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7. Abstract

This report evaluates the thermal hydraulic behavior of tank C-106 during and following the process test conducted from March 10, 1994 to June 15, 1994. During and following the process test the thermocouples on the thermocouple tree in riser #14 began to indicate significantly higher temperatures in the sludge than the low temperatures typically observed at this location. The thermocouples on the thermocouple tree in riser #8 during this same time period indicated temperature variations consistent with normal seasonal effects. This report summarizes the analyses conducted to understand the phenomena that caused the temperature history at riser #14.

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TANK 241-C-106 PROCESS TEST REPORT

May 1995

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TANK 241-C-106 PROCESS TEST REPORT

1.0 INTRODUCTION

A process test was initiated in tank 241-C-106 to decrease the liquid level in order to minimize the environmental impact of a tank leak as well as to establish a lower minimum operating level to reduce corrosion potential in the tank liner. This process test was performed in accordance with Process Test Plan WHC-SD-WM-PTP-026 (Sutey 1993) and initiated via Process Memo 94-018 (March 1994).

The process test was initiated March 10, 1994. Water addition to the tank was temporarily discontinued to allow the liquid level to decrease, through evaporation, at a rate of approximately 2 to 3 inches per month (5500 to 8300 gallons per month). The test ended June 15, 1994, and water additions resumed on June 17, 1994.

This report evaluates the thermal-hydraulic behavior of tank 241-C-106 during and following the process test. During and following the process test the thermocouples on the thermocouple tree in riser #14 began to indicate significantly higher temperatures in the sludge than the low temperatures typically observed at this location. The thermocouples on the thermocouple tree in riser #8 during this same time period indicated temperature variations consistent with normal seasonal effects. This report summarizes the analyses which were conducted to understand the phenomena causing the temperature history at riser #14.

2.0 TANK BACKGROUND

Tank 241-C-106 is a 2000 m^3 (530,000 gal) capacity single-shell tank (SST) 23 m (75 ft) in diameter located in the Hanford Site C Tank Farm. The C Tank Farm is one of the original tank farms that was constructed at the Hanford Site during 1944 and 1945. Tank 241-C-106 has been used for radioactive waste storage since mid-1947.

During the late 1960's, a program to recover strontium and cesium from aging waste stored in the A and AX Tank Farms was instituted at the Hanford Site. A sludge washing/decanting process took place in the 244-AR vault, requiring the washing of accumulated slurry with water to remove soluble constituents. The original intent was to decant the wash solution [Plutonium-Uranium Extraction (PUREX) sludge supernate] from the solids by settling the solids and then pumping off the supernate (the liquid portion of a solid-liquid separation process) to tank 241-C-106. The decanting step proved to be ineffective, however, and strontium solids were drawn into and transferred with the wash solution to tank 241-C-106, where they accumulated.

By mid-1971 it became obvious that unacceptable quantities of strontium had been transferred with the PUREX sludge supernate when temperatures in excess of 100 °C were observed in tank 241-C-106. Because the tanks in the C-Farms were not equipped for the storage of self-boiling waste, transfers of PUREX sludge supernate were halted, and tank 241-C-106 was immediately placed on an active ventilation system. Since mid-1971 water has been added periodically to the tank, in order to keep the sludge wet and promote heat transfer. Tank 241-C-106 was placed on inactive status in 1979 and is currently categorized as sound (i.e., not leaking).

A structural integrity evaluation for in situ conditions in tank 241-C-106 was completed in 1994 (Julyk 1994). This evaluation included a historical review of related design documents, a thermal-history simulation, a material-property degradation simulation, and an assessment of structural capacity as measured against project-specific structural acceptance criteria.

Tank 241-C-106 is a Watch List tank as a High Heat-Load tank (Hanlon 1994). The current estimate, January 1995, of the total heat load is 102,000 Btu/hr (Bander 1993).

3.0 INSTRUMENTATION

This section describes the type of instrumentation in tank 241-C-106 including its accuracy and presents the data collected to date. Instrumentation for tank 241-C-106 consists of a Food Instrument Corporation (FIC) liquid-level gauge mounted in riser #1, an Enraf liquid-level gauge mounted in riser #7, two thermocouple (TC) trees mounted in riser #8 (tree #1) and riser #14 (tree #2), and a tank pressure/vacuum gauge mounted on riser #7 (Figure 3.1). In 1994 all the liquid-level and temperature instruments were connected to the Tank Monitoring and Control System (TMACS), which makes continuous offsite monitoring possible. The exhauster used to ventilate tank 241-C-106 has been changed several times since the tank was placed on an active ventilation system in 1971.

3.1 LIQUID LEVEL

The FIC gauge has an accuracy of +/- 0.25 cm (0.1 in.) under ideal conditions. Actual field experience indicates errors can be significantly higher due to riser elevation errors and the condition of the local FIC gauge. Waste build-up on the FIC probe can also adversely affect the accuracy of the liquid-level readings at any given point in time. A measurement precision of +/- 0.63 cm (0.25 in.) was empirically established for the FIC with a specification limit of +/- 1.3 cm (0.50 in.) (Schofield 1994).

Figure 3.2 shows the liquid level as measured by the FIC gauge from 1981 through 1988. The height reported is measured in inches from the knuckle of the tank, which due to the dished bottom of the tank is 0.3 m (1 ft) above the bottom center of the tank. The data were taken on a weekly basis during this time period. Figure 3.3 shows the liquid level as measured by the FIC gauge from 1989 through February 1995. These data were taken on a daily basis beginning the middle of 1989. The ventilation system was not operating towards the end of 1990 for about one month and at the beginning of 1992 for about 4 1/2 months. These outages (labeled in Figure 3.3) are reflected by surface level rises. The surface level during the process test is also labeled. Analyses of the surface level data (Crea and Bander 1994) show that the addition of water initially suppresses the evaporation rate for about 1 to 2 weeks to about half of the long-term rate. This can be observed in Figure 3.3 by the change in slope of the surface level data. There is also a seasonal effect (Barrington 1995) that shows more evaporation toward the end of summer and less toward the end of winter.

3.2 WASTE TEMPERATURES

The TC tree in riser #8, which is 10.4 m (34 ft) from the center of the tank, has four TCs in the waste. The bottom TC is 0.1 m (0.3 ft) from the local bottom of the tank and the other three TCs are 0.6 m (2 ft) apart vertically up the tree. It has two TCs in the dome air space.

The TC tree in riser #14, which is 4.7 m (15.5 ft) from the center of the tank, has four TCs in the waste. The bottom TC is 0.34 m (1.1 ft) from the local bottom of the tank and the other three TCs are 0.6 m (2 ft) apart vertically up the tree. It has eight TCs in the dome air space.

3.2.1 Riser #8 Thermocouple Data

The TCs used on the TC tree in riser #8 are of type E, which have a standard accuracy of +/- 1.7 ^{o}C (3 ^{o}F) (Cole-Parmer 1993). Figure 3.4 shows the TC data for TCs 1, 2, 3, 4, and 6, numbering from the bottom of the tree, for 1983 through 1991. The data during this time period is rather sparse. Figure 3.5 shows the TC data for TCs 1, 2, 3, 4, and 6, for 1991 through February 1995. The ventilation outage in 1992 is apparent from the large temperature increases and the seasonal variation is apparent in the 1991, 1993, and 1994 data. Note that there is a time lag in the maximum temperatures at the TCs toward the bottom of the tank from the dome maximum temperatures. The bimonthly decrease of about 10 ^{o}F in 1991 from TC 6, which is in the dome air space, is caused by the periodic addition of cold river water. Heated water was used for water additions starting in 1993.

3.2.2 Riser #14 Thermocouple Data

The TCs used on the TC tree in riser #14 are of type J, which have a typical accuracy of +/- 1.1 ^{o}C (2 ^{o}F) (Cole-Parmer 1993). In 1993 an extensive verification effort was performed on all TCs on the TC tree in riser #14 (Wang 1995). Verification of internal resistances concluded that all riser #14 TCs but one, the 7th TC probe (which is in the dome airspace), were reading correctly.

Figure 3.6 shows the TC data for TCs 1, 2, 3, 4, and 6, numbering from the bottom of the tree, for 1982 through 1992. The data during this time period are rather sparse and very scattered. Figure 3.7 shows the TC data for TCs 1, 2, 3, 4, and 6, for 1993 through February 1995. Also included in Figure 3.7 are the surface level data scaled so that they are separated from the temperature data. Note that there appears to be a correlation between the addition of water and an increase in measured temperatures in TCs 1, 2, 3, and 4. Figure 3.8 is an expanded view of the measured temperatures from the start of the process test through February 1995.

3.3 VENTILATION, PSYCHROMETRIC, AND WATER ADDITIONS

Tanks 241-C-105 and 241-C-106 are currently ventilated by the 296-P-16 exhauster. This exhauster is a portable unit of nominal 3.3 m^3/sec (7,000 ft^3/min) capacity. Nominal exhaust flow rates are 0.57 m^3/sec (1,200 ft^3/min) and 1.1 m^3/sec (2,400 ft^3/min) from tanks 241-C-105 and 241-C-106, respectively. Air is drawn into tank 241-C-106 through an inlet (riser #15) equipped with a high-efficiency particulate air (HEPA) filter. The exhaust air is passed through a deentrainment section (to remove entrained water) and then through a bank of HEPA filters. Deentrained moisture drains back to riser #2 on tank 241-C-106.

