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Los Alamos Plutonium Facility Applied Systems Integration Project Status Report for Period Ending August 31, 1981

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LOS ALAMOS PLUTONIUM FACILITY APPLIED SYSTEMS INTEGRATION PROJECT STATUS REPORT FOR PERIOD ENDING AUGUST 31, 1981

by

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ABSTRACT

The conceptual design of an on-line, near-real-time nondestructive assay instrumentation network for the Los Alamos Plutonium Facility is complete. Analysis of instrument history data indicates that the instrument certification procedures need improvement. Analysis of exhaust filter data has led to the derivation of a buildup prediction equation that is a function of throughput. This suggests that development of a generalized model is possible. A number of routine reports are now available from the Plutonium Facility/Los Alamos Safeguards System including inventories and active reports.

I. INTRODUCTION

The objective of this project is to define, test, and evaluate the integration of materials accounting and physical protection elements into a system to enhance the safeguarding of nuclear materials in plants such as the Los Alamos Plutonium Facility (TA-55). Functional systems that are typical of such nuclear plants are physical protection, plant operations, process control, materials control, and materials accounting. Usually these systems are functionally independent with one exception; the latter two are considered to function together as the materials control and accounting (MC&A) system. Safeguarding nuclear materials is typically within the purview of the physical protection (PP) and MC&A systems operating independently with the combined goal of preventing diversion of nuclear material (NM). Plant operations and process control information systems that are of potential value for NM safeguards frequently are not readily available for safeguards purposes. Thus, safeguards draws on the PP and MC&A systems, which at best may be poorly coordinated and may not use information available from other plant systems. Integration of information from the various systems will result in increased safeguards effectiveness with improved response time and assurance.

Ideally, an integrated safeguards system design would be included in the initial design of a facility, thereby minimizing constraints on the system. However, most existing facilities would also benefit from even a retrofitted integrated safeguards system if it were well designed and operationally proven. It should be apparent that, although the design of a system for existing facilities will be site specific, there will be features common to all facilities, for example, data acquisition, data processing and data analysis, perimeter monitoring, measurement techniques, and access/egress control. Also, retrofitted systems will probably not be ideal; tradeoffs in design will result from a variety of factors.

An integrated safeguards system supports the facility management function in which a number of subsystems collect, evaluate, and transfer information to a facility data coordination center (FDCC).

The FDCC, in conjunction with the subsystems, initiates appropriate responses to the transferred information. The systems concept illustrated in Fig. 1 is for a site with a single safeguarded facility. For a site such as Los Alamos with a number of separate safeguarded facilities, the FDCC would transfer information to a site (Laboratory)-wide safeguards and security system. An economically attractive alternative for sites with multiple safeguarded facilities is to use the computer power available with the materials access area (MAA) and PP data handling systems to perform the functions of the FDCC, thereby eliminating one link in the communications chain with the site-wide system. Discussions with both Los Alamos and other Department of Energy (DOE) facility personnel indicate that this latter approach is probably preferred.

The design of an integrated system for a prototypical plutonium processing facility using TA-55 as a base line was undertaken jointly by Sandia National Laboratories and Los Alamos National Laboratory. The system as designed, though effective, was impractical for retrofitting to the actual facility. Heavy reliance was placed on physical protection techniques in part because of the advanced developmental state of such techniques vis-à-vis MC&A techniques.

Development and evaluation of alternative integrated safeguards systems that could be implemented in the existing facility and that use more advanced MC&A techniques than those currently in use were recommended as a sequel to the initial study and are in progress. The program is to design and demonstrate an integrated safeguards system that is both effective and conceptually acceptable to the facility operators. The target date is September 1984. The initial effort concentrates on perfecting the rapid-inventory capabilities of the TA-55 materials control and accountability system, making inventory and related data available in near-real-time in a format usable in an integrated system, while assuring the integrity of the accountability data. The current tasks include development of on-line, near-real-time nondestructive assay (NDA) instrument networks, holdup measurement systems, and a rapid physical inventory and materials balance capability. This

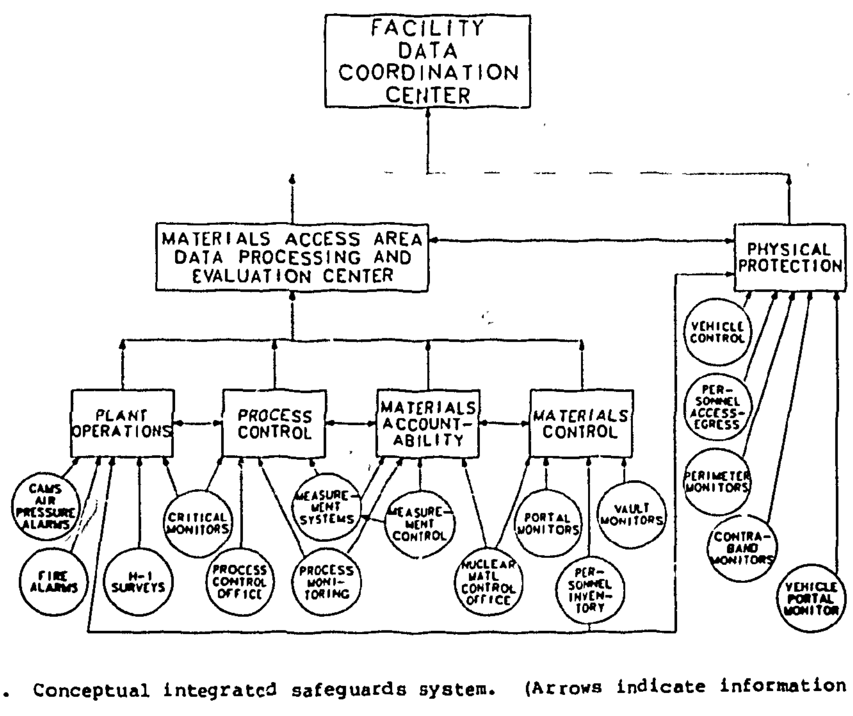

Fig. 1. Conceptual integrated safeguards system. (Arrows indicate information flow.)

II. DEVELOPMENT PROGRAM DESCRIPTION

The basic approach to an integrated safeguards system that could be implemented at TA-55 and the planned development program are described in the following paragraphs. Because the major effort will be the development of more advanced MC&A techniques, the discussion emphasizes that aspect of the program.

The computer system currently envisioned for the MAA data acquisition, processing, and evaluation functions is a distributed processing system: groups of NDA instruments and terminals in the plant production and support areas would be connected to minicomputers that, in turn, would be connected to a main computer (presumably the existing Plutonium Facility/Los Alamos Safeguards System [PF/LASS] computer). The functions of the main computer would include (1) maintenance of materials and personnel inventory data bases, (2) maintenance of a materials control program data base, (3) processing of inquiries and report generation, (4) provision and analyses of near-real-time materials accounting data, (5) coordination of data from the MAA subsystems, and (6) transfer of data to the FDCC or, alternatively, coordination of the MAA data with the PP data for transfer to the sitewide system and facility operations.

The main computer will not be involved in the control of instruments or in the generation of transaction records, thus releasing the main computer for other activities. Minicomputers, serving as preprocessors, will act as instrument control devices and will also process data from terminals and measurement instruments. These processed data will then be used to update the main computer data base. This structure would release the main computer from dealing with instruments directly, although it could respond to inquiries about system-wide instrument status by querying the preprocessors.

This type of distributed processing system is more versatile than the present TA-55 system in that it has the option of easily handling new and different tasks and additional instruments. It is also more efficient in that operator delays are reduced because computer system access is improved. It is also more reliable; for example, if the main computer should be unavailable for use, the preprocessor computers would store the data until the main computer is back on-line. It also has much more growth potential; the addition of dozens more instruments would require that the main computer look at only one more preprocessor computer.

Computer security problems associated with a distributed processing system will have to be addressed in the development program. It has been assumed, for purposes of this study, that the entire system will be within a single secured facility, thus eliminating problems associated with transmission lines crossing unsecured areas. It is possible, however, that an integrated safeguards system at TA-55 will communicate with the Los Alamos Central Alarm Station and LASS, necessitating secure communications links. This possibility will be considered at an appropriate point in the development program.

