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ANALYSIS OF ICPP PROCESS MONITORING SYSTEM DATA COLLECTED DURING AUGUST-OCTOBER, 1981

~~Mike Spry 12-20-91~~
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OCTOBER 1982

Idaho Falls, Idaho 83401

EXXON NUCLEAR IDAHO COMPANY, Inc.

Prepared For The
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ANALYSIS OF ICPP PROCESS MONITORING SYSTEM DATA COLLECTED DURING AUGUST - OCTOBER, 1981

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ABSTRACT

As part of the FY-1982 advanced safeguards development program, selected process data collected during August-October 1981 by the ICPP Process Monitoring Computer System (PMCS) were analyzed. This analysis is the first major effort of its kind using data from this VAX 11/780 computer based system. These data were from the first, second, and third processing cycles.

Several process events were identified and isolated for analysis to conserve limited program resources. These included process input (G-Cell) batch transfers, continous first-cycle feed activities, transfers into N-Cell intercycle storage, and continuous second-cycle feed activities. The analyses principally used Scanivalve plant precision data from tank bubbler probes, temperature data, and plant digital data. Some useful assessments are given to the process data information, but they should be considered preliminary since not all collected data could be analyzed. Also, several data limitations are noted and recommendations are given for system improvements.

It is believed that this analysis effort demonstrates the potential utility of the system for improved safeguards applications; yet, further, similar analysis efforts are needed to extend and complete a demonstration to characterize ICPP process data in general.

SUMMARY

Significant portions of a VAX 11/780-based computerized process monitoring system were installed at the ICPP by the end of FY-1981. At that time the system provided tank bubbler probe pressure measurements having plant instrument accuracies, temperature measurements (tank liquids and steam jets), and plant digital signals (sampler monitors, etc.). These were available principally for the input (G-Cell) process areas. An effort during FY-1982 analyzed available system data to evaluate the usefulness of the process data and also examine the system performance in detail.

The system data selected for review included the 20-day period August 8-27, 1981 for first-cycle data evaluations and the 24-day period September 21 - October 14, 1981 for second- and third-cycle evaluations. These data were selected to represent times when the respective process areas were active, as well as when the process monitoring system was functioning in a nominal manner under the existing configruation. Only selected plots from the available data were analyzed.

Data analyses were accomplished via playback from special historical data tapes which contained the subject data. A special plotting program GETDATAP was written to drive an HP-2648A graphics terminal from the VAX 11/780 computer. An HP-2631G graphics printer produced the plots directly from the terminal.

The process data evaluations considered accountability operations for accountability tanks G-105 and G-155 as well as their batch transfers to the input feed tank G-106. A minor incomplete transfer was detected, and the volume calibration equation on the PMCS for G-155 appears inaccurate. The steam jet dilutions for batch transfers to G-106 appear to be about 2 to 3%. In general, it is believed that these evaluations demonstrate how process monitoring can be used to verify accountability measurements and procedures.

Also considered were H-131 transfers into N-Cell intercycle storage and the determination of process feed rates by the tank depletion method using least-squares data smoothing. The former produced questionable results because of the continuous feed to H-131 (the evaporator catch tank) and the small volume of the tank, while the latter shows promise for both analysis and near real-time system use.

Typical uses of system measurements are explained, and several data problems are noted and analyzed including data dropouts, bubbler probe plugging, poor quality volumetric data when the density probe is uncovered, the effect of liquid temperature excursions, Scanivalve system accuracy, and Scanivalve data spikes. Several recommendations are given for system improvement.

This analysis effort was useful to improve the system understanding as well as demonstrate the potential utility of the system for improved safeguards. Further analysis work is recommended using considerably more process data examples. The methods used to accomplish such work should be reviewed and improved as possible, preferrably with more automation of the analyses.

The detailed conclusions and recommendations for system improvement are summarized in Table I.

TABLE I - OUTLINE SUMMARY OF DETAILED CONCLUSIONS AND RECOMMENDATIONS

A. PROCESS DATA EVALUATIONS

1. Awareness of limitations is required to avoid false conclusions.
2. Operations for accountability tanks G-105 and G-155 show that:
   (a) high precision data is needed in future evaluations,
   (b) a minor incomplete transfer for Batch #4006 was detected,
   (c) the volume cal. equation for G-155 is inaccurate, and
   (d) steam jet dilutions for transfers to G-106 are 2 to 3%.
3. Concerning H-131 transfers into N-Cell, it is observed that:
   (a) the analysis quality is now very limited (see text) and
   (b) the new M-Cell mod. should provide needed improvements.
4. Process feed rates by tank depletion for first and second cycles appear feasible, but:
   (a) the data contain considerable noise (see text) and
   (b) an unevenly spaced smoother is needed due to data gaps.

B. SYSTEM IMPROVENENTS FOR ENHANCED DATA QUALITY

1. The VAX 11/780 move to CPP-637 should reduce data gaps.
2. The Scanivalve subsystem could be improved by:
   (a) upgrading the reference calibration signals (see text),
   (b) software editing of data spikes pending correction, and
   (c) general upgrading of the plant transmitters (see text).
3. Plant digital signals require an automatic test feature.
4. An increased data rate is needed for temperature signals.
5. Volumetric calculations can be improved by:
   (a) using electromanometer cal. equations for G-105 and G-155,
   (b) improving bubbler probe pressure measurement accuracy,
   (c) including pressure measurement corrections,
   (d) filtering density data before use in vol. calculations, and
   (e) including temperature corrections (see text).

C. DATA ANALYSIS METHODS

1. The GETDATAP plotting program, HP-2648A Graphics Terminal, and HP-2631G Graphics Printer were basically adequate.
2. The data availability and plotting program should be improved.
3. Performance trade-offs between DEC and HP terminals connected to the VAX 11/780 Computer should be evaluated.
4. Each analyst should have his own terminal for improved access.

CONTENTS

APPENDICES*

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*Note: Appendicies A, B, C, D, E, and G will be distributed to UC-15 addressees upon request to W. J. Harris or C. E. Johnson, Exxon Nuclear Idaho Co., Idaho National Engineering Laboratory, PO Box 2800, Idaho Falls, ID 83401.

FIGURES

FIGURES (Continued)

TABLES

I. INTRODUCTION

For several years U.S. Department of Energy (DOE) has supported a program at the Idaho Chemical Processing Plant (ICPP) for the development of improved safeguards techniques. This report is, in a sense, a progress report of the application of process monitoring for safeguards enhancement.

Currently, the uses of process monitoring for Safeguards are not well defined. DOE Manual Chapter 5630.2 requires process monitoring but has not specified individual functions. The program at the ICPP is evaluating the uses of process monitoring data in various surveillance roles for safeguards assurances.

Process monitoring is a supplement to conventional physical security and SNM accountability. The information obtained from the process will back up these conventional techniques and should permit a more timely response to a loss of special nuclear material (SNM), either through an operational problem or a possible diversion.

The following applications have been suggested for process monitoring in safeguards:

1. Verify plant accountability activities by: (a) assuring that transfer, mixing, sampling, and measurement procedures were done correctly and completely and (b) assuring that all material was measured correctly and measured only once by monitoring plant flow-path routes.

2. Rapidly detect SNM losses or improper handling of SNM within the process by using the output of plant process sensors and special safeguards sensors to detect the "signatures" of unauthorized operations in time to stop them.

3. Assure adequate SNM controls by providing near-real-time accountability, i.e. use the process monitoring system to provide data on volumes and flow variables needed to estimate the amounts of SNM in various parts of the process and detect deviations from normal conditions.

Objectives of the ICPP safeguards program have been to demonstrate the practicality of these applications, measure the limitations, and define additional work needed to improve detection sensitivity and reliability.

The ICPP program investigates the safeguards uses of process monitoring in an operating reprocessing plant. The major program efforts have been installing the process monitoring sytem in the ICPP, collecting information during scheduled plant runs, and data analysis. This report represents the first in depth analysis of the available process data.

Because of program funding limitations, the analysis deferred several tasks to FY-1983, such as the operation of high precision tank monitoring sensors, the review of special diversion detectors, and the development analysis programs for direct operational safeguards support. Consequently, the data available for this report came from a selected set of plant signals (the plant level and density transducers and from status sensors on valves, pumps, samplers, sparges, etc.).

The several plots of data selected for analysis within the current effort are presented in separate Appendices not included with the main report. The system data collected over the 20-day period August 8-27, 1981 (data window #1) are useful for First-Cycle data analysis; the data collected over the 24-day period September 21 - October 14, 1981 (data window #2) are useful for Second- and Third-Cycle data analysis. These data were selected to represent times when these process areas were active and the process monitoring system was functioning properly under the existing configuration.[a] Not all of the data in the appendices were analyzed. Only data showing significant events were considered and these data are the basis of this main report.

As further discussed in later sections, the location of the analysis computer (3 miles from the plant) and the requirement to quickly get the system installed in time for plant runs contributed some data problems. Many of these problems have been corrected by improved equipment configuration, but further improvements are desired.

This report is intended for safeguards applications. However, the conclusions and problems reported should be of interest to production and safety personnel who can use the information produced by an effective plant monitoring system.

The next two sections of this report (sections II and III) provide the reader with a brief description of the process and the data acquisition and analysis equipment installed as part of the program. Section IV describes typical data obtained by the system. Section V and VI present detailed results of the analyses. Section V includes some of the problems found in the data and shows some examples of data for validation of accountability measurements and monitoring of plant transfers and flows. Section VI summarizes conclusions based on the recent analyses.

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[a] Appreciation is expressed to C. M. Amartys who coordinated the selection of data windows #1 and #2.

II. PROCESS DESCRIPTION

The Idaho Chemical Processing Plant (ICPP), completed in 1951, is a government-owned facility operated by the Exxon Nuclear Idaho Company (ENICO). The plant's purpose is to separate enriched uranium from spent nuclear fuel. The process uses 3 liquid-liquid extraction cycles to separate the uranium from the accompanying fission products. The process begins with the dissolution of complete fuel elements in nitric or hydrofluoric acid solutions. After adjustments are made to acidity, the volume and concentration of urnaium are measured. The solutions are then fed to the four, pulsed columns in the first-cycle extraction system used for extraction, scrub, strip, and wash. Tributyl phosphate dissolved in a hydrocarbon is the extractant. The first-cycle product is evaporated to concentrate it and then placed in intercycle storage tanks until all the fuel in that campaign has passed through the first-cycle.

After that, the stored product is fed from intercycle storage into the 2nd and 3rd cycle extraction columns for additional purification. The extraction used in these cycles is methyl isobutyl ketone (hexone). Packed columns are used. Each cycle uses two packed columns; one for extraction and one for stripping. There is an evaporator after each cycle to reconcentrate the product. The third-cycle final product is concentrated uranyl nitrate solution, which is stored in surge tanks before denitration.

The uranyl nitrate solution from the surge tanks is fed to a fluidized-bed denitrator. This converts it to the final plant product, a granular uranium trioxide. This solid is bagged, weighed, canned, and stored prior to shipment.

Input accountability measurements are made in two large tanks, G-155 and G-105. The solution is mixed, sampled, and its volume and weight measured using bubbler probes. The plant output accountability measurement is made on the solid UO_3 product. Product cans are sampled and weighed for the accountability material balance. Waste tanks are sampled and measured before transfer to the evaporators to measure the uranium losses.

The dissolvers, accountability tanks, and first-cycle feed tanks are not critically safe by geometry. Criticality control for these tanks is handled by soluble nuclear poisons or by instrumentation and administrative control. The input accountability tanks are large, water jacketed tanks with dished bottoms. Normal batch size is about 2000 liters. The first-cycle feed tank, G-106, is slightly larger than the accountability tanks.

The N-Cell intercycle storage tanks, the Z-Cell surge tanks, and the U-, W-, and Y-Cell waste collection tanks are organ pipe banks arranged as critically safe arrays of 5" stainless steel tubes. The J-Cell tanks, used for recycle and recovery operations, contain internal nuclear poision plates allowing uranium solutions up to 150 g/L.

Measurement of levels and densities of liquids in plant vessels is made with bubbler probes. The spacing for density probes is usually 10 inches above the primary (level) probes. Plant transducers convert the pressure signals from these probes to standard 3-15 psig pneumatic signals. First-cycle transfers are made with steam jets or air lifts. Pumps are used for some of the 2nd and 3rd cycle transfers. Air sparges mix most tanks.

Data shown in this report were taken during Run #37, scheduled to start July 1, 1981 and be completed November or December 1981. Experimental Breeder Reactor II fuel was processed. This fuel, clad in stainless steel pins and batch canned in stainless steel, was dissolved in the electrolytic dissolver.

Figures 1 and 2 are flow schematics for the 1st and 2nd/3rd cycles respectively. Additional process information is available in the literature.[1]

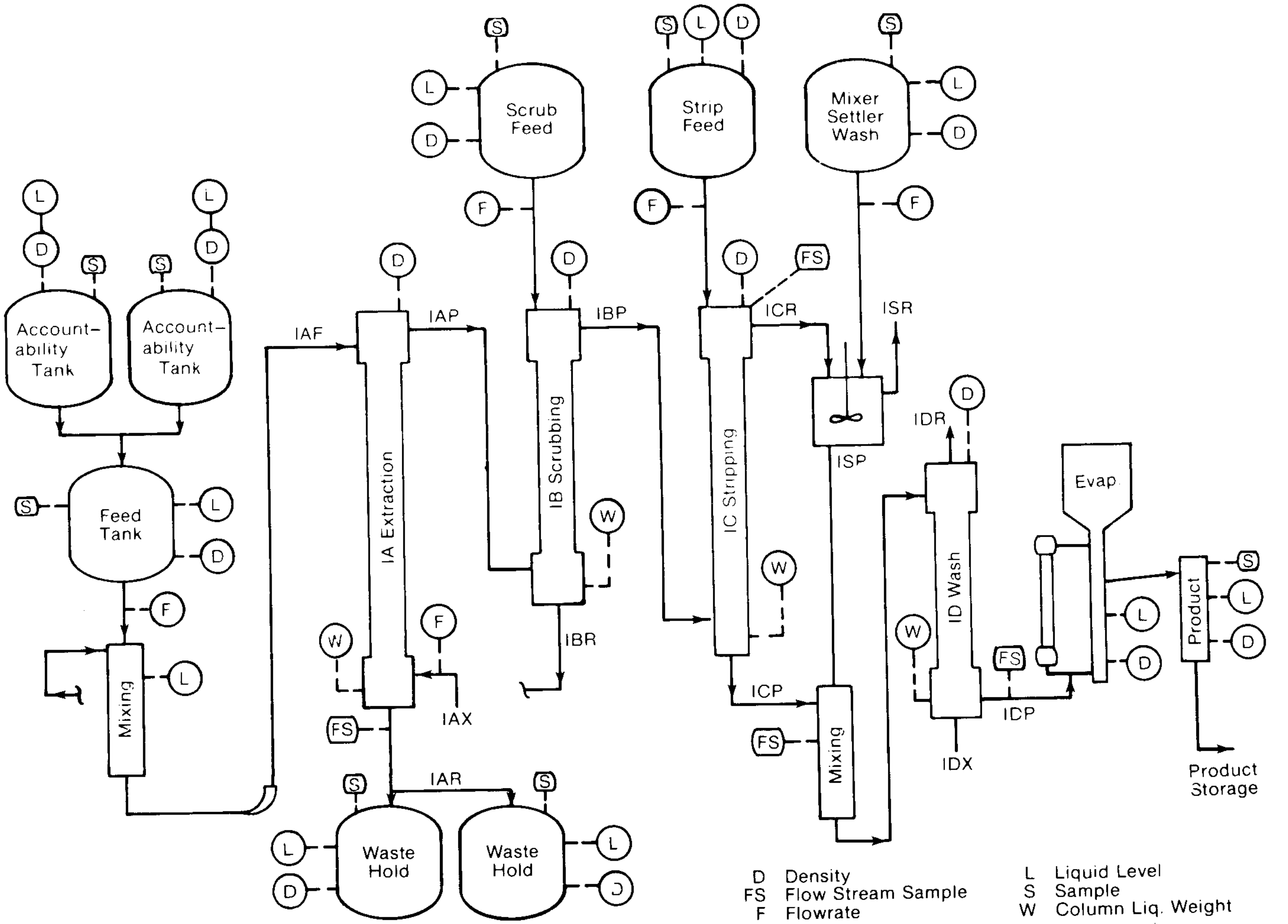

Figure 1. Flow Schematic of ICPP First Cycle

ICPP-A-6708

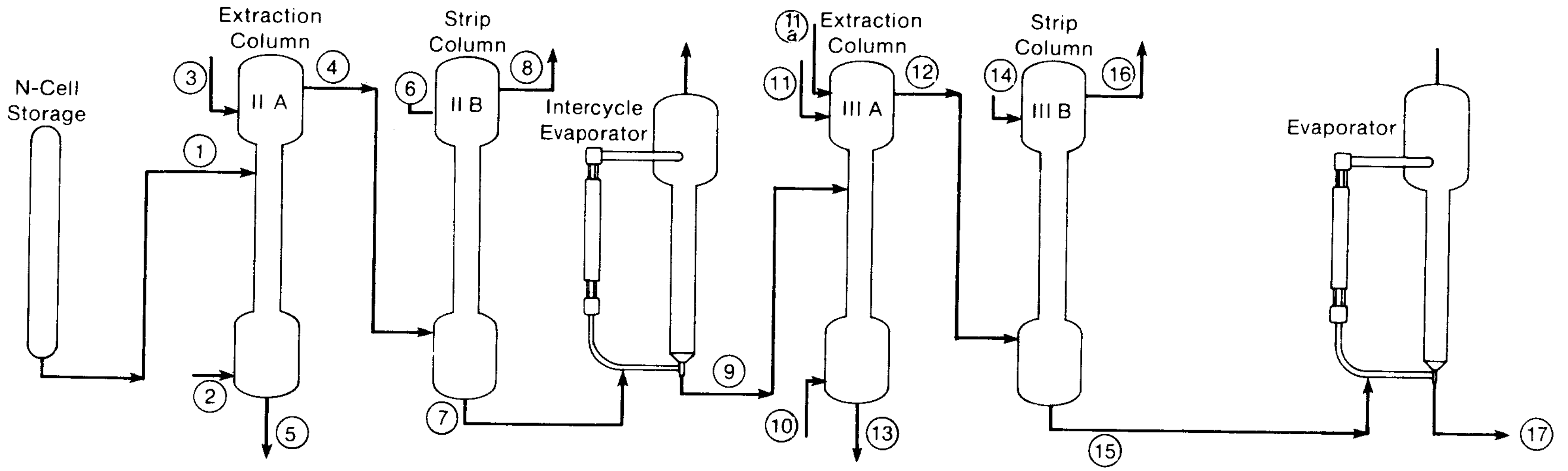

Figure 2. Flow Schematic of ICPP Second and Third Cycles

ICPP-A-9306

III. PROCESS MONITORING SYSTEM DESCRIPTION

1. INTRODUCTION

Many existing reprocessing facilities, including the Idaho Chemical Processing Plant (ICPP), were not designed for central data collection. At the ICPP, process information is displayed on local indicators on instrument panels along the two-hundred-foot length of the operating corridor or on gages and recorders scattered in other areas of the plant.

The first challenge, therefore, facing the process monitoring system installation was to design a system of sensors which would: (1) gather the maximum amount of data utilizing existing instruments when possible or installing new ones when necessary and (2) collect the data at a central location in a form which could be accepted by computers. The second challenge was to design and implement a computer system to control data acquisition, make necessary calculations, and store the raw and interpreted data in a form suitable for later analysis.

2. OVERVIEW OF SENSOR DEVICE CLASSES

The system seeks to provide improved surveillance and control of Special Nuclear Material (SNM). A design criteria document[2] was generated which identified the types and location of sensors required to monitor the operations at the ICPP. This document described device classes and the various applications for each:

Class 1 - pressure switches to obtain information on valve positions, and on sampler and steam jet operation;

Class 2 - flow switches to obtain information on sparge and airlift operation;

Class 3 - monitors for 3-15 psig pneumatic signals, primarily for solution level and density, but useable for anything else in 3-15 psig format;

Class 4 - devices to detect the presence of liquid in forbidden lines, or to prevent siphon access to process solutions;

Class 5 - steam jet monitoring thermocouples;

Class 6 - electrical relays to detect operational status of pumps and other electrical motors;

Class 7 - high precision level and density measurements;

Class 8 - manual valve position monitors;

Class 9 - pneumatic to 4-20 mA current loop transducers for isolated process signals;

Class 10 - thermocouples for monitoring solution temperatures;

Class 11 - current loop monitoring devices;

Class 12 - flow switches to detect movement of small quantities of process liquids; and

Class 13 - tamper indicators to detect power and access status of system components.

The computer system can make use of these classes of data to:

1. Audit the accountability system by:

   (a) providing an independent authentication of accountability measurement values,

   (b) assuring the validity of accountability measurements by verifying proper sparge mixing, sample recirculation, and solution transfers, and

   (c) assuring that no material bypasses the accountability tanks.

2. Assure that SNM in the plant stays there by:

   (a) performing solution mass balances on transfers between plant vessels,

   (b) verifying that solution flow paths are well defined and normal,

   (c) verifying constancy of volume in static tanks, and

   (d) promptly detecting presence of liquid in abnormal places which indicate possible losses or diversion attempts.

3. Check system integrity by:

   (a) monitoring system power supply and tamper indicators,

   (b) injecting reference signals for response checks, and

   (c) cross-checking redundant data.

4. Provide a data base for troubleshooting abnormal occurences by:

   (a) maintaining an accurate,time correlated record of events as data files,

   (b) allowing rapid access to these files, and

   (c) allowing the use of numerous programs to analyze data and generate tabular or graphical output reports.

3. COMPUTER SYSTEM DESCRIPTION

3.1 Data Aquisition Supervisory System (DASS)

As illustrated in Figure 3, data acquisition is controlled by a Hewlett-Packard 9845T computer. This machine controls two HP-9825S computers each of which is interfaced to data acquisition hardware using an IEEE-488 bus. Timing is provided by HP-98035A real-time clocks.

One HP-9825S controls a Computer Products Wide Range Analog Multiplexer and three Computer Products Digital Multiplexers. This system (SYSTEM A) scans the analog data (Device classes 5, 9, 10, and 11) once per minute. Digital data (Device classes 1, 2, 4, 6, and 13) are received both on real-time interrupts generated by state changes and by 15 minute scans of all digital inputs.

The second HP-9825S (SYSTEM B) controls the three Scanivalve pneumatic multiplexers (Class 3 devices), the five boxes of the Precision Level and Density System (PLDS) (Class 7 devices), and the Ruska pressure controller. The Scanivalves are controlled with specially designed Recording Devices Inc. Scanivalve Controllers which provide a simple command language, data storage buffers, and automatic data scaling to reference pressures. Reference pressure of 3 and 15 psig are provided by Schwien and Son precision regulators. Scanivalve data are obtained once per minute.

The PLDS system boxes use a pneumatic wafer switch (Scanco, Inc.) to multiplex primary pneumatic level and density signals from up to ten tanks to a pair of Paroscientific precision pressure transducers. Precision data are gathered every 15 minutes when the system is active, but such data were deactivated for the time periods analyzed due to electromechanical problems.

The Ruska pressure controller provided calibration pressure signals to the PLDS boxes and to the three Scanivalve units. The PLDS boxes will be returned to service in FY-1983 on a third HP-9825S controller.

3.2 Data Communication Links

The two HP-9825S computers communicate with their data collection hardware using the IEEE-488 bus with HP-59403A Common Carrier Interface (CCI) pairs. The links between the HP-9825S's and the HP-9845T also use the IEEE-488 bus with CCIs but required Bell System 209A Modems to drive a telephone line between the buildings where they were housed: CPP-637 to CFA-633, approximately 3 miles, during the data collection periods. All data were transmitted across this link to the HP-9845T, which formatted the data for transmission to the VAX 11/780 data analysis computer. Communication to the VAX 11/780 was handled via a local RS-232C link. All transmitted data blocks contained information on the time and date of data acquisition. (The analysis computer has since been moved to the ICPP area, eliminating the need for the telephone modems during data acquisition.)

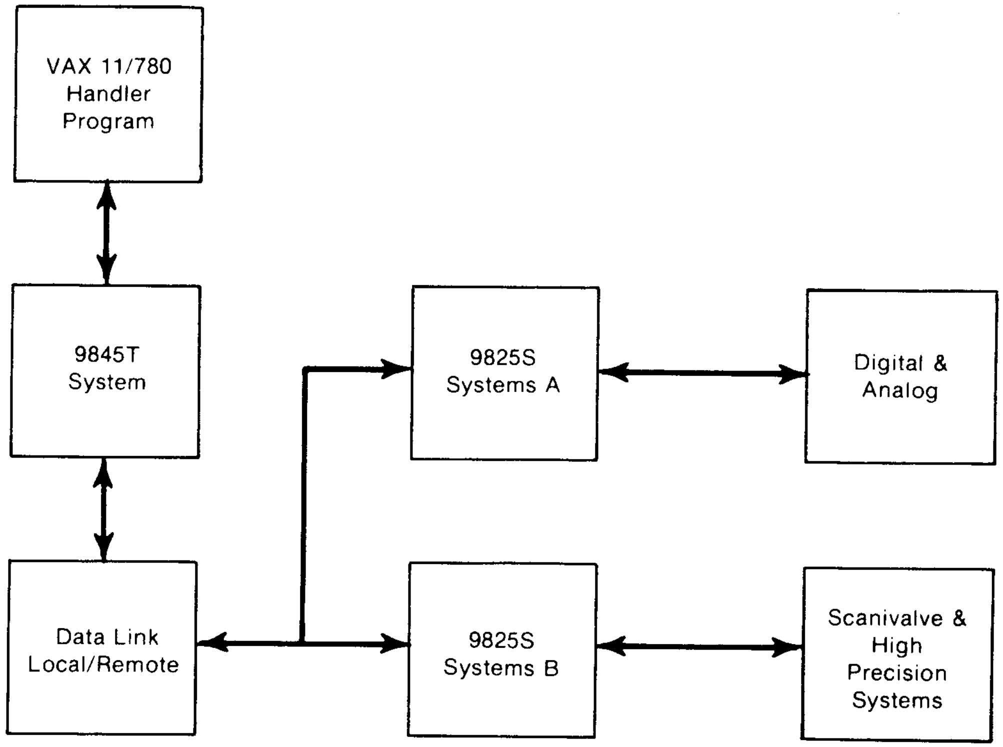

Figure 3. Data Acquisition System

ICPP-A-9307

3.3 Data Analysis Computer System,

Data analysis and storage are on a Digital Equipment VAX 11/780 computer system. This system stores raw data history files on magnetic tape, and decodes the data into analyst files. The decoding process uses stored information on data locations, calibration equations, and numerical values to calculate analyst file entries in engineering units. Analyst files are kept resident on a disk unit for approximately 8 hours. When the storage data stack fills, the earliest entries are transferred to tapes for long term storage.

The VAX 11/780 system includes a system console, several analyst terminals, and a plant support terminal. The latter provides plant operators and shift engineers with selected real-time data.

3.4 Data Analysis Plotting Methods

The data selected for analysis in this report were stripped and sorted onto special data tapes for playback under analyst request. Using program SELECTDAT, selected data files were brought from the data tapes into temporary disk storage on the VAX 11/780 where they could be accessed by the GETDATAP playback plotting routine. The data were plotted on a HP-2648A Graphics Terminal with hardcopy provided by a HP-2631G Graphics Printer.

IV. TYPICAL SENSOR DATA PLOTS

1. EXPLANATION OF DATA PLOTS

This section of the report illustrates typical data plots. It also explains how measurements are taken and some of the limitations of the data.

Most of the plot labels are self explanatory. The data name has three sections that indicate the vessel or device, the type of measurement, and the type of sensor. For example, the data name G155-DR-SV indicates that the vessel measured was a plant tank or vessel in G-Cell, the measurement is the output of the density transmitter, and the measurement device was a Scanivalve pneumatic scanner. The series number further defines equipment types: 100 series devices are tanks, columns, or evaporators; 200 series devices are pumps; 500 series devices are transfer jets; and 600 series devices are samplers.

In some of the plots when data are missing, the dropout (data gap) is indicated by a zero value for the duration of the missing data. This should not be confused with a genuine data excursion. In some plots the data were smoothed, as indicated in the headings. In most of the plots, lines are drawn between successive data points.

Plots of the digital device status are shown on the same time base used for the analog plots. The device status is given as any of four states: State 1 is OFF, State 2 is ON. Changes in state should be detected as they occur. If for some reason the changes were because of software and communications problems, the changes would be picked up by a 15 minute check. For these cases the data could be up to 15 minutes late. States 3 and 4 are generated when this happened. State 3 is an ON-to-OFF and State 4 is an OFF-to-ON transistion detected late.

2. TANK LIQUID MEASUREMENTS

Most tank measurements in the ICPP use bubbler probes extending into the tank carrying a slow flow air. Figure 4 is a simplified diagram of the usual measurement system. The air pressure in each probe displaces the liquid when immersed. The lower (level probe) is near the bottom of the tank. The next probe (density probe) is usually 10 inches above the lower probe. The third probe (reference probe) just enters the vessel headspace. Pressure differences between these probes are measured with two differential pressure transducers and a standard 3-15 pisg signal is generated and transmitted to plant instruments. The two 3-15 psig pneumatic signals directly drive plant density and level recorders and provide the data for computing tank level, specific gravity, and volume. Some of these signals are described in the next section.

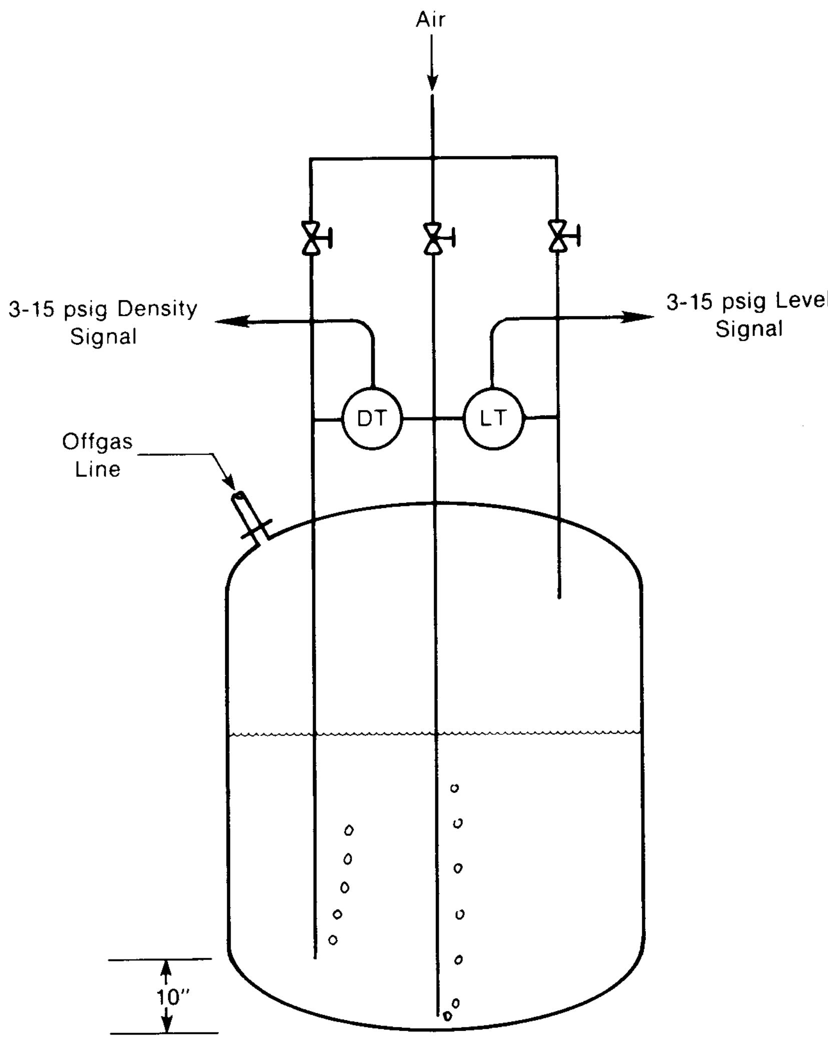

Figure 4. Level and Density Measurements With Bubbler Probes

ICPP-A-9308

3. LEVEL (LR) MEASUREMENTS

Level measurement comes from a plant LR transducer. The transducer is calibrated so that a 3-15 psig signal is generated for a specific range (e.g. 100 inches of water) of pressure differential between the headspace probe and the bottom (LR) probe. This signal is proportional to the product of the specific gravity and the level. It is not a direct level measurement.

Figure 5 is a typical LR plot of a transfer into tank G-155. It shows two additions: a slow feed from the dissolver (A) and a fast transfer (B). It also shows the steam jet transfer to another tank (C) that empties the tank.

4. DENSITY (DR) MEASUREMENTS

This measurement comes from a plant DR transducer. The inputs for this type of transducer come from the differential pressure across the two probes at the bottom of a tank. For most tanks they are approximately 10 inches apart. If both probes are immersed, the differential pressure is directly proportional to the density of the liquid.

There are two factors that will affect the interpretation of these plots. First, if the density probe is not completely immersed, the differential pressure observed is only a fraction of the pressure corresponding to the real density. Second, the zero point and range of the transducers are set to provide measurements over a limited range. This is typically 7 to 10 inches of water for organic liquids and 10 to 15 inches of water for aqueous liquids. Differential pressures outside these ranges are not accurate and pressures much outside the ranges will cause the transducer output to limit. The normal output range is 3 to 15 pisg. A typical pneumatic transducer will limit near 0 psig at the lower limit and near 17 pisg at the upper.

This means that DR values, when the tank is nearly empty, are suspect. Typically, as a tank fills, the DR reading will be stable near its low limit until the probe differential pressure approaches its calibrated range. The reading will then climb until the density probe is immersed. DR readings above 3 psig mean that the transducer is in its calibrated range but do not prove that the density probe is immersed or that the reading is correct.

Figure 6 is a DR plot for tank G-155 corresponding to the LR plot of Figure 5. Note that the tank was full enough during additions (LR plot) so that the density probe was immersed and the DR readings are stable during the first addition (Region A) and the second addition (Region B). The liquid added in the second addition had a lower density, indicating a different origin. At the time the tank was emptied, the level dropped below the density probe and the transducer output pressure bottomed out at about 1 psig.