Psychrometric and various pressure measurements for Hanford waste tanks have historically been manually taken at approximately monthly intervals. For tank 241-C-106, various pressure and dry and wet bulb temperatures are routinely measured at several locations. The accuracy of these various measurements are listed in Appendix D of (Minteer 1995). Since tanks C-105 and 241-C-106 share a common exhauster, psychrometric measurements are taken in the outlet duct of each tank and at a location in the ventilation system after the two flow streams mix. Ambient measurements are also taken.

Table 3.1 shows ventilation and psychrometric data taken during and after the process test. The ventilation was increased in July 1994 in order to enhance the evaporation from the liquid surface. The multiple readings in August were taken to obtain an estimate of the diurnal variability of the psychrometric data. From these measurements, the quantity of water which leaves the tank during a given time period can be determined. Manually and infrequently taking such measurements results in a high uncertainty, on the order of 80% to 120% (Minteer 1995), in the quantity of water determined to have left the tank.

Water additions are documented by filling out a Water Addition Data Sheet. Starting in September 1994 this sheet requires the date and volume of water added and also time, liquid-level measurements, water meter readings, and temperature of water at the start and ending of the water addition. Table 3.2 shows the major water additions made in 1994.

3.4 IN-TANK PHOTOGRAPHY

Videos were taken during the process test and afterward. The first videos were taken on April 22, 1994 when the tank liquid level was 72.2 in.

Two tank risers on opposite sides of the tank were used, which allowed examination of the entire waste surface, the waste-tank wall interface, the FIC plummet, existing in-tank equipment, tank walls, and the underside of the dome. This set of videos showed that the layer of crust above the solid waste, formed from precipitation of minerals in the river water additions, was exposed all the way around the tank for about two feet away from the wall and the liquid pond extended over the remainder of the tank.

The second set of videos was taken on June 15, 1994, when the indicated liquid level was 69.5 in. For these videos improved lighting was available and this allowed inspection of details previously missed. The layer of crust above the solid waste was exposed and estimated to constitute about 20 percent of the surface area and the liquid pool covering the remainder. The FIC plummet was resting on part of some abandoned material and was no longer indicating the liquid surface level. The liquid surface level was estimated to be about 67 in. The exposed solid waste surface contained numerous puddles of liquid waste and appeared to be wet. Additional videos have been taken periodically in order to obtain information about conditions in the tank.

4.0 THERMAL HYDRAULIC ANALYSES

During and following the process test, TCs on the TC tree in riser #14, which is located midway between the center of the tank and the tank wall, began to indicate significantly higher temperatures in the sludge waste than the typically low temperatures observed at this location. This is illustrated in Figure 3.7. Temperatures increased at the bottom TC in riser #14 from about 125 to 217 °F following the process test. Temperatures at the TCs in riser #8, which are near the tank wall, became only slightly elevated during 1994 relative to seasonal norms as illustrated in Figure 3.5. This can be accounted for by the above average summer temperatures in 1994.

The following sections present results of thermal hydraulic analyses which explain the phenomena occurring in tank 241-C-106. The main elements in the analyses include the formation of voids due to steam in the central bottom of the tank and a convective gap around the TC tree in riser #14.

4.1 SURFACE LEVEL SIMULATION

A 2-D model of tank 241-C-106 was developed using the GOTH computer code (Thurgood et al. 1995). GOTH is based on the GOTHIC computer code (Thurgood 1992 and George 1993). GOTHIC (Generation of Thermal-Hydraulic Information for Containment) is a general purpose thermal-hydraulics computer program for design, licensing, safety, and operating analysis of nuclear power plant containments and other confinement buildings. The 2-D model consists of the tank, the inlet and outlet ventilation gas flows, and the soil beneath, to the side, and above the tank. The model uses the measured ventilation data and the water addition data as input. The model allows for the formation of voids when the temperature of the sludge reaches the saturation temperature, which is estimated to be 228 °F at the bottom of the tank (Bander and Crea

1994). The results of the model simulations (Thurgood et al. 1995) is summarized below.

Figure 4.1 shows a comparison between the measured FIC and calculated liquid surface level when no voids are allowed to form. The measured water addition data were used as input for increasing the volume of liquid in the tank. The flat portion of the measured data at a level of 69.5 in. is due to the FIC plummet resting on some abandoned material as observed in the video taken on June 15, 1994. The model simulates the liquid surface as it would decrease due to evaporation of liquid. Note there is a discrepancy of 2 to 3 in. at the end of the process test between measured and calculated liquid surface level. Also note that the discrepancy goes away in about 5 months indicating that the steam in the sludge had condensed.

The discrepancy between measured and calculated liquid surface level can be accounted for if voids are allowed to form in the sludge where the saturation temperature is reached. Figure 4.2 shows the comparison when voids are allowed to form. During and following the process test, voids are calculated to be generated initially in the lower central region of the tank sludge. This saturation zone or void-bearing sludge region spreads toward the tank wall and a small amount vertically upward. This voidage causes movement of the sludge in both the horizontal and vertical directions. This phenomenon is important for explaining the temperature fluctuations that occurred at the riser #14 TC tree.

A simulation was conducted to predict what would have happened if the process test had been stopped when the liquid surface level reached about 72 in. with no sludge uncovered with water. Water additions are made to maintain the liquid surface level between 72 and 76 in. This simulation is shown in Figure 4.3. Note that after 120 days from the start of the process test, the rate of surface level decrease is much lower for about 5 weeks. This is due to the formation of voids starting to form after 120 days and going away after 5 weeks. This formation of voids occurs while the tank is reaching a new equilibrium level and from the hot summer temperatures. This void formation may have caused some anomalous riser #14 temperature behavior, but not to the extent seen following the process test.

4.2 SEASONAL EVAPORATION RATE

Figure 4.4 shows the evaporation rate correlation developed using the rate of surface level decrease, top curve in the figure, from tank 241-C-106 (Ogden 1995). The sinusoidal form of the evaporation rate caused by seasonal variations can been seen in the figure. Also included in the figure are the average evaporation rates calculated from the rate of surface level decrease between water additions. The increase in evaporation rate following the ventilation outages in November 1990 and June 1992 can clearly be seen. The evaporation rate following the ventilation outage in 1992 continued to be higher for a longer period of time since the ventilation system was off for 4 1/2 months. Note also the apparent decrease in evaporation rate following the process test in 1994. This was probably caused by the formation of voids in the sludge.

4.3 RISER #14 THERMOCOUPLE TEMPERATURES SIMULATION

A thermal model with only conduction in the waste layers of tank 241-C-106 (Bander 1993) predicts higher temperatures at the riser #14 TC locations than at the riser #8 TC locations. The measured temperatures before June 1994 almost always have temperatures lower in riser #14 than in riser #8. This difference between predicted and measured temperatures and the apparent correlation between the addition of water and an increase in measured temperatures in riser #14 would indicate some type of sludge convective motion. The large temperature increase and oscillations in riser #14 following the process test also strongly suggests some type of convective motion in the sludge around riser #14 (Eyler 1995 and Thurgood et al. 1995).

Several liquid filled pot holes in the crust and around the TC trees were observed in the videos taken at the end of the process test. It is postulated that a convective cooling gap may exist between the TC tree in riser #14 and the surrounding sludge. This gap may have closed during the process test as a result of the expansion of the saturation zone in the center of the tank. This would result in the TCs measuring the temperature of the sludge which had been at some radial distance from the TC tree. The annular gap would not have to be as large as the pot holes observed to provide cooling and could be on the order of one sixteenth of an inch thick or smaller.

A convective gap closure model using the GOTH computer code (Thurgood et al. 1995) was developed for simulating the temperatures around the TC tree in riser #14. The model consisted of a 6 ft deep and 6 ft radius of sludge surrounding the TC tree. Initially a heat transfer coefficient was applied between the sludge and the TC tree to maintain the measured temperatures prior to the process test. At the end of the process test, the gap closure was simulated by reducing the heat transfer coefficient to zero. The sludge adjacent to the TC tree heated up at rates consistent with the measured data at the TC tree in riser #14. By subsequently increasing and decreasing the heat transfer coefficient on a daily cycle, the diurnal oscillations at the TC tree following the initial heat up were also simulated. After the peak measured temperature at TC-1 (bottom TC) reached 217 °F on August 14, 1994, the heat transfer coefficient was increased and decreased on a daily basis causing the oscillatory behavior observed in the measured data. The calculated results are compared with the measured data for the bottom three TCs in riser #14 in Figures 4.5 and 4.6. For TC-1 and TC-3, Figure 4.5, the comparison is very good, giving strong support to the plausibility of this explanation for the TCs at riser #14. Results for TC-2, Figure 4.6, suggest some adjustment in the model is needed.

4.4 RISER #8 THERMOCOUPLE TEMPERATURES SIMULATION

The transient thermal model with only conduction in the waste layers of tank 241-C-106 was used to obtain an estimate of the heat source in the tank of 110,000 Btu/h in January 1992 (Bander 1993). This result was based on the TC data in riser #8 during the ventilation outage in 1992. This model was used in a steady state calculation to obtain calculated temperatures at the TC locations in riser #8 and #14 for August 1995. The model predicted 173 °F (maximum measured in August of 164 °F) for the bottom TC in riser #8 and 225

°F (maximum measured in August of 217 °F) for the bottom TC in riser #14 (Bander and Crea 1994). This shows that the conduction model predicts temperatures comparable to the measured ones when the TCs are in good contact with the sludge.

5.0 PROCESS TEST EVALUATION

The primary objective of the process test was to reduce the water level in tank 241-C-106 to approximately 2 in. above the waste surface. The two foot ring of crust along the wall of the tank which was observed in the first video is a non-heat generating material. Thus it can be infered that the heat generating sludge was covered by liquid when the tank liquid level was 72 in. The maximum sludge temperature limit for the process test of 185 °F occurred after the process test was ended and water additions were resumed at a tank liquid level estimated to be 67 in.