The subsystems that are components of an integrated safeguards system (Fig. 1) include physical protection, materials control, materials accountability, process control, and plant operations. TA-55 contains all of the basic subsystems shown in Fig. 1. These subsystems, however, are not fully integrated. We plan to demonstrate that integration of the existing subsystems with the addition of selected procedures, techniques, and instrumentation can produce a complete and balanced integrated safeguards system for TA-55 and similar generic facilities.

Any interference with process operation in a production facility such as TA-55 must be minimized, consistent with operational safety and safeguards requirements. Thus, developmental studies at TA-55 are severely constrained. To avoid this constraint, the program will be conducted using a digital computer* and its subsidiary processors as a prototypical test bed. This will provide the opportunity to develop and demonstrate components, elements, subsystems, integration impact, effectiveness, and tradeoffs in a realistic yet nonoperational environment. Sensitivity exercises will be

*Applied Safeguards Integration Study/Test (ASIST) system.

possible using the away-from-plant (off-line) system. Because the system will be independent of the actual facility, data bases and software support will be transportable to other facilities.

Modeling and simulation techniques are being employed whenever practical using both mathematical and physical models of process operations and measurement systems. The Fast Flux Test Facility (FFTF) process was selected for use as the typical TA-55 reference process. Operational data are used in the modeling and simulation effort. Requisite components that do not exist will be designed, developed, tested, and evaluated off-line insofar as possible. Wherever possible and desirable, in-plant and on-line testing of new components will be performed.

The computer system for this program consists of a Digital Equipment Corporation (DEC) VAX 11/780 as the main ASIST computer, a DEC PDP 11/34 as one of many possible subsidiary processors, and DEC PDP 11/03s to simulate some NDA instrumentation. New NDA instruments also will be incorporated in the ASIST system for test and evaluation.

The above program description has outlined an approach to design and demonstrate an effective and conceptually acceptable integrated safeguards system for TA-55. Rapid physical inventory/materials balance capabilities and holdup estimation and/or measurement are inherent parts of such a system. The capability to obtain rapid physical inventory information and materials balances is essential to the MC&A component of an integrated safeguards system, and the development of this capability is inherent in the efforts described in this section. The estimation or measurement of in-process inventory is also an important aspect of both the MC&A and process control components of the integrated system and is an effort in the development program. Holdup is a part of in-process inventory and, after run-down and/or clean-out, may be the major part. The FY81 development effort has been concerned with these two activities as well as the on-line, near-real-time NDA instrumentation network. The status of these efforts is discussed in the following section.

III. RESULTS AND DISCUSSIONS

A. On-line, Near-Real-Time NDA Instrumentation Network

The DYMAC system (as installed at TA-55) incorporates NDA instrumentation for analyzing and verifying special nuclear material (SNM) content and instructions for handling and measuring the SNM as it passes through the facility. Thirty-six digital electronic balances, two segmented gamma scanners (SGS), three solution assay instruments (SAI), twelve operational thermal neutron counters, and twenty three terminals are located throughout the plant at strategic points. Additional instruments and terminals are located in the vault and in the adjacent cold-support building where the computer is located. Operating procedures require that measurements be made and communicated to the central computer whenever a change occurs in an item, such as a change in its location or physical state, or whenever an item is split or combined with another item. These measurements are either typed on a terminal or transmitted directly to the computer over communications lines that connect some of the electronic balances to the computer. For each transaction the computer uses the measurement data and the information supplied by the process technician to update the inventory data base. The inventory data base may then be queried by process technicians and supervisors to obtain up-to-date information on the status of any item in the plant.

Although all of the NDA instruments are capable of transmitting their measurements directly to the central computer, not all of the balances have been linked directly to the computer. For all the other instruments, the process technician must note the measurement and then enter this information as part of a transaction on a PF/LASS terminal. This form of data entry not only slows processing but provides significant opportunity for recording errors; errors in data entry can result from mistyping responses by accident or can conceal a diversion attempt.

Another difficulty arises from off-line instrumentation. Instead of taking the time to certify an instrument before making a measurement, some process technicians make measurements with one instrument and then report the results using another. To reduce this tendency, a single individual has been assigned responsibility for daily certifying each NDA instrument.

This administrative approach is not overwhelmingly effective, however. Some process technicians avoid using the certified PF/LASS instruments because of the inconvenience of moving materials from their processing location to the instrument and also because they have to walk several times between a local terminal and the instrument to effect a transaction. From a safeguards viewpoint, all measurement instrumentation should be on-line. More than a hundred instruments and terminals need access to the central computer. As it is now configured, only 80 devices may be directly linked to the computer because of software limitations. Even if all of the devices could be linked to the computer, the user response time of the system would be so degraded that the system would not be usable. Currently, the system response time is barely acceptable because of the volume of transactions and process inquiries. Even if all of the current instrumentation is brought on-line, the system must still provide the capability to handle additional users and instrumentation with minimum effect upon response times, and also the capability to initiate a transaction from a local measurement device, or monitor.

A system is envisioned in which groups of NDA instruments, monitors, and interactive terminals in a plant production area would be connected to a local minicomputer. This minicomputer would be a local node in the plant network. With this configuration, the primary function of the central computer would be to maintain a data base of all inventory items in the facility and to process inquiries to that data base from the preprocessors and accountability or processing managers. The central computer would not be involved in the control or monitoring of the instrumentation, nor would it be involved in the generation of valid transaction records. The preprocessors and local node computers would perform these and other functions. A schematic diagram of the prototype network is shown in Fig. 2. A PDP 11/34 was acquired for use as the prototype preprocessor.

Conceptually, the system consists of a central computer with a large disk for data base manipulation, a series of preprocessors with moderate disk capacity, and at level 3, a number of NDA instruments and terminals. Including a microprocessor in an instrument or monitor design is particularly important if it must have the capability of initiating a transaction. With the microprocessor in place, changes in data entry or transaction requirements can be accommodated in the microprocessor software. This offers the clear advantage of not burdening the preprocessor with this task or of requiring hardware changes for the instrument or monitor. If, however, we wish only to monitor the state of a process with a collection of sensors, then this can be easily accomplished by a multiplexor and a single microprocessor or microcomputer. Wherever possible, these instruments should be based on minicomputers or microcomputers. Either the preprocessors or the central computer may initiate an interchange of data with the other.

The hypothetical plant monitored by the level 1 computer is considered to be subdivided into several materials balance areas (MBA) (three in the figure), each served entirely by a single preprocessor (at level 2). Each MBA must be contiguous and must not overlap any other MBA. The MBAs are further subdivided into unit processes; again, each unit process must be contiguous and must not overlap any other unit process.

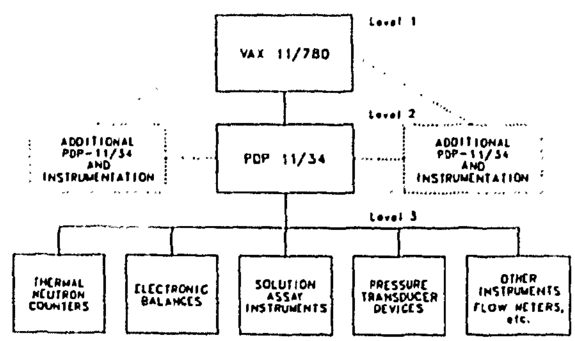

Fig. 2. Prototype network schematic.

Whenever an item crosses a unit process boundary or undergoes a significant change in composition, a transaction is required. The transaction is handled by the level 2 preprocessor and after verification is transferred immediately to level 1 (central computer). Should the level 1 computer be down, the transaction is flagged and transferred at the next opportunity.

The level 2 computer maintains an inventory record and a complete transaction history for every item undergoing processing within the MBA. When the item is transferred out of the MBA, these records are deleted after the material in process (MIP) calculation has been performed, the receiving MBA preprocessor has acknowledged receipt, and the level 1 computer has successfully received the transactions.

