EVALUATION OF

CLASIX-3 CONSERVATISMS

AND QUARTER SCALE TESTS

River Bend Station - Unit 1

August, 1985

1.0 Introduction

Following the TMI-2 accident, the NRC staff expressed concern that the ice condenser and Mark III containment designs might be vulnerable to overpressures produced by hydrogen deflagrations. Consequently the CLASIX computer code was developed to provide a conservative estimate of the hydrogen deflagration pressure. The BWR version of this code, CLASIX-3, contained the same conservatisms as the original CLASIX code. The fact that the CLASIX-3 code was designed to provide a conservative prediction of deflagration pressures in turn resulted in a conservative prediction of temperatures resulting from deflagrations. Recent testing performed by the Hydrogen Control Owners Group (HCOG) at the Quarter Scale Test Facility (QSTF) shows that the pressures and temperatures predicted by CLASIX-3 are overconservative.

The RBS survivability analysis completed to date, based on the CLASIX-3 analysis, indicates that all equipment located in the lower intermediate volume just above the HCU floor will survive the thermal environment present in this region. The survivability analysis completed for hydrogen igniters and igniter power supply cable in the wetwell region indicates that survivability of these components is not assured for the entire 75% MWR transient thermal environment as predicted by CLASIX-3.

The thermal environments predicted by CLASIX-3 are excessively conservative for assessing the ability of equipment in the River Bend Station to survive hydrogen combustion. As indicated above, a number of conservative assumptions have been incorporated in the CLASIX-3 analysis to assure conservative predictions of containment pressure. In addition, based on 1/4 scale testing, the serial deflagrations predicted by CLASIX-3 constitute a significantly more severe thermal environment than the actual thermal environment which would be expected to occur in a Mark III containment.

The following report provides an evaluation of the conservatisms present in CLASIX-3, a discussion of the combustion phenomena observed in 1/4 scale testing and an evaluation of the ability of equipment to survive the thermal environment expected to occur in a Mark III containment.

2.0 Evaluation of Conservatism in CLASIX-3 Assumptions

The CLASIX-3 code assumes that each compartment modeled by the code is instantaneously completely mixed. Thus combustion in a compartment cannot occur until sufficient hydrogen has been injected into the compartment to bring the hydrogen concentration throughout the entire volume up to the hydrogen concentration which has been specified as the concentration required to support combustion. The CLASIX-3 code allows combustion in a volume, e.g. the wetwell, when the average concentration reaches 8%. Upon ignition, the volume is swept out by a flame front assumed to travel at 6 ft/sec. This burn is assumed to go to 85% completion. The CLASIX-3 code accounts for heat losses to walls and other surfaces. The heat losses during burning are directly affected by flame speed since the flame speed will determine the time to lose heat during flame propagation. The degree of conservatism resulting from this combination of assumptions can be quantified by assessing the deflagration pressures and temperatures expected to occur in a Mark III containment.

Two general types of release histories have been injected into the 1/4 scale test facility to date. One (case C', 150 gpm reflood) begins with a quickly increasing hydrogen flow rate which should result in a large vertical hydrogen concentration gradient in the wetwell. The other (case B, 5000 gpm reflood) injects hydrogen for a relatively long period at a low rate before a large spike in hydrogen flow is introduced. This history, at least prior to the spike, should be representative of the minimum vertical hydrogen concentration in the wetwell. A total of 21 scoping tests have been performed with such histories and in no case did the initial lightoff deflagration (only deflagration observed in any test) result in pressures or temperatures approaching those calculated for the full scale plant using CLASIX-3 for the same (scaled up) release histories. Figures 2-1 and 2-2 provide a comparison of pressures predicted by CLASIX-3 and 1/4 scale pressures respectively. Figures 2-3 and 2-4 provide a comparison of temperatures calculated by CLASIX-3 with the 1/4 scale temperatures. Based on the above, the combination of assumptions used in the CLASIX-3 code yield pressures and temperatures well above those which actually are expected to occur in Mark III containment due to deflagrations.

From the above discussion, it can be concluded that CLASIX-3 severely over-predicts both the expected full scale temperatures and pressures. The following discussions identify key CLASIX-3 assumptions which may produce this over conservatism. In the CLASIX-3 code, combustion is assumed to be initiated in a volume when the hydrogen concentration by volume reaches 8%. This represents an upper bound on the hydrogen concentration at which deflagrations would be initiated by igniters. A large number of tests including the recently completed Nevada Test Site Tests demonstrate that mixtures with hydrogen concentrations as low as 5.8% can be ignited. It is completely reasonable, based upon tests completed by Acurex for EPRI, tests completed by Fenwal Laboratories for Westinghouse, and tests completed by Whiteshell Laboratories for EPRI, to conclude that mixtures with volumetric hydrogen concentrations of 6% will be reliably ignited in the Mark III containment.

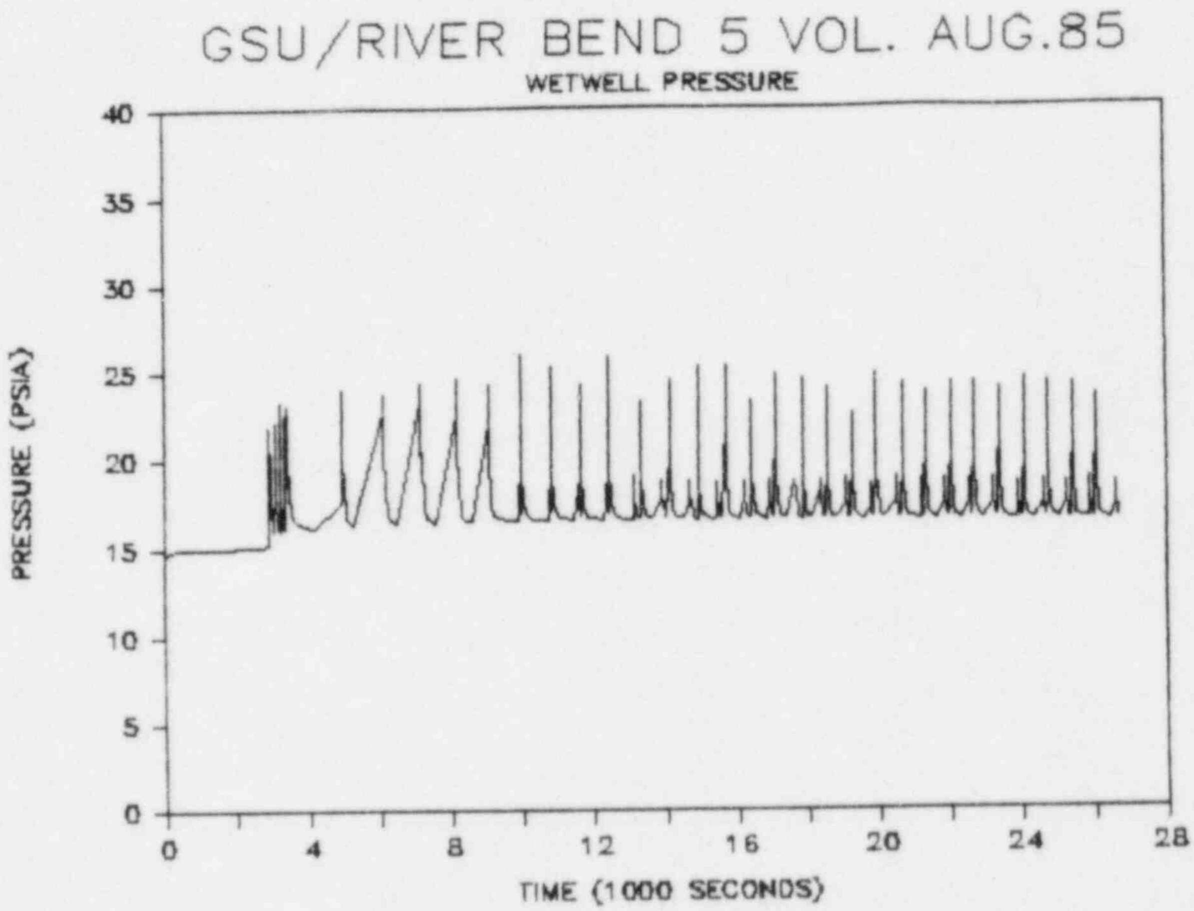
Another CLASIX-3 assumption which may result in over-prediction of temperatures and pressures is combustion completeness. When mixtures with lower volumetric hydrogen concentration are ignited, less of the hydrogen present in the mixture is burned. For example, combustion of mixtures with a hydrogen concentration of 6% by volume will consume only about 65% of the hydrogen present in the mixture even when very high levels of turbulence are present. The combination of initiating combustion at lower hydrogen concentrations than assumed in the analysis of wetwell hydrogen combustion and burning less of the hydrogen would result in a considerable reduction in peak temperature for wetwell burns. Since the peak temperature has a significant effect on radiant heat transfer in equipment survivability analysis, use of higher hydrogen concentrations to initiate combustion and higher burnup fractions results in considerable conservatism in thermal environment definition.

The burn duration assumed in CLASIX-3 will have a direct affect on peak pressures and temperatures. The rate at which energy is added to a volume by hydrogen combustion in the CLASIX-3 computer code is controlled by a burn duration time input for each volume treated by the code. The burn durations used to date in GSU's CLASIX-3 analysis are based on an average flame propagation speed of 6 feet per second. This is a conservative basis for defining combustion duration for the River Bend Station. Flame speeds for combustion propagation decrease significantly when combustion is initiated at lower volumetric hydrogen concentrations such as 6% hydrogen concentration mixtures. In addition, flame speed is related to the turbulence levels present in the containment. Since the River Bend Station does not utilize containment sprays to provide bulk containment heat removal, but rather uses safety grade containment unit coolers, the relative turbulence levels in the River Bend Station containment should be significantly lower than the turbulence levels present in other Mark III containment plants. Lower flame speeds would result in greater burn durations. This would result in more time for pressure equalization, more uniform mixing of the containment air spaces and reduced temperatures due to dilution by the entire containment volume. In addition, a longer burn duration will result in a lower heat addition rate to the containment which will allow more time for heat removal by the RBS containment heat sinks and unit coolers.

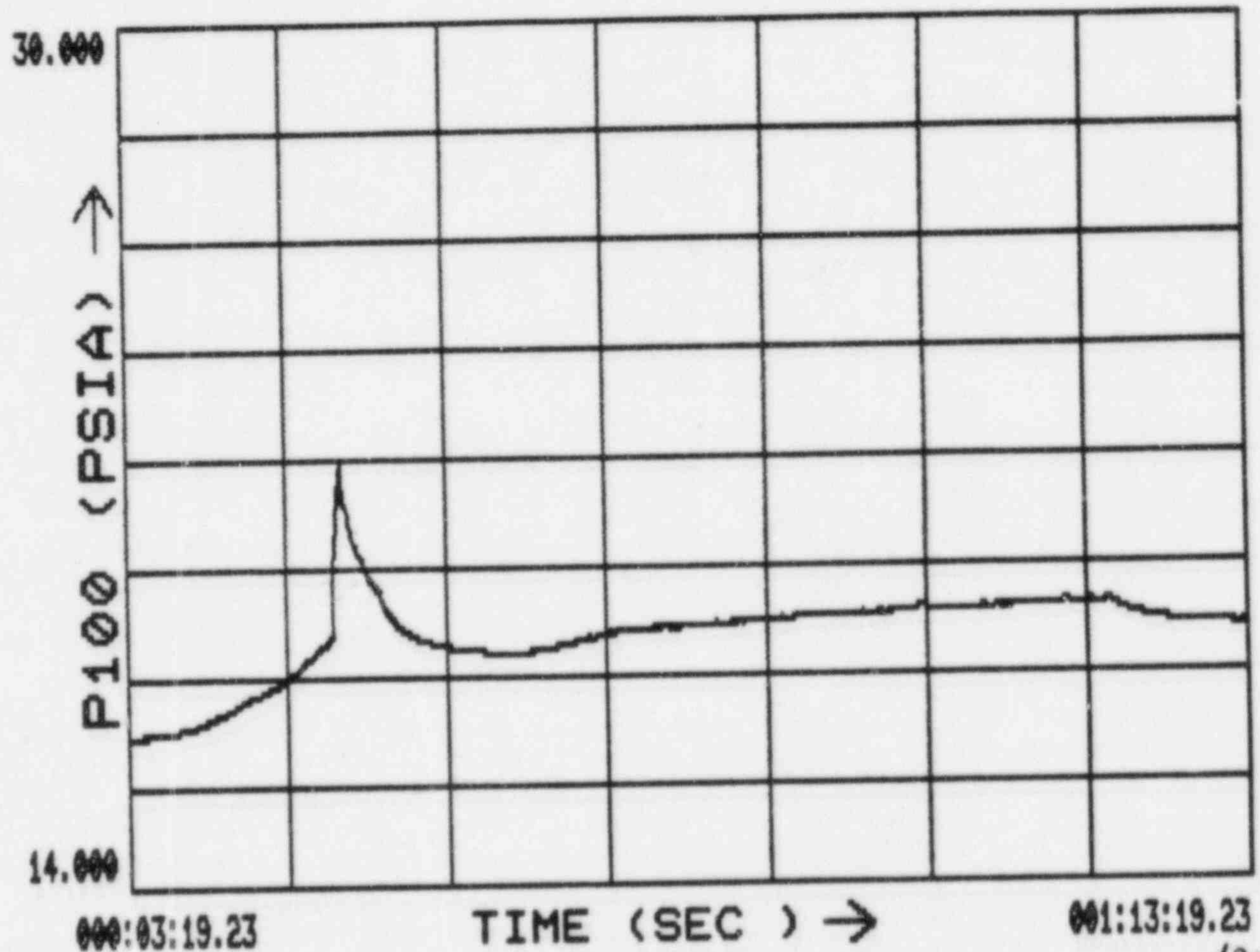
The methodology used to calculate heat transfer from a compartment atmosphere to compartment heat sinks is extremely conservative. At the NRC staff's suggestion, heat transfer correlations used to calculate environmental conditions following design basis accidents have been used to calculate heat transfer to containment passive heat sinks. This methodology is described in detail in NUREG 0588. The conservative character of these heat transfer correlations is intended to provide adequate margins in defining the thermal environments produced after a design basis accident. These conservatisms are not appropriate for definition of thermal environments following degraded core accidents since the same levels of margins are not warranted for less probable recoverable degraded core accidents.

