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Westinghouse Electric Corporation

Tampa Division

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INTERIM REPORT

EVALUATION OF EXPOSURE CONDITIONS FOR THE WATER-SIDE CORROSION TEST OF A SODIUM HEATED STEAM GENERATOR EVAPORATOR MODEL EMPLOYING A DUPLEX TUBE (2160 HOURS AT CRITICAL HEAT FLUX - PHASE III SSGM TESTS)

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ERDA Contract E(04-3)-962

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ABSTRACT

This report describes the specialized corrosion test water steam loop, test procedures, test conditions, and test results. A complete water chemistry and thermal hydraulic performance history is given and evaluated for the Phase III test program. The movement of the dryout location and the heat flux variations in pre- and post-critical heat flux regions are documented and analyzed. On seven occasions during the course of the test program to date, the operating conditions drifted from the CHF reference Phase III operation in the dryout regime into the DNB regime. The corresponding corrosion mechanism experienced differing exposure conditions on these occasions. CHF sensitivity to this apparent "drift" behavior is evaluated. This documentation and evaluation is input for a meaningful corrosion post test examination and also provides additional thermal/hydraulic test data interpretations related to steam generator performance.

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SECTION 1

OBJECT

The objective of the Phase III program was to employ the SSGM, Duplex-Tube, J-Modular, Steam Generator Model in its current installation in the ARD Steam Generator Test Facility to study the effects of water/steam side sodium hydroxide concentration on corrosion phenomena in the Critical Heat Flux (CHF) region at simulated CRBRP Evaporator conditions at full loads.

CHF was to be located 4±0.5 feet from the water/steam exit for a total test time of 90 days (2160 hours). The model was tested at the CRBRP steam generator mass velocity, SSGM maximum heat flux and maximum SSGM steam pressure (1800 psi). The water inlet sodium hydroxide concentration was to be 30ppb nominal.

Prototypicality studies already completed by WTD and reported in Ref. 4, had established (1) that the duplex-tube SSGM unit could be employed to study corrosion effects at the CHF zone as will be encountered in the single-wall CRBRP evaporator, and (2) that thermal-hydraulic behavior at the CHF condition - including the transient thermal response requirements at the water-side of the tube in the CRBRP evaporator - could be modelled prototypically with the SSGM.

SECTION 2

INTRODUCTION

As part of the ERDA funded Liquid Metal Fast Breeder Reactor (LMFBR) program, the Westinghouse Electric Corporation Tampa Division designed and fabricated a single duplex tube sodium-heated steam generator model. This unit, named the Small Steam Generator Model (SSGM), was tested at the Westinghouse Advanced Reactors Division GPL-1/SWL-1 facility. The SSGM was designed, fabricated and tested to proof-test a single tube of duplex wall construction at conditions identical to the alternate concept evaporator for the Clinch River Breeder Reactor Plant (CRBRP) under ERDA Contract E(04-3)-962.

The overall test program was divided into three phases plus a post test exam. The Phase I parametric steady state heat transfer experiment results are reported on in Ref. 1. The Phase II transient test results are reported on in Ref. 2. This report covers the original 2160 hour Phase III steady state corrosion tests. Figure 2.1 summarizes the testing chronology for Phases I, II, and III. The original objective of the Phase III tests was 2160 hours (90 days) at CHF conditions. The Phase III test has been extended to achieve a total time of from 4320 (180 days) to 5760 (240 days) hours.

The CRBRP evaporator design presently identifies recirculation, combined with CHF in the tube. Inasmuch as there is no domestic fossil-fired, straight-tube evaporator operating in the recirculating mode with CHF in the tubes, related operating histories or failure statistics from fossil-fired units are not available. Reference 3 identifies this two-fold combination of recirculation and CHF operation as the principal and unique feature of the CRBRP evaporator.

Several distinctly different, but related, damage phenomena may appear when CHF is allowed to occur in an evaporator tube. All are initiated by the fact that tube wall "Dryout" takes place, even though the steam quality is less than 100%. Since the heat transfer coefficient on the evaporator tube ID is drastically reduced beyond the CHF point, the ΔT through the tube wall will be similarly lowered; and this produces two different tube wall ΔT's in the short transition zone from nucleate boiling to film boiling. Moreover, since the CHF point oscillates along the tube length at frequent intervals, due to alternate wetting and drying of the wall, a short section of evaporator tubing experiences a fluctuating temperature gradient through the wall.

The above phenomena is defined as $\Delta(\Delta T)$, and may be accompanied by the following damage mechanisms:

(1) thermal strain cycle fatigue, or corrosion fatigue, of the tube wall,
(2) thermal fatigue damage to a protective oxide layer on the tube wall,
(3) accelerated corrosion from solution (NaOH) concentration,
(4) formation of local deposits of precipitated impurities.

Because of concentration of impurities in the recirculation drum in the CRBRP design (with recirculation and CHF in the tube), the impurity level - specifically the sodium level - in the recirculation water in the drum (evaporator inlet) will be much higher than that encountered in a once-through unit. This higher concentration entering the unit may result in higher salt concentration at the dryout; and this in turn can lead to accelerated corrosion.

From the above, it is evident that in investigation of the effects of $\Delta(\Delta T)$ and evaporator inlet sodium concentrations in a full sized tube simulation of the CRBRP evaporator at prototypic conditions is urgently needed.

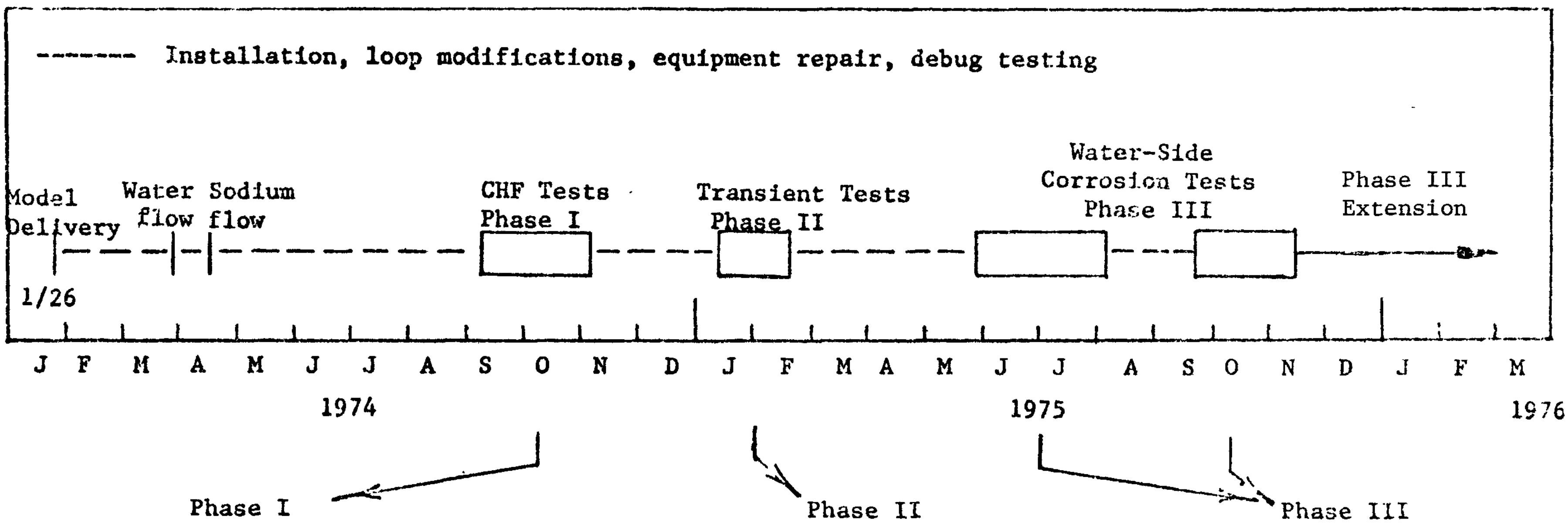
The program employs the SSGM unit in its present configuration. Inasmuch as the SWL-1 Water/Steam Facility is a once-through, circulating system without steam drum or re-circulation capability, the SSGM (and SWL-1) was subjected to water chemistry conditions relating to the CRBRP evaporator inlet. Through adjustment of model inlet water chemistry, accelerated CHF-Corrosion tests were carried out. Both pre- NDT examinations (Ref. 5), coupled with extensive post-test metallographic examination, Ref. 6 will be employed to characterize the corrosion behavior at the CHF-zone in the evaporator. Concurrent with the corrosion studies, the model was employed to aid in characterization of the thermal-hydraulic and structural behavior associated with the CHF zone.

Since the goal of the corrosion programs (Phase III) using the SSGM was to subject the tube bore of the model duplex tube to CRBRP evaporator exposure conditions at the CHF (Critical Heat Flux) location, an evaluation was required at the outset to determine test conditions such that the thermal/hydraulic flow boiling mechanisms were duplicated. It was determined that at the CHF location, a peak heat flux of 240,000 Btu/hr-ft^2 and an associated water/steam mass velocity of 1.6x10^6 lb/hr-ft^2 would have to be maintained over the course of the corrosion test program. It is noted that these conditions correspond to CRBRP evaporator operation at full-load; however, the part load operation is more stringent with regard to CHF behavior and these more severe conditions cannot be achieved in the SSGM due to design limitations. Results of the Phase I test previously reported indicated that these conditions would result in CHF operation in close proximity to the transition region between DNB (Departure from Nucleate Boiling) and LFD (Liquid Film Dryout) mechanisms. It has become evident over the course of the testing performed to date, that on seven separate occasions, the operating conditions drifted from the nominal Phase III CHF mechanism with dryout (LFD) into the DNB regime. It follows that the corresponding corrosion mechanism was not exposed to the reference CRBRP evaporator behavior on these occasions. Detailed computer analysis of the data was required to disclose this behavior and correct the loop operating parameters to recover the reference mode of dryout operation.

These observations of an apparent drift through various CHF mechanisms were somewhat puzzling in that they occurred in spite of the fixed spatial location of CHF near the exit of the model, i.e. within an interval 4-5 ft. from the exit. Additional study has since disclosed that a sensitivity to small changes in sodium inlet temperature and/or sodium flow rate is the source of the CHF migration from LFD into the DNB regime. The possibility that loop instrumentation and/or model tube wall thermal conductance are displaying gradual "aging" effects cannot be discounted at this time.

Cumulative exposure time under steaming conditions at rated pressure ~3500 hrs.

Cumulative exposure at elevated temperature ~4000 hrs.



Investigation of CRBR evaporator flow boiling CHF performance in DNB and LFD regimes.

Investigation of structural adequacy of Duplex Tube and T/TS welds - (135 step increase/decrease transients of 250°F at sodium inlet which exceed in severity the reference scram transients for CRBR)

Investigation of CRBR water side evaporator tube corrosion behavior with sodium (caustic) environment in the LFD regime - (2160 hrs. exposure to date)

Figure 2.1 SSGM Test Program History

SECTION 3

SSGM DESIGN DESCRIPTION

The overall view of the SSGM is shown in Figure 3.1 with a cutaway view of the inlet/outlet regions of model shown in Figure 3.2. The duplex tube and shell cross-sectional view is shown in Figure 3.3.

The Small Steam Generator Model, Figures 3.1 and 3.2, is a shell and tube heat exchanger employing a single 60.88 ft. long (under sodium length) duplex tube as the double barrier between the potentially reactive heat transfer fluids, shell side sodium and tube side water. The model is the same "J" configuration as the Westinghouse Tampa Division CRBRP Demonstration Plant Steam Generator design.

The duplex tube contains four .02 inches deep by .05 inches wide longitudinal grooves located at 90^{o} intervals on the inner surface of the outer tube and running the full length of the tube. The interface separating the inner and outer tubes of the duplex assembly is specified to be a nominal 0.20 mils. This interface is filled with a helium third-fluid at 150 psi static pressure. A fault in either of the tubes of the duplex assembly would be detected by pressure variations of the helium third-fluid by a continuous helium pressure recorder.

Sodium enters the inlet nozzle located near the top of the long leg of the "J", Figures 3.1 and 3.2, cools as it travels down in the annulus between shell and tube, is turned 180^{o} in the U-bend of the shell, continues to cool as it passes up the short leg of the unit before exiting through the outlet nozzle located near the top of the short leg of the unit. Subcooled water enters the inlet nozzle located at the top of the short leg, is heated as it travels down inside the duplex tube, turns 180^{o} at the U-bend, and is heated to a quality mixture as it passes up the long leg of the model before exiting the outlet nozzle located at the top of the long leg.

As shown in Figure 3.2, double tubesheets are used at the ends of both legs of the model to anchor each tube of the duplex assembly. The outside tube is welded to each of the sodium tubesheets (located below the steam tubesheets), the tube ending in the plenum between. The inside tube is welded to the steam tubesheets.

The plenum between the two tubesheets, Figure 3.2, is used to allow helium entry into the grooves of the outside tube of the duplex assembly and tube interface. A helium tap located in each sodium tubesheet and connected to the helium source, is used to fill the grooves, interfaces and plenums with helium. An elliptical connector is used between each sodium and water tubesheet to accommodate any differential expansion which might develop between the tube and this connector during load changes or transient operation.

A shroud, Figure 3.2, which is located inside the sodium inlet plenum is used to limit direct sodium impingement on the duplex tube.

A bird cage type assembly, Figure 3.3, made up of three stay rods welded to tube support sleeves are provided to limit tube vibration in each leg of the unit. The tube support sleeves are 0.5" long 0.75" nominal Schedule 10 pipe. The tube supports are spaced 36" apart, center to center, along the axis of the long and short legs of the SSGM. A total of 18 tube supports were used with 13 of these in the long leg. Two anti-vibration bars were installed in the U-bend to support the tube in this region. A sodium drain, Figure 3.1, is located on the U-shell to allow complete drainage of the sodium after the completion of testing.

A total of 55 thermocouples were mechanically clamped to the long and short leg shells as shown in Figure 3.4. The spacing between these thermocouples was 12 inches. In the long leg of the SSGM, thermocouples were spaced a minimum of four inches (center to center) from the tube support sleeves described in the SSGM Design Description Section of this report. In the short leg of the SSGM the thermocouples were spaced a minimum of two inches (center to center) from the tube support sleeves.

Shell wall thermocouples were oriented 30° from the nearest stay rod. Three thermocouples were mechanically clamped to the U-shell, dividing the U-bend into four equal segments, also shown in Figure 3.4. The sodium inlet and outlet and water/steam inlet and outlet lines also had one thermocouple each clamped to the outside diameter of the pipes. The 62 thermocouples were recorded on 24 point intermittent printout recorders. Sodium inlet and outlet and water/steam inlet and outlet immersion thermocouples were recorded on slow-speed continuous recorders. The shell wall thermocouples were grounded junction Chromel/Alumel with 304 S.S. 1/8 in. diameter sheath.

The nominal CHF location for Phase III corrosion testing is at thermocouple number 4, as shown in Figure 3.4, approximately 4½ feet from the top of the steam outlet tube. The corresponding limit of the water/steam tube pretest inspection (Ref. 5) is 5 feet from the top of the steam outlet tube. Shown for reference in Figure 3.4 are thermocouples 1 through 6.

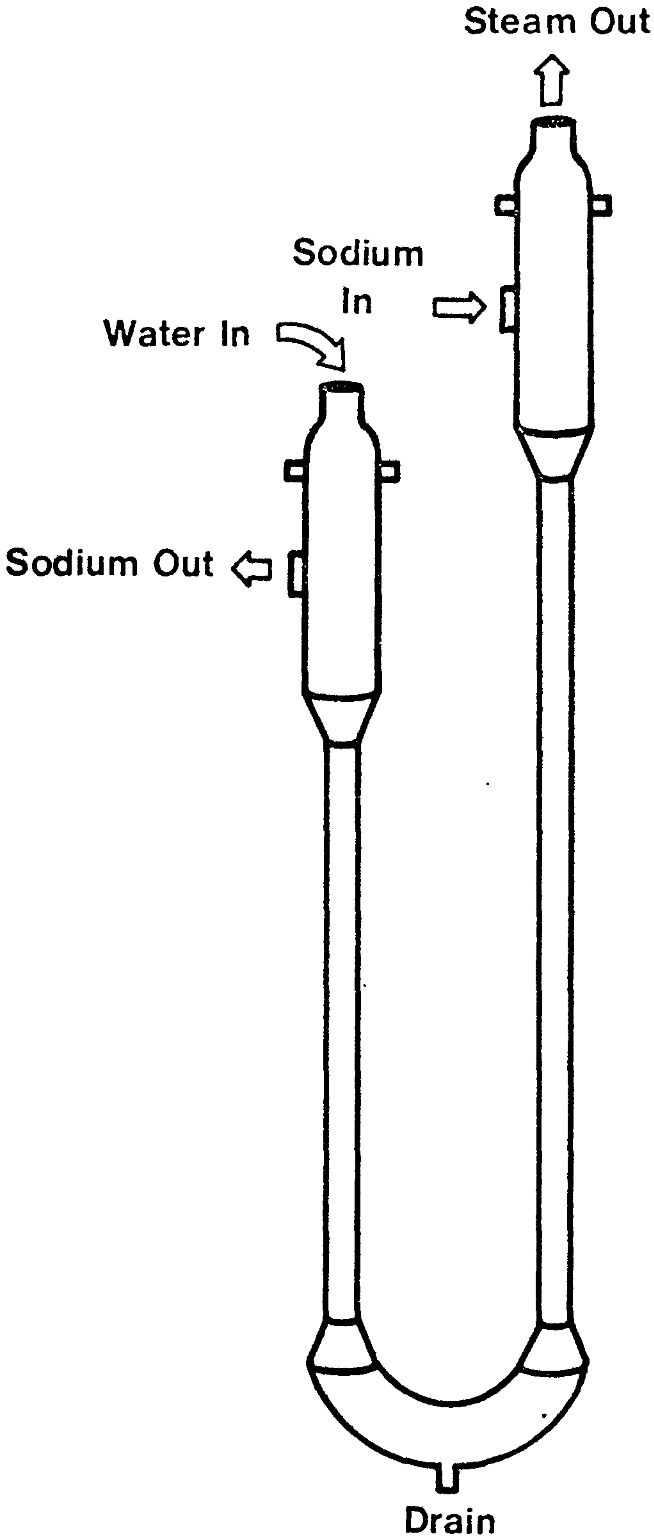


Fig. 3.1. Overall View of SSGM

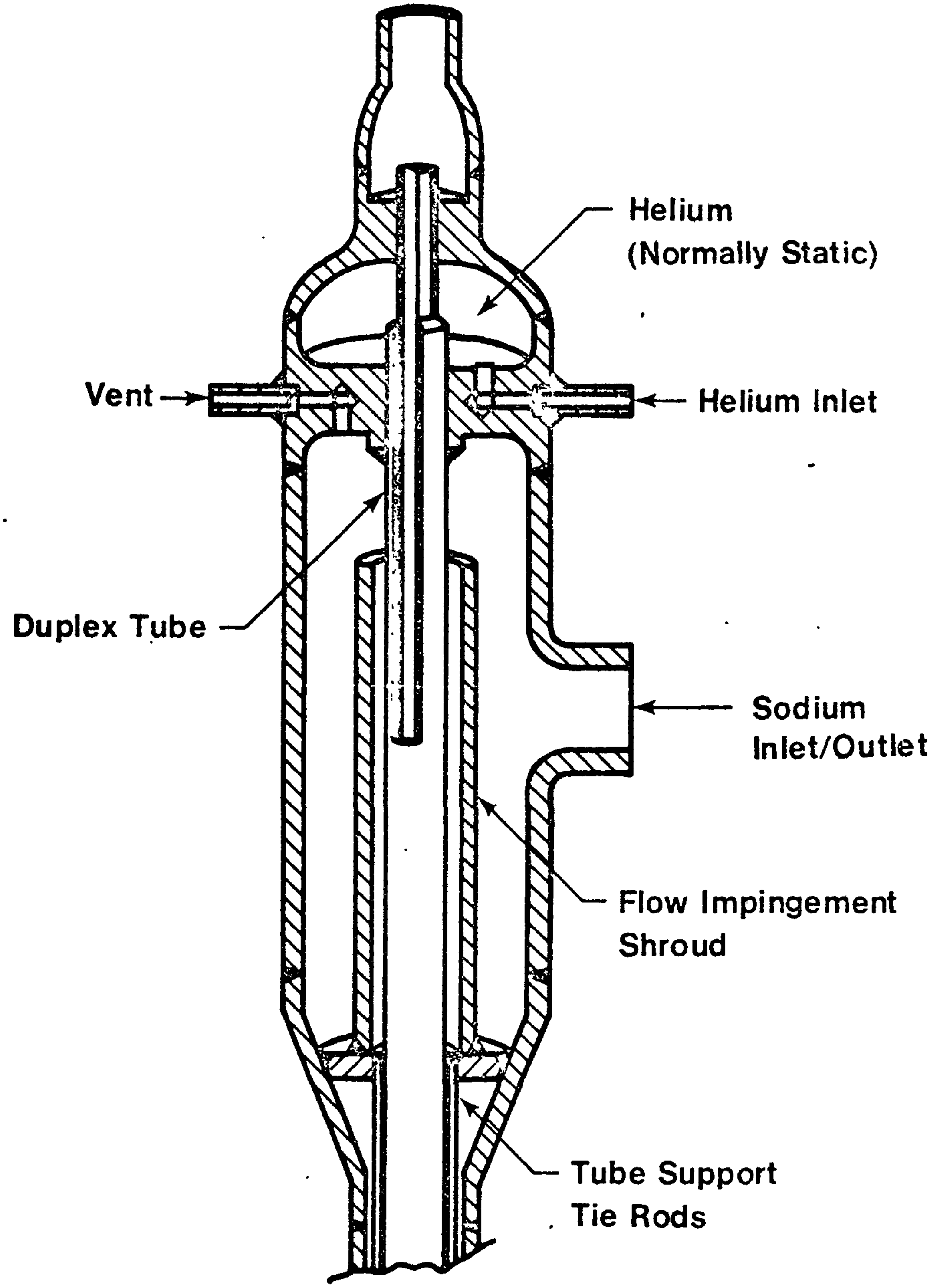


Fig. 3.2. Cutaway View of
Inlet/Outlet Region of SSGM

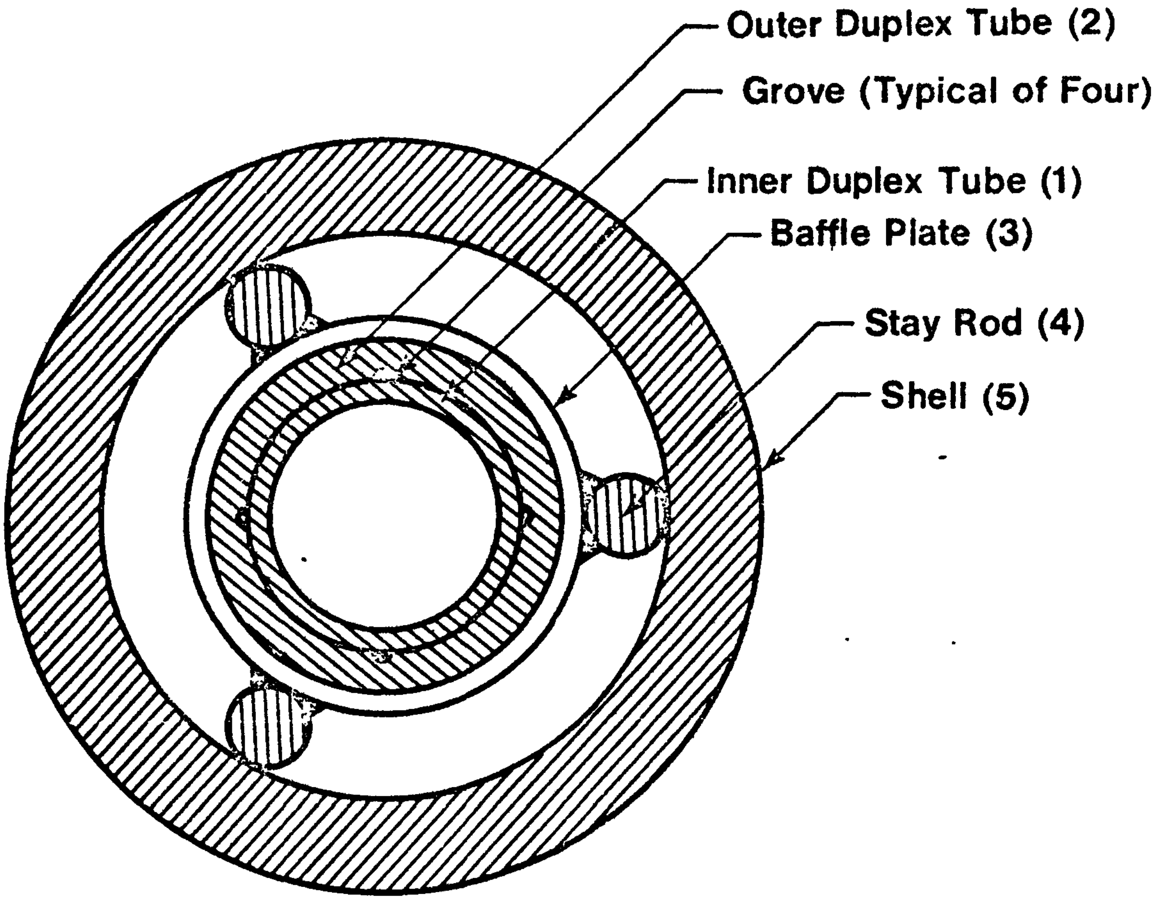


Fig. 3.3. Cross-sectional View of Duplex Tube and Shell. Dimensions are as follows:

Item No.	I.D., inches	O.D., inches
(1)	0.571	0.687
(2)	0.687	0.875
(3)	0.884	1.05
(4)	-	0.19
(5)	1.5	1.9

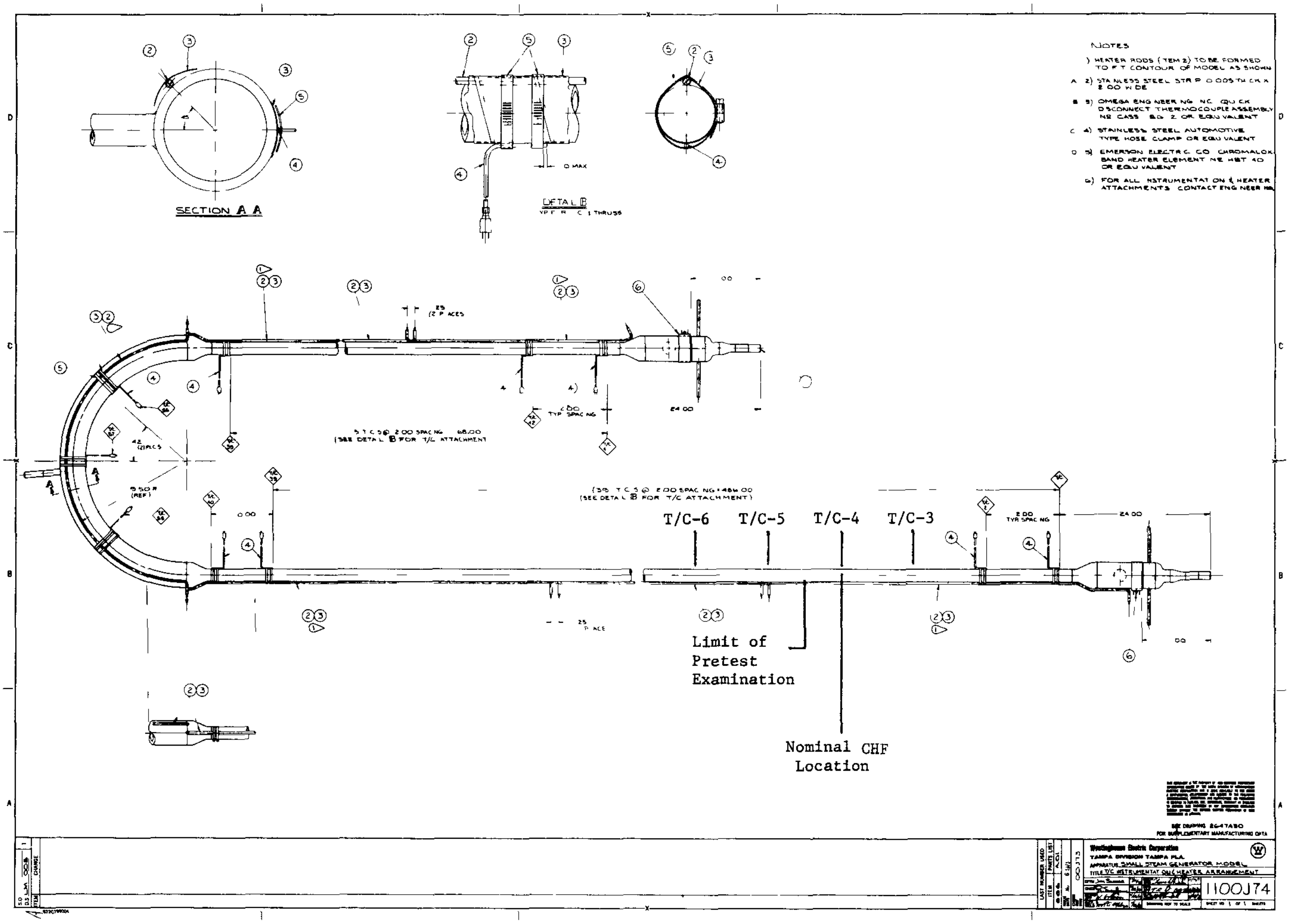


Figure 3.4. SSGM
Thermocouple Locations
and CHF Location

SECTION 4

TEST FACILITY DESCRIPTION

The Steam Generator Test Facility consists of the GPL-1 sodium loop, SWL-1 high pressure, high-temperature water loop, and incorporated steam generator test model. The GPL-1 loop and sodium side of SSGM were described in Ref. 1.

The GPL-1 loop is a high-temperature low-pressure closed sodium loop capable of providing 200 gpm of sodium at 1200°F and 330 psig.

The circulating pump is an electro-magnetic linear induction pump and loop flow rates are measured with electro-magnetic flow meters. Standard sodium chemistry is as follows:

Oxygen	10 ppm (By Hg-Amalgamation)
Hydrogen	2 ppm (max.)
Carbon	20 ppm (max.)
Nitrogen	5 ppm (max.)
Cyanide	2 ppm (max.)

The original SWL-1 loop (Ref. 1, Section 4) was extensively modified for the Phase III corrosion tests. The Phase III system schematic is shown in Figure 4.1.

The feedwater system depicted schematically by Figure 4.1 includes unique features such as:

- Successive demineralization steps to achieve 10 ppb metallic concentrations and <50 ppb total halogens.
- Multi-stage deoxygenation by inert gas sparging followed by a catalyzed hydrazine reaction to attain <7 ppb O_2.
- Chemical batch mixing plus analyses techniques to control and monitor a 30 ppb sodium hydroxide corrosive test additive controlled at pH 9.3 with ammonium hydroxide.

Physically, the pre-treatment feedwater system was designed in three stages with each stage performing one or more successive functions to supply feedwater to the test loop at the required water chemistry parameters. The pre-treatment stages are 1) water purification, 2) multi-function reservoir supply tanks, and 3) reaction loop supply tank.

Two (2) 800 gallon stainless steel tanks (#1 and #2) alternately filled with high purity water are equipped with an argon sparge and a closed cycle recirculation system. The argon sparge (30 cubic feet/hour) is used to effectively deoxygenate the system from 55 ppm to 0.02 ppm in approximately 30 hours. Pump recirculation at 600 gallons per hour is used in conjunction with injection of sodium hydroxide to maintain a thoroughly mixed solution. The deoxygenated sodium hydroxide solution is supplied continuously to the reaction loop tank alternately from the reservoir tanks which allow the other reservoir tank to be prepared (filled, preadjusted and equilibrated to the chemical simulation parameters). Daily sampling and analysis are performed to monitor the required 30 ppb ± 3 ppb sodium concentration.

Treated water of less than 20 ppb oxygen and 30 ± 3 ppb sodium is supplied to the reaction loop supply tank (#3) on demand as controlled by level indicators in the tank. The reaction tank is a 55 gallon stainless steel drum with argon sparging, recirculation mixing and 180°F temperature control features.

Hydrazine solution (N_2H_4) from Tank #4 is injected into Tank #3 for O_2 control (7 ppb Nom.). Ammonium Hydroxide (NH_4OH) from Tank #5 is injected into Tank #3 for pH control (9.0-10.0 nominal). Tanks #4 and #5 are equipped with circulating pumps to keep the solution mixed during storage.

The feedwater make-up pump provides a constant supply of ultra-pure treated water from the reaction tank to the test loop at approximately 10 gallons per hour. No additional feedwater treatment is performed within the test loop.

The effectiveness of the feedwater treatment system is demonstrated by the typical chemistry analysis shown in Table 4.1. (Refer to schematic of Figure 4.1 for sample points).

The comparison of the actual test loop water chemistry with the CRBRP water chemistry requirements is presented in Figure 4.2.

Water chemistry is determined as follows (measurement equipment is described in Section 6, Appendix B):

- Water conductivity of the demineralized water supplied to the batch tanks is continuously monitored by a conductivity cell and continuously recorded.
- The oxygen concentration of the make-up and feedwater is monitored and recorded continuously by an on-line oxygen analyzer.
- The pH level of the make-up and feedwater is monitored and recorded continuously by an on-line pH analyzer.
- The sodium ion concentration of the batch solution, make-up water and feedwater is determined from laboratory analysis of 'grab' samples.
- Other feedwater ion concentrations such as chloride, silica, iron, copper, total dissolved solids and residual hydrazine are determined from 'grab' samples taken periodically.

A complete description of the Phase III feedwater system is given in Appendix B.

Table 4.1

PHASE III FEEDWATER SYSTEM CHEMISTRY
ANALYSIS BY SAMPLE POINT (FIG. 4.1)

Parameter	Tap Water (1)*	Demineralizer (2)	Batch Tank (3)	Reaction Tank (4)	Test Model (5)
Resistivity (ohm-cm)	5.0K	2,500K	2,500K	250K	250K
Chloride	20 ppm	<50 ppb	<50 ppb	<50 ppb	<50 ppb
Oxygen	∿5 ppm	∿5 ppm	10 ppb	2 ppb	2 ppb
Ph	8	7	7.5	9.3	9.3
Sodium	40 ppm	<2 ppb	30 ppb	30 ppb	30 ppb
Hydrazine	N/A	N/A	N/A	67 ppb	67 ppb

*Sample point number, location given in Figure 4.1.

Table 4.2

COMPARISON OF TEST LOOP WATER CHEMISTRY
ANALYSIS WITH CRBRP WATER CHEMISTRY REQUIREMENTS

Parameter	CRBRP	SWL-1 Test Loop
Ph	9.0 - 9.5	9.3
Oxygen	7 ppb	2 ppb
Sodium	5.5 ppb (max.)	30 ppb*
Silica	20 ppb (max.)	6 ppb
Iron	10 ppb (max.)	5 ppb
Copper	2 ppb (max.)	2 ppb
Hydrazine (Residual)	5 ppb (max.)	67 ppb
Total Dissolved Solids	2 ppm (max.)	1.2 ppm

*Additive for Accelerated Corrosion Tests.

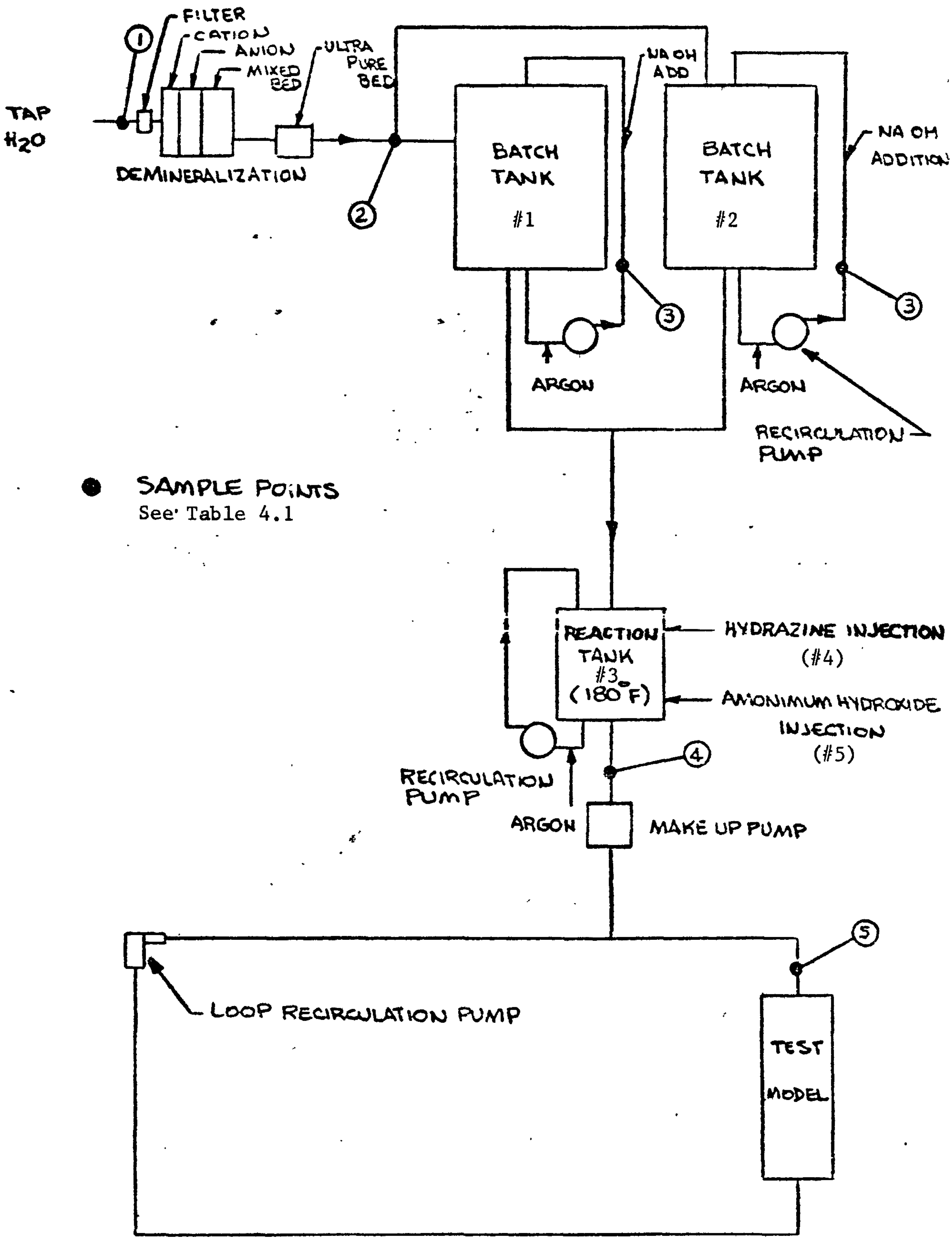


Fig. 4.1. Phase III Feedwater System Schematic

SECTION 5

TEST PROGRAM

As part of the ERDA funded Liquid Metal Fast Breeder Reactor (LMFBR) program, the Westinghouse Electric Corporation Tampa Division designed and fabricated a single duplex tube sodium-heated steam generator model. This unit, named the Small Steam Generator Model (SSGM), was tested at the Westinghouse Advanced Reactors Division GPL-1/SWL-1 facility. The SSGM was designed, fabricated and tested to proof-test a single tube of duplex wall construction at conditions identical to the alternate concept evaporator for the Clinch River Breeder Reactor Plant (CRBRP) under ERDA Contract E(04-3)-962.

The overall test program was divided into three phases plus a post test exam. The Phase I parametric steady state heat transfer experiment results are reported on in Ref. 1. The Phase II transient test results are reported on in Ref. 2. This report covers the Phase III steady state corrosion tests. Figure 2.1 summarized the testing chronology for Phases I, II, and III. The detailed Phase III chronology is given in Appendix A.

A total of 13 startup/shutdown cycles have occurred during Phase III testing. The summary of the number of startup/shutdown cycles for the complete model test is given in Table 5.1. The SSGM accumulated hours at CHF is listed in Table 5.2.

5.1 Thermal/Hydraulic Conditions

The final Phase III thermal/hydraulic test conditions are as follows:

Water flow rate	2860 lb/hr	±2%
Water inlet temperature	542°F	±3°F
Water inlet pressure	1800 psig	+0%/-1%
Sodium flow rate	9000 lbs/hr ± 200 lb/hr	
Sodium Inlet temperature	859°F	+0°F/-3°F

The sodium flow rate is adjusted to 9000±200 lb/hr to achieve CHF between thermocouples #3 and #4, shown in Figure 3.4. This CHF location is 4.0±0.5 ft. from the top of the steam exit tube, and is within the region of the tube I.D. characterized with boroscope mapping and tube bore measurements described in Ref. 5 and summarized in Section 6.1. The actual CHF location versus time is discussed in Section 6.3 under Thermal Performance Evaluation.

5.2 Water Chemistry Conditions

The nominal sodium hydroxide concentration of the model inlet water was specified as 30ppb nominal with estimated variations of ±10%. The remaining water inlet chemistry was specified as close as possible to CRBRP conditions as follows:

pH	9.0 - 10.0
Resistivity	100,000 - 500,000 OHMS-CM
Chloride	20ppb (max)
Oxygen	7ppb (nominal) ±5ppb
Silica	20ppb (estimated)
Iron	10ppb (estimated)
Copper	2ppb (estimated)
Hydrazine (residual)	TBD
Total Dissolved Solids	50ppb (estimated)

For comparison, Phase I, II, and III water chemistry and sodium chemistry specifications are shown in Table 5.3.

