TC-1778

PRETEST PREDICTIONS OF THE THERMAL AND HYDRAULIC RESPONSES OF THE FUELED OPEN TEST ASSEMBLIES TO THE 5 PERCENT POWER NATURAL CIRCULATION FFTF PLANT STARTUP TEST

Hanford Engineering Development Laboratory

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PRELIMINARY DOCUMENT

This document contains information of a preliminary nature prepared in the course of work under U.S. DOE Contract DE-AC14-76FF02170. This information is subject to corrections or modification upon the collection and evaluation of additional data.

PRETEST PREDICTIONS OF THE THERMAL AND HYDRAULIC
RESPONSES OF THE FUELED OPEN TEST ASSEMBLIES
TO THE 5 PERCENT POWER NATURAL CIRCULATION
FFTF PLANT STARTUP TEST

ABSTRACT

Reported are the expected thermal and hydraulic responses of the specially instrumented fueled open test assemblies (FOTA's) to the FFTF's 5 percent power natural circulation plant startup test. This test is the first in the series of 4 natural circulation transient tests.

The FOTA responses are representative of all the driver assemblies in the core.

These calculations, which are made using the Westinghouse Hanford Company's CORA computer program, indicate that the transient is very mild, yet of sufficient magnitude to be of limited benefit for computer program verification and possible calibration.

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Acknowledgment

Thanks are due W. T. Nutt of the Systems Dynamics and Thermal Analysis section for his considerable contribution in automating CORA's problem forcing boundary condition inputs, for identifying the uncertainties in these inputs, for specifying the process measurement time responses, and for his many hours of consultation.

1.0 INTRODUCTION

Best estimate pretest predictions of core performance for the 5 percent power natural circulation FFTF plant startup test are provided in accordance with the NRC recommendation included in Reference (1). Core performance in this case is considered to be typified by the thermal and hydraulic transient responses of the rows 2 and 6 fueled open test assemblies (FOTA's), which are highly instrumented with thermocouples for radial and axial coolant temperature data and flowmeters for assembly coolant flow data.

Each FOTA is a 40 foot long core assembly, consisting of a lower 12 foot in-core fueled section and an upper 28 foot instrument stalk section. The lower section is essentially the same as a regular core driver except for the addition of pin bundle thermocouples in the FOTA. Details of the test articles are given in Reference (2).

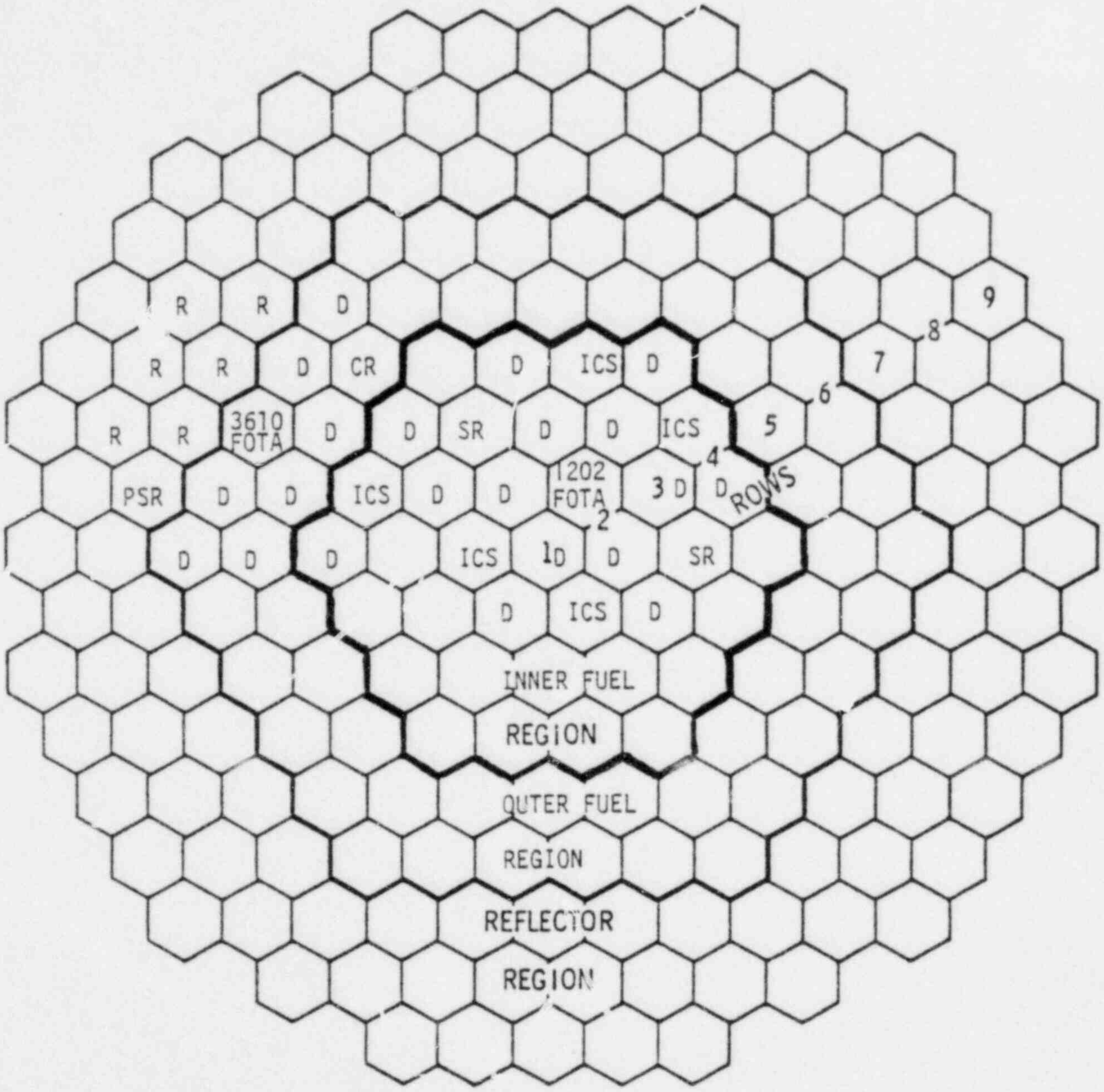
The locations of the two FOTA's within the core are shown in Figure 1.1. The row 2 FOTA, assembly number 1202, is surrounded by 6 drivers of similar characteristics. On the other hand, the row 6 FOTA, assembly number 3610, has reflector assemblies at 2 of its faces. Interassembly heat transfer should be significant for the row 6 FOTA, but of small importance for the row 2 FOTA.

The 5 percent power natural circulation plant startup test procedure is described in detail in Reference (3).

2.0 SUMMARY

Pretest predictions of the thermal and hydraulic responses of the FFTF core to the plant startup 5 percent power natural circulation test are made using the Westinghouse Hanford Company's CORA Computer Program. Detailed temperature and flow data are presented for the rows 2 and 6 FOTA's as being representative of the core response.

Figure 1.1 Locations of FOTA Assemblies Within the Core



D driver
CR control
ICS in-core shim
R reflector
PSR peripheral shim
SR safety

The transient is very mild as shown by the data plots. The peak transient active zone ΔT's are only about 47-59°F as compared to the initial steady state values of about 22-25°F. The peak temperatures occur at about 4 minutes into the transient, with very gradual rises to the peaks and very gradual decays after the peaks.

Even though the transient is mild, the experimental data obtained will show enough variations to be of significant value in checking, and perhaps calibrating, core computer programs.

3.0 CORA COMPUTER PROGRAM FOR ANALYSIS

The predictions were made using the Westinghouse Hanford Company's CORA Computer Program, a preliminary version of which is described in Reference (4). Each FOTA was analyzed as the center assembly in a cluster of 19 assemblies arranged in a hexagonal array. Forcing boundary conditions were obtained from the output of the IANUS System Computer Program (Reference 5) for the nominal test conditions of core irradiation at 2 percent power for 5 hours and 5 percent power for 1 hour before the scram which initiates the test.

The nominal locations of the pin bundle thermocouples are shown in Figures 3.1 through 3.6, and the subdivision of the FOTA assemblies into CORA code parallel flow channels is shown in Figure 3.7.

3.1 PROCESS MEASUREMENT RESPONSES

The time responses for all process measurements are outlined below.

The response of pin bundle thermocouples is given as:

$$T = \alpha T_1 + (1-\alpha) T_2$$

where

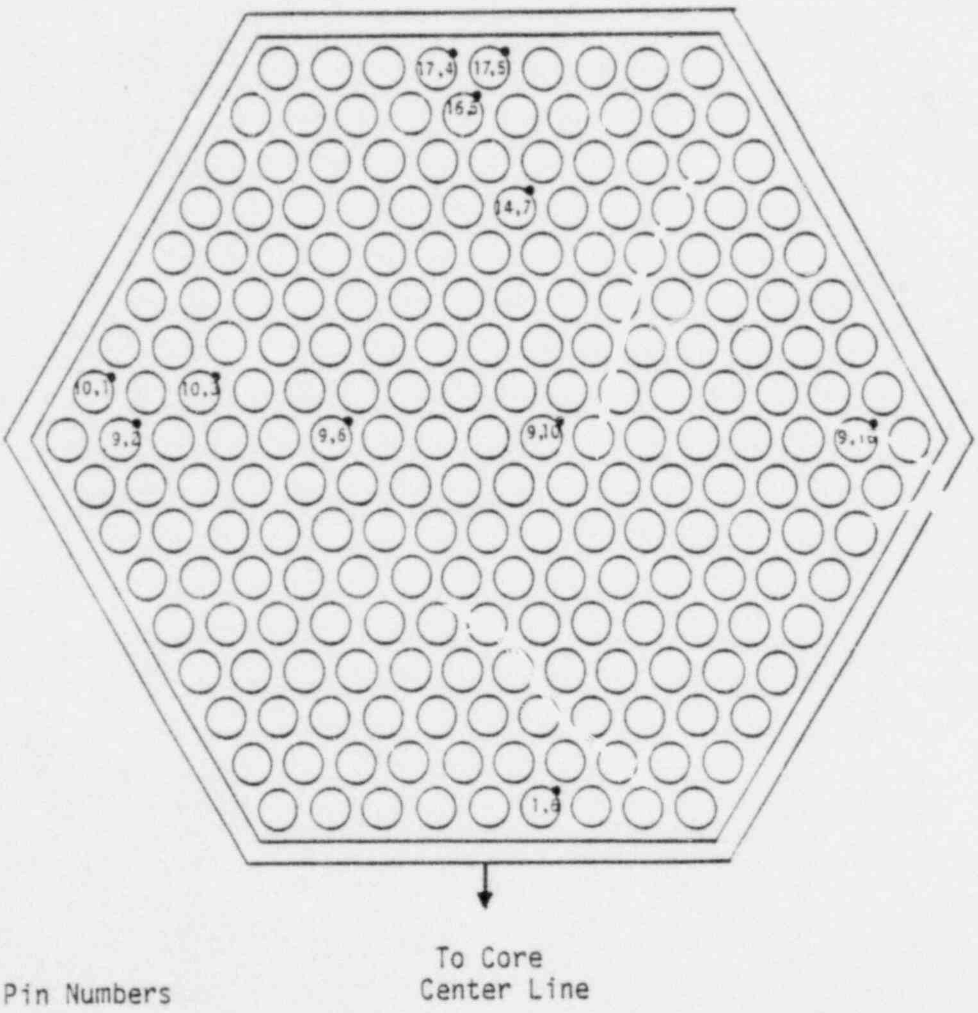
T = as measured coolant temperature

T_1 = indicated temperature for structural tip of the thermocouple

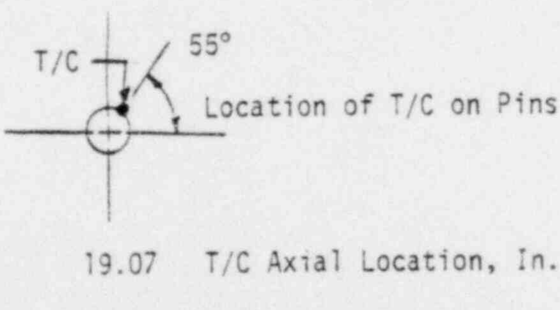
T_2 = indicated temperature for structural sheathing, etc.

α = curve fit constant.

Figure 3.1 Row 2 FOTA Thermocouple Radial Positions for Core Midplane Axial Locations

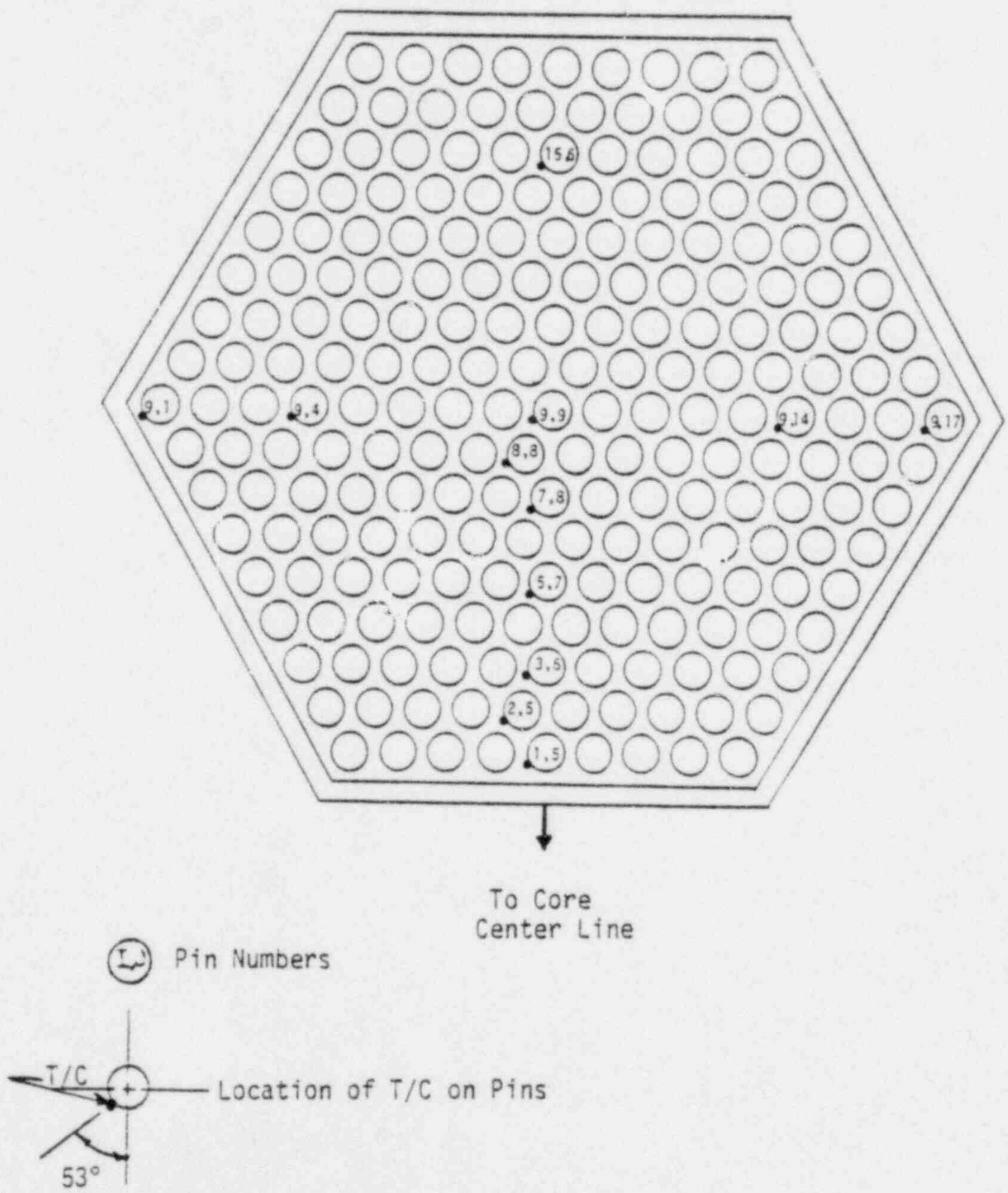


Pin Numbers



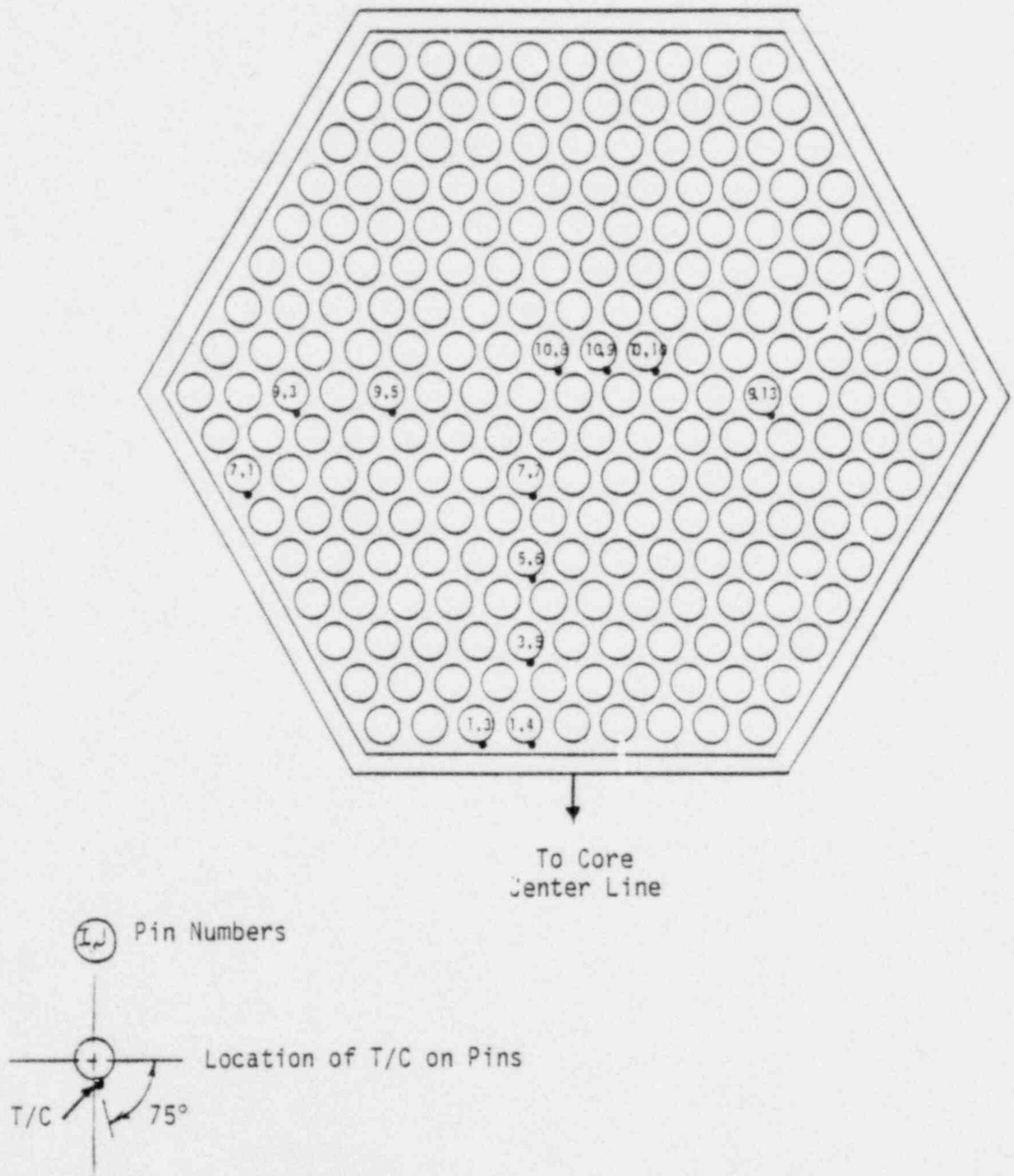
19.07 T/C Axial Location, In. Above Bottom of Fuel

Figure 3.2 Row 2 FOTA Thermocouple Radial Positions for Top of Fuel Axial Locations



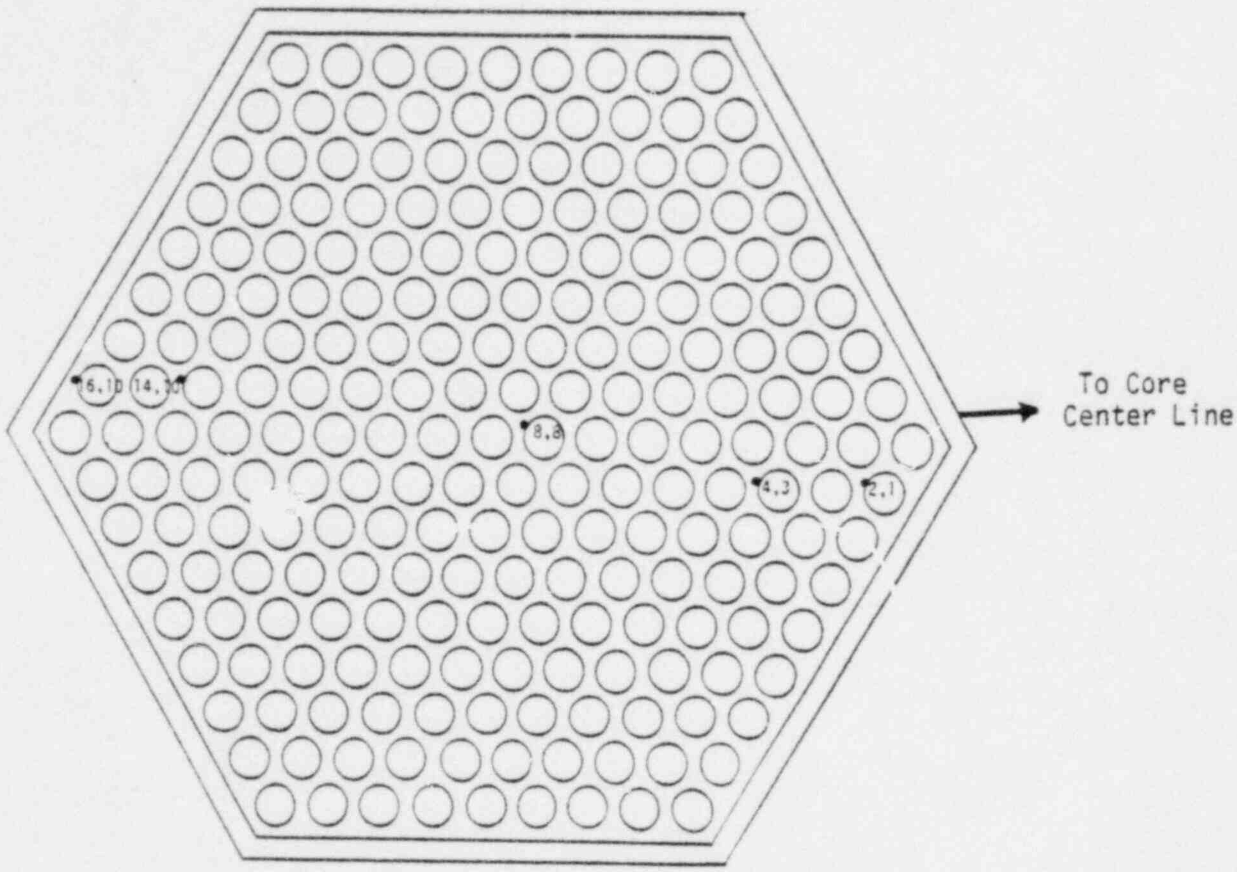
37 - T/C Axial Location, In. Above Bottom of Fuel