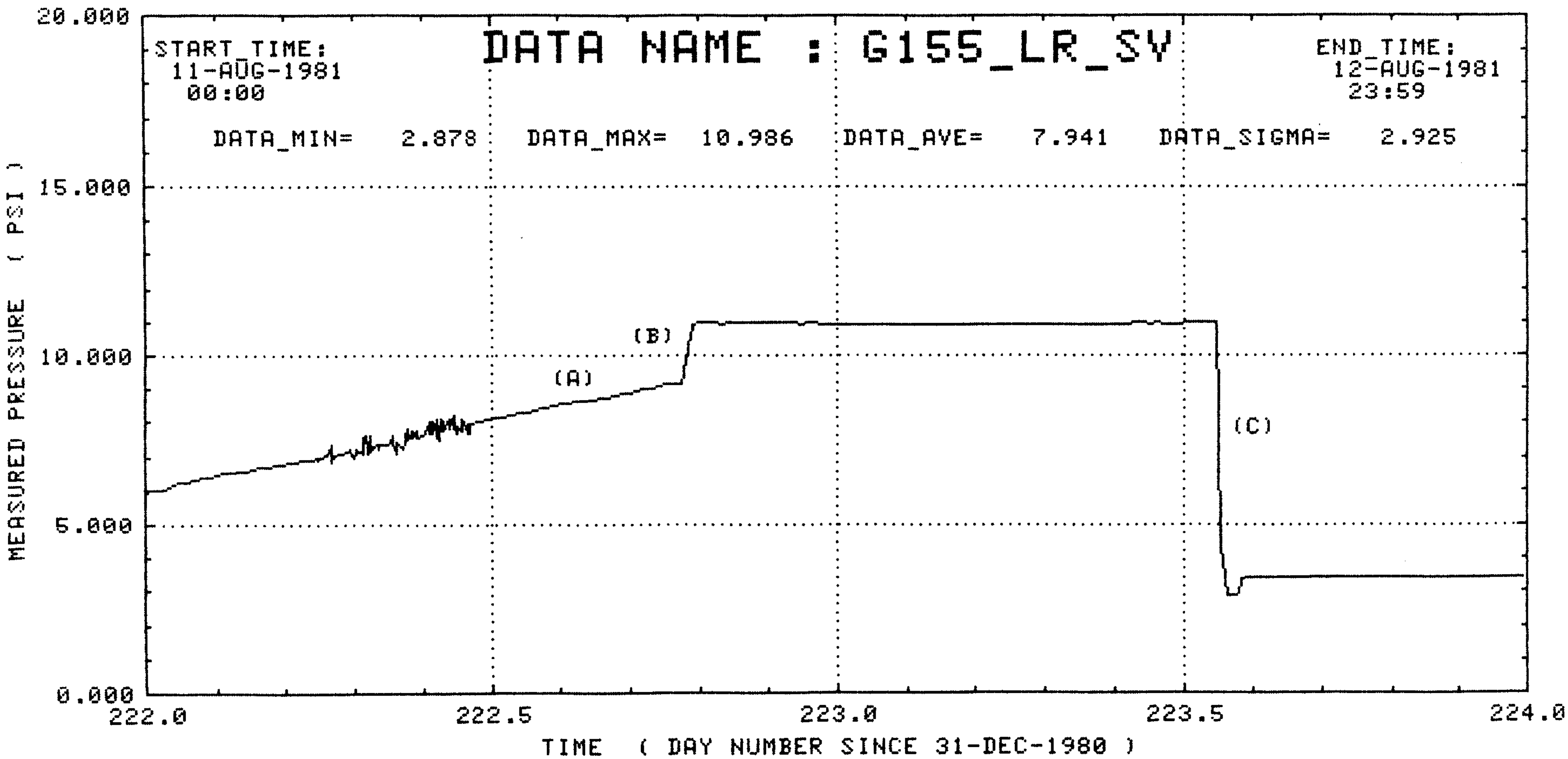

Figure 5. Typical LR Plot for Tank G155 During a Transfer

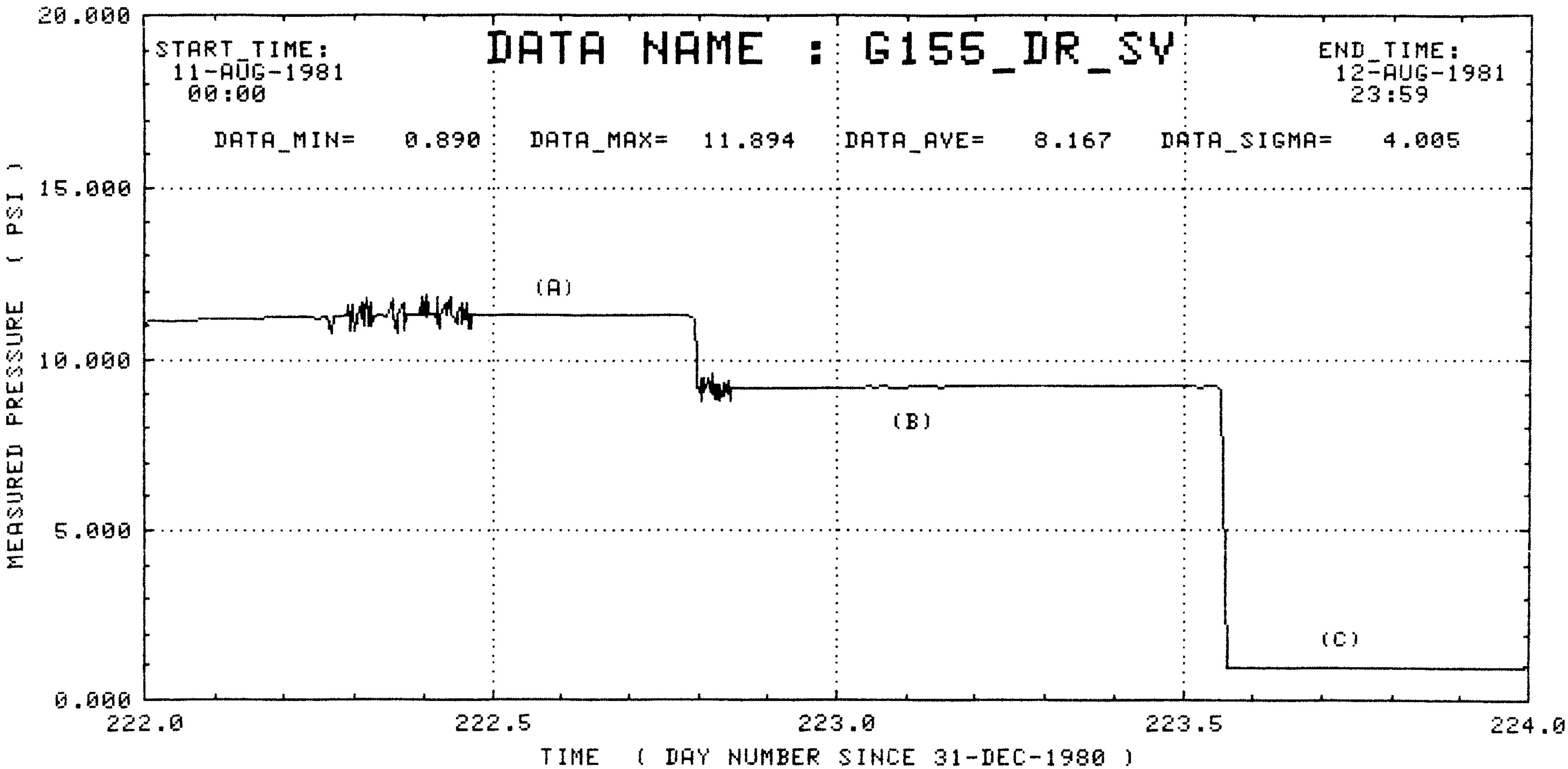

Figure 6. Typical DR Plot for Tank G155 During a Transfer

5. SPECIFIC GRAVITY COMPUTATION

The specific gravity is computed from the DR reading assuming that the density probe is immersed and the differential pressure is within the calibrated range of the density transducer. This specific gravity is calculated for each density point and is stored as a separate data value.

The specific gravity is calculated by an equation of the general form:

SP. G. = ((DR-3)/12)*(SP.G range) + lower limit (4-1)

Figure 7 is the specific gravity plot corresponding to the DR plot shown in Figure 6. Note that the invalid specific gravities of about 0.86 at the end were caused by the DR being out of range and the probe being uncovered.

6. LEVEL AND VOLUME COMPUTATIONS

Tank level and volume calculations are made for each pair of DR and LR readings. The volume computation is stored as a data variable. The actual level of liquid in a tank is a function of the LR reading and the specific gravity of the liquid.

The level is calculated with an equation of the form:

Level (inches) = ((LR-3)/12)*(LR range/Sp.G.) + constant (4.2)

The value of the constant depends upon the LR probe position. In some tanks it can be ignored or is purposely set to zero to reflect the level above the LR probe tip.

The volume of the liquid in the tank is a function of the level and is calculated using a calibration equation. For most tanks, which approximate right cylinders, a simple linear equation is used.

Figure 8 is a plot of the calculated volume of tank G-155 corresponding to the LR data presented in Figure 5. The volumes are invalid in region C because the specific gravity data were invalid.

7. TANK TEMPERATURE MEASUREMENTS

The measurement of the temperature of liquids in plant tanks is usually made with thermocouples. As the data name shows, the measurement of the tank temperature (TT) was made with a type J thermocouple (TJ). Figure 9 is a typical plot of temperatures data in tank G-105. The discontinuities at (A) and (B) are the result of an addition to the tank and an emptying-filling operation.

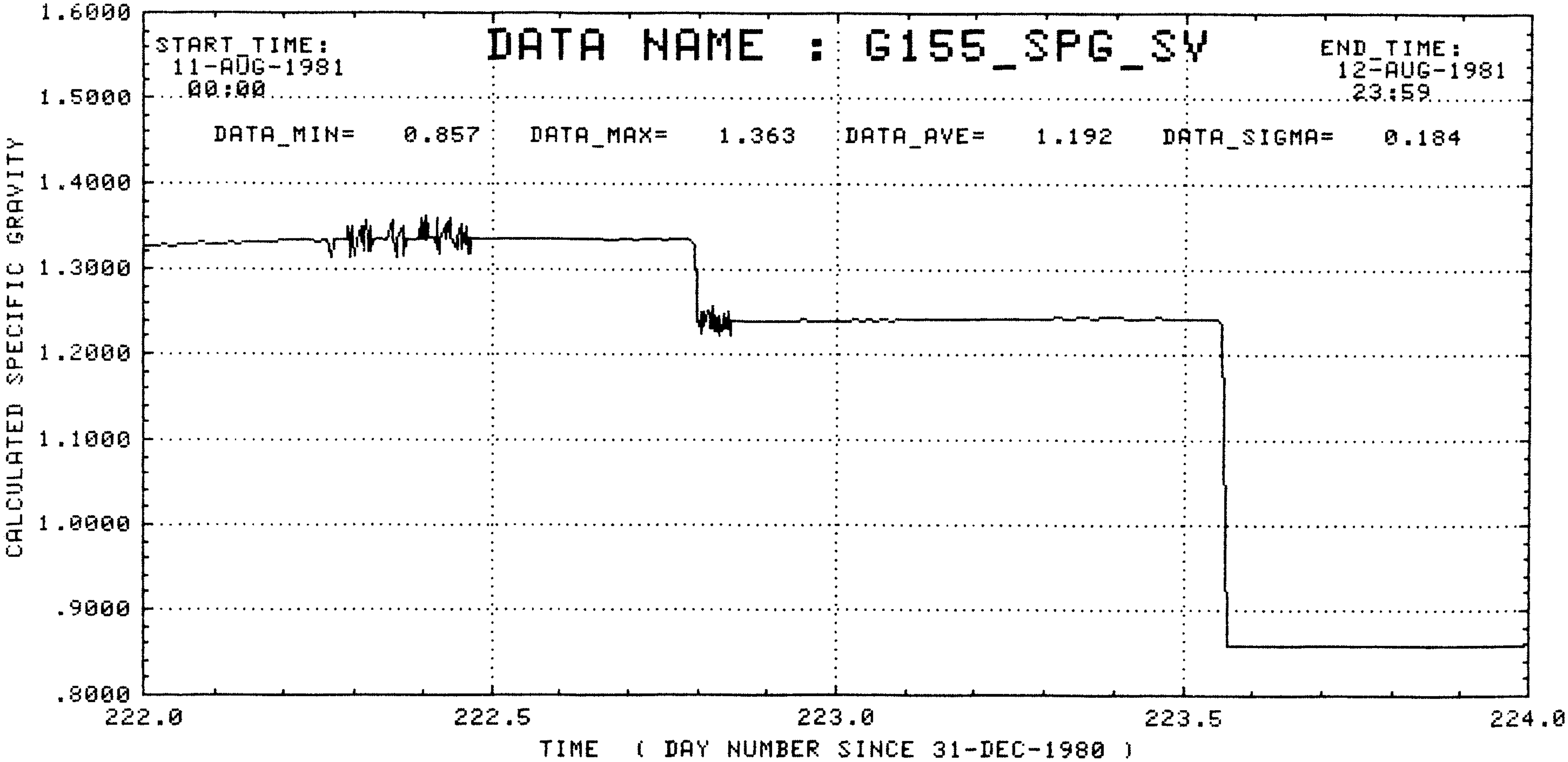

Figure 7. Typical SPG Plot for Tank G155 During a Transfer

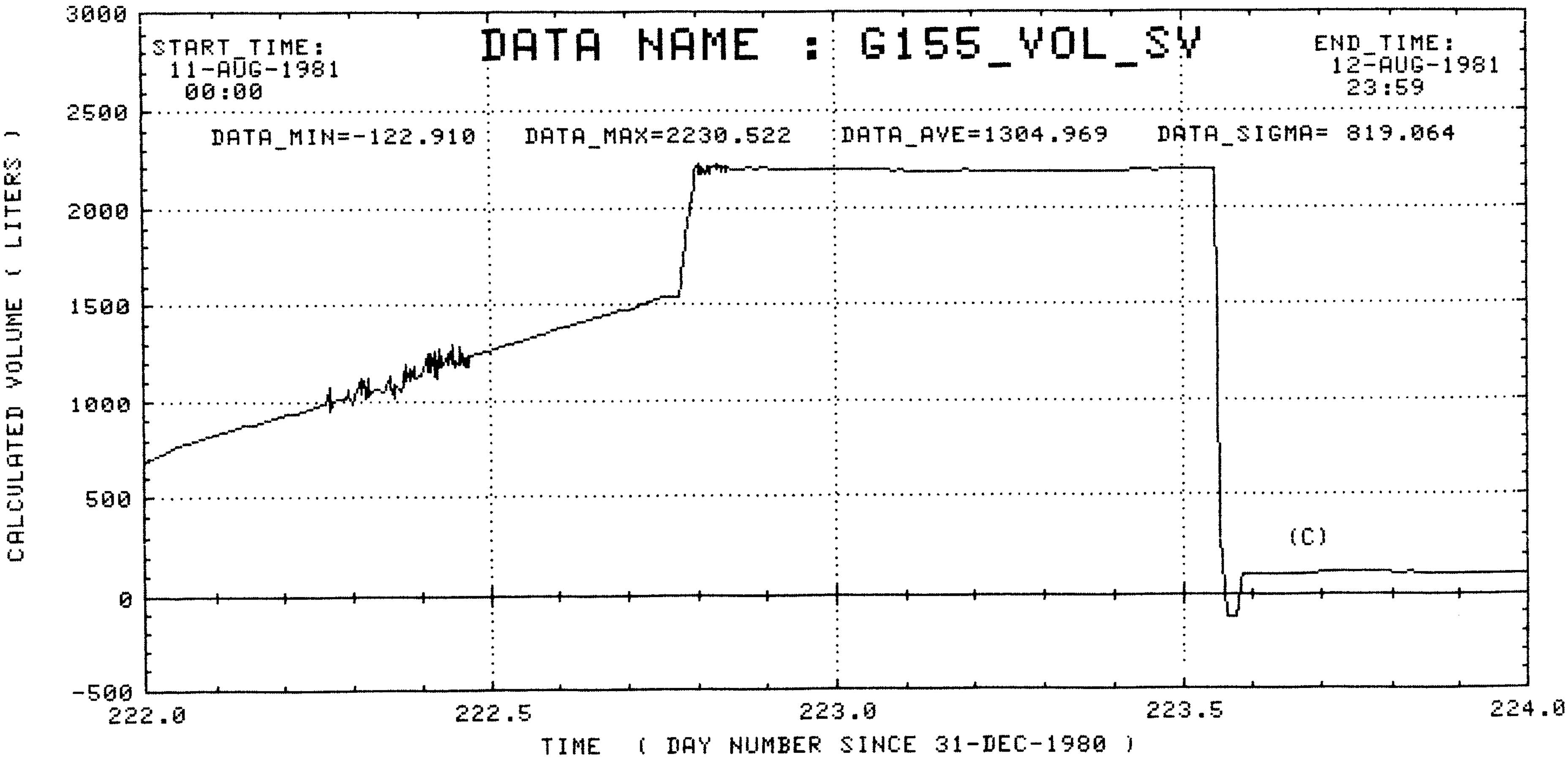

Figure 8. Typical Volume Plot for Tank G155 During a Transfer

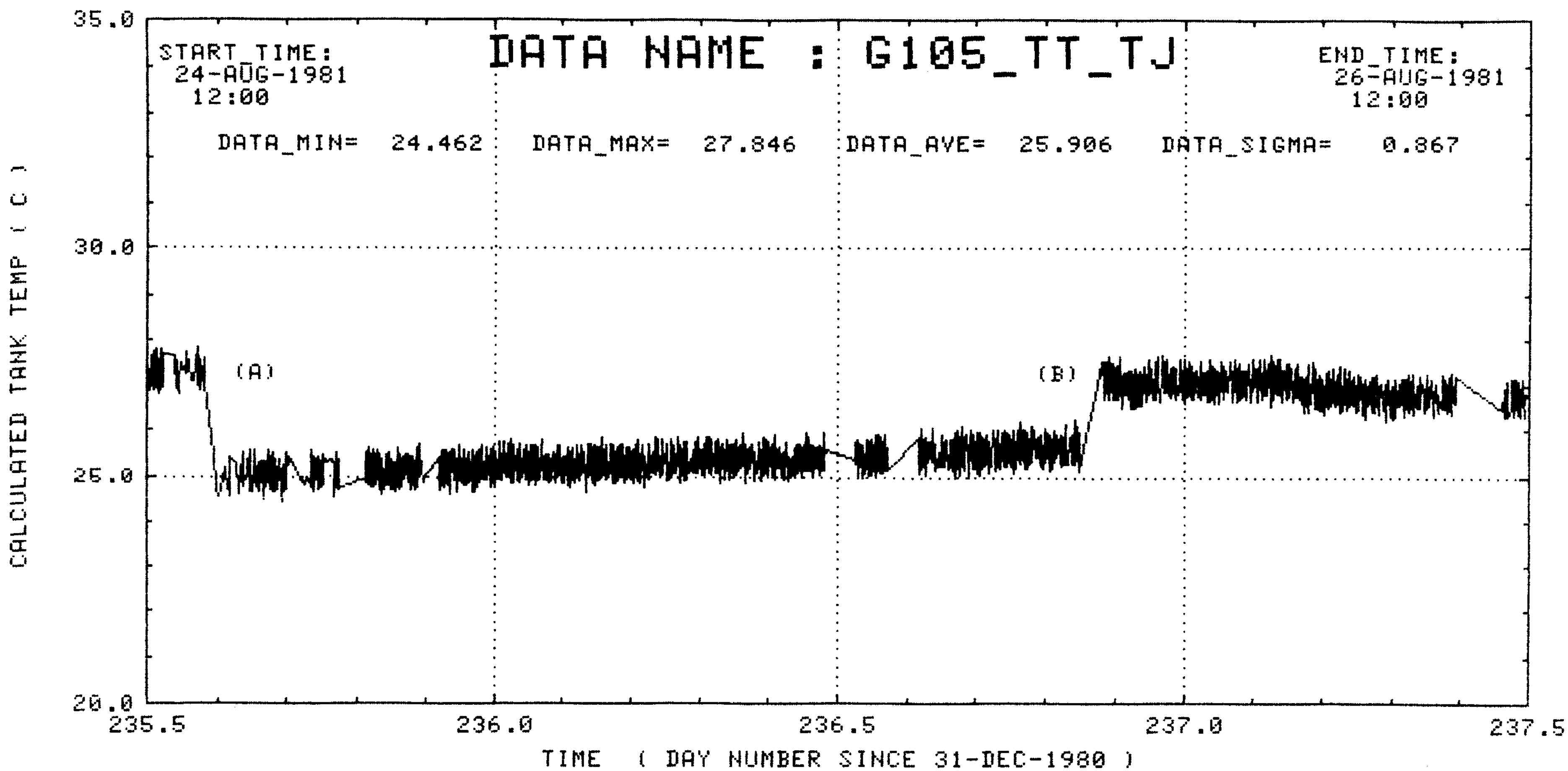

Figure 9. Measurement of Tank Liquid Temperature

8. STEAM JET TEMPERATURE MEASUREMENTS

The outlet temperature profile of steam transfer jets provides information on their performance. A number of these transfer jets are monitored. Figure 10 illustrates how the outlet is monitored. Figure 11 shows a temperature profile for an E-Cell transfer. In Region A, after the steam was applied, the liquid transfer is underway. The liquid is heated by the steam that operate the jet. The Region B, the liquid transfer was completed and pure steam moves through the jet. Region C is the cooldown after the steam supply is stopped and the jet vented. However, this ideal profile is uncommon. It was a slow transfer that allowed time for equilibrium between the thermocouple and the fluid in the jet outlet. Temperature profiles on most transfers involve shorter periods, or smaller amounts of liquid, and may not provide this ideal temperature profile.

Steam jet transfers sometimes have problems due to insufficient vacuum, plugging of transfer lines, or too high temperature at the jet body. The temperature measurement can indicate to the operator or Safeguards worker when the jet was operated and, when compared with volume plots for the source and delivery tanks, some information about the quality of the jet transfer.

An increase in temperature at the end of the transfer would be expected if the transfer removed all possible liquid from the source tank.

9. DATA NOISE ESTIMATES

Signal noise levels set a lower limit for the precision of an unfiltered system measurement. Table II presents noise levels for several plant tank measurements. For convenience, these noise levels were measured, by inspection of data plots, as noise ranges. These range values are roughly 4 times the standard deviation of the noise amplitude. The noise estimates were made from sections of plots free from Scanivalve spikes or data dropouts. They do not include long term noise (data accuracy variations). These noise extimates do include both process noise effects and measurement noise effects. Future work should refine the estimates and separate the values into their respective components.

The noise estimated shown in Table II are for six tanks: G-155 is a 3000 liter accountability tank; J-127, J-134, and J-135 are 800 liter tanks fitted with internal poison plates; N-130 is an array of 8 organ pipe tanks, the total volume of which is about 800 liters; and S-116 is a single organ pipe with a volume of about 70 liters.

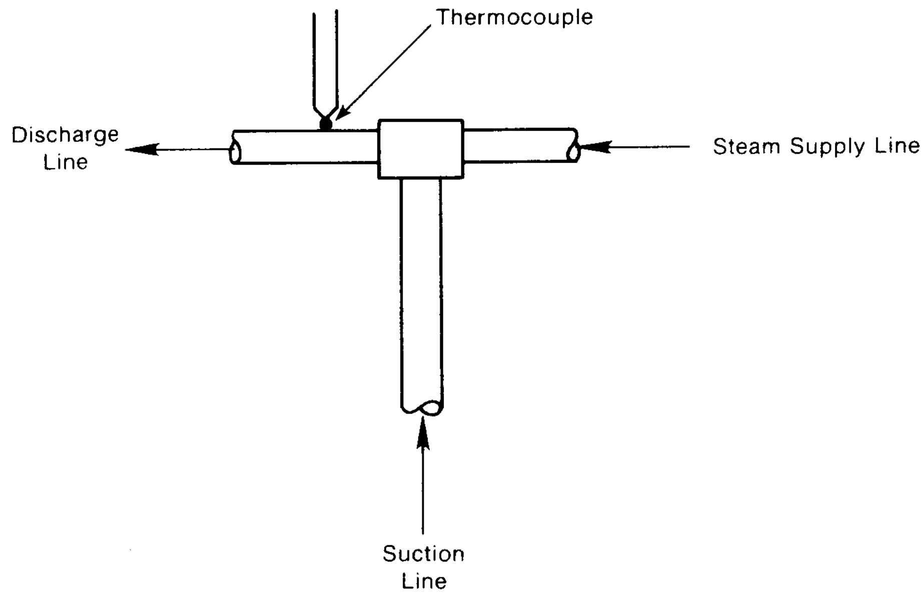

Figure 10. Monitoring Steam Jet Transfers With a Thermocouple

ICPP-A-9309

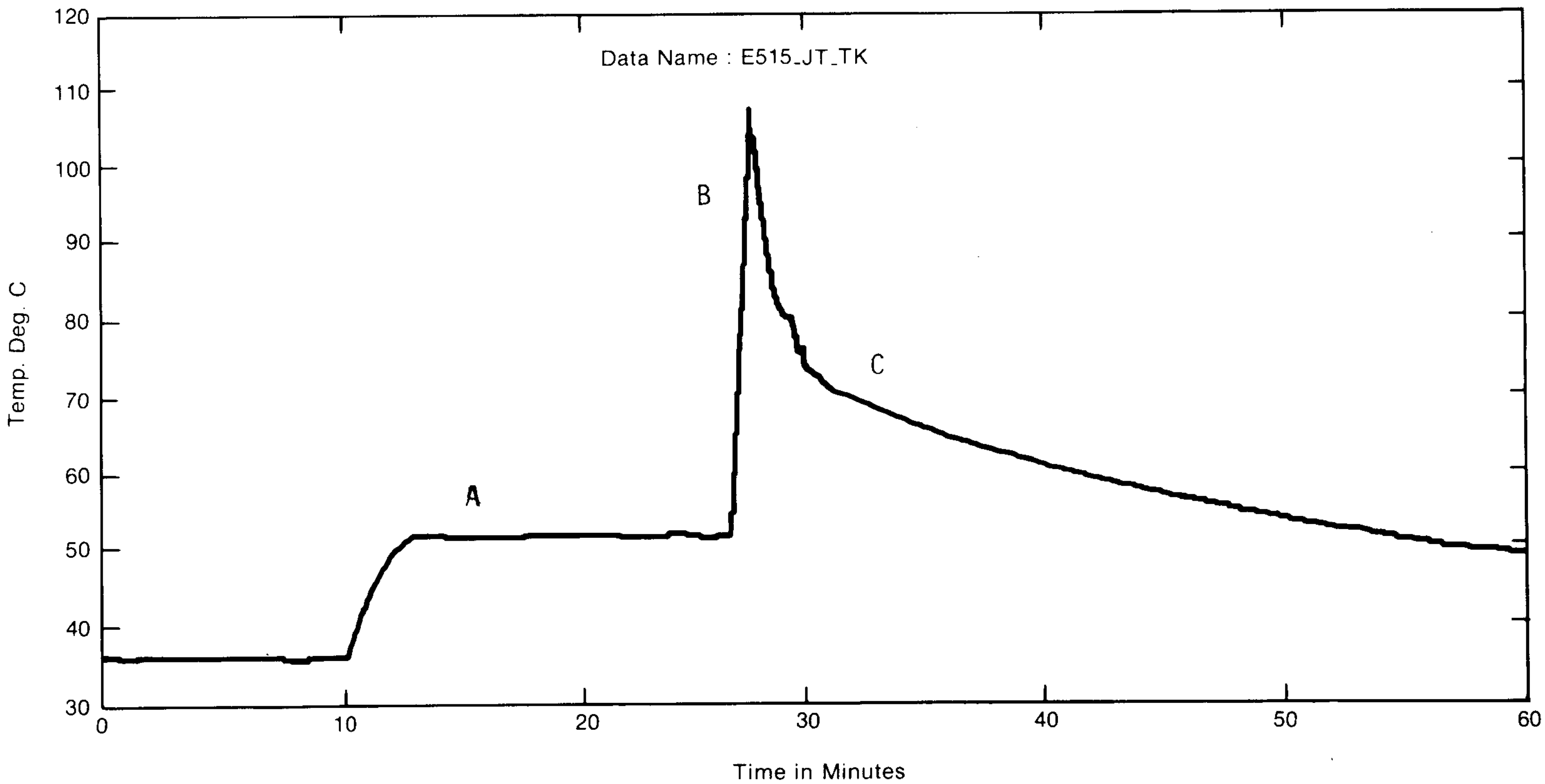

Figure 11. Ideal Temperature Profile of a Steam Jet During a Transfer

ICPP-A-9310

TABLE II

TYPICAL DATA NOISE ESTIMATES

Noise Range (4σ)

Tank	DR (psig)	LR (psig)	SPG	VOL (L)
G-155	0.04	0.018	0.004	4.0
J-127	0.04	0.012	0.0018	0.6
J-134	0.016	0.01	0.0008	0.6
J-135	0.03	0.14	0.001	1.2
N-130	0.12	0.0032	0.004	0.3
S-116	0.04	0.008	0.002	0.5

Noise Range (as % F.S.)

Tank	DR	LR	SPG	VOL
G-155	0.33	0.15	1.0	0.2
J-127	0.3	0.1	0.32	0.07
J-134	0.13	0.08	1.6	0.07
J-135	0.25	0.1	0.2	0.15
N-130	1.0	0.03	0.7	0.04
S-116	0.3	0.07	0.4	0.07

(NOISE RANGE $\backsim$ 4 STD. DEV.)

V. DETAILED ANALYSES AND RESULTS

1. DATA LIMITATIONS

1.1 Data Dropouts

Plant monitoring systems should be expected to fail occasionally. Safeguards measurement programs should not be based on the assumption that the necessary data will always be available. There are a number of problems that could reasonably be expected to cause data loss: local power failure, software or hardware faults in the data acquisition system, unreliable communications links, and maintenance or operator actions.

Figure 12 illustrates a typical incident. The data in the figure show a transfer of liquid from J-135 to J-127. The actual transfer involved an addition of about 67 liters into J-127, yet, this detail was lost in a data dropout. The dropouts in this case are shown by lines dropping to zero. It is believed that they were caused by a combination of a bad data link and software control problems in the data acquisition system. Such a data dropout hinders calculation of flowrates or determination of the time of the transfer. The plot still permits bracketing of the transfer times (between day 267.35 and 267.43) and calculation of a minimum average flowrate.

1.2 Transient Probe Plugging

The level and density probes used in process vessels are sometimes subject to plugging. Such an occurrence may last for an extended time; at other times it is a transient effect. The next three figures illustrate a transient probe plugging episode in a N-Cell organ pipe tank.

The figures show a transfer of about 700 liters between J-128 and the N-140 pipe organ type storage tank. The transfer from J-128 is normal (see Figure 13). The plot of volume in the receiving tank (Figure 14) shows a receipt of at least 700 liters, but with transient surges in indicated volume. A look at the DR recording for the same period (Figure 15) shows a distinct abnormal region and some fluctuations that cause the surges in the calculated volume. Apparently, the density probe data for the period 264.275 to 264.31 were bad. The indicated density goes off scale (15 psig +) and undergoes oscillations, possibly caused by the probe clearing itself or by actions taken by the operators to clear the probe.

Volume data for the period are therefore unreliable. The apparent volume in N-140 after the transfer does not match the transmitted volume. Extrapolation is difficult because the N-140 tank was being used to feed the 2nd-cycle column, P-102, immediately after the transfer. This is shown by the gradual decrease in volume from time 264.31 to 264.43.

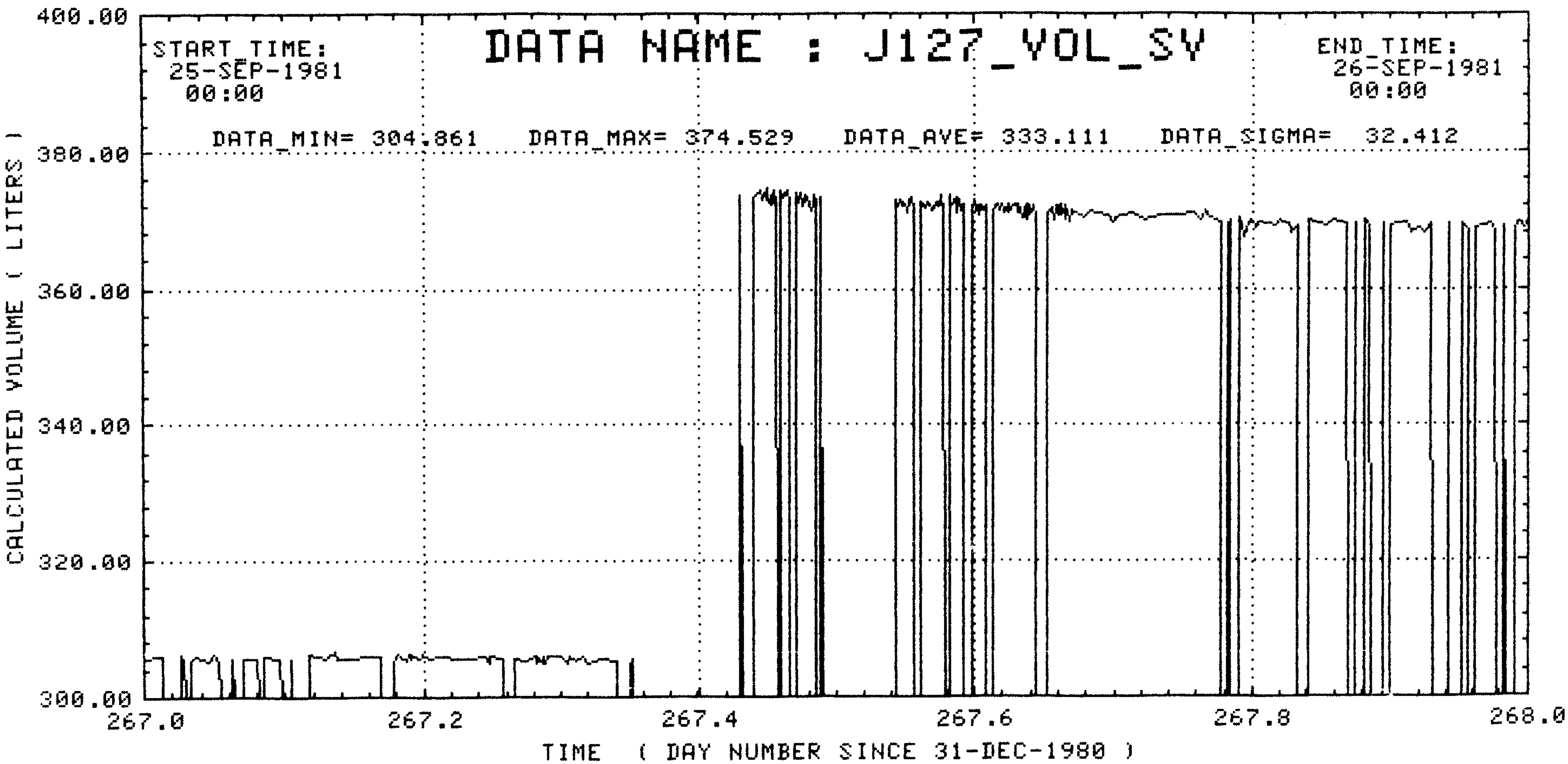

Figure 12. Transfer Data Lost During Data Dropouts

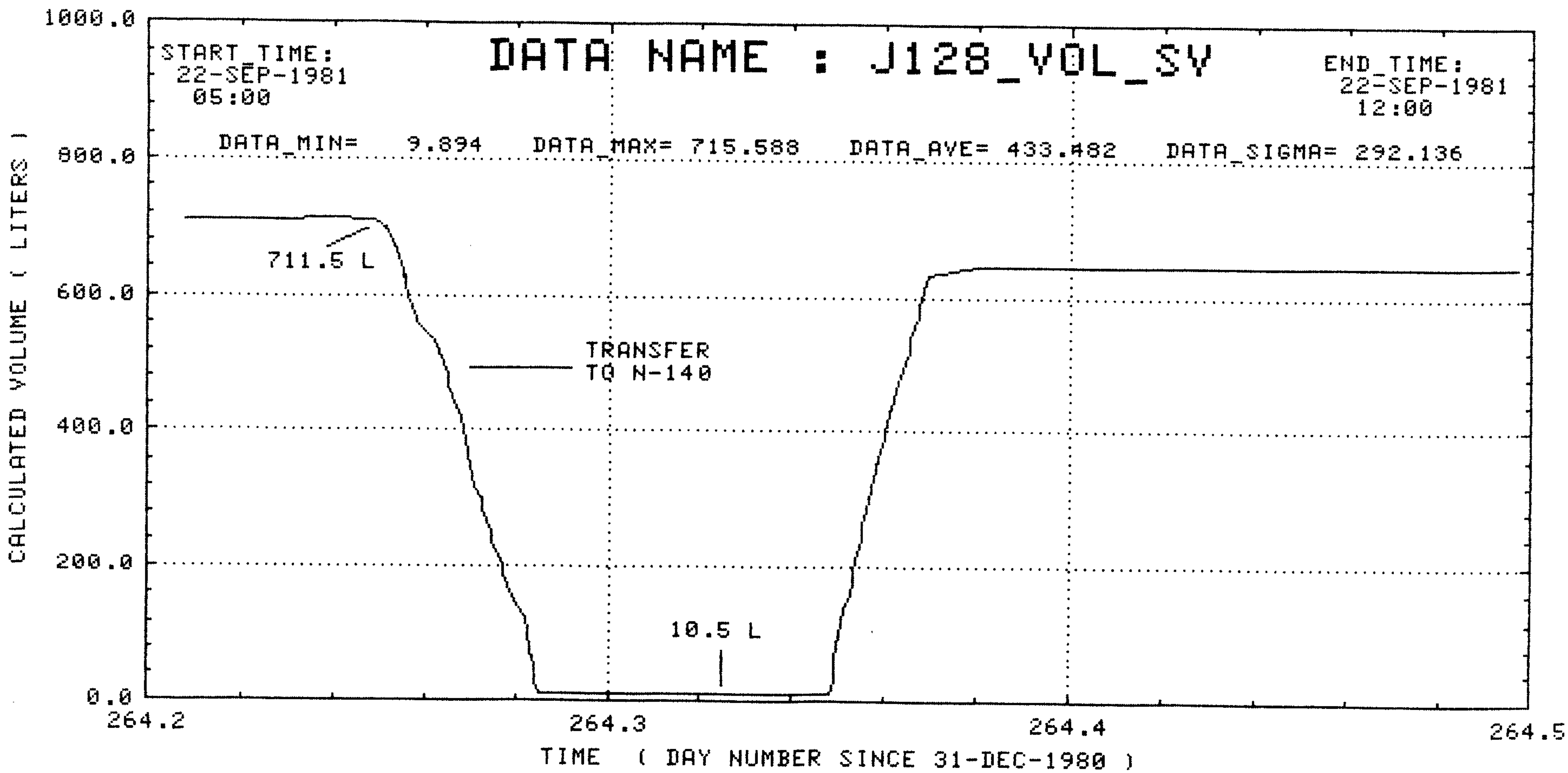

Figure 13. J128 Volume Plot During a Transfer to N140

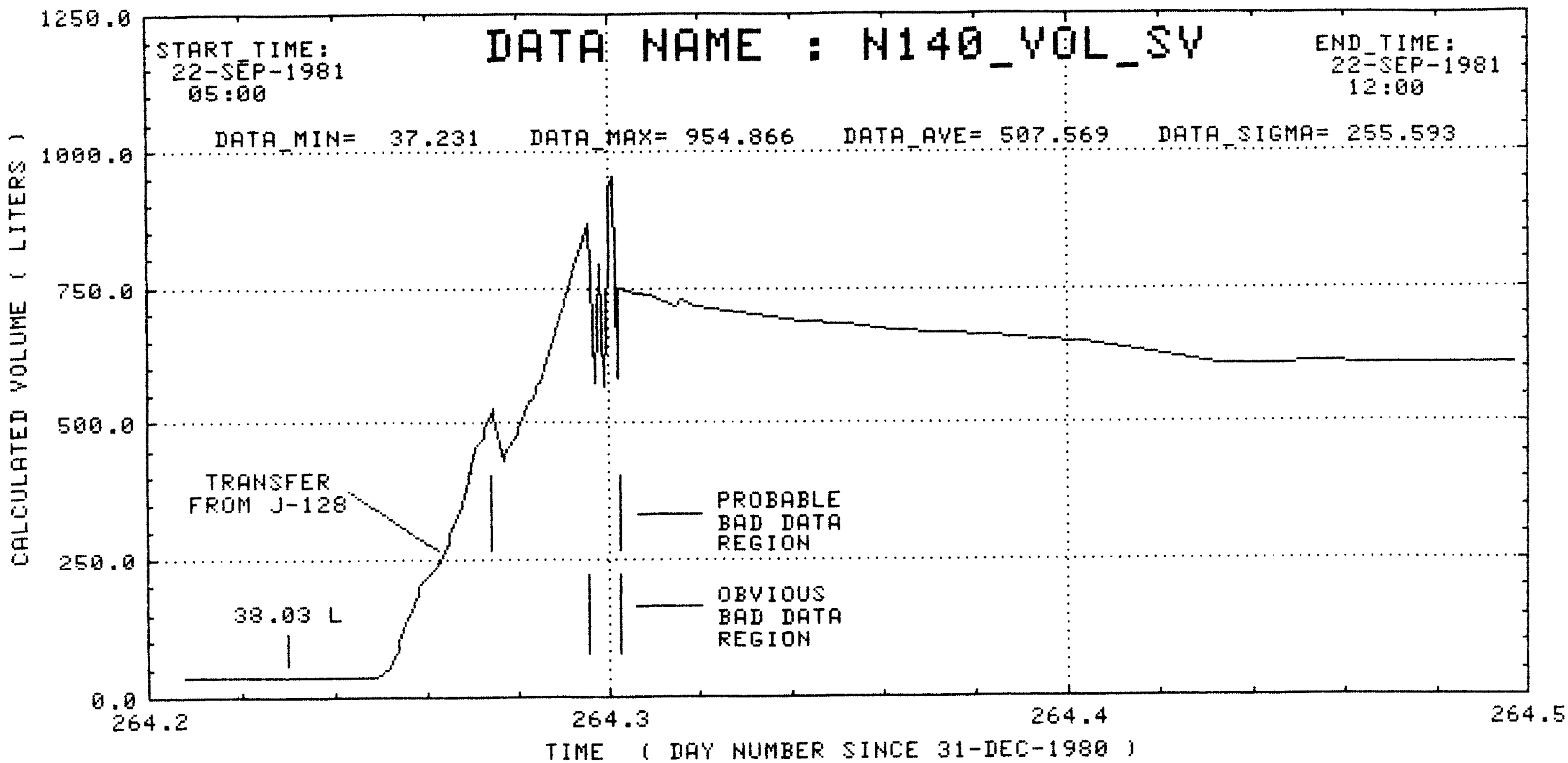

Figure 14. N140 Volume Plot During a Transfer from J128

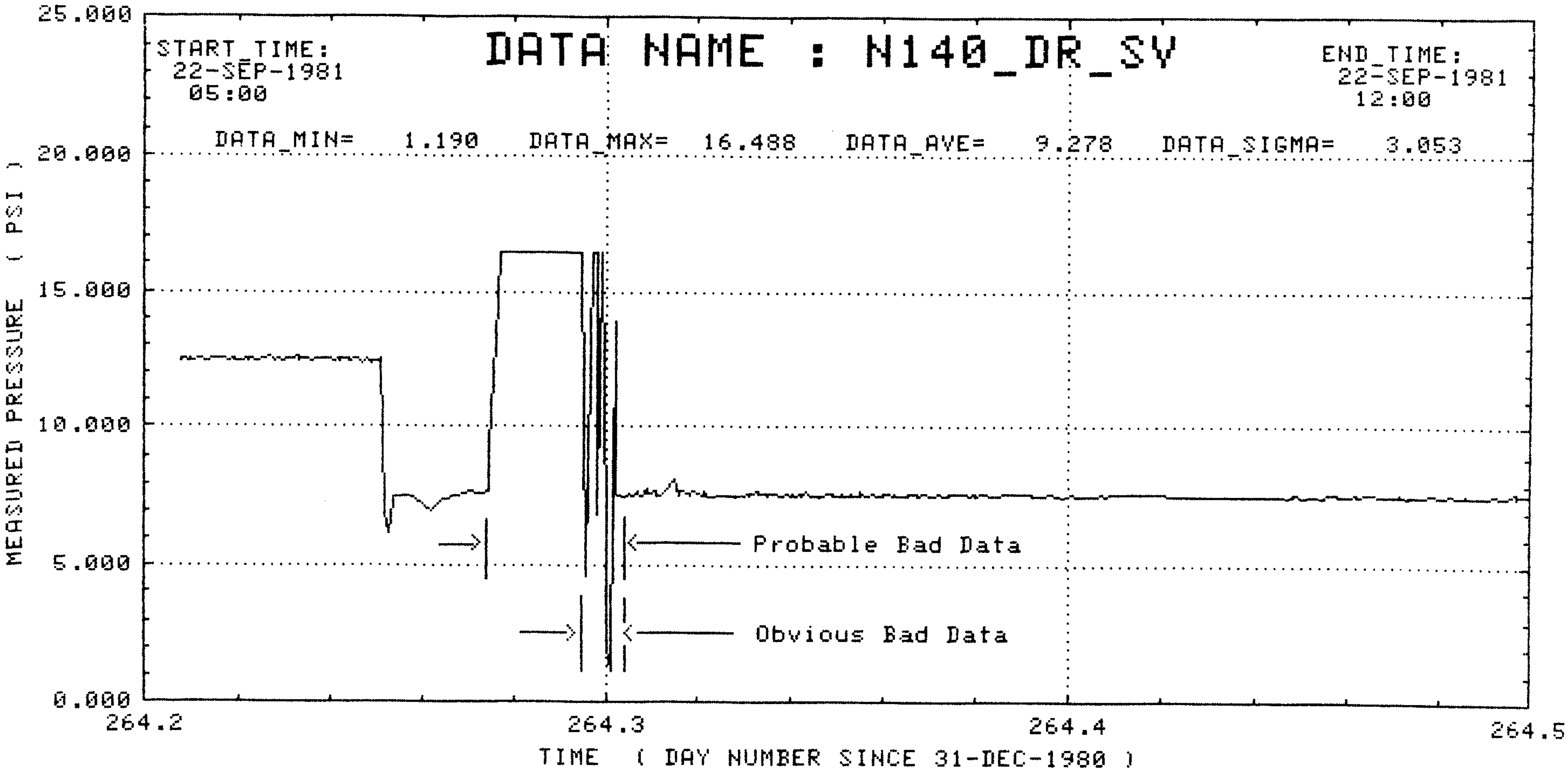

Figure 15. N140 DR Plot During a Transfer from J128

1.3 Slow Probe Plugging

Extended plugging bubbler probes is another problem that can cause bad plant data. Most plants use bubbler probes to measure density and level of radioactive liquids in tanks. Solids can build up at the probe tips and could eventually plug them. This plugging is most likely to occur when the solution being measured is near saturation. A possible mechanism is that the liquid that enters the probe tip each time a bubble collapses is dried by the flow of instrument air, leaving a layer of solids. These deposits could slowly build up until the probe tip becomes restricted and finally plugs. Data taken while the probe is plugged are invalid.