The above CLASIX-3 conservatisms when coupled with the conservative modeling of the River Bend containment heat sinks and conservative modeling of the containment unit coolers result in a thermal environment significantly more severe than that which would be expected at full scale.

FIGURE 2-1



GSU/RIVER BEND 5 VOL. AUG.85
WETWELL PRESSURE
PRESSURE (PSIA)
40
35
30
25
20
15
10
5
0
0
4
8
12
16
20
24
28
TIME (1000 SECONDS)

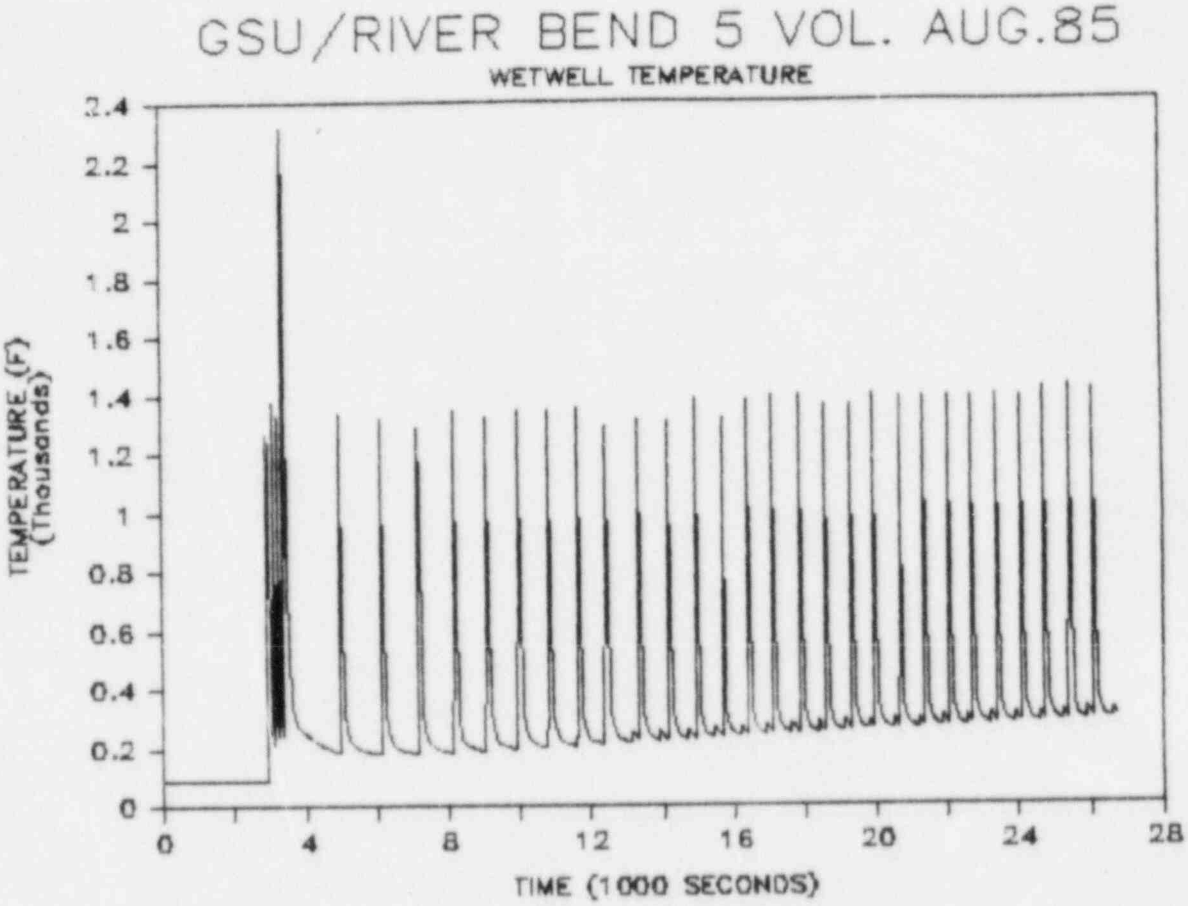


EPRI-FIRST SCOPING TEST FOR CASE B RELEASE, TEST NO. S-08
TEST DATE: 18-JUN-85 START TIME: 14:16:23.8
P100 MINIMUM 16.797 PSIA P100 MAXIMUM 21.814 PSIA

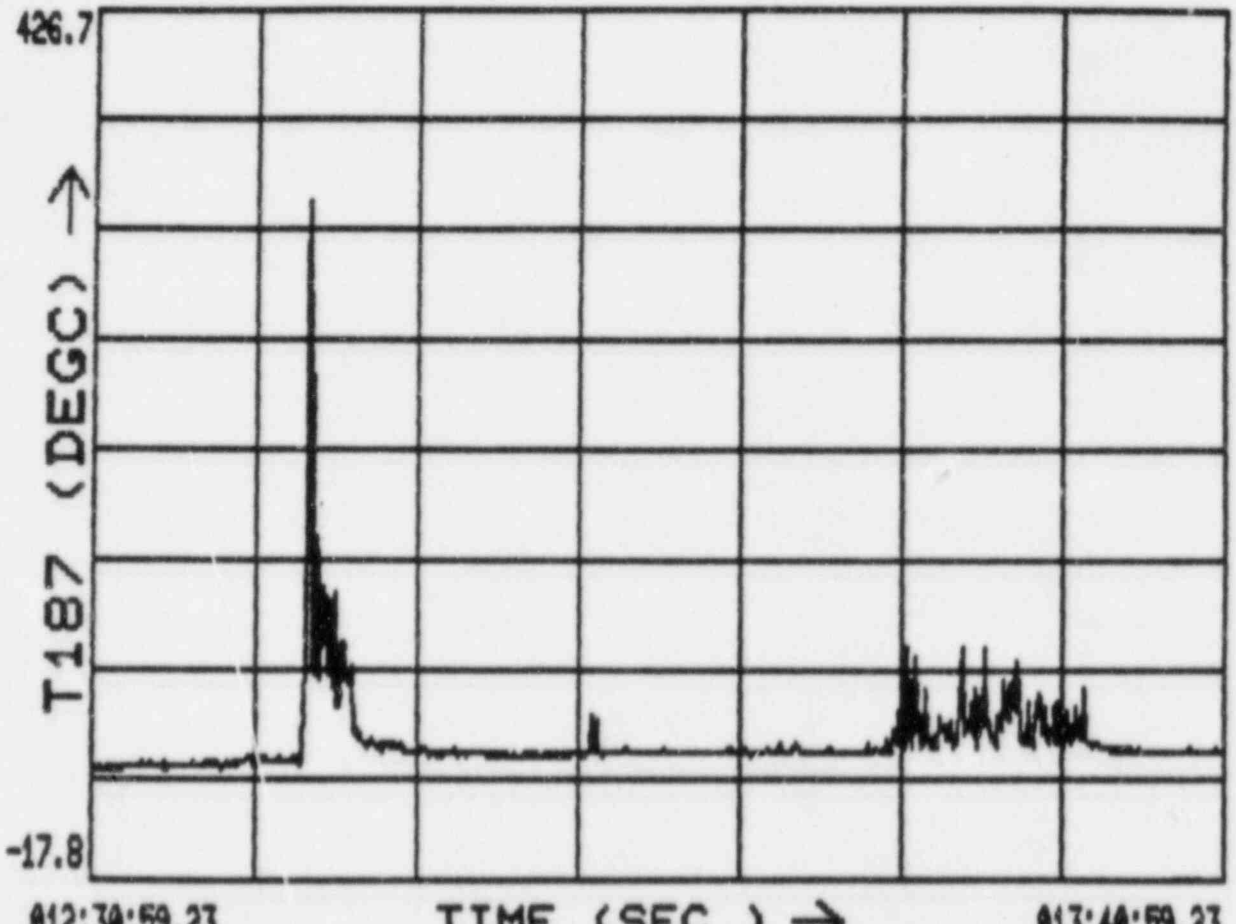
Figure 2-2

Pressure Profile - Test S.08

FIGURE 2-3



GSU/RIVER BEND 5 VOL. AUG.85
WETWELL TEMPERATURE
TEMPERATURE (F) (Thousands)
TIME (1000 SECONDS)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
2.2
2.4
0
4
8
12
16
20
24
28



EPRI-FIRST SCOPING TEST FOR CASE B RELEASE, TEST NO. S-08
TEST DATE: 18-JUN-85 START TIME: 14:16:23.8
T187 MINIMUM 38.5 DEGC T187 MAXIMUM 327.4 DEGC

Figure 2-4.
Temperature Profile for area adjacent to steam tunnel and under HCU floor - Test S.08

3.0 COMBUSTION PHENOMENA OBSERVED IN 1/4 SCALE TESTING

Testing completed in 1983 in a 1/20 scale model of a Mark III containment plant (reference 1) indicated that for full scale hydrogen release rates above approximately 0.4 lbm/sec, steady diffusion flames would be produced on the suppression pool surface. The 0.4 lbm/sec hydrogen flow rate was defined as the threshold above which steady diffusion flames would be expected. It was assumed that the repeated deflagrations predicted by the CLASIX-3 computer code would provide a conservative representation of the combustion phenomena below the diffusion flame threshold.

HCOG committed to complete additional testing in a 1/4 scale simulation of a Mark III containment in order to define the thermal environment produced by steady diffusion flames. Based upon discussions between HCOG and the NRC staff, HCOG also committed to complete testing in the 1/4 scale test facility which would allow HCOG to demonstrate the degree of conservatism present in the CLASIX-3 computer analyses.

HCOG has now completed the scoping test portion of the 1/4 scale test program. HCOG's initial evaluation of the scoping test program results as they relate to evaluation of parameters which could affect the thermal environment produced by diffusive hydrogen combustion are contained in reference 10. The scoping tests have provided considerable information on the combustion phenomena which is expected in full scale Mark III containments. The combustion phenomena observed were not discussed in detail in reference 2.

Three scoping tests were completed to evaluate the threshold for existence of steady diffusion flames. The first two were intended to evaluate the threshold for steady diffusion flames under conditions which would be representative of degraded core accident conditions. The third test was intended to provide a comparison with the threshold testing completed in the 1/20 scale test facility.

Test S.08 was completed to evaluate the threshold for existence of steady diffusion flames under degraded core accident conditions when a single safety relief valve is stuck open. The 330° simulated safety relief valve was assumed to be stuck open for this test. Since all scoping tests were completed using a Mark III plant geometry which has a larger core than River Bend, eight simulated ADS safety relief valves are open for the tests. In order to simulate potential degraded core accident conditions, a hydrogen release history corresponding to hydrogen production following recovery of an ECC system with flow capacity of 5000 GPM was injected. Reference 3 discusses the hydrogen release histories used in the scoping test program. Following the ECCS reflood hydrogen release history, the hydrogen injection rate is dropped to 0.21 lbm/sec (all hydrogen injection rates are full scale equivalent values) and held for approximately one minute. The flow rate was then reduced to 0.14 lbm/sec for another minute. The flow was then decreased to 0.07 lbm/sec and held constant at this value for 45 minutes to define the dominant combustion phenomenon present at very low hydrogen injection rates.

The hydrogen release history used for test S.08 is shown in figure 3-1. This release history presents actual 1/4 scale hydrogen injection flow rates. An initial deflagration established a steady diffusion flame on the suppression pool surface coincident with the rapid hydrogen release associated with reflooding the reactor vessel with an ECC system. Since the release history used in this test has the highest hydrogen injection rate, this will produce the maximum hydrogen gradient in the wetwell compared to other release histories. Infrared video cameras in the test facility showed horizontal propagation of the flamefront with the apparent point of initiation under the steam tunnel. The pressure rise produced by the deflagration was very small indicating that the total amount of hydrogen consumed in the deflagration was not appreciable. This indicates the conservative nature of CLASIX-3 analysis which predicts an approximately 9 psi initial deflagration pressure rise for the same release history. The pressure history for a pressure transducer located in the wetwell is shown in figure 3-2. In addition, the hydrogen concentration which is measured continuously in the wetwell by sensor H190 shows that the hydrogen concentration measured by H190 at the time of the initial lightoff deflagration was approximately 4%. The hydrogen concentration measurement from instrument H190 is shown in figure 3-3. In addition, the hydrogen concentration measured by H001 is approximately 4% and the concentration measured by H002 is approximately 5% at the time of the initial lightoff deflagration. These measurements indicate that the global hydrogen concentration measured in the wetwell and at higher elevations at lightoff is in the range of 4-5%. These measurements agree with the 4.7% hydrogen concentration calculated by assuming that all hydrogen released prior to lightoff is uniformly mixed throughout the containment.

Following the initial lightoff deflagration, hydrogen burned as a steady diffusion flame on the suppression pool surface until the hydrogen injection rate dropped below 0.14 lbm/sec full scale equivalent. At about thirty minutes into the transient, a weak and intermittent diffusion flame appeared in the 315° chimney for approximately 10 minutes. This diffusion flame appeared with no visibly propagating deflagration. The flames appeared to originate under the steam tunnel. A thermocouple trace for instrument T-187 which is immediately adjacent to the steam tunnel and under the HCU floor is shown in figure 3-4. This figure demonstrates the weak character of the diffusion flame in comparison to the diffusion flame present during the earlier high hydrogen release.

