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STUDIES AND RESEARCH CONCERNING BNFP

ON-LINE DENSITY MEASUREMENT

John E. Shiley
Lucius G. Jordan
George A. Huff

MASTER

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[redacted]

ALLIED-GENERAL NUCLEAR SERVICES
POST OFFICE BOX 847
BARNWELL, SOUTH CAROLINA 29812

[redacted]

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ABSTRACT

Three on-line density meters and an on-line conductivity meter were evaluated during the near-real-time uranium mass flow and material inventory safeguard studies conducted in the Allied-General Nuclear Services (AGNS) Engineering Laboratory. Two of these on-line density meters were also utilized to monitor process streams during the May 1981 plant scale natural uranium demonstration run. The results of these on-line density meter tests are reported, and further equipment modifications and testing are suggested.

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1.0 INTRODUCTION

Near-real-time measurement of the nuclear materials inventory in process streams is an objective of the Allied-General Nuclear Services (AGNS) nuclear materials control program. The development and evaluation of an on-line density measurement system is an integral part of such a measurement system. An initial step in the development of an on-line density monitor was accomplished at AGNS during FY 1980.[1] This report covers the further development and evaluation of on-line density monitor systems which have been accomplished at AGNS during the FY 1981 Engineering Laboratory and plant scale natural uranium demonstration runs.

2.0 SUMMARY

On-line density meters were successfully installed and operated in the Engineering Laboratory and on plant process streams during natural uranium demonstration runs. It was demonstrated that they can provide timely and reliable density measurements for process streams and can function as integral components of real-time nuclear material inventory systems.

In the Engineering Laboratory, three density meters and a conductivity meter were installed on process streams. A Mettler/Paar DMA 45 Calculating Digital Density Meter equipped with a continuous flow adapter and a Dynatrol Model CL-10HY Density Cell were installed in parallel on-line of the aqueous 1BP product stream upstream of the 1BP receiver tank. In addition to the two density meters, a Balsbaugh Series 1200 Electrodeless Conductivity Cell was installed on the 1BP stream ahead of the density meters. A Mettler/Paar DPR 412YWS Density Measuring Cell was installed on-line of the organic 1AP process stream being fed to the 1B column. Sample flow through the density monitor loops was motivated by column head pressure. Vent piping was provided to permit purging of air from the lines prior to system startup. The outputs of the Mettler density meters and of digital thermometers measuring the sample stream temperatures at the outlets of the density meters, were interfaced to the laboratory computer system via a laboratory instrument interface unit. The laboratory computer system prompted the interface unit every two minutes throughout the 4-5 hour long Engineering Laboratory runs to accept density and temperature data. The laboratory computer then calculated the sample densities and relayed the data to a printer on the interface unit and to the Material Accounting and Control System (MACS) which updated and stored the density and temperature results every four minutes. Outputs from the Dynatrol Density Cell and the conductivity cell were also relayed to the MACS. Using stored calibration equations, the MACS then calculated and stored density and acid molarity values for the 1BP stream.

Density and acid data provided by the on-line density and conductivity meters were utilized in conjunction with data obtained from tank level instrumentation, weight measuring instrumentation, and X-ray fluorescence instrumentation to provide near-real-time uranium inventories for Engineering Laboratory process streams and vessels during actual run conditions.

During the plant natural uranium demonstration run, "Mini-Run No. 6," the DPR 412YWS density cell was installed on-line of the 2BP process stream and the DMA 45 density meter was installed on-line of the 3BP process stream. Each of the two density meters was inserted in the remote sampler loop of the process stream being monitored by means of tubing connections to a modified sampler needle block. An air disengagement pot was installed in-line with the density meter to remove air from the sample stream. As in the Engineering Laboratory installation, density and temperature data were collected by means of interfacing the meters to the Laboratory computer system via an interface unit. Data were accepted and printed out at the interface unit every five minutes and updated by the MACS every 16 minutes throughout 152 hours of operation. Uranium concentration in the 2BP and 3BP streams were calculated by the the MACS every 16 minutes using the on-line density meter readings and acid concentrations based on on-line conductivity measurements. Thus, near-real-time estimates of the uranium content in the flowing 2BP and 3BP streams were achieved.

The density meters, calibration of the density meters, installation of the meters in the Engineering Laboratory and plant, data collection, and measurement results are discussed in this report.

3.0 METHODOLOGY

3.1 Density Cells

The three density cells used as on-line density monitors during the nautral uranium demonstration runs are all of the hollow mechanical oscillator type. Each cell has a U-shaped sample tube oscillator which is electromagnetically excited in an undampened harmonic fashion. The period of oscillation of the sample tube depends on the effective mass of the tube which varies with changes in sample density. Thus, by measurement of the period of oscillation of the sample tube, the density of a sample can be determined.

3.1.1 Mettler/Paar DMA 45 Calculating Digital Density Meter

The DMA 45 has a borosilicate glass (Duran 50) oscillator tube of about 0.7 milliliter capacity mounted in the center of a double-walled cylinder fused at both ends. The space between the sample tube and the inner wall of the cylinder is filled with gas of high thermal conductivity. By passing a theromstatically controlled liquid between the walls of the cylinder, the temperature of a static sample may be equilibrated at the desired temperature, and some degree of temperature regulation can be attained on a flowing sample.

A built-in quartz crystal controlled timer in the electronic section of the DMA 45 performs a period measurement every two seconds and transmits the result to the built-in arithmetic processor. A four-position switch allows selection of the output display to show the period of oscillation (T), the sample density (ρ), or the instrument calibration constants A and B. On the rear of the DMA 45 is a four-pin connector which can be used for connecting an external density cell. Placing the connector switch in the "external" position permits the output from an external cell to be displayed on the DMA 45.

Calibration of the DMA 45 internal cell requires determination of the period of oscillation of the oscillator tube when filled with air and when filled with water. These periods are temperature dependent, and therefore, the cell must be well thermostated at the desired sample measurement temperature when the periods of air and water are determined. If a different sample measurement temperature is desired, the periods of air and water must be determined for the new measurement temperature. Since sample temperature fluctuations were expected during the runs, the temperature dependence of the periods (T) of air and water was determined over the range of 22-28°C. It was found for the DMA 45 that:

$$T_{H_2O} = 61478 - 6.977 \times \text{Temp, °C}$$

$$T_{air} = 45697 - 2.824 \times \text{Temp, °C}$$

3.1.2 Mettler/Paar DPR 412YWS Density Measuring Cell

The DPR 412YWS (referred to as the DPR 412) is one of the density measuring cells available as part of the Mettler/Paar DPR 2000 system which is designed to provide continuous measurement of density in industrial control systems. The cell has a 2.6-millimeter inner diameter stainless steel oscillator tube mounted in a cylindrical stainless steel housing through which a thermostatically controlled liquid can be passed. For additional temperature control, the "W" model (note W in full model designation) has a built-in stainless steel spiral heat exchanger which permits circulation of the thermostatically controlled liquid around the sample carrying tube before it connects to the oscillator. The total capacity of the sample tubing contained in the heat exchanger and oscillator housing is 6-7 milliliters.

Calibration of the DPR 412 was accomplished on thermostated static air and static water samples. Since the DPR 412 is an oscillator cell only and has no output presentation of its own, it was connected to the DMA 45 as an "external" cell. With the "int/ext" switch on the DMA 45 in the "ext" position, the periods of air and water for the DPR 412 cell were displayed on the DMA 45. As with the DMA 45, the temperature dependence of the periods (T) of air and water was determined. It was found for the DPR 412 that:

$$T_{H_2O} = 56250 + 9.833 \times \text{Temp, °C}$$

$$T_{air} = 50856 + 10.147 \times \text{Temp, °C}$$

3.1.3 Dynatrol Model CL-10HY Denisty Cell

The third cell used was the Dynatrol Model CL-10HY Density Cell by Automation Products, Inc. The Dynatrol cell contains a one-half inch diameter stainless steel U-tube oscillator and can be installed to take the full flow of a process stream. That the unit is built for industrial service is reflected in its size (about 36 inches x 14 inches overall) and weight.

A converter unit converts the output of the Dynatrol cell into a compatible signal for recorders and controllers and also contains the power supply which provides regulated power for vibration of the U-tube. The converter used with the Dynatrol Cell was the EC-213 GA model which was modified to provide an output of 250-1250 millivolts.

Calibration of the cell was carried out according to the manufacturer's recommendations. The converter zero and span dials were set such that distilled water gave an output of 250 millivolts and nitric acid having a density of 1.1996 grams/milliliter yielded an output of 1250 millivolts to correspond to a recorder span of 0-100%.

3.2 Conductivity Monitor

The conductivity monitor utilized in the Engineering Laboratory natural uranium runs was the Series 1200 from Balsbaugh Laboratories, Inc. The conductivity cell of this monitor has no electrodes, but instead uses toroidally wound coils to induce and sample electric currents in the sample solution. The magnitude of the induced currents is proportional to the electric conductivity of the solution. A precision thermistor in the cell provides the signal for automatic temperature compensation circuits.

The Series 1200 meter was set up for a 250-1250 millivolt output corresponding to a full scale meter range of 0-200 millimho/cm. Calibration of the Series 1200 meter output was checked as directed in the manufacturer's instruction manual by using a decade resistance box connected through the conductivity cell with a loop of 16 gauge wire. Following this check, several nitric acid solutions of known concentration in the range of 0.1-0.5 molar were introduced into the cell and the meter readings recorded. The measured conductivity values for the nitric acid solutions were in good agreement with literature values.

3.3 On-Line Monitor Installation

3.3.1 Plant Installation for Mini-Run No. 6, May 1981

During the plant natural uranium demonstration run, Mini-Run No. 6, the DPR 412 density cell was installed on-line of the 2BP process stream, and the DMA 45 density meter was installed on-line of the 3BP process stream. In order to install the density meters on-line of the 2BP and 3BP process stream, it was necessary to install each density meter in-line with the remote sampler loop for the process stream it was to monitor. This was the only access to these streams outside of the shielded process cell.

The 2BP and 3BP remote samplers operate in the same way: Liquid from the process line circulates to a sampling station and then back to the process by means of a vacuum assisted air lift (see Figure 3-1). The air lift transports the solution to be sampled into the sample bottle through a supply needle mounted on the needle block. Liquid leaves the sample bottle through a return needle and returns to the process line. Air leaving the return needle vents through the valve pot. If liquid is drawn up into the valve pot, a float-operated needle valve throttles the jet suction line. If the liquid level continues to rise, the float opens another valve that allows air to enter from the jet discharge line, thereby reducing vacuum and liquid lift within the sampling loop.