When an item first comes into the MBA, the initial inventory record is sent to the responsible preprocessor by the level 1 computer. If the level 1 computer is down, the preprocessor can still initiate a transaction that is flagged to identify it as not complete because of level 1 failure. An alternative to this simple administrative procedure is to send the transaction record directly to the receiving preprocessor. This requires an additional communications network link between the preprocessors. Additional network software and application codes would be required. Clearly, this procedure would provide a backup for the level 1 computer when it is down and a completely independent data path when the level 1 computer is operating.

This transfer of information is initiated by the transaction that ships the material into the MBA. Consider as an example the shipment of an item from MBA 1 to MBA 2. This action requires that two transactions be written. The first, in MBA 1, indicates that a shipment is to travel between MBA 1 and MBA 2. The second transaction, in MBA 2, acknowledges receipt of that shipment (assuming it arrives successfully). When the shipping transaction is written in preprocessor 1 and transferred to the level 1 computer, several actions occur. The level 1 computer sends the appropriate inventory record to preprocessor 2 properly flagged to indicate that a shipment is on the way. At the same time, clocks are started in the level 1 computer and in both preprocessors. When the shipment is received, the RECEIVE transaction causes the level 1 computer to send signals to each preprocessor that disarm the clocks and signal the shipping MBA to delete the associated records.

If the receiving MBA does not execute a RECEIVE transaction within 20 min, the receiving preprocessor notifies the receiving MBA supervisor. If the transaction is not logged within 30 min, the shipping MBA supervisor is notified by his preprocessor. If after 45 min the transaction has not been logged, the plant nuclear materials officer (NMO) receives an alarm from the central computer.

The central computer could itself handle the timing of shipments for all three computers as well as the warnings, but with the two disadvantages that (1) more interchanges between the central computer and the preprocessors would be necessary and, more importantly, (2) if the central computer should fail during the period of the shipment, no warnings of late shipment would be issued.

Each level 2 computer maintains a running total of MIP for each unit process in its jurisdiction. The same information is, of course, available at level 1. Twice each working day these numbers are compared and any discrepancies reported immediately to the NMO. This serves as an additional check on the safeguards integrity of the plant.

Each level 2 computer has a list of passwords allowing access to the computer. These passwords are hierarchical; that is, supervisory passwords allow access to more privileges. For instance, corrective transactions can only be made by high-level personnel.

Each level 2 computer handles balance certification for each instrument in its MBA. The certification transactions are copied to the level 1 computer, but instrument status is maintained at the preprocessor level.

Because some NDA instruments are not able to analyze their raw data, the manipulation of raw data in those cases occurs at level 2. The preprocessor has calibration information on these instruments and has the routines necessary to convert the raw numbers to assay values. If the preprocessors are not to become bogged down, as much data analysis as possible must be performed at level 3. Measures should be taken to ensure the integrity of analysis and data at the instrument level. Independent verification should be considered.

When a transaction is attempted, the preprocessor checks the item ID to verify that it is in the inventory. The preprocessor uses its own files to do this verification. If a new item is being created, the central computer is queried to determine if a duplication is about to occur. The need to make this check could be obviated if all item ID numbers had a designator for the MBA in which the new item was created. For instance, the first character of an item ID could refer to the originating MBA. Whether this can be done will largely depend on the traditions of the target facility.

The preprocessor also maintains a table indicating the instruments that can be accessed from a particular receipt area. Transactions proposing measurements are verified to assure that the measurement instrument proposed is consistent with the location of the material. The transaction is refused if not consistent. To ensure that inoperable instruments do not unduly impede production, the table of accessible instruments can be modified at the supervisory level to allow the technicians to work around such potential bottlenecks.

An effort should be made to provide some custom programs for each preprocessor to satisfy the requirements of a particular MBA. In particular, attention should be given to developing programs to assist processing at the request of the MBA supervisor(s). This effort could significantly affect the ultimate acceptance of the near-real-time accounting system.

The level 1 computer is almost exclusively limited to data base manipulation and report generation. It is the final authority on what is legitimately in the data base. It responds primarily to requests from accountability officers and process control officers for reports, charts, and other output. These reports are an expansion of the types of reports now available at TA-55. The generation of MIP charts, however, can be done on-line because the central computer is almost completely unburdened from housekeeping duties.

The level 1 computer also responds to requests for information from the preprocessors. It is possible for an operator to request through his preprocessor that a certain report be generated for him on the level 1 computer. The results can await him at the level 1 computer or, if appropriate, can be transmitted to him by the preprocessor.

Because the level 1 and level 2 computers are both DEC PDP machines, there are essentially no interfacing problems. The hardware and the software that allow interchange of data between machines are available commercially, minimizing software development needs.

The ability to enter transaction input data from a measurement device would significantly improve operator acceptance. Currently at TA-55, transactions can be initiated only from a PF/LASS CRT, which is usually located some distance from the work station. The logistics contribute to operator frustration with the system, a loss in processing efficiency, and a much greater potential for erroneous entries in the transaction data base. The combination of an on-line measurement device and a local, convenient means of transaction input would enhance the integrity of the accountability data base while improving the use of the process technicians' time.

The ability to initiate transactions from a "primitive" device, such as an electronic balance, pressure transducer, or flowmeter, is limited currently to the transmission of measurement data. No other flexibility exists for data entry into the system. We have a design for a "smart" communications interface unit that can be placed between the preprocessor and the device of interest. This unit will allow data entry by way of a compact ASCII keyboard, data output by a small thermal printer, and both on- and off-line operation of the device. The arbitration for the various options would be handled by a software-controlled microprocessor resident in the interface. Additionally, the communications signals could use either RS-232C or 20-mA connections. This interface will allow convenient data entry for both process monitoring and accountability, while minimizing the operator effort for data entry. The compact size of both the printer and the terminal will allow placement of the data entry devices at the process work station, while avoiding the cost and size of a full screen CRT or hard-copy terminal.

An additional measurement device was incorporated into the prototype preprocessor network - a pressure transducer for measuring the mass of fluid in a processing tank.[1] The microprocessorcontrolled device will send the tank ID and the mass of the fluid (in kilograms) in an ASCII character so that the operator may enter his ID, then the ID of the desired tank; and the pressure transducer system will provide the information. If the cycle is not completed within a preset time, the procedure must be repeated. The tank ID is checked not only by the pressure transducer system but also upon return by the preprocessor.

To maintain the integrity of the measurement values in the transactions data base, a strict on-line measurement control procedure should be adopted for the instrumentation. Measurement control instrument histories can be useful when examining MIP or cumulative summation (CUSUM) charts. To facilitate the analysis of the TA-55 PF/LASS data, analysis, graphics, and plotting codes have been developed on the PDP 11/34. These codes calculate the systematic and random variances for each of the digital electronic balances used in the FFTF process. Because no recalibration data were available, variances were plotted as a function of varying arbitrary recalibration intervals for the period March 1980 to February 1981. An example is shown in Fig. 3. In addition to this analysis, the recorded accuracy values (t statistics) were plotted as a function for each of the balances. An example of these plots is shown in Fig. 4.

With the above codes, an on-line analysis of the instrument history data base is feasible. With the graphics interpretation available immediately, and using the appropriate statistical trend tests, both short- and long-term trends may be visually recognized. Also, the behavior of the MIP and CUSUM charts can be related directly to the instrument history accuracy and precision plots.

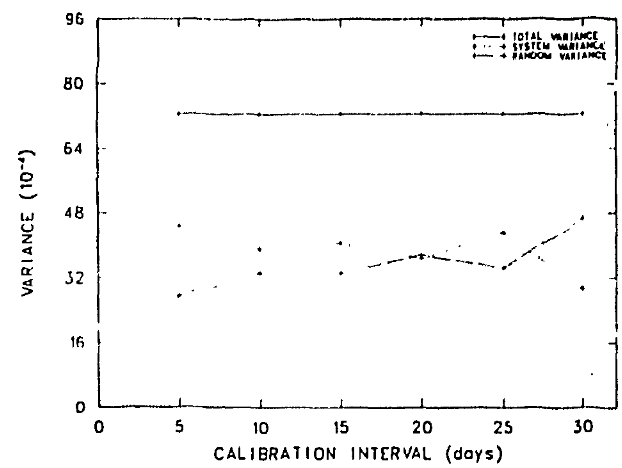

Fig. 3. Analysis of variance; total, random, and systematic as a function of calibration interval for a digital electonic balance.