Test S.10 was completed to evaluate the effects on diffusion flame threshold of assuming that the stuck open relief valve was actually an ADS valve. For this test, only 8 simulated safety relief valves are open. This is similar to the River Bend case in which there would be 7 ADS valves plus one stuck open relief valve open. The same hydrogen release history is used for this test as the release history used for test S.08. The hydrogen release history injected into the facility is shown in figure 3-5.

In test S.10, a steady diffusion flame is established on the suppression pool surface before the rapid hydrogen injection associated with ECC recovery occurs. The initial deflagration which ignites the diffusion flame again appears to originate under the steam tunnel. As with the initial deflagration which occurs for test S.08, a relatively small pressure rise is produced by this deflagration. Figure 3-6 shows the pressure history for instrument P-100. The initial deflagration occurs when the global hydrogen concentration is slightly less than 4% by volume. Figure 3-7 shows the hydrogen concentration measured in the upper region of the wetwell by instrument H-190 for test S.10.

After the hydrogen injection decreases below 0.14 lbm/sec full scale equivalent for test S.10, the diffusion flames on the suppression pool surface extinguish and do not reappear. No additional combustion is visible on the videotapes from the infrared television cameras in the wetwell. As can be observed in figure 3-7, the hydrogen concentration reaches virtually a steady state value during the transient. This conclusion is reinforced by the continuous hydrogen concentration measurements from instrument H-410 which is located immediately below the top of the 45^{o} chimney. Figure 3-8 shows this hydrogen concentration measurement as a function of time. Since hydrogen is being injected throughout the test, it is apparent that some type of combustion must be consuming hydrogen. Thermocouple data in the 45^{o} chimney indicates that some type of weak, localized combustion is occurring in this chimney. Figures 3-9 and 3-10 show temperature traces for thermocouples T-309 and T-410. These thermocouples are in the upper regions of the 45^{o} chimney.

The third test completed to investigate the threshold for establishing steady diffusion flames was test S.04. This test was intended to replicate as closely as possible the threshold tests completed in the 1/20 scale test program. Eight simulated SRV spargers were used in this test. A steady diffusion flame was established as early as possible with an initially high hydrogen flow rate. This prevented accumulation of a significant background hydrogen concentration which HCOG believes contributes to a lower threshold for establishing diffusion flames. The hydrogen flow rate was then stepped down to 0.28 lbm/sec and held at a constant value. The hydrogen flow rate was then reduced to 0.21 lbm/sec and following that to 0.14 lbm/sec. The diffusion flames became intermittent when the flow rate was reduced from 0.21 lbm/sec to 0.14 lbm/sec. The diffusion flames did not extinguish until the flow rate was lowered to 0.07 lbm/sec. The apparent lowering of the flow required for initiation of intermittence, (threshold) at 1/4 scale is partially attributed to the improved modeling of the sparger devices which have vertical slits simulating the flow from each column of sparger holes as opposed to the 1/20 scale spargers which contained only 4 holes in each side of each arm. In addition, the improved overall modeling of the phenomena at 1/4 scale, i.e. fully turbulent flow vs. somewhat laminar flow off the pool at 1/20 scale, is also a contributing factor.

The HCOG completed two tests to identify the limiting thermal environment produced by hydrogen combustion. Test S.11 was completed with a hydrogen release history corresponding to a 150 GPM reflood of the vessel and a sustained hydrogen release of 0.14 lbm/sec full scale equivalent hydrogen release until the total hydrogen produced equaled the amount produced by oxidizing 75% of the active core cladding inventory. The hydrogen release history for this test is shown in figure 3-11. The purpose of this test was to identify a limiting thermal environment produced by diffusion flames when total hydrogen production reached a 75% metal water reaction (75% MWR). The hydrogen was released through the 8 simulated ADS safety relief valves and a single safety relief valve assumed to be stuck open in the 45° chimney. The stuck open relief valve was postulated to occur in the 45° chimney in order to create the most severe diffusion flame environment. Since test S.11 was intended to define a limiting thermal environment for plants with containment sprays, the sprays were actuated when the average containment air space temperature reached 185° in accordance with the existing primary containment emergency procedure guideline.

During test S.11, the initial deflagration which establishes the diffusion flame on the suppression pool surface occurs during the hydrogen production spike associated with initial injection of 150 GPM into the reactor pressure vessel. A steady diffusion flame exists on the suppression pool surface in the 45° chimney throughout the transient. Diffusion flames exist on the pool surface above each sparger device during the hydrogen production spike and reappear twice in the 315° chimney during the sustained hydrogen production portion of the transient. Figure 3-12 shows the temperature profile in the 45° chimney above the HCU floor as measured by thermocouple T-204. Figure 3-13 shows the temperature profile in the 315° chimney above the HCU floor as measured by thermocouple T-287. These two thermocouples represent limiting thermal environments in these two chimneys at the HCU floor.

Test S.09 was completed to evaluate the limiting thermal environment which could be produced by localized combustion for accidents involving total hydrogen production equivalent to 75% MWR. The same hydrogen release history used in test S.11 was used in test S.09 except that the sustained hydrogen injection following the 150 GPM reflood hydrogen was reduced to 0.07 lbm/sec. Figure 3-14 shows the hydrogen release history used in test S.09. As in test S.11, the containment sprays were actuated when the average containment temperature reached 185°F. The hydrogen was released through the eight ADS valves which correspond to the scoping test ADS locations. The stuck open relief valve was assumed to be an ADS valve for this scenario since the only test in which localized combustion had been observed was test S.10 which used only the 8 ADS spargers.

During test S.09 the initial deflagration which establishes the diffusion flame on the suppression pool surface occurs during the hydrogen production spike associated with the 150 GPM reflood. A steady diffusion flame exists in the 45° chimney throughout the period of hydrogen injection into the facility. Figure 3-15 shows the temperature measured by thermocouple T-209 which is above the HCU floor in the 45° chimney. No evidence of the localized combustion which occurred in test S.10 was observed during this test. Thermocouples in the upper regions of the 45° chimney which provided evidence of localized combustion in test S.10 seem to indicate only the presence of diffusion flames on the suppression pool surface. Figures 3-16 and 3-17 show the temperature response for thermocouples located in the upper regions of the 45° chimneys. A comparison of these temperature plots with figures 3-9 and 3-10 verifies that the same phenomenon present in test S.10 is not occurring in test S.09.

The testing completed to date has demonstrated that in a Mark III containment, hydrogen combustion will be initiated before bulk average wetwell hydrogen concentration reaches 6%. The testing has shown that for very low hydrogen generation rates, it is still possible to maintain intermittent diffusion flames on the suppression pool surface. All deflagrations observed to date in the facility are very weak, and in many cases virtually imperceptible. Bulk average hydrogen concentration throughout the test facility never exceeds 6% by volume.

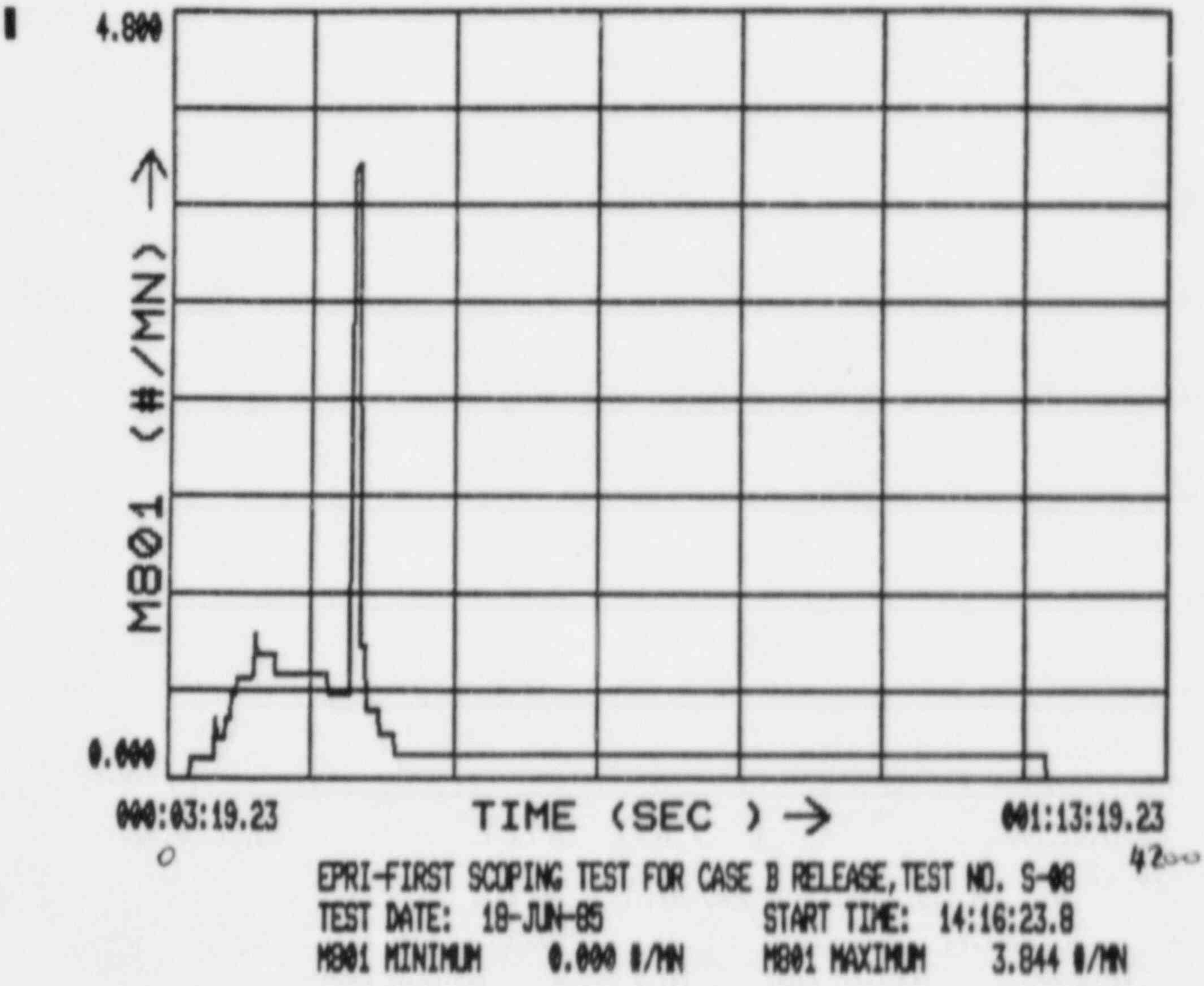
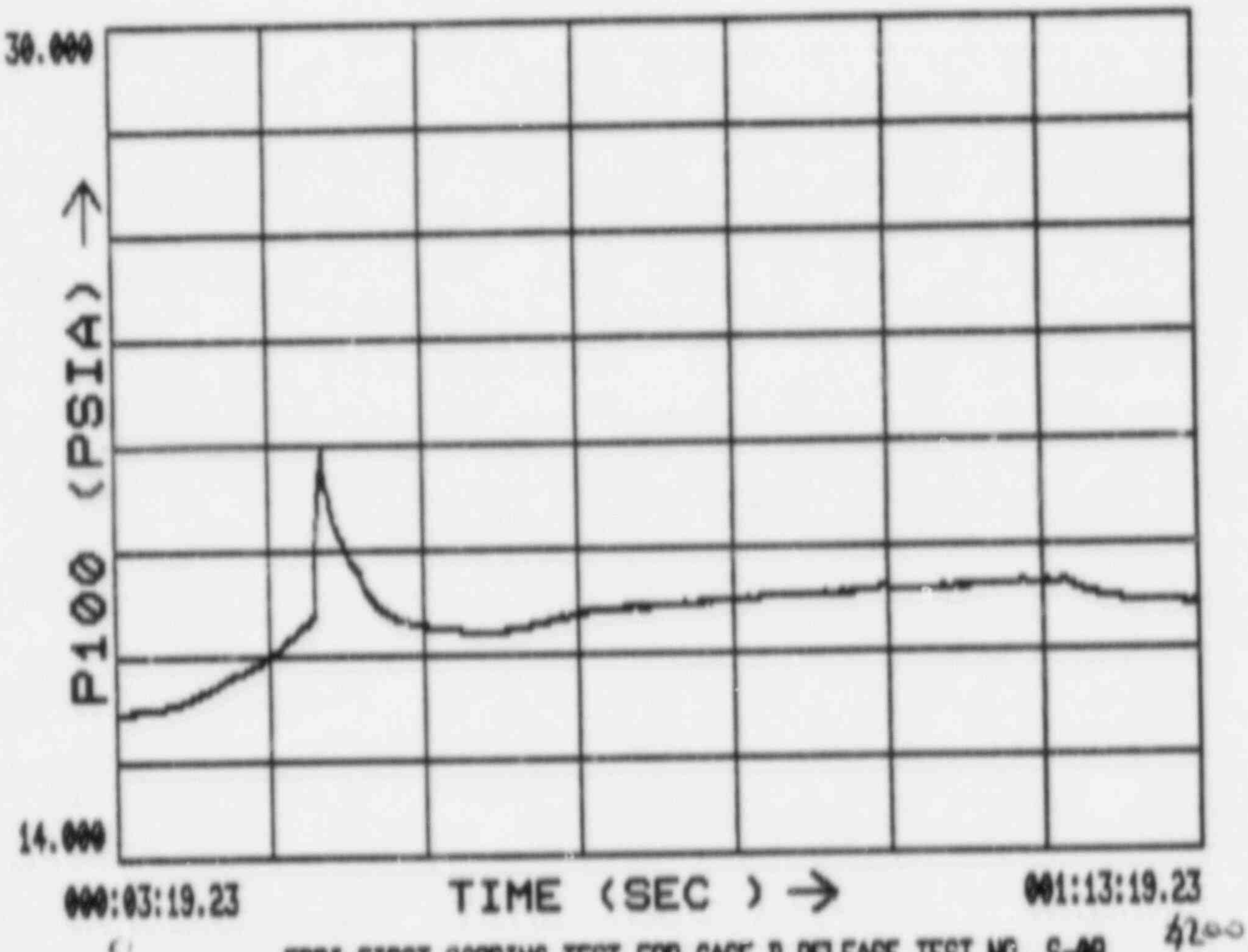