Table 5.1

SUMMARY OF STARTUP/SHUTDOWN CYCLES

Jan. 26, 1974 to Nov. 1975

	Sodium and Water Loops (GPL-1/SWL-1)	Sodium Loop Only (GPL-1)
Phase I	9	2
Phase II	5	-
Phase III	13	-
Total	27	2

SSGM Phase III Accumulated Hours

at CHF, 5/28/75 (0035 HR) to

11/15/75 (0900 HR)

Month	Date	Hour	Hours at CHF	Accumulated Hours for Month	Accumulated Hours
May	5/28/75 5/31/75	0035 2400	95.5	95.5	95.5
June	6/1/75 6/5/75	0000 1832	114.5	551.8	647.3
	6/10/75 6/21/75	1800 2400	270.0		
	6/22/75 6/25/75	2030 1722	68.8		
	6/26/75 6/30/75	2130 2400	98.5		
July	7/1/75 7/1/75	0000 0550	6.0	651.8	1299.1
	7/4/75 7/16/75	1535 0220	273.8		
	7/16/75 7/31/75	1200 2400	372		
Aug.	8/1/75 8/9/75	0000 0815	200.3	206.8	1505.9
	8/23/75 8/24/75	2310 0540	6.5		
Sept.	9/18/75 9/27/75	2105 1830	213.5	213.5	1719.4
Oct.	10/3/75 10/11/75	1645 0019	175.6	175.6	1895.0
Nov.	11/3/75 11/5/75	1430 0935	43.0		
	11/5/75 11/12/75	2030 1630	164		
	11/12/75 11/15/75	2300 0900	58	265	2160

Table 5.3

SSGM WATER SIDE AND SODIUM SIDE CHEMISTRY SUMMARY

SSGM Phase	Water Chemistry	Sodium Chemistry	
I & II	Oxygen - <200 ppb pH - 9 - 9.5 Resistivity = 100 - 500K ohm-cm Chloride < 100 ppb	Oxygen Hydrogen Carbon Nitrogen Cyanide	10 ppm 2 ppm (max) 20 ppm (max) 5 ppm (max) 2 ppm (max)
III	Sodium - 30 ppb (nom.) Oxygen - 7 ppb (nom.) pH - 9-10 Resistivity - 100 - 500K ohm-cm Chloride - 20 ppb (max)		

SECTION 6

TEST RESULTS

6.1 INTERNAL TUBE BORE EXAMINATION

Fiber optics photographs and diatest gauge measurements of the Small Steam Generator Model (SSGM) tube bore were performed on May 2 and 3, 1975 (Ref. 5). The purpose of these photographs and measurements was to provide a limited characterization of the SSGM tube bore prior to conducting a 2160 hour CHF corrosion test. The primary intent of this limited characterization was to assure that no gross changes had taken place in the model tube bore during earlier testing.

The photographs were to be taken at specified elevations and radial locations and at random locations which showed unusual surface markings. Mechanical gauge (diatest) measurements of the tube ID were to follow at these same elevations and radial locations.

The fiber optics tube bore surface photography technique was chosen over that of a straight length borescope as a result of comparative observations of tube bore surface visual clarity and a mechanical gauge (diatest) was chosen for diameter measurements since this method was the simplest technique available for determining whether gross tube diameter changes had taken place during the preceding model test experience and to possibly establish a dimensional correlation between the model tube and archived tube samples which will be utilized for comparison during destructive post test examination.

A more complete nondestructive test program could have included the use of eddy current and ultrasonic probes, pneumatic and electronic gauges and replication techniques but these methods required development and funding which were beyond the scope of this program.

A summary of the conclusions from the internal tube bore examination summary is as follows:

> The fiber optics photographs of dark areas/discolorations may be localized high or low spots on the tube bore surface (eg. magnetite

build-up or pitting/gauges, etc., respectively), however, high spots of significance were not detected with the diatest measurements.

Gross circumferential diameter changes either locally or axially which are possible to detect with the diatest, were not observed.

Fiber optics calibration photographs and 180° separation of light colored streaks at the 1'-6" elevation photographs indicate quite conclusively that these marks were made on the tube bore surface by the internal thermocouple device which was utilized in previous thermal/hydraulic tests.

Internal tube bore diameter measurements when compared with an archived sample of the model tube indicate that the archived tubing may be utilized as a standard of comparison during the model post test examination, however, diameter measurements of model and archived tube show potential maximum deviations of as much as .005 inch.

6.2 WATER CHEMISTRY DATA

Water chemistry data on a daily basis is given in Appendix C, listing date, pH (lab analysis and on-line meter), O_2 (lab analysis and on-line meter, in ppb), Cl (ppm), resistivity (ohm-cm) and Na (ppb). Appendix C includes shutdown periods where water chemistry measurements were applicable. The Appendix C data is plotted versus accumulated time at CHF (See Table 5.2) in Figures 6.1 through 6.4 for sodium, pH, resistivity and oxygen, respectively. Table 6.1 summarizes and compares actual Phase III SSGM water chemistry with the original Phase III specifications and the CRBRP specifications.

The average sodium hydroxide concentration was 31 ppb, very close to the specified 30 ppb. The actual daily variation of sodium hydroxide concentration, as shown in Figure 6.1, was greater than initially estimated (estimate was ±10% of 30 ppb). The average pH was 9.18, well within the specified 9.0 to 10.0 range. For 85% of the 90 day period the pH was within the 9.0-10.0 range (Figure 6.2). The average resistivity was 148,800 ohm-cm (on-line meter), well within the specified range of 100,000 -

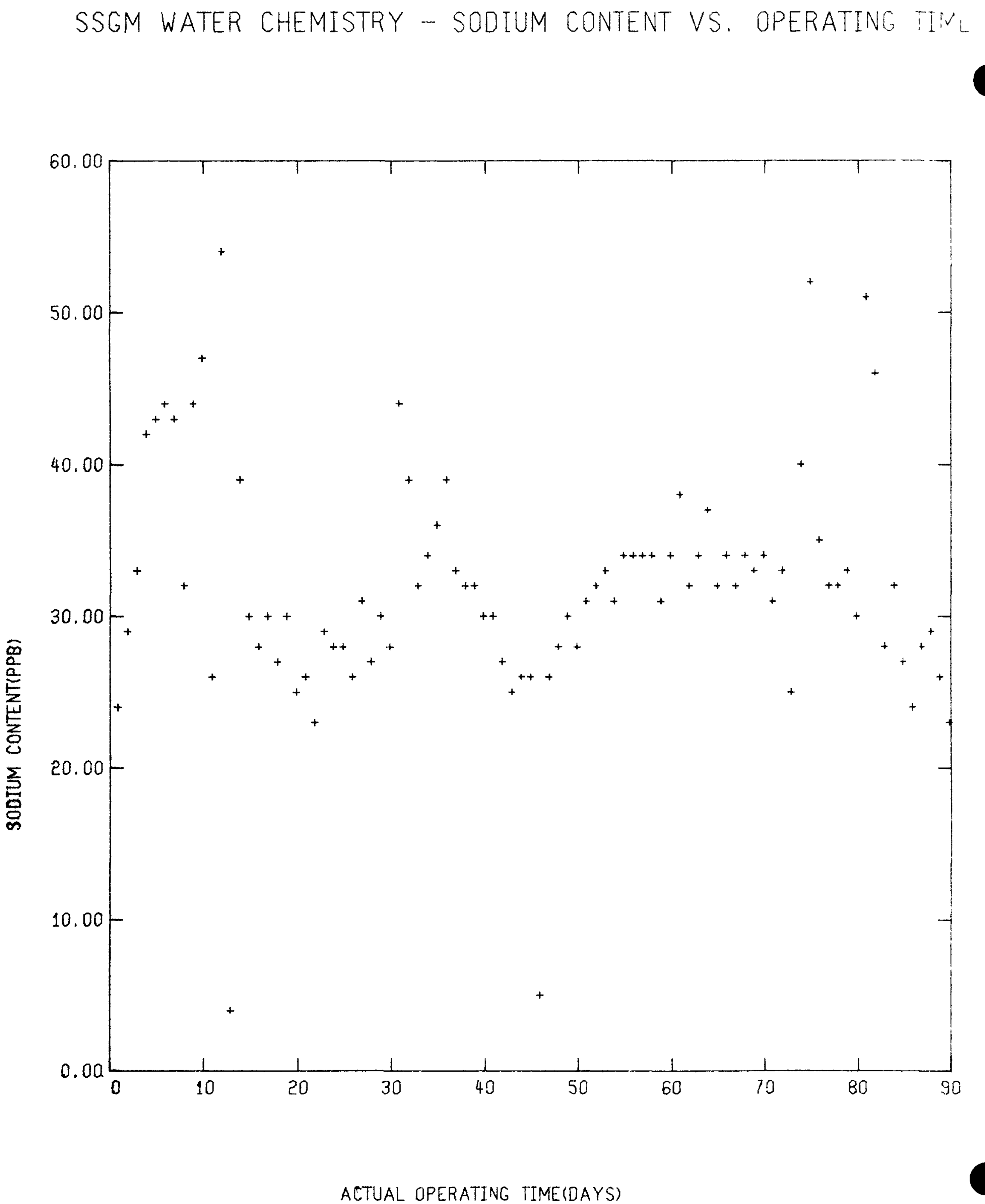
Table 6.1

SSGM PHASE III CORROSION TEST WATER CHEMISTRY,

ACTUAL VERSUS SPECIFICATIONS

Parameters	Specified for CRBRP	Specified for SSGM	Actual for SSGM	References: Figure/Table	References: Appendix
Sodium	5.5 ppb (max.)	30 ppb (±10%, estimated)	31 ppb (avg.)	Figure 6.1	Appendix C
pH	9.0 - 9.5	9.0 - 10.0	9.18 (avg.)	Figure 6.2	Appendix C
Resistivity	333,000 ohm-cm (min.)	100,000 - 500,000 ohm-cm	148,800 ohm-cm (avg.) (on-line meter)	Figure 6.3	Appendix C
Chloride	-	20 ppb (max.)	<50 ppb (typ.)	-	Appendix C
Oxygen	7 ppb (max.)	7 ppb (nom.) (±5 ppb estimated)	2.3 ppb (avg.) (on-line meter)	Figure 6.4	Appendix C
Silica	20 ppb (max.)	20 ppb (est.)	6 ppb (typ.)	Table 4.2	Appendix B
Iron	10 ppb (max.)	10 ppb (est.)	5 ppb (typ.)	Table 4.2	Appendix B
Copper	2 ppb (max.)	2 ppb (est.)	2 ppb (typ.)	Table 4.2	Appendix B
Hydrazine (Residual)	5 ppb (max.)	TBD	67 ppb (typ.)	Table 4.2	Appendix B
Total Dissolved Solids	2 ppm (max.)	50 ppb (est.)	1.2 ppm (typ.)	Table 4.2	Appendix B

Figure 6.1



SSGM WATER CHEMISTRY - SODIUM CONTENT VS. OPERATING TIME
SODIUM CONTENT(PPB)
60.00
50.00
40.00
30.00
20.00
10.00
0.00
0
10
20
30
40
50
60
70
80
90
ACTUAL OPERATING TIME(DAYS)

Figure 6.2

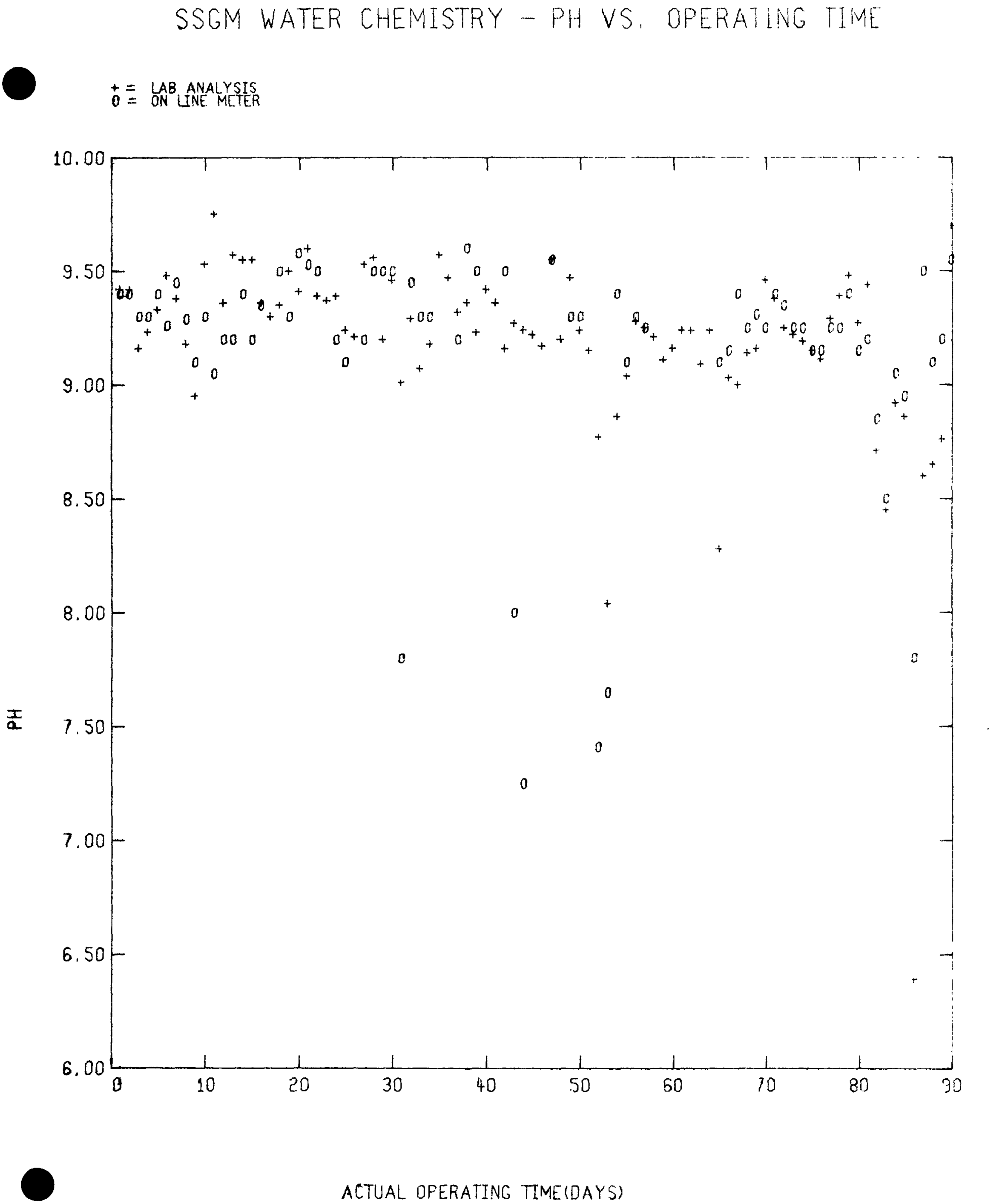

SSGM WATER CHEMISTRY - PH VS. OPERATING TIME
+ = LAB ANALYSIS
0 = ON LINE METER
10.00
9.50
9.00
8.50
8.00
7.50
7.00
6.50
6.00
PH
0
10
20
30
40
50
60
70
80
90
ACTUAL OPERATING TIME(DAYS)

Figure 6.3

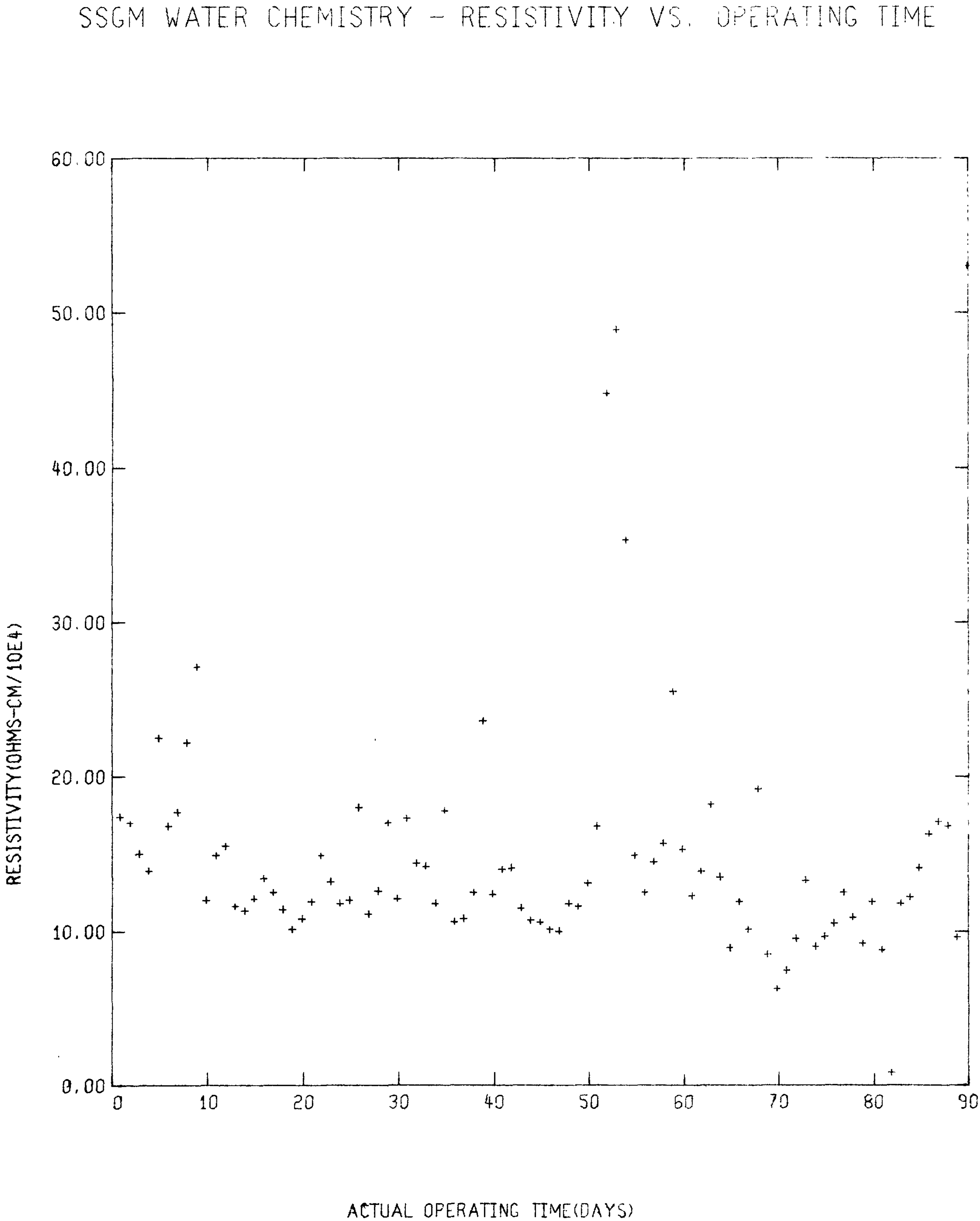
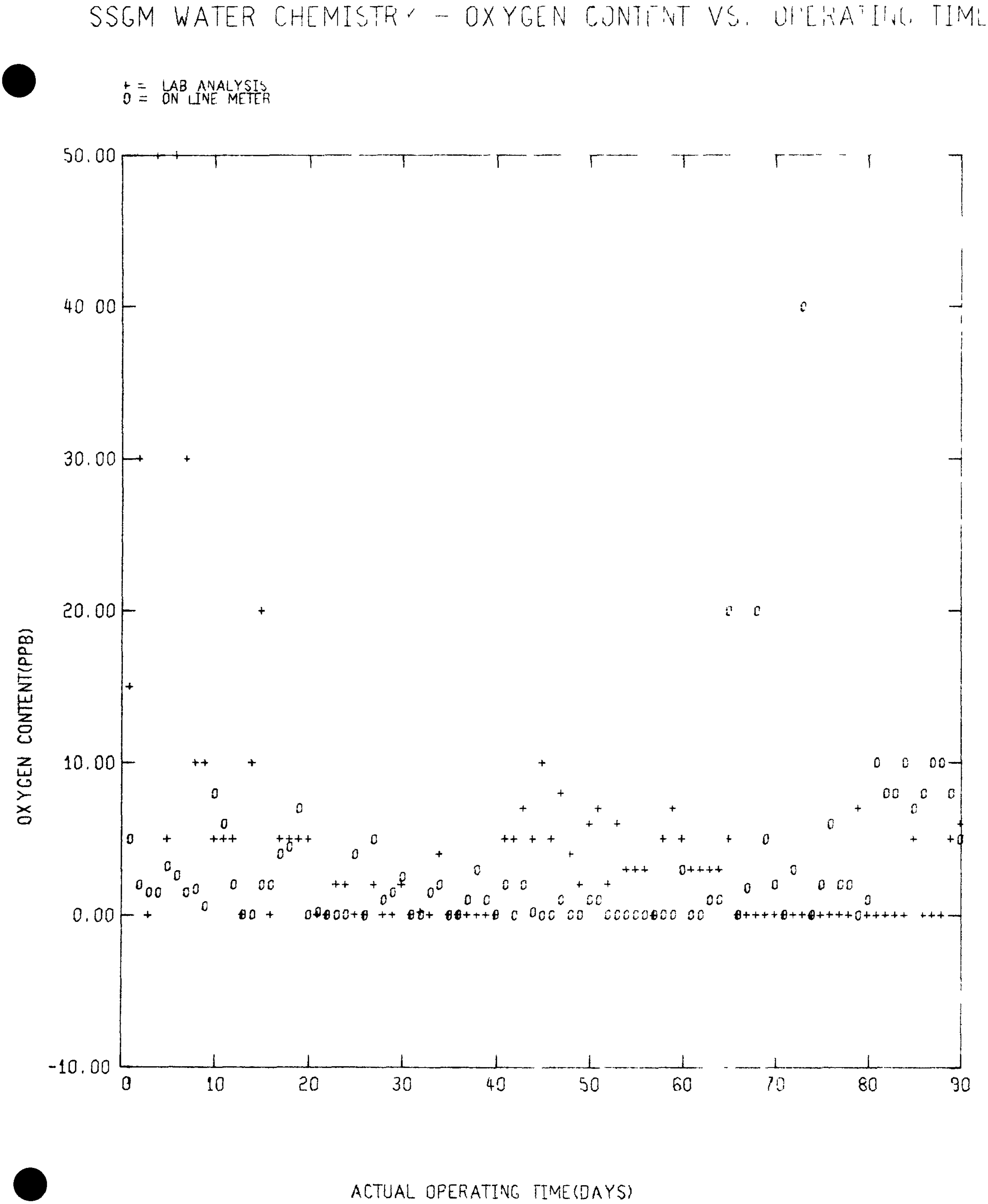

SSGM WATER CHEMISTRY - RESISTIVITY VS. OPERATING TIME
60.00
50.00
40.00
30.00
20.00
10.00
0.00
0
10
20
30
40
50
60
70
80
90
RESISTIVITY(OHMS-CM/10E4)
ACTUAL OPERATING TIME(DAYS)

Figure 6.4



SSGM WATER CHEMISTRY - OXYGEN CONTENT VS. OPERATING TIME
+ = LAB ANALYSIS
0 = ON LINE METER
50.00
40.00
30.00
20.00
10.00
0.00
-10.00
OXYGEN CONTENT(PPB)
0
10
20
30
40
50
60
70
80
90
ACTUAL OPERATING TIME(DAYS)

500,000 ohm-cm range (Figure 6.3).

The chlorine concentration was less than 50 ppb for 95% of the 90 day period as shown in Appendix C. The average oxygen concentration was 2.3 ppb, which was excellent compared to the specified value of 7±5 ppb. For 97% of the 90 day period the specified oxygen concentration was not exceeded (Figure 6.4). The typical concentrations of silica, iron and copper were less than or equal to initial estimates as shown in Table 6.1. Residual hydrazine and total dissolved solids concentrations were obtained as part of the test data and were not controlled variables (Table 6.1).

6.3 THERMAL PERFORMANCE EVALUATION

The SSGM corrosion test program performed to date (2160 hours exposure at CHF) experienced a number of occasions wherein the CHF condition drifted from the CRBRP evaporator reference condition with physical liquid film dryout (LFD) into another regime reflecting a bubbly flow (DNB) condition. A sampling of data over this test period is shown superimposed on a CHF map in Figure 6.5 with the test exposure in accumulated hours shown adjacent to the data points. It is seen that the CHF condition drifted into DNB conditions which required notification from WTD to modify loop operating conditions and thus correct the exposure mechanism to the reference dryout condition. Supporting information for Fig. 6.5 is shown in Appendix D and sample dryout and DNB cases are shown in detail in Appendix E. Computer code data evaluation techniques were required to determine the precise CHF operating mode of the model and these techniques are described in detail in Reference 1 and summarized briefly in the following discussion of the curve fitting and CHF separation procedures.

The 60 sodium shell temperature readings were corrected and arranged in ascending order based on fractional tube length from 0% to 100% length. The computer code then performed a series of high order polynomial curve fits selecting the best curve fit based on the minimization of the sum of the squares of the deviations of the curve fit from the data. Based on the test data, initially a single curve fit method was employed to determine the approximate CHF location and heat transfer mechanism, i.e., liquid fim dryout, transition or DNB (if any). For those CHF cases separated into liquid film dryout or transition (determined by the single curve fit method) a double curve fit method was applied to obtain the best resolution of pre- and post-CHF heat flux and CHF location. According to the final sodium temperature profile determined from the least squares, fitted curve, the flow properties with other parameters were determined from computer code SSGM2. The concept and procedure described above is described in detail in References 1 and 8.

In the present study, 110 sets of data were evaluated in the thermal performance analysis. Referring to the temperature deviation ΔT between test data at CHF and the corresponding value evaluated from the single curve fit, the bona fide dryout heat transfer mechanism at CHF in the present corrosion test was classificated into two categories; namely liquid film dryout ($\Delta T > 2.5^{o}F$) and the transition ($1.5^{o}F < \Delta T < 2.5^{o}F$) as shown in Figure 6.5. It is also noted in the figure that on seven occasions during the course of the test program performed to date, the operating conditions drifted from the nominal Phase III operation in the dryout regime at CHF into the DNB regime. It follows that the corresponding corrosion mechanism was not held at the CRBR evaporator behavior on these occasions.

CHF is located at 4.2 ft. from the top of the steam exit for ~90% of the 2160 hour test duration (Fig. 6.6). For each of the 110 data sets, for those cases reflecting liquid film dryout and transition film dryout, the following data is plotted versus accumulated time in Figures 6.7 through 6.16:

(1) critical heat flux in LFD and transition regimes
(2) post-CHF heat flux in LFD and transition regimes
(3) thermal resistance of the tube wall
(4) inside wall surface temperature in pre- and post-CHF regimes
(5) critical steam quality

Transition film dryout is a special case of liquid film dryout occurring at a relatively low steam quality. Whether the dryout is transition film dryout or liquid film dryout depends on the flow conditions, i.e., sodium flow rate and sodium inlet temperature. For example, in a special test with constant flow rate, the heat transfer mechanism changed from liquid film dryout to transition film dryout due to a slight decrease in sodium inlet temperature. Sodium temperature profiles with CHF location at the four foot position in tube length is shown in Fig. 6.17. Curves 1 and 2 display liquid film dryout cases in which the sodium inlet temperature is higher than 850^{o}F. Curves 3 and 4 display transition liquid film dryout cases in which the sodium inlet temperature is about 10~15^{o}F lower than that of curves 1 and 2. For a test of this duration (2160 hours), a slight change in the flow conditions can hardly be avoided. The heat transfer mechanism at CHF can be expected to alternate from liquid film dryout to transition film dryout.

For the case of transition film dryout with relatively low steam quality at CHF, the liquid droplets in the steam core deposit on the hot surface of the tube wall in the transition film boiling region. Considering the same space and time domain, the heat flux for the transition liquid film dryout in the film boiling region is higher than that associated with liquid film dryout.

The present data analysis evaluates the results for each dryout category individually due to differences in heat fluxes and possibly other parameters. Among the 110 data sets, 73 sets of data reflect liquid film dryout and the remainder indicate that transition film dryout occurs. From the computer evaluation of these cases, the average critical steam quality at CHF is ~23.5% for transition film dryout and ~25% for the liquid film dryout cases as shown in Figures 6.15 and 6.16. The critical heat fluxes shown in Fig. 6.7 and 6.8 display considerable scatter for both transition and liquid film dryout cases. The post-CHF heat fluxes reflect considerably more scatter as shown in Figures 6.9 and 6.10.

The average values are 1.4x10^{5} Btu/hr-ft^{2}-^{o}F for transition film dryout and 10^{5} Btu/hr-ft^{2}-^{o}F for liquid film dryout. Heat flux data scatter could be the result of the varied flow conditions, i.e., slight changes in flow rate lead to variations in the heat transfer characteristics of the flow, varying duplex tube thermal resistance behavior, and changes in the heat flux profile along the tube.

The inside surface temperature of the tube wall relates to differing phenomena in the nucleate boiling region (pre-CHF region) and in the film boiling region (post-CHF). In the pre-CHF region, the temperature is steady with a magnitude of ~629^{o}F for all runs. The temperature data scatters within a large band for the post-CHF region as shown in Figures 6.13 and 6.14. In the pre-CHF region, the water/steam heat transfer coefficient is high for mechanisms of nucleate boiling and liquid film vaporization and the thermal resistance of the tube wall dominates the heat transfer rate. This behavior leads to an anticipated constant inside surface temperature. In the post-CHF region, both thermal resistances of water/steam side and the tube wall dominate the heat transfer rate. In addition, the water/steam heat transfer coefficient is very sensitive to the fluid properties in the thermal boundary (the fluid properties are a function of the wall surface temperature) and the mechanism of the liquid droplet impingement on the hot wall surface. With varying steam qualities and sodium temperature levels, the quantity of the liquid droplets impinging on the hot surface in a given space and time domain is varied. For the present test results, the steam quality at CHF varies from 22% to 27% and the sodium temperature level at the CHF location is in the range from 810^{o}F to 840^{o}F. The corresponding scatter in the wall surface temmperature in the post-CHF film boiling region is expected.

Since the main purpose of the present test is to study the effects on the water/steam side of sodium caustic concentration upon corrosion phenomena in the critical heat flux (CHF) region, the associated changes in the tube surface conditions of the water/steam side will affect the heat transfer phenomenon. For example, in the early stage of the test, the deposition of particulates occurs. If the original tube surface is smooth, the deposition may even slightly improve the heat transfer in the boiling region due to improved nucleation. However, it must be expected that thick deposits will have an adverse effect on heat transfer (9). In addition, possible deposition effects could change the thermal performance of the text model over a long test duration. To investigate this possibility, an extensive analysis of the model thermal performance was carried out.

Referring to the study in Reference 9, the deposition rate is proportional to heat flux so that the high heat flux regions will experience the highest deposition rates. In other words, the greatest deposition occurs in the nucleate boiling regime, and particularly at the critical heat flux location where the heat flux approaches its maximum value. In the present corrosion test, if there is any change in the thermal performance of the model due to the deposition effects, the test data in the CHF vicinity will reflect this effect. The present analysis is concentrated on the test results at two spatial increments in the vicinity of the CHF location.

In one approach, the critical heat flux increment and the heat flux at the post-CHF increment are investigated. Due to the slightly varied flow and exposure conditions at various test times the test results show that both heat flux values at the CHF and post-CHF locations are scattered over a wide range. It is not possible to deduce deposition effects upon heat transfer by simply visualizing these heat flux results. The study was extended by introducing a dimensionless parameter - the ratio of heat flux at the post-CHF location to the critical heat flux. This parameter is less affected by the variations in exposure conditions. This dimensionless parameter, $\bar{Q}$ obtained from the present test results is plotted versus cumulative exposure time as shown in Figures 6.18 and 6.19. These figures indicate that the value of $\bar{Q}$ are scattered somewhat. The mean value of $\bar{Q}$ is essentially consistent with the magnitude of 0.4 for the liquid film dryout cases. For the transition film dryout cases the value is slightly greater than that for liquid film dryout cases and increases slightly with the time.

Next, an investigation of the tube wall thermal resistance behavior at the CHF location was also carried out. Due to possible deposition effects, the thermal resistance of the wall will increase, and it will decrease as the wall loses material caused by possible corrosion or other reactions occurred on the tube surface. If either of the above two cases occurs, the test results of the wall thermal resistance should indicate the corresponding trends. However, in the present test, the heat flux values are scattered for all cases. Since the thermal resistance of duplex tube is a function of the heat flux, the test results cannot directly reflect the mechanism occurring on the tube bore. Recalling the previous work of Reference 1, a linear relationship between the test results and the theoretical prediction of the wall thermal resistance based on a given heat flux was defined as,

$$R = 1.77\, R_{pred} - 6.462 \times 10^{-4} \qquad (1)$$

where the units of R and R_{pred} is $(Btu/hr\text{-}ft^2\text{-}{}^oF)^{-1}$. The ratio of the wall thermal resistances obtained from the correlation equation and the test results should be constant under varied test conditions. The relation can be written in a dimensionless form,

$$\bar{R} = R/R_{exp}.$$

If the tube has changed its configuration and/or physical properties due to deposition/corrosion effects, the dimensionless parameter, $\bar{R}$, will vary. Hence, for studying the tube behavior affected by deposition/corrosion, the dimensionless parameter, $\bar{R}$, instead of the test results, would be analyzed. Furthermore, to normalize the band of the data scatter, a new parameter, $\bar{\bar{R}}$, is introduced here. It is the ratio of the value of individual $\bar{R}_i$ to their mean value written as,

$$\bar{\bar{R}}_i = \bar{R}_i/\bar{R}_m \tag{2}$$

and

$$\bar{R}_m = \frac{1}{N} \sum_{i=1}^{N} \bar{R}_i \tag{3}$$

For the current test results, values of the parameter, $\bar{\bar{R}}_i$, are plotted versus the cumulated time shown in Figure 6.20 and 6.21. Figure 6.20 indicates the parameter $\bar{\bar{R}}_i$ evaluated from the data at the location at which the CHF occurs and Figure 6.21 indicates the parameter $\bar{\bar{R}}_i$ representing data at a location one increment upsteam of the CHF location. Both figures show that the parameter $\bar{\bar{R}}_i$ increases slightly during the first 1000 hours and than decreases during the second 1000-hour period. This means that during the present 2160-hour test period, the wall thermal resistance slightly decreases in the first 1000-hour period and than increases during the second 1000-hour test period. This trend could be caused by deposition effects and the gap behavior at the tube interface. It might be explained as follows:

For a duplex tube with the clean inside surface operated under a given heat flux Q", and the outside and inside tube surface temperature as T_o and T_i the gap thickness at the tube interface is a function of of the temperature differences $\Delta T = T_o - T_i$ and the tube geometry and its properties. Under the above conditions, the axial gap separation Y_i is obtained. The overall wall thermal resistance of the tube, R_T, is the sum of the wall thermal resistance due to the thermal conductivity of tube material, and the gap thermal resistance due to the gap separation Y_i and the gas thermal conductivity, Kg. Where deposition occurs, a deposit layer appears at the inside tube surface and the thickness of the deposition layer in a function of time by saying $Y_d = f_d(t)$. Due to the temperature drop across the deposit layer, the inside surface temperature of the tube will be T_i' which is greater than T_i of the clean surface tube. Then the temperature difference $\Delta T' = T_o - T_i'$ is less than $\Delta T = T_o - T_i$ and it follows that the new gap thickness Y_i' at the interface is less than Y_i for the clean tube. The overall thermal resistance of the tube including the deposition layer, R'_T is the sum of the wall thermal resistance, R_w, gap thermal resistance, R'_g, and the thermal resistance of the deposition layer R_d. Both overall thermal resistance values can be written in the following forms. They are:

$$R_T = R_w + R_g \tag{4}$$

for the clean inside surface tube, and

$$R'_T = R_w + R'_g + R_d \tag{5}$$

for the tube with deposition on its inside surface. Under the same operating condition, R_w in equations (4) and (5) should be nearly equal. The difference between R_T and R_T' should be totally dependent upon R_g and $R_g' + R_d$. R_g, R_g' and R_d are dependent on the thermal conductivity and the thickness of the gas and the deposited materials. They are written as

$$R_d = \frac{Y_d}{K_d} \tag{6}$$

for the deposition layer, and

$$R_g = \frac{Y_i}{K_g}$$

or

$$R'_g = \frac{Y_i'}{K_g} \tag{7}$$

for the gas gap at the tube interface. When R_T is equal to R_T', from equations (6) and (7), it follows that

$$\frac{Y_d}{K_d} = \frac{Y_i - Y_i'}{K_g}\left(\frac{d_i}{d_{interface}}\right) \tag{8}$$

where $Y_i - Y_i'$ = the difference in the gap thickness at the tube interface due to deposition effects. Theoretically, when $\frac{Y_d}{K_d} > \frac{Y_i - Y_i'}{K_g}\left(\frac{d_i}{d_{interface}}\right)$.

the overall wall thermal resistance including the deposition layer will be increased. On the other hand, when $\frac{Y_d}{K_d} < \frac{Y_i - Y_i'}{K_g}\left(\frac{d_i}{d_{interface}}\right)$

the overall wall thermal resistance will be decreased.

As an example for the present test, with helium used for the third fluid system, its thermal conductivity is about .125 Btu/hr-ft-^{o}F. If the thermal conductivity of the deposited material is 2 btu/hr-ft-^{o}F which is about one tenth of the wall thermal conductivity, then from equation (8) the relationship of Y_d and $Y_i - Y_i'$ is

$$Y_i - Y_i' = {}^{Y_d}/_{16} \left(\frac{d_i}{d_{interface}} \right) \tag{9}$$

since d_i=.571" and $d_{interface}$=.687" for the present test tube, equation (9) can be written as

$$\bar{Y} = \frac{Y_d}{Y_i - Y_i'} = 19.3 \tag{10}$$

when $\bar{Y}<19.3$. The overall wall thermal resistance including a deposition layer will be decreased and it will be increased when $\bar{Y}>19.3$.

Because the term $\bar{Y}={}^{Y_d}/(Y_i - Y_i') = 19.3$ is a relatively large ratio, when a thin deposition layer, Y_d, starts to form on the tube surface, the induced temperature change of the wall could reduce the interface gap separation differential $Y_i - Y_i'$ with a magnitude larger than $Y_d/19.3$. In this case, the overall wall thermal resistance including the deposition layer is less than that of the tube with a clean inside surface. When the deposit layer thickness reaches a certain magnitude, the gap separation differential $Y_i - Y_i'$ results in a value less than $Y_d/19.3$ because it is limited by the tube configuration. In this case, the overall thermal resistance will increase as the thickness of the deposition layer increases. According to the present test results, the deposition effect on the thermal performance are consistent with this model. As for the evidence of the tube wall losing material due to possible corrosion effects, this assumption cannot be explained by the present test data. Further testing and additional data are required for continued study of this experimental phenomena.