Figure 3.3 Row 2 FOTA Thermocouple Radial Positions for Top of Pins Axial Locations

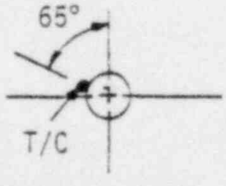


82.76 T/C Axial Location, In. Above Bottom of Fuel

Figure 3.4 Row 6 FOTA Thermocouple Radial Positions for Core Midplane Axial Locations



(I,J) Pin Numbers



Location of T/C on Pins

19.07 T/C Axial Locations, In. Above Bottom of Fuel

Figure 3 5 Row 6 FOTA Thermocouple Radial Positions for Top of Fuel Axial Locations

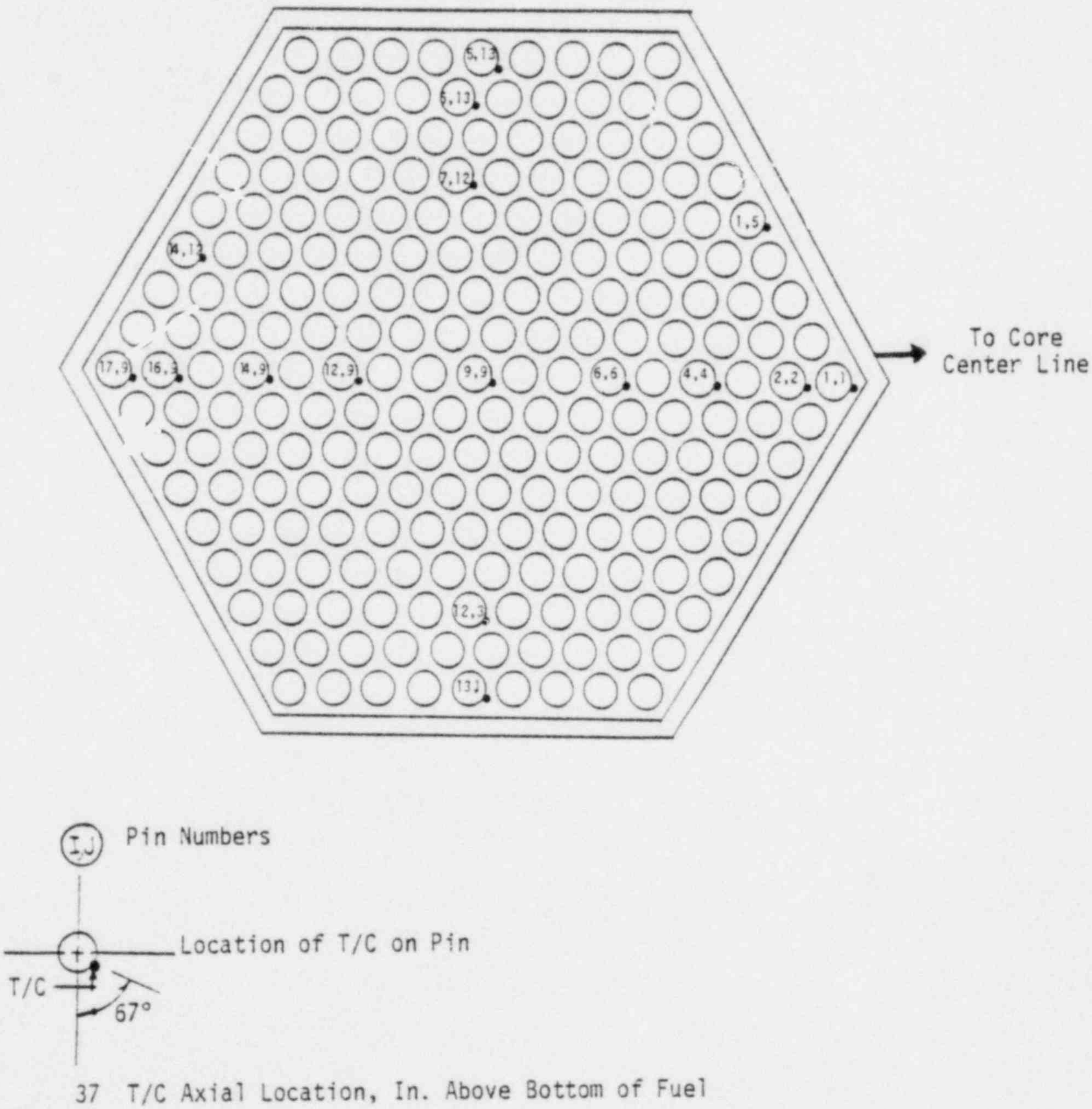
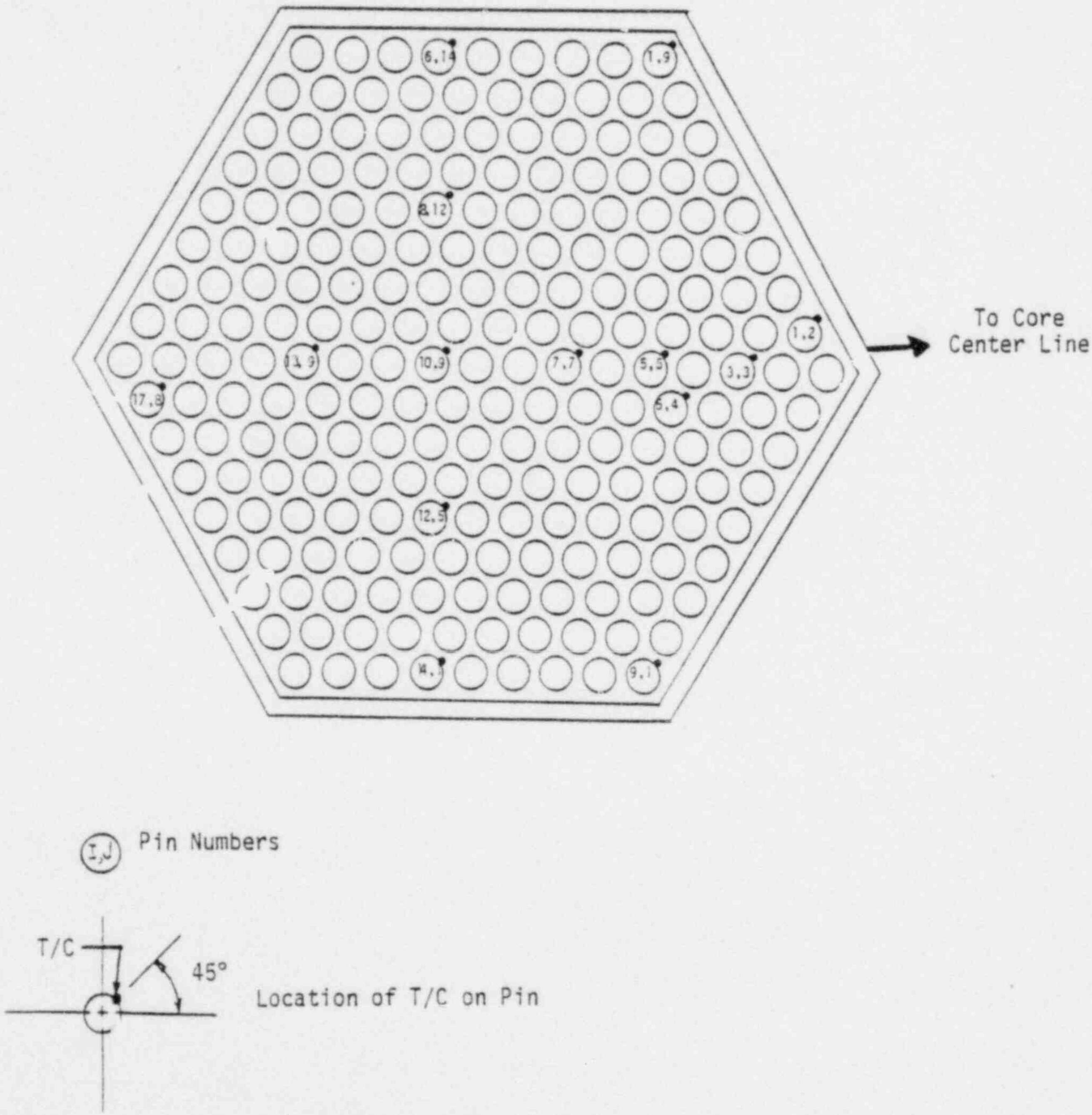
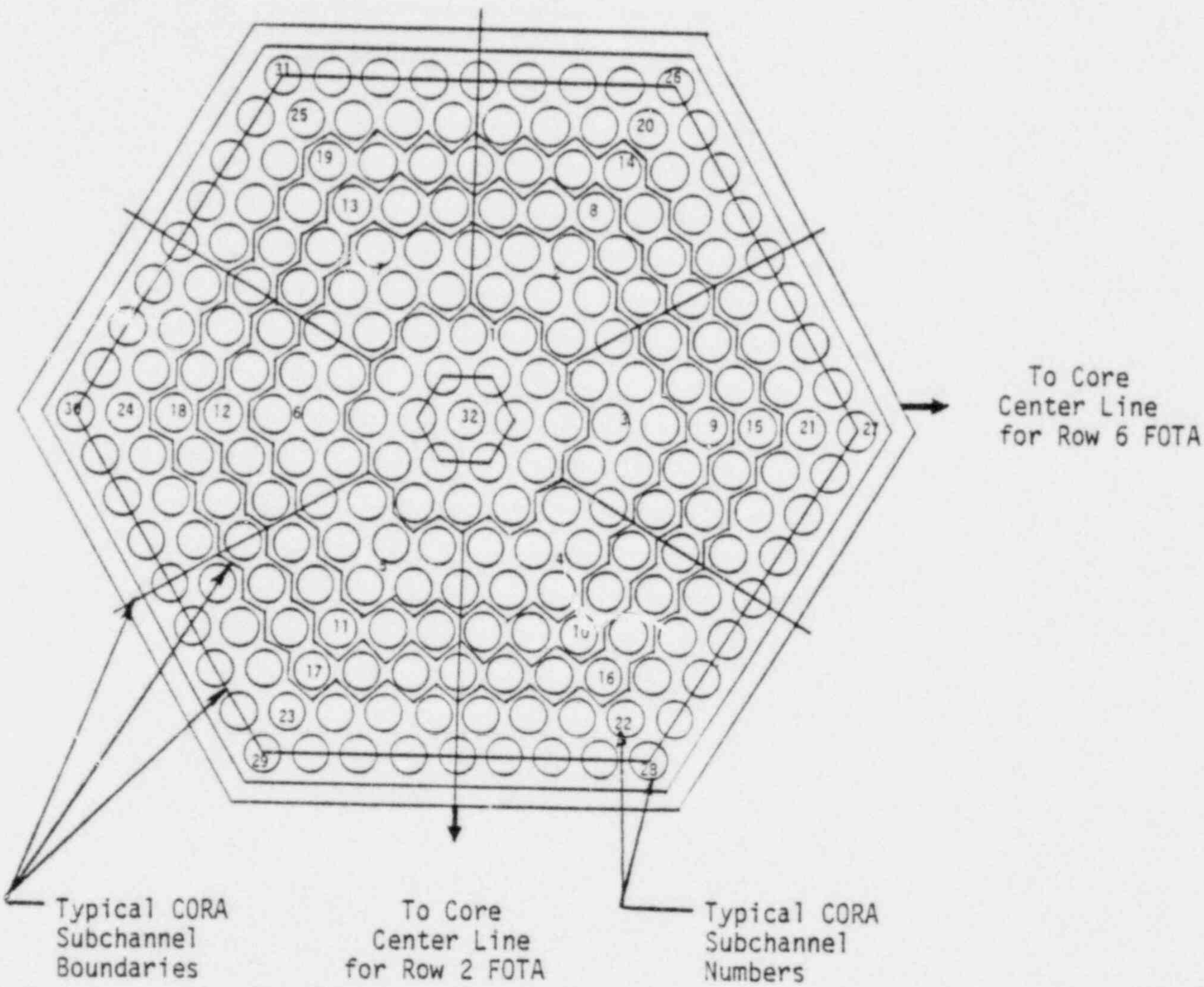


Figure 3.6 Row 6 FOTA Thermocouple Radial Positions for Top of Pins Axial Locations



82.76 T/C Axial Location, In. Above Bottom of Fuel

Figure 3.7 CORA Modeling for the Rows 2 and 6 FOTA Assemblies



The individual indicated temperatures are given by first order equations,

$$\tau_1 \dot{T}_1 = T_{Na} - T_1$$

$$\tau_2 \dot{T}_2 = T_{Na} - T_2$$

where,

τ_1 = time constant for thermocouple tip

τ_2 = time constant for sheathing, etc.

T_{Na} = actual coolant temperature

A good fit of experimental time response test data is obtained with,

$\alpha = 0.7$

$\tau_1 = 0.4$ seconds

$\tau_2 = 3.0$ seconds

Flow meter response is determined using a first order time constant of 3 seconds.

The response time for the thermocouples in the instrument stalks of all assemblies is about 3 minutes.

All time constants include signal conditioning and read out lags.

3.2 DEFINITION OF CALCULATED DATA

Predictions of coolant temperatures at all of the thermocouple locations shown in Figures 3.1-3.6 were made by interpolation of CORA's axial and radial nodal point data, but not all of the predictions are included in this report. Representative results are given for the thermocouples tabulated in Table 3.1. Computed results are saved on tape for the FOTA's and the 12 assemblies adjacent to the 2 FOTA's. Data for the other 24 assemblies are available on microfiche, but in much less detail. Fuel, cladding, duct wall, interstitial coolant, orifice assembly and instrument stalk temperatures are

TABLE 3.1

LIST OF THERMOCOUPLE DATA PLOTTED[(1),(2)]

ROW 2 FOTA		ROW 6 FOTA	
Pin No.	TX No.	Pin No.	TX No.
	Core Midplane		
10, 1	1034	16, 10	9002
9, 10	1009	8, 8	9039
9, 16	1011	2, 1	9022
	Top of Fuel		
9, 1	1032	1, 1	9025
9, 4	1036	2, 2	9026
8, 8	1016	4, 4	9018
9, 14	1012	9, 9	9009
9, 17	1008	14, 9	9004
		16, 9	9003
		17, 9	9001
	Top of Pins		
7, 1	1031	1, 2	9024
9, 3	1035	3, 3	9019
9, 5	1039	5, 5	9017
10, 8	1041	10, 9	9012
9, 13	1010	17, 8	9044
		13, 9	9041

(1) Refer to Figures 3.1 - 3.6 for location of these T/C's within the assemblies.

(2) Data are provided for the instrument stalk T/C's.

available in addition to the pin bundle coolant temperature data. Overall assembly and subchannel flow rate data are also available.

3.3 UNCERTAINTIES IN THE PREDICTIONS

The uncertainties in the predictions are due to:

1. CORA Program modeling and calculational uncertainties,
2. System program modeling and calculational uncertainties,
3. Test performance uncertainties.

The CORA uncertainties include such things as tolerances on heat transfer and fluid flow correlations, uncertainties in pin power deposition data and the like. System code uncertainties are similar. Test performance uncertainties include deviations from the nominal initial steady state power and flow rates. An uncertainty is not included for changes in the makeup of the core from the nominal so-called startup core.

The uncertainties of 2 and 3, above, enter CORA as boundary condition uncertainties.

The CORA calculational uncertainty on coolant temperature predictions is estimated as ±10 percent of the coolant temperature rise to any given axial height, and the flow rate uncertainty is estimated as ±10 percent. These are the uncertainties expected if boundary conditions were specified exactly.

The system program calculational uncertainty is estimated to be ±19 percent of the coolant temperature rise to any given axial height. The test performance uncertainty contribution is estimated to be ±12 percent of the coolant temperature rise.

The combined uncertainty for the coolant temperature rise is ±25 percent, and the combined assembly flow rate uncertainty is about ±18 percent of the indicated transient rates.

4.0 PRETEST PREDICTIONS

Temperature data are provided herein for the thermocouple locations listed in Table 3.1. Data are also given for the FOTA assembly flow rates. Calculated data are based on a core inlet coolant temperature of 594.6°F, as defined by the system computer program.

Each plot includes a curve for the calculated coolant temperature or flow and a second curve of the calculated temperature or flow as adjusted for measurement delays. The latter curves are based on the time responses given in Section 3.1. The uncertainty of these plots is discussed in Section 3.3.

Additional data points are included for the "real" calculated averages at the given core elevations in Figures 4.15, 4.16, 4.35 and 4.36. "Real", in this case, denotes the CORA calculated thermal average of all the pin bundle flow channels and takes into account the flow rates and temperatures of each of these channels. The calculated coolant and adjusted curves are simple averages of all T/C data at the given elevatio-

Row 2 FOTA temperature and flow data are plotted in Figures 4.1 through 4.16 and 4.17, respectively. Row 6 FOTA temperature and flow data are plotted in Figures 4.18 through 4.36 and 4.37, respectively.

5.0 REFERENCES

(1) NUREG-0358, "Safety Evaluation Report Related to Operation of Fast Flux Test Facility," U. S. Department of Energy, Project No. 448, August, 1978.

(2) "Detailed Irradiation Plan for FOTA Test Articles (HF011 and HF012)," J. R. Staines, July 7, 1979.

(3) TP-51-5A008, Part I, "FFTF Reactor Plant Acceptance Test Program Transient Natural Circulation Test," R. D. Redekopp, April, 1980.

(4) TC-1505, "CORA - A Computer Code for Thermal and Hydraulic Coupling of Reactor Core Assemblies," H. G. Johnson, September, 1979.

(5) HEDL-TC-556, "Simulation of the Overall FFTF Plant Performance," S. L. Additon, T. B. McCall, C. F. Wolfe, March, 1976.

Figure 4.1 Calculated Row 2 FOTA Core Midplane Coolant Temperatures for T/C TX1034 on Pin 10,1

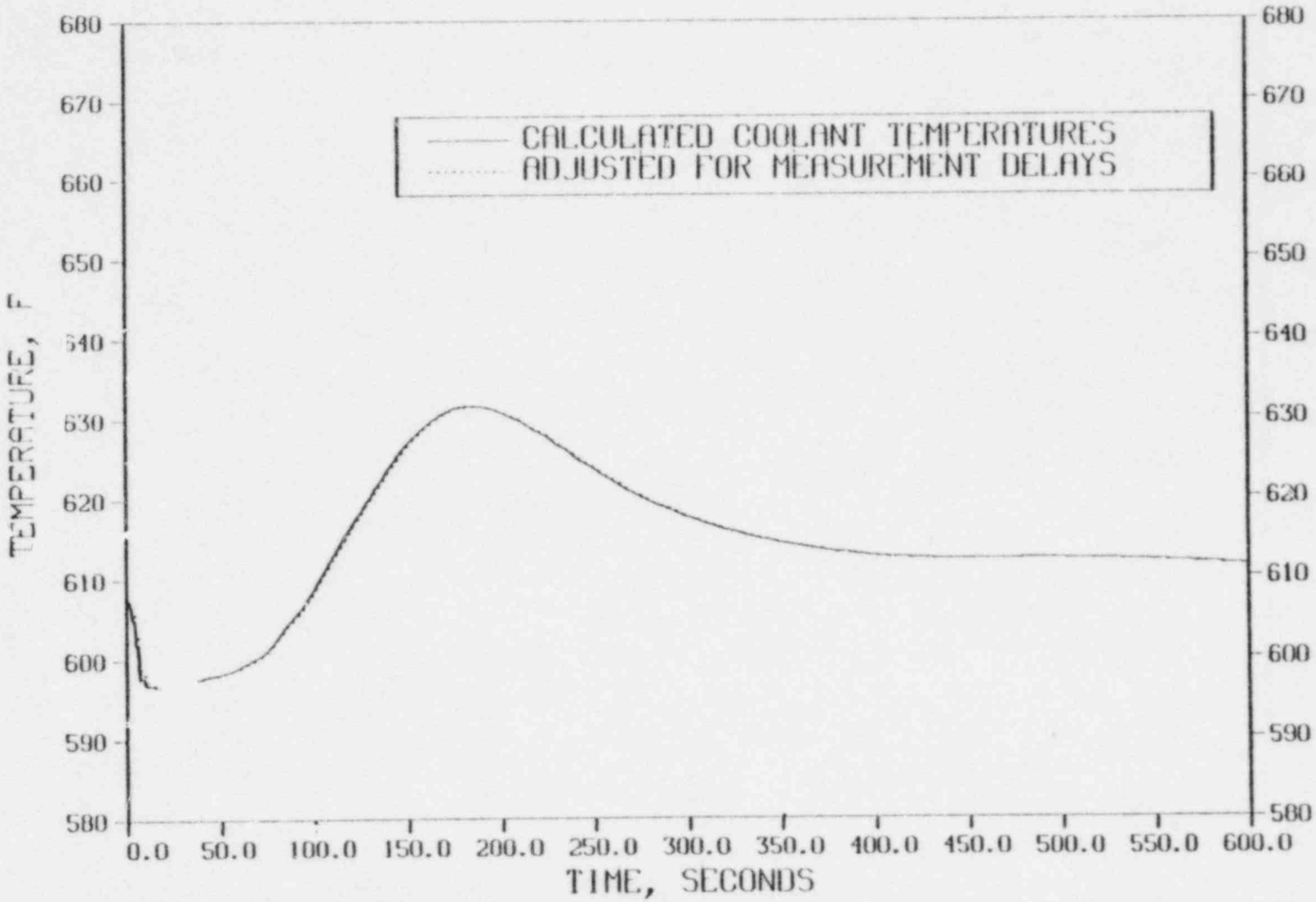


Figure 4.2 Calculated Row 2 FOTA Core Midplane Coolant Temperatures for T/C TX1009 on Pin 9, 10