In addition to the enhanced accounting functions possible with the distributed processing approach, it is also possible to improve the accounting capability of the system. Using existent data from the instrumentation and transaction records, various decision analysis techniques may be applied to detect internal diversions. The decision analysis code DECANAL was installed on the prototype preprocessor PDP 11/34. It is currently being modified and tested to optimize performance on the PDP 11/34. The output of DECANAL

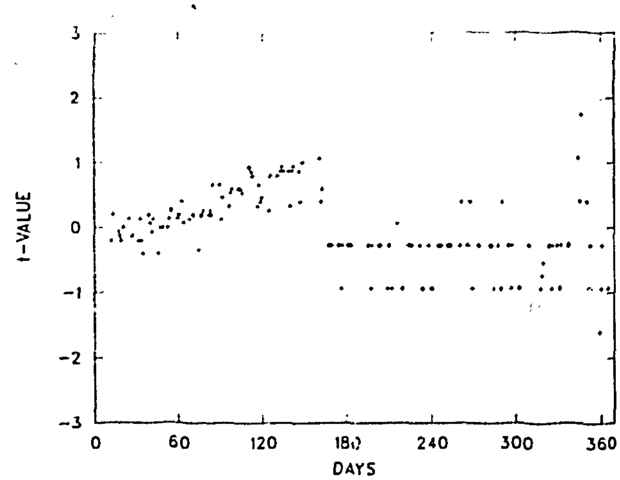

Fig. 4. Accuracy, t-value versus time parameter for digital electronic balance.

will take two forms: printed reports and on-line, real-time color graphics. Requirements and performance criteria are being drafted for the various software graphics packages. With the addition of a decision analysis package to the preprocessor, a complete accounting, process monitoring, and accountability system is available in a modular system.

The preprocessor approach with the smart interface provides significant advantages over the "central computer does all" approach. A distributed system will allow a phase-in of a near-real-time accounting system. If the limited NDA system in a section of the plant meets its goals while having minimum impact on the existing system, additional opportunities might arise.

The distributed system would require less elaborate coordination of the various software packages than a lone central computer. Once satisfactory protocols are developed to assure accurate and reliable data transmission, software efforts for the preprocessor can proceed independently. Additional flexibility also is provided by the preprocessor approach. Reprogramming for additional instrumentation or monitors can be made to the specific preprocessor while not interfering with other preprocessors or the central computer. This flexibility allows a substantial period of "stand-alone" development time, if desired, before linking to the central computer.

B. Holdup Measurement Status

Near-real-time accounting necessitates a knowledge of in-process inventory. A potentially major component under certain conditions is holdup. Projects to develop holdup measurement techniques have been an integral part of the Los Alamos safeguards R&D programs. Efforts devoted to the measurement of holdup at TA-55 presented in this section include the development of a technique for the measurement of glovebox and equipment holdup and glovebox exhaust filter holdup.

The exhaust filter effort has led to the derivation of a buildup prediction equation for a particular exhaust filter. The prediction equation is a function of throughput. It would appear feasible to develop a generalized model that could be applied to any exhaust filter after determination of the filter-specific constants. The ability to estimate the amount of plutonium on a filter would permit accountability personnel to remove the filter holdup from MIP data, thus improving the ability to detect protracted diversion.

The glovebox and equipment measurement technique has been and is being applied to holdup measurements at TA-55 with satisfactory results. The technique could be used to measure holdup after run-down and/or clean-out to develop base line data for holdup prediction models. Interest in establishing such a data base has been expressed by both operations and R&D personnel and was part of the motivation for the initial work in the DYMAC program. Unfortunately, time and funding limitations, coupled with a low priority relative to other tasks, have prevented investigation of the concept. Future planned evaluations of the use of TA-55 historical data for the development of prediction models may require the use of the technique for model verification.

The initial development of a holdup measurement system at TA-55 was motivated by plans to move some potentially contaminated equipment from the old plutonium facility (DP Site) to TA-55 and an interest in establishing baseline information for plutonium buildup studies at TA-55.[2] The procedures developed were similar to passive gamma ray techniques in use at the Kerr-McGee Plutonium Facility and at Los Alamos.[3] The major difference is in the electronics. The TA-55 system uses a multichannel analyzer (MCA), whereas the others used a single- or dual-channel analyzer (for example, a SAM-II).[4]

The TA-55 measurement technique uses a collimated 5- by 5-cm sodium iodide (NaI(Tl)) detector and the MCA (Figs. 5 and 6). The amount of plutonium is estimated from the intensity of the ^{239}Pu gamma rays in the energy region 370 to 450 keV and appropriate correction and calibration factors. The calibration depends on detector geometry and on the assumed distribution of plutonium holdup as the equivalent of a point, line, or area source. Attenuation corrections for glovebox walls, floors, and windows and for equipment items (for example, incinerators) are determined using a ^{137}Cs source.[5]

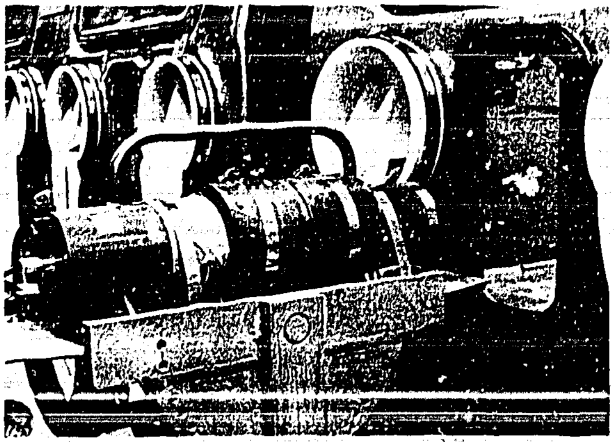

Fig. 5. Holdup measurement system detector.

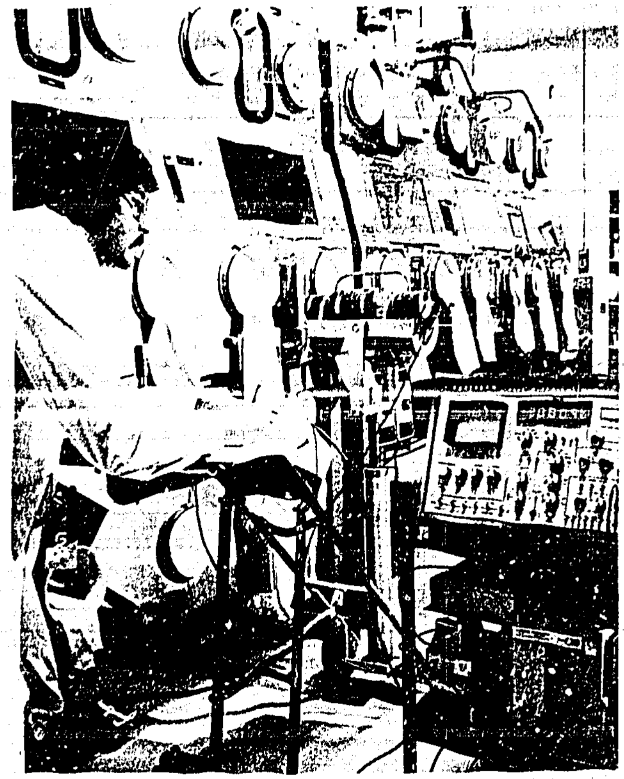

Fig. 6. Holdup measurement system.

The instrumentation is mobile but not readily portable. For situations requiring a truly portable, battery-powered system, a system consisting of a collimated 2.5- by 2.5-cm NaI(Tl) detector with SAM-II electronics is used.

