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STS-35 SCRUB 3 HYDROGEN LEAK ANALYSIS

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During the summer of 1990, space shuttle *Columbia* experienced both an external tank/orbiter disconnect hydrogen leak and multiple internal aft compartment hydrogen leaks. After the third scrub of STS-35, a leak investigation team was organized. In support of this team, an analysis of the data obtained during scrub 3 was performed. Based on this analysis, the engine 2 prevalve was concluded to be the most likely leak location and to account for most of the observed leakage.

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TECHNICAL MEMORANDUM

STS-35 SCRUB 3 HYDROGEN LEAK ANALYSIS

INTRODUCTION

Although considerable analysis had been performed on the previous STS-35 scrub and tanking test data, the wide range of operating conditions and valve configurations tested during scrub 3 was not previously available. With the formation of the STS-35 leak investigation team, an intensive analysis effort was undertaken to characterize the leak and determine its location. This report describes the analysis in roughly the chronological order in which it was performed.

The results of this analysis effort were provided to the leak investigation team as they became available. The results presented here sometimes differ slightly from those provided to the team during the investigation due to error corrections and refinements. However, the conclusions drawn from the results remain unchanged.

During the STS-35 scrub 3 leak isolation test, the behavior of the aft compartment H_2 concentration seemed to indicate a leak in the engine 2 prevalve (PV5). The decrease in H_2 concentration during drain associated with opening the engine 2 prevalve was particularly inditing. However, since the number of different leaks was unknown, all possible locations were considered in the analysis.

SUMMARY

Some of the more important conclusions drawn from this analysis were:

1. The leak did not exist at ambient temperature.

2. The engine 2 prevalve was the most likely leak location.

3. At least 80 percent of leakage came from the engine 2 prevalve.

4. The scrub 2 leak area was twice that of scrub 3 and consistent with the known engine 3 prevalve detent cover seal leakage.

5. Leak area changes cannot be inferred from concentration changes without employing an analysis similar to that used here.

MODEL METHODOLOGY

The basic approach taken was to calculate an aft compartment H_2 concentration based on the measured pressures, temperatures, and valve configurations and evaluate this prediction by direct comparison with the mass spectrometer data.

Prior to STS-35 scrub 3, H_2 flow rates had been calculated for an adiabatic real gas expansion over a range of initial pressures and temperatures. These data were converted to a table which provided relative flow rate as a function of the leak site pressure and degrees of subcooling.

Aft compartment H_2 concentration was calculated by assuming that the H_2 was uniformly mixed in a single volume and using the transient mass conservation equation:

$$\frac{d M_{H_2}}{dt} = \dot{m}_{\mathrm{H}_{2_{\mathrm{in}}}} - \dot{m}_{\mathrm{H}_{2_{\mathrm{out}}}} ,$$

where,

$M_{\mathrm{H}_2} = Y_c M_{\mathrm{N}_2}$

M_{N_2} = mass of N_2 in aft compartment

$\dot{m}_{\mathrm{H}_{2_{\mathrm{in}}}}$ = H_2 leak rate

$\dot{m}_{\mathrm{H}_{2_{\mathrm{out}}}} = Y_c \dot{m}_{\mathrm{N}_2}$

$\dot{m}_{\mathrm{N}_2}$ = aft compartment purge mass flow rate

Y_c = aft compartment H_2 concentration.

While this approach preserves the basic time constant of the aft compartment purge flow (about 90 s), the calculated H_2 concentration begins to respond immediately to a change in leak flow rate. The discrete H_2 transport delay from the leak site to the vent door is smeared over the time constant. In addition, the predictions do not include time delays associated with the mass spectrometer H_2 concentration measurement.

SCRUB 3 MEASURED DATA

Rather than using the measured manifold pressure, a value calculated from measured ullage pressure and estimated liquid height was used. Both the measured and calculated manifold pressures are shown in figure 1.

The measured manifold temperature is compared with the saturation temperature corresponding to the calculated manifold pressure in figure 2. In this study, all saturation temperatures were determined from the pressure by the approximation:

$$\mathrm{TSAT(DEGR)} = 9.96915\ (\mathrm{psia})^{0.288438} + 15.0744\ .$$

For leak rate predictions, temperature data were typically corrected for offsets by comparing the measurement to calculated saturation temperatures at appropriate times.

Engine inlet temperatures are compared with the calculated manifold saturation temperature in figures 3, 4, and 5. Engine inlet pressures are compared with the calculated manifold pressure in figures 6, 7, and 8.

The midrange 5,000 parts per million (p/m) aft compartment H_2 concentration measurements, GGDR2510T, was used to compare with all predictions. However, as shown in figure 9, there were occasional peaks above 5,000 p/m which were clipped by this measurement.

An event timeline was constructed which provides vehicle and facility valve actuation times and is shown in table 1. All data plots were made as seconds from the Space Transportation System (STS) data base Greenwich mean time (GMT) reference time of 90:260:21:47:00.0.

INITIAL MANIFOLD/ENGINE LEAK PREDICTION RESULTS

Initially, leak rate predictions were performed for the manifold based on the calculated manifold pressure and measured manifold temperature (V41T1428A). Predictions for each engine based on measured engine inlet pressure and measured inlet temperature were also performed. These results are compared with the 5,000 p/m range measured data in figures 10 to 13. These predictions did not include any heat leak effects on the leak site temperature.

The comparisons show the manifold prediction correlates much of the data except for the drain time period after 25,000 s. The engine 1 and engine 3 predictions show poor correlation. However, the engine 2 comparison shows good correlation during the drain period.

SPECIAL TEST PREDICTION RESULTS

After the initial manifold and engine predictions were performed, attention was focused on four specific time periods when unusual conditions and H_2 concentration behavior was observed.

A. Recirculation Pump Backspin

The first of these special conditions considered occurred between 9,000 and 10,000 s when, with engines 2 and 3 prevalves closed, the recirculation (recirc) valves were opened and engine 1 recirc began. The aft compartment H_2 p/m dropped as shown in figure 14. This sequence caused the engine 2 and engine 3 recirc pumps to backflow as shown by the recirc pump speed data in figure 15.

The engine 1 inlet pressure and temperature are shown in figures 16 and 17. Engines 2 and 3 inlet temperatures remained offscale high. The manifold temperature also increased during this time.

The recirc pump backspin was clearly the result of vapor flow from the warm engine inlet lines. Based on the recirc pump acceleration and estimated pump delta p, a vapor flow rate of 0.02 lb/s per pump was calculated.

Predicted leak rates were calculated for a leak site temperature corresponding to saturated liquid and saturated vapor when the recirc valve was open and the manifold temperature when closed. The comparisons in figure 18 show good agreement between the measured concentration and the saturated vapor prediction. However, a 120-s time delay was found which could not be totally explained.

The conclusion drawn from this analysis was that the vapor flowing out of recirc pumps 2 and 3 inlet produced vapor at the leak site. Since this occurred during reduced fast-fill and the flow patterns in the manifold were unknown, the leak could have been in the manifold, the prevalves, or the 17-in line.

B. Prevalve Opening at 14,000 s (GMT 261:01:40)

After engine 3 recirc was terminated and the recirc valves were closed, all three prevalves were opened and the p/m level dropped. Subsequent closing of the prevalves resulted in the p/m data returning to their previous level. During this period, the engine 1 bleed valve was closed and the inlet line dry, the engine 2 bleed valve was closed and the inlet line saturated, and engine 3 remained subcooled. The manifold temperature increased when engines 1 and 2 prevalves were opened.

Both engines 1 and 2 were probably producing vapor and a recirculating flow in their inlet lines. As in the previous special test analysis, a prediction was made using the manifold temperature when the engine 2 prevalve was closed and saturated liquid or vapor when the engine 2 prevalve was open. The comparison between the saturated vapor prediction and measured concentration shown in figure 19 indicated good agreement with about a 30-s time delay.

The conclusion drawn from this analysis was that the leak was probably not in the engine 3 prevalve, but further discrimination of the low pressure components was not possible.

C. Initial Fast-Fill and Transition to Reduced Fast-Fill

When the manifold flow rate was reduced from the 8,300 gallons per minute (gal/min) fast-fill rate to the 930 gal/min reduced fast-fill rate, the measured p/m dropped. About 10 min later, the concentration returned to the previous value.

The primary effect of manifold flow on the leak rate is the effect on leak site temperature. As a first approximation, the leak site temperature should be higher than the bulk fluid temperature by an amount proportional to the inverse of the flow rate. A prediction was made assuming a leak site temperature equal to the manifold temperature plus 0.6° during fast-fill and plus 6° during reduced fast-fill. The leak site temperature was arbitrarily returned to the manifold temperature at 3,400 s. The rise in leak rate at this time was thought to be the result of chill down and filling of the volume at the leak site and could not be reasonably modeled. Prior to 1,600 s, the predicted leak rate was set to zero. Figure 20 compares this prediction with the measured concentration.

Three conclusions were drawn from this analysis. The predicted 600 p/m from a saturated vapor leak was not observed in the data. Even a 200-p/m ambient temperature H_2 leak should have been detectable by the mass spectrometer. As shown in figure 21, the measured concentration was less than 30 p/m. This low measured concentration relative to the predicted value confirmed that the effective leak area existed only when the leak site was chilled to operating temperatures and that an ambient temperature leak did not exist.

The second conclusion was that the manifold temperature and assumed heat leak effect was consistent with the measured concentration.

The third conclusion was that, with the prediction available, an ullage pressure effect on the leak rate could be seen in the measured concentration.

D. Prevalve Opening During Drain

During drain (starting at about 25,000 s), each engine's recirc pump was stopped and its prevalve opened. While there was no effect on the p/m data for engines 1 and 3, when engine 2's prevalve was opened the p/m level dropped. The engine 2 effect repeated three times.

As described in case b, each engine was probably producing vapor in its inlet line when its prevalve was open. As previously mentioned, the concentration data behavior was consistent with the engine 2 inlet temperature. Since the 5,700 gal/min drain flow produced a flow velocity of about 8 ft/s and there was no effect on the manifold temperature measurement and since the 17-in line is essentially horizontal, this vapor was very unlikely to rise above the manifold. Thus, these data excluded the 17-in line and the disconnect as possible leak sites. Further, it also excluded the engines 1 and 3 prevalves, since they produced no effect. These data, together with the recirc pump backspin data, indicated that the engine 2 prevalve, PV5, was the most likely leak location.

PV5 SCRUB 3 PREDICTION RESULTS

While the special test analysis had provided many important conclusions and given much insight into the leak behavior, it was felt that a unified model containing all the logic developed to date was required. This unified model would permit verification of all of the assumptions and logic through comparison with all of the concentration data.

The unified model consisted of a set of simple rules for determining the leak site temperature. The leak site temperature was taken to be the manifold temperature when the engine 2 prevalve was closed, otherwise it was taken to be the engine 2 inlet temperature. A heat leak effect was approximated by adding (930 gal/min/manifold flow) to this temperature. This may overestimate the heat leak effect but was judged acceptable. The manifold flow used is shown in figure 22.

To describe the effect of recirc pump vapor backflow, special logic was used to override the leak site temperature and instead used a saturated vapor leak rate. The logic used was that vapor backflow would occur when the recirc valve was open, when the recirc pump was off, when the prevalve was closed, and when the engine inlet temperature was superheated.

When this logic was initially implemented, the model predicted the concentration reduction previously analyzed. However, as shown in figure 23, the model also predicted backflow and concentration reduction at about 11,000 s which was previously unnoticed. In addition, when initially implemented, the logic was applied equally to all three engines. Engine 1 was predicted to have vapor backflow between 21,100 and 12,600 s and between 12,900 and 14,100 s while no concentration reduction occurred in the data. Apparently, the local flow field transported the vapor from the engine 2 recirc inlet to the leak site but did not transport the vapor from recirc pump 1. This result was considered to be additional evidence of an engine 2 prevalve leak since each recirc pump is located directly in front of its prevalve. The final version of the model only applies the backflow logic to engine 2.

The model was run on a PC. A listing of the program is provided in the appendix. The model and all test data used in this analysis are available from the author on a PC floppy disk.

The model prediction is compared with the measured H_2 concentration in figure 24 for the full duration of the data and in figures 25 to 29 with an expanded time scale. Also shown in these figures are event bars which indicate when valves are open or the recirc pumps are on. Figure 30 shows the predicted leak site subcooling along with the manifold subcooling.

Two deviations of the prediction from the measured data are shown in figure 26. The first, at 11,400 s, occurs when closure of the recirc valves terminates vapor backflow throughout the engine 2 recirc pump and the model switches from a saturated vapor leak rate to a leak based on the subcooled manifold temperature. This deviation is thought to be caused by the time required to condense the accumulated vapor volume in the prevalve which is not modeled. A similar time delay was found when vapor backflow was terminated at 9,400 s.

The second deviation occurs at 12,700 s when the engine 2 prevalve is opened, and the model predicts a concentration decrease corresponding to the near saturated engine inlet temperature. The cause of this deviation is unknown. Similar prevalve openings between 14,000 and 15,000 s and during drain produced a concentration decrease as predicted.

To determine if all of the scrub 3 leak could be explained by one PV5 leak, several combinations of a PV5 leak and a manifold leak were predicted. As previously described and shown in figure 10, a pure manifold leak prediction does not include any effect of recirc pump vapor backflow or prevalve opening. Thus, combining the PV5 leak with a manifold leak tends to reduce the magnitude of the predicted concentration reduction for these effects. Figure 31 shows a prediction for an 80-percent PV5 leak combined with a 20-percent manifold leak. Further increases in the manifold leak fraction tends to raise the minimum concentration during the vapor backflow and PV5 open times to a value above the data. Therefore, the 20-percent manifold fraction was judged to be the highest reasonable fraction which could exist and most of the leak was in PV5.

PV5/PV6 SCRUB 2 PREDICTION RESULTS

To further verify the scrub 3 model, predictions were made for scrub 2. Figure 32 shows the calculated manifold pressure, and figure 33 shows the manifold flow rate. Initially, the scrub 3 model was applied to scrub 2 without any modification. Surprisingly, the predicted concentration was almost exactly half the measured data. Although the PV6 detent cover seal was a known additional leak source for scrub 2, the measured scrub 2 concentration was only slightly higher, and this result was totally unexpected.

Subsequent scrub 2 predictions modeled the PV6 leak as a separate second leak with the same leak area and same logic as developed for PV5. The final scrub 2 prediction is compared with the measured concentration in figure 34. The leak site subcooling and manifold subcooling are shown in figure 35. The reasonably good agreement further verified the model but, more importantly, provided further evidence that most of the scrub 3 leak was due to the one PV5 leak.

These results clearly showed that the changes in concentration data between scrub 2 and scrub 3 could not be used to infer changes in leak area. The effects of the different valve configurations and different manifold flows could only be included by applying the model analysis. The scrub 3 leak area was actually half that of scrub 2.

PV5/PV6 TANKING TEST 1 PREDICTION RESULTS

This tanking test was primarily concerned with the orbiter/external tank disconnect leakage. High external H_2 concentrations resulting from the disconnect leakage prevented high fill rates. As shown in figure 37, the manifold flow rate was low for most of the test.

The model prediction H_2 concentration is compared with the measured data in figure 38. This prediction used a leak area 83 percent of that used for scrub 2. There is considerable uncertainty in the actual amount of leak area reduction since significant concentrations were obtained for only two brief periods.

PV5/PV6 SCRUB 1 PREDICTION RESULTS

The scrub 1 manifold flow conditions, shown in figure 41, were very similar to tanking test 1. Engine recirculation was not performed. The model prediction H_2 concentration is compared with measured data in figure 42 for a leak area of 69 percent of that used for scrub 2. Again, considerable uncertainty exists in the amount of this leak area reduction. However, since some additional H_2 leak flow into the aft compartment from the disconnect leak should have existed during scrub 1 and tanking test 1, there does appear to be a trend of increasing leak area with each loading.

CONCLUSIONS

The leak isolation procedures used during scrub 1 and tanking test 1 were designed to further understand the disconnect leak and did not produce useful data relative to an aft compartment leak. With sufficient amounts of the right test data, detailed analysis and modeling can determine the leak location and behavior. Although the results of the STS-35 analysis were not always sufficiently timely to significantly contribute to the leak investigation team's activities, future leak investigation analyses can build on the experience and analysis tools developed here.

Table 1. STS-35 scrub 3 LH_2 leak isolation timeline.

GMT TIME	TIME (SEC)	EVENT	DESCRIPTION	REMARKS - PROCEDURE
260:21:52:11: 6	311.007	OPEN	A3309 CHLDWN VLV OPEN #1 IND	
260:21:56:53: 0	592.007	ON	CHILLDOWN COMPLETE	
260:22:20: 2: 0	1200.008	ON	SLOW FILL TO 2% COMPLETE	
260:22:20:29: 14	2009.015	OPEN	MPS LH2 TOPPING VLV (PV13) OP IND	
260:22:22:22: 14	2122.015	OPEN	MPS LH2 HI PT BL VLV (PV22) OP IND	
260:22:30:10: 14	2590.015	CLOSED	A3301 XFR LINE VLV CLOSED #1 IND	REDUCED FLOW RATE TO 930 GPM
260:22:52:39: 22	3939.023	CLOSED	MPS E1 LH2 PREVLV (PV4) CL IND	ISOLATE LH2 MANIFOLD
260:22:52:46: 22	3946.023	CLOSED	MPS E2 LH2 PREVLV (PV5) CL IND	
260:22:52:50: 22	3950.023	CLOSED	MPS E3 LH2 PREVLV (PV6) CL IND	
260:22:52:55: 22	3955.023	CLOSED	MPS LH2 TOPPING VLV (PV13) CL IND	
260:23:10:27: 27	5007.027	CLOSED	MPS LH2 HI PT BL VLV (PV22) CL IND	ISOLATE HI PT BLEED LINE
260:23:26: 6: 35	5946.035	OPEN	MPS LH2 HI PT BL VLV (PV22) OP IND	
260:23:26:20: 35	5960.035	OPEN	MPS LH2 TOPPING VLV (PV13) OP IND	ISOLATE 4-INCH LINE AND DISCONNECT
260:23:26:34: 35	5974.035	CLOSED	MPS LH2 INBD F/D VLV (PV12) CL IND	
260:23:31:16: 35	6256.035	CLOSED	MPS LH2 HI PT BL VLV (PV22) CL IND	
260:23:53:18: 42	7578.043	OPEN	MPS E1 LH2 PREVLV (PV4) OP IND A	
260:23:53:22: 42	7582.043	OPEN	MPS E2 LH2 PREVLV (PV5) OP IND A	
260:23:53:28: 42	7588.043	OPEN	MPS E3 LH2 PREVLV (PV6) OP IND A	
260:23:55:50: 42	7730.043	CLOSED	MPS E1 LH2 PREVLV (PV4) CL IND	

Table 1. STS-35 scrub 3 LH_2 leak isolation timeline (continued)

260:23:55:54: 42	7734.043	CLOSED	MPS E2 LH2 PREVLV (PV5) CL IND	
260:23:55:58: 42	7738.043	CLOSED	MPS E3 LH2 PREVLV (PV6) CL IND	
261: 0: 1:37: 42	8077.043	OPEN	MPS LH2 HI PT BL VLV (PV22) OP IND	
261: 0: 9:23: 46	8543.047	OPEN	MPS LH2 INBD F/D VLV (PV12) OP IND	ISOLATE ENGINE 1
261: 0: 9:26: 46	8546.047	CLOSED	MPS LH2 TOPPING VLV (PV13) CL IND	
261: 0:21: 5: 50	9245.051	OPEN	MPS E1 LH2 PREVLV (PV4) OP IND A	
261: 0:21:18: 50	9258.051	OPEN	MPS E1 LH2 RECIRC VLV(PV14) OP IND	
261: 0:21:18: 50	9258.051	OPEN	MPS E3 LH2 RECIRC VLV(PV16) OP IND	
261: 0:21:19: 50	9259.051	OPEN	MPS E2 LH2 RECIRC VLV(PV15) OP IND	
261: 0:21:27: 50	9267.051	ON	MPS E1 LH2 RECIRC PUMP (PP1) SPEED	
261: 0:21:36: 50	9276.051	CLOSED	MPS E1 LH2 PREVLV (PV4) CL IND	
261: 0:22:56: 50	9356.051	ON	MPS E2 LH2 RECIRC PUMP (PP2) SPEED	BACKSPIN
261: 0:23: 4: 50	9364.051	ON	MPS E3 LH2 RECIRC PUMP (PP3) SPEED	BACKSPIN
261: 0:23:13: 50	9373.051	OFF	MPS E1 LH2 RECIRC PUMP (PP1) SPEED	
261: 0:23:26: 54	9386.055	CLOSED	MPS E1 LH2 RECIRC VLV(PV14) CL IND	
261: 0:23:26: 54	9386.055	CLOSED	MPS E2 LH2 RECIRC VLV(PV15) CL IND	
261: 0:23:27: 54	9387.055	CLOSED	MPS E3 LH2 RECIRC VLV(PV16) CL IND	
261: 0:23:27: 54	9387.055	OFF	MPS E2 LH2 RECIRC PUMP (PP2) SPEED	
261: 0:23:27: 54	9387.055	OFF	MPS E3 LH2 RECIRC PUMP (PP3) SPEED	
261: 0:37:11: 58	10211.059	OPEN	MPS E1 LH2 PREVLV (PV4) OP IND A	
261: 0:37:21: 0	10221.000	CLOSED	E1 LH2 BLEED VALVE	
261: 0:37:42: 0	10242.000	OPEN	E1 LH2 BLEED VALVE	
261: 0:45:16: 0	10696.000	CLOSED	E2 LH2 BLEED VALVE	
261: 0:45:26: 0	10706.000	CLOSED	E3 LH2 BLEED VALVE	
261: 0:45:32: 58	10712.059	OPEN	MPS E1 LH2 RECIRC VLV(PV14) OP IND	
261: 0:45:32: 58	10712.059	OPEN	MPS E3 LH2 RECIRC VLV(PV16) OP IND	

Table 1. STS-35 scrub 3 LH_2 leak isolation timeline (continued)

261: 0:45:33: 58	10713.059	OPEN	MPS E2 LH2 RECIRC VLV(PV15) OP IND	
261: 0:47: 5: 58	10805.059	ON	MPS E1 LH2 RECIRC PUMP (PP1) SPEED	
261: 0:47:13: 58	10813.059	CLOSED	MPS E1 LH2 PREVLV (PV4) CL IND	
261: 0:56:52: 62	11392.062	OFF	MPS E1 LH2 RECIRC PUMP (PP1) SPEED	
261: 0:56:58: 62	11398.062	CLOSED	MPS E2 LH2 RECIRC VLV(PV15) CL IND	
261: 0:56:59: 62	11399.062	CLOSED	MPS E3 LH2 RECIRC VLV(PV16) CL IND	
261: 0:57:01: 0	11401.000	CLOSED	E1 LH2 BLEED VALVE	
261: 0:57: 4: 62	11404.062	CLOSED	MPS E1 LH2 RECIRC VLV(PV14) CL IND	
261: 0:57:25: 0	11425.000	OPEN	E1 LH2 BLEED VALVE	
261: 0:57:43: 62	11443.062	OPEN	MPS E1 LH2 PREVLV (PV4) OP IND A	
261: 1: 1: 6: 62	11646.062	OPEN	MPS E2 LH2 PREVLV (PV5) OP IND A	ISOLATE ENGINE 2
261: 1: 1:25: 0	11665.000	OPEN	E2 LH2 BLEED VALVE	
261: 1: 2:10: 62	11710.062	CLOSED	MPS E1 LH2 PREVLV (PV4) CL IND	
261: 1: 8:48: 66	12108.066	OPEN	MPS E1 LH2 RECIRC VLV(PV14) OP IND	
261: 1: 8:48: 66	12108.066	OPEN	MPS E2 LH2 RECIRC VLV(PV15) OP IND	
261: 1: 8:48: 66	12108.066	OPEN	MPS E3 LH2 RECIRC VLV(PV16) OP IND	
261: 1: 9: 1: 0	12121.000	CLOSED	E1 LH2 BLEED VALVE (New)	
261: 1: 9: 6: 66	12126.066	ON	MPS E2 LH2 RECIRC PUMP .(PP2) SPEED	
261: 1: 9:13: 66	12133.066	CLOSED	MPS E2 LH2 PREVLV (PV5) CL IND	
261: 1:17:58: 70	12658.070	OFF	MPS E2 LH2 RECIRC PUMP (PP2) SPEED	
261: 1:18: 4: 70	12664.070	CLOSED	MPS E1 LH2 RECIRC VLV(PV14) CL IND	
261: 1:18: 4: 70	12664.070	CLOSED	MPS E2 LH2 RECIRC VLV(PV15) CL IND	
261: 1:18: 4: 70	12664.070	CLOSED	MPS E3 LH2 RECIRC VLV(PV16) CL IND	
261: 1:18:11: 0	12671.000	CLOSED	E2 LH2 BLEED VALVE	
261: 1:18:20: 0	12680.000	OPEN	E2 LH2 BLEED VALVE	
261: 1:18:21: 70	12681.070	OPEN	MPS E2 LH2 PREVLV (PV5) OP IND A	

Table 1. STS-35 scrub 3 LH_2 leak isolation timeline (continued)

261: 1:19:11: 70	12731.070	OPEN	MPS E3 LH2 PREVLV (PV6) OP IND A	
261: 1:19:47: 0	12767.000	OPEN	E3 LH2 BLEED VALVE was 12994.	ISOLATE ENGINE 3
261: 1:20:44: 0	12824.000	CLOSED	E2 LH2 BLEED VALVE	
261: 1:21:10: 70	12850.070	OPEN	MPS E1 LH2 PREVLV (PV4) OP IND A	
261: 1:21:22: 70	12862.070	CLOSED	MPS E1 LH2 PREVLV (PV4) CL IND	
261: 1:21:46: 70	12886.070	OPEN	MPS E1 LH2 RECIRC VLV(PV14) OP IND	
261: 1:21:46: 70	12886.070	OPEN	MPS E2 LH2 RECIRC VLV(PV15) OP IND	
261: 1:21:46: 70	12886.070	OPEN	MPS E3 LH2 RECIRC VLV(PV16) OP IND	
261: 1:21:46: 70	12886.070	ON	MPS E1 LH2 RECIRC PUMP (PP1) SPEED	
261: 1:22: 5: 70	12905.070	OFF	MPS E1 LH2 RECIRC PUMP (PP1) SPEED	
261: 1:23: 1: 70	12961.070	CLOSED	MPS E2 LH2 PREVLV (PV5) CL IND	
261: 1:31:49: 74	13489.074	ON	MPS E3 LH2 RECIRC PUMP (PP3) SPEED	
261: 1:31:57: 74	13497.074	CLOSED	MPS E3 LH2 PREVLV (PV6) CL IND	
261: 1:41:19: 78	14059.078	OFF	MPS E3 LH2 RECIRC PUMP (PP3) SPEED	
261: 1:41:28: 78	14068.078	CLOSED	MPS E1 LH2 RECIRC VLV(PV14) CL IND	
261: 1:41:28: 78	14068.078	CLOSED	MPS E2 LH2 RECIRC VLV(PV15) CL IND	
261: 1:41:29: 78	14069.078	CLOSED	MPS E3 LH2 RECIRC VLV(PV16) CL IND	
261: 1:41:40: 0	14080.000	CLOSED	E3 LH2 BLEED VALVE	
261: 1:41:51: 78	14091.078	OPEN	MPS E3 LH2 PREVLV (PV6) OP IND A	
261: 1:42:10: 0	14110.000	OPEN	E3 LH2 BLEED VALVE	
261: 1:42:39: 78	14139.078	OPEN	MPS E2 LH2 PREVLV (PV5) OP IND A	
261: 1:42:43: 78	14143.078	OPEN	MPS E1 LH2 PREVLV (PV4) OP IND A	
261: 1:43:29: 0	14189.000	OPEN	E1 LH2 BLEED VALVE (New)	
261: 1:43:36: 0	14196.000	OPEN	E2 LH2 BLEED VALVE	
261: 1:44:12: 78	14232.078	CLOSED	MPS E1 LH2 PREVLV (PV4) CL IND	ISOLATE RECIRC LINES
261: 1:44:17: 78	14237.078	CLOSED	MPS E2 LH2 PREVLV (PV5) CL IND	