Installation of density meters in the 2BP and 3BP sampler loops thus required not only breaking into each sampler loop, but also providing a means of removal of entrained air from the circulating liquid samples before they entered the density meters. These two problems were dealt with in the same way for each sample loop:

- Breaking into the sample loop was accomplished by modifying the sampler needle block. A standard needle block contains an internal channel connecting the supply side and return side of the block (see Figure 3-1). This internal bypass allows more rapid circulation of the liquid sample than could be obtained if the full liquid flow had to pass through the sample bottle. Modifications to the needle block involved tapping the supply and return channels of the block from the top of the block to accept tubing fittings and welding the internal bypass channel closed. These modifications converted the internal bypass to an external bypass line in which the density meter could be placed.

- Removal of entrained air from the sample stream was accomplished by installing an air disengagement pot in the new external bypass line upstream of the density meter. The removed air was vented back to the return line of the sample loop.

Once the modified needle blocks and air disengagement pots were installed, the density meters were placed in the external bypass line created in the sampler loops. Connection of the DPR 412 to the air disengagement pot drain and to the needle block return in the 2BP sampler loop was made via stainless steel tubing from the 1/8-inch tube fittings on the sample inlet and sample outlet lines at the heat exchanger section of the cell. The DMA 45 was connected to the air disengagement pot drain and the needle block return in the 3BP sampler loop by means of a continuous flow adapter (Mettler part number 5771) which was installed on the DMA 45. The 1/4-inch diameter stainless steel lines carrying sample circulation to and from the DMA 45 were fitted with reducers to accept the Teflon "spaghetti" tubing required by the continuous flow adapter.

The remote sampler loop as modified for installation of an on-line density meter is shown in Figure 3-2.

3.3.2 Engineering Laboratory Installation of Density Meters and Conductivity Meter

In the Engineering Laboratory, instrument loops were inserted into the 1AP, 1BP, and 1BW process streams specifically for installation of the on-line monitors needed for real-time uranium mass flow and inventory studies. Valving was provided to permit regulation of process stream flow through these instrument loops or to bypass the instrument loops entirely. In addition, valves were provided for purposes of sampling the loop streams and for purging air from the loops on startup.

The DPR 412 density cell was installed on the instrument loop of the 1AP stream which carries the uranium containing organic extractant as feed to the B column. The DMA 45 density meter and the Dynatrol density cell were installed in parallel on the instrument loop of the 1BP stream which is the aqueous uranium containing product from the B column.

The Series 1200 conductivity cell was installed in the 1BP instrument loop just upstream of the two density cells. Local indication of the 1BP stream conductivity was provided by the Series 1200 meter which was mounted near the conductivity cell.

X-Ray Fluorescence Analyzers (XRFA) were installed on each of the three instrument loops. These instruments provided direct determination of uranium concentration in the process stream. The XRFA's will be covered in a separate report to be published in November 1981.

The on-line instrument installations used in the Engineering Laboratory are shown schematically in Figure 3-3.

3.4 Sample Temperature

It is the practice at AGNS to determine individual sample densities at 25°C unless otherwise requested. For consistency and comparison purposes, it was desired that densities and conductivity from on-line monitors also be reported at 25°C.

This temperature requirement presented no particular problem in the cases of the Dynatrol density cell and the Series 1200 conductivity meter, as both are equipped with circuitry for electronic temperature compensation of their outputs. The sensitivity and balance control on the temperature compensation bridge of the Dynatrol EC-213GA converter was adjusted according to the manufacturer's instruction manual to compensate for density shifts caused by variations in sample temperature from the selected reference temperature of 25°C. No adjustments were required for the conductivity meter as it is designed to reference all conductivity readings to 25°C.

To obtain density measurements at 25°C from the DMA 45 and the DPR 412 as installed in both the Engineering Laboratory and the plant, it was necessary to try to maintain the temperature of the flowing samples within the cells at 25°C by circulating thermostatically controlled liquid through heat exchanger sections of the two cells. The source of the thermostatically controlled solution was the reservoir of a refrigerated/heated water bath unit, the controls of which were set to maintain the circulating antifreeze solution at just above 25°C. A Yellow Springs Instruments (YSI) model 703 thermistor probe and digital thermometer were used to monitor the temperature of the thermostatically controlled solution. Throughout the Engineering Laboratory and plant runs the circulating thermostatically controlled solution was maintained in the range of 25.1-25.3°C.

The thermostatically controlled liquid was pumped to the density cells through lines insulated with one-half inch thick Armaflex insulation. The circulation route was as follows: from the reservoir of the water bath to the oscillator section of the DPR 412, out of the oscillator housing of the DPR 412 into the spiral heat exchangers of the DPR 412, out of the spiral heat exchanger into the double walled cylinder of the DMA 45, out of the DMA 45, and back to the reservoir of the water bath. The flow rate for the solution through the density equipment was about four liters per minute.

Sample stream temperatures were measured at the outlets of the density cells using YSI Model 710 thermistor probes. The probes were placed in the sample streams by means of tubing "tees" such that the sample stream had to flow over and around the thermistor before it entered the discharge leg of the "tee" to return to the process. The portions of the sample lines containing the thermistor probes were insulated with one-half inch thick Armaflex insulation. Outputs of the YSI probes were displayed on a Doric Trendicator 410A Digital Thermometer.

3.5 Data Collection

3.5.1 Dynatrol Density Cell and Conductivity Monitor

Data collection from the Dynatrol density cell and the Series 1200 conductivity monitor during Engineering Laboratory runs was fairly straight forward. Output signals in the range of 250-1250 millivolts from the Dynatrol converter and the conductivity meter were sent first to a real-time processor. The processor converted the millivolt signals to signals compatible with the Material Accounting and Control System (MACS), then relayed the converted signals to the MACS. Using equations determined during calibration of the Dynatrol density cell and the conductivity cell, the MACS then calculated a density value for the 1BP stream and an acid concentration for the 1BP stream. Updated density and acid concentration values were calculated every four minutes by the MACS during Engineering Laboratory runs. The values and corresponding times were then stored by the MACS for recall by any of the several terminals linked to the MACS.

3.5.2 DMA 45 and DPR 412

In comparison to the above system, the system utilized to collect data from the DMA 45 and the DPR 412 cells in both the Engineering Laboratory and plant installations was complex. This was true because of the requirements placed on the system, i.e., the data collection system had to obtain density data from two cells and temperature data from two thermistor probes with only one density data processor (the DMA 45) and one digital thermometer (the Doric 410A) available with BCD output.

The DMA 45 has a manual switch which permits processing of the output of an external density cell by the processor section of the DMA 45. The Doric Trendicator 410A is a multipoint digital thermometer with manual switching between measurement points. To meet the data collection requirements, the manual switching circuits of both these instruments were modified such that switching between density cells and thermistor probes could be accomplished electronically by computer command.

The equipment was then set up as shown in Figure 3-4. The YSI thermistor probes from the sample outlets of the DMA 45 and the DPR 412 were plugged into two of the input jacks of the Doric Trendicator and the BCD output of the Trendicator was fed into the instrument interface unit. The output jack of the DPR 412 was plugged into the external cell connector at the rear of the DMA 45 and the internal/external switch was placed in the "internal" position. The BCD output of the DMA 45 was also fed to the interface unit. Data were relayed from the interface unit to the laboratory computer system which calculated the density values and sent them to the MACS for storage and back to the interface unit printer. The four position readout selector switch of the DMA 45 was set in the "period" position in order that period values would be relayed to the interface unit for both the internal and external cells. If the switch were set in the "density" position, a density value based on the calibration factors held in the DMA 45's memory would be calculated by the DMA 45 and sent to the interface unit. Since only one set of calibration factors can be stored, the calculated density value for either the internal or external cell would be incorrect.

The laboratory computer system was programmed to command instrument switching, accept data from the interface unit, and to calculate density values based on the calibration factors of the two cells. At startup, the program requested whether calibration changes were required, if data from both cells were to be taken, and the wait time which determined the interval at which the interface unit accepted data.

A typical data collection cycle for both cells with a specified wait time of five minutes would run as follows:

- Immediately upon entering the wait time, the laboratory computer system would prompt the interface unit to accept four consecutive period values from the DMA 45 internal cell and four consecutive temperature readings from the thermistor probe at the sample outlet of the DMA 45 cell. The computer system accepts the period readings if the range of the set is less than four period units, then averages the period and temperature readings. Upon calculating a density value for the DMA 45 internal cell, the density, time, and sample temperature are relayed to the MACS and the interface unit printer. Then, at the command of the computer, the interface unit would prompt electronic switching of the internal/external switch to the external cell position and the Trendicator switch to the second thermistor probe. After accepting period and temperature data from the DPR 412 cell and the thermistor at the outlet of the DPR 412 cell, the computer would calculate the density of the sample contained in the DPR 412 cell and relay the density, time, and temperature to the MACS and the interface unit printer. At this point the computer would signal the interface unit to activate switching back to the DMA 45 internal cell and thermistor probe. When this switch was accomplished, no data would be taken for the next five minutes at which time the computer would again prompt the data collection cycle to start.

3.5.3 Laboratory Computer System Density Calculations for the DMA 45 and DPR 412 Density Cells

Upon receiving the sample period (T_S) and the sample temperature (t_S) data from either the internal or external cell, the computer performs the following series of calculations:

(1) Calculates the density of water, ρ_{H_2O}, and the density of air, ρ_{air}, at the sample temperature, t_s, using equations for the densities of water and air as a function of temperature.

(2) Calculates the period of water, T_{H_2O}, and the period of air, T_{air}, at the sample temperature, t_s, using the temperature dependent period equations determined during cell calibration. The computer recognizes the cell from which the data are coming and chooses the correct set of period equations for this calculation.

