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MODEL VALIDATION AND SENSITIVITY ANALYSIS OF SOLAR COLLECTOR LOOPS

FINAL TECHNICAL REPORT

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Prepared For

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DISCLAIMER

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ABSTRACT

The experimental solar collector systems at Middlebury College have been modified to permit short time resolution studies of solar collector loop performance. A variety of experiments have been performed to measure the following system properties:

a. collector efficiency
b. collector response to step changes in insolation
c. collector response to the introduction of cold inlet water
d. pump cycling as a function of control sensor location and set points.

Data from these experiments have been supplied to the solar group at Drexel for validation of their analytic collector loop model.

PROJECT DESCRIPTION AND SUMMARY

1. Project timing:

Preliminary purchasing authority under this contract was not approved until 5/21/80, with a formal contract signed on 6/25. Equipment orders were prepared before 5/21, and equipment necessary for system modifications was ordered as soon as purchasing authority was received. Early June was spent on software modifications necessary for the short timescale studies. By mid and late June equipment began arriving, and the time was spent installing equipment. The last items - flowmeters - arrived at the end of the first week in July and were installed immediately. Experimental runs began even before the flowmeters arrived, and continued through 24 July. On 24 July Dr. Fischl and a group of students from Drexel University visited and suggested experiments appropriate to the model. The group left with copies of all our data on floppy disks and in graphical form.

2. System modifications:

Major modifications necessary for this project included the installation of pump power monitors (Hall effect multipliers with precision integrators from Ohio Semitronics) and associated interrupt handling software, installation of a precision mixing valve for precharging the system to desired temperatures, installation of turbine flowmeters and their connection to our data acquisition system, and installation of collector bypass piping and valves for performing transit time experiments. Finally, seven additional sensors were installed on the system A collector, permitting detailed measurement of temperature profiles across the collector and allowing analysis of system sensitivity to the location of the control sensor. An updated system diagram, incorporating major changes, is attached as figure 1.

3. Experimental results:

We performed several basic types of experiments, including step response measurements on empy and full stagnant collector, step response on collector with flow, bypass experiments in which a cold slug was introduced into the collector, and controlled runs to test system sensitivity to variation of control parameters and sensor location. Representative runs of each type are discussed below and appropriate graphs included among the figures.

Collector step response was measured by covering the collector with a large piece of masonite and removing it abruptly. We concentrated on measuring the rise curve because the decay curve is sensitive to the type of cover used to block the sunlight. We found it important to permit the collector to stabilize for many time constants before removing the cover. Figures 2 and 3 show such runs for empty and full collectors respectively. From these data the Drexel group intends to evaluate collector time constants. Step response of a flowing collector was evaluated in the same way, but here it was necessary to measure differential voltages because the dynamic range of the response was much less than when the collector was allowed to go to stagnation temperature. Figure 4 shows analog data from such a run. The data displayed are the sensor voltages, and must be converted to temperatures via the thermistor transfer functions. Digital data on differential voltages was taken at the same time, and has been supplied to the Drexel group. Time constants calculated from these data are consistent with those indicated on preliminary transient data which was shown at the meeting of the Middlebury and Drexel workers at LBL in January, 1980.

Transit time and collector temperature profiles were determined by circulating water through the system but bypassing the collector. The collector was allowed to reach stagnation temperature, then flow was switched abruptly to the collector. Figures 5-7 show results from one such run. It should be noted that the inlet and outlet sensors, S2 and S3, are actually in piping runs just beyond the collector, so they do not get bypassed. But collector plate sensors, S17 at the inlet mainfold through S22 at the outlet mainfold, are initially bypassed and thus at stagnation temperature. Figure 5 shows the entire 20 minute run, with flow switching clearly indicated. Note the pulse of hot water to the outlet, as well as the time delays as successive sensors respond to the change.

Figure 6 shows that same data at higher time resolution. Finally, figure 7 shows "snapshots" of the temperature profile across the collector at successive times. The bottom profile is stagnation, which incidentally shows some stratification across the collector (inlet and outlet temperatures are low because they are not bypassed). Successively higher profiles show clearly the introduction and propagation of the cold slug through the collector, and the eventual attainment of the steady state. These curves yield the transit time through the collector.

Finally, nearly 50 runs were made to show the effects of varying control parameters and sensor locations. A number of these were made while Dr. Fischl from Drexel was here, so that parameters could be adjusted as appropriate to the Drexel collector loop model. Data from a few of these runs are shown in figures 8-10. Figure 8 shows a run in which S18, a sensor near the inlet end of the plate, was used for control. A great deal of cycling occurs despite the divergent set points because the cold slug quickly reaches the control sensor. Note the large amplitude of the cycling, due to the substantial hysteresis in the set points. Figure 9 shows a run in which the sensor nearest the outlet was used for control. In bright summer sun, it is nearly impossible to get cycling with this control sensor unless unrealistically high off set points are used. Beyond the initial pump turn on, no cycling is shown in this run. Finally, figure 10 shows the results of raising the off set point. Here, even though a sensor near the middle of the plate is used, for control, cycling is evident. The runs shown in figures 7-9 are but a small sample of a whole matrix of runs representing virtually every combination of set points and control sensor. Many were performed on a single very clear day, in which insolation was much more constant than in figures 8-10. Together these runs should provide abundant data for the Drexel simulations.

