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CAN A SAFEGUARDS ACCOUNTANCY SYSTEM REALLY DETECT AN UNAUTHORIZED REMOVAL?

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"CAN A SAFEGUARDS ACCOUNTANCY SYSTEM REALLY DETECT AN UNAUTHORIZED REMOVAL?"

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Abstract

Theoretical studies indicate safeguards material balance data from reprocessing plants can be used to detect unauthorized removals of nuclear material. Plant systems have been modeled and simulated data have been used to demonstrate the techniques. But how sensitive are the techniques when used with actual plant data? What is the effect of safeguards applications on plant operability? Can safeguards be acceptable to plant operators and are there any benefits to be derived?

The Barnwell Nuclear Fuel Plant (BNFP) safeguards staff has been devoted to answering these and other questions over the past several years. A computerized system of near-real-time accounting and in-processing inventory determination has been implemented and demonstrated during actual plant test runs. Measured inventories and hourly material balance closures have been made to assess safeguards in an operating plant application. The tests have culminated in actual removals of material from process equipment to investigate the response and measure the sensitivity of the safeguards and data evaluation system.

1. Introduction

A large scale reprocessing facility poses a significant challenge to the safeguards community. Modern safeguards objectives for diversion detection cannot be met with conventional six-month input/output accounting in a five MTU/day facility such as the Barnwell Nuclear Fuel Plant (BNFP). The plutonium throughput of such a facility will amount to 7500 kilograms over an inventory period and a limit of error of 0.5% translates to 38 kilograms.

Studies by safeguards organizations throughout the world have shown that more frequent inventories and material balance closures coupled with sequential material balance statistical analysis techniques can be sensitive to loss or diversion in the scale of international objectives. However, the costly shutdowns and time requirements of conventional inventories preclude conventional material balance closures on a frequent basis. Likewise, the timeliness of closure data and available inspector data evaluation techniques limit the effectiveness of conventional accounting.

The BNFP safeguards staff has been devoted to testing and evaluation of safeguards measurement and data evaluation methods under U. S. Government sponsorship since 1978. During these years, a Computerized Nuclear Material Control and Accounting System (CNMCAS) has been installed, developed, and tested during actual plant test runs. These test runs have used unirradiated natural uranium substituted as feed material to the solvent extraction and plutonium purification sections of the Separations Facility. The computerized system features direct interface to plant instruments and many on-line analytical instruments for data collection, on-line evaluation, and data storage. The goals have been to maximize the available information, understand the characteristics of measurement data in safeguards applications, and implement a safeguards program in such a way as to minimize the impact on plant operability.

Early CNMCAS development and testing centered on accounting and measurement procedures. Material balance closures require accurate and timely input/output measurement. On-line measurement control techniques have become a central part of the procedure. These provide timely detection of measurement problems to allow corrective action while remeasurement or resample are still possible. An effective real-time accounting system has been the result. This makes an on-line "book inventory" available for safeguards evaluation.

Most recent developments have been in the area of in-process inventory measurement. The on-line inventory in a plant such as the BNFP will be 12 to 15 metric tonnes of uranium and 100 to 200 kilograms of plutonium. A routine shutdown and flushout inventory requires two to four weeks. This precludes the use of conventional shutdown inventories for the frequent material balance closures required by modern safeguards data evaluation techniques. The in-process inventory techniques, as implemented at the BNFP during test runs, uses process instruments and on-line data to determine process inventory. Inventory measurements can be made at hourly frequencies without interruption to plant operation.

How sensitive can an installed safeguards system be? Many groups around the world have done considerable research in the area of statistical analysis of safeguards data. The principles have been demonstrated many times with simulated data. At the BNFP, the answer has been pursued one step farther.

Test runs in the full scale facility have been conducted with near-real-time accounting and in-process inventory capabilities in place and functional. During these tests, outside groups were invited to participate and implement their data evaluation techniques. Oak Ridge National Laboratory (ORNL) and Los Alamos National Laboratory (LANL) have been on-site and their presence and function has been similar to national or international "inspectors." The BNFP safeguards staff acted as the interface to these "inspector groups" with responsibilities to provide information and data as would be required under routine operations. The BNFP operations department was the facility operator.