(3) Uses the values calculated in (1) and (2) to calculate the cell constant, 1/A, for the density cell at the sample temperature, t , according to:

$$1/A = \frac{\rho_{H_2O} - \rho_{air}}{T^2_{H_2O} - T^2_{air}}$$

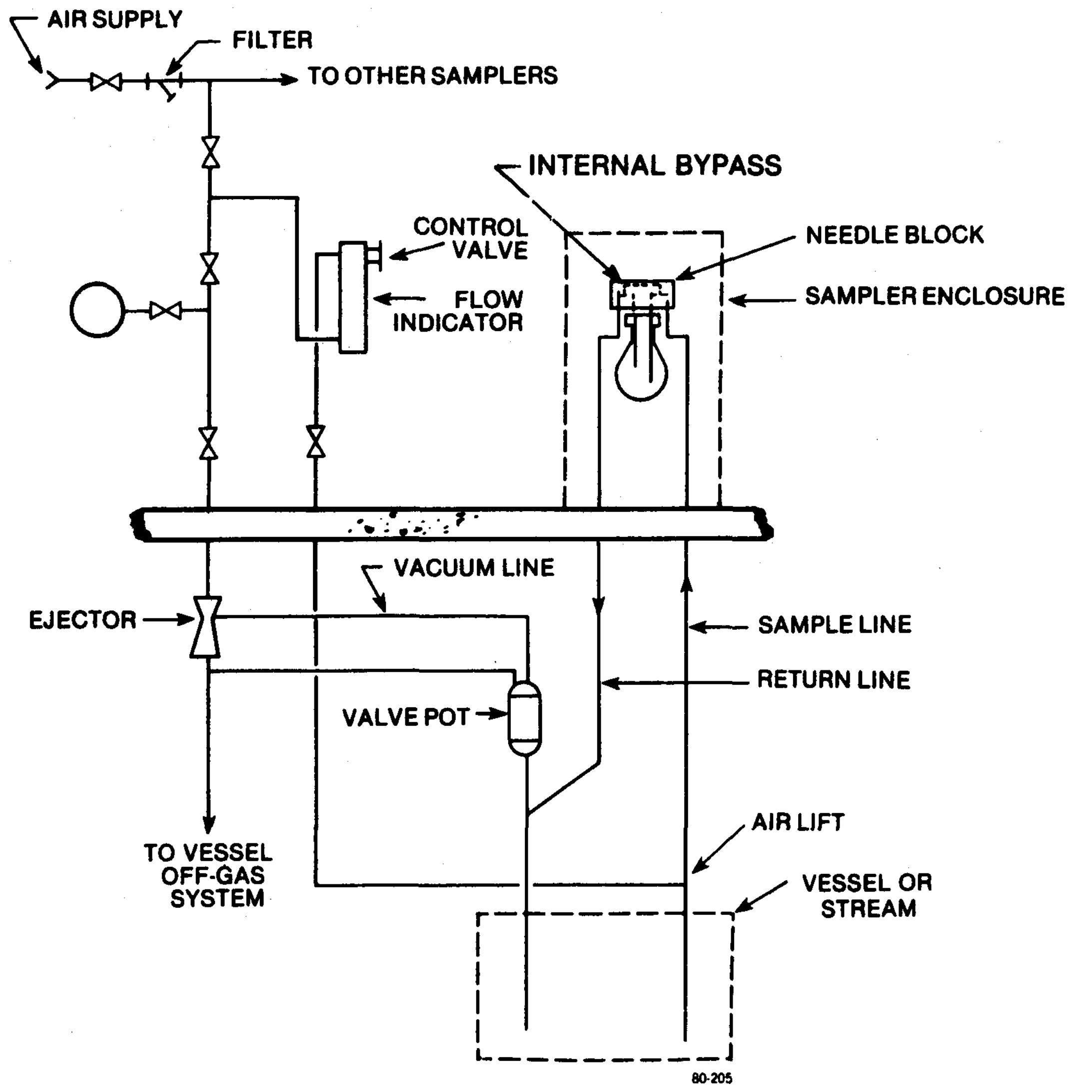
(4) Finally the sample density, ρ_s, at the sample temperature is calculated:

$$\rho_s = 1/A(T^2_s - T^2_{H_2O}) + \rho_{H_2O}$$

where 1/A, T_{H_2O}, and ρ_{H_2O} are the values calculated in Steps (1)-(3) above.

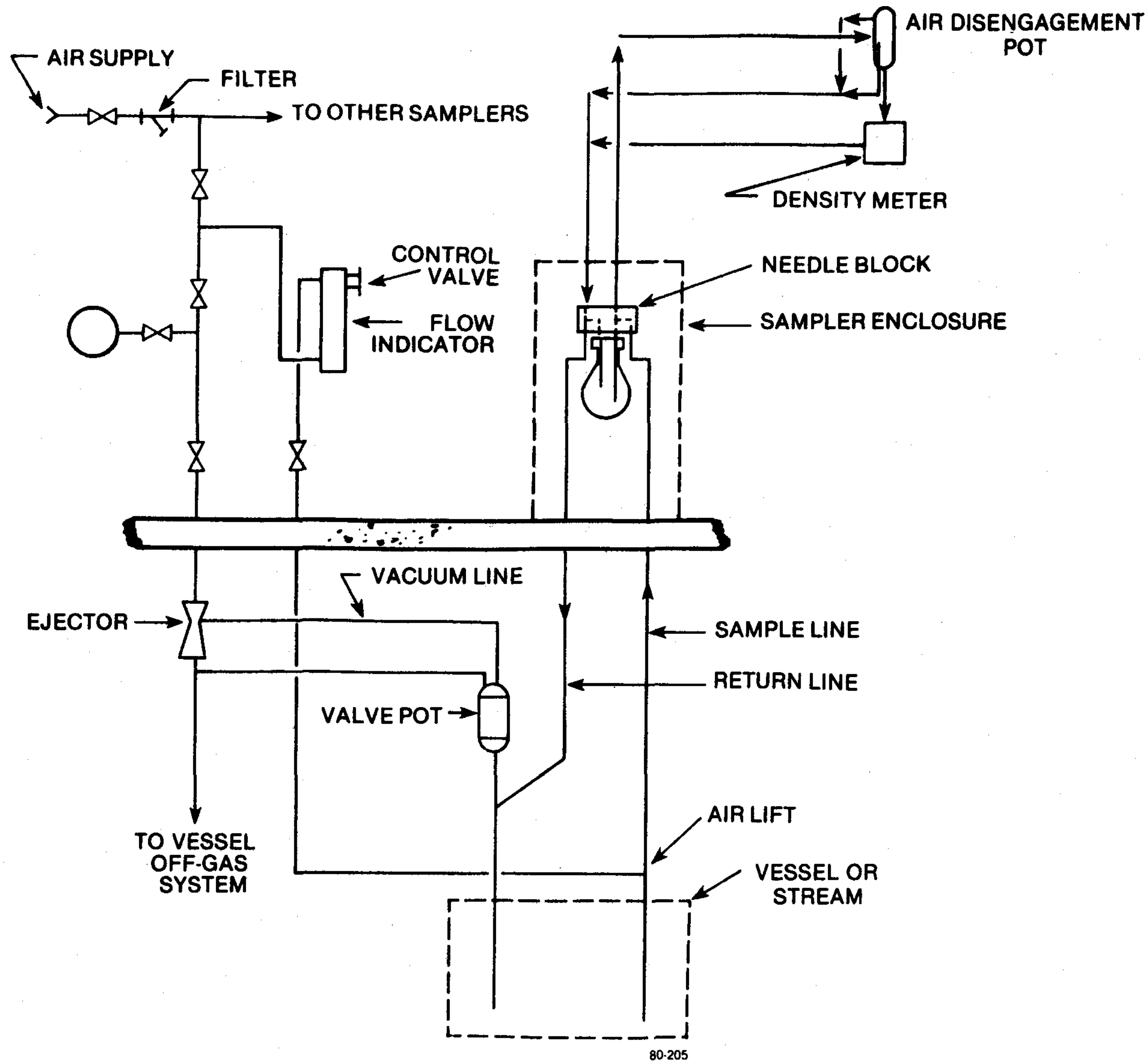
When these calculations have been completed for one cell and the density sent to the interface unit printer and the MACS, the series of calculations is repeated for the period and temperature data received from the second cell.

A section of tape from the interface unit printer is shown in Figure 3-5. The tape shown was produced during a run in the Engineering Laboratory. It gives the density, time of measurement, and sample temperature for both the 1BP and the 1AP streams at approximately two minute intervals. Note the indentation of the left-hand margin of every other line of data. This indentation distingushes the data of the two cells - the indented line being data for the stream flowing through the DPR 412 or external cell. In the example shown in Figure 3-5, it is obvious which density value applies to which stream as one stream was aqueous and the other organic. In the plant run, however, both streams were aqueous, and this method of distinguishing the two streams was most helpful (see Figure 3-6).