All data taken in these experiments was provided to Drexel group both as original data on floppy disks and in graphical summaries. In addition, analog data from a strip chart recorder monitoring selected parameters was also provided. It is anticipated that the Drexel group will attempt to simulate the actual runs with their model and that results of this work will be presented at the next SSEA conference.

Revised 6/80

MIDDLEBURY SOLAR ENERGY PROJECT SYSTEM DIAGRAM

SYSTEM A - System B identical except S13, S14, S15, S29, S30, S31, V11, V12 shared by both systems. AS17-23 on system A only.

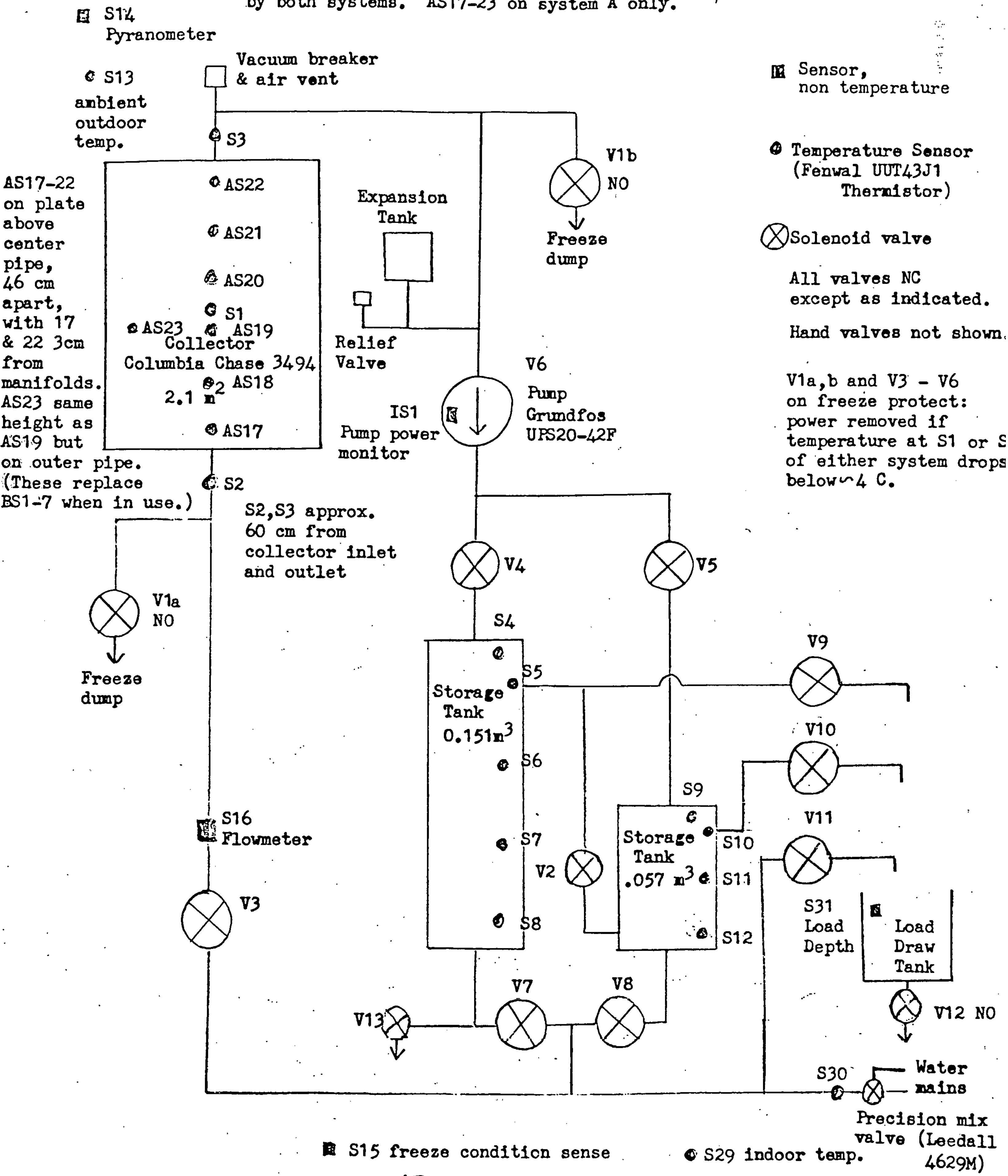


FIGURE 1

Run 1 DATA INTERVAL - 5sec PLOT INTERVAL - 15sec EMPTY COVER|UNCOVE

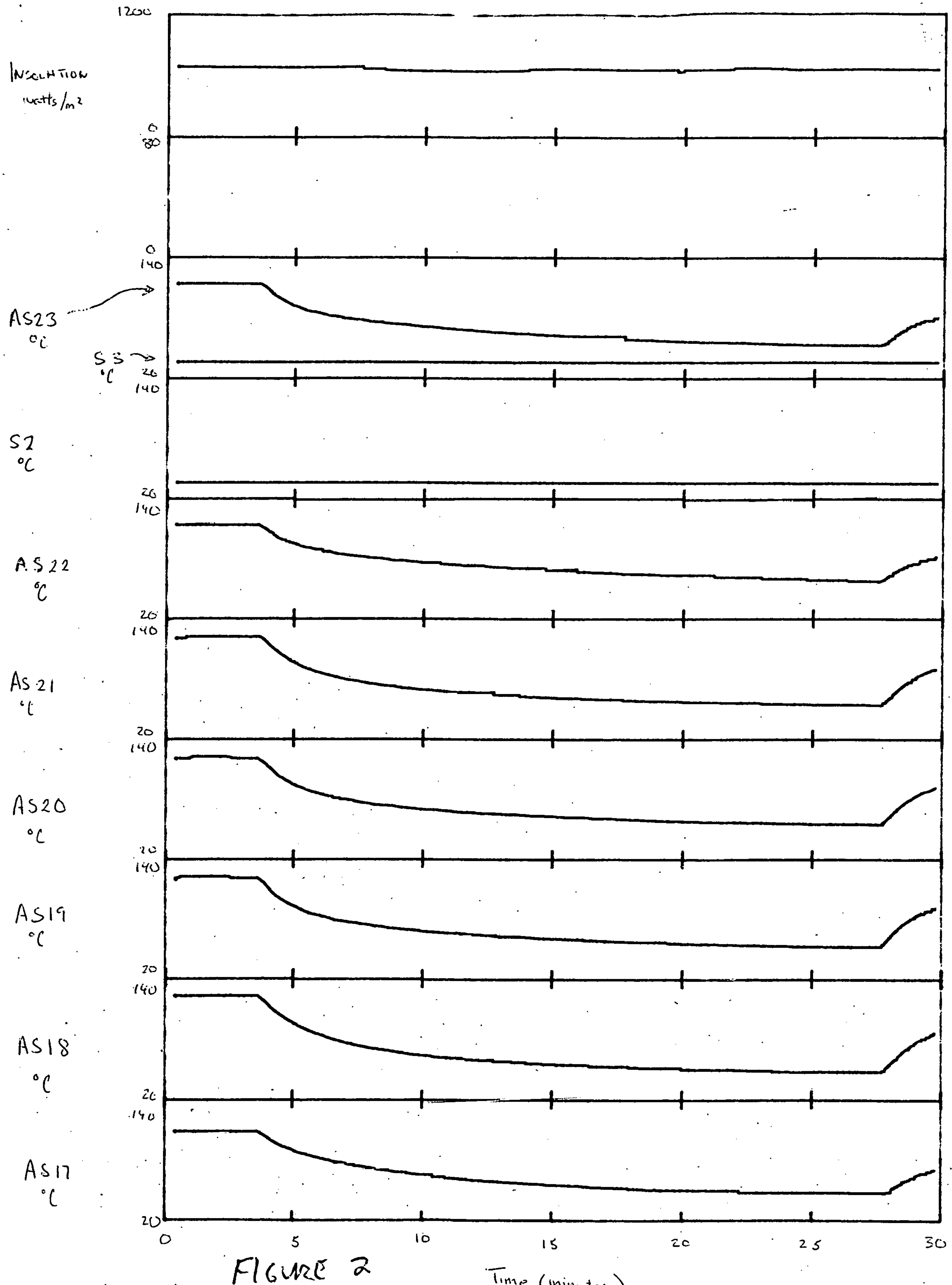
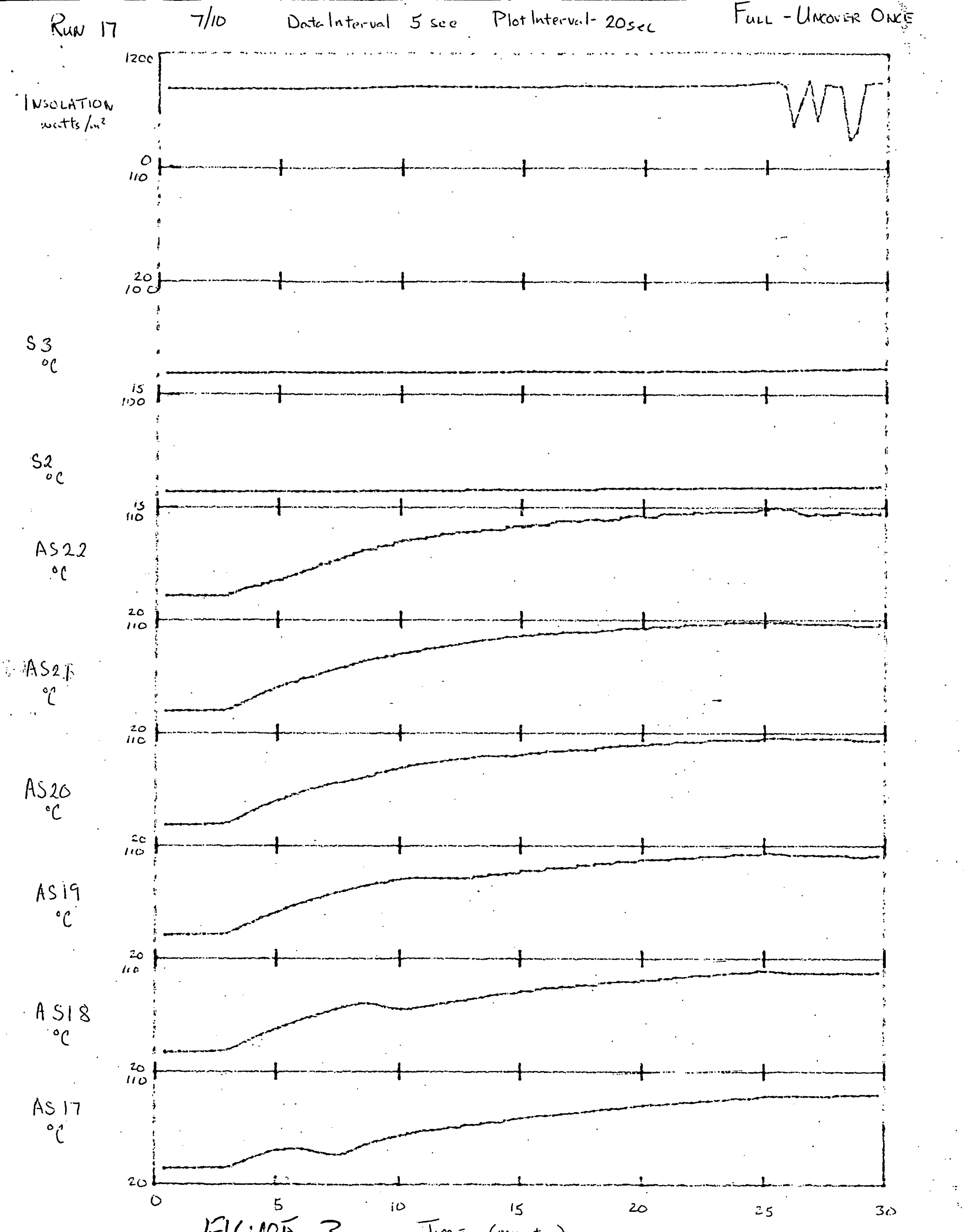
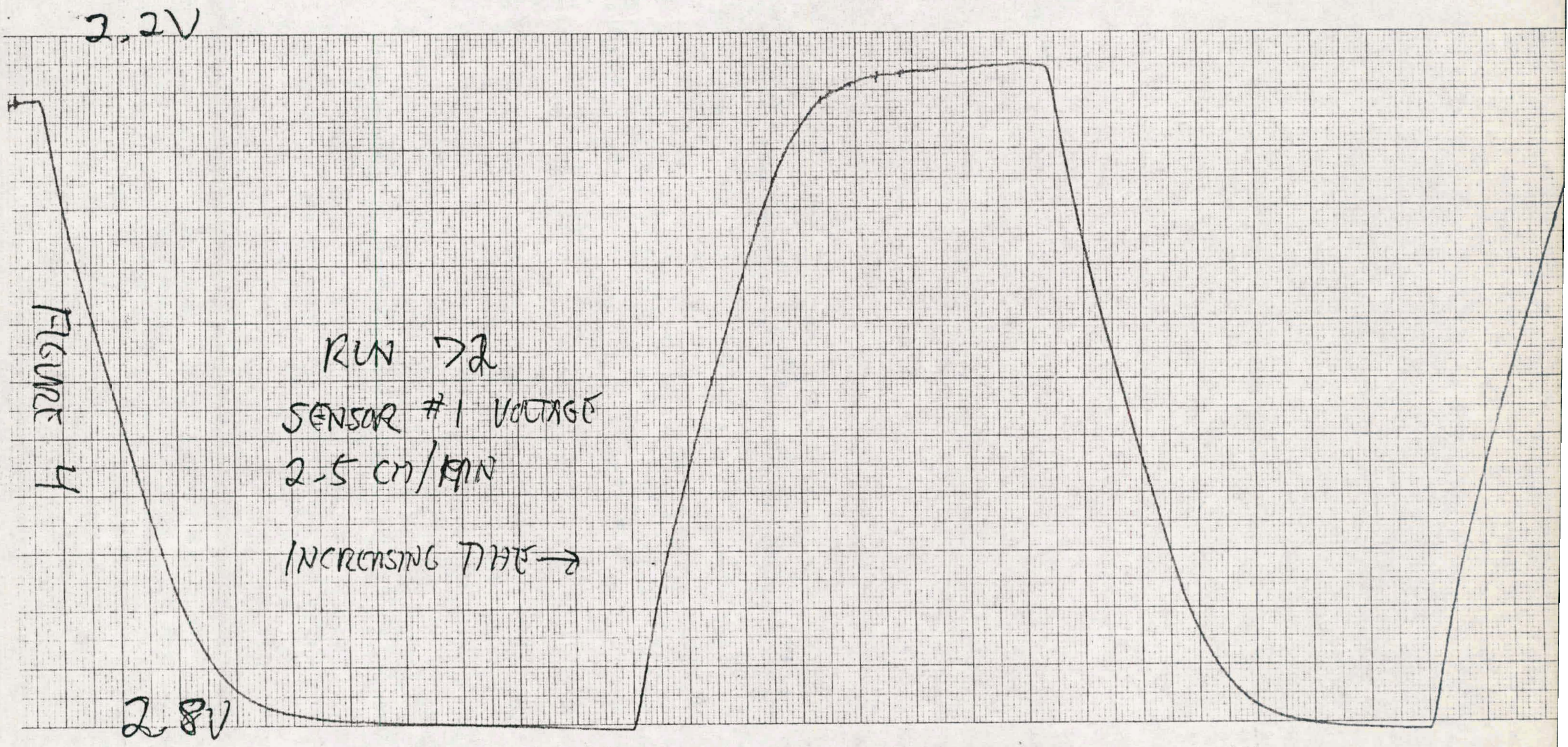


