Development and Testing of a Near-Real-Time Accounting System for the Barnwell Reprocessing Facility

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ABSTRACT

Allied-General Nuclear Services has developed and demonstrated under cold testing conditions a computerized nuclear materials control and accounting system for a large reprocessing plant. The system provides computerized data acquisition, calculation, and retention for conventional accounting measurements as well as for near-real-time estimation of in-process inventories and material balances. Application of this system as a tool for meeting projected safeguards requirements appears likely.

INTRODUCTION

The primary objectives of a nuclear facility accountancy system are first to measure and account for all nuclear materials handled by the plant; second, to perform these measurements with a high degree of timeliness and accuracy; and third (and perhaps most important), to perform the measurements with a minimum of cost and interference for the operator. When one considers nuclear material accountancy for a large fuel reprocessing facility, it appears that these objectives are unobtainable.

To put this problem in context, consider the Barnwell Nuclear Fuel Plant (BNFP). The annual throughput would be 1500 metric tons of enriched uranium and 15,000 kilograms of plutonium contained in over 3000 liquid batch measurements, 500 hulls (fuel cladding) containers, and several thousand trash and miscellaneous waste containers. Simply keeping track of throughput is a monumental task, to say nothing of maintaining timeliness and accuracy and minimizing cost and impact on operations.

It was with these factors in mind that Allied-General Nuclear Services set out in the early 1970's to develop a system that would accomplish the accountancy objectives for the BNFP.

It was not particularly difficult to design an accountancy plan for the BNFP with appropriate material control areas (MCA), flow and inventory key measurement points (KMP), and general requirements. It did however become quite obvious that the only way to achieve the primary objectives was to improve and automate the accountancy techniques for the BNFP.

AGNS ACCOUNTANCY DEVELOPMENT PROGRAM

The AGNS accountancy development program, which was started in 1973 and has continued since 1977, under contract with the United States Department of Energy (DOE), consists of the following major elements.

1. Improvement of bulk measurement methods.
2. Computerization of data acquisition, both from the plant and the analytical laboratory.
3. Computerization of the accountancy functions which include measurement sequences for the KMP's, measurement control, recordkeeping and reporting, and data evaluation and verification.
4. Development of techniques to estimate in-process holdup or inventory which could allow frequent closing of plant material balances.
5. Development of process monitoring techniques which could not only provide information for accountancy, but could aid the operator in running the plant more safely and efficiently.
6. Demonstration of the developments by full scale plant tests using natural uranium as feed.

Three major goals were established for this development program. These were to:

1. Develop a system that could meet NRC, DOE, and IAEA requirements and goals for accuracy, sensitivity, and timeliness.

2. Demonstrate a system that is operable and maintainable using plant personnel.

3. Demonstrate a system that will aid in cost effective and safe operation of the facility, rather than hinder it.

The result of this program is the AGNS Computerized Nuclear Materials Control and Accounting System or CNMCAS.

Improvements in Bulk Measurement Methods

The majority of the bulk measurements at the BNFP involve batch measurement of nuclear materials contained in liquid feed, product, and waste tanks. As a result, the AGNS effort has centered on tank calibration methods, dip-tube manometry, use of high precision differential pressure instrumentation (such as the Ruska Electromanometer), solution mixing and sampling methods, and procedures for measurement and measurement control.

The net result of this effort has been a steady reduction of material balance uncertainties during the plant scale testing. These improvements are discussed later in the text of this paper.

Table 1 presents the results of a bulk measurement assessment test conducted in 1979. This test reflects the measurement possibilities that can be achieved using the techniques and equipment tested by AGNS.

COMPUTERIZATION OF THE BNFP ACCOUNTANCY SYSTEM

Computer Hardware Description

The CNMCAS system consists of five Digital Equipment Corporation (DEC) PDP-11 minicomputers. These are the RDAS Computer (Remote Data Acquisition System), the MACS Computer (Materials Accounting and Control System), the LDS Computer (Laboratory Data System), the PDS Computer (Program Development System), and the MIU Computer (Management Information Unit). Figure 1 shows the layout of these computers.