Table 1. STS-35 scrub 3 LH_2 leak isolation timeline (continued)

261: 1:44:23: 78	14243.078	CLOSED	MPS E3 LH2 PREVLV (PV6) CL IND
261: 1:52:49: 82	14749.082	OPEN	MPS E1 LH2 PREVLV (PV4) OP IND A
261: 1:52:56: 78	14756.078	OPEN	MPS E2 LH2 PREVLV (PV5) OP IND A
261: 1:53: 4: 78	14764.078	OPEN	MPS E3 LH2 PREVLV (PV6) OP IND A
261: 1:53:58: 82	14818.082	OPEN	MPS E1 LH2 RECIRC VLV(PV14) OP IND
261: 1:53:58: 82	14818.082	OPEN	MPS E3 LH2 RECIRC VLV(PV16) OP IND
261: 1:53:59: 82	14819.082	OPEN	MPS E2 LH2 RECIRC VLV(PV15) OP IND
261: 1:54: 0: 82	14820.082	ON	MPS E1 LH2 RECIRC PUMP (PP1) SPEED
261: 1:54: 2: 82	14822.082	ON	MPS E2 LH2 RECIRC PUMP (PP2) SPEED
261: 1:54: 4: 82	14824.082	ON	MPS E3 LH2 RECIRC PUMP (PP3) SPEED
261: 1:54:16: 82	14836.082	CLOSED	MPS E1 LH2 PREVLV (PV4) CL IND
261: 1:54:17: 82	14837.082	CLOSED	MPS E2 LH2 PREVLV (PV5) CL IND
261: 1:54:19: 82	14839.082	CLOSED	MPS E3 LH2 PREVLV (PV6) CL IND
261: 1:57:24: 82	15024.082	CLOSED	MPS E2 LH2 RECIRC VLV(PV15) CL IND
261: 1:57:24: 82	15024.082	CLOSED	MPS E3 LH2 RECIRC VLV(PV16) CL IND
261: 1:57:41: 82	15041.082	CLOSED	MPS E1 LH2 RECIRC VLV(PV14) CL IND
261: 2: 2:53: 85	15353.086	OPEN	MPS E1 LH2 RECIRC VLV(PV14) OP IND
261: 2: 2:53: 85	15353.086	OPEN	MPS E2 LH2 RECIRC VLV(PV15) OP IND
261: 2: 2:53: 85	15353.086	OPEN	MPS E3 LH2 RECIRC VLV(PV16) OP IND
2:30	17004	close	IO F/D
261: 2:25:51: 89	16731.090	OPEN	MPS LH2 TOPPING VLV (PV13) OP IND
3: 0:46	18392	open	IB F/D
261: 3: 7:39: 0	18812.102	ON	STOP FLOW
261: 3: 7:45:105	19245.105	CLOSED	A100679 REPL VLV CLOSED #1 IND
261: 3:14:50: 0	19257.105	ON	AUTO FILL
261: 3:26:41:109	20381.109	OPEN	A100679 REPL VLV OPEN #1 IND
261: 3:27: 6:109	20406.109	CLOSED	MPS LH2 INBD F/D VLV (PV12) CL IND
261: 4: 3:31:121	22591.121	CLOSED	A3301 XFR LINE VLV CLOSED #1 IND

Table 1. STS-35 scrub 3 LH_2 leak isolation timeline (continued)

261: 4: 3:35: 0	22591.121	ON	FAST FILL TO 98% COMPLETE	
261: 4: 3:55:441	22611.441	OPEN	ET LH2 VENT VLV #1 OPEN IND	
261: 4:33:44: 0	23508.129	ON	STOP FLOW	
261: 4:33:50:132	24410.133	CLOSED	A100679 REPL VLV CLOSED #1 IND	
261: 4:37:36: 0	24413.133	ON	AUTO DRAIN	
261: 4:40:58:136	24838.137	CLOSED	MPS LH2 HI PT BL VLV (PV22) CL IND	
261: 4:45:29:136	25109.137	OPEN	MPS LH2 HI PT BL VLV (PV22) OP IND	
261: 4:56:20:140	25760.141	CLOSED	MPS LH2 TOPPING VLV (PV13) CL IND	
261: 4:56:33:140	25773.141	OPEN	A100677 MAIN FILL VALVE OPEN IND	
261: 4:57: 1:140	25801.141	OPEN	MPS LH2 INBD F/D VLV (PV12) OP IND	
261: 5: 0:38:140	26018.141	OFF	MPS E1 LH2 RECIRC PUMP (PP1) SPEED	ENGINE 1 RECIRC TEST
261: 5: 0:46:140	26026.141	OPEN	MPS E1 LH2 PREVLV (PV4) OP IND A	
261: 5: 5: 3:144	26283.145	ON	MPS E1 LH2 RECIRC PUMP (PP1) SPEED	
261: 5: 5:13:144	26293.145	CLOSED	MPS E1 LH2 PREVLV (PV4) CL IND	
261: 5: 6:55:144	26395.145	OFF	MPS E2 LH2 RECIRC PUMP (PP2) SPEED	ENGINE 2 RECIRC TEST
261: 5: 7: 4:144	26404.145	OPEN	MPS E2 LH2 PREVLV (PV5) OP IND A	
261: 5:12: 2:144	26702.145	ON	MPS E2 LH2 RECIRC PUMP (PP2) SPEED	
261: 5:12:11:144	26711.145	CLOSED	MPS E2 LH2 PREVLV (PV5) CL IND	
261: 5:15:20:148	26900.148	OFF	MPS E3 LH2 RECIRC PUMP (PP3) SPEED	ENGINE 3 RECIRC TEST
261: 5:15:29:148	26909.148	OPEN	MPS E3 LH2 PREVLV (PV6) OP IND A	
261: 5:20:48:148	27228.148	OFF	MPS E2 LH2 RECIRC PUMP (PP2) SPEED	
261: 5:20:58:148	27238.148	OPEN	MPS E2 LH2 PREVLV (PV5) OP IND A	
261: 5:24: 1:148	27421.148	ON	MPS E3 LH2 RECIRC PUMP (PP3) SPEED	
261: 5:24:10:148	27430.148	CLOSED	MPS E3 LH2 PREVLV (PV6) CL IND	
261: 5:26:58:152	27598.152	ON	MPS E2 LH2 RECIRC PUMP (PP2) SPEED	
261: 5:27: 8: 0	27608.000	CLOSED	E2 LH2 BLEED VALVE	

Table 1. STS-35 scrub 3 LH_2 leak isolation timeline (continued)

261: 5:31:14: 0	27854.000	OPEN	E2 LH2 BLEED VALVE	
261: 5:31:23:152	27863.152	CLOSED	MPS E2 LH2 PREVLV (PV5) CL IND	
261: 5:31:48:152	27888.152	OPEN	MPS E1 LH2 PREVLV (PV4) OP IND A	
261: 5:31:52: 0	27893.000	CLOSED	E1 LH2 BLEED VALVE	
261: 5:35:11: 0	28091.000	OPEN	E1 LH2 BLEED VALVE	
261: 5:35:20:152	28100.152	CLOSED	MPS E1 LH2 PREVLV (PV4) CL IND	
261: 5:35:42:152	28122.152	OPEN	MPS E3 LH2 PREVLV (PV6) OP IND A	
261: 5:35:45: 0	28125.000	CLOSED	E3 LH2 BLEED VALVE	
261: 5:39:16:156	28336.156	OFF	MPS E3 LH2 RECIRC PUMP (PP3) SPEED	
261: 5:39:38: 0	28358.000	OPEN	E3 LH2 BLEED VALVE	
261: 5:39:45:156	28365.156	OFF	MPS E2 LH2 RECIRC PUMP (PP2) SPEED	
261: 5:39:55:156	28375.156	OPEN	MPS E2 LH2 PREVLV (PV5) OP IND A	
261: 5:48: 9:156	28869.156	ON	MPS E2 LH2 RECIRC PUMP (PP2) SPEED	
261: 5:48:18:156	28878.156	CLOSED	MPS E2 LH2 PREVLV (PV5) CL IND	
261: 5:48:25:156	28885.156	OPEN	MPS E1 LH2 PREVLV (PV4) OP IND A	
261: 5:48:31:156	28891.156	OFF	MPS E1 LH2 RECIRC PUMP (PP1) SPEED	
261: 5:51:34:160	29074.160	ON	MPS E3 LH2 RECIRC PUMP (PP3) SPEED	
261: 5:51:42:160	29082.160	CLOSED	MPS E3 LH2 PREVLV (PV6). CL IND	
261: 5:51:47:160	29087.160	OPEN	MPS E2 LH2 PREVLV (PV5) OP IND A	
261: 5:51:54:160	29094.160	OFF	MPS E2 LH2 RECIRC PUMP (PP2) SPEED	
261: 5:54:32: 0	29094.160	ON	STOP FLOW	
261: 5:54:44:160	29264.160	CLOSED	A100678 AUX FILL VALVE CLOSED IND	
261: 5:58:19:160	29479.160	ON	MPS E1 LH2 RECIRC PUMP (PP1) SPEED	RECIRC RETURN LOCK-UP TEST
261: 5:58:27:160	29487.160	CLOSED	MPS E1 LH2 PREVLV (PV4) CL IND	
261: 5:58:35:160	29495.160	ON	MPS E2 LH2 RECIRC PUMP (PP2) SPEED	

Table 1. STS-35 scrub 3 LH_2 leak isolation timeline (continued)

261: 5:58:42:160	29502.160	CLOSED	MPS E2 LH2 PREVLV (PV5) CL IND
261: 6: 0:32:160	29612.160	OFF	MPS E2 LH2 RECIRC PUMP (PP2) SPEED
261: 6: 0:42:160	29622.160	OPEN	MPS E2 LH2 PREVLV (PV5) OP IND A
261: 6: 0:48:160	29628.160	OFF	MPS E1 LH2 RECIRC PUMP (PP1) SPEED
261: 6: 0:55:160	29635.160	OPEN	MPS E1 LH2 PREVLV (PV4) OP IND A
261: 6: 1: 3: 0	29643.000	CLOSED	E1 LH2 BLEED VALVE
261: 6: 1:10: 0	29650.000	CLOSED	E2 LH2 BLEED VALVE
261: 6: 1:14:160	29654.160	CLOSED	MPS LH2 4IN DISC VLV (PD3) CL IND
261: 6: 1:24:160	29664.160	OFF	MPS E3 LH2 RECIRC PUMP (PP3) SPEED
261: 6: 1:25:160	29665.160	ON	MPS E3 LH2 RECIRC PUMP (PP3) SPEED
261: 6: 1:27:160	29667.160	OFF	MPS E3 LH2 RECIRC PUMP (PP3) SPEED
261: 6: 1:32:160	29672.160	CLOSED	MPS E2 LH2 RECIRC VLV(PV15) CL IND
261: 6: 1:32:160	29672.160	CLOSED	MPS E3 LH2 RECIRC VLV(PV16) CL IND
261: 6: 2:19:160	29719.160	OPEN	MPS E3 LH2 PREVLV (PV6) OP IND A
261: 6: 5:29:164	29909.164	CLOSED	MPS E1 LH2 PREVLV (PV4) CL IND
261: 6: 5:53:164	29933.164	OPEN	MPS E1 LH2 PREVLV (PV4) OP IND A
261: 6: 6:57:164	29997.164	OPEN	MPS LH2 TOPPING VLV (PV13) OP IND
261: 6: 7: 6: 0	30007.000	OPEN	E1 LH2 BLEED VALVE
261: 6: 7:14: 0	30014.000	OPEN	E2 LH2 BLEED VALVE
261: 6: 7:39:164	30039.164	CLOSED	MPS E1 LH2 PREVLV (PV4) CL IND
261: 6: 7:43:164	30043.164	CLOSED	MPS E2 LH2 PREVLV (PV5) CL IND
261: 6: 7:46:164	30046.164	CLOSED	MPS E3 LH2 PREVLV (PV6) CL IND
261: 6: 7:55:164	30055.164	CLOSED	MPS LH2 HI PT BL VLV (PV22) CL IND
261: 6:10:24: 0	30055.164	ON	AUTO DRAIN
261: 6:11:39:164	30279.164	CLOSED	MPS E1 LH2 RECIRC VLV(PV14) CL IND
261: 6:12:41:164	30341.164	CLOSED	MPS LH2 TOPPING VLV (PV13) CL IND

Table 1. STS-35 scrub 3 LH_2 leak isolation timeline (continued)

261: 6:12:55:164	30355.164	OPEN	A100677 MAIN FILL VALVE OPEN IND
261: 6:13:47:164	30407.164	OPEN	MPS LH2 TOPPING VLV (PV13) OP IND

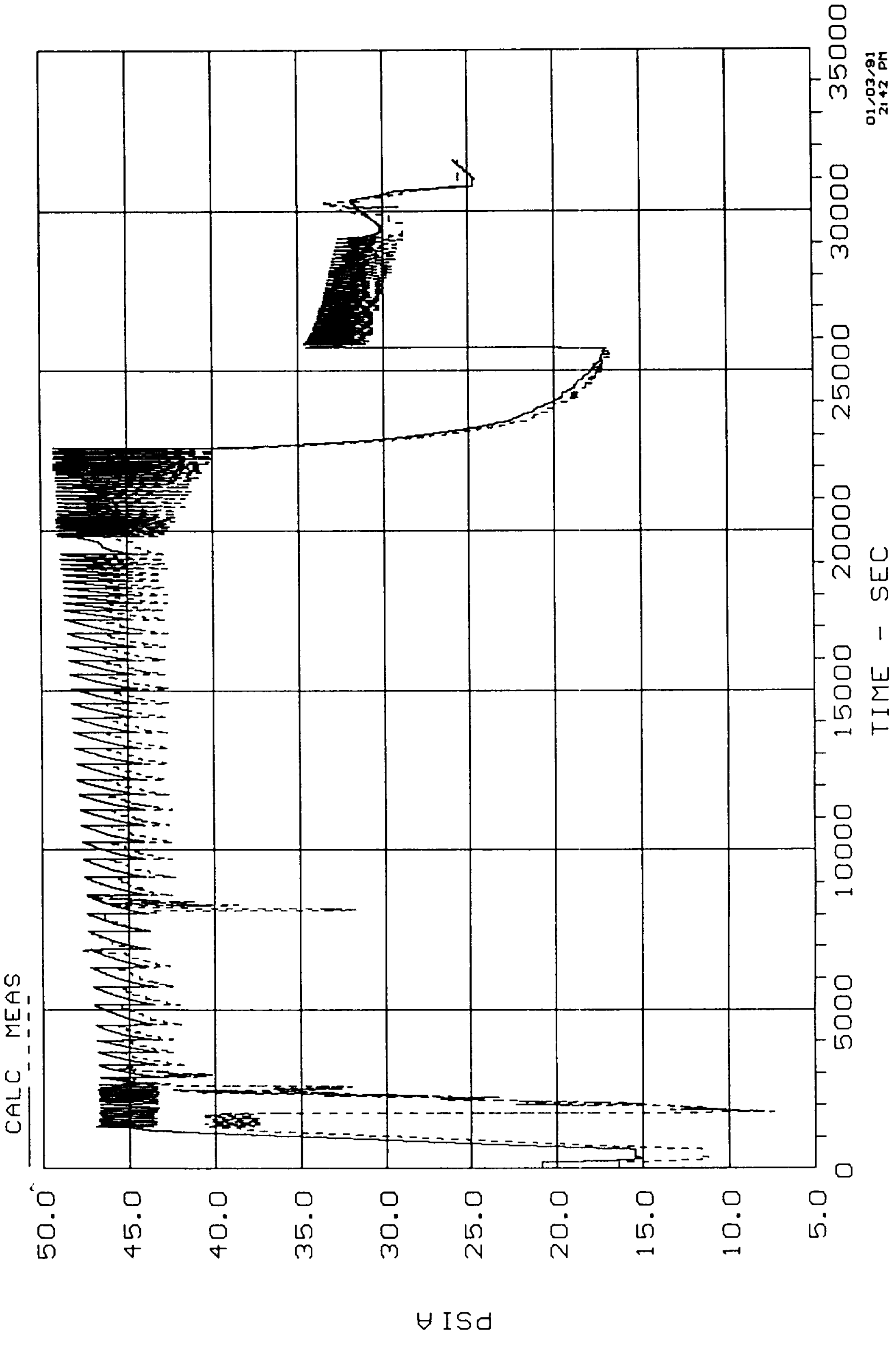

Figure 1. STS-35 S3 manifold pressure.

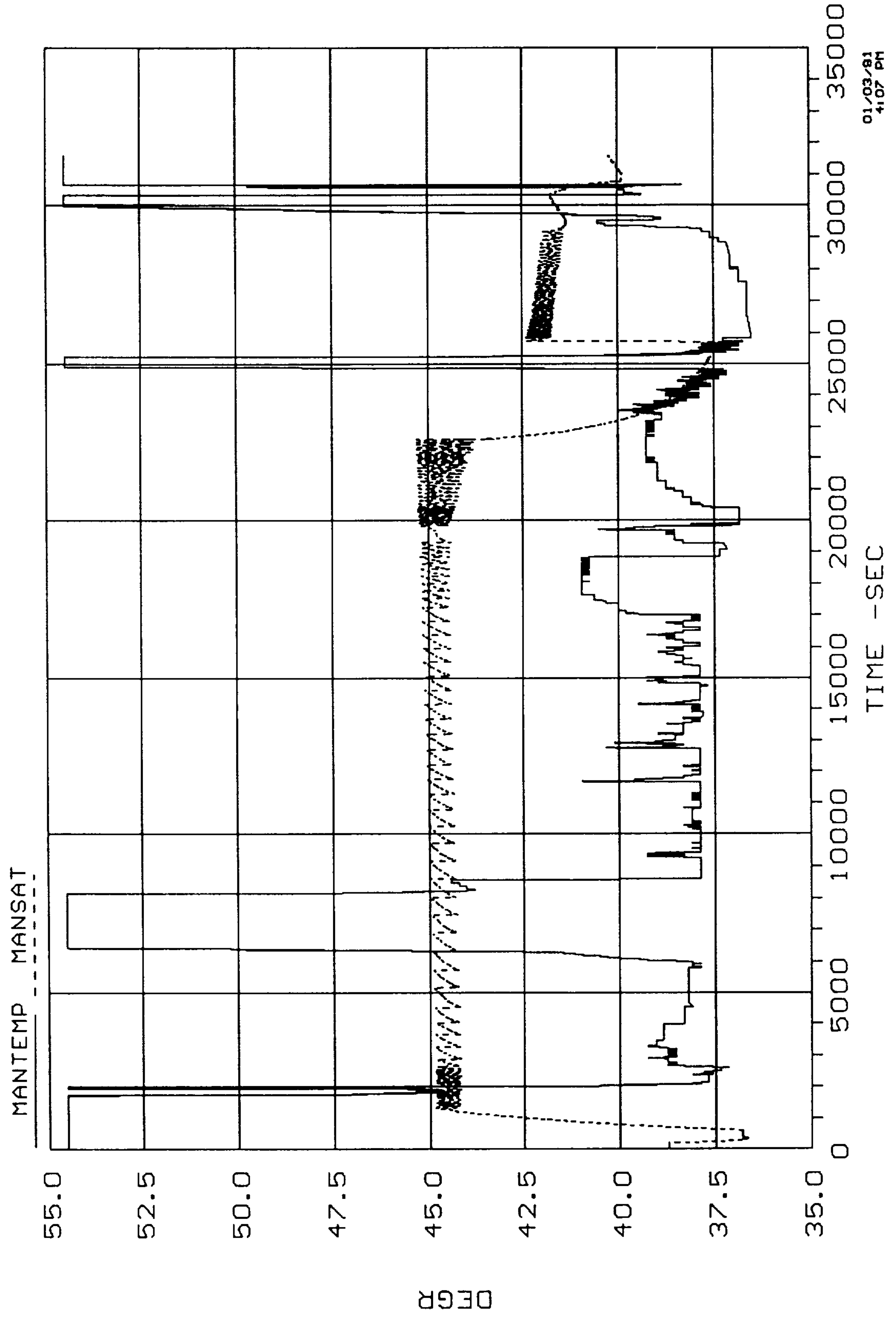

Figure 2. STS-35 S3 manifold temperature

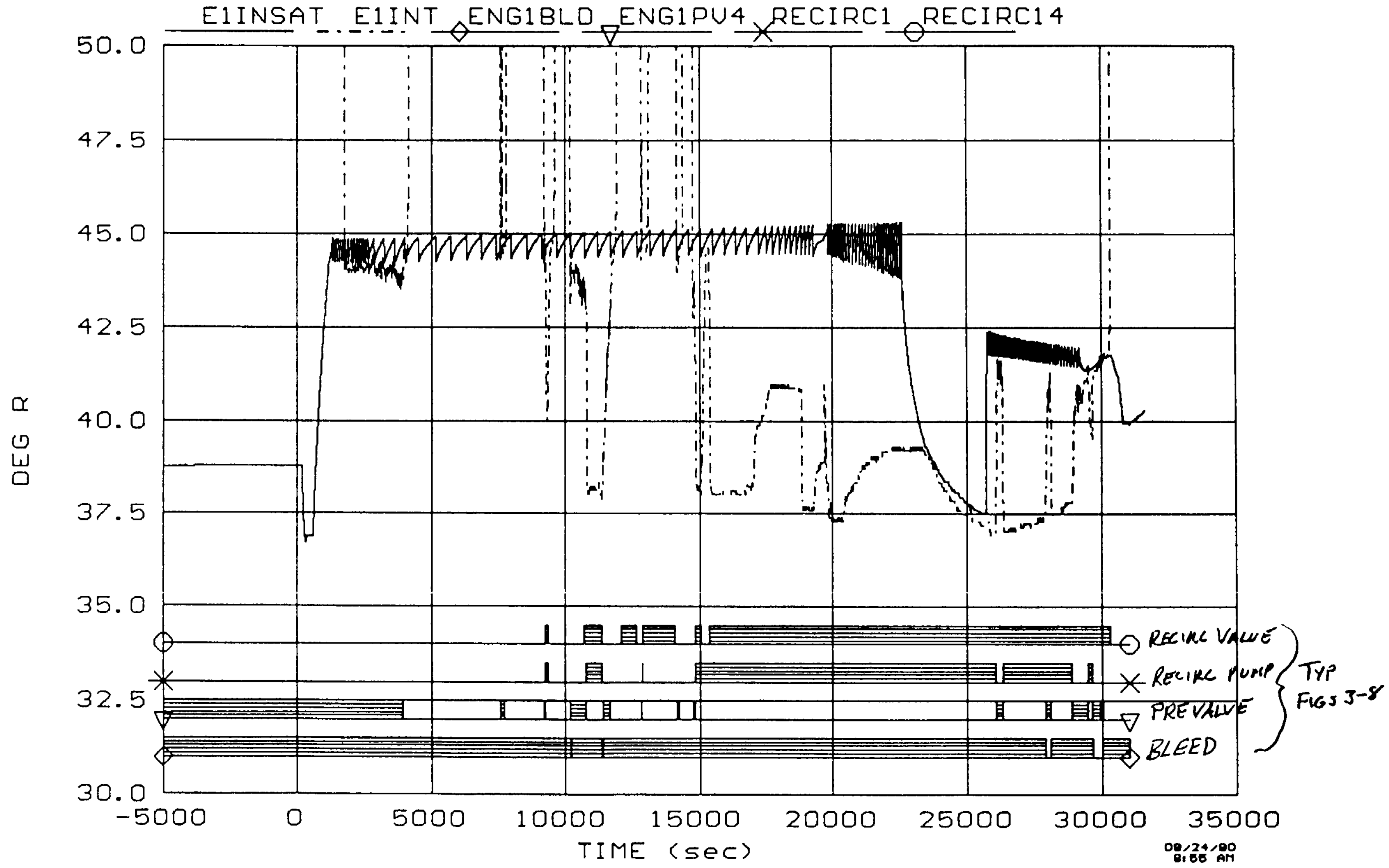

Figure 3. STS-35 S3 engine 1 inlet temperature.