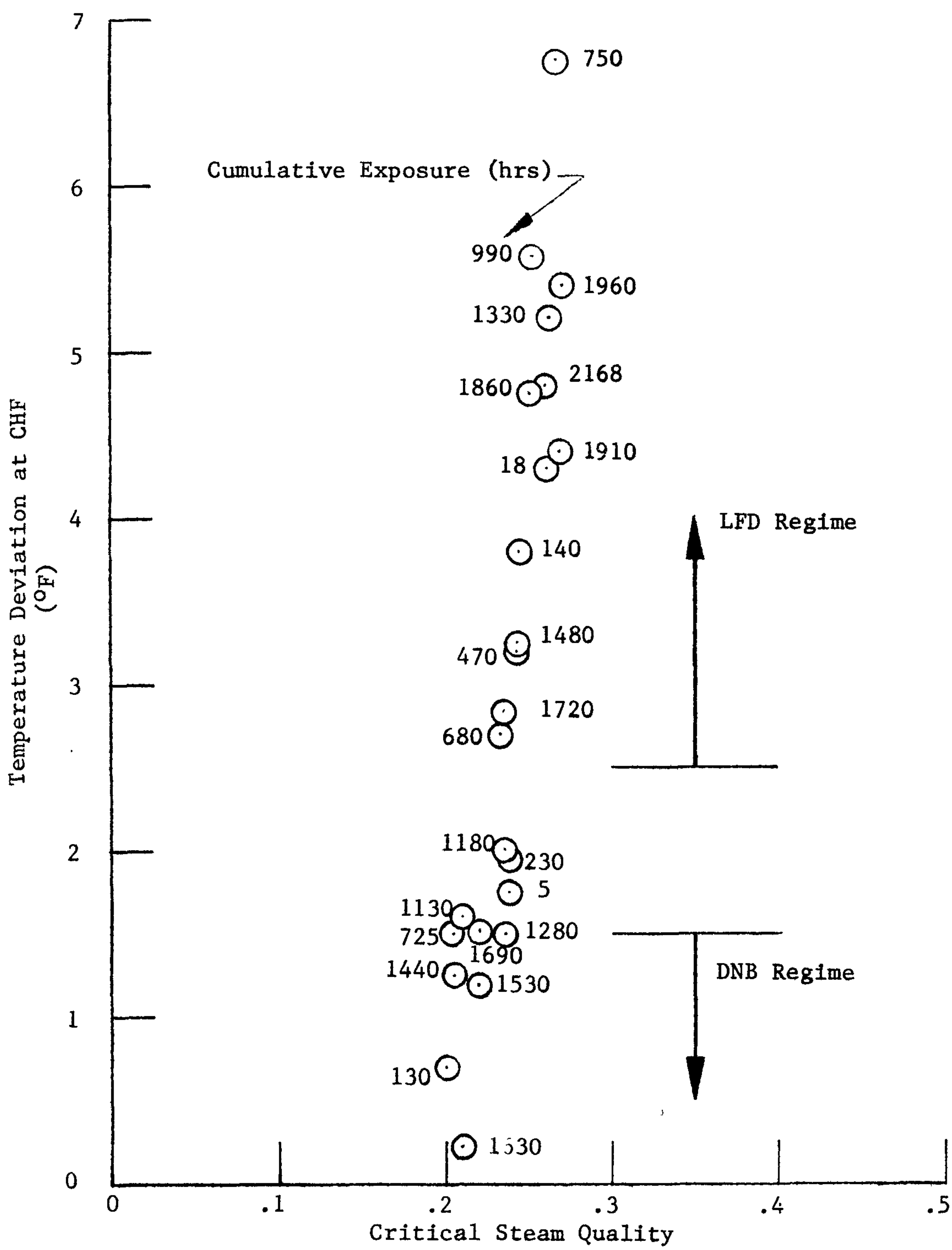


Fig. 6.5 Summary Figure Extracted from WNET-117-1 Indicating Distinction Between LFD and DNB with Addition of Corrosion Test Data Displaying Sensitivity to Loop Operating Conditions