The RDAS Computer performs the functions of reading the plant instruments, converting the instrument outputs to engineering units (i.e., cm of H_2O, °C, etc.), and providing specific readings to the other computers on demand. RDAS is located in the Control Room Area.

MACS is the main processing computer and is located in the Control Room Area of the plant. It performs all the calculations, etc., required for the various accounting and control programs. It sends the data commands to RDAS, as needed, receives the data, executes the programs, stores results, and transmits to the various terminals. Storage capabilities include magnetic tape, one RL01 5.5 megabyte disk system, and an 88 megabyte RP04 multihead disk system. Up to 16 terminals can be supported including LA120 printer/terminals, VT-100 video terminals, LA-180 printer, Centronics line printer, Intecolor Video Console, and a VT-30H video graphics system. MACS also emulates a terminal for the LDS system and receives, sorts, and stores all analytical data reported by LDS. Terminal links to other areas such as the AGNS Administration Building are generally over spare telephone lines.

The LDS Computer is located in the Analytical Laboratory Area. It performs the various lab functions, including sample logging, sample number assignment, computation of results from input variables, and control of the Standards/QC Program. Many analytical instruments are directly interfaced to the computer through converters or micro- processors. LDS has disk and tape data storage and multiple terminals. LDS uses phone lines and installed cables for data links.

PDS is also located in the Control Room Area. It is used for development and initial testing of new programs and as an on-line backup to MACS. It has a number of printers and video terminals, one 5.5 megabyte RL01 disk system, one 88 megabyte RP04 disk system, and a magnetic tape system.

The MIU Computer is located in the AGNS Safeguards Coordination Center (SCC). This computer will be used as an archiving and report generation unit in the future. It has been used in the past to collect and store complete sets of instrument readings from RDAS after each four-minute cycle and has been used for off-line data analysis.

The RDAS/MACS/PDS systems are powered through the Separations Facility uninterruptible power system. This system assures reliable, regulated electrical power to the computers. The LDS Computer is on a separate uninterruptible power system in the laboratory. The MIU system runs on direct commercial power.

With the exception of the LDS Computer, a real-time operating system (DEC's RSC-11M) is used and programs are written in Basic-Plus-2 or Assembly. LDS uses a time-sharing system (DEC's RSTS-E) and Basic-Plus language.

COMPUTERIZED DATA ACQUISITION

Process Measurement Instruments

Process measurement instruments read by RDAS include such things as liquid level, liquid density, temperature, and flow rate instruments. Some of the on-line analytical instruments installed in the BNFP, such as alpha, gamma, and neutron monitors, can also be read directly by RDAS. The majority of these instruments transmit an analog voltage or current signal to the Control Room Area where the output is recorded on strip charts or indicated on dials or gauges and picked up by RDAS.

Several different methods are used to interface these instrument signals to the computer system. Two types of interface units are used for this application. One device is an analog to digital converter and controller called a wide-range controller. This device, which is itself controlled by the RDAS Computer, is used to multiplex up to 512 analog signals into RDAS. The other device, called a Universal Controller, is used to pick up digital signals and to transmit control signals from RDAS.

Liquid levels, liquid densities, and flow rates are generally measured with differential pressure instruments which have electrical analog (current) outputs. The differential pressure represents the pressure drop across an orifice (in the case of the flowmeters) or the back pressures across a pair of purged dip-tubes (in the case of liquid levels or liquid densities). Over 300 of these transmitters are currently connected to RDAS.