Figure 16 presents an example of the effects caused by extended probe plugging. It shows density data for tank N-150 that contains concentrated uranyl nitrate solution. It also illustrates slow plugging. During the plot period there was no addition of material to the tank. The pneumatic density signal has a steady increase caused by the growth of a plug until, at point A, the plug clears itself or is cleared by the operator and the signal drops to a more stable value at point B. For this example only, the lower probe is immersed and is plugging. This is shown by the low pressure (well below the 3 psig zero point) and the increased pressure differential. Note that the signal becomes noisy as the plug forms.

Figure 17 is a plot of the calculated volume in the tank for the same period. Note the blips at points C, D, and E caused by the plugging. The blip at point E could easily be mistaken for an addition and withdrawal of about 100 liters if the plugging had not been noted.

1.4 Incompletely Immersed Density Probe

1.4.1 Example #1. Plant density values will be incorrect if the density bubbler probe is not completely immersed. Volumes calculated using these bad density values will also be incorrect. This can lead to inaccurate conclusions about a transfer.

Figures 18 and 19 show four transfers of liquid from tank S-116 to tank J-135 over a period of two days. The volumes transferred are roughly 29, 18, 43, and 32 liters. Figure 20 shows the volumes computed for the receiving tank. However, the tank had been emptied just before the first of the transfers and the volumes added were not sufficient to cover the density probe (at 10" above the level probe) until the third addition was complete.

The apparent received volumes are roughly 44, 58, 16, and 32 liters. The first three values were calculated from bad density data and do not match. The fourth value, taken with an immersed density probe, does match better. The J-135 LR probe was immersed and its readings for the period (Figure 19) are a better match, except for the second transfer. The reason for this mismatch is not clear, except that liquid may have been entering and leaving S-116 during the transfer and thus resulted in a larger transfer than is shown in Figure 18.

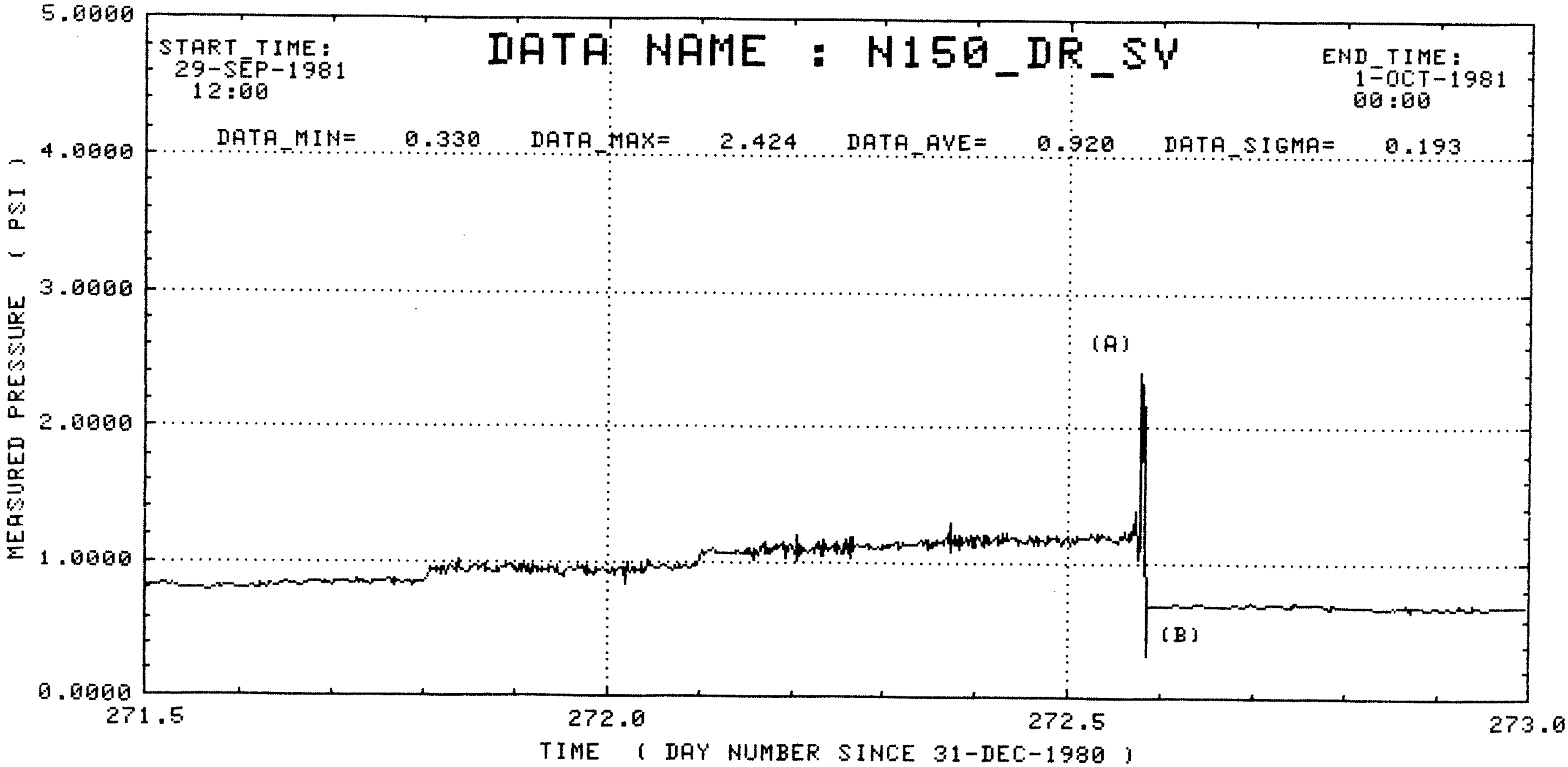

Figure 16. Density Plot Showing Slow Probe Plugging

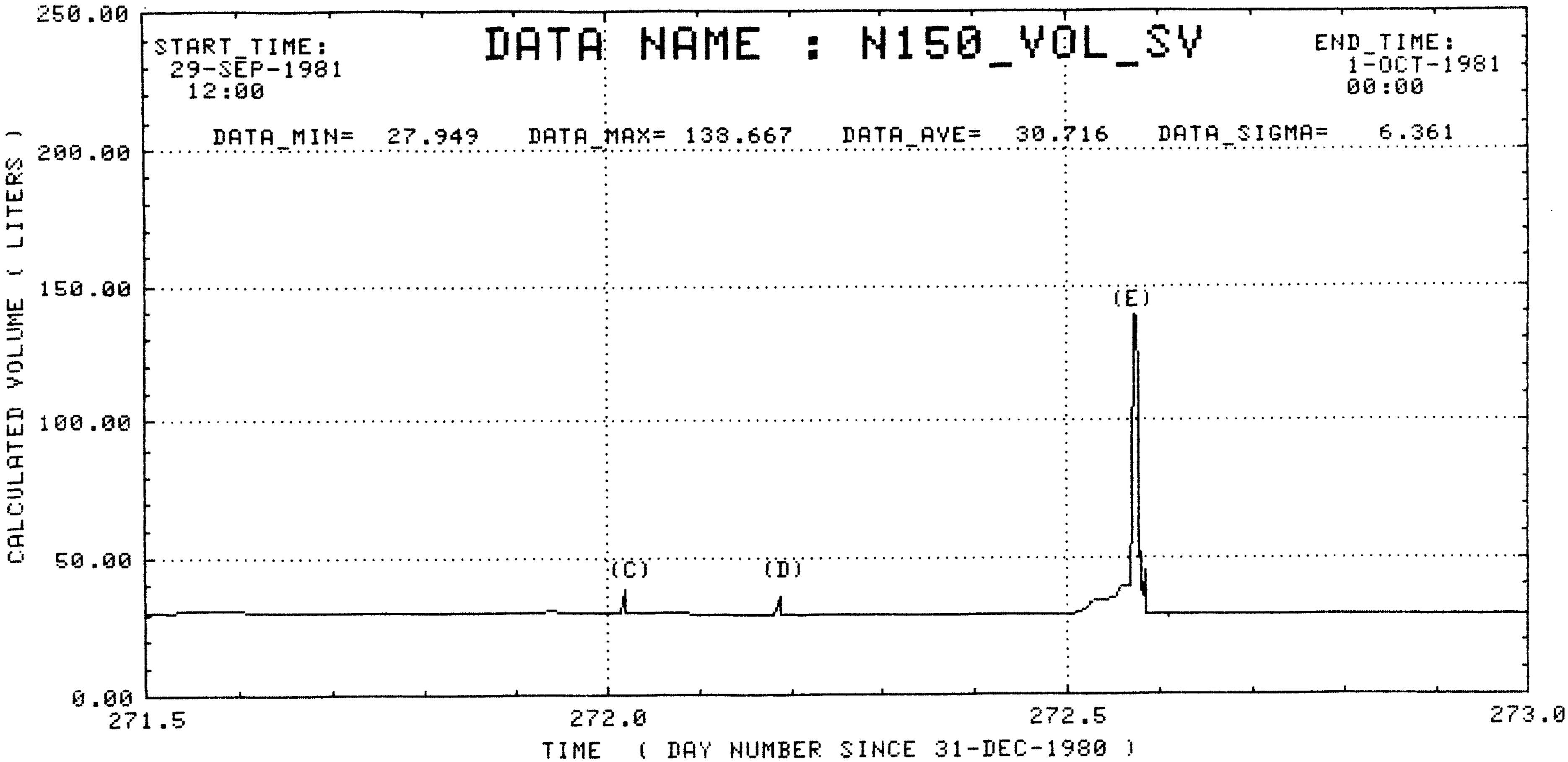

Figure 17. Plot of Calculated Volume During a Plugging Episode

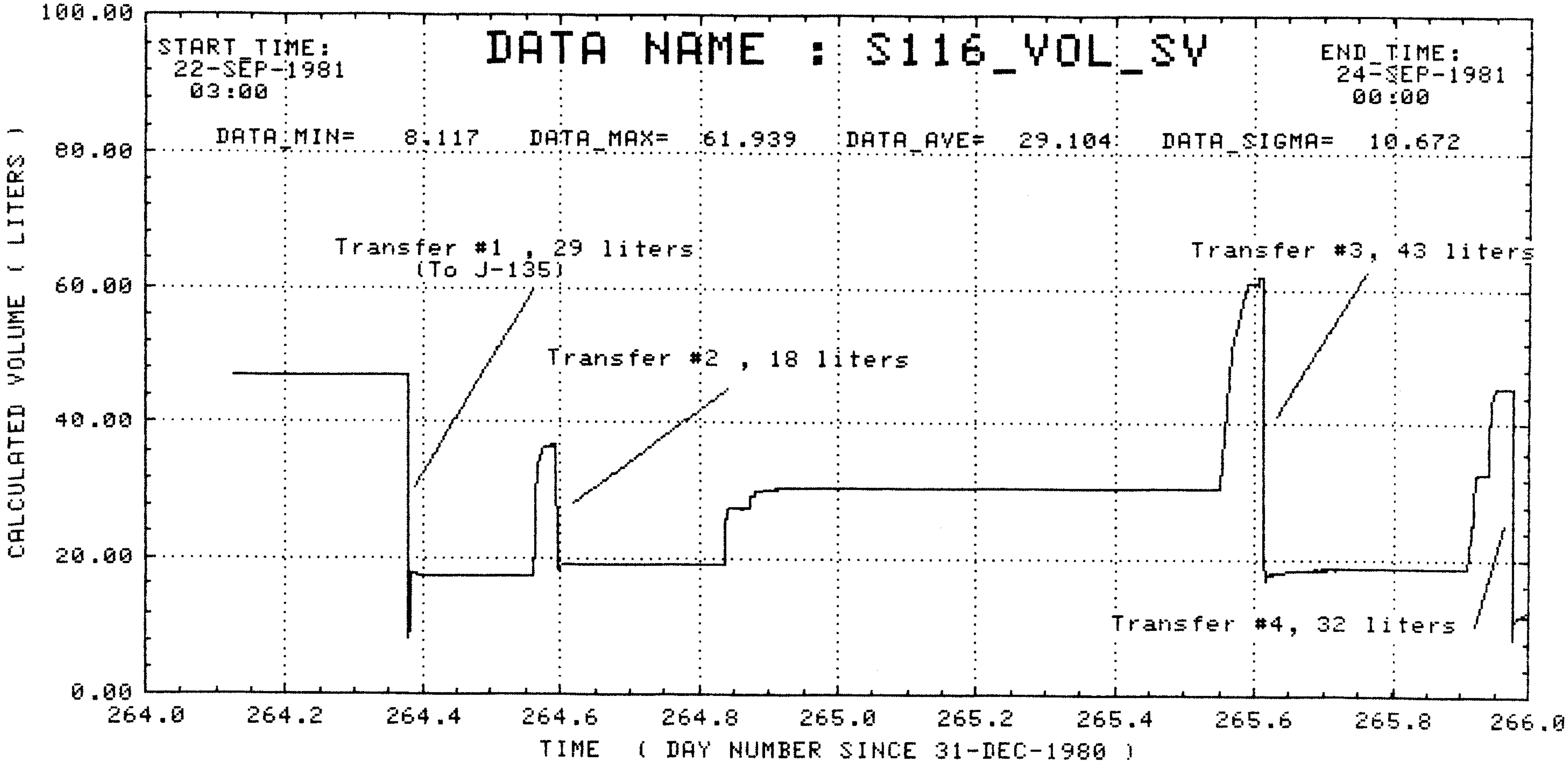

Figure 18. Transfers from S116 to J135

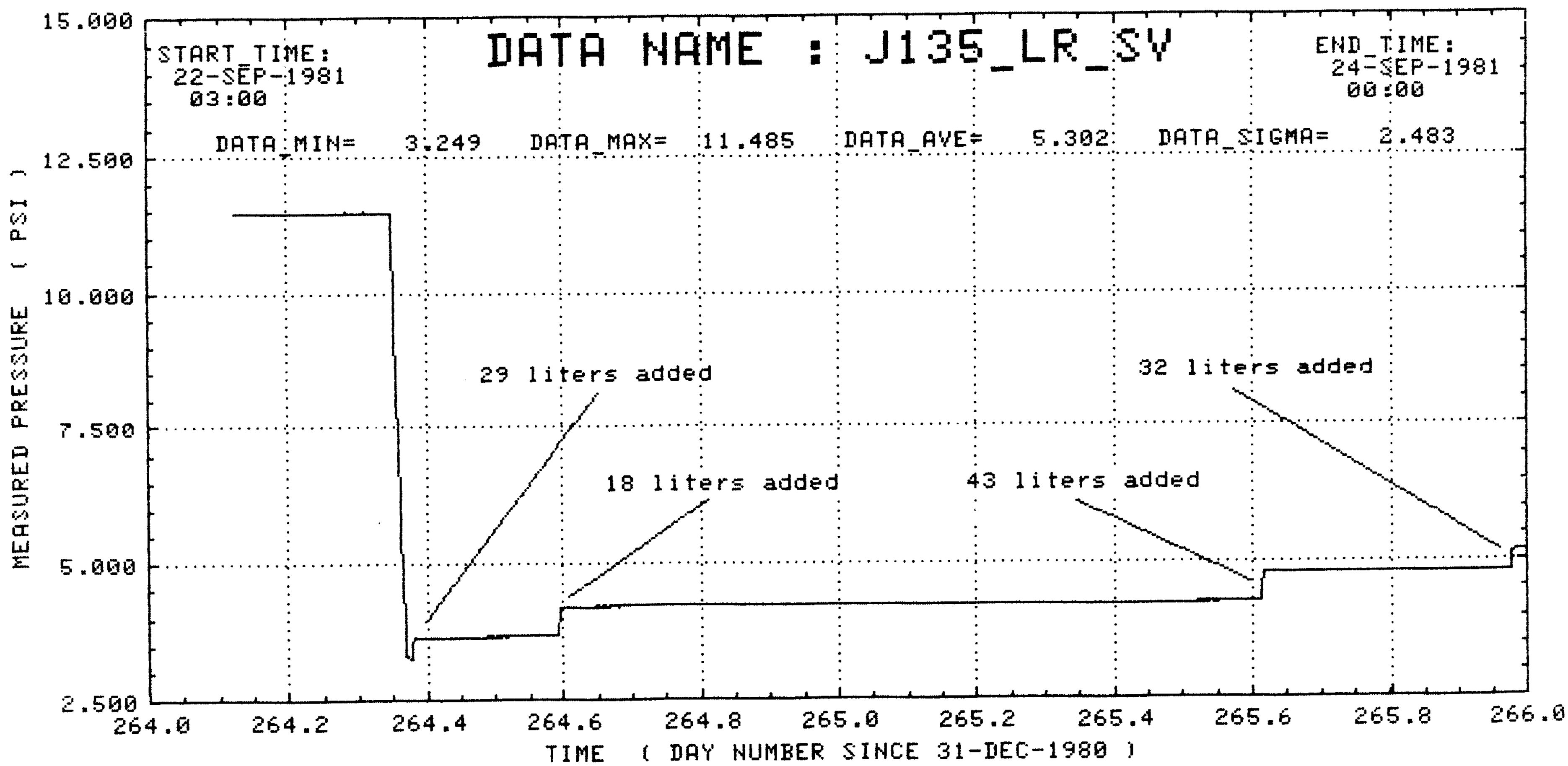

Figure 19. Additions to J135 from S116

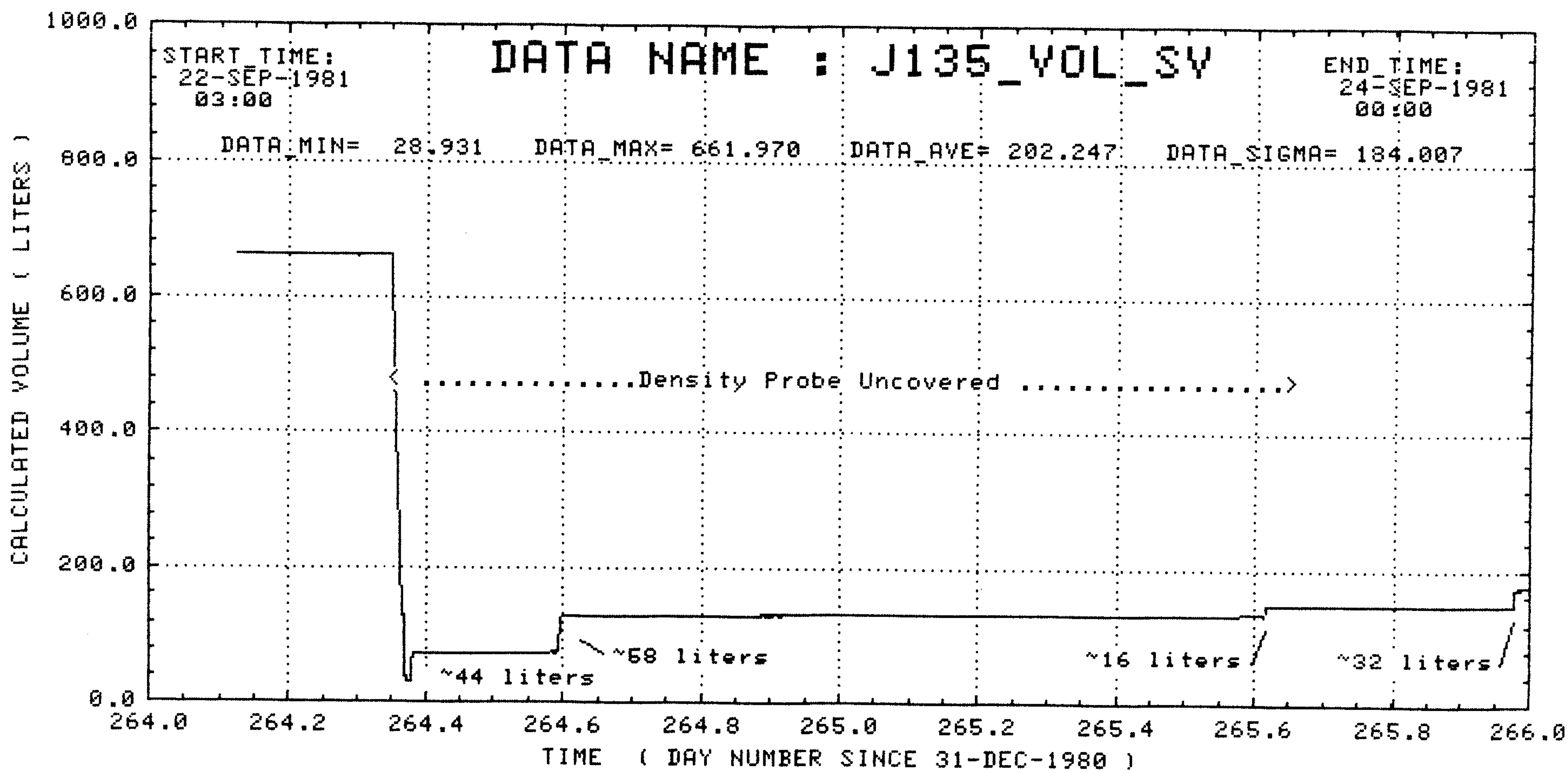

Figure 20. Computed Liquid Volumes for J135 Showing Additions

1.4.2 Example #2. Figures 21 through 24 illustrate further examples of data irregularities generated when a tank density probe is uncovered. They show a transfer from J-Cell collection tank J-135 via evaporator J-125 to receiving tank J-127. Figure 21 shows the slow transfer of liquid from J-135 to the evaporator. Approximately 630 liters of liquid are processed to produce approximately 200 liters of concentrate.

Figure 23 shows the computed specific gravity for J-127. The specific gravity data in Region A are meaningless because the increasing pressure on the density probe has not reached the lower scale limit of the suppressed range. Correct specific gravity values are not obtained until the probe is covered (@ 272.723). Specific gravity values in Region B are climbing towards the correct value as the tank fills. Figure 22 shows the reading of the plant level recorder for J-127 during this period, and Figure 24 shows the computed volume. The trend of addition follows, but accurate values are not obtained until the density probe is covered. The apparent peak at point C is an artifact of the computational process. It is caused by the sharp increase in apparent specific gravity and the slow increase in level in this region. These plots indicate the need for caution in the use of computed volume data where the density probe may not be covered.

1.5 Effect of Temperature Excursions on Tank Readings

Significant changes in the temperature of a tank and its contents can cause changes in the readings of plant instruments. These changes can present problems if precise measurements are attempted without making temperature corrections.

As illustrated in Figure 25, Tank J-128 was heated to boiling during cleanout at the end of a run by passing steam into the tank water jacket. The tank contents were essentially unchanged. The temperature excursion produced changes in the DR, LR, volume, and specific gravity (SPG) plots as illustrated in Figures 26 through 29. As expected, the DR and SPG plots show a decrease with increasing temperature caused by the thermal expansion of the liquid.

The LR pressure can decrease with an increase in temperature because the area of the tank will increase. The LR plot in Figure 27 does show a decrease, but it is more likely that this particular example reflects a small amount of solution boil-off rather than simple tank expansion. The actual level in the tank normally increases because the thermal expansion of the liquid is much higher than that of the tank. The calculated volume data shown in Figure 28 show some increase as expected, but the actual increase due to thermal expansion is slightly confused by the small solution boil-off phenomenon.

