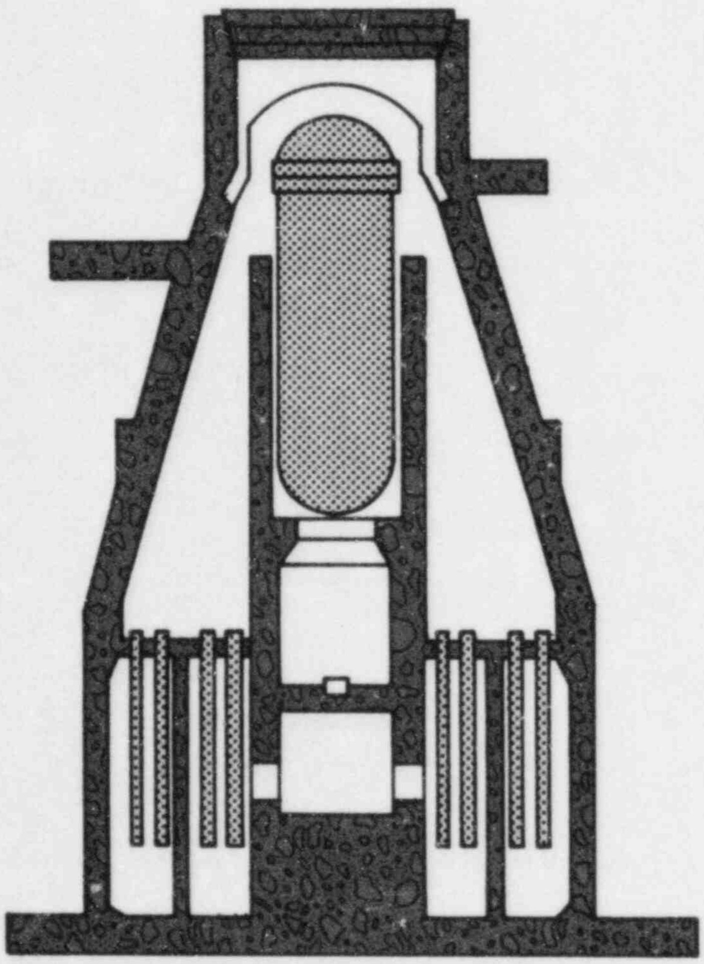
In-Plant SRV Test

Extended Blowdown Test
Evaluation of Suppression Pool Temperature Measurements



La Salle County Station Unit 1

COMMONWEALTH
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LASALLE COUNTY 1
IN-PLANT S/RV TEST

EXTENDED BLOWDOWN TEST
EVALUATION OF SUPPRESSION POOL TEMPERATURE MEASUREMENTS

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PROPRIETARY NOTICE

ABSTRACT

This report presents the results of the extended S/RV blowdown tests performed at the LaSalle County Station Unit 1 in December 1982. These tests were part of an in-plant S/RV test program designed to provide data used to (1) confirm that the containment can safely accommodate all hydrodynamic loads and thermal effects associated with S/RV actuation and (2) demonstrate adequate plant design margins for these effects. The objectives of the extended blowdown tests were to examine the thermal response of the suppression pool to S/RV discharge. Measurements were made to evaluate (1) thermal mixing of the suppression pool and (2) the adequacy of the suppression pool temperature monitoring system (SPTMS) in indicating bulk pool temperature. These measurements also provide plant unique data on which to base the technical specifications concerning suppression pool temperature limits.

Results of the tests show the average local-to-bulk pool temperature difference for S/RV discharge to be 8.1^{o}F with a 95/95 confidence level of non-exceedance of 12.0^{o}F. Tests results also confirm that the SPTMS provides a conservative measure of the bulk pool temperature. An evaluation of the technical specifications concerning suppression pool temperature limits was also made, and where as these limits apply to more than S/RV discharge considerations, the current specifications were found to have a 20^{o}F margin for this phenomenon.

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1.0 INTRODUCTION

1.1 BACKGROUND

In-plant safety/relief valve (S/RV) discharge tests were performed at the LaSalle County Nuclear Power Station in December 1982. Part of these tests was a series of seven extended S/RV blowdowns to examine various aspects of thermal mixing within the suppression pool. A detailed description of the test plan for these tests is given in the Sargent & Lundy report "LaSalle County 1 - In-Plant S/RV Test Plan" [1].

The 18 S/RV's for each reactor at the LaSalle Station provide overpressure protection for the primary system. Discharge steam from each S/RV is routed from the primary system to the wetwell via an S/RV discharge line. Each line terminates at a submerged T-Quencher which is aproximately 23-ft. below the suppression pool surface.

A T-Quencher is a device which distributes steam flow as it enters the pool in order to promote uniform condensation. At elevated pool water temperatures the condensation process may become unstable and thereby produce large hydrodynamic loads within the suppression pool. In order to preclude this possibility, administrative procedures and technical specifications are established such that elevated pool water temperature beyond the stable steam condensation regime cannot occur. An account of the history of this subject and current regulatory requirements is contained in the NRC document NUREG-0783, "Suppression Pool Temperature Limits for BWR Containments" [2].

1.2 TEST OBJECTIVES

The extended blowdown tests were performed as a part of an extensive In-Plant S/RV Test Program [1]. In addition

to the primary test program objective of confirming the design adequacy of the containment to safely accommodate hydrodynamic loading, the objectives of this portion of the test program were to determine plant unique thermal effects, specifically: 1) the maximum local-to-bulk pool temperature difference during S/RV discharge and 2) the adequacy of the suppression pool temperature monitoring system (SPTMS).

1.3 TECHNICAL SPECIFICATIONS

The current operator action points on suppression pool temperature found in the LaSalle Technical Specifications [4] are based upon generic data. The extended blowdown tests provide an opportunity to revise these technical specifications based upon plant specific data. This report uses test data to determine the margins in the current operator action points. Also examined are the factors involved in establishing more realistic operator action points which allow for a wider range of plant operability.

1.4 REPORT OUTLINE

The sections in this report contain the following information:

Section 2 gives a description of the test procedure as well as of the general suppression pool layout.

Section 3 gives a description of both the test and SPTMS instrumentation as well as of the data processing system for test data.

Section 4 presents measured and computed results from the test. A number of general observations about the test are also included.

Section 5 gives an evaluation on use of the SPTMS and an examination of the technical specifications concerning suppression pool temperature.

Section 6 gives a comparison of the measured and computed test results to the acceptance criteria for maximum local pool temperature and SPTMS response.

Section 7 contains references cited in this report.

Appendix A presents the calculations used to obtain the bulk pool temperatures for the seven tests.

Appendix B demonstrates the applicability of the measured data (taken at pool temperatures ranging between 58°F and 97°F) to higher bulk pool temperatures (up to 200°F).

Appendix C contains plotted test data from the seven test runs.

2.0 TEST DESCRIPTION

The LaSalle County Station is a two unit Mark II containment BWR plant. Each reactor has a total of 18 S/RV's and attendant discharge lines and T-Quenchers. Two of these quenchers (C and G) were used in the extended blowdown tests. Quencher C is located at a radius of 36.5 ft and at plant azimuth 230^{o} while quencher G is located at a radius of 20.6 ft and at plant azimuth 210^{o} (Figure 2-1).

Seven extended blowdown test runs were conducted and are identified as Test Run Numbers 69 to 75 inclusive. Quencher C was used for Test Run Numbers 70, 71, 73, 74, and 75, and quencher G was used for Test Run Numbers 69 and 72.

Prior to each test run, steps were taken to bring the pool into thermal equilibrium. Following each extended blowdown test, the pool was mixed and cooled via a combination of RHR trains A and B and the LPCS system operated in the test mode. A minimum of one hour was allowed between the time the systems were shut off and the start of the next test to allow the pool to become quiescent. The time between extended blowdown test runs ranged between four and seven hours.

Data recording was started 15 seconds before the start of each test run and continued for approximately 80 minutes. At time zero the designated S/RV was opened. For the tests which included RHR operation (69 and 72), the RHR system train A was started in the pool cooling mode immediately following the opening of the "G" S/RV. Table 2-1 presents some pertinent information for each of the extended blowdown test runs. Figure 2-1 shows the azimuth of the RHR train A suction (32^{o}) and discharge (163^{o}).

TABLE 2-1

TEST CONDITIONS

Run No.	Date	S/RV Open	S/RV Close	Test Duration	Elapsed Time since previous Test	Reactor Power (%FP)	Reactor Pressure (psia)
69	12/28/82	13:41:55	13:56:56	15:01	2:25:43	47	958-961
70	12/28/82	17:49:57	18:06:58	17:01	3:53:01	46	957-961
71	12/29/83	00:49:53	01:04:19	14:26	6:42:55	46	954-956
72	12/29/83	05:03:52	05:18:57	15:05	3:59:33	46	953-958
73	12/29/82	10:17:53	10:30:45	12:52	4:58:56	46	954-957
74	12/29/82	15:22:51	15:32:24	9:33*	4:52:06	48	953-957
75	12/29/83	19:37:52	19:50:53	13:01	4:05:28	51	956-958

*Extended blowdown stopped due to faulty reading on suppression pool level indication.

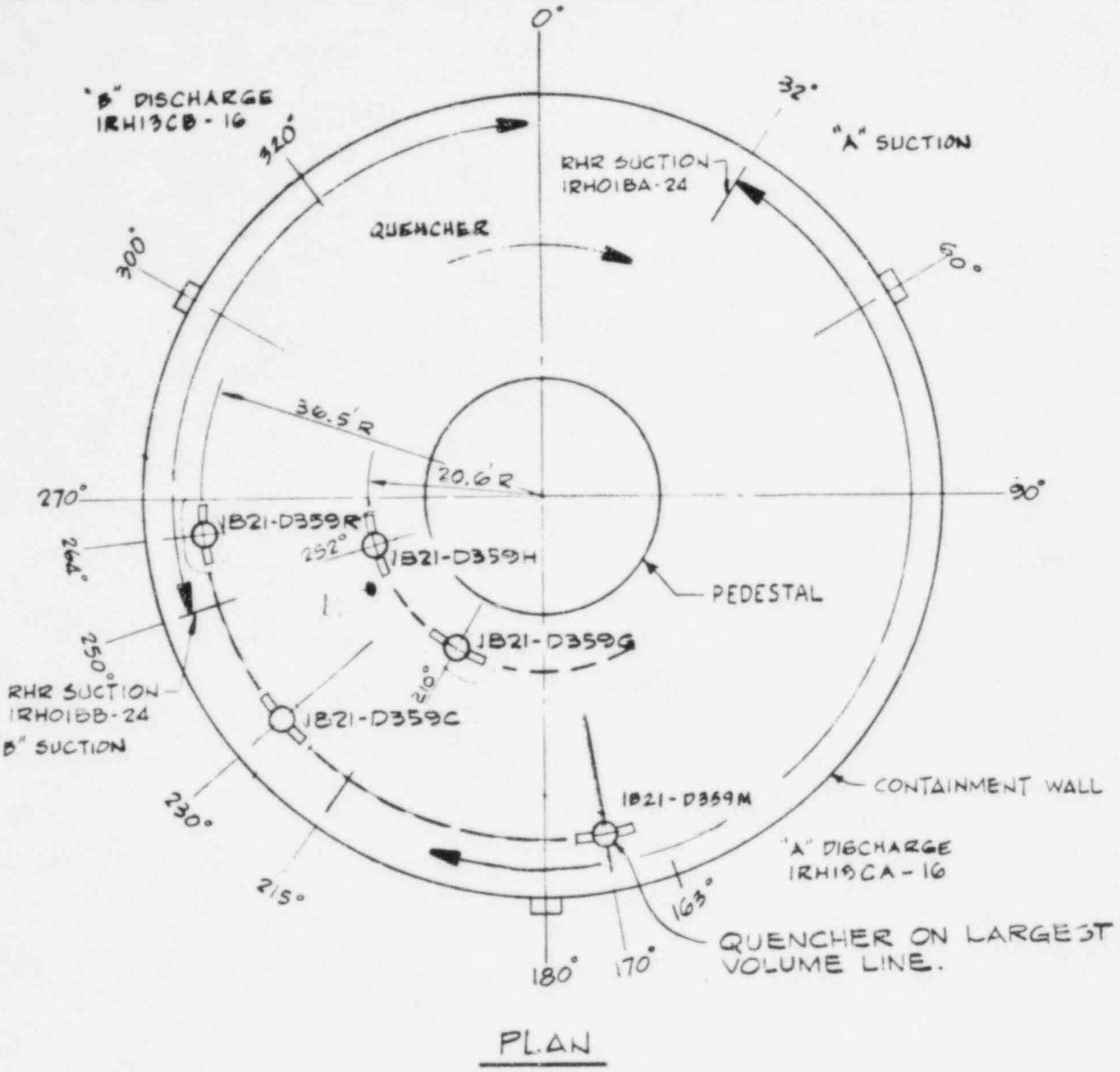

FIGURE 2-1

Suppression Pool Layout - Elevation View

3.0 INSTRUMENTATION

3.1 PERMANENT INSTRUMENTATION (SPTMS)

The suppression pool temperature monitoring system (SPTMS) monitors the pool temperature to provide the operator with the information necessary to prevent excessive pool temperatures during a transient or accident. Temperatures in the pool are recorded and alarmed in the main control room. The instrumentation arrangement in the suppression pool consists of two wall mounted sensors and 14 dual-element SPTMS temperature sensors mounted on support structures near the surface of the suppression pool between adjacent T-Quenchers.

The two wall mounted temperature sensors are dual-element chromel constantan thermocouples located at elevation 683 feet 0 inch, and at azimuths 17° and 197°. Signals from these sensors are used to provide the operator with a general indication of the pool temperature. They are not used in conjunction with any specified or mandated operator action.

The SPTMS temperature sensors consist of 14 dual-element, 100 Ω, platinum RTD's located 8½ inches below the low water level at elevation 698 feet 10 inches. Ten of the sensors are mounted near the outer suppression pool wall at azimuths 0°, 33°, 67°, 113°, 149°, 180°, 211°, 247°, 293°, and 332°. The other four are mounted near the pedestal at azimuths 48°, 128°, 233°, and 308°. Seven of the dual-element RTD's are powered from the ESS-1 power division and seven are powered from the ESS-2 power division. During normal plant operation the SPTMS is in continuous operation recording the suppression pool water temperature in the main control

room. Alarms in the control room provide the operator sufficient notice to take appropriate action to prevent the pool from exceeding the specified temperature limits.

The Technical Specification operator action points are designated TS1, TS3, and TS4. Alarms are given when any one of the 28 sensor elements exceeds TS1 or TS3. Use of the SPTMS to indicate bulk pool temperature is addressed in Section 5.1.

Operator action point TS1 (currently 100°F) is the point at which the operator is to start pool cooling.
Operator action point TS3 (currently 110°F) is the point at which the operator is to scram the reactor.
Operator action point TS4 (currently 120°F) is the point at which the operator is to start depressurization of the reactor.

3.2 TEST INSTRUMENTATION

Thirty-four (34) temperature sensors were used in the extended blowdown test to measure the suppression pool temperature.† The Medtherm PTF-100-10356 was used at all 34 locations. The locations of these sensors are shown in Figures 3-1 and 3-2 and described in more detail in the "In-Plant S/RV Test Plan" [1] and the "In-Plant S/RV Test Final Data Report" [6]. These sensors have a stated accuracy of $\pm 0.5^{\circ}$F and a thermal response time of 5 ms [6].

The temperature sensors were conditioned with the AGM Electronic, Inc. Model EIA-4003 RTD Signal Conditioner. This device provides a filtered, regulated, rectified power supply to individual RTD's. The EIA-4003 amplifies, linearizes, and isolates the output signal from the RTD and provides an output signal to the data acquisition system (the Q.S.I. Model 721).

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†Sensors T6 and T12 were non-functional for all test runs.

3.3 DATA ACQUISITION

The digital data acquisition and recording system was the Q.S.I. Model 721. A block diagram of this system along with the other Data Acquisition, Recording and Playback System (DARPS) equipment is given in the "In-Plant S/RV Test Plan" [1].

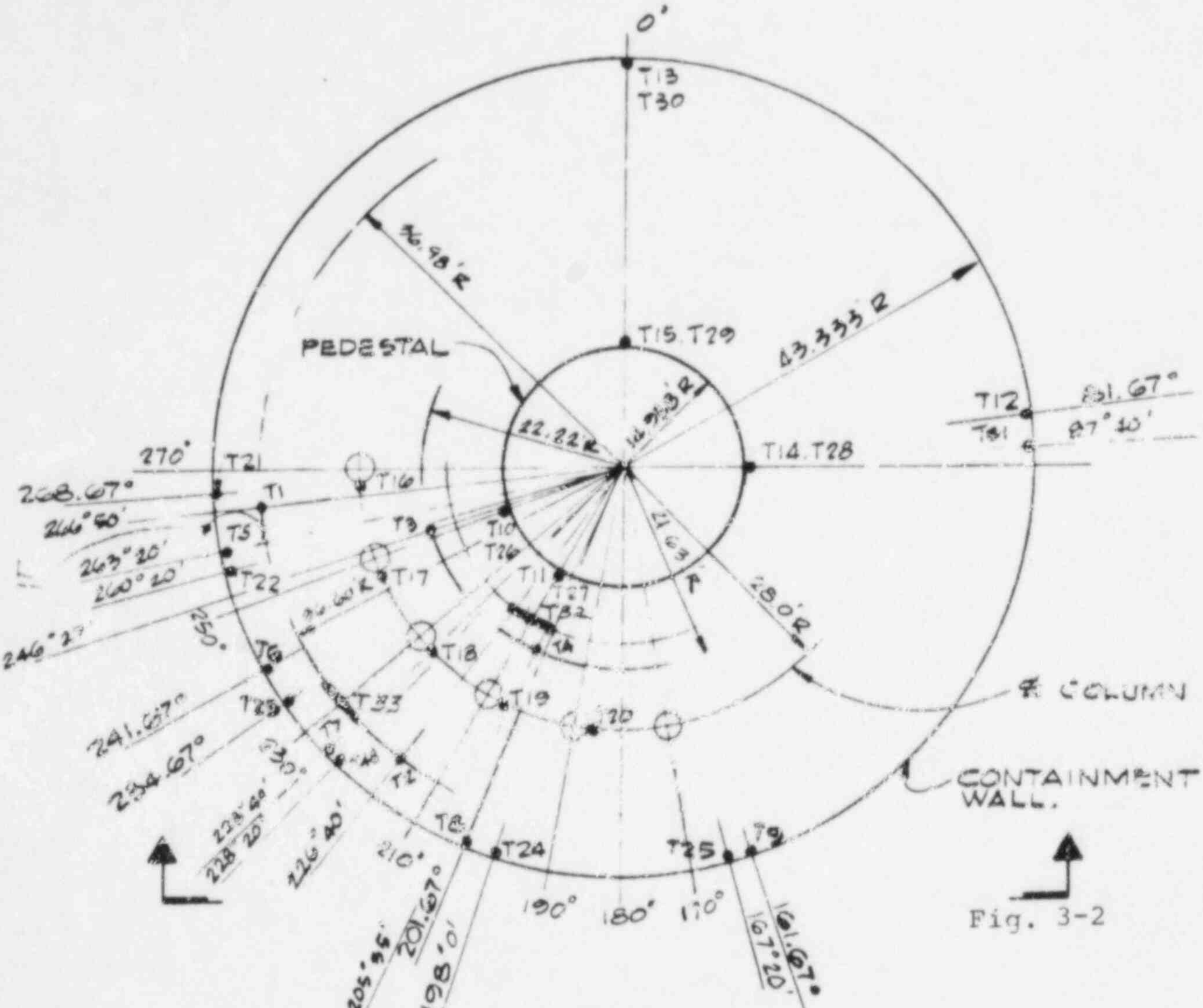
All signal inputs to the system are processed, formatted, and written in IBM compatible form on digital magnetic tape. The tapes so generated may then be processed on any computer system (supporting industry standard magnetic tapes) for data reduction, analysis, and reformatting to any desired standard.

Internally, the test measuring equipment was grouped into four main subsystems: (1) an analog multiplexer; (2) a precision analog-to-digital converter; (3) a high speed digital magnetic tape recorder; and (4) an electronic control logic. Several factors contributed to the high accuracy and high throughput of this system. The analog-to-digital converter was a precision, 12-bit (11 bits plus sign) unit, with crystal referenced sampling rate. The resulting low sample interval jitter eliminates the wow and flutter problems of analog recorders. The digital magnetic tape unit was a high-speed (125 ips), very high density (6250 BPI Group Code Recording GCR) device. This enabled an extremely high data throughput for the system. The GCR technique provided for a very low error rate by correcting any recording errors on-the-fly. Finally, semi-conductor memory was used to buffer data flow through the system. This allowed data acquisition and recording functions to proceed independently, for the highest possible system throughput (up to ¼ million samples/sec.). On-the-spot playback of recorded data, with reconversion to analog form, was also a feature of this system.

3.4 DATA REDUCTION

The general purpose Wyle computer program ADARS was used to perform the required data processing. ADARS provided the framework for coordinating various data files on disc. ADARS had an operator interface which allowed the user to select a wide variety of processing and display options to meet his analysis requirements.

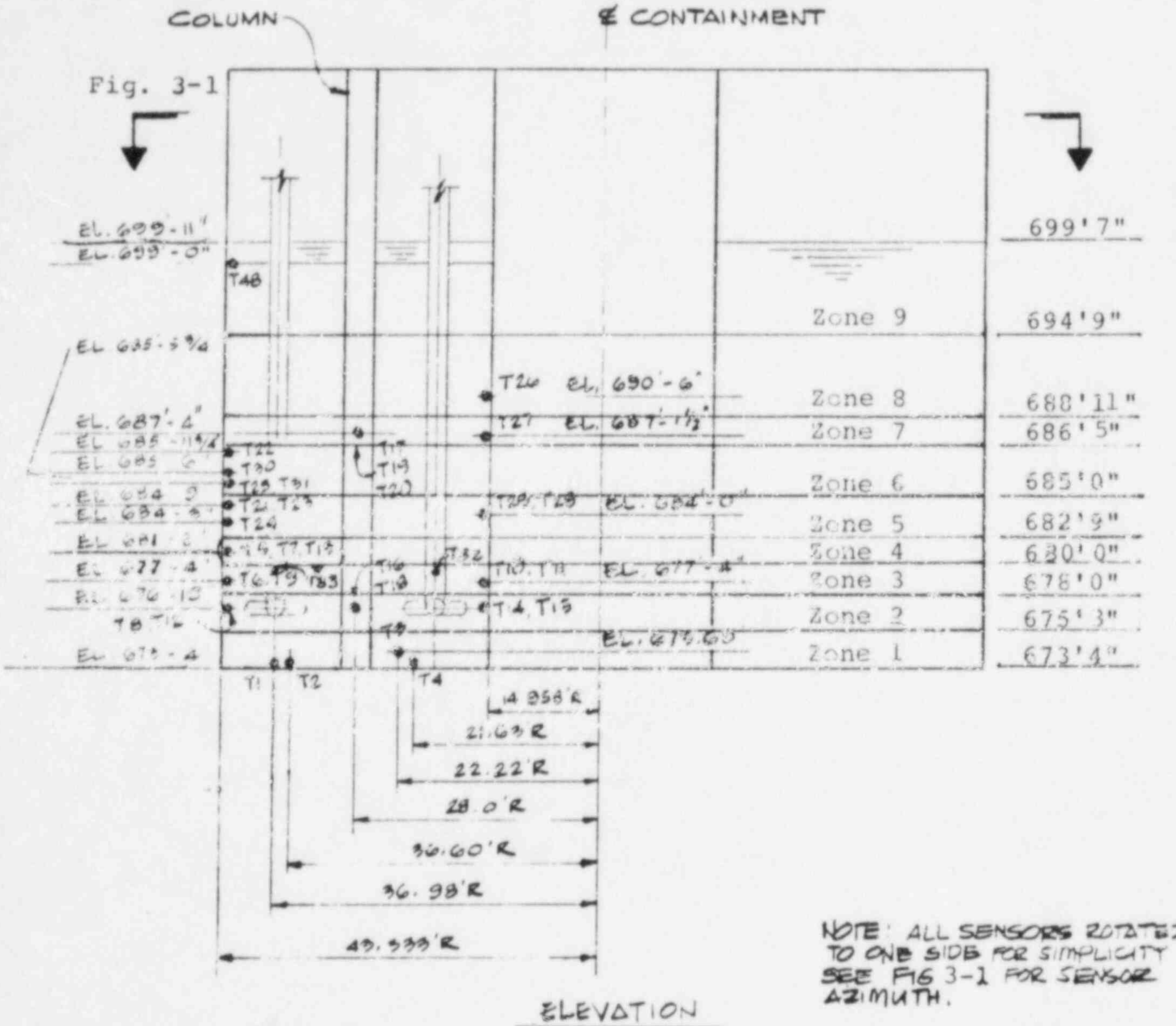
ADARS performed all necessary data reduction to produce the output analysis plots. The major tasks involved in this process included: building a data base of pertinent channel information, demultiplexing the digitized data, conversion of the data to the proper engineering units and producing the analysis plots.



PLAN

(Not to Scale)

FIGURE: 3-1 - TEST TEMPERATURE SENSOR LOCATIONS IN SUPPRESSION POOL - PLAN VIEW



(Not to Scale)

TEMPERATURE SENSOR LOCATION AND ZONE MAP FOR SUPPRESSION POOL - ELEVATION VIEW

FIGURE 3-2

4.0 DISCUSSION OF RESULTS

4.1 BULK POOL TEMPERATURE

The initial and final bulk pool temperature for each test run were obtained by computing the weighted average of test sensor readings ("sensor weighted average" or s.w.a. method). The suppression pool was extensively instrumented with 34 temperature sensors (see Section 3-2). Two of these sensors failed prior to the start of the tests and the remaining 32 sensors were used in calculating the s.w.a. bulk pool temperature. Table 4-1 presents the results of these calculations as well as the blowdown duration for each test run and the average rate of bulk pool temperature rise during the blowdown portion of each test run.

An alternate and independent method of computing the final bulk pool temperature was used for comparison to the "sensor weighted average" method. A mass-energy balance method was used which included the idealization that the pool acted as an isothermal heat sink. Mass-energy addition to the pool was from the discharging quencher and was determined using main steamline mass flow rate and reactor pressure data. Energy removal from the pool was via operation of the RHR system train A. Heat losses to submerged structures and suppression pool walls are negligible and were not included in the model. These two methods (s.w.a. and mass-energy balance) were compared and found to be in good agreement. The pool temperature rise computed using the mass-energy balance method ranged between -2.8% and +6.7% of that computed using the "sensor weighted average" method.

Appendix A presents the details of all bulk pool temperature calculations.

4.2 LOCAL TO BULK POOL TEMPERATURE DIFFERENCE

The local-to-bulk pool temperature difference is the difference between the local pool temperature and the bulk pool temperature at any time during the S/RV discharge. The local pool temperature is defined as the average water temperature in the vicinity of the discharge device and represents the temperature which controls the condensation process occurring at the quencher exit [2].

Because the quencher discharge is predominantly in the horizontal direction, the induced flow pattern is such that the water supplying the quencher front comes from above and below the quencher. Therefore, the local pool temperature is considered to be that indicated by the sensors located immediately above and below the quenchers [2].

The temperature sensors used to determine the local pool temperature for the tests were located directly above and below the quencher arms of the discharging quenchers. Sensors T4 and T32 were used (see Figures 3-1 and 3-2 for sensor locations) for the quencher G discharge cases (Runs 69, 72). Sensors T2 and T33 were used for the quencher C discharge cases (Runs 70, 71, 73, 74, 75).

Sensors T2 and T4 were mounted 41 inches directly below the "C" and "G" quencher arms, respectively. Sensors T32 and T33 were mounted on the "G" and "C" S/RV discharge lines, respectively, 25 inches above the quencher hubs.

Figures C-1 to C-7 show the recorded temperature traces for the local pool temperature sensors; the s.w.a. bulk pool temperature is drawn in for comparison. As shown on the plots, the recorded temperatures fluctuated due to local flow perturbations. These fluctuations represent local mixing of hot and cold regions. The temperature controlling the condensation process is the spatial average of the temperatures around the quench front. It was not practical to extensively

instrument the region near the quench front. These hot and cold regions are not fixed in space but move during the transient driven by local bouyancy effects.

Examination of Figures C-1 to C-7 shows the local-to-bulk pool temperature difference to be a stationary random variable; that is, the average value is constant (or relatively constant) with time. Because the temperature sensors used to measure the local pool temperature were mounted in the inflow region to the quencher and because the local pool temperature is a stationary random variable, the spatial averaging of the local temperature field can be replaced by temporal averaging at single sensor locations.

The local-to-bulk pool temperature difference was determined as the temporal average of the instantaneous local-to-bulk pool temperature differences. This temporal average was obtained by numerically integrating the difference between the individual test sensor readings and the time dependent s.w.a. bulk pool temperature. The local-to-bulk pool temperature difference depends upon the limits of this integration. The natural upper limit for the integration is the time of S/RV closure. However, it is not necessarily appropriate to take the time of S/RV opening as the lower limit of the integration because at this time the local-to-bulk pool temperature difference is zero. To avoid the problem of determining an appropriate lower limit for the integration, this limit was considered to be variable.

Thus a number of integrations of the local-to-bulk pool temperature difference were calculated for each sensor using a variable lower limit of integration and an upper limit as the time of S/RV closure. The lower limit of the integrations ranged between the time of S/RV opening and 4 minutes before the time of S/RV closure. The calculated local-to-bulk pool temperature difference for any particular sensor was taken as the maximum of these different integrations.

Table 4-2 presents the calculated local-to-bulk pool temperature differences for each sensor for each of the test runs. The maximum observed local-to-bulk pool temperature difference of 9.1^{O}F was calculated for the quencher G discharge (Test Run 69) (with RHR cooling) for basemat sensor T4. The average local-to-bulk pool temperature difference for the G quencher runs was 8.1^{O}F and the 95/95 confidence level of non-exceedance temperature was calculated to be 12.0^{O}F. The average local-to-bulk pool temperature difference for the C quencher runs was 6.6^{O}F and the 95/95 confidence level of non-exceedance temperature was calculated to be 11.0^{O}F.

In calculating the local-to-bulk pool temperature difference, the local temperature sensors were corrected for individual bias. This bias is computed in Appendix A and ranges between -0.76^{O}F and +0.60^{O}F for the sensors in question.

4.3 SUPPRESSION POOL TEMPERATURE MONITORING SYSTEM (SPTMS) RESPONSE

SPTMS temperature readings were recorded on a pair of point recorders during each of the seven extended blowdown test runs. These readings were tabulated for selected times during the test. The tabulated temperatures were plotted for positions of relative azimuth (to the discharge quencher) and compared with the corresponding s.w.a. bulk pool temperature for times 0, 4, 8 minutes and final time into the blowdown transient. These results are presented in Figures C-8 through C-14 for each SPTMS division. Temperature readings indicated by the permanent temperature monitoring system were found to be always higher than the s.w.a. bulk pool temperature for all sensors and for all test runs. Table 4-3 lists the temperature difference between the minimum and the maximum of the SPTMS temperature readings and the s.w.a. bulk pool temperature at different times for all the runs.

It was observed that an increase in pool temperature stratification occurred during the S/RV discharge. This stratification supports the above observation that the SPTMS sensors,

which are mounted near the pool surface, read higher than the bulk pool temperature. Figure 4-1 shows the response of the SPTMS to thermal stratification during the test runs. This figure shows three measures of near surface pool stratification. One is the average of the SPTMS readings minus the s.w.a. bulk pool temperature for various times during the transient. The other two are the maximum and minimum SPTMS readings minus the s.w.a. bulk pool temperature, thus giving a bound on this stratification. The SPTMS exhibited a temperature dependent bias relative to the test sensors (up to $6^{O}F$, see Section 4.4) and the SPTMS readings have been corrected for this bias in this figure. The sensors have also been corrected for the individual variation exhibited in a uniform temperature pool.

4.4 GENERAL OBSERVATIONS

Pool Mixing

The buoyancy induced mixing in the pool was found to be vigorous and extensive. After an initial time period (of less than 5 minutes) during which the flow field develops, the temperature rise rate is uniform throughout the pool. This is demonstrated by Figure 4-2. This figure plots the temperature response of sensors T3, T31, and T48 for Test Run 71. Sensor T3 is a sensor mounted on the basemat, 17 feet from the discharging quencher, while sensor T48 is a sensor mounted on the outer pool boundary within 1 foot of the pool surface, 23 feet from the quencher. Sensor T31 is the farthest sensor from the discharging quencher (75 feet). This sensor is mounted on the outer pool boundary just under halfway up from the basemat to the pool surface. The parallel slope of the temperature response of this sensor to those of the other two sensors shows lateral stratification after the initial flow field develops. Also shown on the plot is the s.w.a. bulk pool temperature. This type of response (uniform temperature rise rate after an initial period) is typical of all sensors and all test runs.

RHR System Operation

The effect of RHR system operation on the local-to-bulk pool temperature difference cannot be determined from these tests. However, the influence of RHR operation on measured local-to-bulk pool temperature differences is inferred to be negligible due to 1) the relative location of the discharging quencher and the RHR discharge and 2) the small amount of mixing produced by RHR operation (throughput is less than 0.8% of pool volume/minute).

Local-to-Bulk Pool Temperature Difference

The measured local-to-bulk pool temperature difference was determined for high steam flux and low bulk pool temperature conditions. This local-to-bulk temperature difference is of importance at low steam flux and high pool temperature conditions. Under either of these conditions, the expected local-to-bulk pool temperature difference is lower (see Appendix B) than for test conditions. Thus the local-to-bulk pool temperature difference determined from the test can be conservatively applied to determine the maximum local pool temperature.