A special, high-precision differential pressure device, called a Ruska Electromanometer, is used at AGNS for primary accountability liquid-level and liquid density measurements made at Key Measurement Points (KMP). This device, which consists of a quartz bourdon tube, an electronic sensing system, and a digital voltmeter (DVM) readout, provides accuracy approaching the limiting capability of the dip-tube measurement system. (The pressure change resulting from formation and displacement of the air bubblers on the tip of the dip-tube can be measured with this instrument.) Ruskas at AGNS have a range of 0-700 cm with an uncertainty of about ±0.04 cm or 0.006% of full scale. The Ruska device is, however, susceptible to shifts in the "zero" value. This is due to the inherent instability of the "zero" value on the DVM. To overcome this problem, an automated, computer-controlled zero-check routine was set up for each Ruska. On command from the computer, two solenoid valves are closed, blocking off the dip-tube sensing lines and a third solenoid is opened, equalizing the pressure on both sides of the Ruska pressure cell. The computer then reads the "zero" value and deducts it from the actual reading (taken previous to the zero check). The solenoid valves are then switched back to the normal configuration. This is typically done once every 4 hours. AGNS currently has nine Ruska units in service.

The output potential voltage of each thermocouple is read directly through the wide-range controller. To compensate for reference temperature, the terminal junctions of each thermocouple are made on a special insulated plate (called a Unithermal Reference Plate) inside the computer. The plate temperature is sensed using a resistance thermal device. The voltage reading and reference junction temperature are then used to compute the sensor temperature with an RDAS program. Over 130 thermocouples are currently read by RDAS.

The data acquisition programs and hardware receive the output signals from the process instruments (levels, densities, temperatures, and flow rates) and the on-line analytical instruments (such as the alpha monitors). With the exception of several of the on-line analyzers which are connected to LDS, these instruments are connected to RDAS via one of the controllers described earlier. The programs control the order of reading each instrument (or controller channel) and convert the signals to engineering units using the specific calibration data for each instrument. These readings are then "handled" via one of three different "scan modes" as shown below. The readings are stored in memory in RDAS and are available to all the other computers on demand.

Instruments are assigned to one of three "scan modes" to accommodate the different requirements. These scan modes include:

<u>Scan Mode 1</u>: General instruments - one reading per cycle, no averaging. Currently a complete reading cycle is accomplished in 4 minutes.

<u>Scan Mode 2</u>: Special readings - locks on and reads all Scan Mode 2 instruments for 20 seconds, saving all readings. Computes average and stores. Memory retains last five averages.

<u>Scan Mode 3</u>: Same as Scan Mode 2, except three averages retained.

RDAS also has upper and lower alarm for each instrument reading and can print out alarm messages or display alarms on a video terminal.

<u>Laboratory Analytical Instruments</u>

Laboratory instruments are interfaced to the LDS Computer system. Two laboratory instruments, a mass spectrometer and a multichannel analyzer have their own dedicated minicomputers for control, data acquisition, and data reduction and are connected to LDS via a serial data link for reporting and long-term storage of data.

Other laboratory instruments are linked to the system with a Laboratory Instrument Interface Unit (LIIU). This unit also serves as an input/output terminal to enter analyst and sample identification, to prompt analyst entry, and to print data and results. Analytical instruments linked to the computer in this manner include densimeters, titrators, spectrometers, fluorimeters, and balances.

On-Line Analytical Instrumentation

A variety of on-line analyzers are installed or planned for the BNFP, including alpha, gross gamma, and X-ray fluorescence monitors, isotopic concentration monitors (gamma), spectrophotometers, and density meters. These devices can be used extensively in estimating the process holdup or in-process inventory and, as a result, are connected to CNMCAS. Frequency of reading depends on the count-time for each instrument. Computer-collected data on process volumes and flow rates, combined with current composition data obtained from the on-line monitors will permit rapid and frequent holdup estimates.

ACCOUNTANCY FUNCTIONS

Measurement

The measurement programs, which reside in MACS and PDS, coordinate batch measurement activities for the process KMP's. These programs acquire data from RDAS and LDS, prompt the plant operator to perform various operational steps, calculate solution and uranium quantities, print batch summaries, and transfer information to the accounting data base on completion of each batch. A typical function sequence is given below.

1. Batch Initiation - Next sequential batch number is obtained from the accounting programs.

2. Before Receipt Measurements - "Heel" volume in the KMP is determined. This is generally the "heel" from the previous batch.