FIGURE 2



Run 17
7/10
Data Interval 5 sec
Plot Interval - 20 sec
Full - Uncover Once
Insolation watts/m²
1200
0
110
20
100
S3 °C
15
100
S2 °C
15
110
AS22 °C
20
110
AS21 °C
20
110
AS20 °C
20
110
AS19 °C
20
110
AS18 °C
20
110
AS17 °C
20
0
5
10
15
20
25
30
Time (minutes)

FIGURE 3


2.2V
FIGURE 4
RUN 72
SENSOR #1 VOLTAGE
2.5 CM/MIN
INCREASING TIME →
2.8V

Run Number 18 7/10 Data Interval 1sec Plot Interval 10 sec Full - Bypass

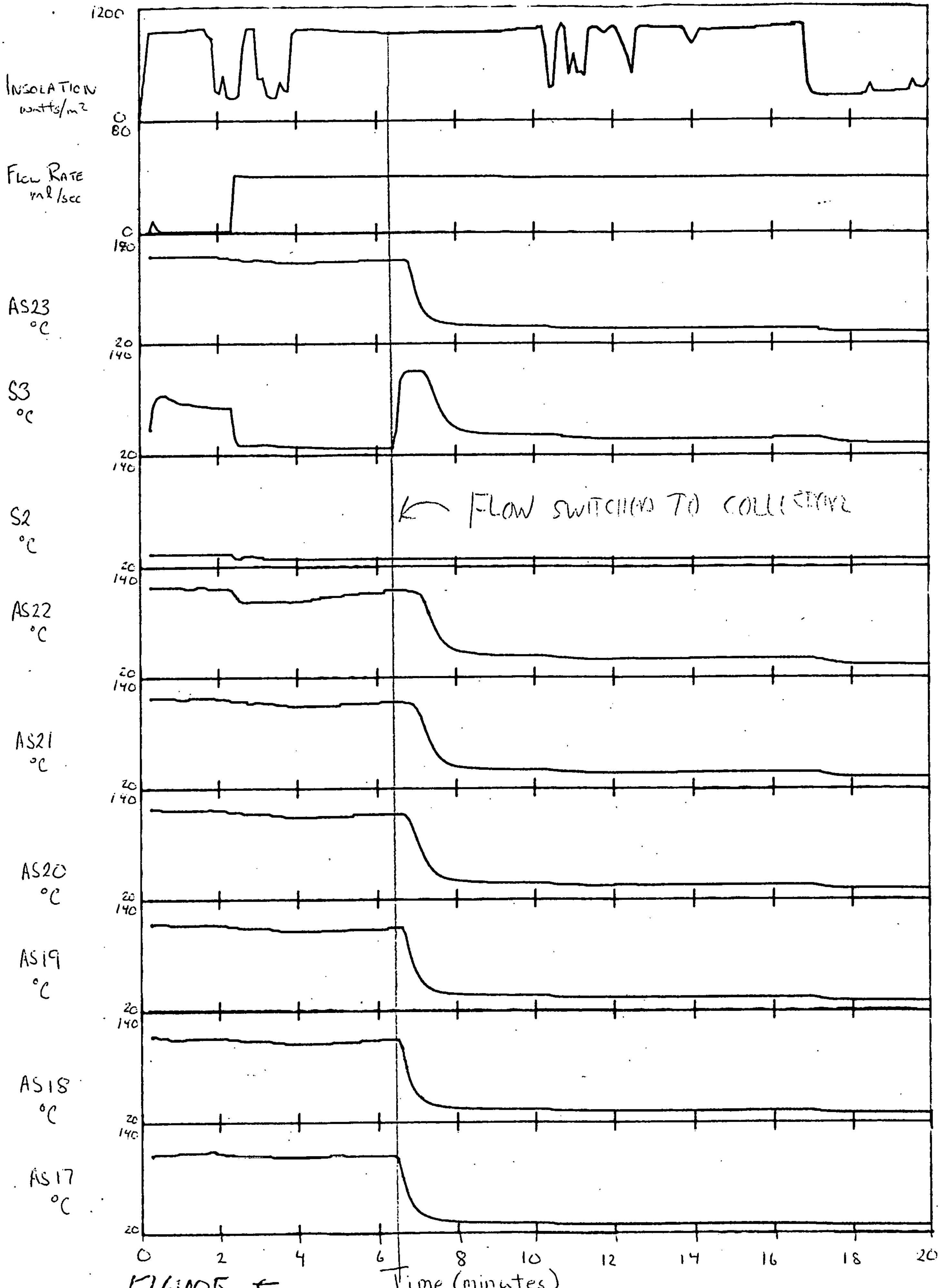


FIGURE 5