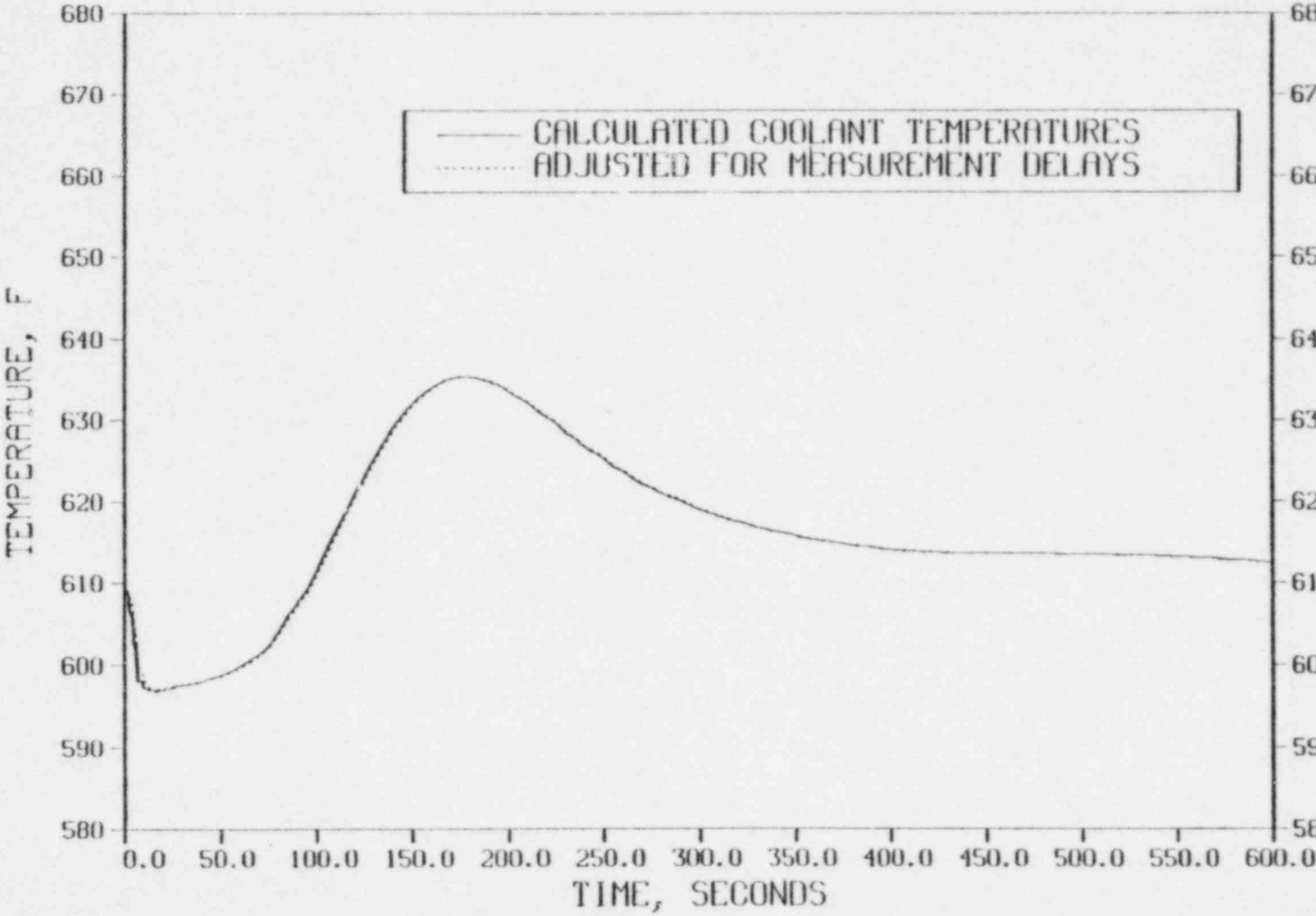


Figure 4.3 Calculated Row 2 F01A Core Midplane Coolant Temperatures for T/C TX1011 on Pin 9,16

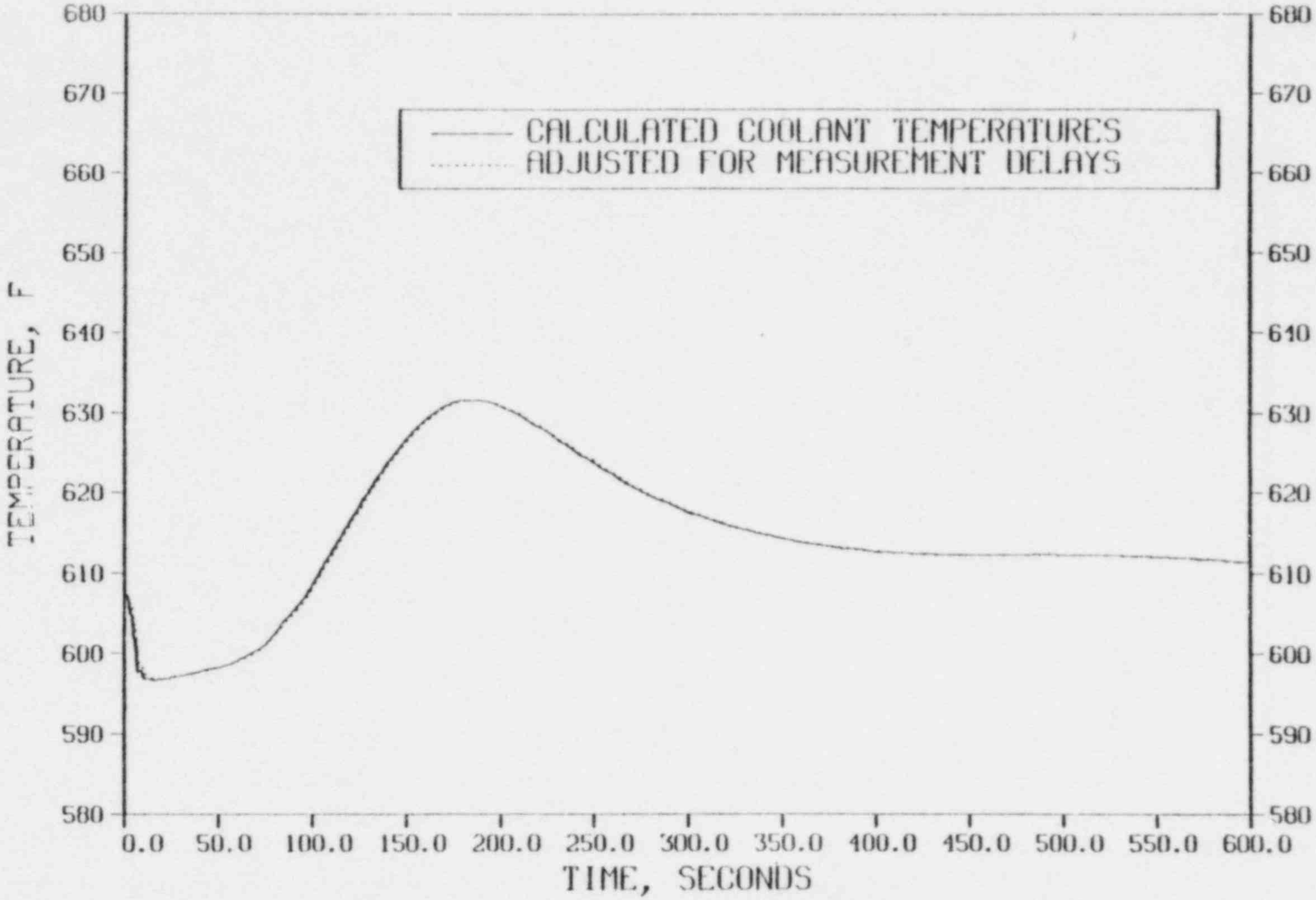


Figure 4.4 Calculated Row 2 FOTA Top of Fuel Coolant Temperatures for T/C TX1032 on Pin 9,1

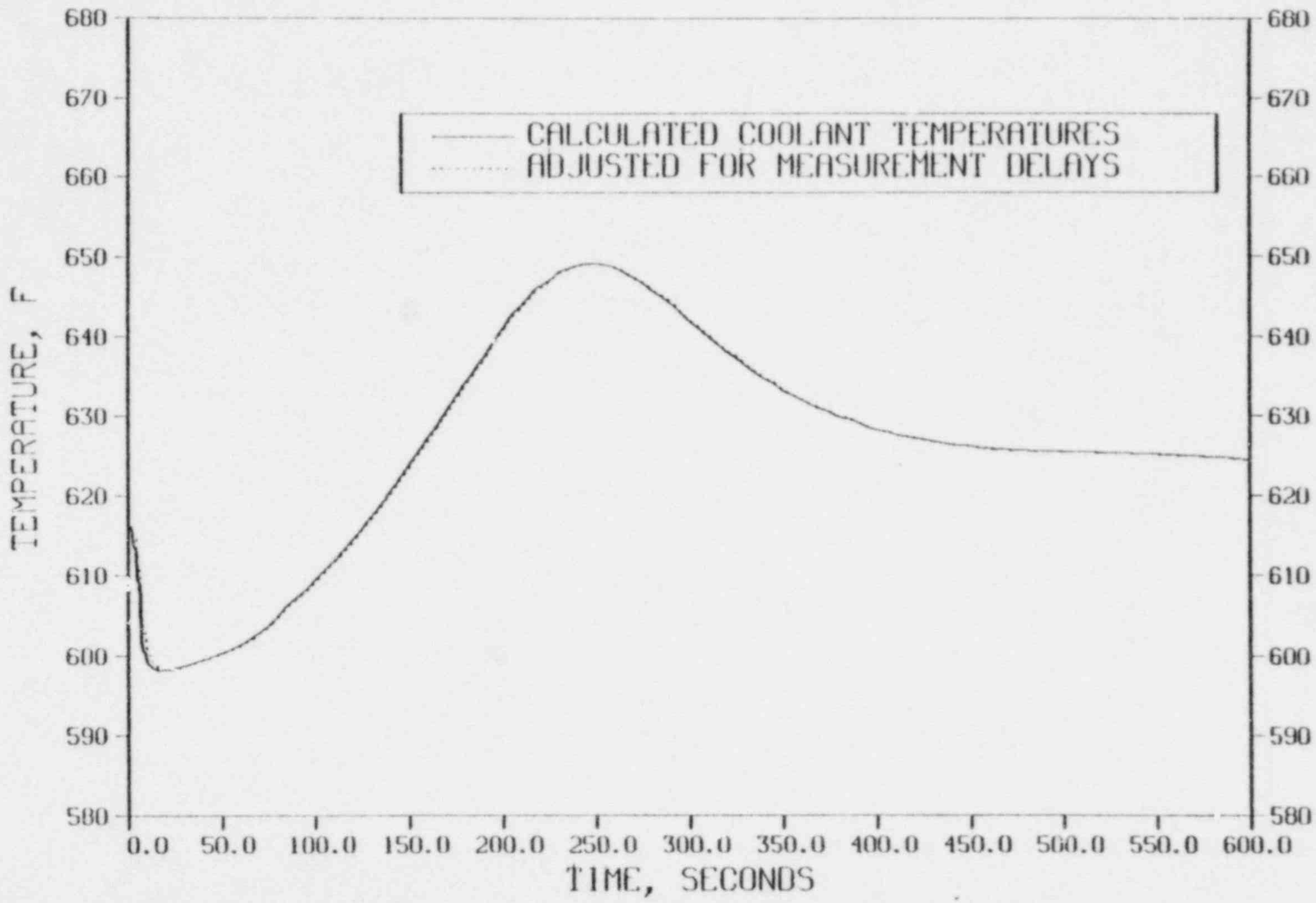


Figure 4.5 Calculated Row 2 FOTA Top of Fuel Coolant Temperatures for T/C TX1036 on Pin 9,4

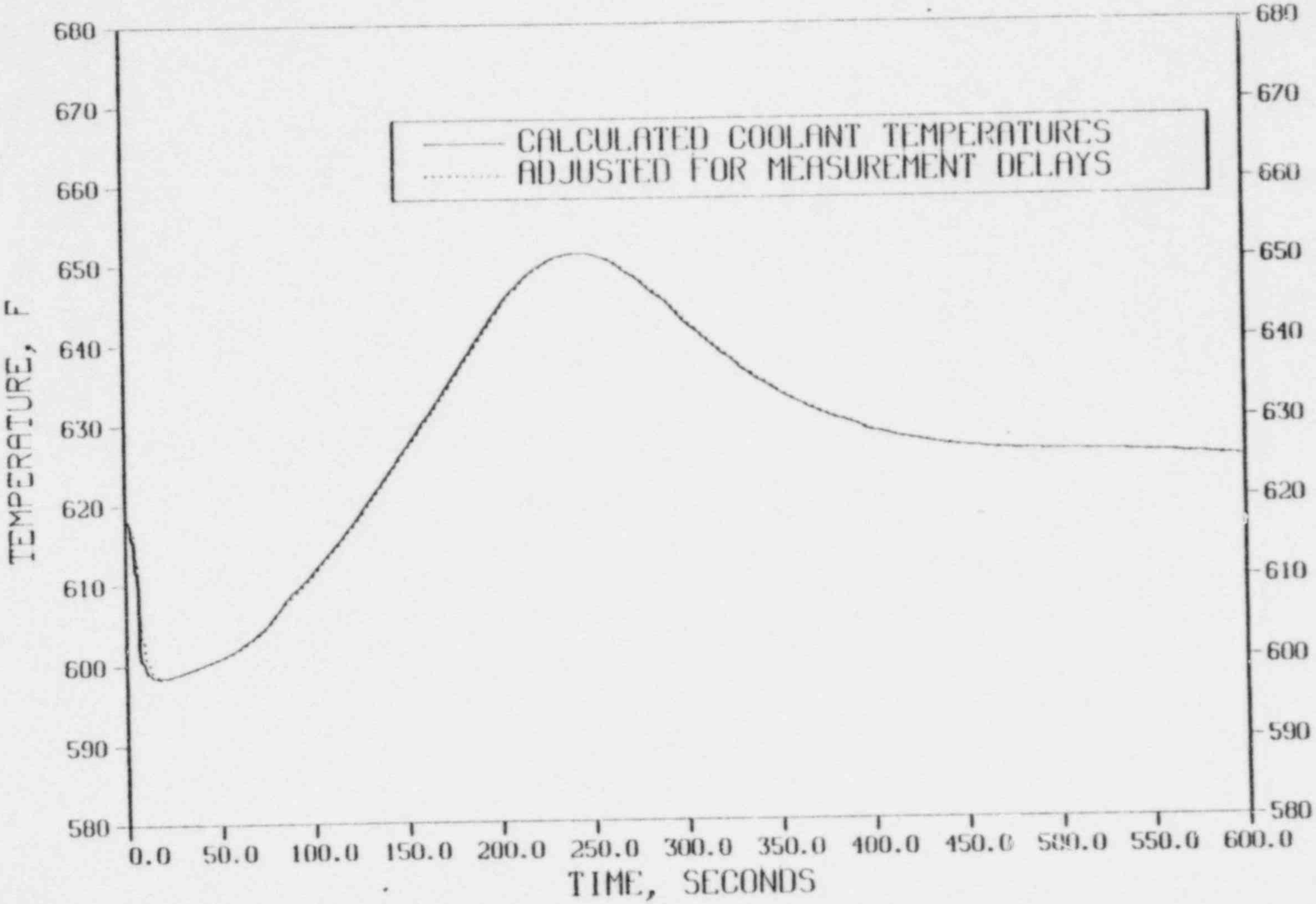


Figure 4.6 Calculated Row 2 FOTA Top of Fuel Coolant Temperatures for T/C TX1016 on Pin 8,8

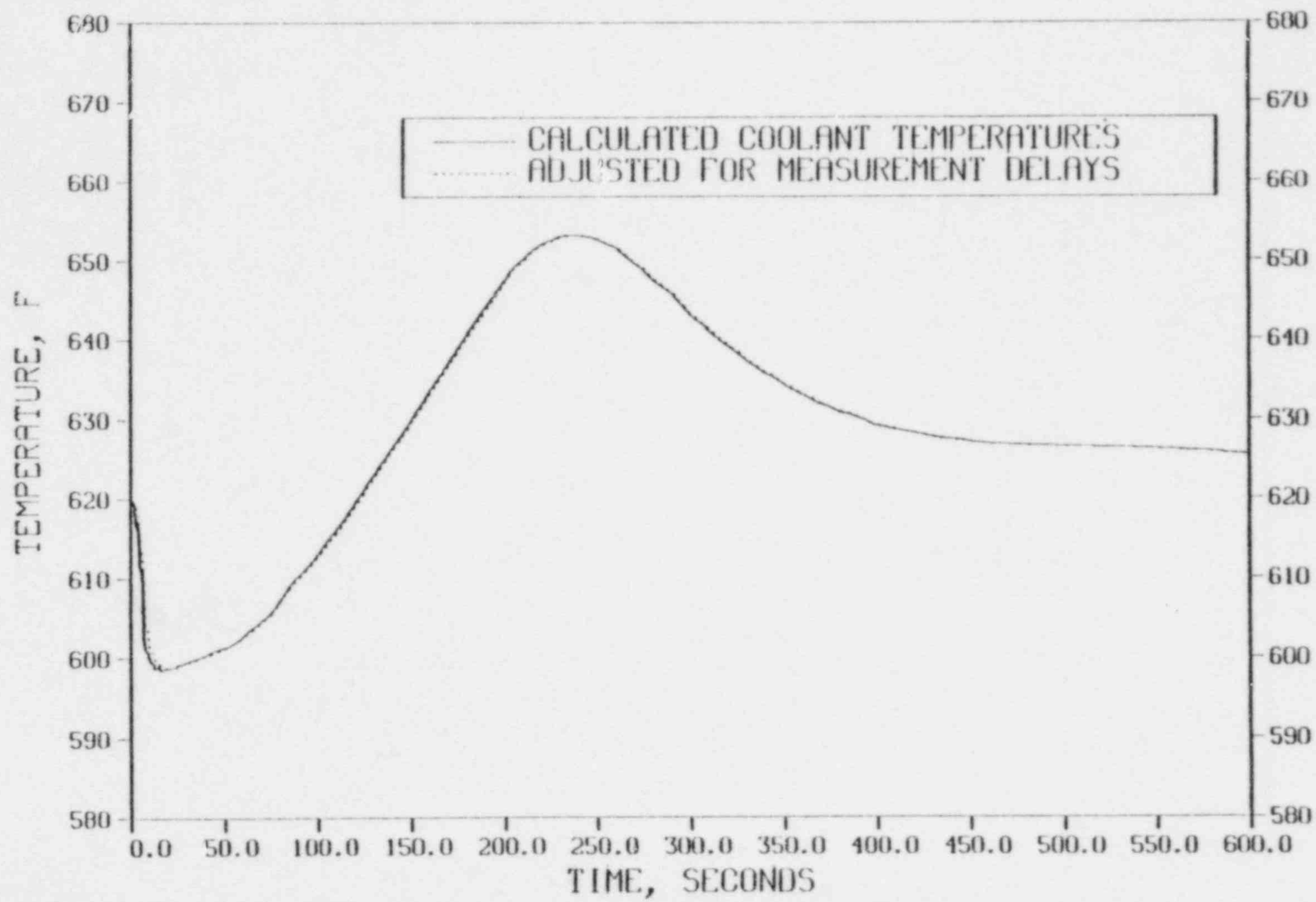


Figure 4.7 Calculated Row 2 FOTA Top of Fuel Coolant Temperatures for T/C TX1012 on Pin 9,14

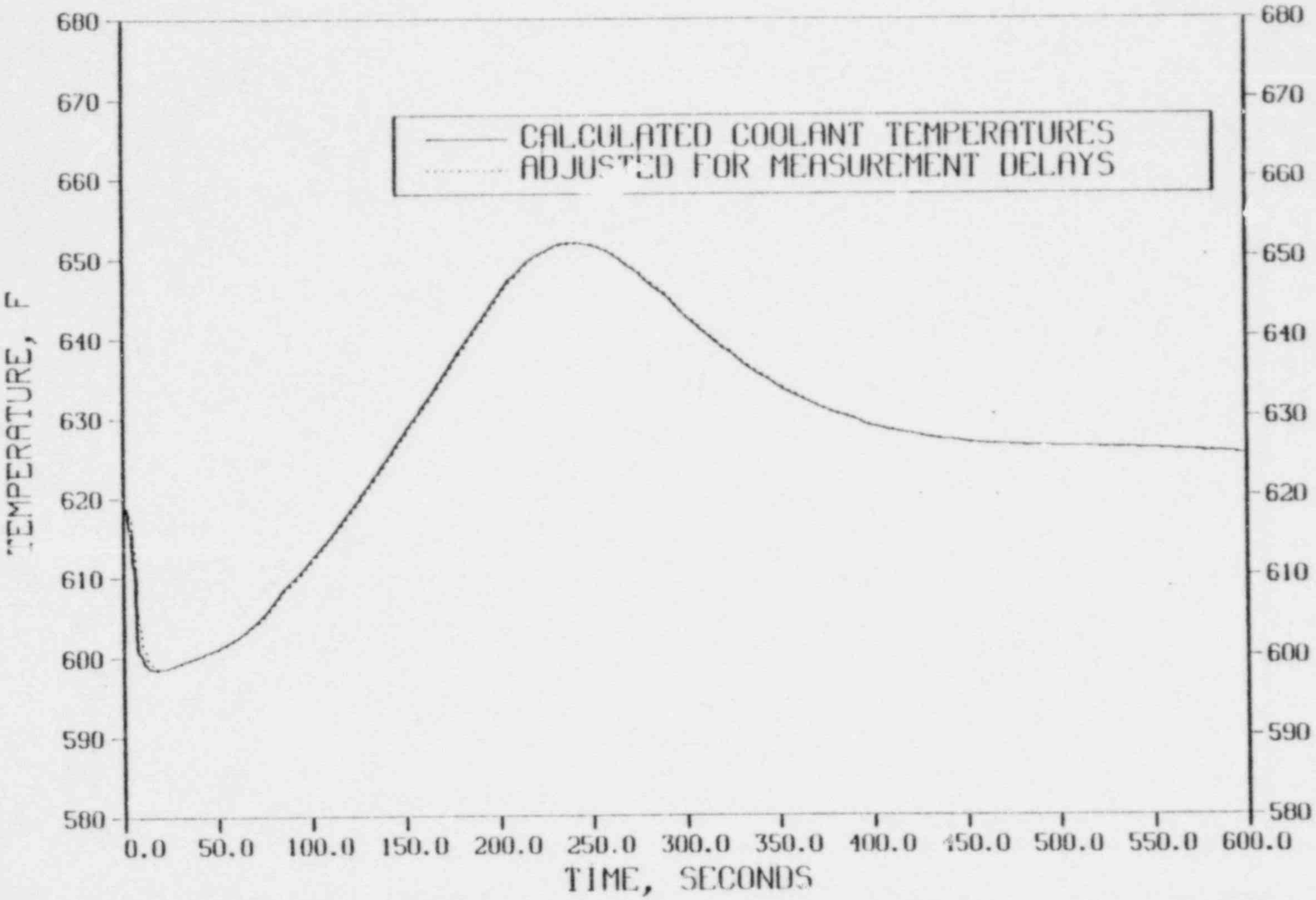


Figure 4.8 Calculated Row 2 FOTA Top of Fuel Coolant Temperatures for T/C TX1008 on Pin 9,17