6.0 CONCLUSIONS

- The process test objectives and criteria were satisfied and data obtained during the process test were as specified in the process test plan (Sutey 1993). The data obtained after the process test ended were very beneficial in providing measurements for use in modeling events which occurred in the tank.

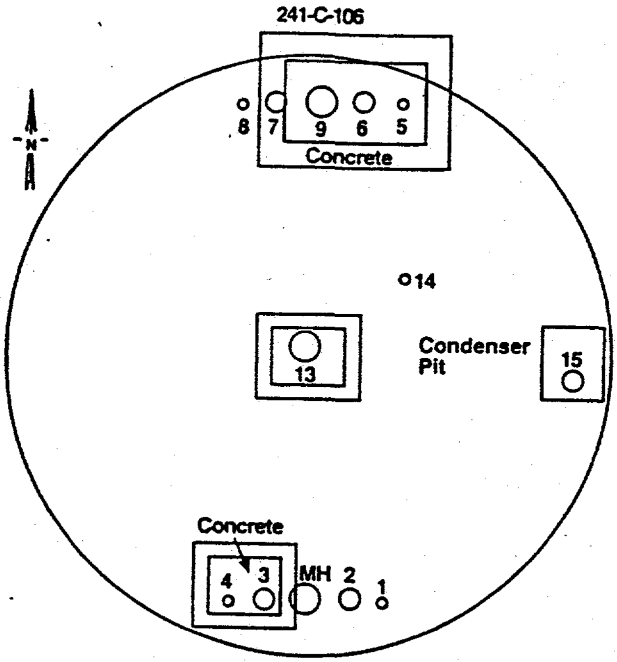
- Comparison of process test/post process test simulations and tank surface level data confirm that the growth of steam voids is necessary to account for the actual observed surface level measurements. However, the simulations also indicate that the saturation zone has now likely been cooled below the saturation temperature and the steam voids have condensed as a result of fall/winter meteorological conditions.

- If the process test had been stopped when the liquid level reached 72 in. and water additions made to maintain the liquid level between 72 and 76 in., there would have been only a couple of months when there was an increase in void formation while the tank was reaching a new equilibrium level.

- Closing of a convective gap at the TC tree in riser #14 by sludge motion caused by void formation and collapse in the center of the tank is a plausible explanation for the temperature rise and oscillations that occurred following the process test. Temperature increases and subsequent decreases following the addition of water could be attributed to a change in the gap structure.

- The conduction model is a good estimate of the temperature distributions when there are no void formations and the TCs are in good contact with the sludge.

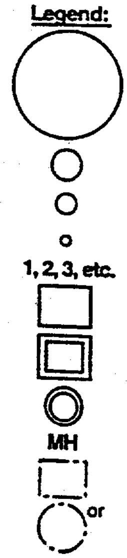
Figure 3.1. Riser Locations for Tank 241-C-106



241-C-106

No.	Dia.	Elev.	Description and Comments
1	4"	646.15	FIC, BM
2	12"	646.18	Exhauster Riser
3	12"	647.24	Lead Covered WC
4	4"		Recirculating Dip Leg WC
5	4"		Recirculating Dip Leg WC
6	12"	646.01	Sluicing Access/Flange
7	12"	646.48	OBSV Port/Press. Gauge
8	4"	645.66	B-221 Temperature Probe
9	42"		Sludge Pump
13	26"		Distributor Jet WC
14	4"	645.5	Temperature Probe
15	12"		Air Inlet Filter

Legend:



3 1/2 in. circle is tank outline

Risers

42"

12" in proportion to size

4

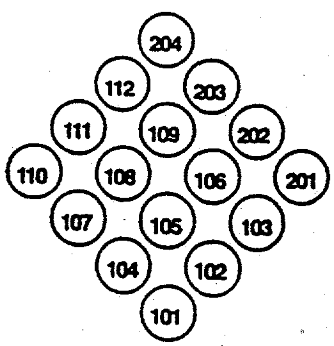
1, 2, 3, etc. Riser number - may not agree with field ID

Various size rectangles are pits - may have label

Double rectangle indicates weather covered pit unless otherwise identified.

Caisson (USU 72" dia.) - covered

A 42" manhole at dome top - no riser to surface



241-C Farm Layout

29210056.5

Figure 3.2. Historical FIC Surface Level Data (1981 through 1988)

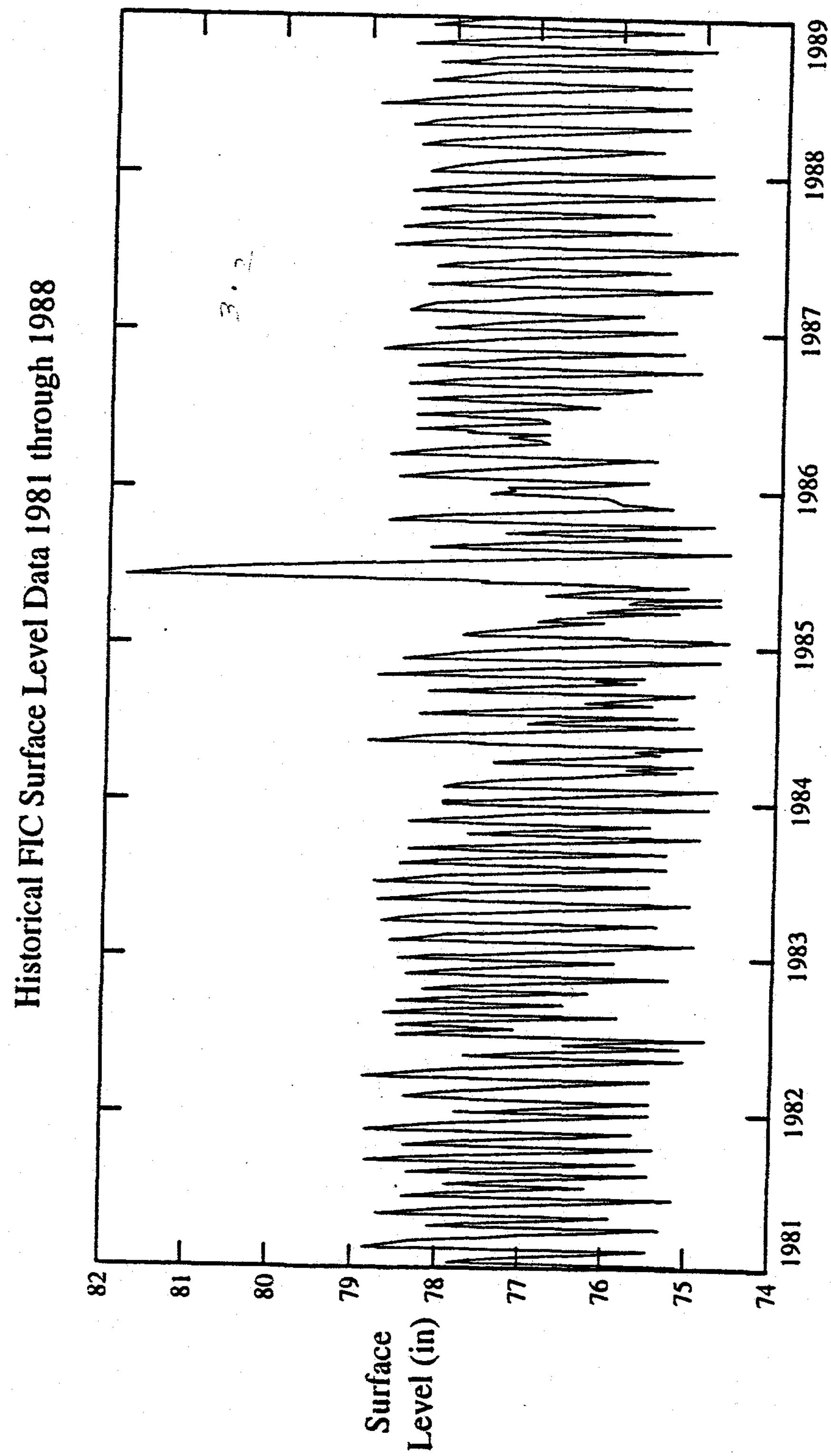


Figure 3.3. Historical FIC Surface Level Data (1989 through February 1995).