The technique using the MCA system was used to measure the residue plutonium levels in 30 gloveboxes transferred from DP Site to TA-55.[6] As many measurements as were physically practical were made on all accessible sides of the gloveboxes resulting in up to 50 measurements of 100-s duration per box. The measurements indicated that the gloveboxes were quite clean.[4] For example, eight gloveboxes had a total residual plutonium of 44 ± 22 g (^{239}Pu).[5] An additional 12 gloveboxes indicated a total residual level of 182 ± 142 g plutonium. The data for the individual boxes are shown in Table I. In the calculation of the residual plutonium, a lower-level-of-detection (LLD) count was used whenever the measured count minus the background count was less than the LLD count. The LLD count is related to the background count as follows.

$$LLD = 2.828\ k\ (N_B)^{1/2} ,$$

where

N_B = background count and

k = 1.645 for $\alpha = \beta = 0.05$; α and β have the usual statistics definitions.

Thus, for clean gloveboxes the residual plutonium calculated in this manner represents an upper bound on the amount of material present.

The system is used regularly upon request from TA-55 personnel for measuring holdup in gloveboxes and equipment. These measurements are used for both process and accounting purposes. In general the results of these measurements are only documented internally; however, Ref. 5 describes measurements made on (1) two cleaned gloveboxes, (2) a cleaned-out incinerator, and (3) three 36-in.-diam. steel "bathyspheres."

Holdup measurements using the method described on gloveboxes and equipment in conjunction with completion of processing a batch of material were proposed by both operations and safeguards personnel. Such measurements could establish nominal holdups in each unit process that could then be used for in-process inventory estimation. To date it has not been possible to implement a program to carry out such measurements because of time, manpower, and funding limitations.

TABLE I

RESIDUAL PLUTONIUM LEVELS IN TA-55 GLOVEBOXES

Glovebox No.	Residual Pu (g)
GB 307	48 ± 62
GB 314	16 ± 8
GB 347	23 ± 17
GB 431	16 ± 10
GB 443	10 ± 5
GB 445	10 ± 4
GB 446	8 ± 3
GB 447	13 ± 8
GB 448	8 ± 6
GB 449	10 ± 7
GB 450	9 ± 4
GB 451	12 ± 9

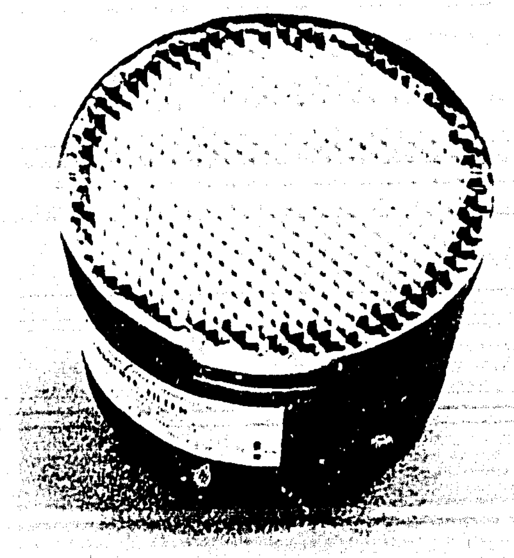

Fig. 7. HEPA filter.

An in-line filter monitor has been developed and tested at TA-55 (Ref. 4, pp. 76-78; Ref. 7-9). The unit was initially installed on a glovebox in which PuO_2, UO_2, and carbon are blended, milled, and prepared for making advanced fast breeder reactor (FBR) fuel. Currently, the unit is installed on a glovebox in which PuO_2 is screened, ground, blended, and packaged as feed material for FFTF fuel fabrication.

Glovebox air is exhausted through at least three stages of filtration to remove airborne contamination. A high-efficiency particulate air (HEPA) filter (Fig. 7) located in a filter housing on top of the glovebox (Fig. 8) removes most of the particulate matter. Additional filtration in the building glovebox exhaust system traps any airborne particles that pass through the glovebox filter.

The in-line filter holdup monitor system consists of a 5-cm by 5-cm NaI(Tl) detector and an electronics package as shown in Fig. 9. Gamma rays emitted from the filter are detected by the NaI(Tl) detector and analyzed by single-channel analyzers (SCAs). Three SCAs are used for determining the plutonium gamma-ray peak area for FBR fuel. An automatic gain-control (AGC) amplifier minimizes shifts from counting-rate variations and photomultiplier-tube aging. The system was stabilized by setting the SCA discriminators in the AGC amplifier at the 662-keV gamma-ray peak emitted from a 1-μCi ^{137}Cs source. The SCA outputs, including the output from the AGC amplifier, are fed to counters that are interfaced to a printing unit. The printer is a digital printing accessory and program control center for the data acquisition system. The data from each counter in the system are printed in sequence, with an automatic paper-tape advance for each new data word. By presetting the printer to recycle and the counter/timer to a specific counting time interval, the system will continuously collect and print the data. This automatic system minimizes operator intervention once the system has been calibrated and set up for measurements. The MCA (a Tracor-Northern NS-710) is used only during the initial setup.

The system that was installed in the FBR fuel operation was calibrated with three plutonium filter standards. The Los Alamos Analytical Chemistry Laboratory prepared the standards by adding known quantities of PuO_2 to filters of the same type used in the glovebox exhaust system. Each standard was prepared by sprinkling PuO_2 powder evenly over the surface of the filter while drawing air through it, thus simulating the type

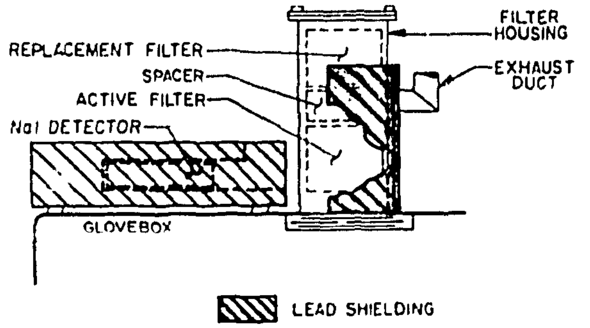

Fig. 8. Filter monitoring system installation.

of filter loading that might be observed in a glovebox exhaust filter. The individual filter standards were then sealed with aluminum foil covers packaged in double plastic bags and centered in plastic boxes having 6-mm-thick walls. The calibration system setup, including detector shielding and collimation, was the same as the in-plant setup at TA-55. Pulse pileup and dead-time corrections were determined using a 1-μCi ^{137}Cs source. A 10-g reactor-grade plutonium source was used as a transmission source for measuring sample self-attenuation.[9]

The monitoring system successfully detected plutonium in the FBR fuel preparation glovebox filter. The plutonium buildup in the active HEPA filter was measured during the preparation of 16 batches of advanced carbide fuel. The data were taken after each batch of PuO_2, UO_2, and carbon had been weighed, mixed, blended, milled, and unloaded from ball-mill jars. The results are plotted as a function of batch in Fig. 10(a). The buildup is essentially linear. The error bars represent both statistical counting uncertainties and uncertainties associated with calibration. A counting time of approximately 100 min is required to obtain a statistical uncertainty of less than 1%. Figure 10(b) shows the amount of plutonium buildup per processed batch. The average detected accumulation of plutonium per batch, as indicated by a dashed line, is 0.096 ± 0.037 g.