Several separations plant runs have been conducted. As part of these runs, various quantities of uranium solutions were actually removed from various process points and by various removal schemes. These removals tested the response and sensitivity of the data and the evaluation methods. The tests culminated with a special "black hat" test where the plant operations group was given a "free hand" to make an undetected removal. A 9.1 kilogram removal was made over an 80-hour period. The plant safeguards monitor group, without knowledge of the removal scheme, was able to detect a removal, quantify the removal, and isolate the removal point using the computerized accounting system in place at the BNFP.

The exercise has been valuable in many respects. It has demonstrated the capabilities of a carefully implemented safeguards program in a large reprocessing facility. It has provided an unequalled demonstration of safeguards measurement and data evaluation capabilities achievable under actual plant operation conditions. It has demonstrated to the plant operations organization that a cooperative effort at safeguards data collection can provide valuable process control information to enhance plant operability. And finally, it has highlighted the problems of interfacing to "inspectorate" groups.

2. The Safeguards Computer System

The center of the Safeguards accountancy system at the BNFP is the Computerized Nuclear Material Control and Accounting System (CNMCAS). This is a distributed processing system using a network of Digital Equipment Corporation (DEC) PDP 11 series minicomputers. The system features a material accounting and control (MACS) computer for data processing, data evaluation, and storage. The Remote Data Acquisition System (RDAS) is interfaced to over 500 instruments and sensors throughout the plant. It provides measurement data to MACS and the other computers in the system on demand. The Laboratory Data System (LDS) interfaces to many of the analytical laboratory and on-line analyzers. It provides analytical sample results to MACS and the other computers.

3. Testing Over Five Years

The computerized system has evolved and software development has continued over the last five years. Periodic testing has been accomplished over the years by operating the plant in test runs with natural uranium substituted as feed material for the solvent extraction and plutonium purification systems. The "feed" materials are measured with procedures and equipment installed for use during routine "hot" operations. The "feed" solutions are processed through the solvent extraction systems of the Separations Facility. Routine waste and product accountability batch measurements are made using installed measurement capabilities to close the material balances. However, to close the test loop, product solutions are collected, batchwise measured with routine accountability techniques, and cycled back to the front of the system where they are remeasured as input. With this closed-loop approach, sizable throughput quantities have been realized for material balance and system tests with a minimum of actual material on hand.

This mode of operation has distinct advantages for testing, especially in the area of in-process inventory measurement investigations. With the closed-loop operation, a known amount of material is placed in the system at the start. The actual inventory remains the same except for adjustments for waste solution removals. The actual inventory is known without the problems of input/output measurements and direct evaluation of inventory measurement capabilities can be made.

Between 1977 and 1979, a throughput of almost 500 metric tonnes of uranium was realized for the full Separations Facility. Data for almost 1800 accountability batches and 10 physical inventories were collected. These early tests focused on conventional input/output accounting. The goal was to develop near-real-time accounting to make an instantaneous "book inventory" available. The definition of near-real-time is critical to the BNFP program. At the BNFP, it means the data are constantly updated when any new information becomes available. The "current" book inventory is available for use at any time. There is no delay to await sample results or other measurements that may be delayed by hours or days. The best available data at the time is used, whether it is of process control or accountability quality.

As the problems of providing an on-line book inventory were solved, on-line measurement techniques became available, and understanding of process measurements improved, in-process inventory (holdup estimation) became the focus of developments. Experiments with in-process inventory were initially conducted for the entire separations process during the early runs as a "proof of principle" experiment. The first limited computerization was accomplished in 1979.

In 1980, reduced funding levels forced a less costly mode of testing than full-plant demonstration runs. As a result, the concept of "mini-runs" was devised. The mini-run cycle used only the plutonium portion of the solvent extraction system. Natural uranium is substituted for plutonium in the process solutions, but the actual plant equipment and support systems are used. The mini-run cycle contains four pulsed column contactors, a packed diluent wash column, a product evaporator, and seven product feed or blend tanks. Support systems include aqueous waste collection and evaporation systems, a solvent surge and recycle tank, acid and water recovery and recycle, and the off-gas system.

