguards system.

To implement dynamic materials control based on the foregoing structure, we have defined four subsystems:

Fig. 1. DYMAC functional structure.

- nondestructive assay,
- data communications,
- data base management, and
- real-time materials control.

Each subsystem represents an area of technology that we are developing or adapting for use in nuclear fuel cycle facilities.

NONDESTRUCTIVE ASSAY

The timely, in-line measurements available through nondestructive assay provide the basis for real-time materials control. Once we have identified the types of materials that pass the various measurement points, optimal NDA instrumentation can be developed or adapted from existing designs for in-line* operation. LASL has been developing a number of NDA systems for use in the new plutonium facility: a solution measurement system, a specialized thermal-neutron coincidence counter, a fast-neutron coincidence system for heterogeneous materials having high (α, n) backgrounds, isotopic verification using high-resolution gamma spectroscopy, product verification stations, and a variety of digital readout weighing devices.

Our design philosophy for plutonium materials has been to keep the delicate parts of the instrument (detectors and electronics) outside the glovebox environment whenever possible. In designing for glovebox use, we also considered the limitations imposed by having to work through gloves. We focused our attention on the operational aspect of instrument use, which can dramatically influence measurement cost as reflected through operator time. We avoided this problem by cooperating closely with the process operators during instrument development.

One goal in the evolution of NDA instrument design was to minimize operator action. This was partially accomplished by incorporating a minicomputer or microprocessor into the instrument to handle control functions, data acquisition, and data analysis. The minicomputer approach was used for the segmented gamma scanner (SGS).⁵ The DYMAC system transmits assay results, including limits of error, directly to a central computer. The assay results are also available to the process operator.

*This means in the glovebox line.

An integral part of the DYMAC system is a rigorous standards and measurement control program that assures the credibility of the assay data. The program provides quantitative limits-of-error information and ensures that the individual instruments function properly by checking their precision and calibration accuracy. The central computer maintains a calibration schedule for all instruments to remind operators when to remeasure the standards. The calibration history of each instrument is stored as a permanent record for real-time comparison of present and past performance. In some cases, diagnostic procedures have been incorporated as an integral part of the instrument independent of the central computer. For example, high-resolution gamma-ray systems commonly have a built-in gamma source for counting-loss corrections. When no measurement sample is present, the gamma ray can be used as a diagnostic test of instrument performance. The operator is not involved unless a problem is detected.

DATA COMMUNICATIONS

Data communications provide the link between the process areas and the central computer. Data flows between interactive terminals and the computer. It flows directly from the measurement instruments to the computer without going through a terminal.

Information in the data base must be accurate. Inaccurate information can lead to high false-alarm rates and result in insensitivity to a real problem. To achieve the 99.9% accuracy level that we must maintain will require the right combination of terminals, operator training, data diagnostics, and an overlay of data verification.

Two types of terminals were evaluated during Phase I: a video terminal with no hardcopy and a hardcopy teletype-like terminal. In future applications it may be possible to simplify the terminals to a few function keys and some way of identifying the inventory item.

We have been also deliberating the question of terminal access to the computer data base: who can enter data and how much information can that person extract? To serve production control needs, system data must be made available to the production area, but restrictions can be placed on its accessibility. This will require a personnel identification scheme to identify the person using the terminal.

It is important that terminal users enter data accurately. To instill a sense of responsibility in them, a carefully planned training program will cover the mechanics of terminal operation and emphasize the importance of accurate data for safeguarding SNM. We are making every effort to incorporate incentives for accuracy. The dialogue between operator and computer can immediately eliminate some types of errors: does the item (batch) exist in the inventory? is the location correct? is the proposed move logical in terms of process flow? Errors caught before entry into the data base are the easiest to correct.

DATA BASE MANAGEMENT

The data base management subsystem organizes the mass of incoming data into a file structure for easy retrieval. Organization by specified key will allow the data to be used for multiple purposes, e.g., for production control, criticality, and safeguards. The software technology, which allows larger and larger amounts of data to be accessed via terminal in reasonable time on modest-sized computers, has already been developed for use in many fields ranging from personnel and payroll departments to continuous-inventory warehouses. This software development is available for use in material control. The total DYMAC system software handles incoming data from terminals and instruments, and requests for output information; monitors shipments of material; and reviews calibration standards of all the measurement systems.

The DYMAC/TA-55 data base will consist of 5 000 to 10 000 items, each consisting of approximately 200 characters of pertinent information.

REAL-TIME MATERIALS CONTROL

The goal of the DYMAC system is to be able to state the location and amount of all SNM within the facility at any point in time. It does this on a unit-process basis. The materials control subsystem draws on the data base to provide current inventory listings by location, material type, custodian, or any other key contained in the data record. As material moves through a unit-process accounting area, a material balance and its uncertainty are calculated. The balance is recorded by process area and batch. This information can then be used to make control charts using the cusum⁶ technique, for example. The materials control subsystem monitors the charts for deviations that fall outside the control limits. When these occur it notifies the

nuclear materials officer via terminal. The nuclear materials officer investigates and, if necessary, shuts the process down. The materials control subsystem generates a number of printed reports to meet internal and government requirements. Because the data is always current, the subsystem can produce reports within a short time; the only constraints are the speed of the line printer and the need to continue servicing incoming data.

The materials control subsystem monitors shipments of material within a facility for complete delivery within a specified time. When the material leaves an area, an operator enters an incomplete transaction via terminal and the subsystem records the time. After a prescribed period elapses, it verifies that the transaction was completed; this signifies receipt of the material at the delivery point. If the material did not arrive, it alerts the nuclear materials officer.

CHAPTER 3

NONDESTRUCTIVE ASSAY

The ability to measure nuclear material in a timely and accurate way is vital to the DYMAC approach for in-plant materials control. NDA instruments make tighter material control possible by filling in three gaps in measurement technology: (a) difficult-to-sample materials such as scrap, (b) timely in-line measurements of process material, and (c) product materials, such as fuel rods, for which destructive sampling would be unacceptable.

NDA activities during Phase I centered on three areas: installing and operating equipment inside gloveboxes, improving the off-line instrumentation in the counting room, and establishing measurement control techniques for verifying instrument performance.

Four instruments were adapted for glovebox use: the solution assay instrument (SAI), digital electronic balance, load cell weighing device, and thermal-neutron coincidence counter (TNC). Each of these instruments had proven its usefulness in stand-alone operation under controlled conditions. In-glovebox usage imposed additional demands on operational design, maintenance, and performance in less than ideal conditions. For the most part, the instruments did not perform as well inside the glovebox as they did in the laboratory. Nevertheless, performance in each case was well within acceptable limits and promises to improve as we gain more operational experience.

SOLUTION ASSAY INSTRUMENT*

Most scrap recovery processes dissolve scrap material and then purify the resultant solution by means of ion exchange or solvent extraction processes. A recovery facility must be able to measure SNM content of solutions for material balancing. Ideally, the entire batch of solution should be measured. But often it is not possible to measure an entire batch; in that case a sample is taken of the solution, assayed, and related to the total by a volume or weight ratio.

A system that assays solution samples, based on gamma-ray spectroscopy, was designed for in-glovebox use in the LASL plutonium recovery facility. The SAI replaced the procedure in which a sample is removed from the glovebox and sent to the analytical laboratory for radiochemistry. In the SAI the Ge(Li)

*Referred to in other reports as the plutonium solution assay system (PUSAS).

detector is located outside the glovebox (see Fig. 2); it views the sample through the glovebox floor. The sample (25-30 ml. of solution) is isolated from other plutonium in the vicinity by a lead counting well that also contains a plutonium transmission source mounted in a tungsten shutter that can be rotated in and out of the detector's view. The assay is based on the intensity of gamma rays from ^{239}Pu (414 keV, 129 keV), ^{241}Pu (149 keV), and in some cases, ^{241}Am (208 keV), corrected for sample attenuation and pulse pileup.⁷ The initial requirements called for the SAI to measure solutions in the range of concentration from 0.5 to 20 g/L. At a later stage in Phase I, there was a need to measure samples in the 0.1- to 0.5-g/L range with high americium content.

Two unanticipated installation steps were necessary to reduce background count rates to acceptable levels. Removal of plutonium contamination from the glovebox floor immediately beneath the sample holder by wiping the surface with water-damp rags only reduced the surface contamination to approximately 2 g Pu/m² (0.2 g Pu/ft²). Subsequent scrubbing with an abrasive cleanser followed by washing with a 10% HCl solution further reduced the background by a factor of 20. The second step was to decouple the Ge(Li) detector lead

shielding from the glovebox. Electronic or vibration-induced noise from the glovebox was eliminated by providing a 1-mm air gap between the lead shielding and the glovebox floor.

Initial calibration proceeded without difficulty and sample analyses began. A program was set up with the LASL Analytical Chemistry Group (CMB-1) to analyze ash-leach liquid samples in quantity. Samples from 18 batches of ash-leach solution were assayed in the SAI. A portion of each sample was sent for comparative assay via isotopic dilution mass spectroscopy. After an initial set of samples was

Fig. 2. Plutonium solution assay instrument.

measured, it became apparent that the volumetric dispensing of 30.0-mL aliquots of the ash-leach solutions into the SAI measurement bottles was imprecise and biased. To circumvent this problem, the volume of each sample was determined from the sample net weight and specific gravity.

Table I lists the SAI and isotopic dilution assay results for each sample plus the ratios of the assays. The standard deviation for the ratio is 0.013 on a mean value of 0.981. We expected better agreement between the two methods, thus an error analysis was performed on the measurements: the isotopic dilution mass spectroscopic method in total, specific gravity determination, sample weighing, and counting statistics. The first three measurements were tested by replicate measurements, and the counting statistics error was calculated from sample and calibration standards counting data (refer to Table II). Propagation of these error components yields a total error of 1.55%. At

TABLE I
SAI VS ISOTOPIC DILUTION ASSAY OF ASH-LEACH SOLUTIONS

Sample Number	SAI Assay (plutonium g/L)	Isotopic Dilution Assay (plutonium g/L)	Ratio ^a	Corrected SAI Assay	Corrected Ratio
1	5.313	5.40	0.984	5.392	0.999
2	0.940	0.950	0.990	0.954	1.004
3	1.058	1.08	0.980	1.074	0.994
4	4.347	4.44	0.979	4.412	0.994
5	2.033	2.07	0.982	2.063	0.997
6	4.603	4.86	0.947	4.672	0.961
7	3.585	3.71	0.966	3.638	0.981
8	3.520	3.579	0.986	3.573	0.998
9	2.488	2.55	0.976	2.525	0.990
10	2.511	2.55	0.985	2.549	0.999
11	2.665	2.68	0.994	2.705	1.009
12	2.676	2.755	0.971	2.716	0.986
13	1.173	1.166	1.006	1.191	1.021
14	0.539	0.553	0.975	0.547	0.989
15	1.335	1.352	0.988	1.355	1.002
16	1.346	1.379	0.976	1.366	0.991
17	0.663	0.678	0.977	0.673	0.993
18	1.008	1.017	0.991	1.023	1.006

^aSAI value divided by isotopic dilution value.

TABLE II
ERROR ANALYSIS

Error Component	Relative Standard Deviation (%)
Isotopic dilution mass spectroscopy	0.95
Specific gravity determination	0.22
Sample weighing	0.13
Counting statistics	1.20

this point a significant bias was discovered and corrected in the calibration of the SAI.

The biasing effect was loss of mass, apparently by diffusion, from the solution standards with which the SAI was calibrated. This effect has also been seen in uranium solution standards packaged in the same type of plastic bottles. The loss was approximately 0.1-g total solution per month, which in about 1.5 yr of storage changed the volume of the standards sufficiently to produce a 1.5% change in specific response, relative to samples with the correct volume. The effect is due primarily to the operation of the $1/r^2$ law and is a consequence of the necessarily small distance (about 4.3 cm) between the sample bottle and detector. Thus, all the SAI results should be multiplied by 1.015, resulting in an average ratio of 0.995 with the same standard deviation of 0.013.

The evaluation demonstrated that the SAI can accurately measure plutonium solution under glovebox conditions. It also pointed out the need for better solution standard procedures. Based on this experience, we plan to use a solid plutonium working standard that will be compared every 3 months with freshly made solution standards.

During SAI evaluation, a new process began generating peroxide and oxalate filtrate solutions that require assay. These filtrates have concentrations of 0 to 0.5 g Pu/L that produce low counting rates in the SAI. For a filtrate concentration of 0.25 g Pu/L and a 20-min count, precisions of 15% relative standard deviation are typical. However, a problem occurred in the assay of the peroxide filtrates. The peroxide precipitation process separates

americium and plutonium with the americium remaining in the filtrate. The americium gamma rays from the 208-keV peak were so intense that pulse pileup at 414 keV made a plutonium assay very difficult. Further development is necessary before the SAI can be used for this type of sample. A software diagnostic was added to the SAI to detect and notify the operator of this condition.

ELECTRONIC BALANCE

Weighing devices form an important class of NDA instruments. In the case where a sample has been chemically analyzed, weight often provides the relationship between the sample's plutonium content and that of the total batch. For metal, weight provides a direct measurement value. Even for solutions where the comparison is usually made on a volume basis, the DYMAC system prefers a weight ratio. This is because of the availability of commercial digital readout weight devices that can be directly coupled to a computer.

We purchased a commercial electronic balance and installed it inside the glovebox where the SAI is located, to weigh solution samples. The total batch of solution was weighed using a load cell system. Thus the plutonium contained in the total solution batch was equal to the SAI sample assay multiplied by the ratio of the weights. We built an electronic interface to transmit the weight result directly to the central computer.

Because the balance was located in a corrosive atmosphere of acid fumes, its electronic components needed protection. We replaced its original aluminum case with a stainless steel enclosure and isolated the pan mechanisms from the internal electronic and mechanical components by means of an oil seal. As expected, the oil seal slightly degraded the balance performance.

The balance has been functioning in the corrosive glovebox environment for 9 months with no visible deterioration. Performance data taken 6 months after installation is given in Table III. We took the data by zeroing and calibrating the lower range (0-200 g), taking data, switching to the higher range (2 000 g) without recalibrating, and completing the data taking. The data show a bias for the higher range values. Balance precision and stability are quite good.

A second balance of the same type but higher capacity was installed in the metal fabrication area. This unit did not perform satisfactorily: it had linearity problems, zero return, and was sensitive to the placement of the

TABLE III
IN-GLOVEBOX PERFORMANCE DATA FOR ELECTRONIC BALANCE

Date	Low-Range Measurements ^a								High-Range Measurements ^b					
	Using 20-g standard		Using 50-g standard		Using 100-g standard		Using 200-g standard		Using 500-g standard		Using 1000-g standard		Using 2000-g standard	
	$\bar{W}_j^c$	$S(W_j)^d$	$\bar{W}_j$	$S(W_j)$	$\bar{W}_j$	$S(W_j)$	$\bar{W}_j$	$S(W_j)$	$\bar{W}_j$	$S(W_j)$	$\bar{W}_j$	$S(W_j)$	$\bar{W}_j$	$S(W_j)$
8-12-76									500.0	0.0000	1000.1	0.0816	2000.1	0.0577
8-13-76									499.7	0.6957	1000.2	1.0064	1999.5	0.1165
8-16-76									500.0	0.0746	1000.0	0.1302	2000.0	0.3523
8-17-76									499.6	0.5000	999.6	0.1500	1999.2	0.1000
8-18-76									499.9	0.0835	999.8	0.3284	2000.0	0.4334
8-19-76									501.1	2.1547	1000.4	0.1000	1999.9	0.0500
8-30-76			49.96	0.0082	99.94	0.0780	199.83	0.0751						
8-31-76			49.97	0.0359	99.90	0.0082	199.78	0.0100						
9- 1-76			49.97	0.0128	99.90	0.0155	199.81	0.0146						
9- 2-76			49.96	0.0096	99.89	0.0082	199.80	0.0263						
12-16-76	19.99	0.0094	49.98	0.0052										
1- 3-77	20.00	0.0667	50.02	0.0190										
4-11-77	20.02	0.0100	50.02	0.0100	100.00	0.0084	199.98	0.0112						
4-12-77	20.00	0.0100	50.01	0.0000	99.99	0.0059	199.97	0.0071	501.8	0.0577	1003.5	0.0577	2006.5	0.0000
4-13-77	20.00	0.0141	50.00	0.0114	99.97	0.0217	199.97	0.0112	501.8	0.0000	1003.4	0.0816	2006.6	0.0488
4-14-77	20.01	0.0045	50.01	0.0179	99.99	0.0239	199.98	0.0200	501.8	0.1673	1003.5	0.1304	2006.8	0.0548
4-15-77	20.00	0.0055	50.01	0.0195	99.98	0.0134	199.97	0.0132	501.8	0.0447	1003.4	0.1000	2006.5	0.0837

^a200-g maximum.

^b2000-g maximum.

^cAverage weight of x number of runs for given standard.

^dOne standard deviation of repeated runs.

weight on the pan. We attribute these problems to the knife-edge design of the balances. Therefore we purchased electronic balances, based on an electromagnet design, from two other manufacturers for evaluation. These have performed much better than the knife-edge-design balance. (This evaluation occurred after the formal completion of Phase I and is not included in this report.) Based on the total experience with all balances, we conclude that electronic balances will perform satisfactorily in a glovebox environment and have written specifications for them to be installed at the new facility.

LOAD CELL

We evaluated load cell systems for weighing heavier items than balances can handle, such as solution tanks. Various load cell configurations were tested in the laboratory and three suspension-type systems were installed in a recovery glovebox at DP Site.

Once the weighing system can be made environmentally compatible, then the primary problems are long-term stability, measurement reproducibility, and in-box calibration procedures. To explore these problems, a microprocessor-based evaluation system was used to simulate the measurement sequences. We wanted to familiarize personnel with the capabilities of a microprocessor as a sub-assembly with an eye toward solving some instrumentation problems at the new plutonium facility. Table IV summarizes the evaluation as it pertains to reproducibility and stability of the load cells tested in compression mode as shown in Fig. 3. Certain conclusions can be drawn from the table:

- a. the bias is not significant,
- b. there are no obvious long-term trends,
- c. the relative random error

$$\sigma_{\epsilon} = \frac{s(w_j)_P}{\bar{W}} = 0.03\% \quad , \quad \text{and}$$

- d. the long-term systematic error (relative)

$$\sigma_{\delta} = \frac{\left[(\bar{w} - w_0)^2 + s^2(\bar{w}_j)/m + \Delta^2/6 \right]^{1/2}}{\bar{W}} = 0.02\% \quad .$$

These evaluations illustrate the out-of-glovebox capabilities of the load cells.