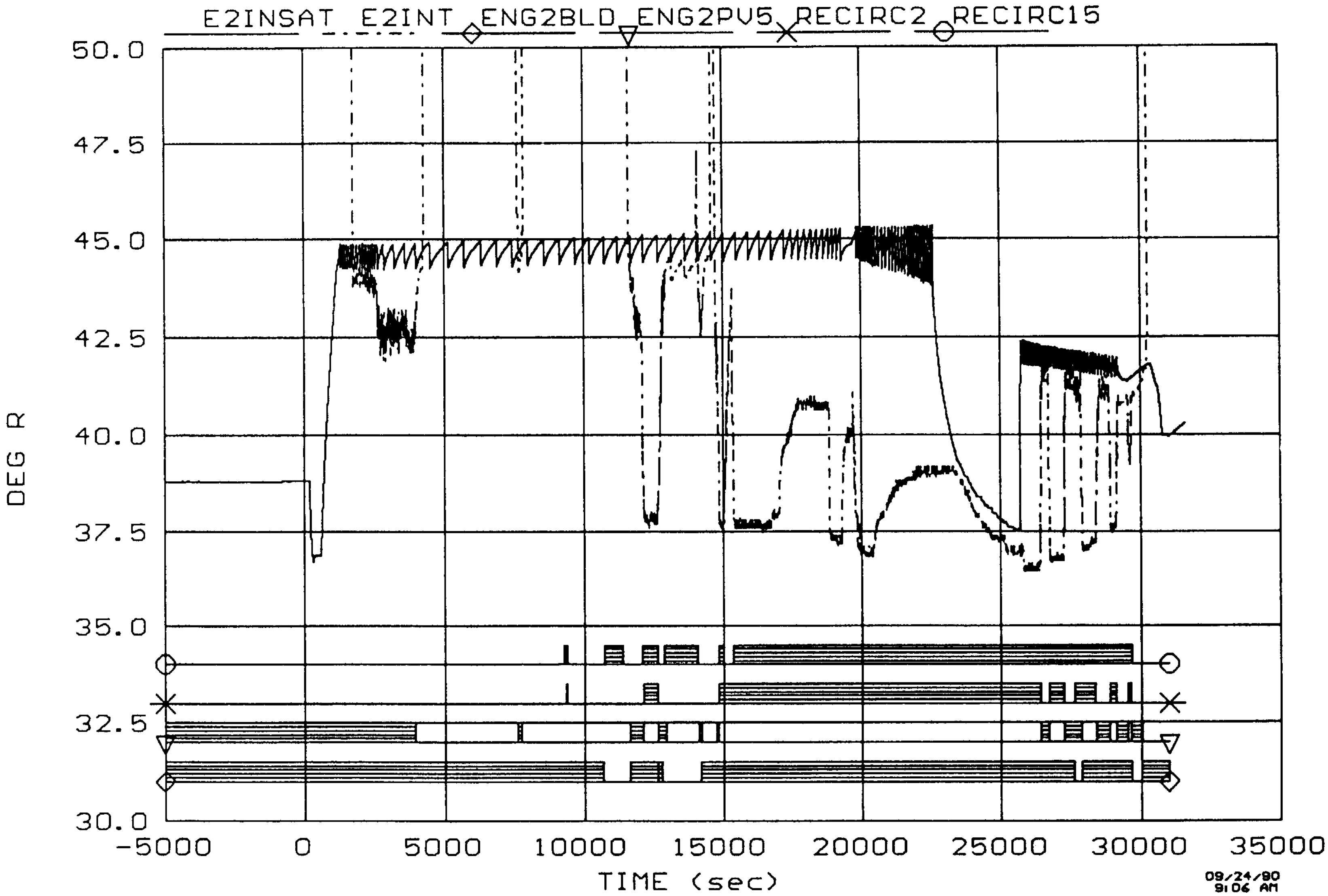

Figure 4. STS-35 S3 engine 2 inlet temperature.

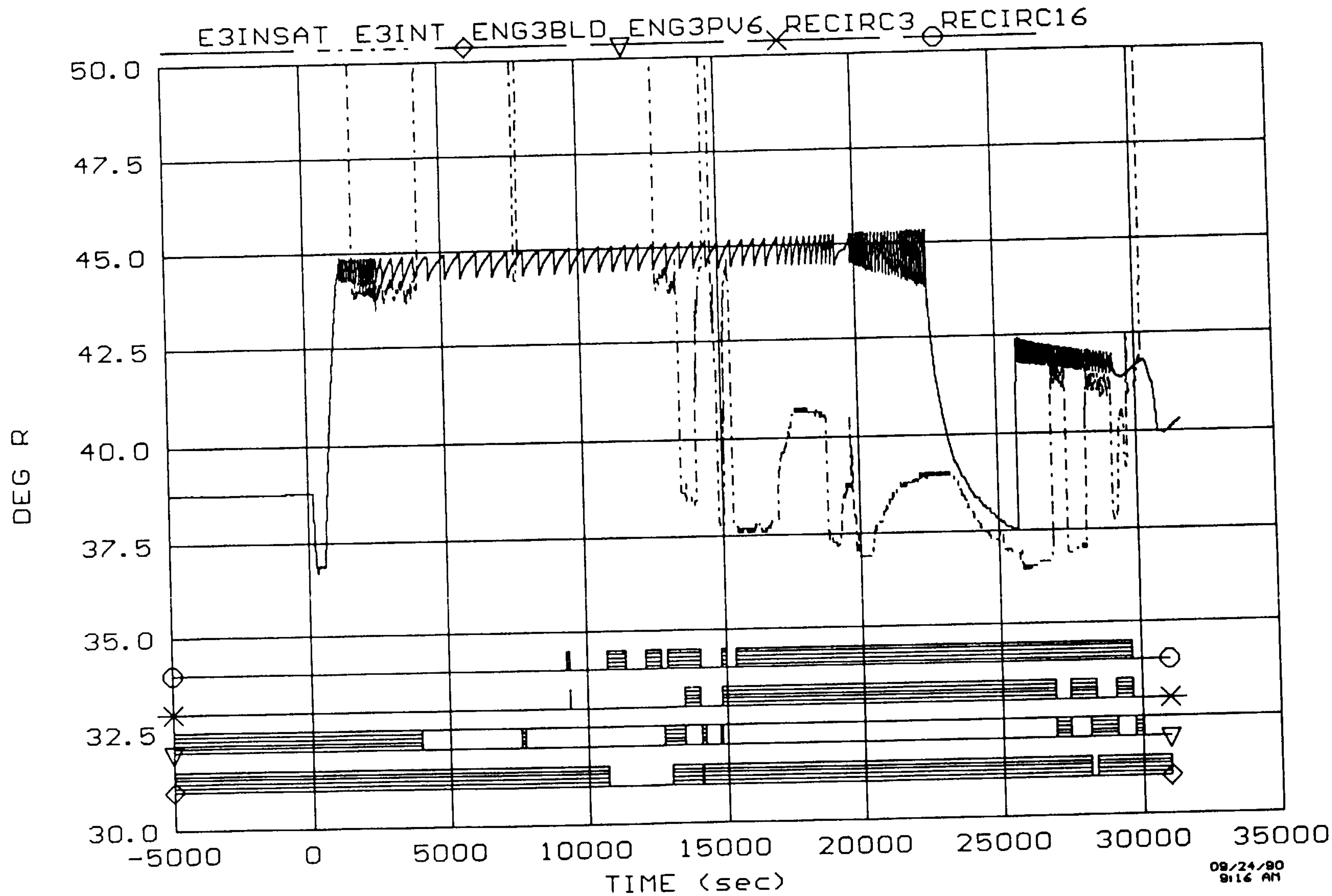

Figure 5. STS-35 S3 engine 3 inlet temperature.

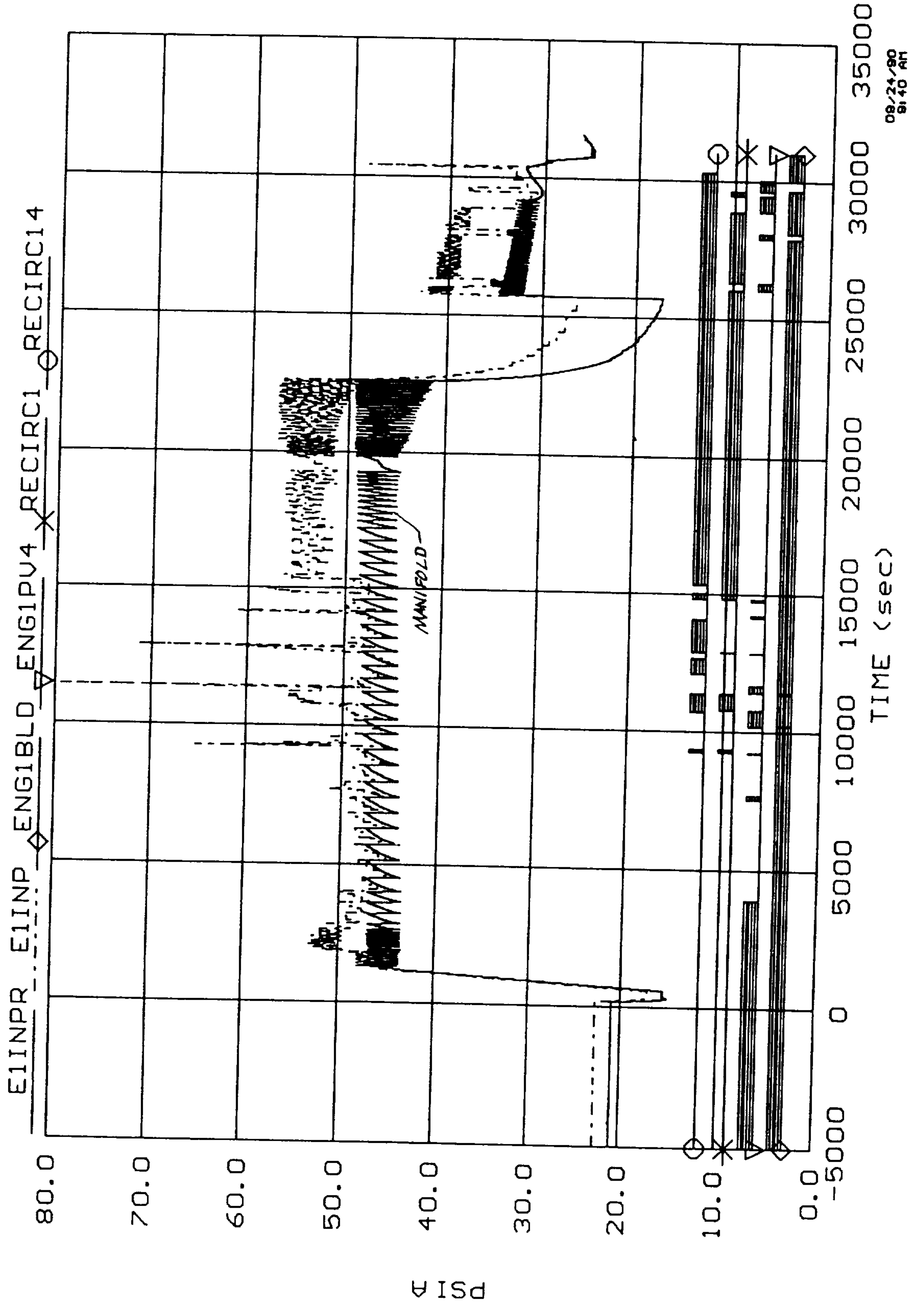

Figure 6. STS-35 S3 engine 1 inlet pressure.

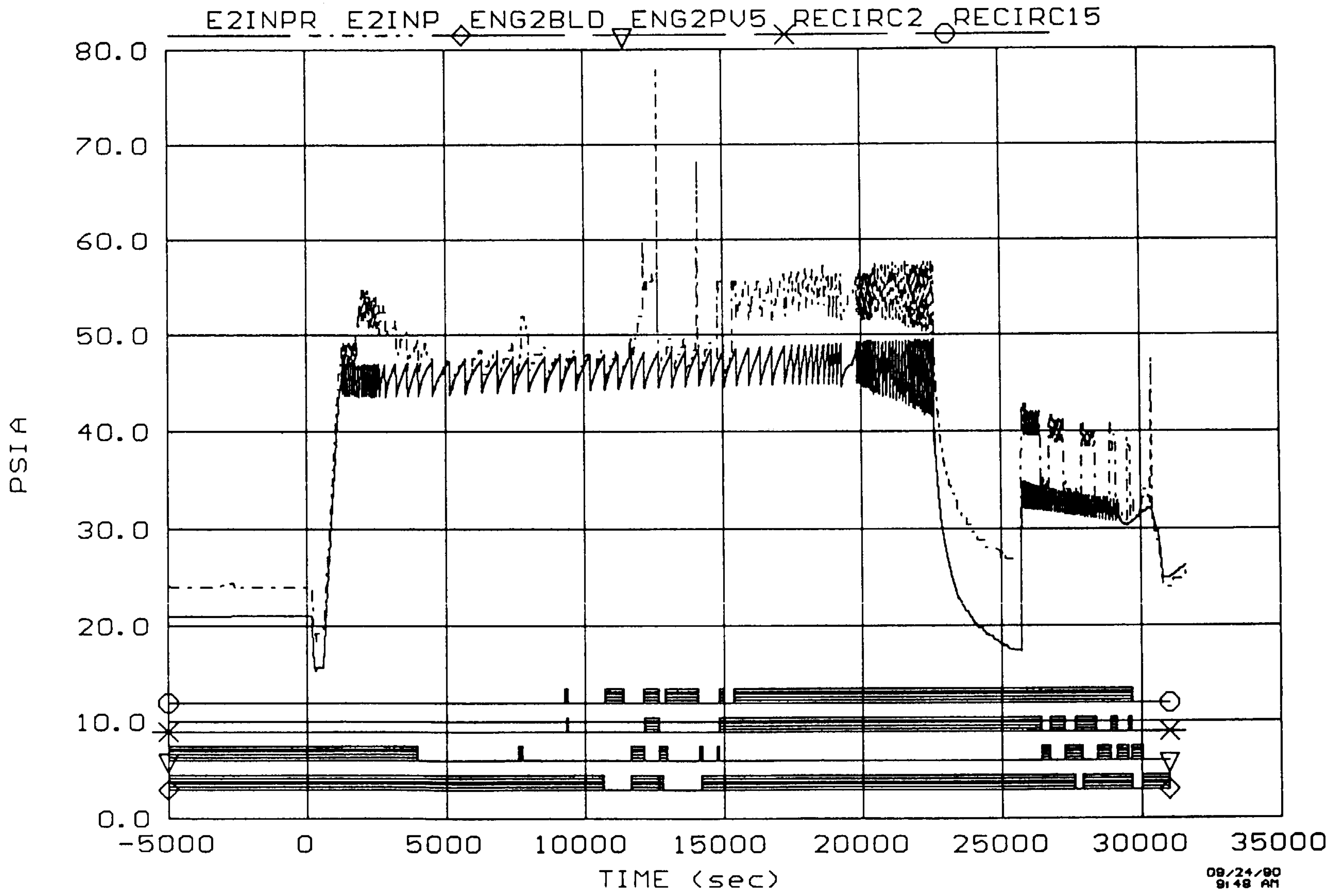

Figure 7. STS-35 S3 engine 2 inlet pressure.

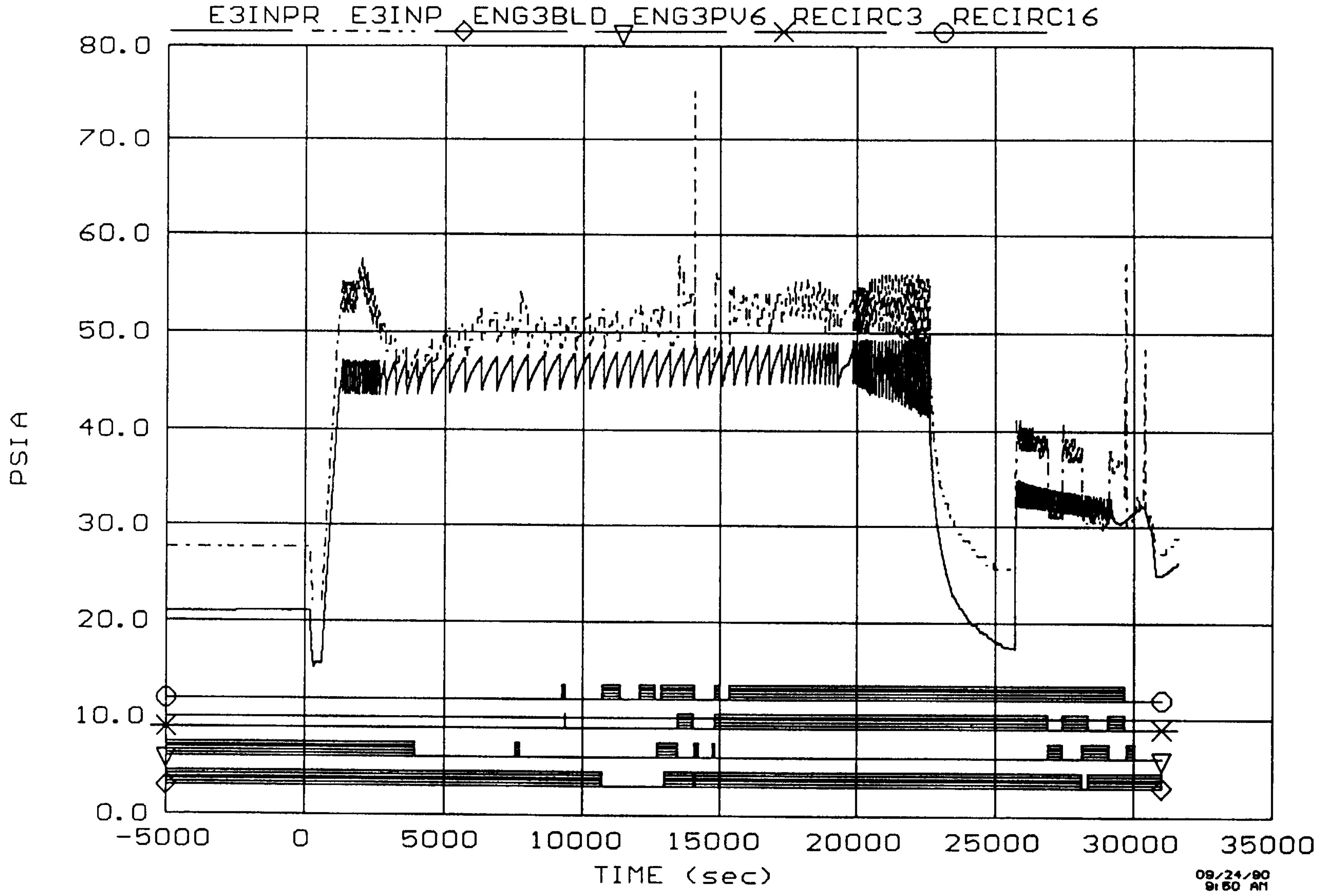

Figure 8. STS-35 S3 engine 3 inlet pressure.

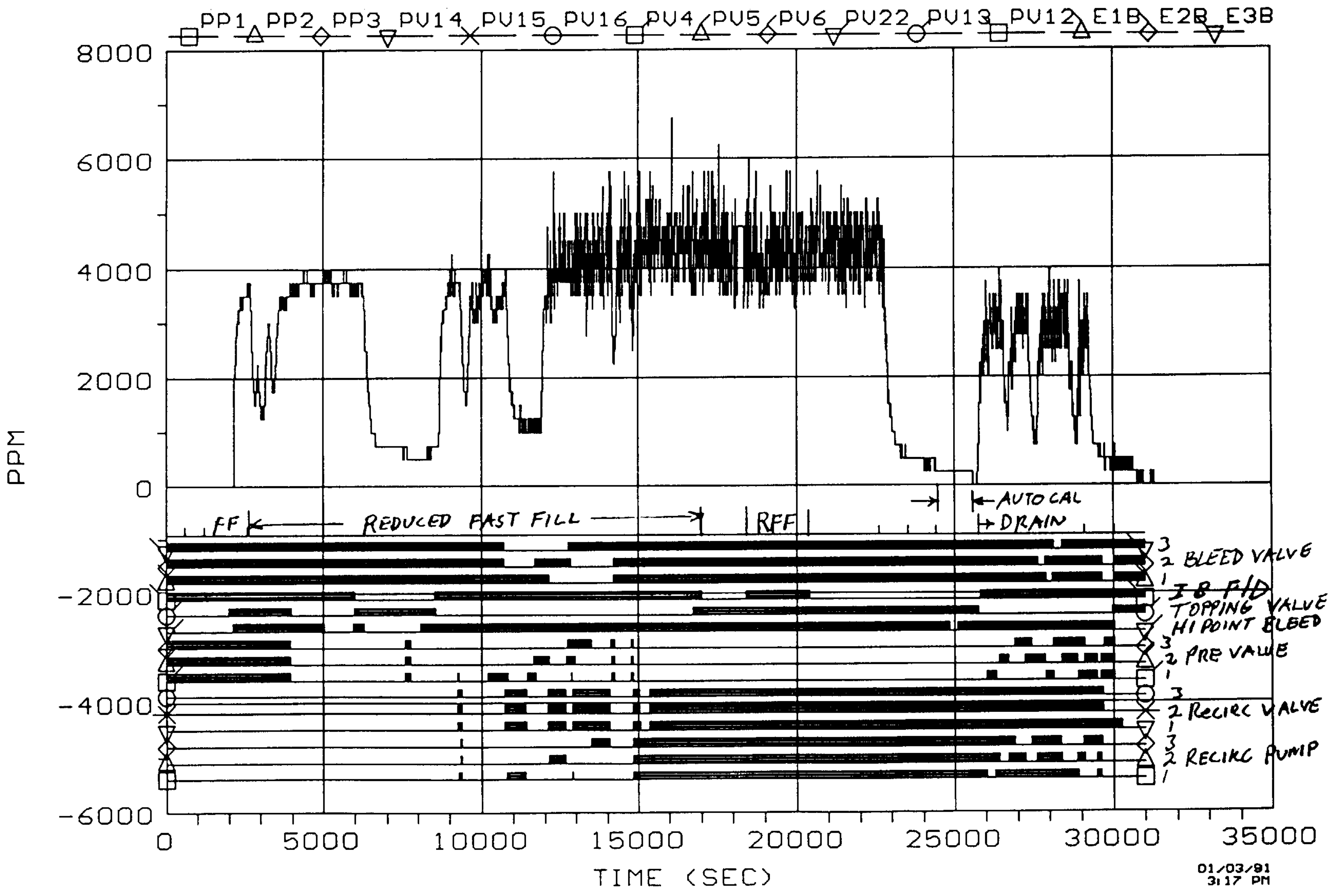

Figure 9. STS-35 S3 aft compartment high range H_2 concentration.

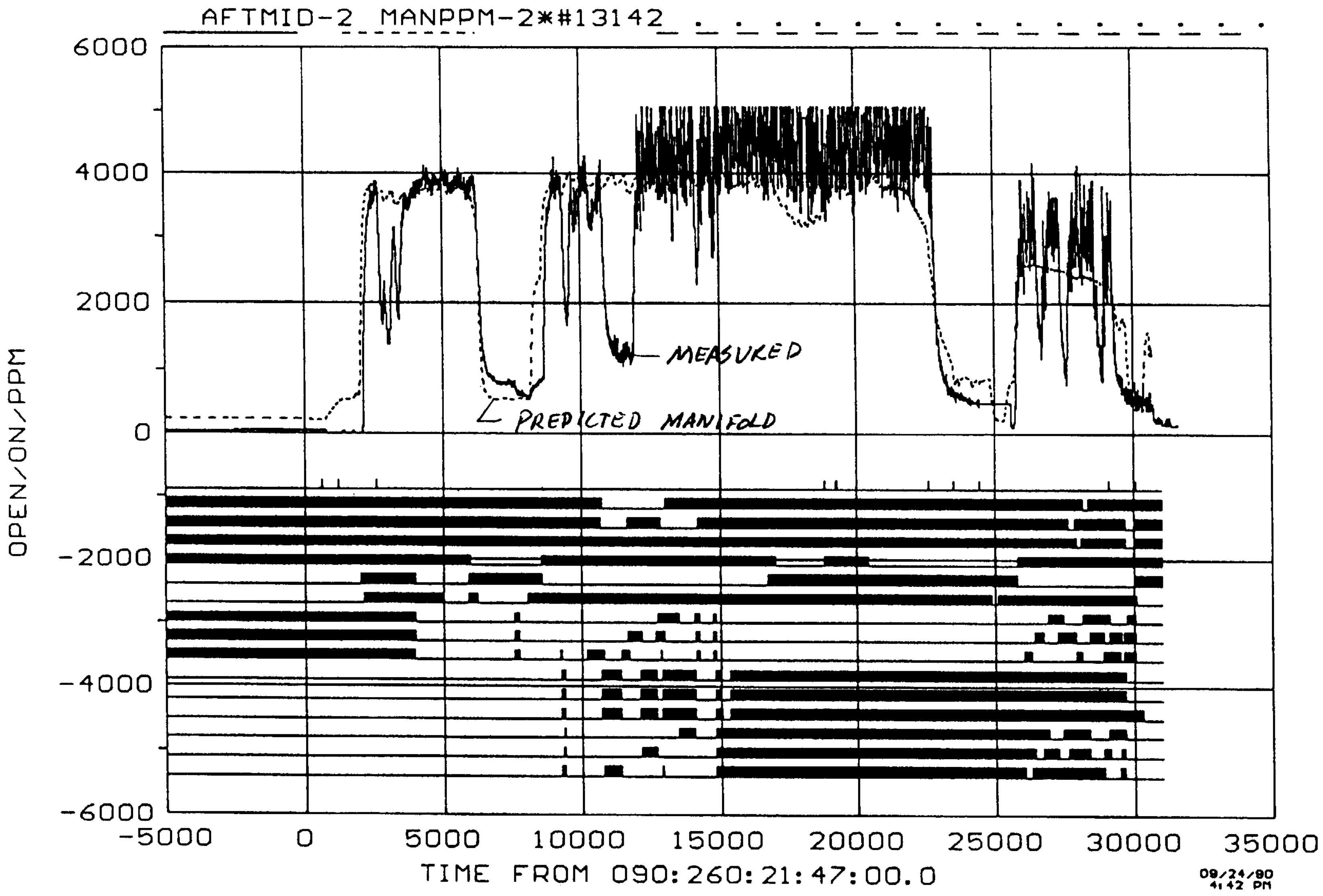

Figure 10. STS-35 scrub 3.

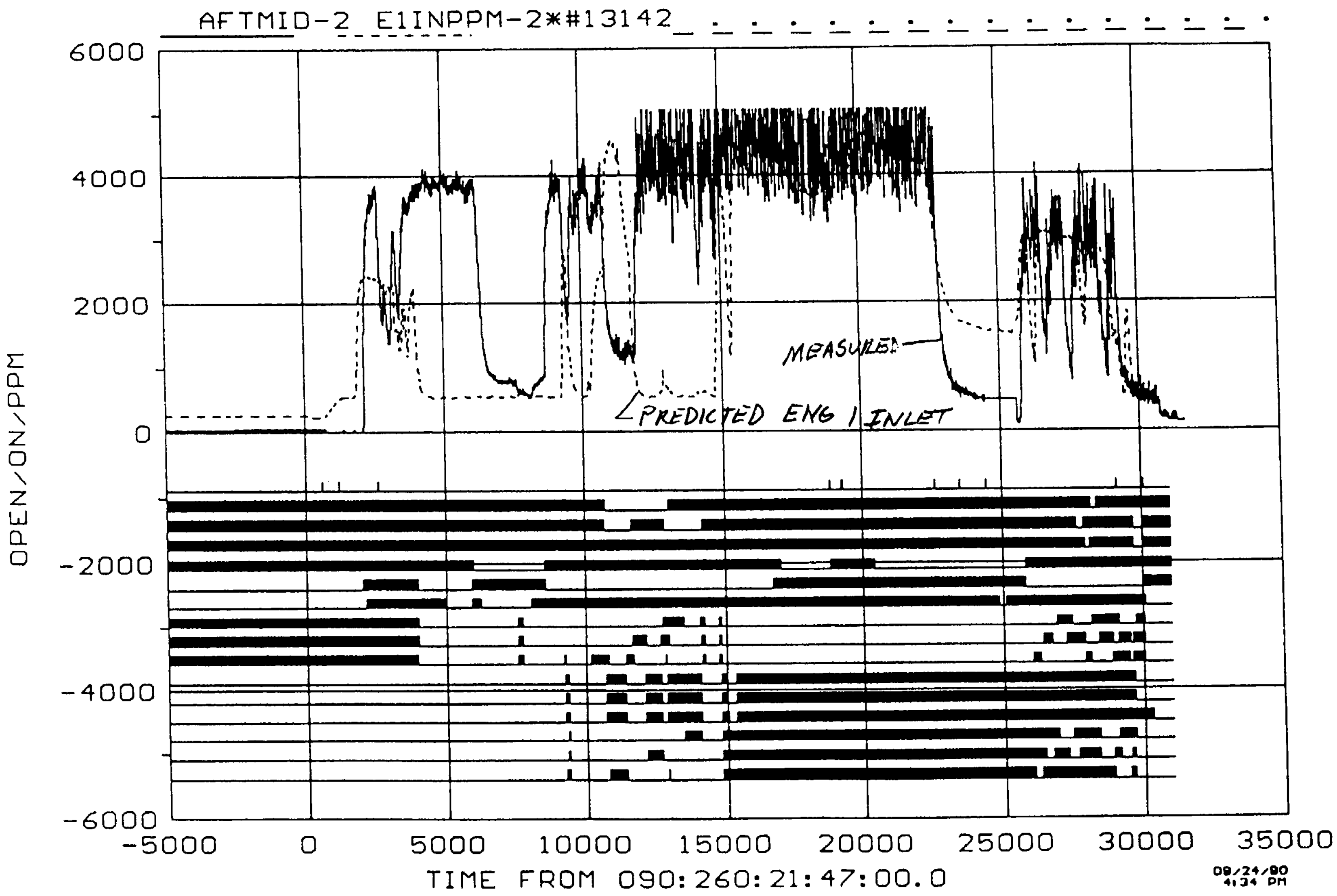

Figure 11. STS-35 scrub 3.