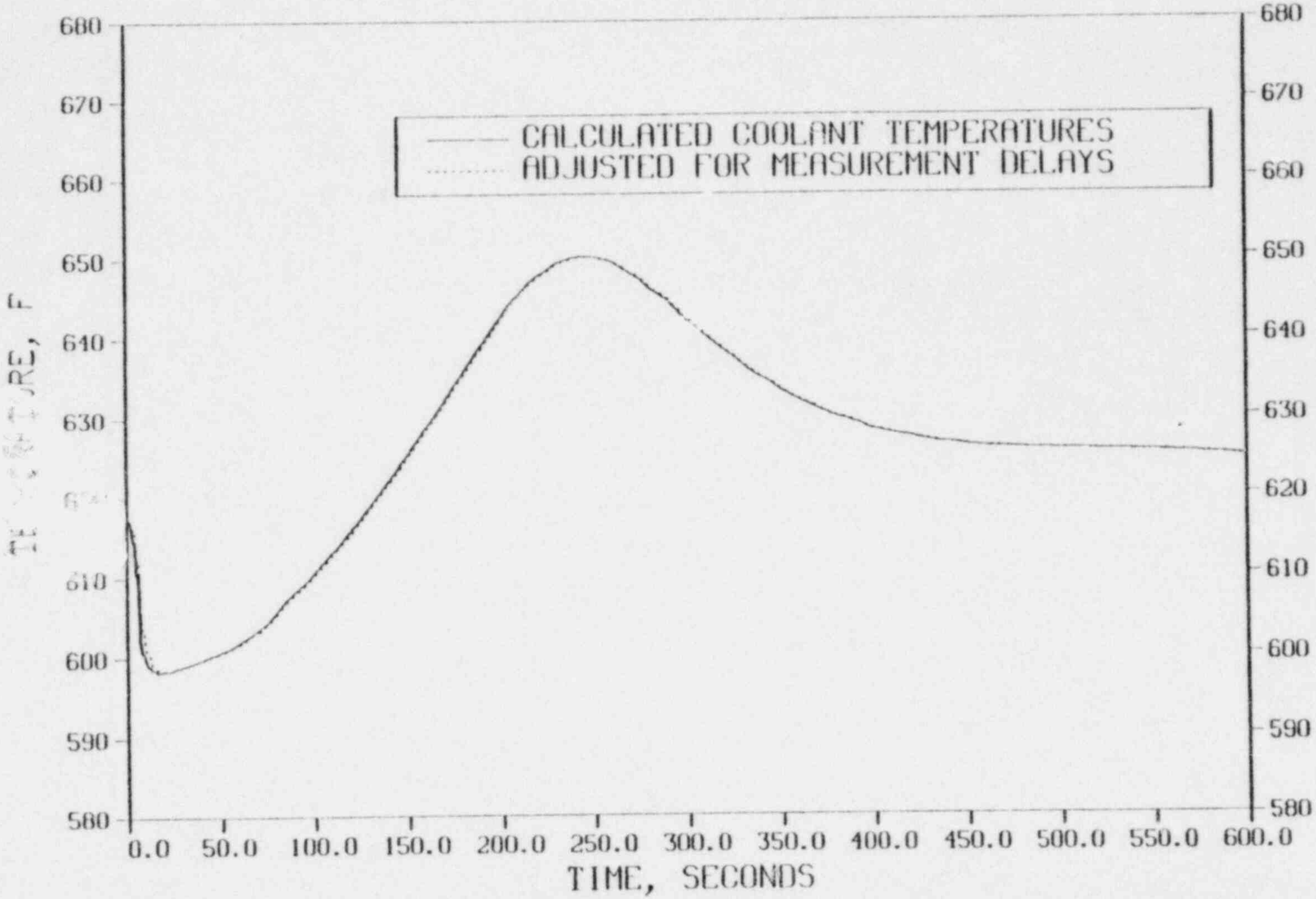


Figure 4.9 Calculated Row 2 FOTA Top of Pins Coolant Temperatures for T/C TX1031 or P:n 7,1

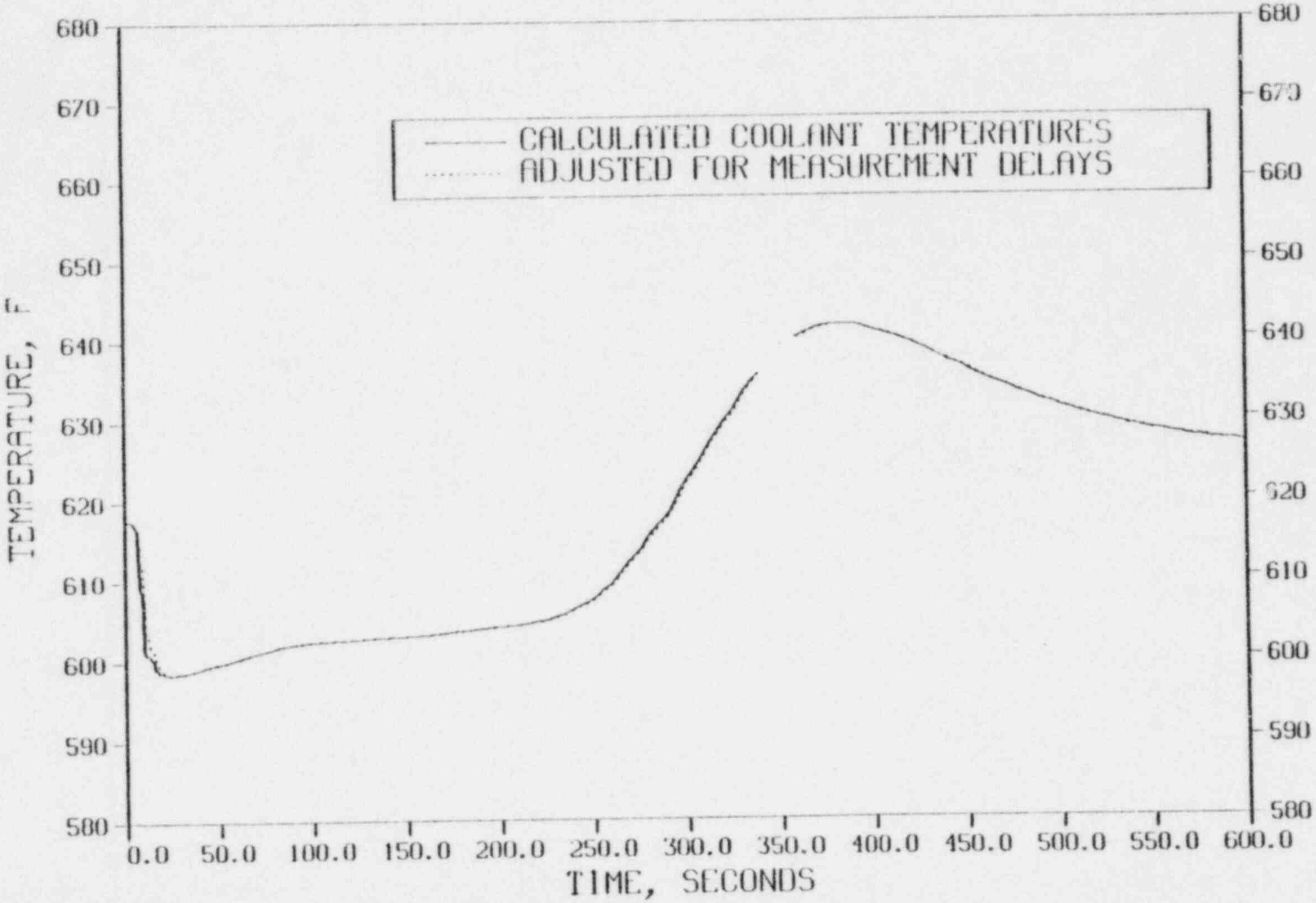


Figure 4.10 Calculated Row 2 FOTA Top of Pins Coolant Temperatures for T/C TX1035 on Pin 9,3

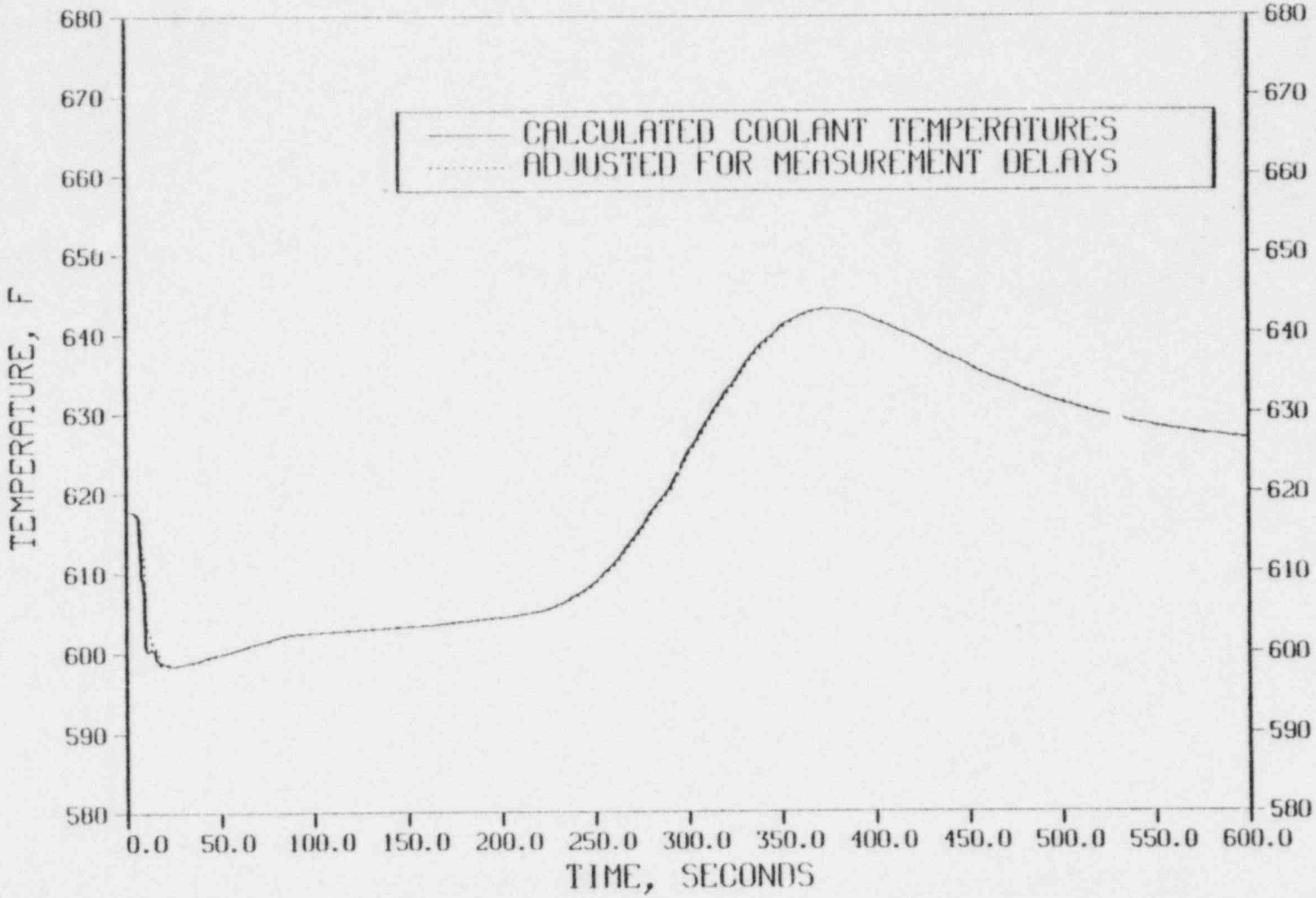


Figure 4.11 Calculated Row 2 FOTA Top of Pins Coolant Temperatures for T/C TX1039 on Pin 9,5

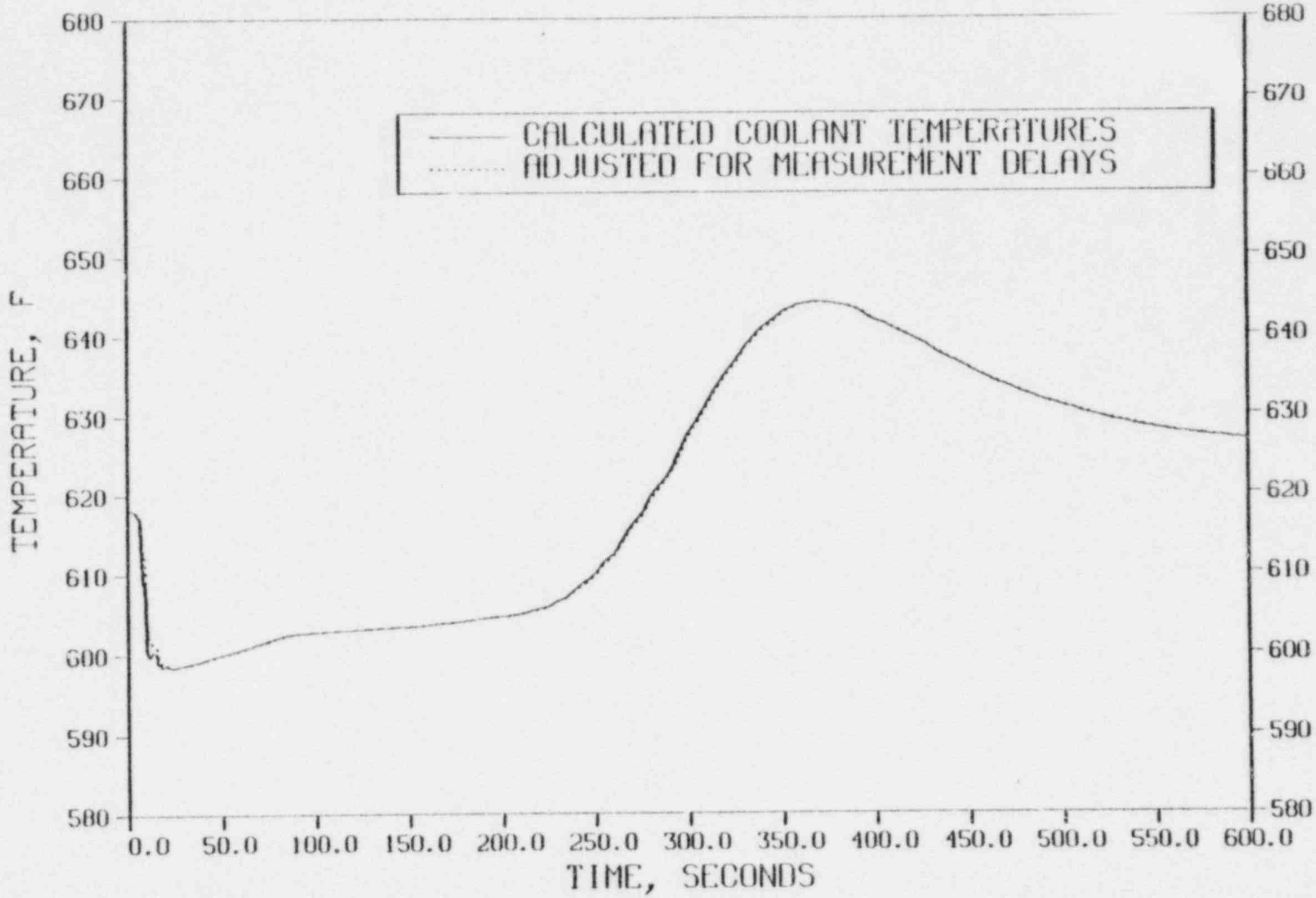


Figure 4.12 Calculated Row 2 FOTA Top of Pins Coolant Temperatures for T/C TX1041 on Pin 10,8

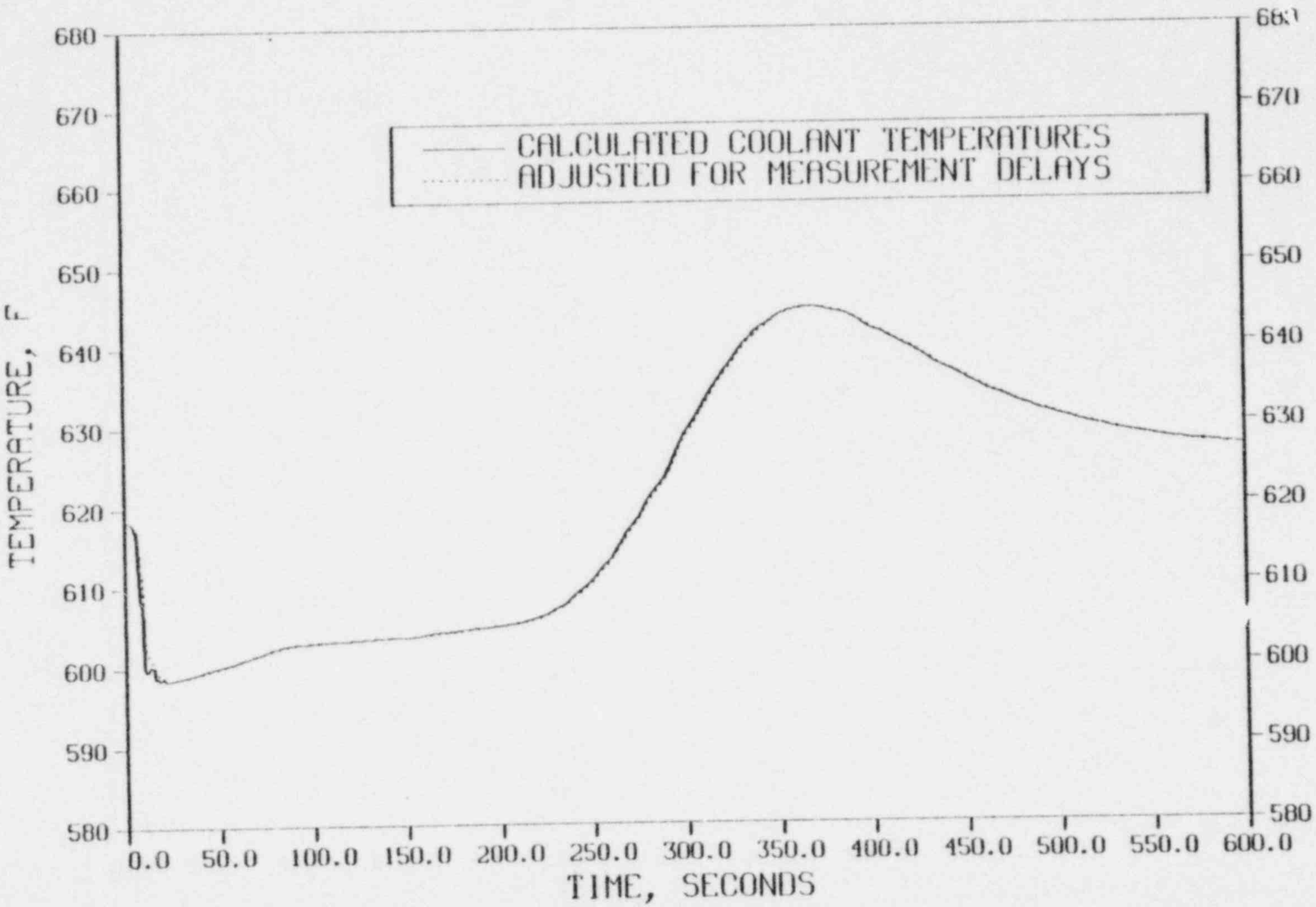


Figure 4.13 Calculated Row 2 FOTA Top of Pins Coolant Temperatures for T/C TX1010 on Pin 9,13

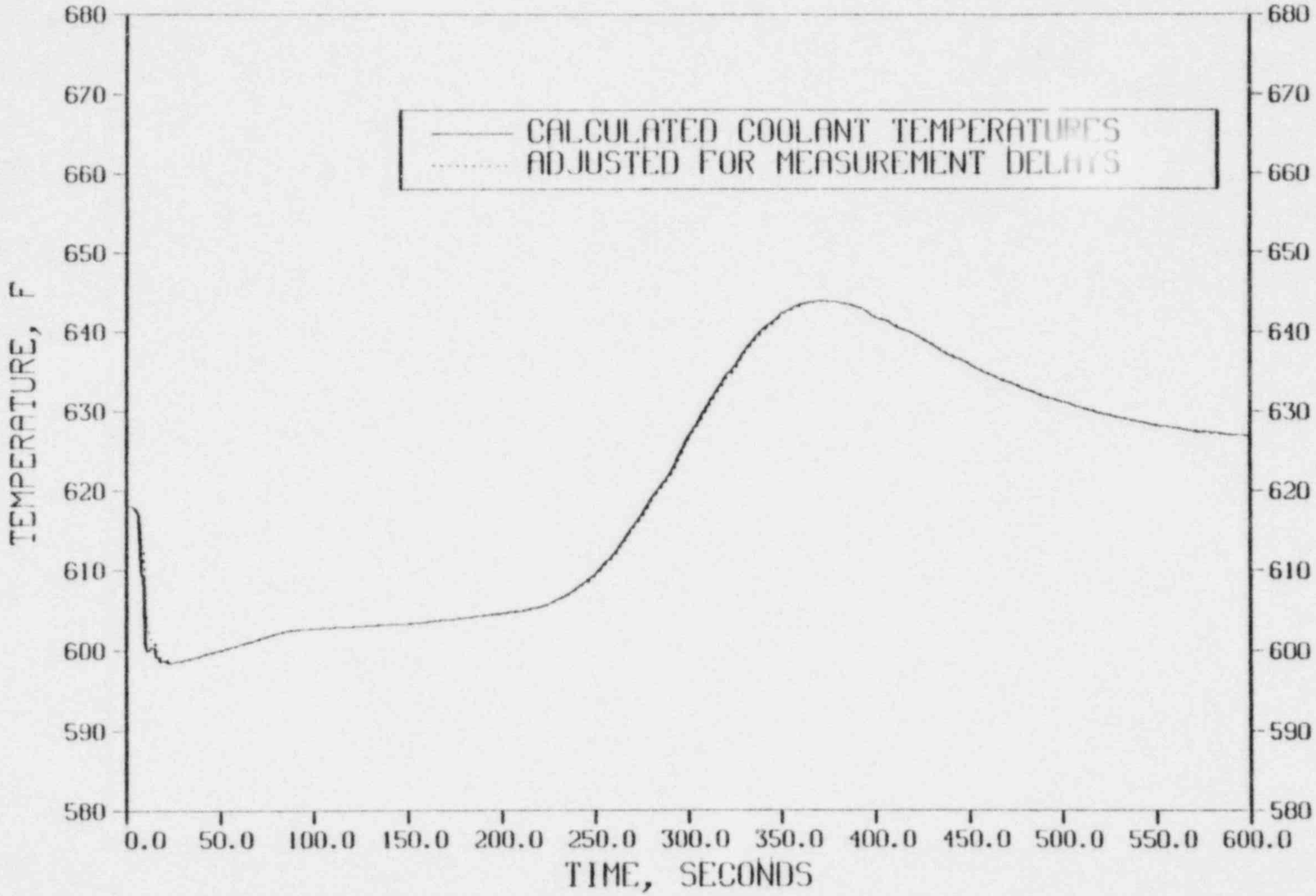


Figure 4.14 Calculated Row 2 FOTA Instrument Stalk Coolant Temperatures at T/C Location