As with previous test runs, the mini-run product solutions were measured, batchwise transferred to the front of the cycle, and remeasured as input to maintain the closed-loop test approach. The input solutions were diluted with recovered acid and water to become feed for the extraction cycles. Seven mini-runs were conducted during 1980 to 1981. Each lasted one week with continuous around-the-clock operations.

A cumulative throughput of over 6000 kilograms was realized.

The mini-run concept allowed focus of attention on in-process inventory development. The cycle contained a cross-section of typical reprocessing plant equipment and process measurement equipment. The plutonium processing portion of the plant is particularly sensitive from a safeguards standpoint. It forms an ideal test bed.

An in-process inventory program has evolved and has been tested. The single most important consideration during development and implementation has been that the in-process inventory cannot require any special samples, special measurements, or any interruption of operations. It must be completely transparent to plant operations. A further constraint has been that results of in-process inventory measurements be available immediately. There must be no delay to await particular results or measurements. The inventory measurement program must run automatically, superimposed on operations activities. This requires the use of all available, process control and safeguards measurement data. It requires the use of the best available information which may range from current to several hours old. However, the benefit is that there is no impact of the safeguards applications to plant operability.

The computerized in-process inventory program produced hourly inventory measurements throughout the mini-runs. Over 1400 individual inventory measurements were made over the seven runs. In addition to these measurements, data sets of all available instrument readings were recorded every four minutes during the runs for additional safeguards evaluations.

4. Bringing in the "Inspectorate"

The problem of safeguards in a large reprocessing plant has been the focus of attention of many groups. The BNFP has often been used as the reference facility for these investigations. As the mini-run concept emerged, it was an ideal opportunity for other groups to test their ideas under actual operating conditions. Two such groups, Oak Ridge National Laboratory (ORNL) and Los Alamos National Laboratory (LANL), were invited to participate.

Both organizations had been developing data evaluation techniques to be used by national and international safeguards inspectorates. The mini-runs provided the opportunity to test these techniques. CNMCAS was made available to perform their monitor and evaluation routines. LANL and ORNL implemented their specific data evaluation software. The safeguards group at the BNFP handled the data-collection software. Each of the monitor groups specified the data requirements for their individual programs. The data-collection routines were implemented to obtain the measurement data, arrange it in data sets, and make the data sets available to the various programs for on-line processing.

During these tests, the ORNL and LANL presence was like that of a "national" or "international" inspector. The safeguards group at the BNFP acted as the "facility operator" to provide the data to the "inspector." The goal was to demonstrate the sensitivity and timeliness of on-line measurement and evaluation techniques.

The modern techniques of data analysis require large amounts of data. The problems of obtaining these data and transferring them to the inspector are not well understood. Likewise, these evaluation techniques have been developed and demonstrated on simulated data. The nature of actual plant data and the effects on evaluation techniques were also unanswered questions.

The preliminary negotiations and the actual implementation of the monitor programs would be required for actual operations as they were for the BNFP test runs. The preliminary studies by the inspector groups had used design and process information much the same as would be available in a "design information questionnaire" for modern facilities. The significant difference was in the level of verification the groups required or attempted. There was little attempt to perform verification activities. The data provided was simply accepted. As the runs progressed, understanding the problems of data supply and verification became additional goals.

These inspector groups brought an excellent understanding of measurement technology. They were aware of (and in many cases responsible for) the latest measurement techniques and equipment. However, the dynamic nature of reprocessing operations makes timeliness of measurements of critical importance. In many cases, the latest in measurement technology may be impractical to implement. As the tests progressed, it was apparent to all that timeliness considerations for the information required dictate the use of a wide range of "process control" type data.

For process-control measurement equipment, accuracy and precision must be balanced with cost, reliability, and maintainability. Tests have shown the performance of this equipment can be significantly improved with computerized "frequent" bias checks. During the test runs, comparisons of on-line measurements to infrequent samples or precision measurements were used to determine bias adjustments and maintain calibration correction coefficients. A series of computer programs was developed to monitor the effects of these corrections on instrument performance.