Plutonium buildup rate in the low-throughput FBR fuel preparation-glovebox filter was relatively

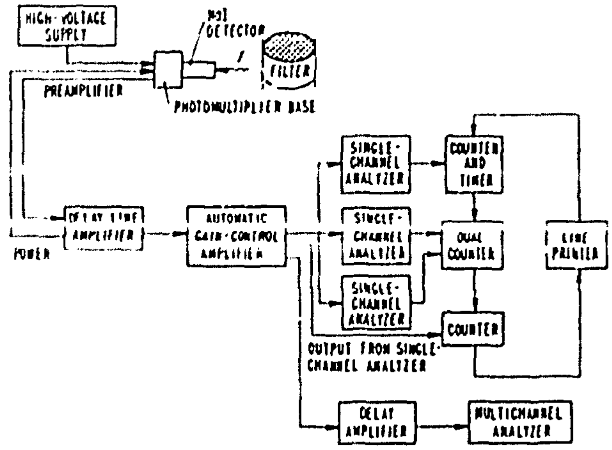

Fig. 9. Filter monitor system electronics schematic.

low. At the end of 1980 the detector was relocated to monitor the plutonium buildup on a high-throughput glovebox exhaust filter. Filter type and orientation and the detector installation were identical to that already described. The SCA-based counting system was replaced with a Canberra series 30 MCA. The filter system monitored from January 1981 to present has been installed on a glovebox in which PuO_2 is blended, screened, and packaged. The operation is the last step of a high-purity PuO_2 process that generates PuO_2 for FFTF reactor fuel fabrication. Throughput for the glove-box is nominally 20 kg/month. Figure 11 shows the correlation of approximately weekly holdup measurements with throughput. There is distinct evidence of nonlinearity, although over the limited range of throughput, a linear fit would represent the data rather well. The holdup-throughput relationship is approximated by a quadratic function (forced through the origin); the least-squares fit is shown in Eq. (1).

$$Pu(g) = 0.1930(X) + 0.0008443(X)^2 \quad , \qquad (1)$$

where X = throughput in kilograms plutonium.

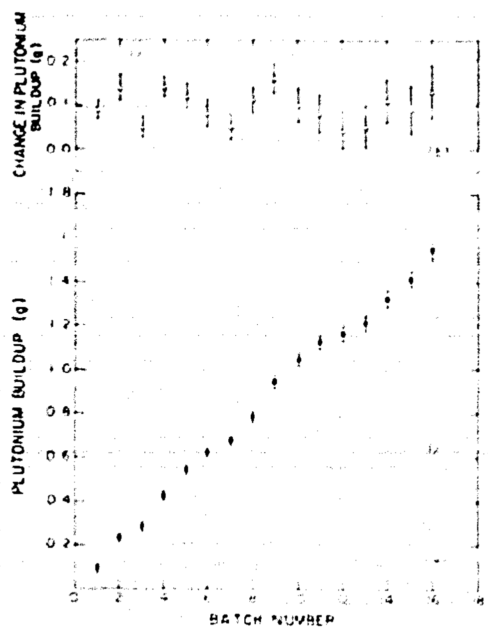

Fig. 10. Plutonium buildup in the glovebox exhaust filter as a function of batch.

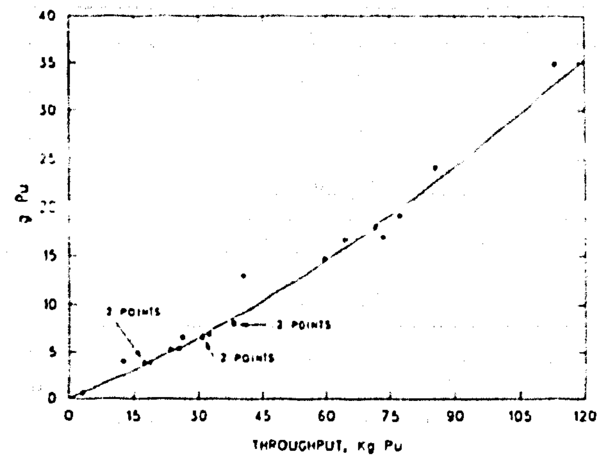

Fig. 11. Plutonium dioxide blending and screening box filter holdup.

The 15th observation (13.0, 40.3) is out of line with the rest of the data and is not used in the above quadratic fit. The remainder of the data are consistent. Residual mean square from the fit is $\sigma^2 = 0.532$. An average standard error over the range of throughput is 0.764-g plutonium. At high throughputs (>85 kg), this is slightly higher. Also, no evidence of variance increasing with the magnitude of response (heteroscedasticity) as would be the case if the relative error remained constant is present over the range of the data given. Figure 11 indicates that filter holdup varies in a predictable manner as a function of process throughput. Presently, plutonium retained by the filters remains unmeasured (with the exception of this one filter) until the filters are replaced. Replacement frequency varies but is typically yearly, but may vary from 3 months to several years. Because the facility filter plutonium holdup remains unmeasured for long periods, the filter plutonium holdup is charged to a MIP account. The summation of plutonium holdup in all the TA-55 filters is unknown, but probably is only on the order of a few hundred grams of plutonium. Charging this amount of plutonium to MIP accounts clearly reduces the ability of the accountability personnel using the MIP account data to detect protracted plutonium diversion. A program to (1) develop algorithms to predict plutonium holdup on all filters versus throughput and (2) develop a computer code to calculate up-to-date plutonium holdup on every facility filter would allow the filter holdup data to be removed from the MIP data and increase the ability to detect protracted diversion. If the Fig. 11 plutonium holdup function is typical of all facility filters, then step (1) of this program would be relatively simple to complete: assume the linear holdup-throughput function for all glovebox filters and obtain the slope of the respective curves by using a 0,0 origin and a single cumulative throughput-measured plutonium holdup point. This latter point could be determined when the filters are replaced. This predictive holdup approach may be applicable to many facility items such as gloveboxes, furnaces, tanks, pipes, and ducts.

C. Rapid Physical Inventory and Materials Balance Status

As noted previously the ability to obtain rapid physical inventory information and materials balances is an essential component of an integrated safeguards system. This section reviews the current capabilities of the PF/LASS and the results of the research and development (R&D) in the areas

TABLE II

PF/LASS REPORTS

REPORT TITLES

On-Line	Off-Line
Inventory by location	Inventory by account
Inventory by account	Inventory by location
Inventory by account with remarks	Inventory by project
Internal activity of item	Inventory by special designator
Internal activity of item with remarks	Inventory based on item description
External activity of item	Condensed inventory
Item status	General ledger
Items in transit	Transaction activity
Transaction lookup	

of rapid physical inventories and materials balance effort presently in progress. It must be emphasized that, although PF/LASS is an operational system, it is not static and the operational staff constantly is striving to improve and upgrade the system. Because of this the following discussion of the capabilities of the system represents the present situation and will change as a result of the efforts of the operational staff with or without the safeguards R&D efforts.

The PF/LASS system provides a number of off-line reports as well as on-line reports that are available to the operator on his terminal display (Table II). The off-line reports are available on request and, in general, contain more information about the inventory than the on-line reports. The time period covered by this report is limited by the mass data storage and access time capability of the PF/LASS computers. [illegible]e period covered by the data is currently [illegible] to 3 months. Brief descriptions of these reports are presented in the following paragraphs.

1. On-line Reports.

a. Inventory by Location. The Inventory by Location report displays the current item-by-item inventory for the requested location. Information about each item includes account, material type, item identification (ID), receipt area,* special nuclear material (SNM) amount, bulk amount, shelf, item description, operational safety limits, and seal number. The total SNM amount at the location is also included in the report.

b. The Inventory by Account. The Inventory by Account report displays the current item-by-item inventory for the requested account. Information about each item includes account, material type, item ID, receipt area, SNM amount, bulk amount, shelf, item description, and seal number. The Inventory by Account with Remarks report provides the remarks filed from the transaction in addition to the information in the Inventory by Account report.

c. The Internal Activity of Item. The Internal Activity of Item report displays all transactions that have affected an inventory item during the previous 6 to 10 wks. It only displays transactions that occurred inside the plutonium facility. The report is a useful tool for tracing errors. For each transaction, the report displays a line that gives the amount of SNM transferred, material type, item ID, receipt area, location, the date the activity took place, and the transaction number assigned. The Internal Activity of Item with Remarks report provides the remarks filed from the transaction as well as the information above.

d. The External Activity of Item. The External Activity of Item report provides information similar to the Internal Activity report except that it pertains to external transactions, that is, transactions between shipping/receiving accounts 770 or 771, or clearing account 777 and an account outside the plutonium facility. Hence, this report only displays transactions for items entering or leaving the facility, or other special NMO transactions that also affect the station balance.