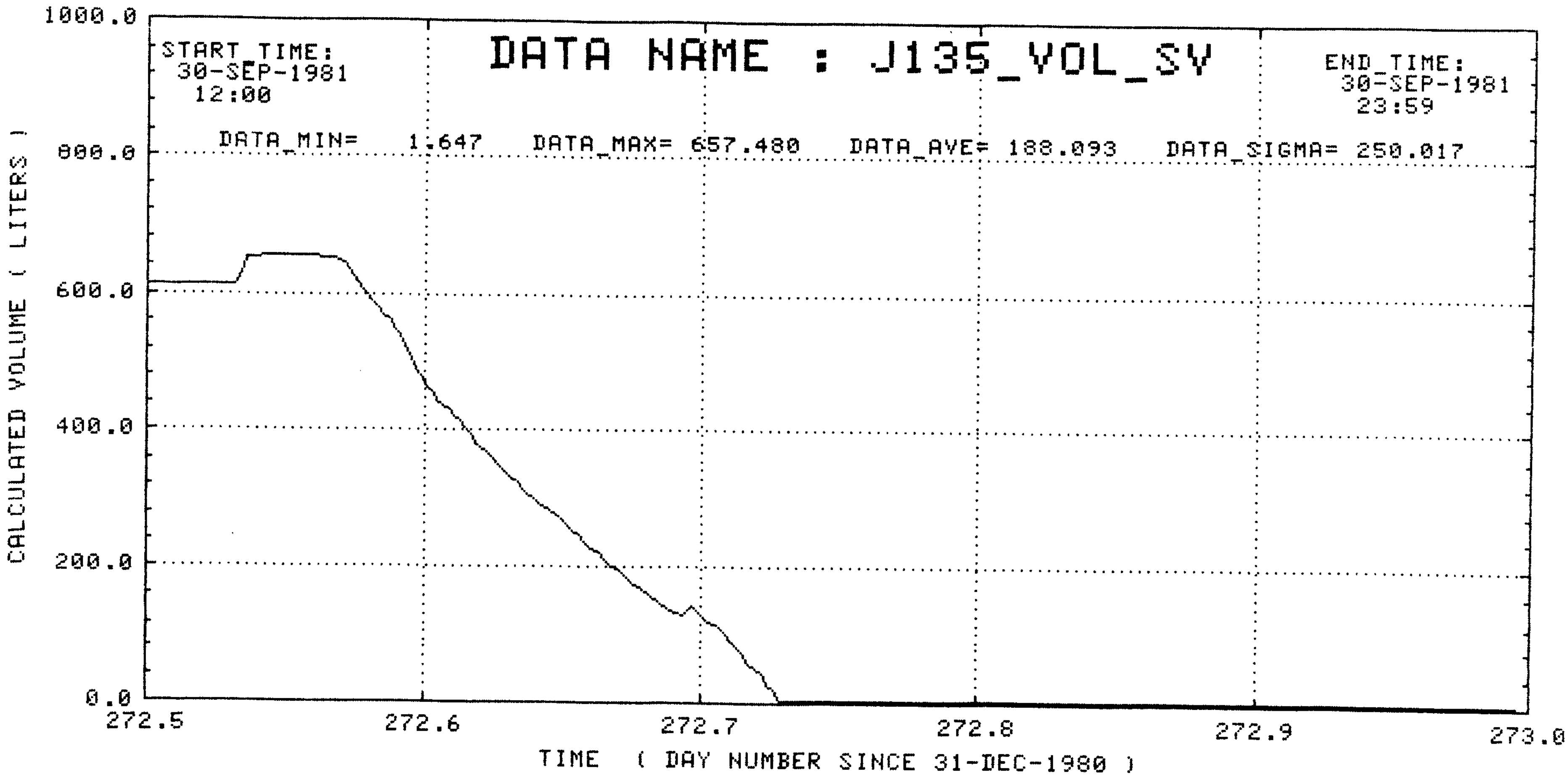

Figure 21. Transfer from J135 to J127

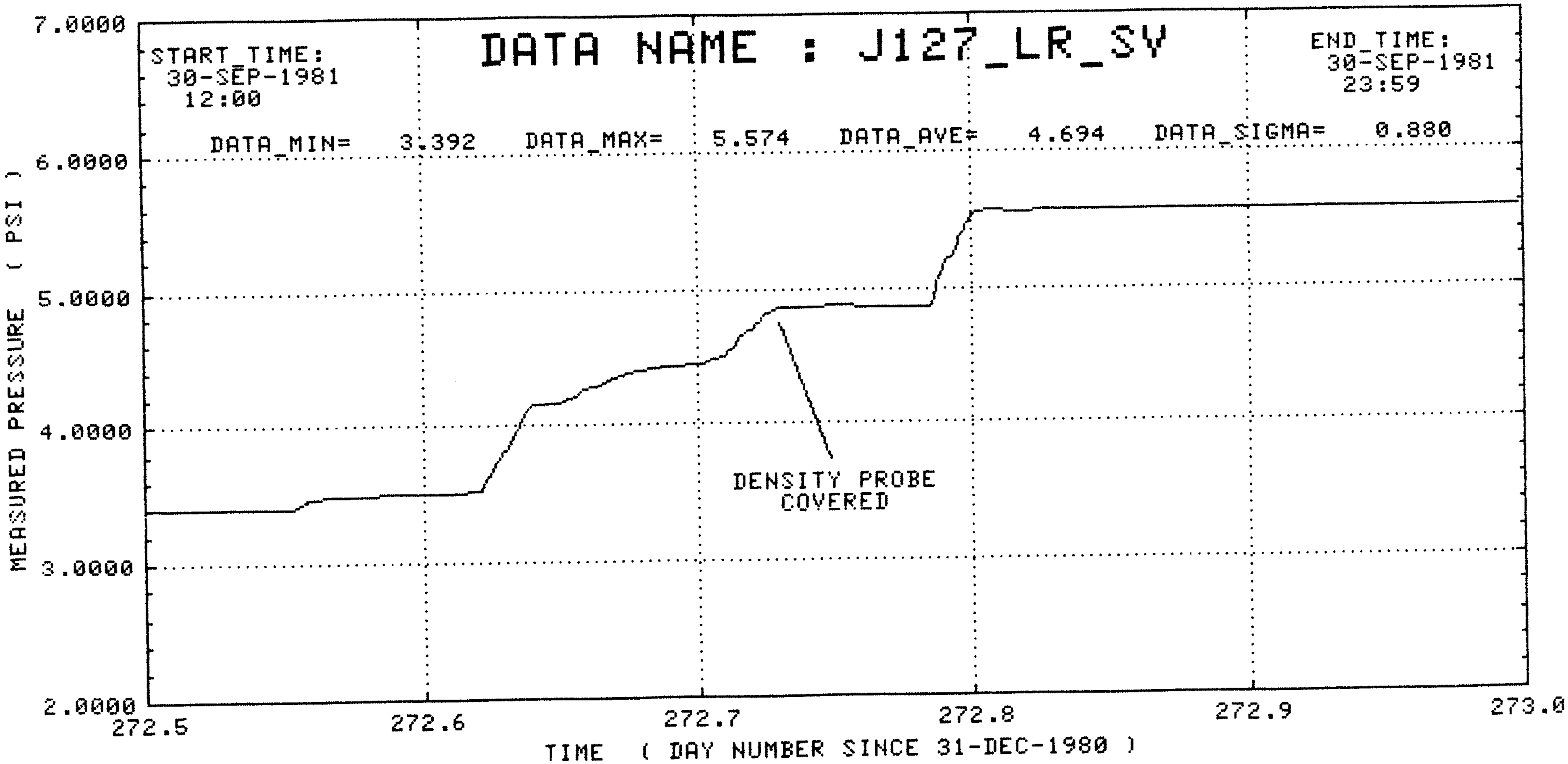

Figure 22. LR Plot for a Transfer into J127 from J135

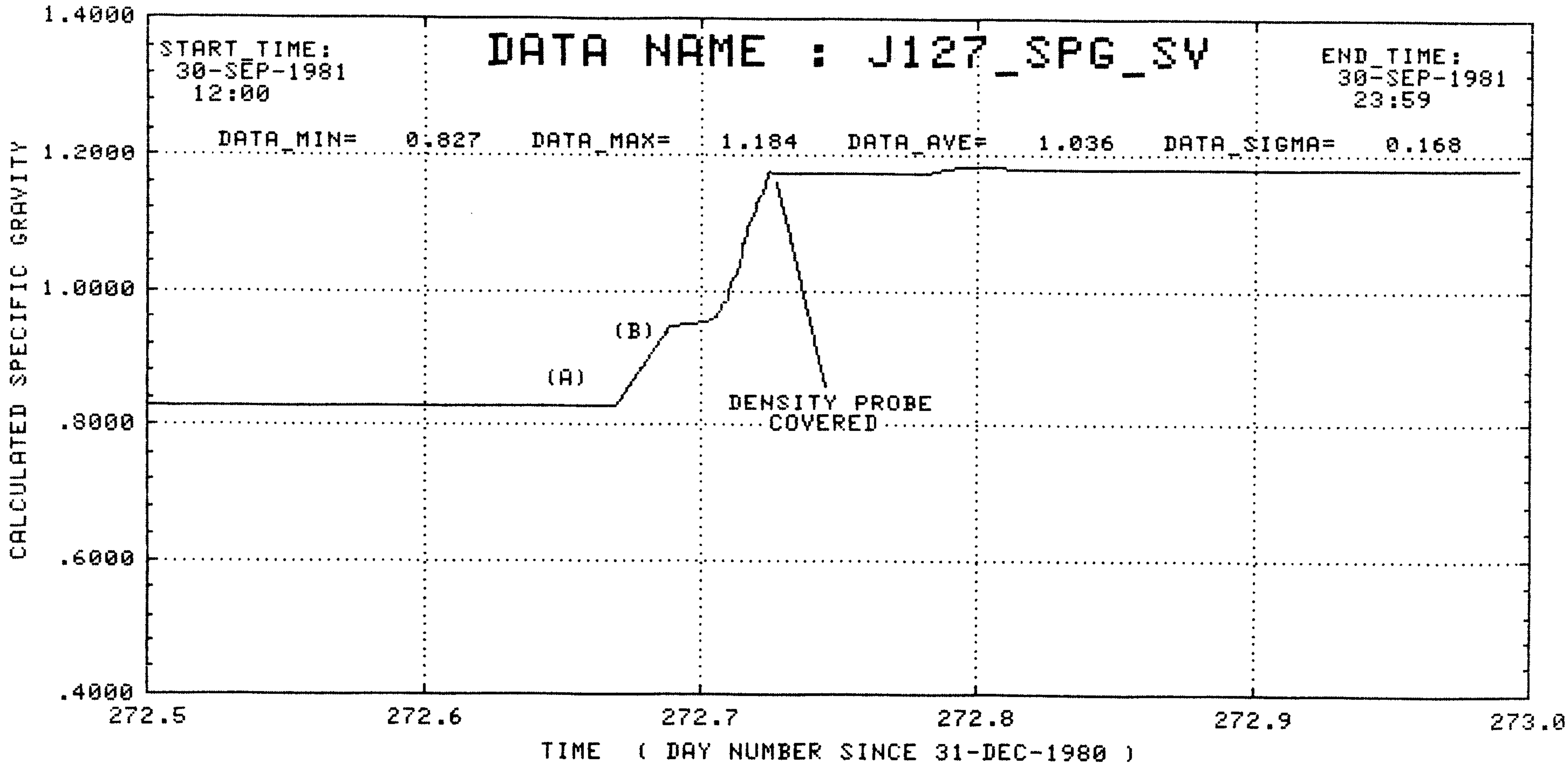

Figure 23. SPG Plot for a Transfer into J127 from J135

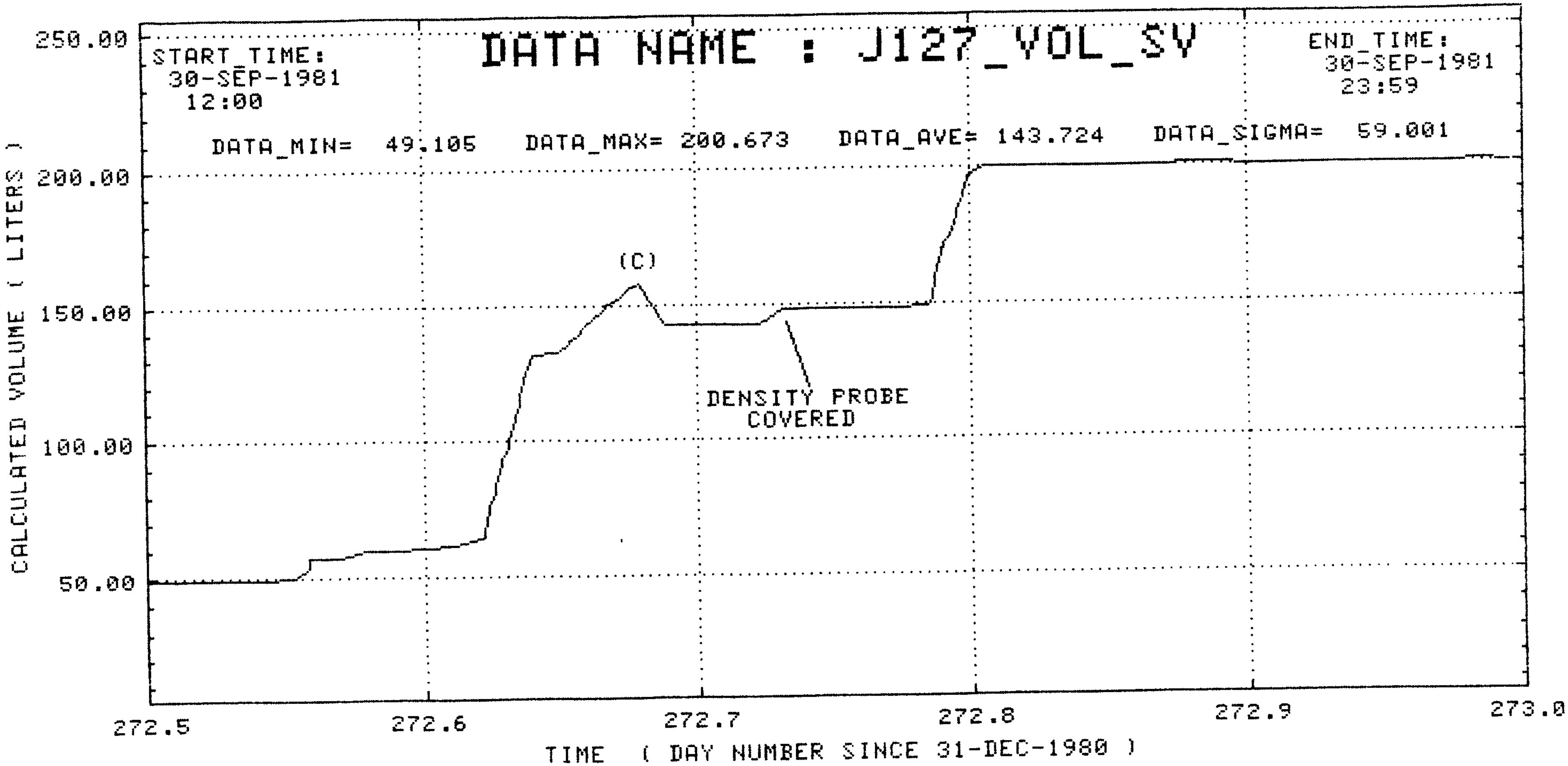

Figure 24. Volume Plot for a Transfer into J127 from J135

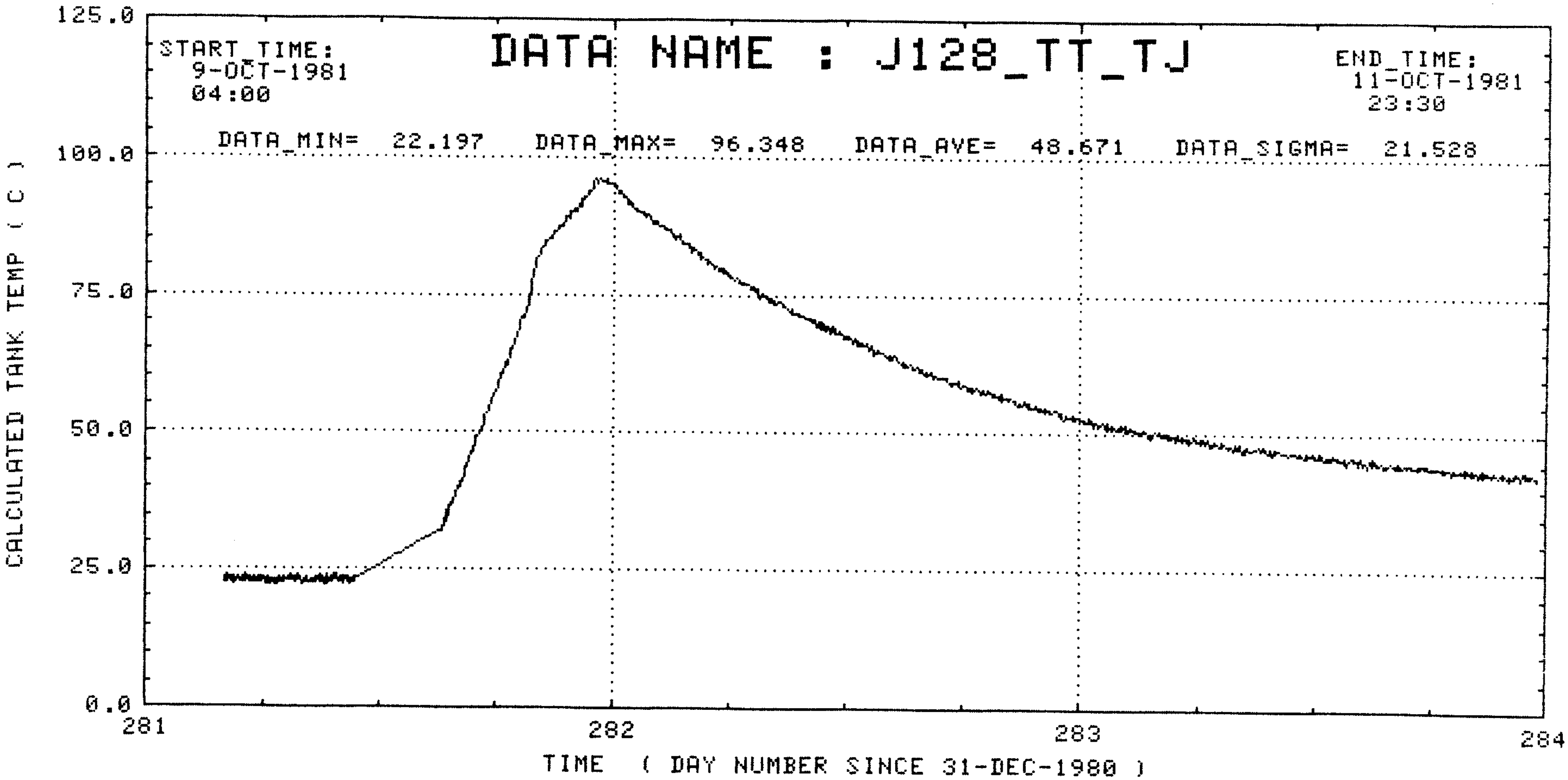

Figure 25. Temperature Excursion in J128

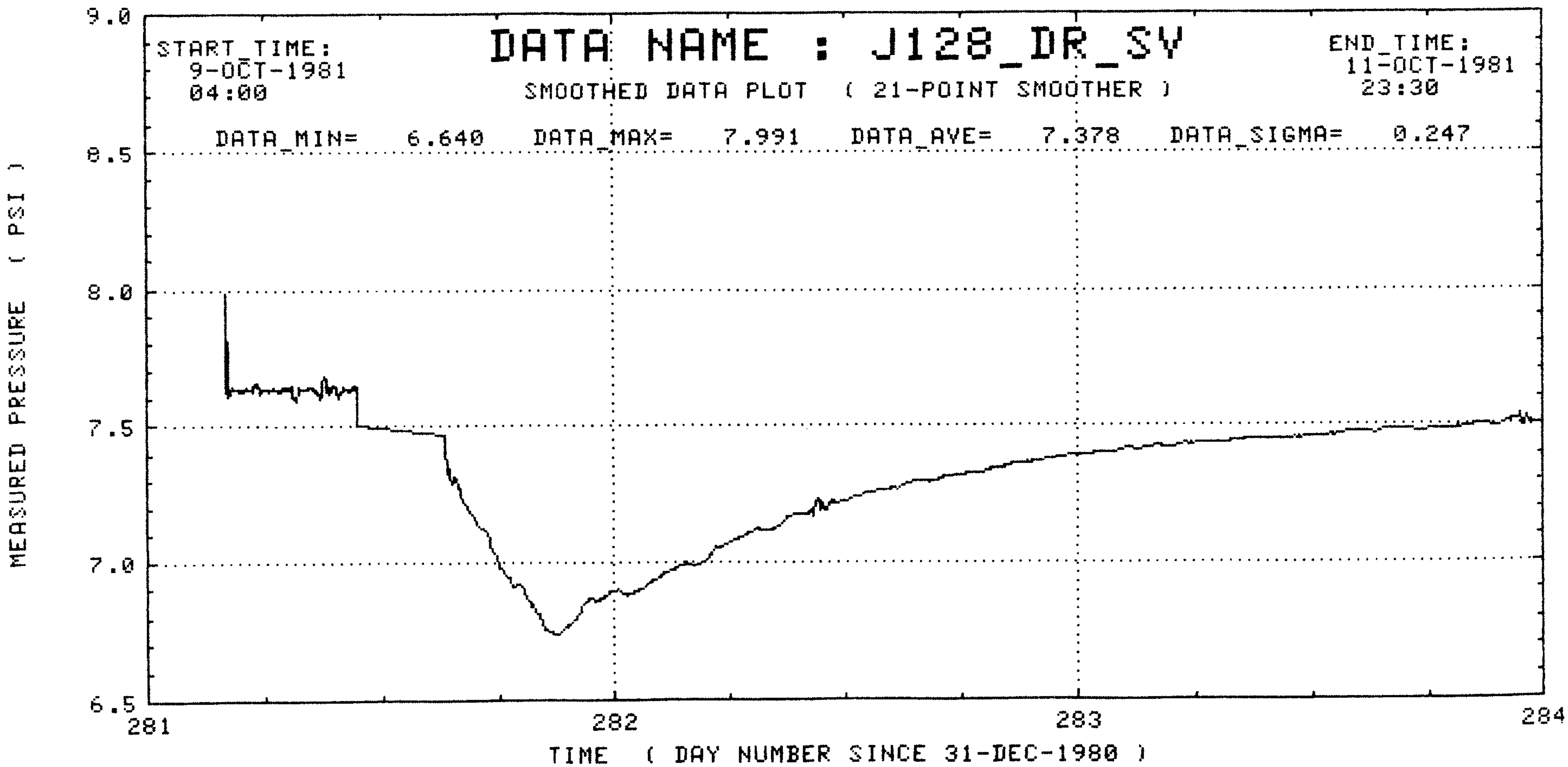

Figure 26. Density Transmitter Signal During Thermal Excursion

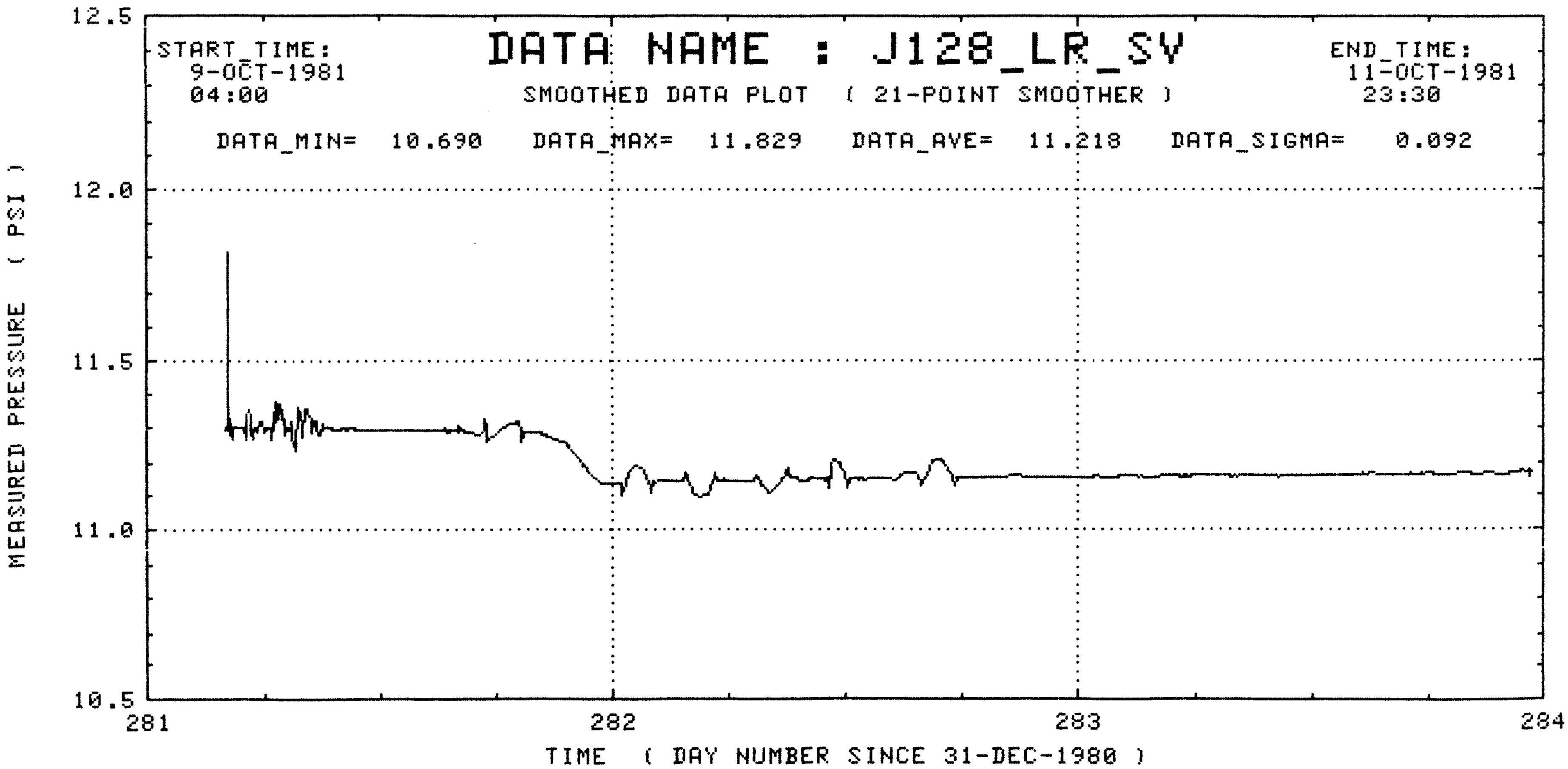

Figure 27. Level Transmitter Signal During Thermal Excursion

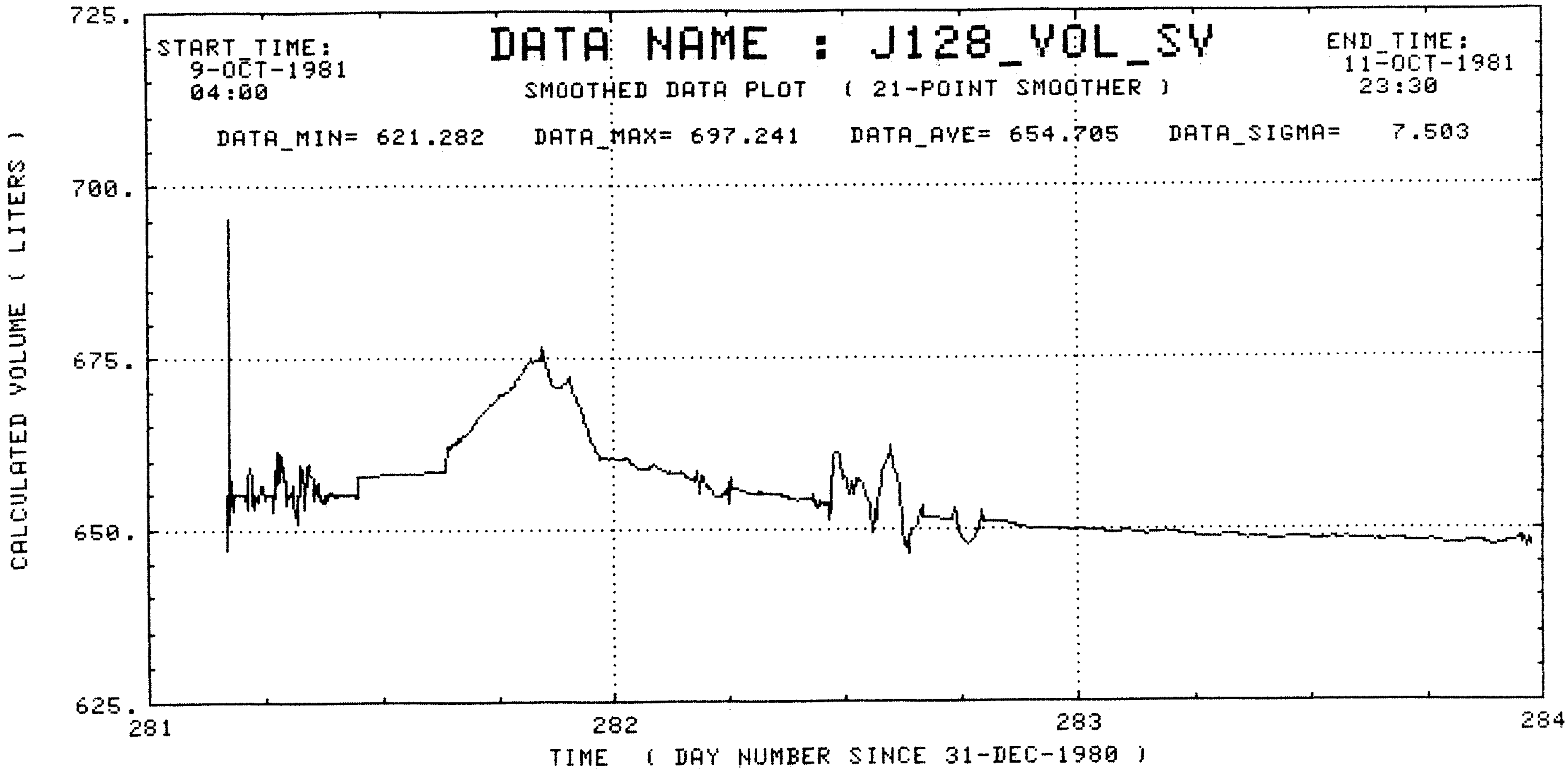

Figure 28. Calculated Volume Plot During Thermal Excursion

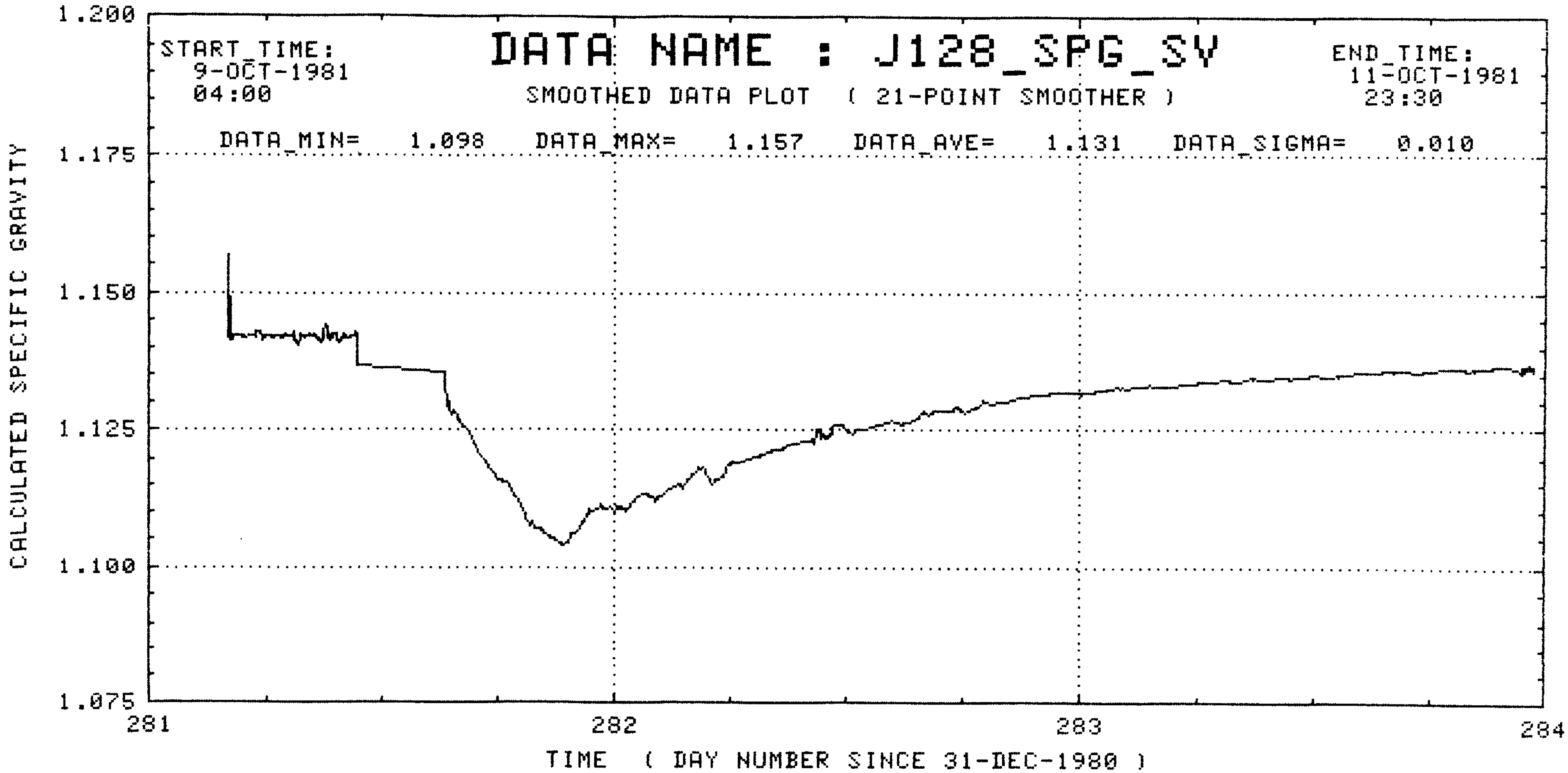

Figure 29. Calculated Specific Gravity Plot During Thermal Excursion

Temperature corrections for density, level, and volume calculations should normallly be used if precise measurements/estimates are desired. To generally illustrate these type of corrections, let S_0 be the known probe tip separation distance for the bubbler probes at calibration temperture T_0. At temperature T_1 this distance would be [5]

$$S_1 = (1 + \alpha \, \Delta T)S_0 \; , \tag{5-1}$$

where α is the coefficeint of linear expansion (assumed the same for both probe and tank materials) and

$$\Delta T = T_1 - T_0 \; . \tag{5-2}$$

The liquid density ρ_1 at temperature T_1 is calculated using the above S_1 as

$$\rho_1 = \frac{P_{L1} - P_{D1}}{S_1 \frac{g}{gc}} \; , \tag{5-3}$$

where:

P_{L1} = major (level) probe differential pressure relative to the vapor head,

P_{D1} = minor (density) probe differential pressure relative to the vapor head,

g = local acceleration due to gravity, and

gc = units conversion constant.

Similarly, the liquid level above the major probe tip at temperature T_1 is calculated using density ρ_1 as

$$L_1 = \frac{P_{L1}}{\rho_1 \frac{g}{gc}} \; . \tag{5-4}$$

The volume within a tank below measurement level L is generally calibrated as a polynominal function g(L) at the calibration temperature T . With L_1 the measurement level at temperature T_1, a mark on the tank surface corresponding to level L_1 back at temperature T_0 would be at the reference level L_r related to L_1 as

$$L_r = \frac{L_1}{1 + \alpha\ \Delta T} , \tag{5-5}$$

where again α is the coefficient of linear expansion for the tank material. The reference volume of the tank below this reference level at temperature T_0 is thus

$$V_r = g(L_r) = g\left(\frac{L_1}{1 + \alpha\ \Delta T}\right) . \tag{5-6}$$

Due to thermal expansion of the tank material, the new tank volume at temperature T_1 corresponding to the reference volume at temperature T_0 can be approximated using a Taylor series expansion (keeping only the linear terms) as

$$V_1 \simeq V_r + \left(\frac{\partial V}{\partial T}\right)_{V_r} \Delta T \simeq (1 + 3\alpha\ \Delta T)\ V_r , \tag{5-7}$$

where

$$\left(\frac{\partial V}{\partial T}\right)_{V_r} \simeq 3\alpha\ V_r \tag{5-8}$$

and 3α is the approximate coefficient of cubical expansion for the tank. Consequently, substituting (5-6) into (5-7) yields the desired form[6]

$$V_1 \simeq (1 + 3\alpha\ \Delta T)\ g\left(\frac{L_1}{1 + \alpha\ \Delta T}\right) . \tag{5-9}$$

This functional form is independent of liquid expansion characteristics except through variation of L_1 due to physical changes in S_1, P_{L_1}, P_{D_1}, and ρ_1 and their interrelations given by (5-1), (5-3), and (5-4).

1.6 Incomplete Volume Calibration Equation

Simple linear tank calibration equations were used for most plant tanks. These would be completely valid if plant tanks were simple right cylinders. The tanks are not, however, and they may have internal structures and dished bottoms which would make the linear equations invalid. Figure 30 is a plot of volume data for a transfer out of tank G-105. The data indicate negative volumes after the transfer, which are not valid. The cause is the use of both bad density data and a volume equation which is used outside the range for which it was calibrated. The bad density data were obtained after uncovering of the density probe. The volume equation was nominally valid only for liquid levels of 10 or more inches. The calculated levels were negative because the LR transmitter output dropped below 3 psig.

1.7 Scanivalve Data Spikes

Data spikes were occasionally observed on te Scanivalve data, as illustrated in Figures 31 through 34. The data spikes in these examples came from Scanivalve Unit #1, but similar data spikes have sometimes been observed from Scanivalve Units #2 and #3 (see data plots in Appendix E). When one unit behaves erratically, the other may still be stable. The problem is thus not caused by a common source such as the 3 and 15 psig Schwien and Son, Inc. regulator signals.

The exact cause of the problem within a Scanivalve instrumentation unit is unknown, but it appears to be somewhat random and is "magnified" when it occurs on either the high or low calibrate (Schwien regulator) signals. This magnification may be demonstrated using the equation for recomputed pressure (see Appendix F) given as

$$P_{recomputed} = \frac{12P + 3P_{15} - 15\ P_3}{P_{15} - P_3} \qquad (5\text{-}10)$$

where:

P = process signal pressure,

P_3 = nominal 3 psig reference pressure, and

P_{15} = nominal 15 psig reference pressure.

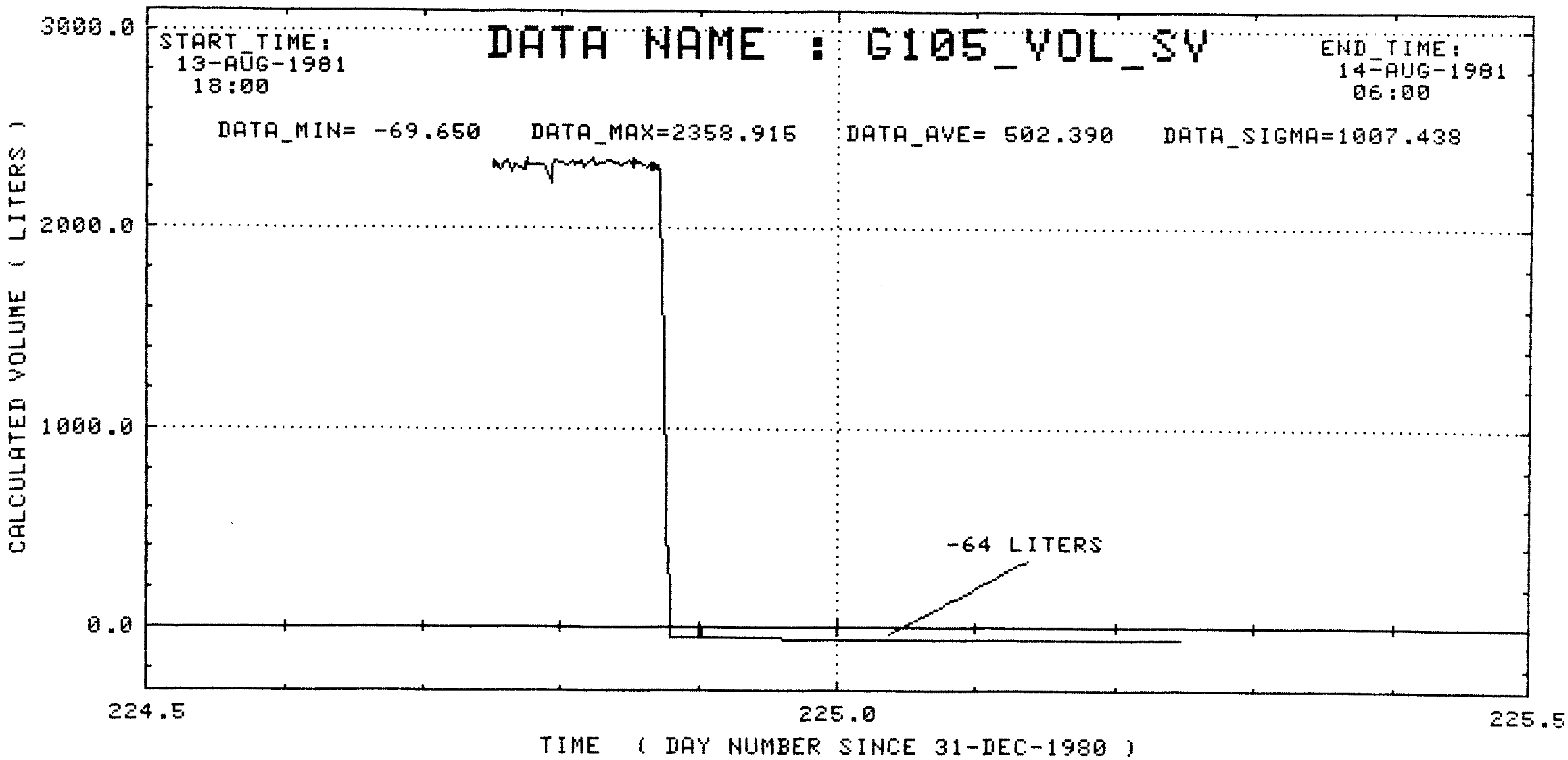

Figure 30. Example of Erroneous Negative Volumes

If the P_{15} reference pressure contains some delta spike δ_{15} above the nominal value $\overline{P}_{15}$, as in Figure 31, such that

$$P_{15} = \overline{P}_{15} + \delta_{15}, \tag{5-11}$$

then by Taylor series expansion the recomputed pressure will become

$$P_{recomputed} \approx \overline{P}_{recomputed} + \left(\frac{\partial P_{recomputed}}{\partial P_{15}}\right) \delta_{15}$$

$$\approx \overline{P}_{recomputed} - \left(\frac{P - 3}{12}\right) \delta_{15} \; . \tag{5-12}$$

Similarly, if the P_3 reference pressure contains some delta spike δ_3 above the nominal value $\overline{P}_3$, as in Figure 32, such that

$$P_3 = \overline{P}_3 + \delta_3 \; , \tag{5-13}$$

then the recomputed pressure will become

$$P_{recomputed} \approx \overline{P}_{recomputed} - \left(\frac{15 - P}{12}\right) \delta_3 \; . \tag{5-14}$$

It is seen from equations (5-12) and (5-14) that both the δ_{15} and δ_3 spikes map negatively onto measured pressures in the 3 to 15 psig range, and their effect is proportional to the measured pressure. From (5-12) it is seen that a δ_{15} spike has maximum effect at $P = 15$ and near zero effect at $P = 3$. Conversely, as seen from (5-14), a δ_3 spike has maximum effect at $P = 3$ and near zero effect at $P = 15$.

This is confirmed by observing that the times of the positive spikes in Figure 31 coincide nearly exactly with the negative spikes in Figure 33. As expected, the positive spikes in Figure 32 do not appear as negative spikes in Figure 33 because the measured pressure is near 15 psig. However, the negative spikes in Figure 34 are a composite of the P_{15} and P_3 delta spikes, because the nominal pressure is near mid-scale (actually about 5.8 psig).