During the initial discussions, the "inspectors" demanded precisely accurate measurements to meet idealized performance standards. Process control data was available but the statistics of such measurements generally do not satisfy safeguards requirements. The nature of the operator/inspector interface is such that the inspector will not trust or accept these data. He is less likely to accept them if correction and calibration factors are applied to make spot-check readings and reported values disagree. The operator generally realizes the problems of process control measurements and is reluctant to provide them for the safeguards application in fear the inspector will not use them properly or will misinterpret the information resulting in "false alarms." This usually results in a "standoff" where the inspector settles for a few untimely measurements and the operator continues to operate the plant with process control data that sometimes even he does not trust. It boils down to a problem of confidence.

To solve the problem, the instrument performance programs were offered for use by plant operators and the "inspectors." This started as an attempt to demonstrate that process control measurements could be substituted and accepted to improve timeliness with a minimum of sacrifice in overall accuracy and precision. In reality, these are verification tools. Routine samples and spot measurements made as normal practice, as well as inspector verification measurements, provide the "standards" to verify the performance of the process control measurements. These verification tools give the inspector the confidence he needs to accept the data and correction or calibration factors. Additionally, the operator has realized a new confidence in the data he needs to operate. Safeguards and process control have the common goal to improve measurement capabilities.

Bringing in the inspectorate and the ensuing discussions of timely and accurate measurements highlighted a fact that the needs of both groups are served by a cooperative effort. Indeed, the needs can only be achieved with a cooperative effort. Accuracy is sacrificed for timeliness in process control. A cooperative and open effort at process control measurement improvement and verification techniques returns accuracy to process control measurements. The enhanced process control applications and the additional information provided to the inspector serve to enhance plant operability.

5. The Diversion Tests

The mini-run program included a number of diversion tests to demonstrate the sensitivity of the safeguards measurement system and the evaluation techniques. Over the course of the seven mini-runs, 22 abrupt removals ranging from a few hundred grams to five kilograms were made from various process vessels. Seven protracted removals were also made. During these protracted removal tests, process streams were partially diverted over 12- to 16-hour periods to achieve 5- to 10-kilogram removals.

These tests were carefully planned and announced to check the response of the safeguards measurement system and the various data analysis techniques. In virtually all cases, the removals could be detected in the safeguards measurement data. However, the tests demonstrated that it takes a number of different techniques and detailed understanding of measurement systems and plant processes to analyze the data.

The sensitivity of the data and the level of understanding required to make the safeguards evaluations are evident from the results of the final test. This was a "black hat" test conducted during the final mini-run. Previous removal tests had specified the quantities, location, and removal scheme. This final test gave a "free hand" to the operations group to attempt an undetected removal. The only constraints were to remove at least eight kilograms sometime during an 80-hour period. There were no constraints on the method of removal or the removal point. The safeguards monitor groups were to detect the removal, determine the quantity, and isolate the removal point if possible using the available safeguards measurement data.

The safeguards investigation started with the basic in-process inventory data. These data were measured to allow hourly material balance closures. Analysis of the data on either side of the "time window" showed a quantity of 16.4 kilograms missing. A simple CUSUM analysis of the data during the period of concern showed a steady increase in material missing. This indicated a constant removal over the period.

However, more information was needed. The nature of the mini-run cycle is such that aqueous waste streams are continually collected and concentrated. They are measured only at the end of each week. Thus, the material in the aqueous waste acts like a removal in the in-process inventory data evaluation. The quantities can be estimated from integration of aqueous waste stream flow and concentration. This must be accepted as an estimate since samples are infrequent and concentrations may vary considerably. The safeguards data indicated the aqueous waste streams carried 2.4 kilograms to the concentrator during the period. Thus, 14 kilograms were apparently missing.

At this point, in the safeguards context, a removal was indicated. However, with the nature of process control data in the safeguards application, additional "proof" was necessary.

The CUSUM analysis of the in-process inventory data showed a steady increase in the material missing over the period. An analysis of the data with respect to time showed the missing material increased at the rate of 147 grams/hour. After adjustment for the aqueous waste streams, the removal appeared to be constant at about 100 grams/hour throughout the period.

At this point, there was evidence of a removal and it appeared to be at a constant rate over the 80-hour period. The initial analysis showed 14 kilograms. At 100 grams/hour over the 80-hour period, a total of around 8 kilograms was indicated. A removal of 8 to 14 kilograms was then apparent.