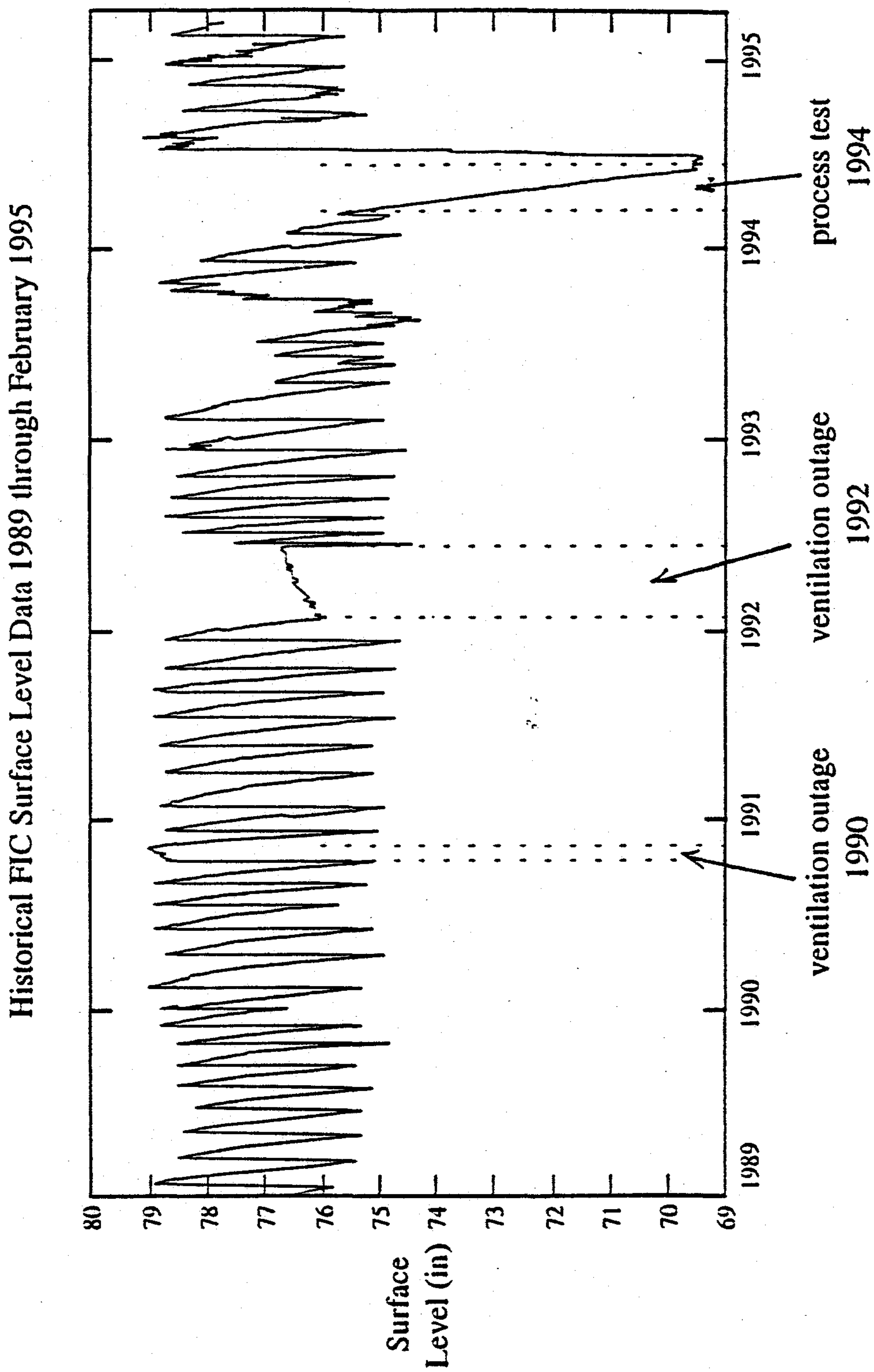


Figure 3.4. Measured Temperatures Tank C-106 Riser #8
(1983 through 1991)

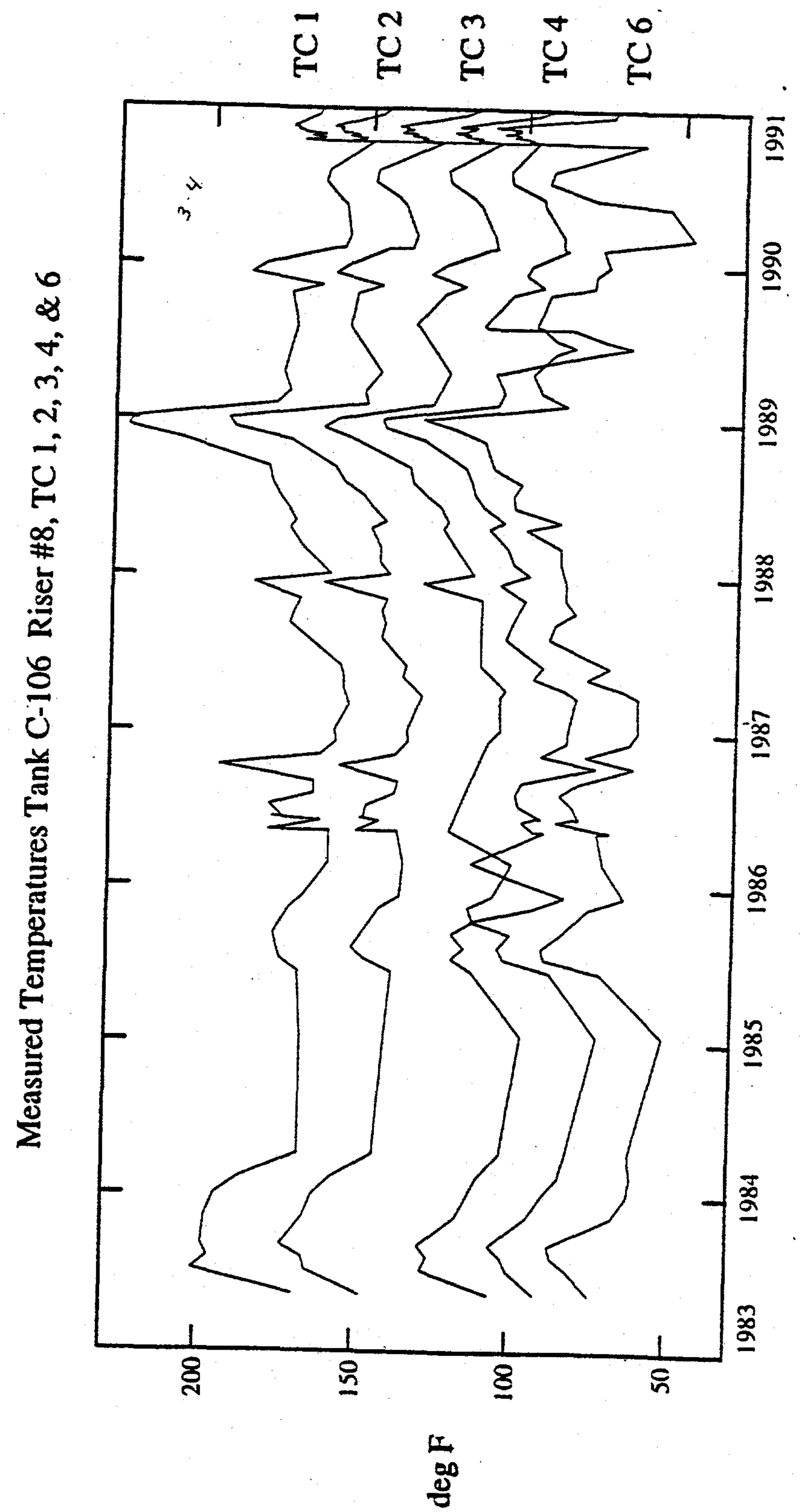


Figure 3.5. Measured Temperatures Tank C-106 Riser #8
(1991 through February 1995)

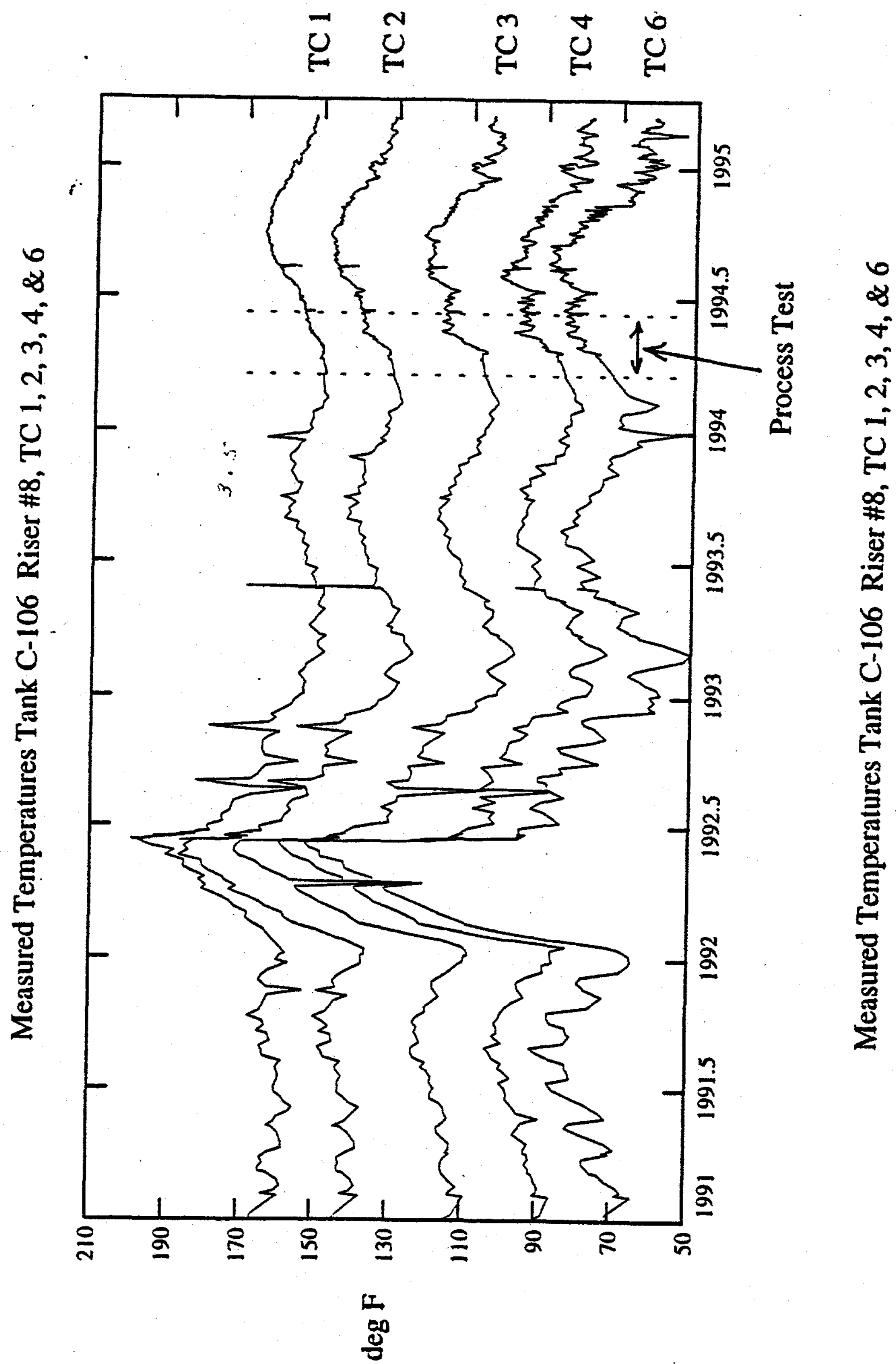


Figure 3.6. Measured Temperatures Tank C-106 Riser #14
(1982 through 1992)