3. Before Sample Measurements - A set of level density and temperature measurements is taken after the KMP is filled and mixed.

4. Sample Request - MACS sends a sampler batch number and required analysis.

5. After Sample Measurement - Upon receipt of a message from LDS that acceptable samples have been taken, MACS obtains another set of level, density, and temperature data. Volumes are calculated and estimates of uranium concentration are made based on solution density and temperature. This information is provided to the measurement control programs to give an indication of the random component of the error factor.

6. After Transfer Measurement - A set of heel measurements is made after the batch is transferred to the receiving tank.

A summary report is then generated for process control purposes. This summary includes all readings, calculated volumes, and weights and a measurement comparison analysis.

Measurement Control

The measurement control program, which is run in parallel with the measurement programs, provides for various automated checks and comparisons of measurement data to:

1. Identify and control measurement anomalies prior to transfer of a batch and prior to acceptance of data into the accounting files. This is done mainly by comparison of readings from redundant instruments, comparison of duplicate measurements, and comparison of related measurements, such as lab density and in-tank density.

2. Provide trend and error analysis from stored data.

3. Propagate limits of error for measurement.

Automated Calibration

One of the major problems in any accounting system is identifying and controlling measurement errors. At the BNFP, the majority of the measurements are made with differential pressure devices on pneumatic dip-tubes. Frequent calibration of these instruments is necessary to insure maximum precision, however manual recalibration is expensive, time-consuming, and disruptive.

As an alternative, AGNS has designed and installed a computerized, automatic calibration system for 30 selected differential pressure transmitters. The system provides for redundant measurement of the dip-tube differential pressures with a high-precision reference standard (parallel mode) or calibration of an instrument "off-line" with selected pressure inputs (calibration mode). In both cases, the computer controls electric solenoids for mode and instrument selection, collects data from both the selected instrument and the reference standard, calculates and maintains a bias adjustment table and retains historical records for review and analysis. With this system, standard process instruments with systematic errors reaching 2-5% of span can be routinely corrected to ±0.2%. This system offers a relatively inexpensive alternative to the purchase of more stable instruments or frequent manual recalibration.

Item and Seal Control

The item and seal control function involves control and accounting of identifiable items such as fuel assemblies, product or waste containers, and tamper seals.

Physical Inventory

The physical inventory programs coordinate performance of the plant physical inventory, acquire instrument and analytical data for each vessel, calculate quantities, generate status reports, and monitor inventoried vessels for unauthorized changes.

Accounting

The accounting programs define accounting control units and produce accounting summary and material balance reports. (Accounting control units consist of individual measurement batches, lots consisting of several batches, and an inventory period consisting of several lots.) Lot number, batch number, and measurement point number are controlled by the accounting programs.

Near-Real-Time Accounting

The near-real-time accounting programs developed at AGNS provide the capability to estimate the current holdup or in-process inventory for the separations plant. (Current programs are for uranium holdup estimation, however the techniques are directly applicable to plutonium estimation.)

Performance of the in-process inventory measurement requires that liquid-level, density, and temperature readings be taken for each tank that contains SNM and that an estimate of uranium/plutonium concentration be established for each tank. An immediate concentration estimate is obtained from on-line monitor readings, or by derivation from process parameters such as solution density. When subsequent analytical analysis results are available that data is compared to the on-line data and then substituted for the in-line data in the inventory calculations. Hold-ups in columns are being estimated in a number of ways including modeling, measurement of column weight changes, and through performance of running material balances. Waste streams will generally have on-line analytical monitors associated with them. Combining measured flow rate with the output of the on-line monitor will permit estimation of material loss via each of these streams. Process line volumes have been determined. By applying appropriately estimated concentrations, the line hold-ups can also be estimated.