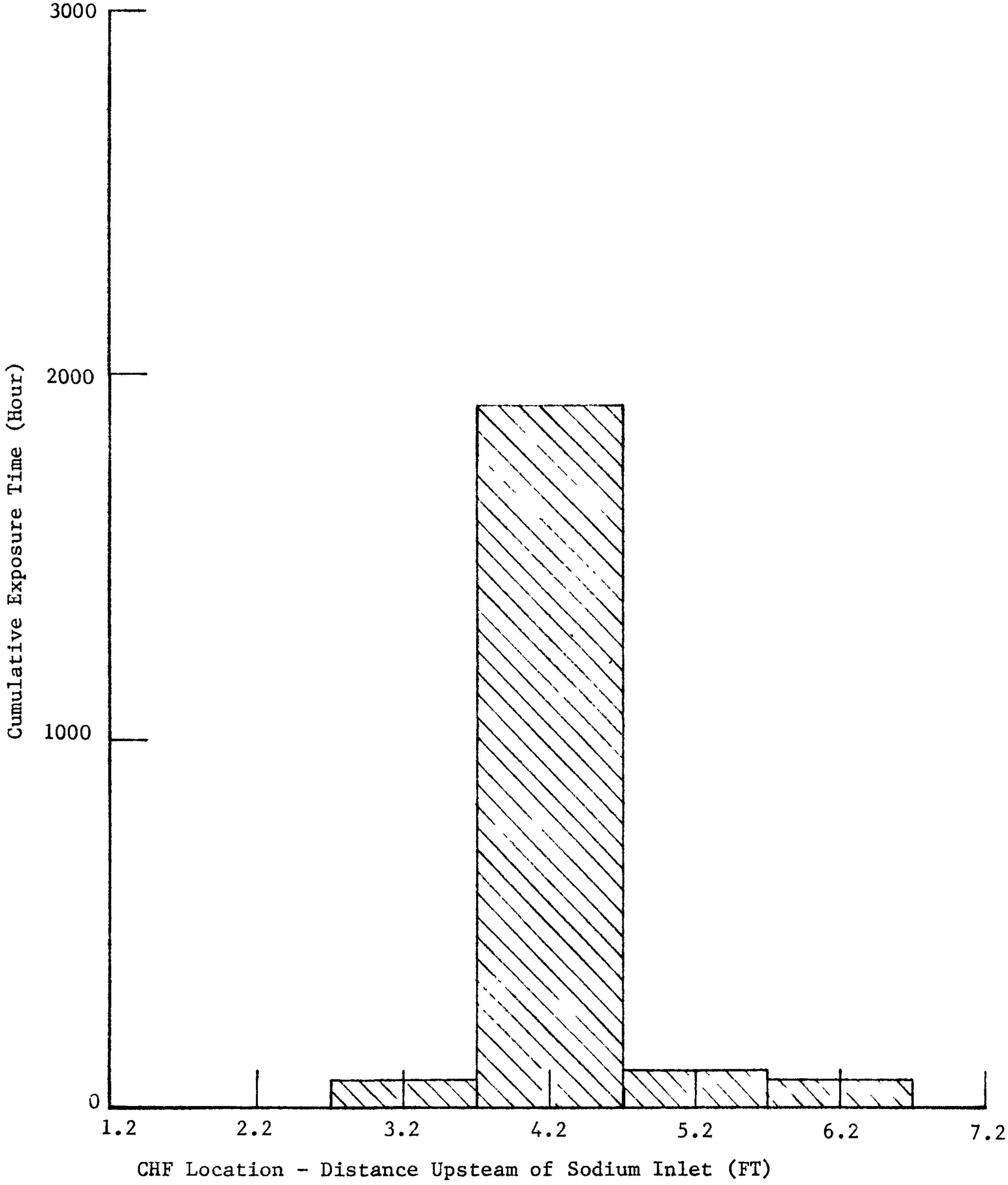


Fig. 6.6 Histogram Defining CHF Exposure Location in SSGM Tube

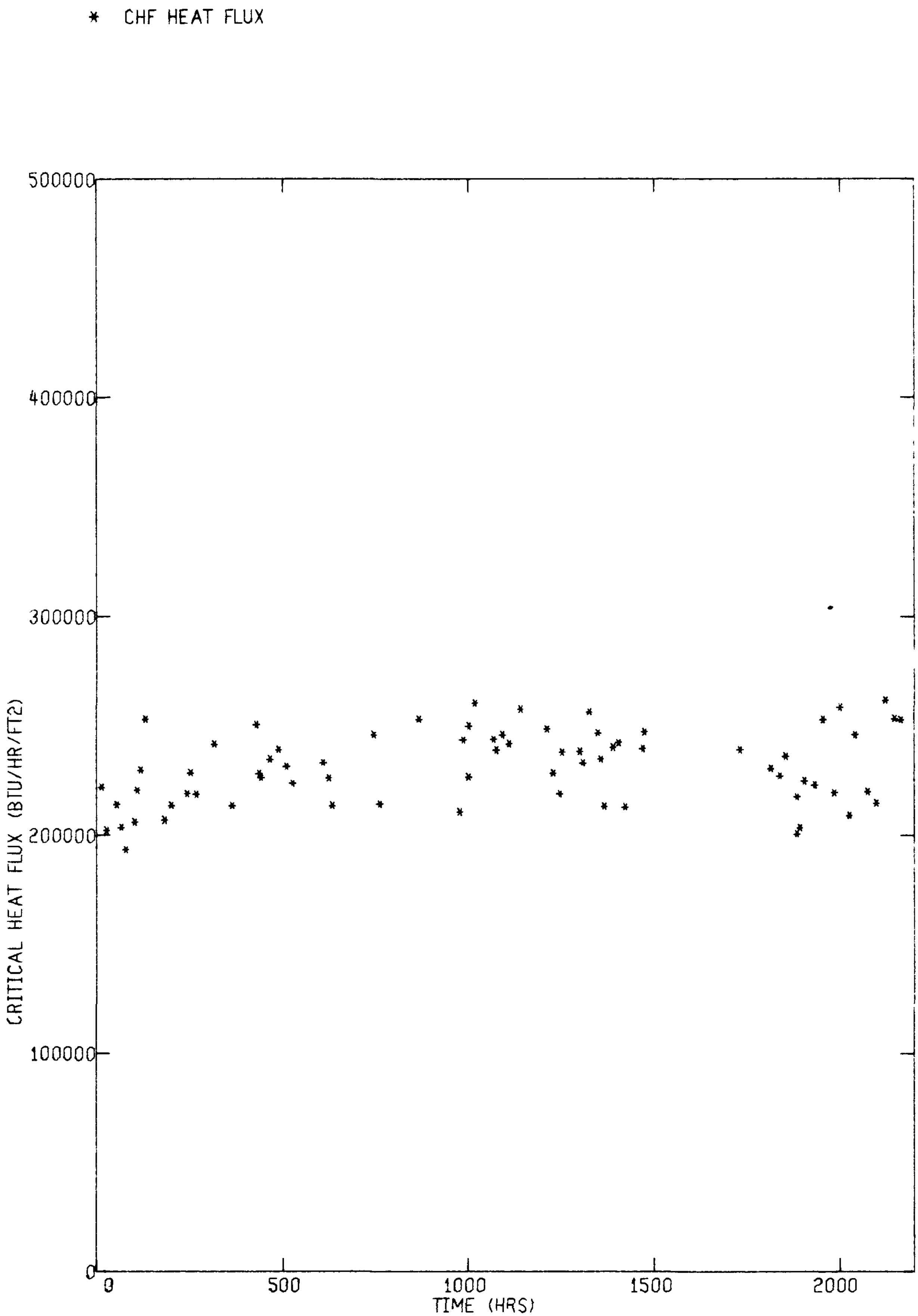


FIGURE 6. 7 CRITICAL HEAT FLUX VERSES TIME
– LIQUID FILM DRYOUT

PROCEDURE PLOTD 12 12 75

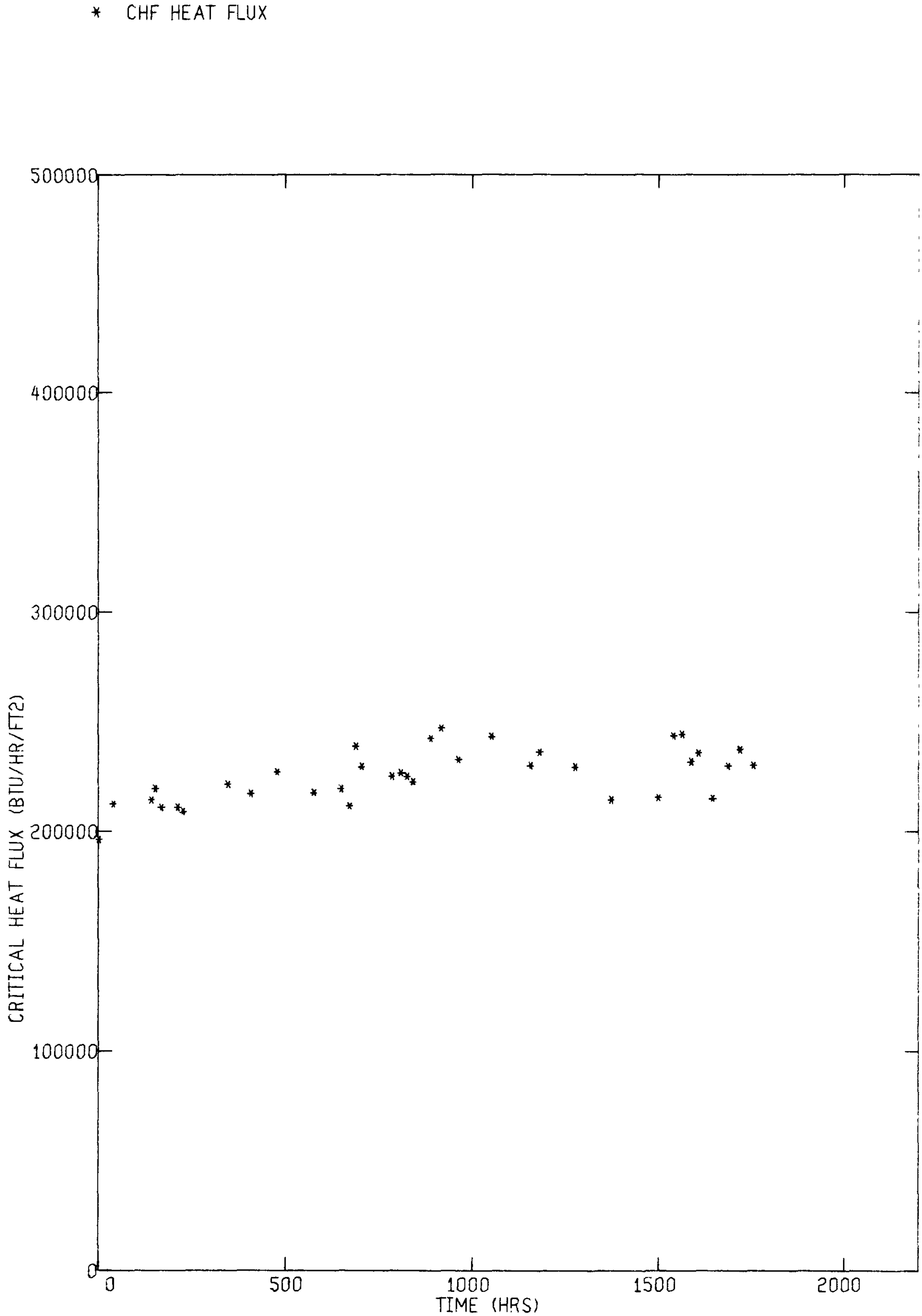


FIGURE 6.8 CRITICAL HEAT FLUX VERSES TIME -TRANSITION

PROCEDURE PLOTD 12 12 75

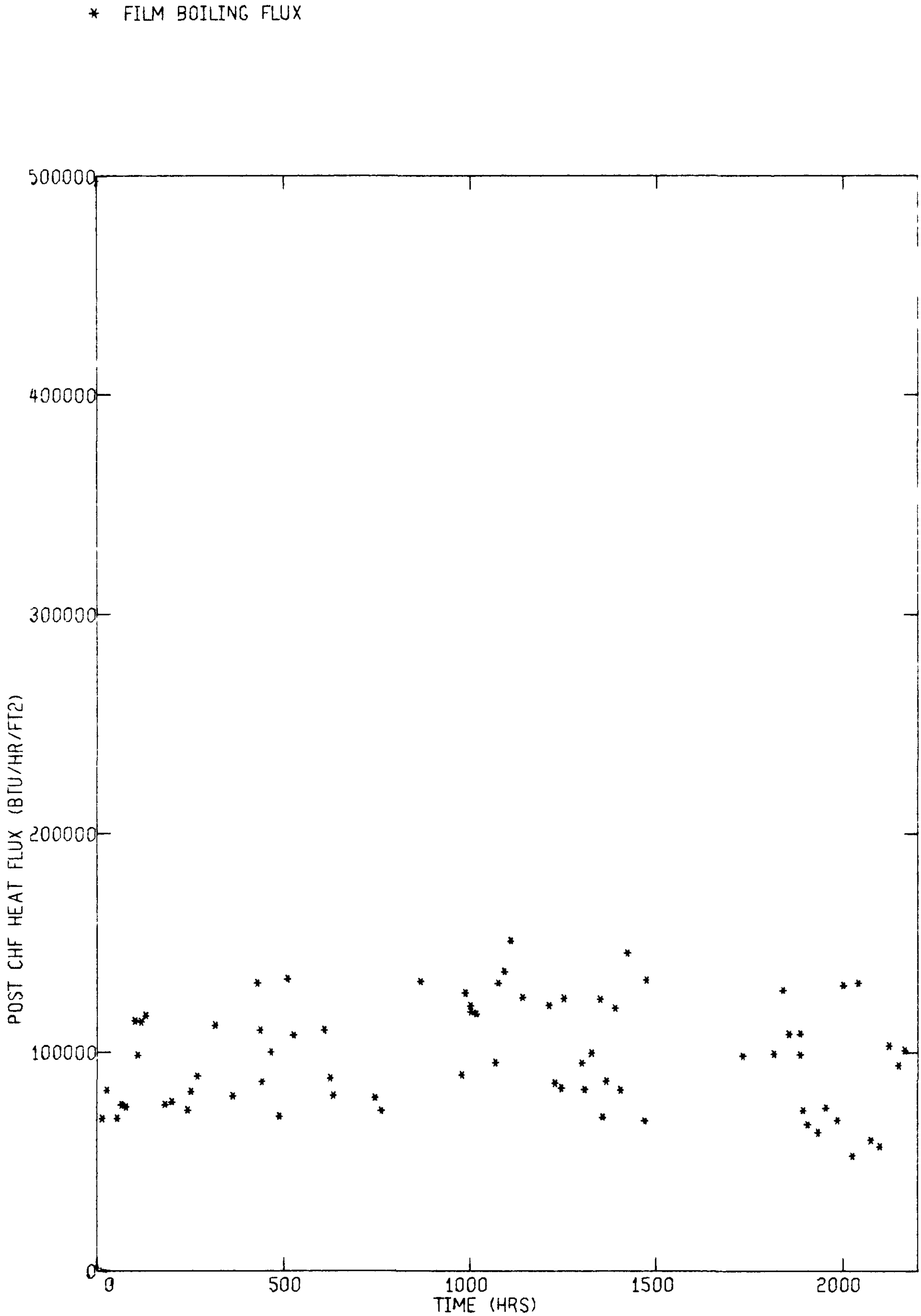


FIGURE 6.9 POST CHF HEAT FLUX VERSES TIME
- LIQUID FILM DRYOUT

PROCEDURE PLOTD 12 12 75

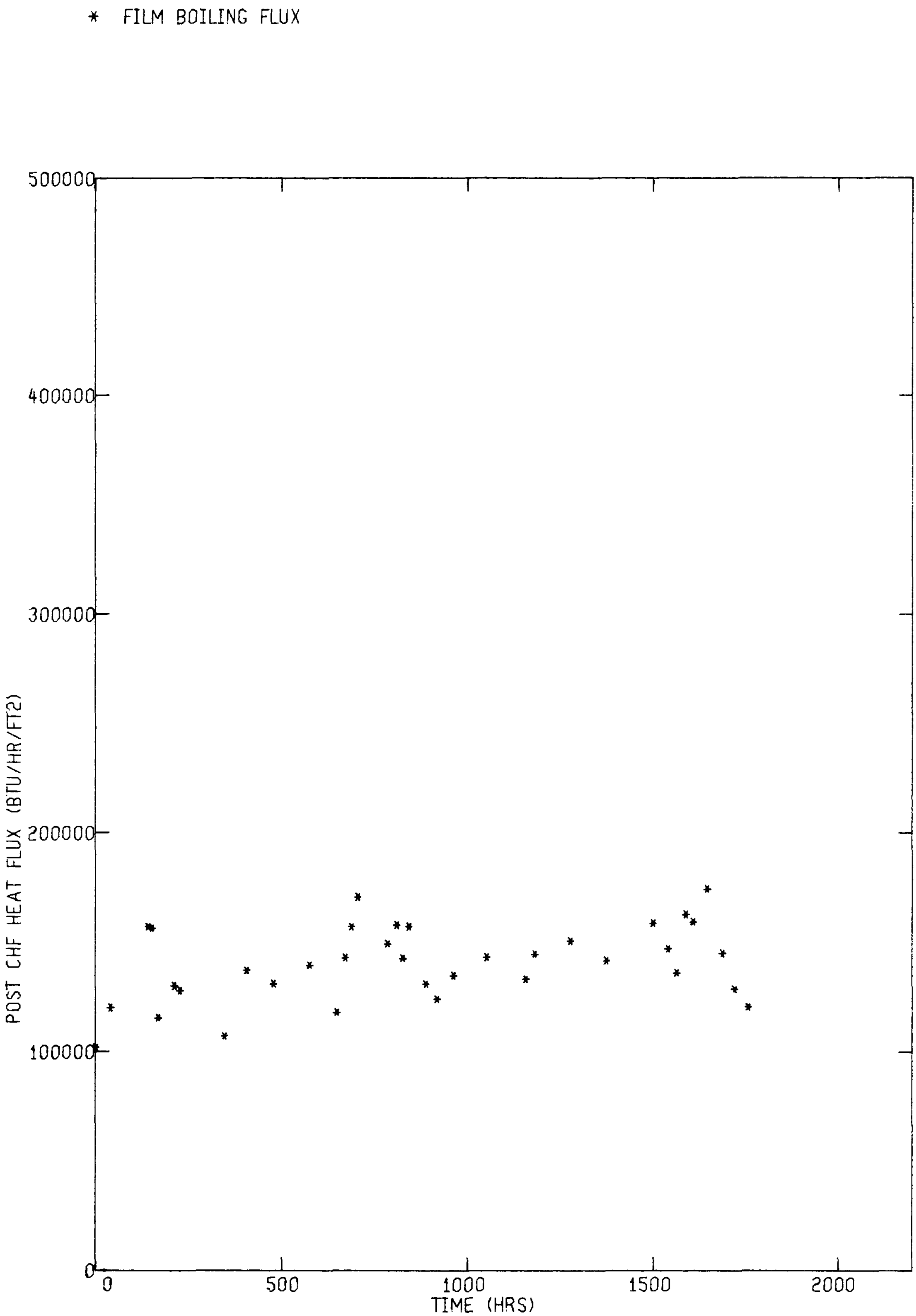


FIGURE 6.10 POST CHF HEAT FLUX VERSES TIME
- TRANSITION

PROCEDURE PLOTD 12 12 75

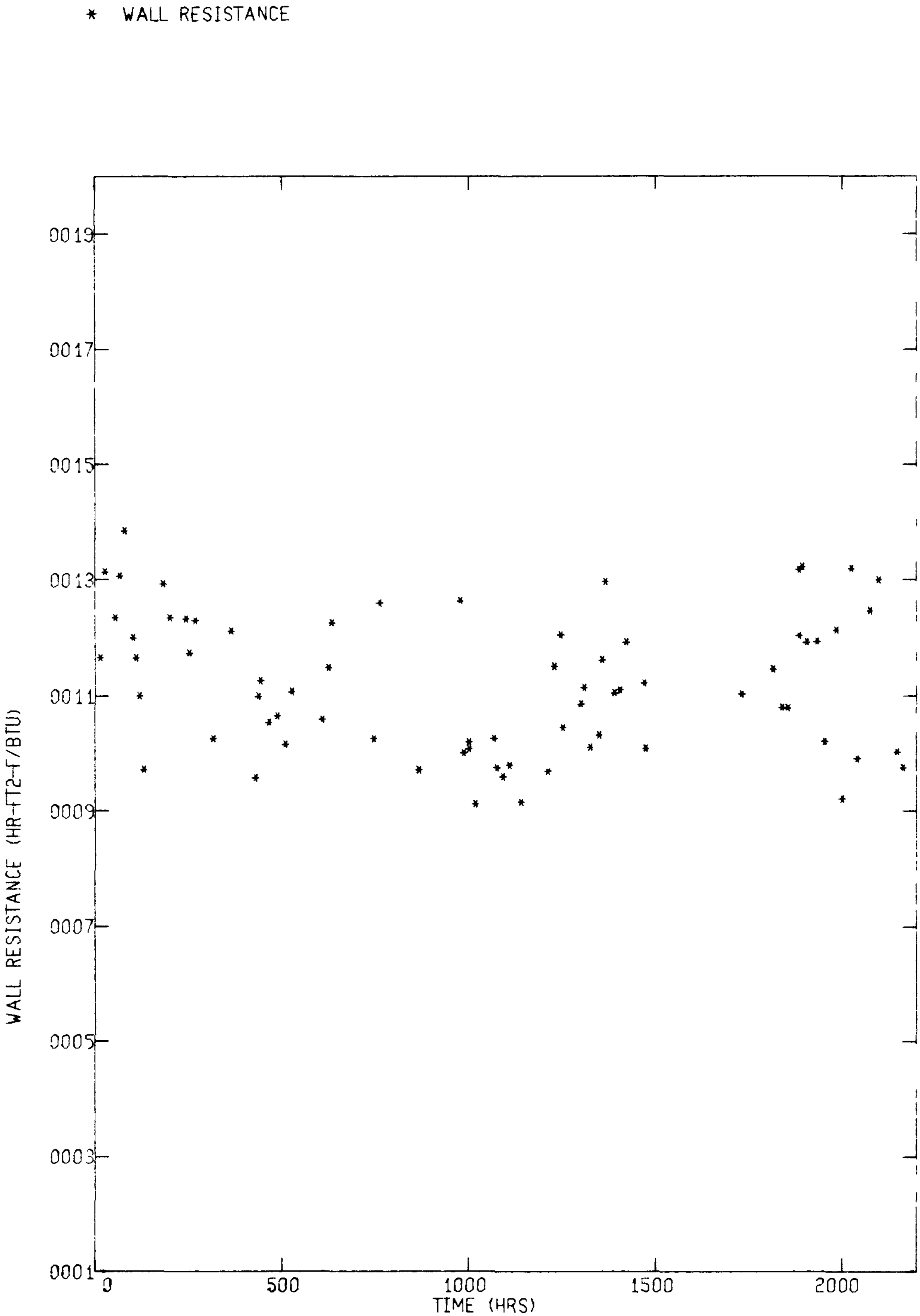


FIGURE 6.11 TUBE THERMAL RESISTANCE VERSES TIME
- LIQUID FILM DRYOUT

PROCEDURE PLOTD 12 12 75

* WALL RESISTANCE

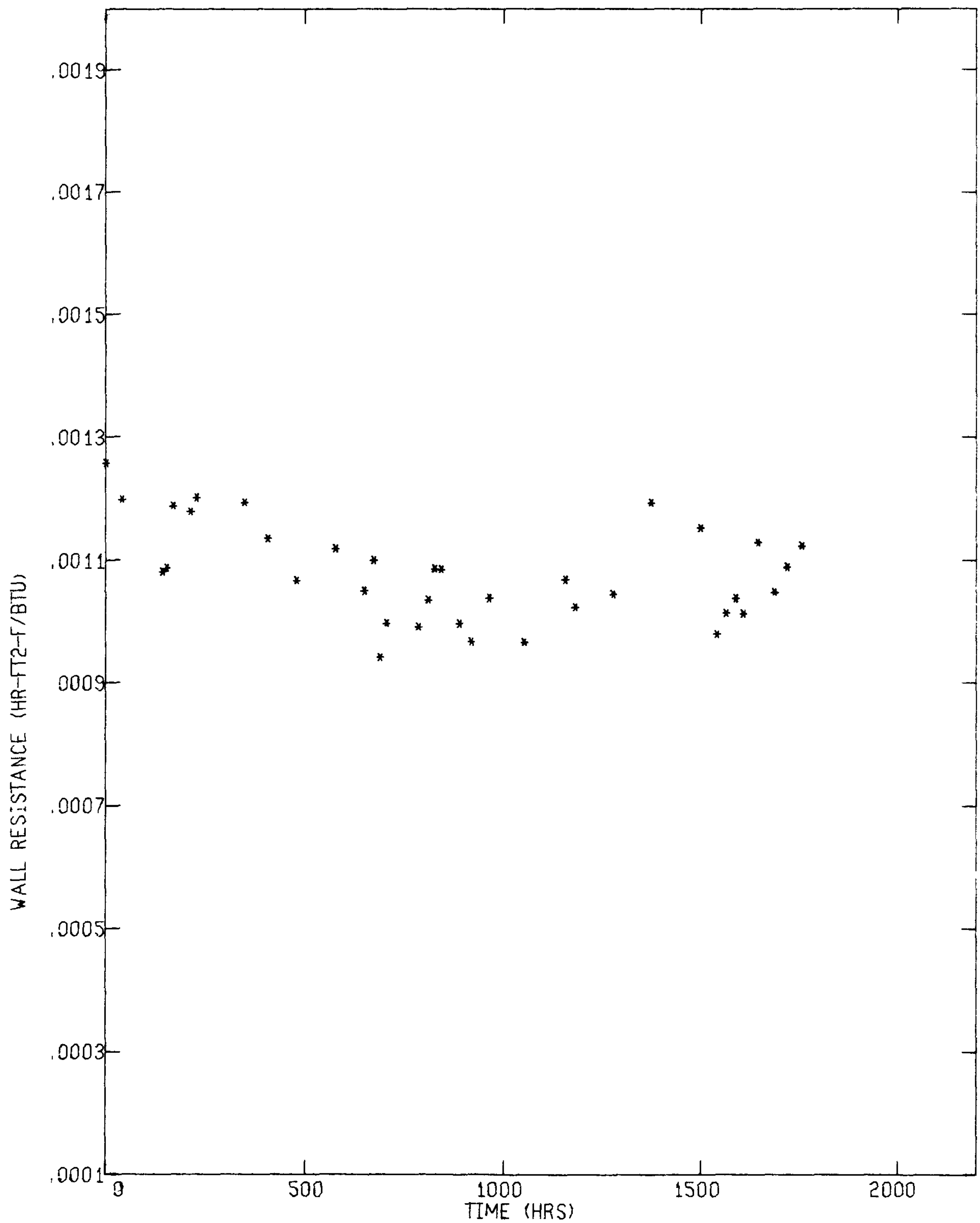


FIGURE 6.12 TUBE THERMAL RESISTANCE VERSES TIME
– TRANSITION

PROCEDURE PLOTD 12 12 75

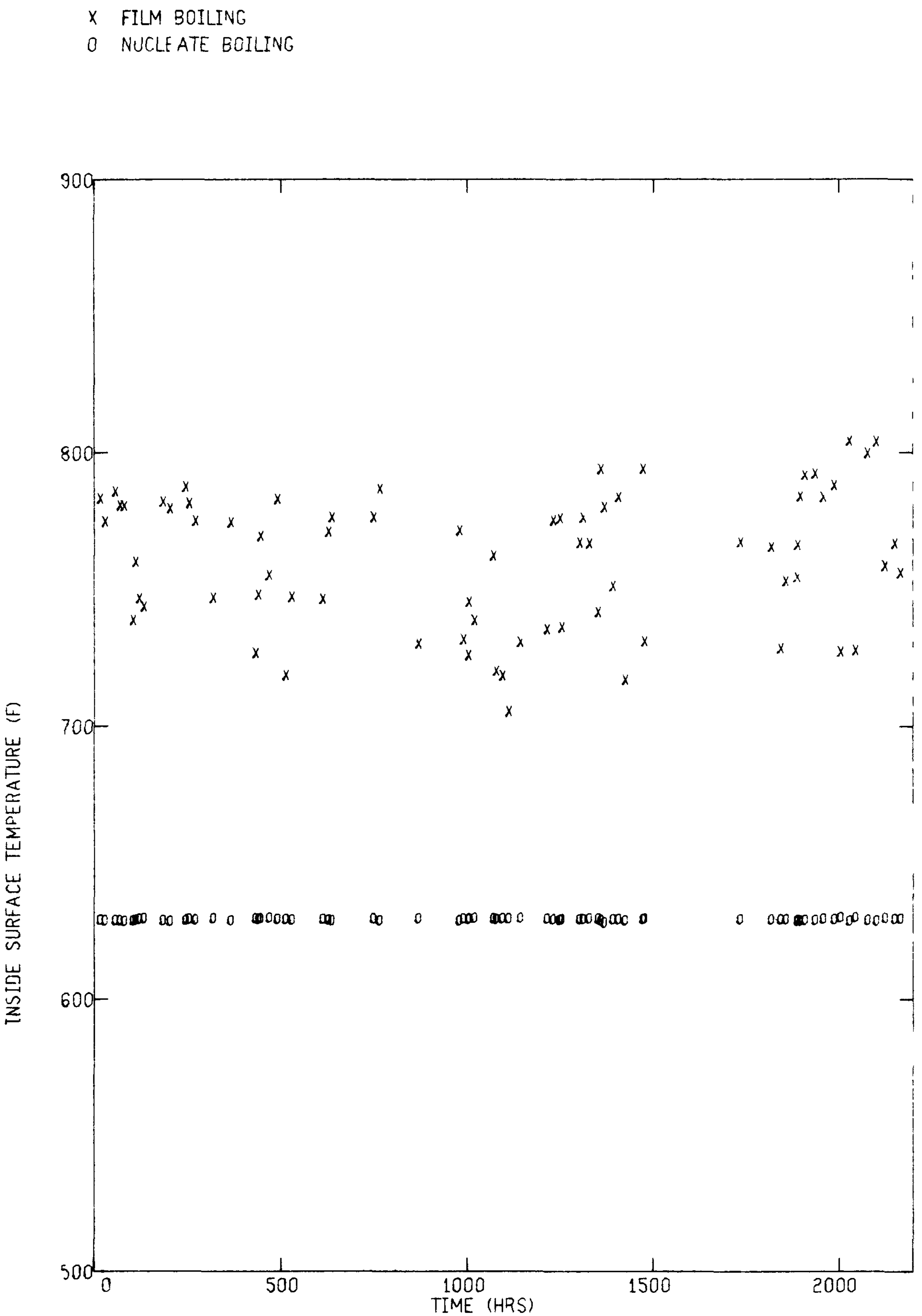


FIGURE 6.13 INSIDE WALL SURFACE TEMPERATURES VERSES TIME – LIQUID FILM DRYOUT

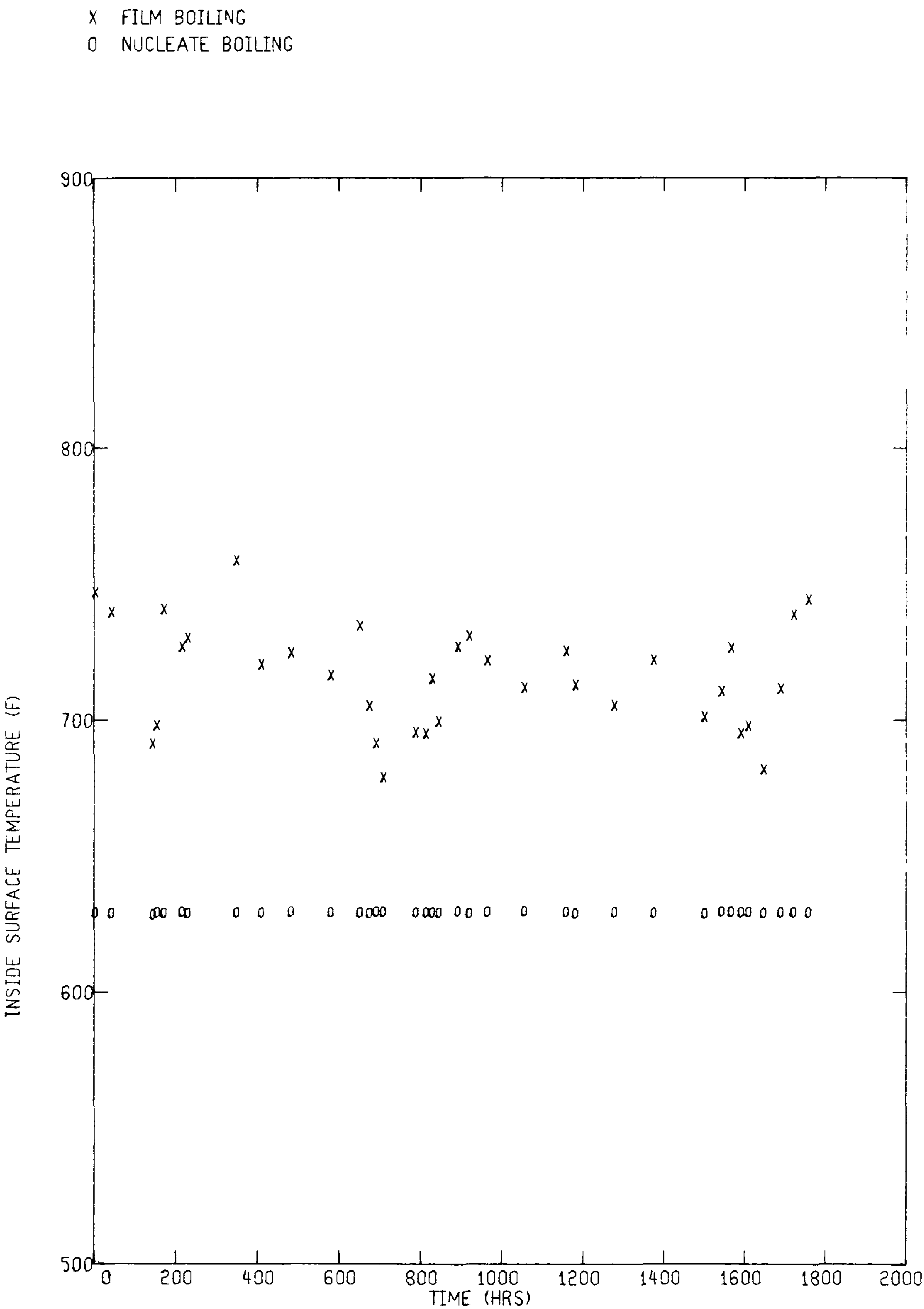


FIGURE 6.14 INSIDE WALL SURFACE TEMPERATURES VERSES TIME - TRANSITION

PROCEDURE PLOTO 12 12 75

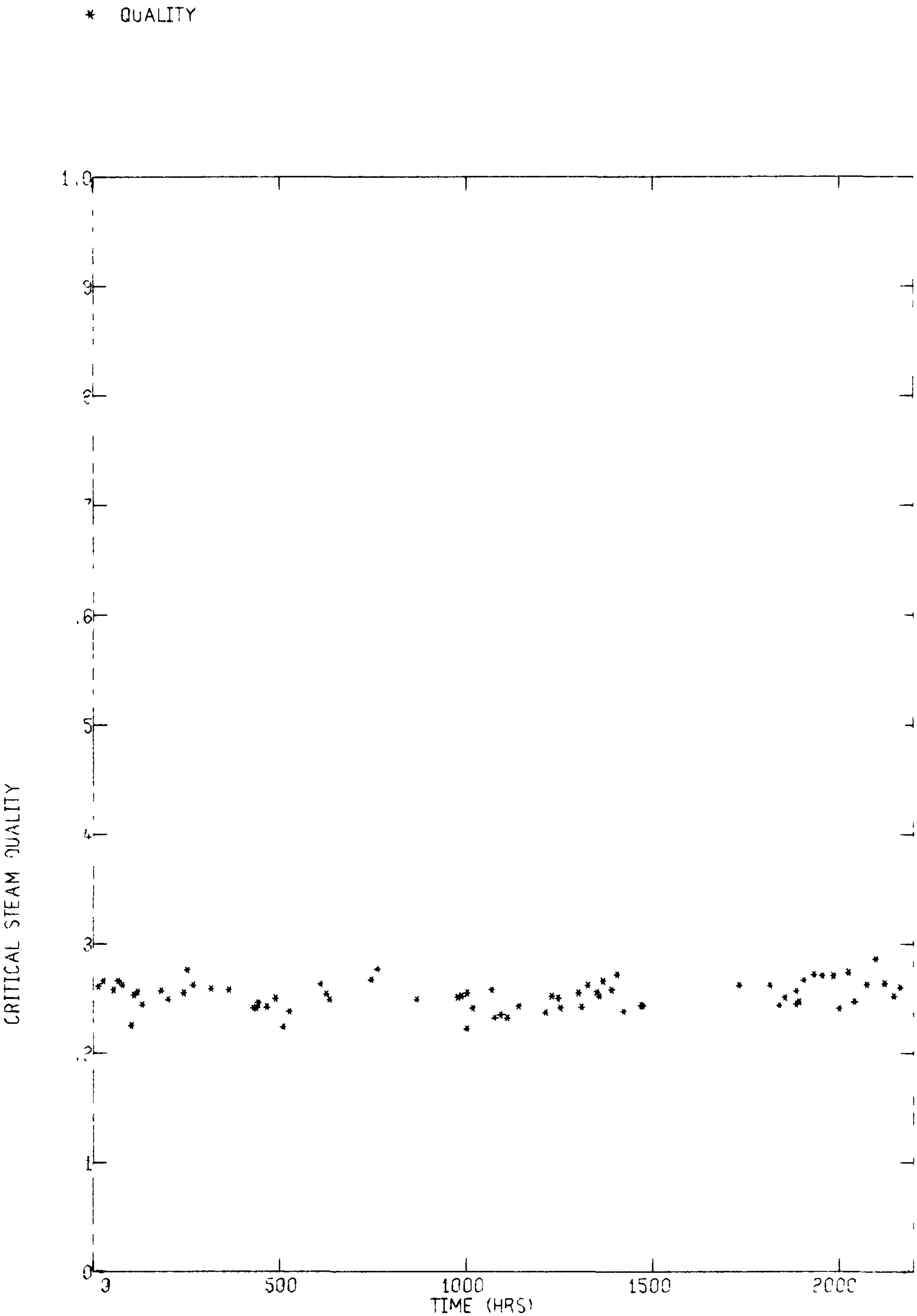


FIGURE 6.15 CRITICAL STEAM QUALITY VERSES TIME
- LIQUID FILM DRYOUT

PROCEDURE PLOTD 12 12 75

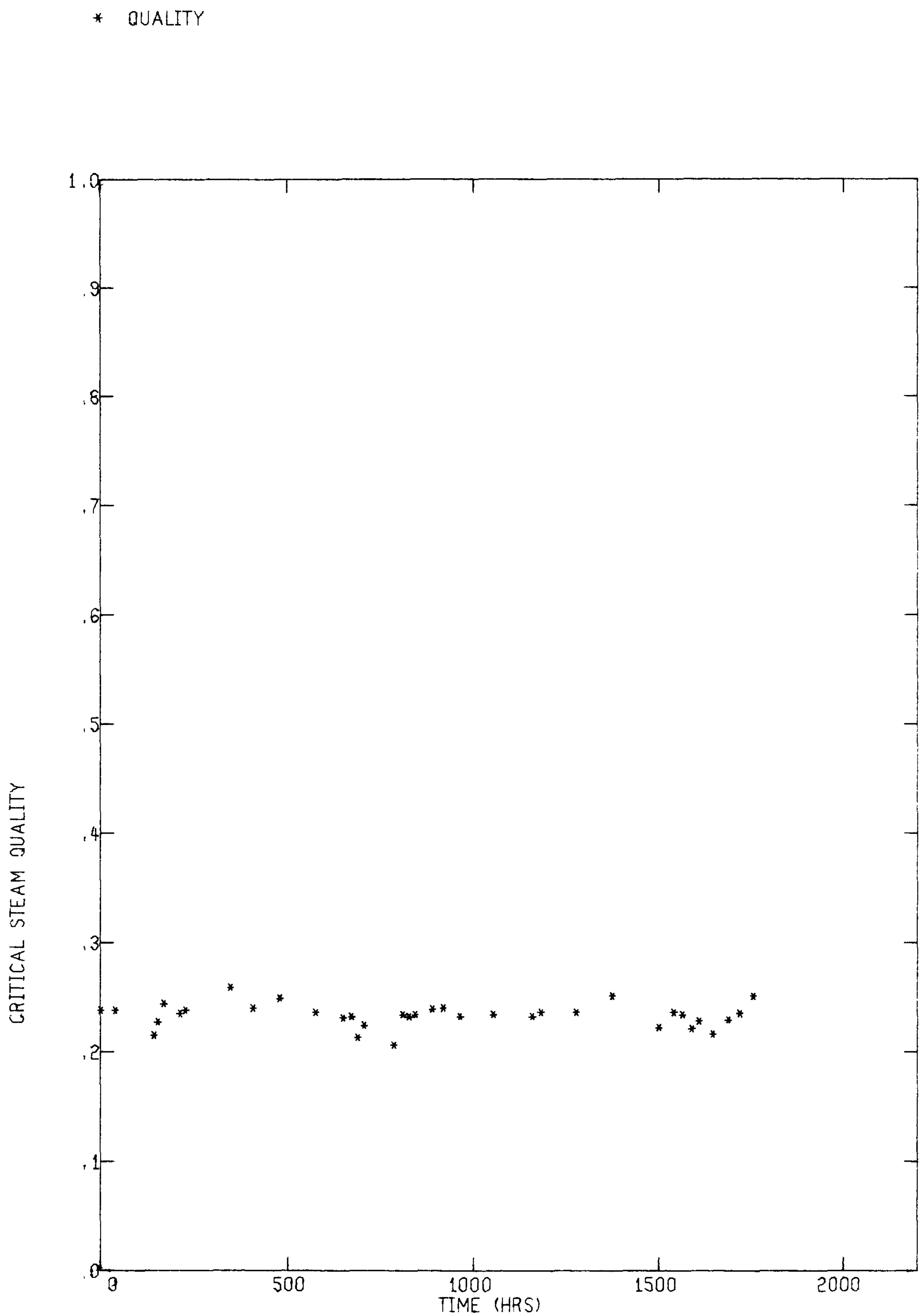


FIGURE 6.16 CRITICAL STEAM QUALITY VERSES TIME
– TRANSITION

PROCEDURE PLOTD 12 12 75

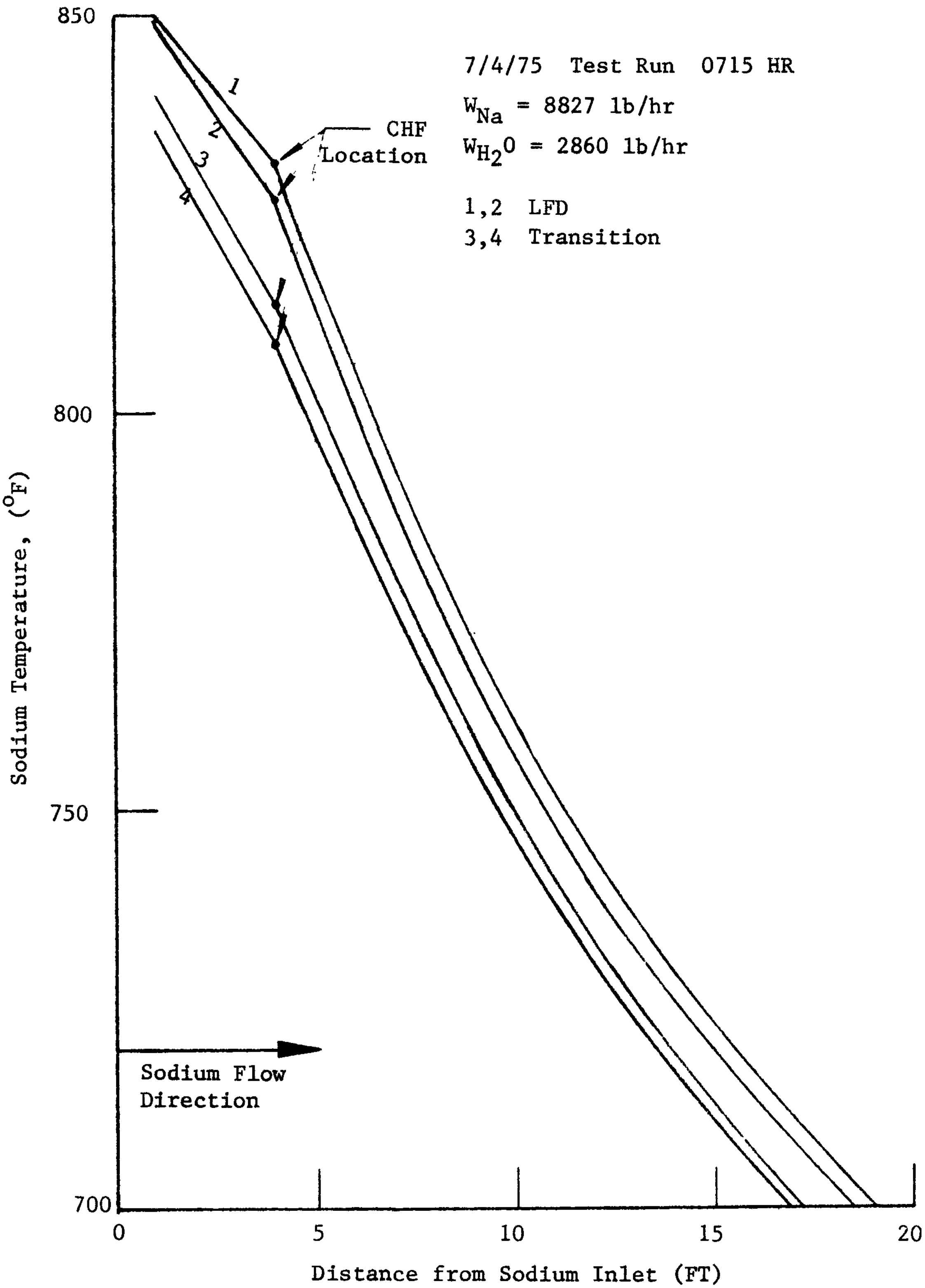


Fig. 6.17 CHF Sensitivity to Sodium Inlet Temperature

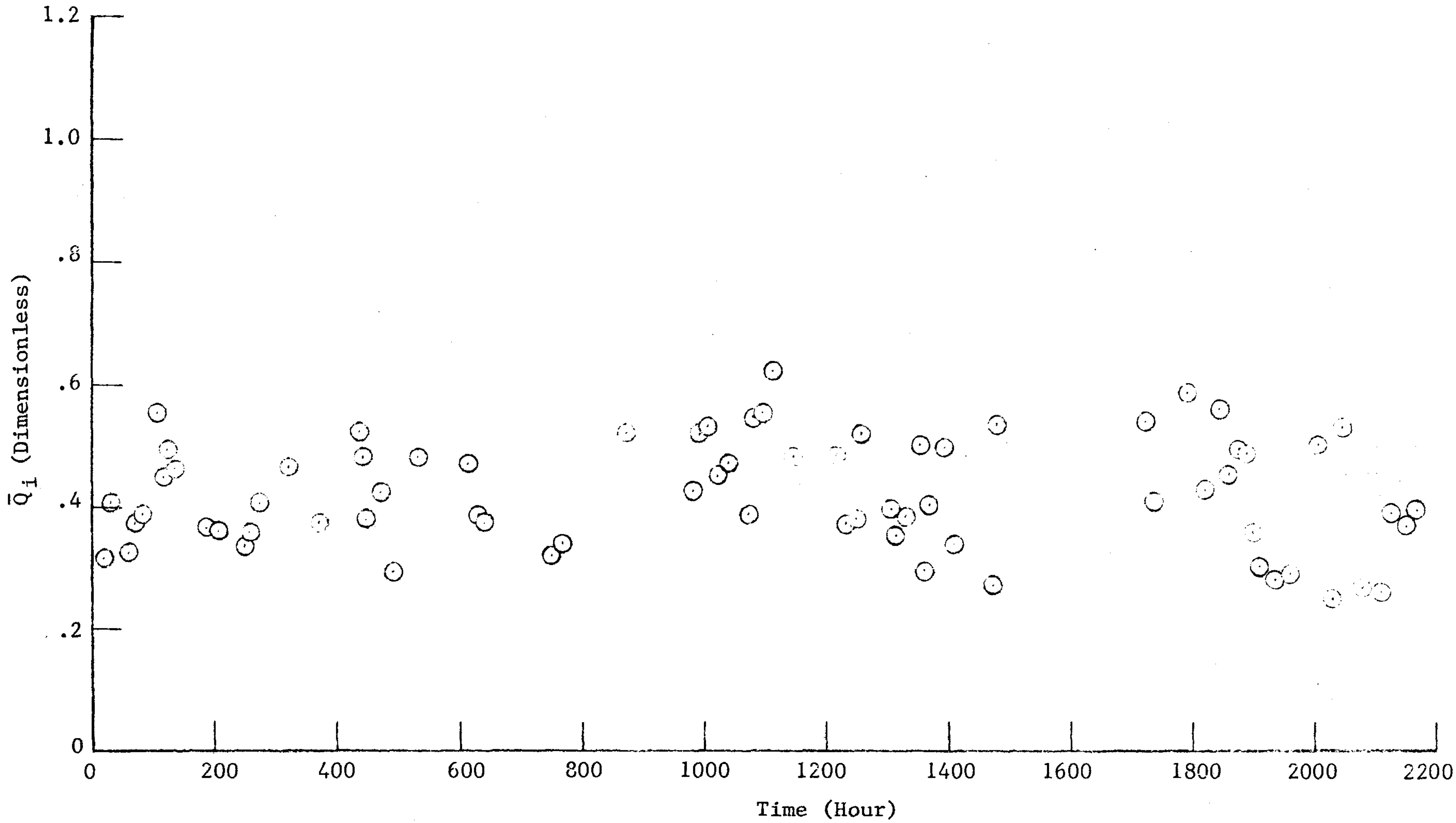


Fig. 6.18 CHF Heat Flux Ratio Versus Exposure Time for LFD Cases

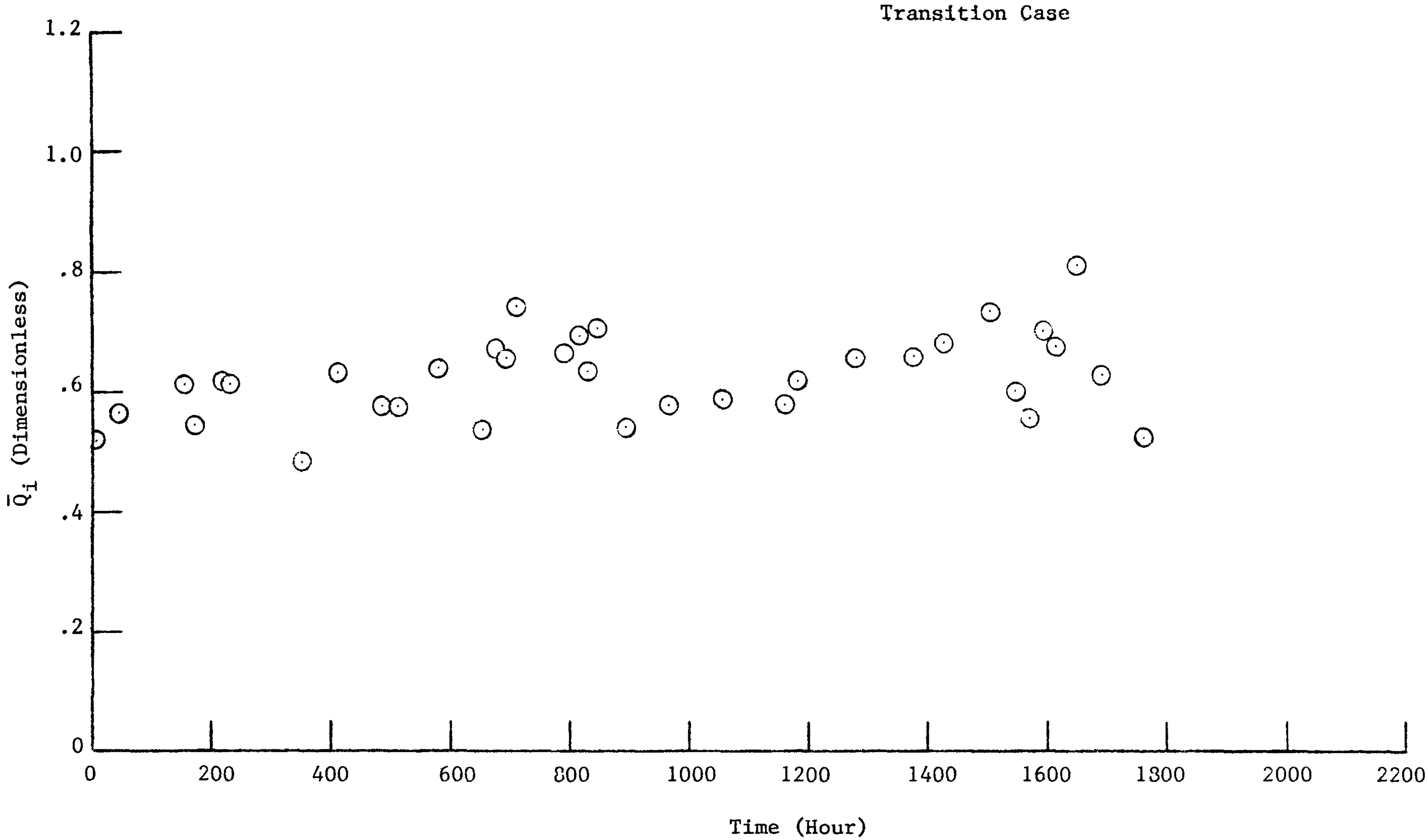


Fig. 6.19 CHF Heat Flux Ratio Versus Exposure Time for Transition Cases

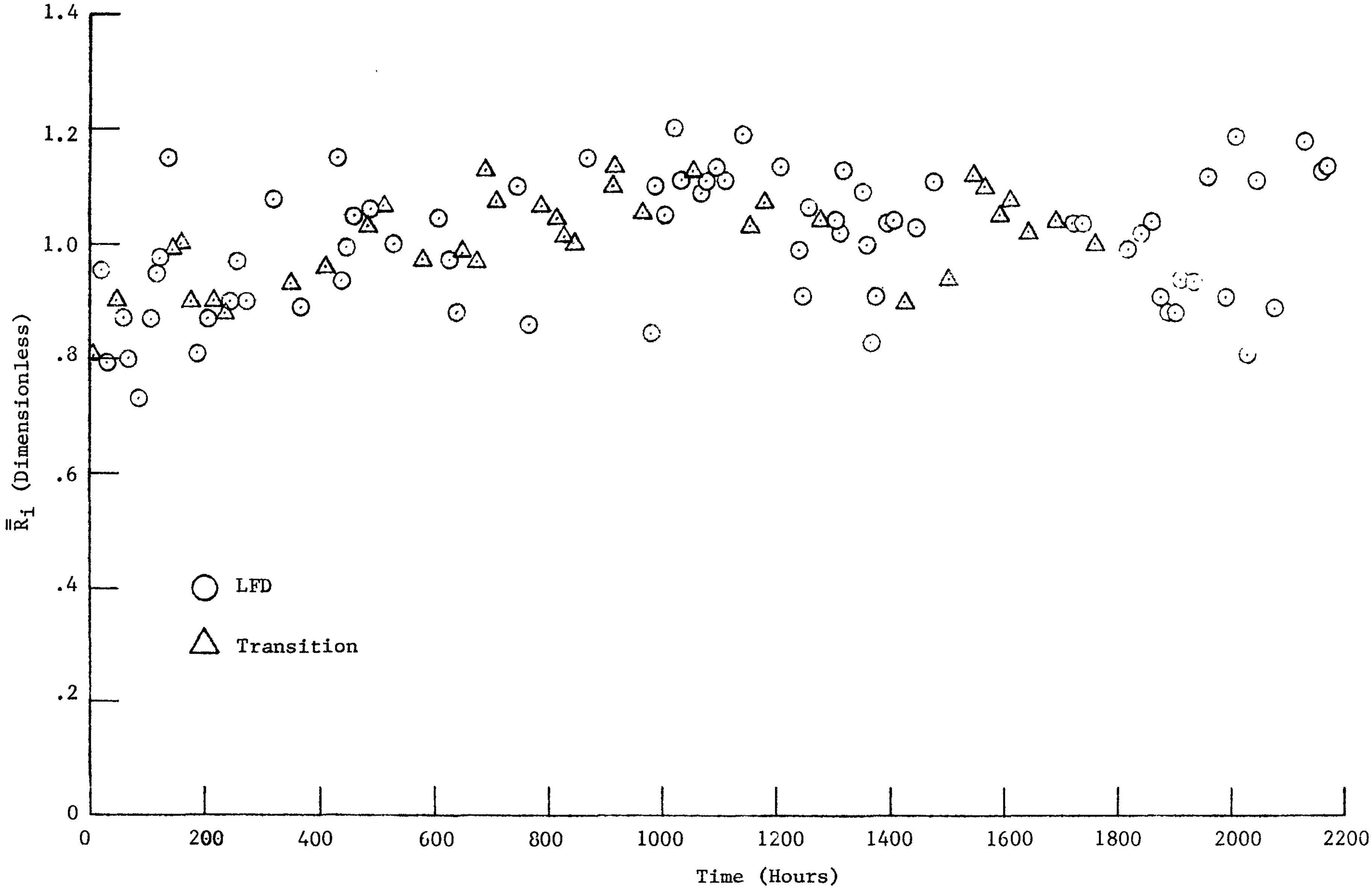


Fig. 6.20 Normalized Wall Resistance Ratio at CHF Versus Exposure Time

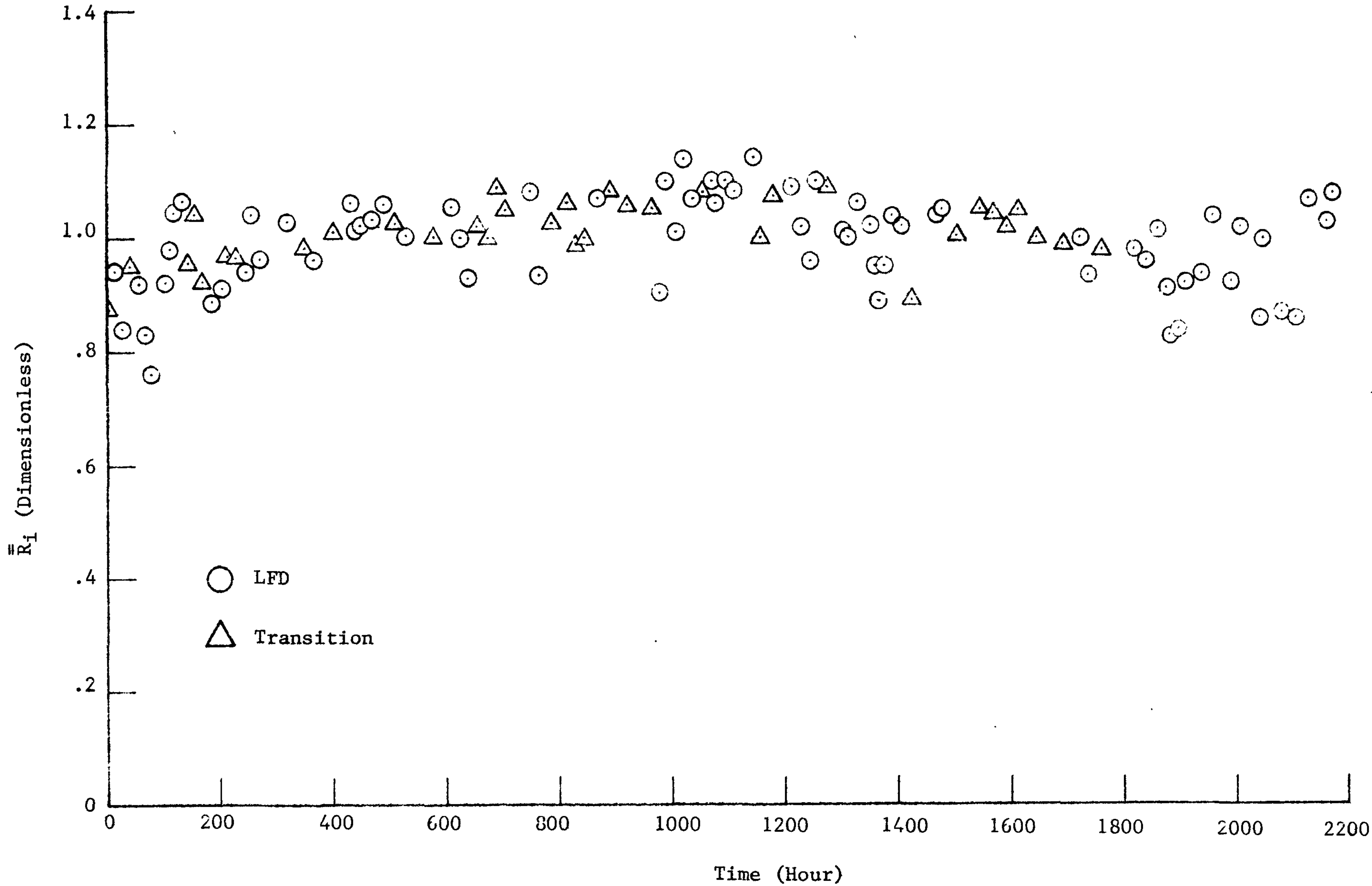


Fig. 6.21 Normalized Wall Resistance Ratio at a Location One Foot Upstream of the CHF Location - Versus Exposure Time

SECTION 7

DISCUSSION AND CONCLUSIONS

As discussed in Section 6.1, fiber optics photographs and diatest gauge measurements of the Small Steam Generator Model (SSGM) tube bore were performed on May 2 and 3, 1975. The purpose of these photographs and measurements was to provide a limited characterization of the SSGM tube bore prior to conducting a 2160 hour critical heat flux (CHF) corrosion test. The primary intent of this limited characterization was to assure that no gross changes had taken place in the model tube bore during earlier testing.

The fiber optics photographs and diameter measurements serve as permanent records of the model tube bore condition and give evidence that no gross surface condition or diameter anomalies were present.

The first 2160 hours of the Phase III corrosion test have been successfully completed. The feedwater system modifications made for the Phase III tests are described in Section 4, Test Facility Description, and in Appendix B. Those modifications were successful in providing an average 31ppb sodium hydroxide concentration (Section 6.2, Table 6.1) at the feedwater inlet to the model. The sodium hydroxide is the corrosion test additive (See Introduction, Section 2). Other average water chemistry parameters (Table 6.1) were 9.18 pH (9.0-10.0 required), 148,800 ohm-cm resistivity (100,000-500,000 ohm-cm required), less than 50ppb chloride (20ppb maximum required), and 2.3ppb oxygen (7ppb ± 5ppb required).

As discussed in Section 6.3, the heat transfer evaluation in the region upstream of CHF indicated a slight decrease in wall thermal resistance followed by a slight increase over the course of the 2160 hours testing to date. It was also determined that CHF transition mechanisms, from LFD to DNB,are highly sensitive to loop operating conditions and require detailed evaluation to maintain the reference CRBRP evaporator full-load conditions in the tube bore. It is also noted that CRBRP part-load conditions are more stringent with regard to CHF and cannot be achieved in the SSGM due to design limitations.

SECTION 8

ACKNOWLEDGEMENTS

The authors wish to acknowledge Mr. A. Lohmeier for specific direction as Project Manager; G. Bieberbach for mechanical design; J. C. Dougherty, P. J. Langford and E. W. Pianka for the structural analysis; W. G. Harris for transient thermal/hydraulic analysis; C. E. Sessions, D. G. Harman and W. H. Kindell for manufacturing and inspection; R. L. Laubham of the Westinghouse Advanced Reactors Division for the extensive testing of the model and G. Nickerson for Phase III data reduction.

The United States Atomic Energy Commission and General Electric Company are acknowledged for support through Task 27 LMFBR Steam Generator Development Program.

SECTION 9

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APPENDIX A

SSGM Chronologic History
at Westinghouse Electric Corp.
Advanced Reactors Division

May 7, 1975	Began Phase III SSGM testing.
	Began circulation of SWL-1.
May 14, 1975	GPL-1/SSGM fill and circulated @ 400°F.
May 16, 1975	SSGM/GPL-1/SWL-1 brought up to testing conditions.
May 17, 1975	SWL-1 pre-heater not working properly. SSGM/GPL-1/SWL-1 shutdown necessitated for repairs of pre-heater. DP-1 assumed.
May 19, 1975	SSGM/GPL-1/SWL-1 filled and circulated @ 400°F.
May 20, 1975	SSGM/GPL-1/SWL-1 brought up to testing conditions.
May 21, 1975	Began taking assumed DNB points. DP-2, DP-3, DP-4, DP-5, DP-6, DP-7.
May 22, 1975	Continued with assumed DNB points. DP-8, DP-9, DP-10.
	WTD personnel at WARD to locate true DNB point for testing.
	Ran through a series of flow variations to locate DNB point @ 859°F sodium temperature. Model flow @ 9,266 lbs/hr, 12,220 lbs/hr, 12,894 lbs/hr, 8,800 lbs/hr, 7,000 lbs/hr.
May 23, 1975	DNB conditions at 12,881 lbs/hr @ 859°F DP-1 taken.
May 24, 1975	Phase III DNB conditions continue. DP-2, DP-3, DP-4, DP-5, DP-6, DP-7.
May 25, 1975	Phase III DNB conditions continue. DP-8, DP-9, DP-10, DP-11, DP-12.
May 26, 1975	Phase III DNB conditions continue. DP-13, DP-14, DP-15, DP-16, DP-17, DP-18.
May 27, 1975	Phase III DNB conditions continue. DP-19, DP-20, DP-21.
May 28, 1975	Phase III DNB conditions continue. DP-22, DP-23, DP-24, DP-25, DP-26, DP-27.
May 29, 1975	Phase III DNB conditions continue. DP-28, DP-29, DP-30, DP-31.
May 30, 1975	Phase III DNB conditions continue. DP-32, DP-33, DP-34, DP-35, DP-36.
May 31, 1975	Phase III DNB conditions continue. DP-37, DP-38, DP-39, DP-40, DP-41, DP-42.

June 1, 1975	Phase III DNB conditions continue. DP-43, DP-44, DP-45, DP-46, DP-47, DP-48.
June 2, 1975	Phase III DNB conditions continue. DP-49, DP-50, DP-51, DP-52, DP-53, DP-54.
June 3, 1975	Phase III DNB conditions continue. DP-55, DP-56, DP-57, DP-58, DP-59, DP-60.
June 4, 1975	Phase III DNB conditions continue. DP-61, DP-62, DP-63, DP-64, DP-65, DP-66.
June 5, 1975	Phase III DNB conditions continue. DP-67, DP-68, DP-69.
	SSGM/GPL-1/SWL-1 shutdown; loss of power due to electrical storm.
June 9, 1975	SSGM/GPL-1/SWL-1 fill and circulated at 400°F.
June 10, 1975	SSGM/GPL-1/SWL-1 brought up to DNB conditions. DP-70.
June 11, 1975	Phase III DNB conditions continue. DP-71, DP-72, DP-73.
June 12, 1975	Phase III DNB conditions continue. DP-74, DP-75, DP-76.
June 13, 1975	Phase III DNB conditions continue. DP-77, DP-78, DP-79.
June 14, 1975	Phase III DNB conditions continue. DP-80, DP-81, DP-82.
June 15, 1975	Phase III DNB conditions continue. DP-83, DP-84, DP-85.
June 16, 1975	Phase III DNB conditions continue. DP-86, DP-87, DP-88.
June 17, 1975	Phase III DNB conditions continue. DP-89 (436 hours @ DNB Point) DP-90, DP-91
June 18, 1975	Phase III DNB conditions continue. DP-92, DP-93.
June 19, 1975	Phase III DNB conditions continue. DP-94, DP-95, DP-96.
June 20, 1975	Phase II DNB conditions continue. DP-97, DP-98, DP-99.

June 21, 1975	Phase III DNB conditions continue. DP-100, DP-101, DP-102.
	Sodium temperature dropped to 400°F due to malfunctioning electrical relays.
June 22, 1975	Electrical fire in the GPL-1/SWL-1 air supply room caused a system shutdown. The SSGM/GPL-1/SWL-1 system was refilled immediately after repair and brought up to DNB conditions. DP-103.
June 23, 1975	Phase III DNB conditions continue. DP-104, DP-105, DP-106.
June 24, 1975	Phase III DNB conditions continue. DP-107, DP-108, DP-109.
June 25, 1975	Phase III DNB conditions continue. DP-110, DP-111. An electrical storm caused a SSGM/GPL-1/SWL-1 shutdown.
June 26, 1975	SSGM/GPL-1/SWL-1 system fill and circulated. System was brought up to DNB conditions.
June 27, 1975	Phase III DNB conditions continue. DP-112, DP-113.
June 28, 1975	Phase III DNB conditions continue. DP-114, DP-115, DP-116.
June 29, 1975	Phase III DNB conditions continue. DP-117, DP-118, DP-119.
June 30, 1975	Phase III DNB conditions continue. DP-120, DP-121, DP-122.
July 1, 1975	Decreased temperature to 400°F for a normal shutdown due to GPL-1 pump powerstat failure.
July 4, 1975	SSGM/GPL-1/SWL-1 system filled and brought up to DNB conditions. DP-123.
July 5, 1975	Phase III DNB conditions continue. DP-124, DP-125, DP-126.
July 6, 1975	Phase III DNB conditions continue. DP-127, DP-128, DP-129.
July 7, 1975	Phase III DNB conditions continue. DP-130, DP-131, DP-132.

July 8, 1975	Phase III DNB conditions continue. DP-133, DP-134, DP-135 (805 HRS. @ DNB POINT)
July 9, 1975	Phase III DNB conditions continue. DP-136, DP-137
July 10, 1975	Phase III DNB conditions continue. DP-138, DP-139
July 11, 1975	Phase III DNB conditions continue. DP-140, DP-141, DP-142
July 12, 1975	Phase III DNB conditions continue. DP-143, DP-144, DP-145
July 13, 1975	Phase III DNB conditions continue. DP-146, DP-148
July 14, 1975	Phase III DNB conditions continue. DP-149, DP-150, DP-151
July 15, 1975	Phase III DNB conditions continue. DP-152, DP-153, DP-154
July 16, 1975	Loss of shop air ruptured oil line on compressor-lowered sodium temperature to 650°F - repairs made - DP-155.
July 17, 1975	Phase III DNB conditions continue. DP-156, DP-157, DP-158
July 18, 1975	Phase III DNB conditions continue. DP-159, DP-160, DP-161
July 19, 1975	Phase III DNB conditions continue. DP-162, DP-163, DP-164
July 20, 1975	Phase III DNB conditions continue. DP-166, DP-167
July 21, 1975	Phase III DNB conditions continue. DP-168, DP-169, DP-170
July 22, 1975	Phase III DNB conditions continue. DP-171, DP-172, DP-173
July 23, 1975	Phase III DNB conditions continue. DP-174, DP-175, DP-176
July 24, 1975	Phase III DNB conditions continue DP-177, DP-178, DP-179

July 25, 1975	Phase III DNB conditions continue DP-180, DP-181
July 26, 1975	Phase III DNB conditions continue DP-182, DP-183, DP-184
July 27, 1975	Phase III DNB conditions continue DP-185, DP-186, DP-187
July 28, 1975	Phase III DNB conditions continue DP-188, DP-189, DP-190
July 29, 1975	Phase III DNB conditions continue DP-191, DP-192, DP-193
July 30, 1975	Phase III DNB conditions continue DP-194, DP-195, DP-196
July 31, 1975	Phase III DNB conditions continue DP-197, DP-198, DP-199
August 1. 1975	Phase III DNB conditions continue DP-200, DP-201, DP-202
August 2, 1975	Phase III DNB conditions continue DP-203, DP-204, DP-205
August 3, 1975	Phase III DNB conditions continue DP-206, DP-207, DP-208
August 4, 1975	Phase III DNB conditions continue DP-209, DP-210, DP-211
August 5, 1975	Phase III DNB conditions continue DP-212, DP-213, DP-214
August 6, 1975	Phase III DNB conditions continue DP-215, DP-216, DP-217
August 7, 1975	Phase III DNB conditions continue DP-218, DP-219, DP-220
August 8, 1975	Phase III DNB conditions continue DP-221, DP-222, DP-223
August 9, 1975	Phase III DNB DP-224 was taken. SSGM (SWL-1) GPL-1 Shutdown due to chem-pump bearing failure. T-SCT-DKS-75-46

August 11, 1975	Began disassembly of the chem-pump
August 12, 1975	Continued disasssembly of the chem-pump
August 13, 1975	Began looking at alternate ideas to secure another pump
August 19, 1975	Procured new bearings for the pump. P.O. #239208
August 20, 1975	Began chem-pump reassembly and installation into SWL-1 system
August 21, 1975	Chem-pump was started and stopped several times. The SWL-1 system was filled and circulating.
August 23, 1975	SSGM/GPL-1/SWL-1 fill and brought up to DNB conditions for 6 hours - then the chem-pump failure - stator and rotor damage. T-SCT-DKS-75-46
September 15, 1975	The SWL-1 system was started and put on a normal H_2O chemistry circulation condition.
September 19, 1975	DNB conditions reached continued Phase III testing. DP-225, DP-226
September 20, 1975	Phase III DNB conditions continue. DP-227, DP-228, DP-229
September 21, 1975	Phase III DNB conditions continue. DP-230, DP-231, DP-232
September 22, 1975	Phase III DNB conditions continue. DP-233 at 1145 AM 1625 hrs. @ DNB conditions
September 22, 1975	Continued with Phase III DNB Conditions DP-234, DP-235
September 23, 1975	Continued with Phase III DNB Conditions DP-236, DP-237, DP-238
September 24, 1975	Continued with Phase III DNB Conditions DP-239, DP-240, DP-241
September 25, 1975	Continued with Phase III DNB Conditions DP-242, DP-243
September 26, 1975	Continued with Phase III DNB Conditions DP-244, DP-245

September 27, 1975	Continued with Phase III DNB Conditions DP-247 @ 1830 hours. Loop dump - rupture disc-Na side shutdown - 1752.75 hours at DNB Conditions
September 28, 1975	Began repairs of the GPL-1, Na rupture disc line.
September 29, 1975	Repairs to be made per MIT 1740.
October 2, 1975	Repairs Complete on GPL-1.
October 3, 1975	SSGM/GPL-1/SWL-1 system fill and circulating.
October 4, 1975	Phase III DNB conditions continue SP-248, DP-249.
October 5, 1975	Phase III DNB conditions continue DP-250, DP-251, DP-252.
October 6, 1975	Phase III DNB conditions continue DP-253, DP-254, DP-255.
October 7, 1975	Phase III DNB conditions continue DP-256, DP-257, DP 258.
October 8, 1975	Phase III DNB conditions continue DP-259, DP-260, DP-261.
October 9, 1975	Phase III DNB conditions continue DP-262, DP-263, DP-264.
October 10, 1975	Phase III DNB conditions continue DP-265, DP-266, DP-267.
October 11, 1975	0019 HRS loop dump rupture disc failure - 1927.3 hrs @DNB conditions.
October 12, 1975	Began repairs of GPL-1-SSGM per MIT 1771
October 20, 1975	Repairs complete-preparation for SSGM-GP-1-SWL-1
October 21, 1975	SSGM-GPL-1-SWL-1 filled and circulating for ten hours. System Scram caused by faulty alarm relay
October 22, 1975	SSGM-GPL-1-SWL-1 filled and circulating at 400°F
October 23, 1975	Began increasing temperature to DNB conditions at 600°F. System shutdown caused by rupture disc failure.
October 24, 1975	Meeting with W Tampa respresentative concerning rupture disc failures.
October 27, 1975	Third review meeting held concerning rupture disc failures T-SCT-CRS-75-94
October 28, 1975	Loop repairs underway per MIT 1795

October 31, 1975	SSGM-GPL-1/SWL-1 filled and circulating at 400°F.
November 1, 1975	System circulating at 400°F.
November 2, 1975	System circulating at 400°F.
November 3, 1975	Increased sodium temperature to DNB conditions DP-268.
November 4, 1975	Phase III DNB conditions continue DP-269, DP-270
November 5, 1975	Phase III DNB conditions continue DP-271 Power failure-SSGM-GPL-1/SWL-1 dropped 400°F.
	System back up to DNB conditions DP-272.
November 6, 1975	Phase III DNB conditionc continue DP-273, DP-274, DP-275.
November 7, 1975	Phase III DNB conditions continue DP-276, DP-277, DP-278.
November 8, 1975	Phase III DNB conditions continue DP-279, DP-280, DP-281
November 9, 1975	Phase III DNB conditions continue DP-282, DP-283, DP-284.
November 10, 1975	Phase III DNB conditions continue DP-285, DP-286, DP-287.
November 11, 1975	Phase III DNB conditions continue DP-288, DP-289, DP-290.
November 12, 1975	Phase III DNB conditions continue DP-291, DP-292. Phse III DNB conditions interrupted for @ 7 hrs. instrumentation power loss.
November 13, 1975	Phase III DNB conditions continue DP-293, DP-294, DP-295.
November 14, 1975	Phase III DNB conditions continue DP-296, DP-297, DP-298.
November 15, 1975	Phase III DNB conditions continue DP-299, DP-300, DP-301.

APPENDIX B

Effective Boiler Feed
Control for Test Loops (SWL-1)

DOCUMENT NO 5284

EFFECTIVE BOILER FEED CONTROL FOR TEST LOOPS

D. K. Schmidt/Z. L. Kardos

Approved by:

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December, 1975

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ABSTRACT

EFFECTIVE BOILER FEED CONTROL FOR TEST LOOPS

The Clinch River Breeder Reactor Program (CRBRP) requires that the associated steam generator development testing facility construct an effective water supply having chemical control plus system monitoring to support a small inventory test loop.

A pretreatment feed water system that chemically controls an ultra critical flow-through test loop was developed for the CRBRP sodium heated steam generator model test (0.27 MWt). The test parameters require very stringent control of the water supply including comprehensive chemical analyses plus on-line system monitoring of the aqueous steam generator side. The feed water system includes unique features such as:

1) Successive demineralization steps to achieve 10 ppb metallic concentrations and 50 ppb total halogens.

2) Multi-stage deoxygenation by inert gas sparging followed by a catalyzed hydrazine reaction to attain <7 ppb O_2.

3) Chemical batch mixing plus analyses techniques to control and monitor a 30 ppb sodium hydroxide corrosive test additive controlled at pH 9.3 with ammonium hydroxide to assure the test systems' reliability.

The effectiveness of this system is supported by a successful 2160 hour corrosion test that provides a comparison of on-line monitoring and analytical test data. A detailed discussion of the chemical control requirements and design considerations is presented along with specific analytical techniques and potential larger system applications.

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EFFECTIVE BOILER FEED CONTROL FOR TEST LOOPS

Steam Generator Development Testing In Support Of The Clinch River Breeder Reactor Program (CRBRP) Requires Effective Means Of Monitoring And Maintaining Feed Water Chemistry In A Small Inventory Test Loop.

1.0 INTRODUCTION

The Westinghouse Advanced Reactors Division One MWt Sodium Heated Steam Generator Test Facility required an ultra pure water supply to duplicate CRBR plant operating conditions.

The aqueous side of the steam generator test facility which is typical of most small volume systems, presented special problems in maintaining chemistry parameters. A multiple function, feed water pre-treatment system was developed to duplicate the plant "worst case" water chemistry and included a deliberate sodium hydroxide contamination.

2.0 BACKGROUND

The Westinghouse Advanced Reactors Divison has, for many years, operated a one MWt liquid sodium heated steam generator test facility in support of steam generator development for Liquid Metal Fast Breeder Reactors (LMFBR). Most of the previous development work has been performed to verify heat transfer analysis needed to develop design codes. The duplication of water chemistry parameters, although important, was not critical to the heat transfer tests; however, with the unique features of LMFBR and specifically CRBR Steam Generator designs, extremely well controlled testing with ultra pure feed water was required to study the DNB (Dry Nucleate Boiling) zone, water - side corrosion effects. To meet these needs, a multiple function pre-treatment feed water system capable of maintaining ultra pure water was developed.

The CRBRP evaporator design presently identifies recirculation, combined with DNB in the tubes. Since domestic fossil-fired evaporators do not operate with this two-fold combination of DNB in the tubes and recirculation, this feature is unique to the CRBR design; and there are no available statistics on operating histories or failures related to this feature. Several test programs have been identified to provide the necessary data to assess potential damage phenomena. Several distinctly different, but related damage phenomena may appear when DNB is allowed to occur in an evaporator tube. All are initiated by the fact that tube wall "Dryout" takes place, even though the steam quality is less than 100%. One of these phenomenae is accelerated corrosion resulting from solution (NaOH) concentration in the "dryout" region.

Because of impurity concentration in the CRBRP recirculation drum design plus DNB in the tube, the impurity level, specifically the sodium salt concentrations in the evaporator inlet, will be much higher than that encountered in a once-through design. This higher salt concentration entering the unit will result in a significant salt concentration at the "Dryout"; and this in turn can lead to accelerated tube corrosion.

A Duplex - Tube, J - Modular, Steam Generator Model was installed in the Steam Generator Test Facility and tested to study the effects of sodium hydroxide concentration on the corrosion phenomena at the DNB "dryout" at simulated CRBRP evaporator conditions.

Inasmuch as the ARD Steam Generator Test Facility is a once-through, circulating system without steam drum or re-circulation capability, the model was subjected to water chemistry conditions relating to the CRBRP evaporator inlet. Through adjustment of the model inlet water chemistry, accelerated DNB-Corrosion Tests were carried-out. The model was examined by non-destructive test (NDT) methods prior to testing and extensive post-test metallographic examination, will be carried out to characterize the corrosion behavior at the the DNB-zone in the evaporator.

3.0 PRE-TREATMENT FEED WATER SYSTEM DESCRIPTION

The feed water system depicted schematically by Figure 1 includes unique features such as:

- Successive demineralization steps to achieve 10 ppb metallic concentrations and <50 ppb total halogens.
- Multi-stage deoxygenation by inert gas sparging followed by a catalyzed hydrazine reaction to attain <7 ppb O_2.
- Chemical batch mixing plus analyses techniques to control and monitor a 30 ppb sodium hydroxide corrosive test additive controlled at pH 9.3 with ammonium hydroxide.

Physically, the pre-treatment feed water system was designed in three stages with each stage performing one or more sucessive functions to supply feed water to the test loop at the required water chemistry parameters. The pre-treatment stages of 1) water purification, 2) multifunction reservoir supply tanks, and 3) reaction loop supply tank are discussed in detail:

3.1 Water Purification - Tap water is passed through a 10 micron filter, a multiple bed demineralizer, and an ultra-pure, mixed-bed ion exchange unit to provide 300 gallons per hour of high purity water with greater than 2 megohm resistivity. The multiple bed demineralizer consists of three separate one cubic foot units containing cation, anion, and mixed bed resin, respectively, which allows quick change over to new columns when the units are depleted.

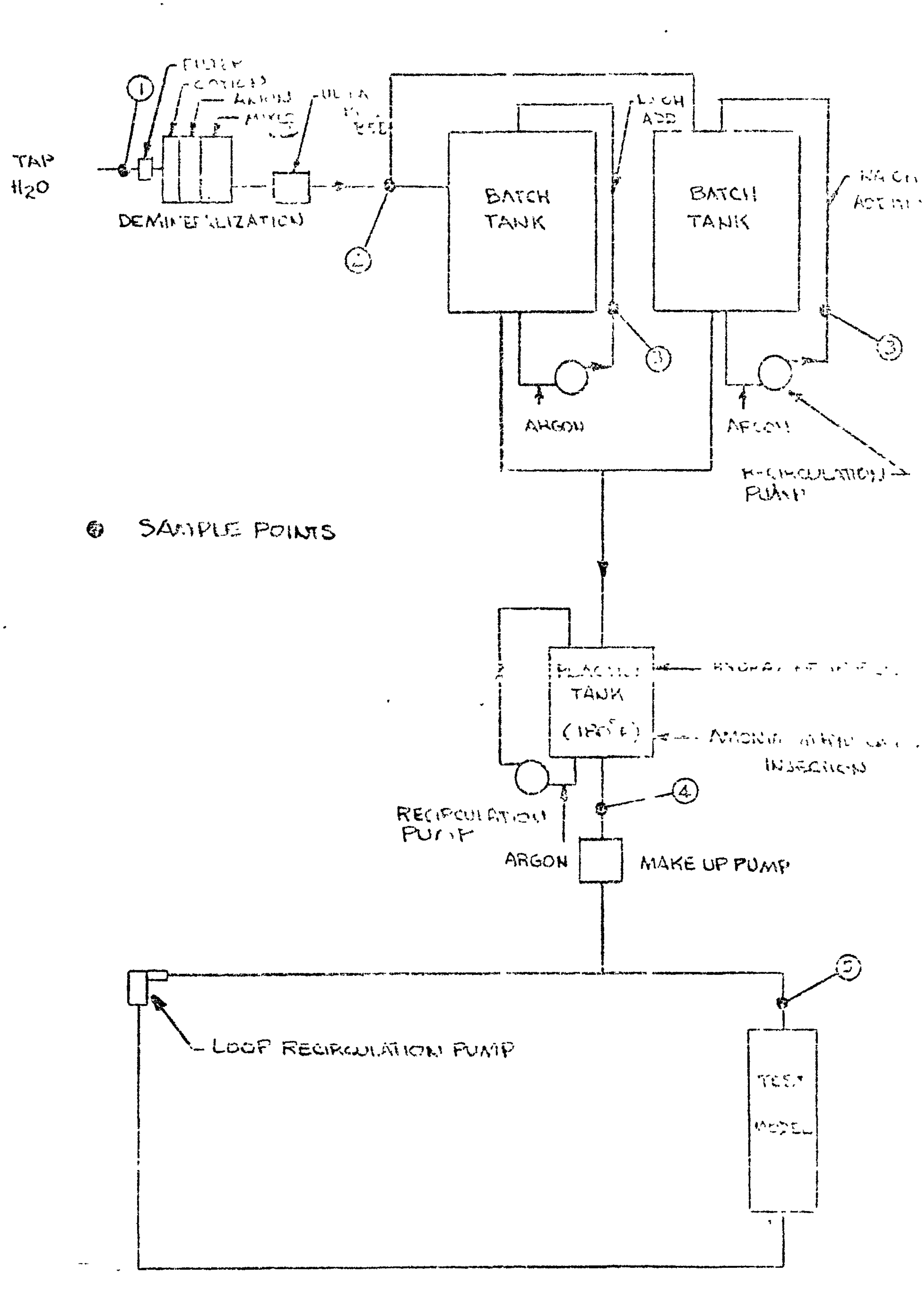


FIGURE 1. SYSTEM SCHEMATIC

The ultra pure ion exchange unit is a five cubic foot mixed-bed ion colum which acts as a polishing unit. The effluent water purity is guarded by an electronic resistivity monitor which will initiate an alarm and divert the effluent water to the drain if the resistivity falls below the 2 megohm limit.