*The term receipt area as used at TA-55 is synonymous with the term unit process.

e. The Item Status Report. The Item Status Report displays information about a single inventory item: the account, material type, creation date, location, shelf, receipt area, project, special designator, item description, SNM amount and uncertainty, isotopic weight, enrichment and uncertainty, bulk amount, measurement code, impurity, composition of ending inventory (COEI) number, seal number, and remarks.

f. The Items in Transit. The Items in Transit report displays all items currently in transit in the facility and provides information about each: the date and time the item was sent, the originating account, material type, item ID, SNM amount, sender, and destination.

g. The Transaction Lookup. The Transaction Lookup report allows the operator to recall on his screen the full display of any transaction made in the previous 2 to 3 months. The report displays all the information in the original transaction: item ID account, receipt area, project, special designator, location, shelf, item description, remarks, date and time that the transaction was completed, the person(s) who made the transaction, destination, SNM amount and material type, bulk amount, enrichment, isotopic weight, impurity, measurement code, seal number, COEI number, and isotopes A, B, C, D, and E. However, the RESULTS summary that appears at the bottom of the screen when an operator makes a transaction does not appear on a transaction lookup.

2. Off-Line reports. The most comprehensive off-line reports are Inventory by Account and Transaction Activity. Reports containing inventory information list the items in the current inventory with their present status and attributes. The time period for transaction activity is 1 month. Transaction activity does not concern the status of items in the current inventory, but rather gives the history of how they arrived at their current status.

a. The Inventory by Account. The Inventory by Account report is a current inventory report sorted by account, material type, and item ID. For each account it gives subtotals, by material type, of the SNM amount and isotopic weight for all accountable and subaccountable items. The total for each account only includes accountable SNM and isotopic weight. A grand total of all accountable SNM and isotopic weight appears at the end of the report. The Inventory by Account report is available for all or selected accounts.

b. The Inventory by Location. The Inventory by Location is a report of the inventory sorted by location, shelf, and material type. It shows the total number of items within each location. For each location it gives subtotals, by material type, for accountable and subaccountable SNM amounts and isotopic weights. The total for each location only includes accountable SNM amount and isotopic weight. A grand total of all accountable SNM and isotopic weight appears at the end of the report.

c. The Inventory by Project. The Inventory by Project report gives a printout of the current inventory sorted by project and material type. For each project it gives subtotals, by material type, of accountable and subaccountable SNM amounts, isotopic weights, and number of inventory items. The total of all accountable material for all projects included in the report appears at the end.

d. The Inventory by Special Designator. The Inventory by Special Designator report provides a printout of the current inventory sorted by special designator and material type. For each special designator it gives subtotals, by material type, of accountable and subaccountable SNM amounts, isotopic weights, and number of inventory items. The total for each special designator only includes accountable material. A grand total of all accountable material for all special designators included in the report appears at the end.

e. The Inventory by Item Description. The Inventory by Item Description is a current inventory report sorted by account, material type, and item description. It gives the total SNM amount and isotopic weight for each accountable and subaccountable material type in the account, as well as a total for all accountable material types in the account.

f. The Condensed Inventory. The Condensed Inventory is an inventory report that only gives totals for the entire facility sorted by account and material type. It gives inventory totals of the SNM amount and isotopic weight for each accountable and subaccountable material type within every account in addition to an accountable total of SNM amount and isotopic weight, for all material types within an account.

g. The General Ledger. The General Ledger report is an extensive summation of all the nuclear material in the facility, sorted by material type and account. It lists the total SNM amount and total isotopic weight for the facility, by material type, for each account printed. It is printed once each processing day for the facility's NMO. The General Ledger gives a beginning and ending balance for each material type and totals for all material shipped and received in that material type. It also compares the general ledger value for that material type with the inventory total for the same material type.

h. The Transaction Activity. The Transaction Activity report sorts activity, internal and external to the facility, by "to" account, "to" material type, "to" item ID, "to" receipt area, date, and time. (Time does not appear on the printout.) It gives subtotals for the net SNM amount and isotopic weight transacted for each item whether it is accountable or subaccountable. It gives another subtotal for the net SNM and isotopic weight transacted for each material type. It gives a total of the net amount transacted for each account.

This variety of reports available for the PF/LASS system on either a real-time basis or within a few hours is one of the major features of the system. The system provides a reasonably rapid book inventory. The timeliness of the system data base deviates from near-real-time to the extent that transactions are not necessarily entered into the data base at the time of the physical transfer of material. Although PF/LASS does not calculate materials balances, the data necessary for such calculations are in the data base.

The primary success of PF/LASS has been a decrease in the amount of time required for inventory. A book inventory report is routinely prepared on the last working day of each week for each glovebox in the reprocessing wing and each day for the metal fabrication wing; the report is then confirmed by the individual responsible for the area.

According to facility staff, annual and semiannual inventories are significantly facilitated by PF/LASS. Under the paper accounting system used at the old facility, the last afternoon and evening before the start of the inspection were always hectic because of the need to balance the books and to eliminate inventory items of negative mass. With PF/LASS, facility personnel say they are so prepared for these inventories that they do not experience last-minute confusion. Furthermore, PF/LASS saves them a day at each inventory. In addition, because auditors now have available the means for a more reliable inventory confirmation, safeguards are improved. Now, NDA instruments are used to confirm items of inventory.

Until recently, facility personnel had to perform a complete shutdown and clean-out before each physical inventory, halting production for 3 to 4 wks. Scrap generated during the clean-out process must itself be reprocessed before regular production can begin again, resulting in further production loss. PF/LASS data are currently being analyzed to provide the basis for foregoing a complete shutdown and clean-out for each bimonthly and annual inventory. DOE regulations make provision for this concept. If this concept can be demonstrated, then complete shutdown can be eliminated at a financial savings of about $1 million per year. There have been two limited demonstrations of this concept with satisfactory results.

Because of reduced errors and a more up-to-date book inventory, accountability of the plant is greatly improved over that of the previous facility. Although not all aspects of certain inventory differences are fully understood, and although not all of the NDA instruments are connected directly to the computer, the timeliness of the data base is a clear improvement over the old paper system.

Some on-line accountability is implemented. Because processes in operation at the facility are varied and complex because of the R&D nature of the plant, other accountability programs need to be developed and implemented receipt area by receipt area. Past emphasis has been on an accounting system. That has now been largely achieved so that accountability can be given higher priority.

When processing of an item in a receipt area is complete, the product is transferred from the receipt area. Material associated with sidestreams, such as waste or scrap, is also transferred either at that time or at some later time. The computer is notified of each of these transferred items by means of transactions. The difference between the SNM content of item(s) entering the receipt area before processing and the SNM content of the items leaving the receipt area after processing is designated as MIP. When a receipt area has been cleared, the central computer determines the MIP (designated as MIPXX where XX identifies an individual receipt area) and adds that amount of SNM to the account that records the MIPs produced in a particular receipt area. Process technicians determine when the MIP will be calculated; if they mistakenly claim that a receipt area is empty, a false value is reported.

Dynamic evaluation and graphic display of MIP data for each receipt area are needed. Although the PF/LASS data base contains all the information necessary for this, the capability has not been implemented. Because graphs clearly display the accountability aspects of each receipt area, they are a key to an effective safeguards program. The present inability to evaluate MIPs in near-real-time is a serious deficiency that should be corrected.

To demonstrate that this capability can be developed on medium-scale computers, we have used PF/LASS data and the Q-4 Prime computer. The transaction data for the 1-yr period February 1980 to February 1981 were read into the Prime computer from magnetic tape. After translation and selection of the set of FFTF data, programs were written to analyze these data and calculate MIPs and CUSUMs with error propagation, including covariances. Errors were assigned to the measurements based on a detailed analysis of the instrument histories that were recorded as part of the measurement control procedures. Finally, programs were developed for plotting these MIP and CUSUM graphs with error bars. Some examples are shown in Figs. 12-15.