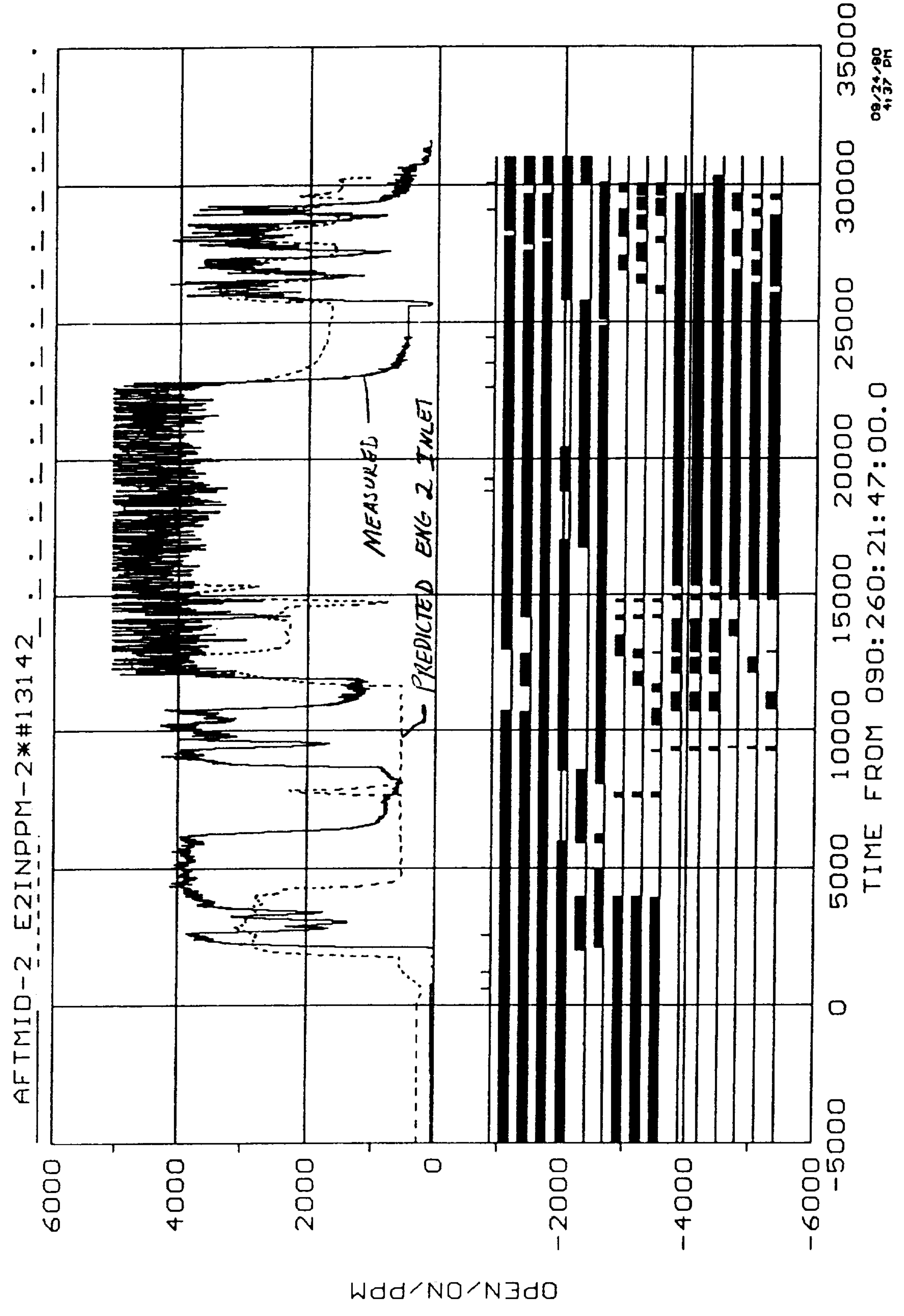

Figure 12. STS-35 scrub 3.

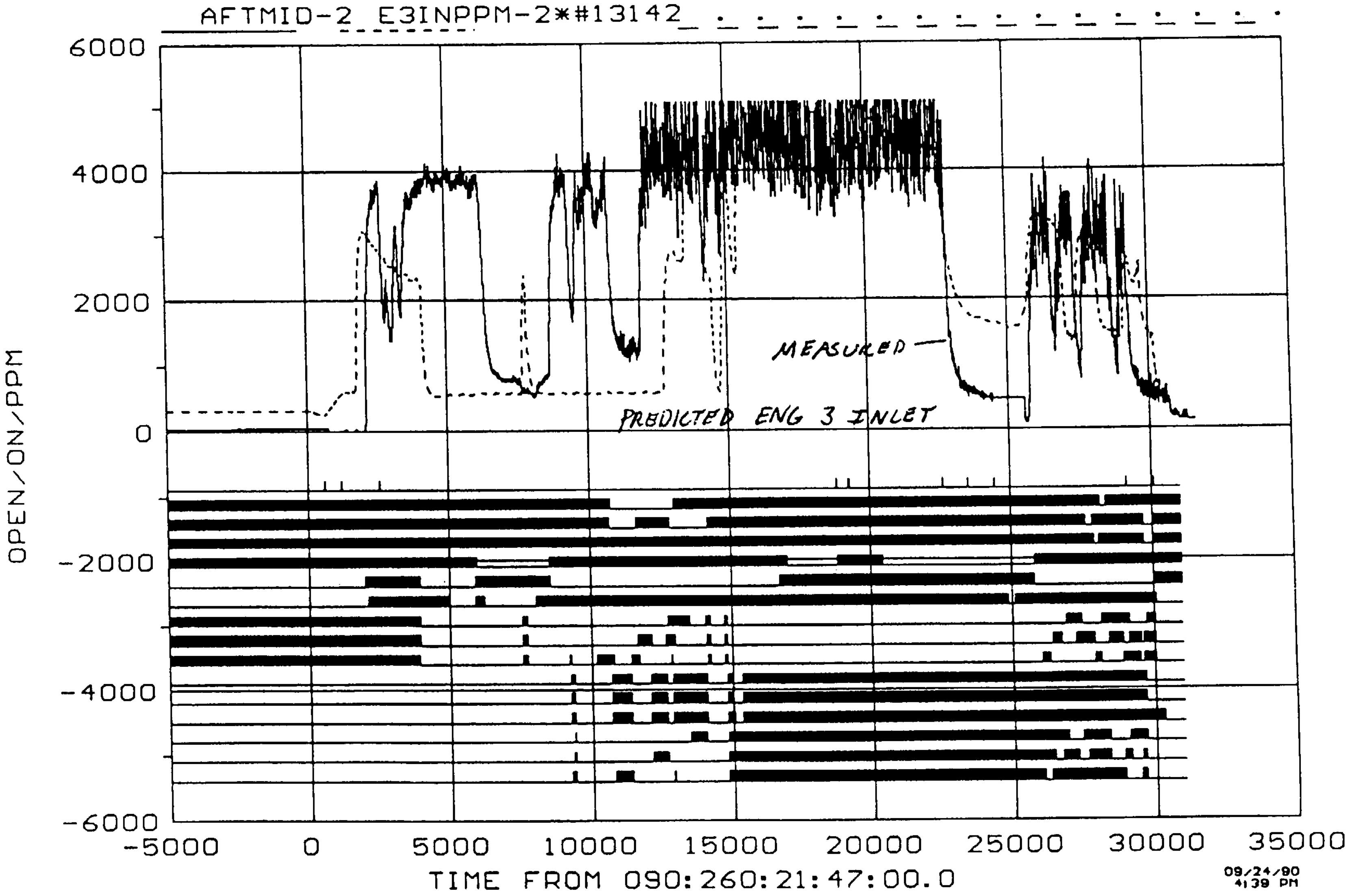

Figure 13. STS-35 scrub 3.

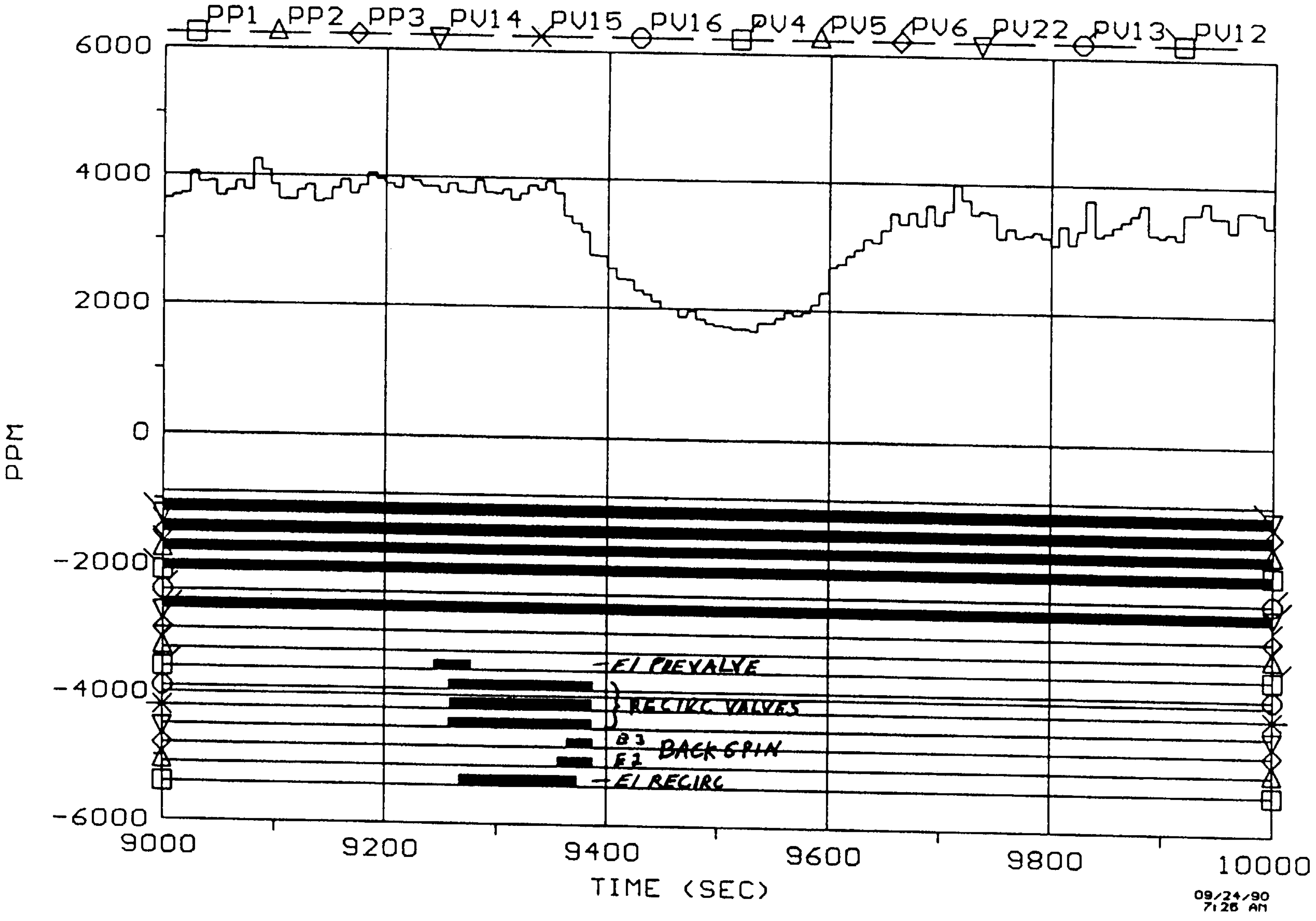

Figure 14. STS-35 S3 aft compartment H_2 concentration.

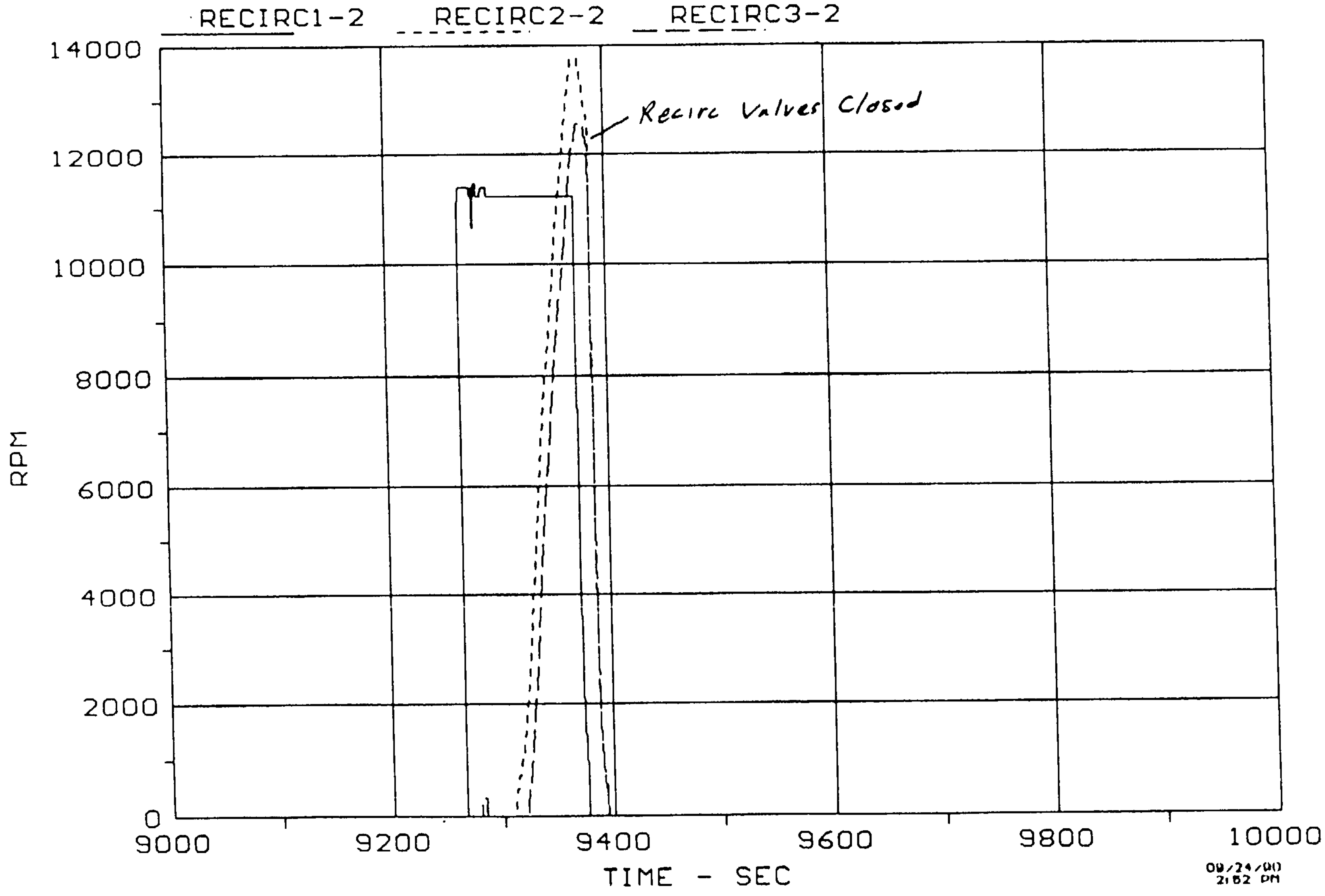

Figure 15. STS-35 S3 recirculation pump speed.

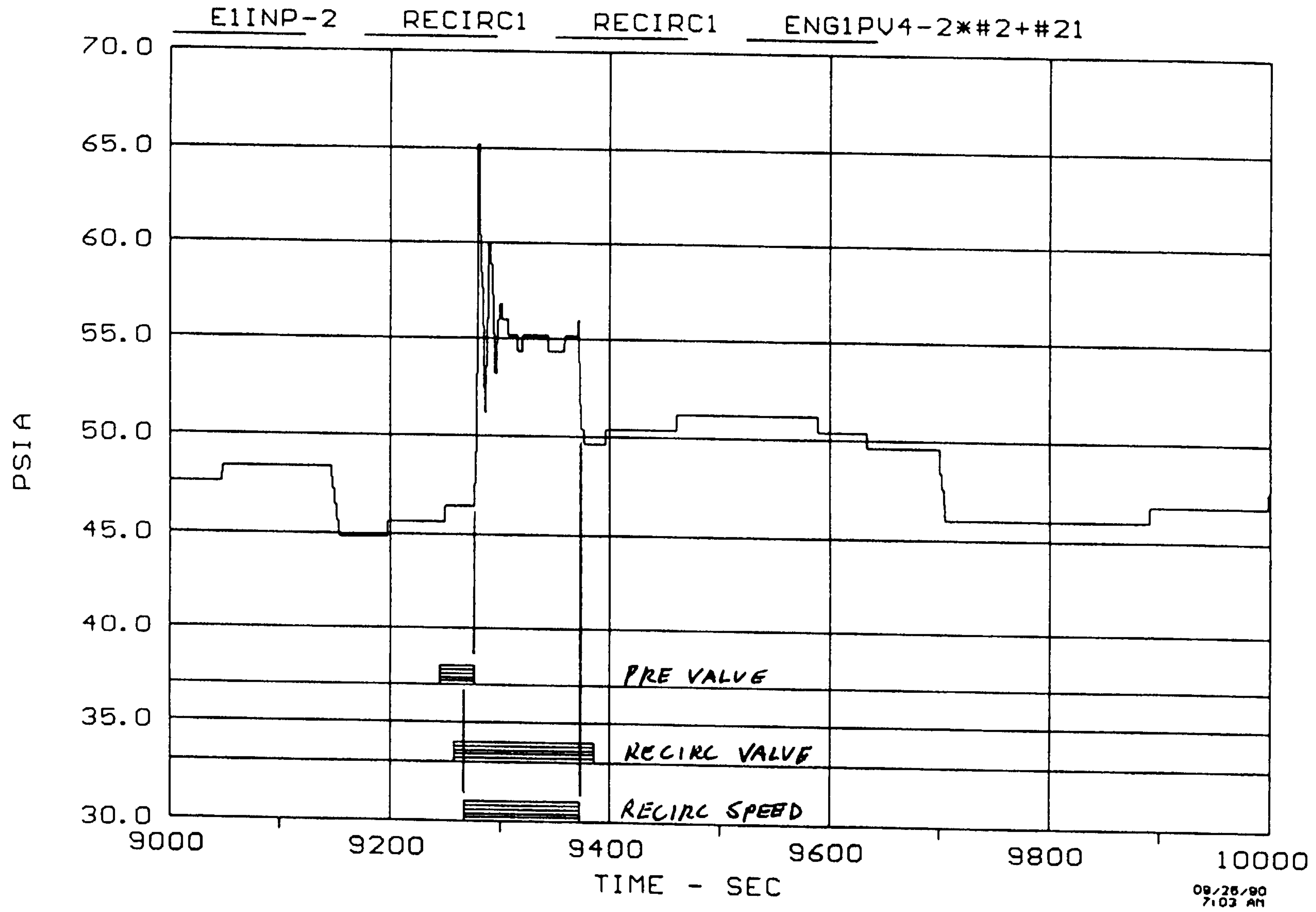

Figure 16. STS-35 S3 engine 1 inlet pressure.

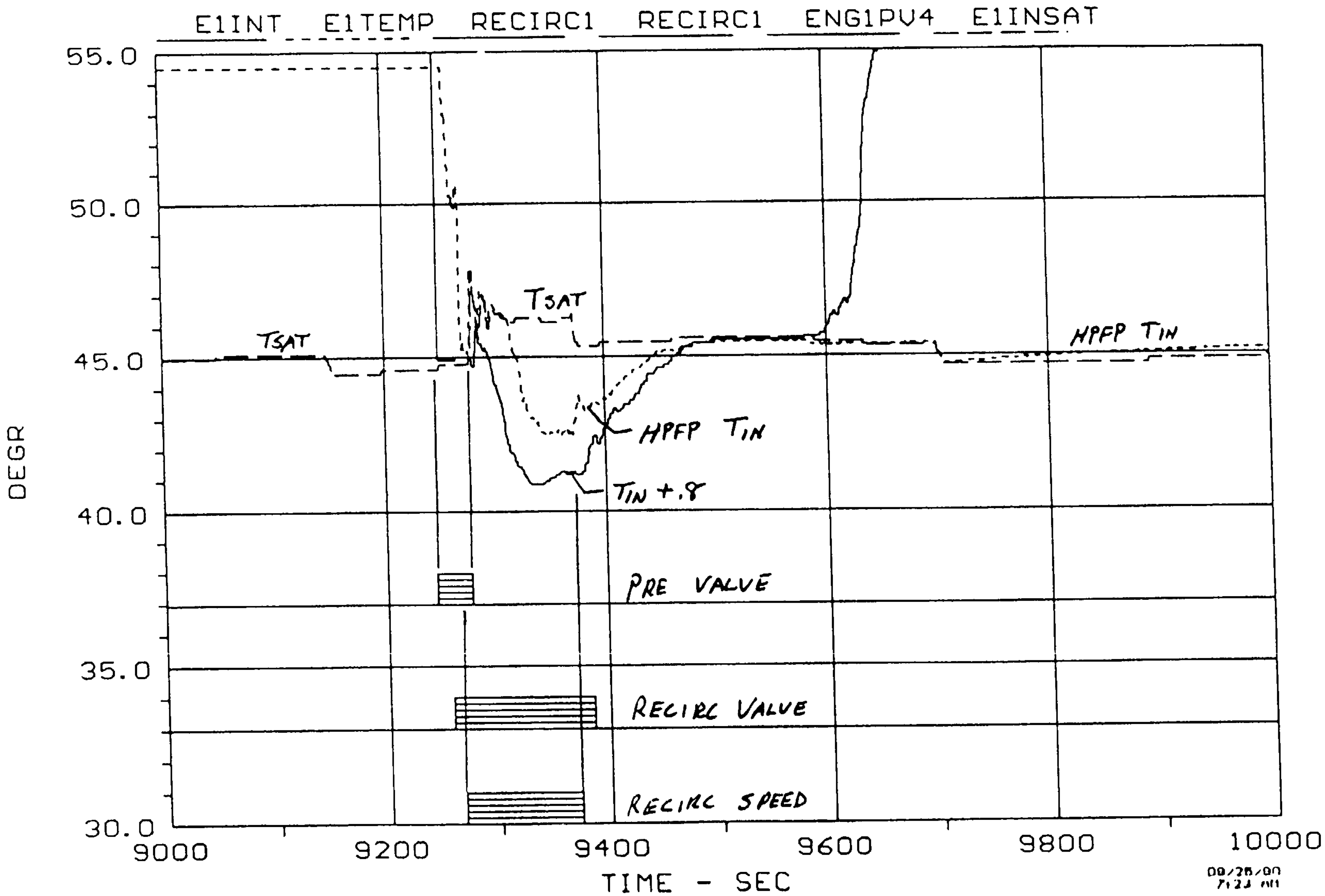

Figure 17. STS-35 S3 engine 1 inlet temperature.

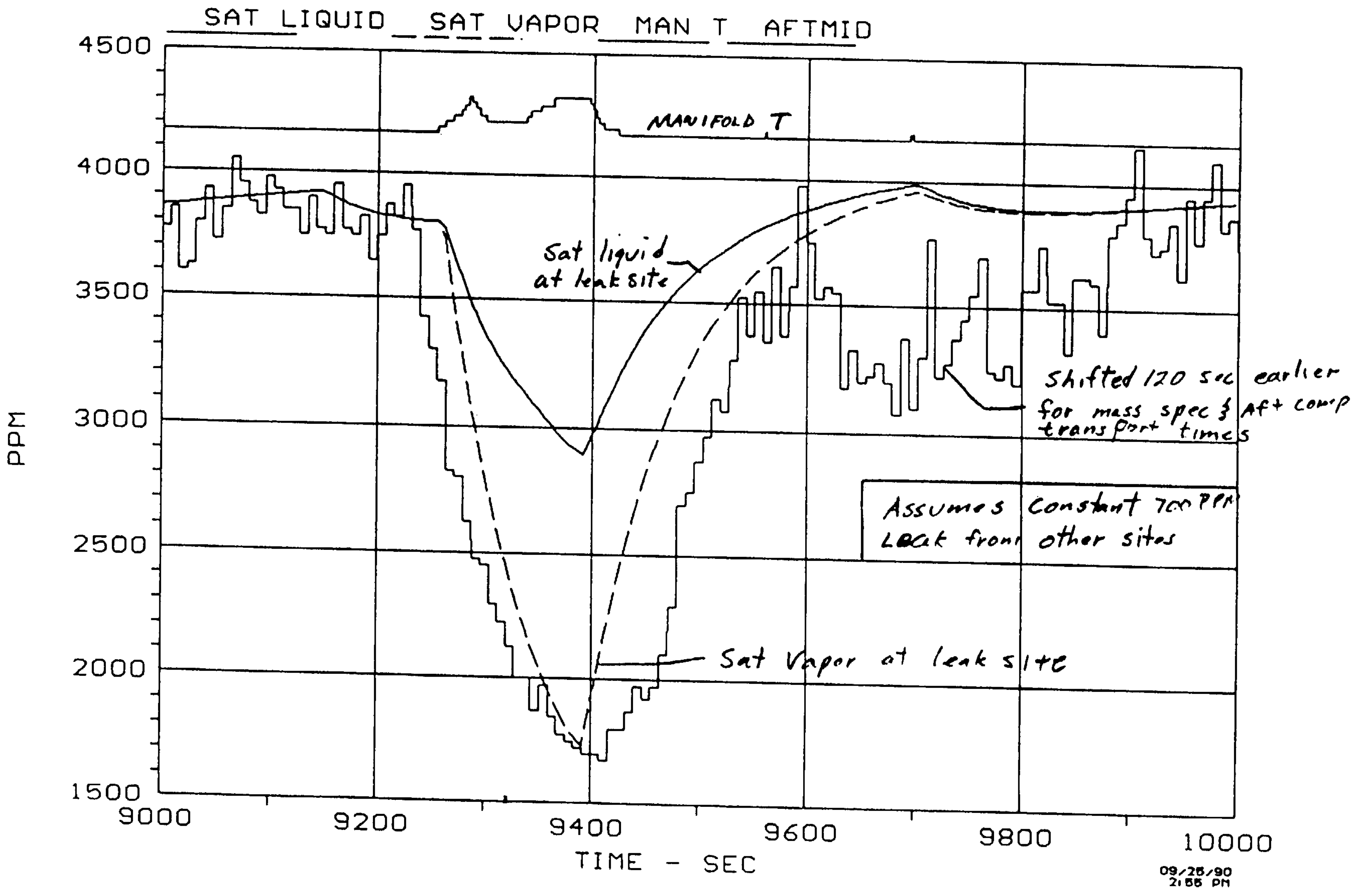

Figure 18. STS-35 S3 predicted aft compartment H_2 concentration.