3.2 Multiple Function Reservoir Supply Tank - Two (2) 800 gallon stainless steel tanks alternately filled with high purity water are equipped with an argon sparge and a closed cycle recirculation system. The argon sparge (30 cubic feet/hour) is used to effectively deoxygenate the system from 5 ppm to 0.02 ppm in approximately 30 hours. Pump recirculation at 600 gallons per hour is used in conjunction with injection of sodium hydroxide to maintain a thoroughly mixed solution. The deoxygenated sodium hydroxide solution is supplied continuously to the reaction loop tank alternately from the reservoir tanks which allow the other reservoir tank to be filled, preadjusted and equilibrated to the chemical simulation parameters. Daily sampling and analysis are performed to monitor the required 30 ± 3 ppb sodium concentration.

3.3 Reaction Loop Supply Tank - Treated water of less than 20 ppb oxygen and 30 ± 3 ppb sodium is supplied to the reaction loop supply tank on demand as controlled by level indicators in the tank. The reaction tank is a 55 gallon stainless steel drum with argon sparging, recirculation mixing, and 180°F temperature control features. Auxilliary drums are provided to contain a pH 10.5 ammonium hydroxide solution and a 15 ppm hydrazine solution. These solutions are automatically metered into the reaction tank during each fill cycle to obtain pH adjustment and final deoxygenation of the feed water within the reaction tank. The feed water make-up pump provides a constant supply of ultra-pure treated water from the reaction tank to the test loop at approximately 10 gallons per hour. No additional feed water treatment is performed within the test loop.

4.0 EFFECTIVENESS OF PRE-TREATMENT SYSTEM

The effectiveness of the feedwater treatment system is demonstrated by the typical chemistry analysis presented below: (Refer to schematic shown in Figure 1 for sample points).

TABLE I

Parameter	Tap Water (1)	Demineralizer (2)	Batch Tank (3)	Reaction Tank (4)	Test Model 5
Resistivity (ohm-cm)	5.0K	2,500K	2,500K	250K	250K
Chloride	20 ppm	<50 ppb	<50 ppb	<50 ppb	<50 ppb
Oxygen	~5 ppm	~5 ppm	10 ppb	2 ppb	2 ppb
Ph	8	7	7.5	9.3	9.3
Sodium	40 ppm	<2 ppb	30 ppb	30 ppb	30 ppb
Hydrazine	N/A	N/A	N/A	67 ppb	67 ppb

Reaction Tank Concentration before chemical reaction:

Hydrazine	200 ppb
Ammonium Hydroxide	200 ppb

The comparison of the typical values of actual test loop water chemistry with the plant water chemistry requirements is presented:

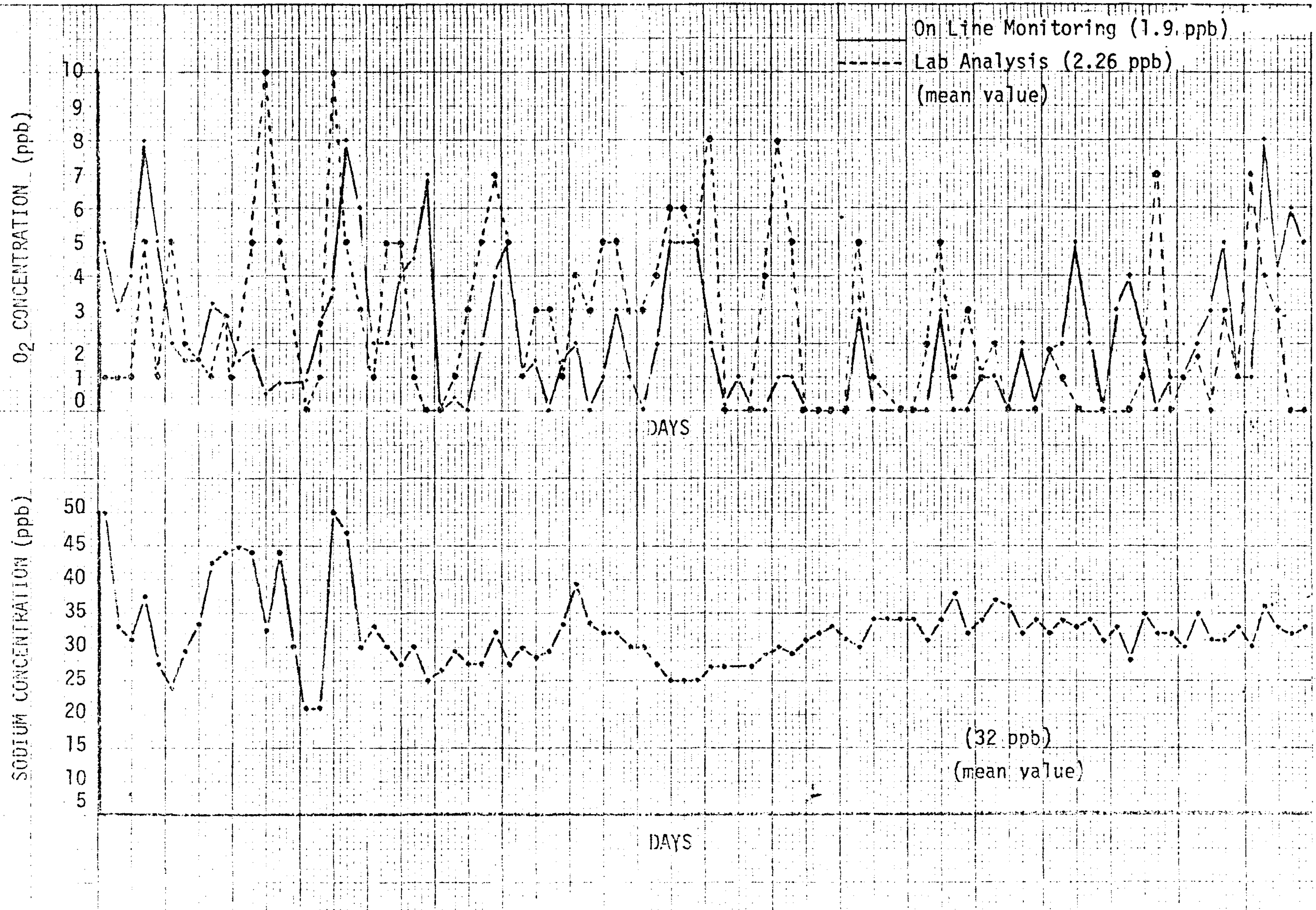
TABLE II

Parameter	Plant	Test Loop
Ph	9.0 - 9.5	9.3
Oxygen	7	2 ppb
Sodium	5.5 ppb (max.)	30 ppb*
Silica	20 ppb (max.)	6 ppb
Iron	10 ppb (max.)	5 ppb
Copper	2 ppb (max.)	2 ppb
Hydrazine (Residual)	5 ppb (max.)	67 ppb
Total Dissolved Solids	2 ppm (max.)	1.2 ppm

Other typical test loop water constituents were: Al - 10.0 ppb, B - 2.0 ppb Ca - 20 ppb, Cr - 1.4 ppb, K - 50 ppb, Li - 0.2 ppb, Mg - 8.0 ppb, Mn - 2.0 ppb, Mo - 50 ppb, Ni - 1.1 ppb, Ti - 1.4 ppb.

*Deliberate contamination

Figure 2 is presented to illustrate the excellent control of test loop oxygen and sodium concentrations that was provided by the feed water pre-treatment system throughout the 2160 hour test program.



2 Div - 1 day

FIGURE 2 - Loop Concentrations of Oxygen and Sodium

5.0 Principles of Operation

5.1 Successive Demineralization - The ion column arrangement was selected so that the anion and cation columns which are most easily regenerated remove the bulk of the metallic concentrations and the halogens. The first mixed bed ion column removes most of the remaining impurities and is an interchangeable regenerative column, while the second mixed bed column is an ultra pure non-regenerative bed free of potential regeneration contaminates. The second mixed bed acts as a polishing unit and provides back-up for break through of the previous columns. The demineralization provides feedwater of <10 ppb metallic concentrations and <50 ppb total halogens.

5.2 Multi-Stage Deoxygenation - An argon sparge of the reservoir supply tanks is the first step in deoxygenation; this step effectively reduces the feedwater oxygen concentration from <5000 ppb to <20 ppb. Argon gas is injected on the suction side of the recirculation pump which results in liquid-gas mixing and displaces all absorbed gases with the argon sparge gas. The displaced gases are vented from the top of the tank where a constant pressure cover gas is maintained. The second deoxygenation step is performed in the reaction tank by the addition of hydrazine to effectively reduce the oxygen concentration to <7 ppb. A catalyzed hydrazine is used to obtain a rapid chemical reaction which is dependent on; 1) thorough mixing, 2) elevated temperature and 3) elevated pH, all of which are provided by the reaction tank system.

5.3 pH Adjustment - The feed water is adjusted from pH 7.5 to 9.3 in the reaction tank by the addition of ammonium hydroxide which is injected simultaneously with the hydrazine.

5.4 Sodium Hydroxide Corrosive Test Additive - Due to the stringent requirement for maintaining a corrosive contaminate of 30 ± ppb sodium, a batch mixing technique is used. A premeasured solution of sodium hydroxide is injected into the deoxygenated filled reservoir tank; equilibration through mixing is accomplished by the pump recirculation.

6.0 Feed Water Chemistry Monitoring

The sample points for feed water chemistry monitoring are shown in Figure 1. During operation of the steam generator model, grab samples from all points were taken and analyzed on a daily basis for pH, resistivity, chlorides, oxygen and sodium concentrations; Also on line monitoring for oxygen and pH was performed on a sample flow from points 4 and 5. On line monitoring of resistivity at point 2 was also performed. Of primary interest is the comparison of results of oxygen determination obtained by on-line instrumentation versus laboratory analysis. The mean values of 90 data points are tabulated:

Sample Location	Sample Point	Laboratory Results (ppb-O_2)	On-line Instrument Results (ppb-O_2)
Reaction Tank	4	3.5	0.21
Test Loop	5	2.3	1.9

Oxygen by visual colormeteric laboratory analysis is discernible in ~2 ppb increments with comparative standards at the 0, 5, 10 ppb level. Since possible oxygen contamination of the visual sampler can occur during sampling removal and during the color indicator injection, analysis by the on-line oxygen instrument and the laboratory colormeteric method are in excellent agreement at ± 5 ppb.

6.1 On Line Monitoring - Oxygen monitoring was performed with a model Mark IV Cambridge instrument which is direct reading and is specific only for oxygen gas. The sensor is isolated from the flowing sample water by a clean hydrogen atmosphere and was unaffected by conductivity, pH, metallic oxides, or the chemical additives present in the sample. pH was determined by a Cambridge Model 2831A/2890 direct reading instrument with a 7-12 pH range. An in-line cell/transmitter unit (a salinity type unit) provided resistivity monitoring. This unit was a Model EWC-01-200R/TX2-P, manufactured by Electronic Switch Gear Co.

6.2 Analytical Sampling and Analysis - The oxygen sample collection device was a glass bulb equipped with vacuum stopcocks located at opposite sides, plus a rubber septum for reagent injection. A sample purge requiring a minimum of (5) five bulb volumes was flushed through the oxygen sampling bulb before the collected sample was isloated. An indigo-carmine reagent was immediately injected and the developed color compared to the visual standards. Comparison was accomplished within 2 minutes of sample collection. The visual standard conforms to ASTM Method A-D888-65 which is a visual oxygen color comparison against a series of standards ranging from 0 to 60 ppb oxygen in increments of 5 ppb oxygen which provides data accurate to ± 2 ppb.

Atomic absorption analysis in accordance to ASTM D 1428-64B was performed for the low level sodium determinations. Typical sodium values of before and after chemical control are 2 and 30 ppb sodium respectively. The low level sodium standards were prepared twice weekly from double demineralized double distilled water and stored in precleaned polyethylene vials. Each standard series was compared against the previous standard to insure freedom from contamination. A 5% relative standard deviation is the norm for the daily standard calibration curve of 0 to 70 ppb sodium.

The low level chloride analysis was based on ASTM D 512-67B, but utilized a spectrophotometer to measure the turbidity of the silver chloride reactions at 500 nanometers in a 5 cm light path. This procedure has a detection limit of 50 ppb based on a 40 milliliter aliquot.

The measurements of conductivity and pH conform to ASTM methods D 1125-65 and D 1293-65 respectively.

7.0 FUTURE APPLICATIONS

The basic design of the pretreatment feed water supply system was constructed with flexibility in mind. Sampling and monitoring points were set at all critical areas so potential troubles could be quickly defined and corrected. Each individual subsection can function independently of the others or be by-passed. Larger demineralization capacity can be conveniently added as needed. The deoxygenation of the reservoir tanks can use any suitable gas (nitrogen, helium, argon) for sparging. The present gas sparging system utilized a single pass-through, low pressure system with a vented reservoir tank, however, the vented gas could be re-purified and recirculated to provide a more economical means of gas sparging. The reservoir and the reaction tanks both provide means of adding and controlling special chemical additives as required by specific applications.

This system has potentials for use in larger systems either through adding more units (demineralization, reservoir, reaction tanks) or by constructing a larger scale system. In either case similar results should be expected as indicated by the presented data.

APPENDIX C

SSGM/SWL-1 Water Chemistry Data

SSGM/SWL-1 WATER CHEMISTRY PHASE III

Date	pH Lab Analysis	pH On Line Meter	O_2 Lab Analysis (PPB)	O_2 On Line Meter (PPB)	Cl (PPM)	Resistivity (OHMS-CM)	Na (PPB)	Comments
5-21-75	6.54		60(1)		.08	1,020,000	<2.0	
5-22-75	9.09	9.4	100(1)	30	<.05	63,900	48	
5-23-75	9.28	9.2	60(1)	5.0	<.05	139,000	51	
5-24-75	9.10	9.4	60(1)	3.0	<.05	140,000	33	
5-25-75	8.96	9.4	40(1)	4.0	<.05	131,000	31	
5-26-75	9.55		60(1)		<.05	108,000	38	
5-27-75	9.22	9.8	50(1)	8.0	<.05	194,000	26	
5-28-75	9.42	9.4	15(2)	5.0	<.05	174,000	24	
5-29-75	9.42	9.4	30(2)	2.0	<.05	170,000	29	
5-30-75	9.16	9.3	*7100(1)	1.5	<.05	150,000	33	
5-31-75	9.23	9.3	50(2)	1.5	<.05	139,000	42	
6-1-75	9.33	9.4	5(2)	3.2	<.05	225,000	43	
6-2-75	9.48	9.26	50(2)	2.6	<.05	168,000	44	
6-3-75	9.38	9.45	30(2)	1.5	<.05	177,000	43	
6-4-75	9.18	9.29	10(2)	1.7	<.05	222,000	32	
6-5-75	8.95	9.1	10(2)	.6	<.05	271,000	44	
6-6-75	9.40	9.3	40(2)	118	<.05	153,000	30	
6-7-75	9.49	9.5	30(2)	.8	<.05	191,000	21	

SSGM/SWL-1 WATER CHEMISTRY PHASE III

Date	pH		O_2		Cl (PPM)	Resistivity (OHMS-CM)	Na (PPB)	Comments
	Lab Analysis	On Line Meter	Lab Analysis (PPB)	On Line Meter (PPB)				
6-8-75	9.26	9.5	30(2)	2.6	<.05	177,000	21	
6-9-75	9.54	9.4	15(2)	3.5	<.05	151,000	51	
6-10-75	9.53	9.3	5(2)	8	<.05	120,000	47	
6-11-75	9.25	9.05	5(2)	6	<.05	147,000	26	
6-12-75	9.30	9.2	5(2)	2	<.05	155,000	54	
6-13-75	9.57	9.2	0(2)	0	<.05	116,000	4	
6-14-75	9.55	9.4	10(2)	0	<.05	113,000	39	
6-15-75	9.55	9.2	20(2)	2	<.05	121,000	30	
6-16-76	9.36	9.35	0(2)	2	<.05	134,000	28	
6-17-75	9.30	-	5(2)	4	<.05	125,000	30	
6-18-75	9.35	9.5	5(2)	4.5	<.05	114,000	27	
6-19-75	9.50	9.3	5(2)	7	<.05	101,000	30	
6-20-75	9.41	9.58	5	0	<.05	108,000	25	
6-21-75	9.60	9.53	0	.2	<.05	119,000	26	
6-22-75	9.39	9.50	0	0	<.05	149,000	23	
6-23-75	9.37		2		<.05	132,000	29	
6-24-75	9.39	9.2	2	0	<.05	118,000	28	
6-25-75	9.24	9.1	0	4	<.05	120,000	28	

SSGM/SWL-1 WATER CHEMISTRY PHASE III

Date	pH Lab Analysis	pH On Line Meter	O_2 Lab Analysis (PPB)	O_2 On Line Meter (PPB)	Cl (PPM)	Resistivity (OHMS-CM)	Na (PPB)	Comments
6-26-75	9.21		0		<.05	180,000	26	
6-27-75	9.53	9.2	2	5	<.05	111,000	31	
6-28-75	9.56	9.5	0	1	<.05	126,000	27	
6-29-75	9.20	9.5	0	1.5	<.05	170,000	30	
6-30-75	9.46	9.5	2	2.5	<.05	121,000	28	
7-1-75	9.23	9.4	70	8	<.05	124,000	29	
7-2-75	9.41		0		<.05	212,000	29	
7-3-75	9.14		5		.07	150,000	28	
7-4-75	9.01	7.8	0	0	.07	173,000	44	
7-5-75	9.29	9.45	2	0	.06	144,000	39	
7-6-75	9.07	9.3	0	1.5	<.05	142,000	32	
7-7-75	9.18	9.3	4	2	.23	118,000	34	
7-8-75	9.57		0		<.05	128,000	36	
7-9-75	9.47		0	0	<.05	106,000	39	
7-10-75	9.32	9.2	0	1	<.05	108,000	33	
7-11-75	9.36	9.6	0	3	<.05	125,000	32	
7-12-75	9.23	9.5	0	1	<.05	236,000	32	
7-13-75	9.42		0	0	<.05	124,000	30	

SSGM/SWL-1 WATER CHEMISTRY PHASE III

Date	pH		O_2		Cl (PPM)	Resistivity (OHMS-CM)	Na (PPB)	Comments
	Lab Analysis	On Line Meter	Lab Analysis (PPB)	On Line Meter (PPB)				
7-14-75	9.36		5	2	<.05	140,000	30	
7-15-75	9.16	9.5	5		<.05	141,000	27	
7-16-75	9.26		5		<.05	95,000	9	
7-17-75	9.27	8.0	7	2	<.05	115,000	25	
7-18-75	9.24	7.25	5	.2	<.05	109,000	26	
7-19-75	9.22		10		<.05	106,000	26	
7-20-75	9.17		5		<.05	101,000	5	
7-21-75	9.55	9.55	8	1	<.05	100,000	26	
7-22-75	9.20		4	0	<.05	118,000	28	
7-23-75	9.47	9.3	2	0	<.05	116,000	30	
7-24-75	9.24	9.3	6	1	<.05	131,000	28	
7-25-75	9.15		7	1	<.05	168,000	31	
7-26-75								
7-27-75	8.77	7.41	2	0	<.05	448,000	32	
7-28-75	8.04	7.65	6	0	<.05	489,000	33	
7-29-75	8.86	9.4	3	0	<.05	353,000	31	
7-30-75	9.04	9.1	3	0	<.05	149,000	34	
7-31-75	9.28	9.3	3	0	<.05	125,000	34	

SSGM/SWL-1 WATER CHEMISTRY PHASE III

Date	pH		O_2					
	Lab Analysis	On Line Meter	Lab Analysis (PPB)	On Line Meter (PPB)	Cl (PPM)	Resistivity (OHMS-CM)	Na (PPB)	Comments
8-1-75								
8-2-75	9.25	9.25	0	0	<.05	145,000	34	
8-3-75	9.21		5	0	<.05	157,000	34	
8-4-75	9.11		7	0	<.05	255,000	31	
8-5-75	9.16		5	3	<.05	153,000	34	
8-6-75	9.24		3	0	<.05	123,000	38	
8-7-75	9.24		3	0	<.05	139,000	32	
8-8-75	9.09		3	1	<.05	182,000	34	
8-9-75	9.24		3	1	<.05	135,000	37	
8-10-75	9.22		3	0	<.05	138,000	36	
8-23-75	8.84		0	0	<.05	363,000	36	
9-17-75	8.74		>100		<.05	141,000	21	
9-18-75	9.14		5	0	<.05	106,000	32	
9-19-75	8.28	9.1	5	2	<.02	89,000	32	
9-20-75	9.03	9.15	0	0	<.05	119,000	34	
9-21-75	9.0	9.40	0	1.8	<.05	101,000	32	
9-22-75	9.14	9.25	0	2	<.05	193,000	34	
9-23-75	9.16	9.31	0	5	<.05	84,800	33	

SSGM/SWL-1 WATER CHEMISTRY PHASE III

Date	pH Lab Analysis	pH On Line Meter	O_2 Lab Analysis (PPB)	O_2 On Line Meter (PPB)	Cl (PPM)	Resistivity (OHMS-CM)	Na (PPB)	Comments
9-24-75	9.46	9.25	0	2	<.05	62,700	34	
9-25-75	9.38	9.4	0	0	<.05	74,600	31	
9-26-75	9.25	9.35	0	3	.30	95,200	33	
9-27-75	9.34	9.4		4	<.05	123,000	28	
9-28-75	9,22	9.25	0	4	<.05	133,000	25	
9-29-75	9.27	9.35	0	4	0.4	139,000	39	
9-30-75	9.47	9.25	0	4	<.05	127,000	34	
10-1-75	9.38	9.15	0	0	<.05	115,000	31	
10-2-75	9.16		0	4	<.05	162,000	30	
10-3-75	9.42		0	0	<.05	119,000	34	
10-4-75	9.19	9.25		0	<.05	90,600	40	
10-5-75	9.15	9.15		2	<.05	96,400	52	
10-6-75	9.11	9.15	0	6	<.05	105,000	35	
10-7-75	9.29	9.25	0	2	<.05	125,000	32	
10-8-75	9.39	9.25	0	2	<.05	109,000	32	
10-9-75	9.48	9.40	7	0	<.05	91,900	33	
10-10-75	9.27	9.15	0	1	<.05	119,000	30	
10-20-75	9.30	9.20	0	2	<.05	95,800	42	

SSGM/SWL-1 WATER CHEMISTRY PHASE III

Date	pH		O_2					
	Lab Analysis	On Line Meter	Lab Analysis (PPB)	On Line Meter (PPB)	Cl (PPM)	Resistivity (OHMS-CM)	Na (PPB)	Comments
10-21-75	9.21	9.0	0	7	<.05	89,000	32	
10-22-75	8.78	9.0	0	6	<.05	102,000	39	
10-23-75	8.15	8.85	0	7	<.05	106,000	43	
10-29-75	9.15		5		<.05	111,000	41	
10-30-75	9.00	9.25	0	10	0.37	85,000	36	
10-31-75	8.74	8.45	10	4	0.08	87,000	28	
11-1-75	9.42	9.50	0	0	0.11	96,000	20	
11-2-75	9.35	9.25	0	0	<.05	100,000	19	
11-3-75	9.36	9.45	0	8	<.05	94,100	32	
11-4-75	9.44	9.20	0	10	0.36	88,300	51	
11-5-75	8.71	8.85	0	8	<.05	108,000	46	
11-6-75	8.45	8.50	0	8	<.05	118,000	28	
11-7-75	8.92	9.05	0	10	0.20	122,000	32	
11-8-75	8.86	8.95	5	7	<.05	141,000	27	
11-9-75	8.60	8.90	0	8	<.05	178,000	27	
11-10-75	8.46	8.75	0	10	<.05	140,000	29	

SSGM/SWL-1 WATER CHEMISTRY PHASE III

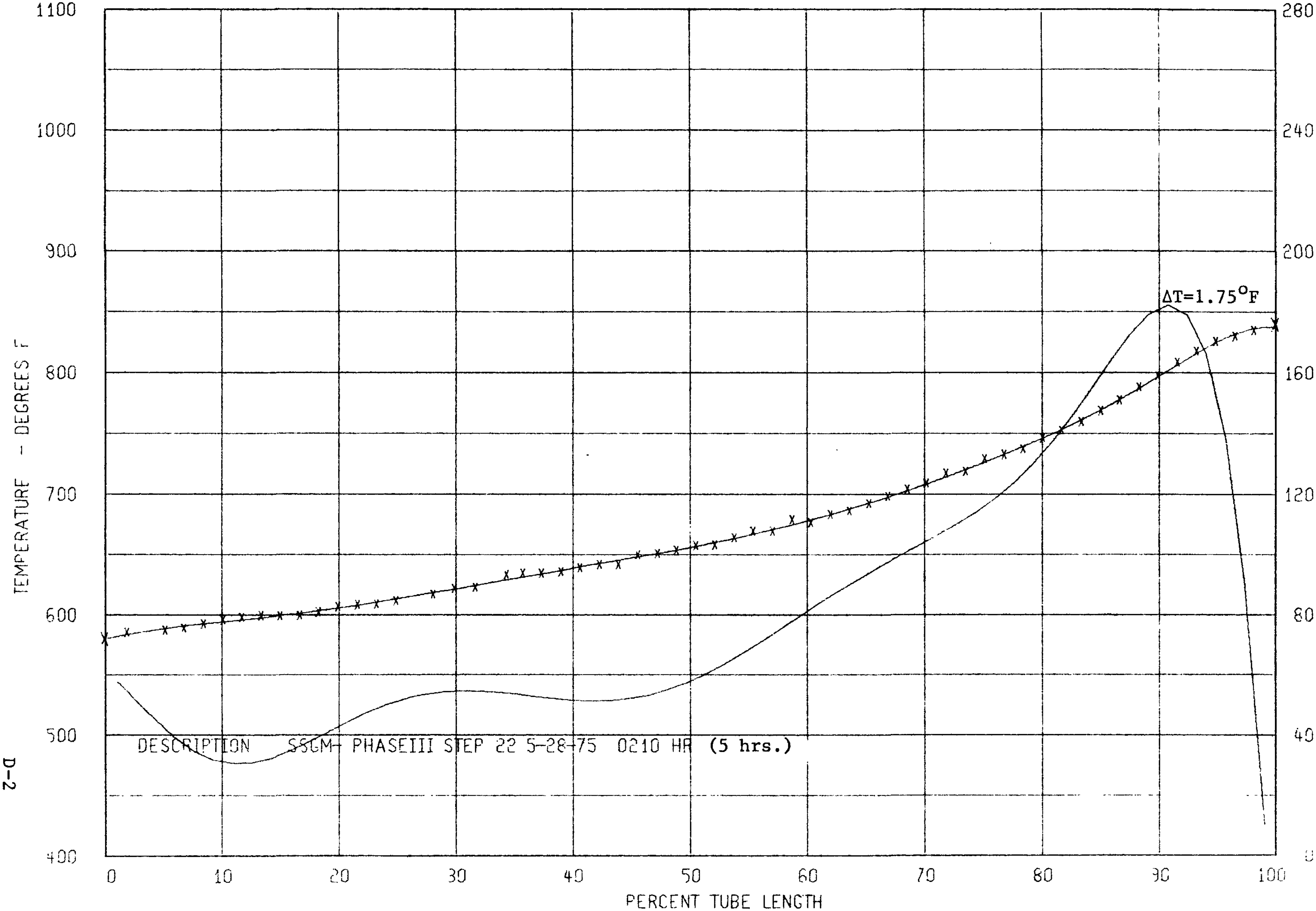
Date	pH Lab Analysis	pH On Line Meter	O_2 Lab Analysis (PPB)	O_2 On Line Meter (PPB)	Cl (PPM)	Resistivity (OHMS-CM)	Na (PPB)	Comments
11-11-75	6.39	7.80	0	8	<.05	163,000	24	
11-12-75	8.60	9.50	0	10	<.05	171,000	28	
11-13-75	8.96	9.25	0	10	<.05	120,000	27	
11-14-75	8.65	9.10	0	10	<.05	168,000	29	
11-15-75	8.76	9.20	5	8	<.05	96,000	26	

Notes: (1) O_2 determined by the modified Winkler Method.

(2) O_2 determined by the Indigo-Carmine Method.

APPENDIX D

Curve-Fit Data Evaluation for Separation of CHF into DNB/Transition/LFD Regimes



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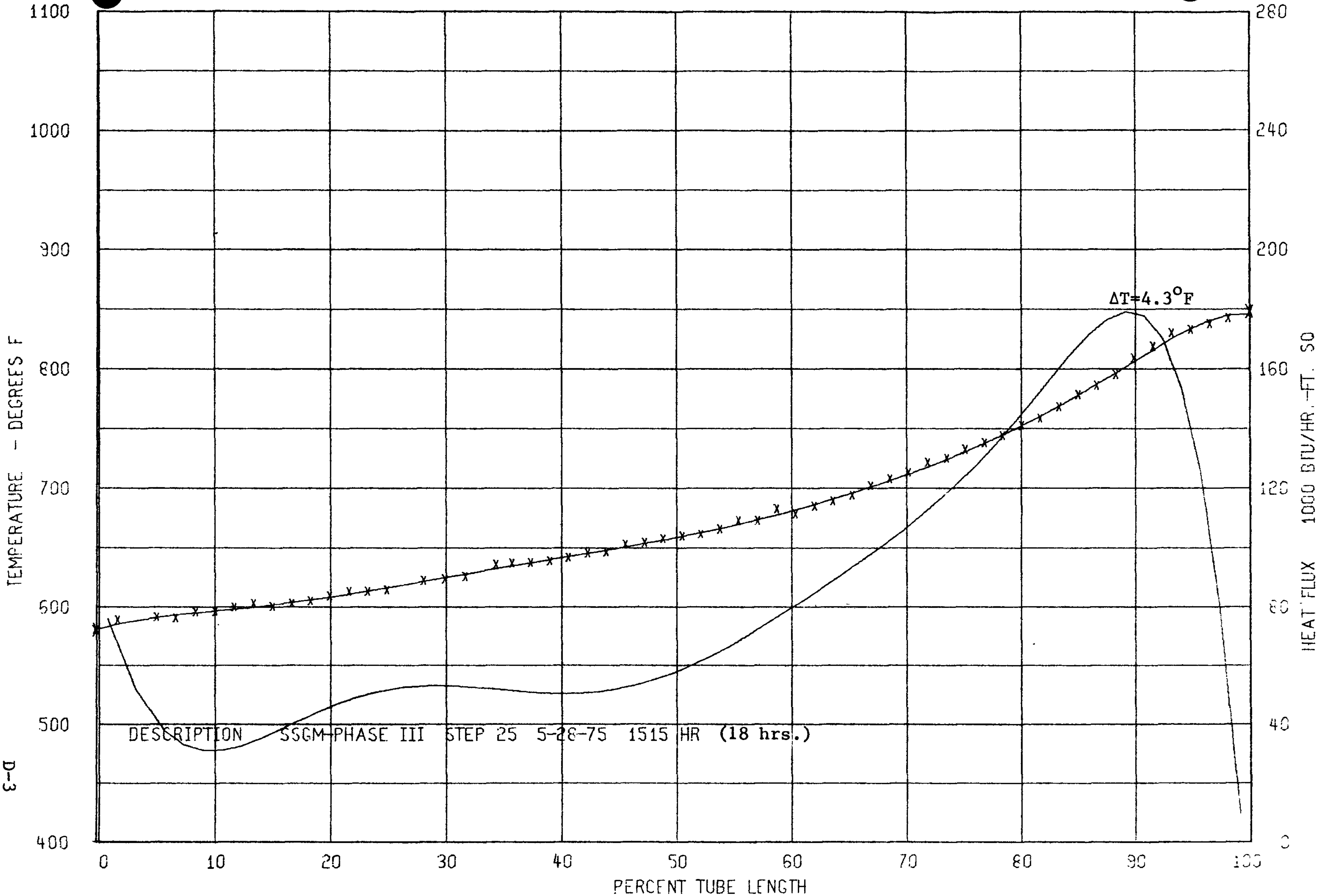

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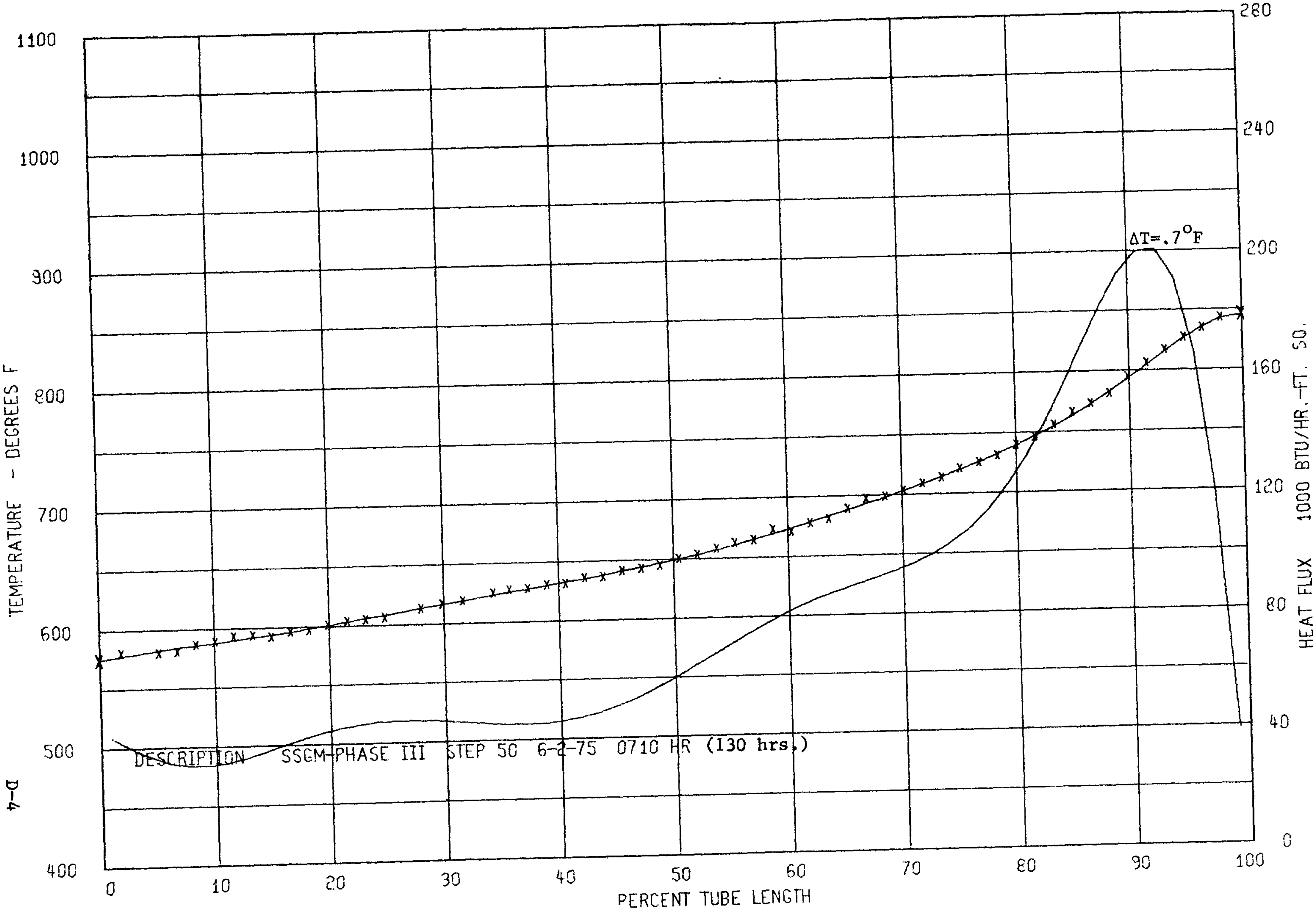

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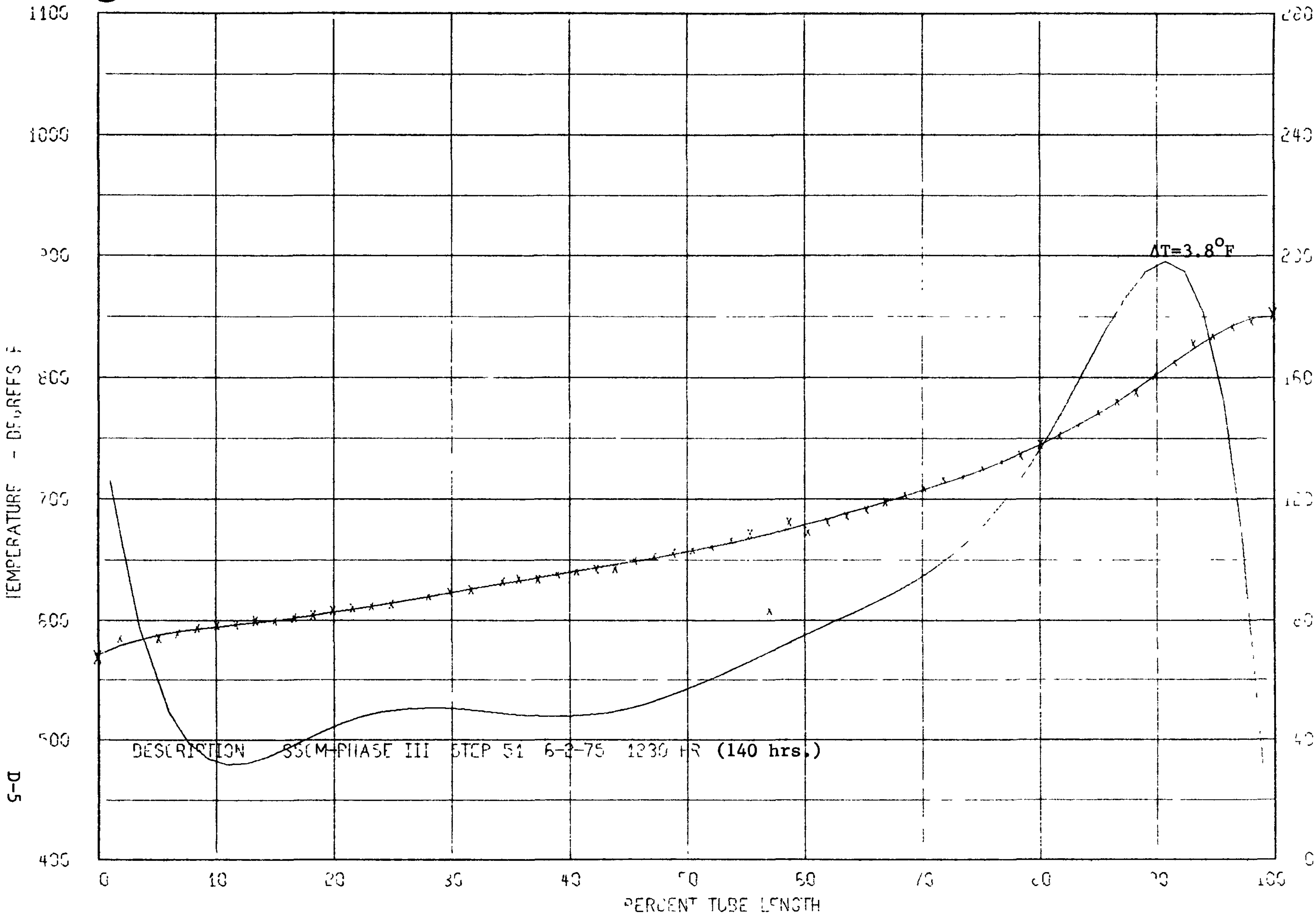

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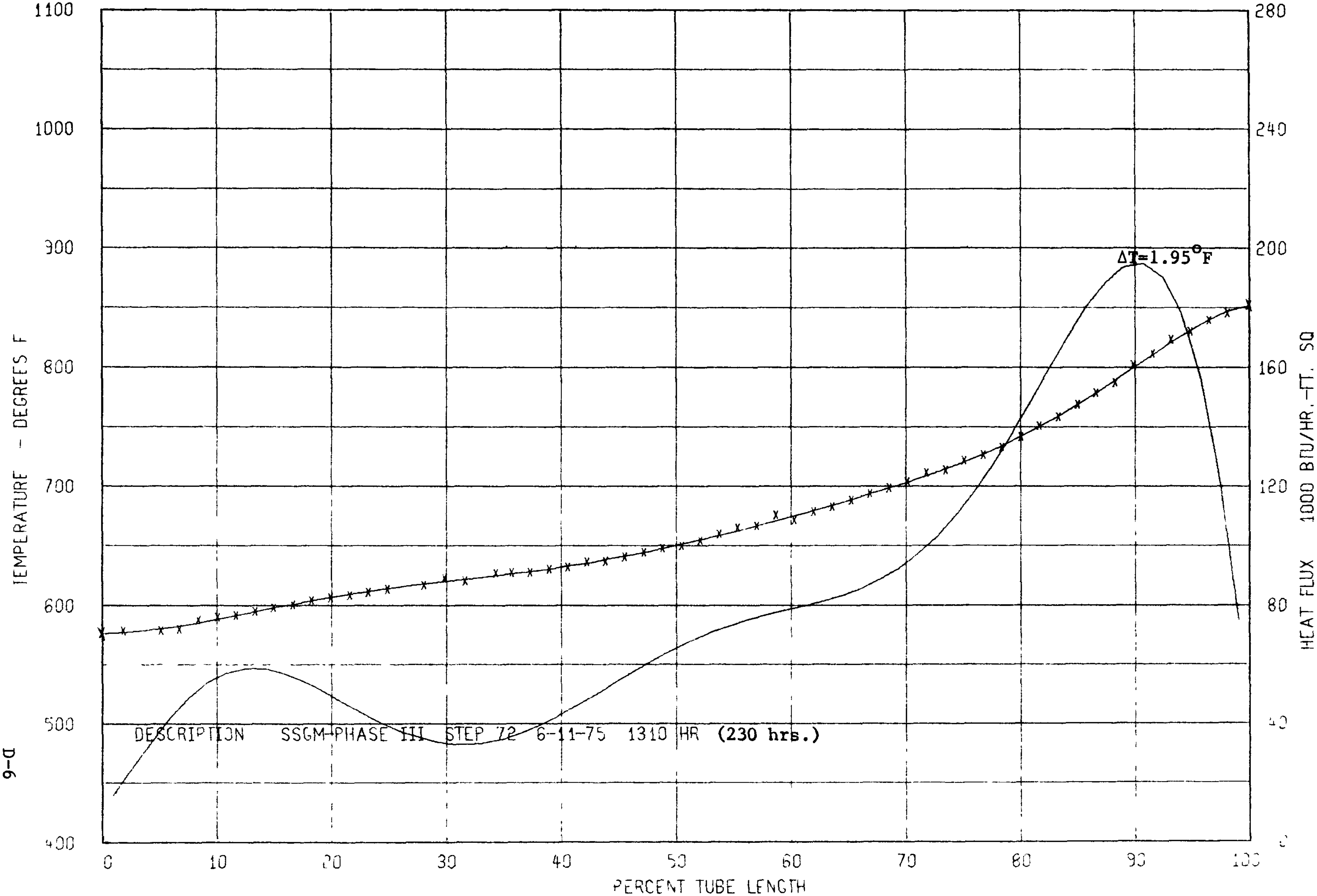