SPTMS Versus Test Sensor Bias

Examination of the temperature readings from the SPTMS and test sensors indicated a bias between the two systems. This bias was evaluated by comparing the average of the 28 SPTMS sensor element readings to the reading from test sensor T48 at the start of each test run. (The elevation of T48 is within 2 inches of the elevation of the SPTMS sensors.) The initial temperature conditions in the pool were uniform azimuthally (see Appendix A), making data from this portion of the transient applicable as a measure of this bias. The bias (i.e., SPTMS average reading minus T48 reading) was found to be well correlated with the reading from T48 (i.e., with temperature) and the linear regression correlation coefficient of this data was -0.953. The points from the seven test runs are plotted on Figure 4-3. Also shown on the figure is the bias between the six closest

SPTMS sensors and T48 at the time of S/RV closure for each of the seven test runs. (Figure 4-4 shows the locations of these six closest SPTMS sensors and of T48). These data points are not as well correlated as those for the initial conditions and this is to be expected. The pool is not in equillibrium at the time of S/RV closure and the pool temperature is not uniform azimuthally. This most probably accounts for the scatter in these data points.

In presenting the response of the SPTMS (see Tables 4-3, 6-1, Figures C-8 to C-14) the raw data from the SPTMS was compared to the s.w.a. bulk pool temperature without correlation for the bias between the SPTMS and test sensors. However, above 100°F the indicated bias between the two systems is less than 2°F. Thus all conclusions about the adequacy of the SPTMS are valid even accounting for the indicated bias between the two systems.

In presenting the response of the SPTMS to thermal pool stratification during the test runs (Figure 4-1), a correction was made for the bias between the SPTMS and the test sensor based upon the linear regression analysis of the data taken from the start of each test run. Thus the stratification shown is a true measure of the actual stratification near the pool surface.

TABLE 4-1

S.W.A. BULK POOL TEMPERATURE+

Run No.	G-Quencher# 69	G-Quencher# 72	C-Quencher 70	C-Quencher 71	C-Quencher 73	C-Quencher 74	C-Quencher 75
Initial Temperature (°F)	58.9	76.4	61.6	66.5	71.0	72.5	74.9
Final Temperature (°F)	78.4	95.9	86.4	87.6	89.4	86.4	94.0
Blowdown Duration (min:sec)	15:01	15:05	17:01	14:26	12:52	9:33	13:01
Average Rate of Bulk Pool Temperature Rise (°F/min)	1.30	1.29	1.46	1.46	1.43	1.46	1.47

+Initial Pool Mass - 8.039×10^6 lbm ±0.4%

#One RHR in pool cooling mode during G-Quencher runs.

TABLE 4-2

LOCAL-TO-BULK POOL TEMPERATURE DIFFERENCE

G QUENCHER RUNS
(with RHR)

Run No.	Sensor T4 (°F)	Sensor T32 (°F)
69	9.1	8.3
72	7.3	7.9

C QUENCHER RUNS
(without RHR)

Run No.	Sensor T2 (°F)	Sensor T33 (°F)
70	2.7	6.3
71	7.7	7.7
73	8.1	7.2
74	6.9	6.5
75	5.8	7.1

SUMMARY

Test Type	Local-to-Bulk Pool Temperature Difference (°F) Average	Maximum Observed	95/95
C Quencher	6.6	8.1	11.0
G Quencher	8.1	9.1	12.0

TABLE 4-3

RANGE OF SPTMS SENSOR READINGS ABOVE S.W.A. BULK POOL TEMPERATURE (°F)

Quencher	Run No.	t = 0 min	t = 2 min	t = 4 min	t = 8 min	$t = t_f$ [2]	$T_{b,f}$ [2]
G	69	6.2/10.7	3.7/13.4	6.4/14.7	6.6/15.5	7.0/14.2	77.1
	72	5.0/9.2	3.0/12.2	4.3/13.4	5.9/12.1	4.7/13.6	95.8
C	70	6.2/10.9	5.3/13.0	5.1/14.7	4.5/14.6	5.3/14.1	83.5
	71	6.6/10.4	4.7/11.1	3.7/12.3	4.2/14.2	3.8/13.4	87.0
	73	5.1/8.6	2.3/9.5	2.1/12.9	3.9/12.9	4.1/13.2	88.2
	74	5.0/8.8	2.4/10.5	3.1/13.0	2.8/12.3	2.2/12.4	87.1
	75	8.2/12.0	5.7/11.2	4.2/13.8	3.4/12.8	3.1/12.9	94.0

1) t_f is 14, 15, 15, 14, 12, 10, and 13 minutes for the runs listed.

2) $T_{b,f}$ is the s.w.a. bulk pool temperature at $t = t_f$.

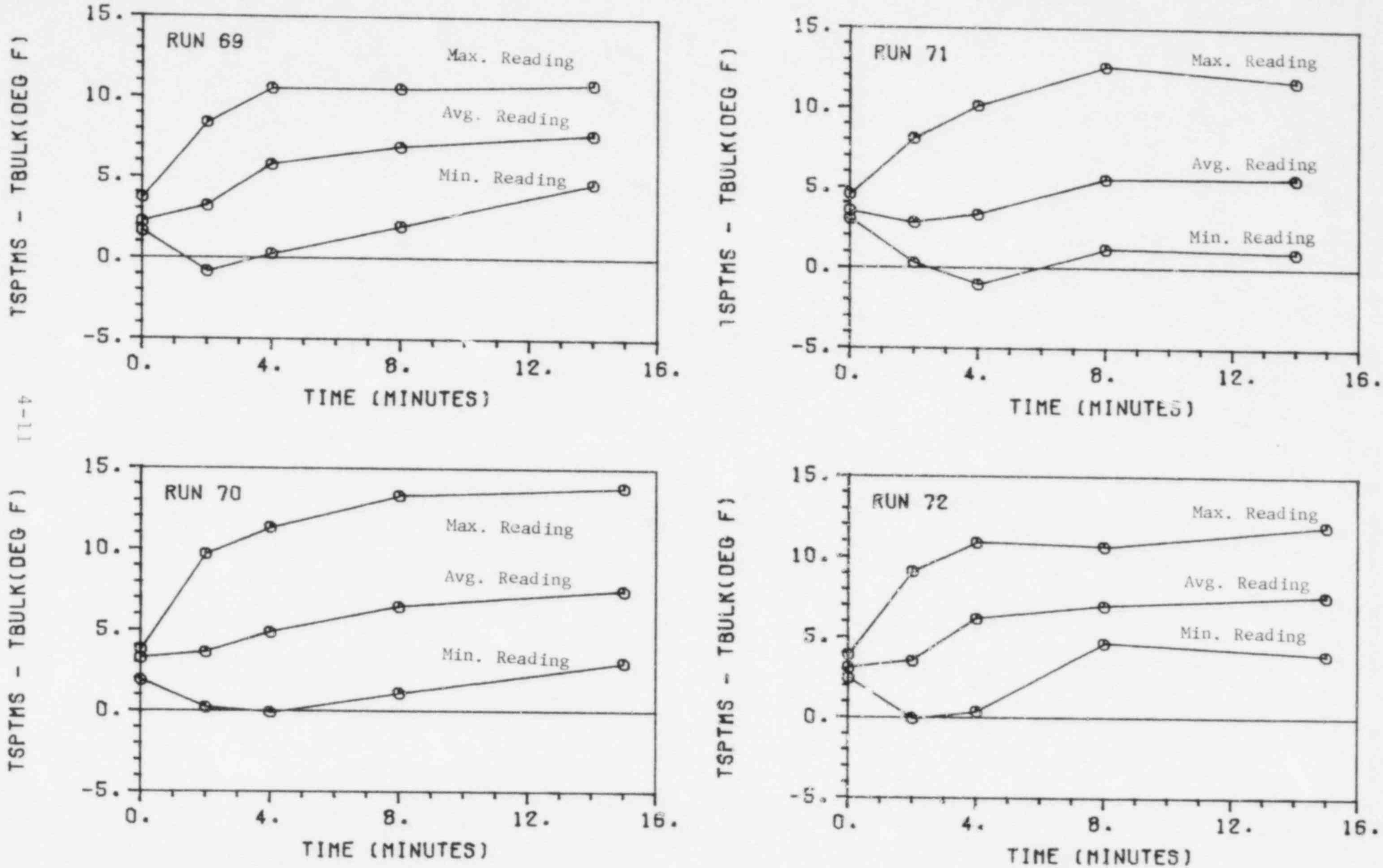


FIGURE 4-1A: SPTMS RESPONSE TO STRATIFICATION EFFECTS

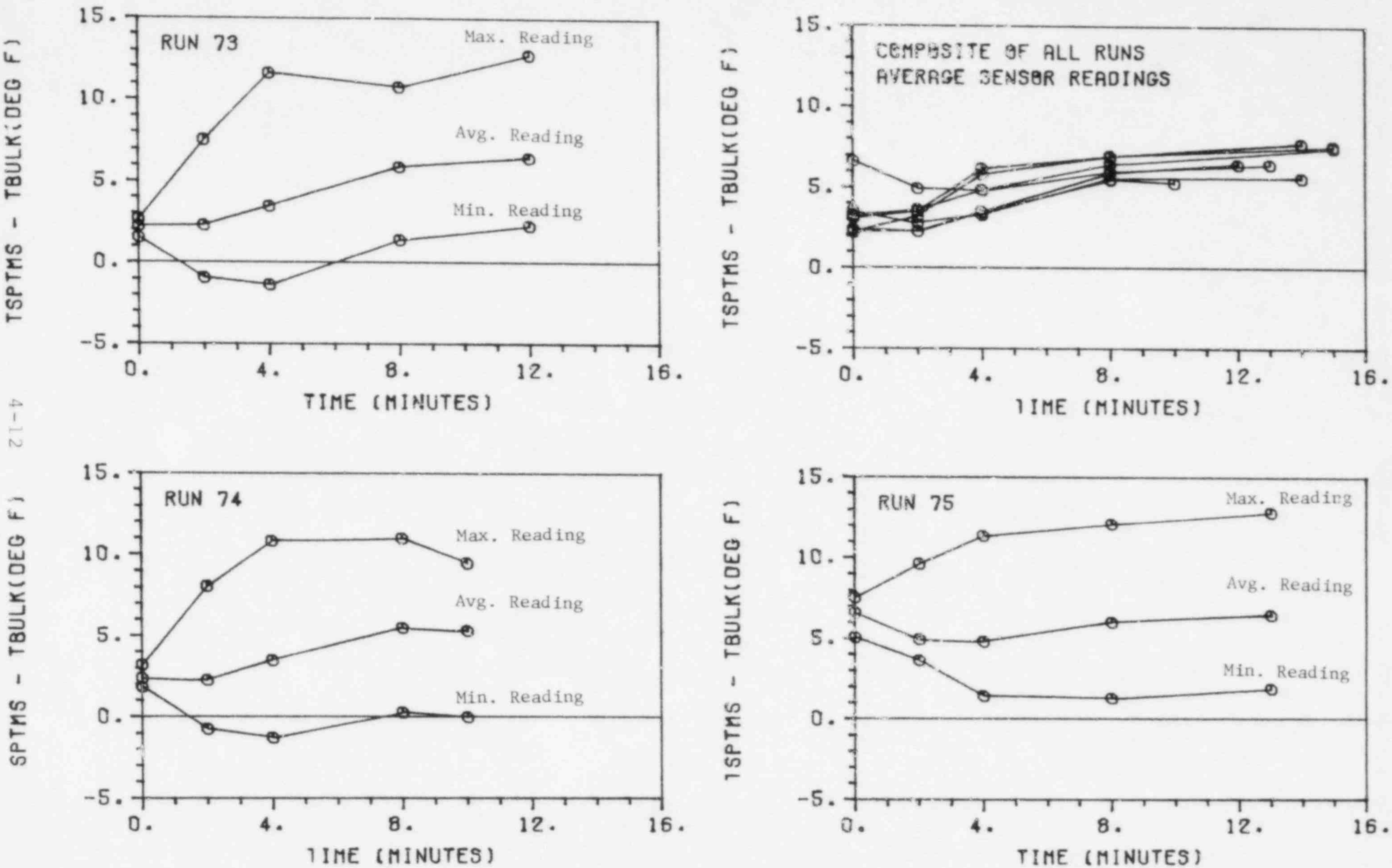


FIGURE 4-1B: SPTMS RESPONSE TO STRATIFICATION EFFECTS

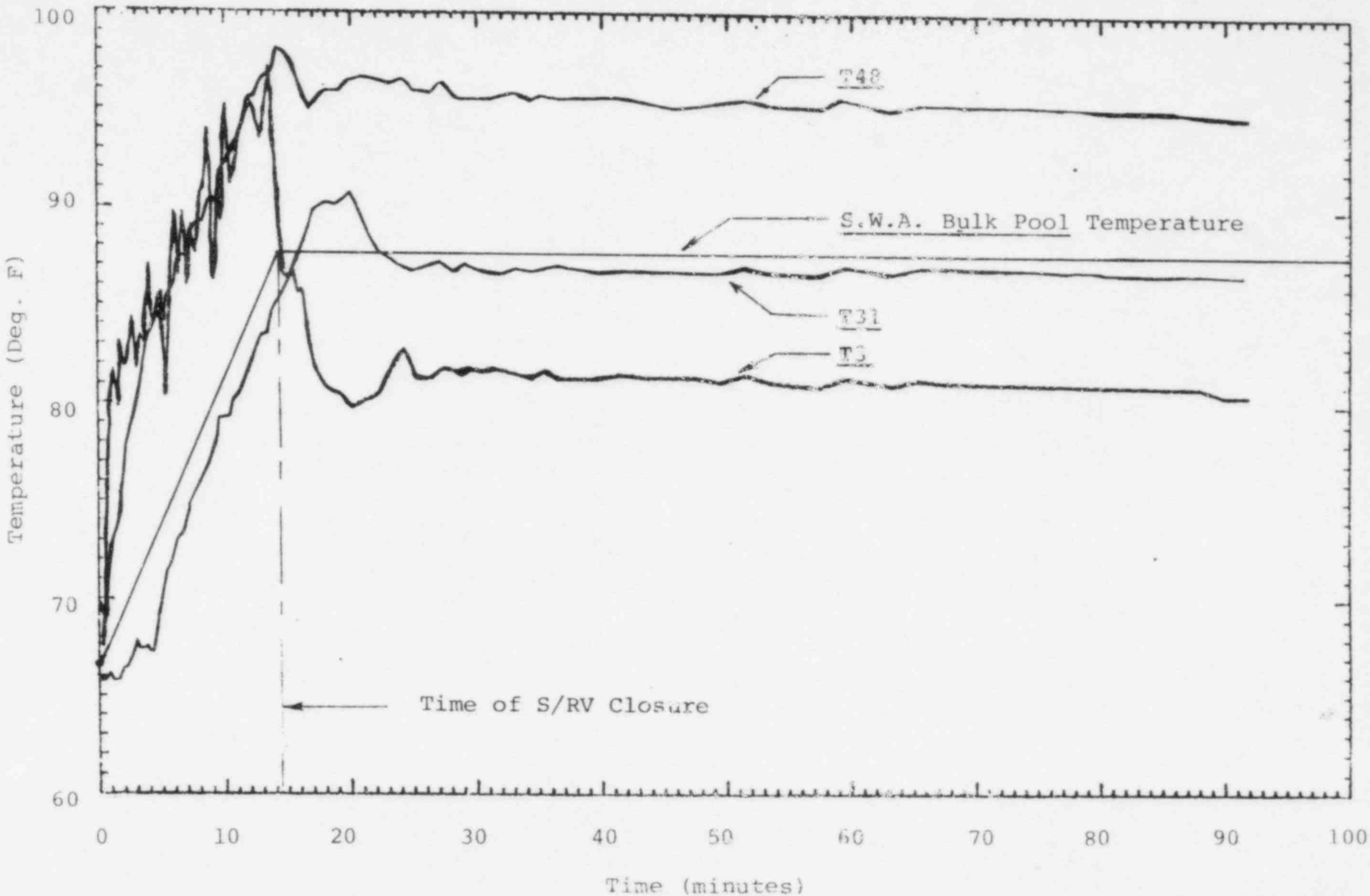


Figure 4-2: T3, T31, and T48 Response - Run 71

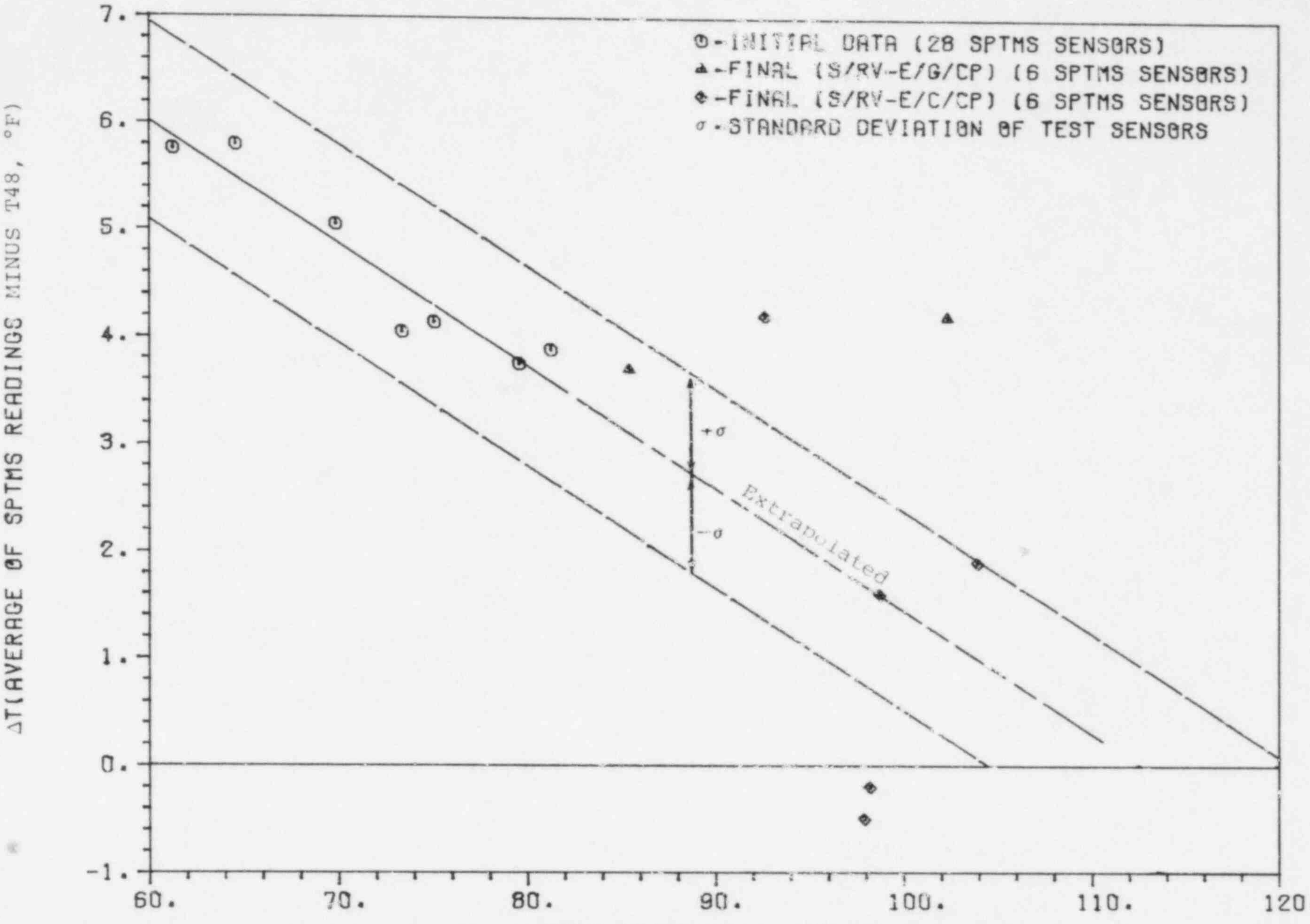


FIGURE 4-3: EVALUATION OF SPTMS BIAS

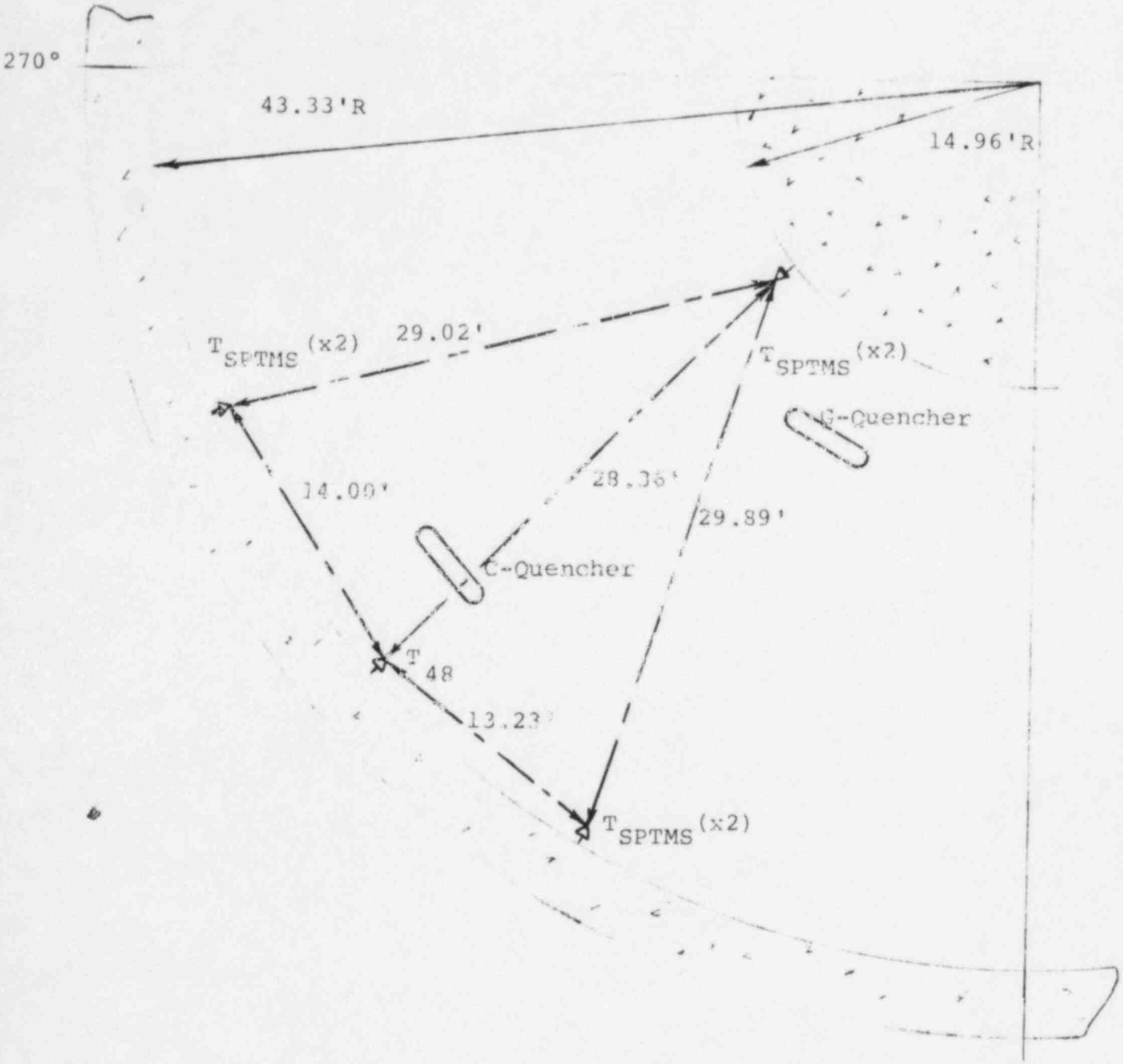


FIGURE 4-4

SENSOR LOCATION FOR SYSTEM BIAS COMPARISON

(El. 699'10")

5.0 EVALUATION OF SPTMS OPERATION AND TECHNICAL SPECIFICATIONS

The technical bases for using the SPTMS to indicate bulk pool temperature and the technical specifications concerned with suppression pool operability were developed based upon generic data with built-in conservativeness to allow for differences between the test conditions under which this generic data was derived and actual plant conditions at the LaSalle County Station. Results from the extended blowdown tests provide a plant unique data base with which to quantify these conservatisms and examine the use of the SPTMS to indicate bulk pool temperature. They also provide the opportunity to develop more realistic technical specification limits and procedures for using the SPTMS which allow for a wider range of plant operability.

There are six places in the Technical Specifications 4 which refer to SPTMS and suppression pool operability and they are found in:

(1) Table 3.3.7.5-1, page 3/4 3-70, Item 4
(2) Section 4.5.3.1 (b), page 3/4 5-9
(3) Section 3.6.2.1 (2), page 3/4 6-16
(4) Section 3.6.2.1, action (c), page 3/4 6-17
(5) Section 3.6.2.1, action (d), page 3/4 6-17
(6) Section 4.6.2.1, page 3/4 6-17 and 6-18

Part 5.1 of this section examines the use of the SPTMS to indicate bulk pool temperature and also addresses items (1), (4), (5), and (6).

Part 5.2 of this section examines the suppression pool limits for temperature and water level and addresses items (2), (3), and (6).

5.1 SPTMS OPERATION

The SPTMS is designed to provide plant operators with a measure of the bulk pool temperature for the purposes of ensuring that the plant is maintained within the established temperature limits for suppression pool operability. The sensor elements of the SPTMS were conservatively installed within 1 ft. of the pool surface so that the majority of sensors would always read marginally higher than the bulk pool temperature (due to thermal stratification in the pool). As discussed in Section 6.3, the current procedure for using the SPTMS to indicate bulk pool temperature is very conservative. This section examines alternative methods of using the system under which plant operability can be improved.

The bulk pool temperature indication from the SPTMS may be different than the actual bulk pool temperature due to a number of factors. These factors have been grouped into four categories which are discussed below:

(1) overall SPTMS system bias,
(2) variation amongst sensors due to calibration errors and drift,
(3) thermal stratification in the pool, and
(4) the procedure for combining individual sensor readings to indicate bulk pool temperature.

Overall SPTMS System Bias

An overall system bias was observed between the SPTMS and the Wyle installed test sensors (see Figure 4-3). This bias was temperature dependent and ranged linearly between $+6^{O}F$ at $60^{O}F$ to $+1.5^{O}F$ at $100^{O}F$. The Wyle temperature sensors are believed to provide a more accurate measure of pool temperature due to the comprehensive calibration procedure used to ensure data accuracy [6]. This procedure included calibrating the integrated unit of temperature sensor and signal conditioning device at three temperatures

over the range of test conditions thus eliminating inaccuracies due to individual component variations. Individual test sensors were also found to exhibit almost no drift from test to test ($0.1^{\circ}F$, see Appendix A).

On the other hand, the calibration procedure for the SPTMS is less rigorous. Individual sensor elements were vendor certified to industry standard tolerance. The portion of signal loop from the input to the signal conditioner through to the point recorder is periodically calibrated. However, without any integrated calibration test from SPTMS sensor element through point recorder, there is an insufficient data base upon which to account for this indicated system bias in using the SPTMS. It should be noted that the indicated bias over the range of interest ($100^{\circ}F$ to $120^{\circ}F$) is small ($< 2^{\circ}F$).

Individual Sensor Variation

Individual sensors were found to exhibit variation in a uniform temperature (azimuthally) pool. The standard deviation of this variation from the mean was $1.3^{\circ}F$. The easiest method of treating individual sensor variation is to separate it from the other three factors (i.e., system bias, stratification, and procedure) and to simply allow for a certain amount of individual sensor variation in setting pool temperature limits. The allowance considered in this report for individual sensor variation in setting suppression pool temperature limits is $4^{\circ}F$.

Thermal Stratification

The SPTMS readings are expected to be higher than the bulk pool temperature due to thermal stratification within the pool (See Figure 4.1). To examine this effect in detail, consideration must be given to the process which is causing the pool temperature to rise. The pool temperature rise can be caused by either chronic or acute conditions and

the required response time to these conditions is very different.

Chronic heatup conditions are factors which act over long periods of time and cause the pool temperature to rise very slowly ($< 3^{o}F/hr$). Examples of these conditions are 1) pool heatup due to heat transfer from the reactor building and drywell and 2) heatup due to leaky S/RV's. It is the nature of these conditions that they gradually develop over time making plant operators cognizant of these conditions thus allowing special procedures to be instituted (e.g. periodic RHR operation) which will prevent pool temperatures from exceeding the temperature limits. The distributed nature of these pool heatup sources would result in much less stratification than for acute heatup events. Thermal stratification for chronic heatup conditions was not measured and thus no credit can be taken for adjusting the SPTMS bulk pool temperature indication for pool stratification. However, plant operators have many options for maintaining the pool within operable temperature limits under chronic heatup conditions (e.g. RHR and LPCS (test mode) operation).

Acute pool heatup conditions include such events as small break LOCA and inadvertent actuation of an S/RV. Small break LOCA conditions are not of interest here (reactor scram would be brought about by other than a high pool temperature signal) and thus only inadvertent actuation of an S/RV will be addressed. Under this event, the pool temperature rise rate is large ($2^{o}F/min$) as is the resultant thermal stratification.

Results from the test data show that despite the best efforts of the operators to thoroughly mix the pool before the start of each test, a stratification layer near the surface was evident which was on average $3^{o}F$ higher than the bulk pool temperature. Following actuation of an S/RV, this stratification increased, although it did not change significantly

in the first two minutes of the blowdown (<.5^{O}F). The average temperature of the stratified surface layer above bulk pool temperature increased from an initial 3^{O}F to; 4.5^{O}F at 4 minutes, 6.2^{O}F at 8 minutes, and 6.7^{O}F at the time of valve closure.

Pool stratification can be indirectly factored-in to the bulk pool temperature indication by selecting an appropriate procedure for the use of the SPTMS.

Procedure for Using the SPTMS

As discussed in Section 6.3, the original method of using the SPTMS to indicate bulk pool temperature for the purpose of taking operator action was purposefully conservative. Test data now provide a basis upon which to develop more realistic procedures for using the SPTMS to indicate bulk pool temperature. The test data also allow examination of a hypothetically degraded SPTMS by interpreting the data with the assumption that certain sensor elements are inoperative.

To develop workable methods for using the SPTMS to indicate bulk pool temperature, the response of the system relative to the bulk pool temperature during S/RV discharge was examined. Figures C-15 to C-21 show the response of the SPTMS at 0, 2, 4, and 8 minutes into the blowdown with corrections made to the raw SPTMS data for overall system bias (see Figure 4-3) and individual sensor variation (in order to eliminate extraneous factors). From these plots, the number of sensor locations per division which have at least one sensor element reading below bulk pool temperature has been determined and tabulated in Table 5-1. Results show that no more than one location per division had sensor elements reading below bulk pool temperature except at 2 minutes into the blowdown.

All of the SPTMS sensor elements which read below the bulk pool temperature at 2 minutes were within 1^{O}F of the bulk

pool temperature. Taking this into consideration, provided the available margin on the technical specification pool temperature limits is more than 1°F, for practical purposes no more than 1 sensor location per division need be considered to read below the bulk pool temperature. Thus, a conclusion is made that a conservative measure of bulk pool temperature is provided from any 2 sensor locations per division with only one operative sensor element per location (for a total of 4 sensor elements in the pool).

From the derived data presented in Figures C-15 to C-21, which show no more than 1 sensor location per division to have at least one sensor element reading more than 1°F below the bulk pool temperature, an alternative method of combining SPTMS readings for comparison to operator action points can be proposed. This method would dictate that a specific action be carried out only when all sensor locations but 1 per division have sensor elements which read above the temperature limit for the action. The operators' task in performing this procedure could be facilitated by having bold lines printed on the SPTMS point recorder strip charts at the technical specification temperature limits (TS1, TS3, TS4).

The sections of the Technical Specifications 4 concerned with SPTMS operation are discussed below.

(1) Table 3.3.7.5-1, Page 3/4 3-70, Item 4
This technical specification states that in order for a division of the SPTMS to be termed "OPERABLE", all seven channels must be working with at least 1 sensor/well. This requirement is more stringent that necessary

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After considering a 4°F margin for SPTMS calibration and drift errors.

and, as established herein, no more than 2 working channels per division (not in the same sensor well) are required to provide a conservative measure of bulk pool temperature.

(4) Section 3.6.2.1, Action (c), Page 3/4 6-17

This specification requires that "with one suppression pool water temperature instrumentation division inoperable, restore the inoperable instrumentation to OPERABLE status within 7 days"..." with the final requirements determined after demonstration of correlation of pool bulk temperature as measured by each division to pool bulk temperature as measured by both divisions." Table 5-2 presents a comparison of bulk pool temperature as measured by each division to the temperature as measured by both divisions for a hypothetically degraded SPTMS. This degraded SPTMS considers the highest reading sensor element from each sensor location to be inoperative and additionally that of the remaining seven sensor elements from each division, the four highest reading sensor elements are considered inoperative. It is concluded that even in this degraded condition, either division can provide a conservative measure of bulk pool temperature and thus either division is sufficient for indicating bulk pool temperature. The actual time requirements for restoring the inoperable, redundant instrument division is not within the scope of this report; however, it has been established that temperature indications from two pool locations in either division can adequately represent bulk pool temperature and hence the definition of an operable SPTMS division should be based upon having at least two operable sensor locations within the division.

(5) Section 3.6.2.1, Action (d), Page 3/4 6-17

This specification requires "with both suppression pool water temperature instrumentation divisions inoperable, restore at least one inoperable... water temperature division to OPERABLE status within 8 hours...". Results of the tests (Table 5-2) have shown either division of the SPTMS to provide a conservative measure of bulk pool temperature and thus this requirement does not require change based upon the extended blowdown test (i.e. no more than one division need be restored in the allotted time).