The "unit process accounting" approach was used to isolate the removal point. As the first step, mass balances around each of the four pulsed columns were calculated from the safeguards and process data. These balances use flow measurements and on-line concentration estimates to calculate the instantaneous mass balances.

As an illustration, these data are presented in Figure 1. The safeguards analysis must consider the nature of the data. With the plant at steady operation, the mass balances should be zero. However, slight biases in the measurements produce non-zero results. The inspector must look for "consistency" of data. In the figure, the "1" and "2" balances exhibit this consistency and are not likely the removal point. The "3" and "4" balances show some deviations. However the nature of the reprocessing operation must be considered in this analysis. As conditions in a pulsed column change, a column will "unload." The product stream will show an increase of material and the calculated mass balance will reflect it. Likewise, the next column in the stream will show a corresponding increase. This is the case with the "3" and "4" balances in the data shown. There are corresponding offsets. The column balance data do not indicate the removal.

A somewhat different approach was used to investigate the product concentration and measurement portion of the mini-run cycle. Rather than instantaneous balances, a cumulative balance approach was used. The balance used an integration of the flow and concentration with time from the final column as input. Batch transfers from the product tank are used as output. A portion of the data from the period of concern is shown in Figure 2. The current holdup (H) and the cumulative inventory difference (I) are shown for measurement sets.

The data show the holdup increasing as the product tank fills. As each tank is transferred, the holdup drops. The curious shift in the inventory difference after each transfer is due to random error effects on each batch. This is the nature of the data and the safeguards investigator must look beyond.

A closer examination involves a linear fit of the inventory differences to time after adjusting for the apparent random errors of the product transfer measurements. This analysis showed a steady increase of approximately 200 grams/hour. This could be an actual removal or just bias in the input flow integration. A careful review of the column mass balance data and this same inventory analysis on data recorded before the period of concern indicate the actual bias was on the order of 100 grams/hour. Thus, this inventory analysis indicated there was a removal from this portion of the plant during the time in question. The data actually showed a slightly higher removal rate at the start. The data showed an apparent replacement of about two kilograms after 8 to 10 hours with a constant 100 grams/hour removal for the duration of the period. Integration of these indications showed a total of about 10 kilograms removed.

With this evidence, the operations organization was "accused" of a 8- to 14-kilogram removal by a continuous "bleed" from "somewhere between the 3B column and the product tank." At this point they "confessed to the removal of 9.1 kilograms from a "bleed" in the product concentrator takeoff line. Their rate checks confirmed the higher rate at the start of the period with a continuous rate of about 100 grams/hour. The only "mistake" from the safeguards indications was that no material was replaced.

6. Conclusions

The objective of test runs at the BNFP has been to show that process data made available for safeguards evaluation can be sensitive to removals at the magnitude of international concern in large reprocessing plants. Diversion test results have shown they can. The measurement programs can be superimposed on plant activities with no impact on plant operability. Indeed, the computerization and measurement improvements that can be realized by the safeguards application can enhance operability through better process contol information and quicker response to indicated problems. But it takes a combination of data analysis techniques and a detailed understanding of plant processes and measurement techniques to make the safeguards application work.

There is an increasing awareness throughout the safeguards community that process control data is required to meet safeguards objectives of timeliness and sensitivity. There is an increasing awareness that the process control and safeguards functions are complimentary. There will always be concern by the operator that inspectors will misinterpret the data. There is the concern that they will misuse the information or not be capable of handling the amount of process information necessary to make the techniques work. Likewise, the problem of verification by the inspector grows with the amount of information involved with the near-real-time accounting and in-process inventory. The inspector must use his verification activities as constructive learning tools to understand the plant and gain confidence in the operator-supplied information. He must use verification in a broad sense to learn to trust the operator on many points. He must gain confidence in the operator quality control, measurement control, and computer systems. All these problems are superimposed on the political problems of international safeguards implementation. These are some of the experiences and areas of continuing investigation that have resulted from the test runs at the BNFP.