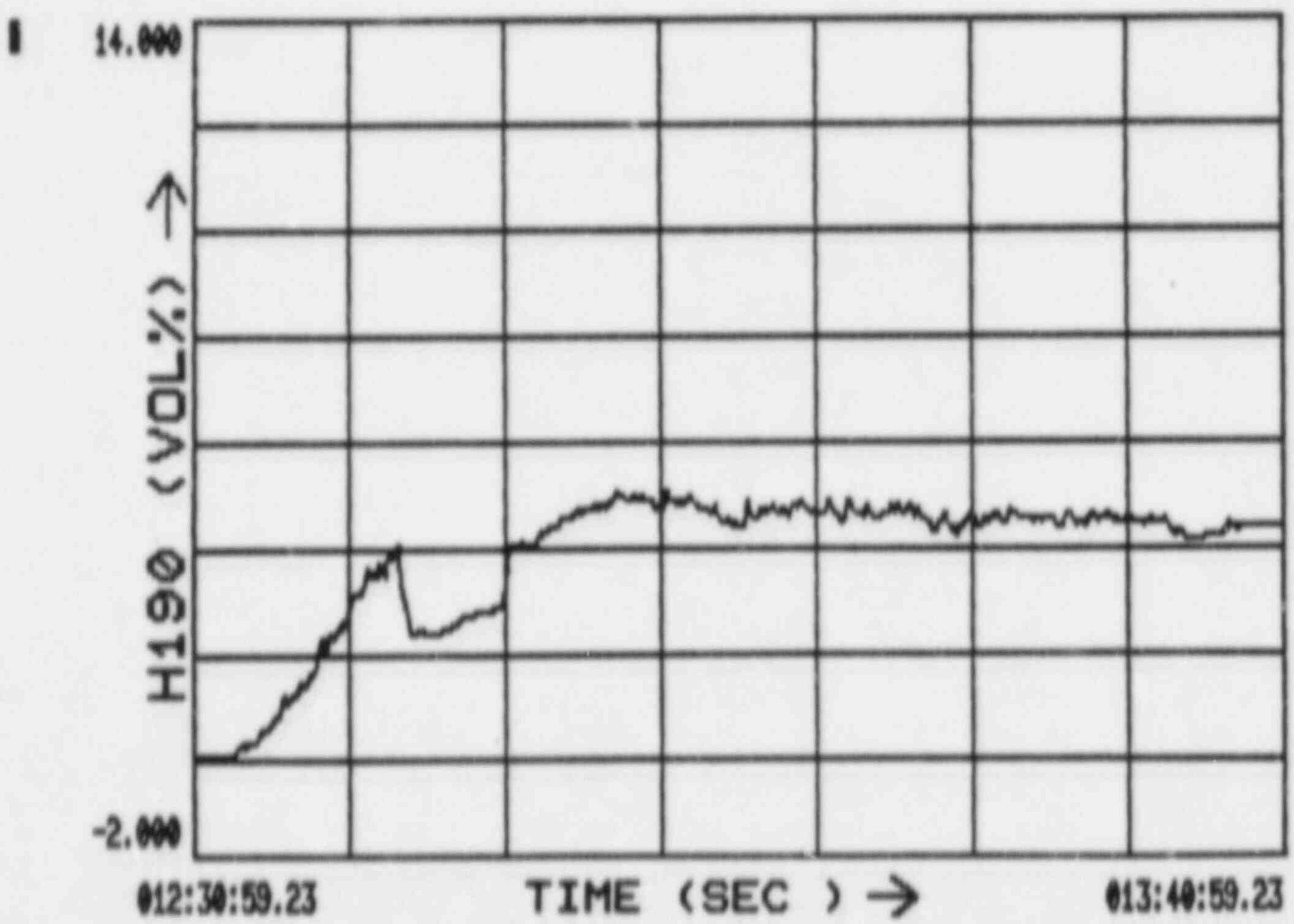
Figure 3-1.
Hydrogen Release History - Test S.08



EPRI-FIRST SCOPING TEST FOR CASE B RELEASE, TEST NO. S-08
TEST DATE: 18-JUN-85 START TIME: 14:16:23.8
P100 MINIMUM 16.797 PSIA P100 MAXIMUM 21.814 PSIA

Figure 3-2.

Pressure Trace (wetwell) - Test S.08



EPRI-FIRST SCOPING TEST FOR CASE B RELEASE, TEST NO. S-08
TEST DATE: 18-JUN-85 START TIME: 14:16:23.8
H190 MINIMUM -0.065 VOL% H190 MAXIMUM 4.979 VOL%

Figure 3-3.
Hydrogen Concentration in 45° Chimney
in wetwell - Test S.08

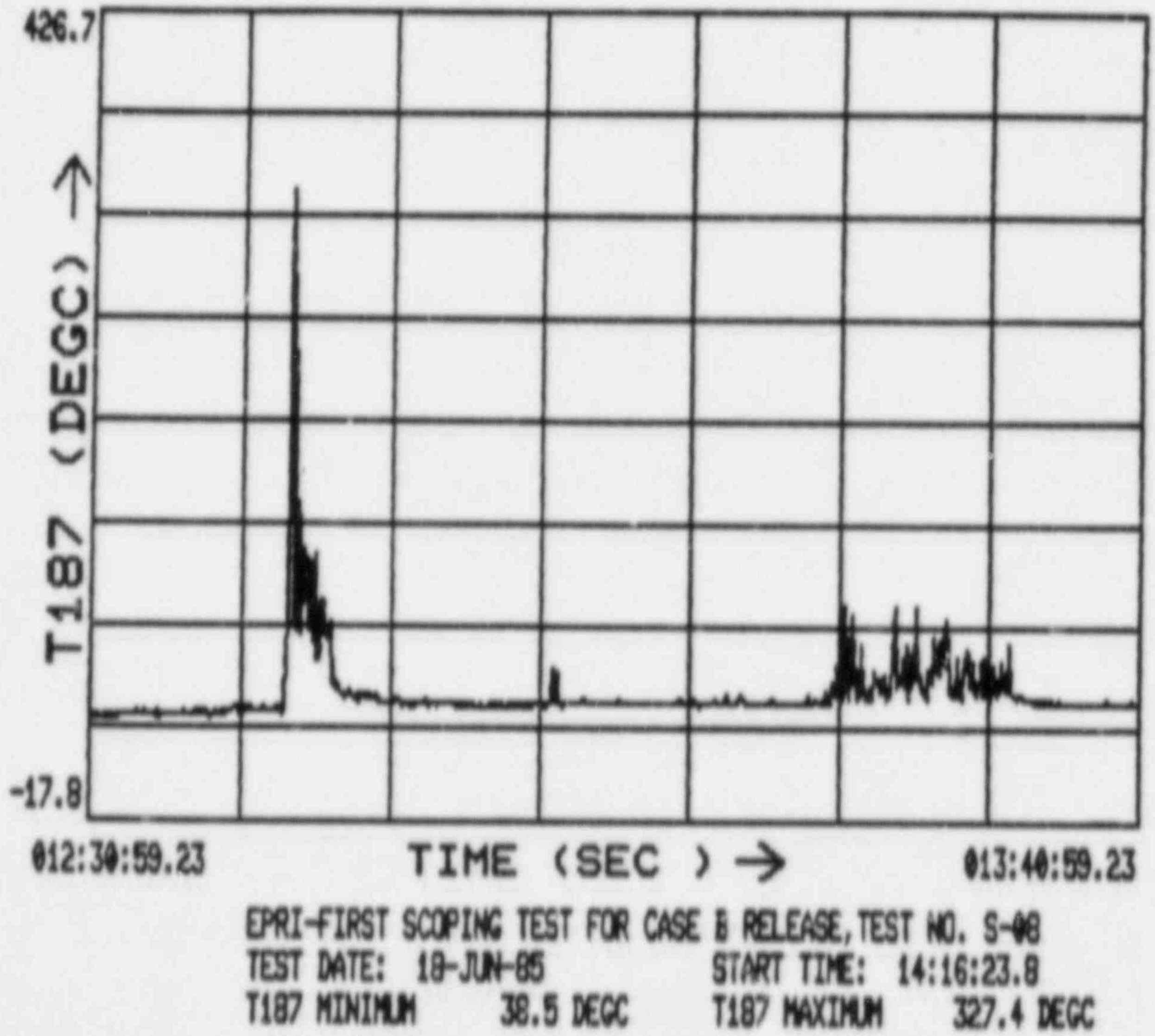
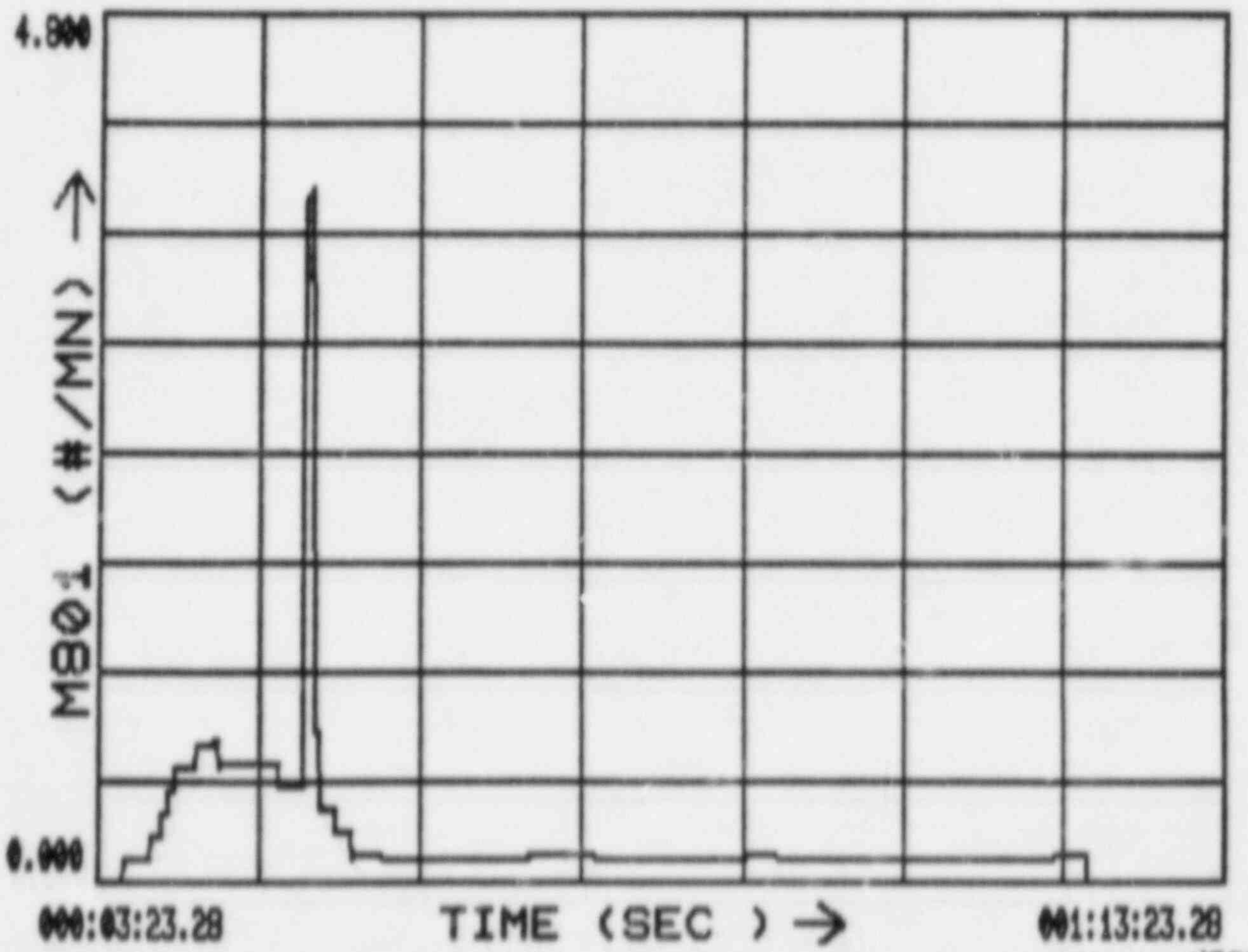


Figure 3-4.
Temperature Profile for area adjacent to steam tunnel and under HCU floor - Test S.08