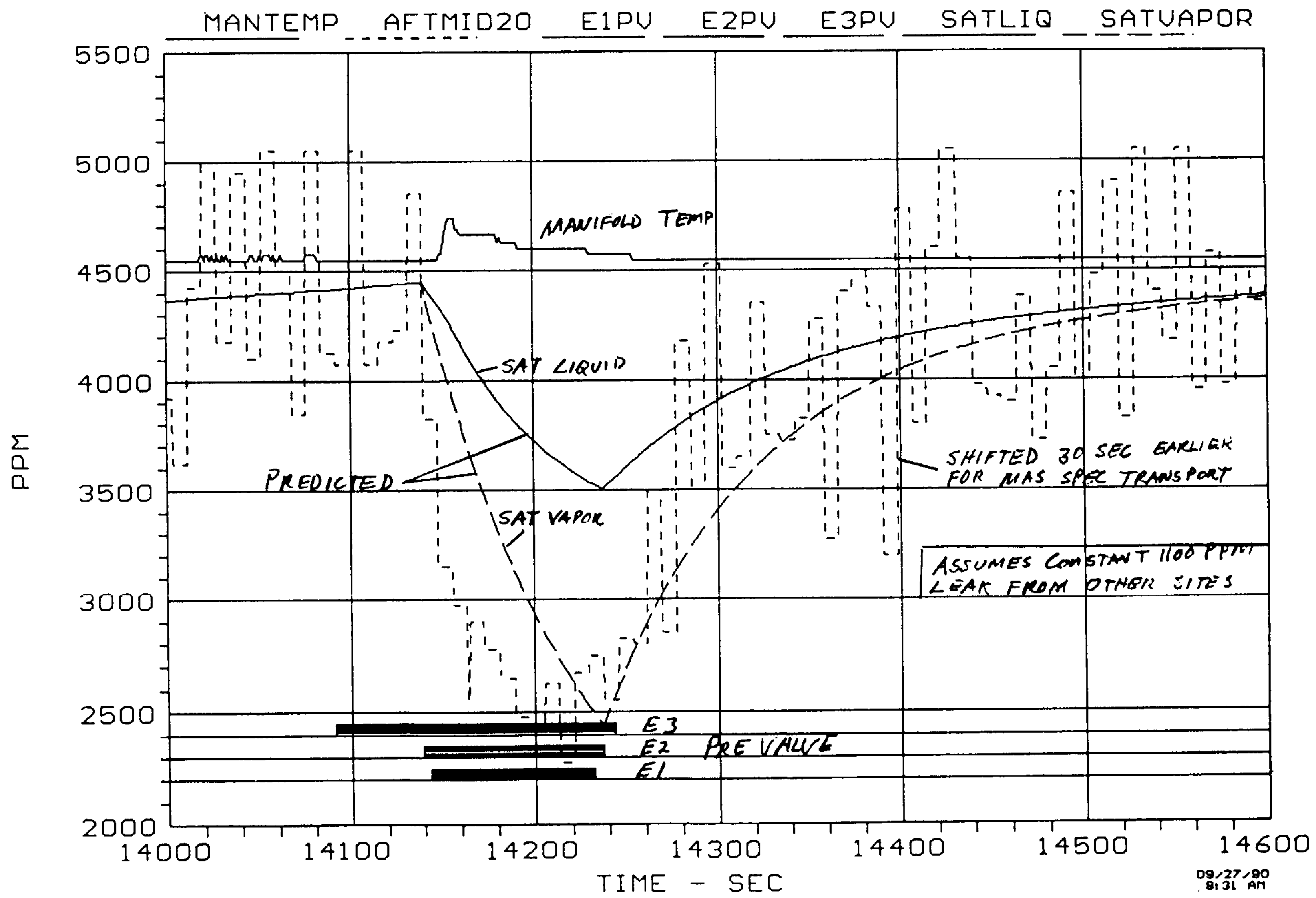

Figure 19. STS-35 S3 predicted aft compartment H_2 concentration.

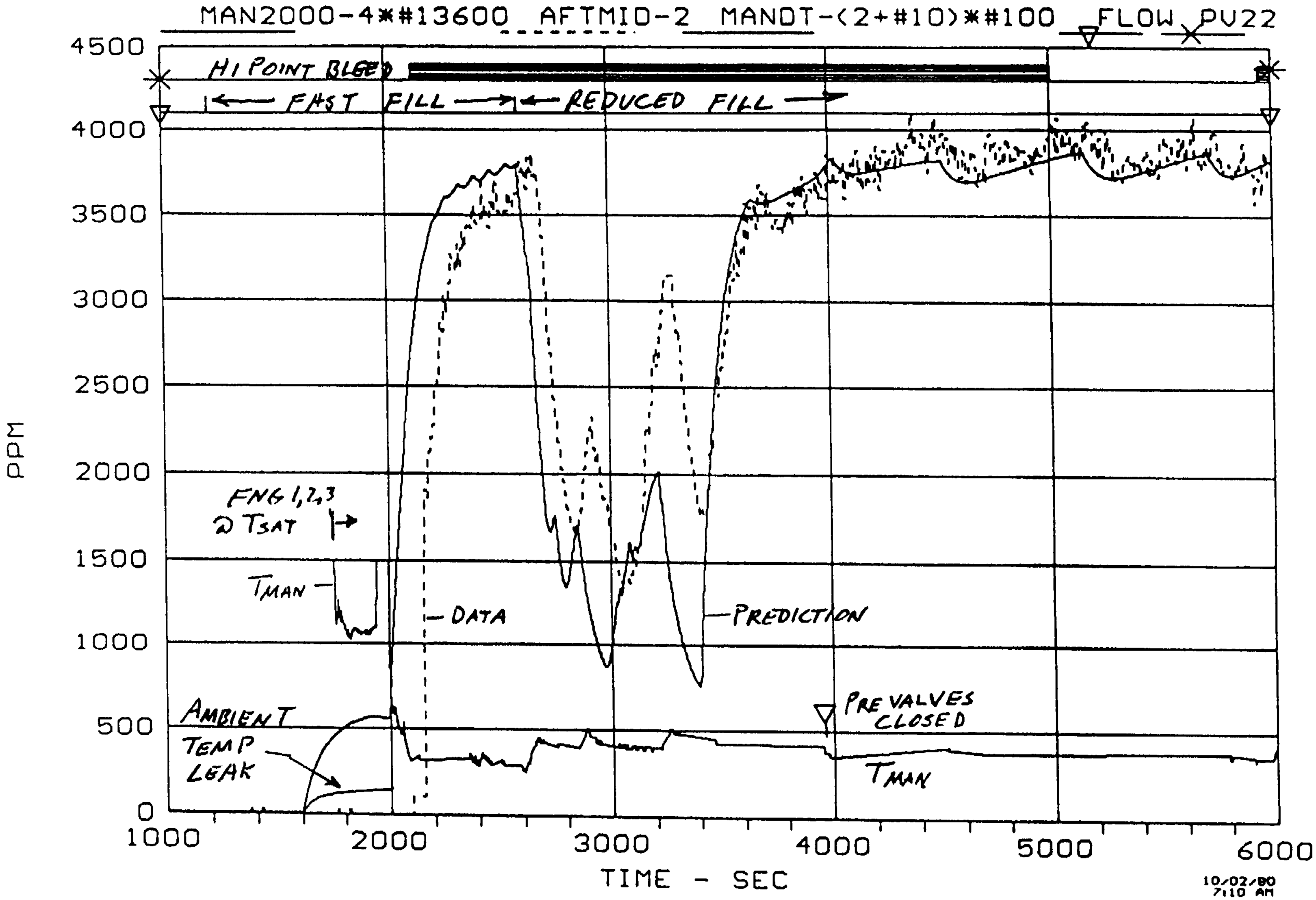

Figure 20. STS-35 S3 fast-fill/reduced-flow transition.

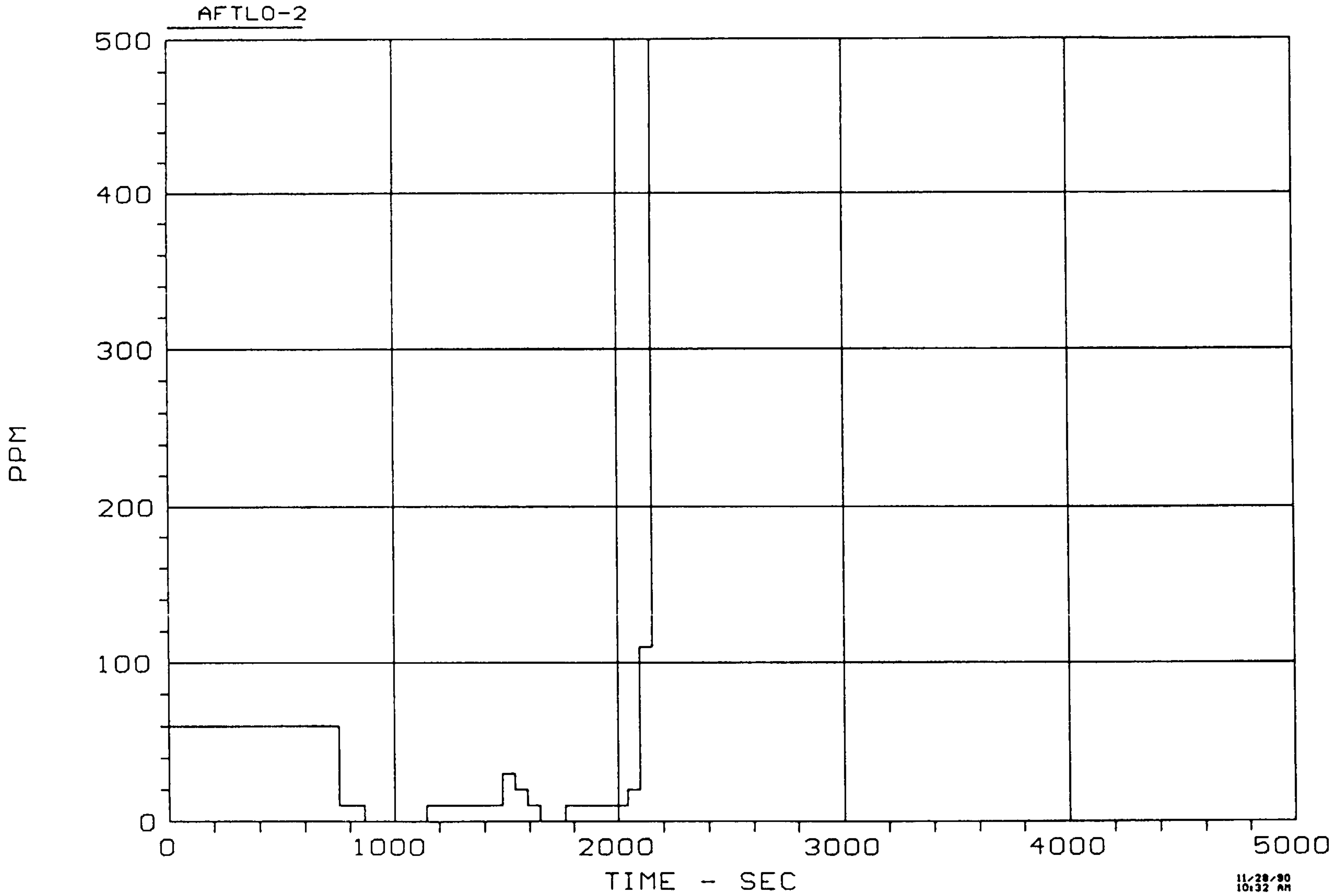

Figure 21. STS-35 S3 low range aft compartment H_2 concentration.

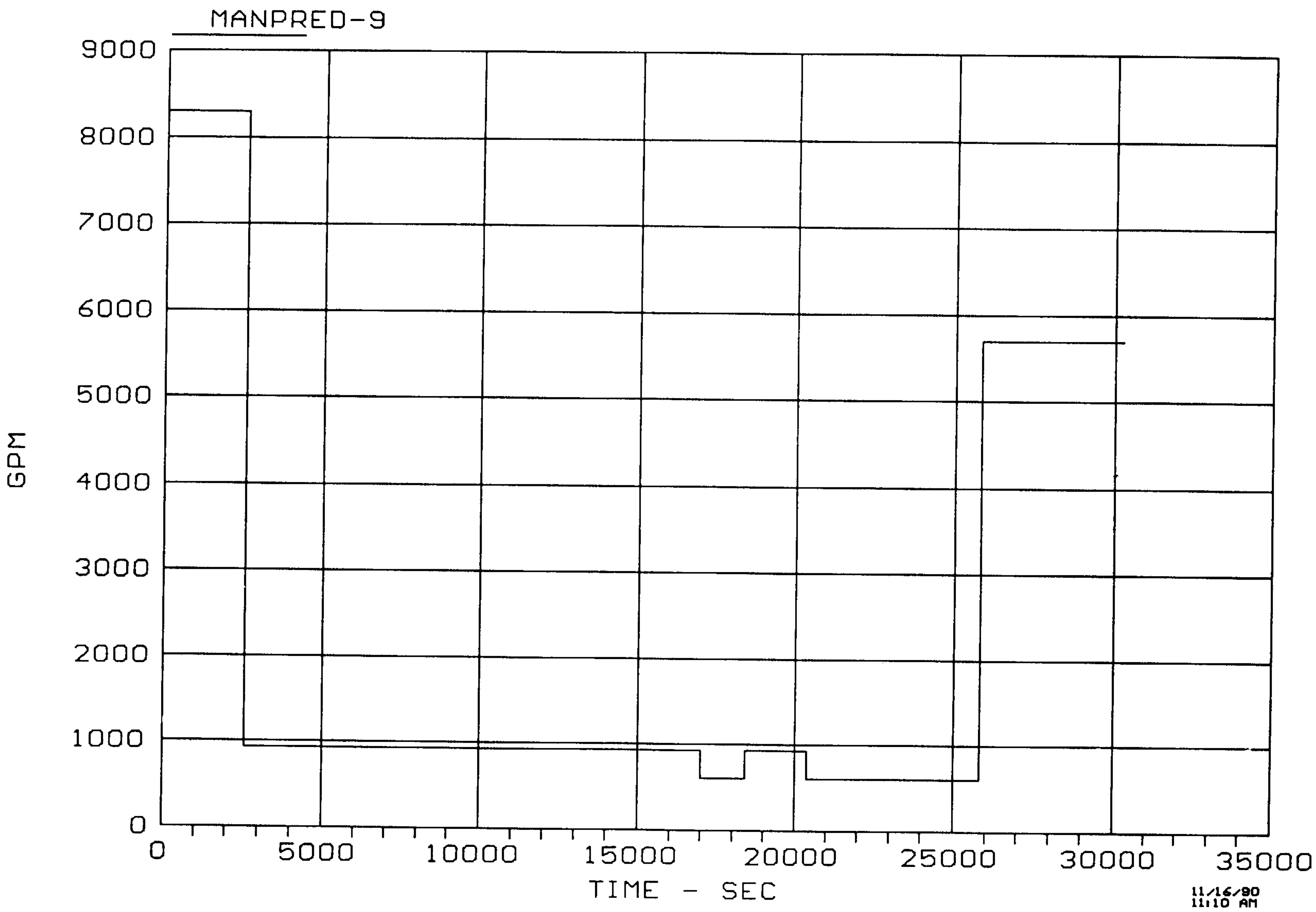

Figure 22. STS-35 S3 manifold flow.

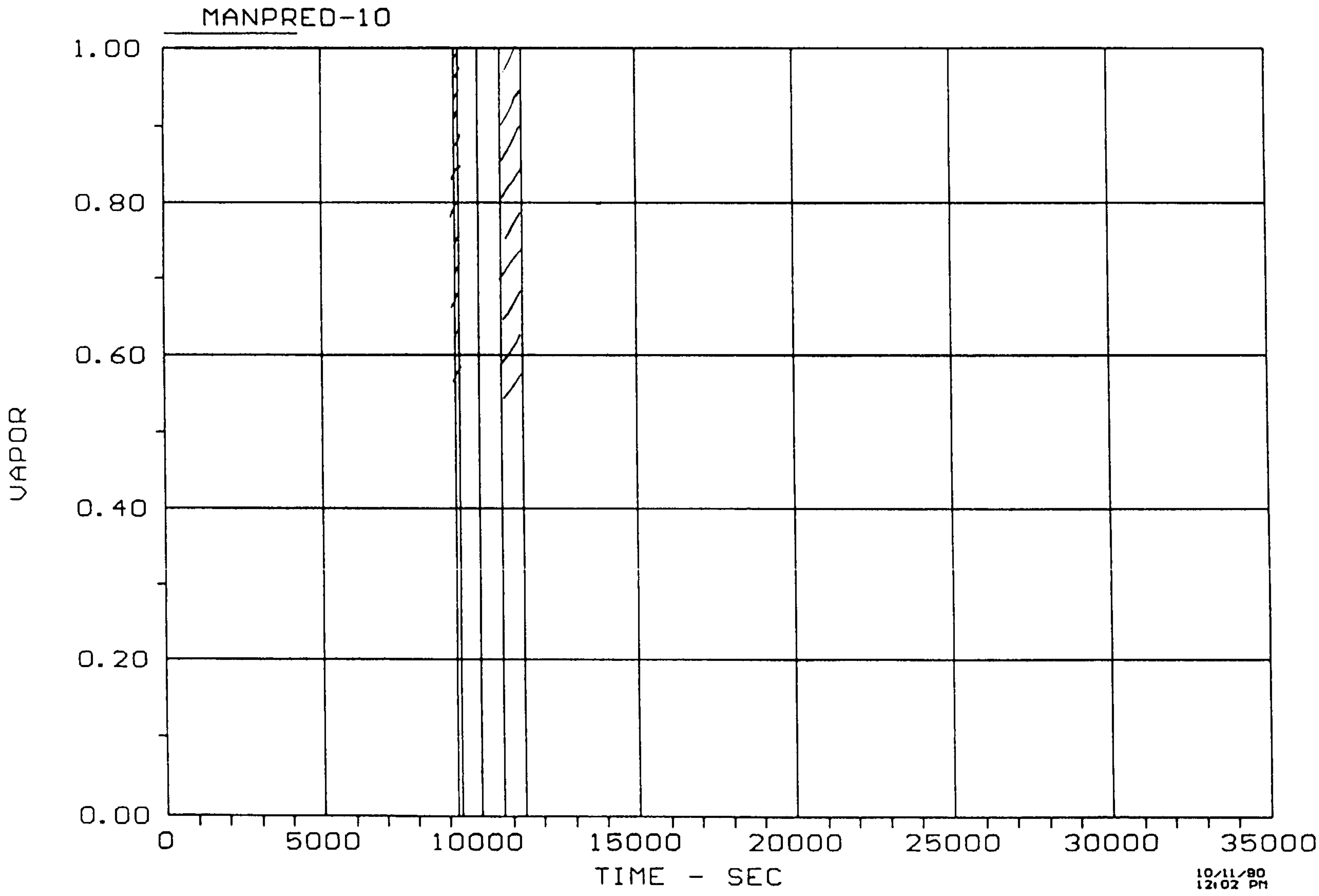

Figure 23. STS-35 S3 engine 2 recirculation pump vapor.

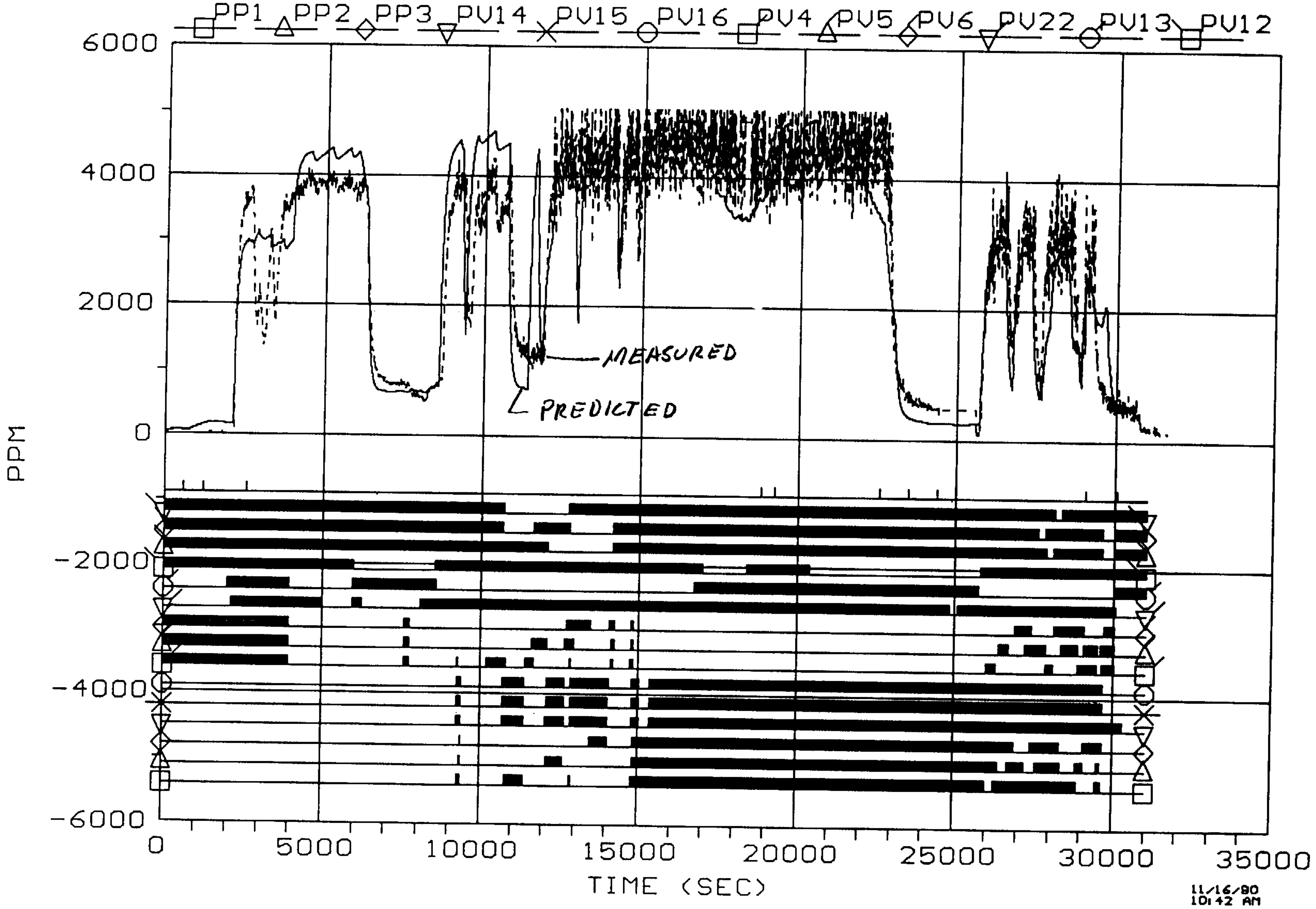

Figure 24. STS-35 S3 predicted PV5 leak.

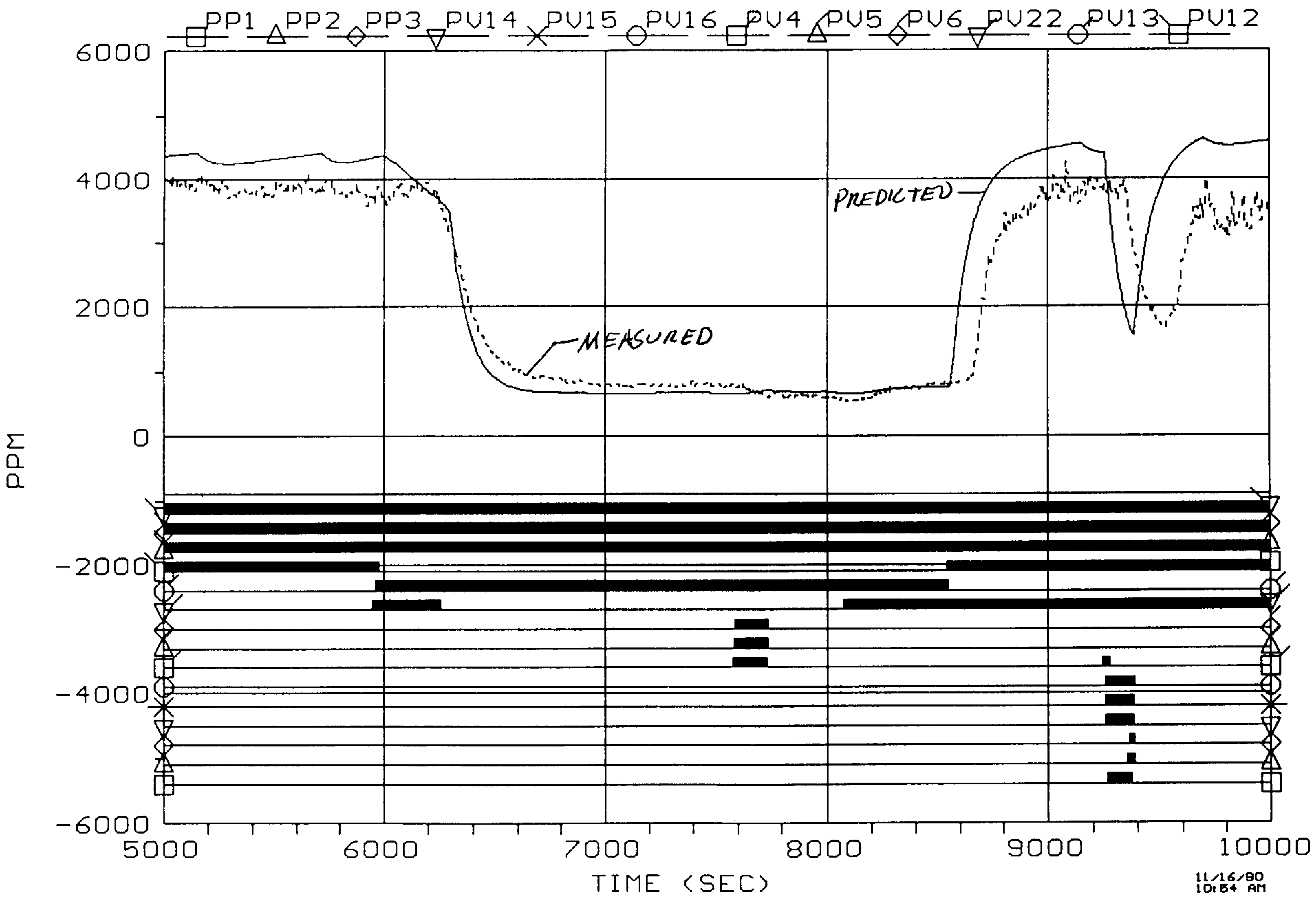

Figure 25. STS-35 S3 predicted PV5 leak.