The costs of a program are significant. The cost to the operator is a computerized measurement and process control system. However the benefits of an on-line process control system to plant operability are enormous. Product quality, reduced downtime, timely response to plant problems are all benefits that justify the cost of such an installation. The costs to the inspectorate are less well defined. It will take dedicated inspectors with learned skills. It will take individual attention to cooperate with specific facilities. There must be a continuous interaction to maintain the trust and flow of information in both directions.

What has been demonstrated at the BNFP is that when the political problems and the problems of mutual trust by the inspector and the operator are overcome, the measurement system with existing technology can be very sensitive to unauthorized removals or diversion.

Figure 1

This a plot of the column balances calculated from process control data.
The parameters are calculated as follows:

2A FEED (2AF) BY 1BP FLOW X 1.06 AND X-RAY FLUORESCENCE FOR 1BP
2A PRODUCT/2B FEED (2AP) BY 2AX FLOW X 1.12 AND ORGANIC U CALC USING 2A COLUMN TOP DENSITY X .98
2B PRODUCT/3B FEED (2BP) BY 2BX FLOW X 1.1 AND LOW U CALC WITH ON-LINE DENSIMETER AND CR-667 + .1
3A PRODUCT/3B FEED (3AP) BY 3AX-FLOW X 1.1 AND ORGANIC U CALC USING 3A COLUMN TOP DENSITY X .983
3B PRODUCT (3BP) BY 3BX-FLOW X 1.1 AND LOW U CALC WITH ON-LINE DENSIMETER AND CR-667 + .1
(2AW) BY 2AF+2AS FLOW AND MOST RECENT SAMPLE
(2BW) BY 2AX FLOW AND MOST RECENT SAMPLE
(3AW) BY 2BX+3AF BUTT+3AS FLOWS AND MOST RECENT SAMPLE
(3BW) BY 2AX FLOW AND MOST RECENT SAMPLE

The individual column balances are constructed from the above parameters as follows:

BALANCE 1 = (2A FEED)-(2AW)-(2A PRODUCT)
BALANCE 2 = (2B FEED)-(2BW)-(2B PRODUCT)
BALANCE 3 = (3A FEED)-(3AW)-(3A PRODUCT)
BALANCE 4 = (3B FEED)-(3BW)-(3B PRODUCT)