EPRI-SCOPING TEST, CASE "B" RELEASE, ADS ONLY, TEST NO. S-10

TEST DATE: 21-JUN-85 START TIME: 13:47:24.6

M801 MINIMUM 0.000 #/MN M801 MAXIMUM 3.833 #/MN

Figure 3-5.
Hydrogen Release History - Test S.10

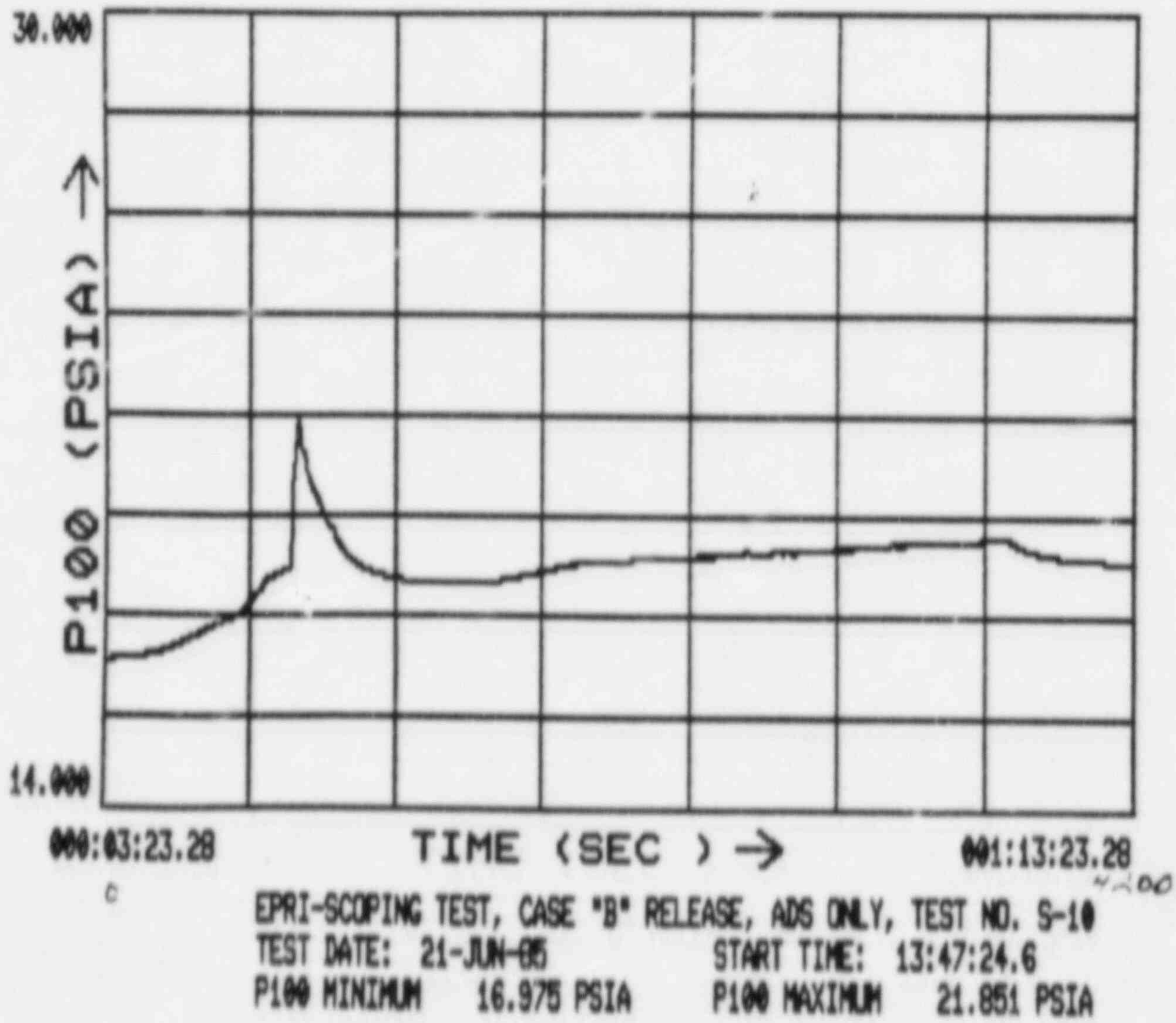
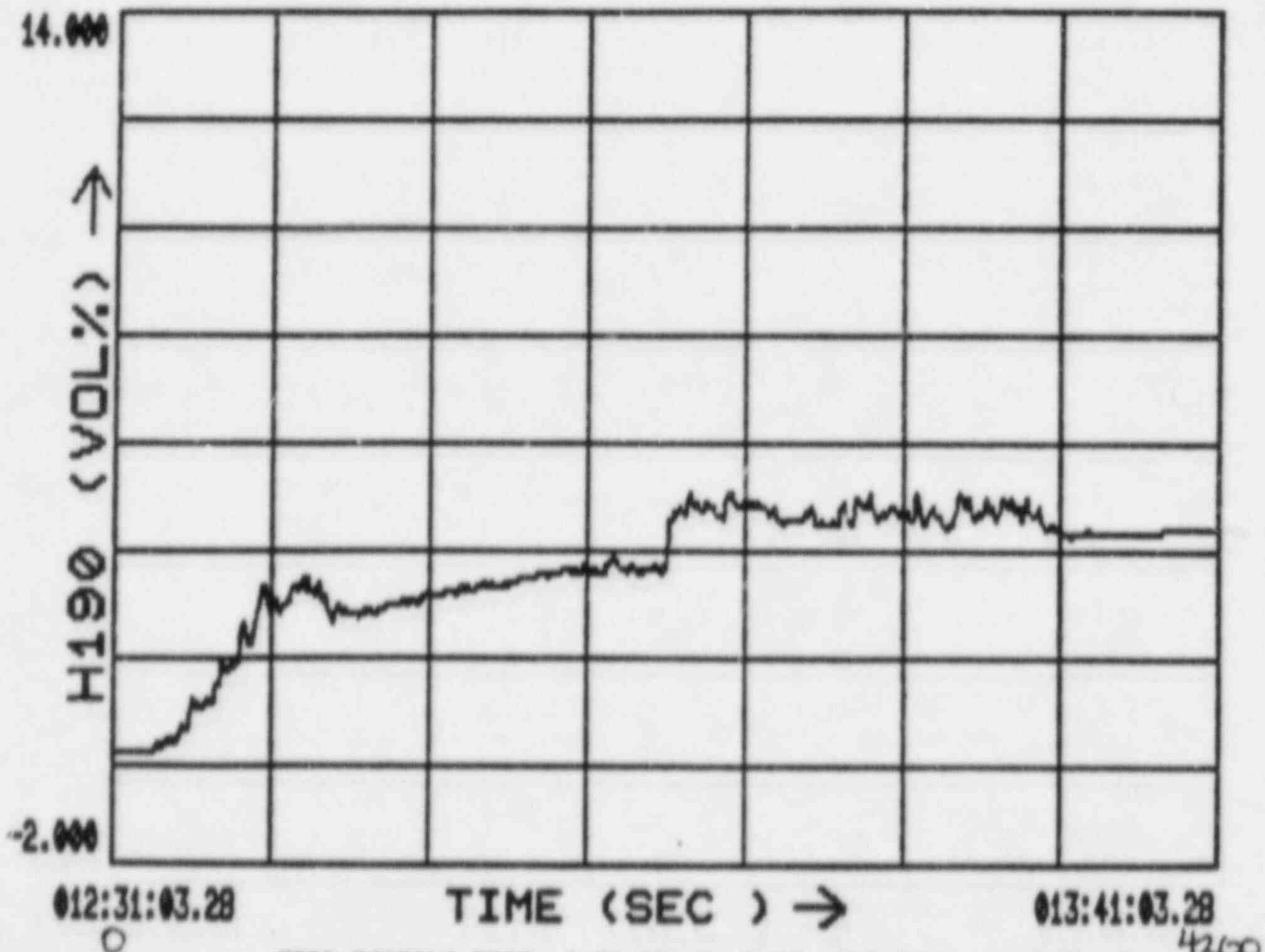


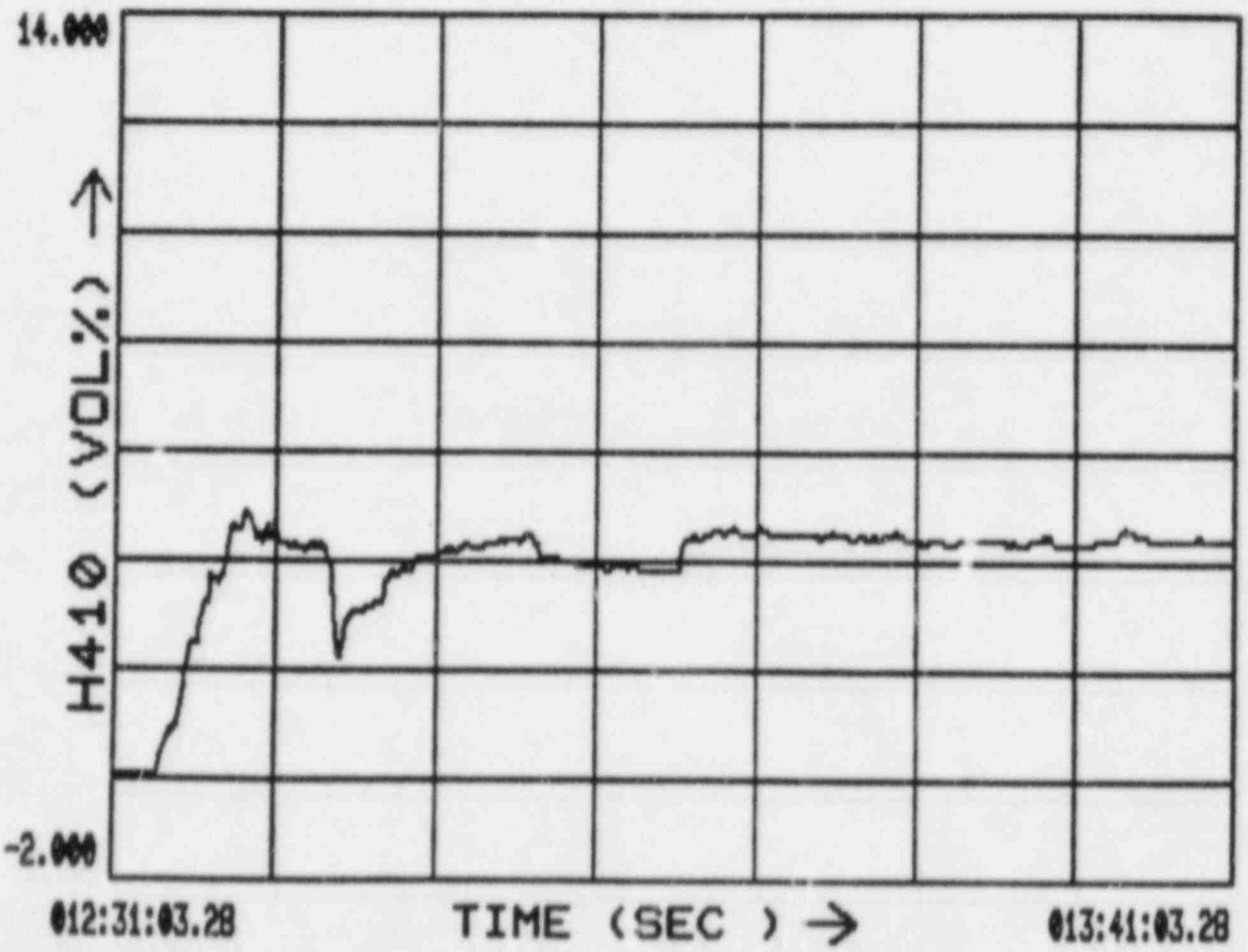
Figure 5-6.

Pressure Trace (wetwell) - Test S.10



EPRI-SCOPING TEST, CASE "B" RELEASE, ADS ONLY, TEST NO. S-10
TEST DATE: 21-JUN-85 START TIME: 13:47:24.6
H190 MINIMUM 0.059 VOL% H190 MAXIMUM 4.979 VOL%

Figure 3-7.
Hydrogen Concentration in 315° Chimney in wetwell - Test S.10



EPRI-SCOPING TEST, CASE "B" RELEASE, ADS ONLY. TEST NO. S-10
TEST DATE: 21-JUN-85 START TIME: 13:47:24.6
H410 MINIMUM -0.053 VOL% H410 MAXIMUM 4.794 VOL%