Run 18 7/10 Data + Plot Interval - 1 sec FULL BYPASS

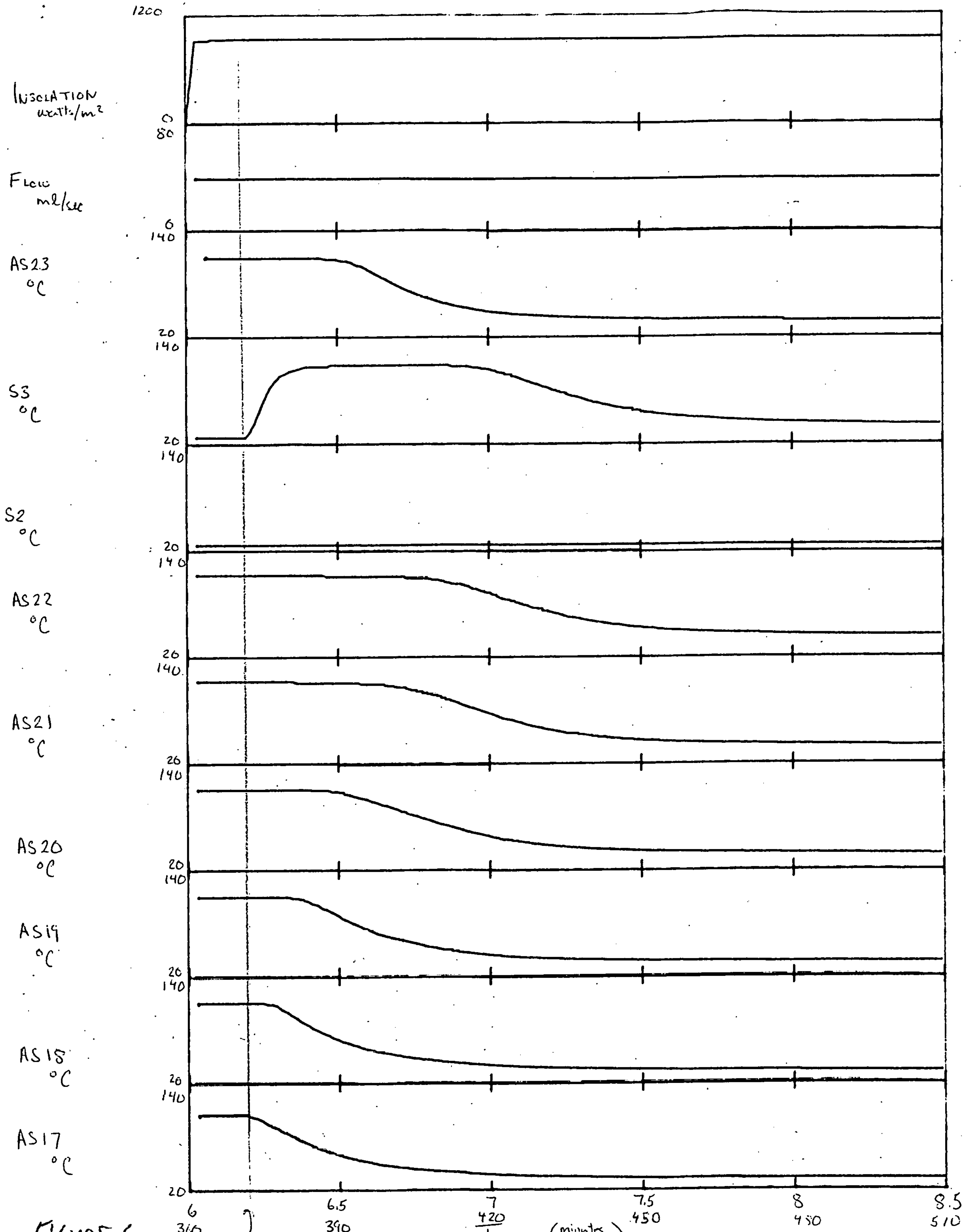


FIGURE 6

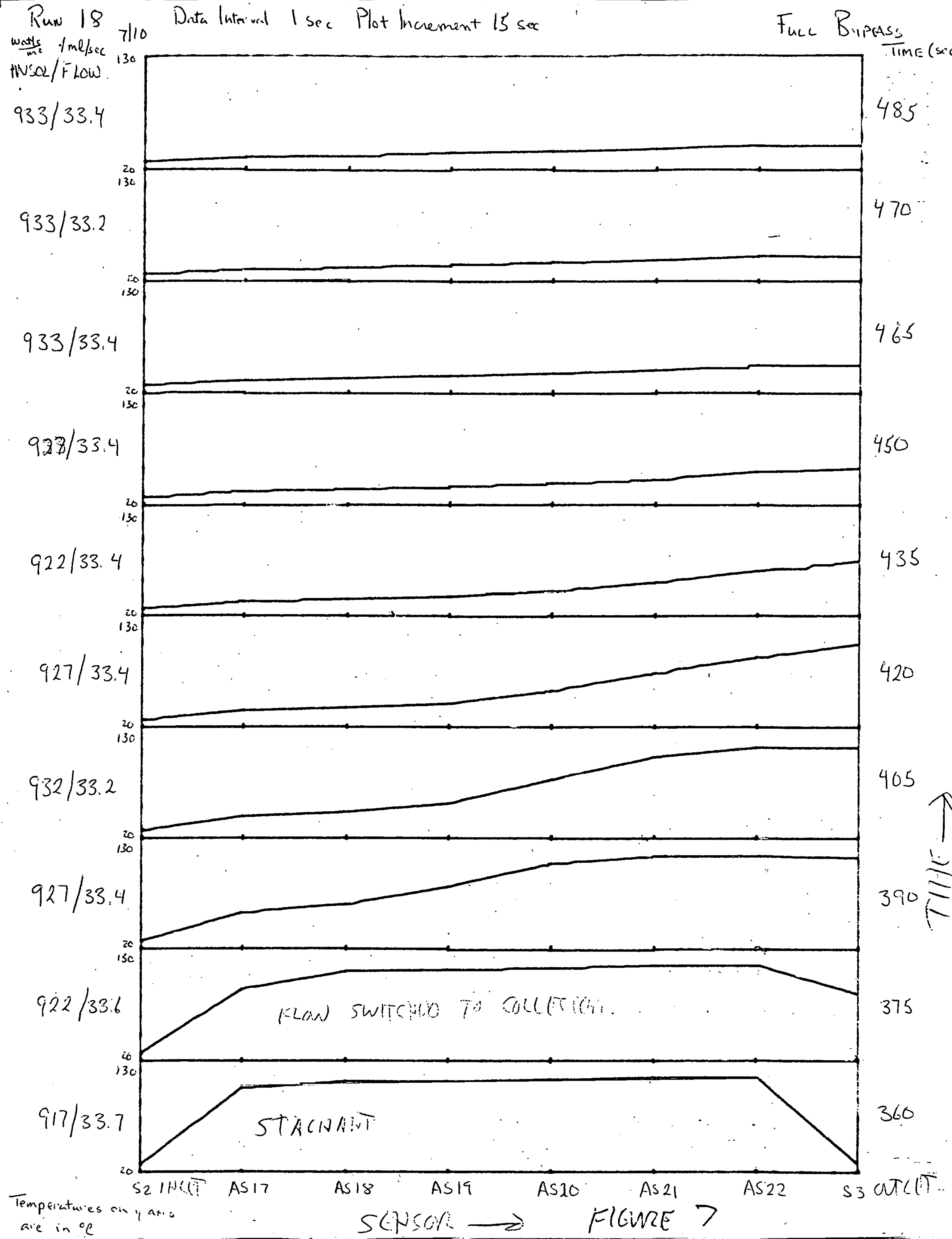

Run 18 7/10
Data Interval 1 sec Plot Increment 15 sec
Full Bypass
watts/m² / ml/sec
HVSOL/FLOW
TIME (sec
933/33.4
485
933/33.2
470
933/33.4
465
938/33.4
450
922/33.4
435
927/33.4
420
932/33.2
405
927/33.4
390
922/33.6
375
FLOW SWITCHED TO COLLECTION.
917/33.7
360
STAGNANT
130
20
S2 INLET
AS17
AS18
AS19
AS10
AS21
AS22
S3 OUTLET
TIME
Temperatures on y axis are in °C
SENSOR