(6) Section 4.6.2.1, Page 3/4 6-17 and 6-18

This action covers general surveillance requirements for suppression chamber OPERABILITY. Paragraph C requires all fourteen suppression pool water temperature instrumentation channels to be OPERABLE by performance of channel checks, functional tests, and channel calibration. As established previously in this section, a minimum of two OPERABLE channels in a division are sufficient to conservatively indicate bulk pool temperature.

5.2 TECHNICAL SPECIFICATIONS

A part of the restrictions on suppression pool operability are maximum temperature and minimum water level. Using data from the extended blowdown tests, an examination of those restrictions is made here.

The operator action points for suppression pool temperature are designated TS1, TS3, and TS4 (see Section 3.1) and are currently set to 100°F, 110°F and 120°F respectively. A parametric study of the six bounding suppression pool transients identified in NUREG-0783 [2] was performed to examine the margin built-in to these operator action points. This study examined the effect of varying these operator action points on the ultimate pool temperature. Results of the study are detailed in Table 5-3 and shown in Figure 5-1.

Figure 5-1 shows the margin between the local pool temperature and the local pool temperature bound as a function of time for the three parametric cases. Each parametric case consists of the six bounding transients defined in NUREG-0783[2] and each curve on Figure 5-1 shows the lower bound of the temperature margin for each of the six cases of one of the parametric cases. As indicated on the figure, different scenarios are bounding at various times following reactor scram. This figure shows the minimum temperature margin to occur at the end of each of the parametric cases.

Table 5-3 presents the input operator action points for the study and shows the temperature margin between the maximum local pool temperature and the local pool temperature bound (as determined from NUREG-0783[2]). The local pool temperature was obtained by adding $12^{\circ}F^{\dagger}$ to the calculated bulk pool temperature to account for the local-to-bulk pool temperature difference. Operator actions at technical specification action points were assumed to occur $4^{\circ}F$ above the set points to allow for SPTMS calibration and drift errors. As shown by Case 3, the margin in the current technical specification operator action points (TS1, TS3, TS4) is found to be $20^{\circ}F$ for S/RV discharge phenomena.

There are many considerations involved in establishing the Technical Specification operator action points on suppression pool temperature. Ultimately, the setpoints must be soundly established to ensure that the maximum local pool temperature does not exceed the NRC dictated local pool temperature bound. Figure 5-2 presents the constituents which make-up the bounding local pool temperature for the three parametric cases of operator action points summarized in Table

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† See Section 4.2.

5-1. These constituents include allowance for instrument calibration and drift errors, temperature rise during design basis transients, and the local-to-bulk pool temperature difference.

The minimum water level in the suppression pool is determined by more than just considerations of S/RV transients. However, a minimum level can be calculated for S/RV discharge phenomena (i.e. the six transients of NUREG-0783[2]). This level is computed by using the final pool temperature margin in Table 5-3 and reducing the initial pool mass by the required amount to result in a margin of 0°F for each of the three parametric cases. This computation also involves recomputing the local pool temperature bound (as it decreases with decreasing pool water level). Details of these calculations are not presented here but the results for minimum pool water level are included in Table 5-3.

The sections of the Technical Specifications [4] concerned with pool temperature limits and minimum water level are discussed below.

(2) <u>Section 4.5.3.1 (b), page 3/4 5-9</u>

This technical specification requires the low suppression pool water level alarm setpoint to be "greater than or equal to 26'4"... with the final setpoint determined based upon results of the startup test program. The pool water level of 26'2½" was used in determining the initial pool water mass for use in suppression pool temperature transient studies. While this level depends upon more than just S/RV discharge phenomena (e.g. LOCA), the limit for this phenomena could be much lower depending upon TS1, TS3, and TS4 (see Table 5-3).

(3) Section 3.6.2.1 (a), page 3/4 6-16

This specification requires that for the suppression chamber to be OPERABLE "the pool water volume ... shall be ... between 131,900 ft^3 and 128,800 ft^3, equivalent to a level between 26'10" and 26'2½", to be verified by results from the S/RV testing program. These test results only have an effect on the minimum water volume and as discussed in the previous paragraph, this volume is sufficient but could be less for S/RV discharge phenomena (see Table 5-3).

Section 3.6.2.1.a.2 gives the specification for the operator action points on suppression pool temperature. As discussed previously, the current setpoints have a 20°F margin for S/RV discharge phenomena.

(6) Section 4.6.2.1, page 3/4 6-17 and 6-18

This section of the technical specifications details the surveillance requirements for suppression chamber OPERABILITY and includes references to TS1, TS3, and TS4. Test results show these operator action points to be conservative.

TABLE 5-1

SPTMS Locations Reading Below Bulk Pool Temperature

Time into Transient (min)	Run Number (Division 1/Division 2) 69	70	71	72	73	74	75
0	0/0	0/0	0/0	0/0	0/0	0/0	0/0
2	2/2	0/0	0/0	0/0	2/2	1/4	0/0
4	0/0	0/0	1/0	0/0	1/1	1/0	0/0
8	0/0	0/0	0/0	0/0	0/0	0/0	0/0
t_f	0/0	0/0	0/0	0/0	0/0	0/0	0/0

This table shows the number of SPTMS locations for each division where at least 1 sensor element reads below the s.w.a. bulk pool temperature for various times during the blowdown transient. The SPTMS sensor readings have been corrected for both system bias and individual sensor variation.

t_f is 14, 15, 14, 15, 12, 10, and 13 minutes for the runs listed, respectively.

TABLE 5-2

COMPARISON OF THE DEGRADED† SPTMS DIVISIONS
(Indicated Bulk Pool Temperature, °F)

Test Run No.	0 min	Time Since S/RV Actuation 4 min	8 min	$t=t_f$ [1]
Run No. 69				
Both Divisions	65.5	71.8	79.5	86.4
Div. 1/Div. 2	65.5/66.3	72.5/71.8	79.5/79.9	86.4/87.5
s.w.a. Bulk	58.9	64.1	69.3	77.1
Run No. 70				
Both Divisions	68.9	70.9	80.6	90.0
Div. 1/Div. 2	68.9/69.6	74.4/70.9	80.6/81.4	91.5/90.0
S.W.A. Bulk	61.6	67.4	73.3	83.5
Run No. 71				
Both Divisions	73.4	77.5	84.1	92.6
Div. 1/Div. 2	73.4/74.3	77.8/77.5	84.1/84.9	93.3/92.6
S.W.A. Bulk	66.5	72.3	78.2	87.0
Run No. 72				
Both Divisions	82.3	88.8	94.4	102.5
Div. 1/Div. 2	82.3/82.9	88.8/89.0	94.4/95.1	102.5/103.0
S.W.A. Bulk	76.4	81.6	86.7	95.8
Run No. 73				
Both Divisions	76.6	80.4	88.9	94.4
Div. 1/Div. 2	76.8/76.6	81.3/80.4	90.0/88.9	95.0/94.4
S.W.A. Bulk	71.0	76.7	82.4	88.2
Run No. 74				
Both Divisions	78.1	82.0	90.0	92.8
Div. 1/Div. 2	78.4/78.1	83.6/82.0	90.5/90.0	93.3/92.8
S.W.A. Bulk	72.5	78.3	84.1	87.1
Run No. 75				
Both Divisions	84.0	85.5	92.5	98.9
Div. 1/Div. 2	84.8/84.0	86.6/85.5	92.5/92.9	99.6/98.9
S.W.A. Bulk	74.9	80.8	86.6	94.0

†For a description of the hypothetical "Degraded SPTMS" see Section 5.1.
1) t_f is 14, 15, 14, 15, 12, 10, and 13 minutes for the runs listed.
2) s.w.a. bulk is sensor weighted average temperature at time t.

TABLE 5-3

Parametric Study of Technical Specification

Limits on Suppression Chamber Operability

Parametric Case	TS1 (°F)	TS3 (°F)	TS4 (°F)	Final Margin (°F)	Minimum Water Level††
1†	100	110	120	13.5	23'7"
2	110	120	130	6.9	24'9"
3	120	130	140	0.4	26'2"

† Current Operator Action Points

†† Current T.S. minimum level - 26'2½"

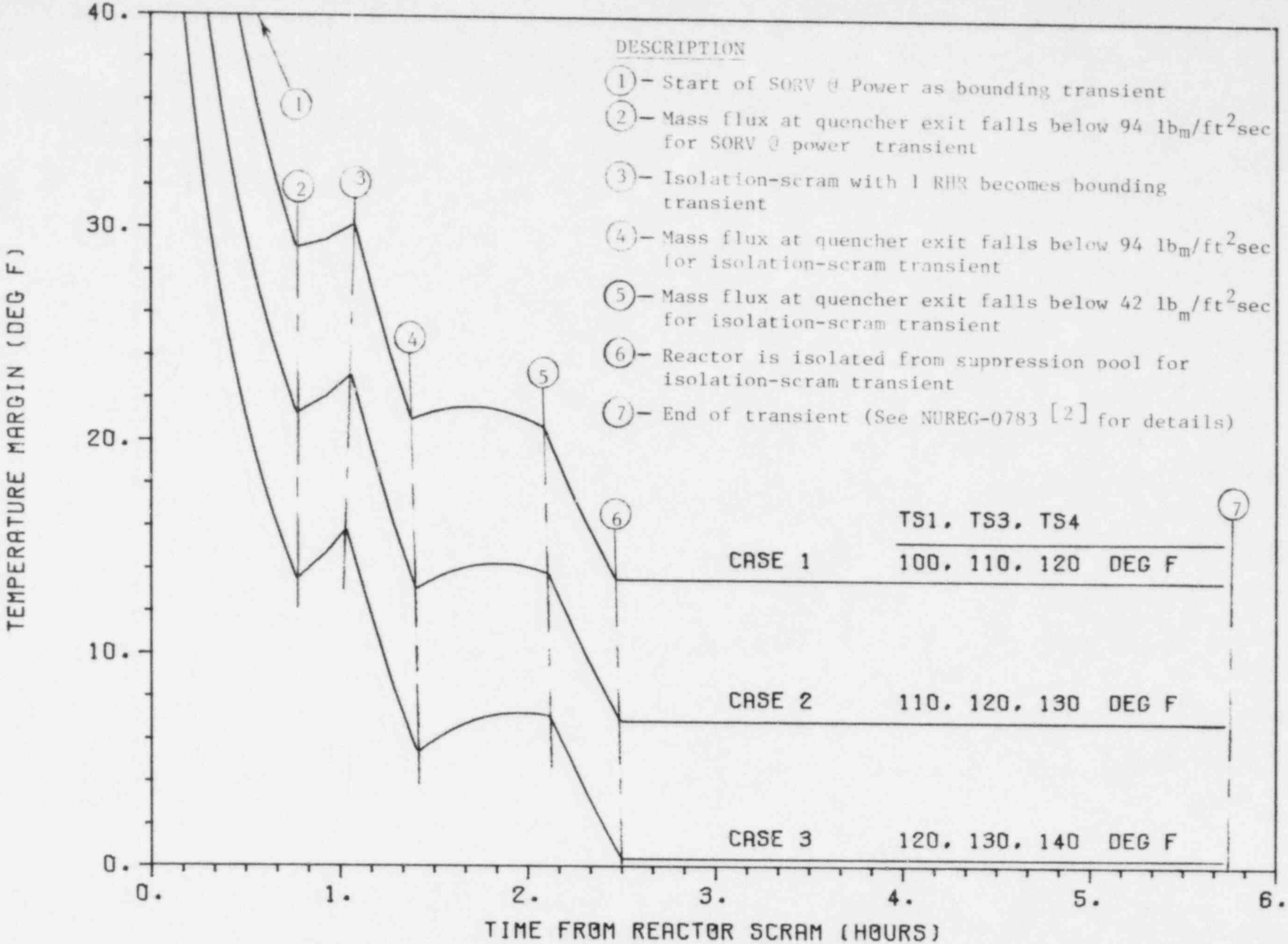
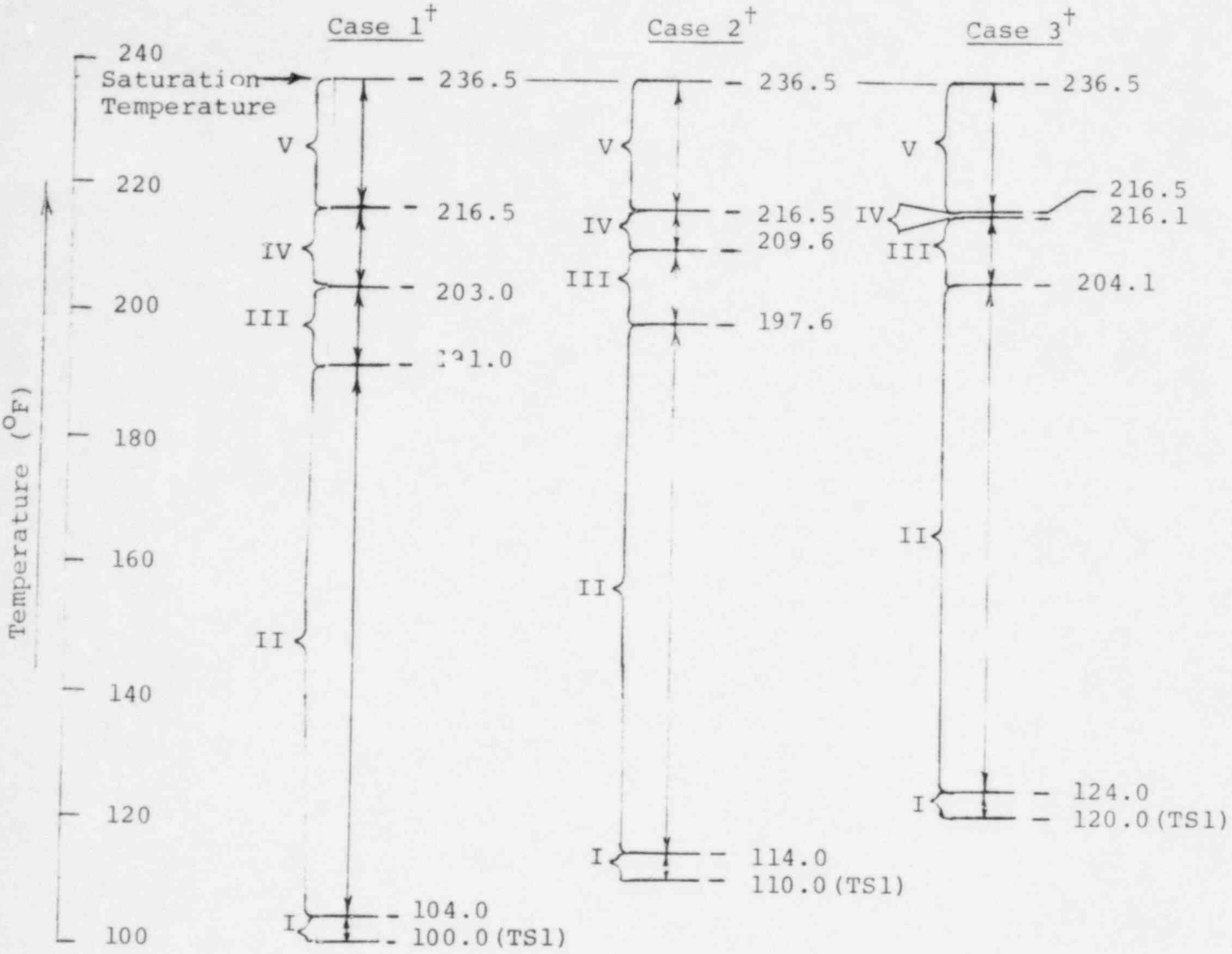


FIGURE 5-1: PARAMETRIC STUDY - SUPPRESSION POOL TEMPERATURE MARGIN



Region Description	ΔT (°F) Case 1	Case 2	Case 3
I Allowance for SPTMS calibration and drift error	4.0	4.0	4.0
II Temperature rise during NUREG-0783 [2] transients	87.0	83.6	80.1
III 95/95 local-to-bulk pool temperature difference	12.0	12.0	12.0
IV Margin (Unaccounted)	13.5	6.9	0.4
V NRC Safety Margin	20.0	20.0	20.0

Figure 5-2

Anatomy of the Suppression Pool Temperature Limit

†See Table 5-1

6.0 COMPARISON OF RESULTS TO ACCEPTANCE CRITERIA

This section compares test results to the current acceptance criteria concerning suppression pool temperature limits delineated in NUREG-0783[2]. These acceptance criteria involve the local pool temperature limit and the suppression pool temperature monitoring system (SPTMS) response. The current technical specifications concerning operator action points and the current administrative procedures for using the SPTMS to indicate bulk pool temperature were used in this comparison. Section 5 of this report examines the margins built-in to the current technical specifications and proposes alternate methods of using the SPTMS to indicate bulk pool temperature. The portions of NUREG-0487[5] concerned with acceptance criteria for the SPTMS are also included in this section.

6.1 ACCEPTANCE CRITERIA

Local Pool Temperature

Historically, to meet the requirements of NUREG-0487[5], the LaSalle local pool temperature limit for licensing purposes was set equal to a constant of 200°F. However, by resolution of NRC Task Action Plan (TAP) 39, presented in NUREG-0783[2], this limit has been revised. Thus, the local pool temperature limit became a bounding local pool temperature which does not have a single value but rather is a function of plant conditions such as steam mass flux at the quencher exit and the amount of subcooling of suppression pool water near the steam quench front. For the LaSalle station this temperature bound ranges between 200°F and 216.5°F.

The acceptance criterion for local pool temperature is that the analytically derived local pool temperature (obtained using the methodology of NUREG-0783[2]) be marginally less than the local pool temperature bound at all times during each of the six design basis transients. This margin is

assignable to instrument drift and error which is factored-in to the instrument setpoints.

Suppression Pool Temperature Monitoring System (SPTMS)

The acceptance criteria for the suppression pool temperature monitoring system (SPTMS) are given in NUREG's 0487[5] and 0783[2]. The specific criteria to which results from the extended blowdown tests were to be compared are as follows:

(1) "The total number of monitoring locations shall not be less than eight. Monitoring locations shall be distributed evenly around the pool". (III.C.1.d2 of [5])

(2) "Instrument setpoints for alarms shall be established so that the primary system can be shutdown and depressurized" (III.C.1.d5 of [5]) ... without having the suppression pool exceed the temperature limit.

(3) "Each applicant or licensee shall demonstrate adequacy of the number and distribution of pool temperature sensors to provide a reasonable measure of the bulk pool temperature". (5.8(1) of [2])

(4) "... operating procedures...shall be used to minimize the actions required by the operator to determine bulk pool temperature". (5.8(3) of [2])

(5) "Instrument setpoints for alarms shall be established so that the plant will operate within the suppression pool temperature limits discussed above". (5.8(4) of [2])

6.2 LOCAL POOL TEMPERATURE

The basis for determining the maximum local pool temperature was a set of six S/RV discharge transients defined in NUREG-0783[2] and detailed in the LaSalle Design Assessment Report [3]. Analysis of these transients produced a set of time-dependent suppression pool temperature responses which depend upon the operator action points from the Technical Specifications [4].

These responses have been used to define a bulk pool temperature envelope for the six transients as a function of time. The resulting bounding temperature envelope is presented in Figure 6-1. Also shown in this figure is the analytically derived local pool temperature envelope obtained by adding the 95/95 local-to-bulk pool temperature difference of 12^{O}F (determined from test data, see Section 4.2) to the bulk pool temperature envelope. The operator action points used in this analysis included a 4^{O}F margin above those given in the Technical Specifications to allow for SPTMS inaccuracies due to calibration error and drift.

The local pool temperature is defined as the spatial average temperature in the vicinity of the discharge device. The bulk pool temperature is "the temperature calculated by plant transient analyses" [2]. The local-to-bulk pool temperature difference is the temperature difference between the local and bulk pool temperatures. Figure 6-1 presents the maximum temperature envelope for both bulk and local pool temperature as a function of time and shows the bounding local pool temperature as determined from analysis and measurement to be below the local pool temperature bound throughout the six limiting transients. Thus the acceptance criterion for the local pool temperature limit is met.

6.3 SUPPRESSION POOL TEMPERATURE MONITORING SYSTEM (SPTMS)

The SPTMS is described in Section 3.1. The first acceptance criterion for the SPTMS is that the total number of monitoring locations be at least eight. This criterion is met since there is a total of 14 dual-element sensor locations in the suppression pool.

Acceptance criterion (2) relates to instrument setpoints and the bounding pool temperature. The criterion is met for the current technical specifications as is demonstrated by the analysis summarized in Figure 6-1. This figure shows

the bounding local pool temperature to be 13.5°F below the local pool temperature bound. As shown in Section 5.2, there is a 20°F margin in the current operator action points on suppression pool temperature.

The current method for obtaining the bulk pool temperature indication from the SPTMS is to hand record individual sensor element readings from the point recorders and to then compute the arithmetic average of these readings. However, this method is only used for periodic surveillance of the suppression pool temperature. Action on technical specification setpoints (based upon bulk pool temperature) is based upon a different procedure. Once alerted to a high temperature condition in the suppression pool (alarmed when any of the 28 sensor elements exceeds the setpoint), an operator closely monitors the point recorders and action is taken on a particular technical specification setpoint when a) any three sensor elements from either recorder exceed the setpoint and b) any one sensor element from the other recorder exceeds the setpoint [8].

To demonstrate the adequacy of this method for indicating bulk pool temperature for the purpose of taking action on technical specification setpoints, the "indicated" bulk pool temperature† has been determined from the SPTMS test data. The difference between this "indicated" temperature and the bulk pool temperature as measured by test sensors is tabulated in Table 6-1. This difference is on the order of 12°F and is due primarily to thermal stratification within the pool (see Section 5.1 for a discussion of pool stratification). Thus acceptance criterion (2) is met as the procedure for using the SPTMS to take action on technical specification setpoints is conservative.

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†Using the highest three sensor elements from one division and the highest sensor element from the other.

Acceptance criterion (3) requires the applicant to demonstrate the adequacy of the number and distribution of SPTMS sensors. Figures C-8 through C-14 present the readings for the SPTMS sensors at various times during each of the seven extended blowdown test runs. These figures show the response of the SPTMS to be fairly uniform for all sensors indicating good thermal mixing azimuthally around the pool (near the pool surface). For example, in Figure C-8B at 14 minutes into the transient, the data shows several sensors to be within 2°F of the highest reading sensor for each division. From these plots it is evident that for any particular quencher there is a large number of sensors which give a conservative measure of bulk pool temperature (some more than 120° away from the discharging quencher) and thus the distribution and number of sensors is adequate.

Acceptance criterion (4) (minimal operator actions) is met as the operator† must only confirm that at least 3 sensors from one SPTMS division and at least 1 sensor from the other division exceed the setpoint for any particular operator action [8]. When this occurs, the appropriate action is taken. The SPTMS recorders are side-by-side in the control room to facilitate the determination of bulk pool temperature.

Acceptance criterion (5) is similar to (3) and is met as described above. With a stuck-open relief valve, the rise rate of the pool temperature is less than 2°F/min allowing the operator ample time to respond to control room alarms.

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†alerted by an alarm when any of the 28 sensor elements exceeds operator action points TS1 or TS3.

TABLE 6-1

SPTMS PERFORMANCE

(INDICATED - S.W.A.[†] BULK POOL TEMPERATURE)

Test Run. No.	Time into Extended Blowdown (min) 0	4	8	F
69	9.6	13.5	12.6	12.3
70	10.2	13.6	14.0	13.9
71	9.5	10.5	12.4	10.5
72	7.9	11.7	11.4	10.5
73	8.0	10.8	11.5	12.6
74	8.1	11.1	11.0	10.2
75	11.4	10.2	11.4	12.0

[†]S.W.A. - sensor weighted average

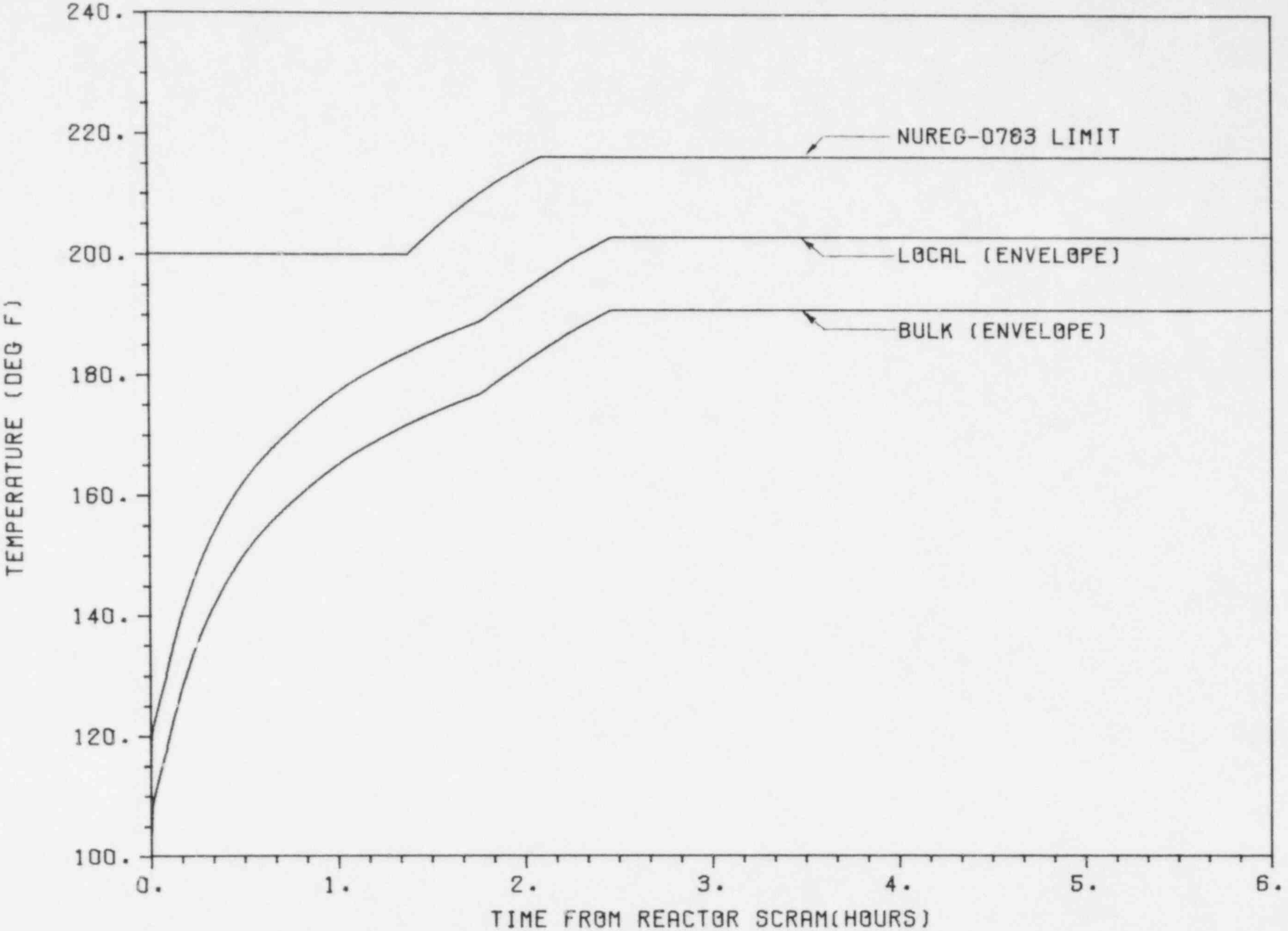

FIGURE 6-1: SUPPRESSION POOL TEMPERATURE ENVELOPE

7.0 REFERENCES

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5. U.S. Nuclear Regulatory Commision, "Mark II Containment Lead Plant Program Load Evaluation and Acceptance Criteria", NUREG-0487, October 1978.
6. Wyle Laboratories, "LaSalle County 1 In-Plant S/RV Test Final Data Report," Volume 1, May 10, 1982. (Proprietary)
7. Commonwealth Edison Co., LIS-CM04 Rev. 1, April 17, 1982.
8. Commonwealth Edison Co., LOP-CM03 Rev. 1, May 19, 1982.

APPENDIX A

BULK POOL TEMPERATURE CALCULATIONS

A.1 "SENSOR WEIGHTED AVERAGE" METHOD

The initial and final bulk pool temperatures were computed by taking a weighted average of corrected test sensor readings. All thirty-two of the working test sensors were used in this calculation. Individual weighting factors were determined by a two-step procedure. First the pool was divided into nine horizontal zones based upon the groupings of the individual sensor elevations. These nine zones were assigned individual weights based on relative volume. Table A-1 presents data for the nine zones including the test sensors within each of the zones and the weighting factor for each zone.

The second step in this procedure was to apportion individual zone weights amongst the sensors within that zone. The apportionment was done on a zone by zone basis with general rules for assigning weights to sensors. For example, sensors located closely together would have lower individual weighting than for an isolated sensor on the far side of the pool. When possible, the angles between adjacent sensors within a zone were bisected and individual sensor weights were set proportional to the area enclosed by the angle bisectors (relative to the cross-sectional area of the pool).

Individual sensor weighting factors, raw data, and bulk pool temperatures for initial and final pool conditions are presented in Tables A-2 and A-3, respectively. The raw data was read directly from sensor traces for the initial conditions. It was not possible to read directly the final sensor temperatures because at the time of S/RV closure, the test sensor readings oscillated for approximately five minutes with an amplitude of 5°F to 10°F. To obtain the appropriate final sensor temperature readings, the long-term temperature curve was extrapolated back to the time of S/RV closure.

In computing the bulk pool temperatures, individual sensor readings were corrected for the observed sensor bias. These correction factors are given in Table A-4 along with the individual sensor bias observed at the start of each test. It was assumed that the pool was quiescent at the start of each test and that the pool temperature was azimuthally uniform. A linear regression of sensor temperature reading versus sensor elevation was performed for each test run. All sensors but T48 were included in this analysis. (The location of T48 is far from that of the other 31 sensors). The sensor residual (or bias) was then calculated by subtracting the linear regression estimate from the raw data. These residuals were found to be very consistent from test to test (within 0.1°F) and this fact supports the notion that the pool temperature was azimuthally uniform. Residuals from the final test were not consistent with those from the first six tests. Since the suppression pool was much more thermally stratified in this case than in any other case (12°F from top to bottom vs. 3.5°F), this data was discarded when determining correction factors for individual sensors. The result of applying these correction factors to individual sensor readings for input to the "sensor weighted average" method was to raise the initial and final bulk pool temperatures by 0.1°F.

A.2 ENERGY BALANCE METHOD

The final bulk pool temperature was calculated by an alternative method using the first law of thermodynamics for an open system. Mass and energy addition to the pool was from the steam discharge while heat removal was via operation of RHR Train A. The calculations were treated separately for the five cases with no RHR operation and the two cases with RHR operation.

Runs With No RHR

For test runs with no RHR we have

$$U_f = U_i + \dot{m}_{SRV} h_{SRV} \Delta t \qquad \text{(A-1)}$$

where

$$U = m_p c_v (T_p - 32)$$

and using

$$m_{p,f} = m_{p,i} + \dot{m}_{SRV} \Delta t$$

and substituting into (A-1)

$$T_{p,f} = 32 + \frac{m_{p,i} c_v (T_{p,i} - 32) + \dot{m}_{SRV} h_{SRV} \Delta t}{m_{p,i} + \dot{m}_{SRV} \Delta t} \qquad \text{(A-2)}$$

where

U_i, U_f	- initial and final internal energy of the suppression pool (Btu)
$\dot{m}_{SRV}$	- mass flow rate of the S/RV (lb_m/sec)
h_{SRV}	- enthalpy of S/RV flow (Btu/lb_m)
Δt	- duration of S/RV flow (sec)
$m_{p,i}$, $m_{p,f}$	- initial and final pool mass (lb_m)
c_v	- specific heat of water (= 1 Btu/lb_m °F)

The initial pool mass was determined from the initial pool water level and temperature. The S/RV mass flow rate was determined from the change in main steam line flow during the test. The S/RV flow enthalpy was taken as that of saturated steam at reactor pressure (which was determined from a strip chart). Table A-5 presents the input parameters to Eq. (A-2) and the calculated final bulk pool temperature.

Runs With RHR

For test runs 69 and 72, in addition to S/RV flow the pool temperature was being changed by RHR operation. Thus from the first law of thermodynamics for an open system we have:

$$\frac{dU_p}{dt} = \dot{m}_{SRV}\, h_{SRV} + \dot{m}_{HX}(h_{HX} - h_p) \qquad \text{(A-3)}$$

where

U_p - suppression pool internal energy (Btu)

t - problem time (sec)

$\dot{m}_{SRV}$ - mass flow rate of S/RV (lb_m/sec)

h_{SRV} - enthalpy of S/RV flow (Btu/lb_m)

$\dot{m}_{HX}$ - mass flow rate of RHR Train A (lb_m/sec)

h_{HX} - return specific enthalpy of RHR flow (Btu/lb_m)

h_p - specific enthalpy of pool water (Btu/lb_m)

now

$$\frac{dU_p}{dt} = \frac{d}{dt}(m_p c_v (T_p - 32)) = m_p c_v \frac{d(T_p - 32)}{dt} + c_v (T_p - 32) \frac{dm_p}{dt} \qquad \text{(A-4)}$$

and from mass conservation

$$\frac{dm_p}{dt} = \dot{m}_{SRV} \qquad \text{(A-5)}$$

Now let

$$T_p^{*} = (T_p - 32) \qquad \text{(A-6)}$$

and because the change in pool mass is small (<3%) set

$$m_p \approx m_p^* = (m_{p,i} + m_{p,f})/2 \qquad (A-7)$$

where

$m_{p,i}, m_{p,f}$ - initial and final pool masses (lb_m)

Now

$$h_{HX} - h_p = \varepsilon\,(c_p(T_{SW} - T_p) \qquad (A-8)$$

where

ε - RHR-HX effectiveness

T_{SW} - service water temperature (°F)

Substituting (A-4), (A-5), (A-6), (A-7) and (A-8) into (A-3) and rearranging we obtain

$$\frac{dT_p}{dt} + \alpha T_p = \beta \qquad (A-9)$$

where

$$\alpha = (\dot{m}_{SRV} + \dot{m}_{HX}\varepsilon(c_p/c_v))/m_p^*$$

and

$$\beta = [\dot{m}_{SRV}h_{SRV} + \dot{m}_{HX}\varepsilon c_p(T_{SW}-32)] \div c_v m_p^*$$

Now solving (A-7) we get

$$T^*_{p,f} = T^*_{p,i}e^{-\alpha t_f} + \frac{\beta}{\alpha}\,(1-e^{-\alpha t_f}) \qquad (A-10)$$

Table A-6 presents the input parameters used in determining the final bulk pool temperature based on Eq. (A-10). The initial pool mass and S/RV mass flow rate and enthalpy were determined as described in the previous section. The service water temperature was obtained from the test condition log sheets. The RHR mass flow rate and effectiveness were taken from [A1]. The effectiveness assumed was that for an unfouled heat exchanger.