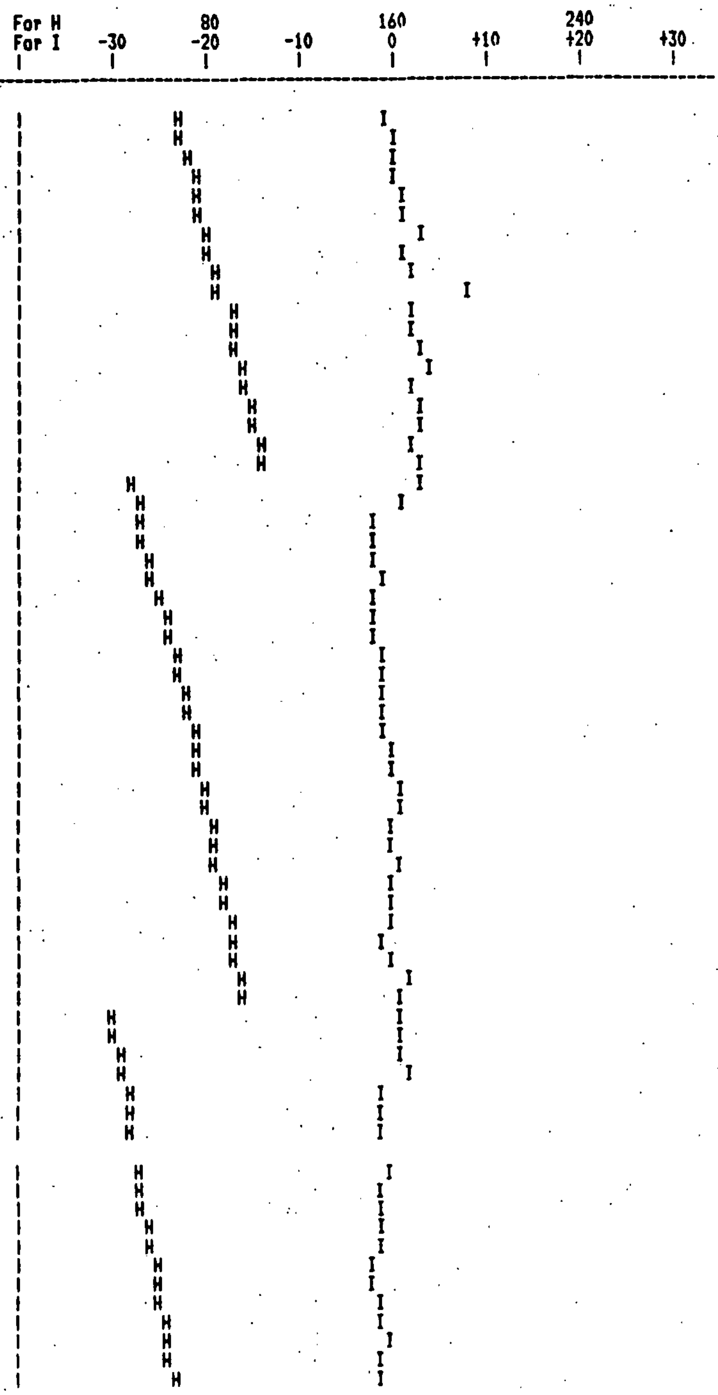
```
       -3Kg/hr         -1.5          0Kg/hr         1.5           3Kg/hr
           !             !             !             !             !
------------------------------------------------------------------------
21-Aug-81
 181 05:14AM                       2 3 ! 14
 185 06:18AM                          21    4
 189 07:21AM                        32 1         4
 193 08:44AM              3          21!                 4
 197 09:46AM              3         2  ! 1            4
 201 11:26AM                   3   2   !  14
 205 12:30PM                      32   !  1  4
 209 01:50PM                    3   2  !     1   4
 213 02:54PM               3          2!   1        4
 217 04:43PM                     3  2  ! 1       4
 221 05:54PM                    3  2   ! 1    4
 225 06:58PM                     3 2   ! 1   4
 229 08:02PM                     3  2  ! 1     4
 233 09:05PM                    3   2  ! 1        4
 237 10:10PM                       3 2  !  1    4
 241 11:14PM                        2  !    14
22-Aug-81
 245 12:17AM                      3  2 !    1   4
 249 01:21AM                      32   !    1      4
 253 02:26AM                     3 2   !   1        4
 257 03:29AM                    3   2  !   1         4
 261 04:33AM                3       2  !   1        4
 265 05:38AM                3       2  !   1      4
 269 06:42AM                    3   2  !   1     4
 273 07:46AM                    3   2  !   1       4
 277 08:50AM                 3       2 !1          4
 281 09:54AM                3        2 !   1      4
 285 10:57AM                3       2  !  1       4
 289 12:02PM                   3   2   !   1   4
 293 01:05PM                      3 2  !   1
 297 02:09PM                        2  ! 1  4
 301 03:14PM                         243 1
 305 04:17PM                         2 !  3 1
 309 05:22PM                         24!3 1
 313 06:25PM                      2 4  !  1
 317 07:29PM                        2  3 4 1
 321 08:34PM                       2   4 3 1
 325 09:38PM                       2   3   1
 329 10:42PM                        2  ! 31  4
 333 11:46PM                          234 1
23-Aug-81
 337 12:49AM                         23!4   1
 341 01:53AM                         23!  14
 345 02:58AM                          2!  1 4
 349 04:02AM                         2 3 14
 353 05:05AM                        2  !3 1
 357 06:10AM                         2 31  4
 361 07:13AM                         2 341
 365 08:17AM                        2 3! 1 4
 369 09:22AM                         2 43 1
 373 10:25AM                        2 4!3  1
 377 11:30AM                       2   3 41
 381 12:34PM                        2 3! 1 4
 385 01:38PM                         2 3 41
 389 02:42PM                        2 3!  1
 393 03:45PM                        2  3   1
 397 04:50PM                       2   43  1
 401 05:54PM                       2   3 4  1
 405 06:58PM                       2   !3  1
 409 08:02PM                        2  3   1
 413 09:06PM                       2   4 31
 417 10:10PM                       2   !3 41
 421 11:14PM                       2   !34 1
```