Two types of load cell systems were considered: a compression system, which requires multiple cells and a modified base plate under the column (see Fig. 3), and a tension system, which uses a single cell and a lifting mechanism to facilitate column suspension during weighing (see Fig. 4). We decided to use the tension approach in view of lower cost, less susceptibility to damage from spills, simpler in-box set-up procedure, improved transducer accuracy, and minimum in-box electrical connection.

TABLE IV
LOAD CELL EVALUATION

Sample Number	$\bar{w}_j^a$ (g)	$s(w_j)^b$ (g)	$s(w_j)_p^c$ (g)	$\bar{w}^d$ (g)	$s(\bar{w}_j)^e$ (g)	$(\bar{w}_j - w_0)^f$ (g)
1	12 276.68	4.54	4.54	12 276.68	---	-2.11
2	12 275.55	2.27	3.41	12 276.12	0.77	-3.24
3	12 289.16	4.34	3.72	12 280.46	7.56	10.37
4	12 277.82	2.27	3.36	12 279.80	6.31	-0.97
5	12 275.55	2.27	3.14	12 278.95	5.79	-3.24
6	12 272.15	2.62	3.05	12 277.82	5.88	-6.64
7	12 275.55	5.71	3.43	12 277.49	5.42	-3.24
8	12 286.89	2.27	3.29	12 278.67	6.02	8.10
9	12 277.82	4.34	3.40	12 278.57	5.65	-0.97
10	12 278.95	0.00	3.06	12 278.61	5.32	0.16
11	12 277.82	4.34	3.18	12 278.54	5.05	-0.97
12	12 277.82	7.75	3.56	12 278.48	4.82	-0.97
13	12 268.75	6.80	3.81	12 277.73	5.35	-10.04
14	12 275.55	2.27	3.70	12 277.58	5.19	-3.24
15	12 272.15	2.62	3.63	12 277.21	5.18	-6.64
16	12 290.29	4.54	3.68	12 278.03	5.98	11.50
17	12 277.82	4.34	3.72	12 278.02	5.80	-0.97

^aAverage for four weighings.

^bStandard deviation of the same four weights.

^cPooled standard deviation (cumulative).

^dCumulative average.

^eStandard deviation of average ($\bar{w}_j$) values.

^fBias, $w_0 = 12\ 278.79$.

The load cell weighing system is composed of five assemblies as shown in Fig. 5. The BLH-U2M1 load cell* (which has a 45-kg capacity) and the suspension rigging (shown in Fig. 4) provide a means to raise the column approximately 1 cm off the floor of the glovebox, make a weight measurement, and return the column to its resting position on the glovebox floor. Stainless steel components are used wherever possible because of the corrosive atmosphere. The load cell assembly is the only part of the weighing system subject to contamination and chemical corrosion; all other assemblies are remote to the glovebox.

The second assembly is the load cell junction and switching box. The full system at DP Site has three columns to weigh, only one of which will be ready to transfer its contents at a given time. Three assemblies like that shown in Fig. 4 are located in a single glovebox line. The junction box selects the load cell connected to the column to be weighed and sends that signal to the rest of the instrumentation.

Third is the signal-conditioning electronics (BLH-450 transducer indicator*), which contains circuitry that scales and amplifies the small load cell voltages and presents them to a digital panel meter that displays a digital value while providing analog-to-digital conversion to a rear panel connector. Fourth is the operator control panel and microprocessor-switch-interfacing electronics (shown in Fig. 6) along with the signal conditioner. Fifth is the microprocessor (Intel 80/10) assembly, which consists of a front panel with pilot light, fuse, and ON-OFF switch; a single-board computer system; and power supplies. The microprocessor software provides weighing sequence control, weight calculation, error detection, and data

Fig. 3. Multiple cell-compression system.

*BLH Electronics, Inc., Waltham, MA.

output. Data output is implemented with a serial data port that is software- and hardware-programmed for 300-baud, 20-mA current loop transmission to the DYMAC NOVA 840 at DP Site.

Installation of the load cell systems in the glovebox went smoothly and was completed in a day. Operating experience has pointed out some problems. The placement of the lifting mechanism for suspending the solution tank made it difficult to operate through the gloveports. In the laboratory the mechanism worked well, but in the glovebox the operator--constrained by the gloveport location--had to reach up to the handles at an awkward angle. More attention will be paid to this aspect of the design at the new facility. A more serious problem involves the calibration procedure, which requires handling heavy weights of 10 to 30 kg. At DP Site, the system was calibrated with two weights of approximately 10 kg each. The weights were placed on the solution columns by hand, a difficult and awkward procedure. The weights will increase to 30 kg at the new facility, requiring a mechanical apparatus to put them in place.

Fig. 4. Single cell tension system.

Fig. 5. Load cell weighing system.

Fig. 6. Signal conditioner and operator control panel for load cell weighing system.

Table V presents a set of performance data for two of the load cell systems taken after 6-months residence in a glovebox environment. The data represent a total of 30 weighings taken over a 2-1/2-week period for each cell. The system calibration had not been changed since installation. In the initial setup, one calibration factor was used for all three cells because only one channel of electronics was available. This introduces biases in the measurements because of differences between the load cells. Under more favorable conditions, namely a separate preamplifier for each load cell and more frequent calibrations, the bias evident in Table V should be removed. A comparison of random errors shows that the load cells performed less well in the DP Site glovebox configuration than under laboratory conditions, yielding relative standard deviations of 0.31 to 0.57%. Nevertheless, at this level of performance the load cells are valuable for in-line material measurements.

TABLE V
IN-GLOVEBOX LOAD CELL PERFORMANCE DATA

Calibrated Weight (kg)	Load Cell 1				Load Cell 2			
	Average of Weighings (kg)	Standard Deviation (kg)	RSD ^a (%)	Bias ^b (%)	Average of Weighings (kg)	Standard Deviation (kg)	RSD ^a (%)	Bias ^b (%)
9.825 ^c	9.70	0.023	2.4	-1.3	9.87	0.010	0.1	+0.5
9.820 ^c	9.73	0.008	0.1	-1.0	9.87	0.007	0.1	+0.5
9.825 ^c	9.71	0.089	0.9	-1.2	9.85	0.013	0.1	+0.3
9.820 ^c	9.76	0.008	0.1	-0.7	9.87	0.007	0.1	+0.5
9.825 ^d	9.77	0.086	0.9	-0.6	9.84	0.067	0.7	+0.2
9.820 ^d	9.82	0.055	0.6	-0.0	9.83	0.047	0.5	+0.1
9.825 ^e	9.70	---	---	-1.3	9.84	---	---	+0.2
9.820 ^e	9.72	---	---	-1.0	9.87	---	---	+0.5

^aStandard deviation as a percent.

^bBias is computed from (average of weighings - calibrated weight)/ calibrated weight x 100%.

^cWeighings performed without pause in between.

^dAt least a 5-min pause between weighings.

^eSingle measurement.

THERMAL-NEUTRON COINCIDENCE COUNTER

At many of the process steps, material appears in a form too heterogeneous or dense for accurate gamma-ray assay. If the isotopic composition is well known, then the spontaneous fission coincident neutrons from the even plutonium isotopes (238, 240, 242) can be used to quantitatively determine total plutonium for those items. For a heterogeneous item, chemical sampling is not possible and coincidence neutron counting may be the only method available for measurement. In the case of a dense product material such as PuO_2 powder, chemical analysis of a sample provides a very accurate but untimely determination of plutonium. Neutron coincidence counting provides a timely measurement that can be updated when the analytical results are available. A third situation in which neutron coincidence counting is used is the verification of a nonplutonium-specific measurement such as weight. For plutonium metal, weight provides a very accurate measurement but it is not specific to plutonium. A neutron coincidence count, in addition to weight, provides quantitative verification of the amount of plutonium present.

A thermal-neutron coincidence well counter, which measures the neutron coincidence events resulting from the spontaneous fission of plutonium, was designed and installed in a process line in the recovery section at DP Site. Figures 7-9 show various stages of installation. Cans inside the glovebox are raised into the counting well. The neutron detector itself is outside the glovebox environment as are the associated electronics.

The neutron counter's well diameter is 16 cm. A ring of 15 ^3He gas proportional counters to detect thermal neutrons is positioned in a polyethylene moderator, arranged symmetrically about the well on a circular radius of 13 cm. The cans, when raised into the counting position in the well, are surrounded by cadmium in order to decouple thermal neutrons in the moderator from the material in the can. This reduces the probability of induced fission due to thermalized neutrons in the moderator back-scattering into the sample. The moderator's outer radius is 18 cm, and it has an outer liner of cadmium. This cadmium liner, plus an outer shield of 10-cm-thick polyethylene, ensures low background count rates and improves the instrument's sensitivity. A mockup of this instrument was tested in the process area before installation and the background was measured to be about 1 coincident count/s. The instrument is capable of assaying material quantities as low as a few tenths of a gram.

Fig. 7. Installed glovebox well and support stand.

Fig. 8. The 15 ^3He tubes supported by the high-voltage distribution junction box are being lowered into the moderator. The cadmium liner about the moderator and the partially stacked polyethylene shield are also shown.

Fig. 9. Completed assembly of the in-line thermal-neutron coincidence counter.

The original function of the in-line TNC was to measure residues from various recovery processes. Hence, the detector design emphasized sensitivity by maximizing efficiency. After the TNC was installed, a new process was initiated in the recovery area whose product was 1-kg cans of PuO_2 . These cans were weighed and sampled for chemical analysis but a more timely verification was also requested. Because of excessive deadtime due to the high counting rates from these cans, the TNC was modified to operate at lower efficiency when making these verification measurements.

Phase I operating experience included work with both in-line and out-of-line TNCs. The in-line TNC measured samples with relatively low loadings, which are representative of recovery residues, and verified samples of high loadings, the 1-kg PuO_2 cans. Out-of-line development of neutron coincidence counting went on in parallel at DP Site and in the LASL safeguards laboratory. Appendix C describes the out-of-line development effort.

Table VI presents data taken with the in-line detector at full efficiency on 10-g samples. The scatter of results indicates a relative standard deviation of 9% with no detectable bias, which is an acceptable performance for residue measurements.

TABLE VI
DATA TAKEN WITH IN-LINE TNC, ALL 15 ^3He TUBES CONNECTED

<u>Sample</u>	<u>Percent ^{240}Pu</u>	<u>Chemical Analysis (g Pu)</u>	<u>TNC (g Pu)</u>
LAO 37	11.73	8.75	9.56
LAO 38	12.04	8.68	8.49
LAO 39	11.88	8.63	8.57
LAO 40	11.86	8.76	8.08
LAO 41	11.39	8.75	8.54
LAO 53	11.85	8.73	8.45
LAO1028	11.91	8.76	7.71
LAO1030	11.97	8.76	9.94
LAO1032	11.79	8.77	9.09
LAO1042	11.85	8.70	8.43
Total plutonium		87.29	86.86

To reduce the detector efficiency for the PuO_2 verification measurement, 10 of the 15 ^3He tubes were disconnected. Only one appropriate standard of a comparable plutonium loading was available for calibration at the time these measurements were made. A set of standards that completely span the range of the assay samples will give more accurate results. This is particularly true in this case where the response is nonlinear due to self-multiplication (Appendix C). Table VII presents the results. Each can was counted for 100 s, which resulted in counting statistical uncertainties of 4.5%. Calculation of the standard deviation based on the nine items gives the same value, indicating that the major source of random uncertainty is counting statistics. Pooling the nine data points indicates that in a 900-s count time a verification measurement with a 1.5% uncertainty could be obtained.

Based on the experience with this counter and the parallel development work, design improvements are being incorporated into the TNC systems for the new facility. A more reliable lifting mechanism was designed to replace the pneumatic piston used in the DP Site counter that had not worked well. We decided to design all the TNCs at the new facility so that they could be easily switched between two efficiency values to extend their range of applicability. All the electronic components were redesigned for improved

TABLE VII
DATA TAKEN WITH IN-LINE TNC, ONLY 5 ^3He TUBES CONNECTED

<u>Sample^a</u>	<u>Chemical Analysis (g Pu)</u>	<u>TNC (g Pu)</u>
LA059C1	874	844
LA059C2	874	883
LA059C3	874	872
LA059C4	874	927
LA059C5	874	848
LA059C6	874	859
LA059C7	874	945
LA059C8	874	946
LA059C9	874	871
		$\bar{x} = 880 \text{ g}$
		$s = 40 \text{ g}$

^aPercent of $^{240}\text{Pu} = 11.89$.

performance with this type detector. We decided to add a microprocessor-based data analysis module to the system. This unit will guide the operator through the measurement and calibration process and will also reduce the data to final results. Finally, we will make available complete sets of standards for calibrating the TNCs.

DP SITE COUNTING ROOM

Off-line NDA instrumentation has been in operation at the DP Site counting room for a number of years. The primary function of these measurement systems to date has been to measure material entering the recovery facility either from within LASL or shipments from outside organizations, or material leaving for burial. At the new facility the counting room will take on the added responsibility of verifying all shipments entering or receipts leaving the new facility. Present instrumentation consists of two segmented gamma scanners, one for large items (up to 114 L) and the other for smaller items (2-L size) and two thermal-neutron coincidence counters, again 2-L and 114-L capacities. During Phase I, a computer system was added to control and analyze data from the two TNC units (see Appendix C). At the new facility all the counting room instrumentation will be linked to the DYMAC computer. At DP Site, to prevent unforeseen problems, an interface for data transmission between the SGS and the NOVA 840 computer was satisfactorily built and tested. The TNC interface is an integral part of the TNC data analysis computer.

The DP Site counting room instrumentation is being used to develop a measurement control program, which will play an important role in the DYMAC system at the new facility.

MEASUREMENT CONTROL PROGRAM

It is essential that the measurement information contained in the DYMAC data base be accurate and the accuracy quantified. To accomplish these ends, a measurement control program, under computer control, will monitor the individual performance of some 30 NDA instruments tied to the DYMAC system at the new facility. A prototype control program was designed and operated for the four NDA instruments in the DP Site counting room. This system was not under computer control: the data was manually entered in logbooks. A copy of the counting room program, given in Appendix D, specifies procedures for

calibration and measurement precision, and accuracy verification including frequency of verification, control parameters, and action limits denoting out-of-control conditions. Figures 10-13 show actual control parameter data collected over a 3-month interval for all four systems. The χ^2 control charts examine whether the precision of a particular instrument is within expected limits; the t parameter tests whether the instrument calibration is correct.

When the measurement control program was first implemented, the χ^2 precision control parameter demonstrated its value by detecting an electrical problem in the 2-L TNC. The problem appeared as we were making a series of 15 replicate measurements with the 2-L TNC. We compared each machine-calculated standard deviation, based on the Poisson distribution, with the standard

Fig. 10. Control charts for 2-L SGS.

Fig. 11. Control charts for 114-L SGS.

deviation of the replicate measurement values. Table VIII shows the replicate values and their Poisson standard deviations. The average Poisson standard deviation was 349.3, whereas the standard deviation of the replicate measurement values was 1597.8. The χ^2 parameter is given by

$$\chi^2 = s^2 / \bar{\sigma}^2,$$

where σ and s are the Poisson and replicate standard deviations, respectively. For the series of 15 measurements, we found the value of the χ^2 parameter to be 20.92. When the instrument is operating correctly, the χ^2 distribution for 15 measurements should give χ^2 parameter control limits of 1.69 at 95% confidence and 2.08 at 99% confidence. Therefore, the measured χ^2 parameter indicated that the instrument was out of control. We

Fig. 12. Control charts for 2-L TNC.

installed a more effective instrument ground to correct the problem. Inspection of the data in Table VIII might have resulted in the same conclusion as that reached by the χ^2 parameter, but use of the parameter provided a sound statistical basis for the decision.

Once the grounding problem was solved, the current t and χ^2 control charts have indicated very stable instrument performance. However, a careful examination of the χ^2 chart for the SGS 114-L count shows that the points lie below the expected value of 1, which indicates that the data analysis program has overestimated the uncertainties. Although it is not quite as obvious, the same situation is true for the TNC 2-L counter. The distribution of the t parameter also indicates a problem with calibration for all four

Fig. 13. Control charts for 114-L TNC.

measurement systems. For the gamma-ray devices, t appears distributed at a positive nonzero value, whereas for the neutron counters it is negative. The problem could lie in the assumption of calibration linearity, accuracy of the standards, or uncorrected variation in standard response due to matrix effects. Each of these problems is being investigated as part of the continuing development of measurement control techniques for NDA instruments.

Experience to date demonstrates the effectiveness of the measurement control parameters in identifying certain problems. A necessary addition to the program will be the comparison of NDA assay results, when appropriate, for production (unknown) samples with analytical chemistry or calorimetry results.

TABLE VIII
 χ^2 EVALUATION OF NEUTRON WELL
 COINCIDENCE COUNTER DATA

<u>Reals</u>	<u>Uncertainties</u>
73138	352
73594	353
74193	354
73288	353
73888	353
68678	341
71483	348
70318	345
71518	347
71019	347
70047	344
72553	350
72817	350
73108	351
72998	351
$\bar{x} = 72176$ $s = 1597.8$	$\bar{\sigma} = 349.3$

OTHER APPLICATIONS OF NDA MEASUREMENT CAPABILITY

The interaction of instrument developers and process operators with the instruments during Phase I has led to NDA applications in areas other than material control. Appendix E contains articles excerpted from recent LASL safeguards progress reports about other NDA applications:

- field verification of metal buttons,
- neutron monitoring of a direct metal-to-oxide reduction process, and
- filtrate studies for process development.

CHAPTER 4

DATA COMMUNICATIONS

The basic DYMAC configuration consists of a network of instruments and terminals that communicate with a central computer. The quantity of data sent by a given NDA instrument to the computer will be small; likewise, computer signals to the instruments will consist of only a few control characters. Thus, there will be no need for high-speed communication links with DYMAC instruments. Instead, emphasis for these communication links is on reliability because system integrity depends on the assay value obtained by the instruments.

The terminals transmit to the computer transaction information entered by plant operators when materials move or when they undergo chemical or physical change. The volume of data from the terminals will be greater than that from the instruments; however, data transmission rates will be governed by the operator's ability to enter information at a keyboard. The computer will send voluminous data to the terminals, consisting of prompts and messages to the operator and structuring for transaction entries. By using video display and high-speed communication techniques for these links, the transaction process can be accomplished expeditiously with a minimum amount of operator boredom and frustration.