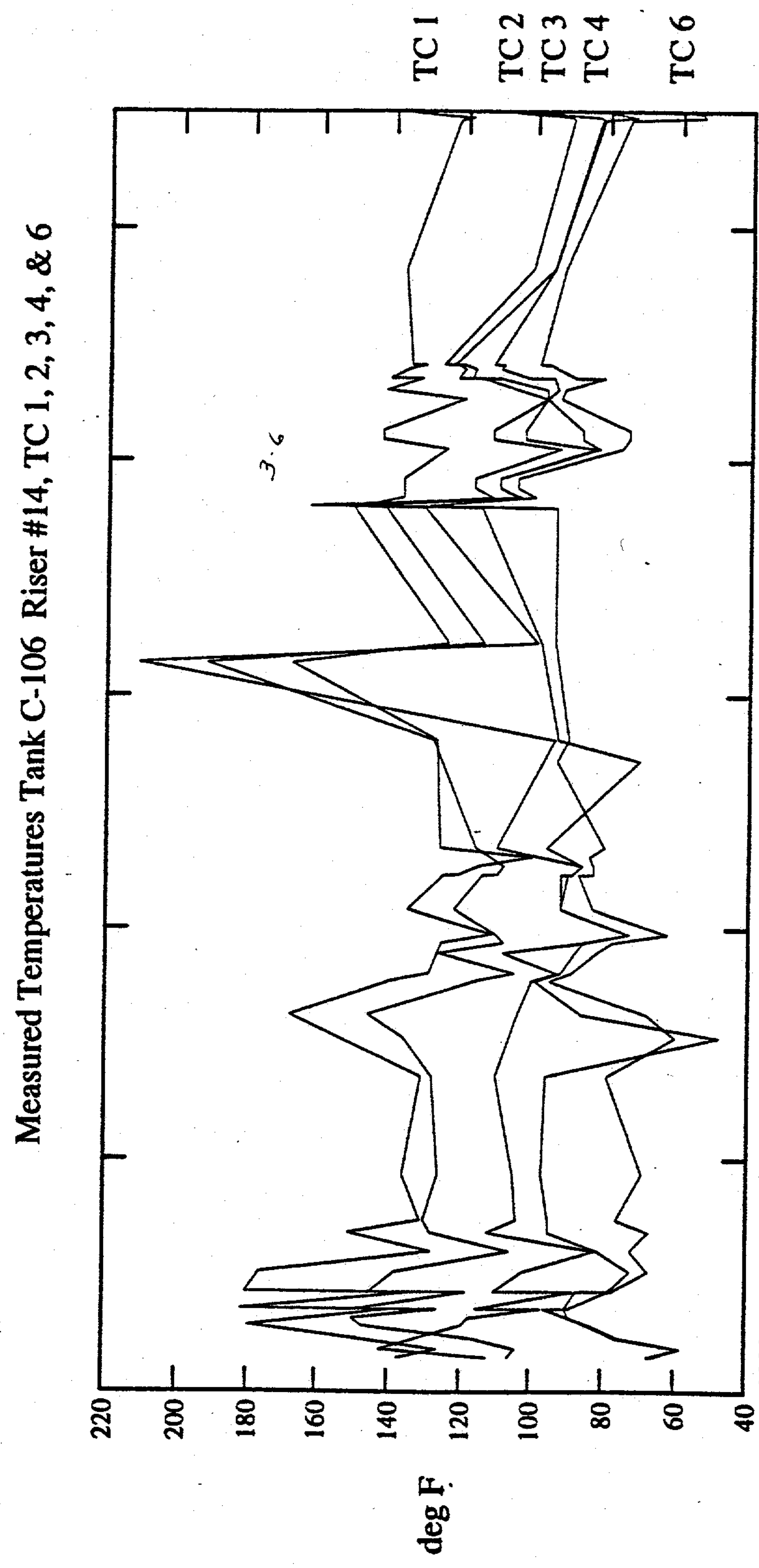


Figure 3.7. Measured Temperatures Tank C-106 Riser #14
(1993 through February 1995)

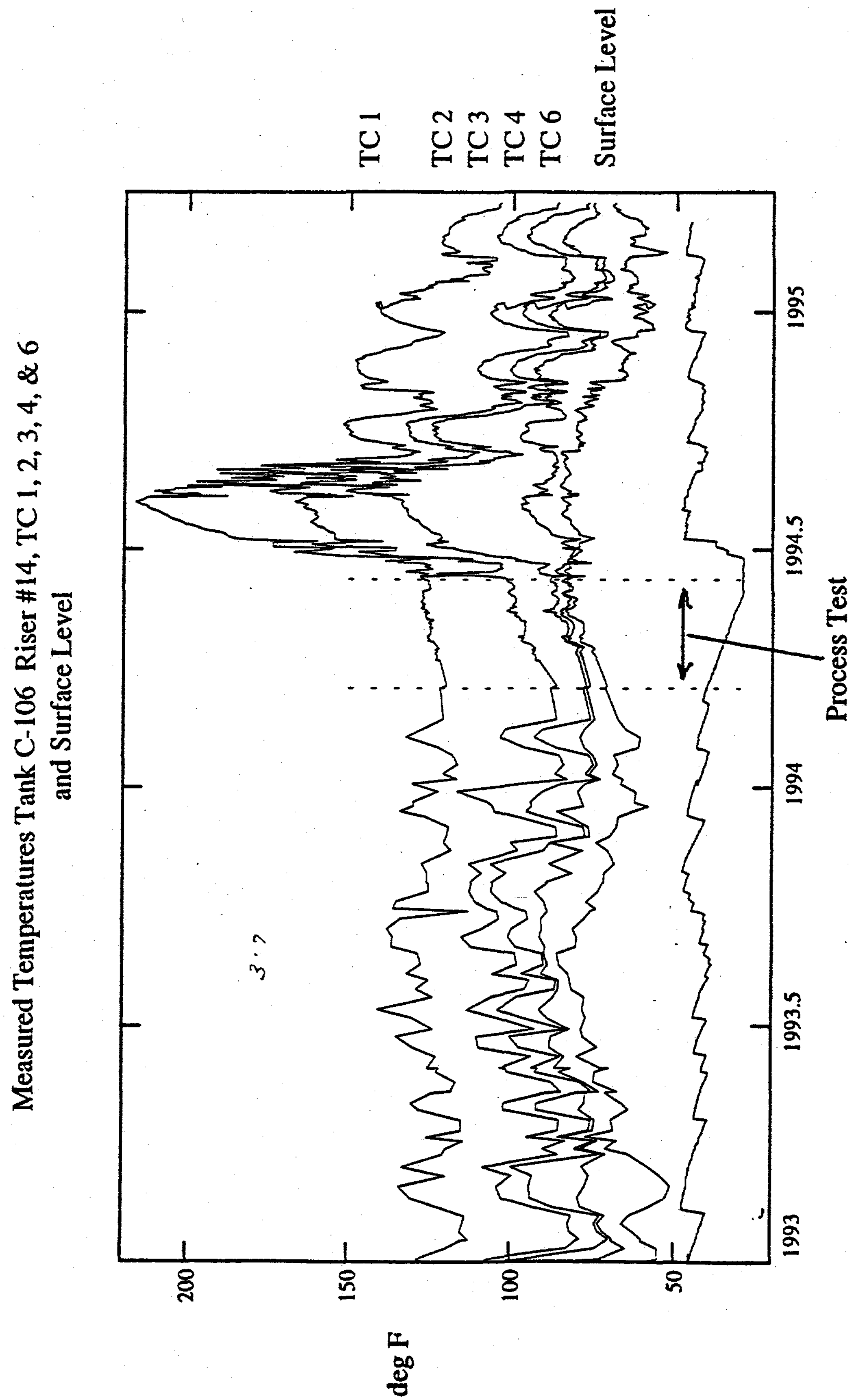


Figure 3.8. Measured Temperatures Tank C-106 Riser #14
(March 1994 through February 1995)