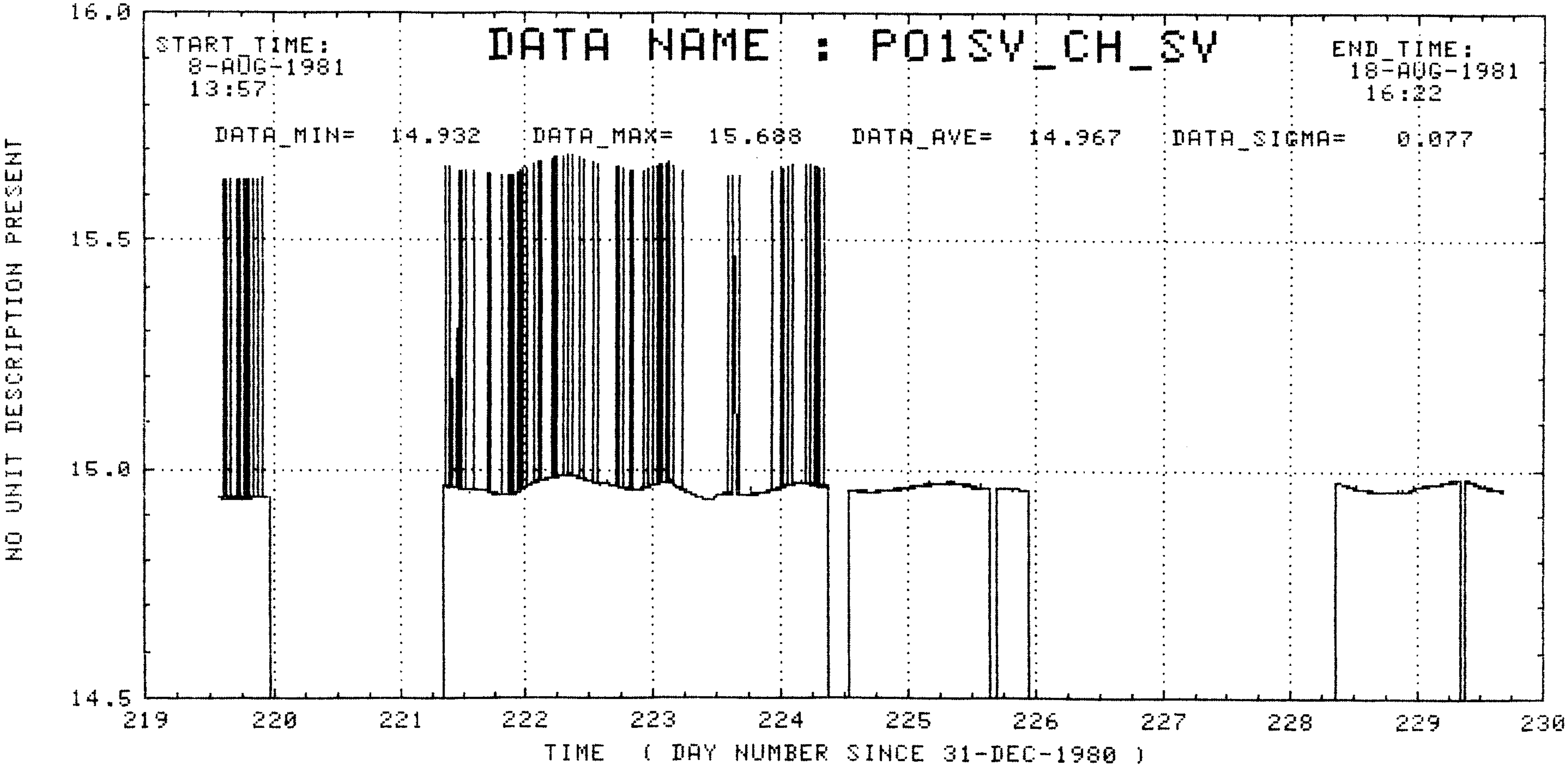

Figure 31. Scanivalve Data Spikes on the High Level Calibrate Signal

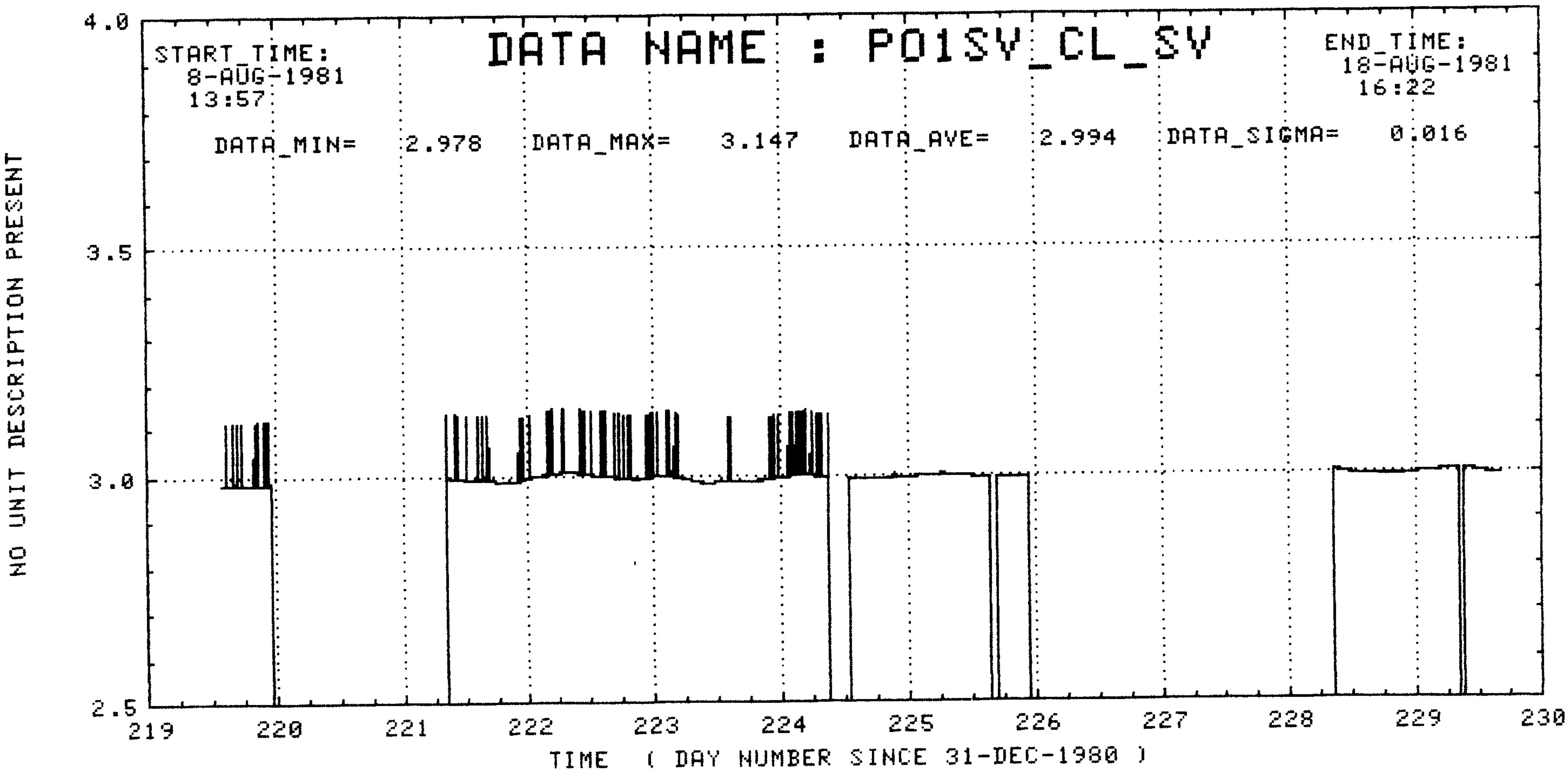

Figure 32. Scanivalve Data Spikes on the Low Level Calibrate Signal

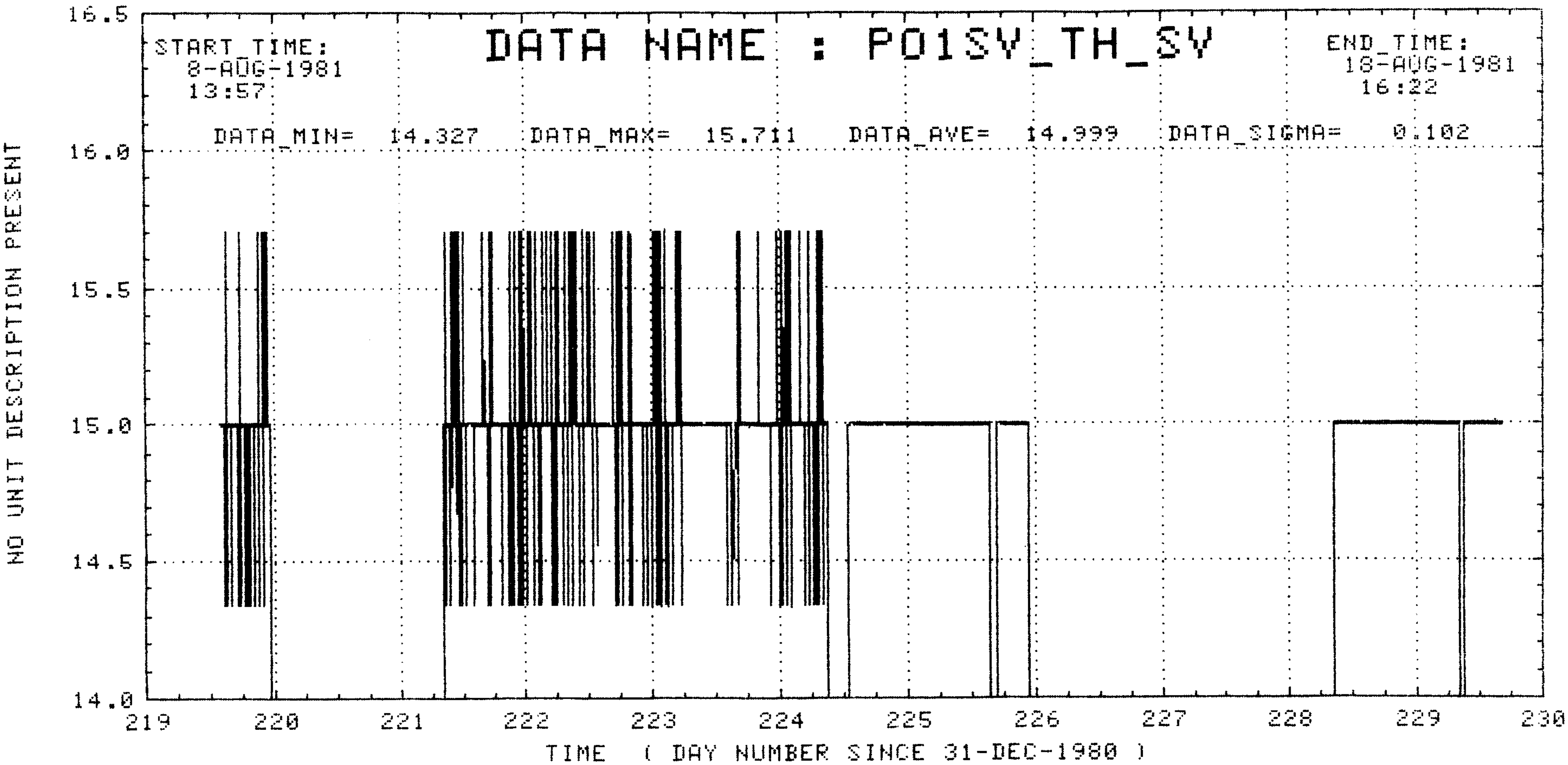

Figure 33. Scanivalve Data Spikes on the Recomputed Calibrate Signal

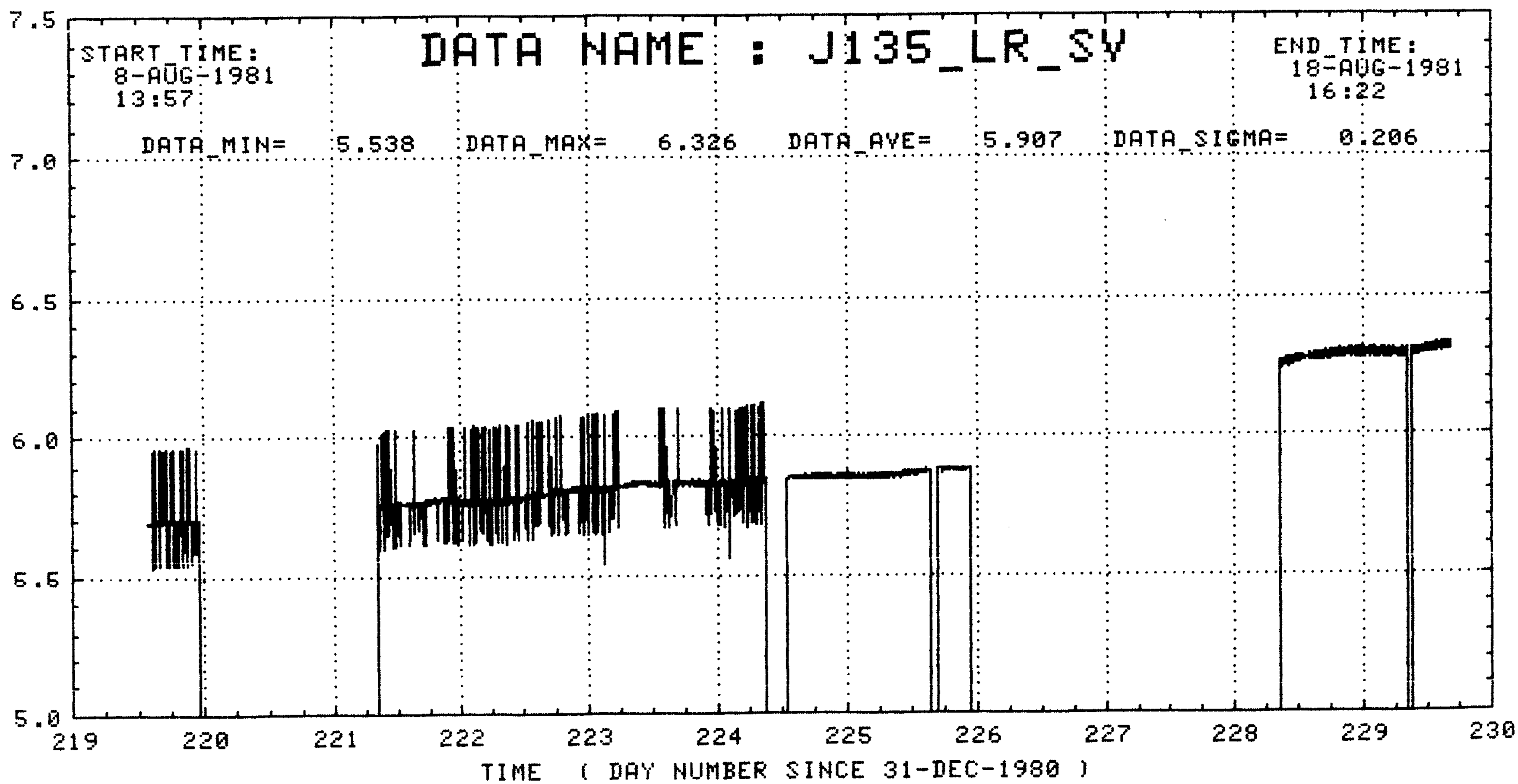

Figure 34. Example of Scanivalve Data Spikes on Process Data

The positive spikes in Figures 33 and 34 are attributed to delta spikes occurring during the actual pressure measurement prior to the application of the recompute equation (5-10). They are the same type of positive spikes as illustrated in Figures 31 and 32 and are apparently proportional to the measured pressure, e.g. +0.7 psig at 15 psig but +0.14 psig as 3 psig.

1.8 Scanivalve Instrumentation Accuracy

The Scanivalve instrumentation precision and accuracy are evaluated in some detail in Appendix F, which makes use of some recent Scanivalve calibration data presented in Appendix G. Conclusions drawn from this evaluation are presented in Section VI of this report.

2. PROCESS DATA EVALUATION

2.1 Typical Operation Profile for an Accountability Tank

A typical sequence of operations for an input accountability batch is illustrated in Figures 35 through 40. The first portion of the volume plot shows tank G-155 gradually filling with dissolver solution routed via the F-Cell centrifuges from the electrolytic dissolver. An abrupt rise in volume and drop in SPG occurs when feed adjustment solution was added from the process makeup (PM) area. Subsequent dissolver solution was then collected in G-105 while the batch in G-155 was held for mixing and measurement.

Data for G-155-SP-FS (the sparge flowswitch) and for G-655-SM-PS (the sampler pressure switch) show that these devices were activated at the appropriate times. However, due to system configuration problems, the exact times of changes of state were lost so that sparge mixing and sample recirculation durations cannot be determined.

Shortly after noon on August 12, the batch was transferred to the column feed tank (G-106). The level data proved that no solution was added to G-155 between the time of sampling and the time of transfer.

A detailed look at the transfer jet thermocouple shows the normal behavior of a steam jet transfer. Temperature rose abruptly from 24 to 35^{o}C when the steam was turned on. During the transfer period ($\sim$9 minutes), the temperature rose gradually from 35 to 39^{o}. The end of the transfer is obscured by a data dropout, but extrapolation of the volume data indicates that the transfer would have ended within the next 1 minute data interval. When the transfer ended, the jet temperature rose rapidly to some temperature greater than 60^{o}C, since it had already cooled to 58^{o}C when the data dropout ended.

The jet pressure switch data show that steam was applied to the jet, but again the digital state changes were lost due to data acquisition control problems existing at the time.

The apparent negative volume at the end of the transfer is due to the calibration curve used for calculating tank volumes. This curve was a linear fit emphasizing the upper regions of the tank where accountability volume measurements are made. No attempt has been made to fit the calibration curve to the special geometry of the tank bottom.

Approximately 20 minutes after the transfer, a small amount of liquid was added to G-155 from either F-Cell or the PM area.

2.2 Comparison of Accountability Tank Measurements

High accuracy volume measurements for first-cycle accountability tanks G-105 and G-155 are made by a Ruska electromanometer system. These data for the process batches during data window #1 were provided by the

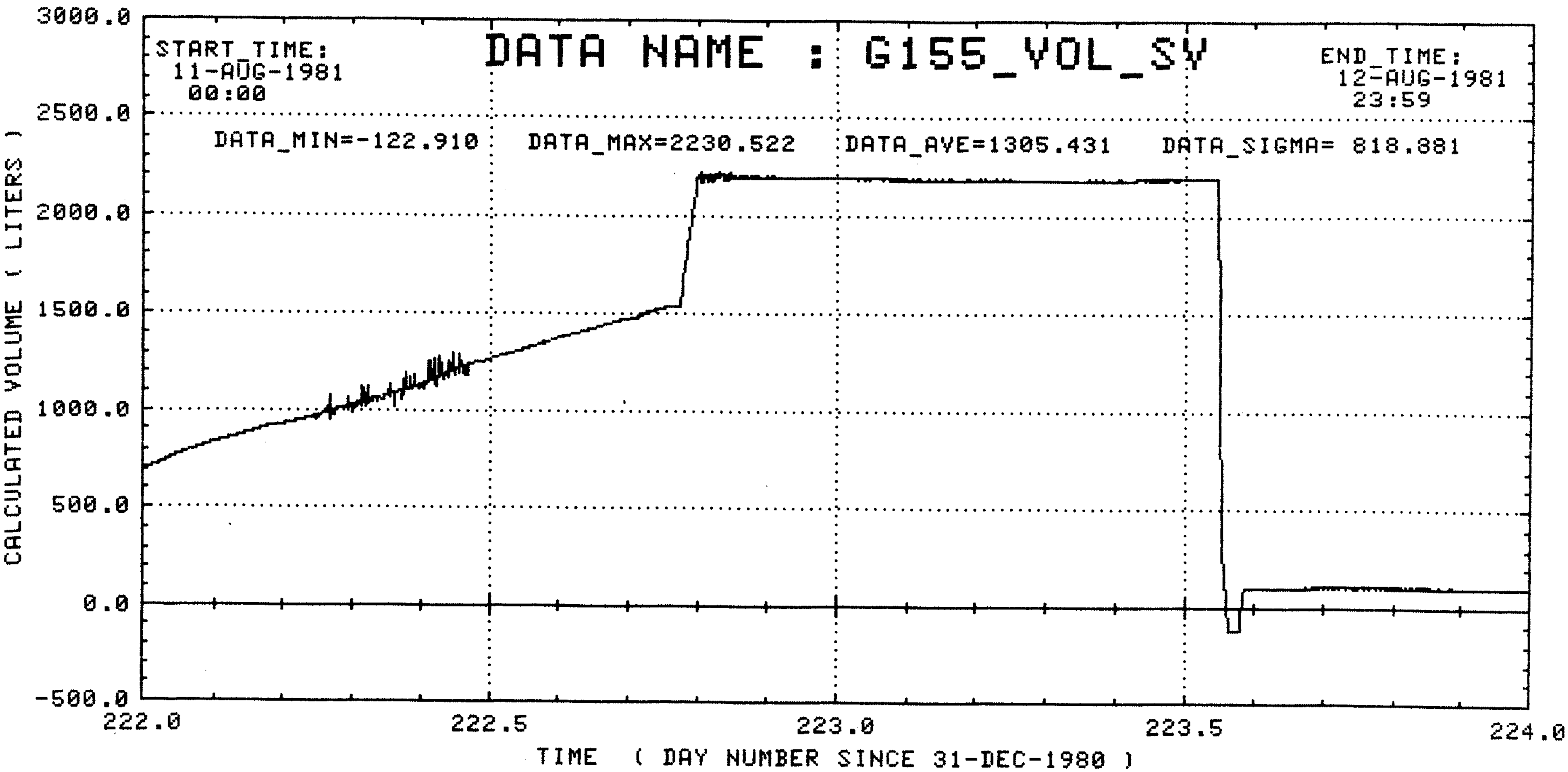

Figure 35. G155 Volume Plot for a Typical Operation Profile

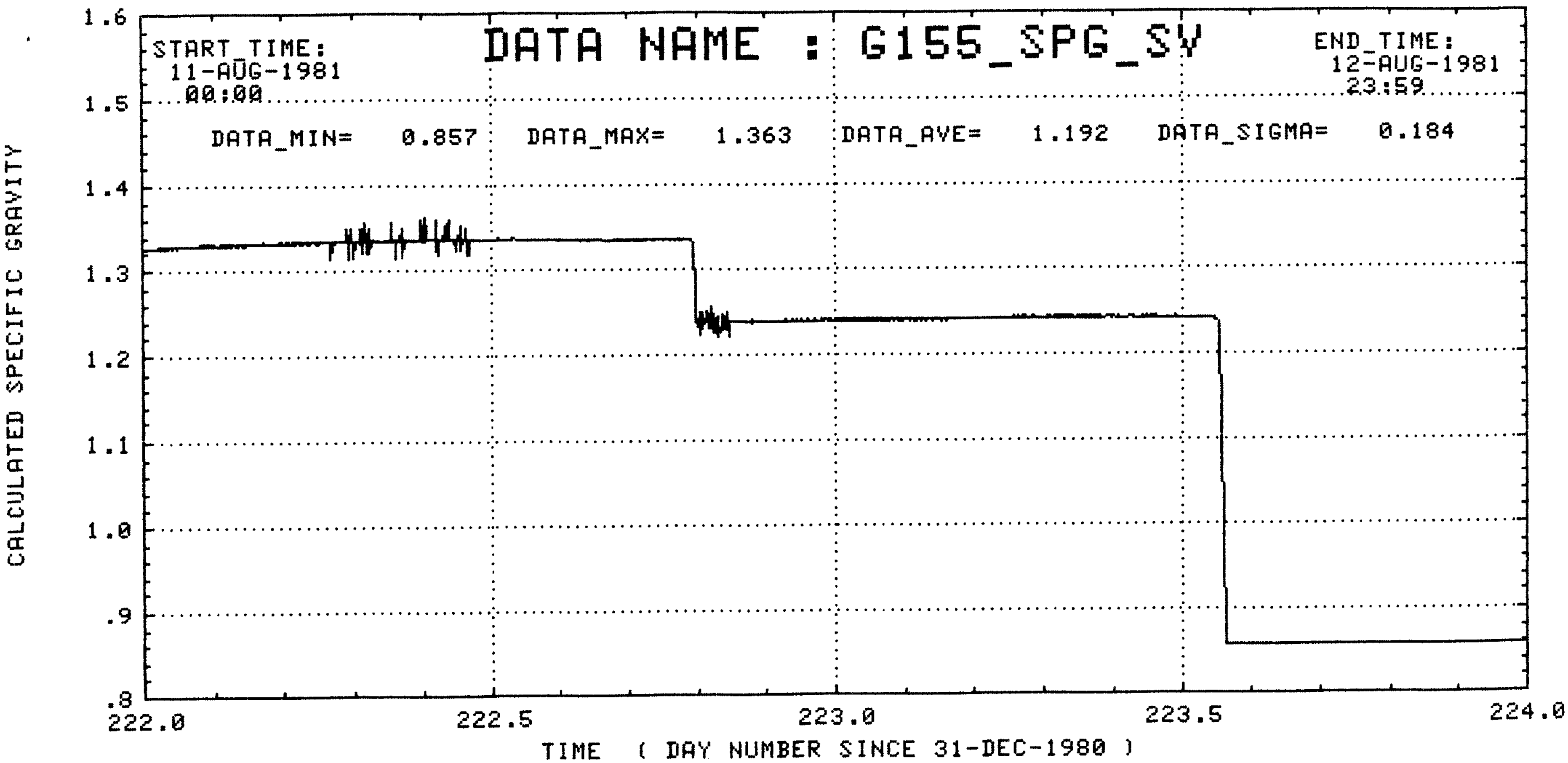

Figure 36. G155 SPG Plot for a Typical Operation Profile

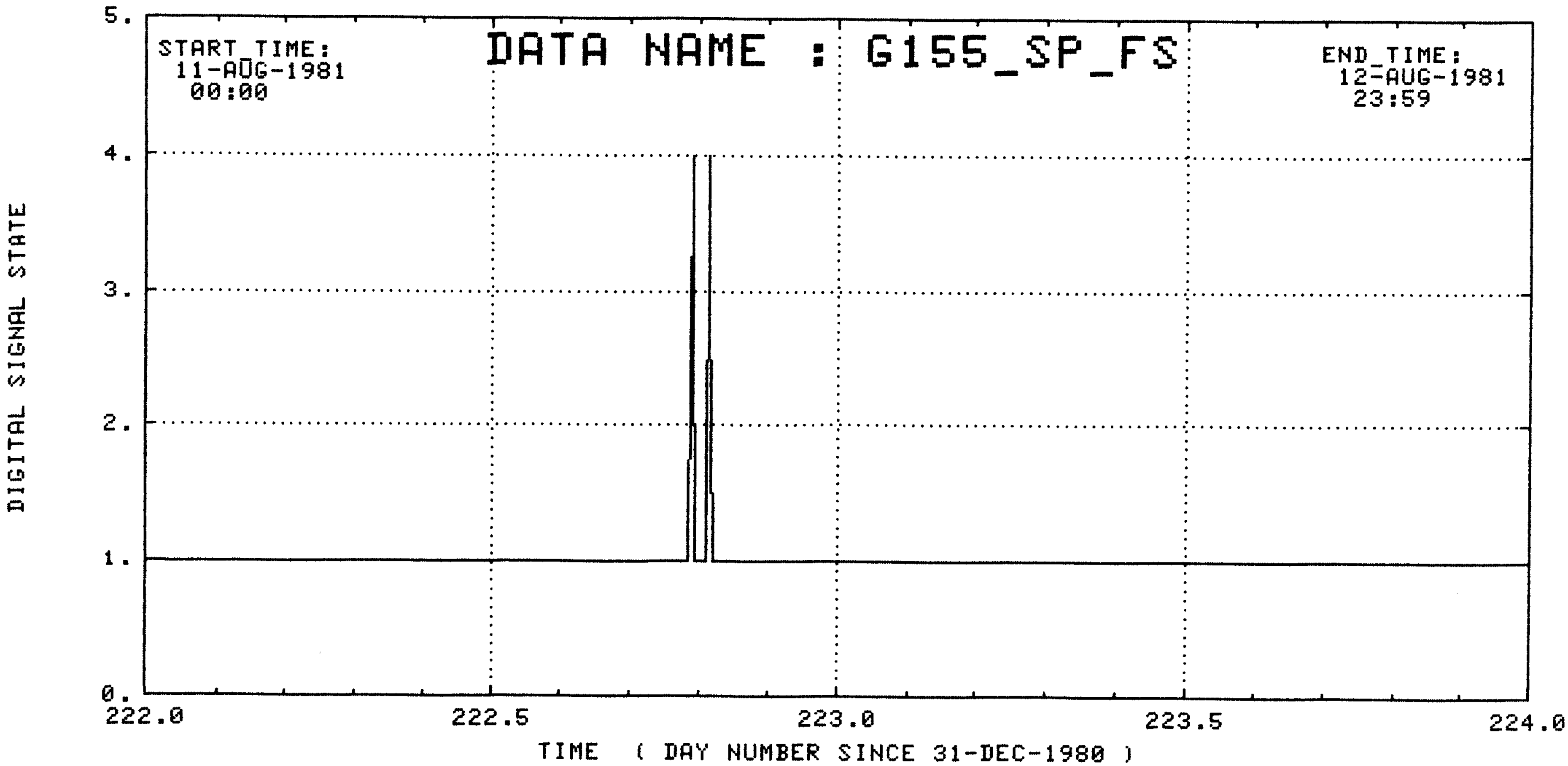

Figure 37. G155 Sparge Flowswitch Data Plot for a Typical Operation Profile

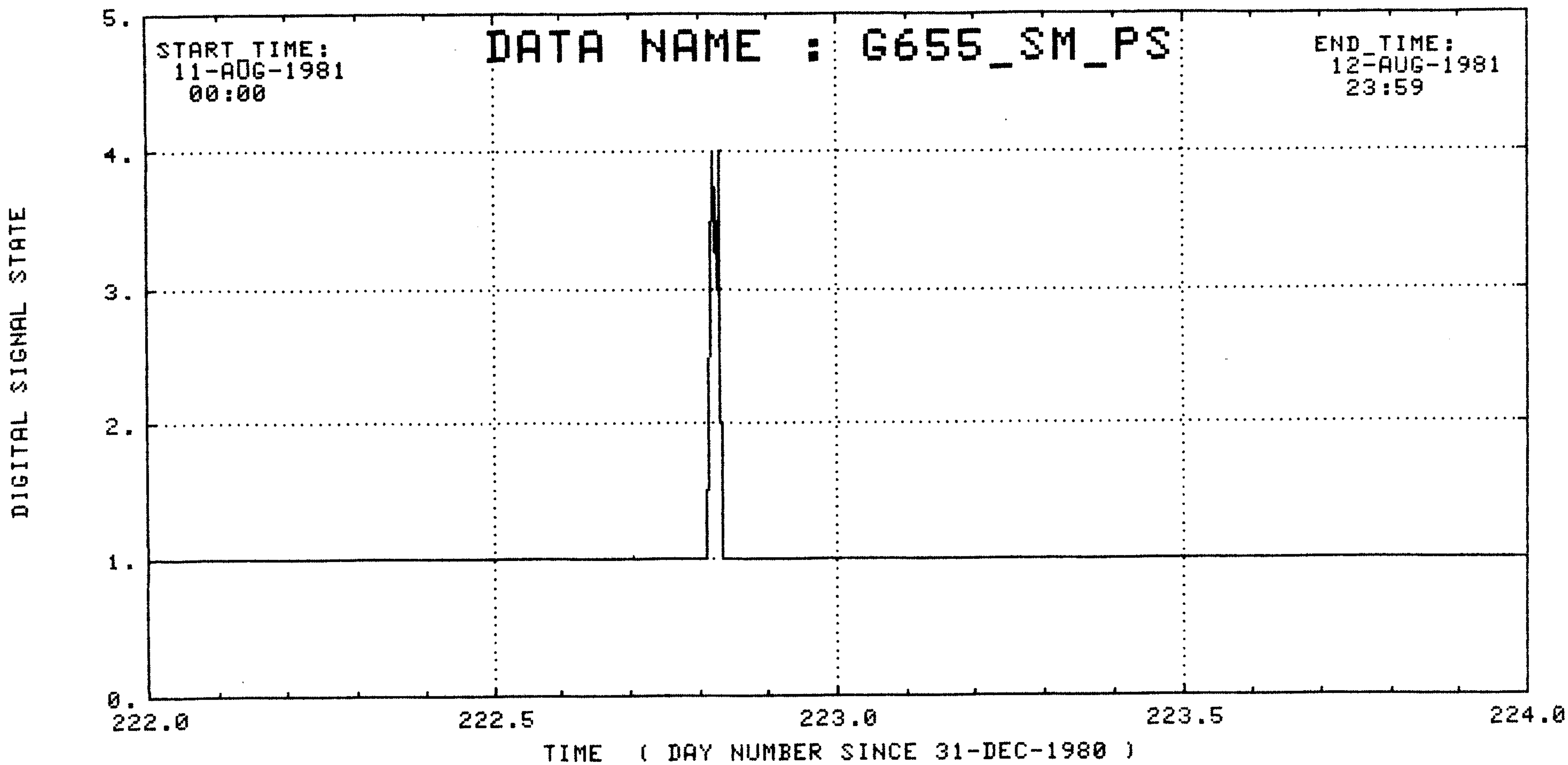

Figure 38. G155 Sampler Pressure Switch Data Flot for a Typical Operation Profile

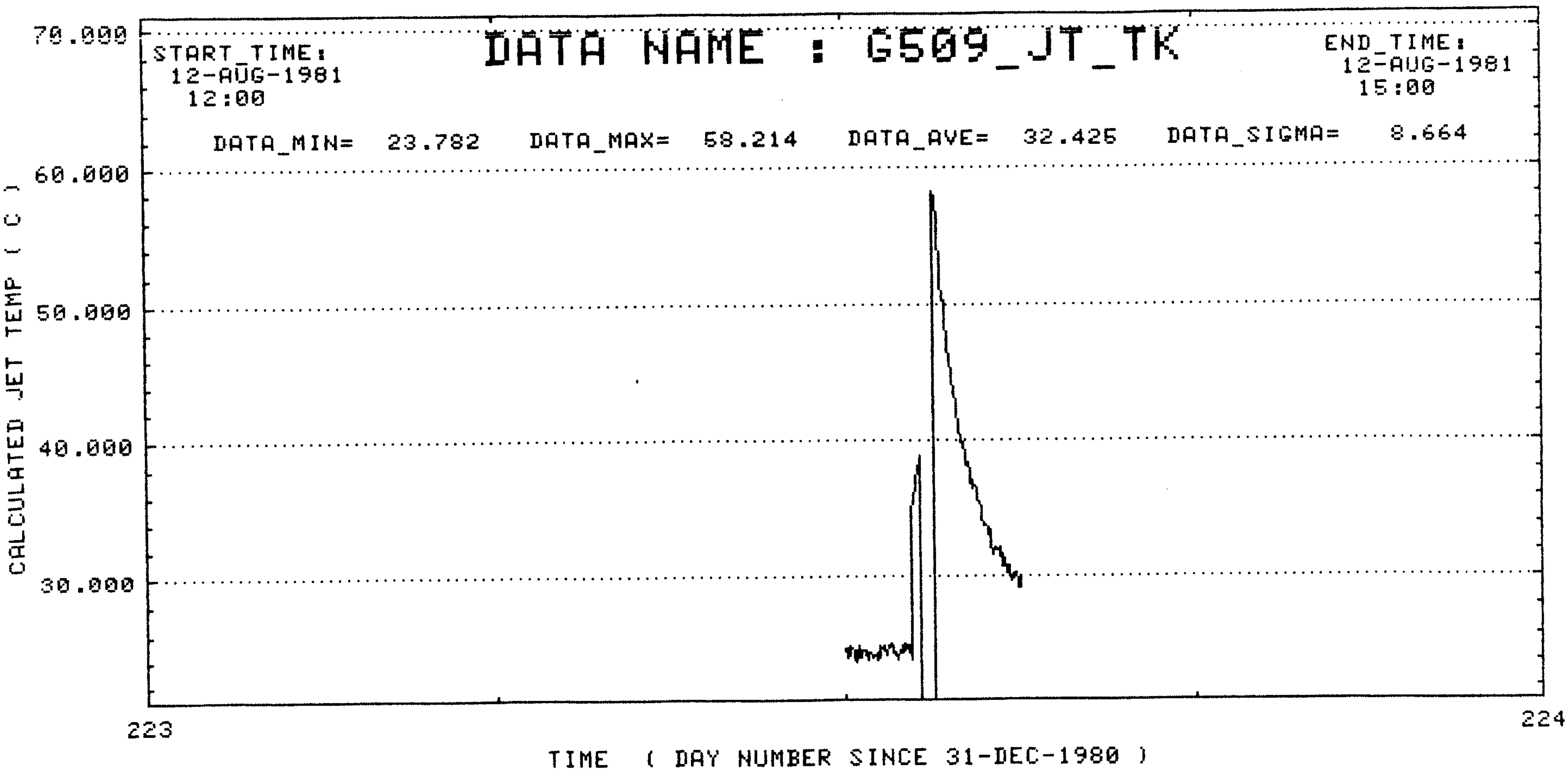

Figure 39. Transfer Jet Temperature Data Plot for a Typical Operation Profile

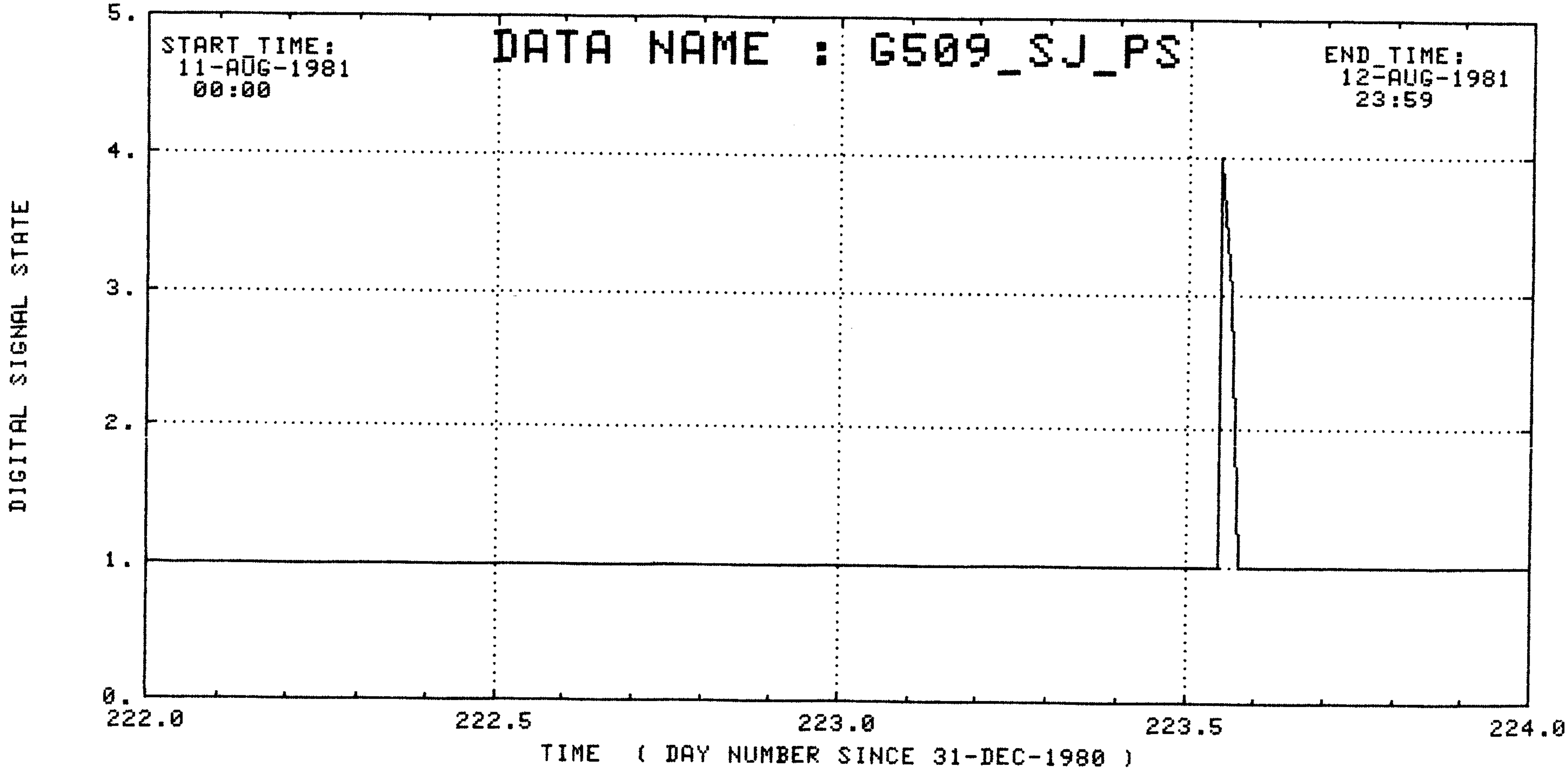

Figure 40. Steam Jet Pressure Switch Data Plot for a Typical Operation Profile

plant safeguards office and are listed in Table III. Also listed in that table are similar measurements obtained from Scanivalve data plots presented in Figures 41 through 47.