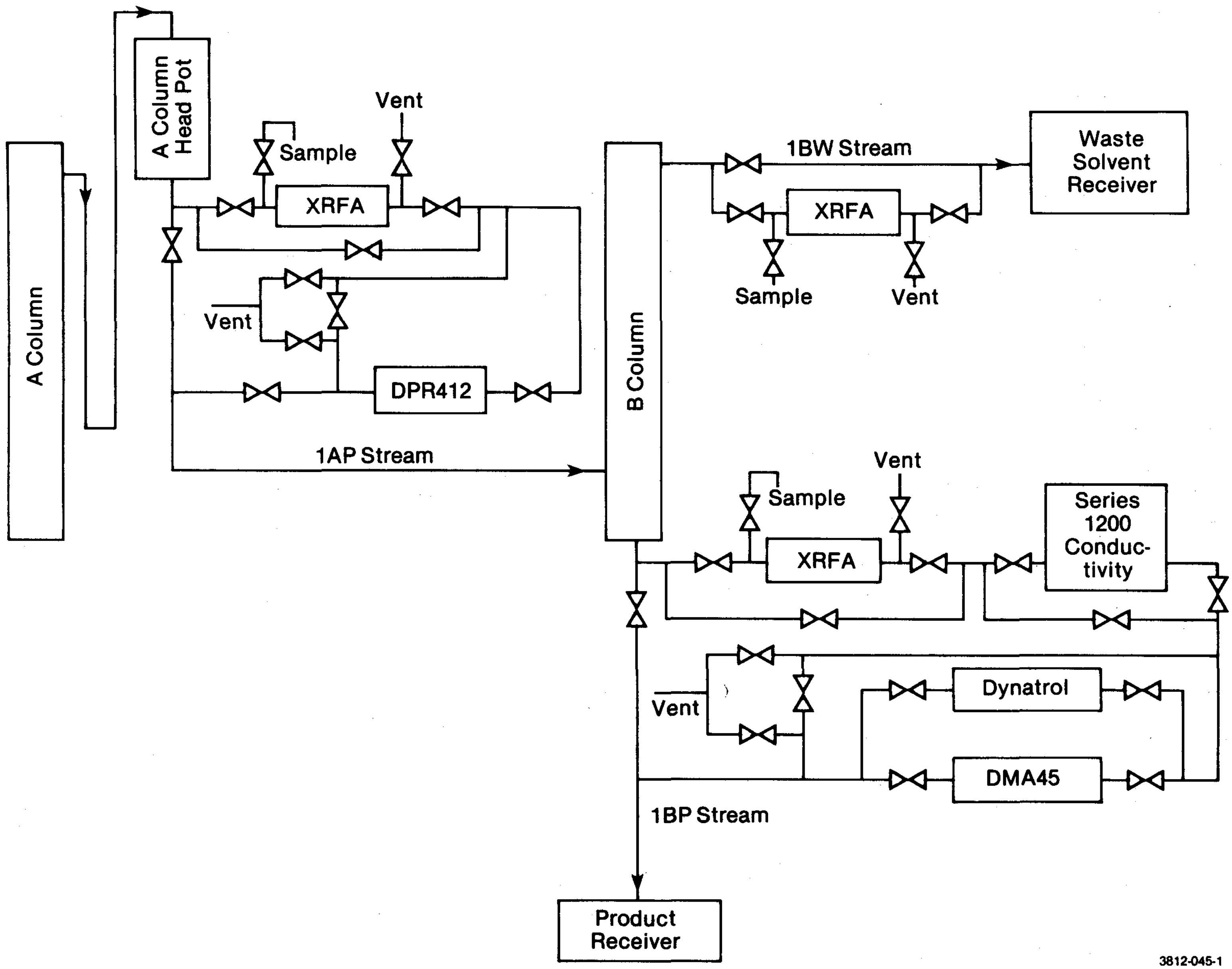
TYPICAL REMOTE NEEDLE BLOCK SAMPLER

FIGURE 3-1



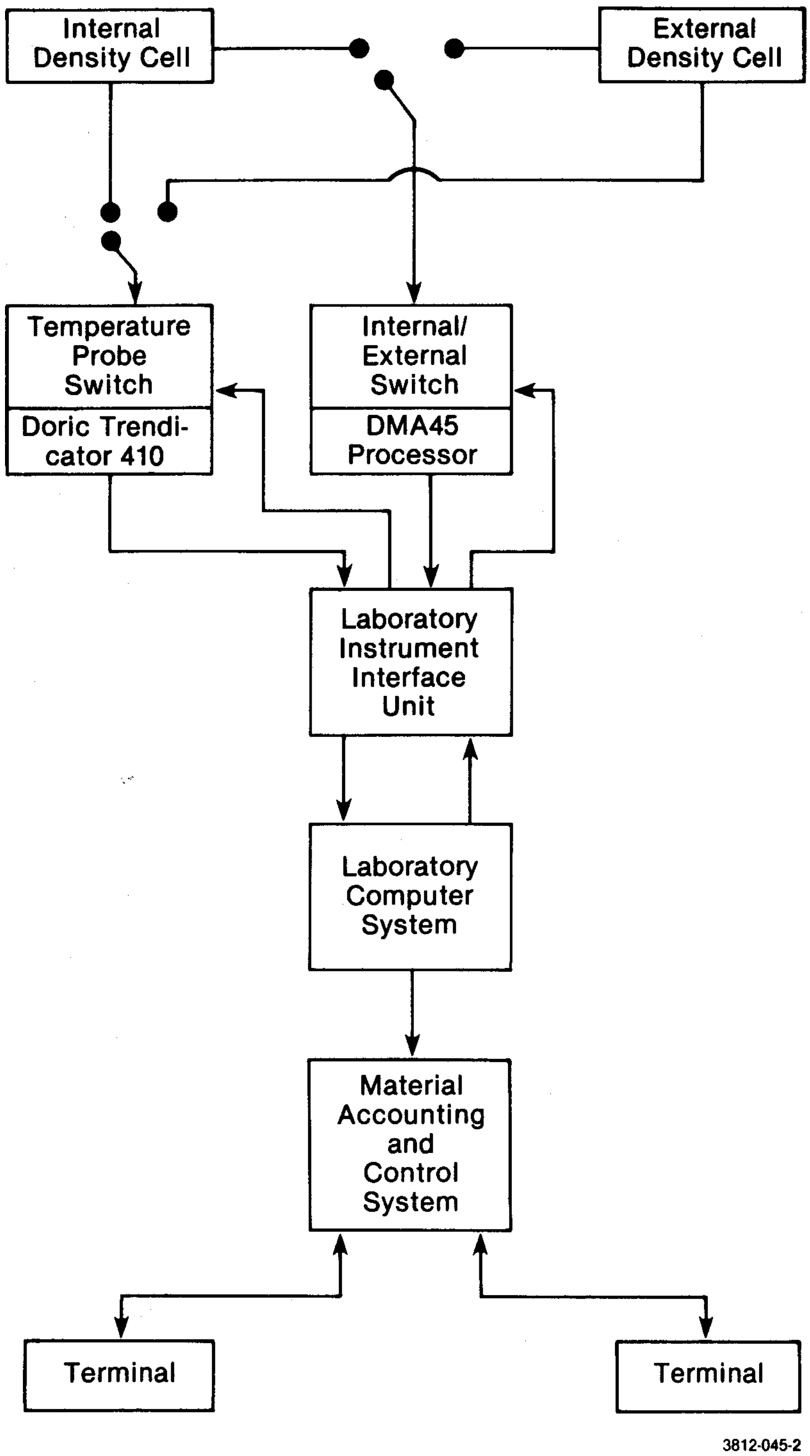
REMOTE NEEDLE BLOCK SAMPLER
AS MODIFIED FOR ON-LINE DENSITY MONITOR

FIGURE 3-2



ENGINEERING LABORATORY ON-LINE INSTRUMENT LOOPS

FIGURE 3-3



DATA COLLECTION SYSTEM FOR DMA 45 AND DPR 412

FIGURE 3-4

```
1.0331,10:48@24.22
   .9097,10:48@24.98        DMA 45
1.0347,10:50@24.24
   .9116,10:51@24.98        1BP Stream
1.0363,10:53@24.26 <------  Density of 1.0363 g/ml at 10:53
   .9123,10:54@24.99        and 24.26°C
1.0379,10:56@24.27
   .9130,10:57@24.99
1.0395,10:59@24.28
   .9137,10:59@25.00
1.0411,11:02@24.29
   .9143,11:02@25.00
1,0428,11:05@24.32
   .9149,11:05@25.00
1.0444,11:07@24.32          DPR 412
   .9152,11:09@25.00
1.0462,11:10@24.33          1AP Stream
   .9154,11:11@25.01 <----  Density of 0.9154 g/ml at 11:11
1.0480,11:13@24.33          and 25.01°C
   .9158,11:14@25.01
1.0498,11:16@24.34
   .9160,11:16@25.02
1.0515,11:19@24.34
   .9161,11:19@25.03
1.0530,11:22@24.34
   .9163,11:22@25.03
1.0543,11:24@24.35
   .9165,11:25@25.04 }
1,0556,11:27@24.36   } <--- Wait time = 2 minutes
   .9165,11:28@25.04
1.0567,11:30@24.37
   .9165,11:31@25.05
1.0579,11:33@24.38
   .9167,11:33@25.05
1.0589,11:36@24.4
   .9167,11:36@25.06
1.0601,11:39@24.41
```

PORTION OF INTERFACE TAPE FROM ENGINEERING LABORATORY RUN

FIGURE 3-5

```
1.0696,19:41@23.5
  1.0439,19:42@24.98
1.0698,19:47@23.5
  1.0438,19:48@24.97
1.0702,19:53@23.5
  1.0438,19:53@24.97
1.0705,19:59@23.5
  1.0436,19:59@24.97
1.0706,20:05@23.5
  1.0434,20:05@24.98
1.0707,20:11@23.49
  1.0432,20:11@24.98
1,0707,20:16@23.48
  1.0430,20:17@24.96
1.0707,20:22@23.48
  1.0428,20:23@24.98
1.0706,20:28@23.47
  1.0426,20:28@24.98
1.0706,20:34@23.46
  1.0426,20:34@24.96
1.0704,20:40@23.46
  1.0424,20:40@24.97
1.0704,20:46@23.45
  1.0422,20:46@24.96
1.0703,20:51@23.44
  1.0422,20:52@24.97
1.0702,20:57@23.44
  1.0422,20:58@24.96
1.0702,21:03@23.43
  1.0420,21:03@24.97
1.0701.21:09@23.42
  1.0420,21:09@24.97
1.0700,21:15@23.42
  1.0420,21:15@24.98
1.0700,21:20@23.41
  1.0418,21:21@24.98
1.0699,21:26@23.41
```

DMA 45

3BP Stream
Density of 1.0702 g/ml at 19:53
and 23.50°C
(← 1.0702,19:53@23.5)

DPR 412

2BP Stream
Density of 1.0430 g/ml at 20:17
and 24.96°C
(← 1.0430,20:17@24.96)

Wait time = 5 minutes
(→ 1.0422,20:46@24.96 and 1.0703,20:51@23.44)

PORTION OF INTERFACE TAPE FROM PLANT RUN

FIGURE 3-6

4.0 EXPERIMENTAL

4.1 Sample Flow

4.1.1 Sample Flow in Engineering Laboratory Loops

Liquid flow through the 1AP and 1BP piping in the Engineering Laboratory was motivated by head pressure supplied via a head pot in the case of the AP stream and by the B column head pressure in the case of the BP stream. By means of the instrument loop valving (see Figure 3-3) the AP and BP streams could be routed entirely to the instrument loops, partially routed to the instrument loops, or routed to completely bypass the instrument loops. For most runs the AP and BP streams were routed entirely to the instrument loops.

During Engineering Laboratory runs the total flow rates of both the AP and BP streams were maintained in the range of 260-280 milliliters per minute. Following venting of the loops at startup, manual regulation of the valves of the loops bypass lines around the density cells was required to maintain the total desired flow rate of 260-280 milliliters per minute while forcing flow through the density cells.

Several minor sample flow problems were experienced during the Engineering Laboratory runs. It was sometimes difficult to establish flow through the DPR 412 cell on the 1AP stream early in a run despite repeated venting of the line. This difficulty was attributed to low differential pressure between the A column head pot and the B column. The problem usually disappeared shortly after uranium feed to the A column was started and the density of the liquid in the A column head pot had increased. Maintaining a high liquid level in the head pot also helped to overcome this problem.