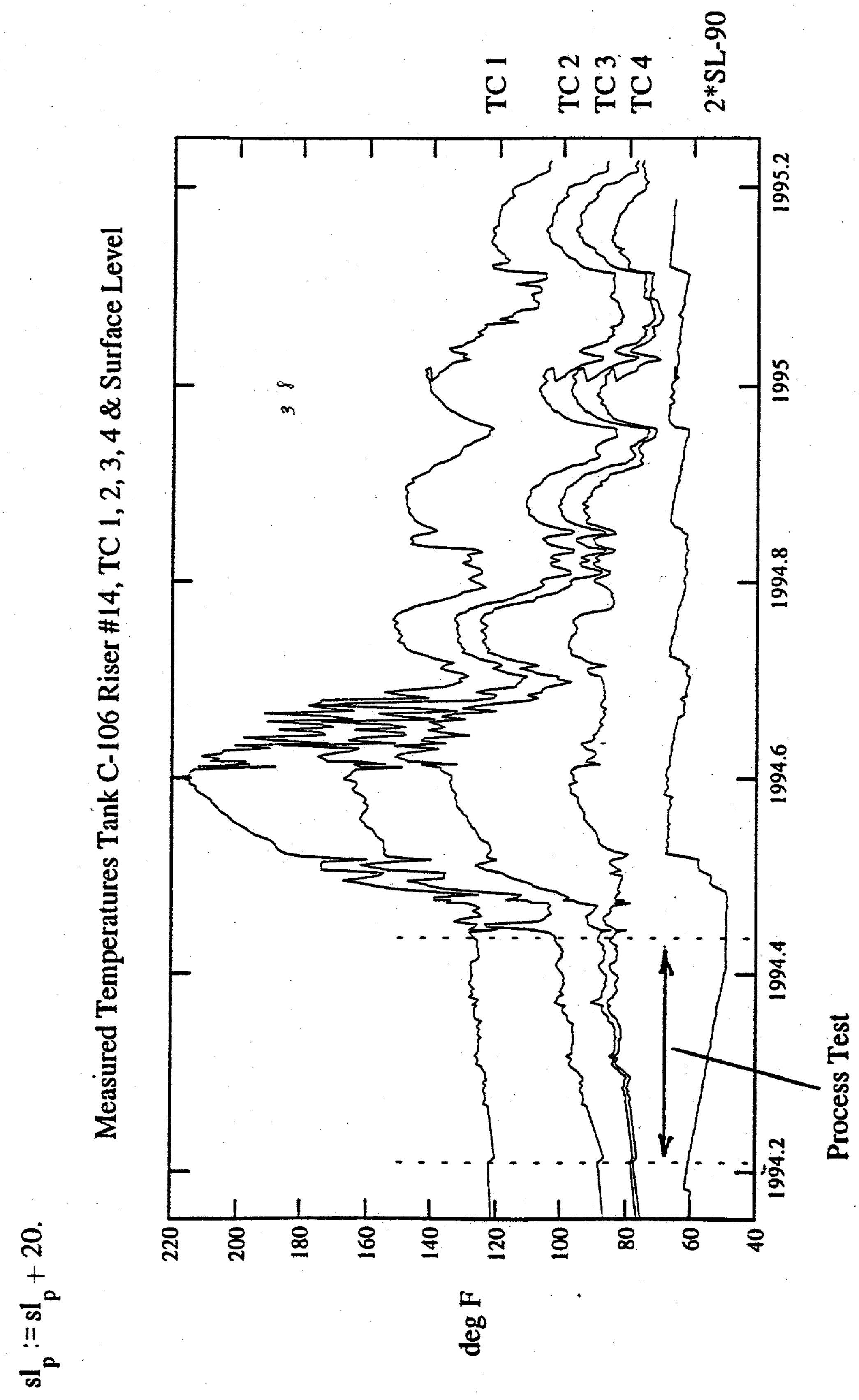


Figure 4.1. Comparison of measured FIC data and GOTH calculated Liquid Surface Level (with no formation of voids in sludge)

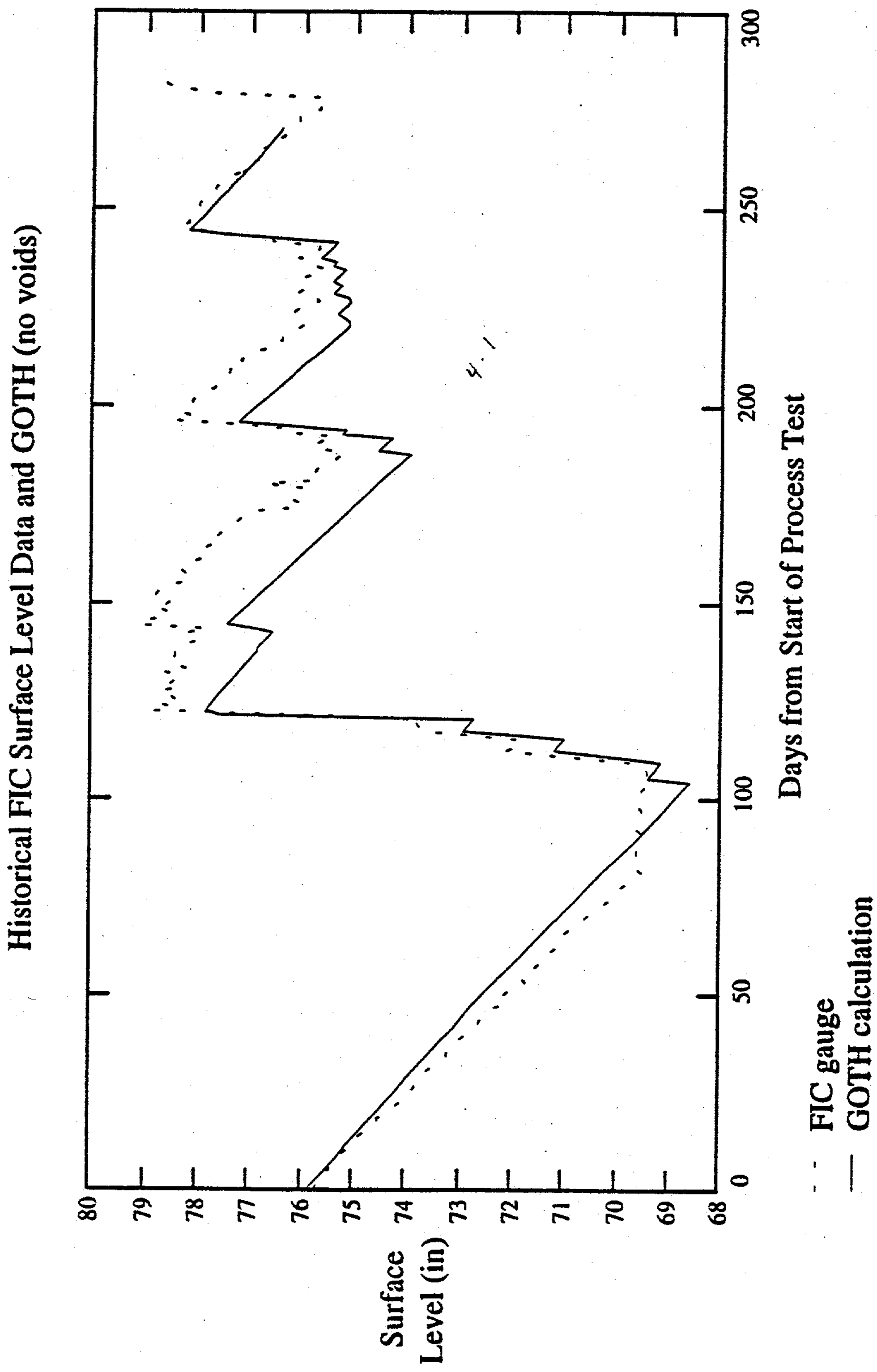


Figure 4.2. Comparison of measured FIC data and GOTH calculated Liquid Surface Level (with formation of voids in sludge)