A.3 COMPARISON OF ZONE METHOD TO ENERGY BALANCE METHOD

Table A-7 presents a comparison of the final bulk pool temperatures calculated using the zone and energy balance methods. For the cases with RHR operation, the zone method yielded lower temperatures while for cases with no RHR operation, the two methods agreed to within 0.6°F.

An explanation for the differences between the two methods may be found in the procedure used to obtain final test sensor readings from the data traces. At the time of S/RV closure, sensor readings oscillated for some time due to the non-equilibrium condition within the pool. To obtain the final temperature for individual sensors, the long term sensor response was extrapolated back to the time of S/RV closure. This was relatively simple for the five cases with no RHR operation as the temperature profiles were flat for the last 40-50 minutes of data recording (e.g. see Figure C-3). Because heat was removed continuously for the two cases with RHR, the temperature readings decreased after the S/RV was closed and this decrease was not linear in most cases. Thus, it was difficult to determine by extrapolation the final sensor readings for runs with RHR operation.

References

A1) Commonwealth Edison Company, LaSalle County Station FSAR, Amendment 45, April 1979, Table 6.2-2.

A-7

TABLE A-1

SUPPRESSION POOL ZONE DESCRIPTION

Zone Number	Number of Sensors In Zone	Sensor Numbers	Midplane Elevation of Sensors	Elevation of Zone Bottom	Zone Height (in)	Zone Weighting Factor
1	4	T1, T2, T3, T4	673'6"	673'4"	23.3"	.07392
2	8	T8, T9, T10, T11 T14, T15, T16, T18	677'1"	675'3"	32.6"	.10343
3	2	T32, T33	678'11"	678'0"	24.6"	.07805
4	3	T5, T7, T13	681'2"	680'0"	32.6"	.10343
5	5	T21, T23, T24, T28, T29	684'4"	682'9"	26.7"	.08471
6	4	T22, T25, T30, T31	685'7"	685'0"	17.6"	.05584
7	4	T17, T19, T20, T27	687'3"	686'5"	29.3"	.09296
8	1	T26	690'6"	688'11"	70.3"	.22302
9	1	T48	699'0"	694'9"	58.2"	.18464

TABLE A-2

INITIAL SENSOR TEMPERATURE READINGS (°F)

Sensor	Run Number 69	70	71	72	73	74	75	Weighting Factor W_i	Sensor Bias (°F)
T1	59.1	61.7	66.6	75.2	70.9	72.3	69.9	.0184800	0.73
T2	58.9	61.5	66.1	75.3	70.9	72.3	69.8	.0184800	0.60
T3	60.4	63.0	67.8	77.1	72.4	73.8	71.3	.0184800	2.17
T4	58.4	61.0	65.7	75.0	70.3	71.6	69.2	.0184800	0.10
T5	57.6	59.9	64.9	75.1	70.1	71.3	69.8	.0188759	-0.65
T6	-	-	-	-	-	-	-	-	-
T7	58.0	60.5	65.2	75.3	70.4	71.5	70.0	.0378094	-0.31
T8	57.5	60.1	64.8	74.6	69.9	71.1	68.8	.0075561	-0.67
T9	59.0	61.6	66.4	76.2	71.4	72.7	70.2	.0160603	0.87
T10	57.8	60.4	65.0	74.6	69.8	71.0	68.7	.0075561	-0.58
T11	58.4	60.7	65.4	75.2	70.4	71.6	69.5	.0075561	-0.07
T12	-	-	-	-	-	-	-	-	-
T13	58.1	60.6	65.4	75.4	70.4	71.5	70.0	.0467447	-0.23
T14	57.7	60.2	64.8	74.5	69.7	70.9	68.7	.0232144	-0.70
T15	58.0	60.4	65.1	74.8	70.1	71.2	68.9	.0263748	-0.40
T16	57.0	59.4	64.0	73.6	68.9	69.9	67.7	.0075561	-1.54
T17	60.1	62.5	67.5	77.8	72.7	74.1	77.7	.0232400	1.81
T18	57.5	60.1	64.7	74.3	69.5	70.7	68.5	.0075561	-0.87
T19	58.7	61.1	66.1	76.4	71.2	72.3	76.2	.0232400	0.32
T20	56.8	59.3	64.2	74.5	69.2	70.5	74.3	.0232400	-1.56
T21	58.6	61.1	66.0	76.0	70.8	72.3	73.9	.0147301	0.24
T22	57.1	59.5	64.3	74.5	69.2	70.5	73.6	.0149372	-1.42
T23	58.1	60.5	65.4	75.4	70.1	71.5	73.2	.0084711	-0.40
T24	58.4	60.9	65.6	75.8	70.5	71.8	72.8	.0170361	-0.06
T25	59.3	61.7	66.7	77.1	71.6	73.0	75.7	.0133861	0.98
T26	58.1	60.6	65.4	75.7	69.9	71.4	77.8	.2230200	-0.55
T27	59.6	62.1	67.3	77.7	72.4	73.8	77.5	.0232400	1.51
T28	59.5	61.9	66.7	76.7	71.6	72.9	73.3	.0232952	1.00
T29	59.3	61.7	66.6	76.7	71.6	72.9	72.3	.0211775	0.92
T30	57.6	60.1	65.0	75.3	69.9	71.3	74.2	.0145339	-0.73
T31	58.8	61.1	66.1	76.3	71.2	72.5	75.0	.0129828	0.41
T32	57.5	60.1	64.8	74.8	69.7	70.9	69.0	.0390250	-0.76
T33	58.1	60.7	65.5	75.3	70.4	71.5	69.6	.0390250	-0.15
T48	61.2	64.6	69.8	79.5	73.3	75.1	81.3	.1846400	-
Bulk Temperature	58.9	61.6	66.5	76.4	71.0	72.5	74.9		

TABLE A-3

FINAL SENSOR TEMPERATURE READINGS (°F)

Sensor	Run Number 69	70	71	72	73	74	75	Weighting Factor W_i	Sensor Bias (°F)
T1	75.5	78.1	79.5	91.8	81.5	79.0	85.5	.0184800	0.73
T2	74.2	79.5	80.8	92.8	83.2	80.0	87.0	.0184800	0.60
T3	75.8	80.8	81.8	93.8	84.5	81.5	88.5	.0184800	2.17
T4	75.0	78.8	79.8	91.2	82.7	79.0	86.1	.0184800	0.10
T5	75.2	83.0	84.8	93.0	87.0	84.0	91.5	.0188759	-0.65
T6	-	-	-	-	-	-	-	-	-
T7	74.9	83.8	84.8	92.5	87.2	83.8	91.5	.0378094	-0.31
T8	74.0	80.5	82.0	89.5	85.0	81.2	89.2	.0075561	-0.67
T9	74.0	82.5	83.8	89.8	86.5	82.5	90.8	.0160603	0.87
T10	74.3	81.0	82.2	91.8	84.0	81.2	88.5	.0075561	-0.58
T11	74.5	81.2	82.2	91.2	85.0	81.5	89.2	.0075561	-0.07
T12	-	-	-	-	-	-	-	-	-
T13	75.2	83.9	85.0	92.5	87.0	83.5	91.5	.0467447	-0.23
T14	73.5	80.1	81.5	90.1	83.3	80.1	88.1	.0232144	-0.70
T15	72.5	80.2	81.8	90.5	84.3	80.8	88.5	.0263748	-0.40
T16	73.0	79.5	81.5	89.9	83.0	79.9	88.0	.0075561	-1.54
T17	79.0	87.3	88.8	99.2	91.1	87.5	95.2	.0232400	1.81
T18	74.0	80.7	81.9	91.5	84.5	81.2	89.9	.0075561	-0.87
T19	78.2	86.0	87.8	98.1	89.5	86.2	93.6	.0232400	0.32
T20	78.0	84.2	85.8	96.0	88.0	84.3	92.0	.0232400	-1.56
T21	77.2	85.5	86.8	95.5	89.0	84.5	93.2	.0147301	0.24
T22	75.8	84.0	85.2	94.5	87.8	84.2	91.8	.0149372	-1.42
T23	74.5	85.1	86.0	95.0	88.0	84.8	92.8	.0084711	-0.40
T24	75.2	85.0	86.5	93.0	88.6	85.0	92.5	.0170361	-0.06
T25	77.2	86.5	87.8	95.0	90.1	86.8	94.5	.0133861	0.98
T26	79.0	86.8	88.0	95.8	88.9	86.8	94.0	.2230200	-0.55
T27	79.5	87.5	88.5	100.0	91.1	88.0	95.2	.0232400	1.51
T28	77.2	85.5	86.8	94.8	89.5	85.2	93.2	.0232952	1.00
T29	77.2	86.0	87.3	96.2	89.5	85.8	93.8	.0211775	0.92
T30	75.5	84.3	86.2	96.0	88.5	84.8	93.0	.0145339	-0.73
T31	75.0	85.8	87.5	94.5	89.1	85.9	93.5	.0129828	0.41
T32	74.5	82.2	83.2	91.3	85.5	82.0	90.2	.0390250	-0.76
T33	75.2	83.0	84.2	92.8	85.9	83.6	90.8	.0390250	-0.15
T48	86.2	95.5	96.1	103.0	98.0	94.8	103.0	.1846700	-
Bulk Temperatire	78.4	86.4	87.6	95.9	89.4	86.4	94.0		

TABLE A-4

INDIVIDUAL SENSOR RESIDUALS (°F)

Sensor	Run Number 69	70	71	72	73	74	75	Mean of First Six Cases (°F)	Std. Dev. of First Six Cases (°F)
T1	.80	.83	1.08	.33	.58	.77	2.20	+0.73	.25
T2	.60	.63	.58	.43	.58	.77	2.10	+0.60	.11
T3	2.09	2.14	2.27	2.21	2.07	2.26	3.46	+2.17	.09
T4	.10	.13	.18	.13	-.02	.07	1.50	+0.10	.07
T5	-.75	-.94	-.75	-.46	-.45	-.53	-2.06	-0.65	.20
T6	-	-	-	-	-	-	-	-	-
T7	-.35	-.34	-.45	-.26	-.15	-.33	-1.86	-0.31	.10
T8	-.83	-.75	-.78	-.57	-.53	-.56	-.73	-0.67	.13
T9	.67	.75	.81	.98	.96	1.02	.40	0.87	.14
T10	-.53	-.45	-.59	-.62	-.64	-.68	-1.10	-0.58	.08
T11	.07	-.15	-.19	-.02	-.04	-.08	-.30	-0.07	.09
T12	-	-	-	-	-	-	-	-	-
T13	-.25	-.24	-.25	-.16	-.15	-.33	-1.86	-0.23	.07
T14	-.63	-.65	-.78	-.67	-.73	-.76	-.83	-0.70	.06
T15	-.33	-.45	-.48	-.37	-.33	-.46	-.63	-0.40	.07
T16	-1.33	-1.45	-1.58	-1.57	-1.53	-1.76	-1.83	-1.54	.15
T17	1.71	1.68	1.75	1.70	1.97	2.04	2.54	1.81	.16
T18	-.83	-.75	-.88	-.87	-.93	-.96	-1.03	-0.87	.07
T19	.31	.28	.35	.30	.47	.24	1.04	0.32	.08
T20	-1.59	-1.52	-1.55	-1.60	-1.53	-1.56	-.86	-1.56	.03
T21	.22	.27	.30	.14	.15	.34	.21	0.24	.08
T22	-1.29	-1.32	-1.43	-1.48	-1.49	-1.51	-.84	-1.42	.09
T23	-.28	-.33	-.31	-.48	-.56	-.47	-.62	-0.40	.11
T24	.02	.07	-.10	-.04	-.15	-.15	-.75	-0.06	.09
T25	.92	.88	.98	1.16	.92	1.01	1.53	0.98	.10
T26	-.32	-.21	-.40	-.69	-.93	-.78	.94	-0.55	.29
T27	1.21	1.28	1.56	1.61	1.67	1.75	2.45	1.51	.22
T28	1.13	1.07	1.01	.89	.96	.97	-.08	1.00	.08
T29	.93	.87	.91	.89	.96	.97	-1.08	0.92	.04
T30	-.78	-.72	-.72	-.65	-.78	-.69	-.02	-0.73	.05
T31	.42	.28	.38	.36	.52	.51	.83	0.41	.09
T32	-.84	-.75	-.81	-.56	-.79	-.84	-1.65	-0.76	.11
T33	-.24	-.15	-.11	-.06	-.09	-.24	-1.05	-0.15	.08
T48[†]									

[†]Not included in analysis.

TABLE A-5

FINAL BULK POOL TEMPERATURE

BY ENERGY BALANCE METHOD

FOR RUNS WITH NO RHR

Parameter	Run Number 70	71	73	74	75
Initial Pool Level	26'2½"	26'2½"	26'4½"	26'3¼"	26'3¼"
Initial Pool Mass ($x\ 10^6\ lb_m$)	8.035	8.030	8.069	8.037	8.034
Initial Pool Temperature (°F)	61.6	66.5	71.0	72.5	74.9
S/RV Mass Flow Rate (lb_m/sec)	167.	167.	169.	172.	175.
S/RV Blowdown Duration (sec)	1021.	866.	772.	573.	781.
RPV Pressure (psia)	959.	955.	955.	955.	957.
S/RV Flow Enthalpy (Btu/lb_m)	1194.	1194.	1194.	1194.	1194.
Final Pool Temperature (°F)	85.8	87.0	89.4	86.5	94.2

TABLE A-6

FINAL BULK POOL TEMPERATURE

BY ENERGY BALANCE METHOD

FOR RUNS WITH RHR

Parameter	Run Number 69	72
Initial Pool Level	26'3¼"	26'2"
Initial Pool Water Mass ($x10^6$ lb_m)	8.057	8.006
Initial Pool Temperature (°F)	58.9	76.4
S/RV Mass Flow Rate (lb_m/sec)	172.	178.
S/RV Blowdown Duration (sec)	901.	905.
RPV Pressure (psia)	960.	955.
S/RV Flow Enthalpy (Btu/lb_m)	1194.	1194.
RHR Mass Flow Rate (lb_m/sec)	1036.	1036.
RHR Effectiveness	.409	.409
Service Water Temperature (°F)	44.	44.
Final Bulk Pool Temperature (°F)	79.7	97.1

TABLE A-7

COMPARISON OF "SENSOR WEIGHTED AVERAGE" METHOD

TO ENERGY BALANCE METHOD

	Run Number						
	With RHR		Without RHR				
	69	72	70	71	73	74	75
Initial Bulk Pool Temperature (°F)	58.9	76.4	61.6	66.5	71.0	72.5	74.9
Final Bulk Pool Temperature (°F)							
"Sensor Weighted Average" Method	78.4	95.9	86.4	87.6	89.4	86.4	94.0
Energy Balance Method	79.7	97.1	85.8	87.0	89.4	86.5	94.2
Temperature Rise ("SWA" Method) (°F)	19.5	19.5	24.8	21.1	18.4	13.9	19.1
Difference (Energy-SWA) (°F)	+1.3	+1.2	-0.6	-0.6	+0.0	+0.1	+0.2
% Difference†	+6.7	+6.2	-2.4	-2.8	+0.0	+0.7	+1.0

†As a % of the total temperature rise

APPENDIX B
APPLICABILITY OF DATA TO HIGHER POOL TEMPERATURES

For the seven extended blowdown tests, the bulk pool temperature ranged between 58°F and 97°F and the local-to-bulk pool temperature differences were determined for pool temperatures in this range. Tests and measurements were not made outside of this range due to restrictions on plant operation included in the Technical Specifications. However, the local-to-bulk pool temperature determinations are only of interest at much higher bulk pool temperatures (160°F to 200°F).

The properties of water, in particular the Prandtl number, vary significantly between the test range and the range over which the test results are to be applied. Since for a fixed geometry the Prandtl number controls the mixing process, the validity of applying measured data from one temperature range to another range must be demonstrated. This appendix shows that the measured local-to-bulk pool temperatures determined from the extended blowdown tests can be applied directly and conservatively to higher pool temperatures.

For the purposes of determing the functional dependence of the local-to-bulk pool temperature difference on bulk pool temperature, the flow field resulting from a discharging T-Quencher may be idealized as an axisymmetric plume [B1]. The condensing steam is the source of bouyancy and the general expression for the centerline plume temperature is:

$$t_o - t_\infty = \frac{h(o)}{Pr} \cdot \frac{Q}{2\pi kx} \qquad \text{(B-1)}$$

where

- t_o - centerline plume temperature
- t_∞ - ambient or bulk temperature
- $h(o)$ - factor (dependent only upon Pr)
- Pr - Prandtl number
- k - thermal conductivity of fluid at t_∞
- x - axial distance along plume
- Q - heat source

By taking the ratio of Eq. B-1 at one temperature to Eq. B-1 at some reference temperature (say 100°F), the functional dependence of plume centerline temperature on ambient temperature can be determined. Notice that this ratio is independent of axial distance along the plume. Figure B-1 presents the functional dependence of plume centerline temperature on bulk temperature for water. Since the local-to-bulk pool temperature difference is analogous to (t_o - t_∞) very near the heat source of the plume, this figure shows that the local-to-bulk pool temperature difference in the range of application is about 96% of the local-to-bulk pool temperature difference for the range of measurement. Thus the measured local-to-bulk pool temperature difference may be directly and conservatively applied to the range of applicability

The idealization of the flow field from a discharging quencher as an axisymmetric plume is for purposes of determining the functional dependence of local-to-bulk pool temperature difference only and should not be taken too literally. There are many effects not taken into account in the idealization such as the finite size of the pool, momentum near the quencher exit, and pool stratification. This analogy may not accurately quantify the bulk pool temperature effect on local-to-bulk pool temperature difference. However, since the basic mechanisms of the two flows are the same, (i.e. heat source induced buoyancy), the functional dependence should be the same.

References

B1) Gebhart, B., Heat Transfer, 2nd Edition, pg. 354, McGraw-Hill, New York, 1971

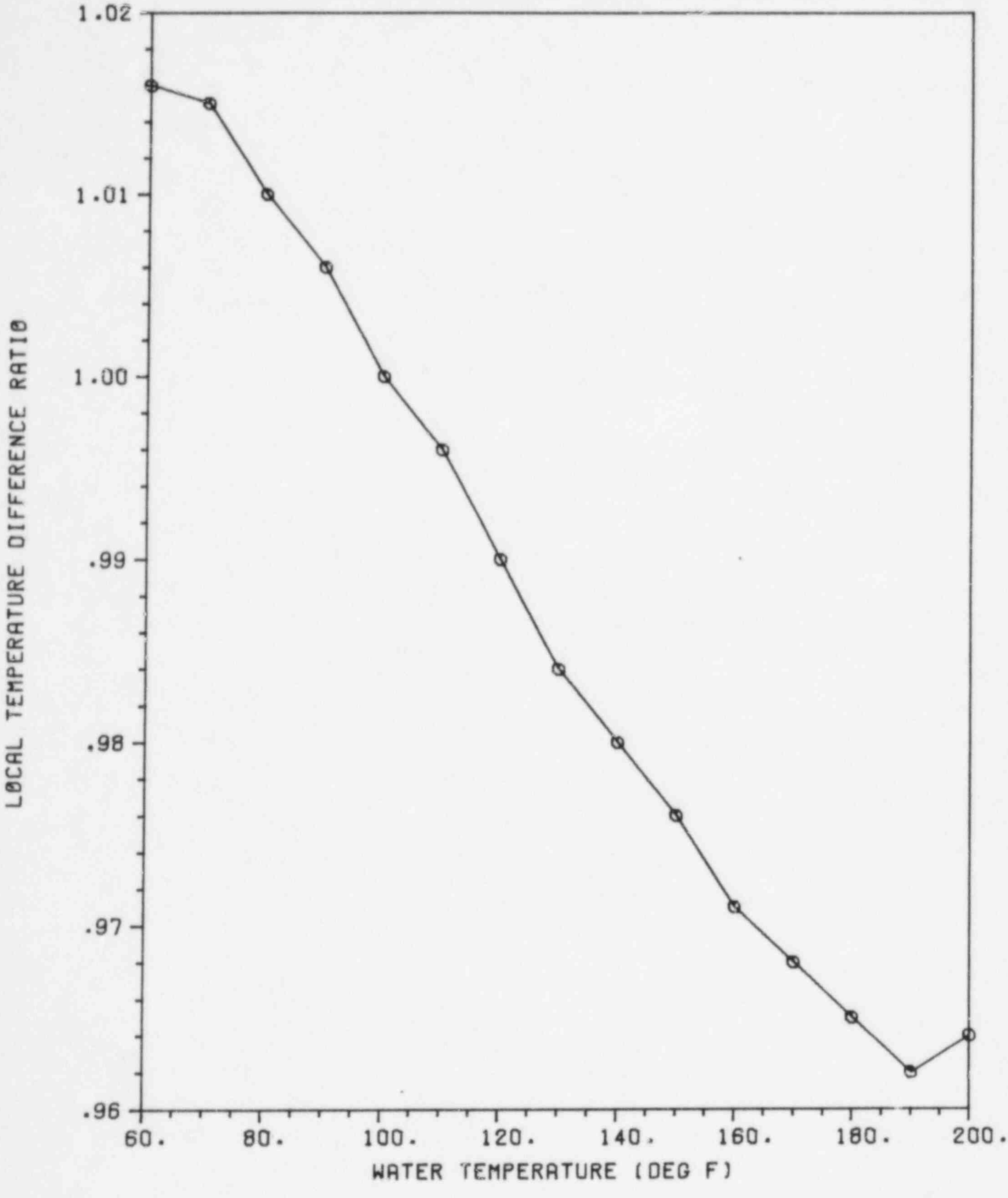
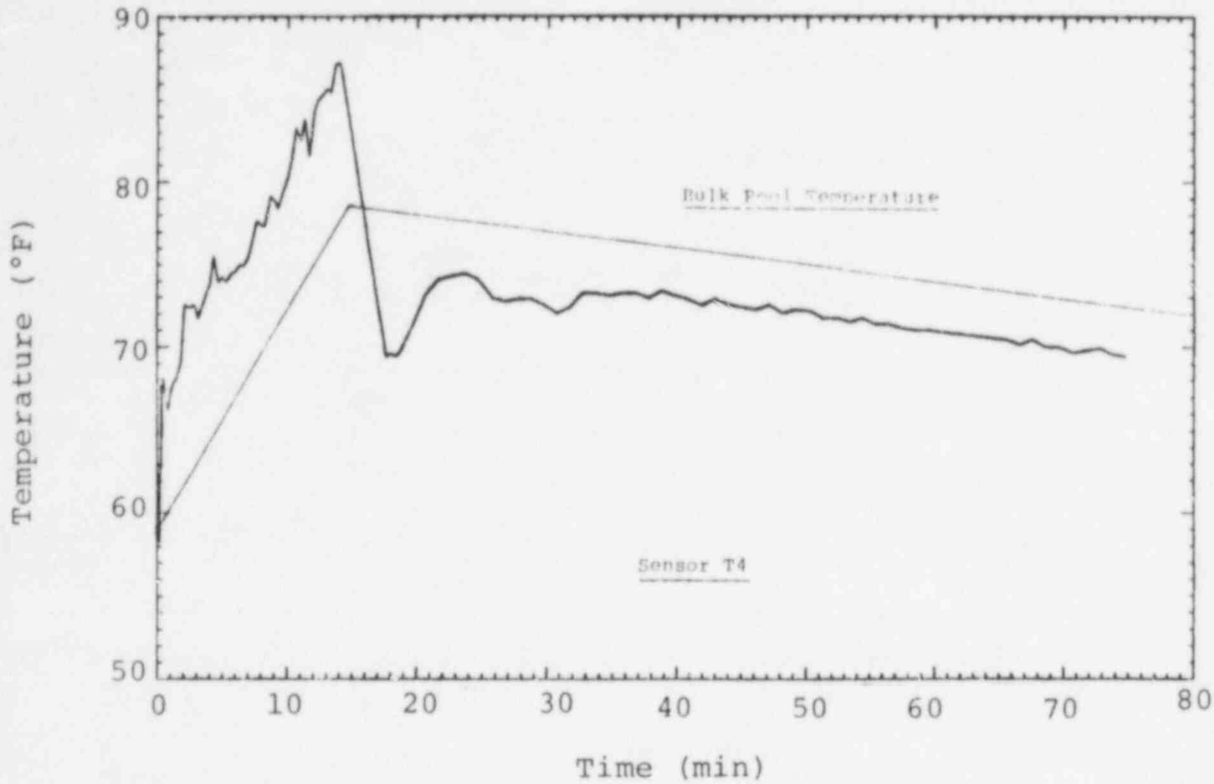


FIGURE B-1: TEMPERATURE DIFFERENCE RATIØ

APPENDIX C

LIST OF FIGURES



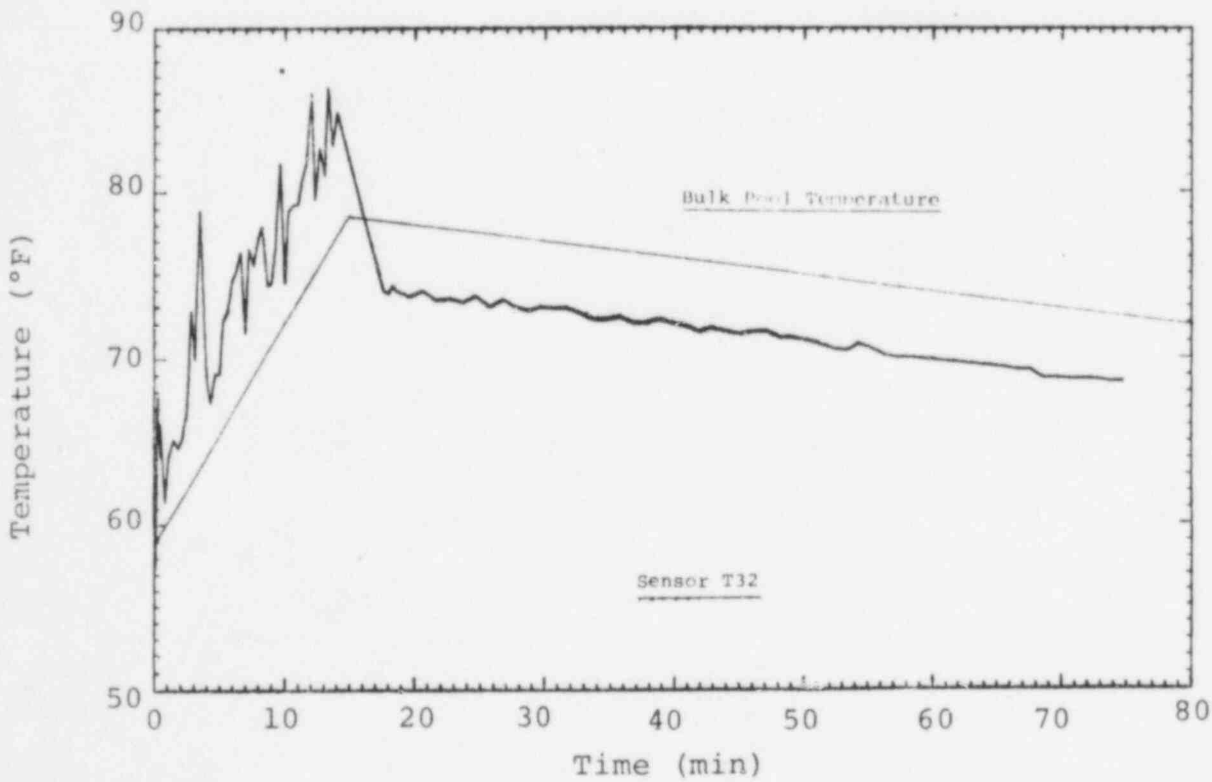
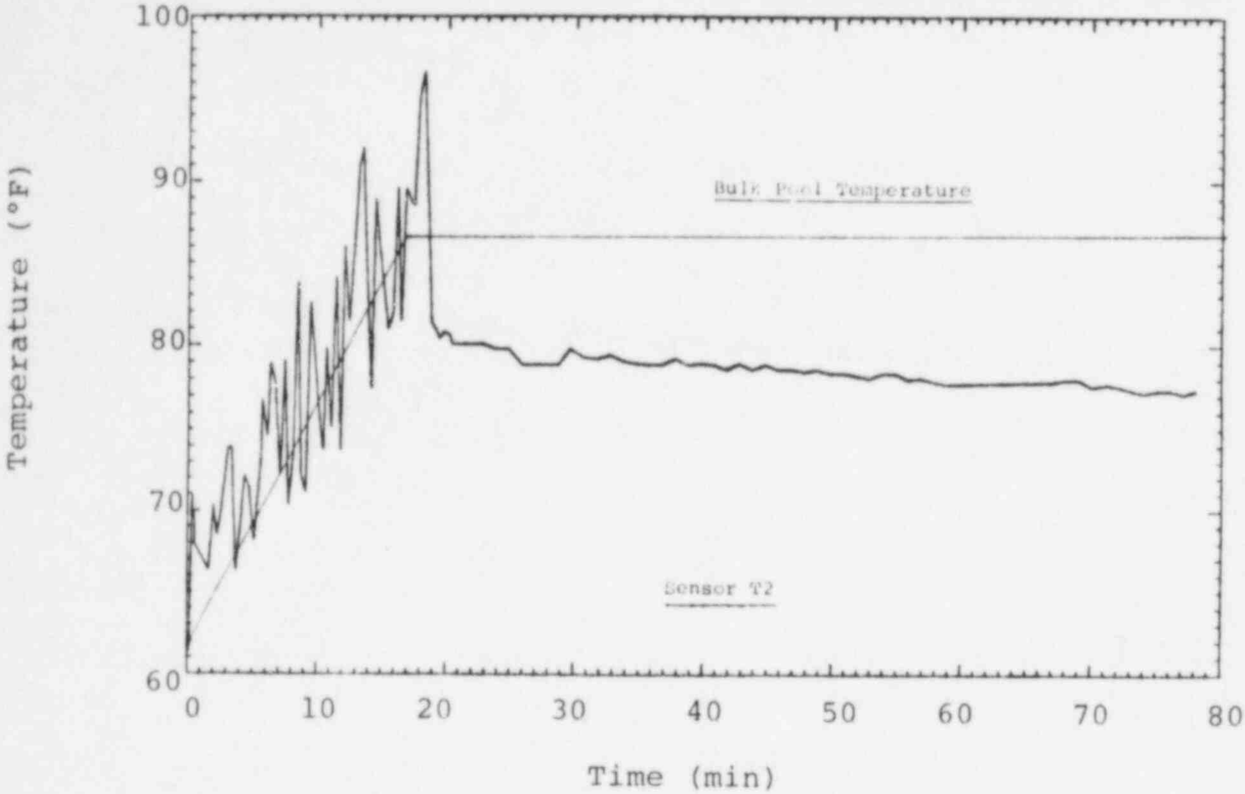