Another sample flow problem resulted from the orientation in which the Dynatrol unit was installed. The Dynatrol cell was installed such that both legs of the U-tube were in the same horizontal plane. This factor coupled with the fact that the Dynatrol, which has a one-half-inch diameter U-tube, was supplied by 3/8 inch tubing made it difficult to keep the U-tube filled with liquid. As a result, steady or decreasing density values for the 1BP stream were often received from the Dynatrol unit when the density of the 1BP stream was known to be increasing as shown by the DMA 45 and the laboratory analysis of samples. It is believed that this problem could be corrected by reinstalling the Dynatrol cell such that the U-tube was vertically oriented.

4.1.2 Sample Flow Through the On-Line Density Meters in the Plant Installation

To start sample flow through the DMA 45 and DPR 412 density meters in the plant installation it was only necessary to place sample bottles on the modified needle blocks of the 3BP and 2BP remote samplers and start sample circulation by supplying air to the ejectors and lift lines. For each of the modified remote sampler loops, the vacuum produced on the return line by the air ejector was sufficient not only to remove air from the sample entering the disengagement pot but also to pull the liquid sample through the density meter.

Total sample flow rate through the 2BP stream sampler needle block was determined during sampler checkout procedures to be 200-250 milliliters per minute. Total sample flow rate through the 3BP stream sampler needle block was determined to be 300-400 milliliters per minute. Of these total flow rates, some 50-60 percent moves through the bypass channel. Thus, 100-150 milliliters of sample per minute were routed to the disengagement pot on the 2BP sampler loop and 150-240 milliliters of sample per minute were routed to the disengagement pot on the 3BP sampler loop. Once the sample liquid enters the disengagement pot it then returns to the needle block return line through tubing connecting the air disengagement pot overflow line to the needle block and through the density cell. Actual flow rates through the density meters were not determined.

4.2 Sample Stream Temperature Control

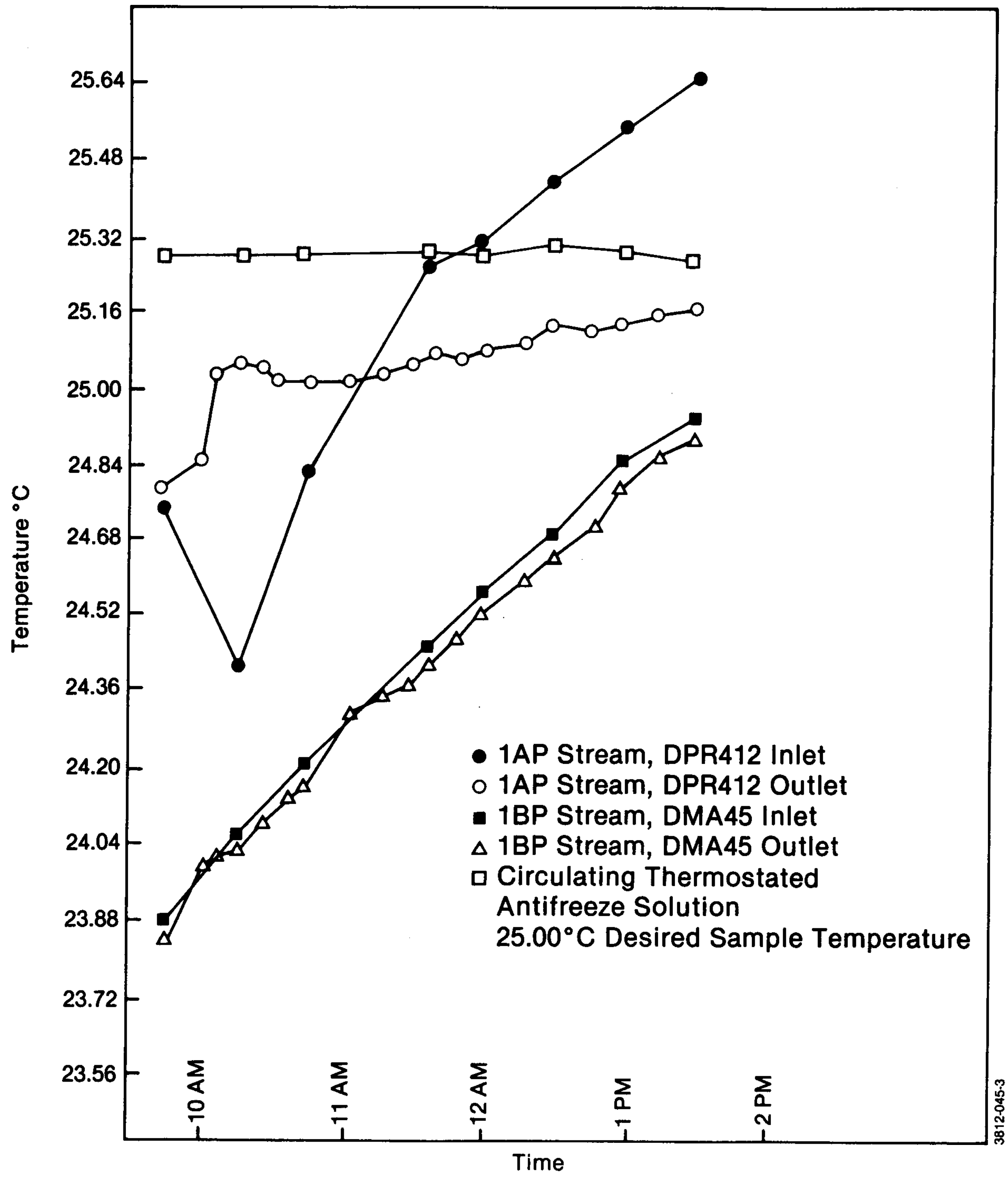
As discussed in Section 3.4, thermostated liquid was circulated through the oscillator housing and heat exchanger of the DPR 412 and through the double-walled cylinder of the DMA 45 in an effort to obtain sample temperatures of 25°C. It was soon discovered that while the temperature of the sample stream at the outlet of the DPR 412 was usually within 0.2° of 25°C, the temperature of the sample stream at the outlet of the DMA 45 usually varied from 25°C by one to two degrees. Data on the temperatures of the sample streams entering the density meters were required. Yellow Springs Instruments Model 709 thermistor probes were attached to the inlet tubing of both the DMA 45 and the DPR 412, and insulated with Armaflex insulation. Sample stream temperatures at the inlet and outlet of both density meters were then recorded.

The temperature data collected during one Engineering Laboratory run is shown in Figure 4-1. These data are typical of sample stream temperature data taken in later Engineering Laboratory runs. Figure 4-1 clearly shows that the heat exchanger of the DPR 412 operated effectively in maintaining the sample temperature near 25°C. On the other hand, Figure 4-1 shows that essentially no heat transfer took place in the DMA 45. This is evidenced by the fact that the temperatures of the sample stream at the outlet of the DMA 45 were nearly identical with the temperatures of the sample stream at the inlet of the DMA 45.

The difference in the heat exchanging capacities of the two density cells was not unexpected. The DPR 412 W Model was designed specifically for controlling the fluctuating temperatures of a flowing sample while the DMA 45 was designed for analysis of static samples where several minutes can be taken to allow the sample to equilibrate to the thermostated liquid temperature.

Temperature data recorded during the plant mini-run reflected those from the Engineering Laboratory. Over the 152-hour period of operation, sample stream temperatures at the outlet of the DPR 412 ranged from 24.6-25.2°C and for 84 of those hours remained between 24.9°C and 25.1°C. During the same 152-hour period, sample stream temperatures at the outlet of the DMA 45 ranged from 23.1-26.1°C.

Throughout the Engineering Laboratory and plant runs the temperature of the sample streams entering the DMA 45 did not vary more than two to three degrees from 25°C. This was fortunate since on-line density data from the DMA 45 was to be compared to laboratory analyses determined at 25°C and these small variations from 25°C would only result in changes in density in the fourth decimal place.



SAMPLE TEMPERATURES ENTERING AND EXITING THE DMA 45 AND DPR 412 DURING ENGINEERING LABORATORY RUN

FIGURE 4-1

5.0 RESULTS

5.1 Engineering Laboratory Results

5.1.1 On-Line Density Results

Density data from a 4-1/2-hour Engineering Laboratory run are shown in Figure 5-1 and Table 5-1. These data are typical of the data collected for any one of the series of Engineering Laboratory runs.

Figure 5-1 is a graphic presentation of the density data collected from the three on-line density monitors. The graph shows a steady density increase in the AP stream, the A column product stream. This density increase is due to the increasing uranium content in the stream as uranium from the aqueous feed is extracted into the organic phase in the A column. Since the AP stream is the feed stream to the B column where the uranium is stripped from the organic phase to produce the aqueous 1BP product stream, the uranium content of the 1BP stream will increase in response to increasing uranium content of the AP stream. This response can be seen in Figure 5-1 as the density of the BP stream starts to turn upward about 30 minutes after the AP stream density begins to increase in response to the start of uranium feed.

As shown in Figure 5-1, about 3 to 3-1/2 hours into the run the on-line density monitors indicated that the densities of both streams had leveled off which in turn indicated that the columns had reached equilibrium. At this point, column profile samples were taken by Engineering and Technology Department personnel. Then, after processing any remaining uranium feed through the columns, the run was terminated.

It can be seen in Figure 5-1 that the data provided by the Dynatrol density cell were in good agreement with that from the DMA 45 for about the first two hours of the run. At that point, the Dynatrol output started to level off. As discussed in Section 4.1.1, this was not due to a deficiency in the Dynatrol unit but was a result of not being able to maintain adequate sample flow to keep the U-tube of the cell filled with liquid. The two upward turns in the Dynatrol output at about 12 PM and 1 PM resulted from attempts to force flow to the cell by manipulating the inlet/outlet and bypass valves in the instrument loop. Only temporary improvements in the Dynatrol response could be accomplished by this technique.

5.1.2 On-Line Acid Results

Conductivity readings were converted to acid concentrations by the Material Accounting and Control System (MACS) which utilized the conductivity versus concentration curve for nitric acid to make the conversion. Use of the nitric acid curve was based on literature[2] results which indicated that the contribution of uranium at the levels expected in the acidic sample stream to the overall conductivity of the sample would be negligible. This proved to be true for the uranium concentration (<70 g U/ℓ) and acid concentrations (<0.5N) observed during the Engineering Laboratory runs.

Table 5-2 compares the acid concentration of the 1BP stream as determined by laboratory analysis of samples taken at one-half hour intervals from the sample points in the instrument loops to the acid concentration determined by the on-line conductivity monitor. As can be seen, the on-line conductivity monitor provided reliable acid concentration values.