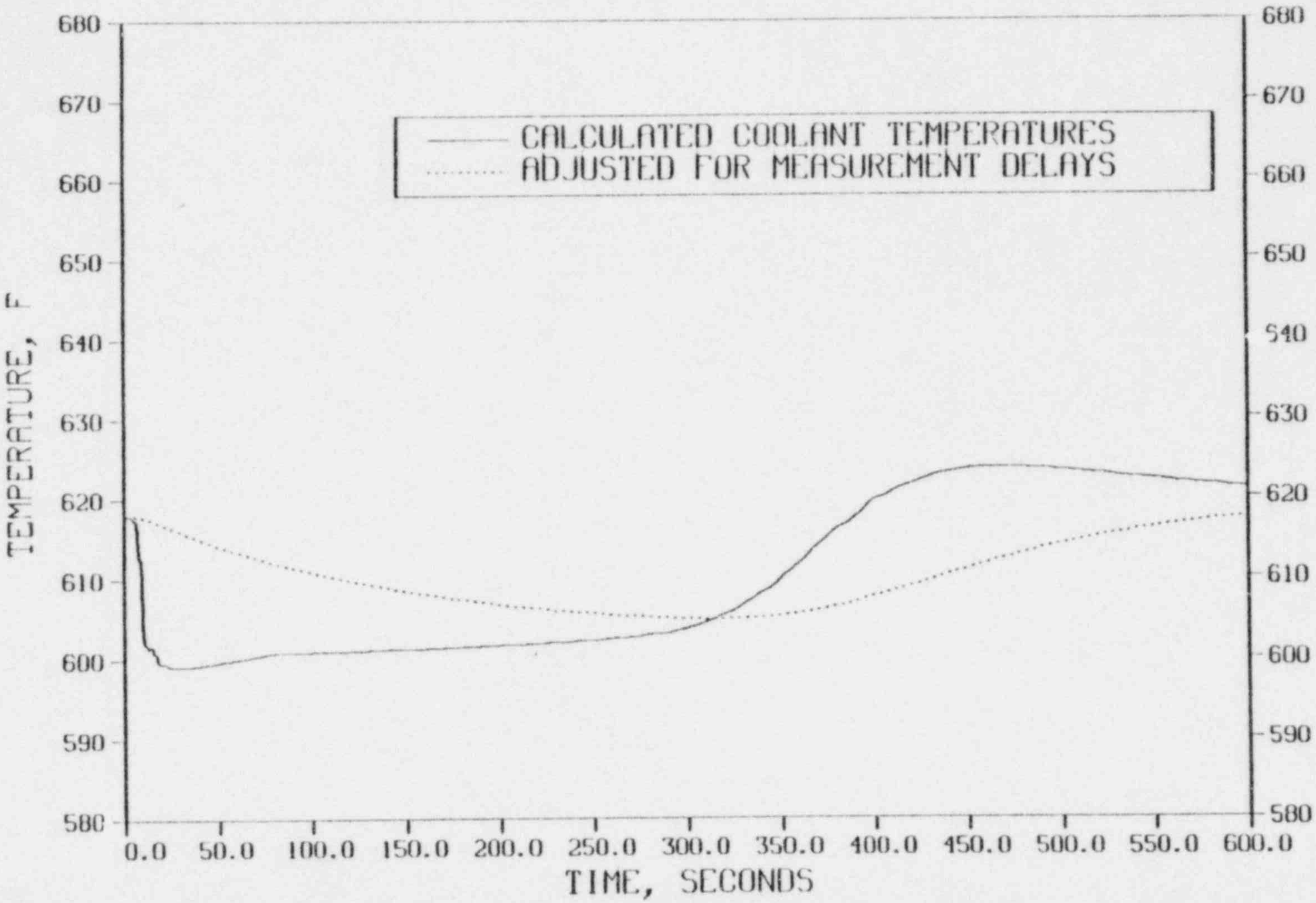


Figure 4.15 Calculated Row 2 FOTA Average Coolant Temperatures at Top of Fuel

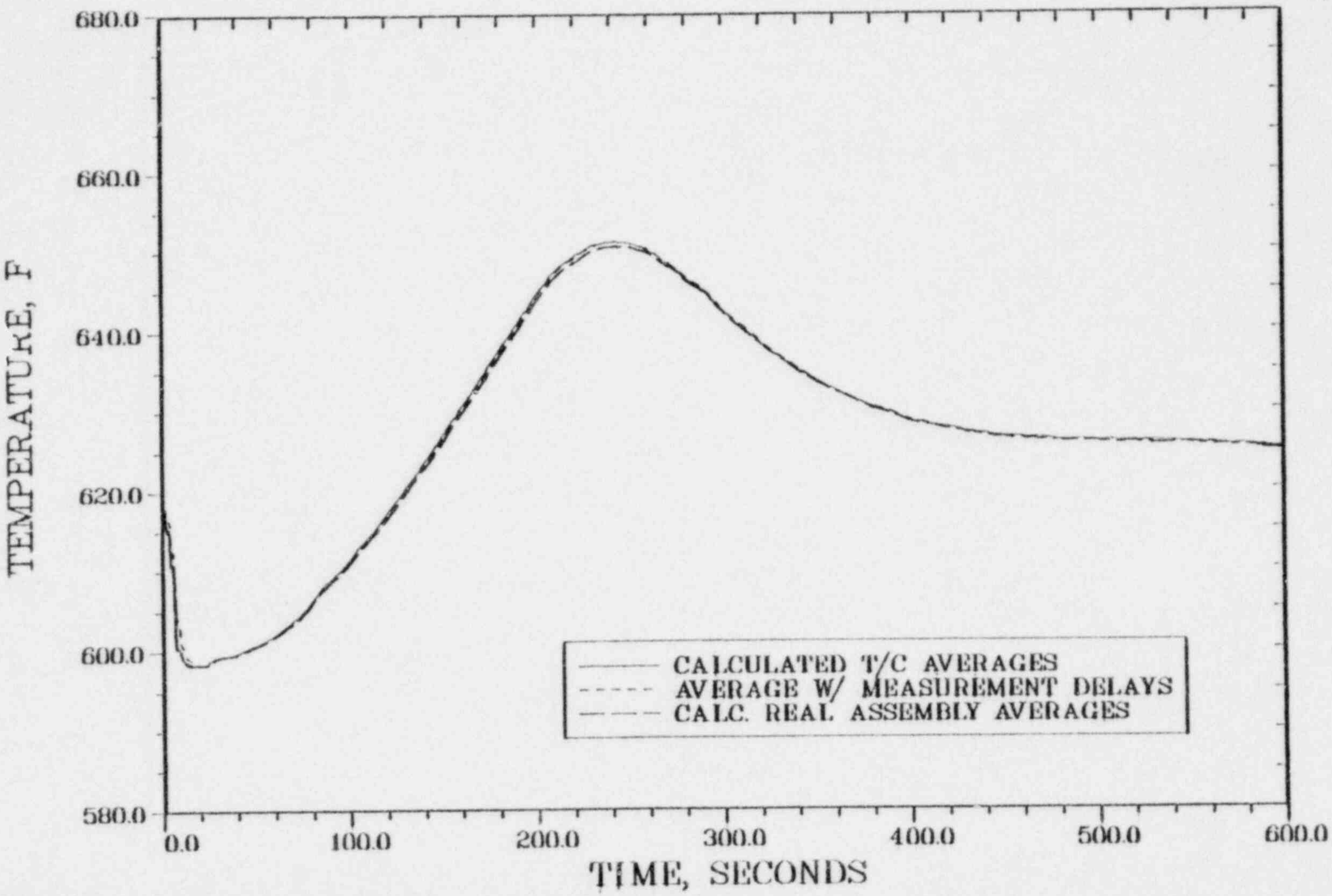


Figure 4.16 Calculated Row 2 FOTA Average Coolant Temperatures at Top of Pins

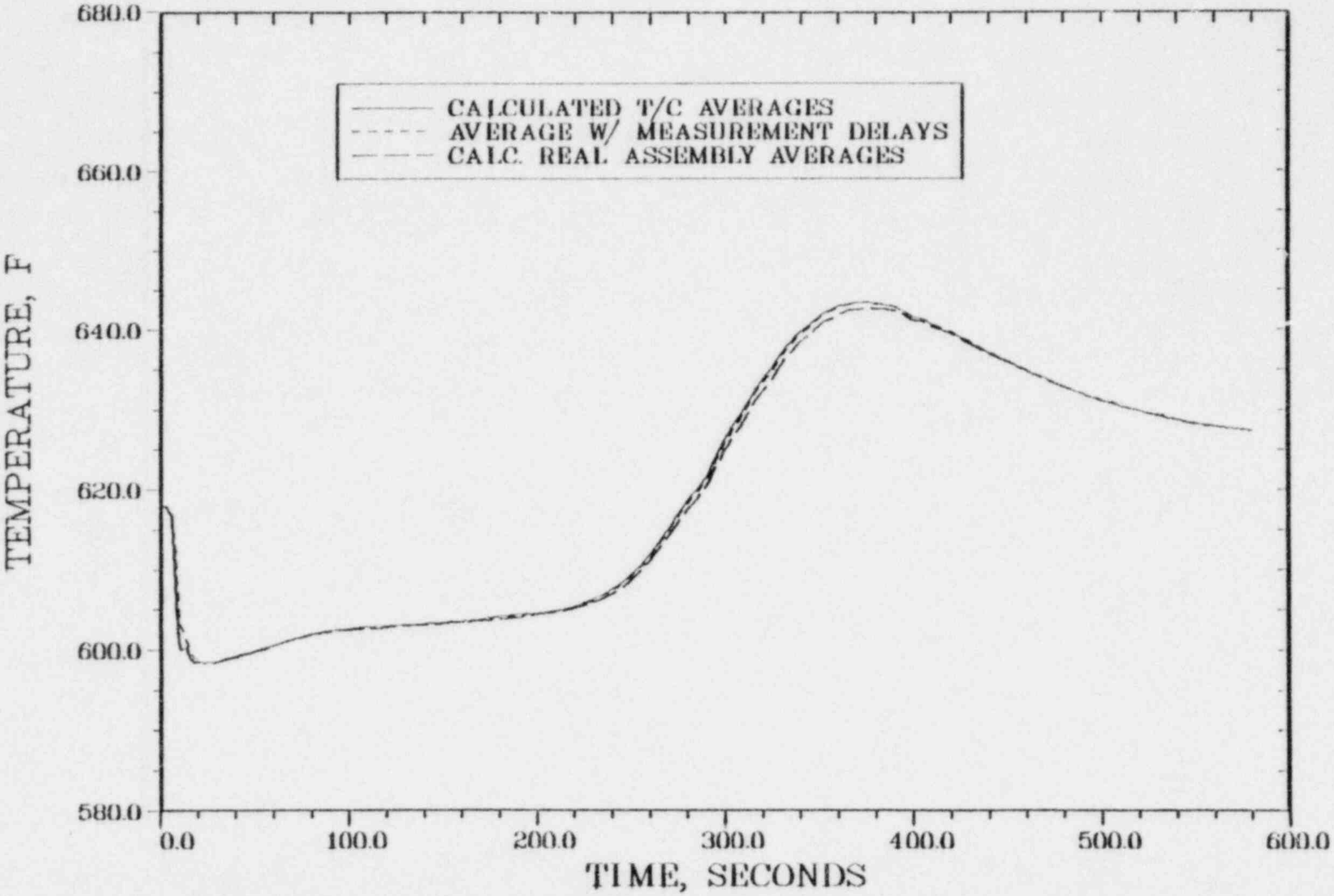


Figure 4.17 Calculated Row 2 FOTA Normalized Assembly Coolant Flow Rates

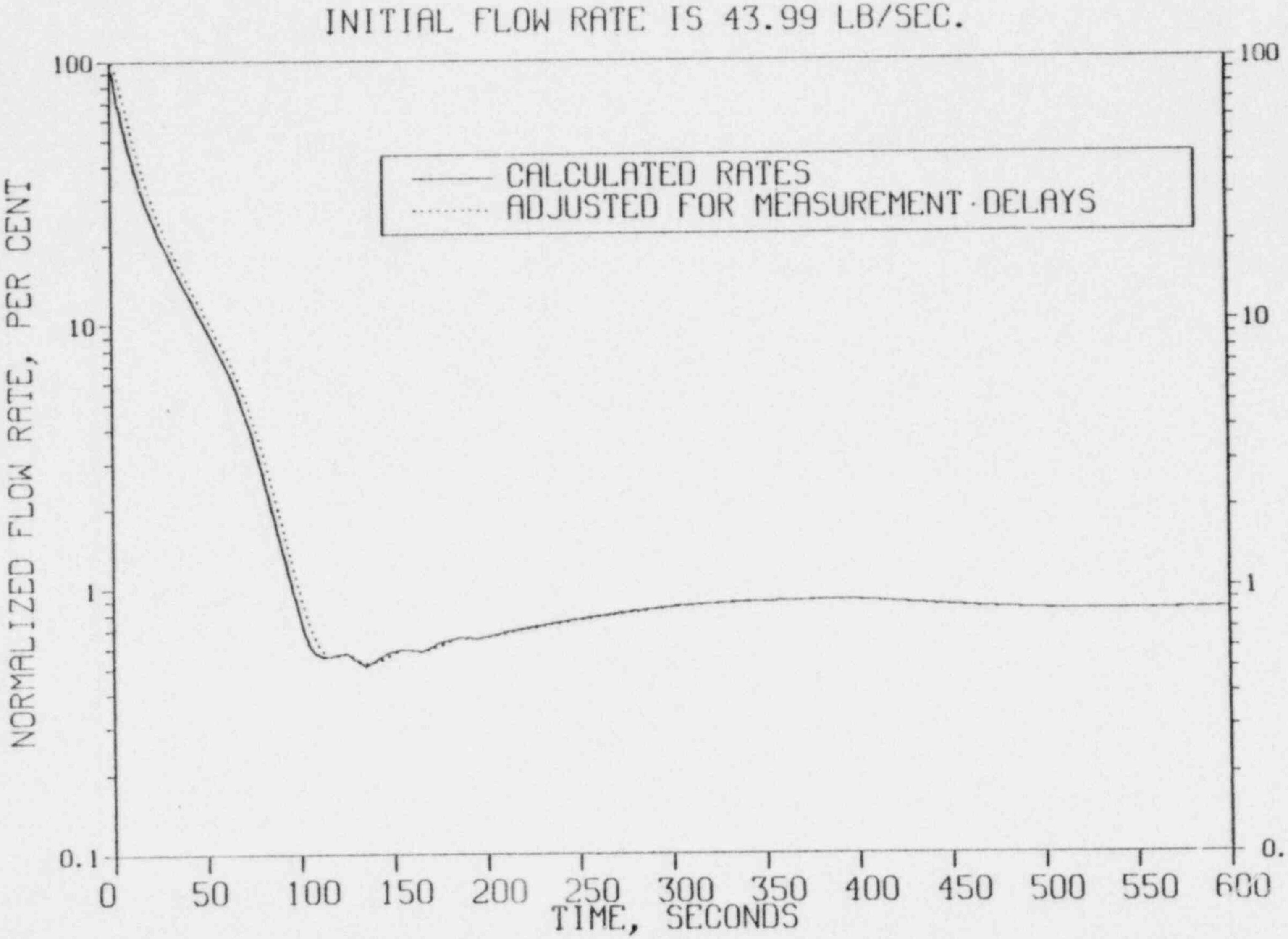


Figure 4.18 Calculated Row 6 FOTA Core Midplane Coolant Temperatures for T/C TX9J02 on Pin 16,10

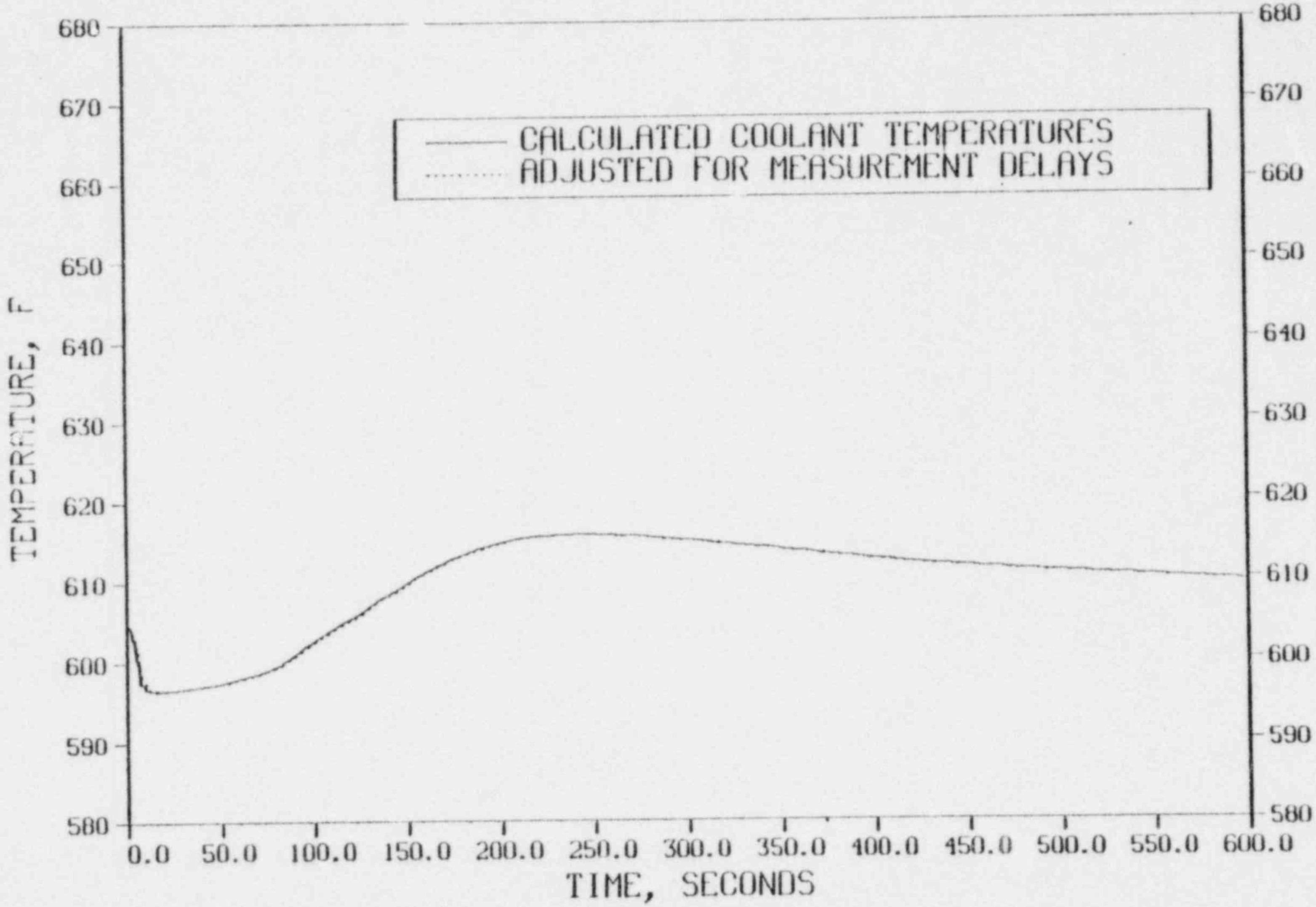


Figure 4.19 Calculated Row 6 FOTA Core Midplant Coolant Temperatures for T/C TX9039 on Pin 8,8

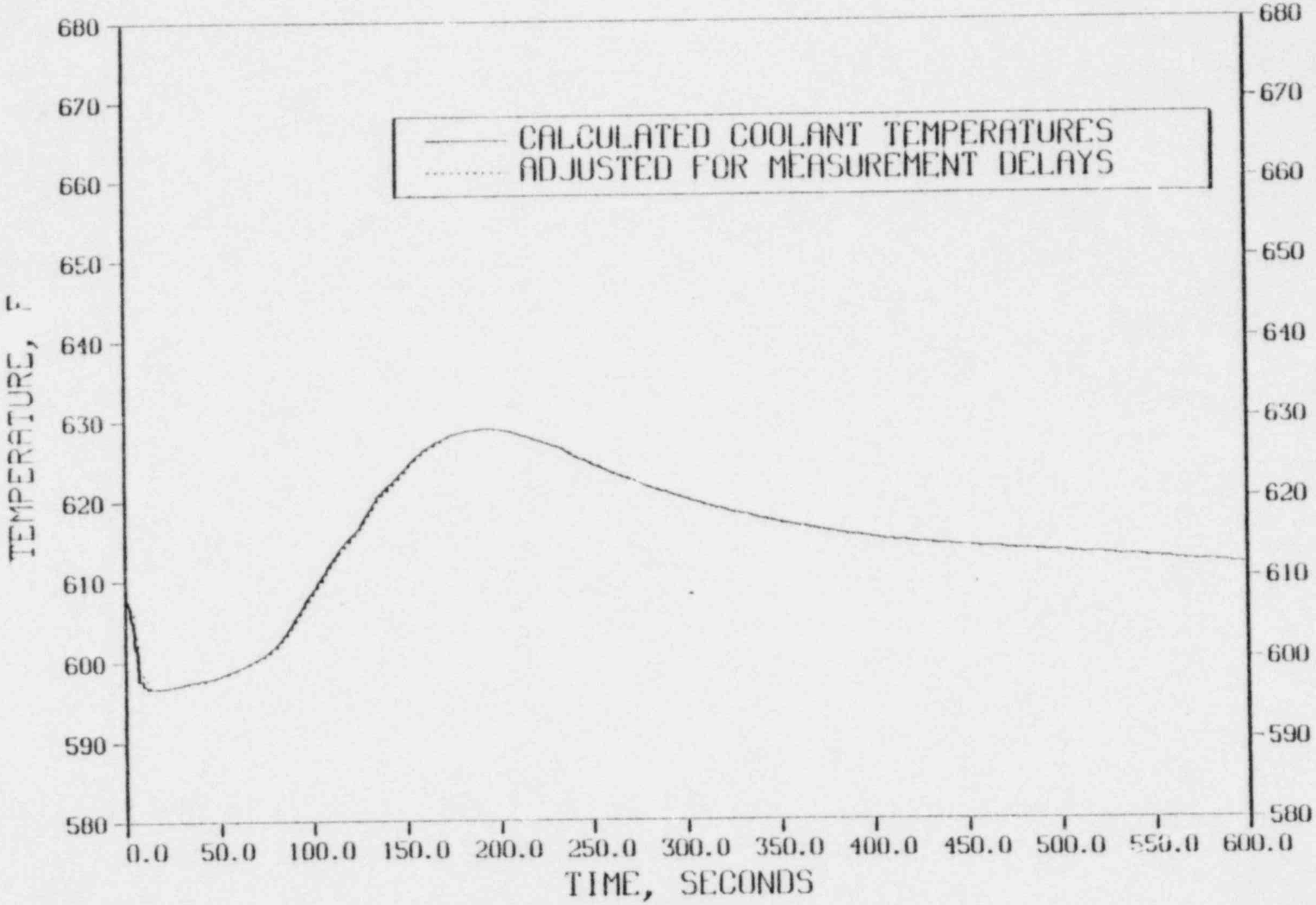


Figure 4.20 Calculated Row 6 FOTA Core Midplane Coolant Temperatures for T/C TX9022 on Pin 2,1