FIGURE 7

RUN 62 TEMP LIMITS 38 - 70
FLOW MAX 50 ML/S, INS MAX 1KW/M^2

ΔT_OFF 2°C
ΔT_ON 10°C
CONTROL SENSOR S18

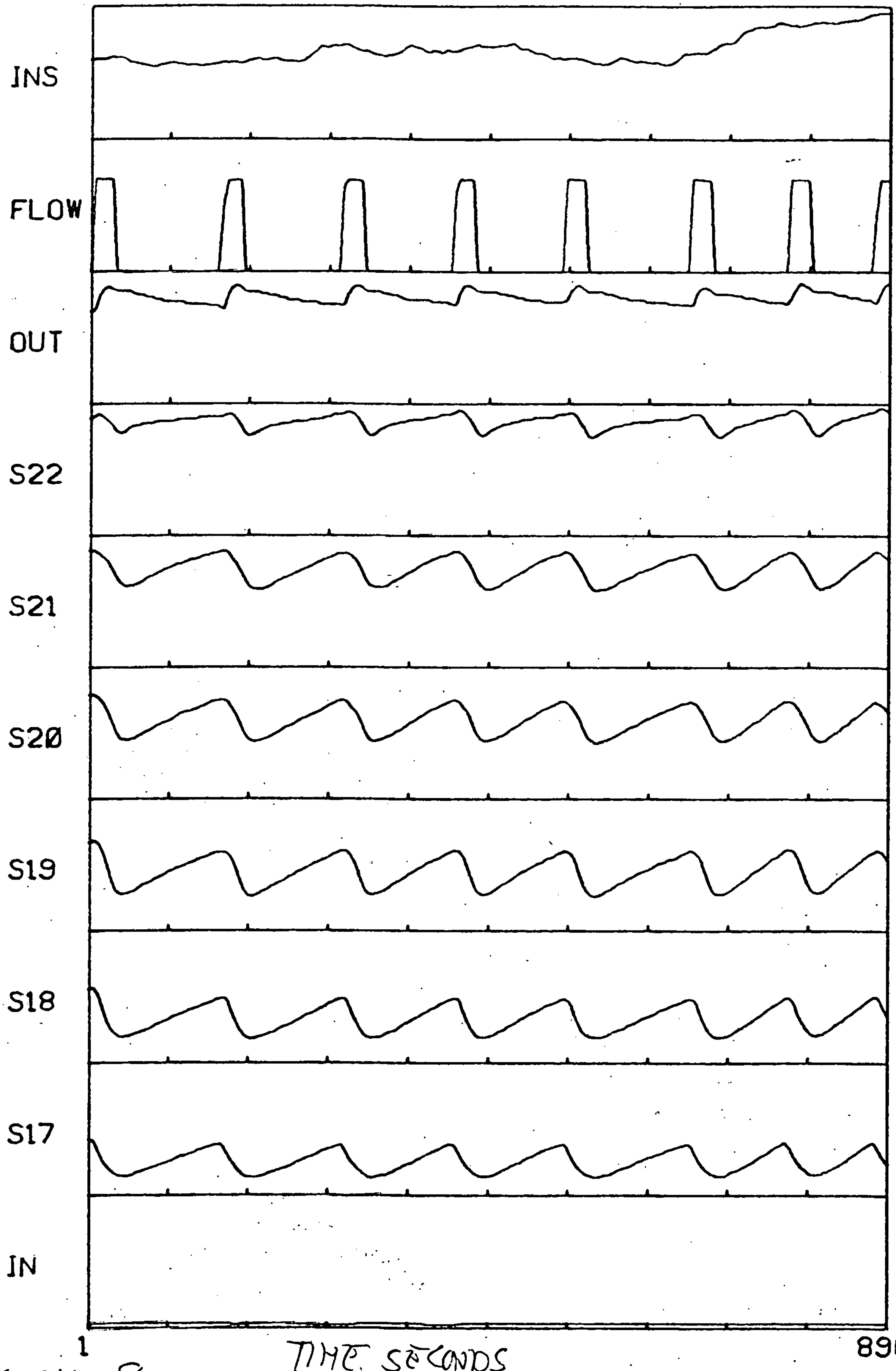


FIGURE 8

ΔT OFF 2°C
ΔT ON 3°C
CONTROL SENSOR S22