Figure C-1: Local Pool Temperature-Run 69



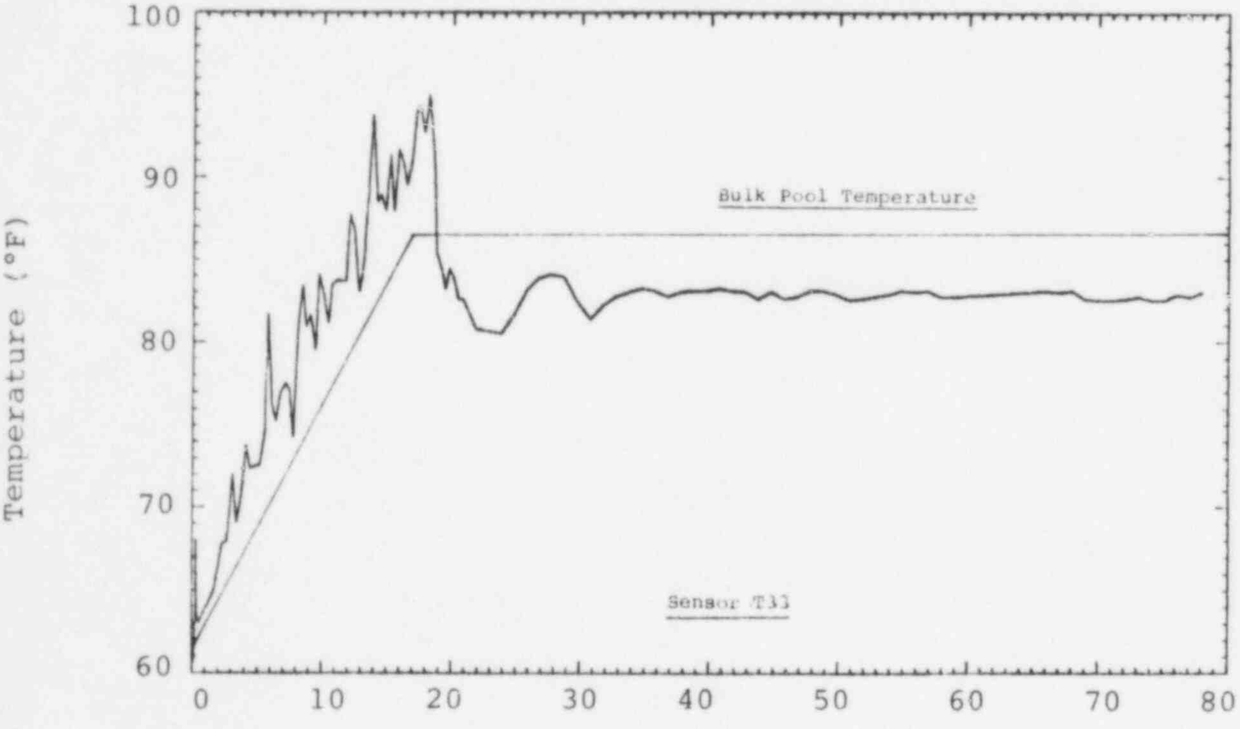
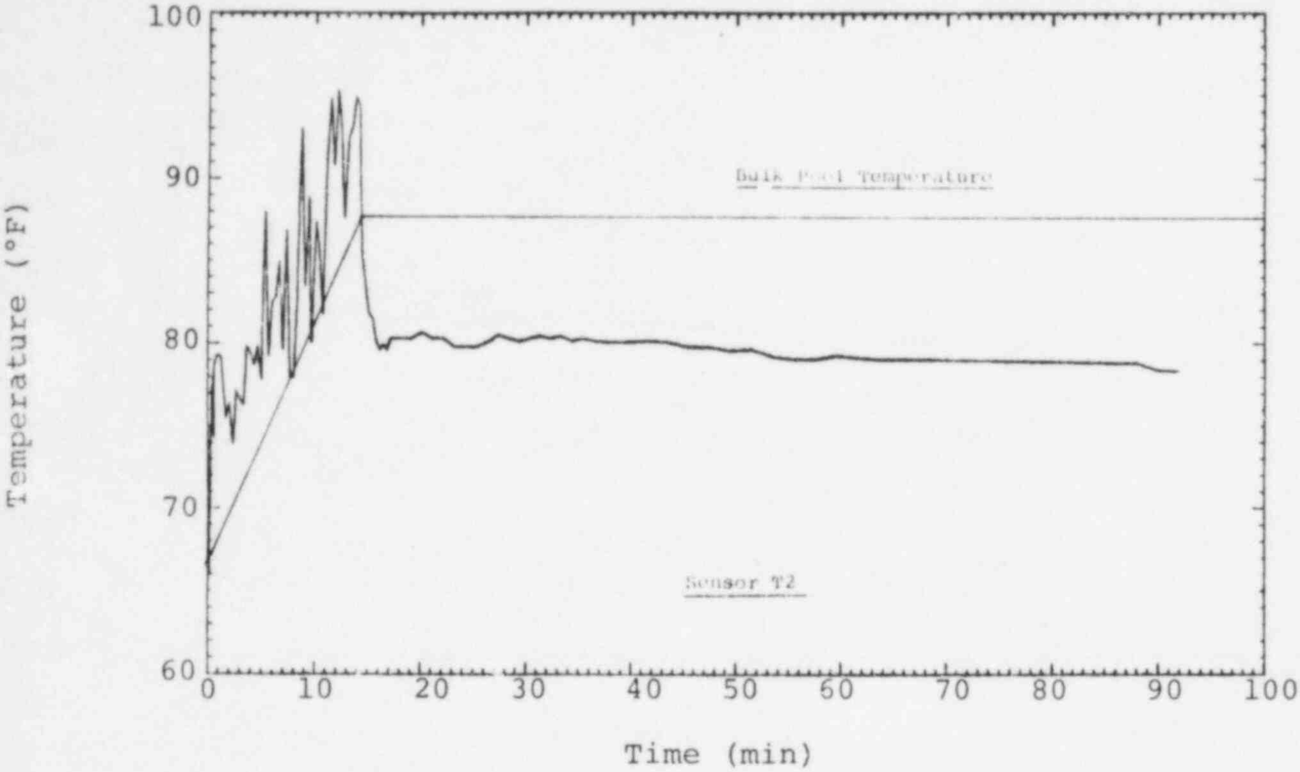


Figure C-2: Local Pool Temperature-Run 70



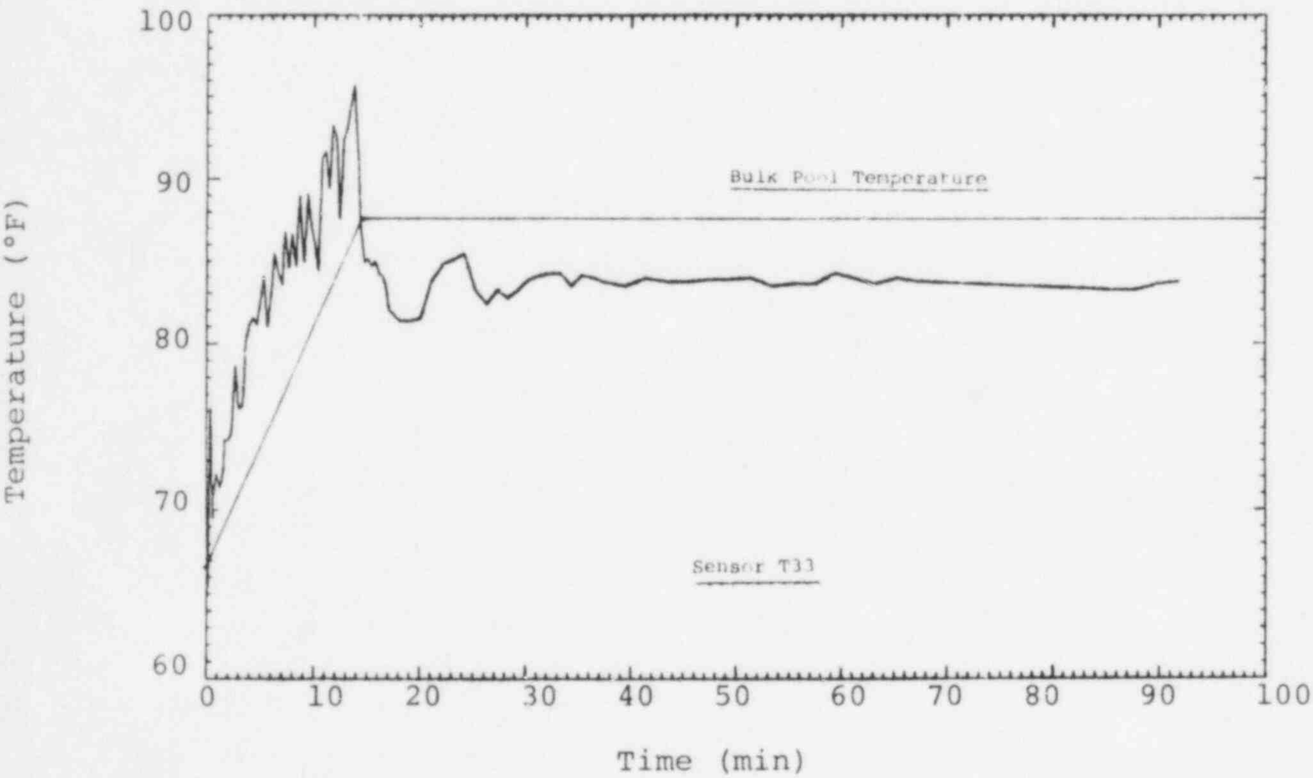


Figure C-3: Local Pool Temperature-Run 71

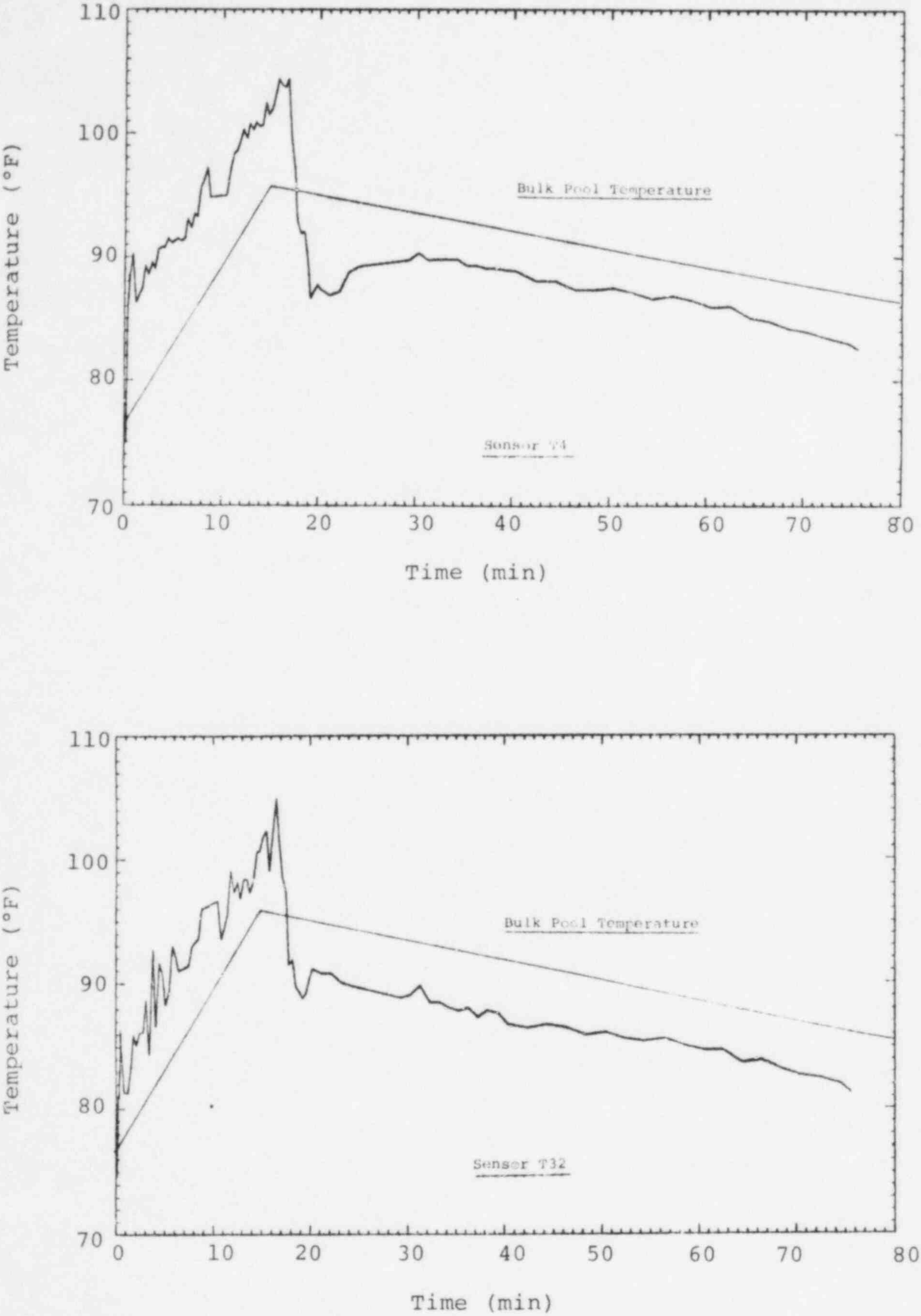
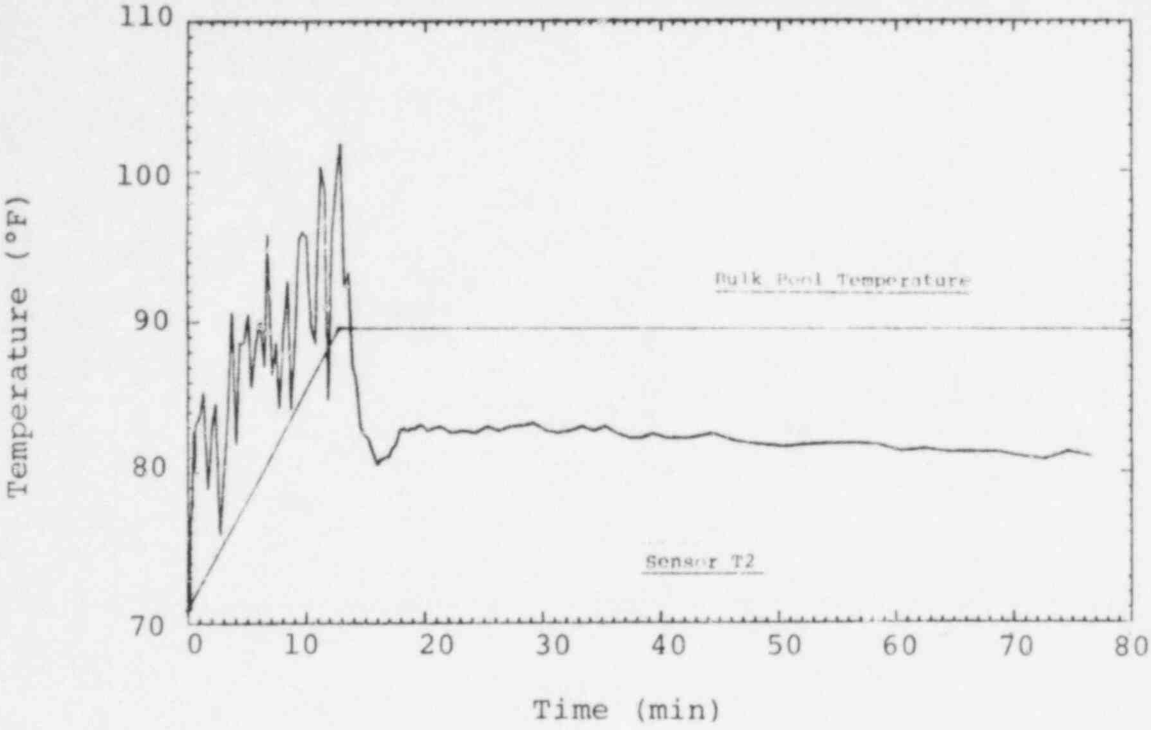


Figure C-4: Local Pool Temperature-Run 72



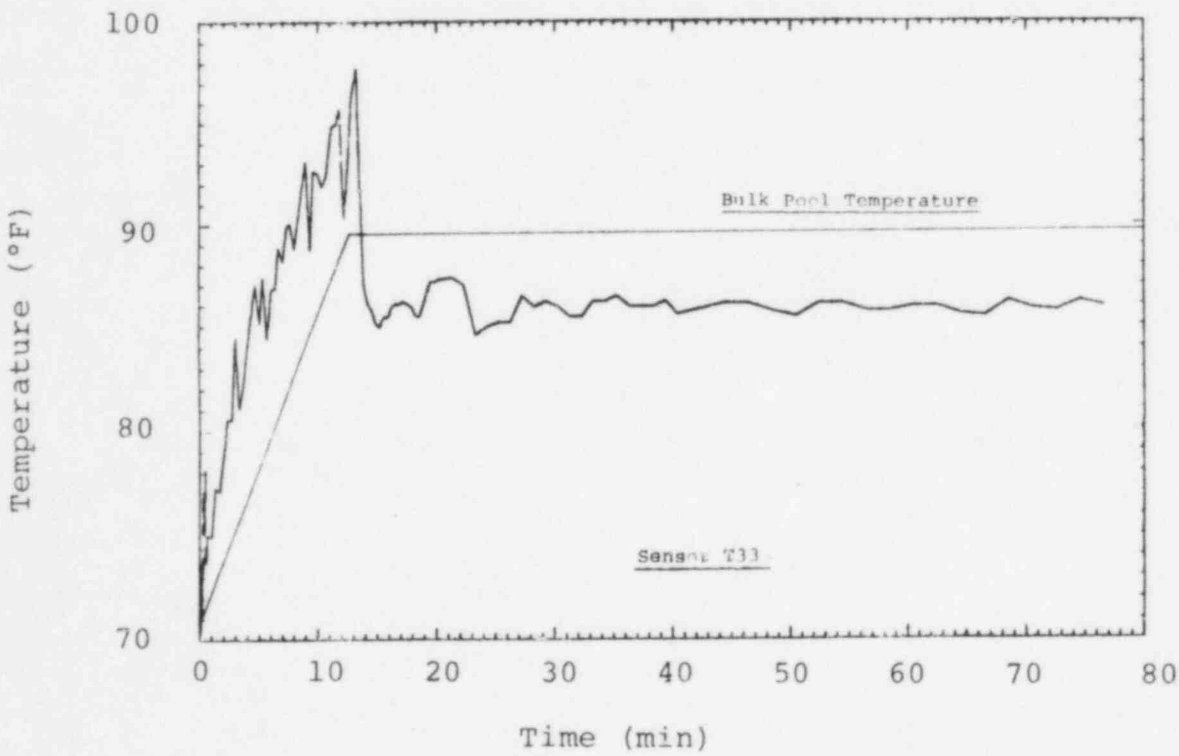
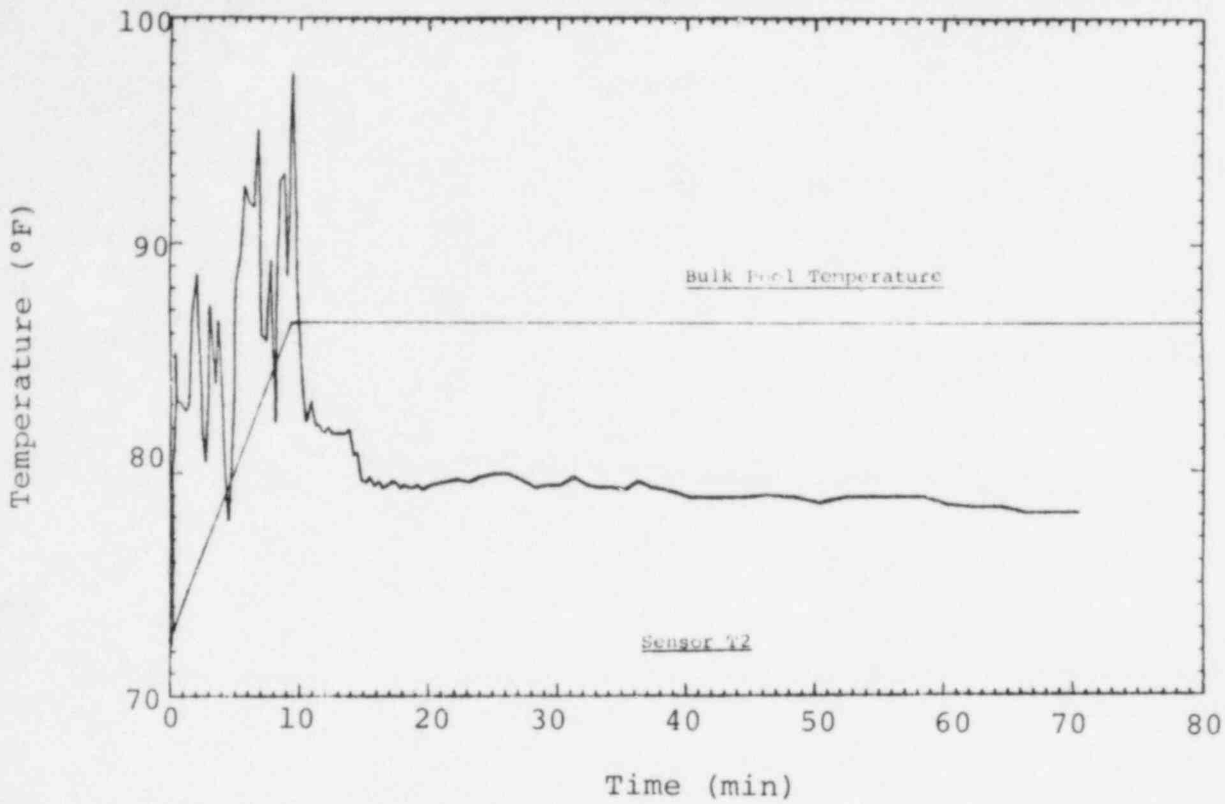