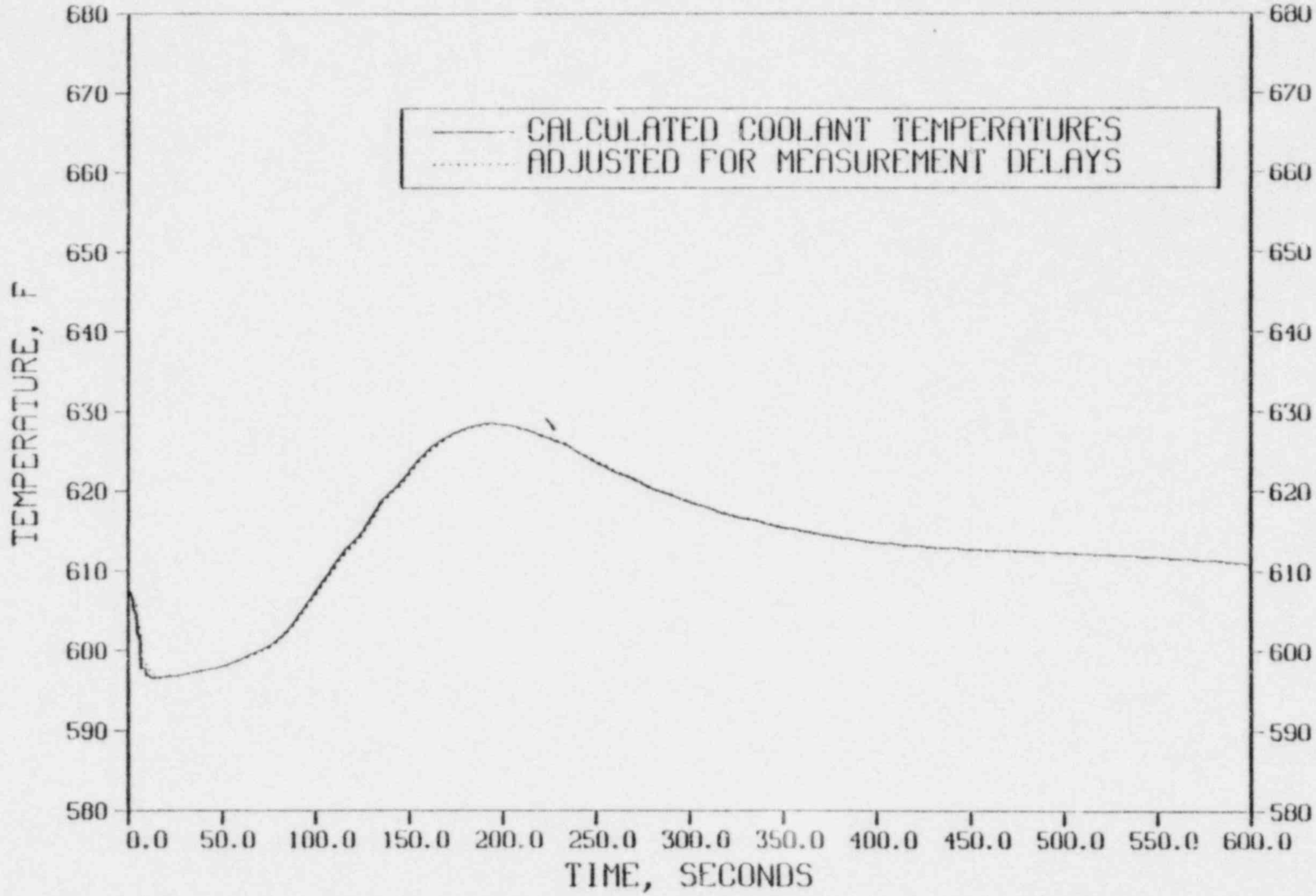


Figure 4.21 Calculated Row 6 FOTA Top of Fuel Coolant Temperatures for T/C TX9025 on Pin 1,1

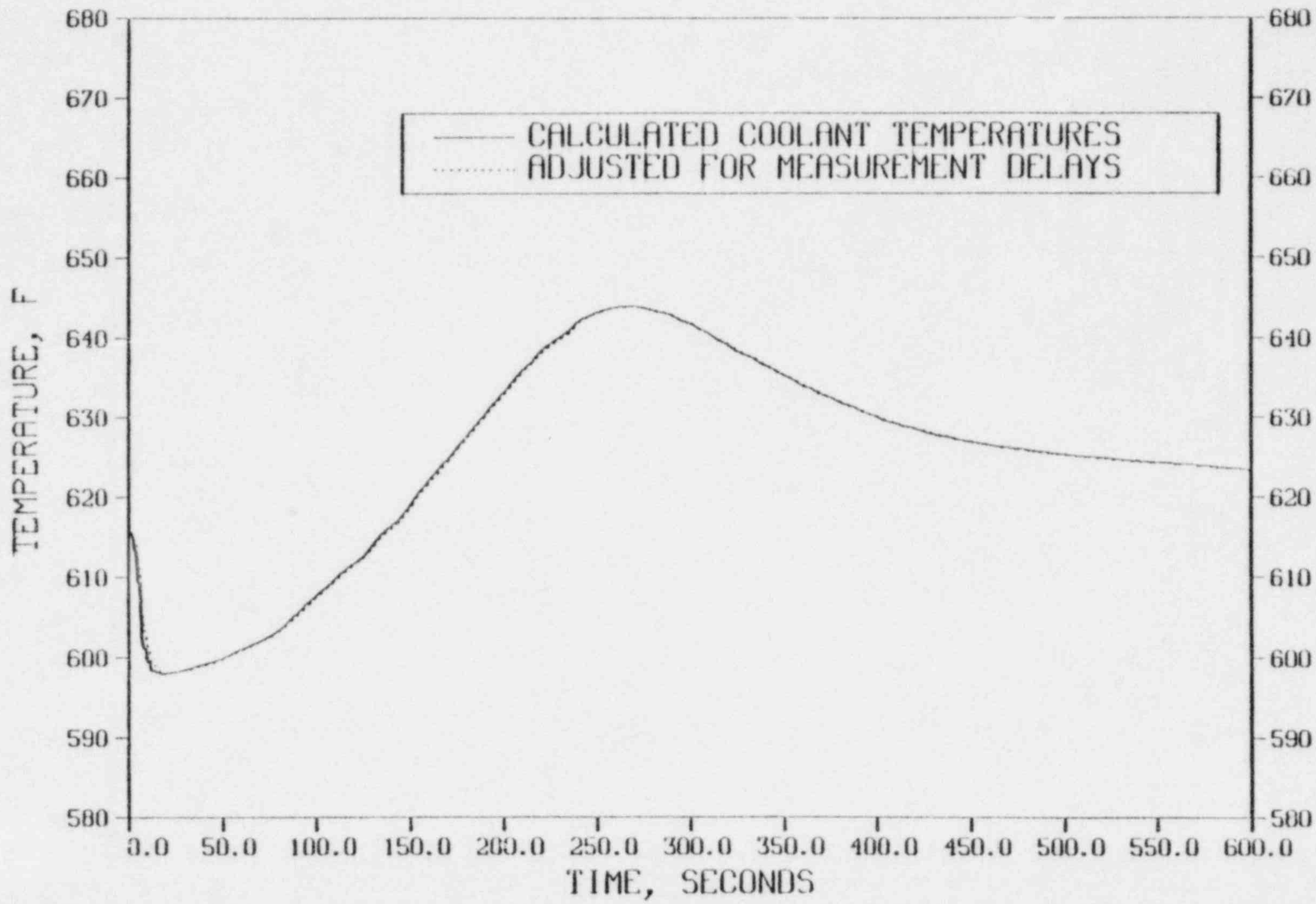


Figure 4.22 Calculated Row 6 FOTA Top of Fuel Coolant Temperatures for T/C TX9026 on Pin 2,2

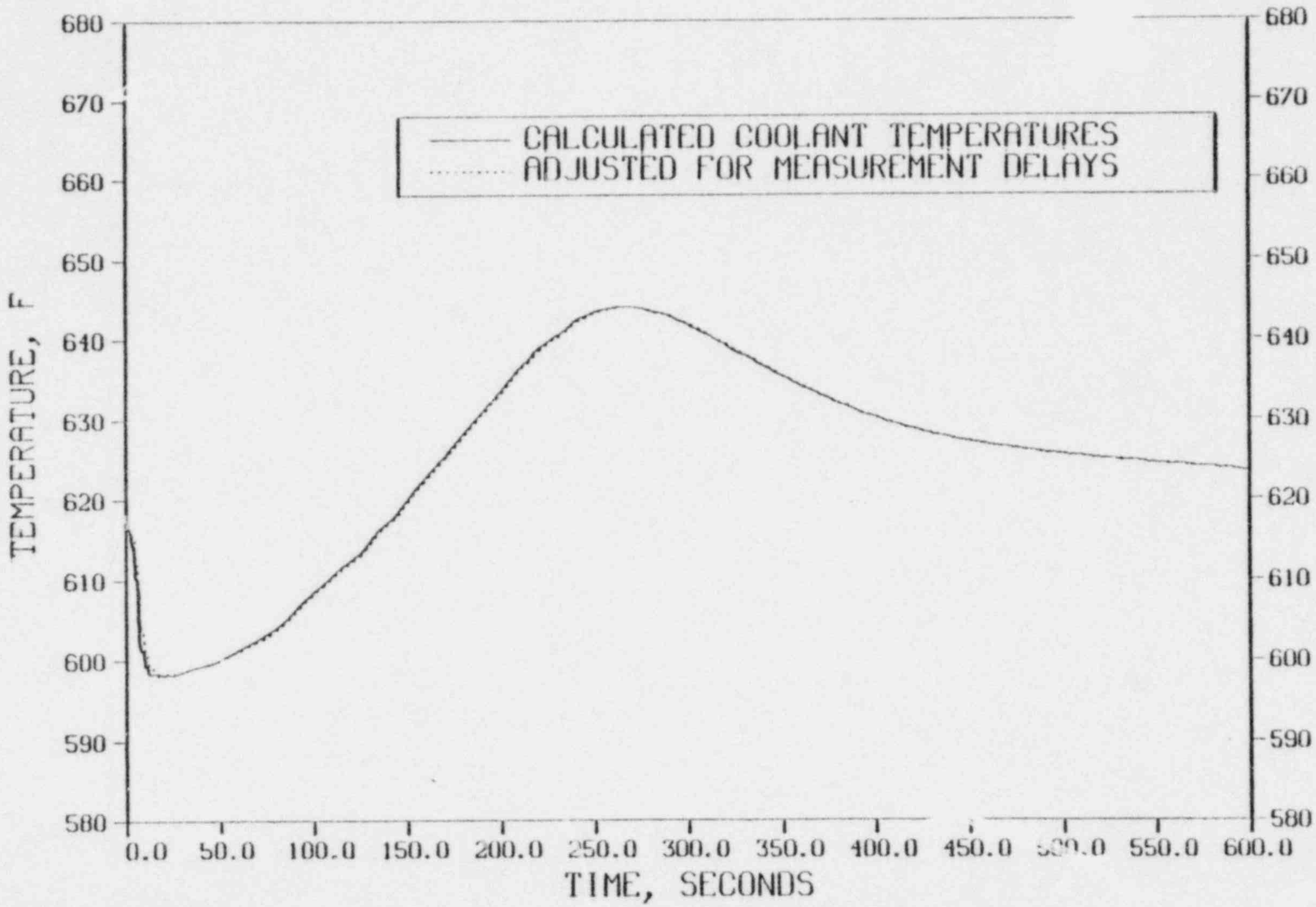


Figure 4.23 Calculated Row 6 FOTA Top of Fuel Coolant Temperatures for T/C TX9018 on Pin 4,4

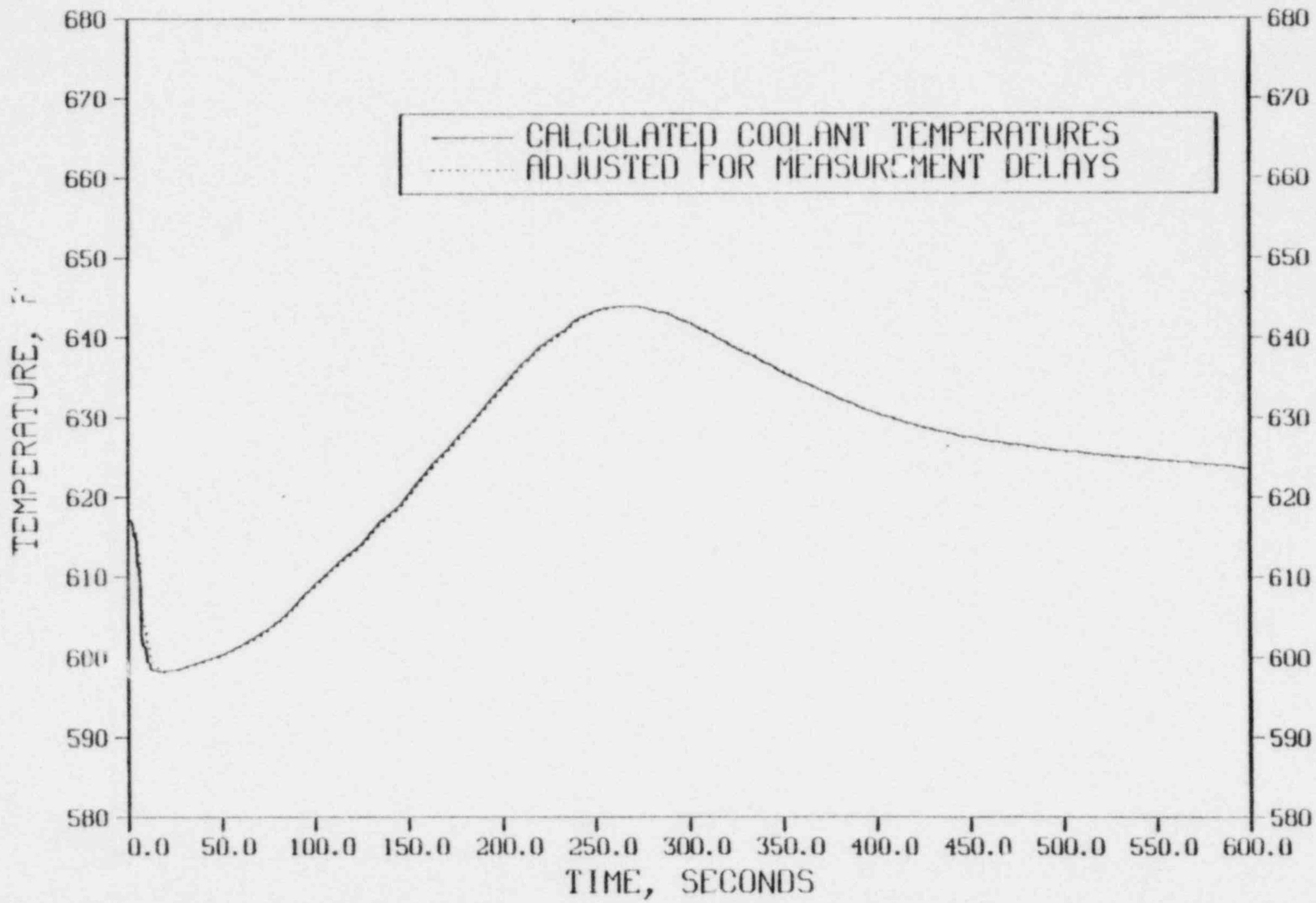


Figure 4.24 Calculated Row 6 FOTA Top of Fuel Coolant Temperatures for T/C TX9009 on Pin 9,9

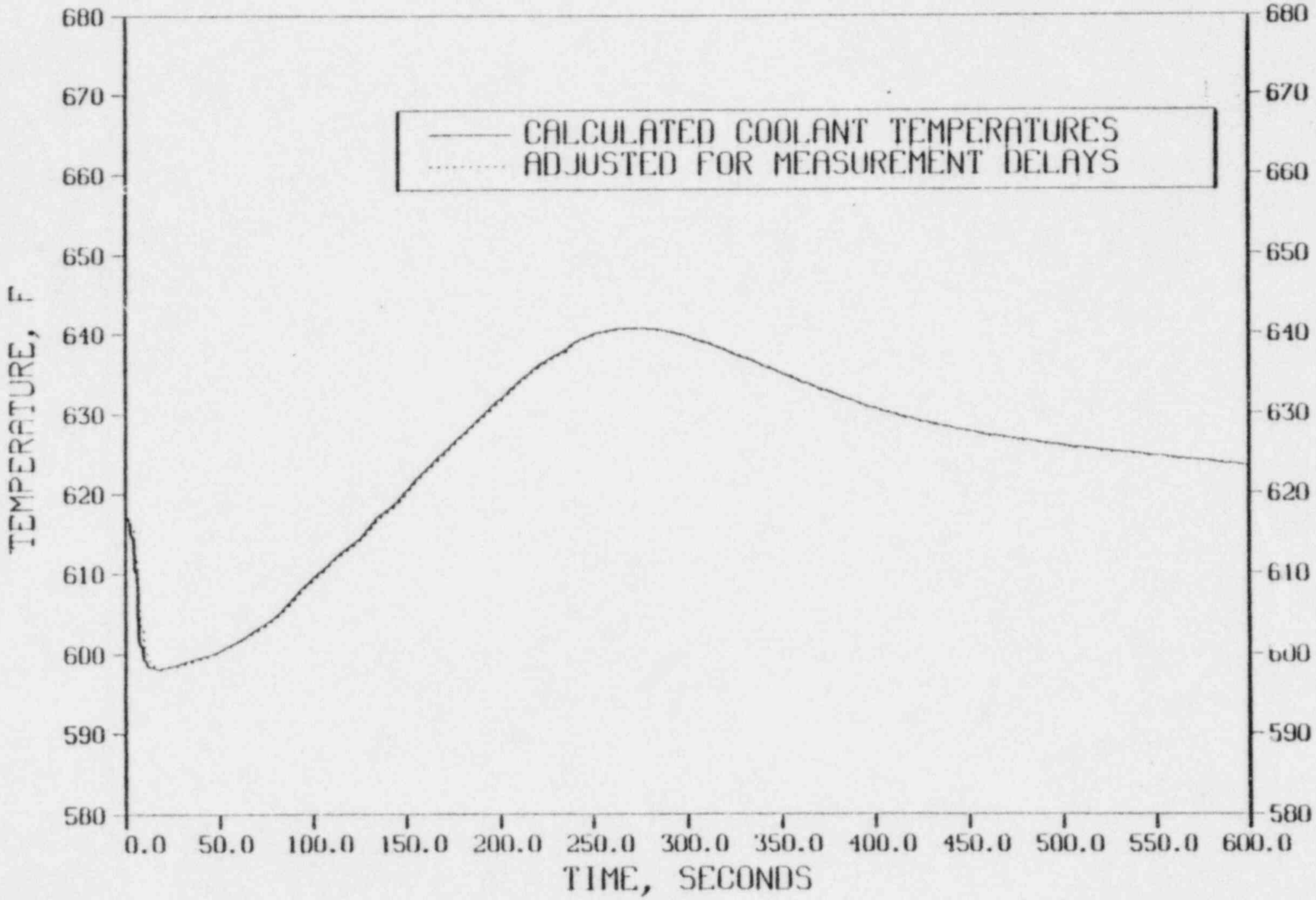


Figure 4.25 Calculated Row 6 FOTA Top of Fuel Coolant Temperatures for T/C TX9004 on Pin 14,9

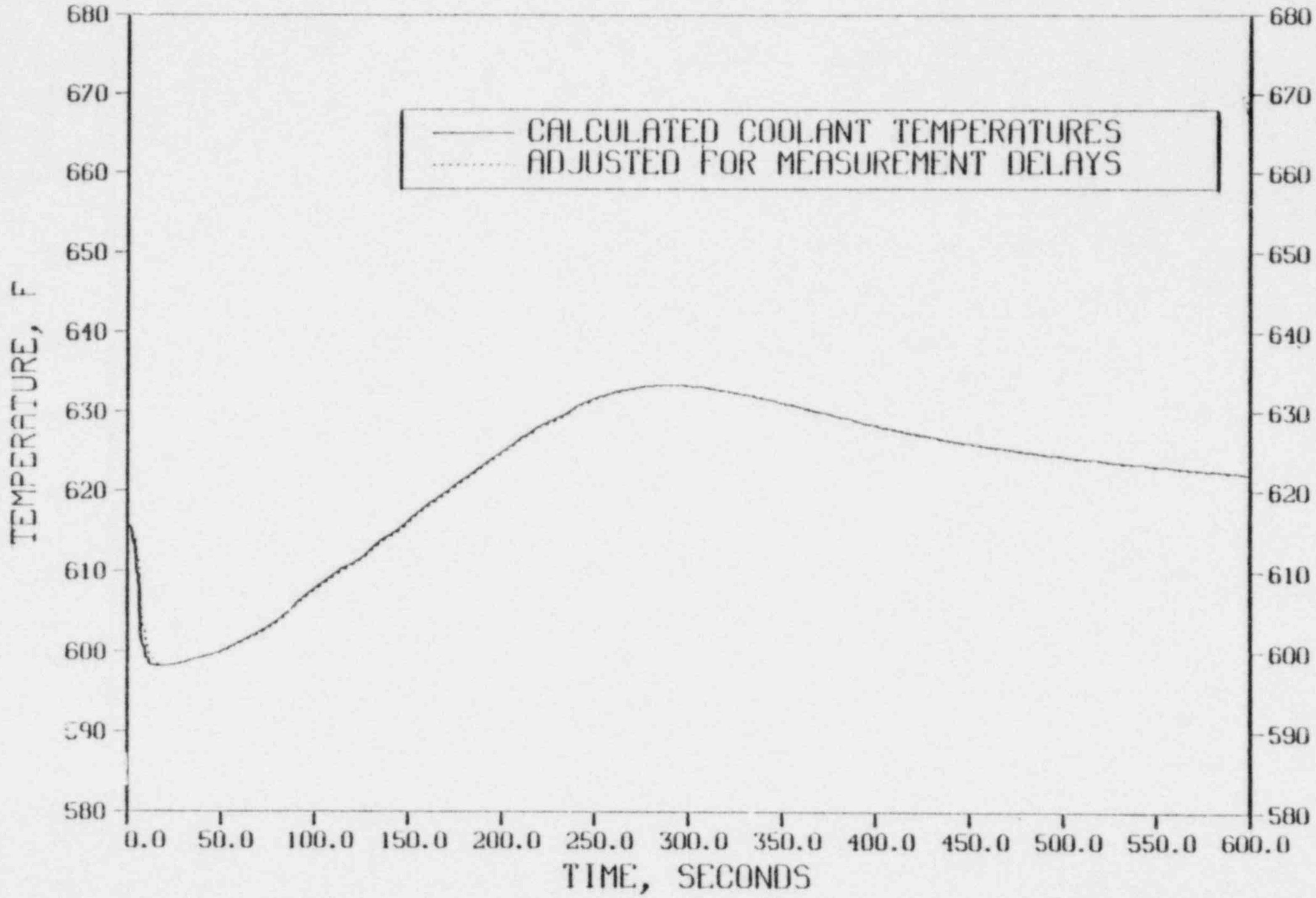


Figure 4.26 Calculated Row 6 FCTA Top of Fuel Coolant Temperatures for T/C TX9003 on Pin 16,9