For the communication aspect of the DYMAC system, we have concluded that serial-by-bit transmission over twisted pair transmission lines represents a reliable and cost-effective approach. Character representation will conform to the American standard code for information interchange (ASCII). Different transmission rates will be used to accommodate the requirements discussed above. The rate for all instruments and for a few nonvideo terminals will be 300 baud, up to 4 800 baud for video terminals, and 9 600 baud for a few special cases where line printers are used to allow high-speed data listing.

At DP Site we tested different methods of driving the transmission lines and decided to use current-loop transmission at the new facility.

INTERACTIVE TERMINALS

The terminal is the point of contact between the operator and the DYMAC system. The interaction between user and machine must therefore be as smooth and effective as possible. We considered three terminal types for DYMAC use:

video keyboard terminal, hardcopy keyboard terminal, and custom terminals with function keys and numeric pad. The first two types have a full alpha-numeric keyboard; one displays on a video screen and the other prints on paper. The custom terminal replaces the full keyboard with a smaller number of keys representing functions such as "move material from A to B." In addition to function keys, such a terminal will often have a 10-key numeric pad. The custom terminal is attractive in that data entry is simplified and requires no knowledge of a typewriter keyboard. However, considering the variety of processes at the new facility, we decided that the function key approach would give the system neither the input capability nor the flexibility it needed. Therefore, we chose keyboard terminals for the DYMAC system. Both types, video and hardcopy, are used--video for its speed of response and hardcopy when a printed record is required.

Two additional features were considered for inclusion as part of the terminal hardware: personnel identification (e.g., badge reader) and automatic item identification (e.g., card reader or bar code reader). We decided to do more development work before making a choice, and will include these features at a later time. The present setup handles personnel identification through the keyboard with the option of a nonprinting code word.

During Phase I, we exposed process operators to the terminals during a series of training sessions. They learned how a computer system works and were able to practice entering real nuclear material transaction data at the terminals. They were enthusiastic about using the terminals. A more extensive training program for the new facility will certify operators to use the DYMAC system.

CHAPTER 5

DATA BASE MANAGEMENT

The DYMAC system is designed to maintain a timely and accurate inventory of SNM within a facility. The inventory must show current balances of SNM at any time and document how it arrived at that point. Maintenance of the inventory, then, is quite dynamic because SNM is constantly on the move within a facility. This inventory is kept current through information transmitted from the processing areas. Traditionally, this has been called an accounting function. The inventory is multipurpose in that it contains information about process status and performance, and financial and material management, in addition to material control. This information is used for process planning and to fulfill reporting requirements to ERDA and the Nuclear Materials Management and Safeguards System (NMMSS).

The DYMAC accounting subsystem has developed from the current LASL accounting system (LAS) for nuclear material. One of the important activities of DYMAC Phase I was to understand LAS in depth and adapt it to DYMAC goals. To this end, we installed an existing NOVA 840 computer at DP Site and wrote software to emulate LAS. Although the DP Site prototype configuration was not ideally suited to this purpose, it nevertheless provided a means for obtaining operating experience, which we needed to specify the hardware/software computer system for the new plutonium facility. Once the prototype successfully duplicated the functions of LAS, important additional features were coded, features that could only be implemented with an on-line, interactive system. From this testing and evaluation with the DP Site prototype grew the design specifications for the TA-55 data base management subsystem and the computer system needed to implement the accounting functions.

CURRENT SNM ACCOUNTING SYSTEM AT LASL

The current LASL accounting system for SNM has been in use for the past 15 yr and has evolved largely through the efforts of Group CMB-11, which handles about 80% of the SNM transfers at LASL. The system works well. However, things have changed since the system began operation 15 yr ago. There has been a notable upgrading of in-line measurement. At the same time, the public has grown increasingly aware of the potential for diversion. These two developments underscore some major drawbacks of LAS.

For one, LAS is not timely and therefore is inaccurate except at certain well-defined points in time. When SNM changes location or form, or enters the custody of another operator, Group CMB-11 records a transaction on multipart paper forms. It sends one copy of the complete form to the SNM accountability group at LASL, which keypunches it onto an 80-character card. (The 80-character limit is yet another drawback of LAS: not enough information can be entered on a card to completely describe the inventory item or the transaction.) At mid-month, and again at the end of the month, the transactions are run through a program that uses the previous period's ending balances (book) and the current period's activity to calculate the new ending balances, or book. This information forms the basis for various management and accountability reports that are then generated. The new book is placed on magnetic tape for use at the close of the next period. If it becomes necessary to produce a current book, it can be generated in 8-10 h provided that all of the transactions are already written and keypunched, an unlikely event.

Another drawback is the widely used method whereby a small sample is submitted for radiochemistry or chemical analysis. Although this method produces a fairly accurate measurement, it requires 5-10 working days to complete. Meanwhile, the lot of SNM has moved on through processing at a best-estimated value. When the analytical measurement becomes available, a supervisor corrects the book by writing transactions to or from certain nonphysical accounts, e.g., MIP (material in process) and MUF.

Most transactions entered into LAS are verified by a supervisor, but mistakes do occur. This is the perennial problem with manual entry--garbage in, garbage out--and another drawback of the system. These mistakes will go undetected until the published book can be compared with the physical inventory. Again, the correction procedure is to write the necessary transactions to correct the book. Corrective transactions in this case and the analytical measurement case are indistinguishable from operational transactions.

The transaction form is the keystone of the accounting system. It contains the information that describes the physical activity in the facility. Figure 14 shows the LAS transaction form currently in use. It contains 25 fields (items of information), which are used to describe processing activity. LAS has the mechanism for unit-process balancing: the transaction form contains a field that can be used to denote a unit process (called a receipt

SS TRANSACTIONS

[illegible]

REMARKS: (GIVE ALL DETAILS NEEDED TO COMPLETELY DESCRIBE ITEM, SUCH AS TYPE AND CONCENTRATION OF ACID OR ACIDS, TYPE & CONCENTRATION OF ORGANICS, FORM OF MATERIAL (SOLUTION, METAL, OXIDE, PLASTIC, ETC.) CONCENTRATION OF CONSTITUENTS, ETC.)

BULK VOLUME OR WEIGHT — UNITS CODE	
CODE	UNITS
1	GRAMS
2	KILOGRAMS
3	MILLILITERS
4	LITERS
5	CONTAINERS
6	LOTS

ISSUED BY _____ **GROUP** _____

RECEIVED BY _____ GROUP _____

TRANSFERRED BY _____
NAME _____ **DATE** _____

POSTED BY _____ CHECKED BY _____

FORM NO. 10-4

PUNCHED BY _____

VERIFIED BY _____

SERIES AC
S 978

WHITE AND PINK COPIES TO A-3

YELLOW COPY TO RECEIVER

GREEN COPY TO SENDER

Fig. 14. LAS transaction form.

area, RA). Operators are required to write a transaction when a material batch crosses a unit-process boundary, and to obtain a measured value for the material. A printout of balances by receipt area is used to control material by unit process.

DYMAC ADAPTATION OF ACCOUNTING SYSTEM

The design of the DYMAC accounting subsystem began with the basic LAS structure and added new features:

- entry of transaction information via interactive terminal,
- direct entry of on-line measurement results,
- real-time updating of the inventory file,
- on-line access to the inventory file, and
- an incomplete transaction file, ITRAN.

These additional features dramatically change the operation and timeliness of the system. The transaction form is no longer limited to 80 characters. In fact, the inventory record at the new facility will be close to 200 characters. Now that the inventory file is on line, the operator need only enter those fields that uniquely identify the item and those fields that are to be changed by the transaction; the data base fills in the rest of the transaction. The computer can immediately check the incoming transaction information for certain errors. It prints out diagnostic messages to the operator if the input does not conform to what it expects. This reduces the number of inaccuracies in the inventory file, which, in turn, reduces the number of false alarms due to input errors. Because the inventory file can be updated in real time and accessed on line, the custodian and the process operator can always obtain the current status of the material, enabling them to compare the physical inventory situation with the book inventory at any point in time. The availability of measurement values through in-line instrumentation allows unit-process balances to be drawn and examined immediately for any problems.

The incomplete transaction file (ITRAN) keeps track of material shipments within the facility. As material leaves a location, the operator notifies the system. The inventory record associated with that item is placed in the ITRAN file along with the clock time of shipment. When the item arrives at its destination, the new custodian completes the transaction and the record is removed from ITRAN. If the item does not arrive within a predetermined time,

the DYMAC system alerts the nuclear materials officer who immediately investigates the cause of the delay. Only with the advent of a real-time system can the ITRAN feature become possible.

ACCOUNTING SYSTEM ACTIVITIES DURING PHASE I

Parallel Runs

The programming team wrote a prototype accounting system, which duplicates LAS, to execute on the NOVA 840. The prototype system accepts 80-character transaction information that is entered through a terminal keyboard, stores it on two disk files (inventory and activity), sorts the records into the LAS format, and prints the results for comparison with LAS runs. The activity file contains all transaction information, providing an audit trail for each inventory record.

A total of five parallel runs, involving thousands of transactions, compared LAS and prototype printouts. Discrepancies between the two printouts were tracked down and resolved. Most of the discrepancies resulted from the awkwardness of operating two independent systems in parallel. We discovered one fundamental problem, due to differences in rounding procedures, that was resolved by having the DYMAC system use the same procedure as LAS.

Evaluation of Parallel Runs

At the completion of the parallel run series, we were confident that the terminal-based prototype system could, at minimum, emulate LAS. From the parallel run experience, we draw certain conclusions that we will apply to the design of the TA-55 data base management subsystem:

- we must pay particular attention to disk file search times, in-core program capability, transaction traffic handling capability, and on-line sorting; and

- we must streamline the entry of transactions at a terminal to minimize information that describes a physical activity.

In addition, we discovered that

- process operators are receptive to the use of terminals, and
- on-line data diagnostics are extremely useful.

Drawing from Phase I prototype experience, we wrote specifications for the TA-55 computer hardware and software and submitted them for procurement.

Appendix F describes the system design and final choice of computer configuration.

The programming design team recognized that implementing the streamlined transaction procedures would require an innovative software approach. To accomplish this, they examined each transaction in a process flow for those fields that remain constant and those that require change. They programmed every transaction so that the operator need only fill in the fields that change. The operator begins by selecting the appropriate transaction from a list displayed on the terminal (see Chap. 6). The computer system then asks questions about those fields necessary to complete the transaction. This prompting procedure reduces the amount of typing and relieves the operator from remembering just what information he has to supply. Although these process-specific transactions reduce his effort, they increase the amount of software that has to be written for each transaction.

A new programming approach, called a packet, has simplified the coding of process-specific transactions. Transaction information is placed in files instead of in the operating code. The file approach makes it relatively easy to add or change a transaction because there is no need to recompile or reload the system. Using this approach, transactions were completely restructured in less than one working day using the NOVA 840. The transaction sequence for an entire process (metal-to-oxide conversion) was programmed in less than 2 weeks. Appendix F describes in some detail the DYMAC software design.

The Phase I prototype proved invaluable as a mechanism for defining the structure of the data base management subsystem, developing the techniques for programming, and specifying the computer system hardware and software.

CHAPTER 6

REAL-TIME MATERIALS CONTROL

The major function of real-time materials control is to compare the unit-process control parameters with alarm levels based on the limits of error associated with the control parameters. Two control parameters are presently in use: the unit-process batch balance and the cumulative sum of these balances, the cusum. Techniques have been proposed for monitoring cusum data automatically with the central computer, for example, the V-mask approach.⁸ The focus of the Phase I activities in this area was to

- collect unit-process data,
- examine the data to confirm its applicability for calculations of control parameters, and
- try the cusum monitoring technique.

PROTOTYPE DYMAC SYSTEM

To collect the unit-process data, a prototype DYMAC system was planned for installation at DP Site. This prototype was to follow material through a few unit processes, collect data, and draw the batch balances. The process chosen was an ash-leach line that could be expanded to include the ion-exchange (IX) and nitrate-to-oxide conversion processes. NDA instruments and terminals linked to the NOVA 840 were installed and tested for this purpose. Instrument installation and software development were essentially complete when ERDA requested that LASL convert from the ash-leach line to a metal-to-oxide conversion process because of programmatic commitments. We agreed to adapt the prototype evaluation activity to the new process. Because of the tight schedule, there was no time to install new equipment. This meant that certain of the original goals had to be dropped and others compromised. Nevertheless, we decided to continue the evaluation program.

DESIGN OF THE DYMAC PROTOTYPE FOR THE ASH-LEACH LINE

We include a description of the ash-leach process here because it illustrates the planning and considerations that go into the design of a unit-process balance area. Nor has all our work been lost: the ash-leach process will resume operation at the new facility. Figure 15 is a flow diagram of the

Fig. 15. Ash-leach process showing NDA measurement points.

ash-leach process. Material flow and types are identified by interconnected square boxes. DYMAC measurement points are indicated by round-cornered boxes.

Presently, most of the ash processed by LASL is generated at the Atlantic Richfield Hanford Co. (ARHCO) facility in Richland, Washington. The ash is a heterogeneous mixture averaging about 5-10 wt% plutonium. It is shipped in small, sealed cans.

Starting at the top of Fig. 15, each can is assayed for ^{239}Pu with an SGS, and for effective ^{240}Pu content with a TNC. These instruments are located in the counting room at DP Site.

The screening step removes fragments of glass, steel, lead, and graphite, which are called ash scrap. An in-line TNC assays the ash scrap. Recovery of the plutonium retained by the ash scrap involves pickling with a hot $\text{HNO}_3\text{-CaF}_2$ solution to dissolve the surface dust that contains the plutonium.

After pickling, the ash scrap is filtered. The filtrate, identified as ion-exchange feed, is assayed with an in-line plutonium solution gamma-counting system, the SAI. The small amount of plutonium retained by the ash scrap heel is assayed in the in-line TNC.

The amount of plutonium left in the clean ash after screening is calculated by subtracting the relatively small amount of plutonium retained by the ash scrap (about 2-5% of the total ash plutonium) from the total plutonium contained in the ash cans. Plutonium in the clean ash is recovered by leaching--selectively dissolving the plutonium from the matrix with a $\text{HNO}_3\text{-CaF}_2$ solution. After leaching, the slurry is filtered. The filtrate is identified as ion-exchange feed and the residue as ash heel. As with the ash-scrap recovery process, the filtrate is assayed with the in-line SAI and the ash heel with the in-line TNC.

A plutonium material balance is calculated by subtracting measured outputs from measured inputs. The ash scrap is accumulated for a few weeks before being processed. In contrast, clean ash batches are processed on a 2- to 3-day basis and account for about 95% of the plutonium entering the ash-leach process. Material balances are maintained for the clean ash portion of the ash-leach process on a 2- to 3-day basis.

Figure 16 shows the equipment that was installed in order to implement the prototype system around the ash-leach process.

METAL-TO-OXIDE CONVERSION PROCESS

In this process, plutonium ingots weighing approximately 2 kg arrive in the receiving area and are unpacked. Accumulated oxide is scraped from the ingot. The ingot is then cut into quarters. Each quarter ingot is dissolved in nitric acid and any residue filtered out. At this point various nitrate solutions are blended to ensure the proper isotopic composition of the finished oxide product. Peroxide is then added and the solution filtered. Americium is removed in the filtrate. The peroxide cake is redissolved with nitric acid, reduced, and precipitated with oxalic acid to form an oxalate cake, which is then calcined. Cans of this oxide are screened, blended, and canned for shipment.

Four unit-process accounting areas were defined as the prototype DYMAC system. Material flow, NDA measurement points, and balance areas are as shown in the Fig. 17 flow diagram.

Fig. 16. Prototype system installed at DP Site for the ash-leach process.

Receiving Balance Area. Input to this balance area is the ingot at the shipper's value. The measured outputs are the scraped oxide, the clean ingot, and the shipping materials. Any material remaining on the books is assigned to the shipper-receiver difference account.

Cutting Balance Area. Input is the measured clean ingot. The measured outputs are the four quarters, the metal sawdust, and the worn-out saw blades. Material remaining on the books is assigned to the MIP account for the cutting box.

Dissolution Balance Area. Input is the quarter ingot. The measured outputs are nitrate solution residues, undissolved metal, peroxide and oxalate filtrates, and the calcined oxide. Remaining book material here is assigned to the MIP account for the dissolution area.

- S SS VALUE AND % PURITY AT SHIPPER'S VALUE
W BULK WEIGHT MEASUREMENT X % PURITY = SS VALUE
F BULK WEIGHT MEASUREMENT X % PURITY X OXIDE FACTOR = SS VALUE
G SEGMENTED GAMMA SCAN MEASUREMENT OF ^{239}Pu MASS
SA SOLUTION ASSAY MEASUREMENT OF ^{239}Pu MASS
N NEUTRON COINCIDENCE COUNT OF ^{240}Pu MASS
Z RATIO OF VOLUME TO BE BLENDED TO THE INITIAL VOLUME

Fig. 17. Metal-to-oxide dissolution process showing NDA measurement points and material balance areas.

Screening Balance Area. Input is the measured calcined oxide and output is the measured product. Any differences are assigned to the MIP account for this screening area.

The SAI was used to measure peroxide and oxalate filtrate samples. Oxide product was weighed, canned, then measured with the TNC. The DYMAC system provided transactions to adjust the SNM value of these items upon receipt of the analytical results.

Because of the sudden change in process, the equipment and its location, as well as operation of prototype system, were not well matched to the process. There were specific problems concerning the equipment for the measurement systems:

- no electronic balances were located in the receiving or cutting areas,
- load cells were not installed on the proper solution columns,
- the SAI was used for residue rather than product measurement, and
- the TNC was used for product rather than residue measurement.

There were also some terminal-related problems:

- no terminals were located in the receiving or cutting areas, and
- the terminal in the ion-exchange room was not needed.

The DYMAC system monitored the metal-to-oxide conversion process in parallel with the LAS paper system for 6 weeks. The major operational difficulty was that the process operators were not allowed to make the transactions themselves because of the tight production schedule. Therefore, two members of the DYMAC staff had to "shadow" the process, making the transactions at the proper time. Often, this procedure led to delays between the physical processing of material and the writing of the transaction describing that activity. That is, timeliness was compromised. In addition, some process activity information was not communicated to the DYMAC personnel writing the transactions. These problems have reinforced our contention that persons who handle the material should themselves write the transaction.