With the capability to measure current in-process inventory (IPI) and with the availability of timely and accurate throughput data, material balances can be closed at a high frequency. The balance formula uses IPI data to establish beginning and ending inventories and the input and ouput changes for the time period constitute the throughput. A standard material balance equation can then be written as follows:

$$(IPI)_{t1} + (\Delta \text{ Inputs})_{t1-t2} - (\Delta \text{ Outputs})_{t1-t2} - (IPI)_{t2} = (MUF)^2$$

The advantage of this approach (as compared to conventional accounting with annual cleanout inventories) is that a small throughput is involved with a resulting smaller uncertainty. If a material balance closure was made at least every <u>five days</u>, the estimated balance uncertainty would be about 8.0 kg (see Table 2). More frequent closures and application of decision theory techniques would reduce the uncertainty (and conversely, improve loss detection) even more. Compared to the uncertainty of 75.0 kg for an annual balance, near-real-time accounting appears to offer significant improvement in capabilities.

Process Monitoring and Surveillance

With the readily available process and analytical data, the possibilities for computerized process monitoring and surveillance applications of the CNMCAS system are virtually endless, limited only by the ingenuity of the safeguards personnel and the resources available to develop and install software and hardware needed for the functions. A wide variety of approaches have been identified at the Barnwell Facility and have been set up on a demonstration basis. Examples of typical programs include:

1. Quantity Transferred Versus Quantity Received Program - This program monitors transfers into and out of key measurement points and compares shipper/receiver volume and uranium content.

2. Summary of Tank Transfers - This program is similar to (1) above, except that transfers within the material balance area are monitored on a near real-time basis. Volume differences of less than 500 milliliters have been detected.

3. Measurement Program Status - This program keeps track of the current status of multiple, simultaneous measurement programs and provides a coded display of the status for the accountability personnel.

4. Penetration Surveillance - This program monitors detection instruments on penetrations through the process containment and provides an alarm message if unauthorized activity is detected.

5. Storage Function - This is a program to monitor level, density, and temperature of Plutonium Nitrate Storage Tanks. This program can be written to discriminate between "normal" changes in tank parameters due to evaporation and radiolysis and "abnormal" changes.

6. Data Base Edit Log - This program monitors and records changes made to the data base.

The example printout is a summary of changes to the accounting files.

Another process monitoring application is in the area of process control. Since CNMCAS has access to process instrument readings and analytical data, it can be a powerful tool for the process operators. CNMCAS has been programmed to provide this type of information via a number of demonstration functions. These include such things as a process status report which is updated every 15 minutes, a set of colorgraphic video displays of process systems which are updated every four minutes, and an operator assistance program which calculates quantities and readings for a feed blending procedure. In addition to this, a number of programs are available which give current instrument readings; calculate current tank volume and freeboard; and provide plant location coordinates for plant instruments, valves, pumps, etc. These programs are available to the operators on demand at a number of different terminal locations.

PLANT SCALE TESTING OF CNMCAS

Full Plant Testing

Initial testing of CNMCAS involved the entire AGNS solvent extraction system and involved measurement, measurement control, and accounting programs for "conventional" material balances. Since the data acquisition, calculation and material balance accounting was kept nearly current with the computer; a near-real-time book physical inventory record was available.

Between 1977 and 1979, almost 500 metric tons of natural uranium were cycled through the process and measured using CNMCAS. During this period, data from over 1790 batch measurements and 10 physical inventories were collected and analyzed. A summary of the results of these tests is shown in Table 2. Table 3 presents the results of a batch measurement comparison test conducted in 1979. As can be seen, a significant improvement has been achieved by application of new instruments and calibration techniques and through computerized data acquisition and quality control. It should be noted, however, that results of this level cannot presently be achieved in a "hot" plant. It is estimated that the "true" uncertainty would slightly more than double, primarily due to problems with sampling and analyzing radioactive solutions.

As measurement techniques and computer programs were improved, AGNS began to experiment with in-process inventory or holdup estimation. These experiments were initially conducted for the entire process with computerization of the program in 1979.

Mini-Run Testing

In 1980, reduced funding levels required AGNS to find a less costly mode of testing and, as a result, the mini-run cycle was devised. This cycle, as shown in Figure 1, involves cycling uranium solutions through the plutonium purification process in a closed loop, supported only by the solvent recycle system, the acid recovery/condensate recycle systems, and the process off-gas system. During 1980 and continuing through 1981, a series of these mini-run experiments with the primary objectives being to refine in-process inventory and process monitoring techniques.