Figure 3-8.
Hydrogen Concentration below top of 45° Chimney
- Test S.10

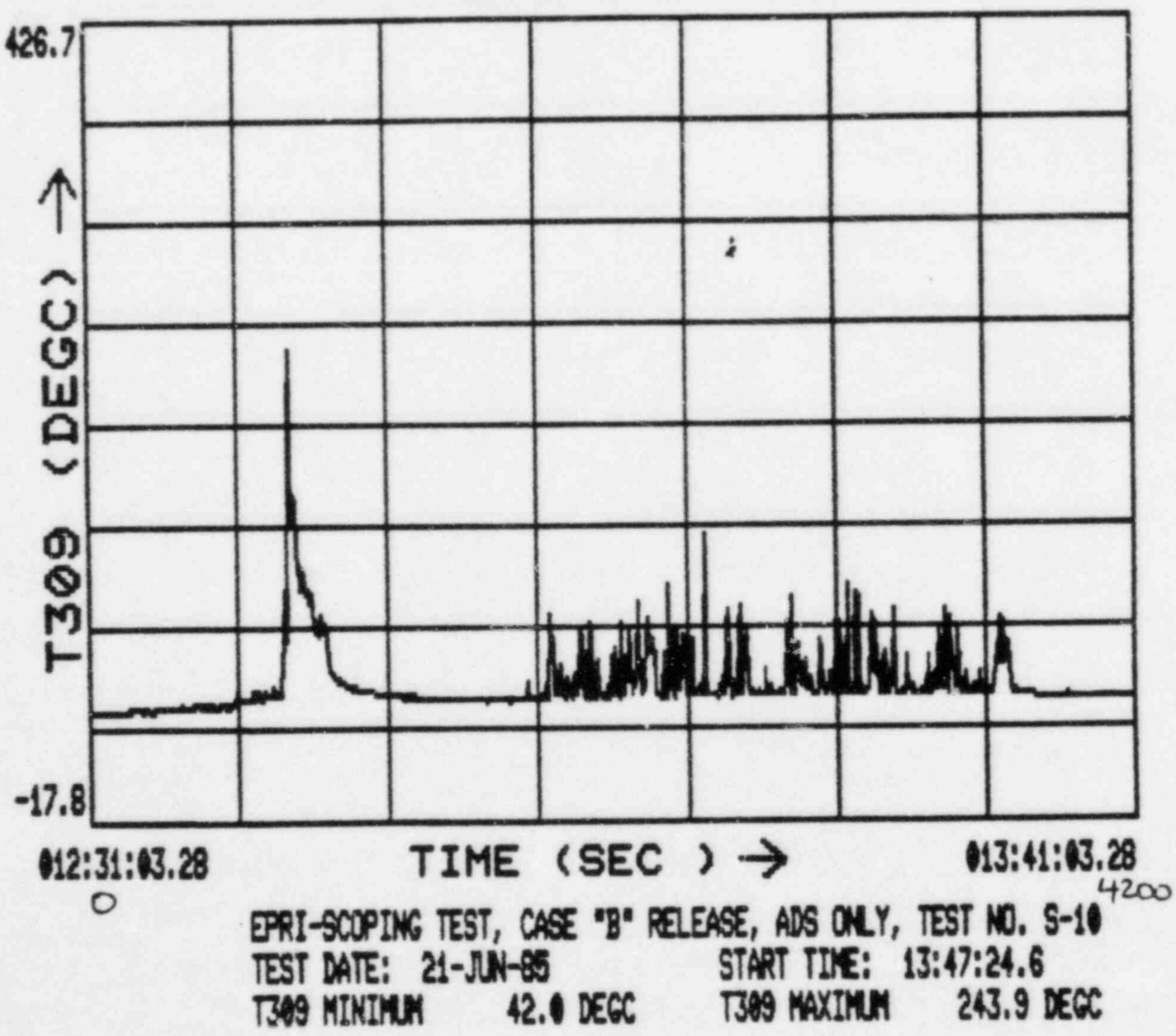


Figure 3-9.
Temperature Profile in upper region of the 45° Chimney - Test S.10

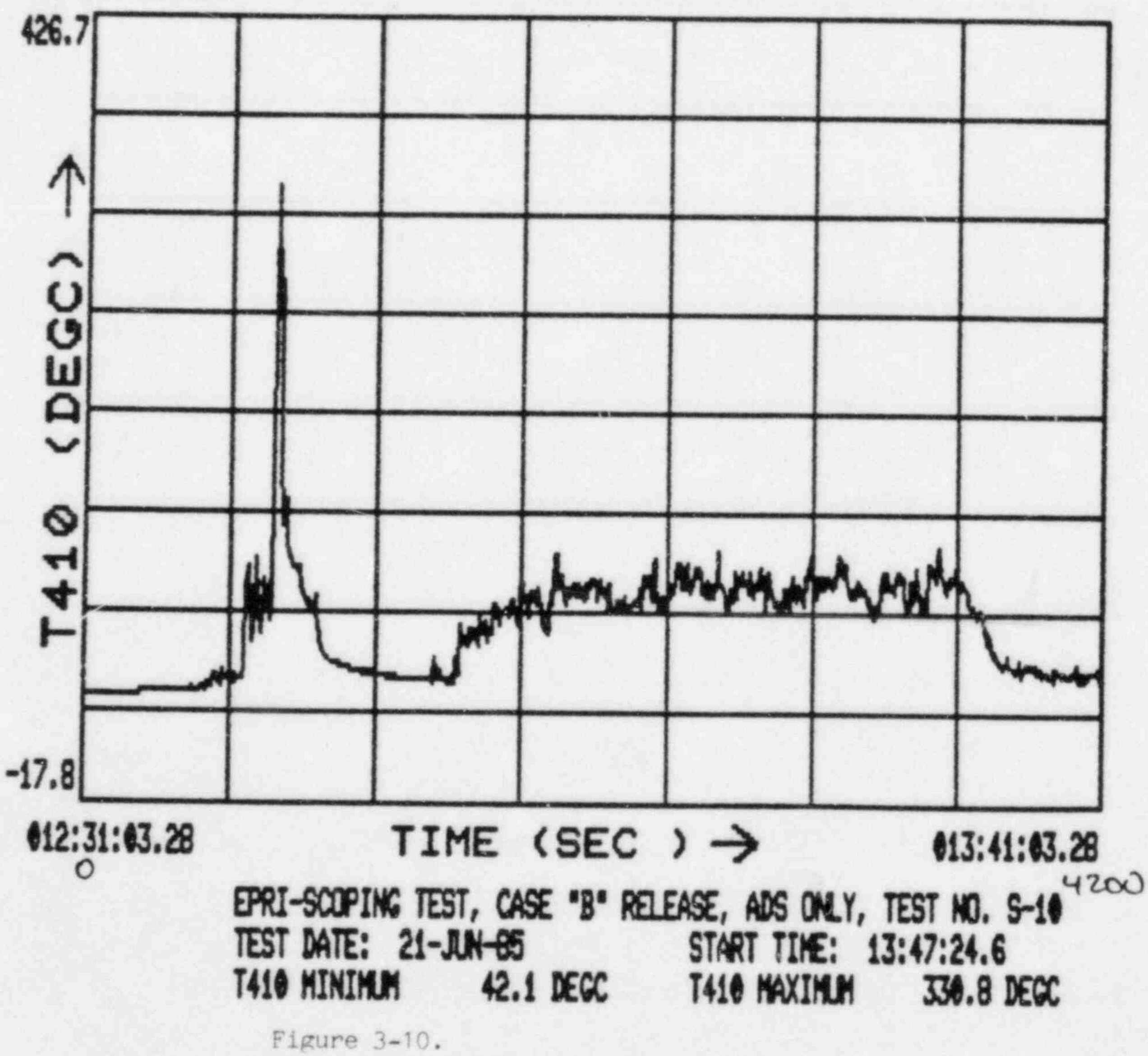


Figure 3-10.
Temperature Profile in upper region of 45°
Chimney - Test S.10

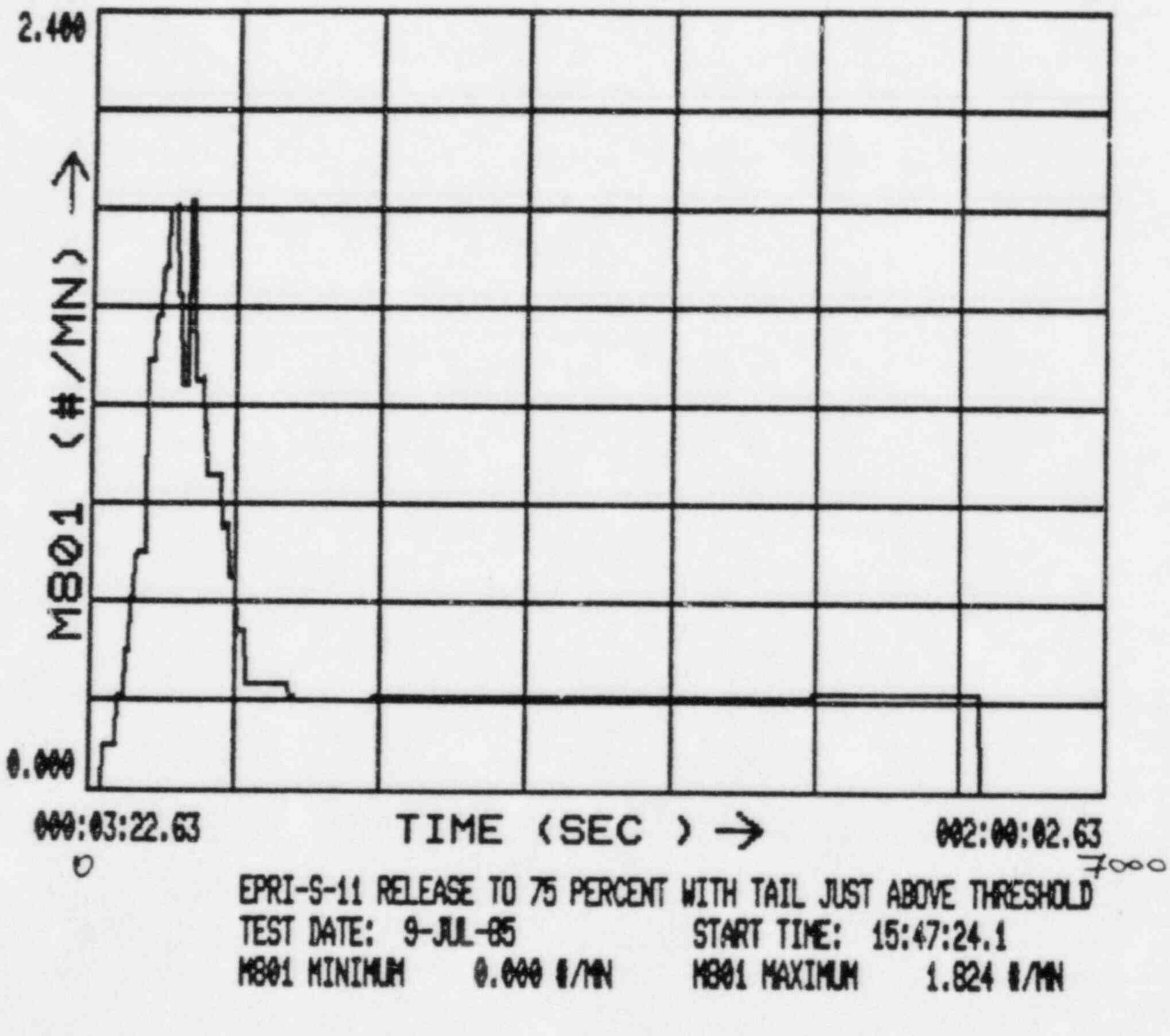
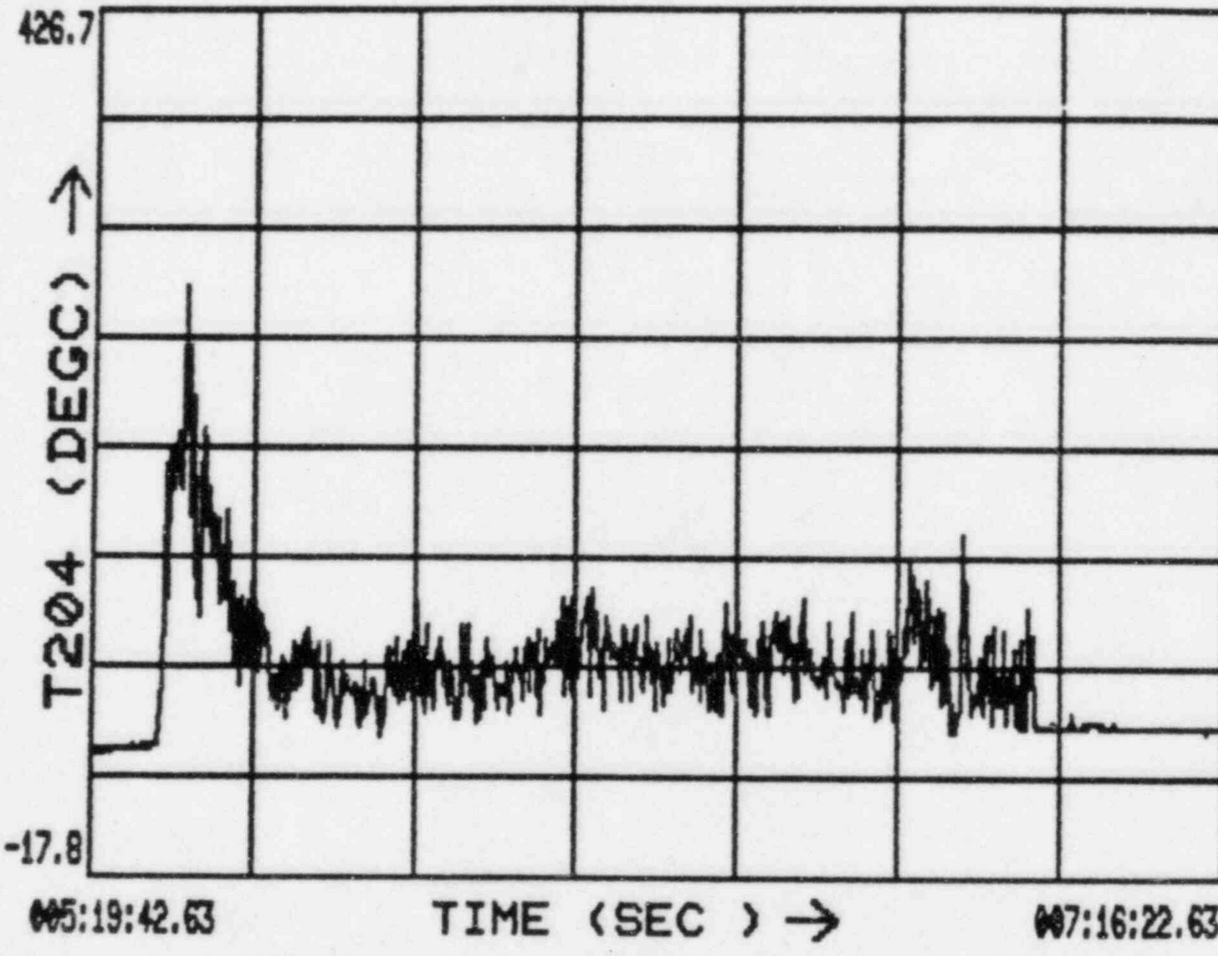


Figure 3-11.
Hydrogen Release - Test S.11



EPRI-S-11 RELEASE TO 75 PERCENT WITH TAIL JUST ABOVE THRESHOLD
TEST DATE: 9-JUL-85 START TIME: 15:47:24.1
T204 MINIMUM 45.5 DEGC T204 MAXIMUM 283.5 DEGC