TRANSACTION PROCEDURES

All aspects of the transaction procedure were given a thorough testing by the prototype system project. The file approach to coding transactions, discussed in Chap. 5, was used to produce transaction formats that are specific to each process. Process-specific transactions lessen the amount of information the operator must enter to write a transaction. They perform diagnostics

on his entries, which result in fewer data input errors. Because of the file structure, the process-specific transaction approach can respond quickly and relatively easily to process modifications.

The chemical process changed considerably from mid-December 1976 to mid-February 1977 during the prototype project operation. Most process changes required a corresponding modification to the software system. The option lists went through three major and several minor revisions in the 2-month period, yet the programmers were able to accommodate these changes.

Process-specific transactions are of two types: transactions used during normal processing, designed to be entered by operators; and transactions that deal with non-physical accounts, to be entered by supervisors. Normal processing transactions are for in-plant immediate transfers, sends, and receives. Supervisory transactions access MIP and shipper-receiver difference accounts, make adjustments to NDA-measured items, and correct transactions. Figure 18 shows option lists for both types of transactions. Operators can access the first type only; supervisors can access both.

OPTIONS
1= ENTER BUTTON
2= SCRAPED OXIDE
3= CLEAN INGOT
4= SHIPPING PS
5= QTR INGOTS
6= CUTTING PS
7= QTRS STOR TO PROC
8/9= NS SOLN (ALL/PART)
10= RESIDUES
11= UNDISSOLVED METAL
12= FS SOLN
13= FS TO PEROXIDE CAKE
14= FS REDISSOLVED
15= FS TO OXALATE CAKE
16= CALCINE
17= PEROXIDE FILTRATE
18= OXALATE FILTRATE
19= FILTRATE TO ION-EXCHANGE
20/21= SCREENING (521,523 / 528)
22/23= SAMPLES (CMB-1 / ARCHIVE)
24= CANNED OXIDE (NCC)
25= REJECTED OXIDE
26= PROCESS SOLIDS TO DRUM
27= *** GENERAL TRANSFER ***
ENTER OPTION *

a. Operator options.

SUPERVISORY TERMINAL OPTIONS
1 = SHIP/REC DIFFERENCE
2 = CUTTING MIP
3 = MF/FS MIP
4 = SSA CORRECTION
5 = SCREENING MIP
6 = NCC CORRECTION
7 = TRANS REVERSAL
ENTER OPTION *

b. Supervisor options.

Fig. 18. Examples of transaction options available for the metal-to-oxide conversion process.

We changed the prototype system to provide for corrective transactions in response to the need for a straightforward way to "back out" a transaction. We implemented a REVERSE option that allows a supervisor to scan the transaction activity (TRAN) file, identify a particular transaction and edit it, after which the system reverses the transaction. The capability to scan the TRAN file has proved useful in other instances, too. All corrective transactions are flagged with a special transaction number to make them easily distinguishable from transactions describing physical actions.

When prototype operation first began, only one terminal was on line. The computer could simultaneously handle program development and process transactions. Because of the number of transactions, a second on-line terminal was added midway through the project. A total of 1 858 transactions were written during the 6 weeks of operation.

PROCESS PROCEDURE PROBLEMS

For unit-process balancing to be effective, all recycled material must be measured. (This point is discussed in Appendix A.) A situation occurred in the dissolution area that violated this principle. Undissolved metal from one lot was recycled in the dissolution pot with metal from the following lot without measurement. The material batch balances showed erratic behavior, which led to the discovery of the problem. The procedure was corrected by requiring a weight measurement for the recycled metal. This episode demonstrated a situation to be avoided at the new facility.

During the 6-week operation of the prototype, a total of 56 000 g of plutonium were converted from metal to oxide. The cusum material balances in the four areas at the end of the operation were:

receiving area	15 g
cutting area	10 g
dissolution area	-48 g
screening area	-566 g

The screening balance was due to a bias in the TNC measurements and the fact that analytical values were not available at the time the balances were drawn. The TNC bias problem was due to deadtime losses, which were corrected, as reported in Chap. 3. One large material balance anomaly in the screening area was detected by the system; an investigation located the material.

Figure 19 shows the cusum chart for the cutting area. It shows the buildup of cusum probably due to scrap and a decrease once the scrap is measured. The chart, while within limits, shows some erratic behavior. For example, the step-like behavior makes it difficult to apply automatic monitoring techniques that look for deviations from smooth trends and which would identify the steps as anomalies. We investigated the causes of the behavior and found that it was due in part to not writing the transactions in a consistent fashion. This pointed out that the monitoring techniques are sensitive to deviation from expected behavior. We conclude from Phase I activities that more operating experience is necessary before automatic monitoring techniques can be used routinely.

Fig. 19. Cumulative sum chart for cutting unit-process area.

CHAPTER 7

SUMMARY OF PHASE I EXPERIENCE

Based on Phase I experience, the design, fabrication, and installation of the DYMAC hardware and software at the new plutonium facility is proceeding smoothly. Although Phase I did not provide all the answers, it was a necessary step in the process of designing a realistic and reliable DYMAC system. From this test-and-evaluation phase, we can summarize our results and draw certain conclusions from them.

We were able to operate instruments in a glovebox environment and detect instrument performance problems. On the whole, NDA instruments performed well inside the glovebox environment at DP Site. We were able to identify operational problems and incorporate design changes in the instrumentation for the new facility: we changed the design of the lifting mechanism for the TNC, instigated a more accurate sample-taking procedure for the SAI, and imposed tighter specifications for electronic balance performance. Background problems occurred for thermal-neutron coincidence counters from (α, n) reactions in impure oxides and for the solution assay instrument from americium gamma rays in peroxide filtrates. We are incorporating additional diagnostics in each instrument system to detect these conditions. The measurement control program demonstrated that the control parameters could detect instrument performance problems. We were able to make a few refinements to the control parameters and procedures, based on 3 months of operating data.

In the area of communications our Phase I experience helped us select communications lines and terminals for the new facility. We decided to use current loop transmission for the communications lines. Data transmission from NDA instruments to the DYMAC computer will be identical to that of the terminals, namely current loop, ASCII characters, with echoing in either direction. We were able to specify the hardware and software interface between NDA instruments and the DYMAC computer. Video terminals will be installed in the process areas; hardcopy terminals will be available in the supervisors' offices. We elected to use commercial keyboard terminals because they afford flexibility and cost less than custom terminals. However, these off-the-shelf terminals will require more effort on the part of the users.

The DYMAC system is built on the existing LASL accounting system. It has an expanded data base with on-line access to it for reports. Updates to the

data base are by transactions that are entered at interactive terminals. Phase I experience demonstrated that process operators are receptive to entering transactions at terminals, provided the time and number of entries necessary to complete a transaction are reasonable. We streamlined the transactions for processing areas and specialized them to reduce the amount of information the operator has to enter. We adopted a packet software approach that enables the programmer to change any specialized process transaction in one working day. Based on the experience of entering, sorting, and printing thousands of transactions, we were able to write the computer hardware and software specifications for the new facility.

In the area of real-time materials control, we worked with the metal-to-oxide conversion process to apply the principle of unit-process balances. We broke the process into four unit processes and made cusum charts for each unit process. The charts proved their usefulness as a tool for materials control. However, further work is necessary before the V-mask technique can be used for automatic computer monitoring of the cusum trends. Our experience demonstrated that the process procedures must be consistent with the basic assumptions of unit-process dynamic balancing; if they diverge, control is lost. For example, the practice of recycling material without measurement led to a problem in monitoring the metal dissolution process.

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REFERENCES

1. J. M. de Montmollin and R. B. Walton, "The Design of Integrated Safeguards Systems for Nuclear Facilities," J. Inst. Nucl. Mater. Management V (III), 317-332 (1976).
2. G. R. Keepin and W. J. Maraman, "Nondestructive Assay Technology and In-Plant Dynamic Materials Control--'DYMAC'," Proc. IAEA Symp. on Safeguarding Nuclear Materials, Vienna, October 1975, IAEA-SM-201/32, Vol. 1, pp. 305-324.
3. J. P. Stewart, "Operating Experience in the Nondestructive Assay of Fissile Material in General Electric's Nuclear Fuel Facility," Proc. IAEA Symp. on Safeguarding Nuclear Materials, Vienna, October 1975, IAEA SM-201/8.
4. J. E. Lovett, "Concepts of Real Time and Semi-Real Time Material Control," J. INMM III (IV), 24-30 (1975).
5. E. R. Martin, D. F. Jones, and L. G. Speir, "Passive Segmented Gamma Scan Operation Manual," Los Alamos Scientific Laboratory report LA-5652-M (July 1974).
6. E. S. Page, "Cumulative Sum Charts," Technometrics 3 (1), 1-9 (February 1961).
7. T. D. Reilly and J. L. Parker, "A Guide to Gamma-Ray Assay for Nuclear Material Accountability," Los Alamos Scientific Laboratory report LA-5794-M (March 1975).
8. D. D. Cobb, D. B. Smith, and J. P. Shipley, "Cumulative Sum Charts in Safeguarding Special Nuclear Materials," submitted to Technometrics.

APPENDIX A

UNIT-PROCESS STRUCTURE

Dynamic materials control is based on a unit-process accounting structure in which a material balance is drawn around a portion of the plant process (we call that portion a unit process) in a dynamic fashion.^{A-1} A unit process is a physical area through which nuclear material passes. We measure all nuclear material that crosses the unit-process boundary. From the incoming and outgoing measurements, we can draw a material balance for a specific unit process. A unit process might consist of a single dissolver tank, an ion-exchange tank, a pellet press, or an entire processing line. The choice of unit-process boundaries depends on (a) how well the nuclear material needs to be localized in space and time and (b) whether we have the capability to measure the material at the boundary.

A control system based on the unit process is dynamic in the sense that we can draw balances without shutting down the process. We do not expect a unit process to have a balance of zero: the balance will instead reflect holdup and unmeasured scrap and waste in that process as well as any missing material. The DYMAC system compares the material balances for each unit process with a preset alarm level; if a balance exceeds the alarm level, we shut down that particular unit process and clean it out to determine the cause of the excessive accumulation. The alarm-level control allows us to base our decisions concerning cleanout and measurement of scrap and waste on the day-to-day performance of the process. After cleanout, if the balance for the unit process continues to exceed the alarm level, we must investigate further.

The control function assumes an added dimension because the system is in real time. We use the term real time in the sense that the computer is kept as up-to-date as possible concerning the status of every unit process. We keep the computer up to date by linking it directly to terminals in the process area and to instruments that measure material in-line.^{A-2} Every time the status of the material changes during processing (whether it be a change in location, name, amount of nuclear material, or form), the process operator steps over to the terminal in his area to update the computer inventory. Using the current inventory, the DYMAC system draws balances, calculates control parameters, and compares the balances with the alarm levels in, essentially, real time.

The unit-process approach has certain requirements. Consider the plant to operate on a batch basis, however large the batch or short the time between batches. Each batch enters the unit process on a measured basis. All combining of batches must be recorded. Any material to be recycled must be measured before recycle. Waste, scrap, and product must be measured on their way out of the unit process. Given these requirements, material balances can be drawn that provide a known level of material control.

We shall illustrate this with a simple example of a unit process (see Fig. A-1). We decide to draw the unit process around a powder-blending operation. Three cans of PuO_2 powder are brought into the unit-process area, opened, and poured into a V-blender. The blender powder is put into a larger can and sent out of the unit process.

Let us go through the powder-blending unit process step by step. The operator measures the incoming powder. His choice of measurement technique will depend on what is known about the material. Is its isotopic composition known? Have we confidence in the value given for grams of plutonium per gram of sample? If we can answer yes to both questions, then a net weight measurement for each container will suffice. Otherwise we will have to use chemical analysis and/or NDA techniques. The operator performs the measurements and notifies the DYMAC system that three cans of PuO_2 at their measured values entered the process. He opens the cans, pours them into the V-blender where they are blended, then pours them into a larger container. He notifies the DYMAC system that he has combined the three cans into one batch. The DYMAC

Fig. A-1. Schematic of a DYMAC unit process.

system now has an expected value for the combined batch based on the input measurements, including a properly averaged isotopic composition.

Before the combined batch leaves the unit process, the operator measures it. If the grams of plutonium per gram of sample can be determined, with confidence, from a weighted average of the three input values, then he simply weighs the batch. Otherwise, he will have to support the weight with chemical analysis or an NDA technique such as neutron-coincidence counting. Let us assume that weighing alone is appropriate: the operator performs the measurement and enters the information into the DYMAC system.

At this point, a type of material balance can be drawn, namely the difference between the input feed and output product. The balance reflects how efficient the unit process is. It may or may not be a valid control parameter, depending on the value of the material balance and how constant that value is.^{A-3} The DYMAC system compares the balance for each batch with an alarm level for that unit process. If the balance is less than the alarm level, the unit process is said to be under control and processing continues. If it is greater, corrective action must be taken, such as shutdown and clean-out of the unit process that is out of control.

In our example, the operator may have spilled powder while pouring it into the blender. Were he to pour the unmeasured spillage into the next batch, separate control of the first and second batches would be lost. A balance could still be drawn around both batches, but timeliness would be sacrificed. Instead, if the material balance exceeds the limits, he must clean up and measure the amount that he spilled. We subtract this amount from the balance to bring the balance within limits.

In any process, waste is generated. In our example, three empty cans remain. We must measure the waste in them. In this case, nondestructive assay has definite advantages over other measurement methods. We can measure the waste on a batch-by-batch basis or allow it to accumulate for some number of batches before measurement. We base our decision on the quantity of waste material that can accumulate by comparing the material balance and the control limit.

The same consideration is true for process holdup. It builds up in the filters and on the walls and floors of the glovebox as processing proceeds. Periodically, at a time determined by the control limits, the unit process is

cleaned out. The holdup that is difficult to remove can be measured in place.^{A-4,A-5}

We set the alarm level for the material balance to be sensitive enough to detect a single theft within the transient time of the batch through the process. The amount that can be detected depends on the measurement uncertainties, the unmeasured scrap and waste, and the holdup. Shipley et al.^{A-6} give representative values for unit processes in a mixed-oxide fuel fabrication facility. The cumulative sum (cusum) of the batch balances, i.e., the material balance for the unit process, provides information about the buildup of in-process holdup, bias in measurements, unmeasured sidestreams, and multiple-theft diversion.

To illustrate the cusum control feature, a simple Monte Carlo model of a unit process has been constructed. The MUF for each batch of material going through the unit process is the difference between the measured input I to the process, and the product P and residue R leaving the process:

$$\text{MUF} = I - P - R \quad .$$

The model assumes that the measurements of input, product, or residue are distributed normally about the true value (I_0 , P_0 , or R_0) with appropriate standard deviation σ_I , σ_P , σ_R . In this example, I_0 , P_0 , and R_0 were assigned the values 1 000 g, 900 g, and 100 g, respectively. Each measurement was assumed to have an associated standard deviation of 10 g so that each MUF estimate has an estimated standard deviation of 17.5 g. These values are typical for many processes. The model further assumes that 100 such batches of material pass through the unit process between physical inventories. Thus, the process treats 100 kg of material in this period. Because diversion is of primary concern to safeguards, the results are discussed in terms of diversion. However, the results and conclusions apply equally to holdup in process equipment or any other cause of a real nonzero MUF.

Three situations were considered: no diversion, uniform diversion, and random diversion. Because a material balance is drawn around each relatively small unit of material passing through the process, a potential diverter who wants to acquire any significant amount of material is forced to remove a sufficiently small quantity from each batch so that the measurement uncertainty will mask his activity. This not only increases the probability that he will

be observed in the act of theft, but also increases the chance that the loss of material will be detected before he has obtained a significant quantity. For the case of uniform diversion, the diverter obtains 1 kg of material by taking 10 g from each of 100 batches of material passing through the process. Because this amount of material is less than one standard deviation of the measured value of the MUF for any single unit of material, its removal from the process would go undetected.

Control chart results of the accumulated MUF for no diversion and for uniform diversion are shown in Fig. A-2 in the form of cusum plots. The midpoint of each bar represents the sum of the MUF values measured for all previous units of material passing through the process, and the length of the bar represents the estimated error (standard deviation) associated with the sum. Without an estimate of the error it would be difficult, if not impossible, to determine whether the value of MUF is significantly different from zero. The value of the cumulative MUF at the end of the period when 100 kg of material have passed through the unit process corresponds to the MUF value that would have been obtained at physical inventory. Because the value for the case of

Fig. A-2. Accumulated MUF for a unit process as a function of successive batches. Data were generated using a simple Monte Carlo model. The upper curve is for uniform diversion of 10 g from each 1-kg batch; the lower curve is for the same throughput but with no diversion.

no diversion is within one standard deviation of zero, we conclude that the data do not indicate missing material.

From the chart for the case of uniform diversion, also shown in Fig. A-2, the value of MUF and its associated error at physical inventory indicate that material is indeed missing. However, if only this value is available for the total MUF for the period between inventories, a diverter may have obtained his entire target quantity of material weeks or even months before it is detected as missing. The cusum chart, however, would arouse suspicion after the diverter has removed only a few tens of grams of material. Similar results were obtained for the case of random diversion.

To summarize, the DYMAC system follows the flow of nuclear material through a processing facility from one unit process to the next in as near real time as the processing allows. The DYMAC system compares the material balances and the cumulative sum of these balances for each unit process to alarm levels. If either the material balances or their cumulative sum exceeds the alarm level, we can quickly pinpoint the unit process and study it to determine the cause of the alarm. In addition, the system compares and correlates the information from sequential unit processes, thus providing checks and balances that ensure that no one has circumvented the system. With this approach, more incisive material control is possible without having frequent facility shutdowns and cleanouts.

REFERENCES

- A-1. J. E. Lovett, "Concepts of Real-Time and Semi-Real Time Material Control," Nucl. Mater. Management III (IV), (1975).
- A-2. R. H. Augustson, "Development of In-Plant Real-Time Materials Control: The DYMAC Program," Nucl. Mater. Management V (III), (1976).
- A-3. J. E. Lovett, "In-Plant Dynamic Materials Control, An International Perspective," Nucl. Mater. Management V (III), (1976).
- A-4. C. H. Kindle, "In-Situ Measurement of Residual Plutonium," Nucl. Mater. Management V (III), (1976).
- A-5. J. W. Tape, D. A. Close, and R. B. Walton, "Total Room Holdup of Plutonium Measured with a Large Area Neutron Detector," Nucl. Mater. Management V (III), (1976).
- A-6. J. P. Shipley et al., "Coordinated Safeguards for Materials Management in a Mixed-Oxide Fuel Facility," Los Alamos Scientific Laboratory report LA-6536 (February 1977).