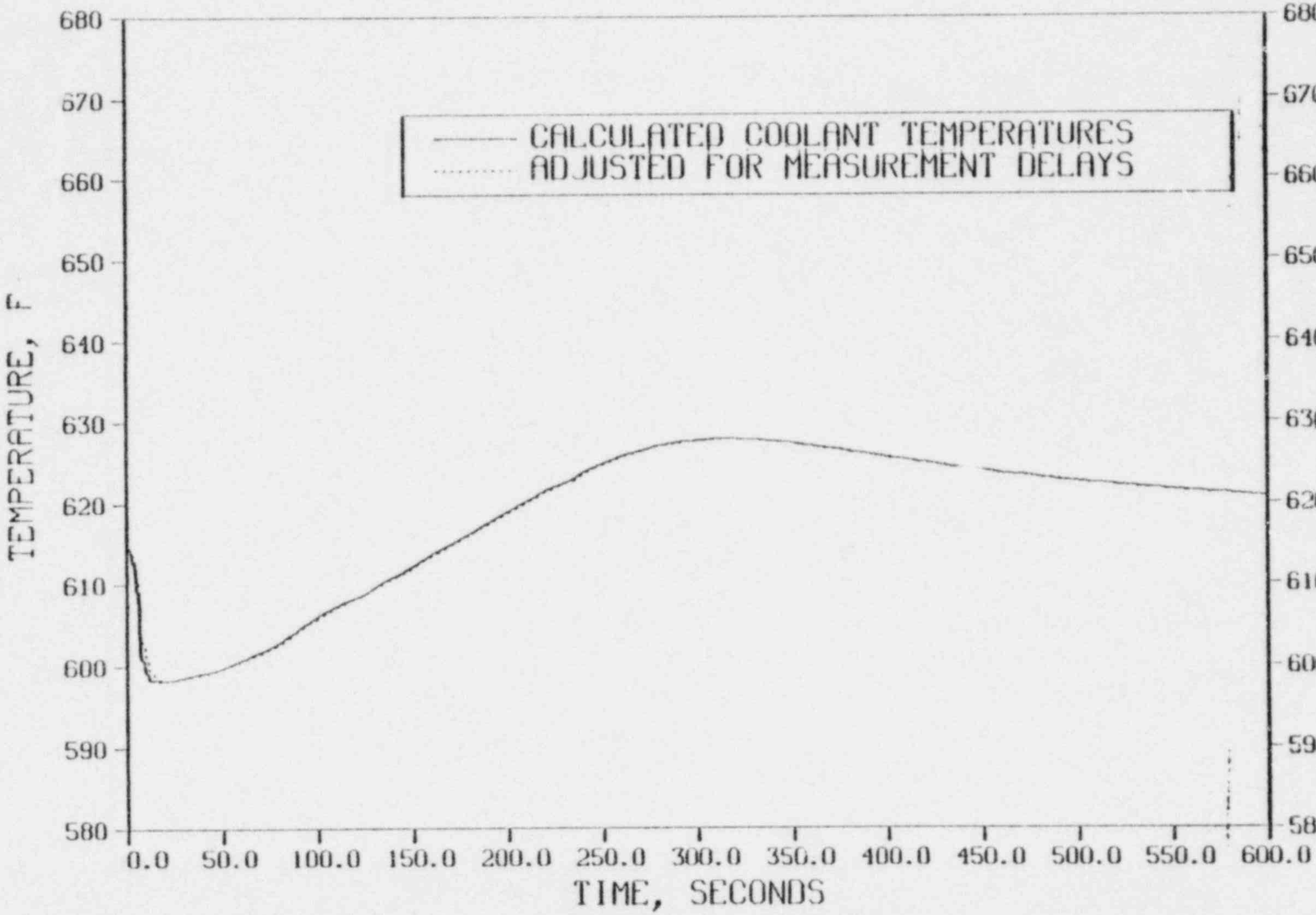


Figure 4.27 Calculated Row 6 FOTA Top of Fuel Coolant Temperatures for T/C TX9001 on Pin 17,9

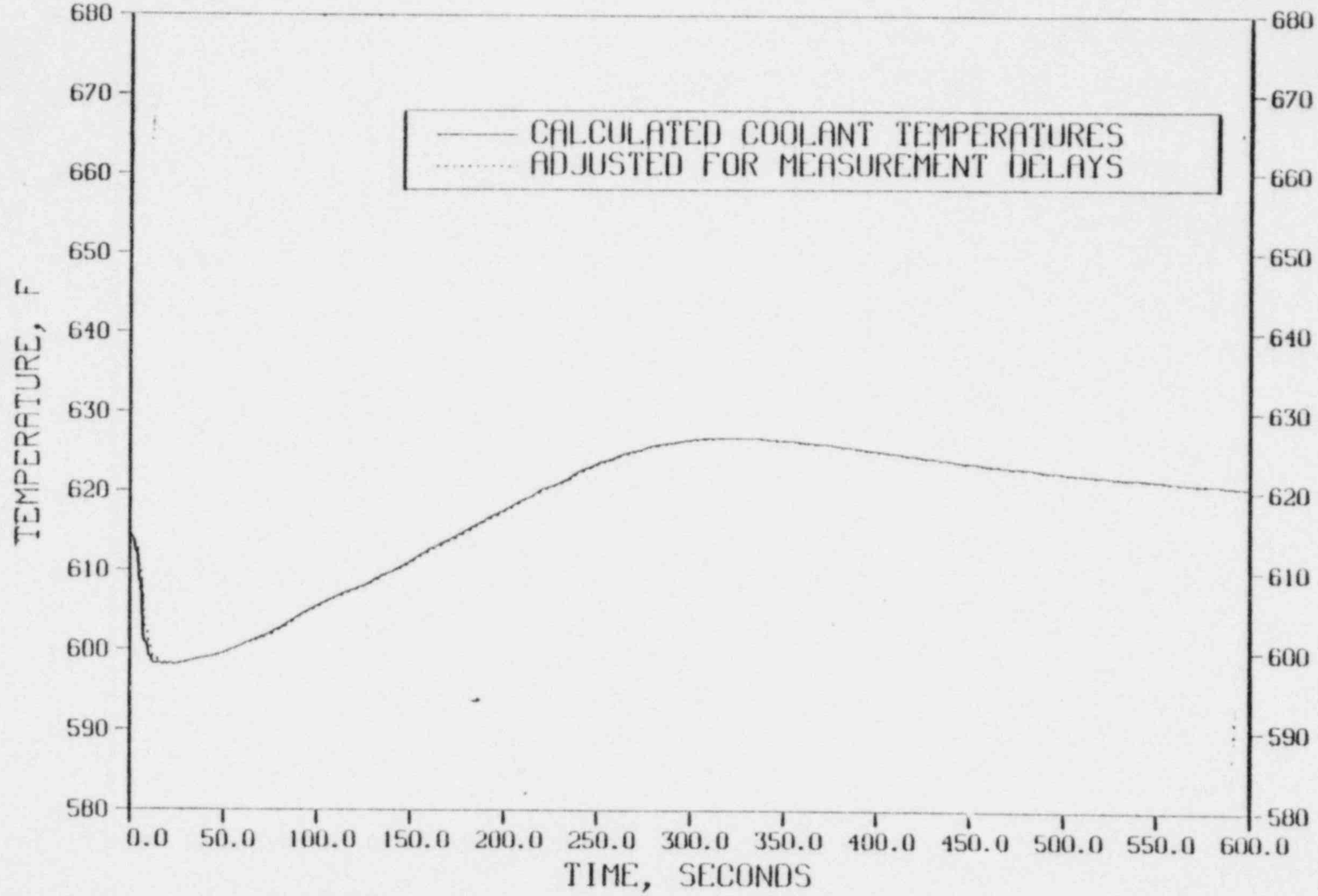


Figure 4.28 Calculated Row 6 FOTA Top of Pins Coolant Temperatures for T/C TX9024 on Pin 1,2

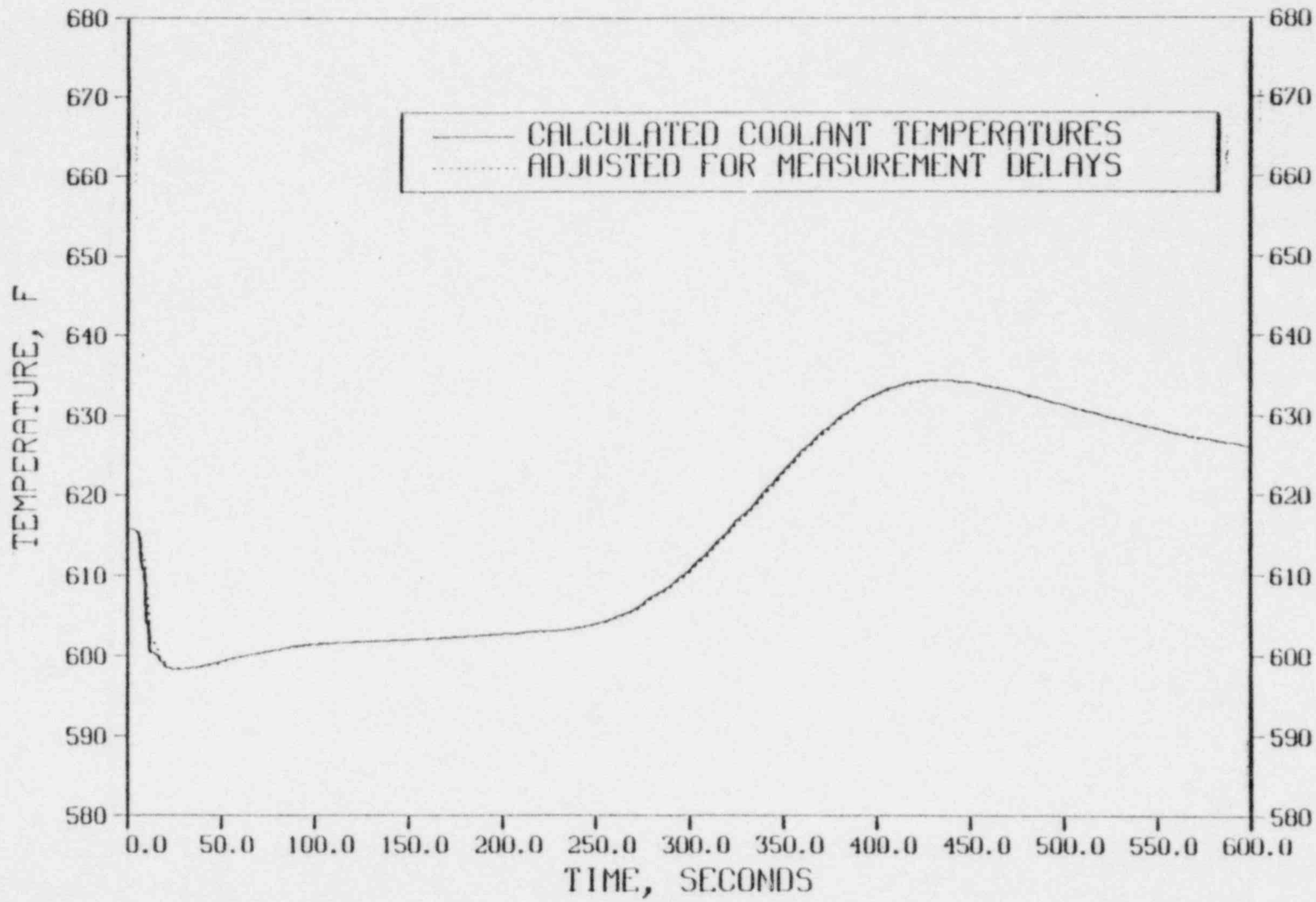


Figure 4.29 Calculated Row 6 FOTA Top of Pins Coolant Temperatures for T/C TX9019 on Pin 3,3

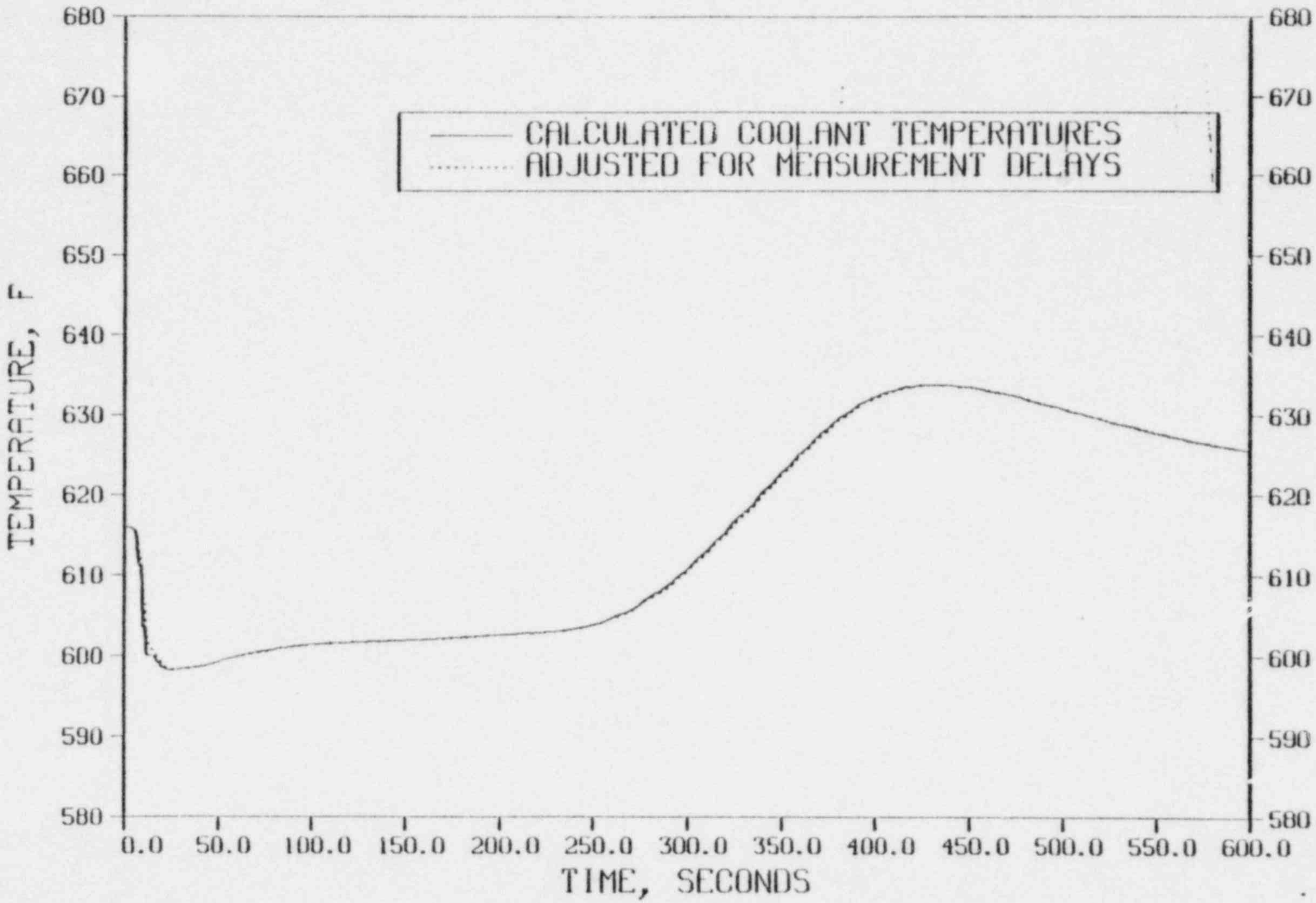


Figure 4.30 Calculated Row 6 FOTA Top of Pins Coolant Temperatures for T/C TX9017 on Pin 5,5

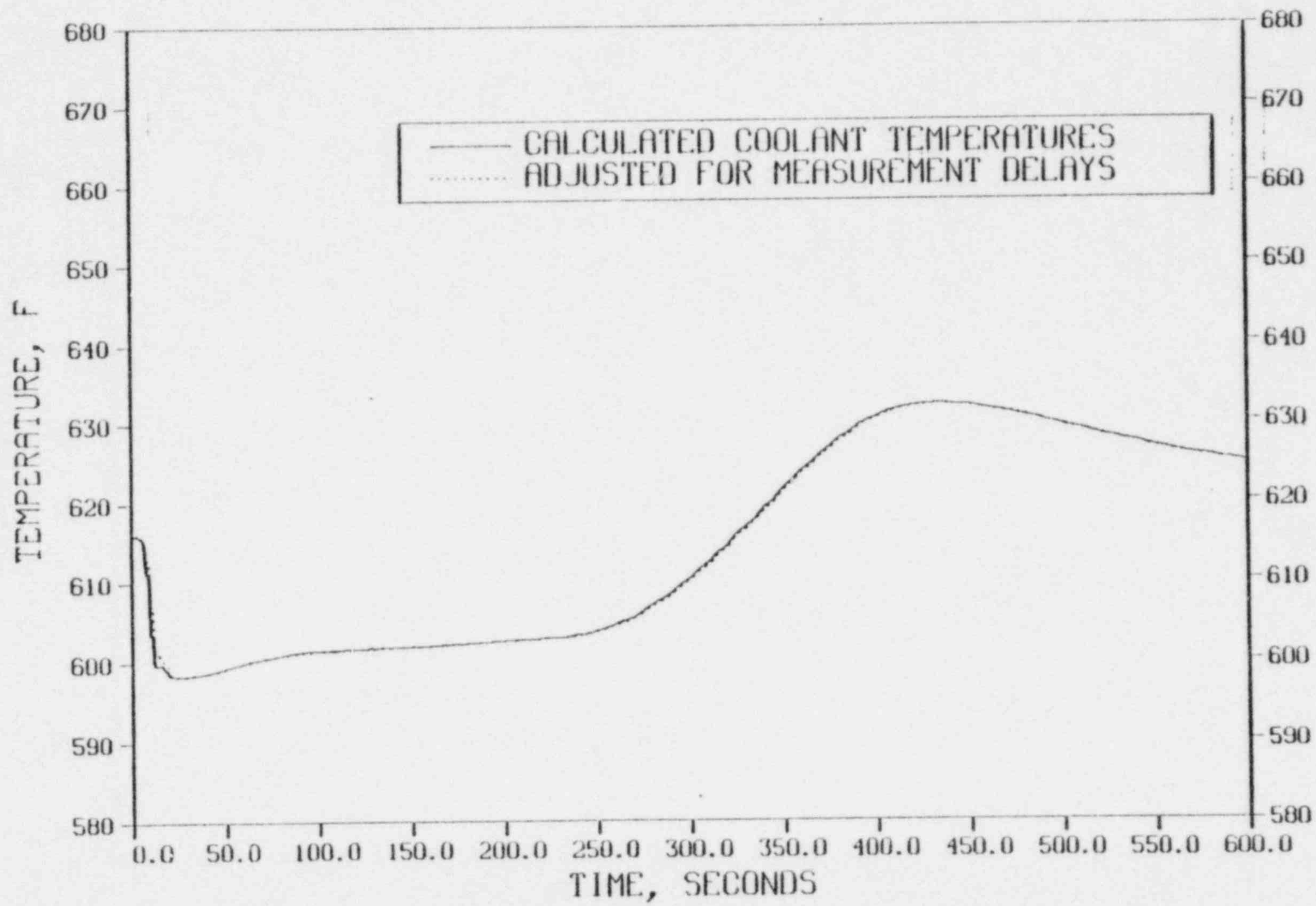


Figure 4.31 Calculated Row 6 FOTA Top of Pins Coolant Temperatures for T/C TX9012 on Pin 10,9

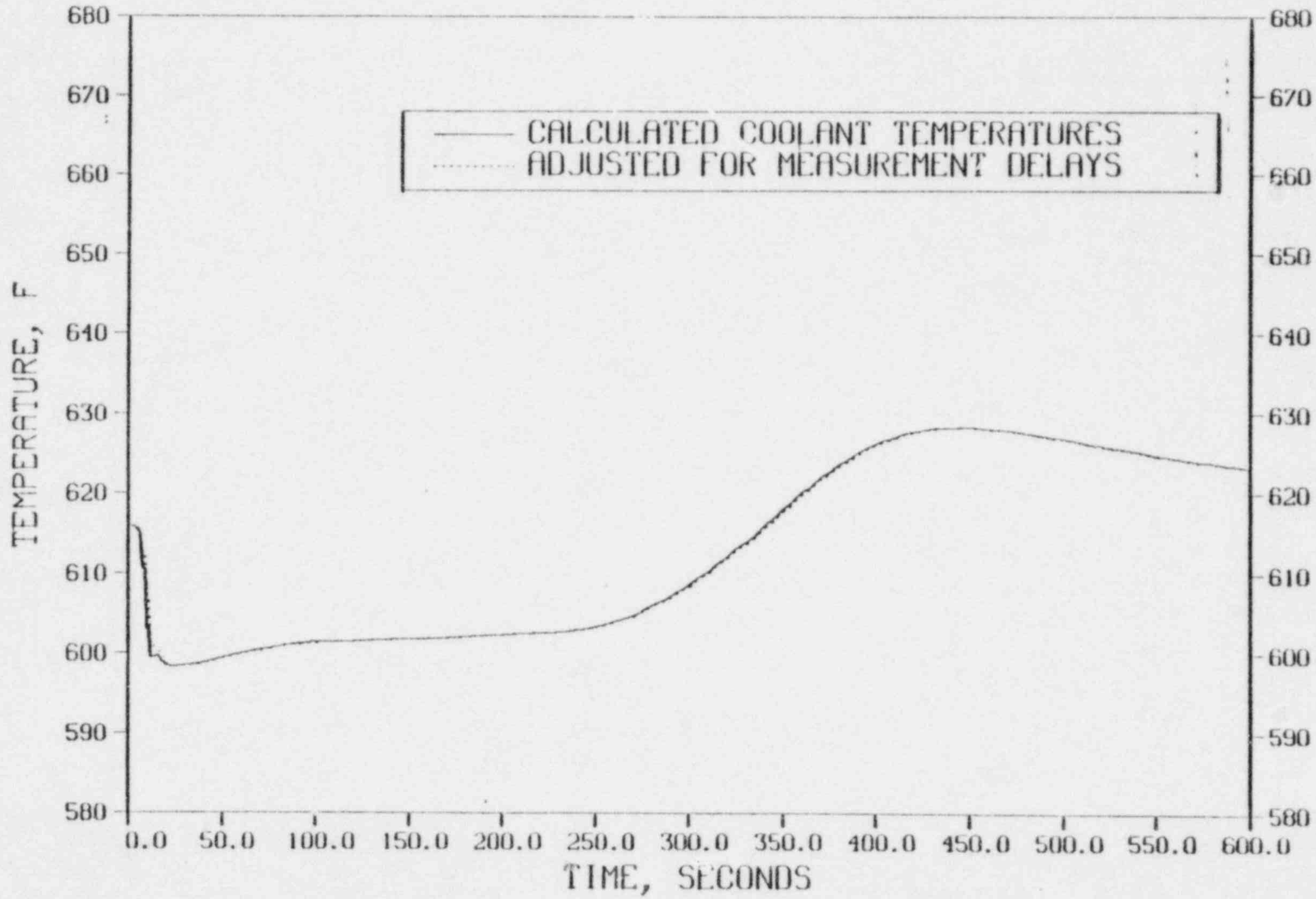


Figure 4.32 Calculated Row 6 FOTA Top of Pins Coolant Temperatures for T/C TX9044 on Pin 17,8