Since the electrmanometer system provides much better volume accuracy (assumed near 1%), a comparison of the two data sets provides a good check on the accuracy quality of the Scanivalve system.

The comparison for tank G-105 is based on three data points (batches #3001, #3003, and #3011). The average difference for G-105 is shown in Table III to be -0.3%, with a standard deviation of 0.7%. These error characteristics demonstrate that the Scanivalve system is operating well within the upper limit accuracy expectation of 3%.

The comparison for tank G-155 is based on four data points (batches #4002, #4006, #4008, and #4010). The average difference for G-155 shown in Table III is 2.2%, with a standard deviation of 0.2%. These error characteristics, when compared to the characteristics for G-105, suggest a probable software (volume calibration equation) discrepancy between the elecromanometer and Scanivalve systems.

The batch volume measurements for the accountability tanks normally assume zero transfer heel. The negative volumes indicated in Figures 41 through 47 following the transfers are generally erroneous values currently provided by the software at low tank level conditions. However, the apparent heel of -75L in Fig. 44 following the transfer of batch #4006 is somewhat different from the corresponding value of approximately -125L observed for similar transfers from G-155 (see batches #4002, #4008, and #4010). This discrepancy suggests an incomplete transfer associated with batch #4006, but the magnitude of the descrepancy should be much less than the apparent 50L difference because of the dished bottom on tank G-155.

2.3 Accountability Tank to Feed Tank Transfers

Following a solution accumulation and accountability measurement in an accountability tank (G-105 or G-155), the process feed solutions are transferred via steam jet to the feed tank (G-106). Such transfer operations are initiated when the feed tank is already at a low level and when additional process feed solution is desired in that tank in order to maintain near continuous feed to the process.

TABLE III

ACCOUNTABILITY TANK LIQUID VOLUME COMPARISON

BATCH NUMBER	ACCOUNTABILITY TANK	DATE OF TRANSFER TO G-106	ELECTROMONOMETER VOLUME (L)	SCANIVALVE VOLUME (L)	DIFFERENCE VOLUME (L)	PERCENT DIFFERENCE
3001	G-105	August 11, 1981	2112.8	2112	- 1	-0.1
4002	G-155	August 12, 1981	2241.2	2193	-48	-2.1
3003	G-105	August 13, 1981	2318.6	2344	-25	-1.1
4004	G-155	August 14, 1981	2440.8	----	----	----
3005	G-105	August 17, 1981	2177.5	----	----	----
4006	G-155	August 18, 1981	2281.0	2230	-51	-2.2
3007	G-105	August 20, 1981	2729.3	----	----	----
4008	G-155	August 21, 1981	2445.2	2395	-50	-2.0
3009	G-105	August 22, 1981	2231.3	----	----	----
4010	G-155	August 24, 1981	2262.9	2208	-55	-2.4
3011	G-105	August 25, 1981	2238.4	2243	+ 5	+0.2

AVERAGE DIFFERENCE FOR G-105:	- 7 L	-0.3 %
STANDARD DEVIATION FOR G-105:	16 L	0.7 %
AVERAGE DIFFERENCE FOR G-155:	-51 L	-2.2 %
STANDARD DEVIATION FOR G-155:	3 L	0.2 %

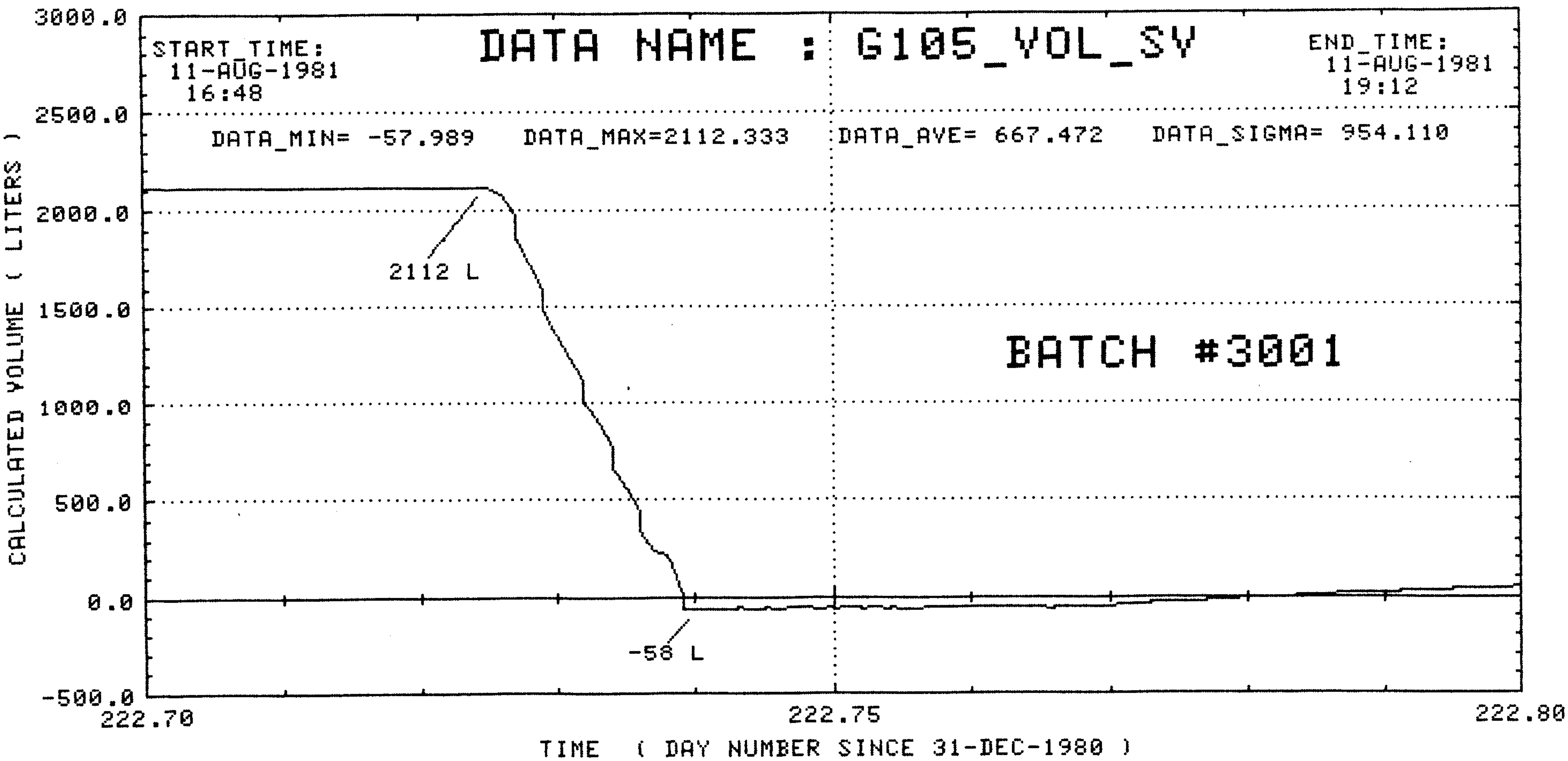

Figure 41. G105 Volume Plot for Batch #3001

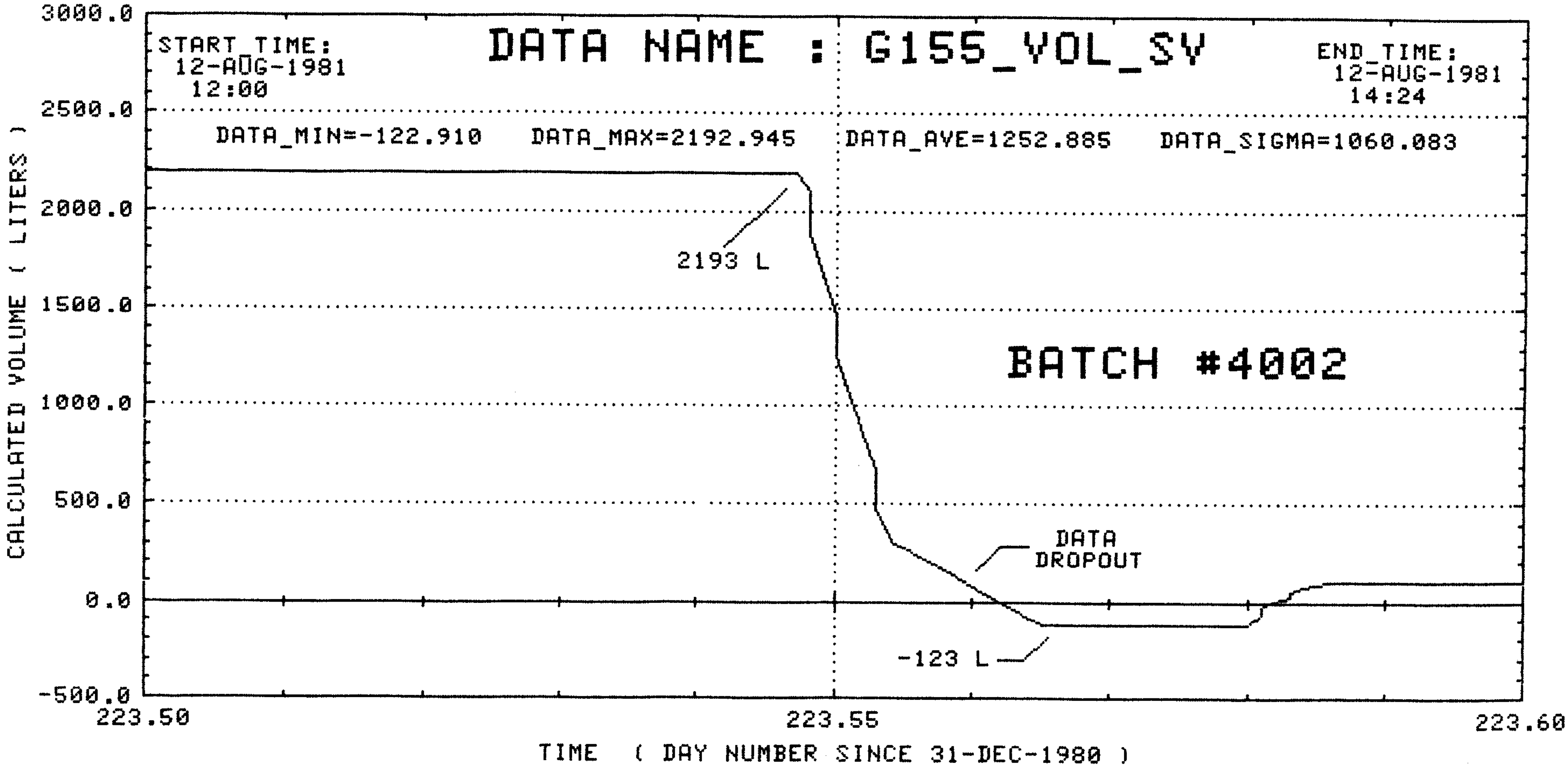

Figure 42. G155 Volume Plot for Batch #4002

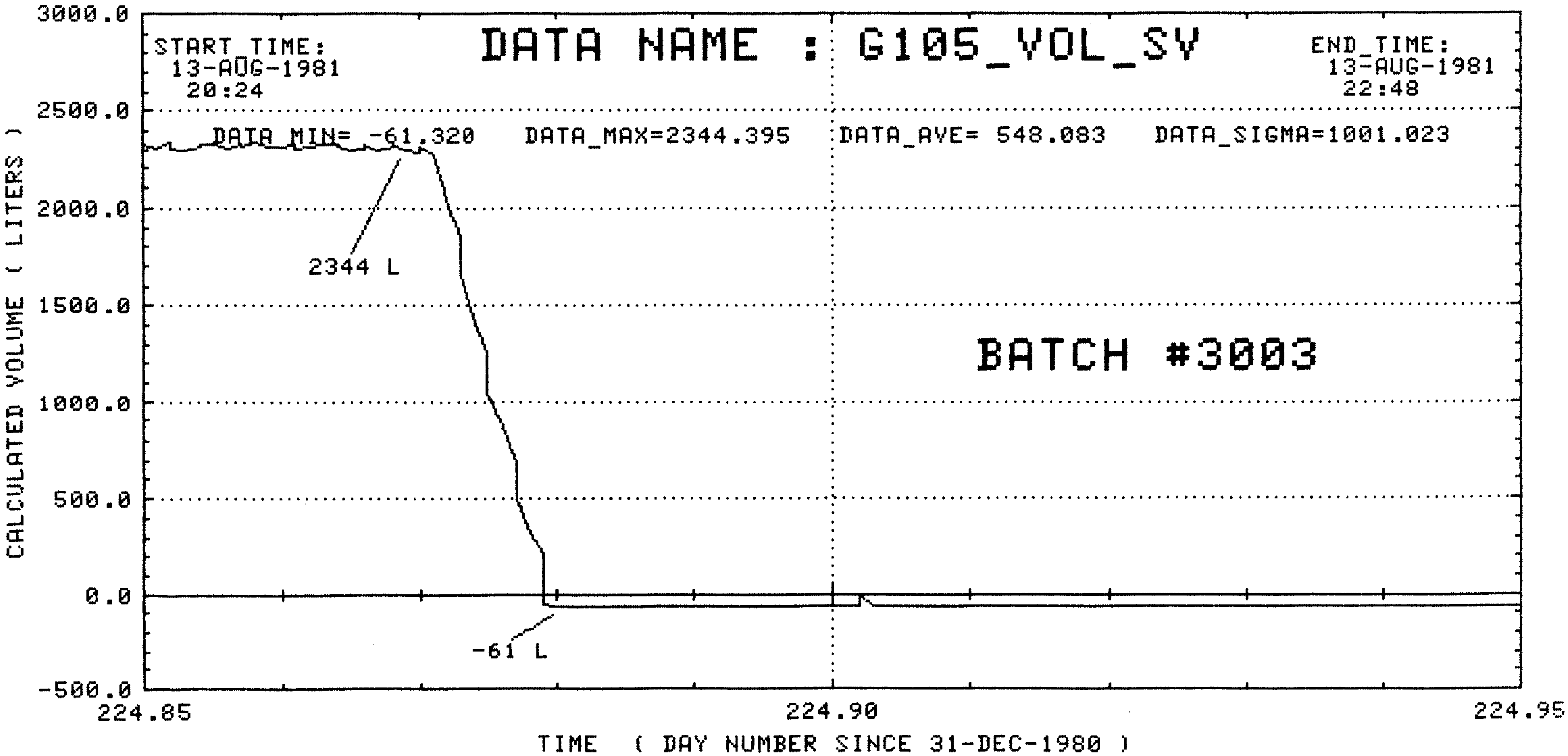

Figure 43. G105 Volume Plot for Batch #3003

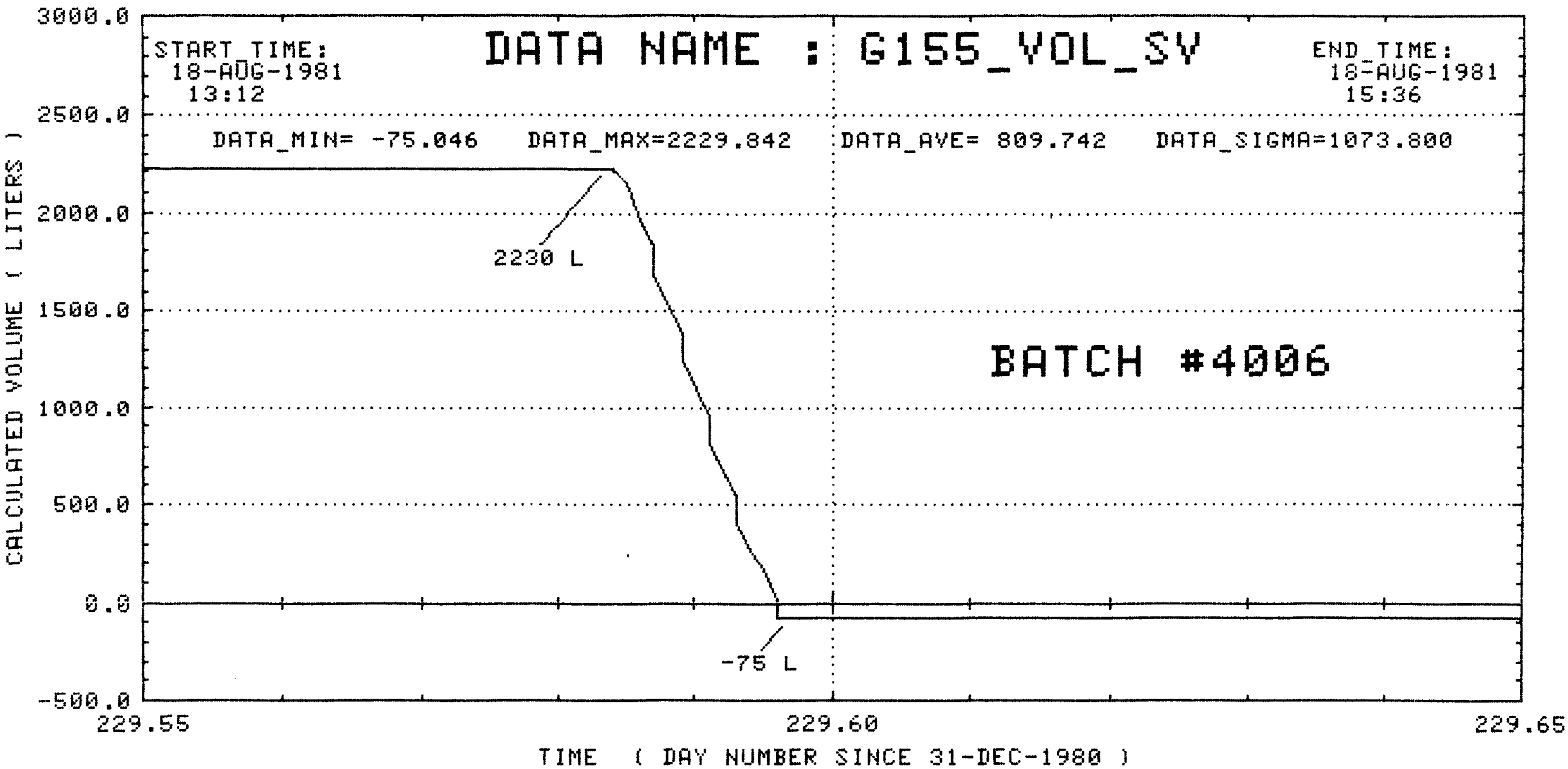

Figure 44. G155 Volume Plot for Batch #4006

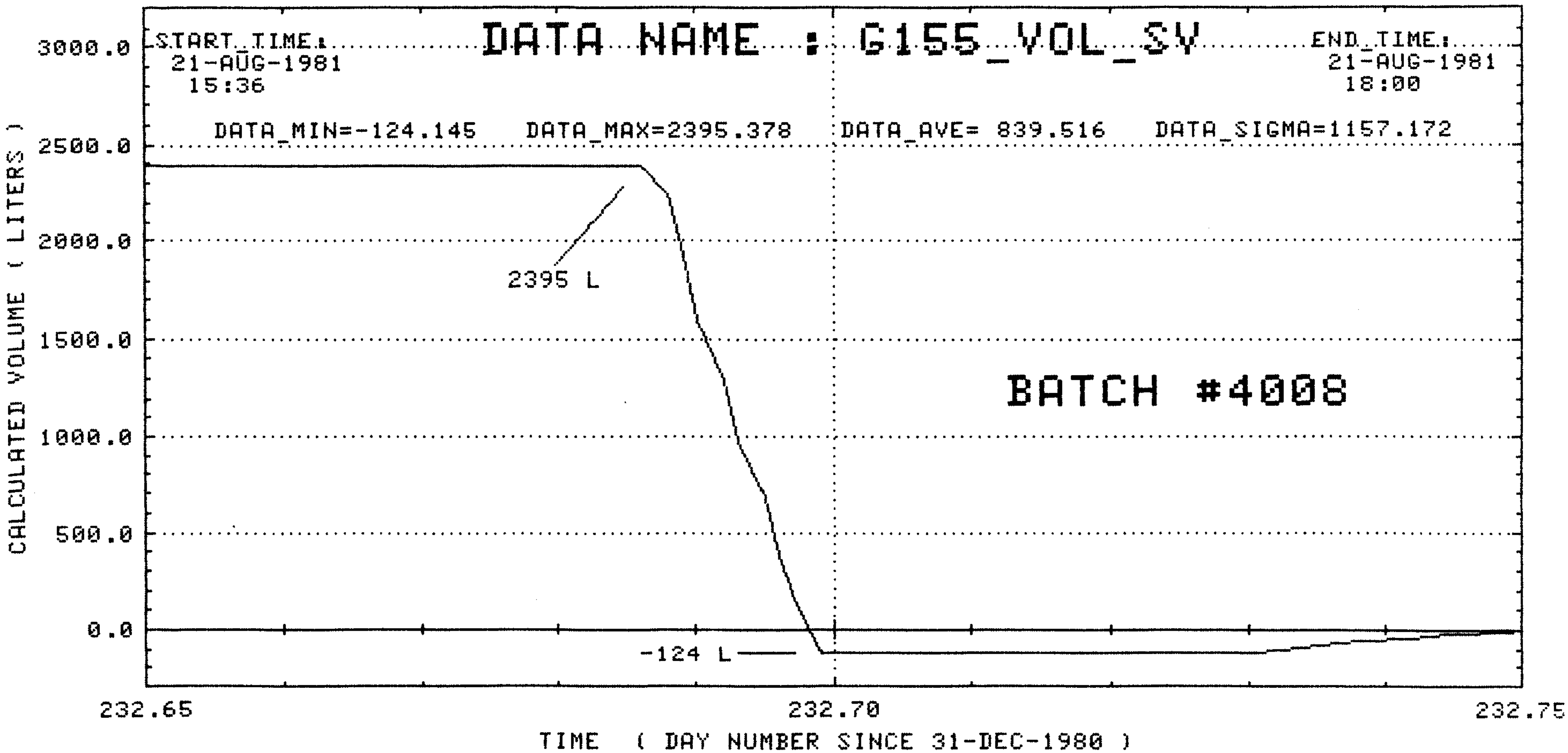

Figure 45. G155 Volume Plot for Batch #4008

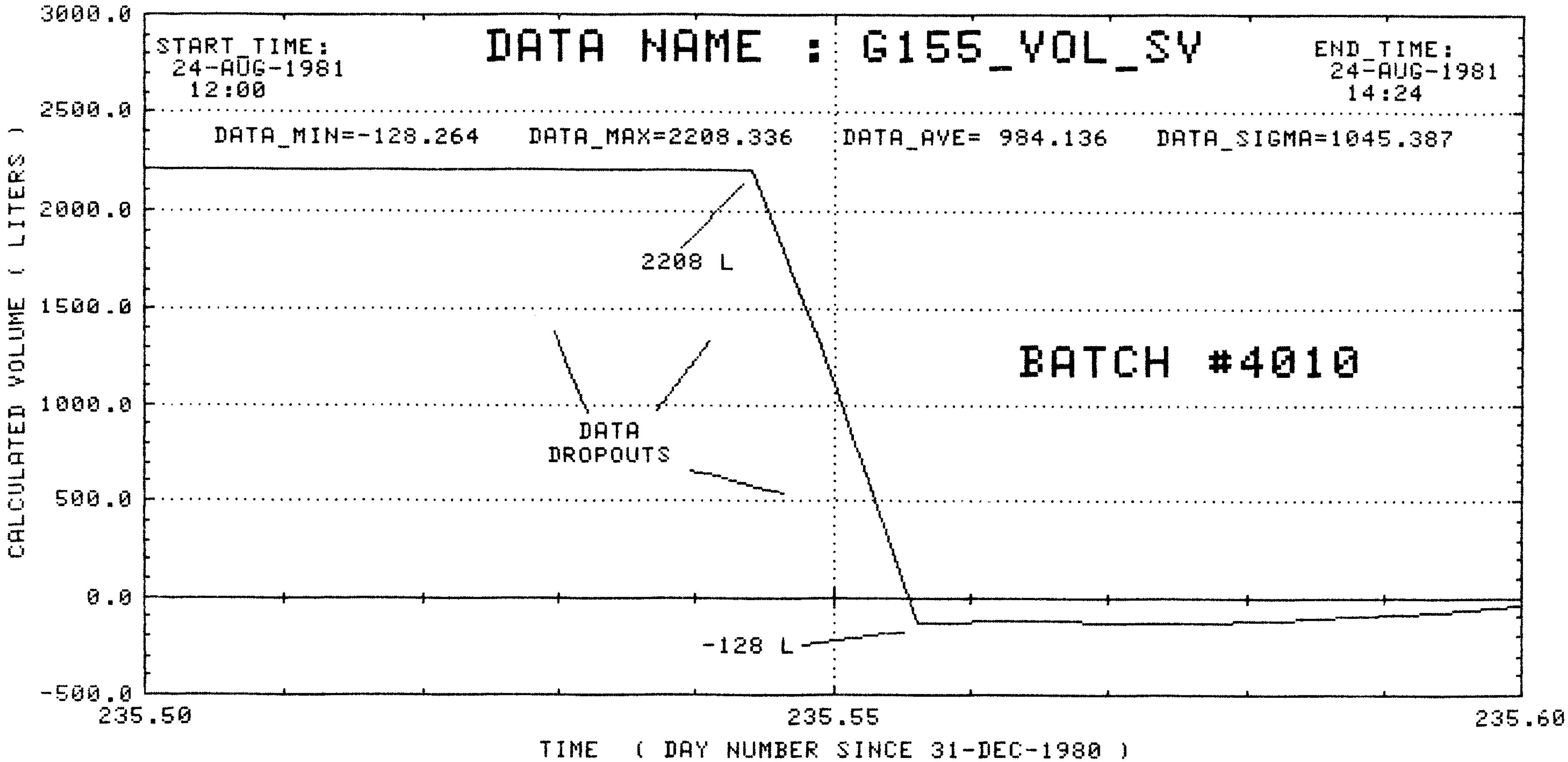

Figure 46. G155 Volume Plot for Batch #4010

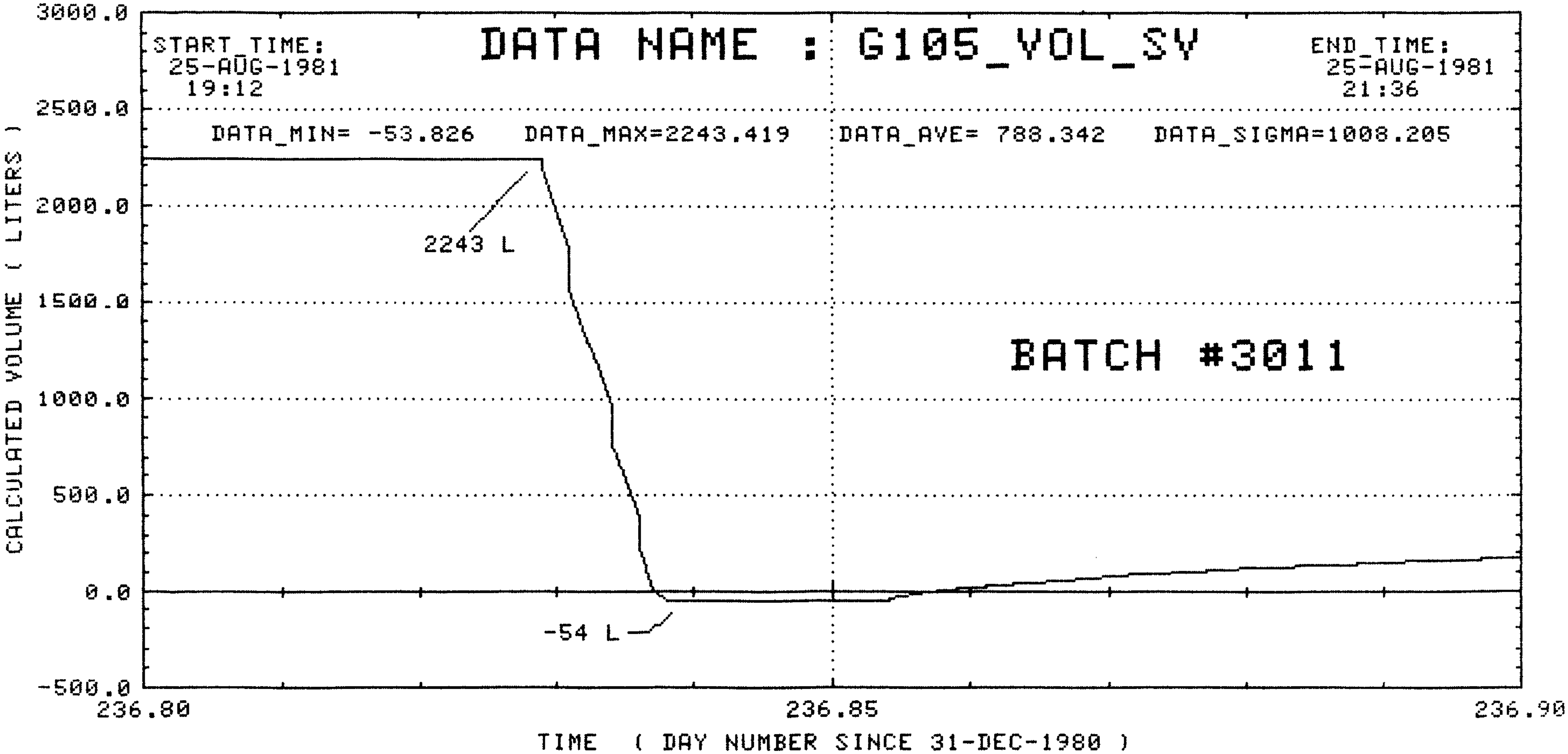

Figure 47. G105 Volume Plot for Batch #3011

The feed tank normally continues to feed the process during the time that a transfer is made into that tank. Including this correction, an estimate for the batch volume received by the feed tank during the transfer is determined from the equation

$$V_{RCVD} \simeq V_I - V_F + \left(\frac{\dot{V}_I + \dot{V}_F}{2}\right) \Delta T \quad , \tag{5-15}$$

where:

V_I = initial volume at the start of the transfer,

$\dot{V}_I$ = initial feed rate to the process at the start of the transfer,

V_F = final volume at the end of the transfer,

$\dot{V}_F$ = final feed rate to the process at the end of the transfer, and

Δt = time duration of the transfer.

These quantities (V_I, $\dot{V}_I$, V_F, $\dot{V}_F$, and Δt), for selected process batch transfers during data window #1, are indicated on the Scanivalve data plots of Figures 48 through 54. The resultant V_{RCVD} values calculated by the above equation are summarized in Table IV.

The feed tank Scanivalve volume recieved during a transfer (see Table IV) can be compared to the corresponding elecromanometer or Scanivalve volume sent by an accountability tank (see Table III). Such volume differences for selected batch transfers are listed in Table IV and expresses in both absolute (liters) and percentage form. A volume difference can be expected due to: (1) steam jet dilution, (2) uncertainty in the feed rate correction used in the equation for V_{RCVD}, (3) volume calibration equation errors, and (4) instrumentation measurement errors.

The Table IV comparison of Scanivalve volume received vs. electromanometer volume sent shows good consistency for both accountability tanks, G-105 and G-155. The average difference is +2.8% for G-105 and +1.9% for G-155. Since the previous comparisons of Table III data suggested no major Scanivalve instrumentation errors (see G-105 data), then assuming reasonably good volume calibration for G-106 and good estimation for V_{RCVD} calculations, it follows that these average differences appear to be reasonable estimates of the actual steam jet dilution magnitude. Such steam jet dilution magnitude was previously expected in the range of 1 to 5%. Combining the data for both G-105 and G-155 gives an average difference of +2.2% with a standard deviation of 0.8%.

TABLE IV

ACCOUNTABILITY TANK LIQUID VOLUME COMPARISON

BATCH NUMBER	ACCOUNTABILITY TANK	DATE OF TRANSFER TO G-106	FEED TANK SCANIVALVE VOLUME RECEIVED (L)	DIFFERENCE FROM ACCNT. TANK ELECTR. VOL. SENT	DIFFERENCE FROM ACCNT. TANK SCANIVALVE VOL. SENT
3001	G-105	August 11, 1981	2185	+72 L (+3.3%)	+ 73 L (3.3%)
4002	G-155	August 12, 1981	2299	+58 L (+2.5%)	+106 L (4.6%)
3003	G-105	August 13, 1981	2380	+61 L (+2.6%)	+ 36 L (1.5%)
4004	G-155	August 14, 1981	----	-------------	------------
3005	G-105	August 17, 1981	----	-------------	------------
4006	G-155	August 18, 1981	2322	+41 L (+1.8%)	+ 92 L (4.0%)
3007	G-105	August 20, 1981	----	-------------	------------
4008	G-155	August 21, 1981	2502	+57 L (+2.3%)	+107 L (4.3%)
3009	G-105	August 22, 1981	----	-------------	------------
4010	G-155	August 24, 1981	2282	+19 L (+0.8%)	+ 74 L (3.2%)
3011	G-105	August 25, 1981	2292	+54 L (+2.4%)	+ 49 L (2.1%)
		AVERAGE DIFFERENCE FOR G-105:		+62 L (+2.8%)	+53 L (+2.8%)
		STANDARD DEVIATION FOR G-105:		9 L (0.5%)	19 L (0.9%)
		AVERAGE DIFFERENCE FOR G-155:		+44 L (+1.9%)	+95 L (+4.0%)
		STANDARD DEVIATION FOR G-155:		18 L (0.8%)	15 L (0.6%)