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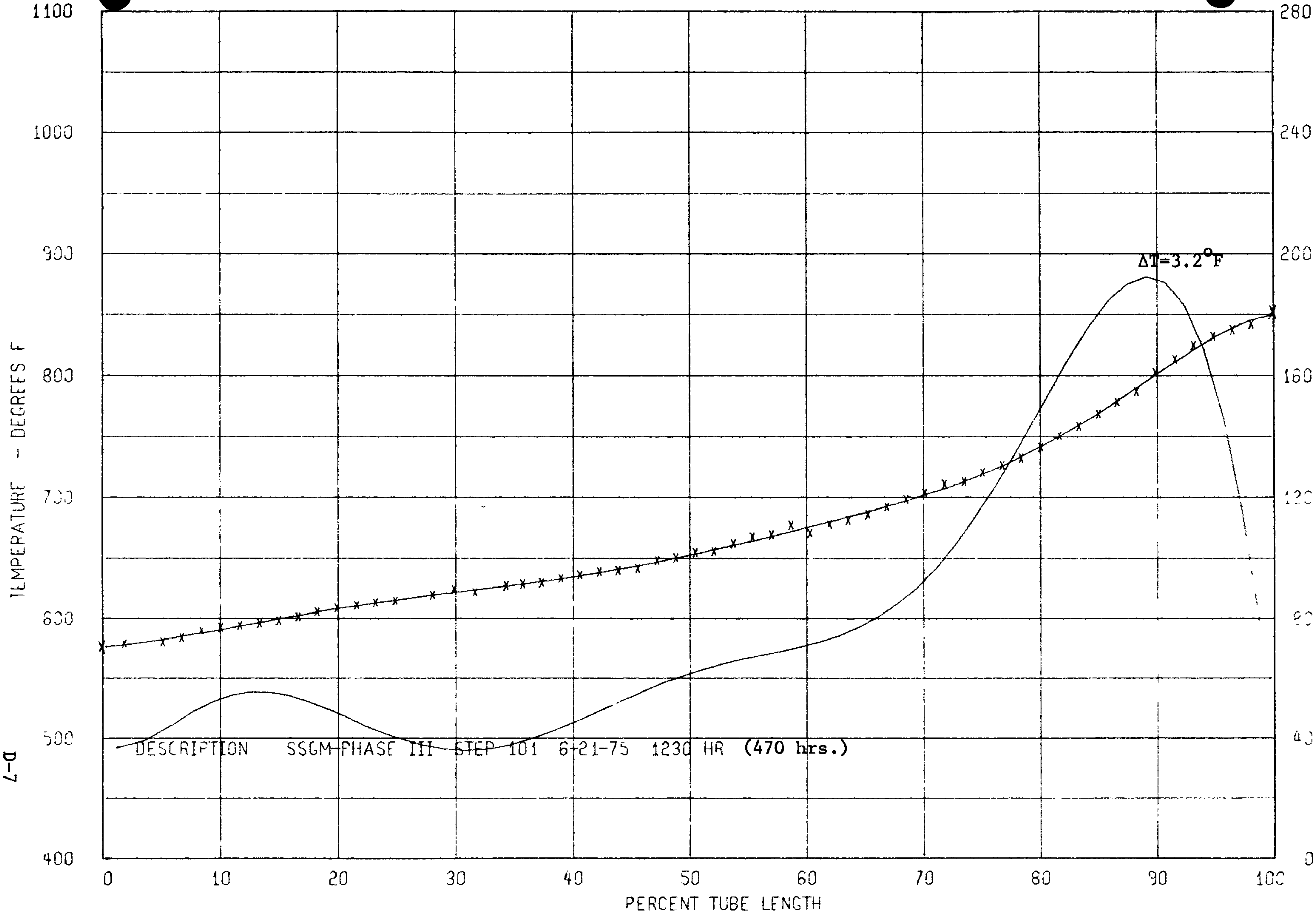

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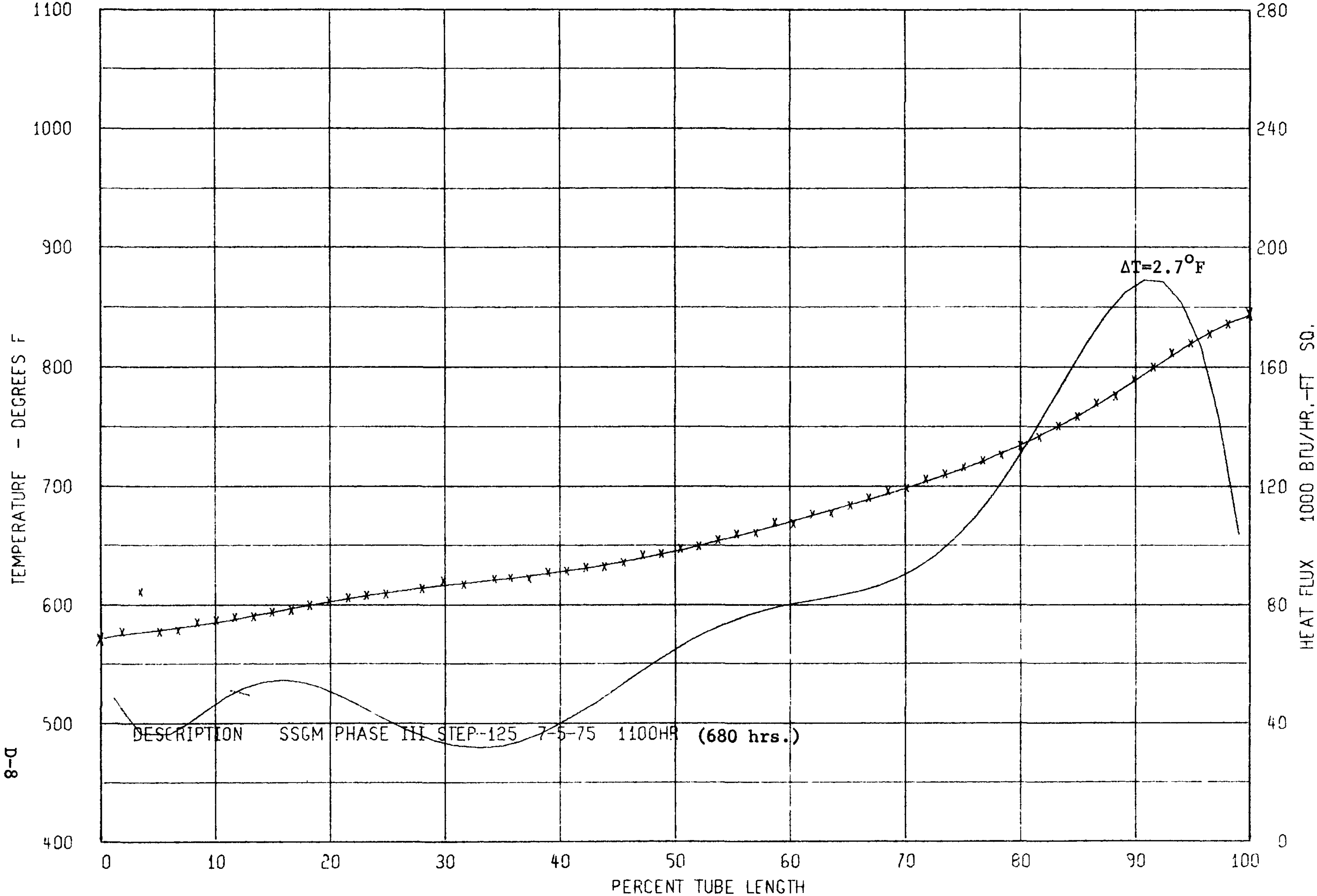

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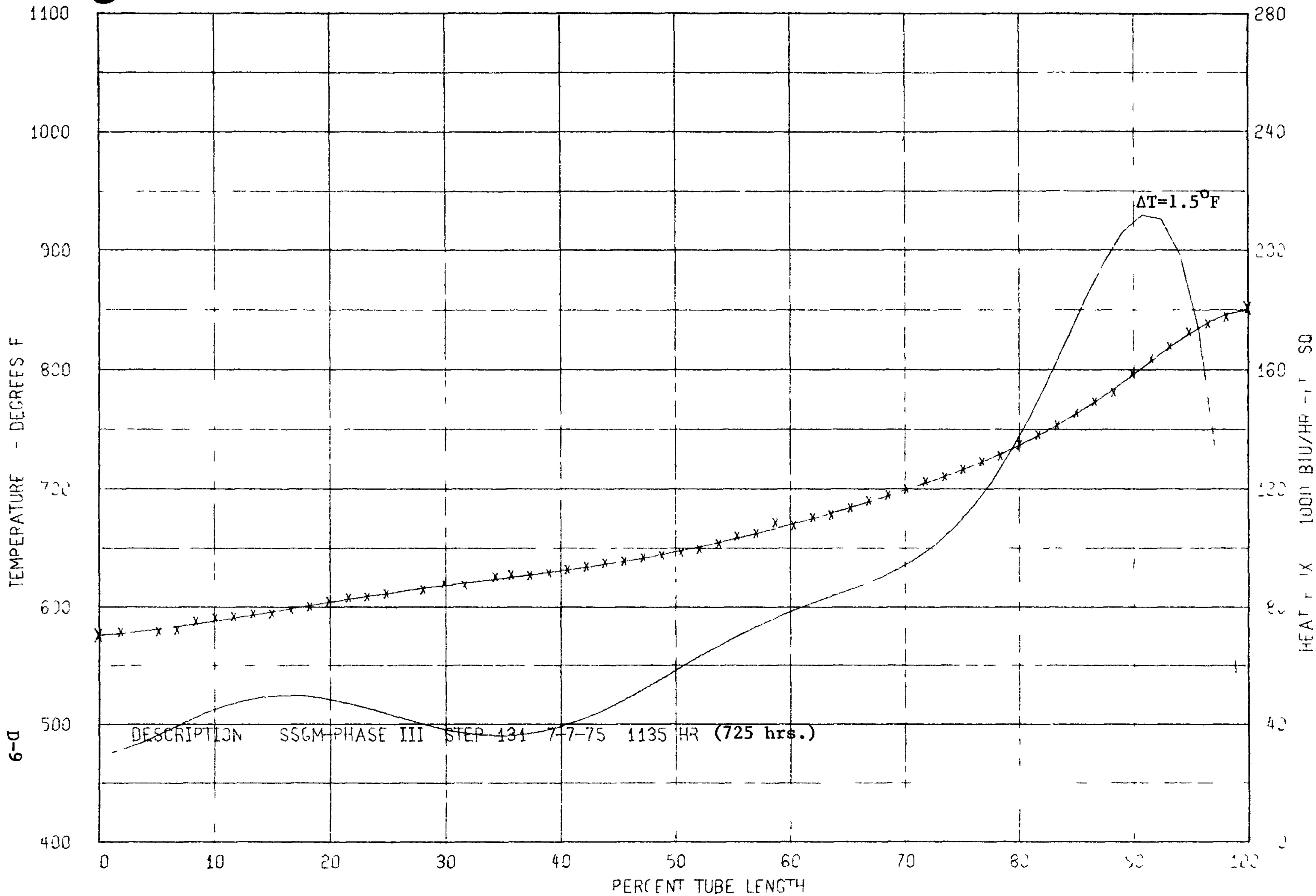

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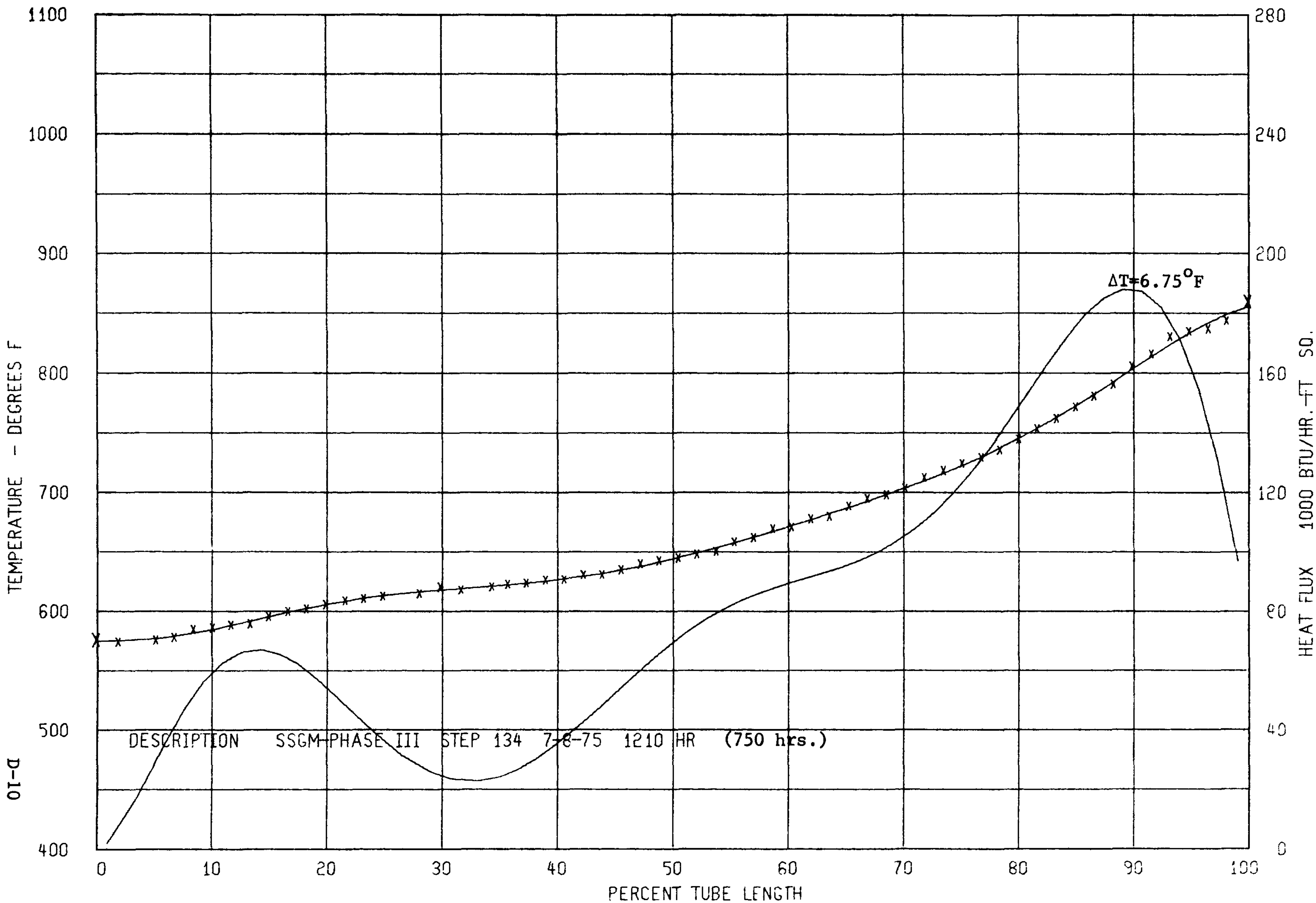

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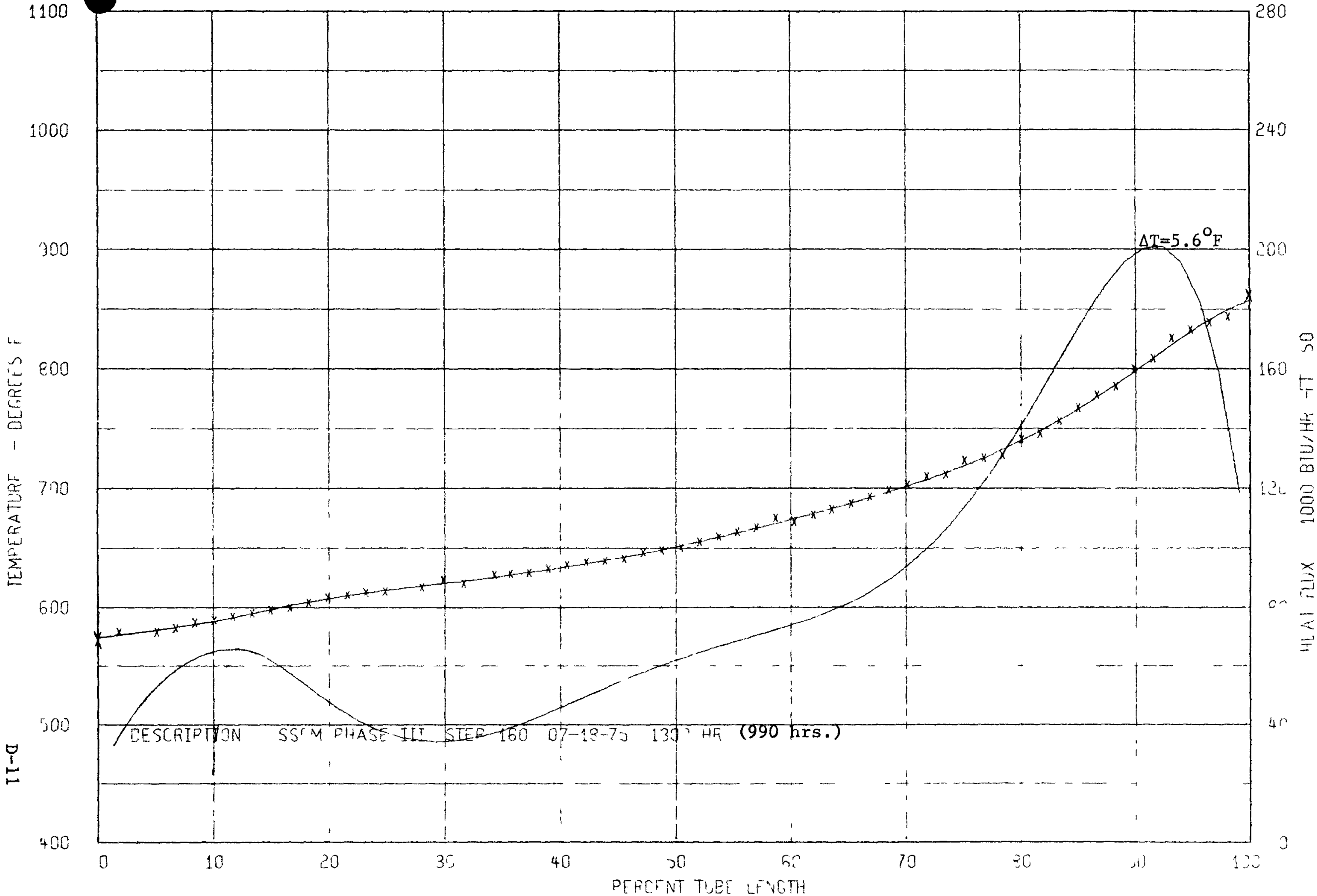

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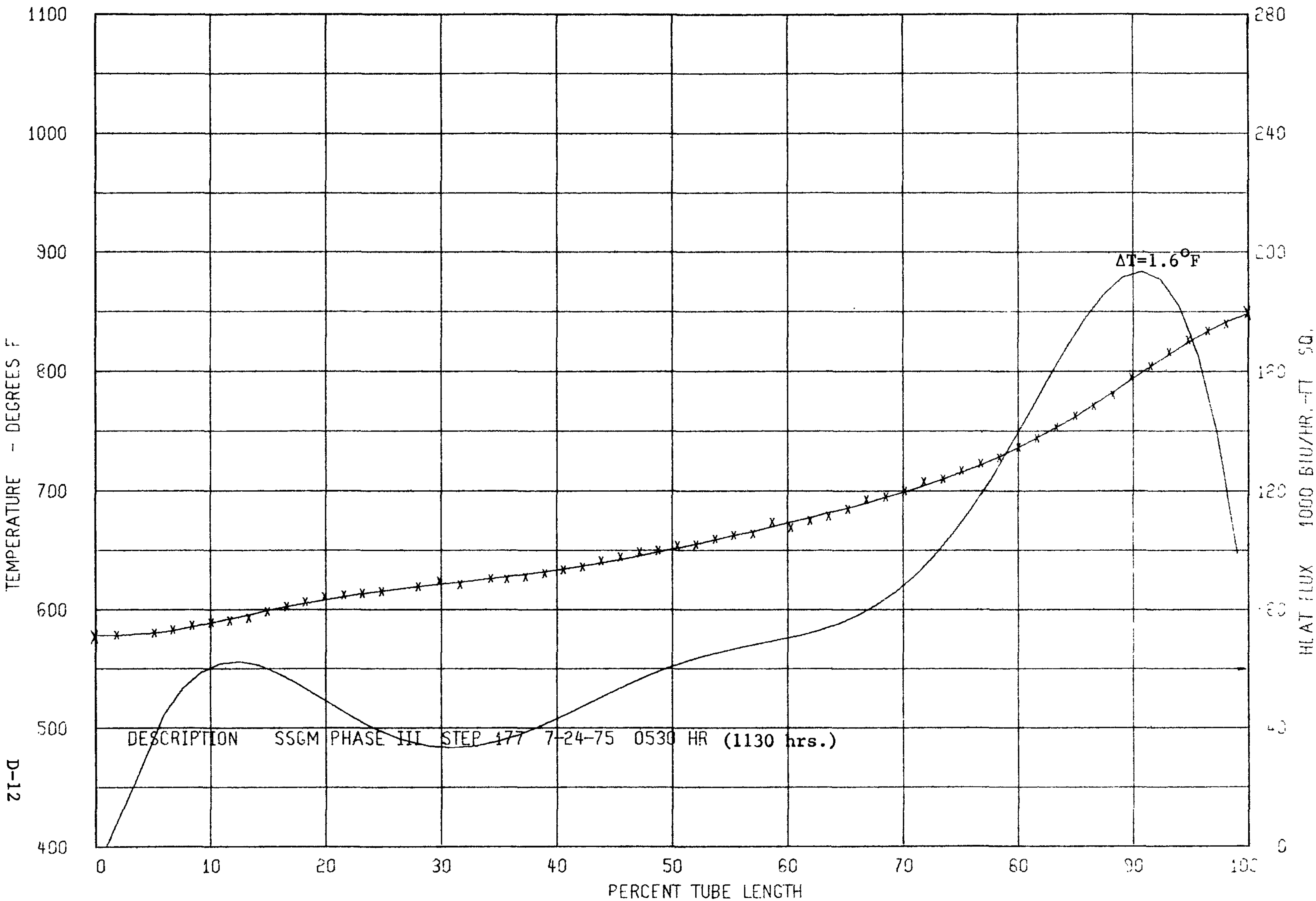

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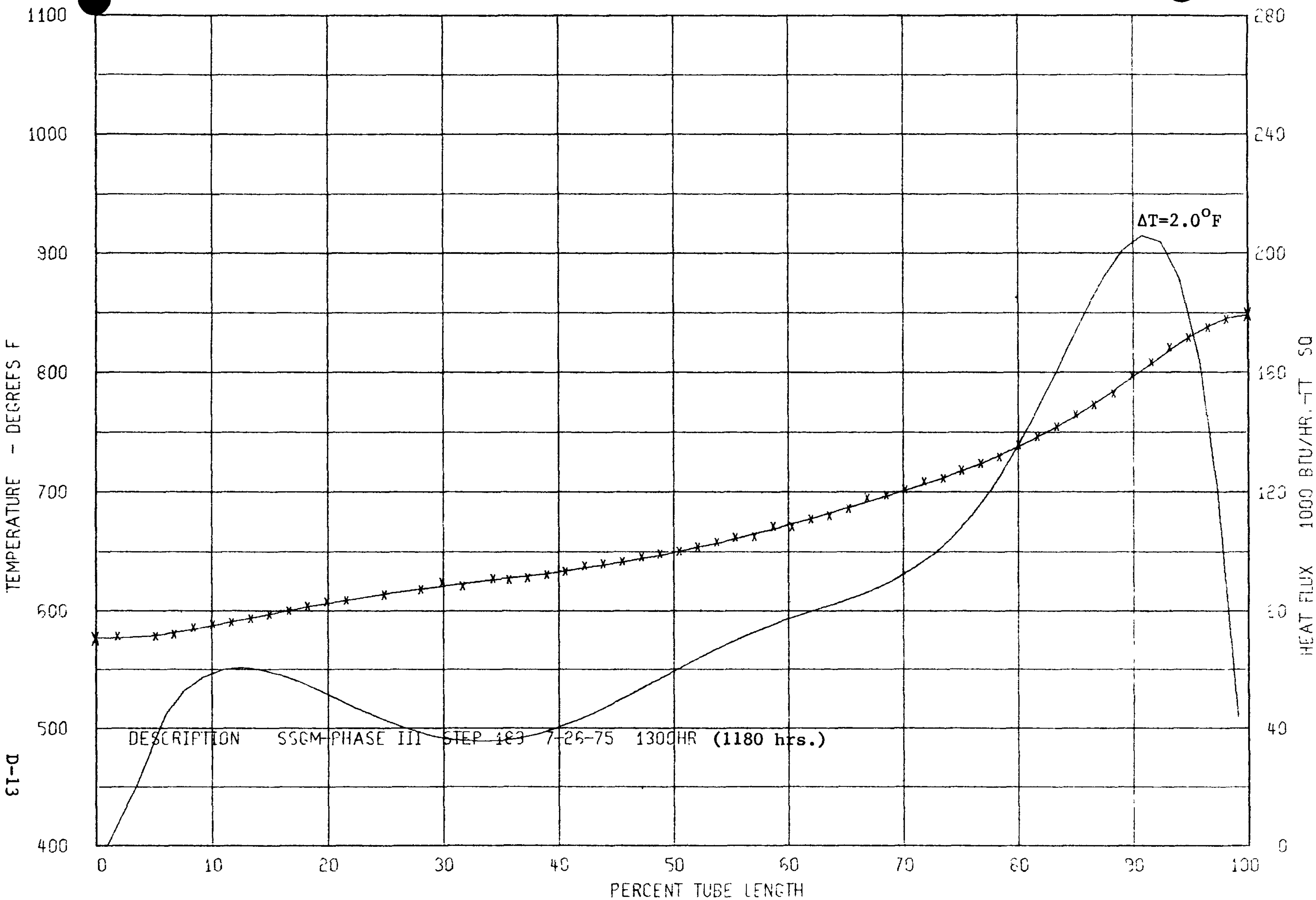

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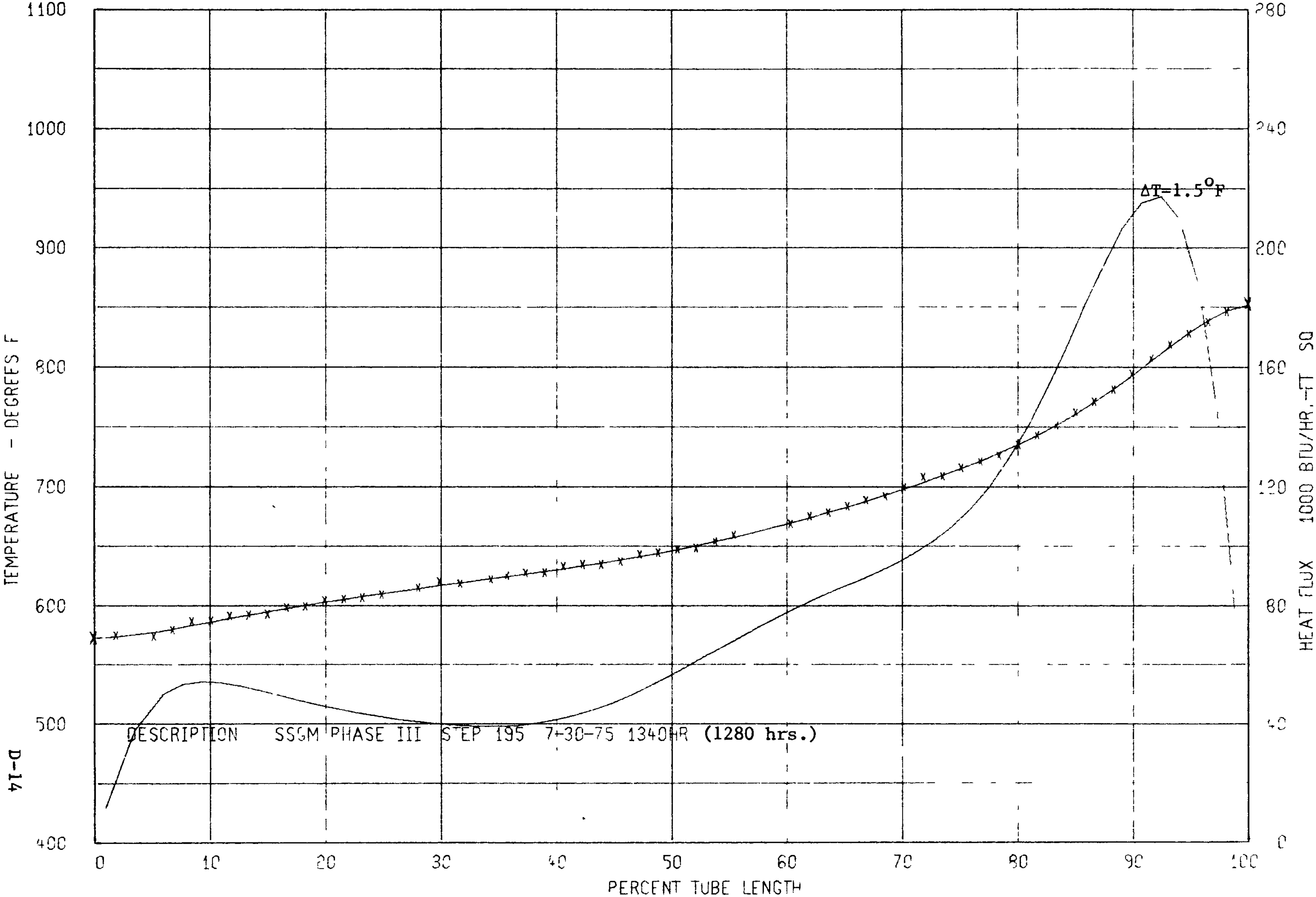

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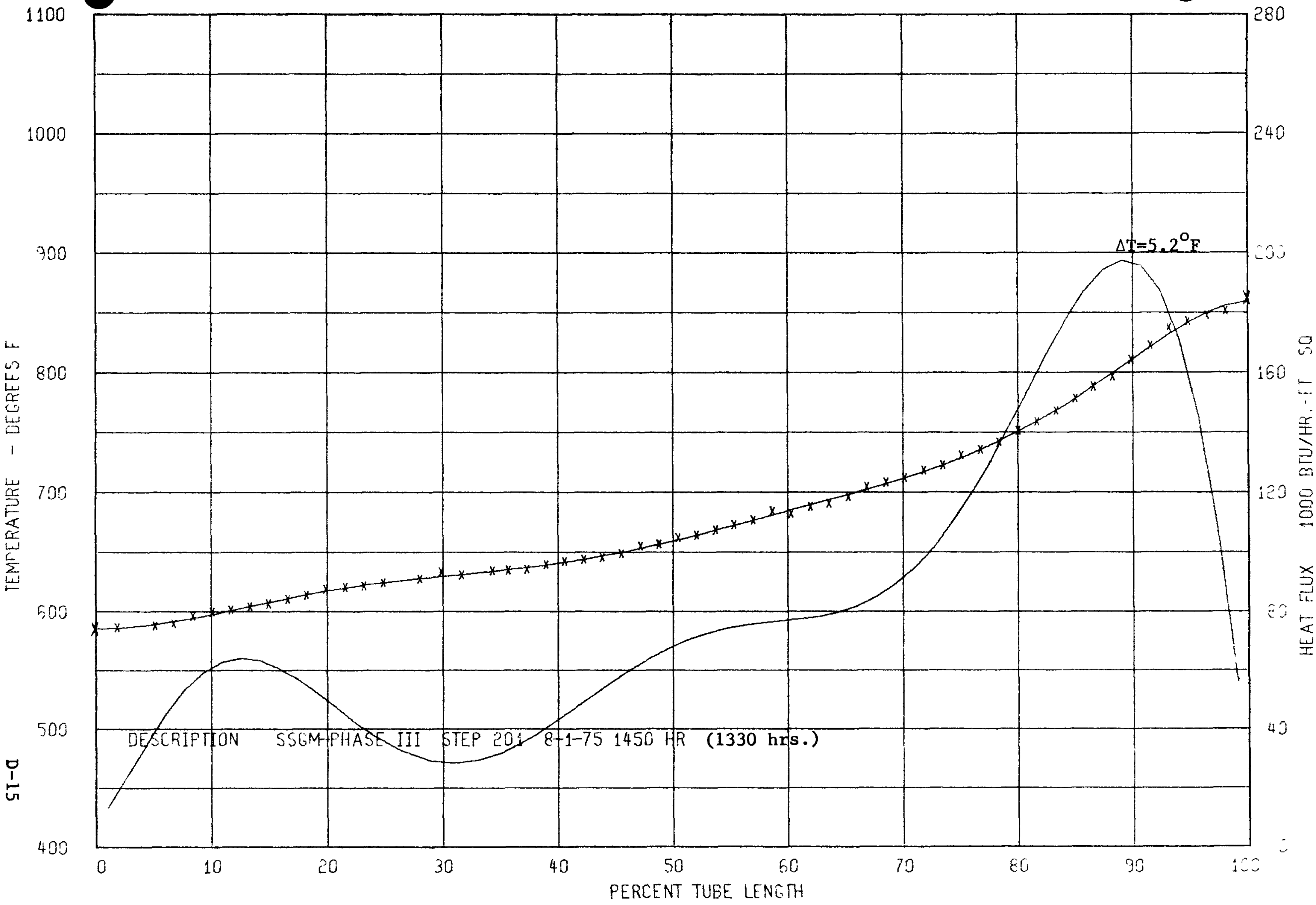

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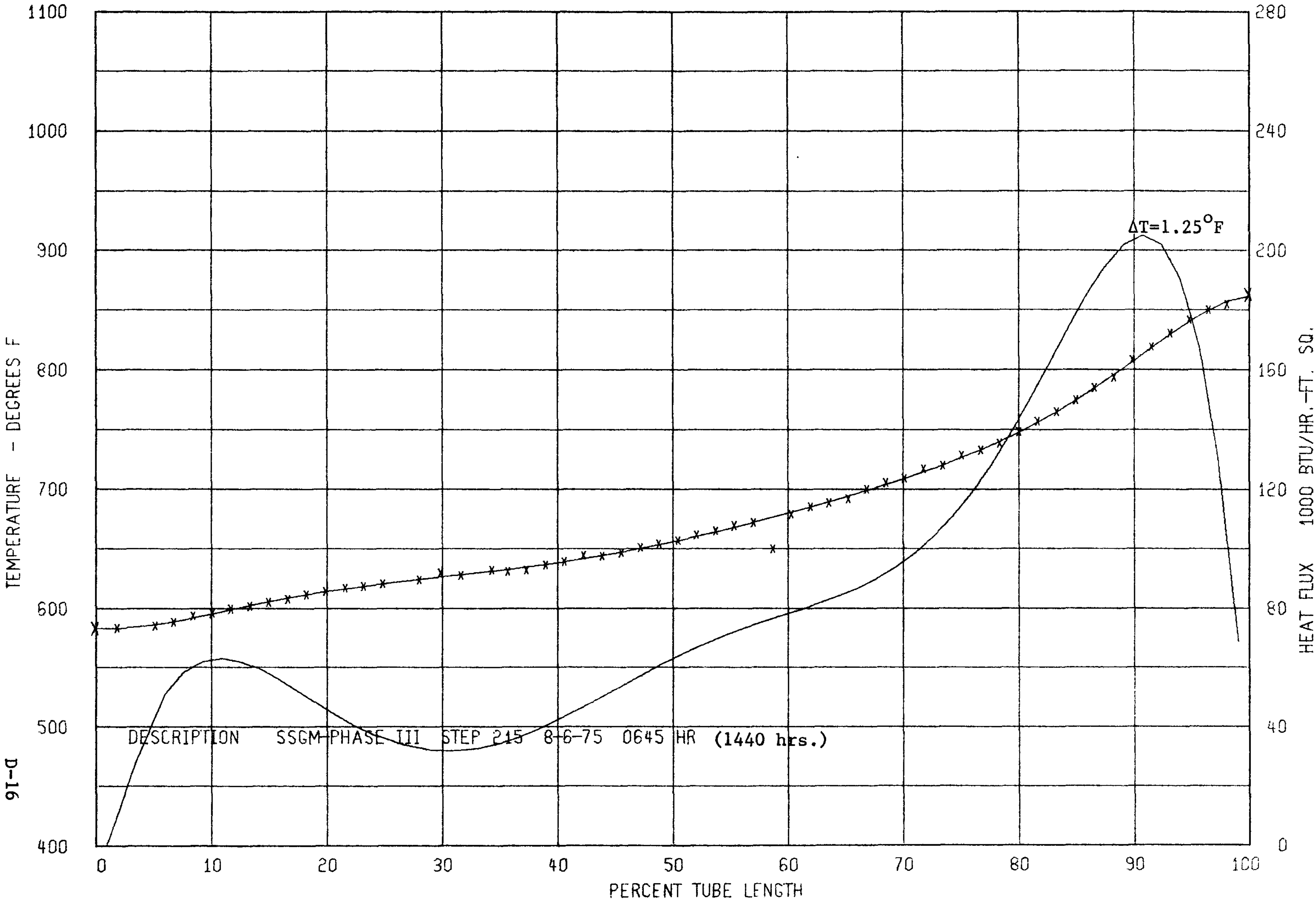

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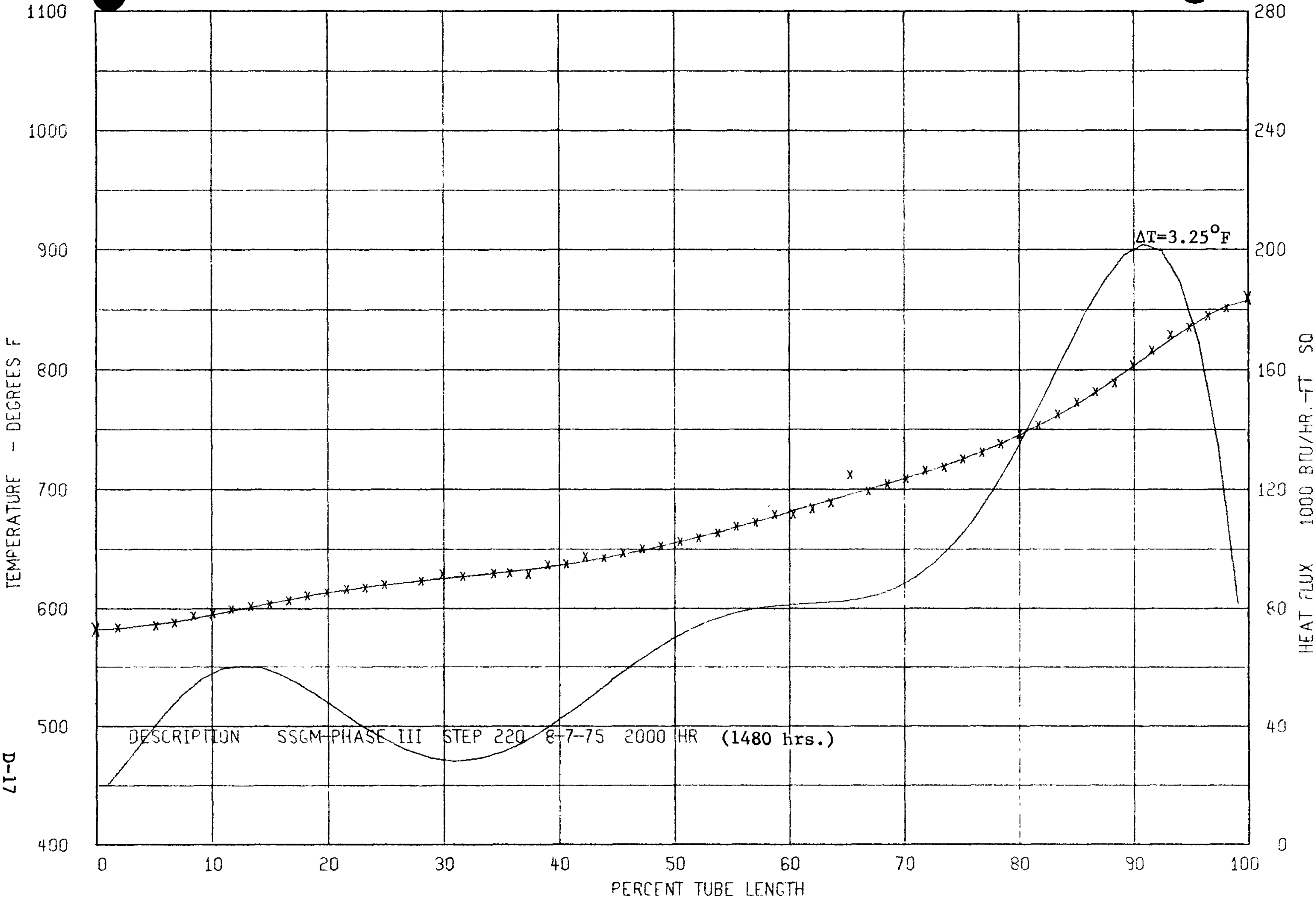