Figure C-5: Local Pool Temperature-Run 73



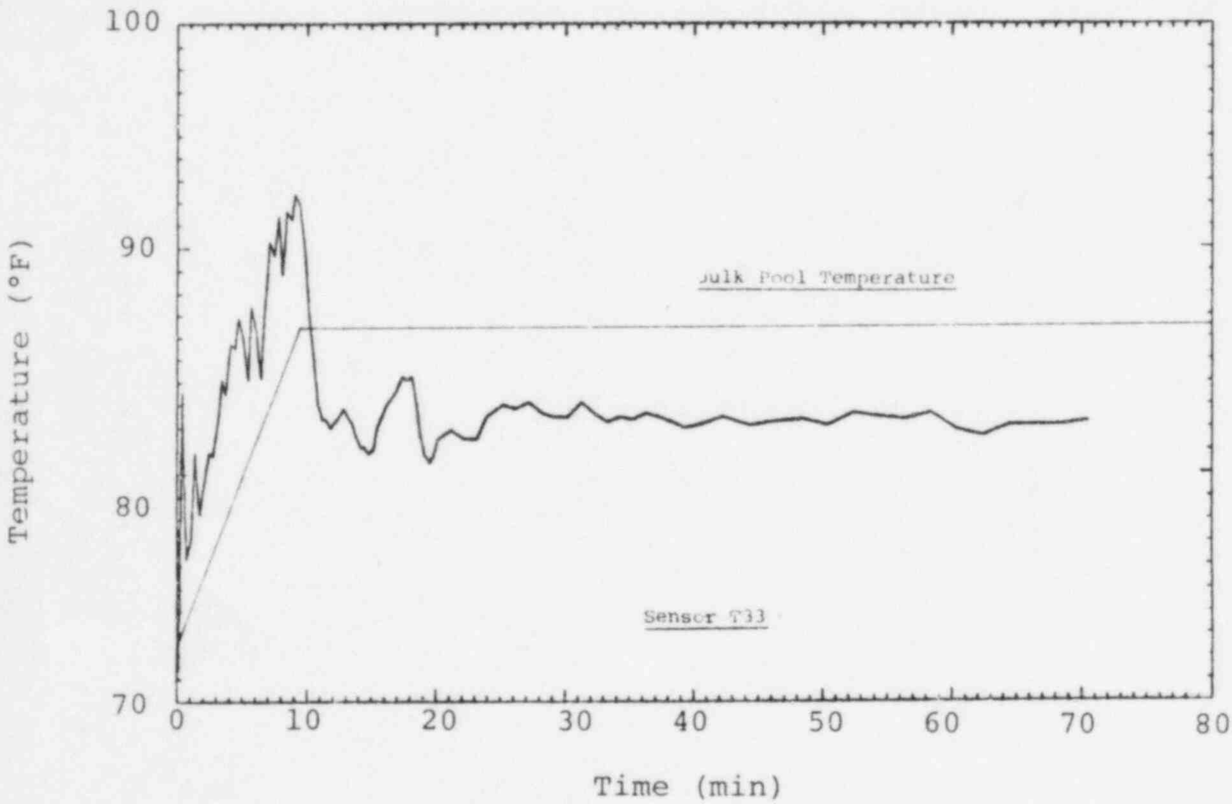


Figure C-6: Local Pool Temperature-Run 74

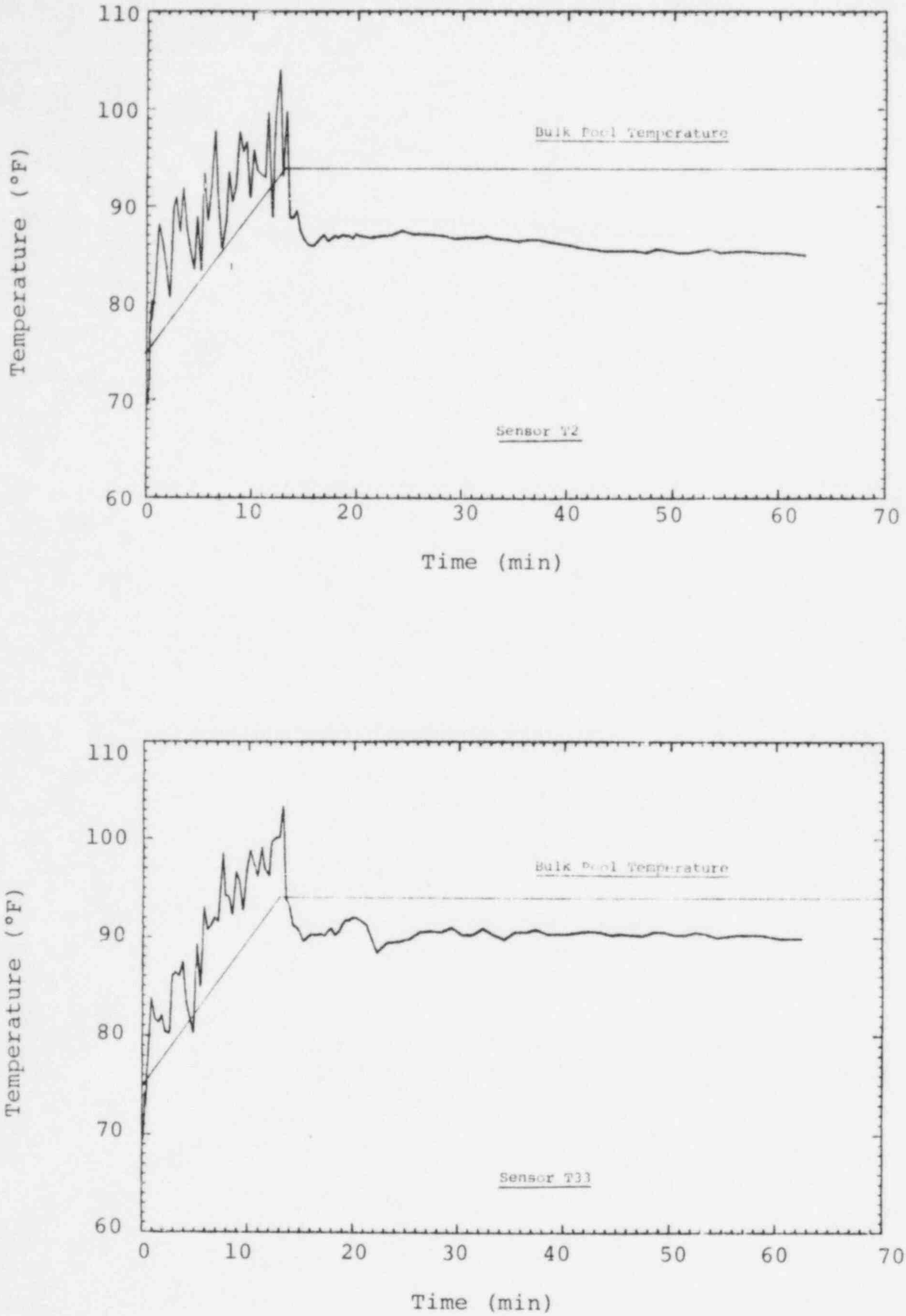


Figure C-7: Local Pool Temperature-Run 75

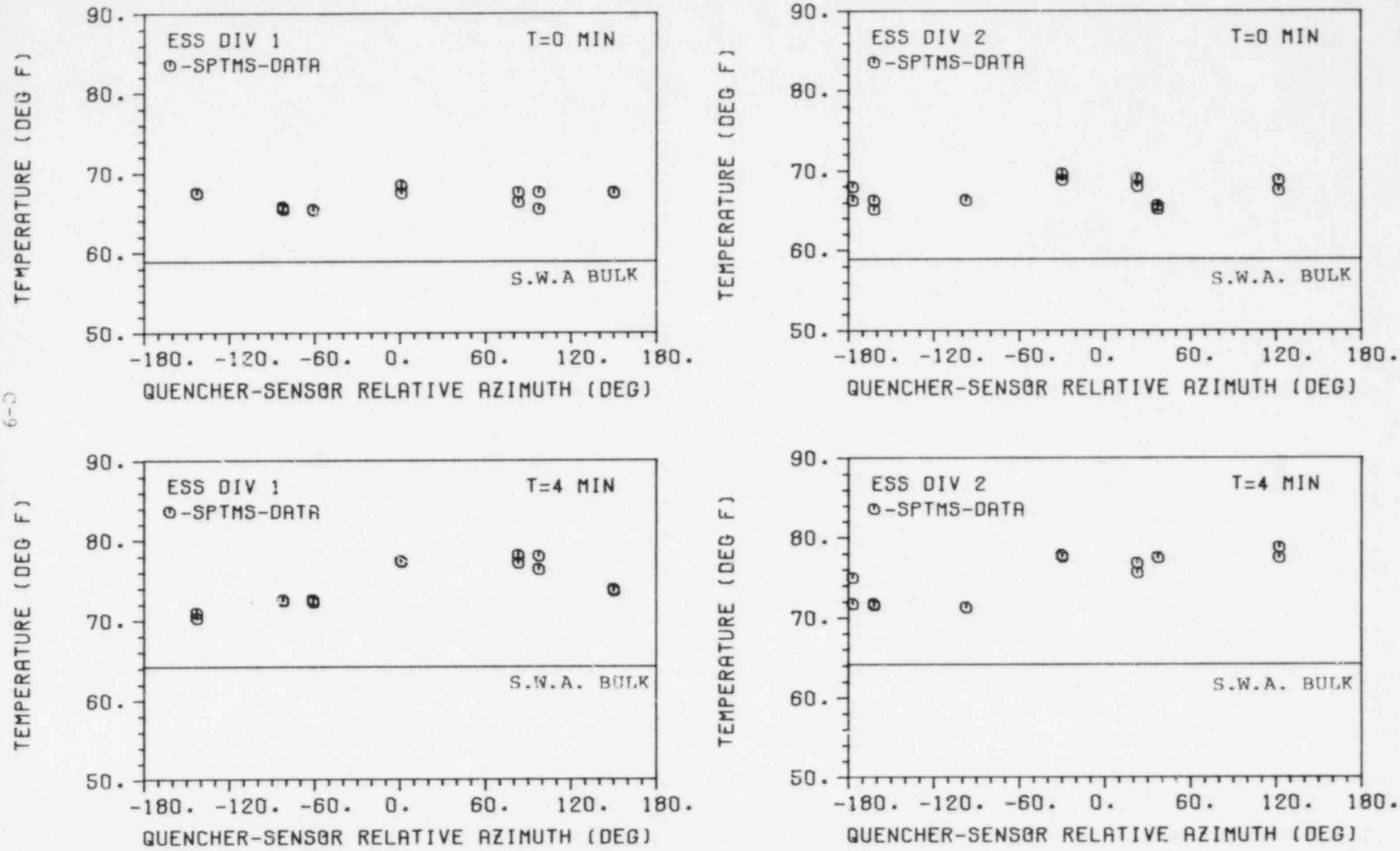


FIGURE C-8A: SUPPRESSION POOL TEMPERATURE MONITORING SYSTEM - RUN 69

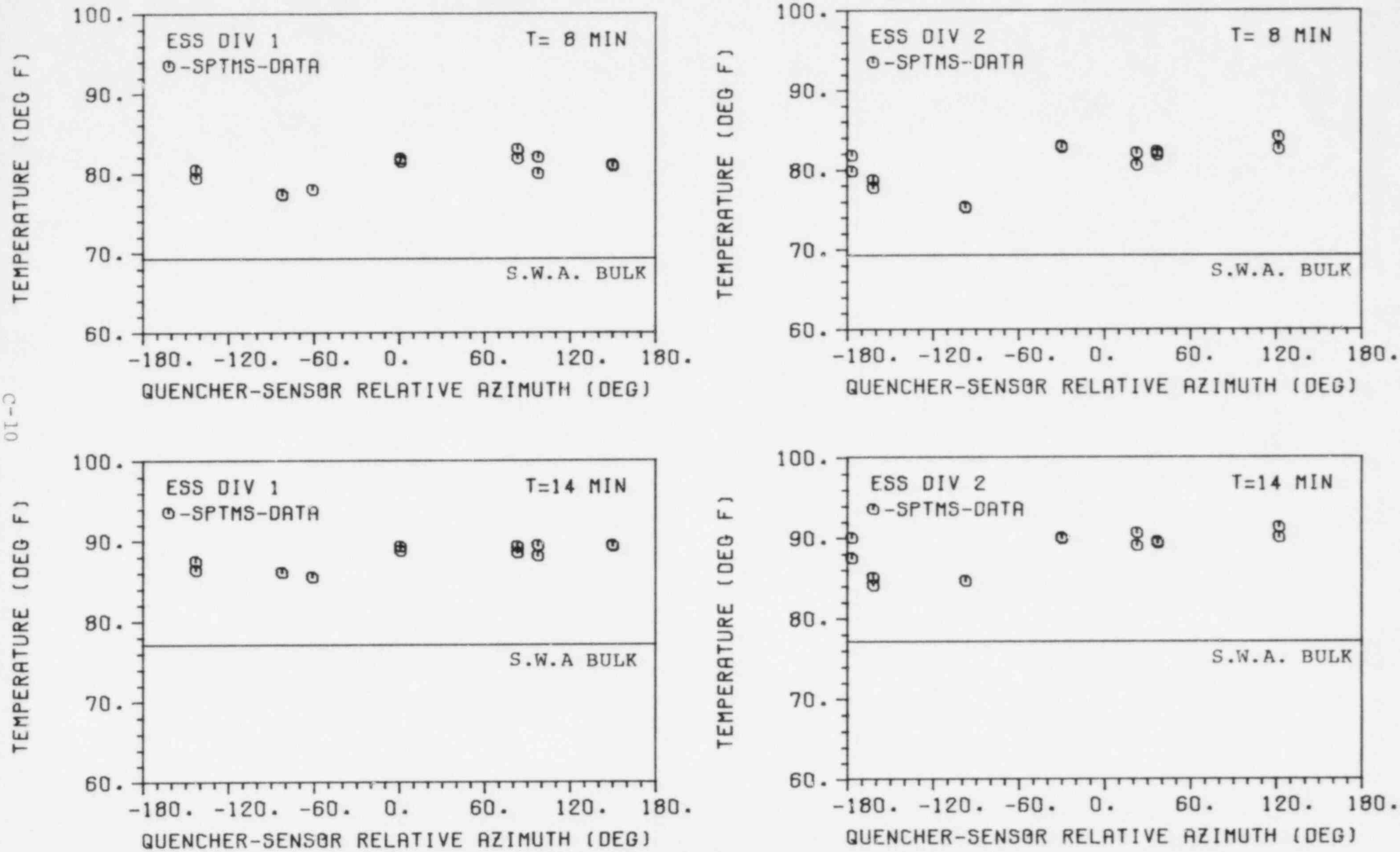


FIGURE C-8B: SUPPRESSION POOL TEMPERATURE MONITORING SYSTEM - RUN 69

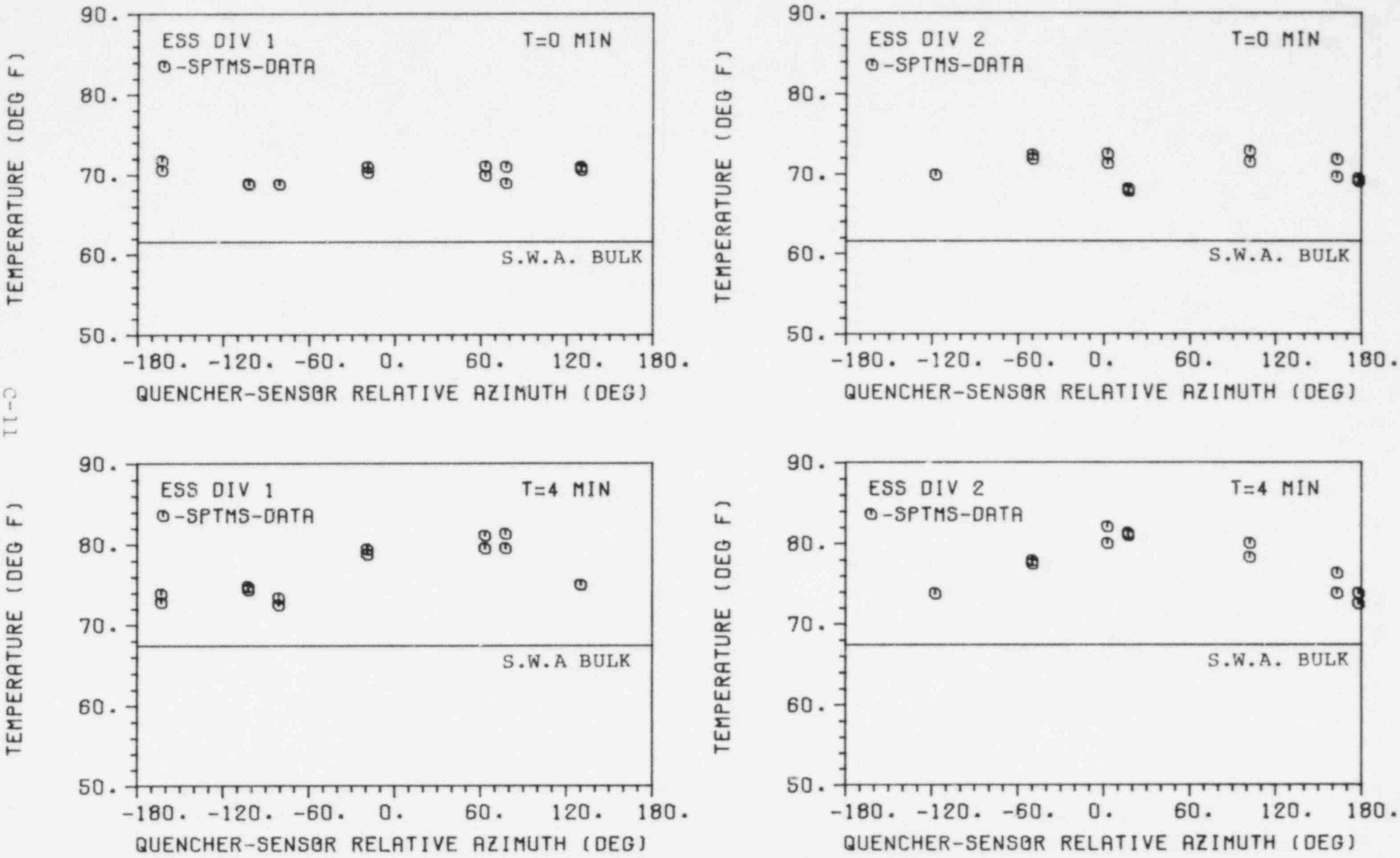


FIGURE C-9A: SUPPRESSION POOL TEMPERATURE MONITORING SYSTEM - RUN 70

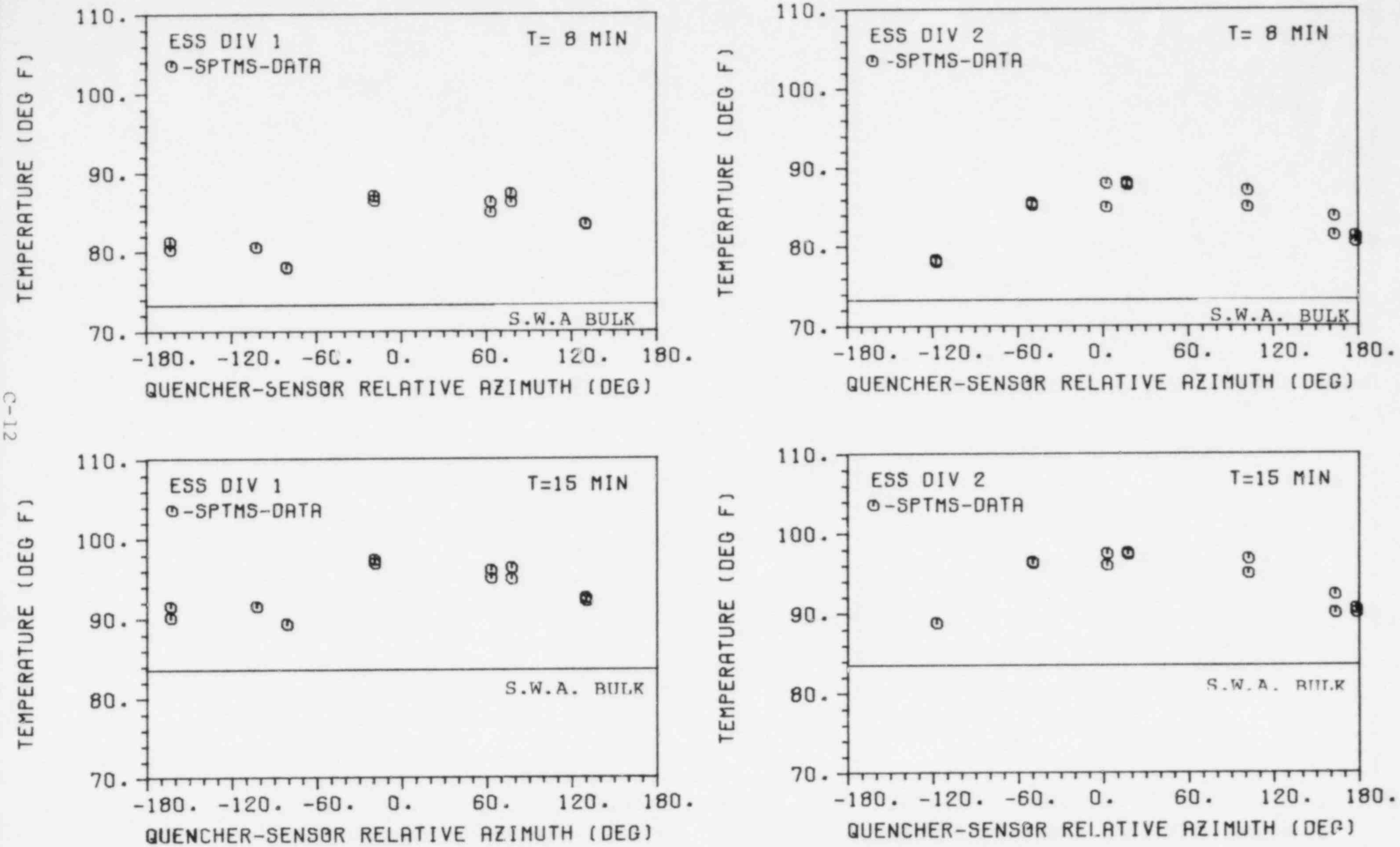


FIGURE C-9B: SUPPRESSION POOL TEMPERATURE MONITORING SYSTEM - RUN 70

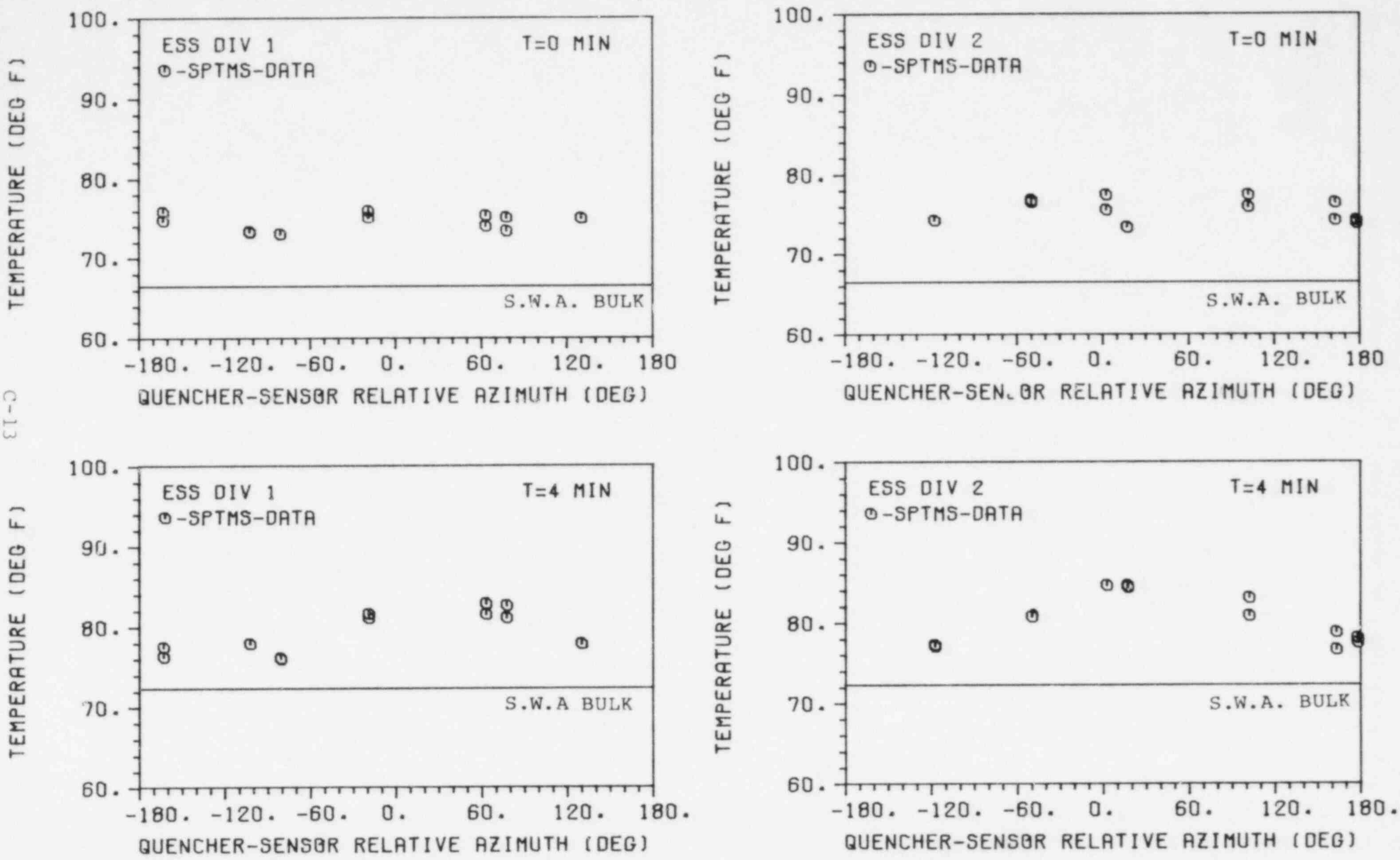


FIGURE C-10A: SUPPRESSION POOL TEMPERATURE MONITORING SYSTEM - RUN 71

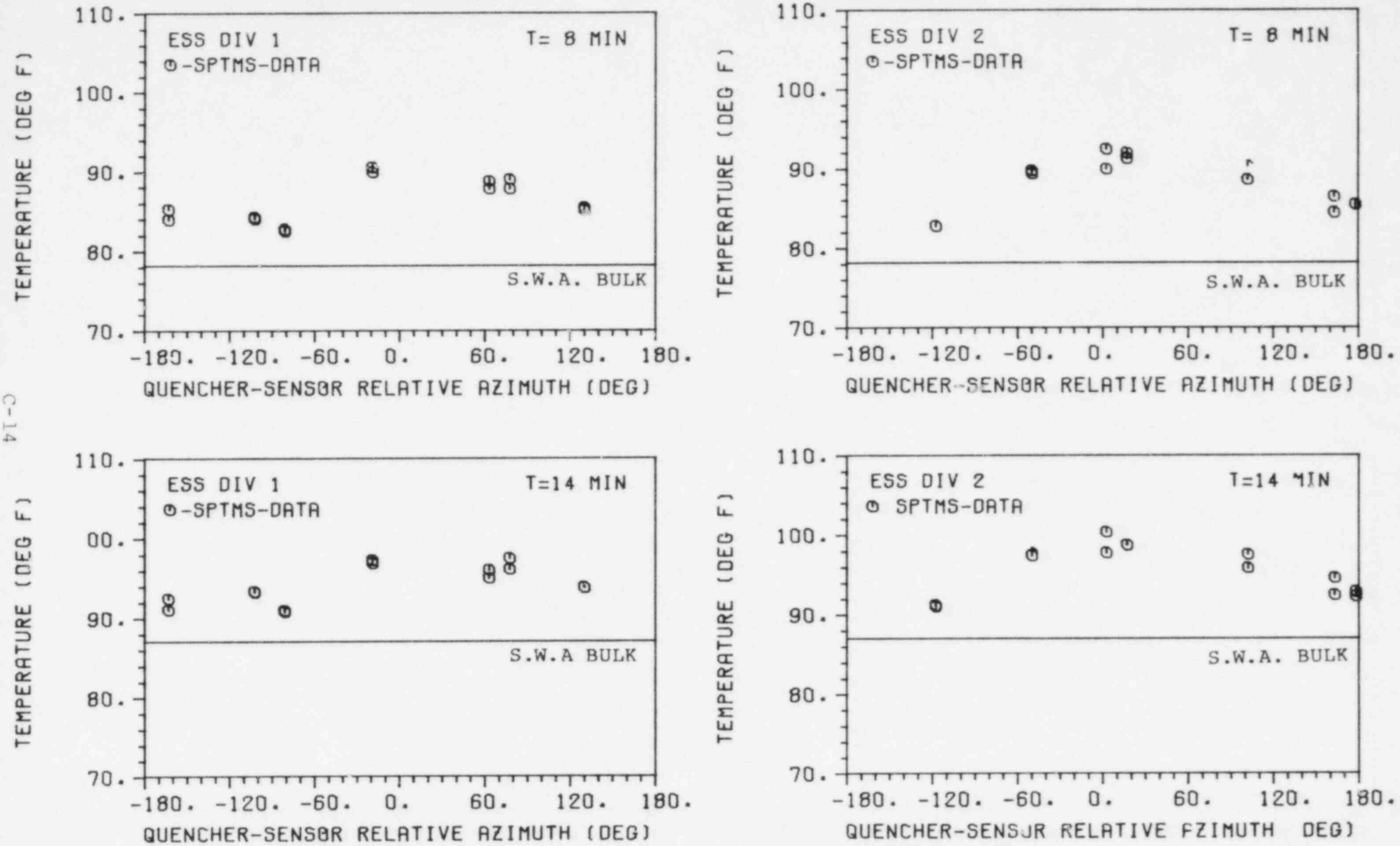


FIGURE C-10B: SUPPRESSION POOL TEMPERATURE MONITORING SYSTEM - RUN 71

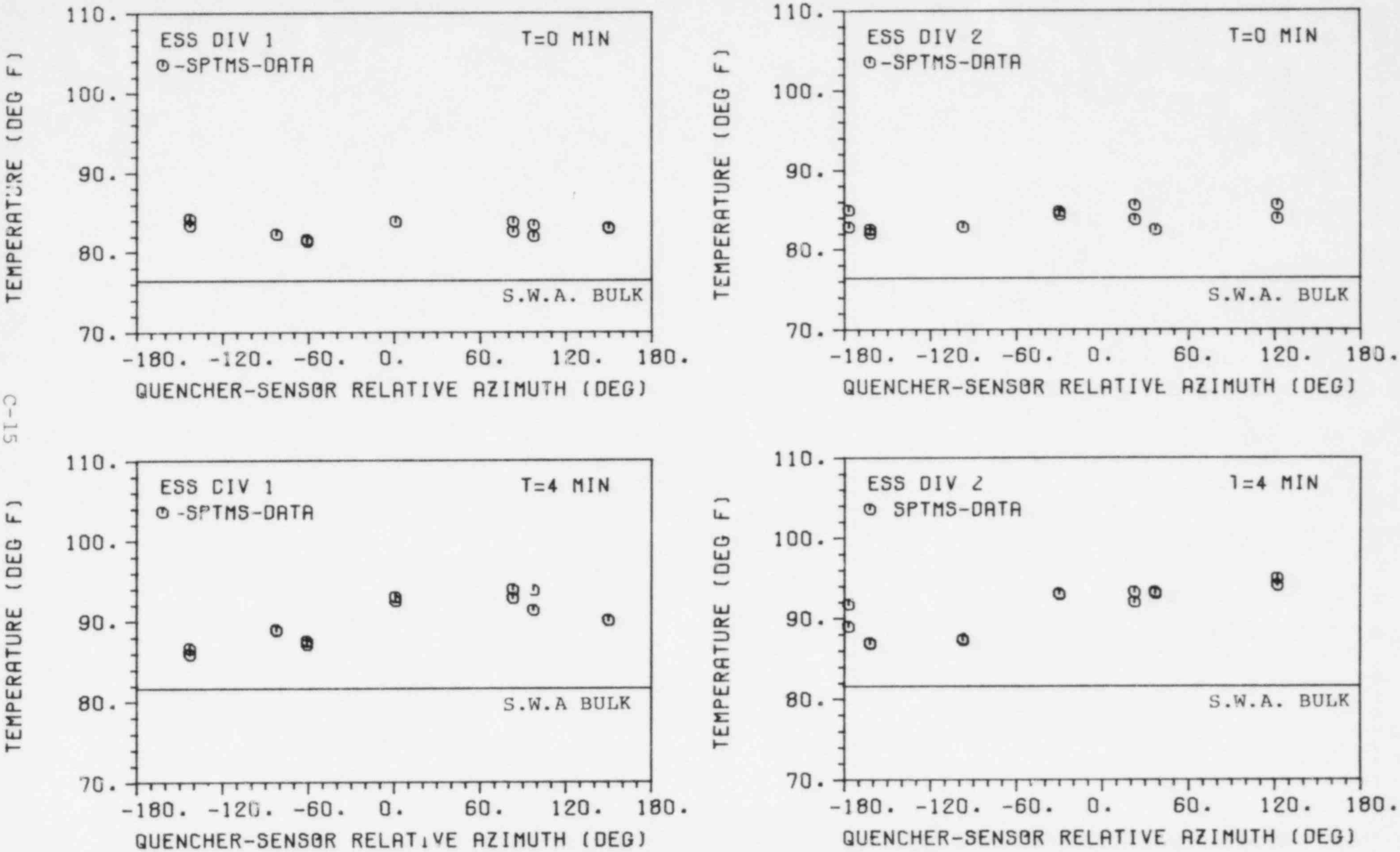


FIGURE C-11A: SUPPRESSION POOL TEMPERATURE MONITORING SYSTEM - RUN 72