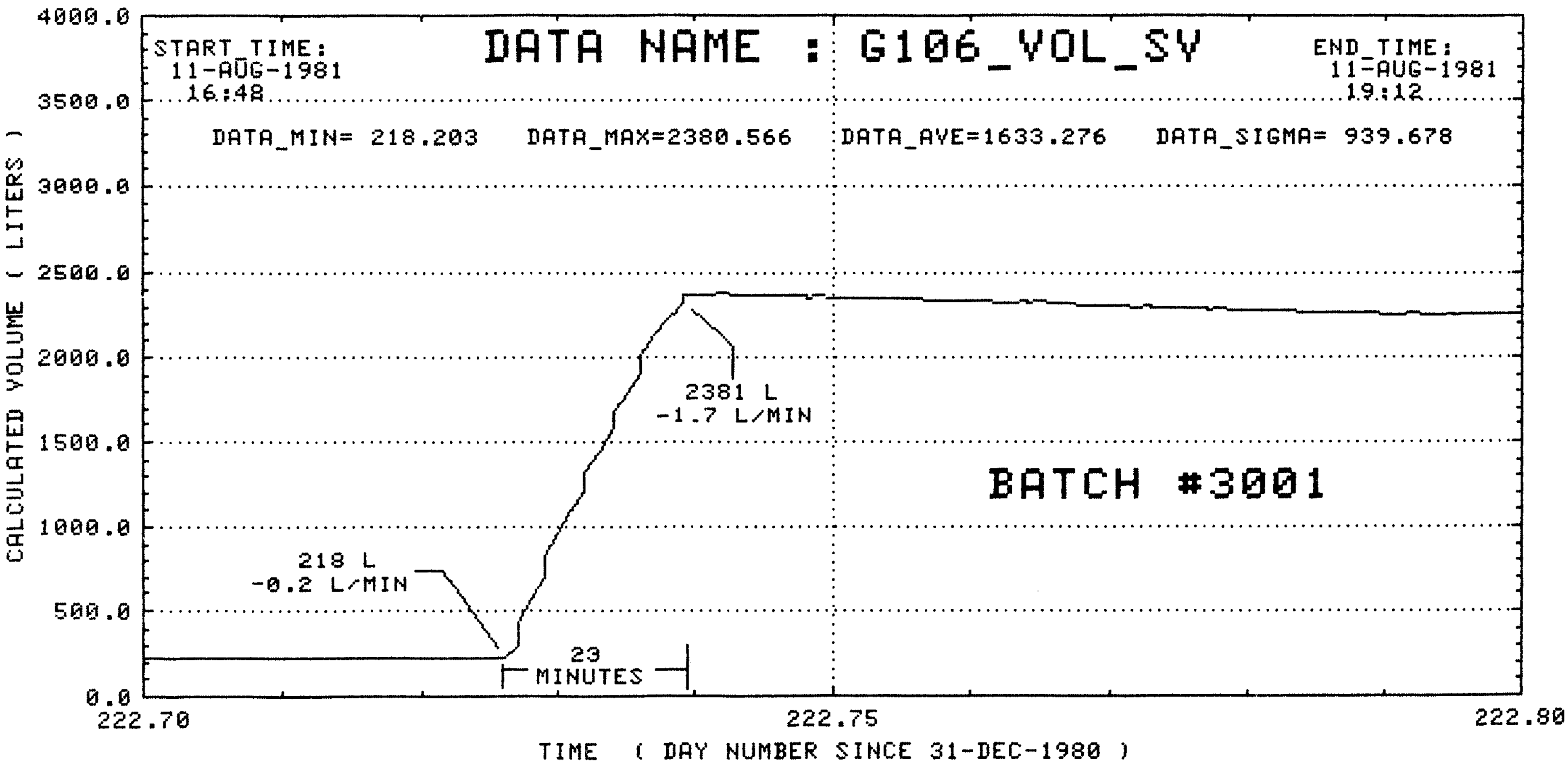

Figure 48. G106 Volume Plot for Batch #3001

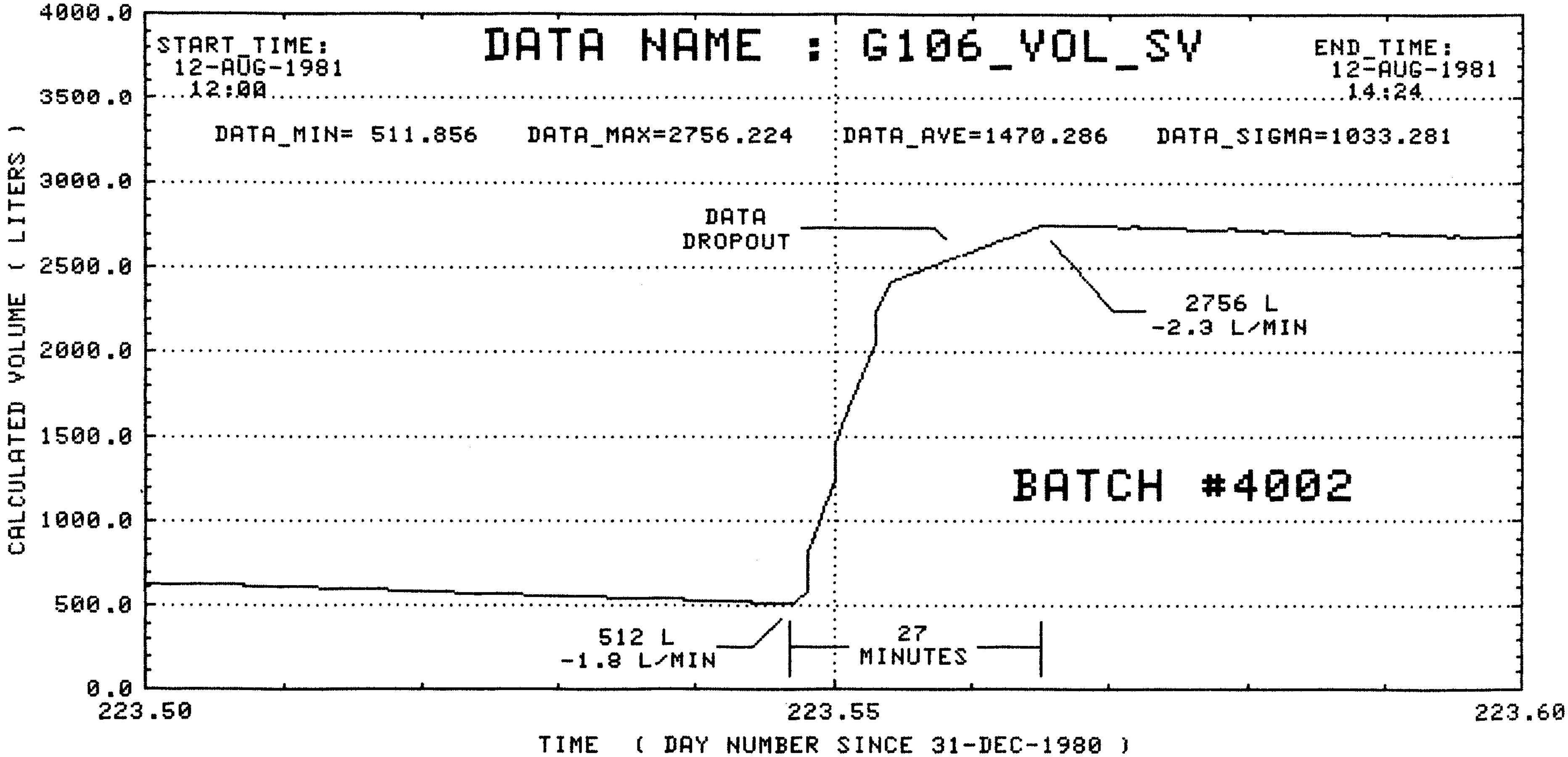

Figure 49. G106 Volume Plot for Batch #4002

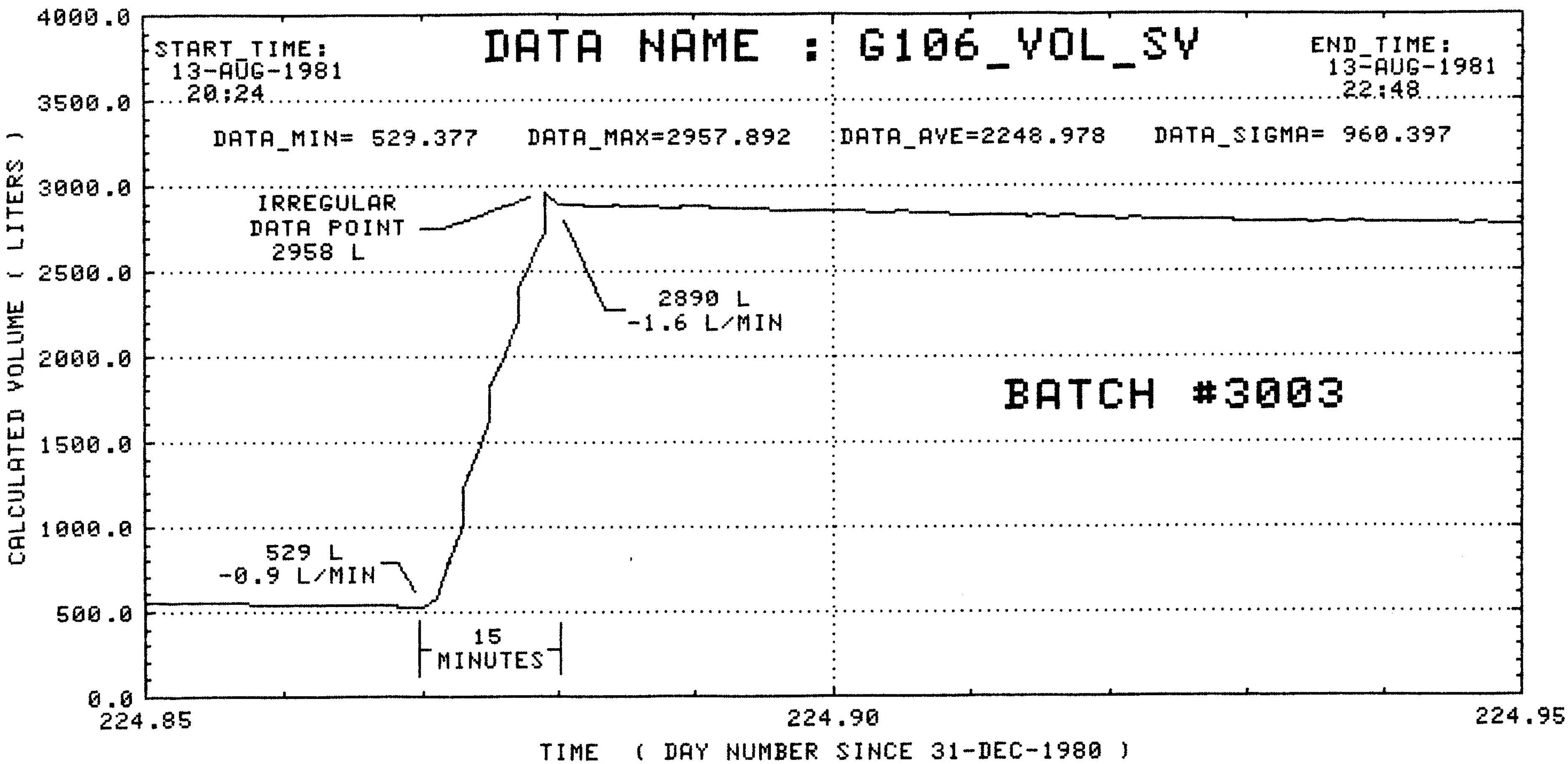

Figure 50. G106 Volume Plot for Batch #3003

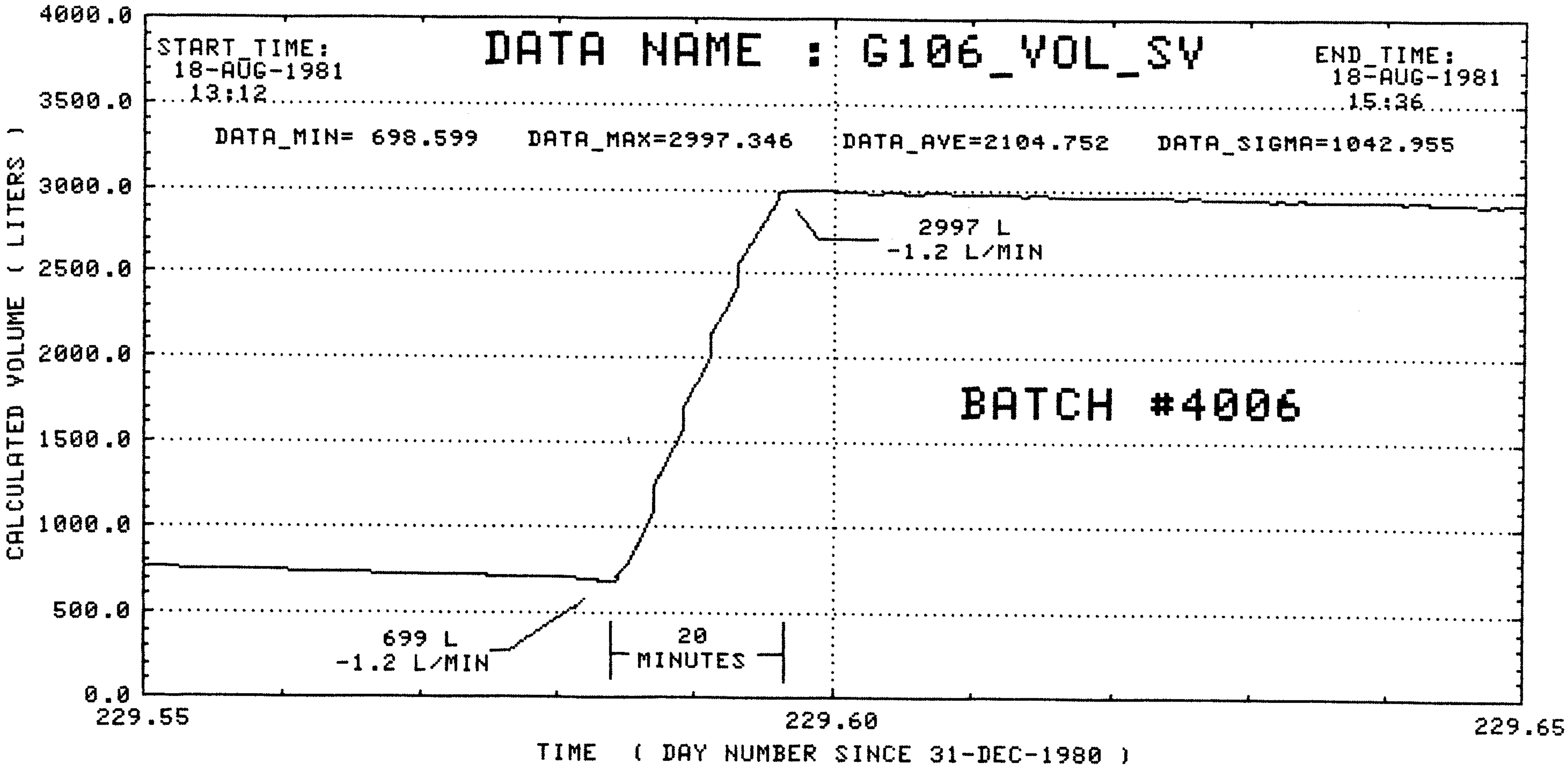

Figure 51. G106 Volume Plot for Batch #4006

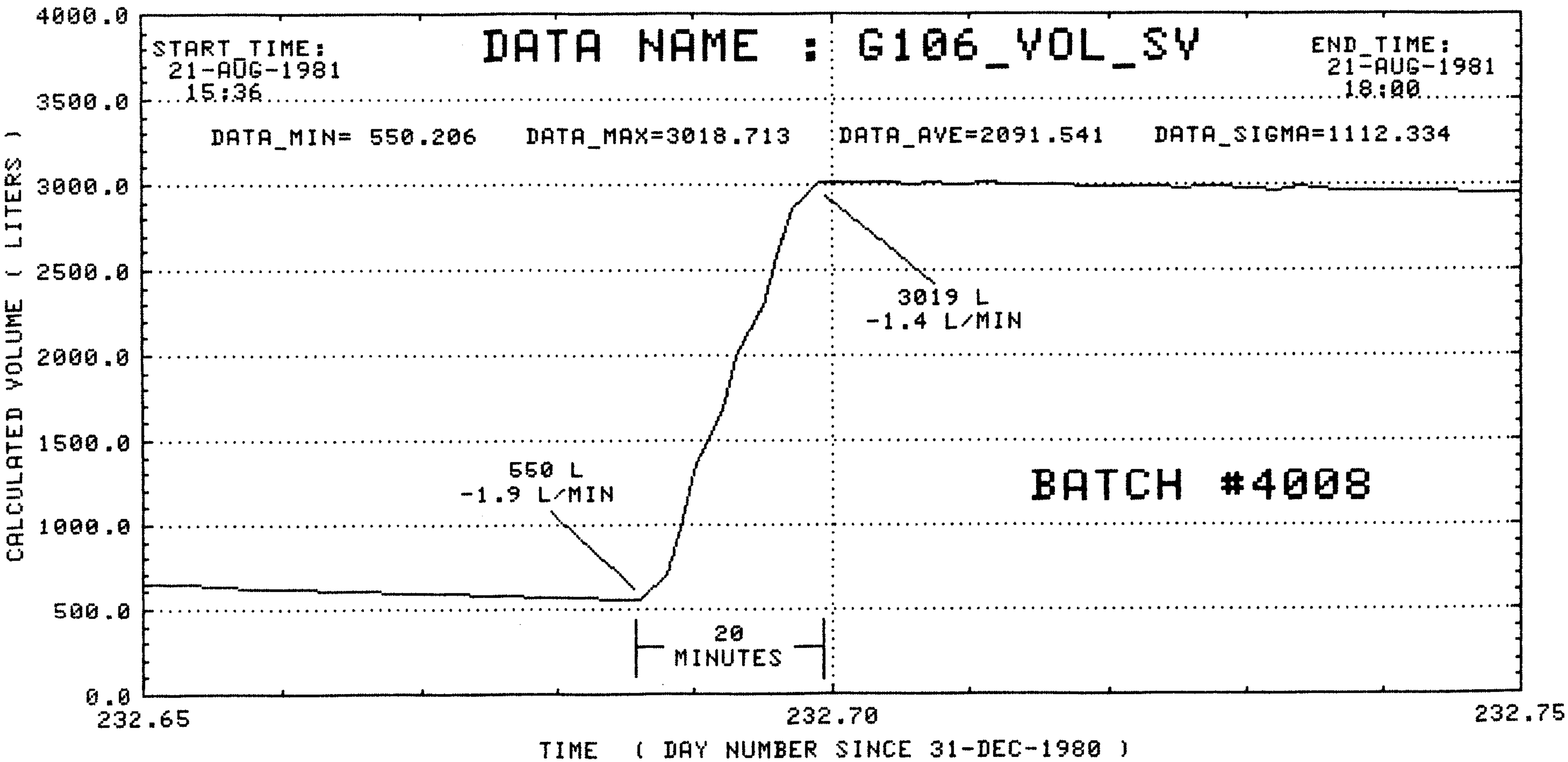

Figure 52. G106 Volume Plot for Batch #4008

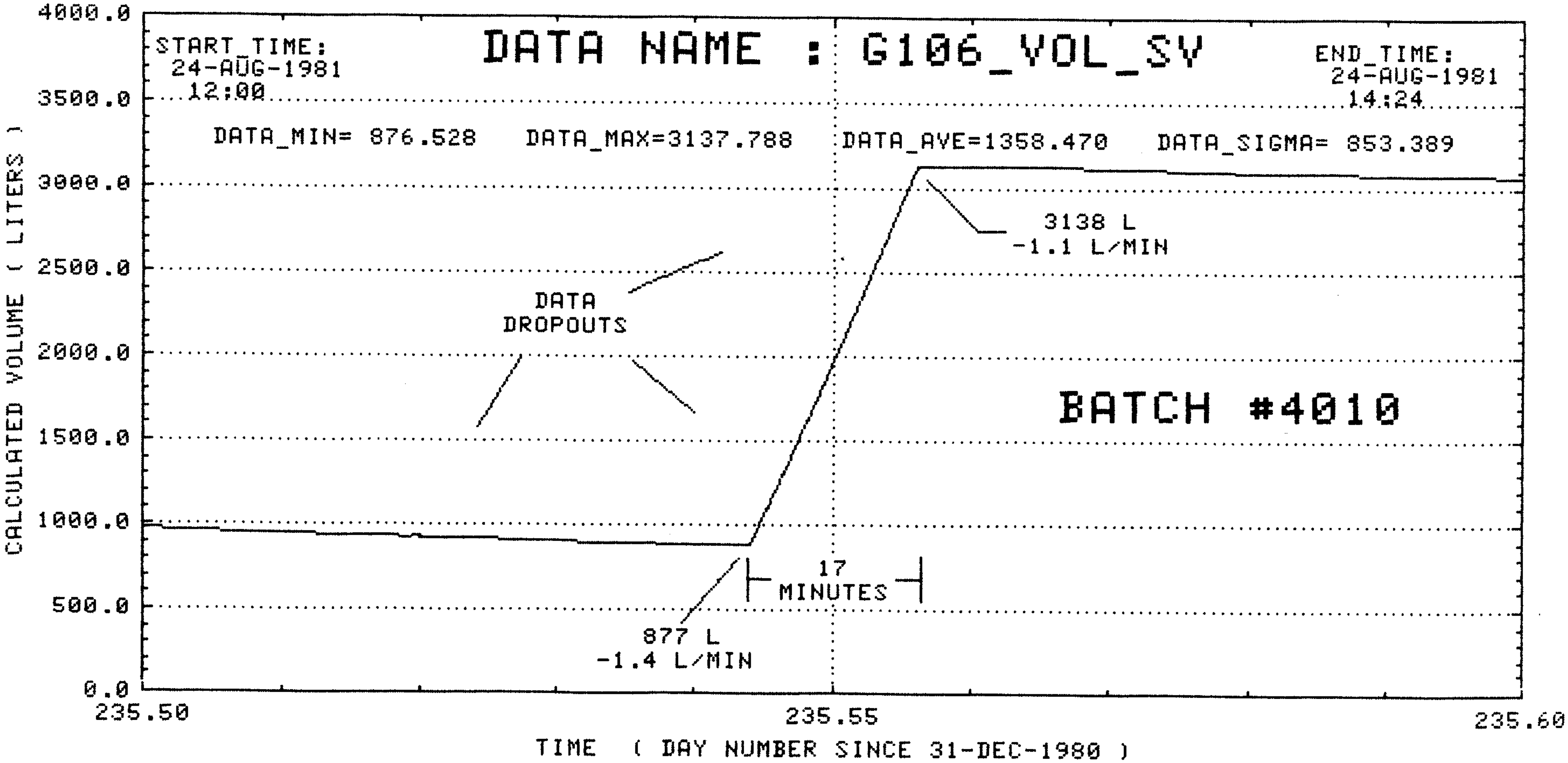

Figure 53. G106 Volume Plot for Batch #4010

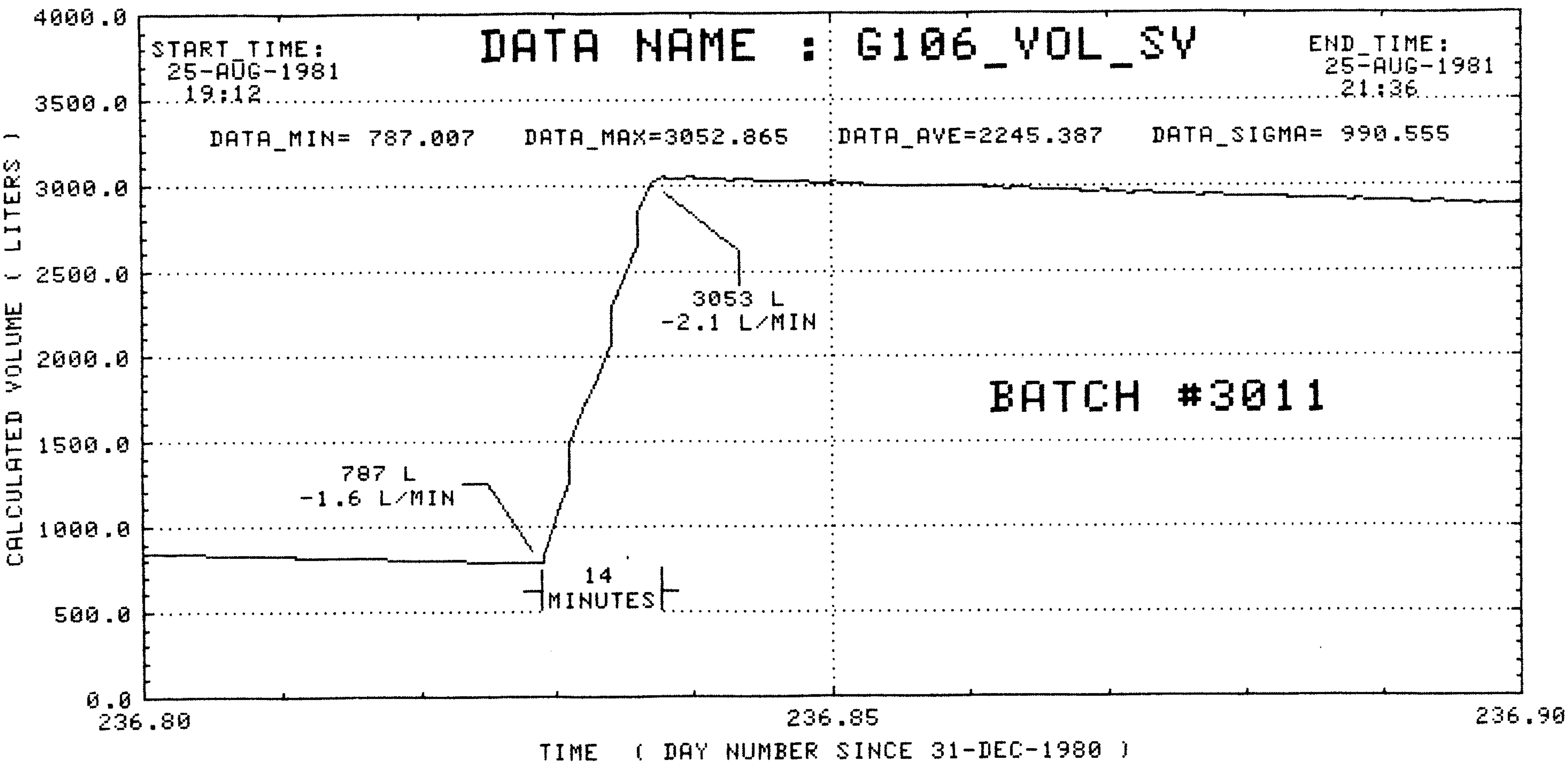

Figure 54. G106 Volume Plot for Batch #3011

Table IV comparison of Scanivalve volume received vs. Scanivalve volume sent shows an inconsistency between accountability tanks G-105 and G-155. The average difference is +2.3% for G-105, while it is +4.0% for G-155. This inconsistency reflects an apparent volume calibration equation discrepancy for G155 Scanivalve data. Such a discrepancy was also detected in the previous data comparisons of Table III.

As a final observation concerning these data, it is of interest to relate the transfer comparison for batch #4006 in Table IV to the possible incomplete transfer suggested by the unusual heel for G-155 indicated in Figure 44. Since the data in Table IV does not suggest any unusual comparison for batch #4006, it is concluded that a large heel quantity did not remain in G-155 following the transfer (see previous section 2.2 for additional discussion). It should be noted, however, that the heel would have to be upwards of 25 to 30 L before it could be detected by the data comparison methods of Table IV using existing data accuracies.

2.4 First-Cycle Process Feed Rate

During a first-cycle campaign, the process feed tank (G-106) feeds the IA column at a near continuous rate, as illustrated by the typical example of Figure 55. The rate of feed to the process is an important process variable and can be evaluated by the tank depletion method (slope of volume vs. time). From Figure 55 it can be quickly estimated with a straight edge that the slope has some non-uniform variation, but the average slope is about -2 liters/minute or equivalently -120 liters/hour.

The inherent data noise for the process feed rate is illustrated by the data plot of Figure 56. This plot presents the time variation of the volume difference between adjacent data points; the illustrated variation is due to process dynamics, process noise, measurement noise, and some inconsistency of the time interval between data points. When the data are presented this way, it can be seen that a considerable amount of data noise exists.

An N-point smoothing algorithm can be applied to the volume data to enhance the estimation of process information. The currently used algorithm in plot program GETDATAP assumes that N (odd) adjacent data points are evenly spaced, and a least-squares curve fit is performed on the raw data over the N-point data window using a parabolic model of the form

$$V = C_1 + C_2\, n + C_3\, n^2 \; ; \; 1 \leq n \leq N \, , \tag{5-16}$$

where n is the data point number relative to the start of the data window.

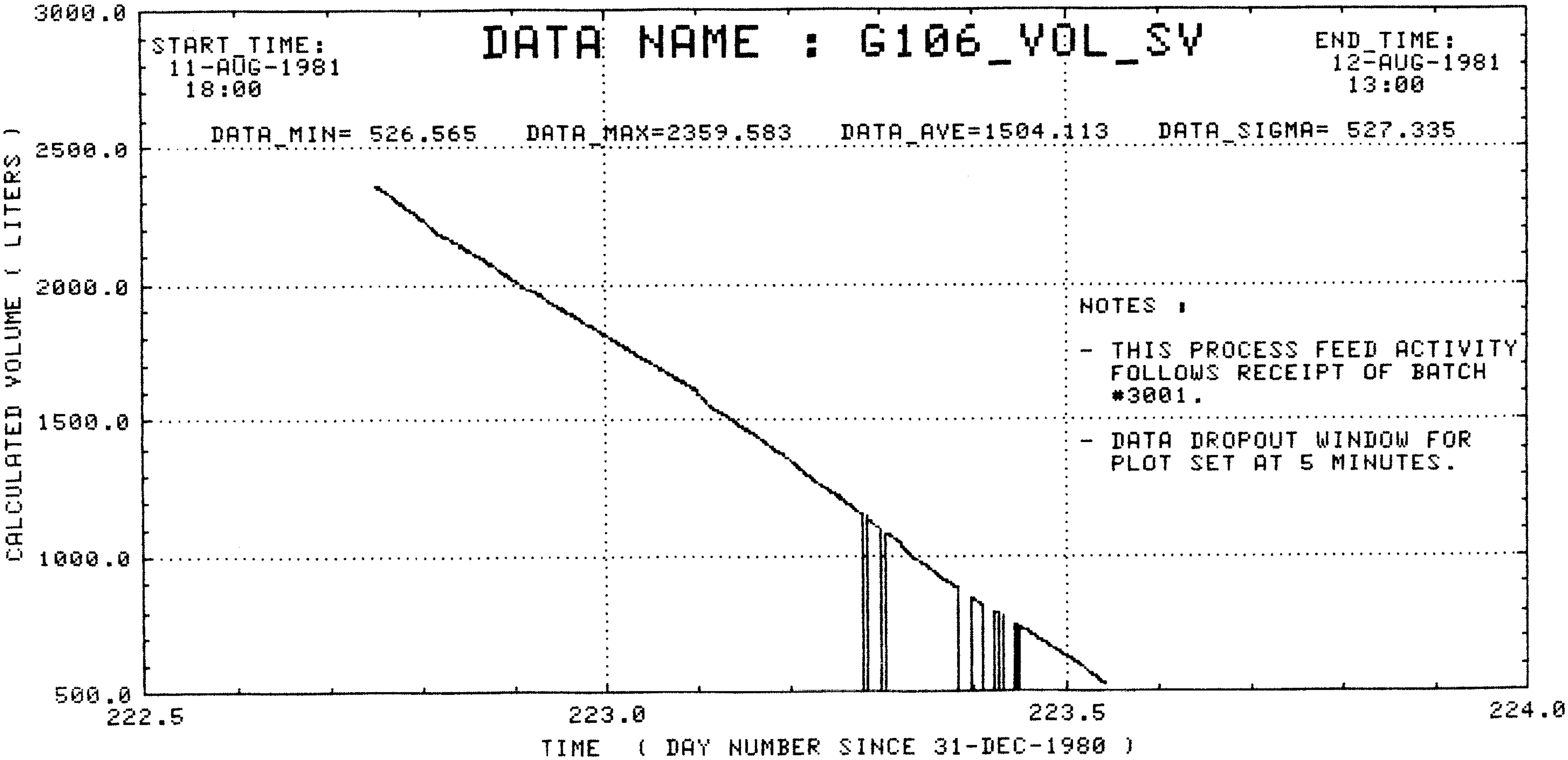

Figure 55. Volume Plot for G106 During Feed to Column IA

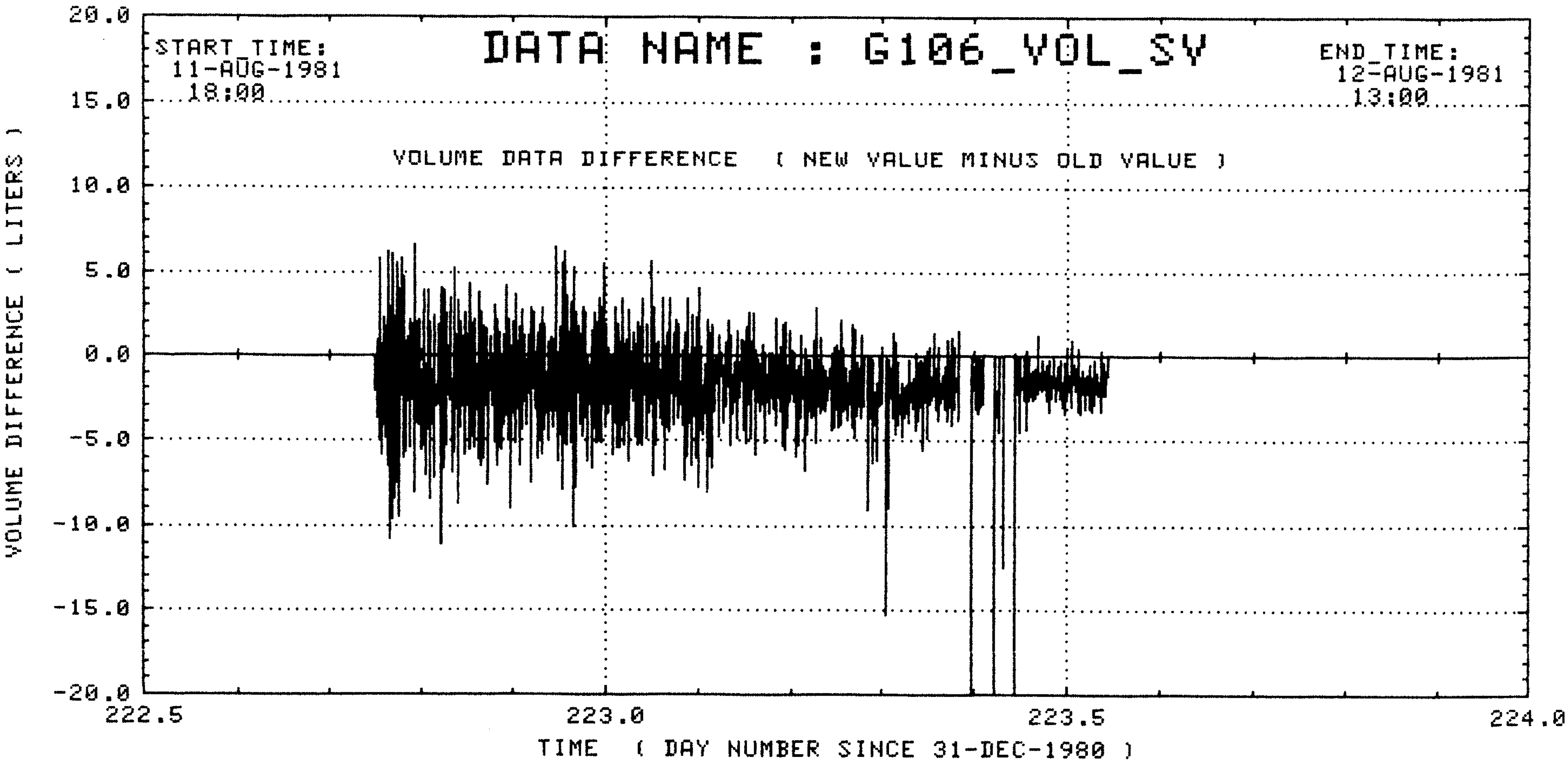

Figure 56. G106 Volume Data Difference Plot

The data window is made to increment along the entire data span after each smoothing calculation is performed, and the resultant center point estimate from each calculation is used as the smoothed output value. The slope of the smoothed data at the window center is

$$\left.\frac{dV}{dn}\right|_{n=N_C} = C_2 + 2C_3N_C \; ; \quad N_C = 1 + \mathrm{INT}\left(\frac{N}{2}\right) , \tag{5-17}$$

and for volume data it has units of liters per data point interval.

The results from applying the smoother algorithm to the volume data of Figure 55 are presented in Figrues 57 and 58. For these data an 11-point smoother was used, and it can be seen that the smoothed data plot (Figure 57) tracks the general variation of the raw data plot (Figure 55) quite well. More impressive is the smoothed slope plot (Figure 58) which can be compared somewhat to the difference data plot (Figure 56). The smoothed slope data provides much improved signal to noise ratio and permits detailed examination of the slope variation characeristics.

The majority of the total data time span had a near constant data point time interval of near 1 minute, so for much of Figure 58 (222.75 through 223.25) the slope data can be equivalently interpreted as volume rate in units of liters per minute. During data dropout times, however, the mean data point time interval increases so that the equivalent correspondence no longer holds. A future improvement for the data processing would be to perform the least-squares smoothing in a more general sense without the simplifying assumption of evenly spaced data points.

2.5 Transfers Into N-Cell Inter-Cycle Storage

A brief analysis of transfers between H-131 and N-Cell indicates that solution volumes cannot currently be routinely tracked to better than 10 to 15% accuracy. Part of the problem is due to the irregular additions into H-131 from the H-130 evaporator. Solution does not feed at a constant rate from H-130; it arrives in slugs of approximately 1 to 2 liters. When such a slug arrives during a transfer, it is not seen by the H-131 level instruments, so an apparent excess volume can arrive in N-Cell. Also, H-131 does not empty during a transfer, and the heel can only be estimated since it is below the density probe.

The other half of the problem is that N-Cell level and density information is always suspect because the storage tanks cannot be mixed. Also, the lines from H-Cell to N-Cell may not always drain completely.

Table V presents a summary and comparison of the three transfers illustrated in Figures 59 and 60.