APPENDIX B

DP SITE PLUTONIUM OPERATIONS (R. S. Marshall)

The LASL DP Site plutonium facility processes two types of isotopic plutonium materials. Material in which ^{239}Pu is the predominant isotope is fissile and is used in nuclear weapons work and reactor fuels development. The ^{238}Pu isotope has a relatively short life, and material in which it is the predominant isotope is used as a power source for space probes.

The ^{239}Pu work at DP Site is sponsored by the ERDA Divisions of Military Application (DMA), Reactor Development and Technology (DRDT), and Production and Materials Management (DPMM). The ^{238}Pu work is sponsored by the ERDA Divisions of Space Nuclear Systems (DSNS) and Applied Technology (DAT). DMA work is concerned with the development of nuclear devices, including metallurgical and chemical research-and-development studies of plutonium and its alloys and compounds. The DRDT effort investigates the suitability of various promising ceramic materials that contain plutonium as potential fuels for use in the liquid-metal fast-breeder reactor (LMFBR) program. The mixed plutonium-uranium-carbide system is under extensive investigation. DPMM work studies reclamation of plutonium in scrap from other facilities. A few ERDA agencies sponsor a minor amount of miscellaneous plutonium work at DP Site. DSNS work with ^{238}Pu includes fabrication of heat generators for space probes as well as metallurgical and chemical research and development of ^{238}Pu metal and compounds.

GENERAL ROLE OF DP SITE IN NUCLEAR WEAPONS PROGRAMS

Fabrication

The development of fabrication techniques and characterization of properties of the metals and alloys used in weapons is vitally important to the production and improvement of weapons. LASL conducts a continuing program to apply past techniques and to adapt and improve them for specific or routine applications in the production plants.

The classical method for preparing plutonium metal--bomb reduction of PuF_4 with calcium--was developed at LASL and is still used by production facilities. This method produces 99.9 wt% pure metal with an overall yield of 98%. Recent research and development concerning direct oxide bomb reduction

has tried to eliminate the intermediate product, PuF_4 . This revised reduction process would substantially reduce neutron radiation exposure to personnel and reduce waste materials associated with the classical process.

Electrorefining processes have been developed at DP Site that further purify plutonium metal to 99.99 wt%. Attainment of this high-purity metal has permitted reassessment of all those physical and chemical properties of plutonium metal that are influenced by impurities. Very high purity metal prepared and encapsulated at DP Site is distributed by the National Bureau of Standards as the primary plutonium standard.

High-purity plutonium metal is alloyed by two methods: bomb reduction and co-melting. The alloying of plutonium with other metals permits changes in the properties of the final material to meet the needs of the weapon designers and to simplify fabrication processes. The alloys are cast into ingots in reusable tantalum crucibles. Ceramic mold coatings preserve the purity of the alloy and a variety of techniques, such as mold-temperature control, controlled cooling rates, and subsequent heat-treating methods, have been developed to produce different physical properties in the plutonium or alloy shape.

Once the ingot with the specified properties is available, it is worked to the required shape and dimensions under conditions that protect the worker from radiation and the part from oxidation. The machining process developed at DP Site uses a partially inert atmosphere to protect the part from oxidation while using volatile liquid (freon) as a lubricant and coolant. This approach has not only minimized the fire potential, but has led to development of a process by which machine turnings can be reused directly without having to be degreased and briquetted before casting.

Property Measurements

An important part of the overall program is the characterization of materials produced, both at DP Site and elsewhere, through measuring chemical and physical properties. This provides useful and vital design information for predicting weapon performance of new materials. Some measurements made during routine and developmental programs are density, hardness, metallography, tensile strength, thermal conductivity, specific heat, coefficient of thermal expansion, electrical resistivity, and sonic moduli. Certain properties are also measured for materials with different impurity levels and processing

histories, and for new materials, not only for basic data but also as part of the quality assurance program.

Current chemical programs include reaction studies of the various liquids with plutonium, solubility of selected elements in molten plutonium and its alloys and compounds, and self-diffusion of the constituents of PuO_2 . The equilibrium solubilities of a number of elements in liquid plutonium and plutonium alloys have been determined. These data are of interest in the electrorefining process, and for selecting crucible and mold materials. Electrochemical studies are dedicated to understanding the basic thermodynamic properties of plutonium in alloys and compounds. Resulting data provide information about the chemical stability of plutonium and its alloys and compounds. The data also aid in selecting container materials, nuclear reactor fuels, isotopic heat sources, and weapon components compatible with plutonium for the expected lifetime of the nuclear component, heat source, or fuel rod.

Recycling

Impure scrap materials that contain recoverable amounts of plutonium are processed at DP Site. The presence of certain elements, even at concentrations as low as a few hundred parts per million, can drastically change the physical and chemical properties of plutonium.

To accomplish this purification, DP Site has developed processes and designed equipment for separating plutonium from all other elements in the periodic table, including neptunium, thorium, zirconium, uranium, cerium, and hafnium. Specialized separation techniques including selective dissolution, ion exchange, solvent extraction, and selective precipitation; these techniques are used either alone or in combinations to achieve adequate purification.

Because a wide variety of special isotopes are purified at DP Site, the equipment has been designed and sized for rapid, thorough cleanout to minimize the possibility of cross-contamination between isotopes. Examples of special isotopes that have been purified at DP Site are 99.9% ^{240}Pu , 98% ^{238}Pu , 75% ^{241}Pu , pure ^{237}Np , 99.6% ^{241}Am , and pure ^{233}U .

ADVANCED FUEL STUDIES FOR THE FAST-BREEDER-REACTOR PROGRAM

The LASL Plutonium Ceramic Fuels Program is a research-and-development function funded by the Fuels and Materials Branch of the DRDT. Originally, work at LASL centered on the fundamental description and the measurement of the basic physical and chemical properties of the plutonium and uranium carbides. Physical, chemical, and thermodynamic properties have been determined over the temperature range from 30 to 3 000 K.

Plutonium and uranium carbide and nitride fuel assemblies have been fabricated at LASL, and steady-state irradiation experiments using the assemblies are being carried out in the experimental breeder reactor EBR-II. These experiments are designed to study the ability of nitride and carbide fuel-pin designs to operate during long-term irradiations under conditions that relate to advanced LMFBR concepts. Postirradiation experiments of the fuel at LASL provided information about fuel swelling, fuel-clad interactions, fission gas release, fuel and fission product redistributions, and overall operating performance and reliability.

SPACE NUCLEAR POWER

LASL is the lead laboratory for the design and development of radioactive heat sources. These heat sources, combined with various electrical generator systems, can be used to provide power for space probes, orbiting satellites, and terrestrial applications. LASL has developed the chemical and physical processes used to prepare $^{238}\text{PuO}_2$ for the heat sources. Fabrication techniques have been developed to convert the high-fired $^{238}\text{PuO}_2$ into final fuel forms. The fuel forms are then studied to characterize the following properties: thermal expansion and conductivity, radiation, thermodynamics, microstructure, thermal and mechanical stress, and helium release rates. All of this work is carried out at DP Site; however, the actual preparation of the fuel, production of the fuel forms, and encapsulation, are performed at Mound Laboratory or Savannah River Laboratory. Recent space probes using heat sources fabricated along LASL guidelines include the Pioneer 10 and 11, and the Viking series.

APPENDIX C
NEUTRON COINCIDENCE WORK

DP SITE COUNTING ROOM ACTIVITIES* (N. Baron)

Nondestructive assay of ^{240}Pu is routinely performed in the DP Site counting room by a comparison measurement using thermal-neutron coincidence counting techniques. Results of this measurement are used to calculate the effective mass of ^{240}Pu with the aid of the relation

$$M_{240}^u(\text{eff}) = \frac{N^u/\epsilon^u}{N^{\text{STD}}/\epsilon^{\text{STD}}} \sum_i \frac{a_i}{a_{240}} \frac{\bar{\nu}_i}{\bar{\nu}_{240}} M_i^{\text{STD}}, \quad (\text{C-1})$$

where the effective mass of ^{240}Pu is defined to be

$$M_{240}^u(\text{eff}) \equiv \sum_i \frac{a_i}{a_{240}} \frac{\bar{\nu}_i}{\bar{\nu}_{240}} M_i^u. \quad (\text{C-2})$$

In Eqs. C-1 and C-2 the summation is taken over the i isotopes of plutonium; N^u and N^{STD} are the true coincidence count rates for the spontaneous fission neutrons of the unknown and standard samples, respectively; a_i is the spontaneous fission rate per gram of isotope i ; $\bar{\nu}_i$ is the number of prompt neutrons emitted per spontaneous fission event of a nucleus of isotope i ; and ϵ^u and ϵ^{STD} are the coincident detection efficiencies for the spontaneous fission neutrons of the unknown and standard samples, respectively. The assumption is made that

$$\epsilon^u = \epsilon^{\text{STD}}. \quad (\text{C-3})$$

This will be true if the matrix of the standard sample is chosen to be the same as that of the unknown sample.

* Excerpted from Los Alamos Scientific Laboratory report LA-6675-PR (January 1977), pp. 39-41.

The approximate total mass of plutonium is also obtained by the relation

$$M_{\text{Pu}}^u \approx \frac{M_{240}^u(\text{eff})}{f_{240}^u}, \quad (\text{C-4})$$

where f_{240}^u is the best estimate of the isotopic abundance of ^{240}Pu in the unknown sample.

Heretofore, the recording of all measurements and the subsequent calculations were done manually. However, recently the two neutron coincidence counting instruments in the DP Site counting room were linked to an on-line PDP-11 computer. This computer and its associated teletype terminal presently are located adjacent to the counting instruments (see Fig. C-1). (Safeguards considerations dictate that in the future the computer will be inaccessible to the operator of the counting equipment.) Such a computerized system can (a) ultimately ensure detection of any attempt to tamper with the counting equipment and (b) significantly reduce the frequency of errors that can be expected when NDA analyses are performed manually.

The software is designed to transmit instructions via common terminal to any measuring instrument linked to the computer regardless of the status of other instruments that are also computer-coupled. For example, other coupled instruments may be waiting to be activated, or they may be counting, or perhaps the computer is analyzing data following a counting run in one of these instruments.

Instructions are given by responding to programmed questions which are initiated by typing either RUN or an interrupt command at the teletype keyboard. These questions

Fig. C-1. The PDP-11 computer and associated terminal control two independent neutron counting instruments: on the lower left is the well-counter and at left center is the barrel-counter.

and their programmed responses are given in Table C-I. After the last question is answered, program execution begins automatically. If the answer to question 2 is YES, then all of the data and resultant analyses for all prior runs during that day will be listed in a compact tabular format by the computer. This feature is intended to serve as a hard-copy summary of the day's measurements made prior to this listing request. However, if the response to question 2 is NO, then the instrument's scalers are reset to zero and subsequently activated to count the sample identified by the response to question 3.

NEW SHIFT REGISTER FOR HIGH COUNT-RATE COINCIDENCE APPLICATIONS*
(J. E. Swansen, N. Ensslin, M. S. Krick, and H. O. Menlove)

Three electronic circuits^{C-1} have been under consideration for use with thermal-neutron coincidence counters. With any of the three circuits large samples of fissionable material can be assayed in the presence of random background rates of at least 30 000 counts/s. However, the variable deadtime counter circuit was vulnerable to changes occurring in the room background during the assay. The updating one-shot circuit required large deadtime

* Excerpted from Los Alamos Scientific Laboratory report LA-6788-PR (June 1977), pp. 4-6.

TABLE C-I
TERMINAL QUESTIONS AND RESPONSES

<u>Question Number</u>	<u>Programmed Questions</u>	<u>Acceptable Responses</u>
1	UNIT NUMBER (2,3) READY?	2 or 3
2	DO YOU NOW WANT A LISTING OF ACCUMULATED DATA?	YES or NO
3	SAMPLE ID?	(any 9-character string)
4	IS THIS A STANDARD?	YES or NO
5	PERCENT ISOTOPIC ABUNDANCE OF PU-240?	(any number)

corrections and had not been used much. Consequently, a new shift-register circuit capable of handling very high rates was built.

A block diagram of the new shift register is shown in Fig. C-2. Some of the features that distinguish it from the previous LASL shift register^{C-2} are:

- (a) The new circuit has only one shift-register gate and two triggers (one prompt and one delayed), thereby eliminating several integrated circuits. In principle it is identical to the earlier shift register, which had two gates and one trigger, although the timing is reversed in the accidental gate.
- (b) The delayed trigger is 1 000 μ s long compared with a typical value of 100 μ s for the older circuit, hence, no real coincidences will be present in the accidental gate.

Fig. C-2. Block diagram of new shift register.

(c) A fixed clock frequency of 2 MHz is used for all timing applications; thus the timing is less critical and does not vary with choice of gate length (8 to 128 μ s).

(d) The predelay can be varied from 1 to 33 μ s, in 1/2- μ s increments, independent of gate length. At high count rates it is important to have a long enough predelay to override all amplifier deadtime and pileup effects, as described below.

(e) The up-down counter has a capacity for 99 counts, as opposed to 9 in the older circuit. This is essential for high count-rate applications. For example, at 100 000 counts/s the average number of events in a 64- μ s gate is 6.4, and nine counts are exceeded about 11% of the time--a large effect, which preferentially reduces the counting of real events.

(f) The scaler readout has been increased from seven to nine digits to accommodate larger counts without overflowing.

The first version of this new circuit has been constructed, and has been tested at high count rates using a thermal-neutron coincidence counter of 20% efficiency, four amplifiers of various designs, and four leading-edge discriminators added together. The tests consisted of assaying a ^{252}Cf fission source in the presence of a large random background from an Am-Li source. Figure C-3 shows that the new circuit can be used at much higher counting

Fig. C-3. Comparison of old and new shift-register circuits at high rates with four bipolar amplifiers (0.2- μ s time constant).

rates than the old. The rates used for Fig. C-3 are not unrealistic; 2 kg of PuO_2 (10% ^{240}Pu) will produce a total count rate of 75 000 counts/s at this efficiency.

The dashed line in Fig. C-3 corresponds to the uncorrected data and the solid line has been corrected for a bias caused by an imbalance between the real and accidental registers. This bias was measured by counting a purely random Am-Li source separately. Careful tests of a later version of the new shift register showed that it has no internal bias. The bias observed here is due to the time required by the amplifiers to return to zero baseline. At high count rates even a slight deviation from zero will affect the ability of closely following pulses to clear the discriminator threshold. Bipolar amplifiers tend to produce a negative bias; unipolar amplifiers, a positive bias. Figure C-4 is an example of the bias for the same amplifiers used in Fig. C-3. The amplifier bias must either be corrected for by measuring a random source or eliminated by careful choice of amplifier design or shift-register pre-delay setting. From a study of various amplifier-discriminator combinations, we chose a fast bipolar amplifier and leading-edge discriminator that will minimize this bias. The amplifier is now being constructed and tested.

When the raw data in Fig. C-3 were corrected for bias, the result was a straight line on a semilogarithmic scale (the solid line in the figure). Therefore, the data can be fit with an updating deadtime correction of

true coincidence

$$= \text{measured coincidence} \times e^{-2\tau T},$$

Fig. C-4. Internal distribution of random pulse events at 120 000 counts/s taken with four bipolar amplifiers (0.2- μs time constant). There is a well-defined deadtime of about 1 μs and a small negative bias in expected distribution out to about 5 μs . One heavy dot/ μs , linear scale. Exponential baseline has been subtracted.

and

$$T = \text{true totals} = \text{measured totals} \times e^{\tau T},$$

where τ is the deadtime, here about 1 μ s, and deadtime corrections of higher order have been ignored. The magnitude of this deadtime can be understood on the basis of amplifier pulse width and shift-register input synchronization time.

The new shift-register circuit works correctly at high rates and experiences only small, easily understood deadtime effects. It is now being packaged for use in the International Atomic Energy Agency (IAEA) high-level neutron coincidence counter (HLNCC) and the DYMAC program.

EFFECTS OF SELF-MULTIPLICATION ON COINCIDENCE COUNTS OF PuO_2 CANS* (N. Ensslin and J. L. Sapir)

One potential application of thermal-neutron coincidence counters is the assay of large amounts of plutonium in oxide form. A typical problem facing the IAEA, the DYMAC program, and other organizations is the assay of 1 to 2 kg of PuO_2 (10-20% ^{240}Pu) in cans 12 to 30 cm high and 8 to 10 cm in diameter. During the past year we have studied the problems of detecting coincidence events in the presence of the large accidental count rates produced by such samples. The new shift register that resulted from this work can operate at rates over 100 000 counts/s with reasonable deadtime corrections. Consequently, the largest remaining problem in the assay of PuO_2 cans now appears to be self-multiplication.

The need for self-multiplication corrections in metallic plutonium is obvious, as is the need for induced-fission corrections in oxides and fluorides. The need for a substantial self-multiplication correction to PuO_2 , however, has been concealed by compensating electronic deadtime effects. To minimize deadtime and isolate multiplication, we used the new shift register to measure a series of PuO_2 standards ranging in size from 20 g (6% ^{240}Pu) to 780 g (10% ^{240}Pu). We also used the new dual-range coincidence counter (described in the next article) in the low-efficiency mode (5.7% efficiency, 16 μ s die-away time). Four fast (0.2- μ s time constant) bipolar amplifiers

* Excerpted from Los Alamos Scientific Laboratory report LA-6788-PR (June 1977), pp. 6-8.

were used in conjunction with four leading-edge discriminators and a shift-register predelay of 6 μ s. Under these conditions amplifier pulse-pileup effects were negligible, and deadtime corrections for coincidence and total events were

$$C = C_m e^{0.0028T}, T(kc) = T_m e^{0.0014T}.$$

These corrections were on the order of 2%. Errors due to statistics, deadtime corrections, detector height response, and uncertainty in the mass of the standards were estimated to be $\leq 1\%$. The corrected data, illustrated in Fig. C-5 and given in Table C-II, show a significant upward curvature.