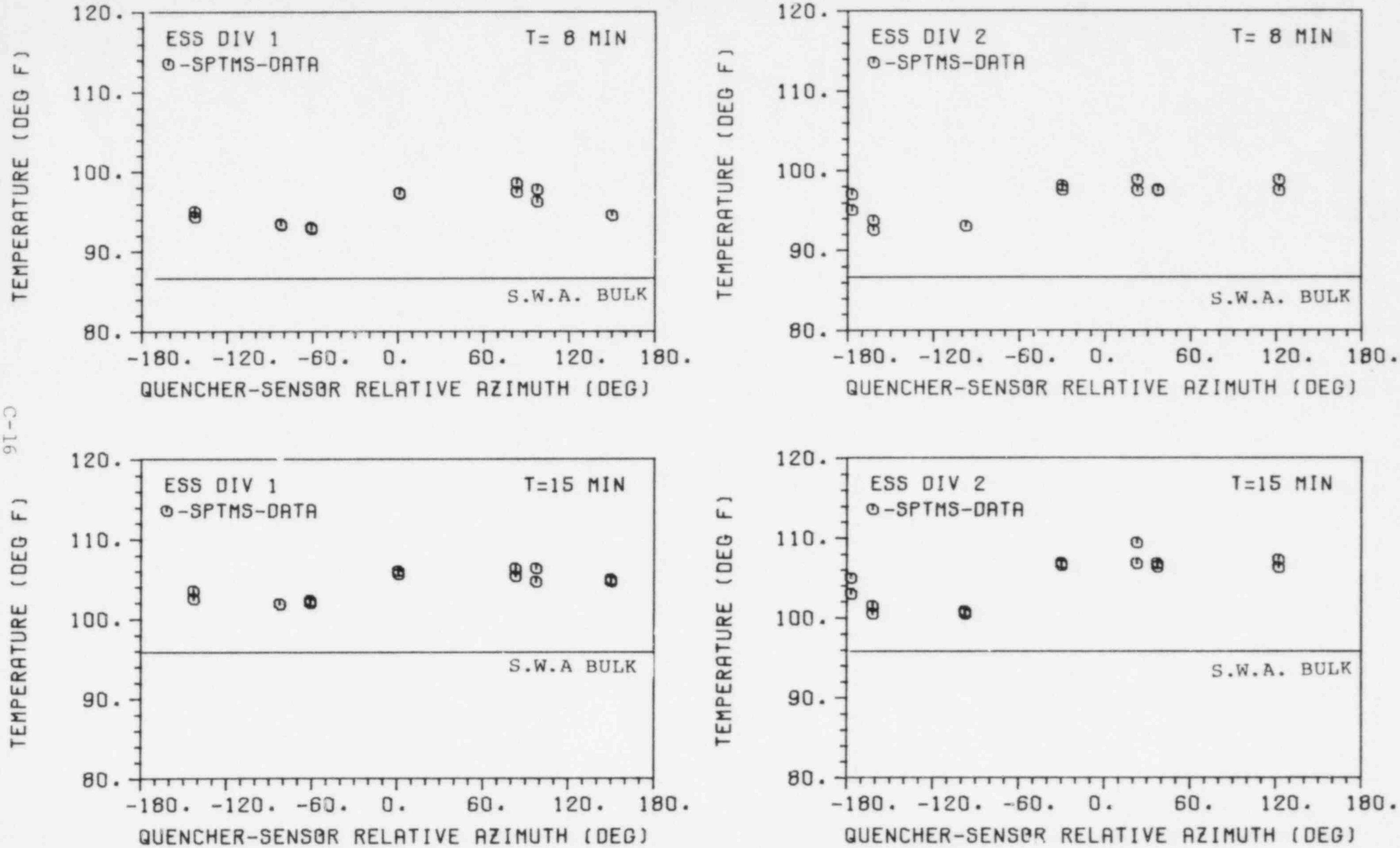


FIGURE C-11B: SUPPRESSION POOL TEMPERPTURE MONITORING SYSTEM - RUN 72

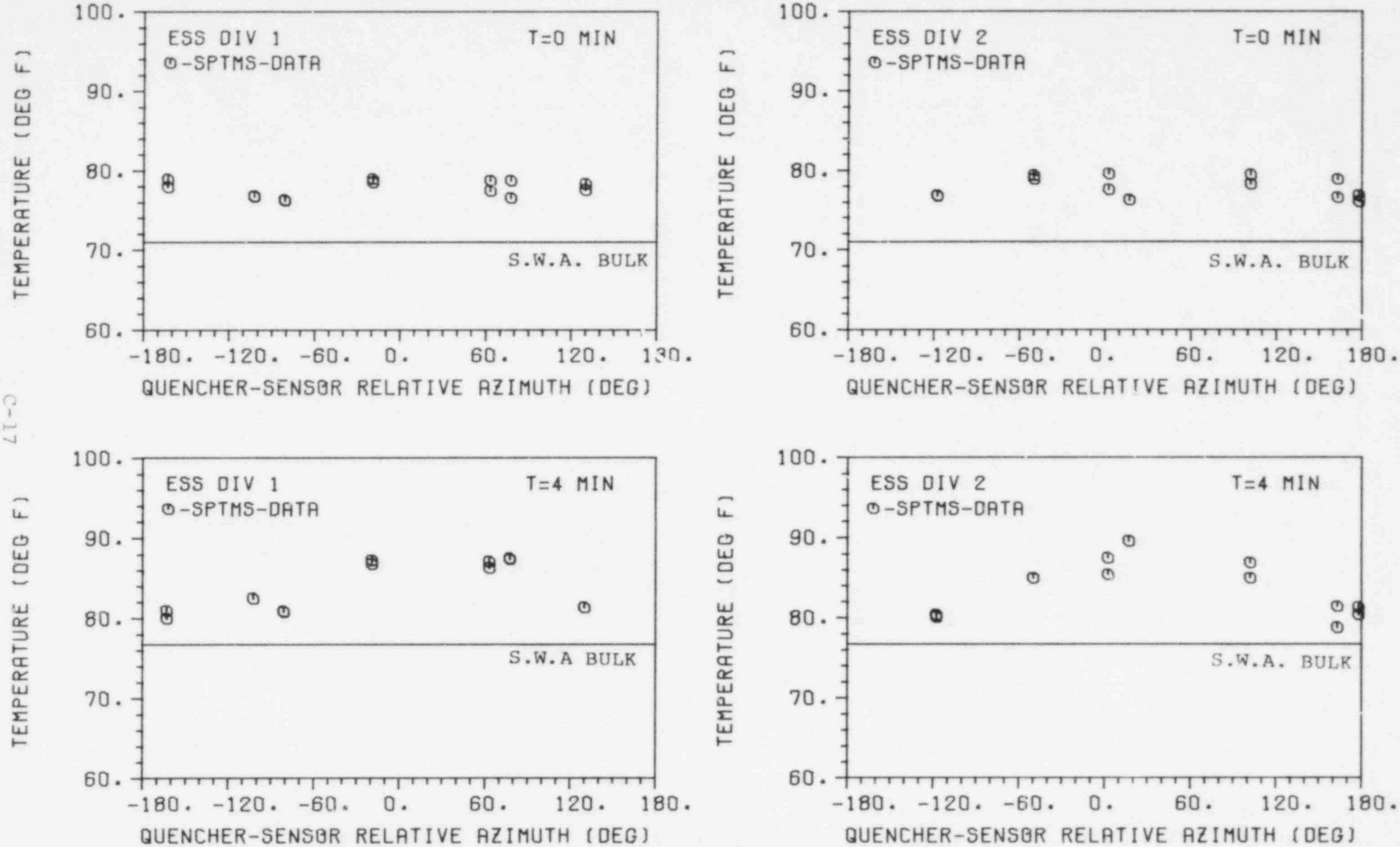


FIGURE C-12A: SUPPRESSION POOL TEMPERATURE MONITORING SYSTEM - RUN 73

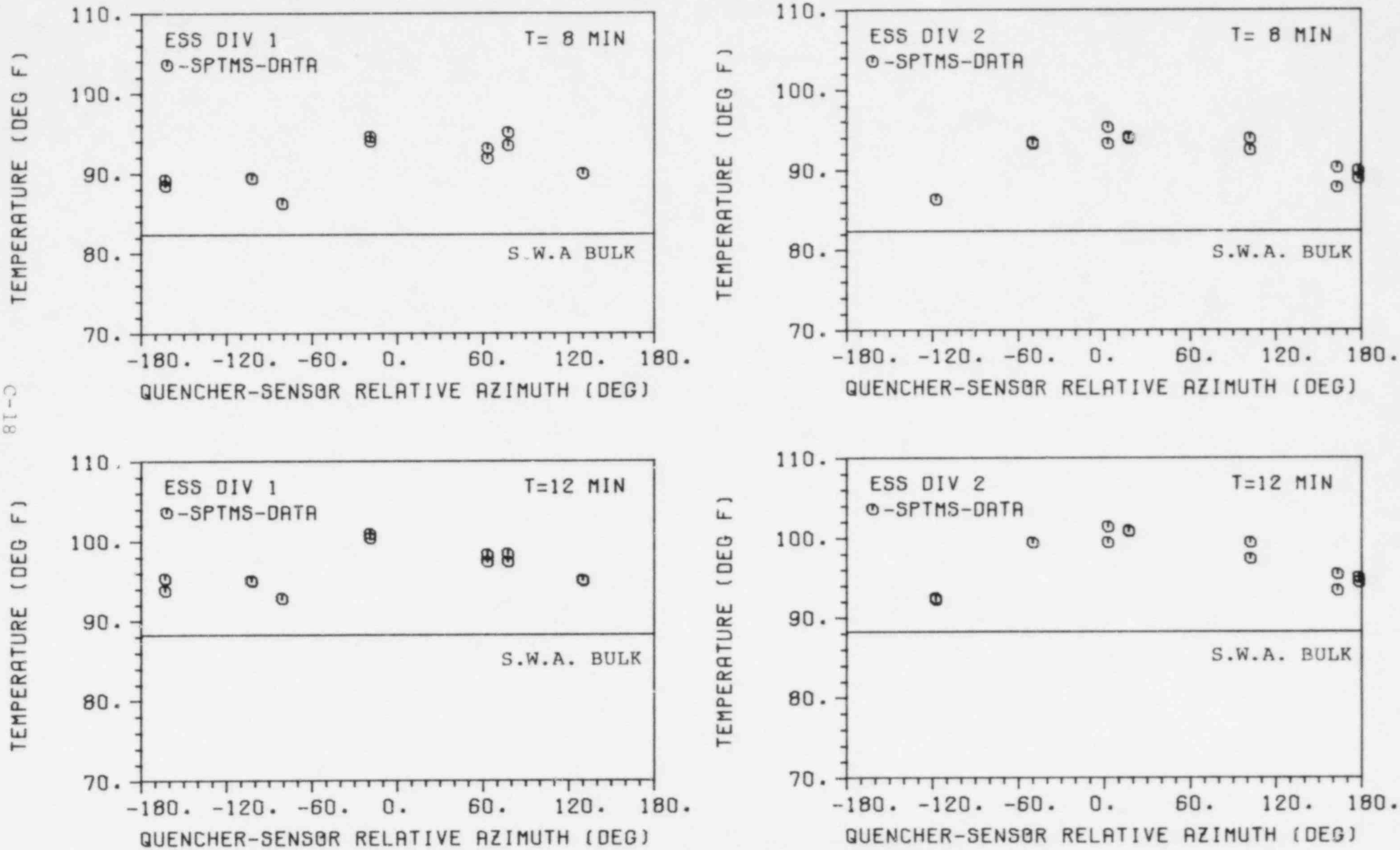


FIGURE C-12B: SUPPRESSION POOL TEMPERATURE MONITORING SYSTEM - RUN 73

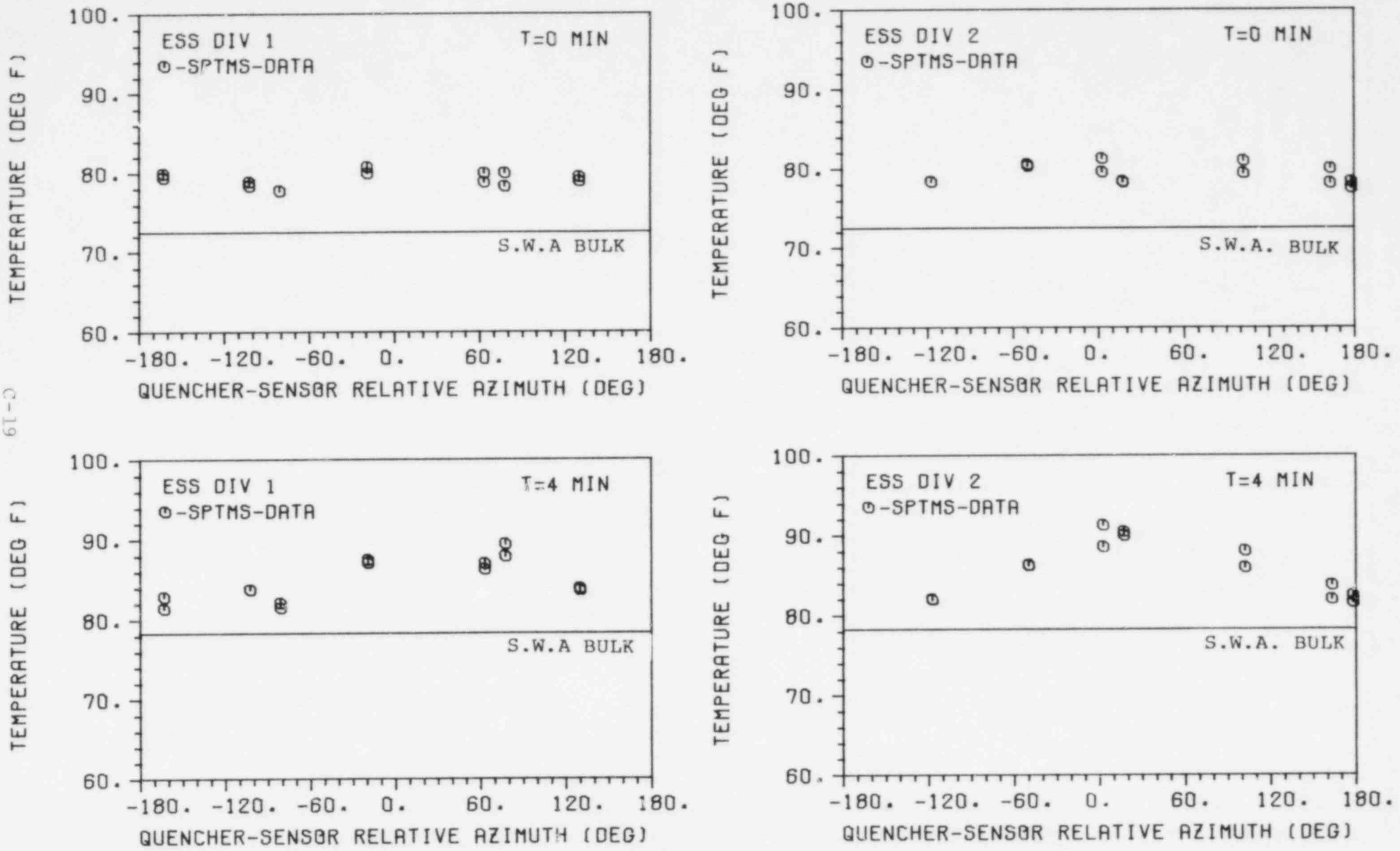


FIGURE C-13A: SUPPRESSION POOL TEMPERATURE MONITORING SYSTEM - RUN 74

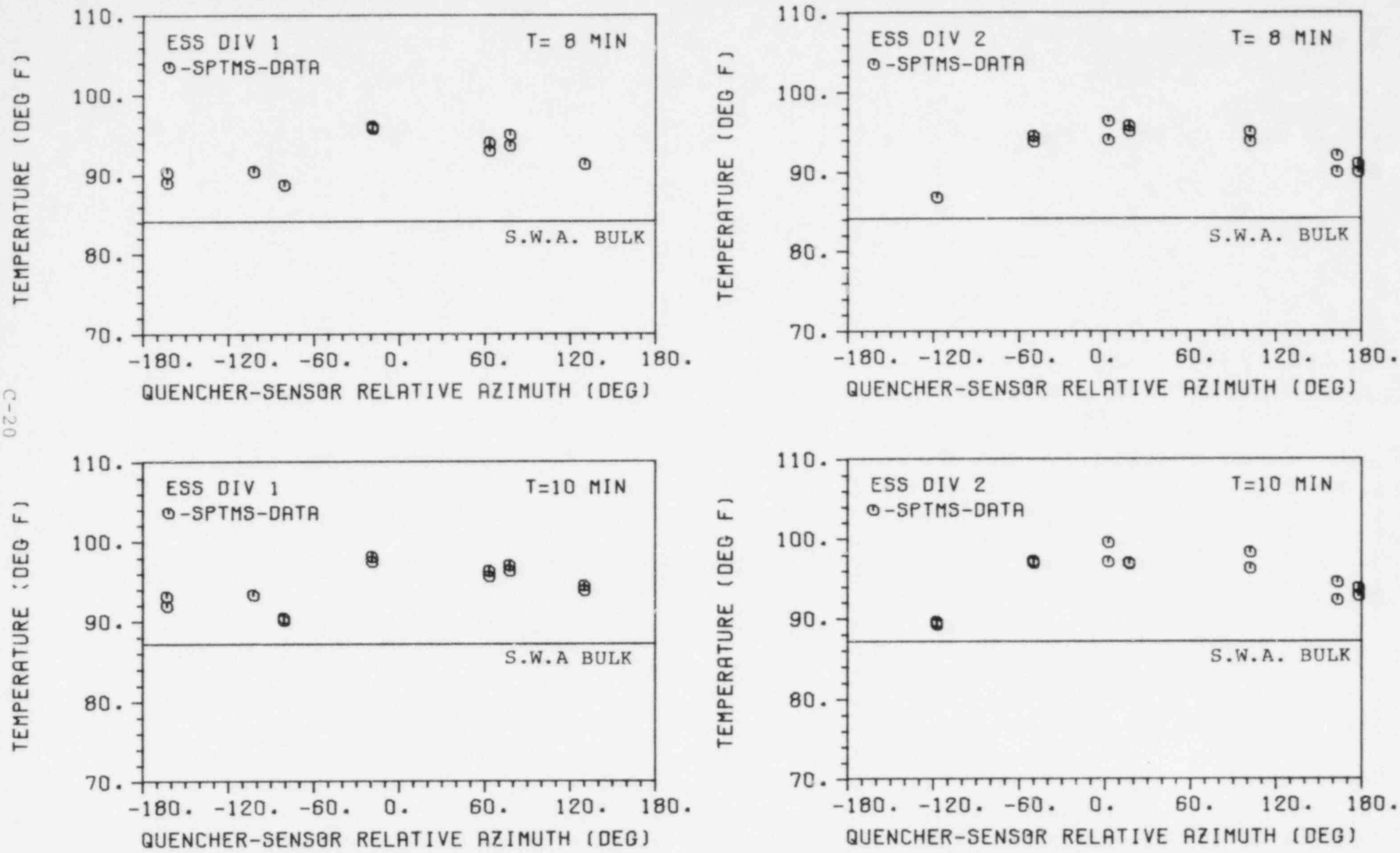


FIGURE C-13B: SUPPRESSION POOL TEMPERATURE MONITORING SYSTEM - RUN 74

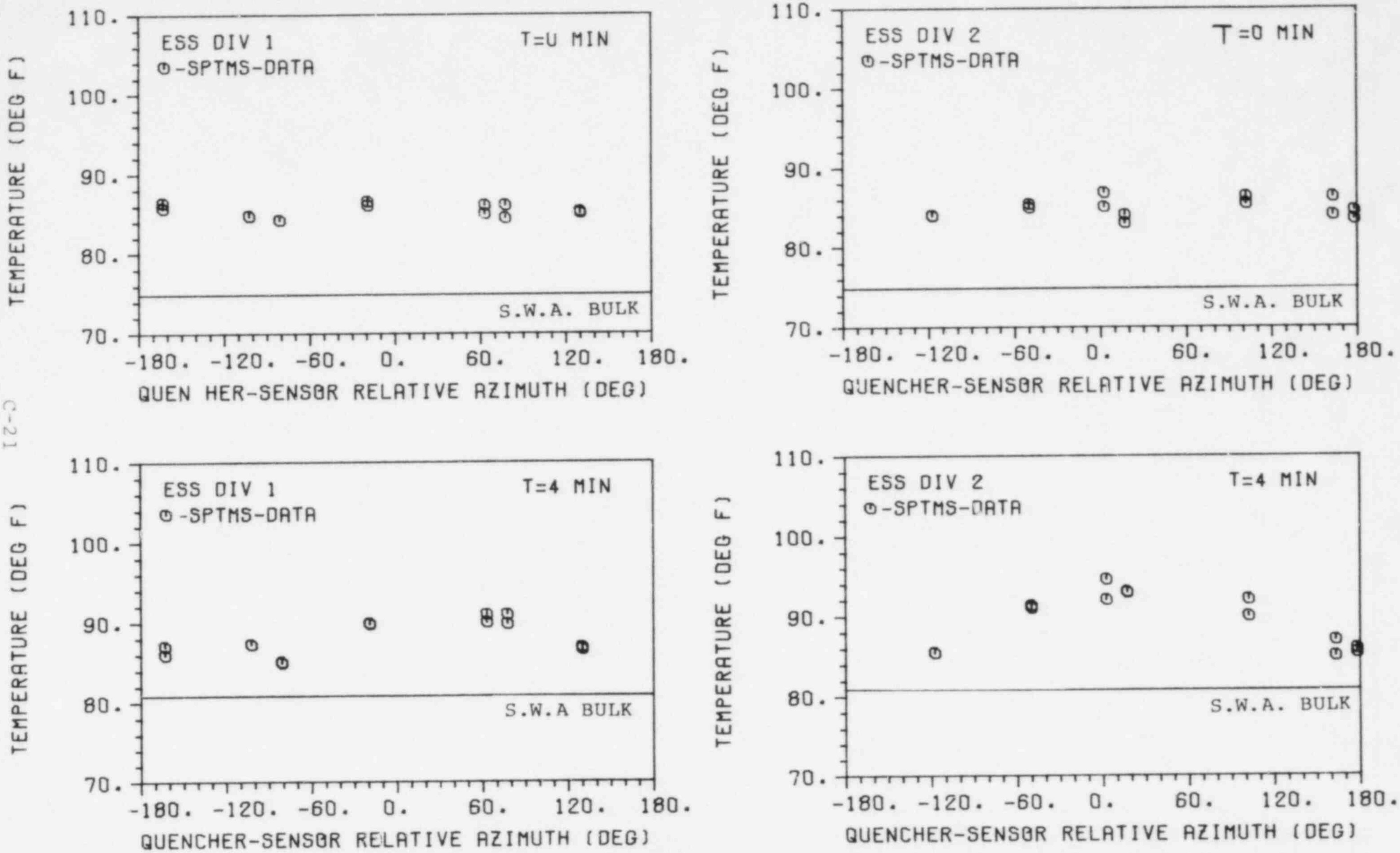


FIGURE C-14A: SUPPRESSION POOL TEMPERATURE MONITORING SYSTEM - RUN 75

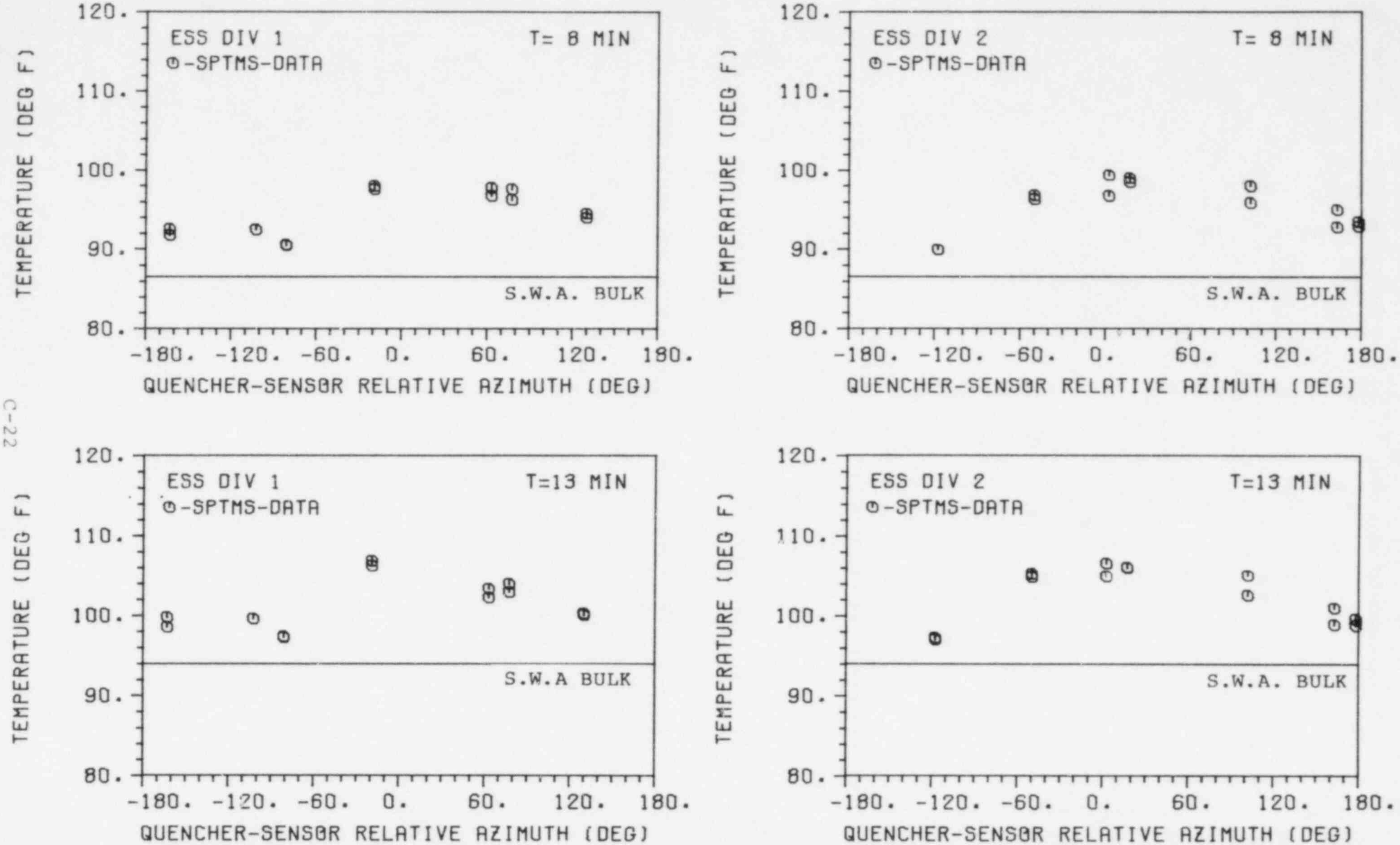


FIGURE C-14B: SUPPRESSION POOL TEMPERATURE MONITORING SYSTEM - RUN 75

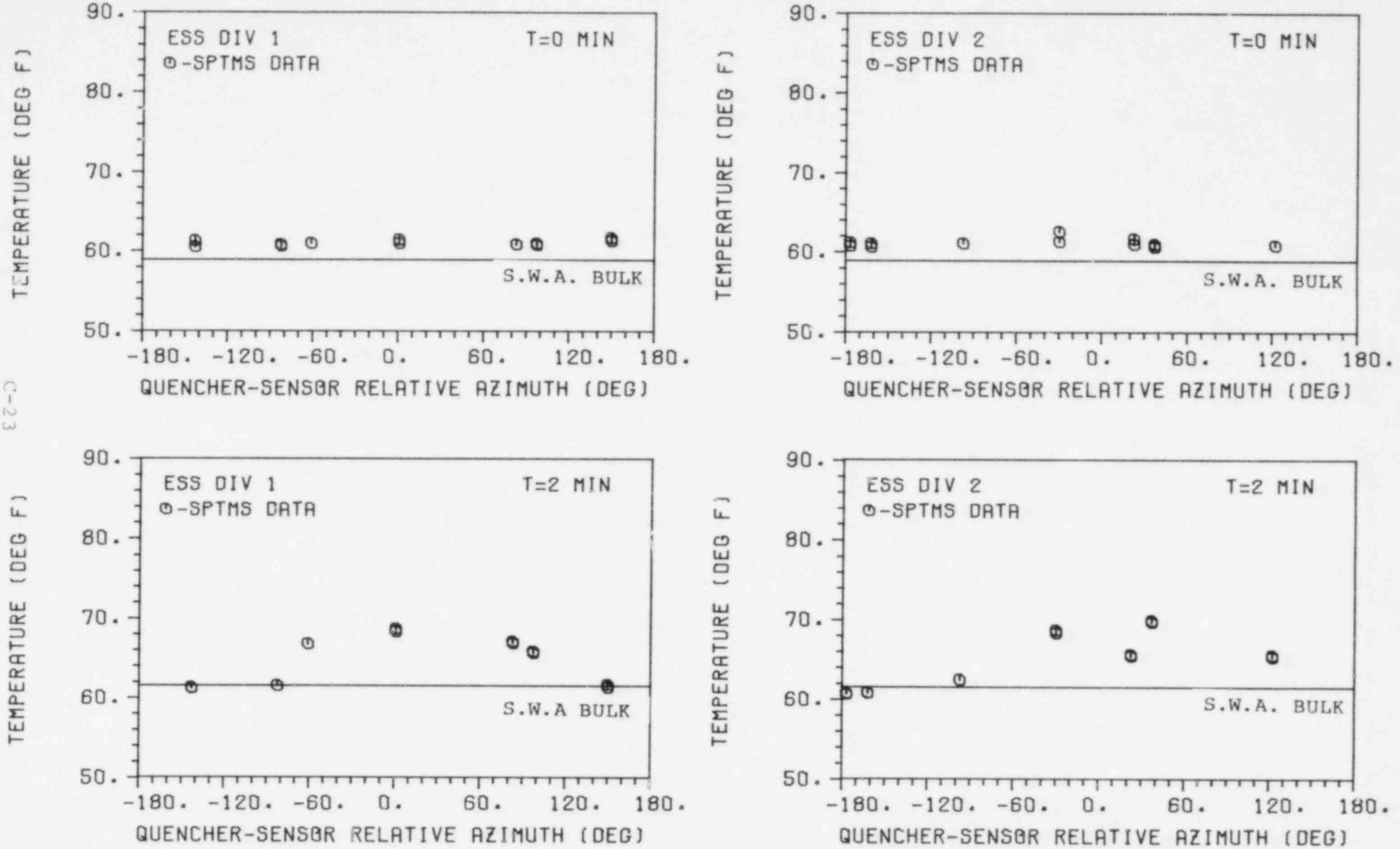
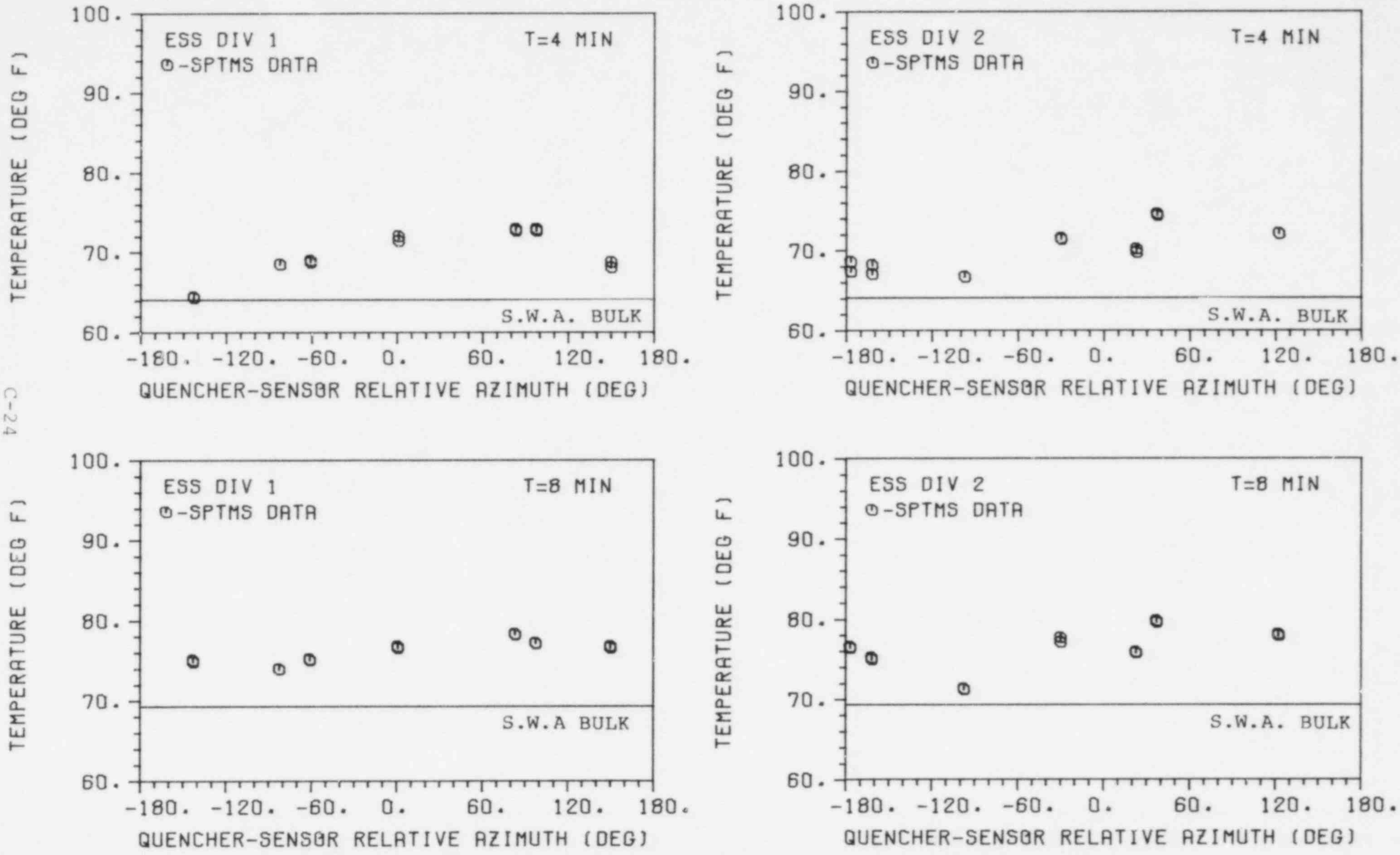


FIGURE C-15A: SPTMS - VARIATION AND SYSTEM BIAS REMOVED - RUN 69



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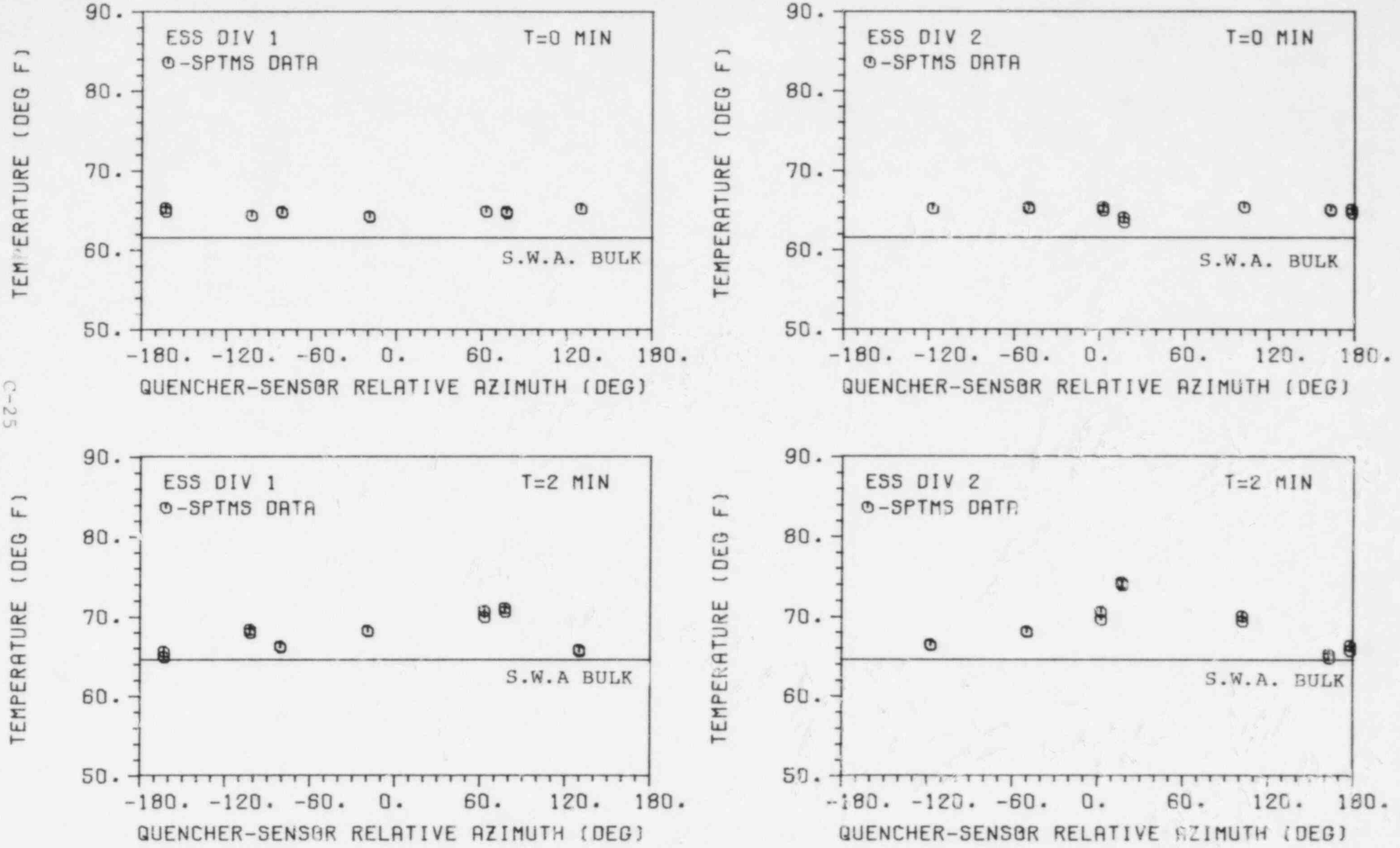