The data shown in Table 5-2 are typical of the on-line acid concentration data reported during other Engineering Laboratory runs.

5.1.3 Real-Time Inventories

The density and acid data provided by the on-line density and conductivity meters were utilized in conjunction with data obtained from tank level instrumentation, weight measuring instrumentation, and X-ray fluorescence instrumentation to provide real-time uranium inventories for Engineering Laboratory process streams and vessels. These real-time inventories were updated automatically every four minutes during Engineering Laboratory runs. A typical real-time inventory report from an Engineering Laboratory run is shown in Table 5-3. Note the entries from the on-line density and conductivity meters.

5.2 Plant Run, "Mini-Run No. 6," On-Line Density Results

Tables 5-4 and 5-5 are condensations of the data collected by the Materials Accounting and Control System (MACS) for the 2BP and 3BP streams during 152 hours of on-line density meter operations. The tables compare the laboratory analytical results with the on-line results including uranium concentrations calculated from the on-line density and acid data.

Laboratory analysis of samples from the 2BP and 3BP streams were performed once each 8-hour shift and updated by MACS. All of the results for the 2BP and 3BP streams obtained during the 152-hour operating period are included in Tables 5-4 and 5-5. On-line data were actually updated and stored by the MACS every 16 minutes during the run, but in the interest of space the condensed on-line data are presented.

Figure 5-2 is a graphic presentation of the uranium concentration data contained in Tables 5-4 and 5-5. The solid lines show the variation of the uranium concentration in the 2BP and 3BP streams during the 152-hour operating period as determined by the on-line monitors. The dotted lines represent the variation of the uranium concentration in the 2BP and 3BP streams during the operating period as determined by laboratory analysis of the routine samples taken once per shift. Plotting of the dotted lines in a stepwise fashion, rather than connecting the point with straight lines, emphasizes that no additional routine analytical results for the 2BP and 3BP streams were produced during the intervals between samples and, thus, no increasing or decreasing trends could be assumed for those intervals. On the other hand, the points on the solid lines can be legitimately connected by straight lines since they represent data derived from continuous monitors which showed the trends to be as indicated by the connecting lines.

Both the on-line results and the laboratory results graphed in Figure 5-2 show the correct long-term trends in uranium concentration changes for the 2BP and 3BP streams. When analyzed by smaller time intervals, however, Figure 5-2 shows instances where the laboratory results were out of phase with the trend indicated by the on-line results. In other instances maxima and minima in the uranium concentrations of the streams which were detected by the on-line monitors were either not detected by the analytical results or were detected at a point which did not indicate the actual extreme of a maximum or minimum. Clearly, on-line monitoring is superior to routine sampling from the standpoint of both process control and nuclear material inventory estimates on process streams.

TABLE 5-1

ANALYTICAL AND ON-LINE DENSITIES FROM ENGINEERING LABORATORY RUN

Sample Time	1AP Stream Density, g/cm³		1BP Stream Density, g/cm³		
	Analytical	On-Line DPR 412	Analytical	On-Line DMA 45	On-Line Dynatrol
8:55 AM	0.8186	0.8185	1.0120	1.0145	1.0107
9:30 AM	0.8275	0.8257	1.0139	1.0142	1.0132
10:00 AM	0.8436	0.8457	1.0166	1.0169	1.0153
10:30 AM	0.8553	0.8550	1.0245	1.0239	1.0219
11:00 AM	0.8565	0.8570	1.0294	1.0294	1.0263
11:30 AM	0.8579	0.8583	1.0326	1.0327	1.0276
12:00 PM	0.8583	0.8584	1.0346	1.0341	1.0303
12:30 PM	0.8581	0.8581	1.0351	1.0346	1.0298
1:00 PM	0.8585	0.8582	1.0355	1.0355	1.0326

TABLE 5-2

ANALYTICAL AND ON-LINE ACID CONCENTRATIONS FROM ENGINEERING LABORATORY RUN

Sample Time	IBP Stream Acid Concentration, N	
	Analytical	On-Line Conductivity
8:55 AM	0.37	0.32
9:30 AM	0.40	0.40
10:00 AM	0.40	0.38
10:30 AM	0.40	0.39
11:00 AM	0.39	0.38
11:30 AM	0.38	0.37
12:00 PM	0.35	0.37
12:30 PM	0.38	0.37
1:00 PM	0.35	0.36

Table 5-3

NEAR-REAL-TIME INVENTORY REPORT FROM ENGINEERING LABORATORY RUN

STATUS AT 11:20 AM   ON 05-May-81   PP RUN # 3   RECORD # 37

RDG	INST	APPL	CHAN	RAW DATA	PS(IN)
1	LT-1	AS LEV	672	28.5342	0
2	LT-2	AF LEV	673	34.4341	0
3	LT-3	AX LEV	674	22.5403	0
4	LT-4	BX LEV	675	28.0042	0
5	DT-4	AW DEN	676	22.1954	20.63
6	LT-5	AW LEV	677	22.1275	0
7	DT-8	BW DEN	678	16.0178	19.4
8	LT-6	BW LEV	679	11.3038	0
9	DT-9	BP DEN	680	20.7111	20.047
10	LT-7	BP LEV	681	6.83652	0
11	WT-1	A COL WR	682	272.714	281.75
12	DT-12	A DEN (B)	683	160.679	166
13	DT-13	A DEN (T)	684	108.81	115.75
14	CIT-6	BP H+	685	67.3996	0
15	DE-3	DYNATROL	686	22.2305	0
16	WT-2	B COL WR	687	239.933	230
17	DT-14	B COL DEN	688	232.61	230

DMA-45= 1.0417 @ 22.46 , DPR-412= .9013 @ 24.76 , DYNATROL DEN = 1.0421 , CIT-6 ACID = .38 ← ON-LINE DENSITY AND ACID RESULTS
XRFA-1 IS 10.14 AT 05-May-81 10:45 AM

TOTAL TAYLOR VOLUME (L) = 1127.94
4 -MINUTE TAYLOR CHANGE (L) = .187134
CUMULATIVE TAYLOR CHANGE (L) = .505493

TOTAL SOLUTION VOLUME (L) = 1066.82
4 -MINUTE SOLUTION CHANGE (L) = .2229
CUMULATIVE SOLUTION CHANGE (L) = .100952

TANK	LL(CM)	V(25)(L)	FR(L/MIN)	CUM(L/MIN)	T(DEG C)	D(G/ML)	H+(M)	U(G/L)	U(KG)
AS	70.339	228.12	-.111	-.108 (8)	22.46	1.0304	.98	0	0
AF	75.837	246.106	-.709	-.724 (8)	22.46	1.1533	3.2	40.13	9.87623
AX	70.508	62.971	-.28	-.268 (8)	22.46	.812	0	0	0
BX	70.699	63.302	-.26	-.258 (8)	22.46	1.0061	.18	0	0
AW	52.24	414.883	.914	.919 (8)	22.46	1.07588	2.33	.003	.00124465
BW	34.774	26.435	.224	.211 (8)	22.46	.825658	.04	0	.201
BP	16.67	25.001	.289	.314 (8)	22.46	1.0417 ←	.38 ←	10.14	.423

TANKS: TOTAL AQ = 977.412 L   TOTAL ORG = 89.406 L   TOTAL U IN TANKS (KG) = 10.501

LINES: TOTAL AQ = 13.53 L   TOTAL ORG = 12.06 L   U HOLD-UP IN LINES (KG) = .12

COLUMN	DR(B)	DR(T)	WR	FF(L/MIN)	SF(L/MIN)	FD-U(G/L)	U(KG)	FD-D(G/ML)
A-07003	.967948	.940047	.967929	-.709	-.28	40.13	1.841	1.1533
B-07004	1.01135	--	1.04319	-.281	-.26	0	0	.9013 ←

TOTAL U IN COLUMNS (KG) = 1.841
COLUMN U BY DIFFERENCE (KG) = .919
TOTAL U INVENTORY (KG) = 12.462
STARTING U (KG) = 11.54

TABLE 5-4

CONDENSED DATA FOR 2BP STREAM COLLECTED FOR
152 HOURS OF DENSITY METER OPERATIONS - PLANT RUN

Date, Time	Analytical Results Density, g/cm^3	Analytical Results Acid, N	Analytical Results U, g/ℓ	On-Line Results Density, g/cm^3	On-Line Results Acid, N	On-Line Results Calculated-U, g/ℓ
13-May-81						
12:32 PM				1.0035	0.09	4.0
04:48 PM				1.0224	0.20	13.9
07:57 PM	1.0467	0.151	31.5			
08:00 PM				1.0456	0.16	34.0
10:08 PM				1.0530	0.12	40.0
14-May-81						
12:16 AM				1.0532	0.10	39.0
12:39 AM	1.0543	0.109	40.0			
04:48 AM				1.0620	0.10	47.5
06:56 AM				1.0600	0.10	46.0
08:00 AM				1.0573	0.10	44.5
08:04 AM	1.0591	0.096	43.1			
08:16 AM				1.0570	0.10	44.0
11:24 AM				1.0500	0.09	39.4
02:36 PM				1.0449	0.09	35.5
03:40 PM				1.0443	0.09	35.1
04:04 PM	1.0456	0.081	34.7			
04:12 PM				1.0443	0.09	35.1
05:48 pm				1.0435	0.09	34.5
07:56 PM				1.0425	0.09	33.7
10:04 PM				1.0385	0.09	30.8
15-May-81						
12:28 AM				1.0420	0.09	33.5
12:38 AM	1.0425	0.078	31.2			
12:44 AM				1.0427	0.09	33.9
02:20 AM				1.0437	0.09	34.6
03:24 AM				1.0437	0.09	34.6
05:32 AM				1.0442	0.09	35.0
07:40 AM				1.0437	0.09	34.6
07:56 AM				1.0437	0.09	34.6
08:01 AM	1.0447	0.073	32.7			
08:12 AM				1.0432	0.09	34.3
09:48 AM				1.0436	0.09	34.5
11:56 AM				1.0427	0.09	33.9
02:04 PM				1.0399	0.09	31.8
04:28 PM				1.0382	0.09	30.5
04:32 PM	1.0390	0.064	29.4			
04:44 PM				1.0374	0.09	30.0
06:20 PM				1.0362	0.09	29.1
08:28 PM				1.0359	0.09	28.9
10:36 PM				1.0354	0.09	28.5
16-May-81						
12:28 AM				1.0315	0.09	22.0
12:41 AM	1.0333	0.062	25.6			