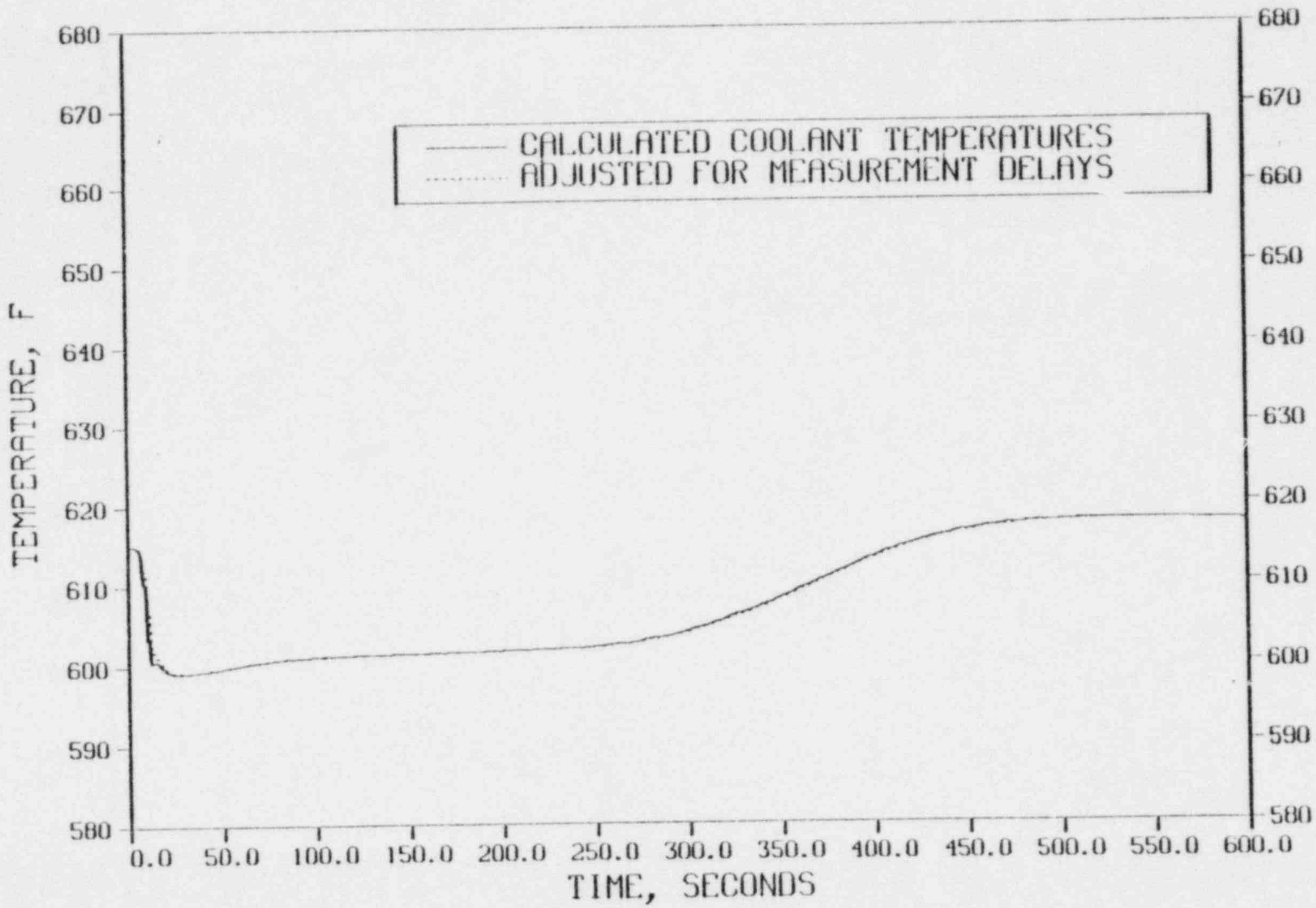


Figure 4.33 Calculated Row 6 FOTA Top of Pins Coolant Temperatures for T/C TX9041 on Pin 13,9

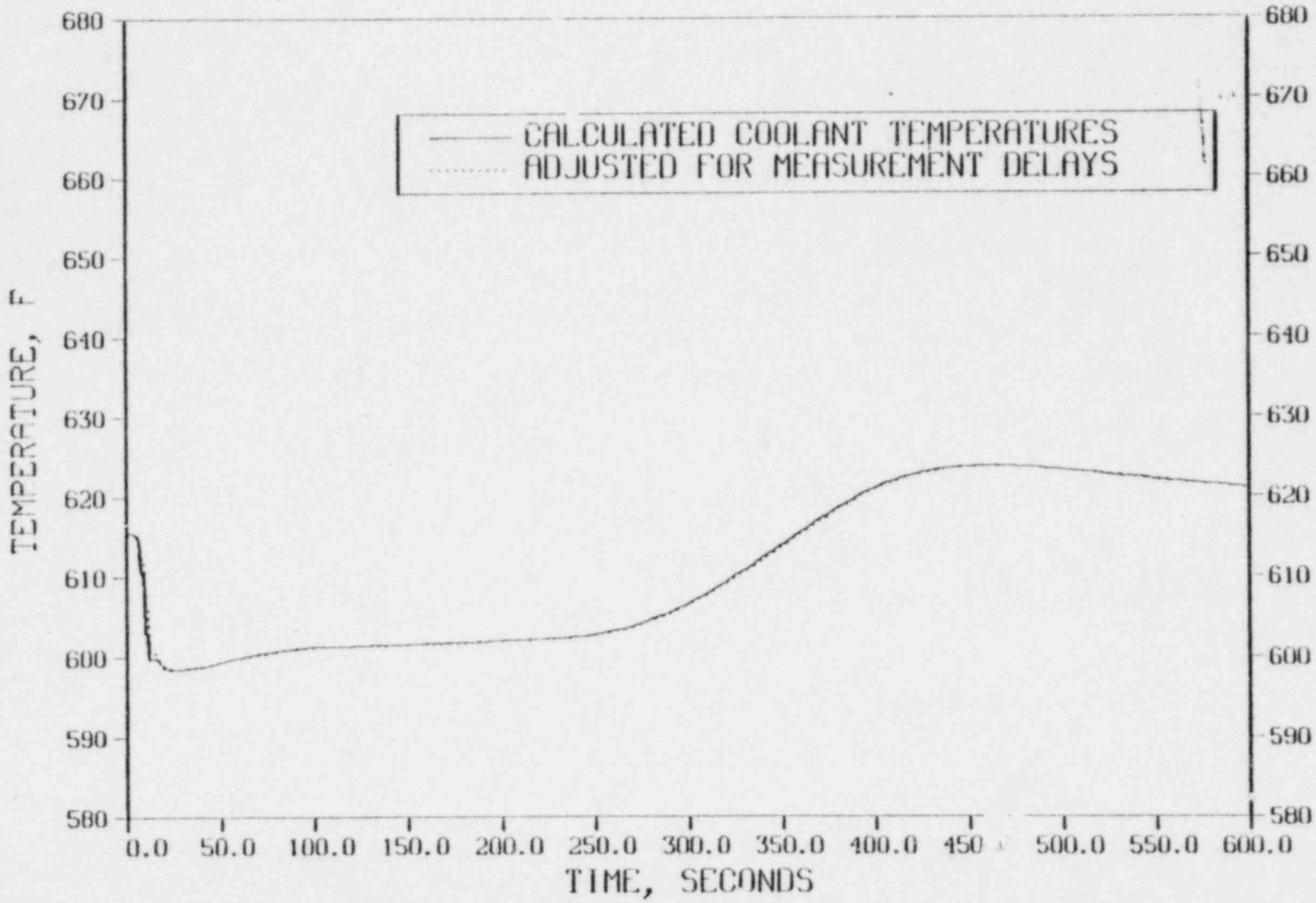


Figure 4.34 Calculated Row 6 FOTA Instrument Stalk Coolant Temperatures at T/C Location

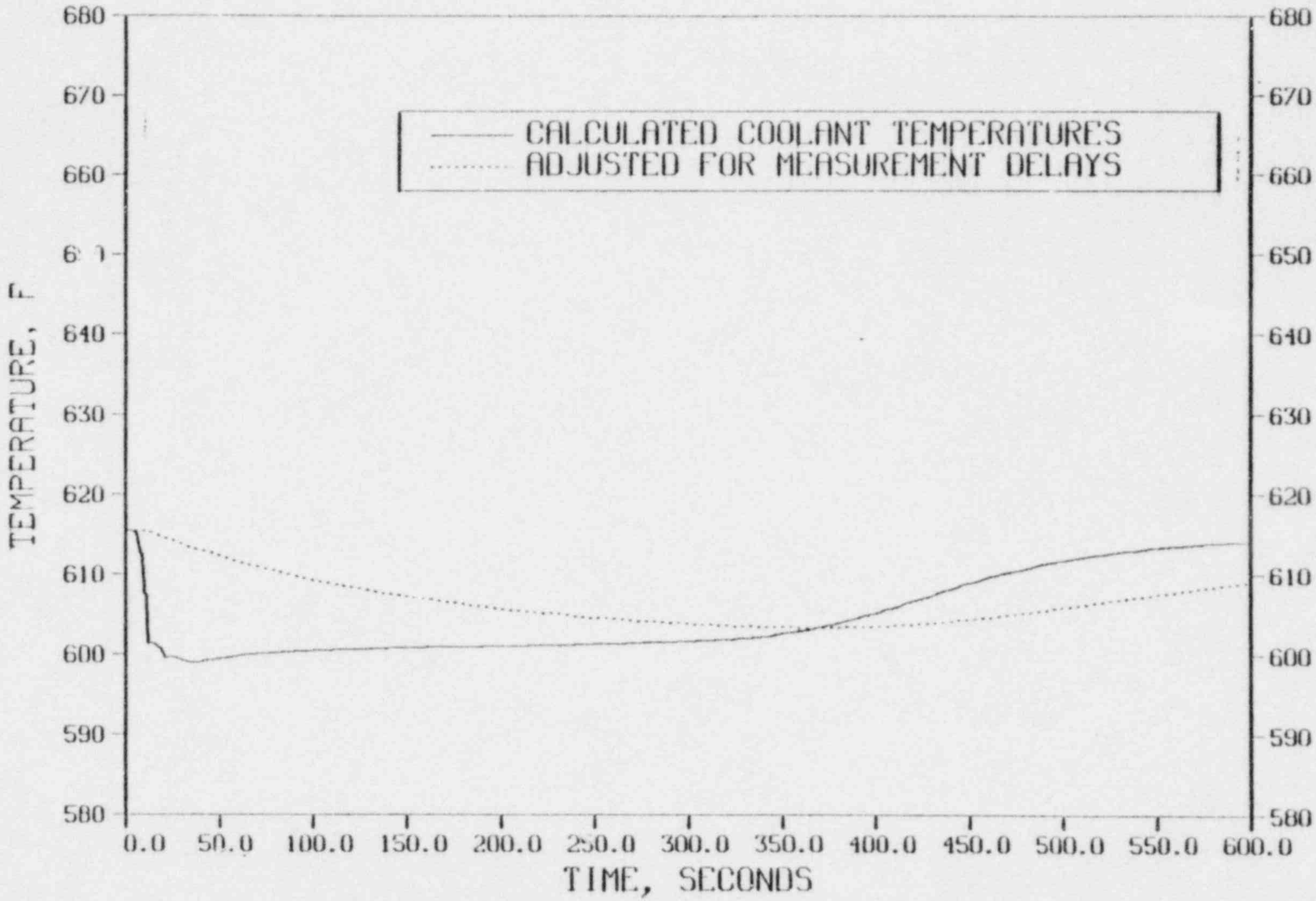


Figure 4.35 Calculated Row 6 FOTA Average Coolant Temperatures at Top of Fuel

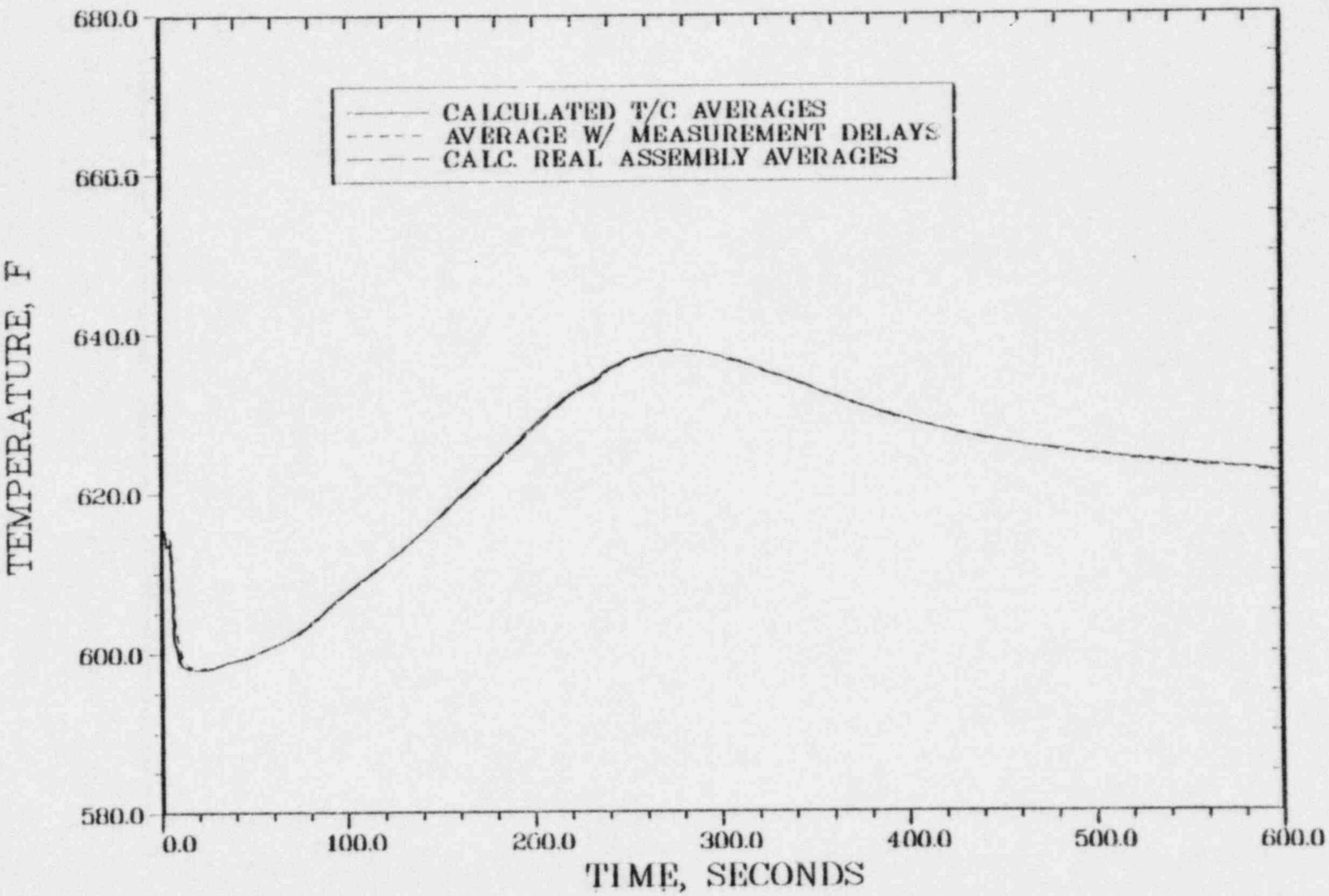


Figure 4.36 Calculated Row 6 FOTA Average Coolant Temperatures at Top of Pins

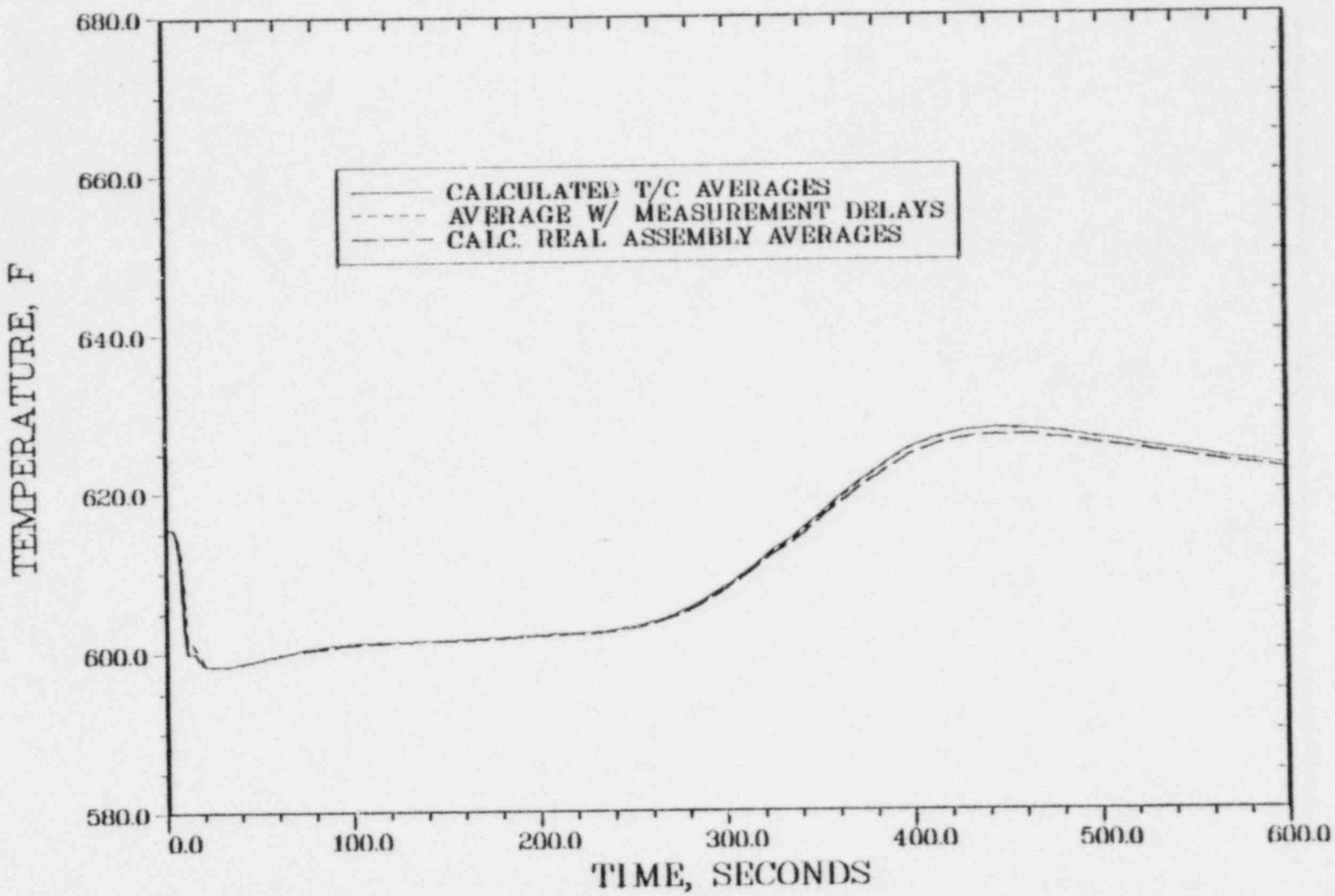
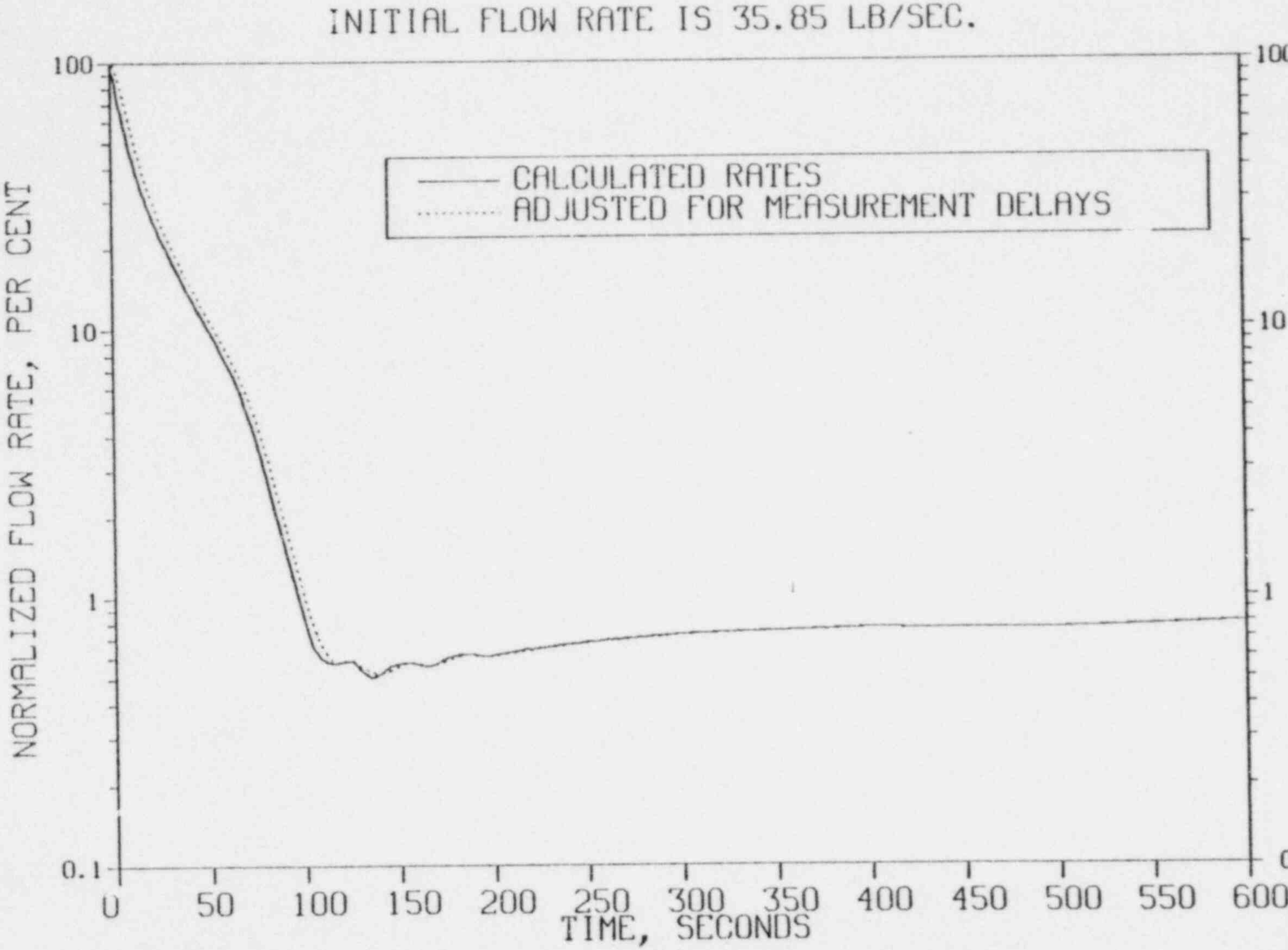


Figure 4.37 Calculated Row 6 FOTA Normalized Assembly Coolant Flow Rates



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