Self-multiplication in the PuO_2 cans was calculated with the two-dimensional transport code TWOTRAN^{C-3} with S_4 angular segmentation and Hansen-Roach 16-group neutron cross sections.^{C-4} The calculations assumed that the cans were bare (unreflected). Future calculations will account for the effects of the cadmium-lined polyethylene detector. The calculated leakage multiplication (number of leakage neutrons per source neutron) is given in Table C-II. Several of the transport calculations were checked with the neutron Monte Carlo code MCN.^{C-5} Agreement between the two methods was very good.

To account accurately for the effects of multiplication on coincidence counts, the discrete leakage multiplication (probability of 1, 2, 3, ..., neutrons leaking per source neutron) should be used rather than

Fig. C-5. Self-multiplication in PuO_2 . Measurement errors are about equal to the size of the circles. Deviation of the data from the straight line is believed due to self-multiplication.

TABLE C-II
SELF-MULTIPLICATION IN PuO₂

Total Plutonium (g)	²⁴⁰ Pu (g)	Assumed Plutonium Density (g/cm ³)	Fill Height (cm)	<u>Coincident Counts</u> g ²⁴⁰ Pu-s	Leakage Multipli- cation, M	Coincident Multipli- cation, C	<u>Coincident Counts</u> x 1 g ²⁴⁰ Pu-s C
20	1.22	---	---	2.35 ± 0.02	---	---	2.34 ^a
60	3.84	0.15	7.4	2.42 ± 0.02	1.0048	1.012	2.39
120	7.67	0.30	7.4	2.53 ± 0.02	1.0101	1.026	2.46
480	37.40	1.29	6.8	2.99 ± 0.03	1.0459	1.119	2.67
459	43.38	1.29	6.5	2.98 ± 0.03	1.0449	1.116	2.67
556	54.92	1.29	7.9	3.03 ± 0.03	1.0482	1.125	2.69
615	64.96	1.29	8.7	3.08 ± 0.03	1.0499	1.130	2.73
779	81.34	1.29	11.0	3.26 ± 0.03	1.0542	1.141	2.86

^aEstimated.

the average multiplication calculated here. The MCN code will be revised to yield this information. For the present, we will estimate coincident multiplication as follows:

(a) The coincident count rate is

$$C \propto \frac{\epsilon^2 \overline{v(v-1)}}{2!} - \frac{\epsilon^3 \overline{v(v-1)(v-2)}}{3!},$$

where ϵ is the detection efficiency and v the multiplicity.

(b) The distribution of actual neutron numbers emitted during spontaneous fission can be included by summing over the discrete probabilities $P(n)$, as determined experimentally, or by using a Gaussian distribution

$$P(v) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-(v-\bar{v})^2/2\sigma^2},$$

where $\bar{v} = 2.17$ for ^{240}Pu , and $\sigma = 1.08$ as recommended by Terrell.^{C-6} Both methods yield similar results here. If we fold in the Gaussian distribution,

$$C \propto \frac{\epsilon^2}{2} [\sigma^2 + \bar{v}(\bar{v} - 1) - \epsilon\sigma^2(\bar{v} - 1) - \frac{\epsilon}{3} \bar{v}(\bar{v} - 1)(\bar{v} - 2)]$$

through second order.

(c) Self-multiplication inside the can takes place on a small timescale compared to the die-away time of the detector. Thus a leakage multiplication M implies a new average multiplicity of $M\bar{v}$. (This cannot hold for induced fissions from (α, n) reactions, because there is no time correlation between the induced and spontaneous fissions.) Then

$$C \propto \frac{\epsilon^2}{2} [M^2\sigma^2 + M\bar{v}(M\bar{v} - 1) - \epsilon M^2\sigma^2(M\bar{v} - 1) - \frac{\epsilon}{3} M\bar{v}(M\bar{v} - 1)(M\bar{v} - 2)]$$

This coincidence multiplication is much greater than the leakage multiplication, as indicated in Table C-II.

The correction for self-multiplication is appreciable despite the low density of the PuO_2 (about 1.3 g/cm^3). However, it is clear both from Fig. C-5 and the last column of corrected coincident counts/g-s in Table C-II that we have removed only about half of the curvature in the data. To increase our understanding of this problem, we will investigate (α, n) reactions, reflection by the well-counter, and an improved handling of coincidence multiplication.

DUAL-RANGE THERMAL-NEUTRON COINCIDENCE COUNTER* (M. L. Evans, H. O. Menlove, and L. G. Speir)

For many applications of neutron well coincidence counters, it is desirable to assay samples that cover a mass range from less than 1 g to greater than 2 kg of PuO_2 . To achieve this wide-range capability, the dual-range coincidence counter has been designed and fabricated. The dual-range

* Excerpted from Los Alamos Scientific Laboratory report LA-6788-PR (June 1977), pp. 8-10.

capability is achieved by having two removable cadmium sleeves near the ^3He detectors. These sleeves can be inserted for low-efficiency operation with short die-away times and removed for high-efficiency counting with a long die-away time.

The geometry of the counter is shown in Fig. C-6. The cadmium sleeves on both sides of the middle polyethylene cylinder (ring 2) are removable. The detector consists of 20 ^3He tubes of 2.54-cm diam filled to a pressure of 18 atm. The inner and outer CH_2 cylinders (rings 1 and 3, respectively) are each 3.0 cm thick. The cadmium sleeve (1.0 mm thick) on the inside of the well stops low-energy neutrons from returning to the sample position, thereby minimizing criticality problems and reducing multiplication for high-mass loadings. The outer cadmium sleeve improves the effectiveness of the exterior CH_2 shield.

Thus, there are two modes of operation: (1) the low-mass range with both removable cadmium sleeves removed for maximum efficiency and (2) the high-mass range with all the cadmium sleeves in place to give a short die-away time and correspondingly short electronic gate width in the coincidence circuitry. For operational mode (1), the singles

Fig. C-6. Dual-range neutron coincidence counter for the assay of plutonium samples in the mass range 1-2 000 g.

efficiency is 20-25% and the neutron die-away time 50 μ s. For operational mode (2), the efficiency decreases to 6 to 10% and the die-away time goes to 15 to 25 μ s.

Monte Carlo studies were performed to determine the physical dimensions of the counter that would yield the desired efficiency, die-away time, matrix material insensitivity, and optimum values for other parameters. The efficiency is especially dependent on the thicknesses of the polyethylene moderator and reflector. In the Monte Carlo program the thicknesses of rings 1 and 3 were taken to be equal and were varied simultaneously to determine the optimum thickness. The results of this study are shown in Fig. C-7 for both configurations (cadmium sleeves in and out). The results indicate that a moderator (and reflector) thickness of about 3.5 cm combines a high efficiency with relative insensitivity to matrix effects for both configurations. At this design thickness, the equivalent hydrogen of about 1-cm thickness of CH_2 can be added to the sample matrix with little change to the counting efficiency as can be seen in Fig. C-7. The calculated efficiencies of the counter shown in

Fig. C-7. Design data for the dual-range counter showing efficiency and die-away time as a function of polyethylene moderator (and reflector) thickness as determined from Monte Carlo studies.

Fig. C- , were about 25% in the high-efficiency configuration and about 7% in the low-efficiency configuration. The corresponding moderator die-away times were approximately 45 and 11 μ s. These calculated design parameters agree well with the preliminary measured values.

SELF-REGULATING THERMAL-NEUTRON COINCIDENCE COUNTING EFFICIENCIES AND EFFECTIVE MASSES* (N. Baron)

A phenomenological approach to passive nondestructive assay by thermal-neutron coincidence counting is described. The principal objective is to account accurately for any modification of the apparent spontaneous-fission coincidence count rate caused by self- and/or induced-multiplication as well as matrix effects. This technique requires the determination of an apparent coincidence-counting efficiency defined to be the quotient of the measured true coincidence count rate divided by the average creation rate of prompt-neutron pairs resulting from spontaneous fission processes. If this efficiency is not an invariant, then the presence of multiplication and/or matrix effects is implied. This efficiency can be written as

$$\text{eff} \equiv \frac{\dot{N}^B}{\sum_{i=1}^n \frac{1}{2} a_i \bar{\nu}_i m_i}, \quad (C-5)$$

where

$\dot{N}^B$ is the coincidence count rate associated with a given gate width and is measured by using the outputs of all the neutron counting tubes in a well-counter having two concentric rings of tubes,

a_i is the number of spontaneous fissions per second per gram of isotope i ,

$\bar{\nu}_i$ is the average number of prompt neutrons emitted per spontaneous fission event of isotope i , and

m_i is the mass of isotope i .

* Excerpted from Los Alamos Scientific Laboratory report LA-6788-PR (June 1977), pp. 34-36.

Equation C-5 can be rewritten as

$$\text{eff} \equiv \frac{2}{a_{240} \bar{v}_{240}} \left(\frac{\dot{N}^B}{M_E} \right), \quad (\text{C-6})$$

where M_E is the effective mass of ^{240}Pu and is defined to be

$$M_E \equiv \sum_{i=1}^n \frac{a_i}{a_{240}} \frac{\bar{v}_i}{\bar{v}_{240}} m_i. \quad (\text{C-7})$$

By rewriting Eq. C-7 as

$$M_E \equiv \frac{\dot{N}^B / \text{eff}}{\text{calibration factor}}, \quad (\text{C-8})$$

we stress that the effective mass of fertile material is determinable from the measured thermal-neutron coincidence count rate if one knows the coincidence counting efficiency, eff , as defined by Eq. C-5. The calibration factor in Eq. C-8 is the reciprocal of the unbracketed terms of Eq. C-6.

The measuring instrument was a thermal-neutron well counter similar to that described in Ref. C-7, p. 13. The inner and outer rings had 12 and 16 ^3He counters, respectively. Using known source strengths, the coincidence count rates were measured (a) with both rings of ^3He counters in the electrical circuit, i.e., $\dot{N}^B$, (b) with only the inner ring of ^3He counters in the electrical circuit, i.e., $\dot{N}^I$, and (c) with only the outer ring of ^3He counters in the electrical circuit, i.e., $\dot{N}^O$. The coincidence count rates were measured using the previously reported LASL shift-register circuit^{C-2} and a gate width of 32 μs .

By the following analysis, we can predict the efficiency, eff , defined by Eq. C-5. The reason for the success of this analysis is still unclear, but we hope that further work will provide a suitable explanation.

If the calculable coincidence count rate, given by

$$\dot{N}^B(\text{calc}) = \dot{N}^I + \dot{N}^O + 2(\dot{N}^I \dot{N}^O)^{1/2}, \quad (\text{C-9})$$

satisfies the relation

$$\frac{\dot{N}^B(\text{calc}) - \dot{N}^B}{\dot{N}^B} < 2\sigma \quad , \quad (\text{C-10})$$

where σ is the statistical counting uncertainty in $\dot{N}^B$, then the efficiency, eff, defined by Eq. C-5 can be predicted reasonably well by the relation

$$\text{eff} = \kappa \frac{\left(\frac{\dot{N}^I}{\dot{N}^O} \right)}{\left(\frac{\dot{T}^I}{\dot{T}^O} \right)} \quad , \quad (\text{C-11})$$

where $\dot{T}^I$ and $\dot{T}^O$ are the "singles" count rates measured by the inner and outer tube rings, respectively.

Otherwise, the coincidence counting efficiency, eff, is correctly given by

$$\text{eff} = \kappa \frac{\left(\frac{\dot{\eta}^O}{\dot{N}^O} \right)}{\left(\frac{\dot{T}^I}{\dot{T}^O} \right)} \quad , \quad (\text{C-12})$$

where $\dot{\eta}^O$ is obtained from the measured values of $\dot{N}^B$ and $\dot{N}^I$ by the relation

$$\left(\dot{\eta}^O \right)^{1/2} = \left(\dot{N}^B \right)^{1/2} - \left(\dot{N}^I \right)^{1/2} \quad . \quad (\text{C-13})$$

The proportionality constant κ in Eqs. C-11 and C-12 is taken to be the average value obtained by measuring p standards and is given by

$$\kappa = \frac{1}{P} \sum_{i=1}^P \left[\text{eff} \frac{\dot{T}^I/\dot{T}^O}{C/\dot{N}^O} \right]_i \quad , \quad (\text{C-14})$$

where

$$C = \dot{N}^I \quad , \quad (\text{C-15})$$

if relation C-10 is satisfied; otherwise,

$$C = \frac{0}{n} \quad . \quad (C-16)$$

Once the coincidence detection efficiency is determined by the criteria set forth in Eqs. C-9 through C-16, the unknown effective mass of spontaneously fissioning material M_E is given by Eq. C-8.

Table C-III shows the results of the analyses of the measurements on six standards with effective masses of ^{240}Pu ranging from 3.84 to 37.4 g. The fact that those standards having a matrix of MgO have a greater count rate than similarly loaded standards having a matrix of diatomaceous earth is probably due to induced fissions caused by neutrons produced by the large $\text{Mg}(\alpha, n)$ reaction. Columns 4 and 7 in Table C-III show that the efficiencies calculated with Eqs. C-11 and C-12 agree well with the efficiencies defined by Eq. C-5. A comparison of columns 4 and 6 demonstrates the self-regulating nature of the count rate ratios relative to variations in coincidence counting efficiencies, and the linear nature of this relationship is shown in Fig. C-8.

The results of conventional calculations of effective masses are shown in column 11 and the errors are listed in column 12 of Table C-III. The calibration factor for this calculation was taken to be the average of the six measured coincident count rates per gram, $\dot{N}^B/M_E$, listed in column 10 of the table. The results of similar effective-mass calculations in which the coincidence count rates were corrected for efficiency as defined by Eqs. C-11 and C-12 are shown in column 8 of Table C-III, and the errors are listed in column 9. The effective masses are generally more accurately predicted by this phenomenological approach than by the conventional technique. In fact, the sum of the effective masses predicted by this efficiency-correction technique, obtained by summing the values in column 8 of Table C-III, is in error by only 0.3%. This is to be compared to the total resulting from the conventional technique, obtained by summing the values in column 11 of Table C-III and which is found to be in error by 4.1%.

The linear relationship of the coincidence count rate corrected for efficiency and the effective mass are emphasized in Fig. C-9 where, for comparison, is also shown the coincidence count rate uncorrected by the coincidence efficiency factor.

TABLE C-III
COINCIDENCE EFFICIENCIES AND RESULTANT EFFECTIVE MASSES

Column											
1	2	3	4	5	6	7	8	9	10	11	12
M_E (g)	$\dot{N}^B$ (counts/s)	Material Form and Matrix	eff (%) Eq. 1	Eq. 10	Count Rate Ratios ^a	eff (%) Eq. 7 or 8	M_E (g) Eq. 4	Percent Error	$\dot{N}^B/M_E$	M_E (g) ^b	Percent Error
3.84	89.8	PuO ₂ + Diatomaceous Earth	4.58	0.0479	0.9558	4.69	3.75	-2.3	23.42	3.41	-11.2
3.84	100.7	PuO ₂ + MgO	5.13	0.0478	1.074	5.27	3.74	-2.6	26.23	3.82	-0.5
7.67	184.1	PuO ₂ + Diatomaceous Earth	4.70	0.0510	0.9210	4.52	7.96	+3.8	24.00	7.86	+2.5
7.67	219.7	PuO ₂ + MgO	5.60	0.0495	1.132	5.56	7.73	+0.8	28.63	8.33	+8.6
15.3	439.0	PuO ₂ + MgO	5.60	0.0495	1.132	5.56	15.4	+0.6	28.60	16.6	+8.5
37.4	1025.0	PuO ₂	5.37	0.0486	1.107	5.44	36.9	-1.3	27.41	38.8	+3.7
<hr/> (75.72) _{total}			<hr/> (0.0491) _{av}			<hr/> (75.48) _{total}			<hr/> (26.38) _{av}	<hr/> (78.82) _{total}	

^aCalculated using $\frac{\dot{N}^I/\dot{N}^O}{\dot{I}^I/\dot{I}^O}$ or $\frac{\dot{N}^O/\dot{N}^I}{\dot{I}^O/\dot{I}^I}$.

^bConventional calculation; $M_E = \dot{N}^B$ / response per gram, where the response per gram is the average of those values listed in column 10.

Fig. C-8. Coincidence counting efficiency vs measured count-rate ratio.

Fig. C-9. Coincidence count vs effective mass.

STUDIES OF THERMAL-NEUTRON COINCIDENCE-COUNTING TECHNIQUES* (N. Baron)

Reported here are the results of further studies of passive thermal-neutron coincidence-counting techniques that could be used to perform accurate NDA of spontaneously fissioning material. These data were obtained with a shift-register neutron-coincidence module^{C-2} and a well counter^{C-7} with two concentric rings of ^3He tubes placed symmetrically about the well. The "coincidence" and "single" count rates for 16 different standards were measured for the inner ring alone, for the outer ring alone, and for the simultaneous response of both inner and outer rings. These standards were either relatively pure plutonium oxide, or plutonium oxide mixed with either ash,

* Excerpted from Los Alamos Scientific Laboratory report LA-6849-PR (August 1977), pp. 39-40.

diatomaceous earth, uranium oxide, or magnesium oxide. Total plutonium in the samples ranged from 55.7 to 779 g, and the effective mass of ^{240}Pu ranged from 3.51 to 81.4 g. Table C-IV shows the matrix and plutonium loading of each standard along with the measured coincidence and single count rates. Using these data, one could empirically define a function of the coincidence and single count rates measured in the inner and outer rings that is linearly proportional to an empirically adjusted power of the effective mass of spontaneously fissioning material. This relation is

$$\frac{\sqrt{\dot{N}^0 \left(\frac{\dot{T}^I}{\dot{T}^O} \right)^2}}{(M_E)^{0.53}} = \text{constant} \quad , \quad (\text{C-17})$$

where $\dot{N}^0$ is the coincidence count rate measured by the outer ring of tubes, $\dot{T}^I$ and $\dot{T}^O$ are the single count rates of the inner and outer rings respectively, and M_E is the effective mass of ^{240}Pu . The measurement uncertainty of $\dot{N}^0$ was about 1%, and for $\dot{T}^I/\dot{T}^O$ about 0.1%. The proportionality constant is given in Table C-IV for each of the measured standards. The standard deviation of the mean value of the proportionality constant for the 16 measured standards is 1.38%. The relative standard deviation of the specific response rate (coincidence counts/gram of ^{240}Pu effective) calculated using the relationship of Eq. C-17 is 2.60%. Assumptions of a linear relation between the effective mass and the coincidence count rate from the simultaneous response of all the detector tubes, $\dot{N}^B$, results in a 7% relative standard deviation in response per gram. The empirical expression shown in Eq. C-17 is more straightforward than previously reported,^{C-8} yielding an improvement in the measurement accuracy. The expression linearizes the calibration curve, thus reducing the variety of standards needed to perform non-destructive assay. Table C-IV data indicate that one can expect the specific response rate of effective ^{240}Pu to have a relative standard deviation of less than 3% for the measurement of PuO_2 powders ranging in plutonium mass from several to about 1 000 g and including a variety of matrix materials.