FIGURE C-16A: SPTMS - VARIATION AND SYSTEM BIAS REMOVED - RUN 70

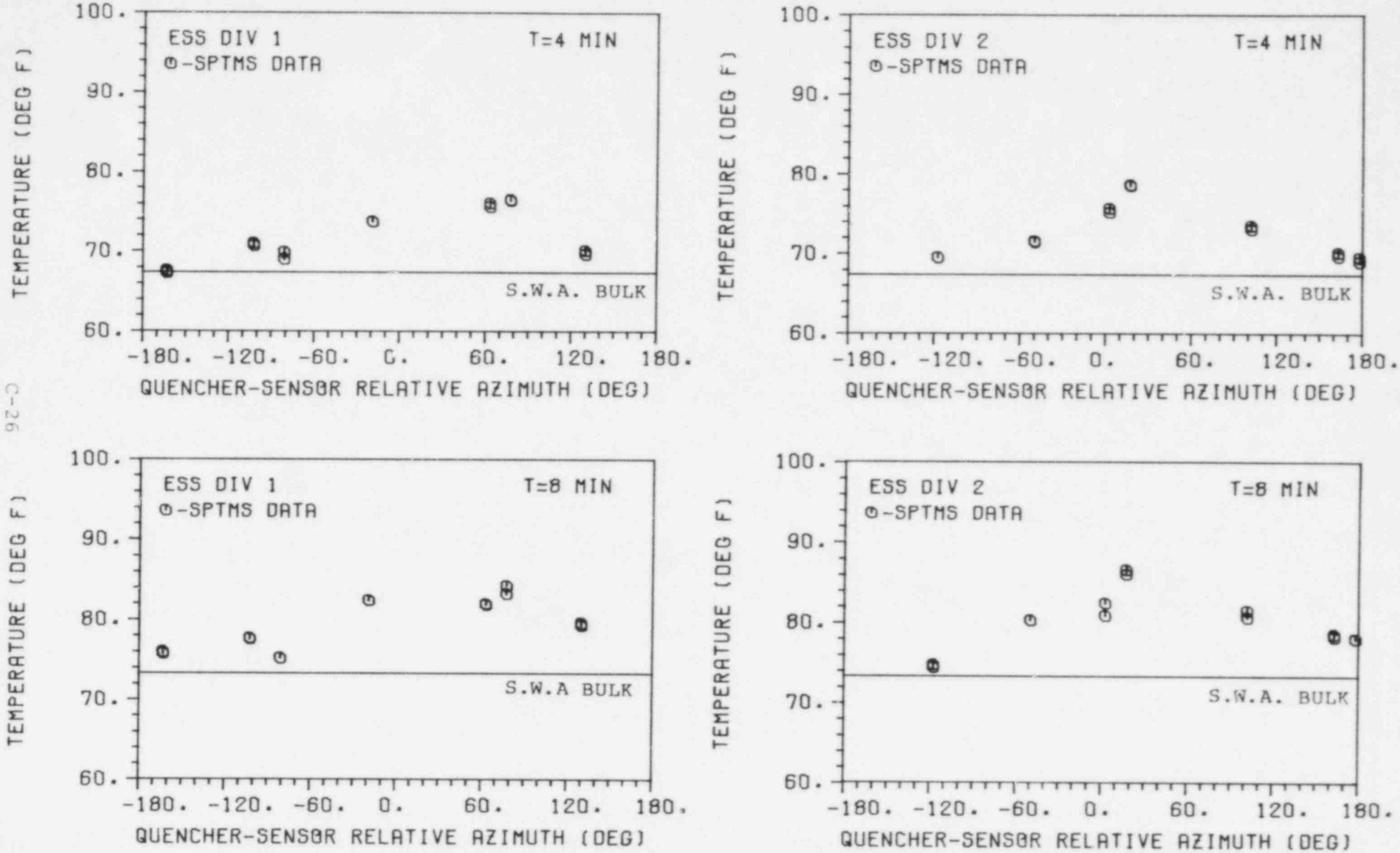


FIGURE C-16B: SPTMS - VARIATION AND SYSTEM BIAS REMOVED - RUN 70

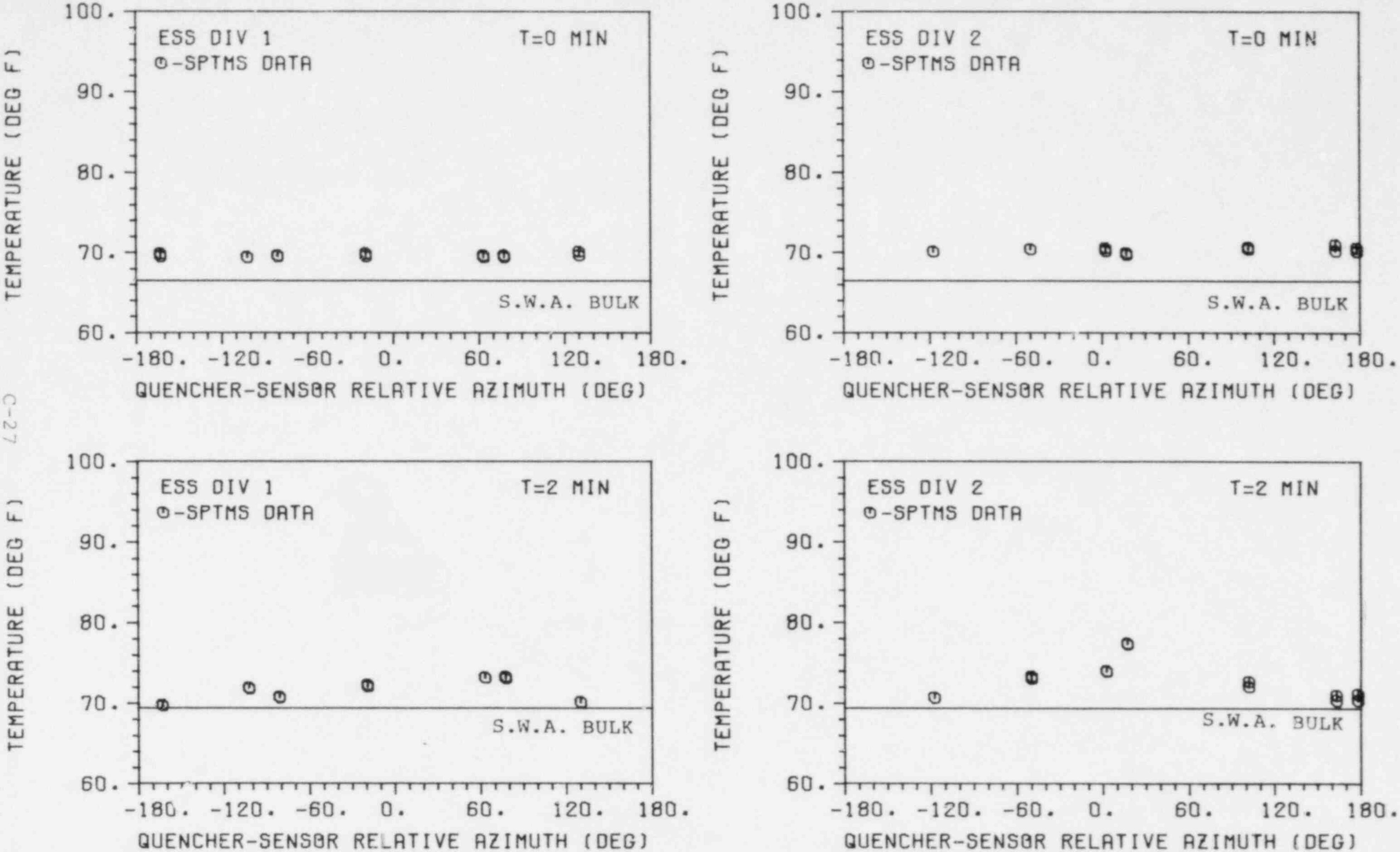


FIGURE C-17A: SPTMS - VARIATION AND SYSTEM BIAS REMOVED - RUN 71

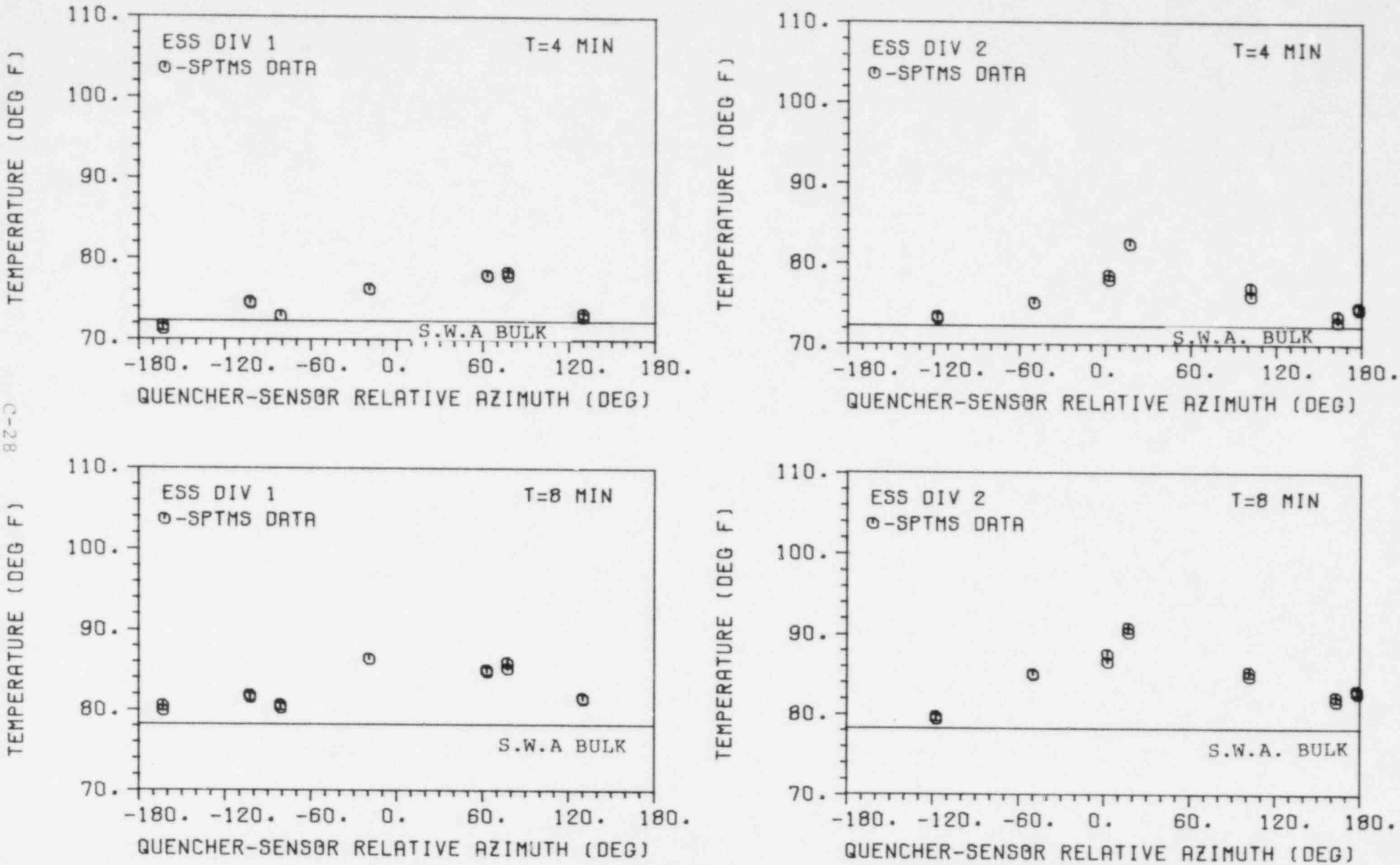


FIGURE C-17B: SPTMS - VARIATION AND SYSTEM BIAS REMOVED - RUN 71

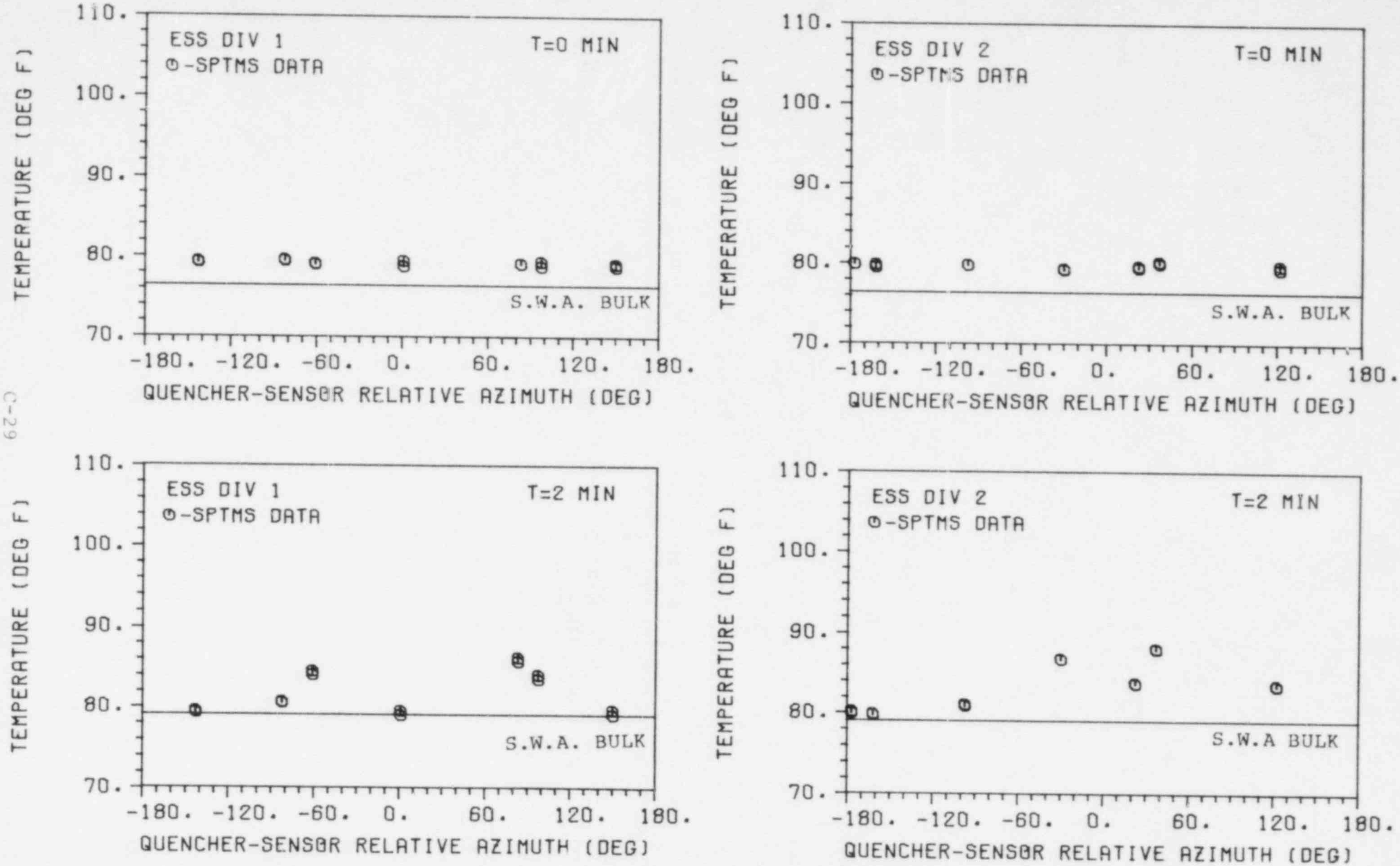


FIGURE C-18A: SPTMS - VARIATION AND SYSTEM BIAS REMOVED - RUN 72

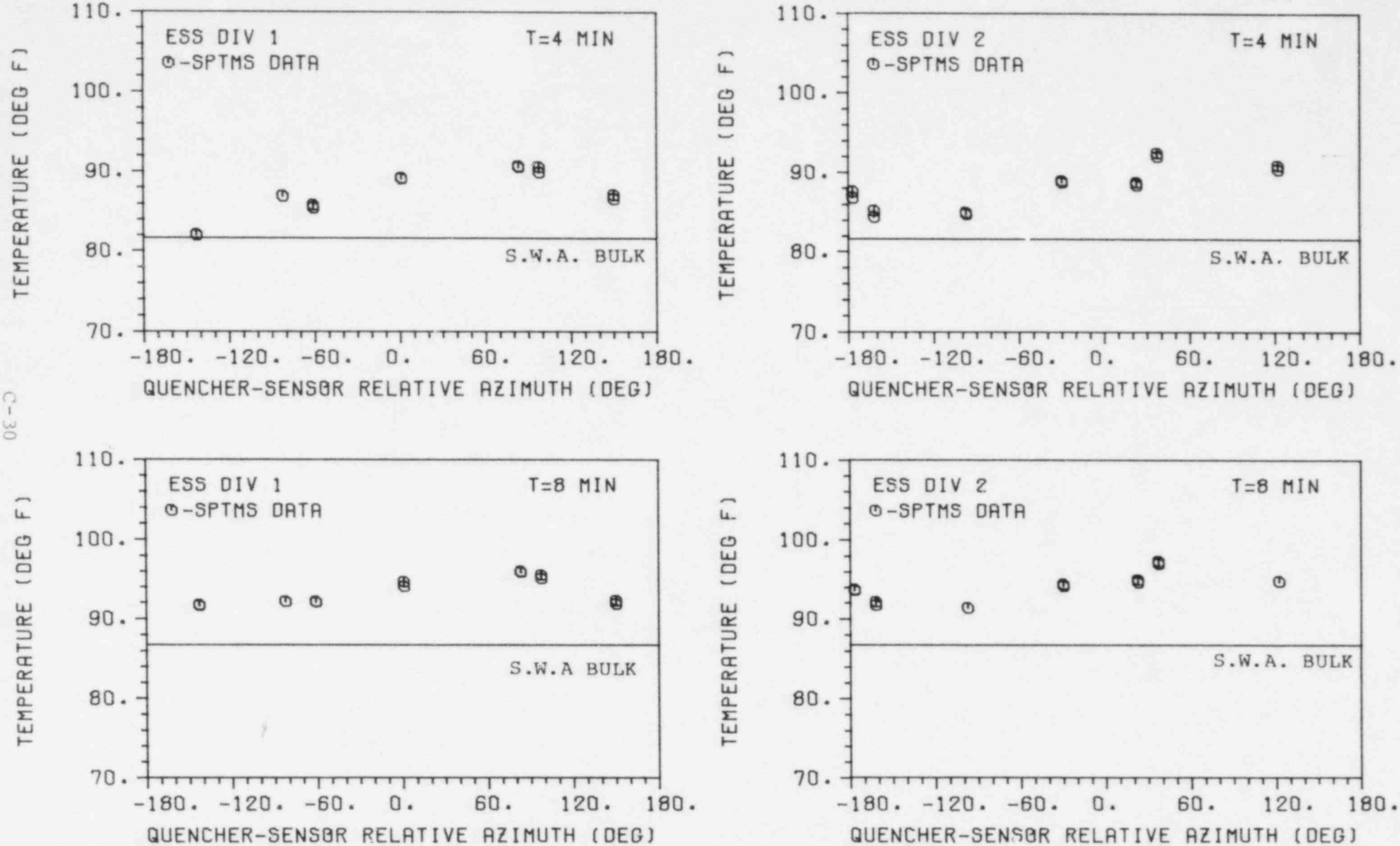


FIGURE C-18B: SPTMS - VARIATION AND SYSTEM BIAS REMOVED - RUN 72

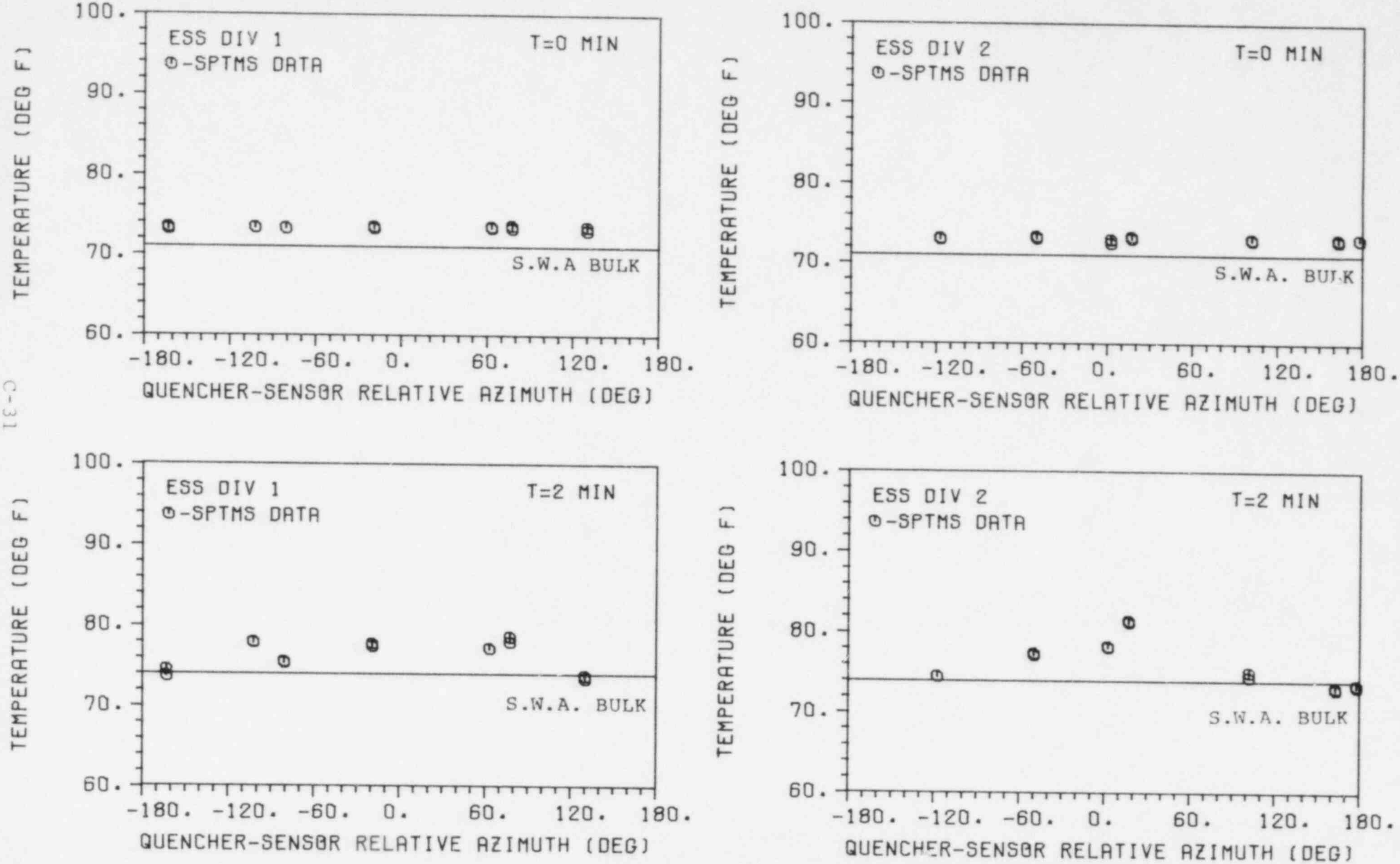
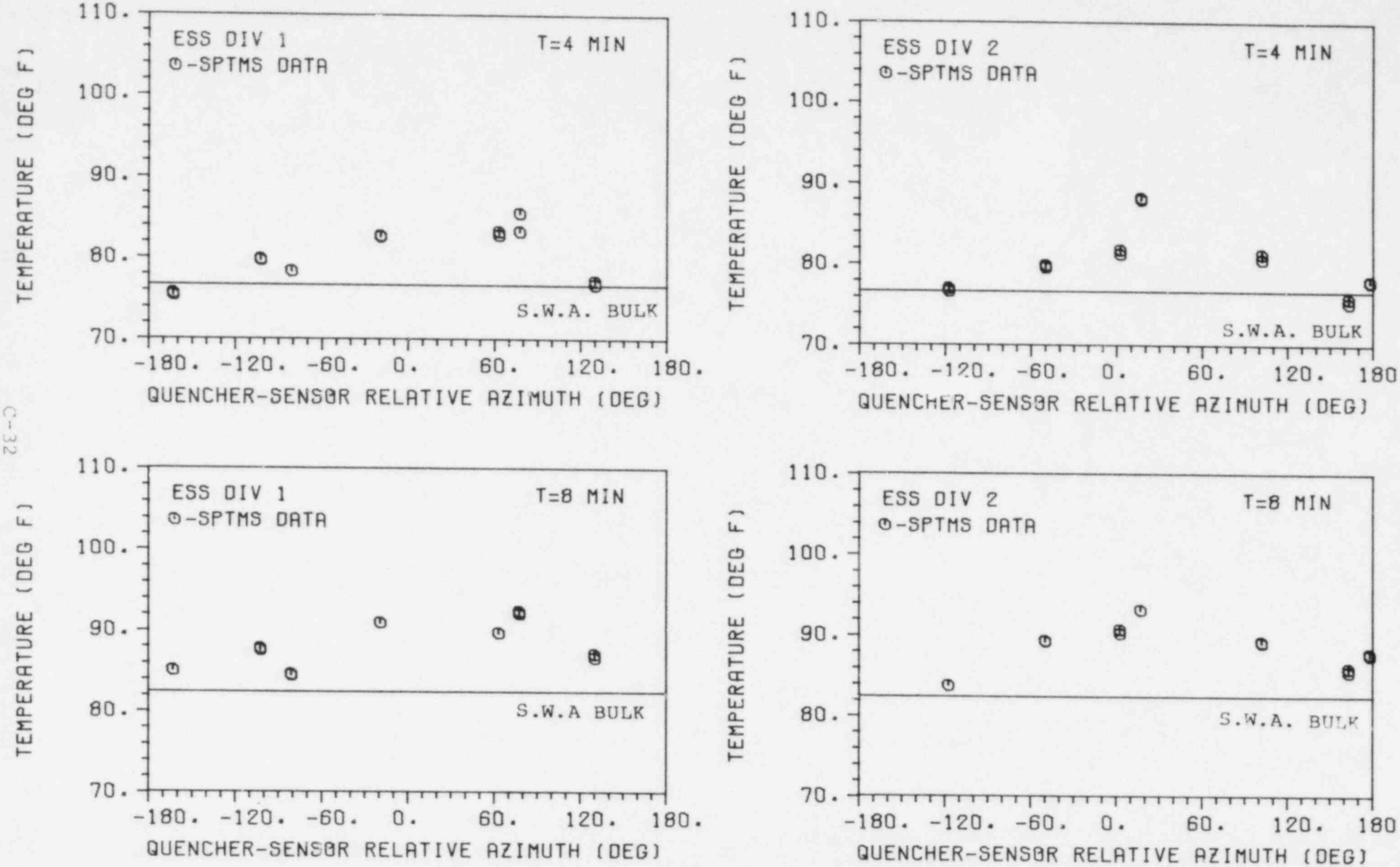


FIGURE C-19A: SPTMS - VARIATION AND SYSTEM BIAS REMOVED - RUN 73



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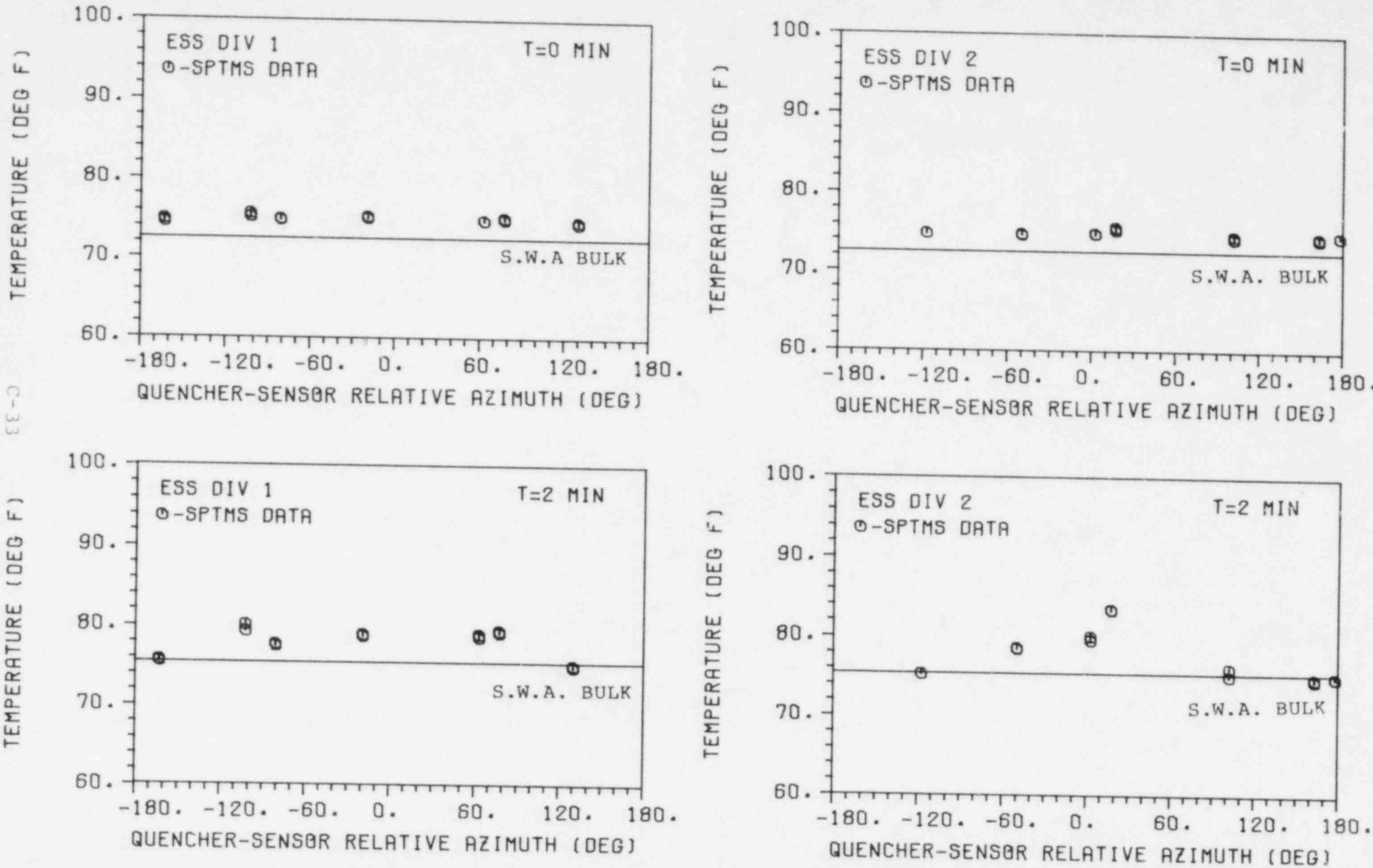

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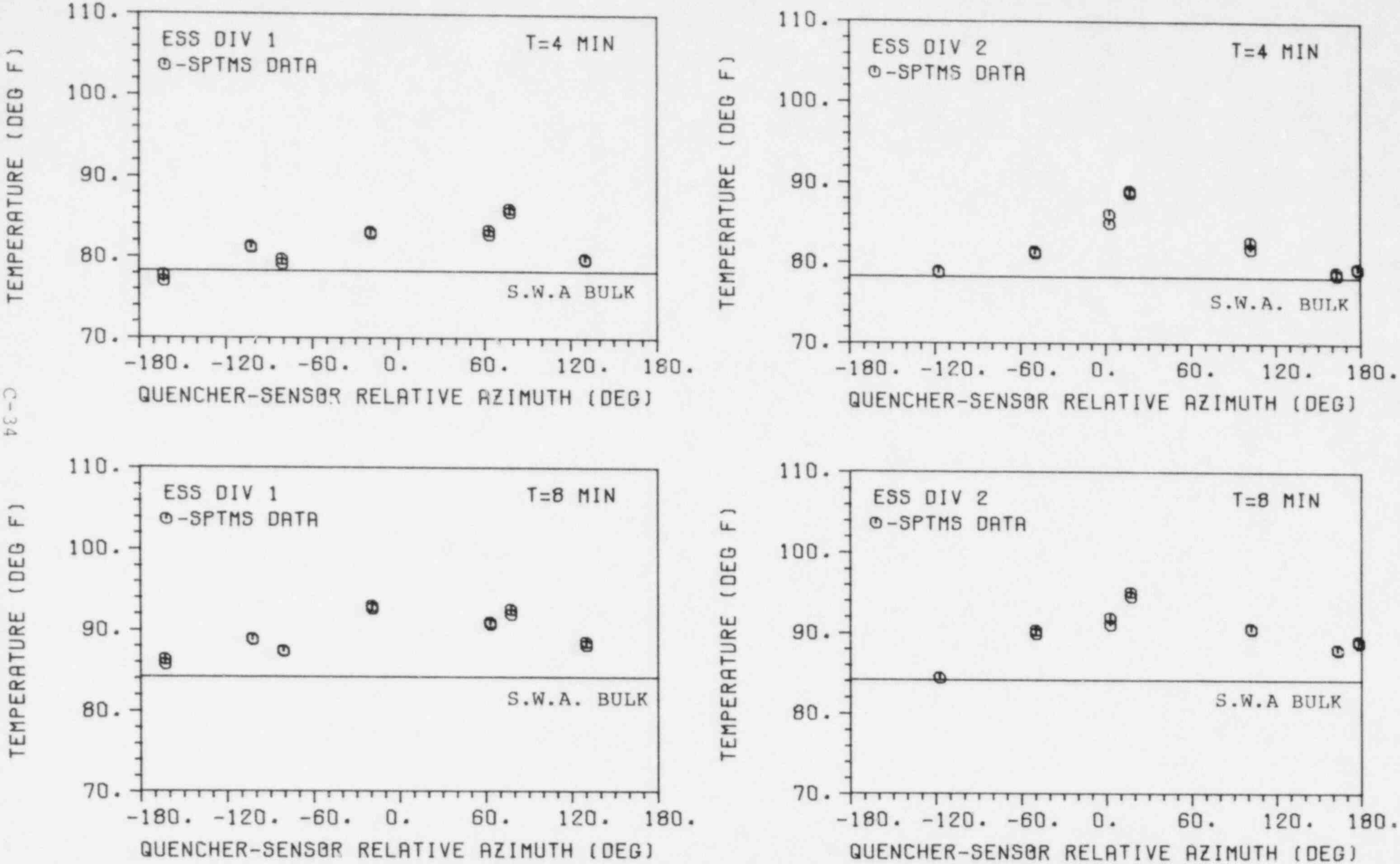

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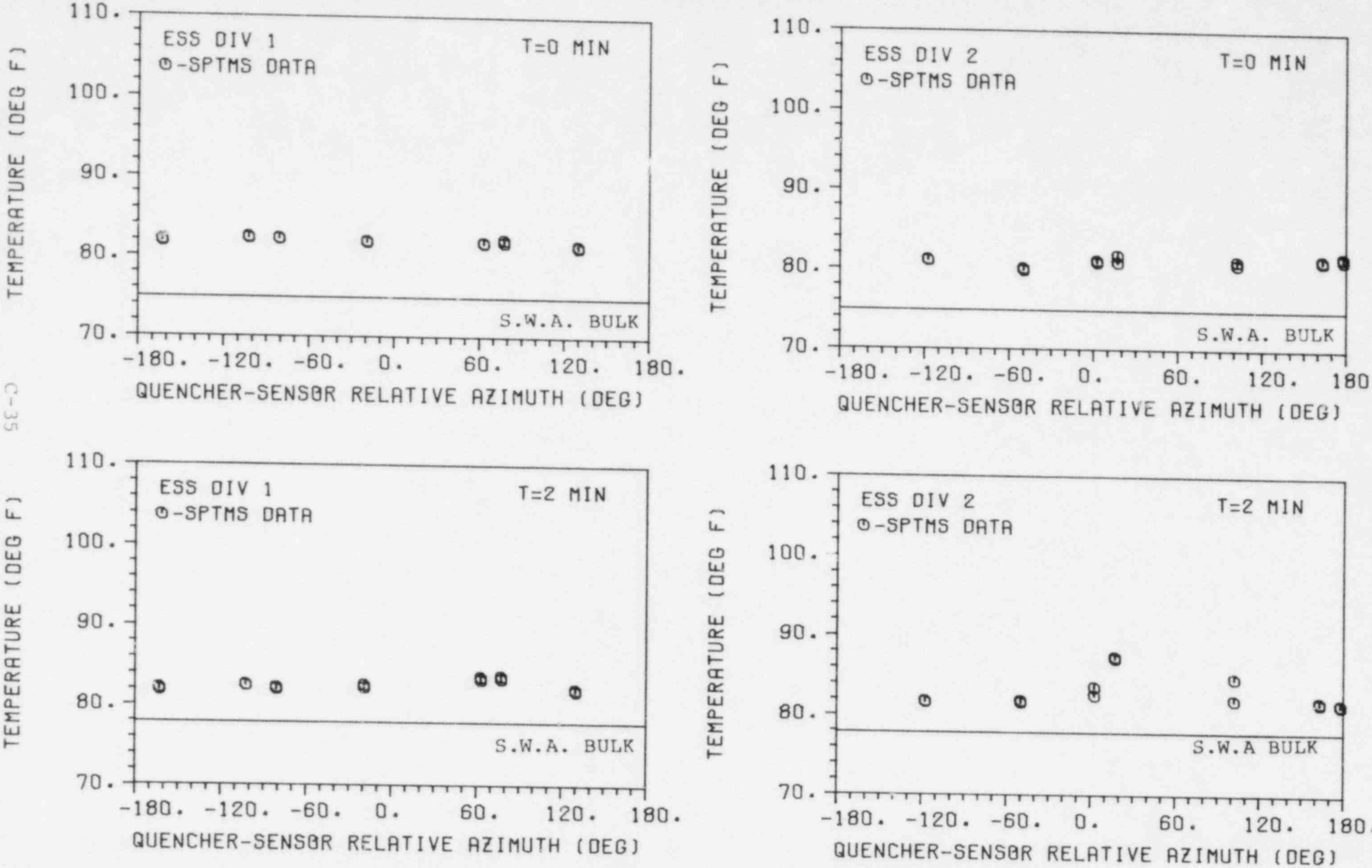

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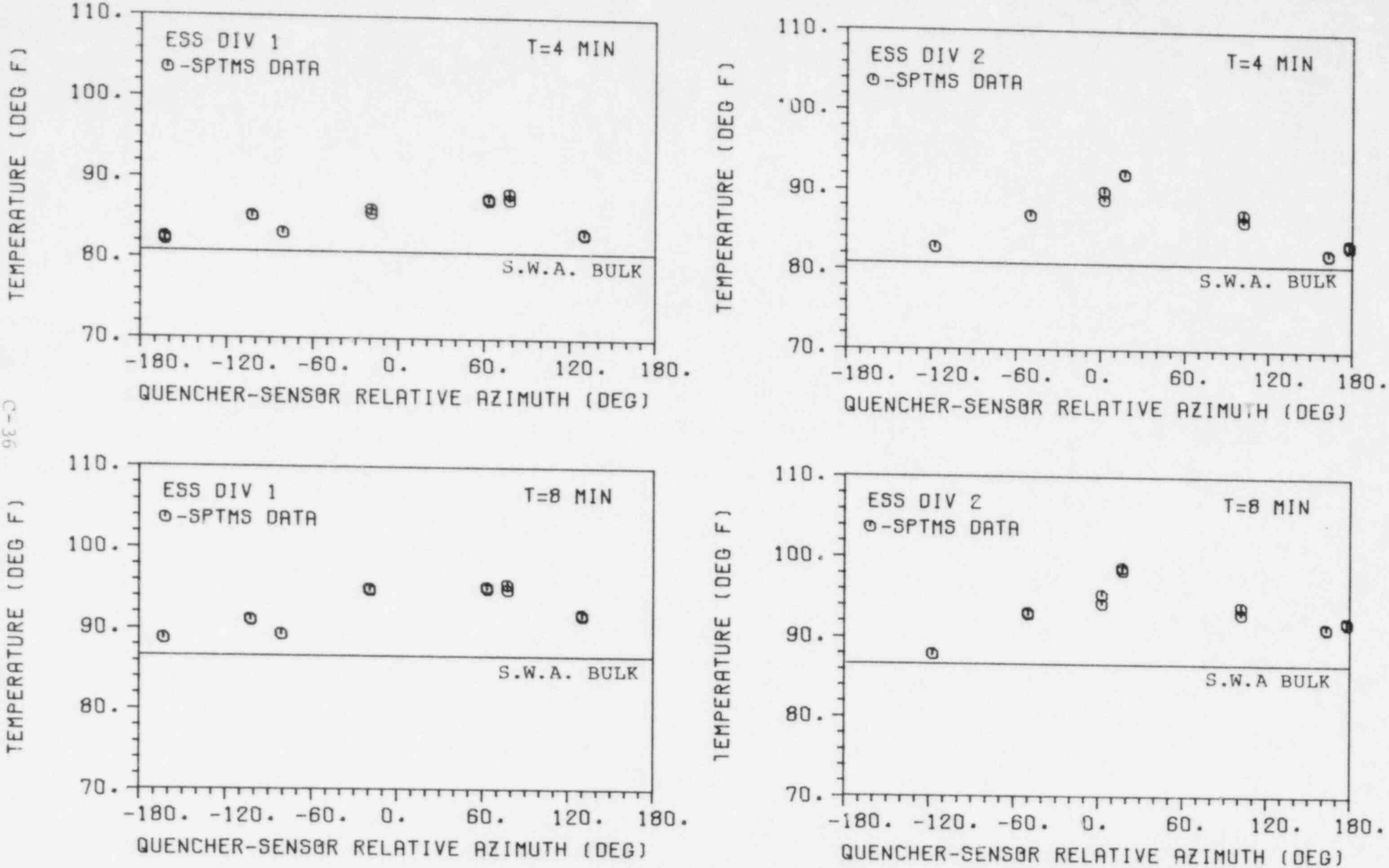

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