Figure 3-12.
Temperature Profile in 45° Chimney above the HCU floor - Test S.11

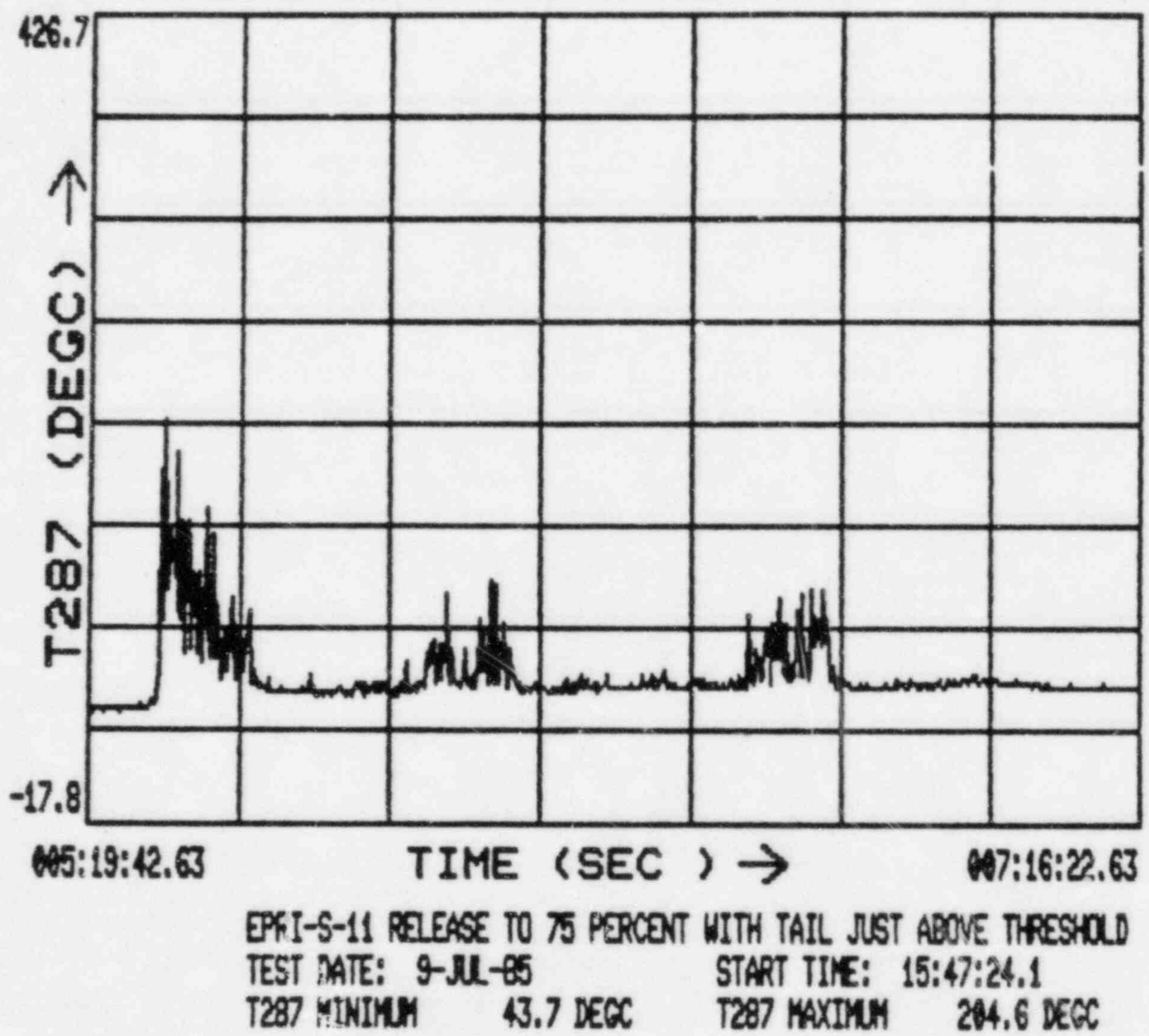


Figure 3-13.
Temperature Profile for 315° Chimney above the HCU floor - Test S.11