Theoretical studies in Group TD-6 at LASL are now being made to gain greater insight into the physical significance of such an analysis using a double-ring well counter.

[illegible]

REFERENCES

- C-1. "Nuclear Safeguards Research Program Status Report, May-August 1976," Los Alamos Scientific Laboratory report LA-6675-PR (February 1977).
- C-2. M. M. Stephens, J. E. Swansen, and L. V. East, "Shift Register Neutron Coincidence Module," Los Alamos Scientific Laboratory report LA-6121-MS (December 1975).
- C-3. K. D. Lathrop and F. W. Brinkley, "Theory and Use of the General Geometry TWOTRAN Program," Los Alamos Scientific Laboratory report LA-4432 (May 1970).
- C-4. G. E. Hansen and W. H. Roach, "Six and Sixteen Group Cross Sections for Fast and Intermediate Critical Assemblies," Los Alamos Scientific Laboratory report LAMS-2543 (November 1961).
- C-5. E. D. Cashwell, J. R. Neergaard, W. M. Taylor, and G. D. Turner, "MCN: A Neutron Monte Carlo Code," Los Alamos Scientific Laboratory report LA-4751 (January 1972).
- C-6. J. Terrell, "Distribution of Fission Neutron Numbers," Phys. Rev. 108, 783 (1957).
- C-7. "Nuclear Analysis Research and Development Program Status Report, May-August 1975," Los Alamos Scientific Laboratory report LA-6142-PR (December 1975).
- C-8. "Nuclear Safeguards Research Program Status Report, September-December 1976," Los Alamos Scientific Laboratory report LA-6788-PR (June 1977).

APPENDIX D

MEASUREMENT CONTROL PROGRAM FOR THE DP SITE COUNTING ROOM (W. R. Severe)

CALIBRATION

Calibration is the process of obtaining a relationship between an instrument response and plutonium mass. To ensure the validity of this relationship over a range of material types and plutonium mass values, several standards are used to determine instrument calibration. We apply linear regression techniques to determine the exact value of this relationship.

Standards

Table D-I gives a complete description of counting room standards.

²³⁸Pu Calibration

The calibration for ²³⁸Pu is an exception. Only one standard is currently available, therefore all calibrations for ²³⁸Pu consist of a single-point calibration.

²³⁹Pu Calibration

Both the SGS barrel counter and SGS can counter are calibrated for assay of ²³⁹Pu. The SGS can counter may be adjusted to two distinct positions to measure several can sizes. Each position is calibrated by the following method: The standards listed in Table D-II are scanned sequentially. This sequence is then repeated. The resulting data are fitted to a straight line by the methods described in Procedure D-1. The SGS barrel counter calibration consists of an identical series of measurements with the data fitted to a straight line as shown in Procedure D-1. The slopes of the calibration lines are used as the calibration constants for their respective systems for all further accountability measurements subject to the provisions of the following sections.

TABLE D-I
DESCRIPTION OF COUNTING ROOM STANDARDS

Standard Identification Number	Major Plutonium Isotope	Enrichment (%)	Total Plutonium (g)	Composition
STD 152	238	80	8.7	$^{238}\text{PuO}_2$ in rags
A 401	239	6.07	37	Hanford ash
B 627	239	6.59	88	Hanford ash
R650012 (430B)	239	6.78	57	Hanford ash
R650018 (610B)	239	6.48	43	Hanford ash
R650022 (628B)	239	7.09	34	Hanford ash
R705003	239	5.74	20.98	$^{239}\text{PuO}_2$ in diatomaceous earth
R705004	239	5.74	20.98	$^{239}\text{PuO}_2$ in diatomaceous earth
R705005	239	5.74	20.98	$^{239}\text{PuO}_2$ in diatomaceous earth
HCC3122	239	5.89	19.60	$^{239}\text{PuO}_2$
ELD DISC-1	239	5.89	5.00	$^{239}\text{PuO}_2$ (metal)
ELD DISC-2	239	5.89	0.90	$^{239}\text{PuO}_2$ (metal)
STD-1	239	7.57	5.02	$^{239}\text{PuO}_2$ in diatomaceous earth
STD-2	239	7.57	5.03	$^{239}\text{PuO}_2$ in diatomaceous earth
STD-3	239	7.57	60.29	$^{239}\text{PuO}_2$ in diatomaceous earth
STD-4	239	6.3	60.02	$^{239}\text{PuO}_2$ in diatomaceous earth
STD-5	239	6.3	60.03	$^{239}\text{PuO}_2$ in MgO
STD-6	239	6.3	120.02	$^{239}\text{PuO}_2$ in diatomaceous earth
STD-7	239	6.3	120.01	$^{239}\text{PuO}_2$ in MgO
STD-8	239	6.3	240.10	$^{239}\text{PuO}_2$ in MgO
STD-9	239	7.57	480.35	$^{239}\text{PuO}_2$

²⁴⁰Calibration

Both the 2-L and 114-L thermal-neutron coincidence counters are calibrated for the assay of ²⁴⁰Pu. The standards listed in Table D-III are run sequentially with a counting time of 500 s each. This sequence is then repeated. A straight line is fitted to the resulting data by the methods described in Procedure D-1. The slope of this line is used as the calibration constant for all subsequent accountability measurements until the constant is redetermined according to the provisions of the measurement control procedures found in the following sections.

TABLE D-II
SGS CALIBRATION STANDARDS

Standard Identification Number	Enrichment (%)	Total Plutonium (g)	²³⁹ Pu (g)	Composition
R705003	5.74	20.98	19.71	PuO ₂ in diatomaceous earth
STD-3	7.57	60.29	55.28	PuO ₂ in diatomaceous earth
STD-4	6.30	60.02	56.04	PuO ₂ in diatomaceous earth
STD-5	6.30	120.01	112.05	PuO ₂ in diatomaceous earth

TABLE D-III
TNC CALIBRATION STANDARDS

Standard Identification Number	Enrichment (%)	Total Plutonium (g)	²⁴⁰ Pu (g)	Composition
STD-1	7.57	5.92	0.45	PuO ₂ in diatomaceous earth
R705003	5.74	20.98	1.20	PuO ₂ in diatomaceous earth
STD-4	6.30	60.02	3.78	PuO ₂ in diatomaceous earth
STD-5	6.30	60.03	3.78	PuO ₂ in MgO
STD-6	6.30	120.02	7.56	PuO ₂ in diatomaceous earth
STD-7	6.30	120.01	7.56	PuO ₂ in MgO

CONTROL OF MEASUREMENT PRECISION

A change in any parameter affecting instrument response may change the instrument precision. The consistency of measurement precision is ensured by a system of precision control.

Control Parameter

The measurement system employed in the counting room automatically computes an estimated variance based on the Poisson distribution (counting statistics). This estimate is verified periodically by comparison with the variance estimate obtained from replicate observations. The methods for computing the variance estimates and the χ^2 control parameter are found in Procedure D-2. A series of 15 replicate measurements of one of the four standards is made for each instrument (2-L neutron counter, 114-L neutron counter, SGS can counter, and SGS barrel counter) a minimum of once every second working day. We recommend that a minimum counting time for the neutron counters be established as 200 s. We maintain a record in the counting room logbook of the χ^2 parameter obtained in this manner.

Control Chart

Values of the χ^2 parameter are plotted on a control chart for each counting instrument. These precision control charts include warning limits at the 0.05 significance level and action limits at the 0.01 significance level. See Procedure D-2 for exact values. Figure D-1 is an example of a control chart for precision.

Fig. D-1. χ^2 control chart.

Control Limits

Whenever a data point falls outside the warning limits, the series of measurements should be repeated. If the repeated data point also exceeds the warning limits, we consider the system to be out of control. No further measurements for accountability purposes should be made using the system until an investigation has been conducted and the appropriate corrective action taken. Whenever a data point exceeds the action limits, we consider the system to be out of control. No further accountability measurements should be made until the situation has been investigated and corrective action taken. The employee must report all out-of-control conditions to his supervisor and note in the logbook the results of the investigation and the nature of the corrective action taken.

CONTROL OF MEASUREMENT ACCURACY

Instrument response is related to plutonium mass by calibration with known standards. To ensure the continued accuracy of this relationship, we use one of the calibration standards to make a calibration check. We make this check twice each day that the instrument is used for accountability measurements.

Control Parameter

The calibration check consists of measuring the standard as an unknown and comparing the measured value with the known standard value. The method for calculating the t parameter is given in Procedure D-3. We record the t parameter in the logbook.

Control Chart

We maintain a control chart for accuracy for each assay system and plot the t parameters on the appropriate charts. The control charts have warning limits at the 0.05 significance level and action limits at the 0.01 significance level. Exact limit values are shown in Procedure D-3. Figure D-2 is an example of a control chart for accuracy.

Control Limits

Whenever a data point exceeds the warning limit, we repeat the measurement. Should the repeated measurement also exceed the warning limit, we

Fig. D-2. t control chart.

consider the system to be out of control. Whenever a data point exceeds the action limits, we consider the system to be out of control. The employee must report the out-of-control condition to his supervisor. An out-of-control system cannot be used for accountability measurements until the condition has been investigated and corrective action taken. Corrective action generally consists of a complete recalibration followed by a calibration check. The employee records in the logbook all out-of-control situations and the nature of the corrective action taken.

PROCEDURE D-1: LINEAR CALIBRATION

The purpose of linear calibration is to obtain a least squares estimate of the relationship of instrument response to plutonium mass. The form of this relationship is

$$y = bx ,$$

where y = counts, counts/s, or other response;

x = plutonium mass (grams of ^{239}Pu or ^{240}Pu); and

b = slope (calibration constant).

We have assumed that the calibration line has zero intercept. This is reasonable because the counting room equipment internally corrects for background. Our assumption has also been confirmed by extensive analysis of response data.

For this model the least squares estimate of b is

$$b = \left(\sum_{i=1}^i x_i y_i \right) / \left(\sum_{i=1}^i x_i^2 \right) .$$

Also calculate

$$s_{y \cdot x}^2 = \left[\sum_{i=1}^i y_i^2 - \left(\sum_{i=1}^i x_i y_i \right)^2 / \left(\sum_{i=1}^i x_i^2 \right) \right] / (n - 1) ,$$

where $s_{y \cdot x}^2$ is an estimate of the variance of the calibration equation and n is the number of measurements (in our case n = 8), and

$$s_b^2 = s_{y \cdot x}^2 / \sum_{i=1}^i x_i^2 ,$$

where s_b^2 is an estimate of the variance of the calibration parameter. These terms (b , $s_{y \cdot x}^2$, and s_b^2) are calculated and recorded in the logbook each time a calibration is made.

PROCEDURE D-2: TO CALCULATE THE χ^2 PARAMETER

All assay systems in the counting room calculate an estimate of precision based on the Poisson distribution. This estimate is given at the 2σ limit, therefore it is necessary to divide the uncertainty by 2 and square the result to obtain the variance estimate.

The average Poisson variance for the series of 15 replicate measurements is

$$\sigma^2 = \frac{1}{15} \sum_{i=1}^i \left(\frac{U_i}{2} \right)^2 ,$$

where σ^2 is the average Poisson variance and U is the uncertainty.

Now, calculate the variance of the 15 measurement responses:

$$s^2 = \frac{1}{n-1} \left[\sum_{i=1}^i R_i^2 - \left(\sum_{i=1}^i R_i \right)^2 / n \right] ,$$

where s^2 = variance between replicates,

R_i = the i^{th} response, and

n = number of observations (15).

The ratio s^2/σ^2 is distributed about unity as

$$\chi_{n-1}^2/f \quad ,$$

where $\chi_{n-1}^2 = \chi^2$ distribution for $n-1$ degrees of freedom, and
 f = number of degrees of freedom = $n - 1$.

This distribution supplies the control limits for s^2/σ^2 (the χ^2 parameter). For 15 replicates the control limits are as follows:

warning limit = 1.69

action limit = 2.08 .

PROCEDURE D-3: TO CALCULATE THE t-PARAMETER .

A calibration check consists of comparing a measured response with a known value. This comparison is made using the ratio

$$t = \frac{(M-T)b}{s_{y \cdot x}} \quad ,$$

where M = measured plutonium mass (grams of ^{239}Pu or ^{240}Pu),

T = known plutonium mass for the measured standard,

b = calibration constant, and

$$s_{y \cdot x} = \sqrt{s_{y \cdot x}^2} \quad .$$

Both b and $s_{y \cdot x}^2$ were calculated at the time of calibration (see Procedure D-1). The t distribution has an expected (mean) value of zero. Conservative values for the t -parameter limits have been established as follows:

warning limits = ± 1.96

action limits = ± 2.58 .

APPENDIX E
OTHER APPLICATIONS OF NONDESTRUCTIVE ASSAY

PLUTONIUM-BUTTON VERIFICATION MEASUREMENTS* (R. S. Marshall and R. Siebelist)

LASL received a shipment of 48 plutonium metal buttons from Atlantic Richfield Hanford Co. (ARHCO). Each button weighed approximately 2 kg and was packaged in a sealed metal can. ARHCO supplied complete plutonium isotopic ratios and metallic impurity information, but the physical dimensions of each button were unknown.

We made verification measurements using the equipment illustrated in Fig. E-1. Our measurements can be considered field measurements in that:

- (a) counting time was limited to 30 s per button;
- (b) can-to-detector distance of 0.5 m was maintained by visually centering each can on the rotator;
- (c) measurements were made in a high-background area just outside a plutonium storage vault;
- (d) measurements were made beside an open door: temperature in the measurement area ranged from an estimated -1°C (30°F) to 4°C (40°F); and
- (e) only 2 h were allotted for equipment setup, calibration, and button measurements.

We performed calibration by repeated measurements of a single 2-kg plutonium button which contained 6% ^{240}Pu . Unfortunately the button had an

* Excerpted from Los Alamos Scientific Laboratory report LA-6788-PR (June 1977), pp. 43-45.

Fig. E-1. Verification measurement setup.

unusual shape: both diameter and height were 5.21 cm. Such a configuration has a neutron multiplication of about 1.74. Generally, 2-kg buttons have a much lower profile, i.e., diameter-to-height ratios of about 5 to 1, and are characterized by neutron multiplication of about 1.5 (see Ref. E-1, Table 9.3 and Ref. E-2, Sec. E, pp. 20-23).

Table E-I lists the kilograms of plutonium (by ARHCO lot ID, either DZA or NX) found by LASL for each button and the value assigned by ARHCO. The LASL-1 column lists the kilograms of plutonium found per button based on a comparison with the calibration button. The LASL-1 data are biased 17% lower than the

TABLE E-I
LASL VERIFICATION MEASUREMENTS OF PLUTONIUM METAL BUTTONS

DZA Lot ID				NX Lot ID			
Button Number	Plutonium (kg)			Button Number	Plutonium (kg)		
	ARHCO	LASL-1	LASL-2		ARHCO	LASL-1	LASL-2
520	2.00	1.57	1.99	148	2.04	1.90	2.10
392	2.05	1.59	2.02	036	1.94	1.64	1.82
523	1.94	1.58	2.00	037	1.56	1.17	1.48
376	1.98	1.60	2.04	008	2.06	2.03	2.24
371	2.04	1.59	2.02	033	1.89	1.59	1.75
438	1.99	1.56	1.90	146	2.01	1.78	1.97
390	1.98	1.53	1.94	161	2.05	2.00	2.22
385	1.86	1.43	1.81	162	2.05	1.94	2.15
378	2.04	1.59	2.02	147	2.02	1.82	2.01
381	2.05	1.64	2.10	226	2.21	1.81	2.07
391	2.02	1.56	1.98	227	2.02	1.86	2.06
516	2.04	1.63	2.07	224	2.04	1.88	2.15
248	2.16	1.75	2.23	140	2.05	1.92	2.13
099	2.14	1.71	2.17	035	1.93	1.64	1.82
249	1.71	1.26	1.60	015	2.05	2.11	2.33
396	1.99	1.60	2.05	034	1.93	1.67	1.81
394	2.03	1.61	2.05	149	1.87	1.68	1.86
393	2.06	1.61	2.05				
442	2.04	1.63	2.07				
443	2.05	1.65	2.10				
435	2.02	1.62	2.06				
420	2.05	1.61	2.05				
421	2.00	1.57	1.99				
397	1.96	1.52	1.94				
080	2.11	1.63	2.07				

ARHCO data. This size of bias would be expected for buttons of 5-to-1 diameter-to-height ratio. Notice that measurements for the DZA buttons are biased considerably more than those for the NX buttons. It turned out that the DZA buttons had a higher diameter-to-height ratio than the NX buttons.

The LASL-2 data were calculated by calibrating the SNAP II detector against the entire group of DZA or NX buttons. Specifically,

$$C_{DZA} = \frac{\sum (\text{neutron counts/30 s})_{DZA}}{\sum (\text{plutonium mass})_{DZA}},$$

and

$$C_{NX} = \frac{\sum (\text{neutron counts/30 s})_{NX}}{\sum (\text{plutonium mass})_{NX}}.$$

These calibration constants were then used to calculate the plutonium content of each button. Results are listed in the LASL-2 column.

Table E-II contains statistical information about the data in Table E-I. Although this information does not reveal a discrepancy in the total shipment, individual buttons that deviate from listed values by more than 3σ can be identified.

TABLE E-II
STATISTICAL INFORMATION FOR PLUTONIUM BUTTON MEASUREMENTS

Button Type	Number of Buttons	Relative Bias ^a (%)	Standard Deviation ^b
DZA	25	-20.3	0.025
NX	17	-9.7	0.068

^aRelative bias = $\{\sum [(LASL-1) - ARHCO] / \sum (LASL-1)\} \times 100$.

^bStandard deviation as calculated from (LASL-2) - ARHCO values, in kilograms of plutonium for each button.

If button diameter-to-height ratios are known within 25% and suitable matching standards are available, button verification measurements made with portable equipment may be possible to $2\sigma = 100$ g of plutonium.