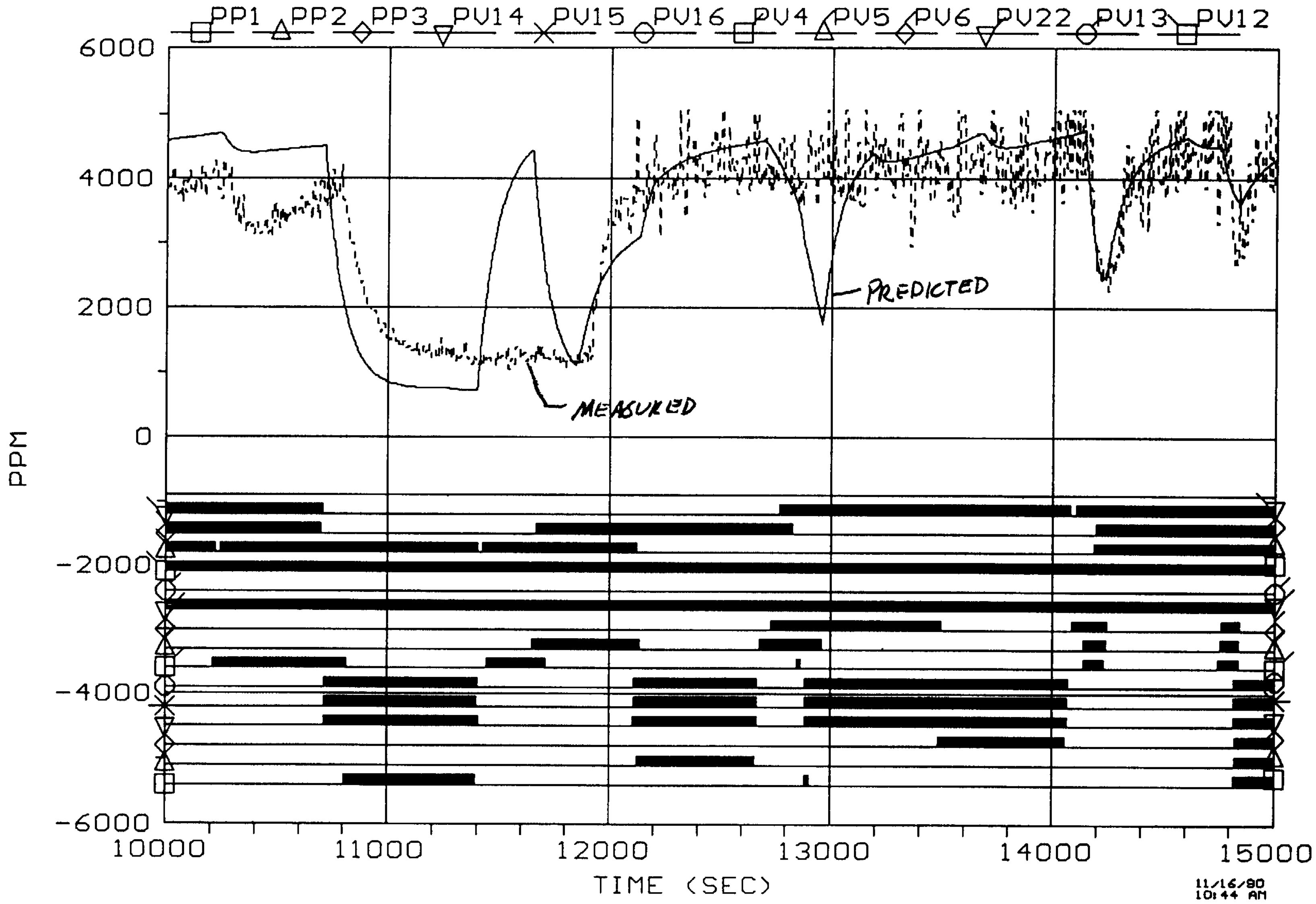

Figure 26. STS-35 S3 predicted PV5 leak.

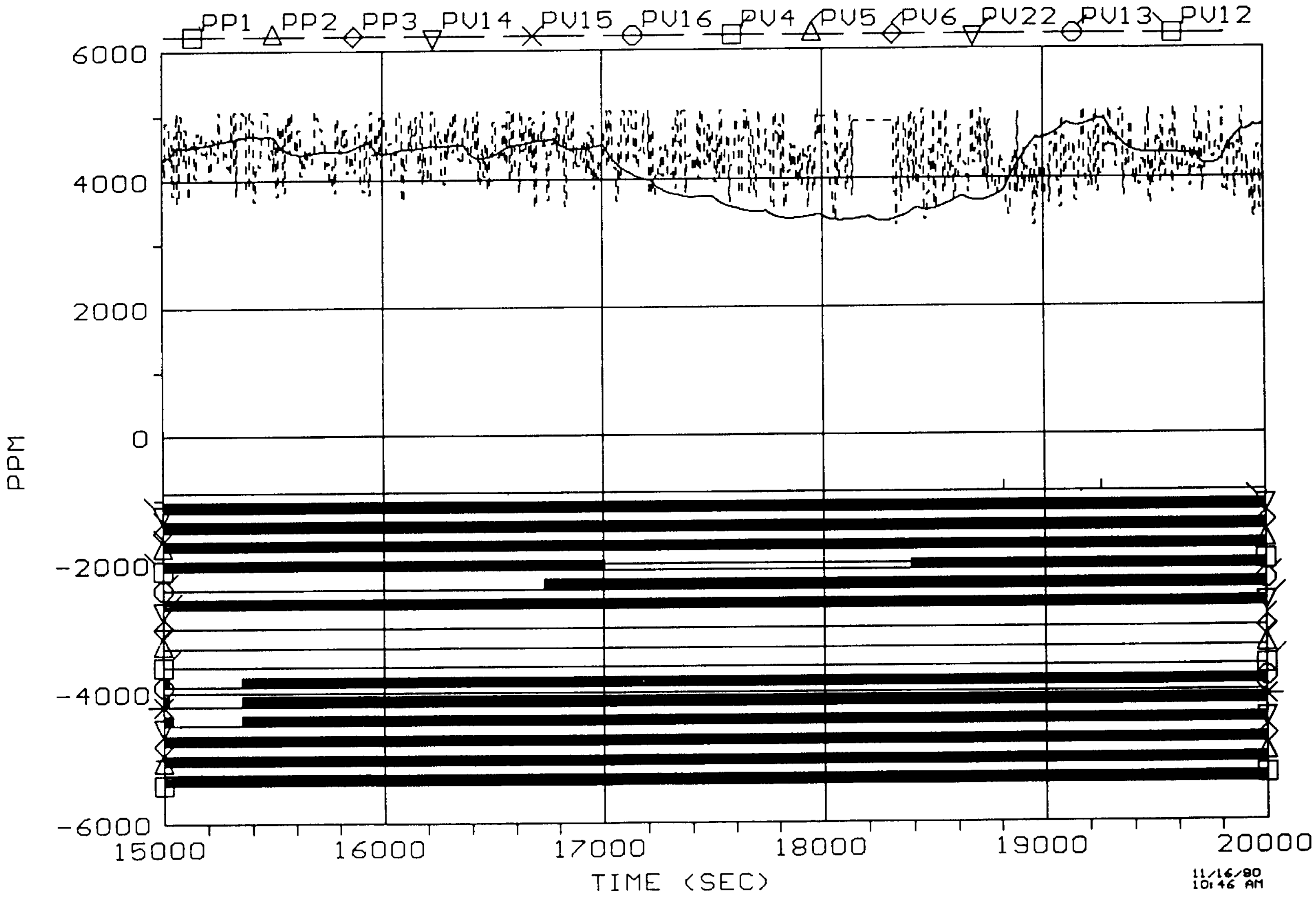

Figure 27. STS-35 S3 predicted PV5 leak.

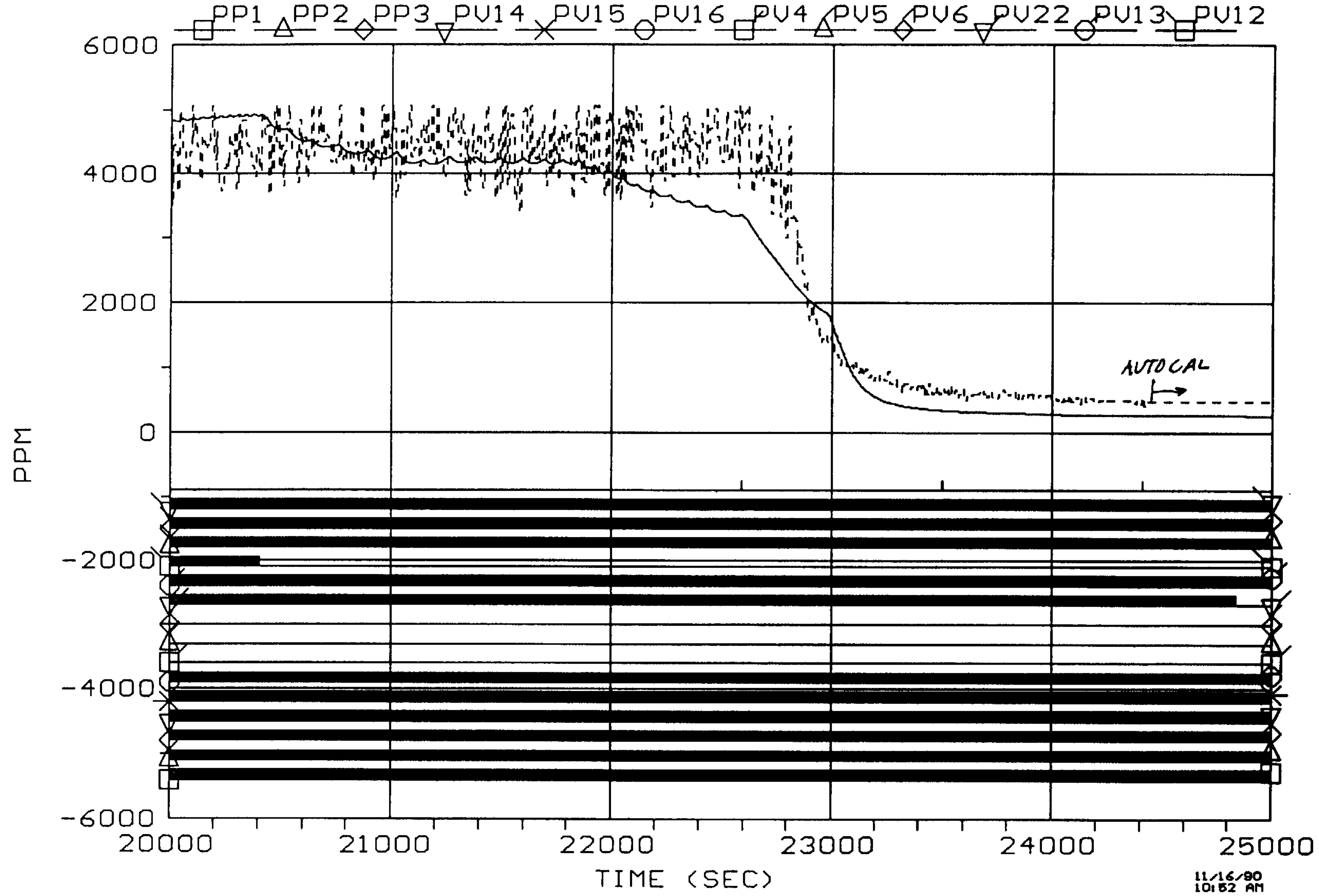

Figure 28. STS-35 S3 predicted PV5 leak.

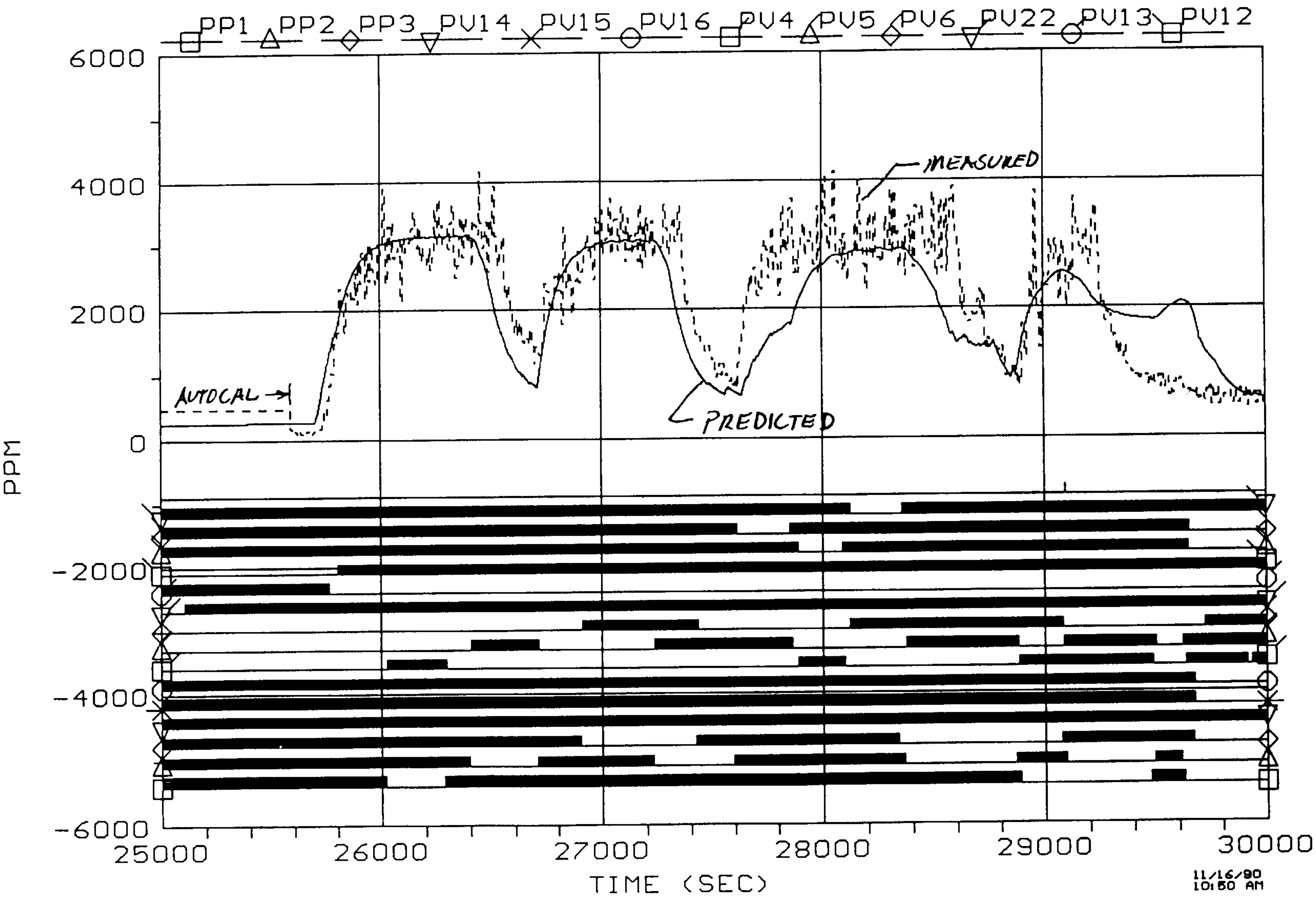

Figure 29. STS-35 S3 predicted PV5 leak.

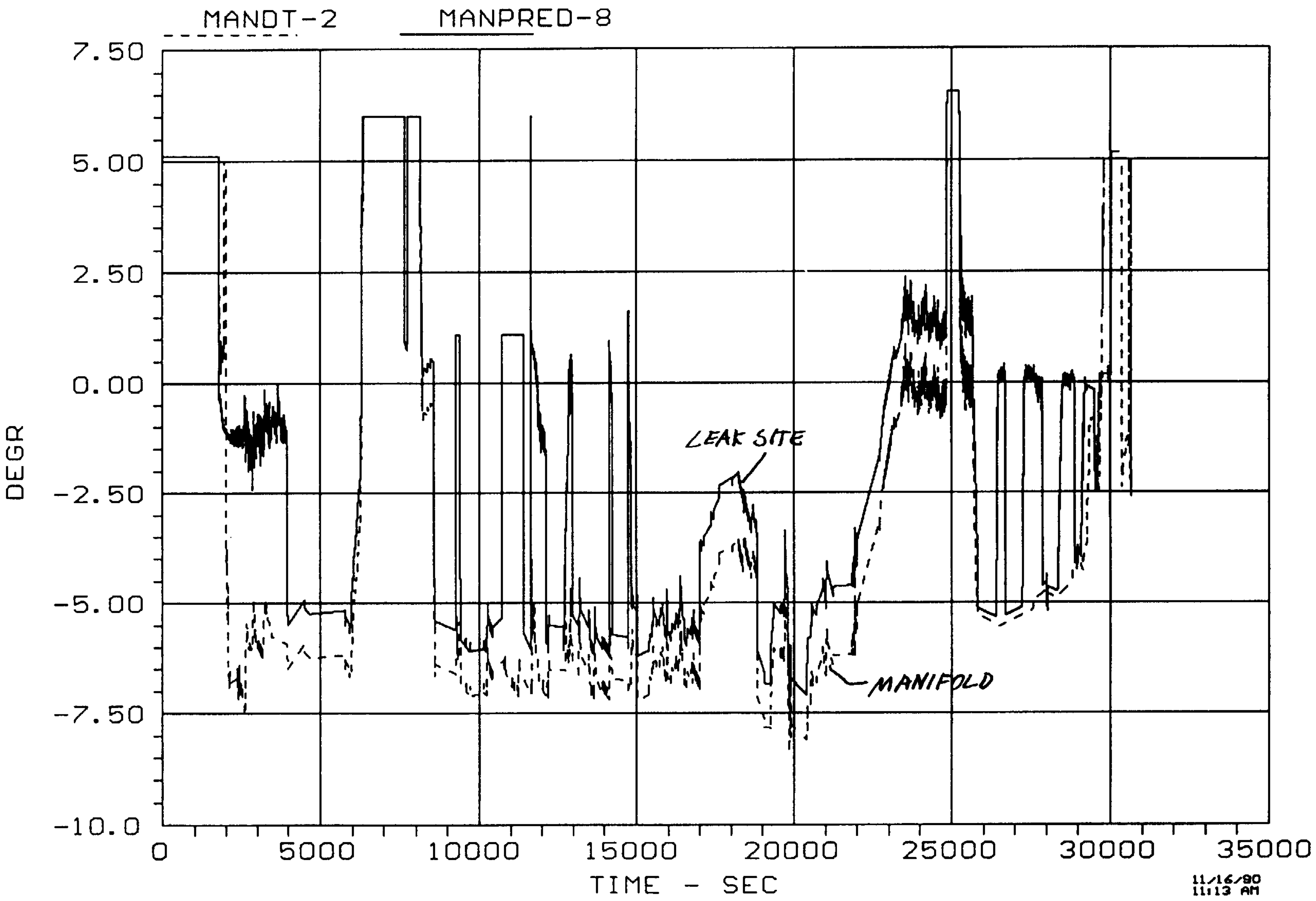

Figure 30. STS-35 S3 leak site subcool temperature.

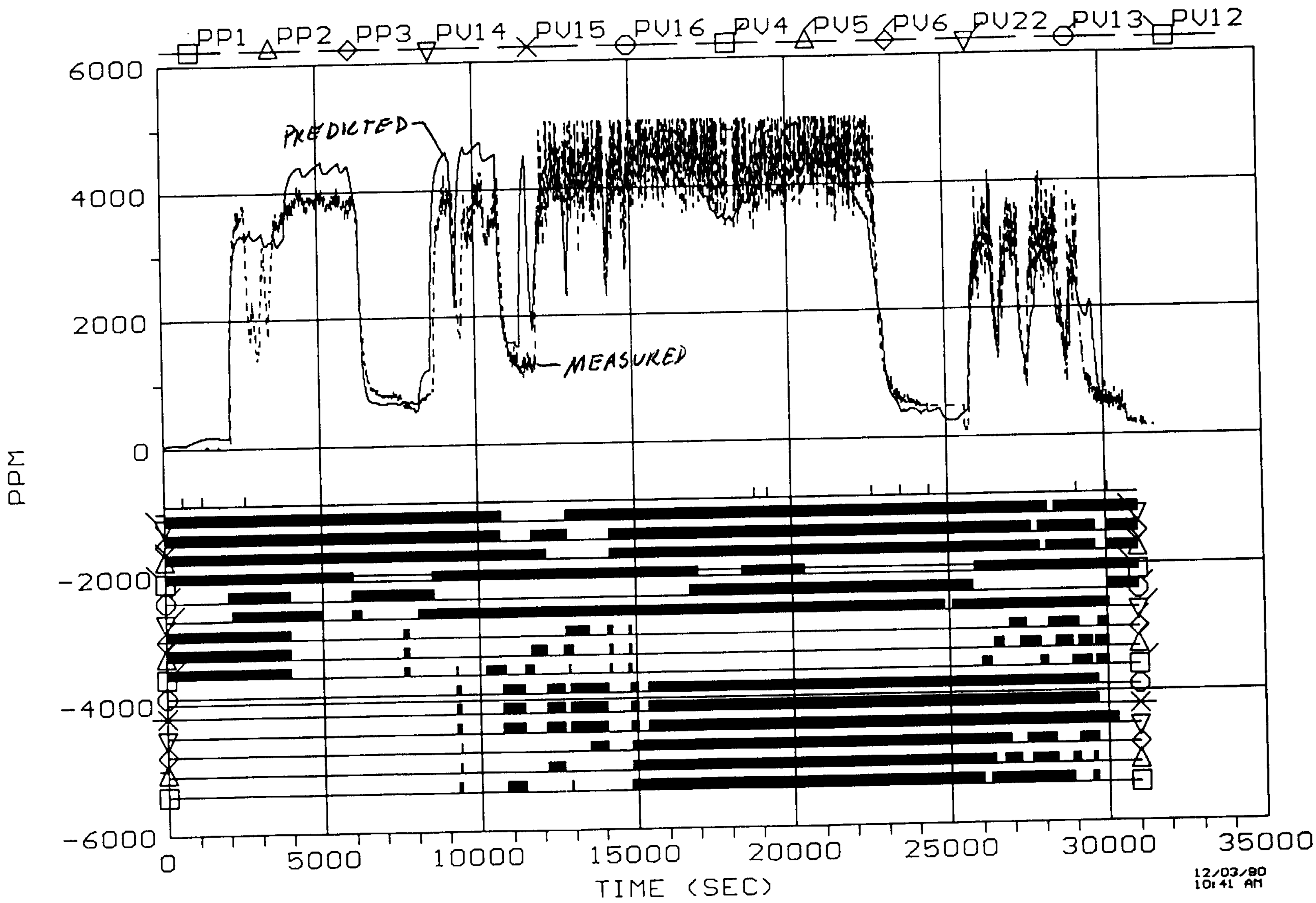

Figure 31. STS-35 S3 80-percent PV5 + 20-percent 17-in line leak.

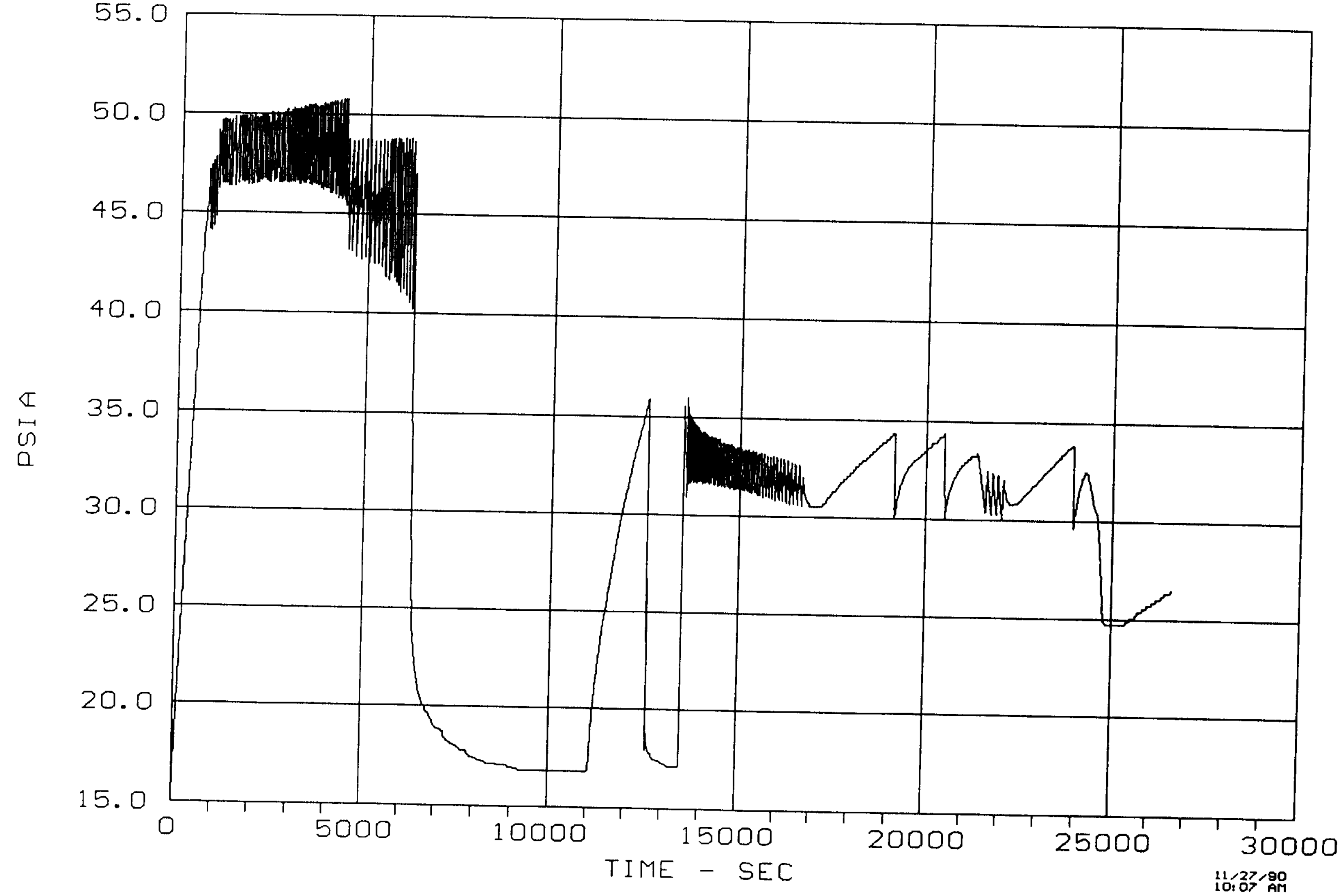

Figure 32. STS-35 S2 manifold pressure.