These graphs do not, by themselves, indicate diversion or lack of it. They do, however, indicate a number of transfers that bear further analysis by the NMO. For example, the single point in Fig. 12 arises because the measurements leading to it are reported as being made by an instrument much less precise than the balances used for all other related measurements. We cannot determine at this late stage if the measurement code was reported

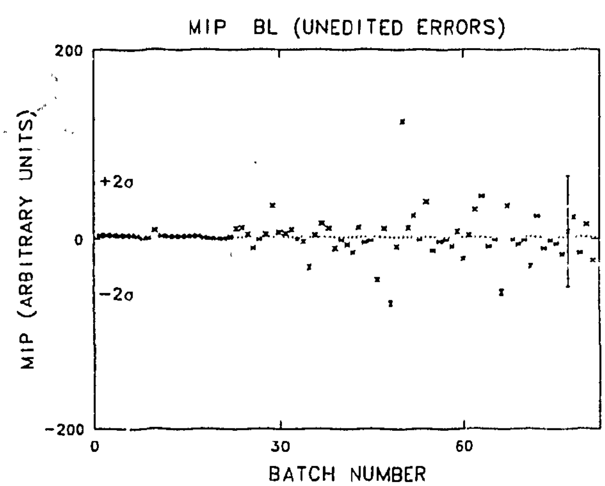

Fig. 12. A plot of MIP for the blending (BL) step of the FFTF process. Several points are well outside the average trend and would probably be investigated by a nuclear materials officer (NMO). The point with the large error bar is also suspicious and would trigger further study.. Our analysis indicates that the large error bar arises because of an error in reporting the instrument that was used to measure two large masses of plutonium—the difference of which was the MIP. This instrument was inherently much less accurate than the instruments used to measure the other points.

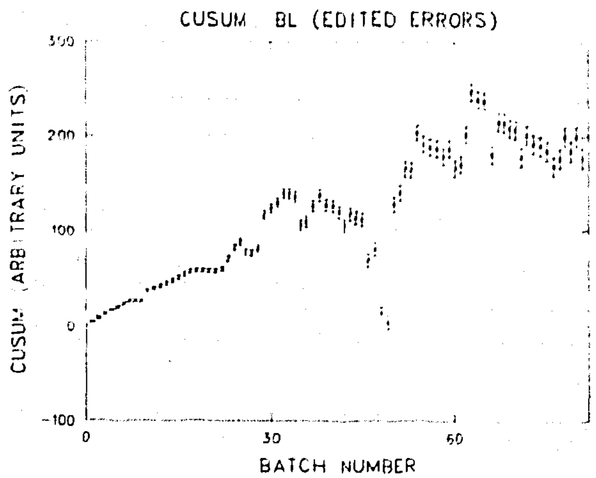

Fig. 13. A plot of the CUSUM for the BL step of the FFTF process. This illustrates how the uncertainty increases as the process operates and shows the effect of a partial cleanout about midway through the year.

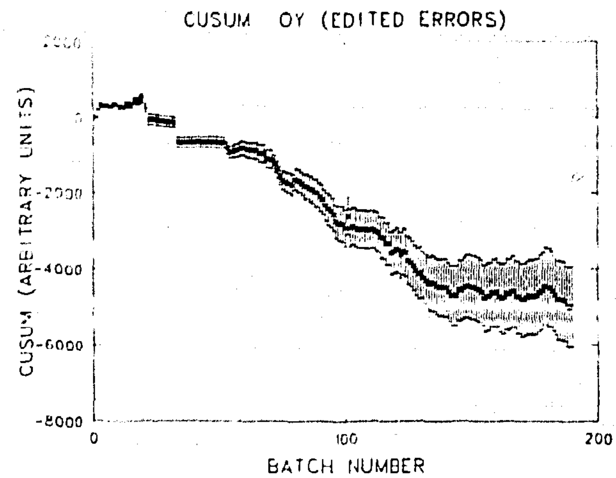

Fig. 14. The CUSUM for the oxolate precipitation (OY) step of the FFTF process. This step feeds the hydrocalcination (HC) step, which is graphed in Fig. 15. The downward trend in Fig. 14 is complemented by the upward trend in Fig. 15 and probably reflects measurement bias in the thermal neutron coincidence counter (TNC) that was adapted for wet oxalate cake measurements. This instrument is used to measure the output of OY and the input of HC.

reported in error causing us to assume an incorrect error, or whether this is, indeed, an imprecise measurement. Experience indicates that the hypothesis of an incorrect measurement code rather than an imprecise measurement is the cause of the discrepancy. In further analysis of that data, the measurement code was arbitrarily changed to a more acceptable one. Had this graph been available to the NMO at the time of the transfer, he could have investigated immediately and either corrected the measurement code, or ensured that such imprecise measurements were not inappropriately made in the future.

IV. FUTURE WORK

An integrated safeguards system based on TA-55 that is both effective and conceptually acceptable to Los Alamos operations will incorporate features that are equally applicable to the nuclear facilities. In addition, although TA-55 is a unique facility, the development of an integrated safeguards system based on that facility will provide valuable support for efforts to develop a generic, integrated safeguards system. Close cooperation between the individuals working on three Los Alamos programs (the TA-55 Applied Systems Integration Study, the TA-55 Implementation Support Study, and the System Concepts Study) is so essential that, at least at times, it will be difficult to determine which study a particular effort belongs to.

With the above in mind, the direction of the future work under TA-55 Applied Systems Integration is presented in the following paragraphs. The R&D efforts proposed as part of the Systems Concepts for DOE Facilities[10] will contribute to this program.

The effort initiated in FY81 will be continued with emphasis on development and demonstration of a computerized MC&A data communications system in the Los Alamos Safeguards R&D VAX 11/780 (ASIST) computer facility. During FY82 distributed processing using real and simulated instruments, preprocessors, and the ASIST computer will be demonstrated. A data base management system will be implemented on the ASIST and proven using PF/LASS data. Development of generic transaction packages will be completed during FY82. Simulation of the

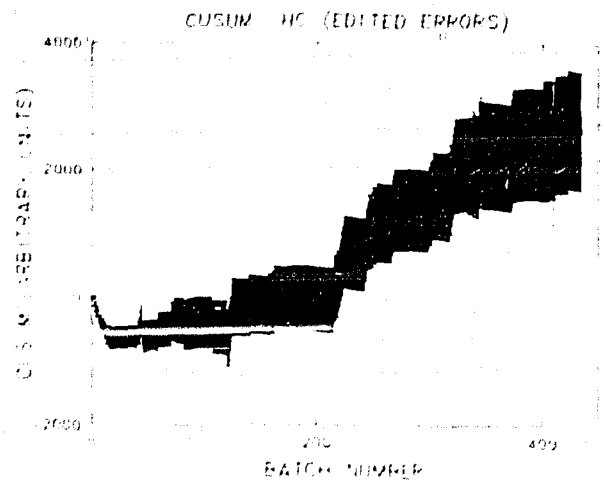

Fig. 15. Graph of the CUSUM for the HC process--should be compared and contrasted with Fig. 14.

MC&A system will be initiated early in FY83, and simulation of the integrated system will be initiated in FY84. The Project Review Committee, consisting of operations and R&D personnel, will review project progress on a regular basis. Subsystem developments will be demonstrated for operations personnel, and where appropriate and desirable, in-plant testing will be negotiated. The Office of Safeguards and Security will be briefed as appropriate.

The efforts planned to achieve the goal established are the following.

1. Evaluate book inventory data on clean-outs
2. Demonstrate communication between the preprocessor and both real and simulated instruments
3. Complete development and installation of intercommunication software for VAX, preprocessor, and smart instruments
4. Evaluate use of holdup models for TA-55.
5. Decide on requirements of the data base management system (DBMS) and on the format of the data base
6. Implement DBMS on the VAX using PF/LASS data
7. Complete development of generic transaction packages for the preprocessor
8. Evaluate run-out versus clean-out book inventory data
9. Simulate distributed MC&A systems
10. Test and evaluate holdup models
11. Simulate full integrated distributed safeguards system. Demonstrate system and negotiate implementation

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