Mini-Run Process and Equipment Description

The mini-run cycle consisted of four pulsed-column contactors (2A, 2B, 3A, and 3B); one packed column (3PS); a product evaporator (3P concentrator); and seven product, feed, and blending tanks. Support systems included aqueous waste tanks, a waste evaporator and an acid fractionator, a solvent surge and recycle tank, an off-gas system, and associated process and chemical distribution systems. This represented a cross section of typical reprocessing plant equipment and, of course, involved the plutonium cycle which is of primary safeguards concern.

A modified Purex solvent extraction flowsheet, using 30 volume percent tributyl phosphate (TBP) in a refined kerosene diluent, was used. Unirradiated natural uranium was used in place of plutonium for the system tests. Uranium feed for the process is provided by recycling the concentrated uranium product solution.

The normal starting inventory for each run was 400 to 500 kilograms of uranium. After attaining equilibrium, a "process holdup" (pulsed columns, lines, product evaporator) of about 70 to 75 kilograms was observed with the remaining material distributed among product tanks.

Test Descriptions

Six mini-run tests have been conducted. Each run was seven days in duration, except for Mini-Run No. 5, which was five days long. Table 4 summarizes the purpose and activities of each of the runs.

EVALUATION OF MINI-RUN DATA

Conventional Accounting

Table 5 is a materials balance summary of the first five mini-runs based on conventional accounting. A total of 3995 kilograms of uranium was processed during the runs at a nominal rate of 150 to 200 kilograms of uranium per day. The cumulative ID for the five runs was 13.3 kilograms of uranium (0.33% of throughput) with a 2σ uncertainty of 11.7 kilograms (0.29%).

The relative percent values for ID and LEID are not as good as 1978 and 1979 results. This is due in part to the fact that waste losses, which are normally difficult to measure precisely, were large compared to throughput (15% of throughput during the mini-runs as compared to 1% of throughput for full-plant runs). As a result, waste measurements had a significant degrading effect on the mini-run overall materials balance performance. (It should be noted, however, that in full-plant operation, these mini-run "waste losses" would actually be internal recycles and would not significantly impact full-plant data evaluation.)

The mini-run ID slightly exceeds the LEID, which is not desirable. This has been traced to an upset in Run No. 1. The first mini-run was very erratic in terms of system/column operation. Inventory data showed a considerable loss of organic from the mini-run system, likely caused by column upsets and overflows. The materials balance data reflect the quantities associated with this loss. Subsequent runs finally recovered most of this material indicating that the "missing" organic was probably distributed as undetected layers on peripheral mini-run storage tanks.

Thus, inventory measurement procedures must consider the possibility of two-phase solutions at all measurement points. The results also point to constraints on measurement technology and implementation due to plant design. The mini-run system is an isolated portion of the fuel reprocessing plant. The full plant is interconnected with recycle pathways, and it is difficult to isolate a portion of the plant and monitor all possible routes of material in and out. An effective safeguards system must consider the full plant.

In-Process Inventory Determinations

During the course of the six mini-runs, about 1250 in-process inventory determinations were made at the rate of one per hour. These determinations were then conditioned, sorted, and fed into the LANL DECANAL (Decision Analysis) programs. (Results of these analyses are reported in the next paper.)

CONCLUSIONS

Near-Real-Time Accounting

AGNS analysis of the sequential MUF values indicates that near-real-time accounting has definite applicability for diversion detection. Plant scale tests indicate that sensitivities on the order of 2% of the normal process inventory are achievable. This should be sufficient to detect loss of plutonium at the 8 kg level for short inventory periods. Since the determination is throughput dependent, however, it is of no benefit over long inventory periods, i.e., once or twice per year.

Process Monitoring

Process monitoring is extremely sensitive as a loss detector under certain circumstances (for example in monitoring tanks for long-term storage of liquid Plutonium Nitrate). Detection of losses on the order of a few hundred milliliters per day is possible.