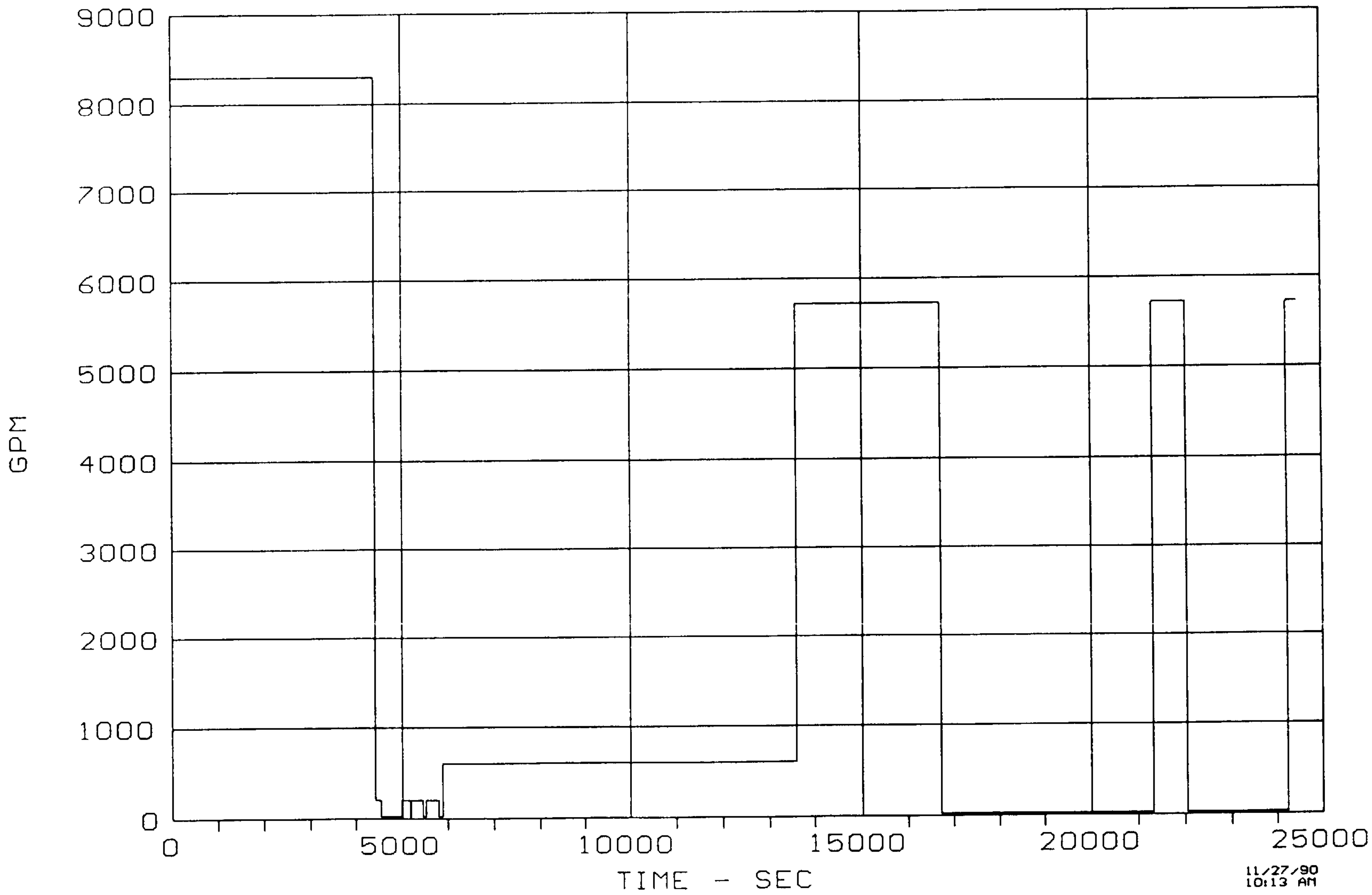

Figure 33. STS-35 S2 flow.

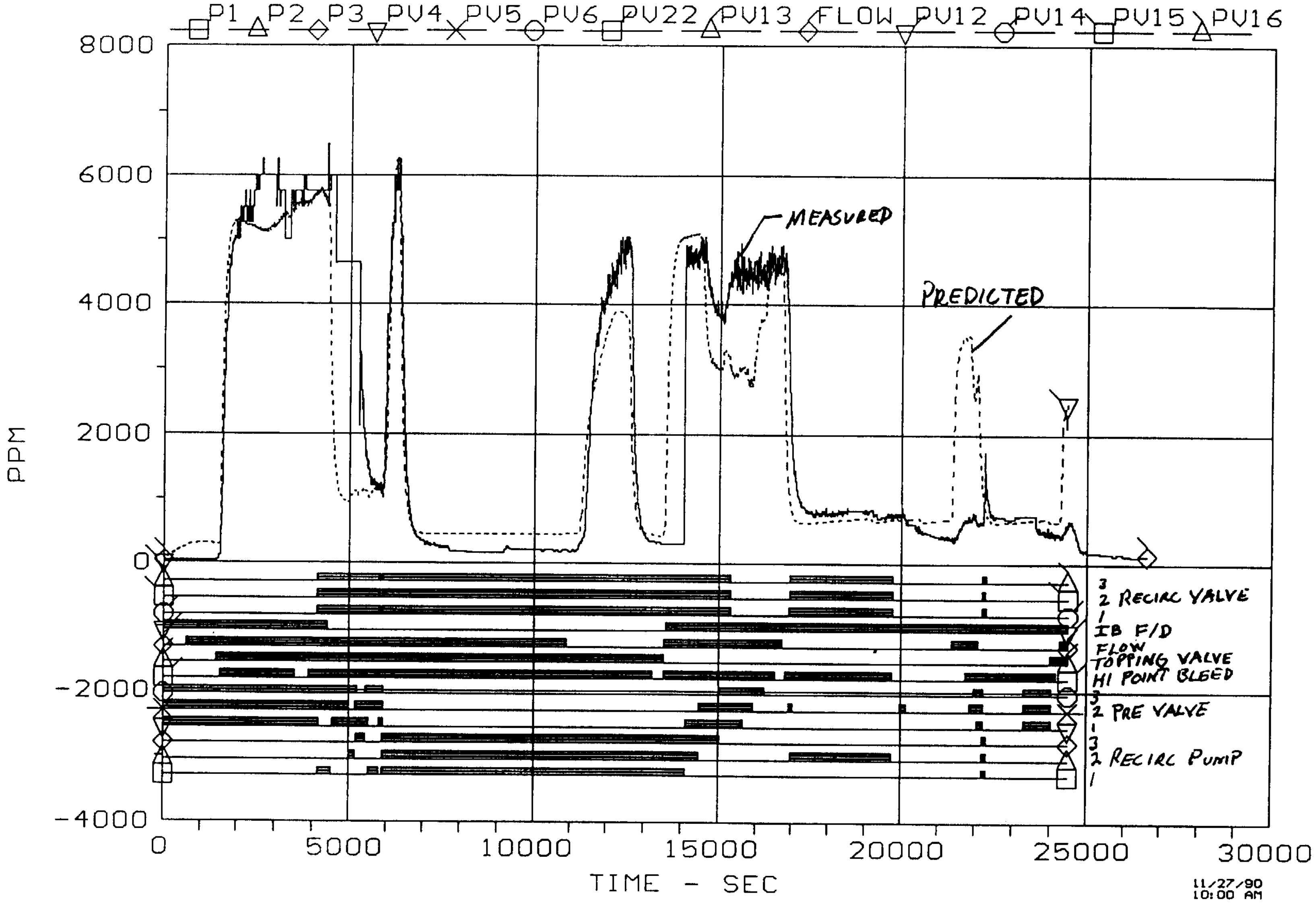

Figure 34. STS-35 S2 predicted versus actual aft H_2 concentration.

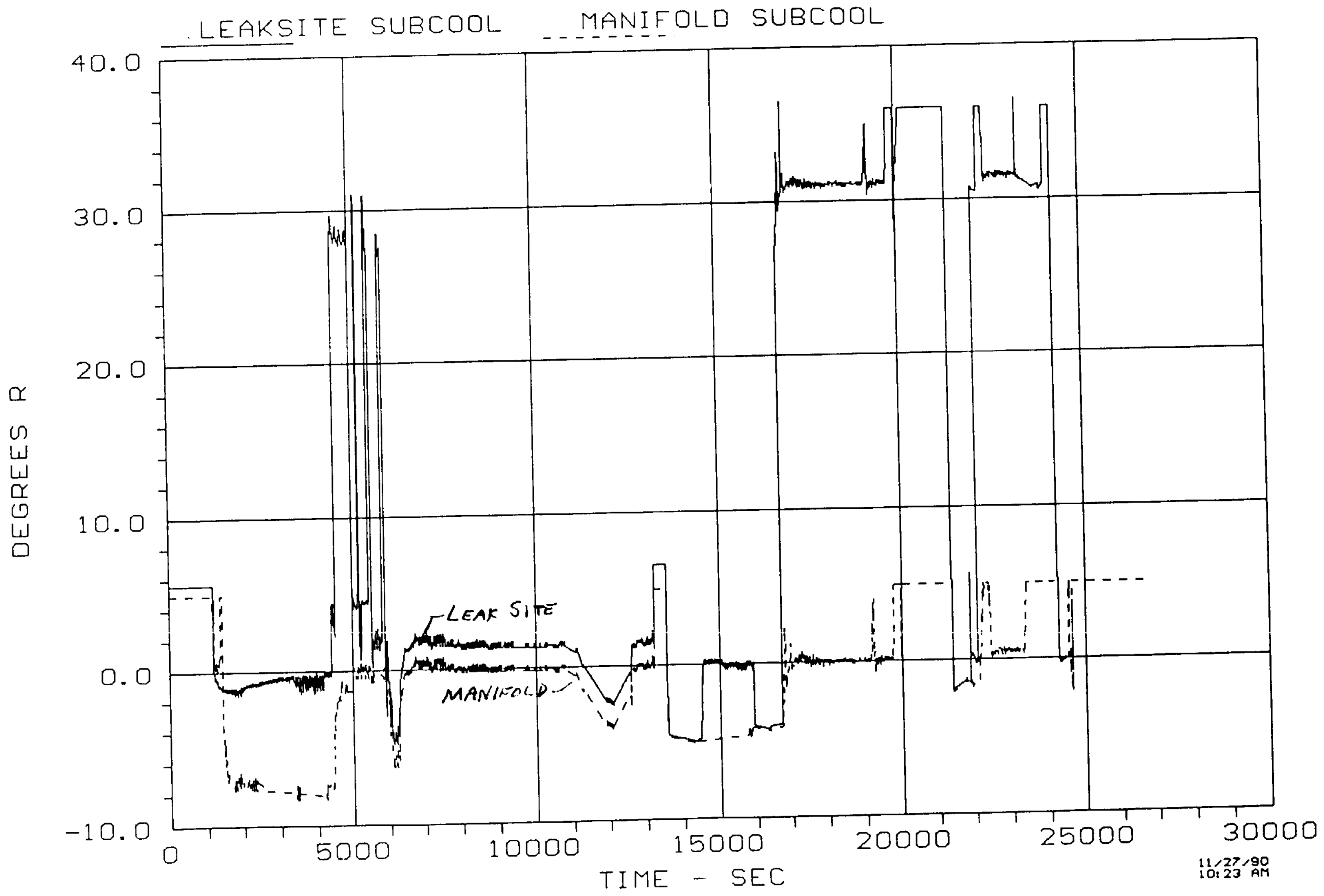

Figure 35. STS-35 S2 leak site subcool versus manifold subcool.

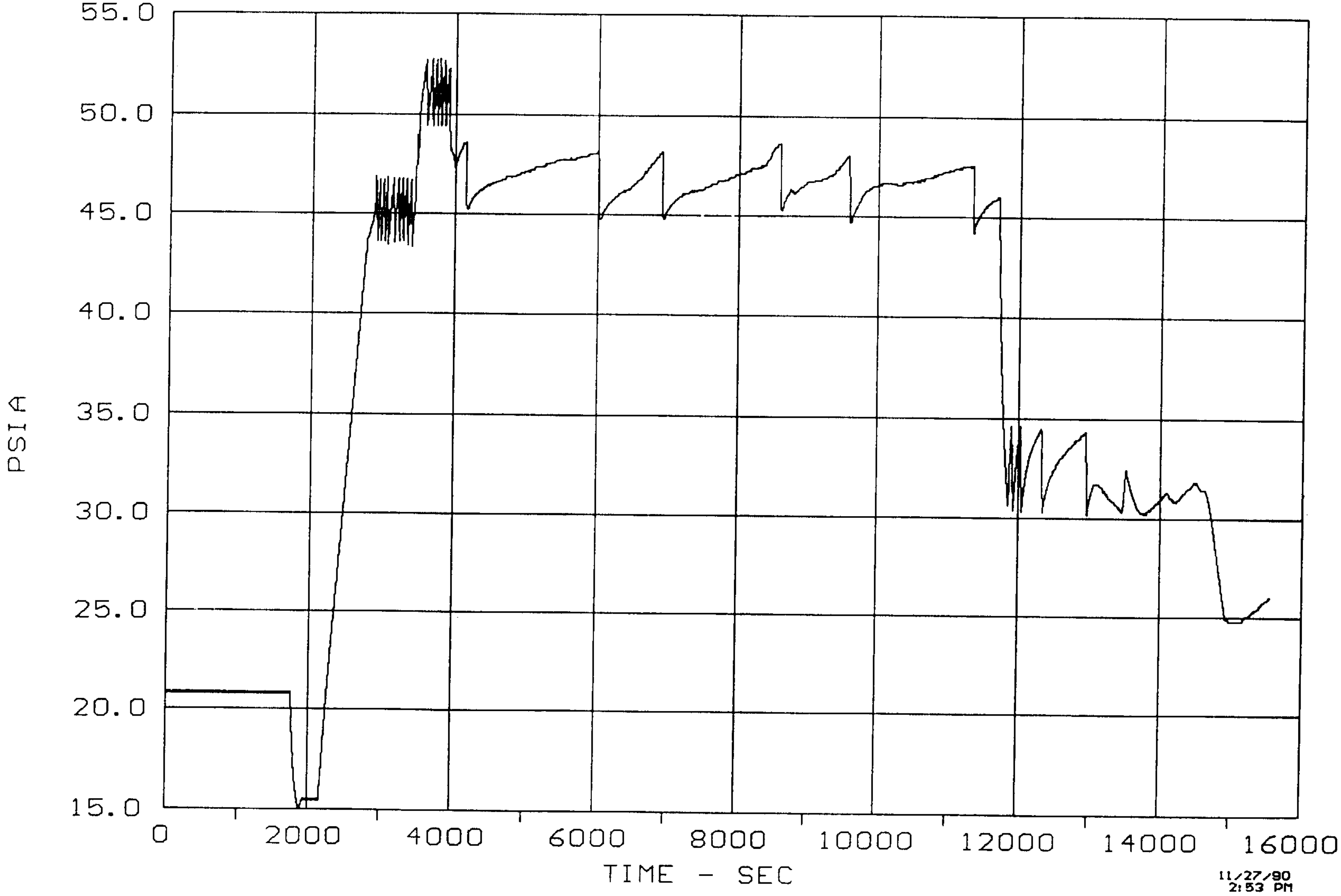

Figure 36. STS-35 T1 manifold pressure.

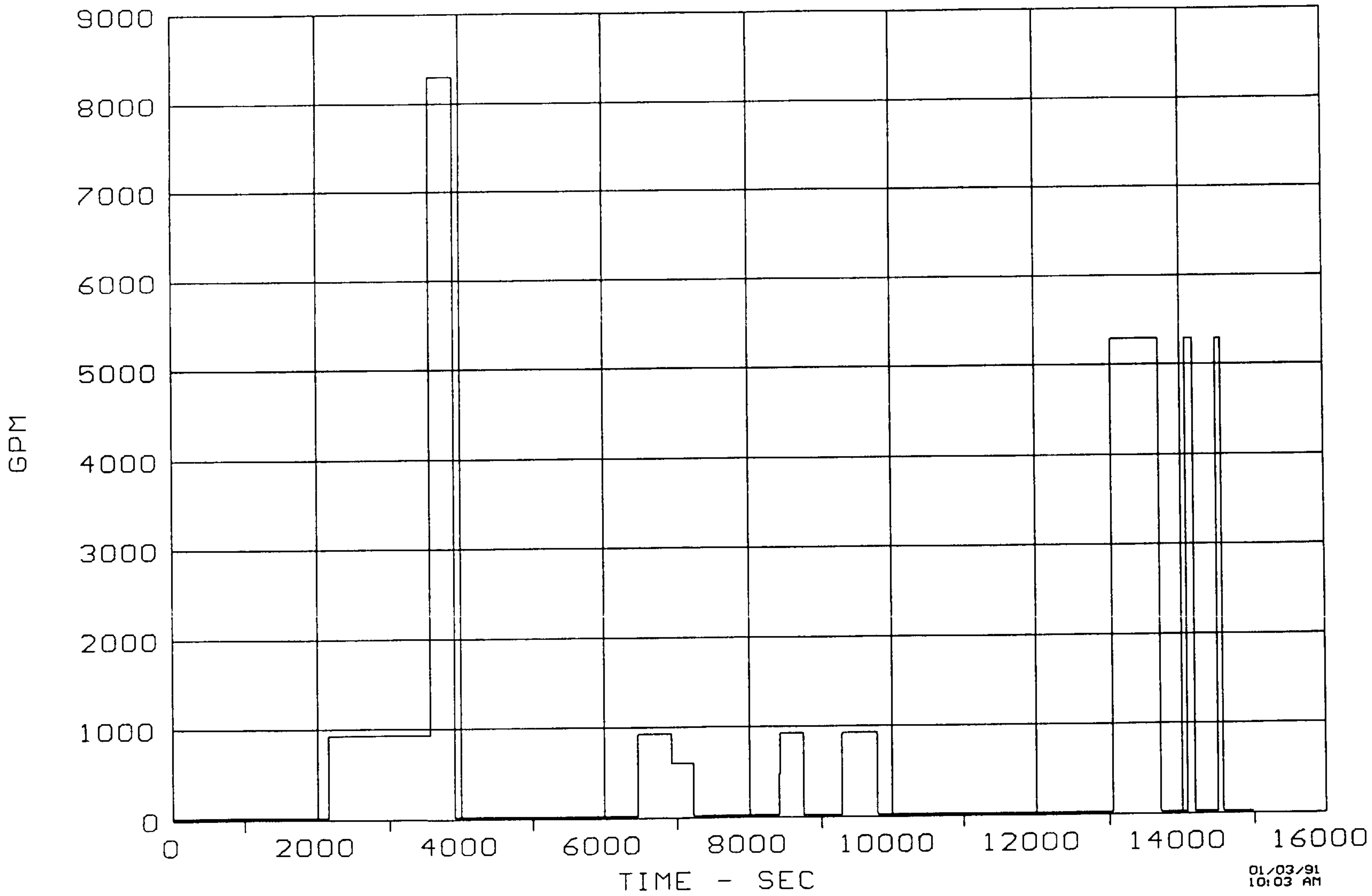

Figure 37. STS-35 T1 flow.

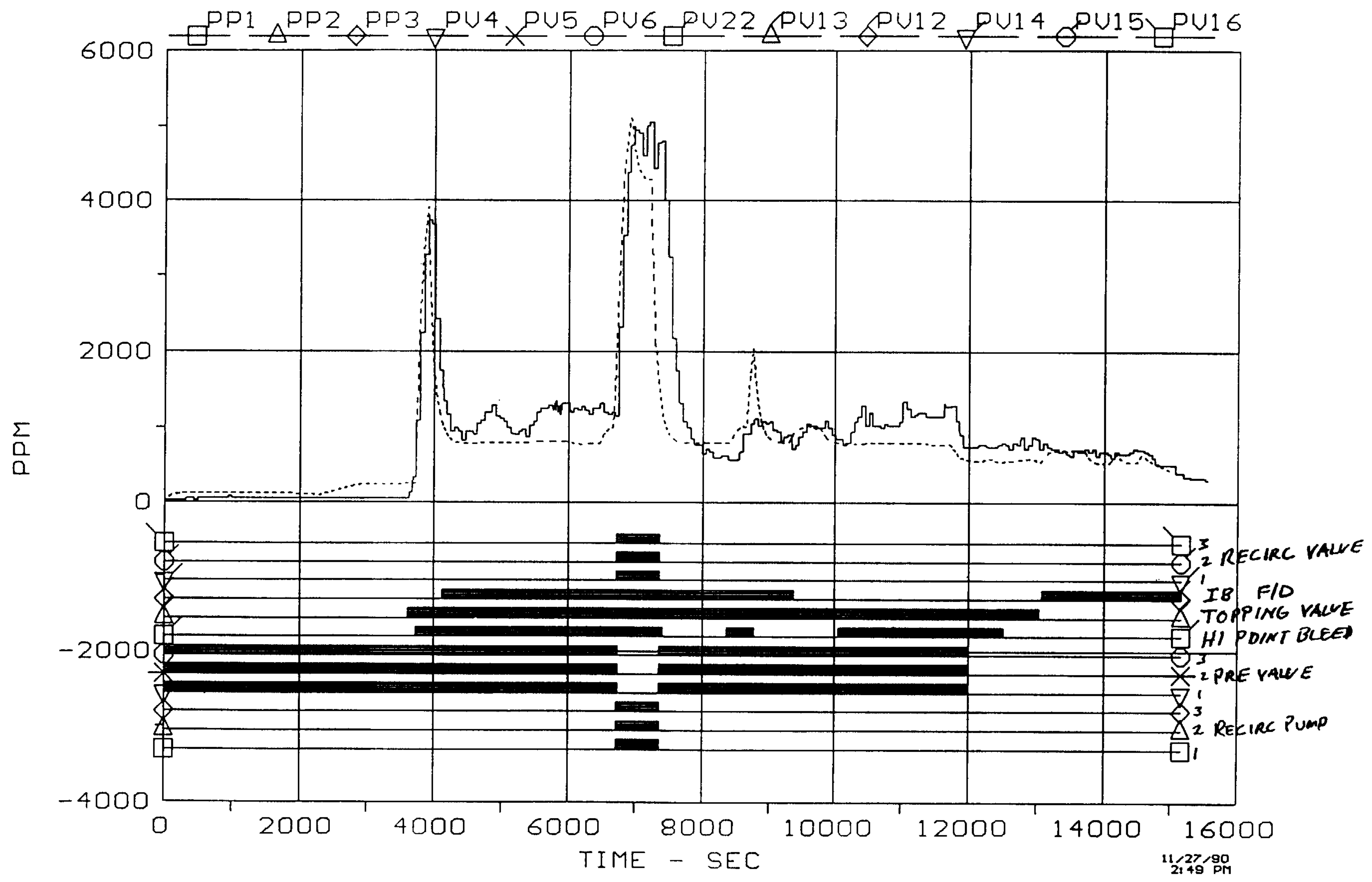

Figure 38. STS-35 T1 predicted versus actual aft H_2 concentration.

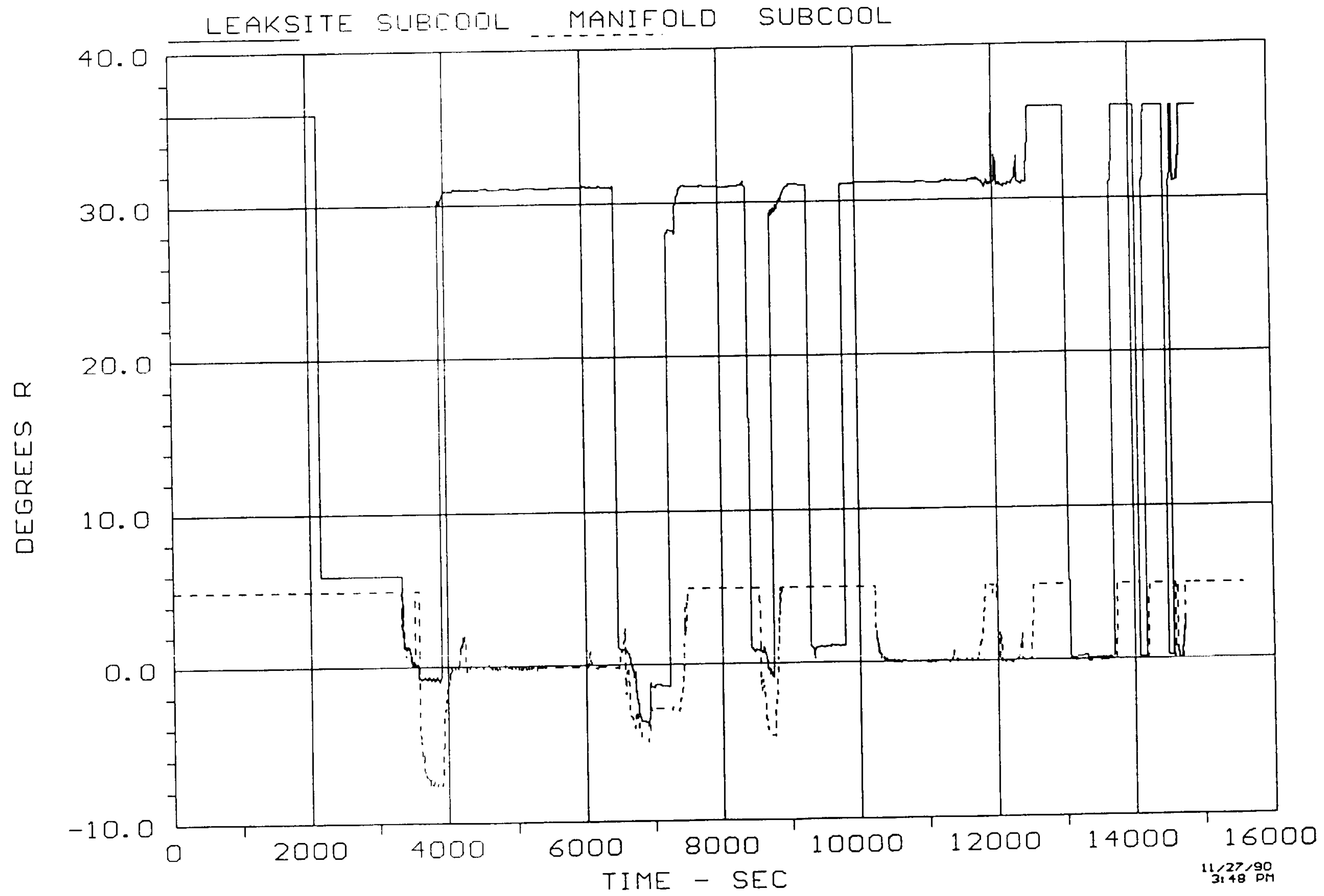

Figure 39. STS-35 T1 leak site subcool versus manifold subcool.