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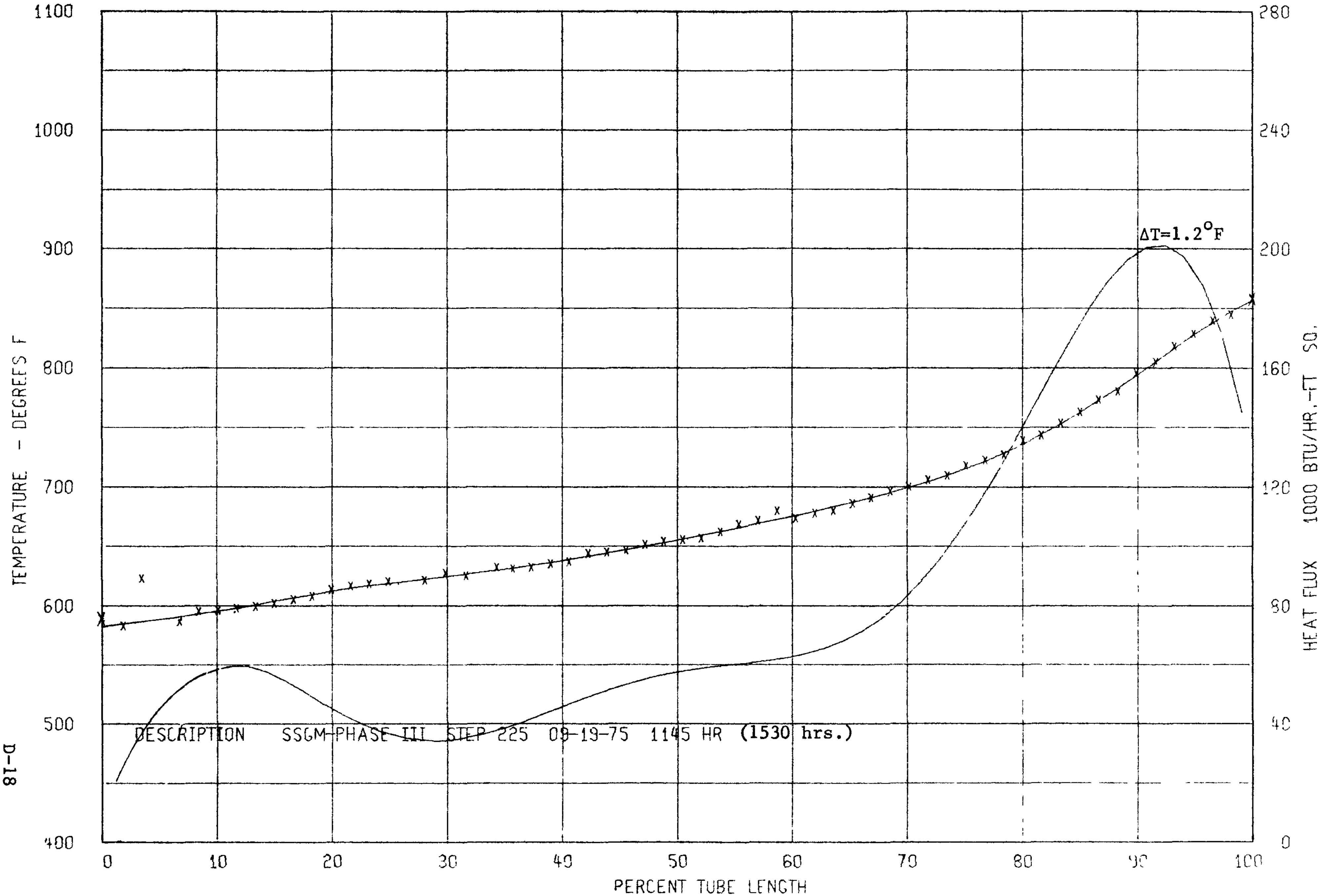

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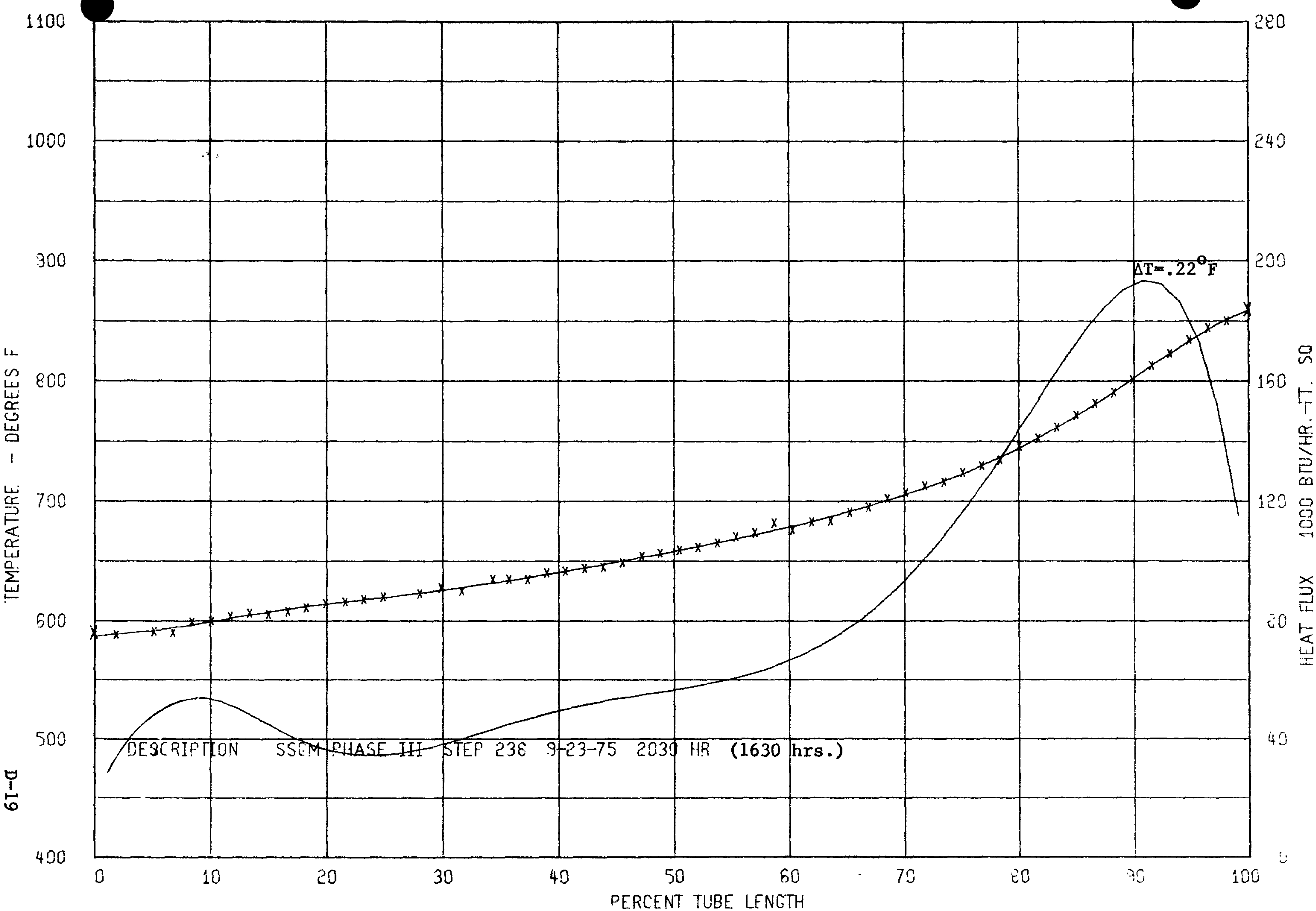

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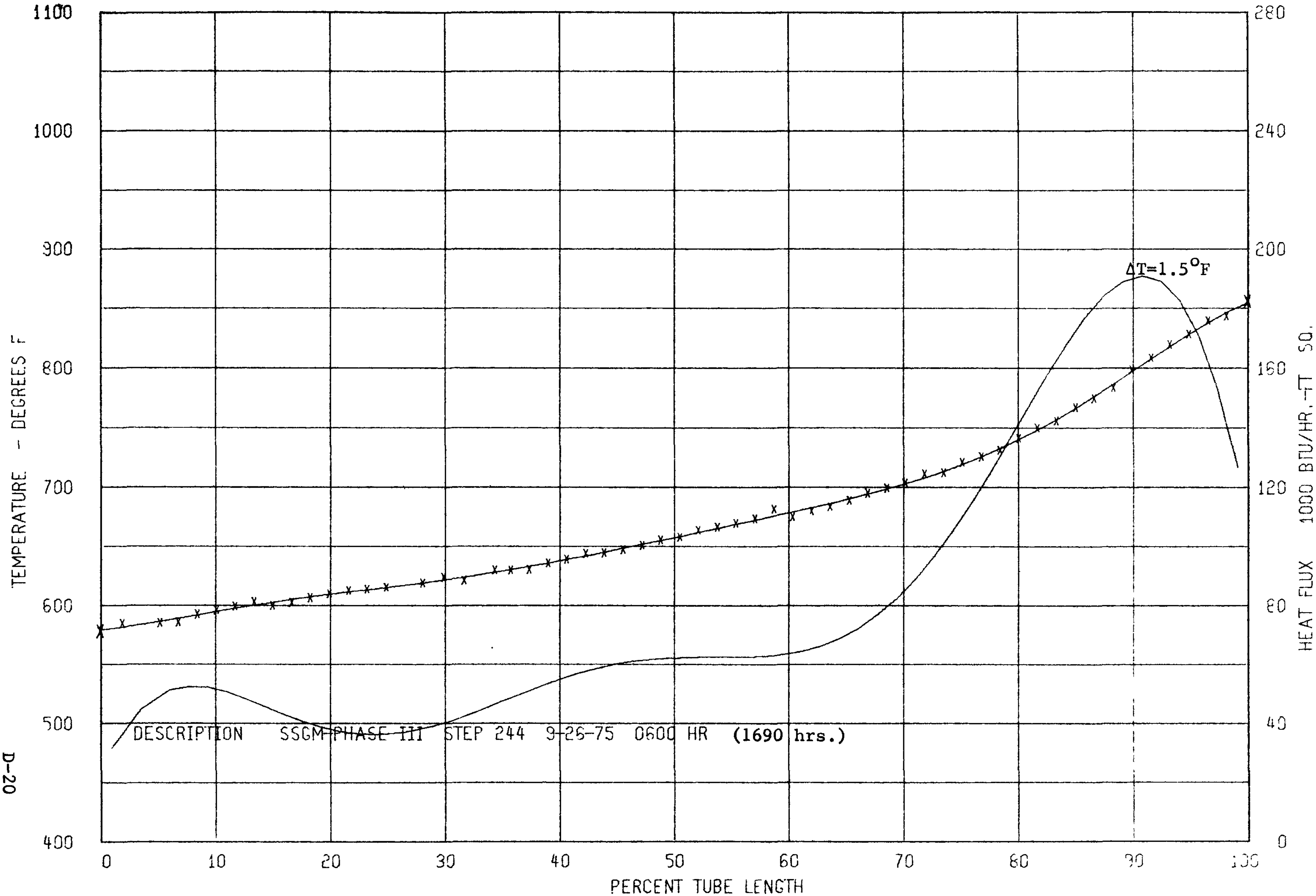

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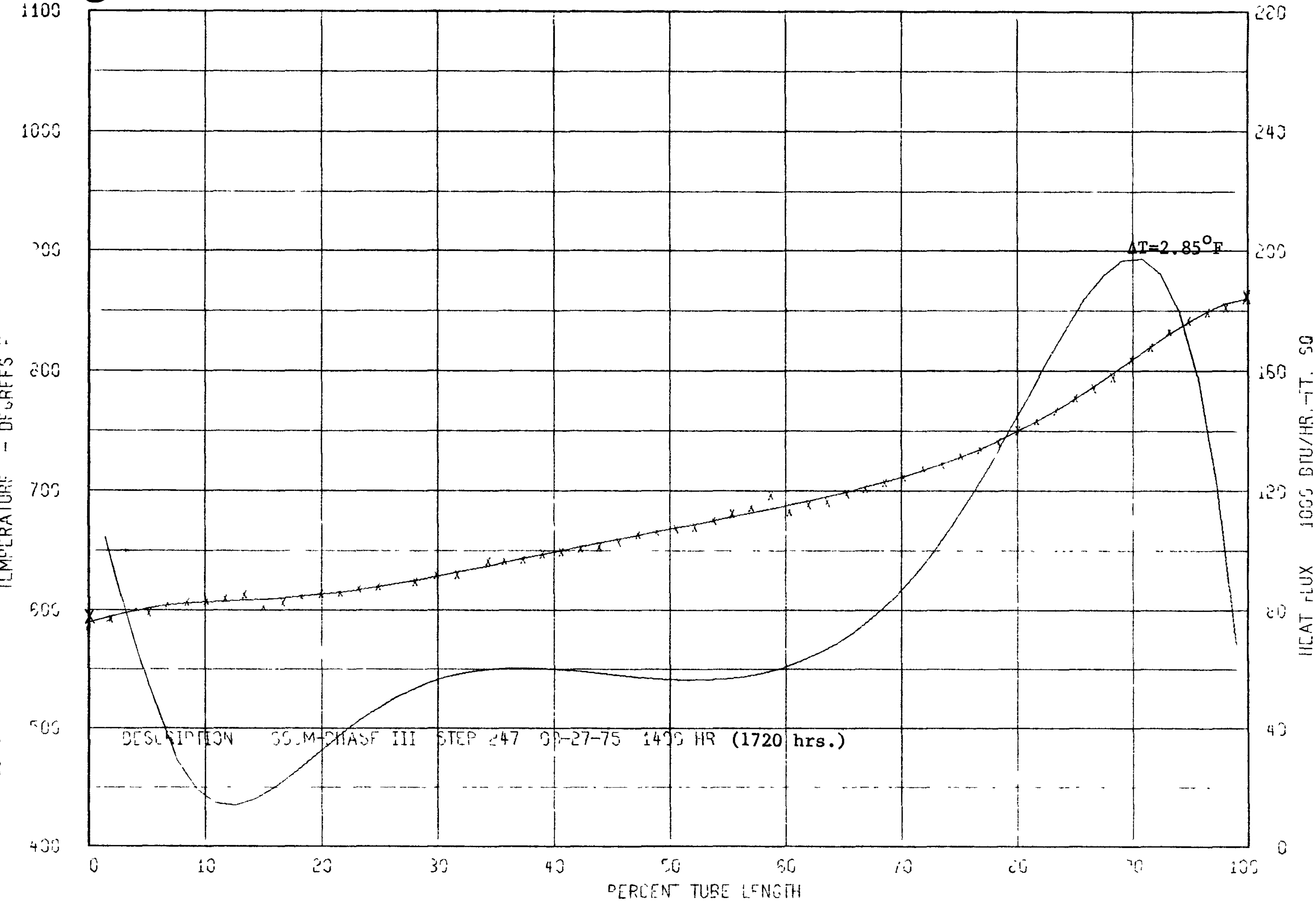

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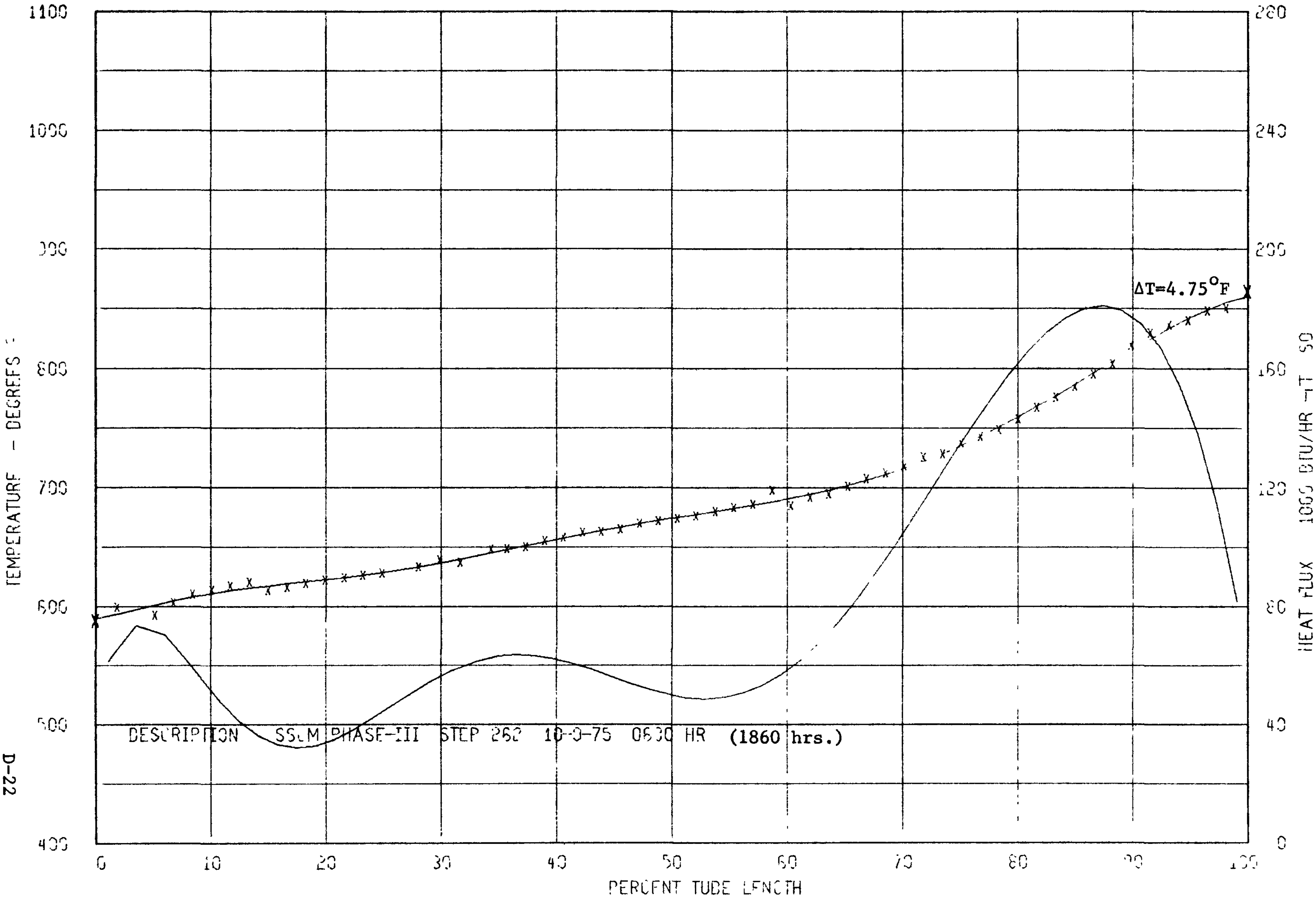
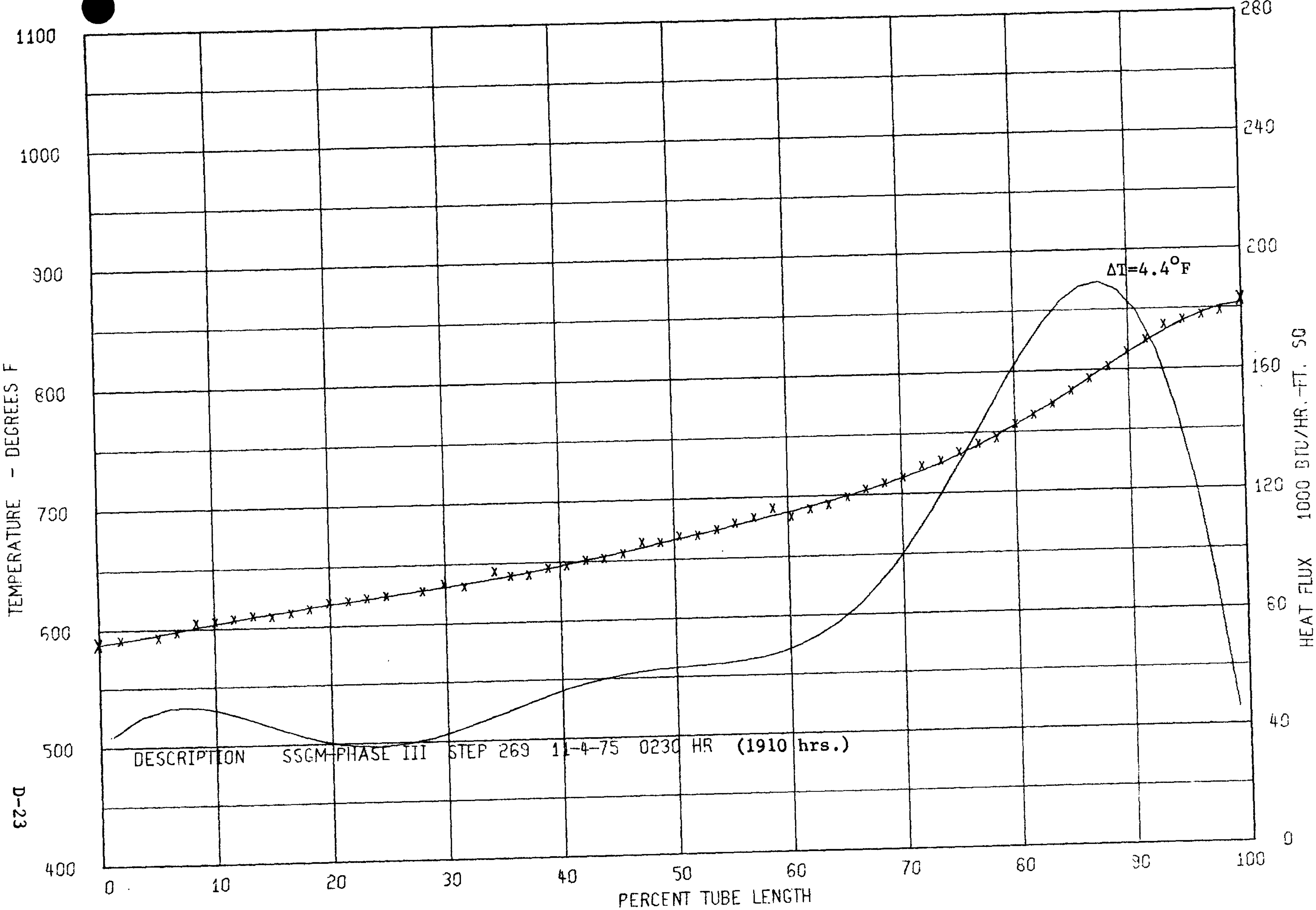


SSGM DATA POINTS AND CURVE FIT



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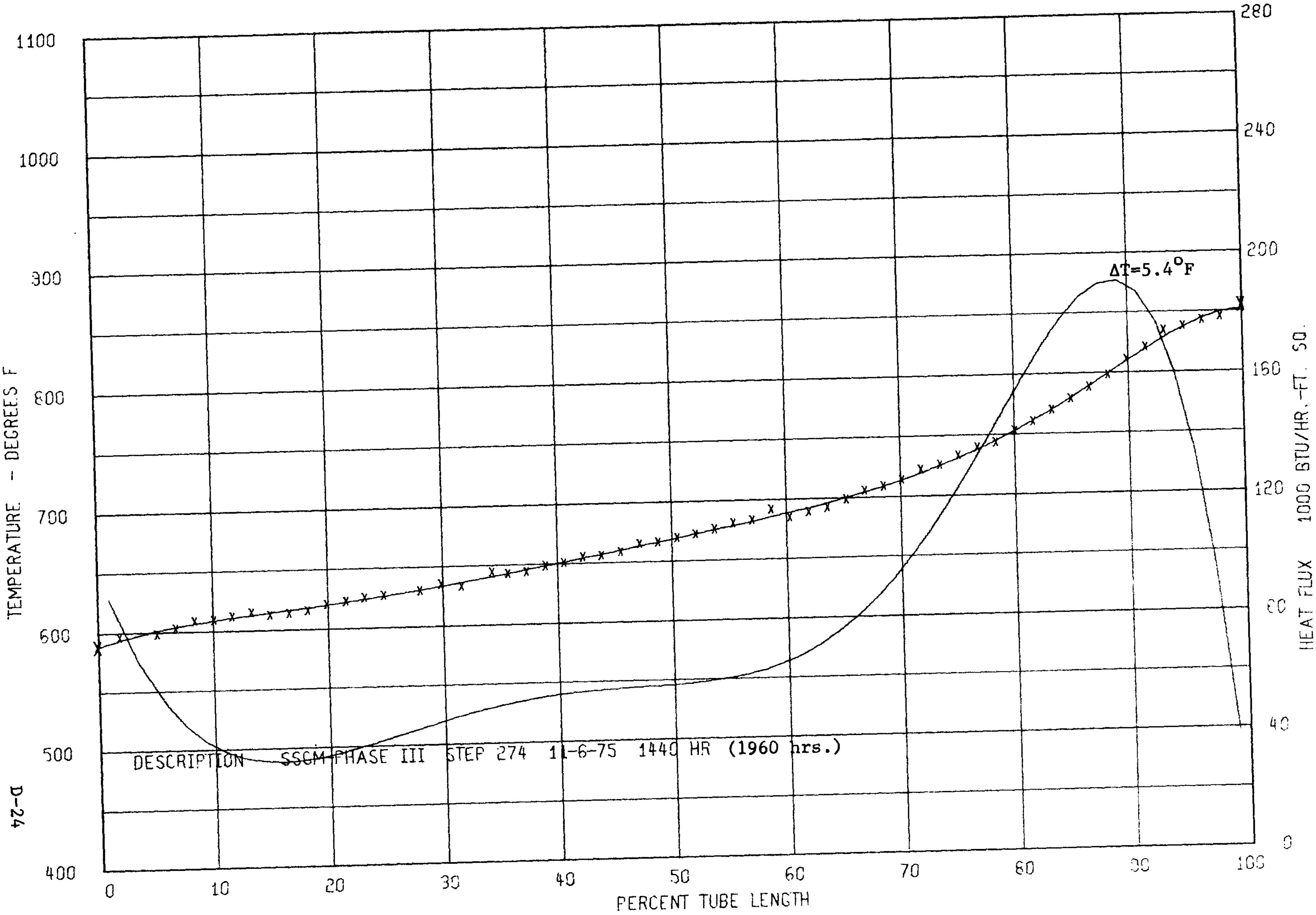

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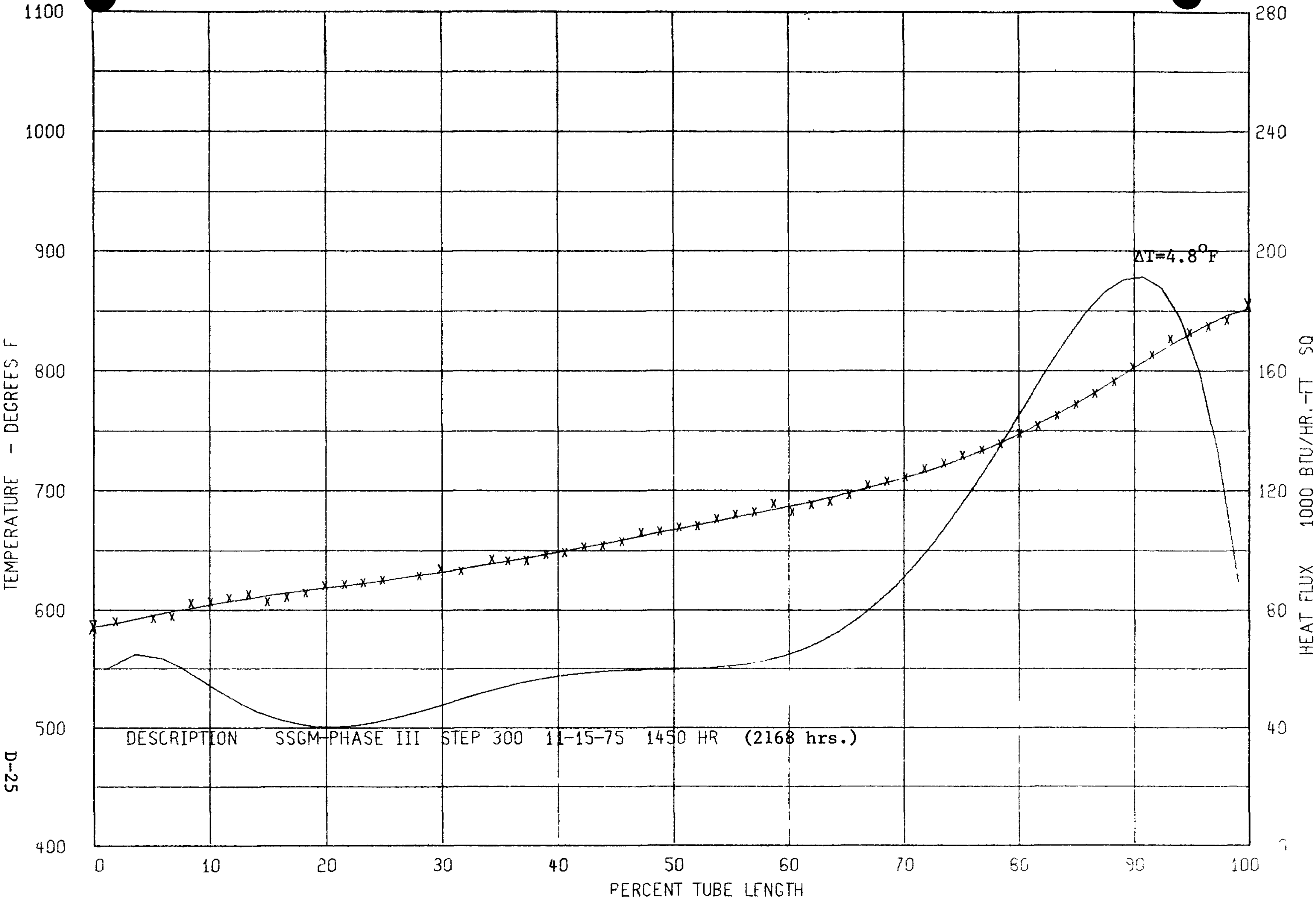


SSGM DATA POINTS AND CURVE FIT

APPENDIX E

Typical CHF Dryout and DNB Cases with Detailed Computer Evaluation of the Thermal Performance Axial Distribution

TEST DESCRIPTION = SCGM-PHASE III, STEP 101, 6-21-75, 1230 HR

HEAT FLOW AND FLUX, WATER/STEAM ENTHALPY, PRESS., TEMP., AND QUALITY BY INCREMENT

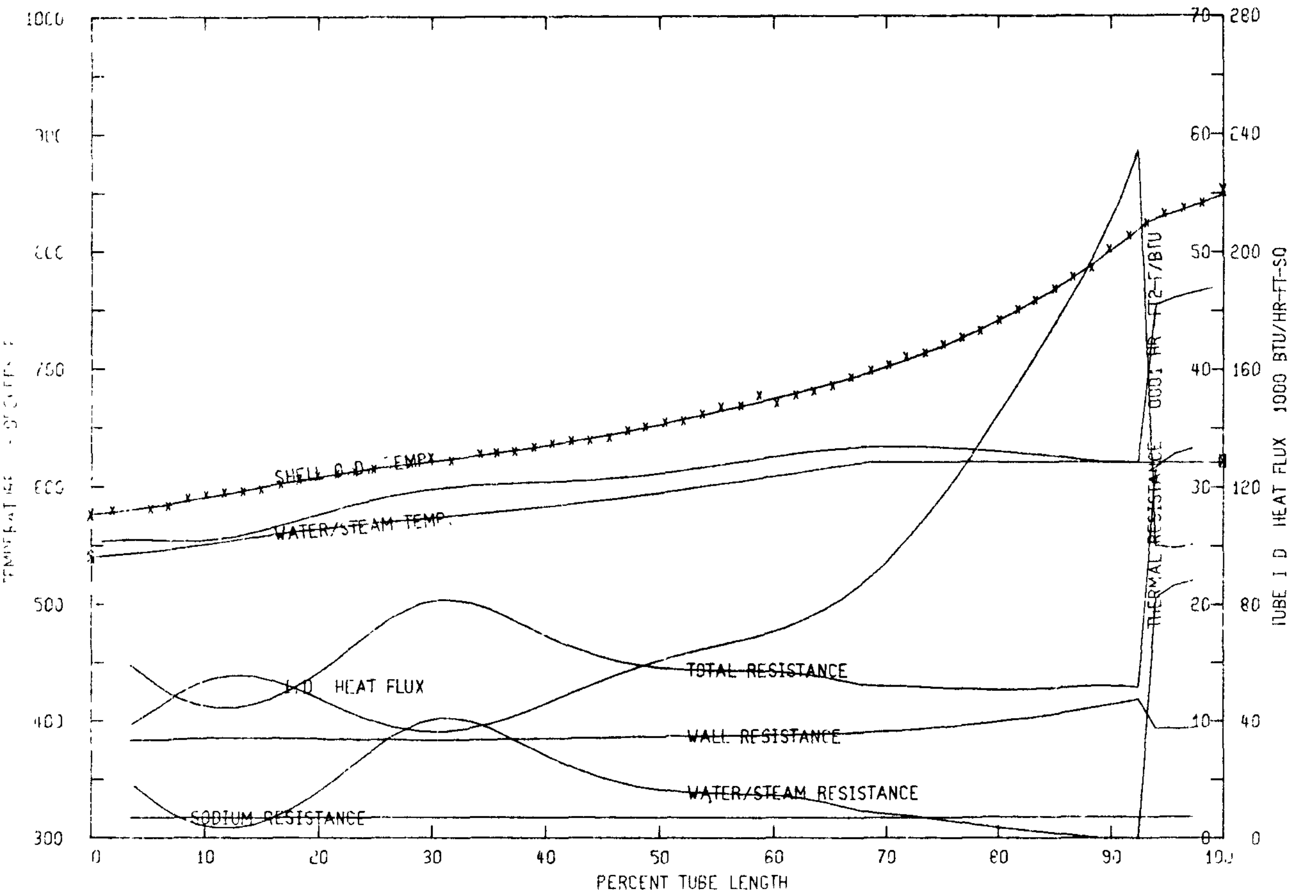
POINT OR INCREMENT	PCT. TUBE LENGTH	SODIUM TEMP F	HEAT FLOW RATE BTU/HR	I.D. HEAT FLUX BTU/HR.FT.SQ.	WATER ENTHALPY BTU/LBM	WATER PRESS PSI	WATER TEMP F	QUALITY
PREHEAT								
1	0.00	576.224	6.13071E+03	3.58352E+04	535.39	1814.47	540.00	
2	1.88	578.455	1.15477E+04	3.80882E+04	537.52	1814.60	541.71	
3	5.16	582.659	6.72416E+03	4.50558E+04	541.54	1814.81	544.91	
4	6.80	585.108	7.41366E+03	4.93748E+04	543.88	1814.92	546.84	
5	8.45	587.809	7.88026E+03	5.20023E+04	546.46	1815.03	548.89	
6	10.09	590.681	8.20924E+03	5.50067E+04	549.20	1815.13	551.07	
7	11.73	593.674	8.34050E+03	5.58863E+04	552.05	1815.24	553.32	
8	13.37	596.716	8.33736E+03	5.55266E+04	554.96	1815.35	555.60	
9	15.02	599.758	8.07674E+03	5.41189E+04	557.86	1815.46	557.86	
10	16.66	602.706	7.74797E+03	5.19159E+04	560.66	1815.56	560.04	
11	18.30	605.535	7.34563E+03	4.92200E+04	563.36	1815.67	562.13	
12	19.94	608.218	6.95191E+03	4.66299E+04	565.91	1815.78	564.09	
13	21.59	610.758	6.48196E+03	4.34329E+04	568.33	1815.89	565.94	
14	23.23	613.127	6.09447E+03	4.08365E+04	570.59	1815.99	567.66	
15	24.87	615.355	1.10578E+04	3.79730E+04	572.71	1816.09	569.27	
16	28.07	619.390	5.08331E+03	3.63262E+04	576.55	1816.26	572.16	
17	29.58	621.588	5.92711E+03	3.61849E+04	578.63	1816.36	573.76	
18	31.68	623.757	8.06292E+03	3.71672E+04	580.70	1816.46	575.26	
19	34.33	627.038	4.85290E+03	3.89258E+04	583.61	1815.93	577.57	
20	35.70	628.815	6.08313E+03	4.07605E+04	585.50	1815.64	578.61	
21	37.34	631.043	6.44088E+03	4.30907E+04	587.62	1815.30	580.36	
22	38.98	633.399	6.85748E+03	4.59707E+04	589.85	1814.96	581.99	
23	40.63	635.912	7.22371E+03	4.84031E+04	592.24	1814.62	583.72	
24	42.27	638.560	7.62505E+03	5.10923E+04	594.75	1814.27	585.53	
25	43.91	641.356	8.01785E+03	5.37243E+04	597.40	1813.93	587.43	
26	45.55	644.297	8.44023E+03	5.62117E+04	600.19	1813.59	589.41	
27	47.20	647.394	8.72326E+03	5.84510E+04	603.13	1813.25	591.46	
28	48.84	650.596	9.02779E+03	6.04915E+04	606.16	1812.90	593.60	
29	50.48	653.911	9.35105E+03	6.22778E+04	609.30	1812.56	595.77	
30	52.13	657.346	9.54064E+03	6.37279E+04	612.56	1812.22	598.01	
31	53.77	660.852	9.76538E+03	6.54338E+04	615.87	1811.88	600.26	
32	55.41	664.442	9.98445E+03	6.69017E+04	619.27	1811.53	602.54	
33	57.05	668.114	1.02875E+04	6.83146E+04	622.74	1811.19	604.85	
34	58.70	671.899	1.04897E+04	7.02873E+04	626.32	1810.85	607.20	
35	60.34	675.760	1.08112E+04	7.24413E+04	629.97	1810.50	609.57	
36	61.98	679.741	1.12001E+04	7.50474E+04	633.73	1810.16	611.98	
37	63.62	683.867	1.17459E+04	7.82275E+04	637.65	1809.82	614.43	
38	65.27	688.196	1.22585E+04	8.21388E+04	641.71	1809.48	616.97	
39	66.91	692.716	1.29546E+04	8.68034E+04	645.98	1809.13	619.56	
NUCLEATE BOILING								
40	68.55	697.495	1.37663E+04	9.22420E+04	650.46	1808.79	621.69	.002
41	70.19	702.576	1.47987E+04	9.85589E+04	655.27	1808.38	621.66	.012
42	71.84	708.041	1.57727E+04	1.05686E+05	660.42	1807.98	621.63	.022
43	73.48	713.869	1.69370E+04	1.13488E+05	665.90	1807.57	621.60	.033
44	75.12	720.131	1.82048E+04	1.21983E+05	671.79	1807.15	621.57	.045
45	76.76	726.866	1.96700E+04	1.31002E+05	678.13	1806.73	621.53	.057
46	78.41	734.148	2.03569E+04	1.40424E+05	684.97	1806.28	621.50	.071
47	80.05	741.912	2.24031E+04	1.50114E+05	692.26	1805.83	621.46	.086
48	81.69	750.218	2.38812E+04	1.60018E+05	700.05	1805.36	621.43	.101
49	83.33	759.070	2.55446E+04	1.70126E+05	708.36	1804.87	621.39	.118
50	84.98	768.565	2.69487E+04	1.80572E+05	717.24	1804.36	621.35	.136
51	86.62	778.581	2.85689E+04	1.91562E+05	726.62	1803.83	621.31	.154
52	88.26	789.216	3.03890E+04	2.03624E+05	736.56	1803.29	621.27	.174
53	89.90	800.531	3.26785E+04	2.17638E+05	747.13	1802.71	621.22	.195
54	91.55	812.710	3.50372E+04	2.34770E+05	758.50	1802.11	621.18	.216
FILM BOILING								
55	93.19	825.781	1.49281E+04	1.00027E+05	770.68	1801.47	621.13	.242
56	94.83	831.354	1.49219E+04	9.93794E+04	775.87	1800.94	621.09	.253
57	96.48	836.927	1.49158E+04	1.00558E+05	781.17	1800.40	621.05	.263
58	98.11	842.500	1.77050E+04	1.02941E+05	786.25	1799.86	621.00	.273
59	100.00	849.118			792.41	1799.22	620.96	.266

TEST DESCRIPTION = SSGM-PHASE III, STEP 101, 6-21-75, 1230 HR

WATER INLET TEMP.,F	=	540.000	SODIUM INLET TEMP.,F	=	852.500
WATER OUTLET TEMP.,F	=	622.000	SODIUM OUTLET TEMP.,F	=	576.000
WATER FLOW RATE, LB/HR	=	2875.000	SODIUM FLOW RATE, LB/HR	=	8826.000
WATER PRESS DROP, PSI	=	19.700	SODIUM PRESS DROP,IN.H2O	=	13.000
WATER OUTLET PRESS,PSIA	=	1795.000	SURFACE ROUGHNESS, FT.	=	0.0000000
PREHEAT FOULING,HRFTSQF/B	=	0.00000	NUCLEATE FOULING FACTOR	=	0.00000
AFTER DNB FOULING FACTOR	=	0.00000	SH. FOULING,HR-FTSQ-F/BTU	=	0.00000
ACTIVE TUBE LENGTH, IN.	=	730.500	BEND RADIUS, IN.	=	9999.000
INSIDE TUBE DIAMETER, IN.	=	.571	OUTSIDE TUBE DIAMETER,IN.	=	.875
HEIGHT OF UNIT, IN	=	514.000	MIN. NA FLOW AREA, SQ.IN.	=	1.080
NUMBER OF TUBES	=	1.000	NUMBER OF TUBE BENDS	=	0.000
ENTRANCE VEL. HEAD LOSS	=	.500	EXIT VELOCITY HEAD LOSS	=	1.000
ENTRANCE UNHEATED LENGTH	=	-0.000	EXIT UNHEATED LENGTH, IN.	=	-0.000
C1-CONDUCTIVITY CONSTANT	=	24.250000	C2-CONDUCTIVITY CONSTANT	=	-.005200

CONSTANTS CALCULATED AT LABEL 3001

RATBEN	=	0.
BENFAC	=	.100E+01
CSAREA	=	.256E+00
EQDIA	=	.476E-01
GW	=	.162E+07
GC	=	.418E+09
G	=	.418E+09
SISLOP	=	.704E+00
RADIN	=	.286E+00
ALPHA	=	.100E+01
K66	=	59