RUN 63 TEMP LIMITS 38 - 93
FLOW MAX 5Ø ML/S, INS MAX 1KW/M^2

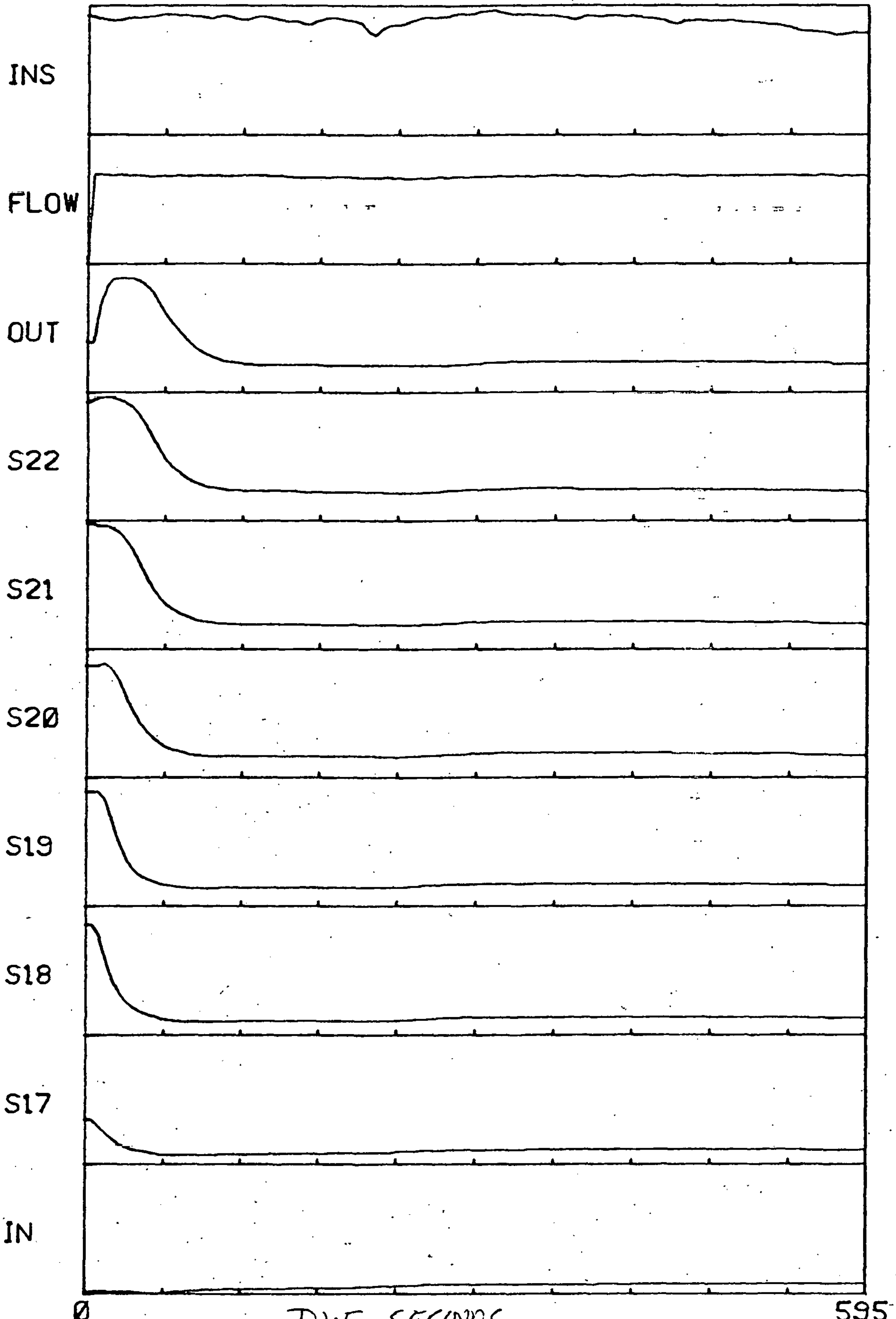


FIGURE 9

ΔT OFF 4°C
ΔT ON 5°C
CONTROL SENSOR -5

RUN 66 TEMP LIMITS 40 - 69
FLOW MAX 50 ML/S, INS MAX 1KW/M^2