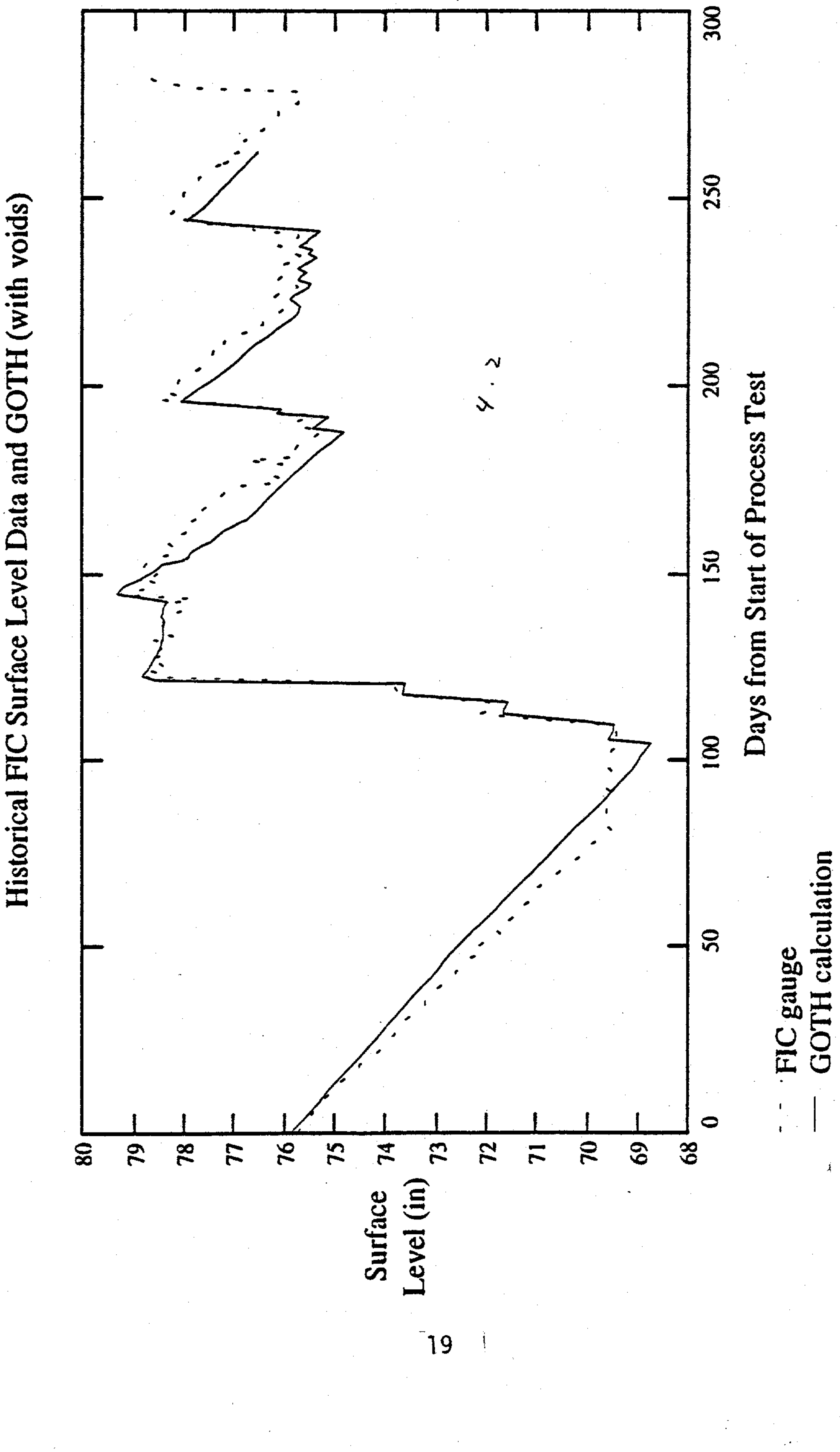


Figure 4.3. GOTH Simulation of Liquid Surface Level
(maintaining surface level between 72 and 76 in.)

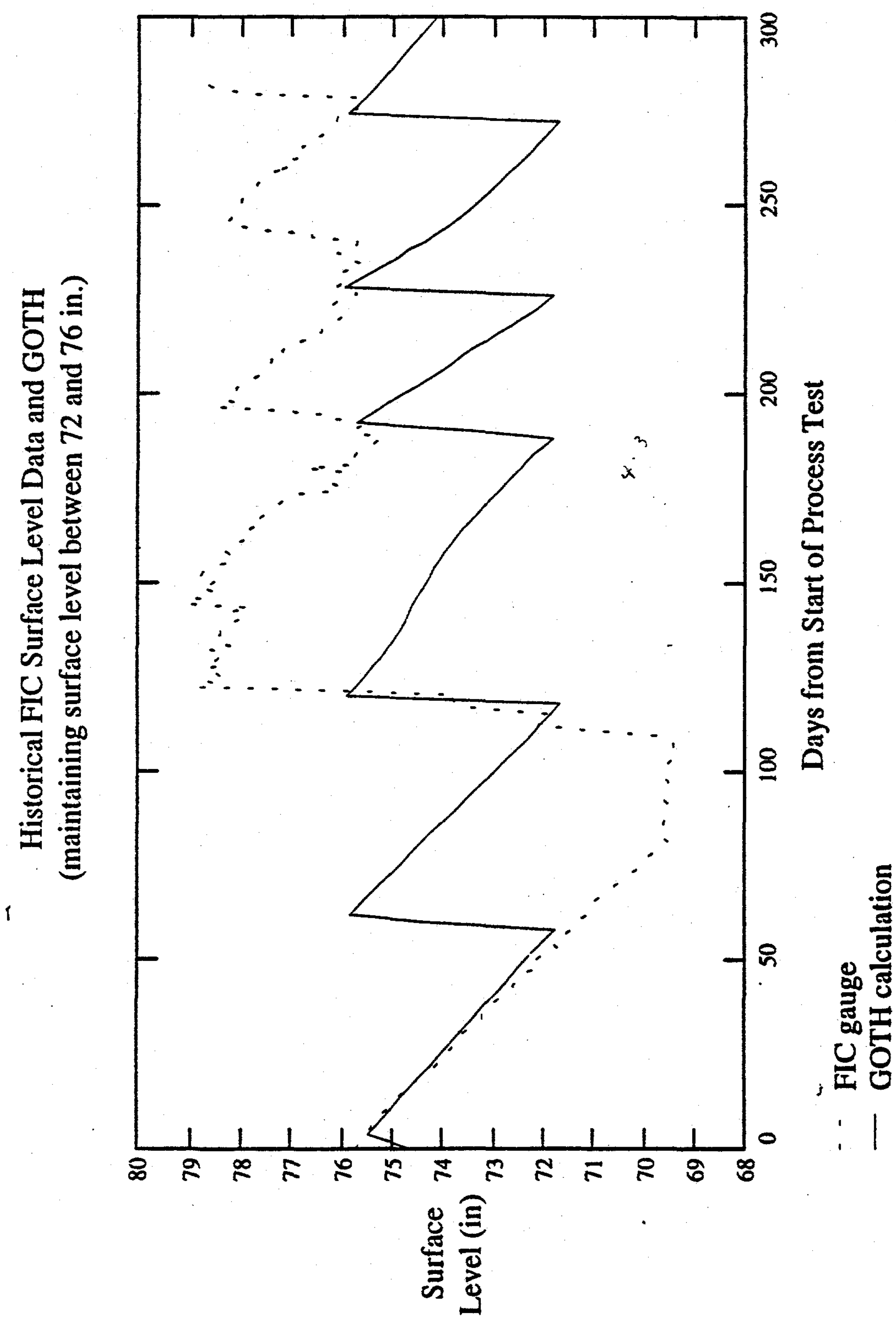


Figure 4.4. Seasonal Evaporation Rate Correlation

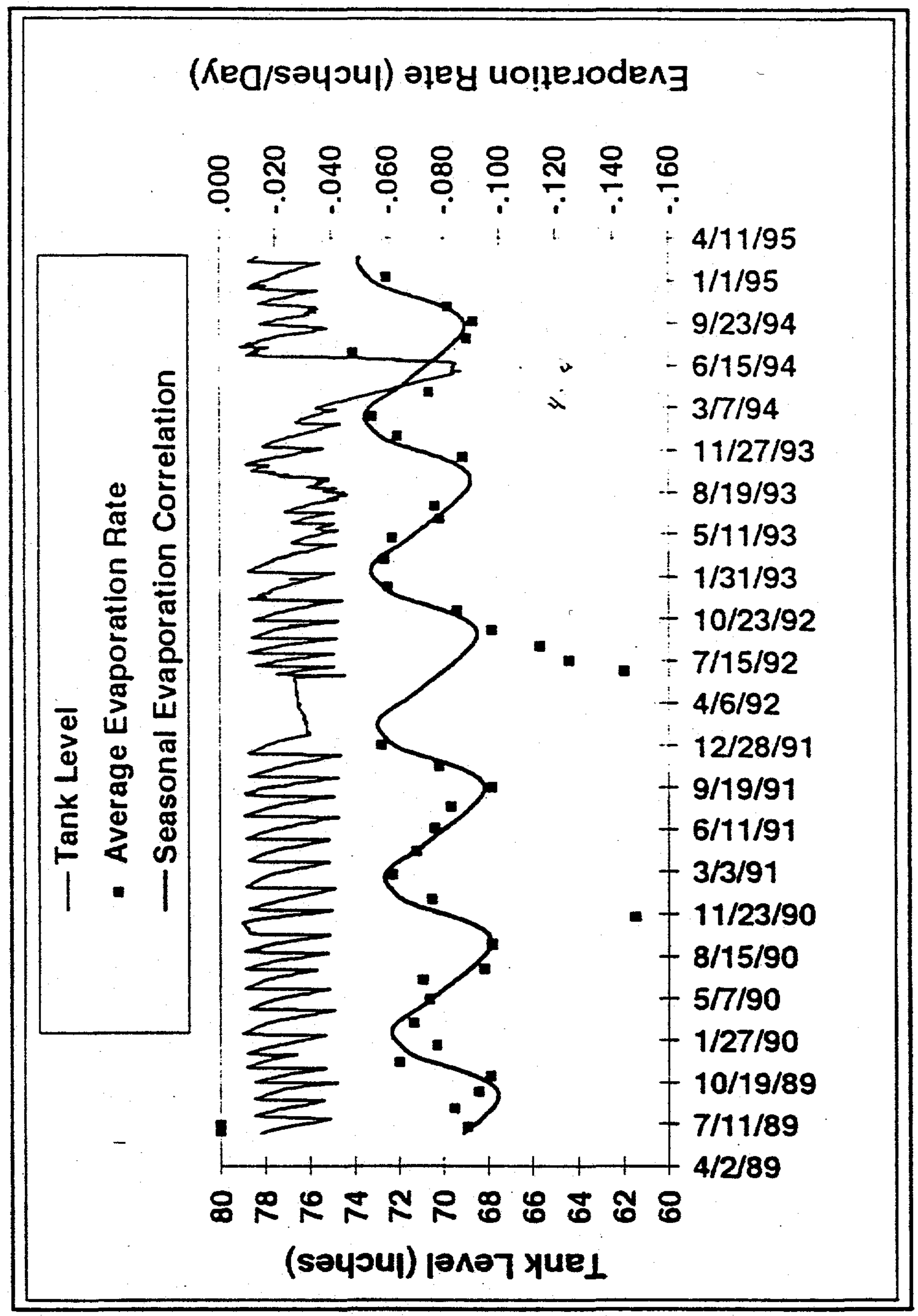


Figure 1. Seasonal evaporation correlation.