NEUTRON MONITORING OF DIRECT OXIDE REDUCTION* (R. S. Marshall, W. R. Severe, and R. Siebelist)

Group CMB-11 is conducting research on the direct reduction of $^{238}\text{PuO}_2$ to ^{238}Pu metal. Group R-1 monitored the progress of the reduction reaction by measuring the emitted neutron flux. We expected that the initial neutron flux, a combination of spontaneous fission neutrons from ^{238}Pu plus (α, n) neutrons, would decrease as the $^{238}\text{PuO}_2$ was converted to ^{238}Pu metal.

Figure E-2 shows the temperature and neutron flux history during a reduction experiment conducted in a molten CaO matrix. Neutron counting was started during the last 8 min of a heating cycle during which the mixture was heated to 820°C . The heating furnace was then cut back to stabilize the molten CaO at 820°C and a stirrer was started. The stirrer brought the PuO_2 (sitting below the less dense molten CaO) into contact with the calcium metal (floating on top of the molten CaO). An exothermic reaction occurred, as can be seen by the temperature spike in Fig. E-2. Notice the rise in neutron flux corresponding to the activation of the stirrer. We attribute this rise to a more favorable counting geometry between the $^{238}\text{PuO}_2$ and the SNAP II neutron detector. The rise is followed by a rapid drop in neutron flux closely paralleling the temperature drop. Both indicators suggest completion of the reduction reaction.

We expected the after-reduction neutron flux to decrease to about 75% of the before-reduction flux and to remain constant after the reaction; Fig. E-2 shows that neither occurred. Examination of emission spectrographic analyses of the PuO_2 feed material and the plutonium metal product revealed that boron was present in the metal at much higher concentrations than in the feed PuO_2 (less than 1 ppm vs 400 ppm). Because boron has a very high cross section for the (α, n) reaction, it seems likely that the dissolution of boron in the molten plutonium explains the high and rising neutron flux.

* Excerpted from Los Alamos Scientific Laboratory report LA-6788-PR (June 1977), p. 37.

Fig. E-2. Neutron flux and temperature history of a $^{238}\text{PuO}_2$ reduction. Arrows indicate time that stirrer was turned on and off.

APPLICATIONS OF THE SOLUTION ASSAY INSTRUMENT* (W. R. Severe, J. L. Parker, R. P. Wagner, and R. Siebelist)

The solution assay instrument is currently being used for two programs. The first program involves measuring filtrate solutions generated in the metal-to-oxide conversion line. There are peroxide filtrates and oxybate filtrates. Both types have a plutonium concentration range of 0 and 0.5 g/L. For a nominal filtrate concentration of 0.25 g of plutonium/L, and a 20-min counting time, 1σ precisions of 15% relative standard deviation are obtained. The S&I solution sample is then sent to Group CMB-1 for radioassay.

We plan to evaluate the relative precision and accuracy of these two methods for several months. If a significant bias is noted, final judgment of system accuracy will be made by comparison with isotopic dilution mass spectroscopy. The radioassay results are currently used for material accountability.

* Excerpted from Los Alamos Scientific Laboratory report LA-6788-PR (June 1977) pp. 42-43.

The second program involves special measurement projects. One of these special projects was the determination of the plutonium metal dissolution rate for the metal-to-oxide conversion process. The concentration of the nitrate solution determined by the SAI is plotted against time in Fig. E-3. When correlated with other variables, this and other dissolution-rate studies made with the SAI helped production personnel optimize the dissolution process.

Fig. E-3. Plutonium metal dissolution rate.

A second special project was to provide rapid measurements of the initial peroxide and oxylate filtrates. The timely measurements made possible by the SAI allowed the final process parameters to be set with minimal delay.

In a third special project, the SAI was used for plutonium metal enrichment measurements. A special collimator and a plutonium metal standard have been fabricated. Plutonium metal entering the metal-to-oxide conversion line will be measured, and an evaluation of the practicability of such a measurement system will be made.

REFERENCES

- E-1. R. H. Augustson and T. D. Reilly, "Fundamentals of Passive Nondestructive Assay of Fissionable Material," Los Alamos Scientific Laboratory report LA-5651-M (September 1974).
- E-2. "Nuclear Analysis Research and Development. Program Status Report. May-August 1973," Los Alamos Scientific Laboratory report LA-5431-PR (November 1973).

APPENDIX F

SOFTWARE DESIGN FOR THE DYMAC ACCOUNTABILITY PROGRAM (R. F. Ford)

DYMAC SOFTWARE DESIGN

DYMAC software design is based on concepts of reentrancy, an operating system, and multitasking.

Reentrant code allows several users to access it simultaneously. Each user thinks the code is dedicated entirely to him. In fact, as a user program runs, there are almost always times when it must wait for an event to take place, usually an I/O function. At that time, unknown to the user, the operation of his program is suspended while some other user gains access to the code until his next waiting point. By using the reentrant approach only one copy of the code need reside in core instead of a copy for each user.

An operating system is a program that manages resources: the computer and its peripherals. Because transactions are event-driven sequences (e.g., a user hits a key, an instrument sends a character), a real-time oriented operating system is required to economically schedule and allocate resources among users based on the occurrence of events. Ideally, this means that the resources are never idle and no user has to wait for service. The executive is the part of an operating system that must reside in core before any processing can take place. Its functions include interrupt handling, overlay, and buffer management. Other operating system modules reside on disk and are brought into core (overlaid) as they are needed. These overlays are required to perform specific, but not immediate, functions such as file maintenance (opening, closing, renaming, or deleting a file) and some peripheral control such as spooling output to slow devices (such as a line printer). The resident portion of the operating system also includes a series of buffers that receive system overlays, disk directories, and data for buffered I/O transfers. The remaining core is for user programs. There is a perennial compromise between operating system size (the resident amount versus an overlay--this governs speed), the size of the user program, and the funds available to increase memory. A user program may overlay its low-usage modules but must provide for and manage its own space. The executive is responsible for allocating resources between itself and the user programs.

As we have seen, the main function of the operating system has been to balance system and user demands for processing time. Now let us introduce the concept of several user programs, or tasks, that compete with each other and with the system for resources: this must be handled by a multitasking operating system that is real-time oriented or event-driven. Ideally, it will schedule the resources so that they are never idle and the tasks never have to wait. In practice, multitasking is always a compromise between the advantages of a large operating system (which means either large amounts of core or the use of overlays), and the fast response time provided by a totally core-resident, event-driven operating system.

When a user at a terminal hits a key, that character is sent via communications lines to the operating system as an interrupt. The operating system identifies the interrupting terminal, examines the character for parity, and echoes it back to the terminal. If a terminal task informs the system that it wants to read a character from its terminal, the character is passed to it. A terminal task can request to read a line from its terminal (where a line is a string terminated by a carriage return); in this case, the characters are placed in a system buffer and only passed to the requesting task when the message is completed, i.e., a return received. Each character is echoed to inform the terminal user that it has been received. Because the DYMAC terminal network runs in a prompt-response sequence, this READ LINE mode is used. Traffic analysis has not been our strong point, and with 25 terminals vying for attention a fast echo may not be possible. If this becomes a problem, we will resort to a hardware solution by inserting a communications processor (in between the computer and the communications lines) that is programmed to duplicate the operating system READ LINE operation. It checks and assembles a character string and passes the completed string to the operating system which, in turn, passes it to the user program. By replacing the software with hardware we free more core for the user program and gain extra processing time.

DYMAC PROJECTED FOR THE NEW PLUTONIUM FACILITY

The DYMAC system to be installed at the new plutonium facility will use a powerful minicomputer with 128 communications lines connected to it. Under the direction of a resident operating system, an executive program will handle real-time accountability processing, and a data base management program will keep the files up to date.

Hardware Description

The system for the new facility that we have selected is a Data General Eclipse C330 with 131 072 words (16 bits to a word) of core memory which can be expanded to 262 144 words. The peripherals include two system consoles; two 5-million-word moving-head disk systems; two 9-track, 75-ips, 800-BPI magnetic tape drives; one 132-column, 600-LPM line printer; and a 128-line (expandable to 256) asynchronous line multiplexer (ALM).

The DYMAC installation date at the new facility was such that design of the computer portion of the system had to begin before the other elements of the system were specified or designed. This imposed some reasonable constraints on the network by the computer.

a. All lines are to be half-duplex, asynchronous communication lines with an upper speed limit of 9 600 baud. The line characteristics will be programmable.

b. All terminals will have a minimum of 72 characters per line; CRTs will have a minimum of 24 lines per page. The character set used will be upper-case ASCII. Transmission will be on a character basis with echo from the computer. A terminal must have an audible device that responds to the ASCII bell code as well as escape and carriage return keys.

c. All instruments that send data to the computer will send it in line mode, i.e., a string of ASCII upper-case characters not exceeding 132 characters per line, terminated by a carriage return. All characters will be echoed by the computer.

Operating Program

The DYMAC accountability program has been designed as a reentrant, event-driven, multitasking program that runs under the direction of an appropriate operating system. From the user's viewpoint the program functions as a series of prompt-response pairs. The program asks him a question; he answers it. Based on his answer certain events occur, e.g., another prompt is issued, a file search is made, an instrument is read.

One way to implement this program is shown in Fig. F-1. In this design, each terminal uses a task whose function is to call the reentrant accountability program with the proper ALM number. A terminal task is a program that identifies the terminal and acts as the interface between the terminal operator and the accountability program. Initially, each task will have to wait

Fig. F-1. Accountability program interfaced with a task per terminal.

to start a transaction, but after some time the various transactions from the terminals will be at different places in the accountability program. The operating system directs which task is to have control. As each task awaits a response (READ LINE) it is suspended and some other task that now has a completed response is restored to the point where it was in the accountability program before it was suspended. At the same time, the operating system collects and sorts all of the characters sent from each terminal until it receives a carriage return. Although this works well, there is a limit to the number of terminal tasks that the operating system can handle effectively. This limit of effectiveness can be a function of the way the operating system is designed, i.e., it may require too much core, or with n tasks the computer may always be busy and some tasks will have to wait. In any case, the design of a task per terminal eventually founders.

To resolve the task overload, we have designed a pool of terminal tasks, shown in Fig. F-2. Here the number of tasks is less than the number of

Fig. F-2. Accountability program interfaced with a pool of tasks where there are fewer tasks in the pool than terminals.

terminals and we rely on the fact that not all terminals are active. For example, if we have 25 terminals and our traffic analysis indicates that most of the time no more than 12 are active, we could start with a pool of 12 terminal tasks. When terminal 13 requests time it receives a BUSY, TRY AGAIN message. Alternatively, its request could be placed in a wait queue until an active terminal signs off; at this time a bell rings to notify the user that his request can now be handled. A software log keeps track of the number of times that nonserviced requests occur and the system can be periodically readjusted based on the nonserviced demand. That is, the number of terminal tasks allowed in the pool will be raised or lowered to accommodate the average number of users who make transactions at one time. A supervisor or special worker can gain immediate access to the program without going through the task pool by assignment of a higher priority than that given the regular users.

During the time that the transaction dialogue is taking place other programs are running, such as report generation and instrument calibration; hence, it is to our benefit to minimize the number of terminal tasks required. For this approach, the executive program monitors terminal requests to start a transaction. It also manages the pool of terminal tasks such that when one becomes free it is connected to the next requesting terminal. The connection lasts for the life of the transaction. In doing a transaction the task-terminal duo go through several prompt-response sequences during which the operating system suspends them until it receives a return, at which time they are reactivated. When the transaction is completed, the executive program frees the task and the data base is updated.

Starting transactions at 12 terminals could tie up all terminal tasks awaiting responses that never come; this is the situation when a user goes for coffee in the middle of a transaction or a line breaks or a terminal malfunctions. To overcome this we have introduced a timer. Before each task leaves to do a READ LINE it informs the timer to abort it if it fails to return in a certain amount of time. The time allowed should be long enough for the total response, that is, the message terminated by a return.

The accountability program can be designed in several ways, all of which involve the concept of an option list from which the user chooses. For the first pass the list is something like SEND and RECEIVE with the SNM residing in the incomplete transaction file in between SEND and RECEIVE. Closer evaluation reveals the fact that many transactions are instantaneous and do not involve a formal SEND and RECEIVE. The option list now becomes TRANSFER and RECEIVE, where the program requires certain types of transfers to be actually received. Still more evaluation reveals that at a particular point in a process the transaction writing involves a lot of fixed information that is entered again and again. Two things become instantly clear: (a) transactions fall into certain types, and (b) we should restart our analysis by defining the characteristics of a transaction. It also is clear that the option list approach is more effective if the option names resemble the process, e.g., MOVE ASH TO SCREENING BOX rather than TRANSFER.

A transaction entails certain basic operations:

- Questions are asked and responses made and evaluated;
- File searches are made;
- Prompts-responses are made for amounts moved and measurements involved;

- Measurements are made;
- More file searches are made (is material going to some place that already exists? e.g., mixing);
- Files are updated.

For example, can A has ash containing 1 000 g of SNM; we wish to transfer a portion of it to screening box 3. The portion moved will be measured by a thermal-neutron coincidence counter. The option name might be MOVE ASH TO SCREENING BOX. This transaction entails the following operations:

- Request the operator's name; request the ID of the lot the SNM is coming from;
- Find that lot ID in the inventory file;
- If not all the lot is being moved, where is the portion to be measured?
- Issue prompts to the user to transmit the data from the NDA instrument and calculate the fissile content of the portion being moved;
- Request the ID of the lot the material will move to; search the inventory file to see if this material will be added to the current inventory or if a new inventory file is to be created;
- Update the inventory file and append the transaction to the transaction file.

We call this group of required operations a packet. Each transaction has its own characteristic packet. When the user requests an option, the appropriate packet is selected from the packet file and passed to the accountability program, which has now developed into a packet interpreter or a table-driven piece of reentrant code that executes the list of instructions in the packet. In addition to a packet file, which is just a table or list of instructions for the accountability program, we also create an image file (equivalent to pre-printed forms) to reduce the dialogue with the user, thus saving time and reducing erroneous input.

This packet and image concept has gained us (a) less user interaction, which saves time and reduces input errors, and (b) a simple, fast scheme for responding to changes in the transaction sequence. This is what we set out to achieve, for if the system inhibits production it will be abused and ignored; no amount of regulations, incentives, or threats will change that fact.

Needless to say, many other reentrant routines support the design of the accountability program.

Data Base Management

Managing a data base means the orderly handling of information, such as a large number of look-alike records in a disk file. Handling means the ability to create a file, search it, sort it, insert whole records, delete whole records, and alter a part of a record.

Take the case of the telephone company. One of its data bases is a list of subscribers. Each record in the data base contains the subscriber's last name, first name and middle initial, address, telephone number, and so forth. When a person first gets a telephone, a new record must be created and inserted in place in the list. When he moves away his record must be deleted. If he moves nearby, his address merely needs to be edited. If he changes his name, that too must be edited. He might request a new number. As these events take place the company is bound by regulation to have this new information in the switchboard operators' hands within 24 hours. Periodically, the list needs to be published for subscribers sorted by state, town, and last name. Internally, this list needs to be sorted by telephone number for maintenance people and account representatives. Monthly changes are posted to the record and a billing list is printed. Information operators search the list for subscribers' telephone numbers all the time. Handling these operations in an orderly fashion is called data base management.

To return to our ash inventory example, let's see how its transfer affects data base management. While a copy of the inventory record for can A is in use, the data base management system cannot allow any other terminal task to make a transaction concerning that record because it may have a new balance when the transaction is completed. However, transactions concerning other records can be made. The record must be locked while an operator is using a copy of it and unlocked when he is finished.

For our pilot installation at DP Site we wrote a sketchy data base management system. Our TA-55 specification asks the vendor to supply that capability. Several vendors responded with a completely designed data base management package and others responded with just tools that we could put together to create our own tailored management scheme. We selected the second approach because of the R&D nature of DYMAC. Once we are finished, it may be possible to define the data base management requirements such that a prepackaged version could be used in another application to save programming time.

DATA INTEGRITY

DYMAC is concerned with data integrity in that the information placed in the data base must be sufficiently correct to allow generation of an accurate book inventory. To ensure data integrity, the accountability program relies on a number of techniques. These techniques, when put into use, can prevent, detect, and subsequently correct the majority of errors that occur during operation. The system emphasizes early detection of invalid data prior to data base update to minimize the domino effect of error propagation.

Interactive man-machine dialogs. In cases where sequences of data or transactions are required, a set of protocols are imposed via the dialog at the transaction terminal.

Syntactical checking of responses. User responses are examined in detail, e.g., an account number must be three digits, a person's name may contain no numerics. Incorrect syntax of the response generates an explicit error message to the user and the prompt reappears on his display.

Image files. The program supplies all fixed information in the transaction to reduce user error.

Use of known data base information. The user only enters the lot ID (i.e., the name) of the material. Other pertinent information, e.g., location, amount of SNM, is supplied from the inventory record.

Inventory pre- and post-transaction searches. When a transaction is initiated, the program searches the inventory to ensure that the lot ID exists. On completion of the dialog, the program again searches the inventory to ensure that either (a) the new lot ID already exists, in the case of a mixing transaction, or (b) does not exist, for all other transaction types.

Logical relationship check. The program checks to validate the relationship between the transaction types, lot ID, account numbers, locations, amounts, and names of the users involved.

Preupdate edit of transaction. Before completion of a transaction and subsequent file update, the entire transaction appears on the display for the user to make any changes needed. He can only change those items that he entered. He cannot edit an image parameter or a quantity supplied by the data base.

Protocol for consistent data collection. All data sent to the computer from any line, terminal, or NDA instrument look alike, that is, ASCII characters with even parity. The program checks each character and echoes it back

to the source for display or comparison. In this way, data collection and checking are the same regardless of source. This avoids data conversion and reduces the likelihood of introducing errors.

Management reporting in near real time. Every morning, process supervisors receive a list of the previous day's activity, which allows them to closely monitor the accuracy of their inventory books.

Inquiry and correction facilities. Inquiry and correction programs allow management to trace back from inconsistent book totals to discover which transactions were in error and to write the required corrective transactions.

Error feedback. All errors are classified by type and are logged. The results are used to update user training programs and serve as the basis for possible changes or enhancements to the accountability program.

Measurement control program. The measurement control program monitors the calibration and accuracy of NDA instruments and generates control charts for each one. The program prevents a suspect instrument from providing measurement data to transactions until it is back in good working order.