TABLE V

H-131 TO N-CELL TRANSFER VOLUME COMPARISON

ITEM DESCRIPTION	VALUE AT TIME 223.4	VALUE AT TIME 223.6	VALUE AT TIME 223.9
H-131 TRANSFER MEASUREMENTS:			
Starting Volume =	15.80 L	15.57 L	16.47 L
Ending Volume =	1.00 L (EST)	1.00 L (EST)	1.00 L (EST)
Volume Sent =	14.80 L	14.57 L	15.47 L
N-100 TRANSFER MEASUREMENTS:			
Ending Volume =	103.04 L	118.27 L	133.07 L
Starting Volume =	87.42 L (EST)	102.76 L (EST)	118.56 L (EST)
Volume Received =	15.62 L	15.51 L	14.51 L
H-131 TO N-100 COMPARISON:			
Volume Received Less Volume Sent =	+0.82 L (+5%)	+0.94 L (+6%)	-0.96 L (-7%)

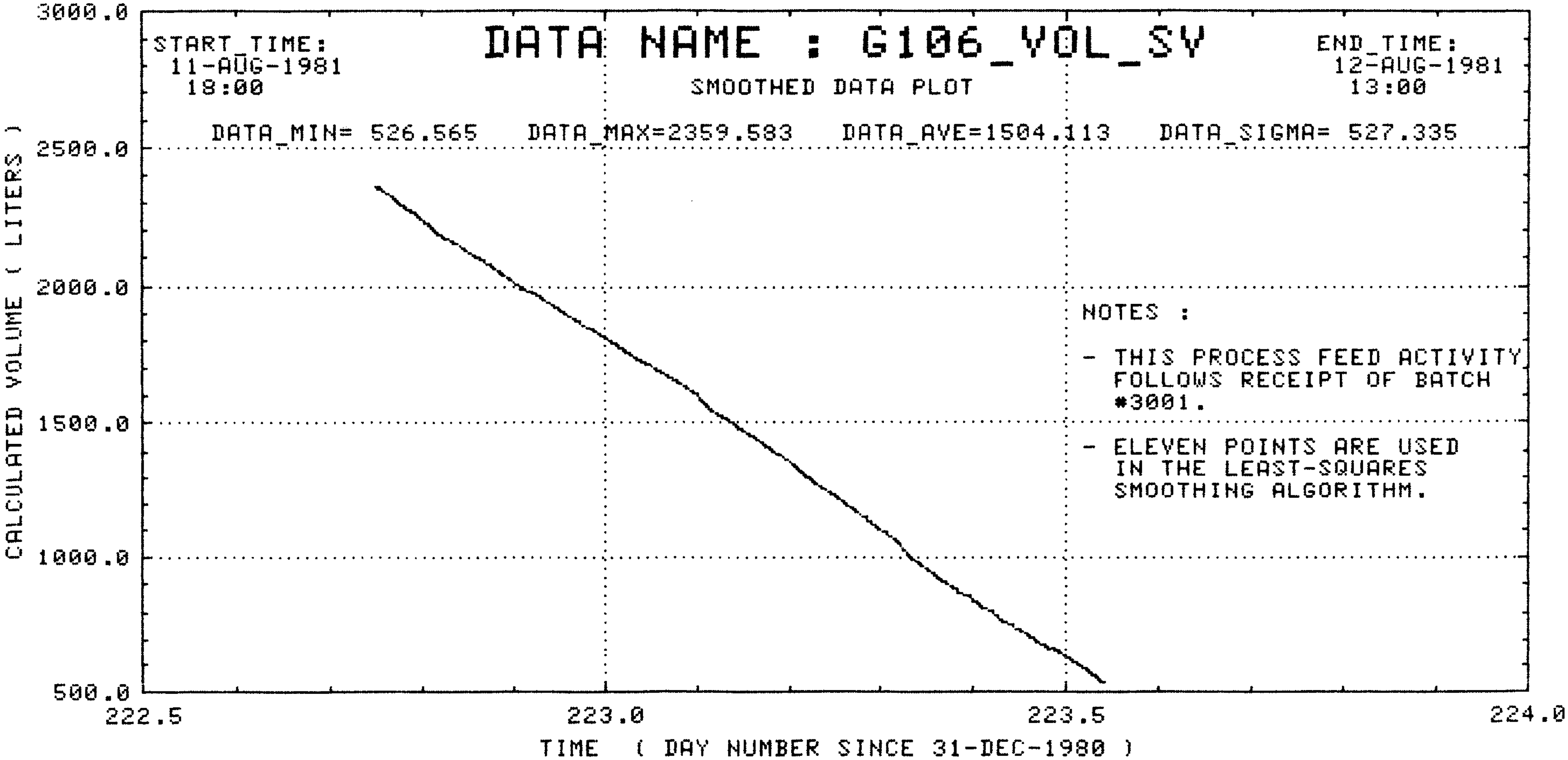

Figure 57. Plot of Smoothed Volume Data for G106

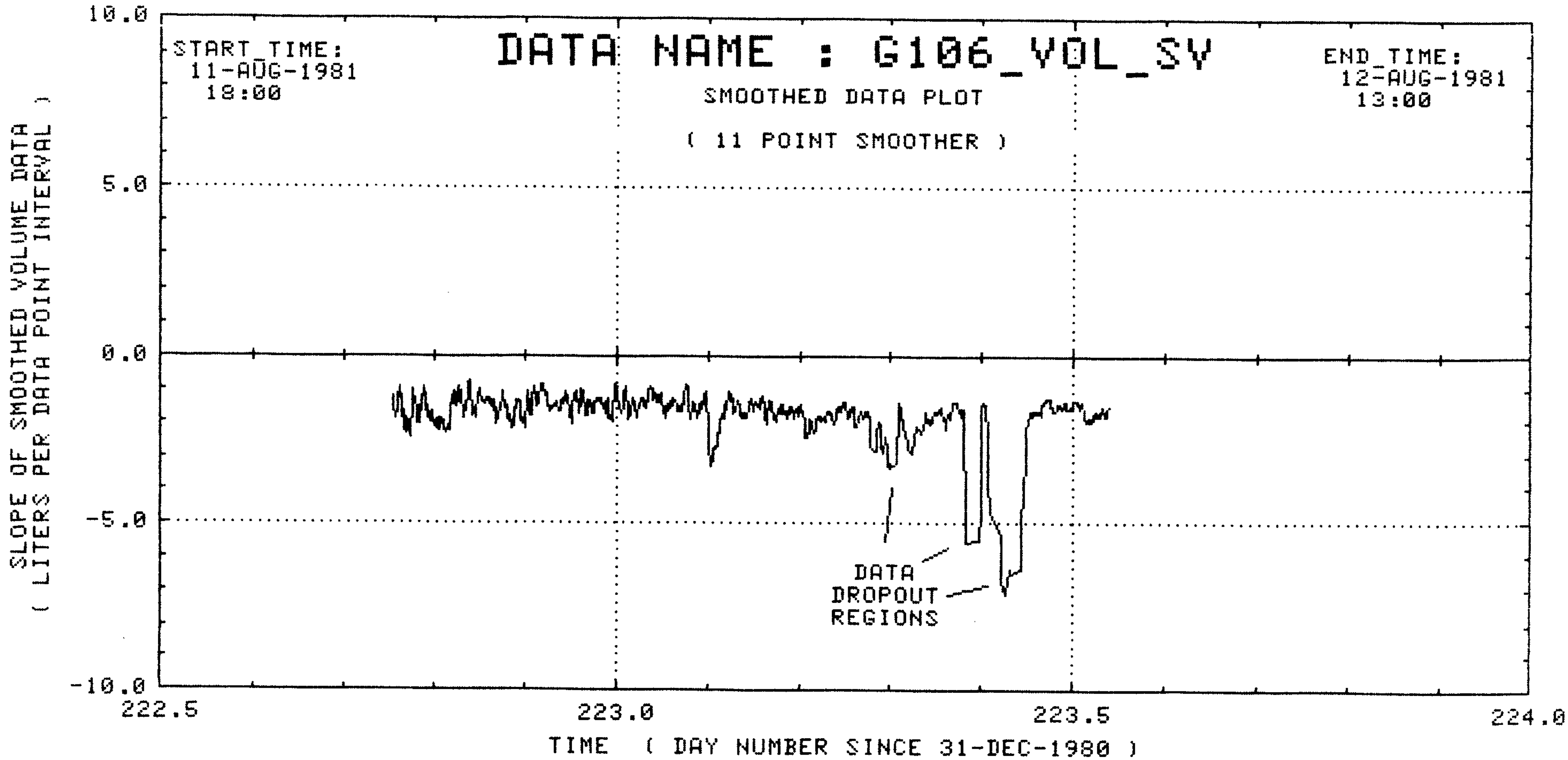

Figure 58. Slope of Smoothed Volume Data for G106

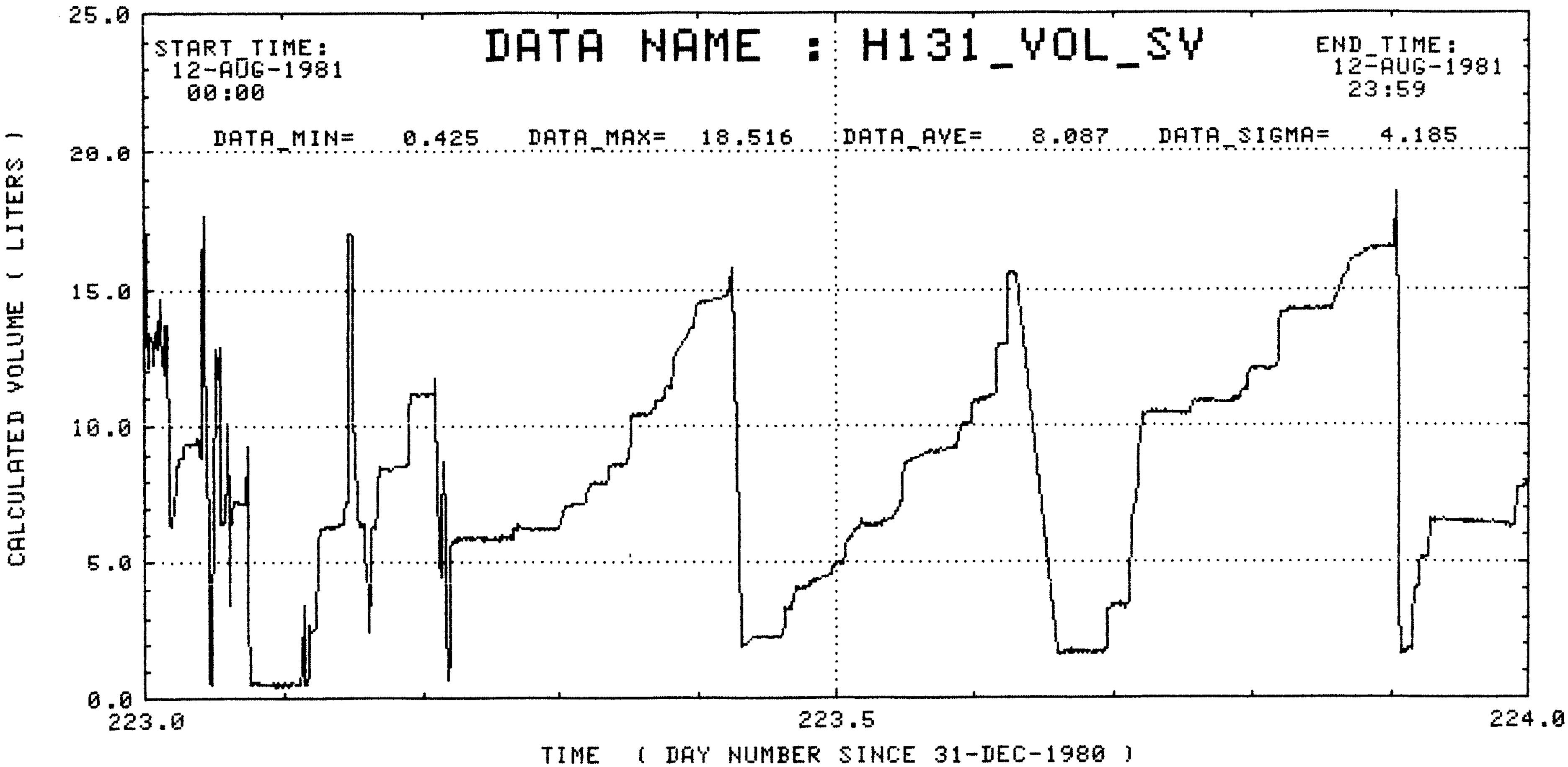

Figure 59. Volume Plot for H131 Showing Transfers to N100

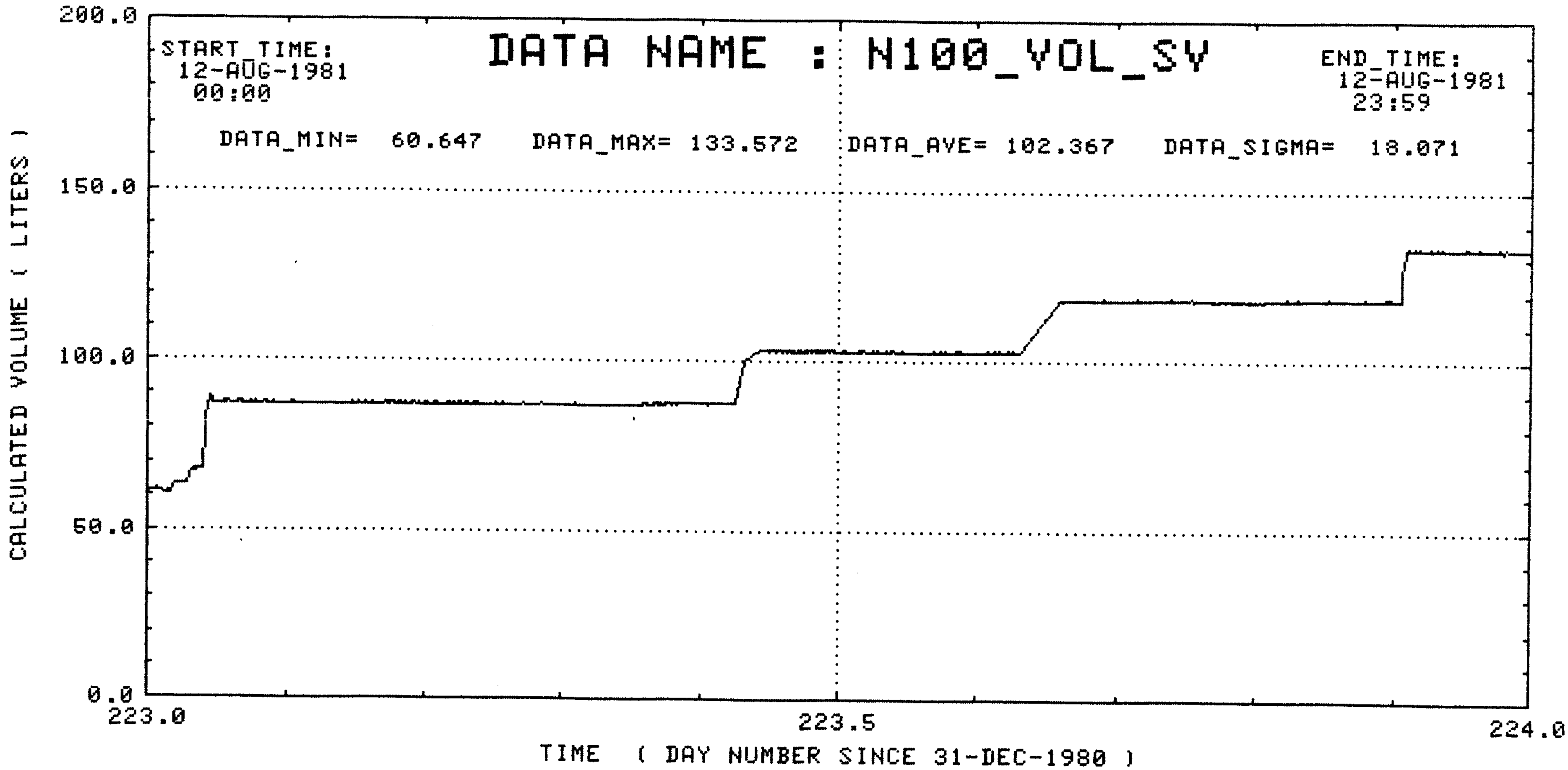

Figure 60. Volume Plot for N100 Showing Transfers from H131

2.6 Second-Cycle Process Feed Rate

During the second- and third-cycle campaign, the N-Cell storage tanks feed the IIA column at a near continuous rate as illustrated by the typical example of Figure 61. The rate of feed to the process is an important process variable and can be evaluated by the tank depletion method (slope of volume vs. time). From Figure 61 it can be quickly estimated with a straight edge that the slope has some non-uniform variation, but the average slope is about -0.13 liters/min or equivalently -8 liters/hour.

The inherent data noise for the process feed rate is illustrated by the data plot of Figure 62. This plot presents the time variation of the volume difference between adjacent data points; the illustrated variation is due to process dynamics, process noise, measurement noise, and some inconsistency of the time interval between data points. There are frequent data dropouts within the total data span, which account for several "spikes" in the difference data. Also, it is interesting to note that the data noise near the center of the plot (say 267.7 through 268.6) is noticeably less than elsewhere, even though frequent small dropouts occur in that region. This characteristic suggests that the data noise is higher at higher feed-tank levels.

As previously discussed in section 2.4, a N-point smoothing algorithm that assumes evenly spaced data points is currently available in plot program GETDATAP. This plotting option was applied to the data of Figure 61 and the results are presented in Figures 63 and 64. These plots were generated using a 51-point smoother, and the large number of points for the smoother was selected because of the small signal to noise ratio illustrated in the early part of the difference data plot of Figure 62.

The smoothed data plot (Figure 63) tracks the general variation of the raw data plot (Figure 61) quite well except near the region of the input transfer from J127. The "overshot" characteristic of the smoothed data in that region is attributed to the large number of points used in the smoother (51 points). Future testing could examine more the characteristics of information exhancement/alteration vs. the number of points used in the smoother.

The correspoinding smoothed slope plot (Figure 64) illustrates that the slope information can be extracted quite well from the raw data, but unfortunately the assumption of evenly spaced data points in the currently used smoother algorithm causes some confusion in interpretation. Early in the plot (say 266.7 through 267.3) there are few dropouts, so the slope nearly corresponds to the volume rate in units of liters per minute. Elsewhere in the plot, however, there are many dropouts which cause the correspondence to no longer be valid. As also mentioned in section 2.4, a future improvement for the data processing would be to perform the least-squares smoothing in a more general sense without the simplifying assumption of evenly spaced data points.

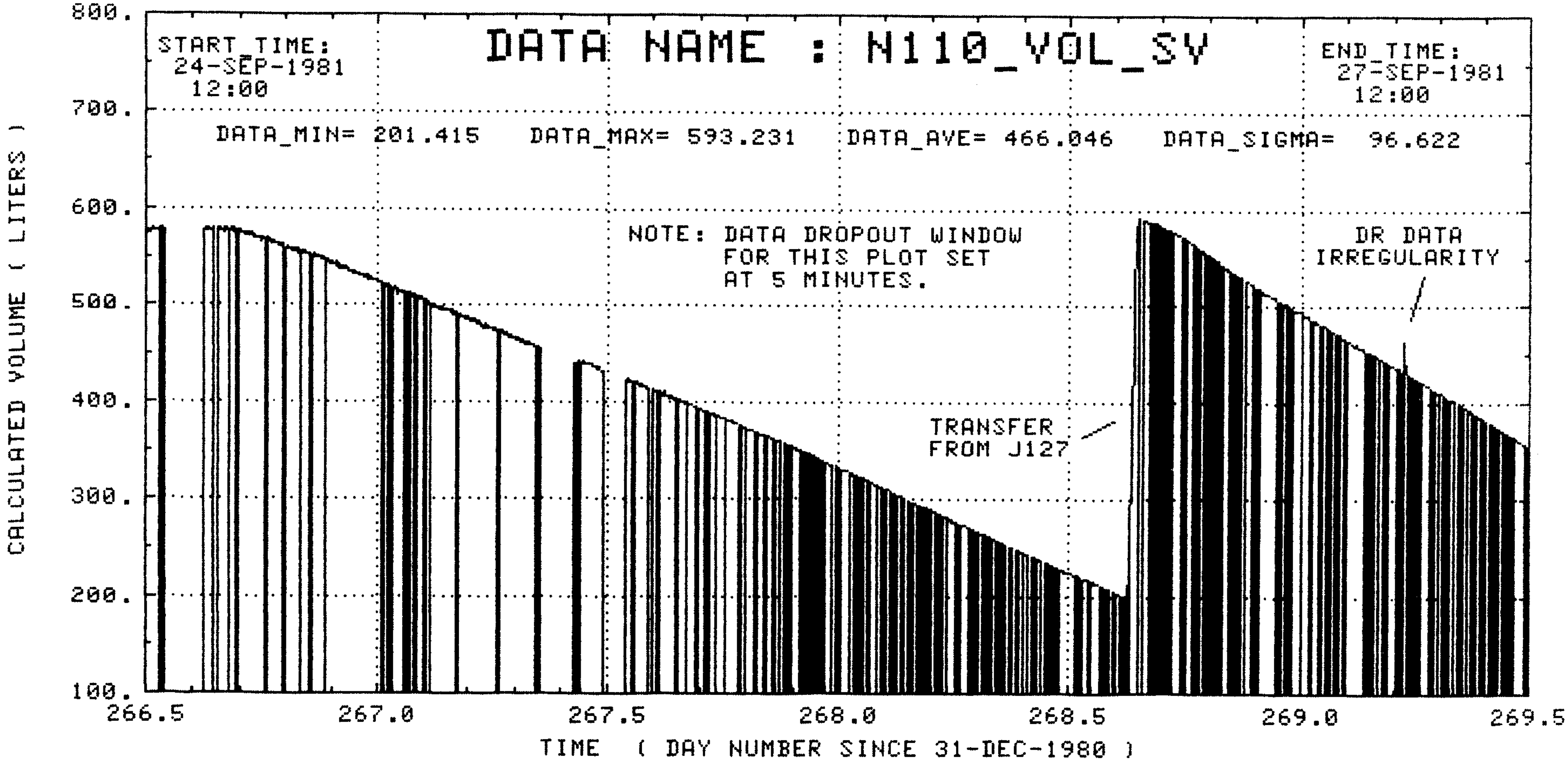

Figure 61. Volume Plot for N110 During Feed to Column IIA

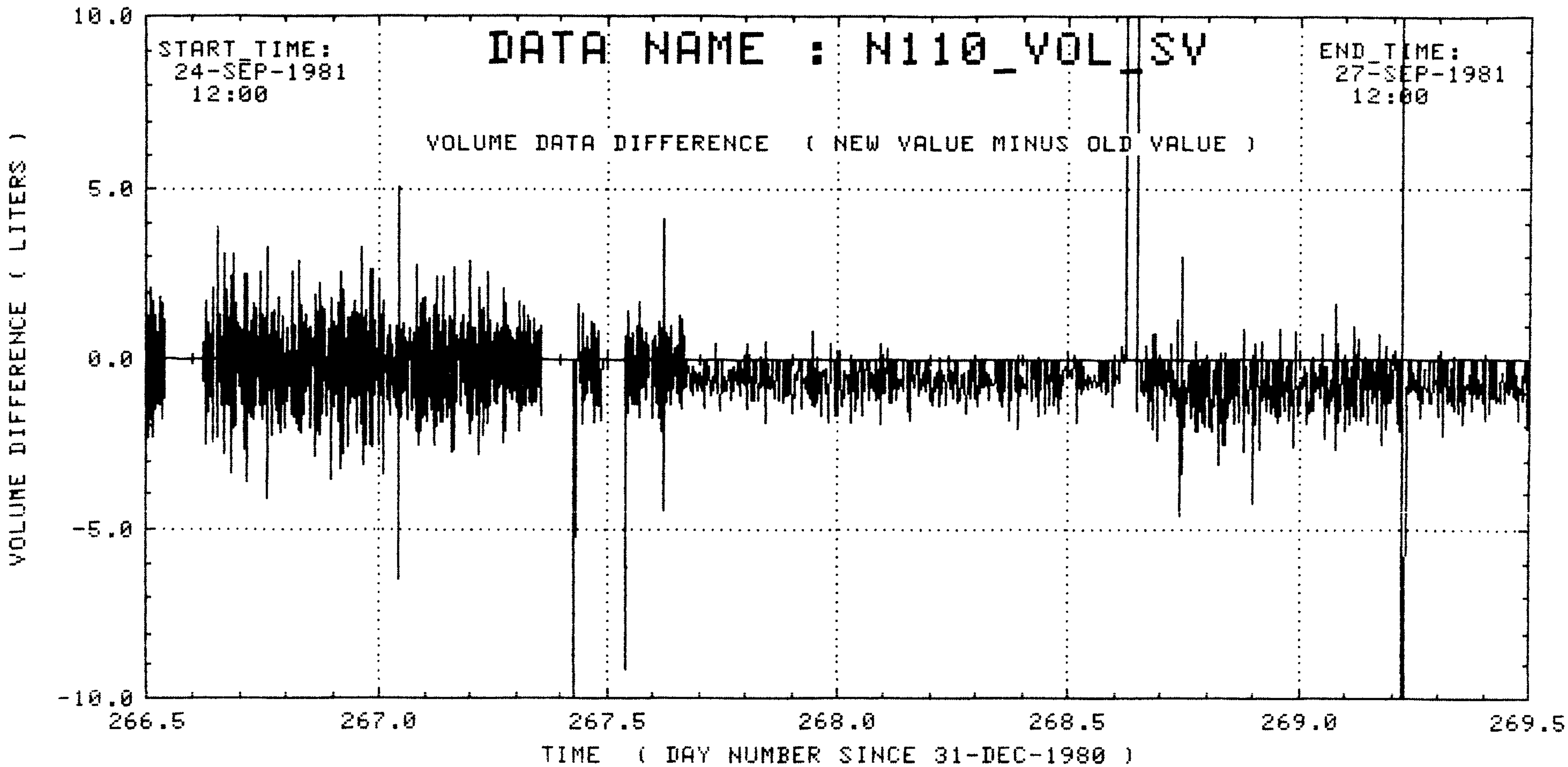

Figure 62. N110 Volume Data Difference Plot

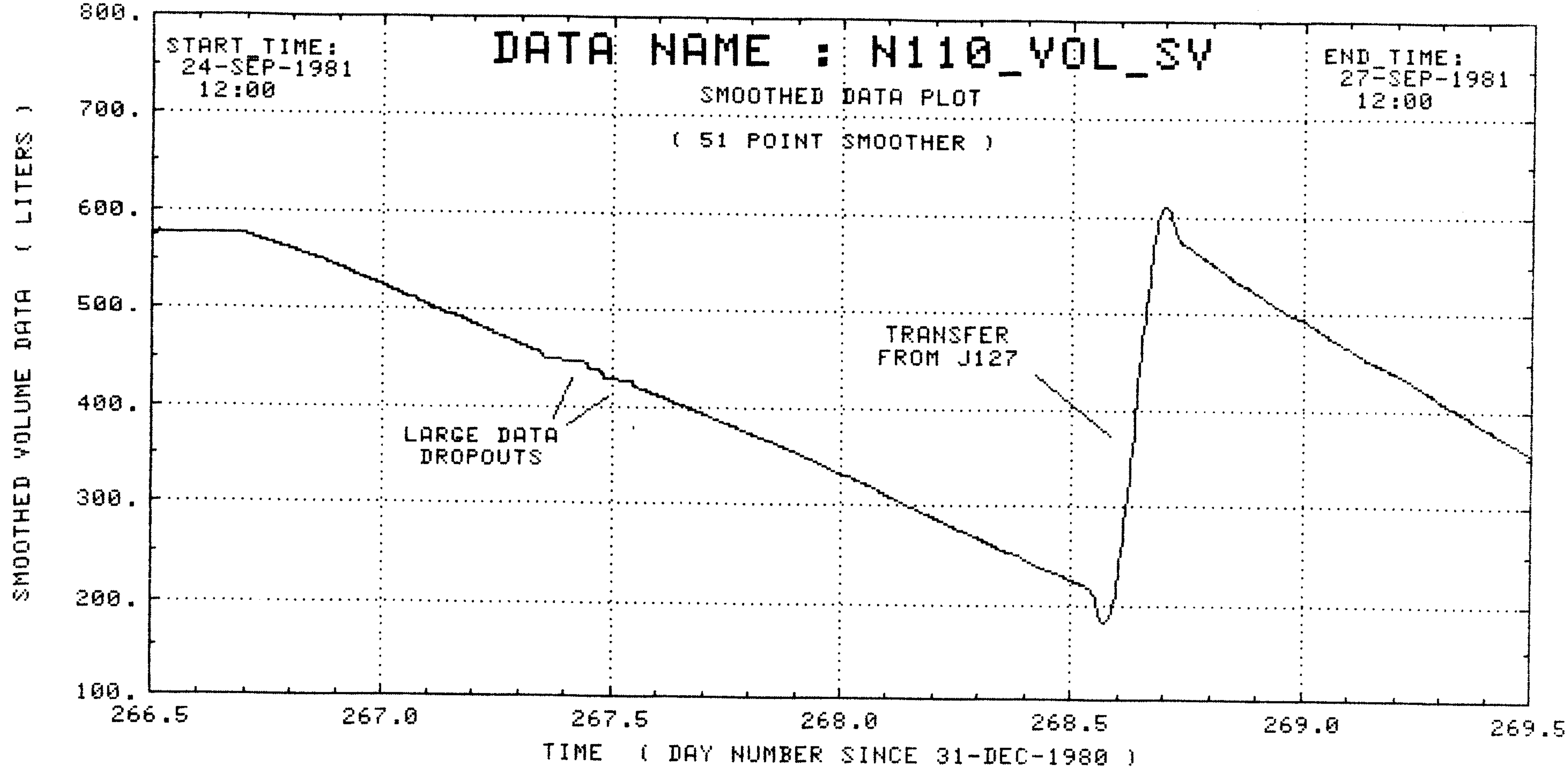

Figure 63. Plot of Smoothed Volume Data for N110

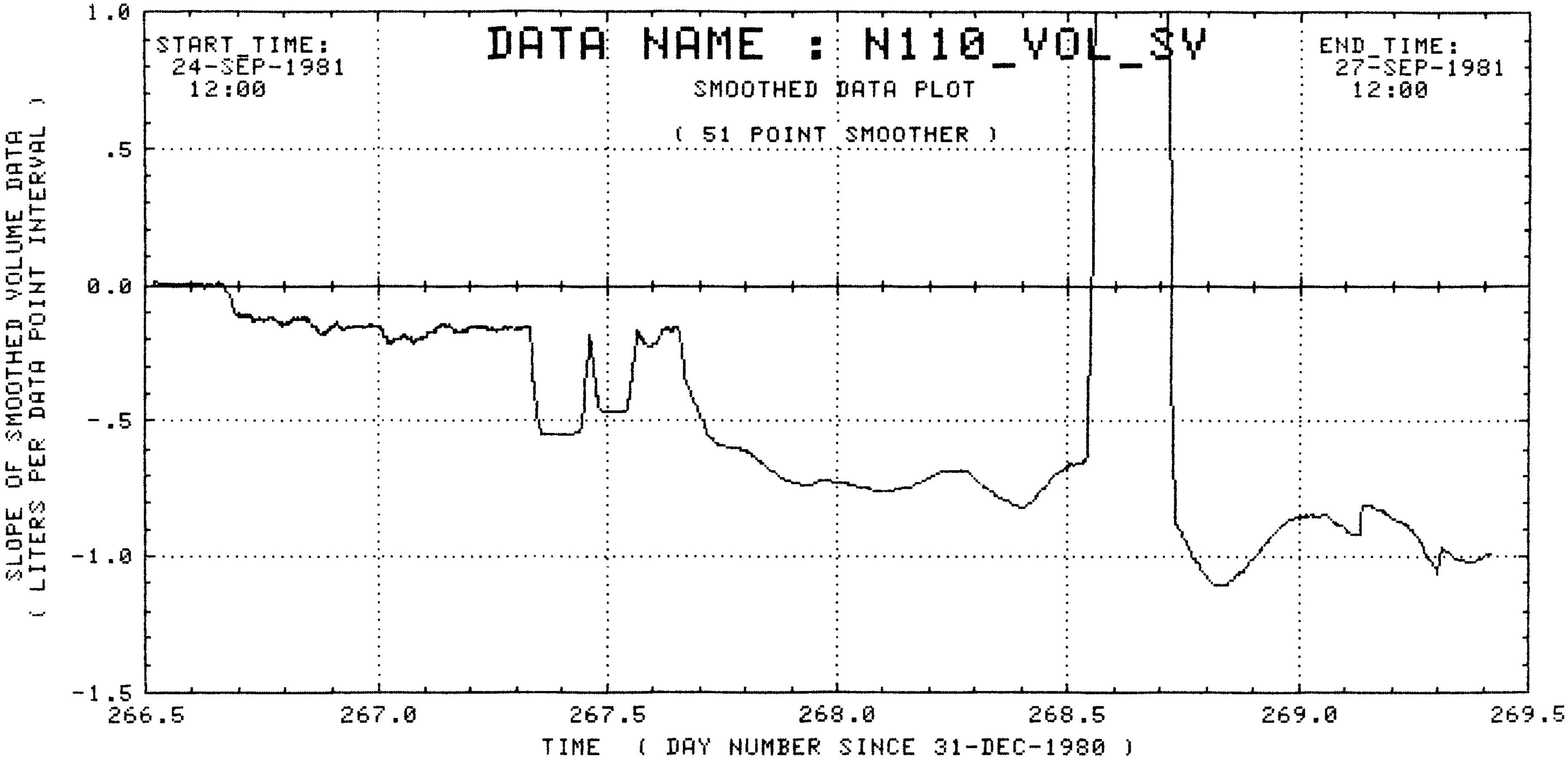

Figure 64. Slope of Smoothed Volume Data for N110

VI. CONCLUSIONS AND RECOMMENDATIONS

1. GENERAL CONCLUSIONS

The introduction (section I) lists three potential safeguards applications of process monitoring: (1) verification of accountability measurements and procedures, (2) verification of process operations, and (3) near real-time detection of abnormal SNM holdup or loss within the process. The latter requires that SNM holdup within the process areas be measured or estimated[3], and safeguards interests are to detect an unexplained loss (or diversion) of SNM on a timely basis. Production and safety interests also desire the SNM holdup information for improved plant protection from a criticality accident.

The analyses of Sections V.2.1 and V.2.2 illustrate examples of how accountability measurements and procedures could be verified, but the general conclusions of this work were limited by the small data sample size and considerable system noise. A thorough demonstration requires that analyses be applied over more accountability operations and that electromanometer type measurements from the PLDS be included in the analyses.

The analyses of Sections V.2.3 and V.2.5 illustrate examples of how some process operations might be verified, but again the general conclusions were limited by the amount of data used and the system intermittency. A thorough demonstration is recommended with analyses applied over extended process operations, more process measurements (such as column and stream flow variables), and improved system data quality.

The analyses of sections V.2.4 and V.2.6 illustrate how two process variables (feedrates to columns IA and IIA) might be obtained via near real-time data smoothing or filtering for process modeling and estimation software. The data noise estimates of Section IV.9 are also useful. However, considerable more process variables must be analyzed for near real-time SNM estimating.

2. DETAILED CONCLUSIONS AND RECOMMENDATIONS

2.1 Process Data Evaluations

2.1.1 Data Limitations. Several data limitations such as data noise, data dropouts, or limited software handling of the raw data can cause false representations of the process variables. Awareness and eventual reduction of these limitations are required for effective process data evaluations.

2.1.2 Accountability Operations. Activity monitoring is useful for the verification of accountability procedures. A minor incomplete transfer for batch #4006 was detected (see sections V.2.2 and V.2.3), and it was concluded that the volume calibration equation used in the VAX 11/780 for tank G-155 is inaccurate. Transfers from G-105 or G-155 into G-106 can be verified within the limits of the Scanivalve system acccruacy and operational uncertainies. Steam jet dilution appeared to be about 3% for G-105 and about 2% for G-155.

2.1.3 H-131 Transfers into N-Cell. The quality of analysis of transfers from H-131 to N-Cell intercycle storage is significantly limited by the present process design configuration and operation. A planned facility modification to install a new evaporator product accountability tank in M-Cell should significantly improve the estimation of inputs into N-Cell storage.

2.1.4 Process feed Rates by Tank Depletion. The process data for feed tanks G-106 and N-Cell are significantly noisy while feeding columns IA and IIA respectively (see Sections V.2.4 and V.2.6). The detailed variation of the feed rates can be determined for off-line analysis purposes by smoothing the data (see Section V.2.4 and V.2.6). An on-line, real-time feed rate determination would require data filtering or at least near real-time data smoothing.

2.2 Recommended System Improvements

2.2.1 Data Dropouts. The majority of data dropouts (or data gaps) experienced in the subject data of this report are attributed to data communication link problems that existed when the VAX 11/780 computer was located at CF-633 (approximately 3 miles south of the ICPP). Since this computer has been moved to within the ICPP complex, the dropout problem and data reliability should significantly improve. Future analysis work should verify the impoved data quality.

2.2.2 Scanivalve System. The Schwien regulator signals currently used provide useful reference signals for verifying data quality; however, there use as on-line calibration signals currently offer neglegible accuracy improvement over the basic accuracy already provided by the Scanivalve units. Improved regulator signals (one at atmospheric pressure) are recommended for improved system accuracy (see Appendix F), and use of the Ruska calibrator will also be helpful.

The Scanivalve data spike problem is specifically attributed to irregular measurement of the Schwien reference signals and the process signals themselves (see Section V.1.7). The instrumentation cause of this problem should be further investigated, but software improvements could be implemented as an interim measure pending corrective measures within the instrumentation. A software algorithm could detect and edit out the data spikes.

The Scanivalve instrumentation system is currently achieving its 1% accuracy specification with high confidence, but use of improved reference signals could push the achievalbe pressure measurement accuracy towards 0.1%. But, a major problem still remains since the plant pressure transmitters are currently limited by an approximate 3% accuracy specification, and this problem would only be correctable as part of a complete instrumentation upgrage or replacement project. The accuracy of the plant transmitters could be improved by providing a parallel, on-line, multiplexed, high accuracy measurement and calibration system similar to the technique used at the Barnwell Nuclear Fuels Plant.[7] This type of modification should be considered for full-scale implementation at the ICPP.

2.2.3 Plant Digital Signal Data. Plant digital signal data were lost not only due to overall data system dropouts. Further data were lost because the interrupt-on-state-change feature in the data acquisition system was not working correctly for most of the early FY-1982 Campaign data considered in this report. This problem has since been reduced by isolating the digital data acquisition interface from other types of data acquisition. There remains however some potential for failure within the Computer Products circuit cards, and an automated test feature now under development[8] is desired to minimize that possibility.

2.2.4 Steam Jet Temperature Data. The temperature profile for a steam jet transfer contains information about the quality of a transfer (see section IV.8), and many transfers are performed rather rapidly (see Figures 39 and 41 through 47). To assist the extraction of information from the temperature profile, it is desired that the data acquisition rate be increased (doubled) from once per minute to twice per minute. Historical records need only be maintained at the new high data rate during data transients, so an edit software algorithm may be desired to keep all data points only when a temperature transient is in progress. This is a simple matter of detecting when the data are changing at a significant rate, i.e. compare new data point values to previous values.

2.2.5 Tank Liquid Volumetric Calculations. Volumetric calculations are required to estimate liquid density, level, and volume from given bubbler probe pressure measurements. The accuracies of these calculations are dependent upon the accuracies of the models which relate measured pressures to the volumetric quantities. High accuracy models are especially required for accountability measurements using high accuracy pressure measurements; less accurate models may be acceptable for other process activities and for use when high quality pressure measurements are not available.

As high accuracy pressure measurements are used in the future, it will become necessary to consider improved model calculations. Such improvements include use of recent instrumentation and tank calibrations, corrections for probe air-flow imbalance, corrections for air density increase in a submerged probe, corrections for air bubble surface tension at the probe tip, and corrections for temperature effects (such as briefly discussed in Section V.1.5).

A relatively easy improvement for accountability tanks G-105 and G-155 would be to use the same model equations in the VAX 11/780 as used by the plant electromanometer system. This may require minor pressure head corrections if pressure measurement deviations are significantly different between the two systems.

An additional improvement would be to estimate the density independent of pressure measurements when the density probe tip is no longer submerged. The last good density data prior to uncovering could be used. This would extend the utility of volumetric calculations to the lower region of the tank. Note that liquid volume estimates having negative values could be avoided by use of limit checks.

A further improvement would be to digitally filter the density data with a low pass filter algorithm prior to use in liquid volume calculations. This is a means to reduce volume date noise and is justified since normally the density data do not change rapidly with time.

2.2.6 Data Analysis Methods. Data analyses for this report were prepared via data playback from special historical data tapes using special plot program GETDATAP. The data playback methods and the plotting program used should be improved in the future to enhance the effectiveness of the analysis by decreasing the manual effort.

A major improvement would enable analyst access to several days of current data maintained on the VAX 11/780 used for production support. Such access would greatly improve the timeliness of the analysis activity. Further, historical data manipulation programs should be made general enough to work with all historical data tapes, not just specially prepared tapes.

The plotting program GETDATAP, which was developed specifically to support analysis activity using HP-2648A terminals, could still be improved in several ways. Such improvements include improved labeling, enhanced plot options (including multiple variables in a single plot), and use of a more general least-squares smoother that does not assume evenly spaced data points.

A final need is to evaluate projected long-term requirements for analysis activities and size the video (graphics) terminal and hardcopy hardware accordingly. The use of HP-2648A graphics terminals connected to the VAX 11/780 has been shown to be reasonably effective, but DEC graphics terminals might be more effective (at least under some conditions) since they would permit use of versatile plotting programs supplied by DEC for use on the VAX 11/780. In any event, a graphics terminal and suitable hardcopy device should be made available for each assigned analyst.

VII. REFERENCES

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