TABLE 5-4 (CONTINUED)

CONDENSED DATA FOR 2BP STREAM COLLECTED FOR
152 HOURS OF DENSITY METER OPERATIONS - PLANT RUN

	Analytical Results			On-Line Results		
Date, Time	Density, g/cm^3	Acid, N	U, g/ℓ	Density, g/cm^3	Acid, N	Calculated-U, g/ℓ
12:44 AM				1.0309	0.09	25.2
02:52 AM				1.0290	0.09	23.7
05:00 AM				1.0366	0.09	29.4
07:08 AM				1.0395	0.09	31.5
07:56 AM				1.0429	0.09	34.0
07:58 AM	1.0438	0.069	32.7			
08:12 AM				1.0434	0.09	34.4
10:20 AM				1.0449	0.09	35.5
12:28 PM				1.0468	0.09	36.9
03:24 PM				1.0441	0.09	34.9
04:12 PM				1.0440	0.09	34.8
04:43 PM	1.0464	0.146	34.1			
04:44 PM				1.0448	0.10	35.2
06:36 PM				1.0447	0.10	35.2
08:44 PM				1.0424	0.10	33.5
10:52 PM				1.0421	0.10	33.3
11:56 PM				1.0391	0.10	31.0
17-May-81						
12:28 AM				1.0378	0.10	30.0
12:36 AM	1.0397	0.084	28.8			
12:44 AM				1.0376	0.10	29.9
02:04 AM				1.0374	0.10	29.8
04:12 AM				1.0384	0.10	30.5
06:20 AM				1.0388	0.10	30.8
07:40 AM				1.0379	0.10	30.1
07:55 AM	1.0386		29.1			
07:56 AM				1.0376	0.10	29.9
08:28 AM				1.0384	0.10	30.5
10:36 AM				1.0382	0.09	30.6
12:44 PM				1.0394	0.09	31.5
02:52 PM				1.0402	0.09	32.1
04:12 PM				1.0401	0.09	32.0
04:22 PM	1.0414	0.086	30.1			
04:28 PM				1.0398	0.09	31.8
06:04 PM				1.0392	0.09	31.3
06:52 PM				1.0398	0.09	31.8
18-May-81						
12:44 AM	1.0408	0.075	29.4			
07:58 AM	1.0416	0.076	31.2			
09:00 AM				1.0401	0.09	32.0
11:08 AM				1.0403	0.09	32.1
01:16 PM				1.0394	0.10	31.3
03:24 PM				1.0411	0.10	32.5
04:28 PM				1.0399	0.10	31.6
04:31 PM	1.0414	0.073	30.6			

TABLE 5-4 (CONTINUED)

CONDENSED DATA FOR 2BP STREAM COLLECTED FOR
152 HOURS OF DENSITY METER OPERATIONS - PLANT RUN

Date, Time	Analytical Results Density, g/cm^3	Acid, N	U, g/ℓ	On-Line Results Density, g/cm^3	Acid, N	Calculated U, g/ℓ
04:44 PM				1.0402	0.10	31.9
06:36 PM				1.0397	0.10	31.5
08:44 PM				1.0394	0.10	31.3
11:56 PM				1.0407	0.10	32.2
19-May-81						
12:44 AM				1.0405	0.10	32.1
12:48 AM	1.0420	0.073	31.8			
01:00 AM				1.0404	0.10	32.0
03:08 AM				1.0409	0.10	32.4
05:16 AM				1.0407	0.10	32.2
07:56 AM				1.0405	0.10	32.1
07:59 AM	1.0416	0.074	31.2			
08:12 AM				1.0403	0.10	31.9
09:32 AM				1.0407	0.10	32.2
11:40 AM				1.0395	0.10	31.4
11:56 AM				1.0396	0.10	31.4
12:09 PM	1.0405	0.073	30.9			
12:12 PM				1.0394	0.10	31.3
02:36 PM				1.0395	0.10	31.4
03:40 PM				1.0389	0.10	30.9
04:26 PM	1.0403	0.07	31.8			

TABLE 5-5

CONDENSED DATA FOR 3BP STREAM COLLECTED FOR 152 HOURS OF DENSITY METER OPERATIONS

	Analytical Results			On-Line Results		
Date, Time	Density, g/cm^3	Acid, N	U, g/ℓ	Density, g/cm^3	Acid, N	Calculated U, g/ℓ
13-May-81						
12:32 PM				1.0068	0.09	7.2
01:52 PM				1.0085	0.12	7.9
04:32 PM				1.0074	0.11	7.3
05:52 PM				1.0076	0.19	5.5
07:12 PM				1.0131	0.17	10.0
08:32 PM				1.0242	0.15	18.7
09:52 PM				1.0323	0.12	25.4
11:12 PM				1.0420	0.12	32.8
11:16 PM	1.0434	0.119	32.4			
11:28 PM				1.0430	0.12	33.5
14-May-81						
12:16 AM				1.0599	0.10	46.3
12:44 AM	1.0471	0.103	34.0			
12:46 AM				1.0467	0.10	
04:00 AM				1.0594	0.10	45.9
05:20 AM				1.0659	0.10	50.9
06:40 AM				1.0762	0.10	58.5
08:00 AM				1.0792	0.10	60.7
08:10 AM	1.0813	0.068	60.1			
08:16 AM				1.0819	0.10	62.7
09:48 AM				1.0900	0.09	69.0
12:28 PM				1.0907	0.09	69.5
01:48 PM				1.0898	0.09	68.8
02:36 PM				1.0893	0.09	68.4
03:22 PM	1.0892					
03:24 PM				1.0885	0.09	67.8
03:56 PM				1.0876	0.09	67.1
04:00 PM	1.0887	0.96	65.4			
04:12 PM				1.0871	0.09	66.8
05:48 PM				1.0831	0.09	63.8
07:08 PM				1.0818	0.09	62.8
08:28 PM				1.0811	0.09	62.3
10:04 PM				1.0783	0.09	60.2
11:08 PM				1.0772	0.09	59.4
15-May-81						
12:28 AM				1.0765	0.09	58.9
12:41 AM	1.0722	0.09	53.0			
12:44 AM				1.0762	0.09	58.7
02:04 AM				1.0692	0.09	53.5
03:24 AM				1.0678	0.09	52.4
04:44 AM				1.0669	0.09	51.8
06:04 AM				1.0662	0.09	51.3
07:56 AM				1.0663	0.09	51.3
08:02 AM	1.0665	0.089	49.6			

TABLE 5-5 (CONTINUED)

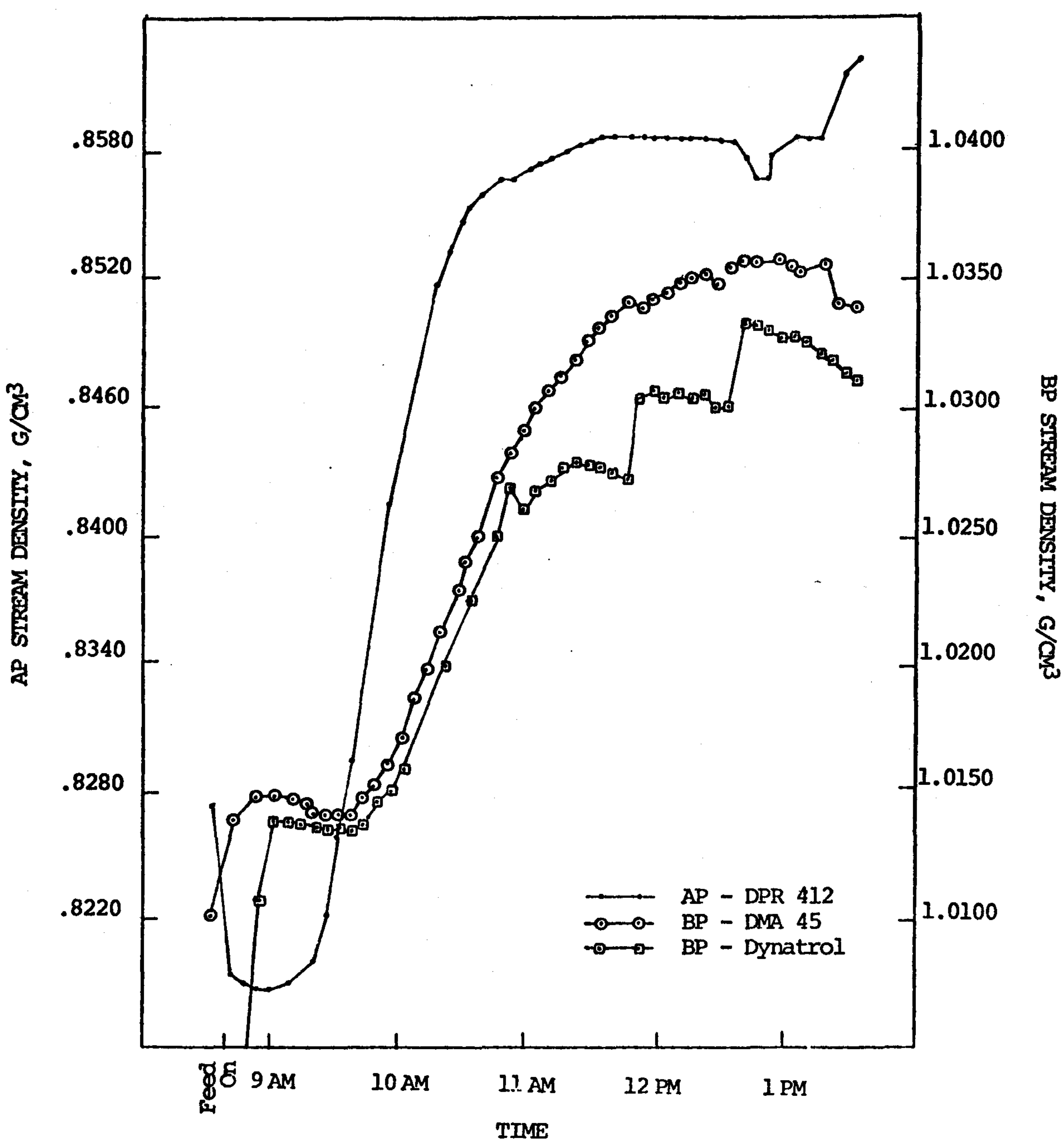
CONDENSED DATA FOR 2BP STREAM COLLECTED FOR 152 HOURS OF DENSITY METER OPERATIONS