Benefits of Computerized Accounting

When one considers the cost of installing an advanced computerized accounting system is estimated to be over $6 million for the entire AGNS facility, there must be some significant benefits realized from the system to justify its installation.

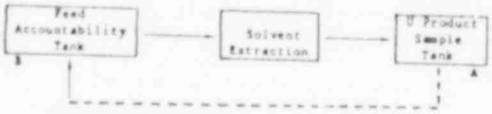
Purely from the safeguards standpoint, benefits include:

1. Improved Accuracy - The computer reads the instrument output directly eliminating errors from chart calibration, estimation of fractional chart percentages, and human errors in reading and transcription.
2. Improved Timeliness - Current accounting data is available on a near real-time basis.
3. Calculations and Monitoring - Use of the computerized system permits such things as near real-time accounting and process surveillance that simply could not be done by hand with a reasonable number of operating and accounting personnel.

The cost benefit of this system is, however, best realized on the operating side. If the computerized accounting system can contribute to only about 15 additional operating days during its lifetime, it will have paid for itself. These additional available operating days can be expected to be gained by shortening or eliminating the downtime required for physical inventories.

TABLE 1

AGNS BULK MEASUREMENT ASSESSMENT TEST



- 130 Transfers from A to B
- Each transfer ~6000 liters/2000 kgU
- Bulk measurements performed at A and B for each transfer
- Average difference = 1.0 kgU (0.05%)
- Standard deviation of differences = ±6.0 kgU (0.3%)
- Calculated to 2 σ limit of error = 0.19%

TABLE 2

UNCERTAINTY COMPARISON
NEAR-REAL-TIME VERSUS CONVENTIONAL ACCOUNTING

Near-Real-Time

5-Day I/O Uncertainty	= 250 kg x 0.5% = 1.3 kg
In-Process Inventory Uncertainty*	= 6.8 kg
Conventional Accounting	8.1 kg
15,000 kg/year x 0.5% =	75.0 kg

*Static inventory ≅ 80 kg x 1.0% = $\left\{ \begin{matrix} 0.8 \text{ kg} \\ 4.0 \text{ kg} \end{matrix} \right\}$ x 2 ÷ $\sqrt{2}$ = 6.8
Dynamic inventory ≅ 80 kg x 5.0% =

TABLE 3

CNMCAS FULL-PLANT TEST RESULTS

Year	MTU Processed	ID*	LEID** (2σ)
1977	83	0.29% (241 kgU)	0.98% (813 kgU)
1978	82	0.04% (33 kgU)	0.28% (229 kgU)
1979	301	0.007% (21 kgU)	0.19% (572 kgU)

*ID = Inventory Difference. This is the difference between inputs and outputs after adjustment for beginning and ending inventory quantities. This quantity is also referred to as MUF or Materials Unaccounted For.

**LEID = Limit of Error of the Inventory Difference. This is the uncertainty of the materials balance for the inventory period.

TABLE 4

AGNS MINI-RUN SUMMARY

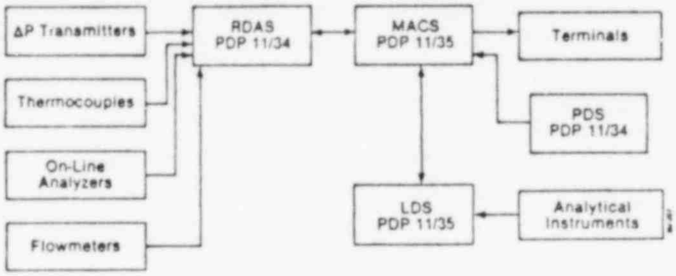
Number	Purpose	Special Test Activities
1	Shakedown	- Program debugging; column inventory experiment
2	Shakedown/baseline run	- Accumulation of steady-state data
3	Announced diversions (all parties informed of diversion timing)	- 17 abrupt (batch) diversions ranging from 5 kg of uranium to 0.25 kg of uranium
		- 4 protracted removals, 16-hour duration each, rates from 0.2 kg of uranium to 0.6 kg of uranium per hour
4	Unannounced diversions (Accounting personnel not informed of timing)	- 3 abrupt removals, 0.3 kg of uranium from c storage tank, 0.5 kg of uranium, and 1.2 kg of uranium from 1BP surge tank
		- 2 protracted removals, 0.5 kg of uranium per hour, approximately 12-hour duration
5	DOE contractor demonstration	- 1 abrupt removal, 0.25 kg of uranium from storage tank
		- 1 protracted removal, 0.85 kg of uranium per hour for 16 hours; column inventory experiment