SSGM TEST RESULTS

TEST DESCRIPTION = SSGM-PHASE III, STEP 101, 6-21-75, 1230 HR

OVERALL U AND R AND INDIVIDUAL RESISTANCES BY INCREMENT, STEAM R UNKNOWN

I	LMTD DEG F	OVERALL U BTU/ HRFT2F	TOTAL RESISTANCE HR.FT.SQ.F /BTU	SODIUM RESISTANCE HR.FT.SQ.F /BTU	WALL RESISTANCE HR.FT.SQ.F /BTU	FOUL RESISTANCE HR.FT.SQ.F /BTU	STEAM RESISTANCE HR.FT.SQ.F /BTU	STEAM FILM COEFFICIENT BTU/ HR.FT.SQ.F	QUALITY	WALL TEMP F
	PREHEAT									
1	36.47	641.2	1.560E-03	1.741E-04	8.318E-04	0.	5.537E-04	2.768E+03		553.82
2	37.20	678.6	1.474E-03	1.742E-04	8.352E-04	0.	4.642E-04	3.301E+03		555.07
3	37.98	774.1	1.292E-03	1.743E-04	8.425E-04	0.	2.750E-04	5.573E+03		553.99
4	38.59	834.9	1.198E-03	1.744E-04	8.476E-04	0.	1.758E-04	8.717E+03		553.53
5	39.27	877.5	1.140F-03	1.745E-04	8.518E-04	0.	1.133E-04	1.353E+04		553.88
6	39.98	897.7	1.114E-03	1.746E-04	8.546E-04	0.	8.467E-05	1.810E+04		555.23
7	40.74	895.3	1.117E-03	1.747E-04	8.559E-04	0.	8.631E-05	1.775E+04		557.61
8	41.51	873.0	1.146E-03	1.749E-04	8.558E-04	0.	1.148E-04	1.335E+04		560.89
9	42.28	835.3	1.197E-03	1.750E-04	8.545E-04	0.	1.676E-04	9.142E+03		564.87
10	43.03	787.3	1.270E-03	1.751E-04	8.523E-04	0.	2.428E-04	6.311F+03		569.31
11	43.77	733.9	1.363E-03	1.752E-04	8.496E-04	0.	3.378E-04	4.536E+03		573.96
12	44.47	679.4	1.472E-03	1.753E-04	8.466E-04	0.	4.499E-04	3.406E+03		578.61
13	45.14	627.9	1.593E-03	1.754E-04	8.438E-04	0.	5.735E-04	2.672E+03		583.06
14	45.78	582.1	1.718E-03	1.755E-04	8.412E-04	0.	7.011E-04	2.186E+03		587.15
15	46.66	531.1	1.883E-03	1.756E-04	8.385E-04	0.	8.689E-04	1.764E+03		592.25
16	47.55	498.5	2.006E-03	1.757E-04	8.372E-04	0.	9.930E-04	1.543E+03		596.48
17	48.18	490.1	2.040E-03	1.758E-04	8.373E-04	0.	1.027E-03	1.492E+03		598.75
18	48.99	495.1	2.020E-03	1.759E-04	8.386E-04	0.	1.005E-03	1.525E+03		600.79
19	49.74	510.7	1.958E-03	1.760E-04	8.408E-04	0.	9.413E-04	1.628E+03		602.10
20	50.35	528.3	1.893E-03	1.761E-04	8.430F-04	0.	8.736E-04	1.754F+03		602.82
21	51.05	550.9	1.815E-03	1.762E-04	8.457E-04	0.	7.934E-04	1.931E+03		603.48
22	51.80	575.3	1.738E-03	1.763E-04	8.488E-04	0.	7.130E-04	2.149E+03		604.10
23	52.61	600.4	1.666E-03	1.764E-04	8.521E-04	0.	6.371E-04	2.405E+03		604.75
24	53.48	623.4	1.604E-03	1.765E-04	8.554F-04	0.	5.721E-04	2.679E+03		605.55
25	54.41	644.4	1.552E-03	1.766E-04	8.587E-04	0.	5.166E-04	2.966E+03		606.53
26	55.40	662.1	1.510E-03	1.767E-04	8.619E-04	0.	4.717E-04	3.249E+03		607.74
27	56.46	675.6	1.480E-03	1.769E-04	8.649E-04	0.	4.384E-04	3.496E+03		609.26
28	57.57	685.7	1.458E-03	1.770E-04	8.676E-04	0.	4.137E-04	3.704E+03		611.02
29	58.74	691.9	1.445E-03	1.771E-04	8.701E-04	0.	3.981E-04	3.850E+03		613.07
30	59.97	695.7	1.437E-03	1.773E-04	8.725E-04	0.	3.877E-04	3.953E+03		615.31
31	61.24	697.2	1.434E-03	1.774E-04	8.747E-04	0.	3.822E-04	4.010E+03		617.72
32	62.58	697.7	1.433E-03	1.776E-04	8.768E-04	0.	3.790E-04	4.044E+03		620.24
33	63.98	698.8	1.431E-03	1.777E-04	8.792E-04	0.	3.740E-04	4.097E+03		622.75
34	65.44	700.9	1.427E-03	1.779E-04	8.818E-04	0.	3.671E-04	4.175E+03		625.22
35	66.98	705.8	1.417E-03	1.780E-04	8.849F-04	0.	3.539E-04	4.330E+03		627.50
36	68.60	713.9	1.401E-03	1.782E-04	8.886E-04	0.	3.340E-04	4.589F+03		629.56
37	70.33	725.8	1.378E-03	1.784E-04	8.931E-04	0.	3.063E-04	5.003E+03		631.33
38	72.19	742.5	1.347E-03	1.786E-04	8.986E-04	0.	2.697E-04	5.683E+03		632.72
39	74.48	760.6	1.315E-03	1.788E-04	9.052E-04	0.	2.308F-04	6.639E+03		633.70
	NUCLEATE BOILING									
40	78.36	768.2	1.302E-03	1.790E-04	9.131E-04	0.	2.097E-04	7.306E+03	.002	634.30
41	83.66	768.8	1.301E-03	1.792E-04	9.224E-04	0.	1.992E-04	7.692E+03	.012	634.46
42	89.34	772.0	1.295E-03	1.794E-04	9.332E-04	0.	1.828E-04	8.384E+03	.022	634.22
43	95.42	776.2	1.288E-03	1.797E-04	9.455E-04	0.	1.632E-04	9.390E+03	.033	633.67
44	101.95	780.8	1.281E-03	1.799E-04	9.595E-04	0.	1.413E-04	1.084E+04	.045	632.80
45	108.99	784.4	1.275E-03	1.802E-04	9.750E-04	0.	1.197F-04	1.280E+04	.057	631.75
46	116.55	786.3	1.272E-03	1.806E-04	9.921E-04	0.	9.922E-05	1.544E+04	.071	630.57
47	124.62	786.1	1.272E-03	1.809E-04	1.011E-03	0.	8.064E-05	1.900E+04	.086	629.35
48	133.24	783.7	1.276E-03	1.813E-04	1.031E-03	0.	6.403E-05	2.393E+04	.101	628.10
49	142.45	779.4	1.283E-03	1.816E-04	1.052E-03	0.	4.903E-05	3.126E+04	.118	626.81
50	152.24	774.0	1.292E-03	1.821E-04	1.076E-03	0.	3.354E-05	4.569E+04	.136	625.28
51	162.61	768.8	1.301E-03	1.825E-04	1.103E-03	0.	1.493E-05	1.027E+05	.154	623.16
52	173.63	765.3	1.307F-03	1.830E-04	1.132E-03	0.	1.000E-07	1.532E+07	.174	621.26
53	185.42	766.0	1.306E-03	1.835E-04	1.158E-03	0.	1.000E-07	1.532E+07	.195	621.22
54	198.09	773.4	1.293E-03	1.840E-04	1.187E-03	0.	1.000E-07	1.532E+07	.218	621.17
	FILM BOILING									
55	207.46	314.6	3.178E-03	1.845E-04	9.390E-04	0.	2.055E-03	7.458E+02	.242	755.24
56	213.07	304.4	3.286E-03	1.847E-04	9.388E-04	0.	2.162E-03	7.088E+02	.253	761.28
57	218.69	300.1	3.333E-03	1.849E-04	9.412E-04	0.	2.206E-03	6.945F+02	.263	765.82
58	224.83	298.8	3.347E-03	1.852E-04	9.452E-04	0.	2.216E-03	6.914F+02	.273	769.87
59									.286	

TEST DESCRIPTION = SSGM-PHASE III, STEP 101, 6-21-75, 1230 HR

WATER/STEAM SIDE PRESSURE LOSS BY INCREMENT

POINT OR INCREMENT	SPECIFIC VOLUME CU.FT./LBM	AVERAGE SPEC.VOL CU.FT./LBM	DELTA SPEC.VOL CU.FT./LBM	VISCOSITY LBM/HR.FT.	AVERAGE VISCOSITY LBM/HR.FT.	REYNOLDS NUMBER	FRICTION LOSS PSI	ACCEL LOSS PSI	HEAD LOSS PSI	BEND LOSS PSI	TOTAL PRESS DROP PSI
PREHEAT											
1	.02118	.02121	.00005	.23401	.23354	3.294E+05	.1356	.0022	-.2637	0.0000	-.1260
2	.02123	.02128	.00009	.23308	.23221	3.313E+05	.2370	.0041	-.4585	0.0000	-.2173
3	.02133	.02135	.00006	.23134	.23084	3.333E+05	.1188	.0024	-.2284	0.0000	-.1072
4	.02138	.02141	.00006	.23034	.22979	3.348E+05	.1197	.0027	-.2292	0.0000	-.1067
5	.02145	.02148	.00007	.22924	.22865	3.364E+05	.1193	.0029	-.2271	0.0000	-.1049
6	.02151	.02155	.00007	.22807	.22746	3.382E+05	.1195	.0031	-.2264	0.0000	-.1038
7	.02158	.02162	.00007	.22686	.22625	3.400E+05	.1198	.0032	-.2256	0.0000	-.1027
8	.02166	.02169	.00007	.22564	.22503	3.419E+05	.1208	.0032	-.2263	0.0000	-.1022
9	.02173	.02177	.00007	.22442	.22383	3.437E+05	.1204	.0031	-.2241	0.0000	-.1006
10	.02180	.02184	.00007	.22325	.22269	3.455E+05	.1206	.0031	-.2234	0.0000	-.0997
11	.02187	.02191	.00007	.22213	.22160	3.472E+05	.1209	.0029	-.2227	0.0000	-.0989
12	.02194	.02197	.00006	.22107	.22057	3.488E+05	.1219	.0028	-.2234	0.0000	-.0987
13	.02200	.02204	.00006	.22008	.21961	3.503E+05	.1214	.0027	-.2214	0.0000	-.0973
14	.02207	.02209	.00006	.21915	.21872	3.517E+05	.1216	.0025	-.2208	0.0000	-.0967
15	.02212	.02218	.00011	.21828	.21750	3.537E+05	.2379	.0046	-.4292	0.0000	-.1866
16	.02223	.02226	.00006	.21672	.21630	3.557E+05	.1349	.0025	-.2419	0.0000	-.1044
17	.02229	.02232	.00006	.21587	.21546	3.571E+05	.1344	.0025	-.2399	0.0000	-.1029
18	.02235	.02239	.00009	.21504	.21441	3.588E+05	.1984	.0039	.3520	0.0000	.5543
19	.02244	.02246	.00005	.21378	.21345	3.604E+05	.1028	.0021	.1814	0.0000	.2864
20	.02249	.02252	.00006	.21311	.21268	3.617E+05	.1233	.0027	.2166	0.0000	.3426
21	.02255	.02258	.00007	.21226	.21181	3.632E+05	.1235	.0029	.2160	0.0000	.3424
22	.02262	.02265	.00007	.21136	.21089	3.648E+05	.1246	.0031	.2167	0.0000	.3444
23	.02269	.02273	.00008	.21041	.20992	3.665E+05	.1241	.0033	.2146	0.0000	.3421
24	.02277	.02281	.00008	.20942	.20889	3.683E+05	.1244	.0036	.2139	0.0000	.3419
25	.02285	.02289	.00009	.20837	.20782	3.702E+05	.1248	.0038	.2131	0.0000	.3417
26	.02294	.02298	.00009	.20727	.20669	3.722E+05	.1259	.0041	.2135	0.0000	.3435
27	.02303	.02308	.00010	.20612	.20552	3.743E+05	.1255	.0043	.2114	0.0000	.3412
28	.02313	.02318	.00010	.20493	.20432	3.765E+05	.1259	.0045	.2104	0.0000	.3409
29	.02323	.02329	.00011	.20370	.20307	3.788E+05	.1271	.0048	.2107	0.0000	.3426
30	.02334	.02340	.00011	.20244	.20180	3.812E+05	.1268	.0050	.2085	0.0000	.3402
31	.02346	.02352	.00012	.20115	.20050	3.837E+05	.1273	.0052	.2074	0.0000	.3399
32	.02358	.02364	.00012	.19984	.19917	3.862E+05	.1278	.0054	.2064	0.0000	.3395
33	.02370	.02377	.00013	.19850	.19781	3.889E+05	.1291	.0057	.2065	0.0000	.3413
34	.02383	.02390	.00014	.19713	.19643	3.916E+05	.1288	.0059	.2041	0.0000	.3389
35	.02397	.02404	.00014	.19573	.19500	3.945E+05	.1294	.0062	.2029	0.0000	.3386
36	.02411	.02419	.00015	.19428	.19354	3.975E+05	.1300	.0066	.2017	0.0000	.3383
37	.02426	.02435	.00016	.19279	.19201	4.007E+05	.1315	.0071	.2016	0.0000	.3402
38	.02443	.02452	.00018	.19123	.19041	4.040E+05	.1314	.0077	.1990	0.0000	.3380
39	.02461	.02486	.00051	.18959	.18879	4.075E+05	.1330	.0222	.1962	0.0000	.3514
NUCLEATE BOILING											
40	.02512	.02604	.00185	.18799	.18735	4.106E+05	.1391	.0804	.1873	0.0000	.4069
41	.02697	.02796	.00199	.18671	.18603	4.135E+05	.1501	.0864	.1755	0.0000	.4120
42	.02896	.03002	.00212	.18534	.18461	4.167E+05	.1599	.0921	.1625	0.0000	.4145
43	.03108	.03222	.00228	.18388	.18310	4.202E+05	.1714	.0989	.1514	0.0000	.4217
44	.03336	.03458	.00245	.18231	.18147	4.239E+05	.1836	.1063	.1411	0.0000	.4310
45	.03581	.03713	.00265	.18063	.17972	4.281E+05	.1980	.1149	.1322	0.0000	.4451
46	.03845	.03986	.00282	.17881	.17784	4.326E+05	.2108	.1224	.1224	0.0000	.4556
47	.04127	.04278	.00301	.17687	.17583	4.375E+05	.2258	.1309	.1140	0.0000	.4707
48	.04428	.04589	.00321	.17479	.17369	4.429E+05	.2417	.1396	.1063	0.0000	.4875
49	.04750	.04922	.00344	.17258	.17140	4.488E+05	.2601	.1493	.0997	0.0000	.5092
50	.05094	.05275	.00363	.17021	.16897	4.553E+05	.2763	.1576	.0925	0.0000	.5264
51	.05457	.05649	.00385	.16772	.16639	4.623E+05	.2951	.1673	.0864	0.0000	.5487
52	.05842	.06047	.00410	.16507	.16366	4.700E+05	.3149	.1779	.0807	0.0000	.5734
53	.06251	.06472	.00441	.16226	.16074	4.786E+05	.3379	.1914	.0758	0.0000	.6051
54	.06692	.06928	.00473	.15923	.15761	4.881E+05	.3582	.2053	.0704	0.0000	.6339
FILM BOILING											
55	.07165	.07266	.00203	.15598	.15529	4.954E+05	.3747	.0882	.0671	0.0000	.5301
56	.07368	.07470	.00203	.15460	.15391	4.998E+05	.3869	.0883	.0657	0.0000	.5409
57	.07571	.07673	.00203	.15322	.15253	5.044E+05	.3919	.0883	.0632	0.0000	.5434
58	.07775	.07895	.00242	.15184	.15102	5.094E+05	.4668	.1049	.0712	0.0000	.6428
59	.08016			.15020							

TEST DESCRIPTION = SSGM PHASE III, STEP 238, 9-23-75, 2030 HR

HEAT FLOW AND FLUX, WATER/STEAM ENTHALPY, PRESS., TEMP., AND QUALITY BY INCREMENT

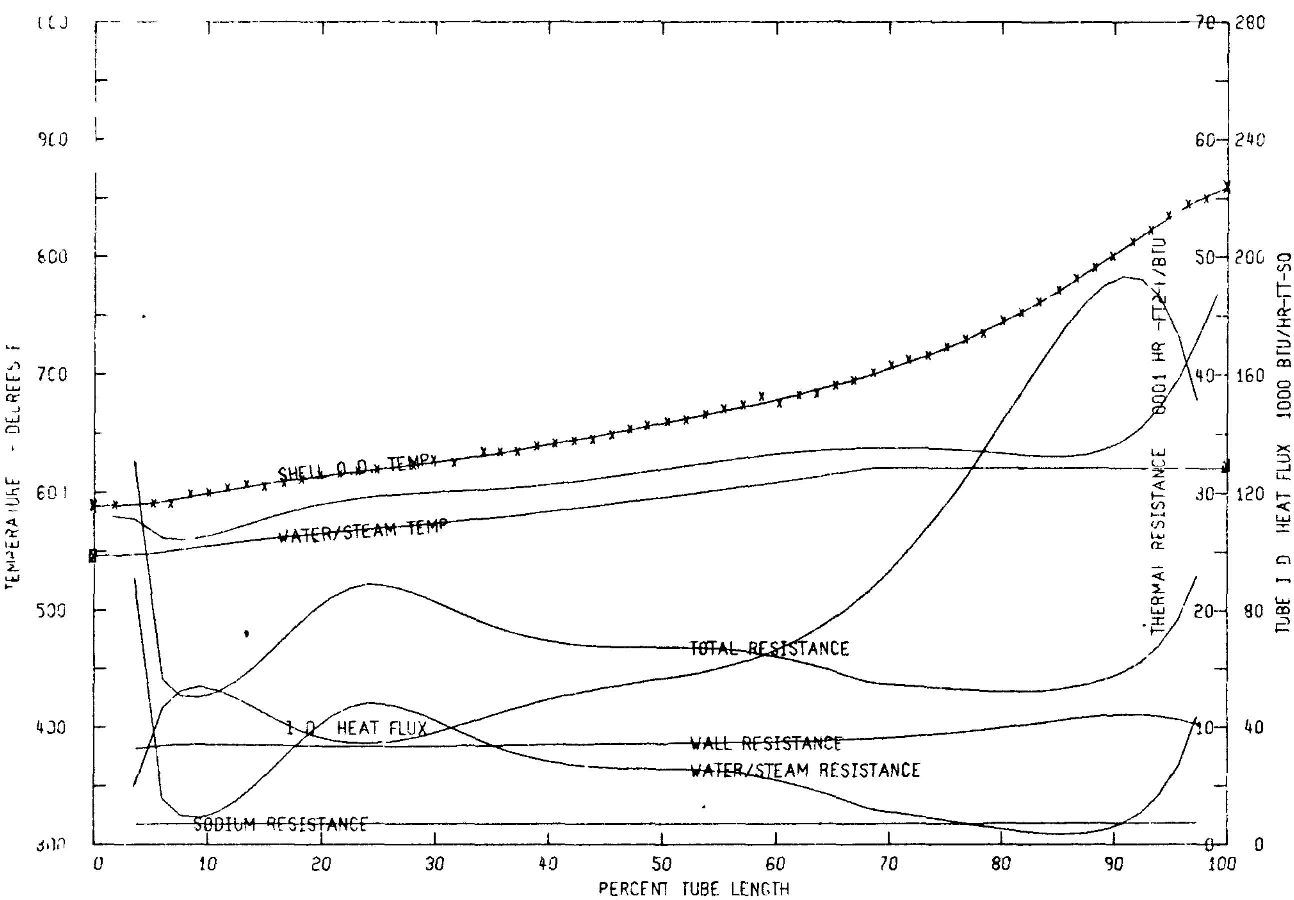
POINT OR INCREMENT	PCT. TUBE LENGTH	SODIUM TEMP F	HEAT FLOW RATE BTU/HR	I.D. HEAT FLUX BTU/HR.FT.SQ.	WATER ENTHALPY BTU/LBM	WATER PRESS PSI	WATER TEMP F	QUALITY
PREHEAT								
1	0,00	588,000	2,28061E+03	1,33306E+04	542,85	1814,77	546,08	
2	1,66	588,831	3,93232E+03	1,98750E+04	543,65	1814,89	546,65	
3	5,16	590,993	6,98118E+03	4,67780E+04	545,71	1815,11	548,30	
4	6,80	593,538	7,90019E+03	5,26151E+04	548,14	1815,21	550,23	
5	8,45	596,419	8,07277E+03	5,40923E+04	550,88	1815,32	552,40	
6	10,09	599,364	7,88353E+03	5,28243E+04	553,69	1815,43	554,61	
7	11,73	602,241	7,46171E+03	4,99979E+04	556,43	1815,53	556,75	
8	13,37	604,965	6,98283E+03	4,65055E+04	559,03	1815,64	558,78	
9	15,02	607,515	6,41408E+03	4,29781E+04	561,46	1815,74	560,66	
10	16,66	609,858	5,94707E+03	3,98488E+04	563,69	1815,85	562,38	
11	18,30	612,031	5,57071E+03	3,73270E+04	565,76	1815,95	563,97	
12	19,94	614,067	5,34506E+03	3,55980E+04	567,70	1816,06	565,46	
13	21,59	616,021	5,16880E+03	3,46340E+04	569,56	1816,16	566,88	
14	23,23	617,911	5,13756E+03	3,44247E+04	571,35	1816,27	568,24	
15	24,87	619,790	1,02935E+04	3,53485E+04	573,14	1816,38	569,59	
16	26,07	623,556	6,15042E+03	3,73407E+04	576,72	1816,56	572,29	
17	29,80	625,807	6,43010E+03	3,92556E+04	578,86	1816,67	573,89	
18	31,68	628,161	1,01005E+04	4,18843E+04	581,10	1816,77	575,56	
19	34,33	631,860	5,52760E+03	4,43376E+04	584,61	1816,22	578,15	
20	35,70	633,885	6,87697E+03	4,60797E+04	586,53	1815,93	579,57	
21	37,34	636,405	7,15047E+03	4,79123E+04	588,92	1815,59	581,31	
22	38,98	639,026	7,44008E+03	4,95508E+04	591,41	1815,24	583,12	
23	40,63	641,754	7,61767E+03	5,10429E+04	594,00	1814,90	584,99	
24	42,27	644,548	7,81690E+03	5,23778E+04	596,65	1814,56	586,89	
25	43,91	647,416	7,98871E+03	5,35290E+04	599,37	1814,22	588,82	
26	45,55	650,348	8,19575E+03	5,45835E+04	602,15	1813,87	590,79	
27	47,20	653,357	8,29899E+03	5,55545E+04	605,00	1813,53	592,79	
28	48,84	656,402	8,43785E+03	5,65385E+04	607,88	1813,19	594,79	
29	50,48	659,502	8,64442E+03	5,75717E+04	610,82	1812,84	596,82	
30	52,13	662,679	8,75833E+03	5,86860E+04	613,82	1812,50	598,87	
31	53,77	665,899	8,95913E+03	6,00314E+04	616,87	1812,16	600,93	
32	55,41	669,194	9,19505E+03	6,16123E+04	619,99	1811,82	603,02	
33	57,05	672,577	9,53940E+03	6,35322E+04	623,18	1811,47	605,15	
34	58,70	676,088	9,82364E+03	6,58241E+04	626,50	1811,13	607,32	
35	60,34	679,705	1,02406E+04	6,86178E+04	629,92	1810,79	609,54	
36	61,98	683,477	1,07276E+04	7,16810E+04	633,48	1810,44	611,82	
37	63,62	687,430	1,13713E+04	7,57326E+04	637,21	1810,10	614,17	
38	65,27	691,622	1,19735E+04	8,02298E+04	641,17	1809,76	616,63	
39	66,91	696,038	1,27349E+04	8,53311E+04	645,33	1809,42	619,18	
NUCLEATE BOILING								
40	68,55	700,737	1,35981E+04	9,11150E+04	649,76	1809,07	621,71	,000
41	70,19	705,757	1,46576E+04	9,76191E+04	654,49	1808,67	621,68	,010
42	71,84	711,171	1,56424E+04	1,04813E+05	659,59	1808,26	621,65	,020
43	73,48	716,952	1,68122E+04	1,12651E+05	665,03	1807,85	621,62	,031
44	75,12	723,169	1,80745E+04	1,21110E+05	670,88	1807,43	621,59	,043
45	76,76	729,857	1,95397E+04	1,30134E+05	677,16	1807,01	621,56	,055
46	78,41	737,092	2,08375E+04	1,39623E+05	683,96	1806,57	621,52	,069
47	80,05	744,813	2,22810E+04	1,49296E+05	691,21	1806,12	621,49	,084
48	81,69	753,075	2,37377E+04	1,59056E+05	698,96	1805,65	621,45	,099
49	83,33	761,884	2,53016E+04	1,68508E+05	707,22	1805,16	621,41	,116
50	84,98	771,281	2,64614E+04	1,77307E+05	716,02	1804,65	621,37	,133
51	86,62	781,117	2,75030E+04	1,84028E+05	725,22	1804,13	621,33	,152
52	88,26	791,379	2,84240E+04	1,90463E+05	734,81	1803,59	621,29	,171
53	89,90	801,963	2,90309E+04	1,93345E+05	744,70	1803,03	621,25	,190
FILM BOILING								
54	91,55	812,782	2,87115E+04	1,92384E+05	754,80	1802,45	621,20	,211
55	93,19	823,491	2,77938E+04	1,86235E+05	764,79	1801,86	621,16	,231
56	94,83	833,866	2,60118E+04	1,73238E+05	774,45	1801,27	621,11	,250
57	96,48	843,583	2,24037E+04	1,51443E+05	783,50	1800,67	621,07	,268
58	98,11	851,980	1,98264E+04	1,15241E+05	791,31	1800,08	621,02	,283
59	100,00	859,393			798,21	1799,41	620,97	,297

TEST DESCRIPTION = SSGM PHASE III, STEP 238, 9-23-75, 2030 HR

WATER INLET TEMP.,F =	546.000	SODIUM INLET TEMP.,F =	860.000
WATER OUTLET TEMP.,F =	623.500	SODIUM OUTLET TEMP.,F =	588.000
WATER FLOW RATE, LB/HR =	2875.000	SODIUM FLOW RATE, LB/HR =	8827.000
WATER PRESS DROP, PSI =	20.000	SODIUM PRESS DROP,IN.H2O =	14.000
WATER OUTLET PRESS,PSIA =	1795.000	SURFACE ROUGHNESS, FT. =	0.0000000
PREHEAT FOULING,HRFTSQF/B=	0.00000	NUCLEATE FOULING FACTOR =	0.00000
AFTER DNB FOULING FACTOR =	0.00000	SH. FOULING,HR-FTSQ-F/BTU=	0.00000
ACTIVE TUBE LENGTH, IN. =	730.500	BEND RADIUS, IN. =	9999.000
INSIDE TUBE DIAMETER, IN.=	.571	OUTSIDE TUBE DIAMETER,IN.=	.875
HEIGHT OF UNIT, IN =	514.000	MIN. NA FLOW AREA, SQ.IN.=	1.080
NUMBER OF TUBES =	1.000	NUMBER OF TUBE BENDS =	0.000
ENTRANCE VEL. HEAD LOSS =	.500	EXIT VELOCITY HEAD LOSS =	1.000
ENTRANCE UNHEATED LENGTH =	-0.000	EXIT UNHEATED LENGTH, IN.=	-0.000
C1-CONDUCTIVITY CONSTANT =	24.250000	C2-CONDUCTIVITY CONSTANT =	-.005200

CONSTANTS CALCULATED AT LABEL 3001

RATBEN	=	0.
BENFAC	=	.100E+01
CSAREA	=	.256E+00
EQDIA	=	.476E-01
GW	=	.162E+07
GC	=	.418E+09
G	=	.418E+09
SISLOP	=	.704E+00
RADIN	=	.286E+00
ALPHA	=	.100E+01
K66	=	59



SSGM TEST RESULTS

TEST DESCRIPTION - SSGM PHASE III, STEP 238, 9-23-75, 2030 HR

OVERALL U AND R AND INDIVIDUAL RESISTANCES BY INCREMENT, STEAM R UNKNOWN

I	LMTD DEG F	OVERALL U BTU/ HRFT2F	TOTAL RESISTANCE HR.FT.SQ.F /BTU	SODIUM RESISTANCE HR.FT.SQ.F /BTU	WALL RESISTANCE HR.FT.SQ.F /BTU	FOUL RESISTANCE HR.FT.SQ.F /BTU	STEAM RESISTANCE HR.FT.SQ.F /BTU	STEAM FILM COEFFICIENT BTU/ HR.FT.SQ.F	QUALITY	WALL TEMP F
PREHEAT										
1	42.09	206.7	4.838E-03	1.745E-04	8.111E-04	0.	3.853E-03	3.977E+02		579.84
2	42.44	305.6	3.272E-03	1.745E-04	8.175E-04	0.	2.280E-03	6.721E+02		577.04
3	43.00	709.8	1.409E-03	1.746E-04	8.458E-04	0.	3.884E-04	3.945E+03		561.12
4	43.67	786.3	1.272E-03	1.747E-04	8.526E-04	0.	2.444E-04	6.269E+03		559.70
5	44.39	795.2	1.258E-03	1.748E-04	8.546E-04	0.	2.280E-04	6.720E+03		561.55
6	45.12	764.0	1.309E-03	1.750E-04	8.535E-04	0.	2.805E-04	5.463E+03		565.35
7	45.84	711.8	1.405E-03	1.751E-04	8.506E-04	0.	3.793E-04	4.041E+03		570.14
8	46.52	652.3	1.533E-03	1.752E-04	8.470E-04	0.	5.108E-04	3.000E+03		575.22
9	47.16	594.6	1.682E-03	1.753E-04	8.434E-04	0.	6.630E-04	2.311E+03		580.12
10	47.77	544.4	1.837E-03	1.754E-04	8.403E-04	0.	8.213E-04	1.866E+03		584.53
11	48.33	504.0	1.984E-03	1.754E-04	8.378E-04	0.	9.710E-04	1.578E+03		588.37
12	48.88	475.3	2.104E-03	1.755E-04	8.362E-04	0.	1.092E-03	1.403E+03		591.54
13	49.41	457.4	2.186E-03	1.756E-04	8.355E-04	0.	1.175E-03	1.304E+03		594.11
14	49.93	449.9	2.223E-03	1.757E-04	8.355E-04	0.	1.212E-03	1.265E+03		596.14
15	50.73	454.7	2.199E-03	1.758E-04	8.367E-04	0.	1.187E-03	1.291E+03		598.32
16	51.59	472.3	2.117E-03	1.759E-04	8.392E-04	0.	1.102E-03	1.390E+03		599.95
17	52.26	490.2	2.040E-03	1.760E-04	8.414E-04	0.	1.023E-03	1.499E+03		600.92
18	53.16	514.2	1.945E-03	1.761E-04	8.446E-04	0.	9.241E-04	1.658E+03		602.11
19	54.01	535.7	1.867E-03	1.762E-04	8.476E-04	0.	8.430E-04	1.818E+03		603.25
20	54.78	549.7	1.819E-03	1.763E-04	8.498E-04	0.	7.932E-04	1.932E+03		604.29
21	55.50	563.4	1.775E-03	1.764E-04	8.521E-04	0.	7.465E-04	2.053E+03		605.56
22	56.34	574.0	1.742E-03	1.765E-04	8.542E-04	0.	7.115E-04	2.154E+03		607.06
23	57.21	582.2	1.718E-03	1.766E-04	8.562E-04	0.	6.848E-04	2.238E+03		608.75
24	58.13	588.0	1.701E-03	1.767E-04	8.580E-04	0.	6.658E-04	2.302E+03		610.61
25	59.08	591.3	1.691E-03	1.769E-04	8.597E-04	0.	6.547E-04	2.341E+03		612.67
26	60.06	593.0	1.686E-03	1.770E-04	8.612E-04	0.	6.481E-04	2.365E+03		614.87
27	61.09	593.4	1.685E-03	1.771E-04	8.627E-04	0.	6.453E-04	2.375E+03		617.18
28	62.15	593.7	1.684E-03	1.772E-04	8.642E-04	0.	6.430E-04	2.383E+03		619.53
29	63.25	594.0	1.683E-03	1.774E-04	8.657E-04	0.	6.404E-04	2.393E+03		621.90
30	64.39	594.8	1.681E-03	1.775E-04	8.674E-04	0.	6.364E-04	2.408E+03		624.27
31	65.57	597.5	1.674E-03	1.776E-04	8.693E-04	0.	6.268E-04	2.445E+03		626.53
32	66.80	601.9	1.661E-03	1.778E-04	8.716E-04	0.	6.121E-04	2.503E+03		628.70
33	68.10	608.8	1.643E-03	1.779E-04	8.742E-04	0.	5.904E-04	2.596E+03		630.71
34	69.47	618.4	1.617E-03	1.780E-04	8.774E-04	0.	5.618E-04	2.728E+03		632.56
35	70.91	631.4	1.584E-03	1.782E-04	8.812E-04	0.	5.243E-04	2.923E+03		634.16
36	72.46	647.4	1.545E-03	1.784E-04	8.856E-04	0.	4.808E-04	3.187E+03		635.55
37	74.12	666.7	1.500E-03	1.785E-04	8.908E-04	0.	4.305E-04	3.559E+03		636.68
38	75.93	689.6	1.450E-03	1.787E-04	8.970E-04	0.	3.745E-04	4.092E+03		637.51
39	77.94	714.4	1.400E-03	1.789E-04	9.041E-04	0.	3.167E-04	4.839E+03		638.08
NUCLEATE BOILING										
40	81.55	729.1	1.372E-03	1.791E-04	9.124E-04	0.	2.800E-04	5.472E+03	.000	638.35
41	86.80	733.9	1.363E-03	1.793E-04	9.219E-04	0.	2.613E-04	5.864E+03	.010	638.31
42	92.43	740.0	1.351E-03	1.795E-04	9.328E-04	0.	2.390E-04	6.412E+03	.020	637.98
43	98.46	746.7	1.339E-03	1.798E-04	9.451E-04	0.	2.144E-04	7.146E+03	.031	637.37
44	104.94	753.1	1.328E-03	1.801E-04	9.589E-04	0.	1.889E-04	8.114E+03	.043	636.50
45	111.94	758.7	1.318E-03	1.804E-04	9.743E-04	0.	1.634E-04	9.378E+03	.055	635.42
46	119.45	762.8	1.311E-03	1.807E-04	9.915E-04	0.	1.389E-04	1.104E+04	.069	634.16
47	127.48	764.3	1.308E-03	1.810E-04	1.010E-03	0.	1.176E-04	1.303E+04	.084	632.92
48	136.05	762.9	1.311E-03	1.814E-04	1.030E-03	0.	9.984E-05	1.535E+04	.099	631.79
49	145.19	757.4	1.320E-03	1.818E-04	1.050E-03	0.	8.883E-05	1.725E+04	.116	631.16
50	154.84	747.2	1.338E-03	1.822E-04	1.070E-03	0.	8.643E-05	1.773E+04	.133	631.36
51	164.93	731.3	1.367E-03	1.826E-04	1.088E-03	0.	9.720E-05	1.577E+04	.152	633.04
52	175.40	708.6	1.411E-03	1.831E-04	1.102E-03	0.	1.264E-04	1.213E+04	.171	636.98
53	186.15	677.8	1.475E-03	1.835E-04	1.109E-03	0.	1.824E-04	8.402E+03	.190	644.24
FILM BOILING										
54	196.95	637.4	1.569E-03	1.840E-04	1.108E-03	0.	2.773E-04	5.527E+03	.211	655.99
55	207.54	585.6	1.708E-03	1.844E-04	1.093E-03	0.	4.300E-04	3.564E+03	.231	673.39
56	217.63	519.5	1.925E-03	1.849E-04	1.065E-03	0.	6.752E-04	2.269E+03	.250	697.43
57	226.74	435.9	2.294E-03	1.853E-04	1.023E-03	0.	1.086E-03	1.411E+03	.268	728.39
58	234.69	320.4	3.121E-03	1.856E-04	9.644E-04	0.	1.971E-03	7.776E+02	.283	769.20
59									.297	

TEST DESCRIPTION = SSGM PHASE III, STEP 238, 9-23-75, 2030 HR

WATER/STEAM SIDE PRESSURE LOSS BY INCREMENT

POINT OR INCREMENT	SPECIFIC VOLUME CU,FT,/LBM	AVERAGE SPEC,VOL CU,FT,/LBM	DELTA SPEC,VOL CU,FT,/LBM	VISCOSITY LBM/HR,FT,	AVERAGE VISCOSITY LBM/HR,FT,	REYNOLDS NUMBER	FRICTION LOSS PSI	ACCEL LOSS PSI	HEAD LOSS PSI	BEND LOSS PSI	TOTAL PRESS DROP PSI
PREHEAT											
1	,02136	,02137	,00002	,23079	,23061	3,336E+05	,1362	,0008	-,2617	0,0000	-,1246
2	,02138	,02140	,00005	,23044	,23000	3,345E+05	,2379	,0022	-,4559	0,0000	-,2158
3	,02143	,02146	,00006	,22956	,22904	3,359E+05	,1192	,0026	-,2274	0,0000	-,1056
4	,02149	,02152	,00007	,22852	,22794	3,375E+05	,1201	,0029	-,2281	0,0000	-,1050
5	,02155	,02159	,00007	,22736	,22676	3,393E+05	,1197	,0030	-,2260	0,0000	-,1032
6	,02162	,02166	,00007	,22617	,22559	3,410E+05	,1199	,0030	-,2252	0,0000	-,1023
7	,02169	,02173	,00007	,22502	,22447	3,427E+05	,1202	,0029	-,2245	0,0000	-,1014
8	,02176	,02179	,00006	,22393	,22342	3,443E+05	,1212	,0027	-,2252	0,0000	-,1013
9	,02182	,02185	,00006	,22292	,22246	3,458E+05	,1207	,0025	-,2232	0,0000	-,1000
10	,02188	,02191	,00005	,22199	,22157	3,472E+05	,1209	,0024	-,2227	0,0000	-,0994
11	,02194	,02196	,00005	,22114	,22074	3,485E+05	,1211	,0022	-,2221	0,0000	-,0988
12	,02199	,02201	,00005	,22034	,21996	3,497E+05	,1228	,0022	-,2230	0,0000	-,0987
13	,02204	,02206	,00005	,21957	,21921	3,509E+05	,1215	,0021	-,2211	0,0000	-,0975
14	,02209	,02211	,00005	,21884	,21847	3,521E+05	,1217	,0021	-,2206	0,0000	-,0968
15	,02214	,02219	,00010	,21811	,21738	3,539E+05	,2380	,0043	-,4290	0,0000	-,1867
16	,02223	,02227	,00006	,21665	,21622	3,558E+05	,1350	,0026	-,2418	0,0000	-,1042
17	,02230	,02233	,00006	,21579	,21533	3,573E+05	,1345	,0028	-,2398	0,0000	-,1026
18	,02236	,02241	,00010	,21488	,21417	3,592E+05	,1985	,0044	,3517	0,0000	,5547
19	,02246	,02249	,00006	,21347	,21308	3,610E+05	,1029	,0025	,1812	0,0000	,2865
20	,02252	,02255	,00007	,21269	,21222	3,625E+05	,1234	,0031	,2163	0,0000	,3428
21	,02259	,02263	,00007	,21174	,21124	3,642E+05	,1237	,0033	,2156	0,0000	,3426
22	,02266	,02270	,00008	,21075	,21023	3,659E+05	,1248	,0034	,2162	0,0000	,3444
23	,02274	,02278	,00008	,20972	,20919	3,677E+05	,1243	,0036	,2141	0,0000	,3420
24	,02282	,02287	,00009	,20867	,20813	3,696E+05	,1247	,0037	,2133	0,0000	,3417
25	,02291	,02295	,00009	,20760	,20705	3,716E+05	,1250	,0038	,2125	0,0000	,3414
26	,02300	,02305	,00009	,20650	,20595	3,735E+05	,1261	,0040	,2130	0,0000	,3431
27	,02309	,02314	,00009	,20539	,20482	3,756E+05	,1258	,0041	,2108	0,0000	,3407
28	,02319	,02324	,00010	,20426	,20369	3,777E+05	,1261	,0043	,2099	0,0000	,3404
29	,02328	,02334	,00010	,20312	,20253	3,798E+05	,1273	,0044	,2103	0,0000	,3421
30	,02339	,02344	,00011	,20195	,20136	3,820E+05	,1270	,0046	,2081	0,0000	,3397
31	,02349	,02355	,00011	,20077	,20017	3,843E+05	,1274	,0048	,2072	0,0000	,3393
32	,02360	,02366	,00011	,19957	,19895	3,867E+05	,1279	,0050	,2062	0,0000	,3390
33	,02372	,02378	,00012	,19833	,19770	3,891E+05	,1291	,0053	,2064	0,0000	,3408
34	,02384	,02390	,00013	,19706	,19640	3,917E+05	,1289	,0055	,2041	0,0000	,3385
35	,02397	,02403	,00014	,19575	,19506	3,944E+05	,1294	,0059	,2030	0,0000	,3383
36	,02410	,02418	,00015	,19438	,19367	3,972E+05	,1300	,0063	,2018	0,0000	,3381
37	,02425	,02433	,00016	,19295	,19219	4,003E+05	,1314	,0069	,2017	0,0000	,3400
38	,02441	,02449	,00017	,19144	,19064	4,035E+05	,1313	,0074	,1992	0,0000	,3379
39	,02458	,02470	,00025	,18984	,18901	4,070E+05	,1322	,0109	,1975	0,0000	,3405
NUCLEATE BOILING											
40	,02483	,02574	,00183	,18818	,18755	4,102E+05	,1376	,0794	,1895	0,0000	,4065
41	,02666	,02764	,00197	,18692	,18624	4,131E+05	,1484	,0856	,1775	0,0000	,4115
42	,02863	,02968	,00210	,18556	,18484	4,162E+05	,1582	,0913	,1644	0,0000	,4138
43	,03073	,03186	,00226	,18411	,18333	4,196E+05	,1695	,0982	,1531	0,0000	,4208
44	,03299	,03421	,00243	,18256	,18172	4,233E+05	,1817	,1055	,1426	0,0000	,4298
45	,03542	,03674	,00263	,18088	,17998	4,274E+05	,1959	,1141	,1336	0,0000	,4437
46	,03805	,03945	,00280	,17907	,17811	4,319E+05	,2087	,1217	,1237	0,0000	,4541
47	,04085	,04235	,00300	,17714	,17611	4,368E+05	,2236	,1302	,1152	0,0000	,4689
48	,04385	,04545	,00319	,17508	,17398	4,422E+05	,2394	,1387	,1073	0,0000	,4854
49	,04704	,04875	,00341	,17288	,17171	4,480E+05	,2577	,1479	,1007	0,0000	,5063
50	,05045	,05223	,00356	,17054	,16931	4,544E+05	,2737	,1547	,0934	0,0000	,5219
51	,05401	,05587	,00372	,16809	,16681	4,612E+05	,2920	,1614	,0873	0,0000	,5407
52	,05773	,05965	,00383	,16553	,16422	4,685E+05	,3108	,1664	,0818	0,0000	,5590
53	,06156	,06352	,00392	,16290	,16156	4,762E+05	,3320	,1701	,0773	0,0000	,5793
FILM BOILING											
54	,06548	,06742	,00388	,16021	,15888	4,842E+05	,3491	,1683	,0724	0,0000	,5898
55	,06935	,07123	,00376	,15755	,15627	4,923E+05	,3677	,1631	,0685	0,0000	,5993
56	,07311	,07487	,00352	,15498	,15377	5,003E+05	,3877	,1529	,0656	0,0000	,6062
57	,07663	,07816	,00305	,15257	,15153	5,077E+05	,3987	,1323	,0620	0,0000	,5931
58	,07968	,08103	,00270	,15049	,14957	5,143E+05	,4782	,1173	,0694	0,0000	,6648
59	,08238			,14866							