Figure 2

Material Balance Analysis around 3B Column to Pu Product Sample Tank
For Mini Run No. 7
From data set no. 190 at 07:38 AM on 21-Aug-81
To data set no. 255 at 02:57 AM on 22-Aug-81

The Cumulative Holdup is Represented by an (H)
The Inventory Difference (HLDP-JPI) is Represented by an (I)

	Kgs Column Input	Kgs Prod Tk Output	Kgs Cumul Hldp	Kgs Meas Inv
21-Aug-81				
190 07:38AM	.8	0	68.5	69
191 07:54AM	1.4	0	69.9	70.3
192 08:26AM	2.9	0	72.8	73.2
193 08:44AM	1.7	0	74.5	74.2
194 08:59AM	1.4	0	76	75.2
195 09:14AM	1.5	0	77.4	76.5
196 09:30AM	1.6	0	79.1	76.5
197 09:46AM	1.7	0	80.7	79.5
198 10:02AM	1.7	0	82.4	80.9
199 10:34AM	3.5	0	86	77.8
200 11:10AM	4.1	0	90	88.4
201 11:26AM	1.8	0	91.8	89.7
202 11:42AM	1.7	0	93.5	90.4
203 11:57AM	1.6	0	95.1	91.6
204 12:14PM	1.8	0	96.9	94.8
205 12:30PM	1.7	0	98.5	95.4
206 12:49PM	2	0	100.5	97.1
207 01:14PM	2.6	0	103.1	100.6
208 01:35PM	2.1	0	105.2	101.7
209 01:50PM	1.4	57.5	49.1	46
210 02:06PM	1.5	0	50.6	49.8
211 02:22PM	1.5	0	52.2	54.1
212 02:38PM	1.5	0	53.7	55.3
213 02:54PM	1.5	0	55.2	57
214 03:09PM	1.5	0	56.7	58.1
215 03:26PM	1.7	0	58.3	60
216 04:27PM	5.9	0	64.2	66
217 04:43PM	1.5	0	65.8	68
218 05:07PM	2.3	0	68.1	68.8
219 05:22PM	1.5	0	69.6	70.4
220 05:38PM	1.6	0	71.2	72.5
221 05:54PM	1.6	0	72.8	73.7
222 06:10PM	1.7	0	74.5	75.7
223 06:25PM	1.6	0	76.1	76.5
224 06:42PM	1.7	0	77.8	77.8
225 06:58PM	1.6	0	79.4	78.9
226 07:14PM	1.6	0	81.1	80.6
227 07:30PM	1.6	0	82.7	82.7
228 07:46PM	1.6	0	84.3	83.9
229 08:02PM	1.6	0	85.9	85
230 08:18PM	1.6	0	87.5	87.4
231 08:34PM	1.5	0	89	89.5
232 08:50PM	1.5	0	90.6	90.1
233 09:05PM	1.4	0	92	92.7
234 09:21PM	1.5	0	93.5	93
235 09:38PM	1.6	0	95.1	93.3
236 09:54PM	1.5	0	96.5	95.7
237 10:10PM	1.5	57.6	40.5	39.3
238 10:26PM	1.5	0	42	41.2
239 10:41PM	1.4	0	43.4	42.7
240 10:57PM	1.5	0	44.9	43.3
241 11:14PM	1.6	0	46.6	47.8
242 11:30PM	1.5	0	48.1	49
243 11:46PM	1.5	0	49.6	50.2
22-Aug-81				
244 12:02AM	1.5	0	51	51.3
245 12:17AM	1.4	0	52.4	53.1
246 12:33AM	1.5	0	53.9	54.6
247 12:50AM	1.6	0	55.5	56.9
248 01:05AM	1.3	0	56.8	58
249 01:21AM	1.4	0	58.2	60
250 01:38AM	1.5	0	59.6	61.4
251 01:53AM	1.3	0	60.9	61.6
252 02:10AM	1.4	0	62.4	63
253 02:26AM	1.4	0	63.8	63.9
254 02:41AM	1.3	0	65.1	66.1
255 02:57AM	1.4	0	66.5	67.2



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