---Process and Program Enhancements Installed---

TABLE 5

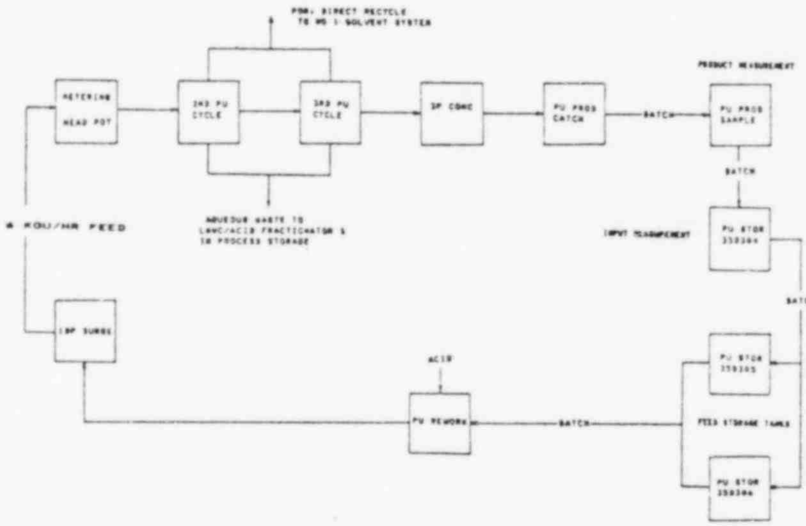
MINI-RUNS MATERIALS BALANCE SUMMARY

	With Input/Output (kgU)		Without Input/Output (kgU)	
Run No. 1	BI	7.00	BI	7.00
	Input (1-21)	1173.58	Input	501.37
	Product (1-15)	671.03	Waste	126.88
	Waste (S.C.)	126.88	EI	339.08
	EI	339.08		
	ID	43.59	ID	42.41
Run No. 2	BI	339.08	BI	339.08
	Input (22-41)	1080.64	Input	169.59
	Product (18-35)	914.74	Waste	121.69
	Waste (1-5)	121.69	EI	398.62
	EI	398.62		
	ID	-15.33	ID	-11.64
Run No. 3	BI	398.62	BI	398.62
	Input	699.07	Input	88.31
	Product	608.81	Waste (LAWB)	194.94
	Waste (LAWB 6-11)	194.94	(GWP)	1.09
	(GPW)	1.09	EI	296.13
	EI	296.13		
	ID	-3.28	ID	-5.23
Run No. 4	BI	296.13	BI	296.13
	Input	924.69	Input	193.30
	Product	726.11	Waste (LAWB)	134.65
	Waste (LAWB 12-18)	134.65	(HWW)	2.49
	(HWW)	2.49	EI	368.26
	EI	368.26		
	ID	-10.68	ID	-15.97
	Cumulative (Runs 1-4)	14.37		9.57
Run No. 5	BI	368.26	BI	368.26
	Input	416.27	Input	--
	Product	421.67	Waste (LAWB)	71.76
	Waste (LAWB 19-25)	71.76	EI	292.18
	EI	292.18		
	ID	-1.08	ID	4.32
	Cumulative (Runs 1-5)	13.29		13.89



CRMCAS HARDWARE LAYOUT

FIGURE 1



MINI-RUN CYCLE: PLUTONIUM PURIFICATION PROCESS

FIGURE 2