Figure 4.5. Comparison of Measured TC Data and GOTH Simulation Using Gap Closure Model (TC-1 and TC-3)

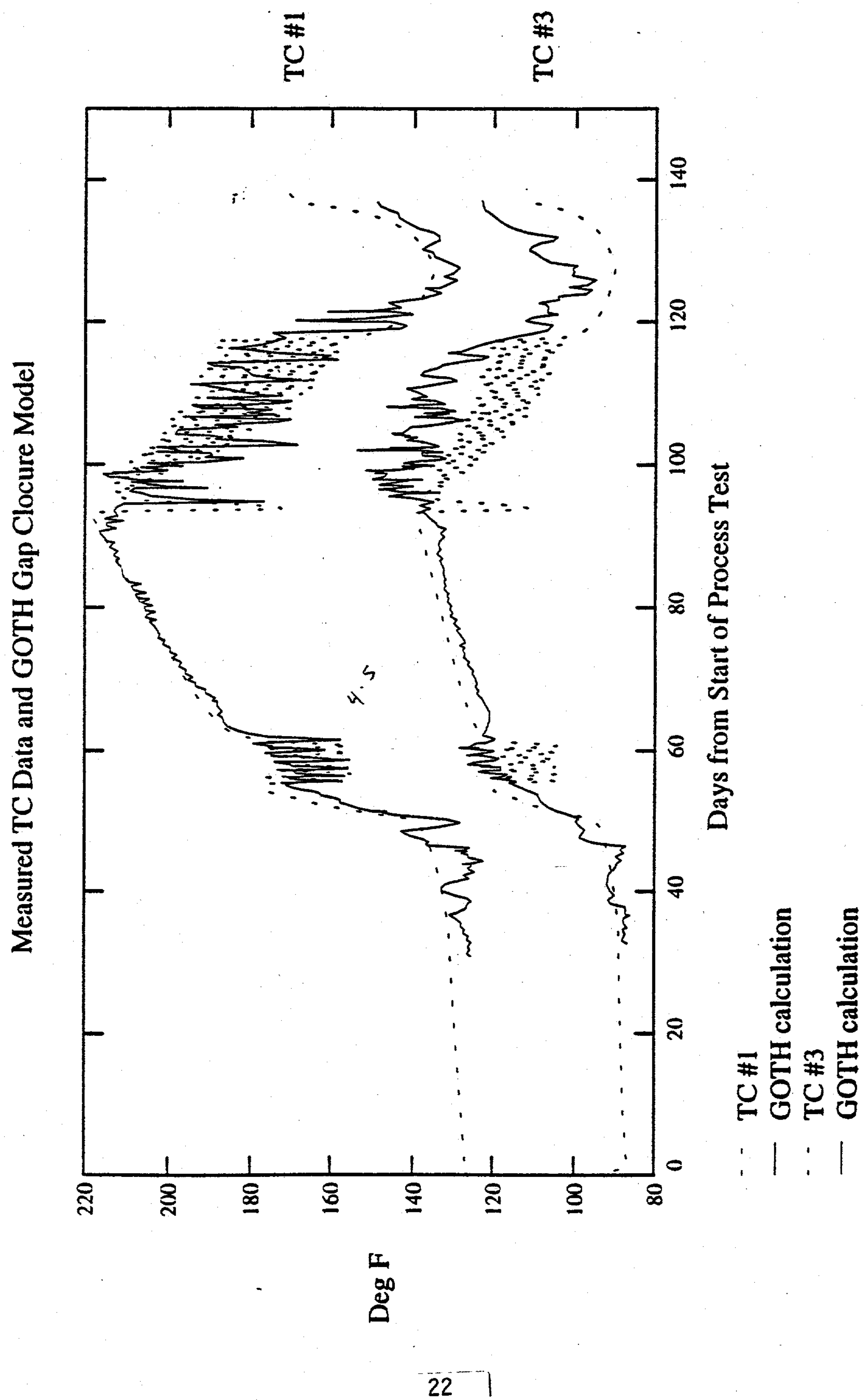


Figure 4.6. Comparison of Measured TC Data and GOTH Simulation Using Gap Closure Model (TC-2)

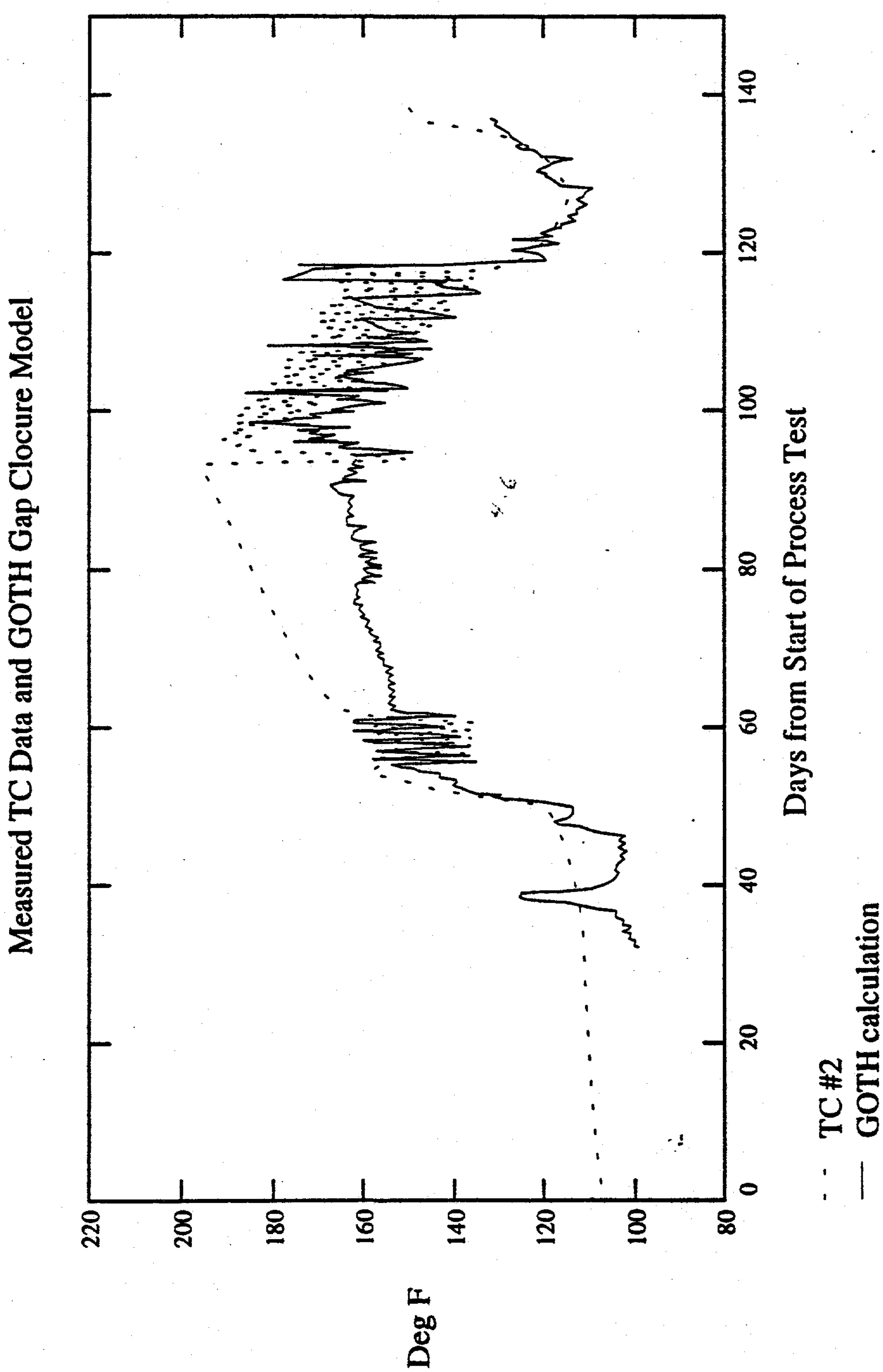


Table 3.1. Ventilation and Psychrometric Data (during and after Process Test).

Date	Time	Airflow (cfm)	Temperatures (°F)			
			ambient (inlet)		C-106 (outlet)	
			dry bulb	wet bulb	dry bulb	wet bulb
4/15	1000	1172	54	46	74	67
5/20	0840	1724	59	55	68	66
6/02	0845	1439	59	48	80	71
7/06	1715	1484	87	65	78	70
7/29	1030	2330	83	60	82	73
8/01	0930	2311	86	62	84	72
	1800	2181	98	66	86	70
	1820	2246	97	66	86	70
	1835	2176	97	65	86	70
8/03	0100	2059	89	69	84	72
	0600	2026	82	67	82	77
	0845	2017	83	68	84	78
	1030	1952	90	69	86	79
	1245	1968	100	69	92	78
	1415	2040	102	71	89	77
8/05	0515	2184	88	65	85	74
	0700	2206	84	54	85	74
	0900	2220	73	56	83	74
9/02	0830	2475	64	56	82	75

Table 3.2. Water Additions Tank C-106 (1994).

Date	Type of water	Amount (gal)
1/27	Processed	2647
1/28	Processed	3182
3/3	Processed	2936
6/17	Processed	2347
6/22	Processed	1749
6/23	Processed	2273
6/24	Processed	2122
6/28	Processed	2706
6/29	Processed	3075
7/3-5	Raw	14,425
7/26	Processed	2900
9/12	Processed	1896
9/13	Processed	3000
9/15	Processed	2727
9/16	Processed	3242
11/1	Processed	3100
11/2	Processed	3329
11/3	Processed	1915
12/8	Processed	7567
12/9	Processed	1883

raw water temperature = 60-80 °F
processed water temperature = 80-120 °F

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