	Analytical Results			On-Line Results		
Date, Time	Density, g/cm³	Acid, N	U, g/ℓ	Density, g/cm³	Acid, N	Calculated U, g/ℓ
08:12 AM				1.0668	0.09	51.7
09:32 AM				1.0653	0.09	50.6
12:12 PM				1.0658	0.09	51.0
01:32 PM				1.0656	0.09	50.8
02:52 PM				1.0662	0.09	51.3
04:12 PM				1.0668	0.09	51.7
04:33 PM	1.0680	0.089	49.5			
04:44 PM				1.0669	0.09	51.8
06:04 PM				1.0647	0.09	50.2
07:24 PM				1.0644	0.09	49.9
08:44 PM				1.0625	0.09	48.5
10:04 PM				1.0593	0.09	46.2
11:24 PM				1.0560	0.09	43.7
16-May-81						
12:44 AM				1.0498	0.09	39.1
12:44 AM	1.0510	0.076	37.7			
01:00 AM				1.0509	0.09	40.0
02:20 AM				1.0437	0.09	34.6
03:40 AM				1.0424	0.09	33.7
05:00 AM				1.0536	0.09	42.0
06:20 AM				1.0602	0.09	46.8
07:56 AM				1.0605	0.09	47.1
08:04 AM	1.0543	0.084	41.6			
08:12 AM				1.0598	0.09	46.5
09:32 AM				1.0542	0.09	42.4
10:52 AM				1.0532	0.09	41.7
12:12 PM				1.0511	0.09	40.1
02:20 PM				1.0510	0.09	40.0
03:40 PM				1.0567	0.09	44.3
04:44 PM				1.0657	0.09	50.9
04:44 PM	1.0783	0.990	58.3			
05:00 PM				1.0663	0.09	51.4
06:20 PM				1.0669	0.09	51.8
07:40 PM				1.0699	0.10	53.8
09:00 PM				1.0702	0.10	54.1
11:40 PM				1.0696	0.10	53.6
17-May-81						
12:28 AM				1.0696	0.10	53.6
12:40 AM	1.0676	0.112	49.5			
12:44 AM				1.0696	0.10	53.6
02:04 AM				1.0689	0.10	53.1
03:24 AM				1.0693	0.10	53.4
04:44 AM				1.0677	0.10	52.2
06:04 AM				1.0655	0.10	50.6
07:24 AM				1.0624	0.10	48.3

TABLE 5-5 (CONTINUED)

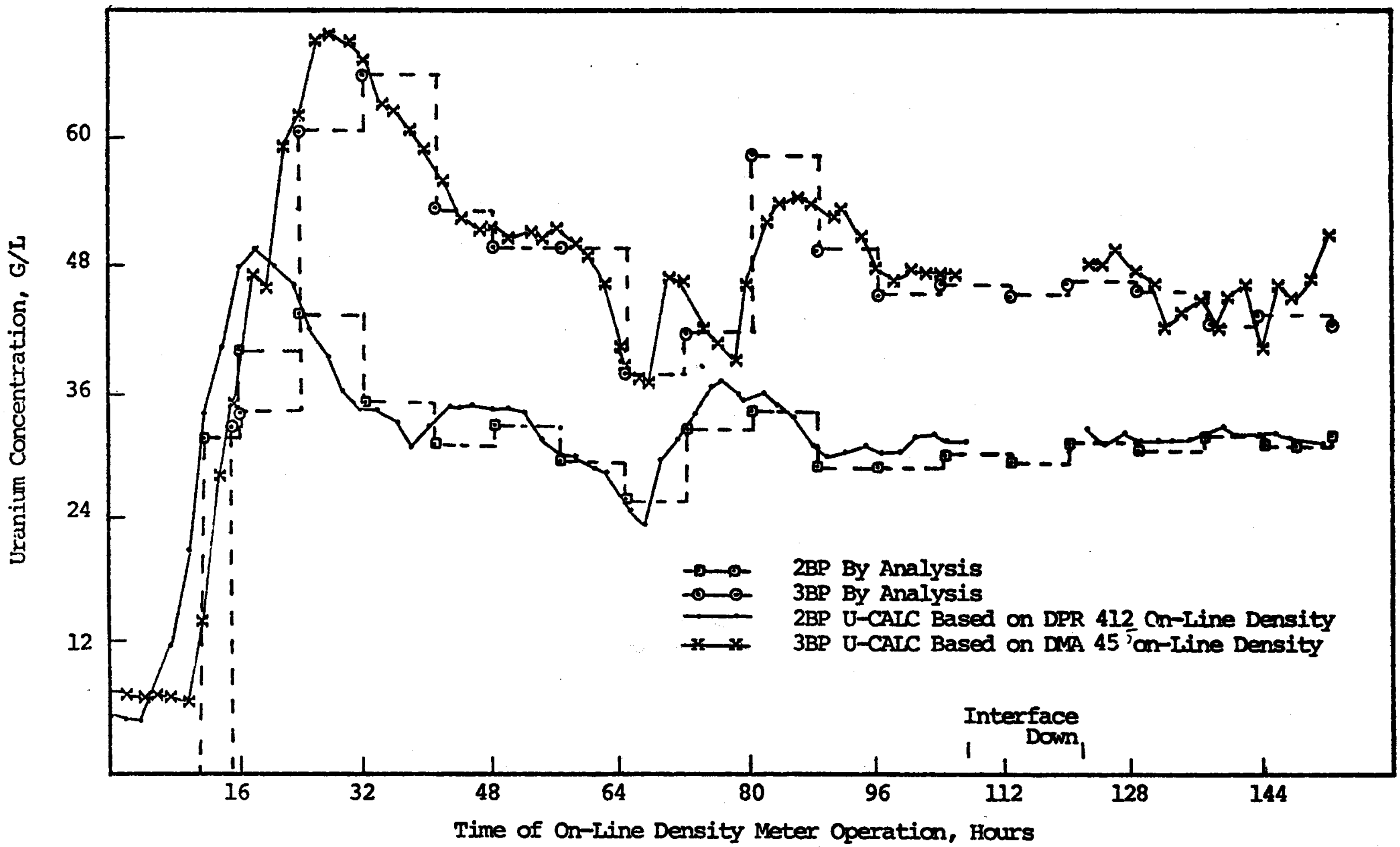
CONDENSED DATA FOR 2BP STREAM COLLECTED FOR 152 HOURS OF DENSITY METER OPERATIONS

	Analytical Results			On-Line Results		
Date, Time	Density, g/cm^3	Acid, N	U, g/ℓ	Density, g/cm^3	Acid, N	Calculated-U, g/ℓ
07:56 AM				1.0613	0.10	47.5
08:00 AM	1.0622	0.094	45.7			
08:12 AM				1.0608	0.10	47.1
09:32 AM				1.0586	0.09	45.7
10:52 AM				1.0607	0.09	47.2
12:12 PM				1.0609	0.09	47.4
02:52 PM				1.0607	0.09	47.2
04:12 PM				1.0606	0.09	47.2
04:19 PM	1.0628	0.099	45.9			
04:28 PM				1.0606	0.09	47.2
05:32 PM				1.0605	0.09	47.1
06:52 PM				1.0599	0.09	46.6
18-May-81						
12:49 AM	1.0633	0.105	45.3	Laboratory Instrument Interface		
08:03 AM	1.0631	0.106	46.3	Unit Being Repaired		
10:04 AM				1.0619	0.09	48.1
11:24 AM				1.0621	0.09	48.3
12:44 PM				1.0629	0.10	48.6
02:20 PM				1.0641	0.10	49.5
03:40 PM				1.0616	0.10	47.7
04:12 PM				1.0611	0.10	47.3
04:27 PM	1.0611	0.099	45.3			
04:28 PM				1.0606	0.10	46.9
05:48 PM				1.0600	0.10	46.5
07:08 PM				1.0541	0.10	42.1
08:28 PM				1.0545	0.10	42.4
09:48 PM				1.0561	0.10	43.6
11:08 PM				1.0578	0.10	44.9
19-May-81						
12:44 AM				1.0531	0.10	41.4
12:51 AM	1.0560	0.072	42.4			
01:00 AM				1.0540	0.10	42.1
02:20 AM				1.0545	0.10	42.4
03:40 AM				1.0568	0.10	44.2
05:00 AM				1.0602	0.10	46.7
06:20 AM				1.0580	0.10	45.0
07:56 AM				1.0513	0.10	40.1
08:04 AM	1.0591	0.097	43.4			
08:12 AM				1.0532	0.10	41.5
09:32 AM				1.0572	0.10	44.5
10:36 AM				1.0592	0.10	45.9
11:56 AM				1.0582	0.10	45.2
12:16 PM	1.0565	0.099	42.5			
01:00 PM				1.0561	0.10	43.6
02:20 PM				1.0608	0.10	47.1
03:56 PM				1.0662	0.10	51.1
04:25 PM	1.0644	0.101	47.7			



ON-LINE DENSITIES FOR ENGINEERING LABORATORY RUN

FIGURE 5-1



<u>URANIUM CONCENTRATION IN 2BP and 3BP STREAMS VERSUS TIME - PLANT RUN</u>

<u>FIGURE 5-2</u>

6.0 CONCLUSIONS

On-line density meters can provide timely and reliable density values for process streams. As a result, they can be utilized as process control instruments and, more importantly, they can function as integral components of real-time nuclear material inventory systems.

All three of the density cells discussed in this report are capable of providing reliable on-line density data. The DMA 45 is designed for laboratory use and requires the care in handling appropriate to laboratory instruments. It is not intended nor is it recommended for industrial service. The Dynatrol density cell is designed for industrial service. However, its size, weight and volume of sample hold-up could prove to be disadvantageous in certain nuclear facility applications where space, ease of maintenance (either contact or remote), and small sample hold-up are important considerations. The DPR 412 cell or a similar cell from the Mettler/Paar DPR 2000 system is recommended for use in on-line applications in nuclear processing since they are both compact and rugged.

Further work is required to develop systems to permit in-place flushing and calibration of on-line density cells. Evaluation of a Mettler/Paar cell having electronic temperature compensation would also be useful since supplying the thermostatically controlled liquid to a number of on-line density cells in order to maintain a specific sample temperature is not practical in an industrial environment.

7.0 REFERENCES

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(2) Moeken, H.H., Marchand, J.F.P., deVries, R., Determination of Uranyl Nitrate and Nitric Acid Based on In-Line Density and Conductivity Measurements, Anal. Chim. Acta, 57, pp 230-232, (1971).

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