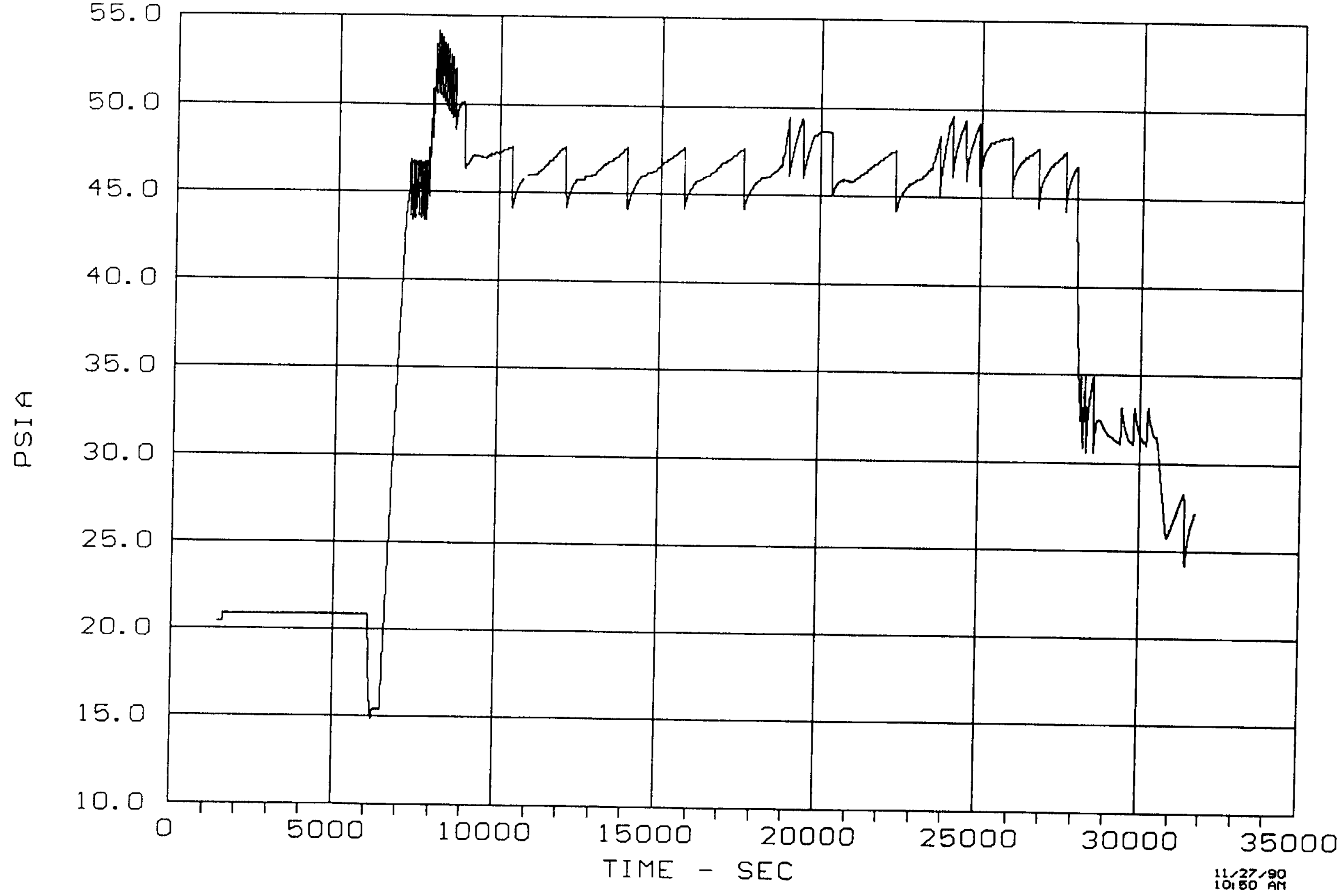

Figure 40. STS-35 S1 manifold pressure.

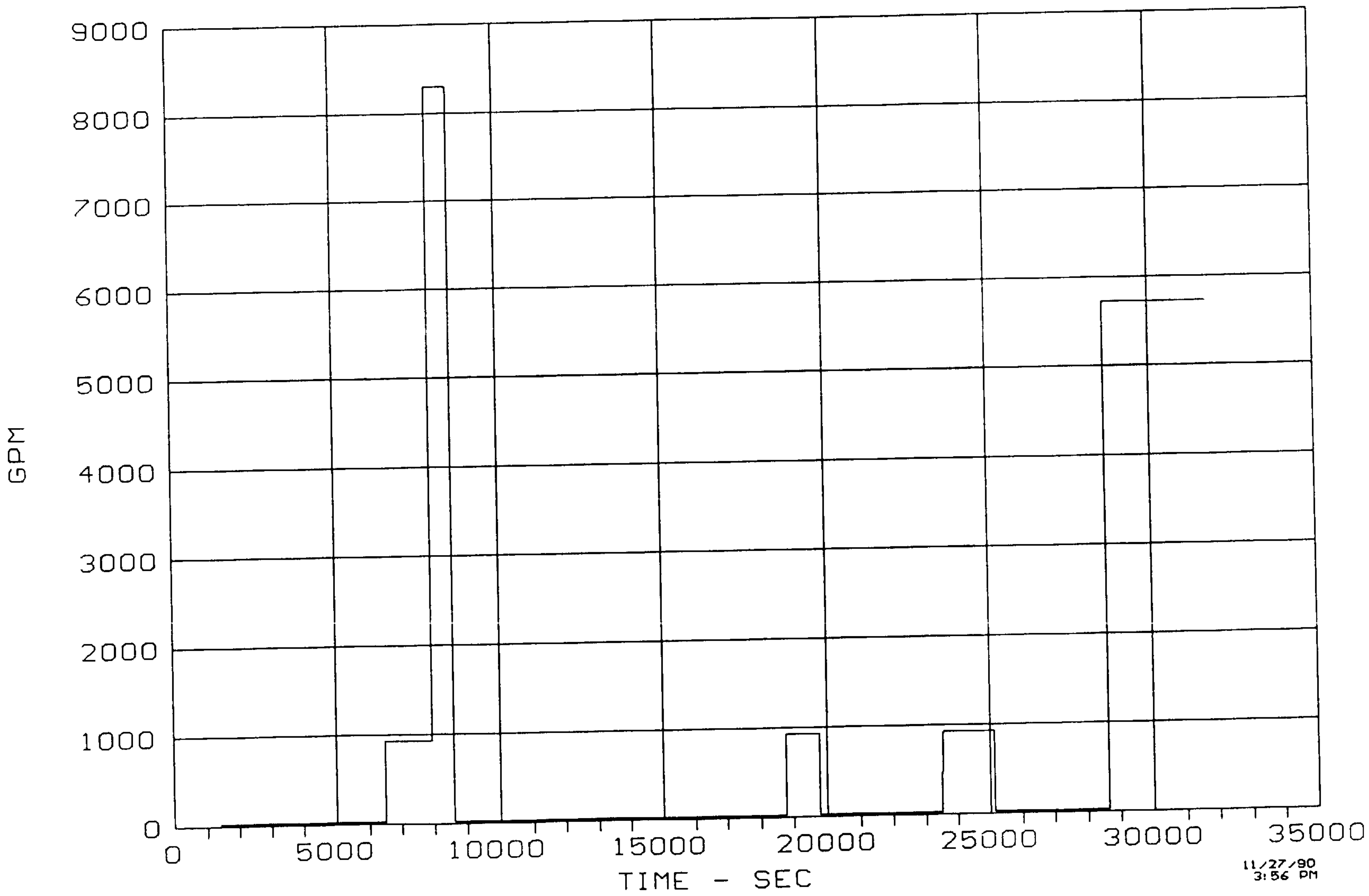

Figure 41. STS-35 S1 flow.

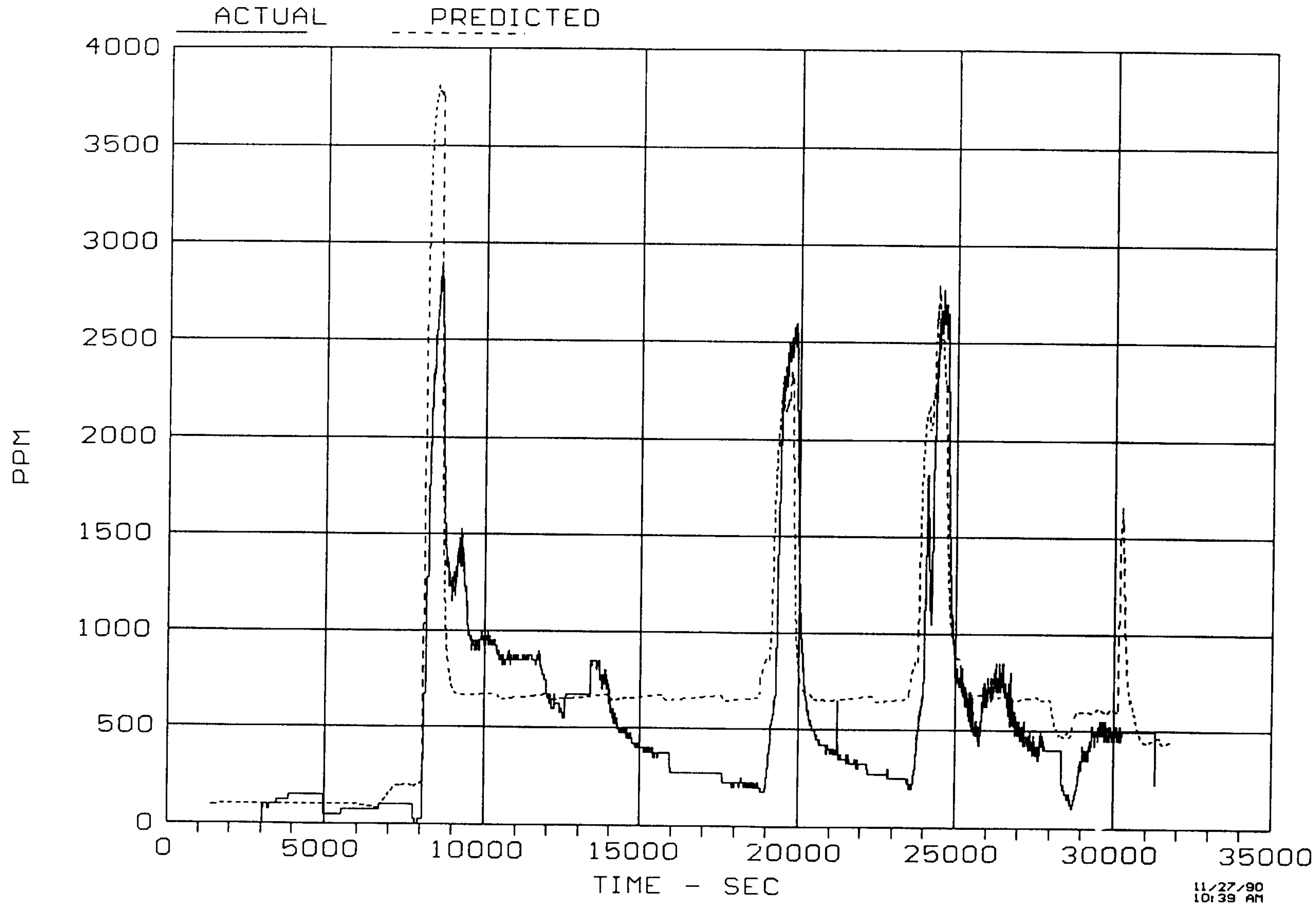

Figure 42. STS-35 S1 predicted versus actual aft H_2 concentration.

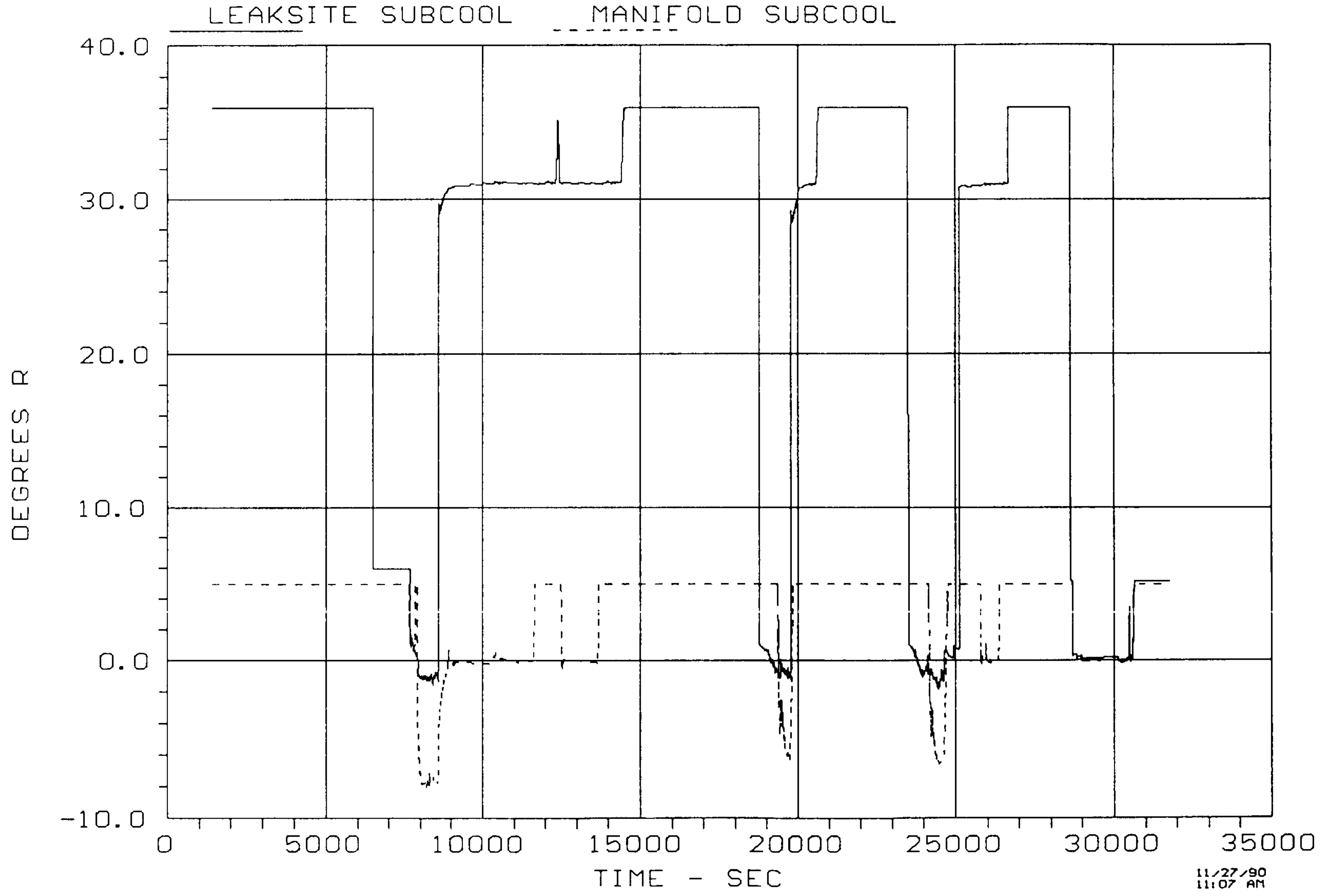

Figure 43. STS-35 S1 leak site subcool versus manifold subcool.

APPENDIX

```
c Routine to calculate Aft Comp PPM based on subcooling and pressure
c STS35S3 PV5 leak model
c
        parameter( vol    = 4550. )             ! aft comp volume  (ft3)
        parameter( volin3= vol*1728.)           !    "        "    (in3)
        parameter( purge = 235.   )             ! aft comp purge   (lb/min)
        parameter( w      = 1728.*purge/.072 )! purge flow        (scim)
c
        parameter( nrec1 = 2 )   !recirc1
        parameter( nrec2 = 3 )   !recirc2
        parameter( nrec3 = 4 )   !recirc3
        parameter( npv14 = 5 )   !pv14
        parameter( npv15 = 6 )   !pv15
        parameter( npv16 = 7 )   !pv16
        parameter( npv4   = 8 )  !pv4
        parameter( npv5   = 9 )  !pv5
        parameter( npv6   = 10)  !pv6
        parameter( npv22 = 11)   !pv22
        parameter( npv13 = 12)   !pv13
        parameter( npv12 = 13)   !pv12
        parameter( nbld1 = 14)   !e1bld
        parameter( nbld2 = 15)   !e2bld
        parameter( nbld3 = 16)   !e3bld
c
        real a1(34)
        real a2(22)
        real event(17)
        real tempin(3)
c
c       LEAK RATE TABLE
c
        data a1/32.,0., -15.35, 2.16, -11.35, 2.12, -7.35, 1.82,
     *     -5.35, 1.62, -4.35, 1.5, -3.35, 1.37, -2.35, 1.24,
     *     -1.35, 1.14, -.35, 1.03, 0.0, 1.0, .1, .28, .5, .274,
     *     .65, .27,  4.65, .25,  14.65, .22,  24.65, .21/
c
        data a2/20.0, 0.,  20., .35, 25., .50, 30., .60,
     *       35., .72, 40., .81, 45., .91, 50., 1.0,
     *       55., 1.09, 60., 1.18, 70., 1.28 /

c
        TSAT(psia) = 9.969152*(psia)**.2843842 + 15.07444
c
c
        open(unit=1,file='d:\sts35s3\mandt.bin',status='old',
     *       form='unformatted',access='direct')
c
        open(unit=2,file='d:\sts35s3\manpr.cal',status='old',
     *       form='unformatted',access='direct')
c
        open(unit=3,file='d:\sts35s3\manpred.bin',form='unformatted',
     *       status='unknown',access='direct',recl=40)
c
        open(unit=7,file='d:\sts35s3\t\events.evn',status='old')
```

```
c
      open(unit=8,file='d:\sts35s3\e1indt.bin',status='old',
     *     form='unformatted',access='direct')
      open(unit=9,file='d:\sts35s3\e2indt.bin',status='old',
     *     form='unformatted',access='direct')
      open(unit=10,file='d:\sts35s3\e3indt.bin',status='old',
     *     form='unformatted',access='direct')
c
      write(5,'(a)') ' Enter Tsat Tolerance '
      read(5,*) tolinp
c
      read(1 ) timb,tempb
      read(2 ) tim2,prs1
c     read(8 ) time1,teme1
      read(9 ) time2,teme2
c     read(10) time3,teme3
c
      tim   = tim2
      timxv = tim
      tprint= tim
      prs2 = prs1
      ppm1 = 0.
      ppm2 = 0.
      ppm3 = 0.
c
c     MAIN TIME LOOP
c
  200 continue
      tim=tim+1.                              ! Time step fixed at 1 sec
      tol = tolinp
c
c     SET MANIFLOD FLOW RATE
c
      if( tim .lt. 2590 ) then
        flow = 8300.
      else if( tim .lt. 17004. ) then
        flow = 930.
      else if( tim .lt. 18392. ) then
        flow = 600.
      else if( tim .lt. 20406. ) then
        flow = 930.
      else if( tim .lt. 25801. ) then
        flow = 600.
      else if( tim .lt. 35000. ) then
        flow = 5700.
      end if
c
  205 continue
      if( tim .lt. timb ) goto 210
        tima=timb
        tempa=tempb
        read(1,end=900) timb,tempb            ! Update manifold temp
        tprint=tim-1.
      goto 205
```

```
c
  210   continue
        if( timb-tima .gt. .01 )
     1    tempm=tempa+(tim-tima)*(tempb-tempa)/(timb-tima)
c
  215   continue
c       if( tim .lt. time1 ) goto 216
c         time1p=time1
c         teme1p=teme1
c         read(8,end=900) time1,teme1          ! Update engine 1 temp
c         tprint=tim-1.
c       goto 215
c
  216   continue
c       if( time1-time1p .gt. .01 )
c    1    tempin(1)=teme1p+(tim-time1p)*(teme1-teme1p)/(time1-time1p)
c
  315   continue
        if( tim .lt. time2 ) goto 316
          time2p=time2
          teme2p=teme2
          read(9,end=900) time2,teme2          ! Update engine 2 temp
          tprint=tim-1.
        goto 315
c
  316   continue
        if( time2-time2p .gt. .01 )
     1    tempin(2)=teme2p+(tim-time2p)*(teme2-teme2p)/(time2-time2p)
c
  415   continue
c       if( tim .lt. time3 ) goto 416
c         time3p=time3
c         teme3p=teme3
c         read(10,end=900) time3,teme3         ! Update engine 3 temp
c         tprint=tim-1.
c       goto 415
c
  416   continue
c       if( time3-time3p .gt. .01 )
c    1    tempin(3)=teme3p+(tim-time3p)*(teme3-teme3p)/(time3-time3p)
c
  218   continue
        if( tim .lt. timxv ) goto 219
          read(7,fmt=*,end=900) timxv,event    ! Update events
          read(7,fmt=*,end=900) timxv          ! Look ahead for next time
          backspace(7)
          tprint=tim-1.
        goto 218
c
  219   continue
c
 220    if(tim.lT.tim2) goto 230
        tim1=tim2
        prs1=prs2
```

```
      read(2,end=900) tim2,prs2              ! Update pressure
      tprint=tim-1.
      goto 220
c
 230  continue
      if( tim2-tim1 .gt. .01 )
     1  prs=prs1+(tim-tim1)*(prs2-prs1)/(tim2-tim1)
c
c
c     CHECK FOR VAPOR AT PV5 INLET FROM ENG 2 RECIRC PUMP INLET
c
      vapor = 0.0
      if( event(npv15) .gt. .1 .and.
     1      event(nrec2) .lt. .1 .and.
     2      event(npv5 ) .lt. .1 .and.
     3      tempin(2) .gt. 1.           ) vapor = vapor+1.
c
c     SET LEAK TEMPERATURE
c
      if( event(npv5).gt. .1 ) then
        temp = tempin(2)
      else
        if( vapor .gt. .1 ) then
          temp = .1                    ! Assume sat vapor leak
        else
          temp = tempm
        end if
      end if
c
      temp = temp+1.*930./flow
c
c     GET LEAK FLOW
c
      call intrp(a1,temp-tol,fact1a)
      call intrp(a1,temp,fact1b)
      call intrp(a1,temp+tol,fact1c)
      call intrp(a1,tempm,fact1m)
c
      call intrp(a2,prs,fact2)
c
      wleak1 = fact1a*fact2
      wleak2 = fact1b*fact2
c     80% PV5, 20% manifold case
c     wleak2 = .8*fact1b*fact2+.2*fact1m*fact2
      wleak3 = fact1c*fact2
c
      if(tim.lt. 2122.)then                  ! Ambient temp leak
        wleak3 = .21*fact2
        wleak3=wleak3*sqrt((TSAT(prs)+temp+tol)/540.)
        wleak2=wleak3
        wleak1=wleak3
      end if
c
c     GET PPM
```

```
c
        ppm1 = ppm1+(wleak1-ppm1*1.e-6*w)*1.e6/volin3/60.
        ppm2 = ppm2+(wleak2-ppm2*1.e-6*w)*1.e6/volin3/60.
        ppm3 = ppm3+(wleak3-ppm3*1.e-6*w)*1.e6/volin3/60.
c
        if( tim.gt.0. .and. tim .ge. tprint ) then
          tprint = tim+10.
          write(3) tim,ppm1,ppm2,ppm3,
     1                   wleak1,wleak2,wleak3,
     2                   temp,flow,vapor
        end if
c
        goto 200
c
 900    close(unit=1)
        close(unit=2)
        close(unit=3)
        close(unit=4)
c
        end
c
c

        SUBROUTINE INTRP(A,X,Y)
C
C General purpose interpolation routine.  A() is the array to
C interpolate, X in the independent variable, and Y is the
C returned dependent variable.  The A() array should be
C configured as follows:
C
C   a(1)  Real   -  number of x and y entries (n = 2 * x/y pairs)
C   a(2)  Real   -  zero
C   a(3)  Real   -  X1
C   a(4)  Real   -  Y1
C   a(5)  Real   -  X2
C    .     .        .
C    .     .        .
C a(n+2)  Real   -  Ym  where m=n/2
C
C Note that both a(1) and a(2) are reset by INTRP after the first
C call, and should not be changed by the calling program
C
        REAL A(*),A1,A2
        INTEGER*4 I1,I2
        EQUIVALENCE (A1,I1),(A2,I2)
C
        A1=A(1)
        A2=A(2)
        IF(I2.NE.0) GOTO 20       ! check if initialized
        I1=A1+1                   ! reset to integer
        A(1)=A1                   ! and store
        I2=3                      ! set current index at bottom
C
   20   IF(X-A(I2)) 30,40,50
```

```
   30   IF(I2.EQ.3) GOTO 40      ! at bottom, use first value
        I2=I2-2                  ! else backup
        GOTO 20                  ! and try again
C
   40   Y=A(I2+1)                ! use current value
   45   A(2)=A2                  ! restore current index
        RETURN                   ! and done
C
   50   IF(I2.EQ.I1) GOTO 40     ! at top, use last value
        D1=A(I2+2)-X
        IF(D1.LE.0) GOTO 60      ! not far enough
        Y=A(I2+3) - D1*(A(I2+3)-A(I2+1))/(A(I2+2)-A(I2))
        GOTO 45
C
   60   I2=I2+2                  ! move foward
        GOTO 20                  ! and try again
        END
```

APPROVAL

STS-35 SCRUB 3 HYDROGEN LEAK ANALYSIS

By Dave Seymour

The information in this report has been reviewed for technical content. Review of any information concerning Department of Defense or nuclear energy activities or programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

J.P. MCCARTY
Director, Propulsion Laboratory

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