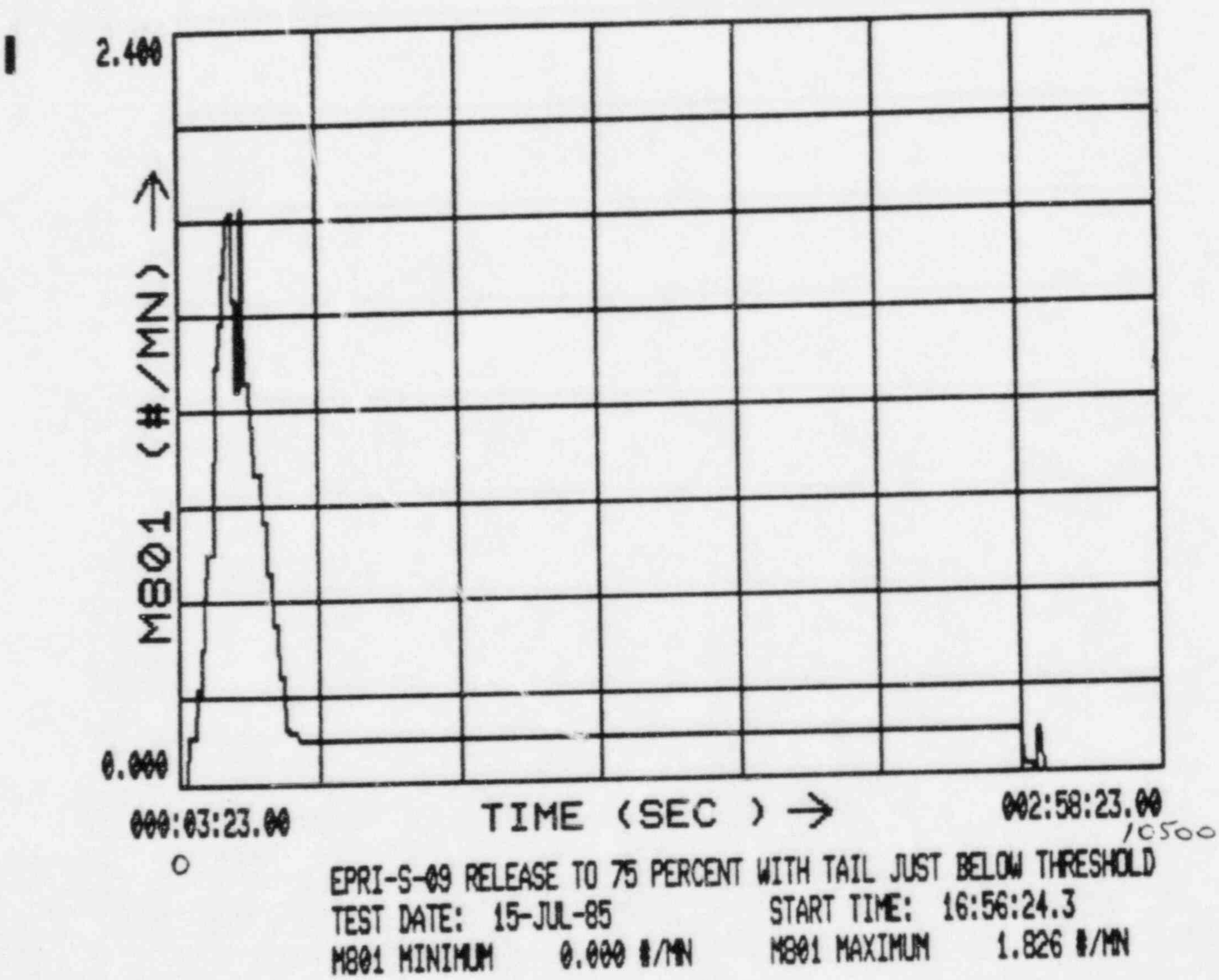


Figure 3-14.
Hydrogen Release - Test S.09

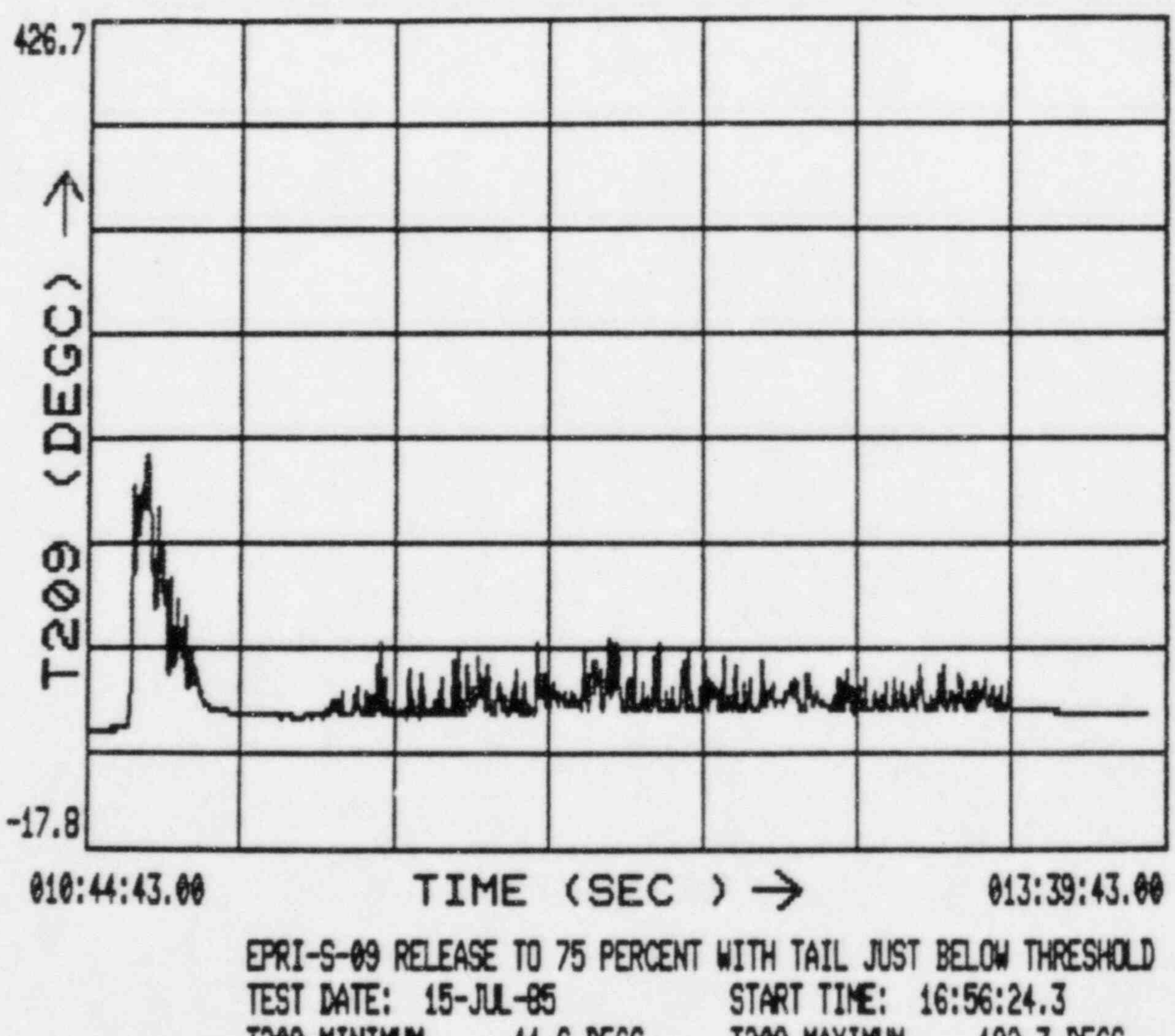


Figure 3-15.
Temperature Profile for 45° Chimney above the HCU floor - Test S.09

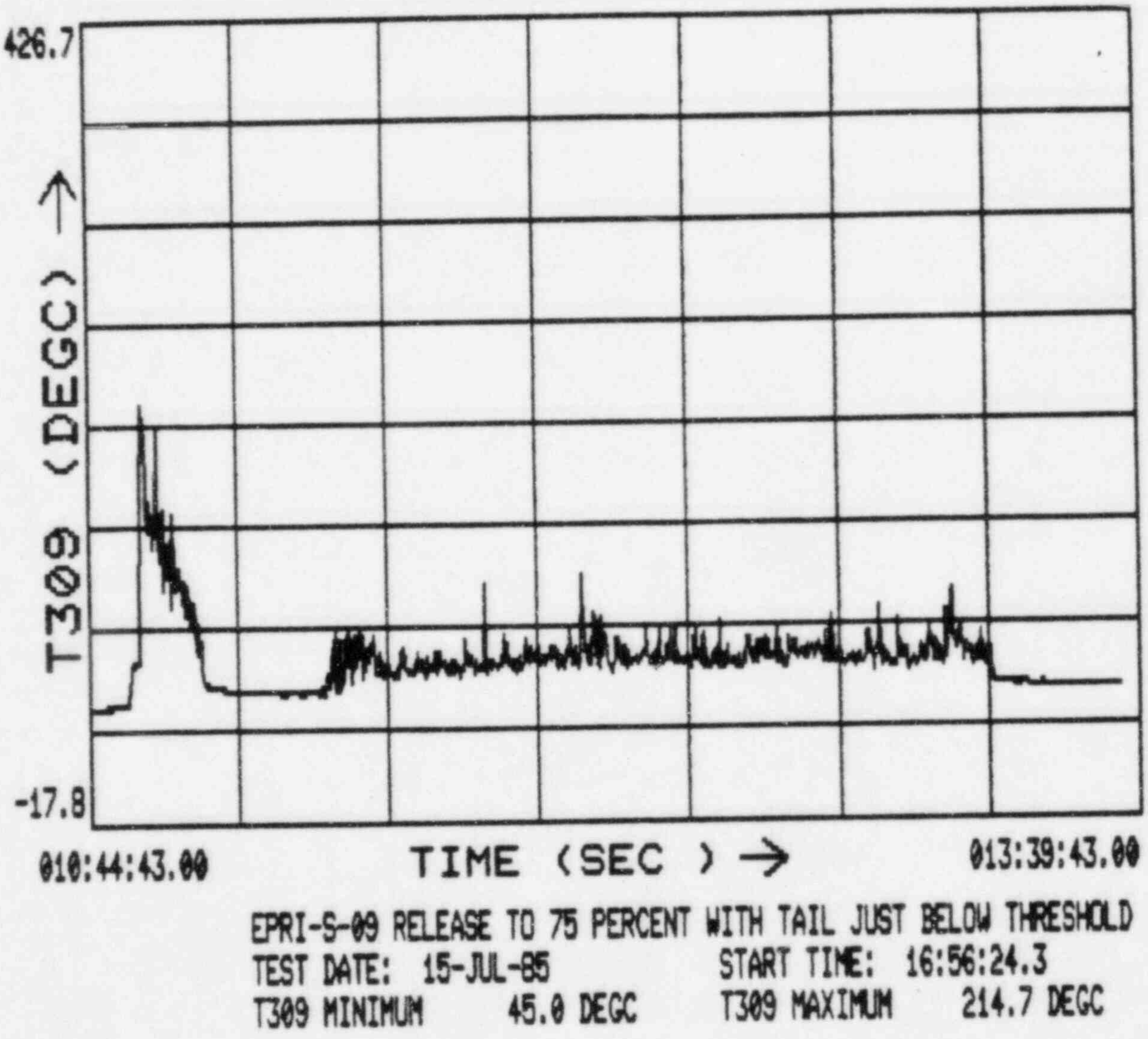


Figure 3-16.
Temperature Profile for upper regions of 45°
Chimney - Test S.09

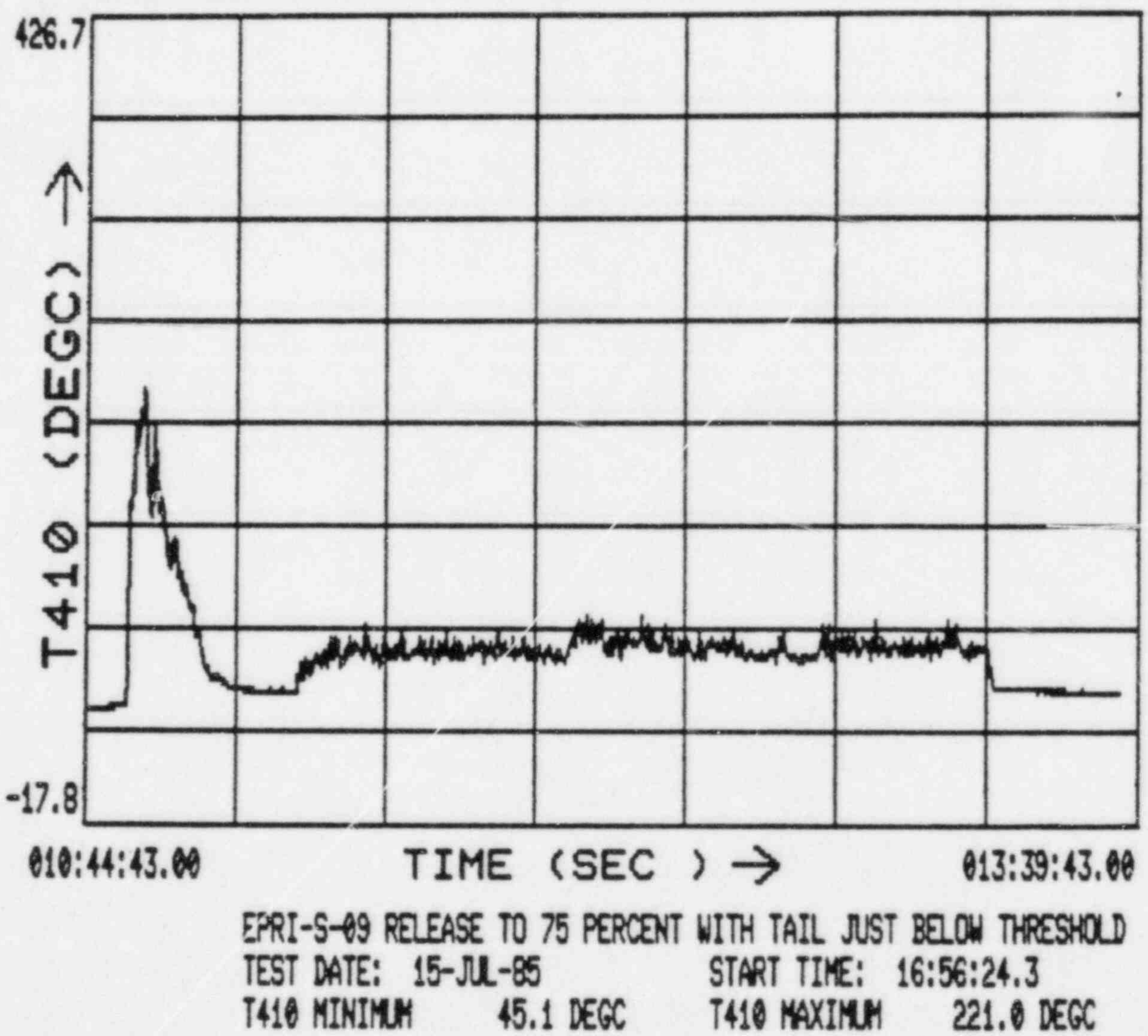


Figure 3-17.
Temperature Profile for upper regions of 45°
Chimney - Test S.09

4.0 Assessment of Equipment Survivability

Gulf States Utilities has provided a preliminary assessment of equipment's capability to survive deflagrations. As noted in section 2.0, a number of conservative assumptions were included in the CLASIX-3 analysis which was used to define thermal environments for assessing equipment survivability. The analysis discussed in reference 4 showed that the calculated peak equipment surface temperature or the temperature of the critical component for the igniters and cable located in the wetwell exceeded the equipment qualification temperature. As noted in section 3.0 of this report, additional testing in the HCOG's 1/4 scale test facility has indicated that the CLASIX-3 predictions of thermal environments is excessively conservative. Gulf States Utilities has completed additional analyses to assess equipment's ability to survive combustion phenomenal observed in the 1/4 scale testing.

The 1/4 scale facility has been designed to allow simulation of each Mark III containment's plant unique geometry. The scoping testing phase of the 1/4 scale test program has been completed using the plant unique geometry for another Mark III containment. This geometry also provides a reasonable basis for assessing equipment survivability at the River Bend Station. The principle geometric difference between the scoping test geometry and The River Bend Station is the significant flow restriction present at the refueling floor in the River Bend Station design. This flow restriction will not affect conditions in the wetwell or near the HCU floor. Tests completed in the 1/20 scale test facility demonstrated that the extensive restriction to flow at the refueling floor elevation will not alter the character of combustion.

A HEATING-6 model of the hydrogen igniter has been developed to provide verification of the modeling documented in reference 4. This model was used along with the thermal environment measured in the 1/4 scale facility to calculate the igniter's temperature response. Data from test S.12.2 was used for this analysis. This test involves total hydrogen release corresponding to 75% MWR. Although the containment sprays were operational for this test, this test is believed to provide the best basis using currently available 1/4 scale test data for assessing equipment's ability to survive accidents where total hydrogen generation equals 75% MWR. The use of sprays in this test will not affect the applicability of test results to River Bend since the sprays were not activated until the very end of release history A'. Since sprays are not activated until late in the transient, the prior thermal environment, which poses the greatest threat to equipment survivability, is applicable to RBS.

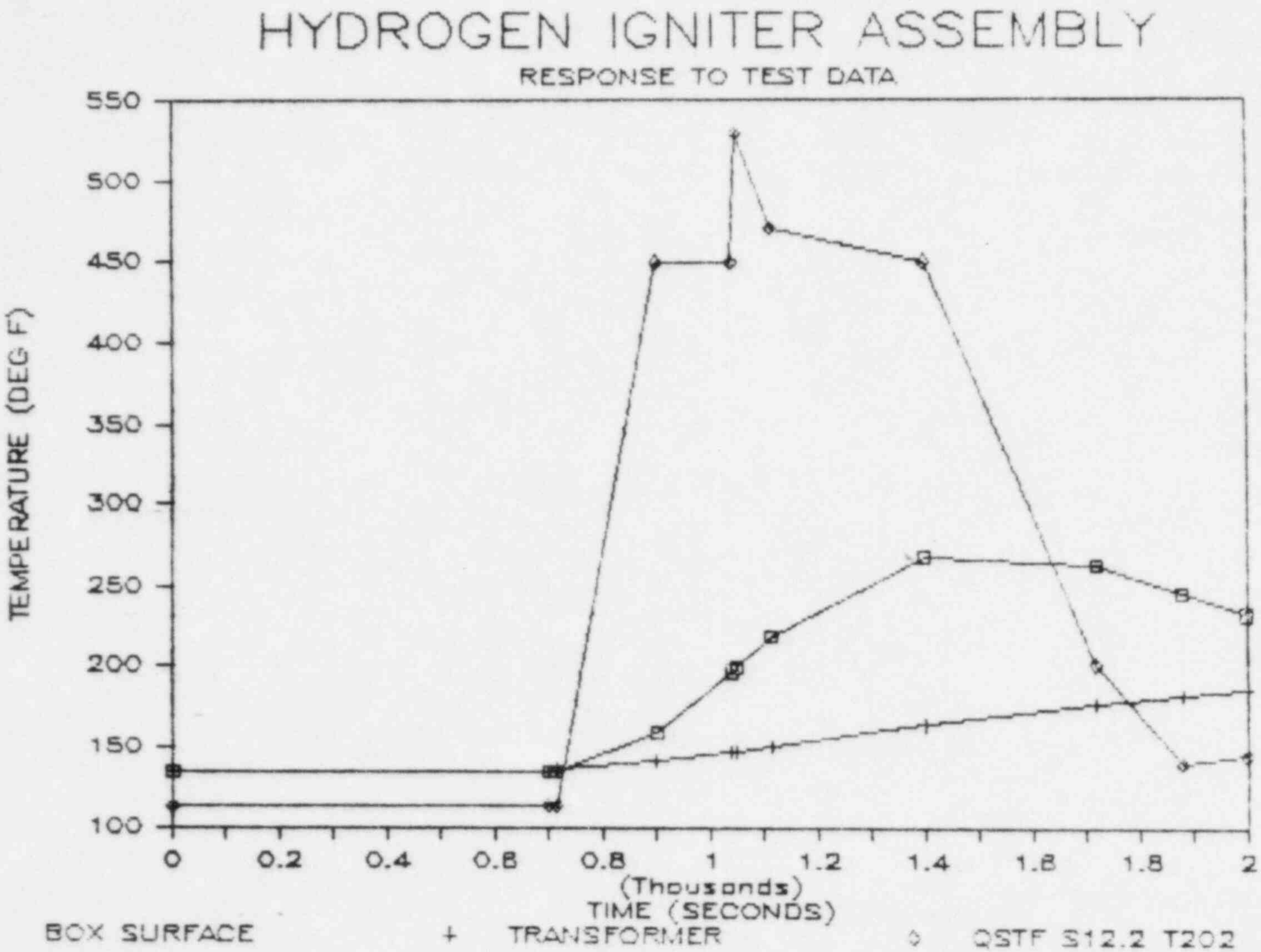
Temperature data from thermocouple T-202 in the 1/4 scale facility was used to evaluate the thermal response of the igniter. Thermocouple T-202 represents a limiting diffusion flame thermal environment in the 45^{o} chimney for test S.12.2. Since the safety relief valve sparger which is assumed to be stuck open is placed in the 45^{o} chimney, the 45^{o} chimney should represent the most limiting thermal environment.

The igniter assembly surface temperature and the temperature of the igniter transformer are plotted in figure 4-1. This figure also shows the temperature trace which has been hand digitized from 1/4 scale test data. Figure 4-2 shows the temperature data measured by thermocouple T-202 during test S.12.2. Free convection has been used in this calculation along with radiation from the combustion products plume. As indicated in figure 4-1, the igniter's response remains well below the equipment qualification temperature.

The response of a hydrogen igniter power supply cable to the 1/4 scale thermal environment has also been calculated. The conduit through which the hydrogen igniter cable is routed is included in the HEATING6 model. The temperature of the conduit, the cable insulator, and the conductor are shown in figure 4-3. Figure 4-4 shows the 1/4 scale temperature plot for thermocouple T-200 which has been used for analysis of the cable thermal response. This thermocouple was selected for evaluating the response of the igniter power cable in order to provide diversity in the thermal environments used to assess equipment survivability. As with the analysis for the igniter, free convection to the boundary of the conduit has been used. Because the analysis has been completed in cylindrical coordinates, the radiation has been applied uniformly to the entire circumference of the cable. This represents a significant conservatism in the analysis. Even including this conservatism, figure 4-3 indicates that the cable's ability to survive is not jeopardized.

The response of a pressure transmitter to the diffusion flame thermal environment has also been calculated. Data from thermocouple T-200 was used for assessing the ability of the pressure transmitter to survive hydrogen combustion. This thermocouple was used to assess survivability of the pressure transmitter because several HCOG member plants have instrument racks containing pressure transmitters located near the steam tunnel. This location corresponds to the location of thermocouple T-200 in the 1/4 scale facility. Figure 4-5 shows the surface temperature for the pressure transmitter as a function of time along with the hand digitized temperature data from thermocouple T-200. As with the analyses of the igniter and the igniter power cable, free convection and radiation have been applied to the boundaries for the component. Figure 4-5 demonstrates that the pressure transmitter has considerable margin in its ability to survive hydrogen combustion.

Figure 4-1.


HYDROGEN IGNITER ASSEMBLY
RESPONSE TO TEST DATA
TEMPERATURE (DEG F)
550
500
450
400
350
300
250
200
150
100
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
(Thousands)
TIME (SECONDS)
BOX SURFACE
+ TRANSFORMER
◇ QSTF S12.2 T202

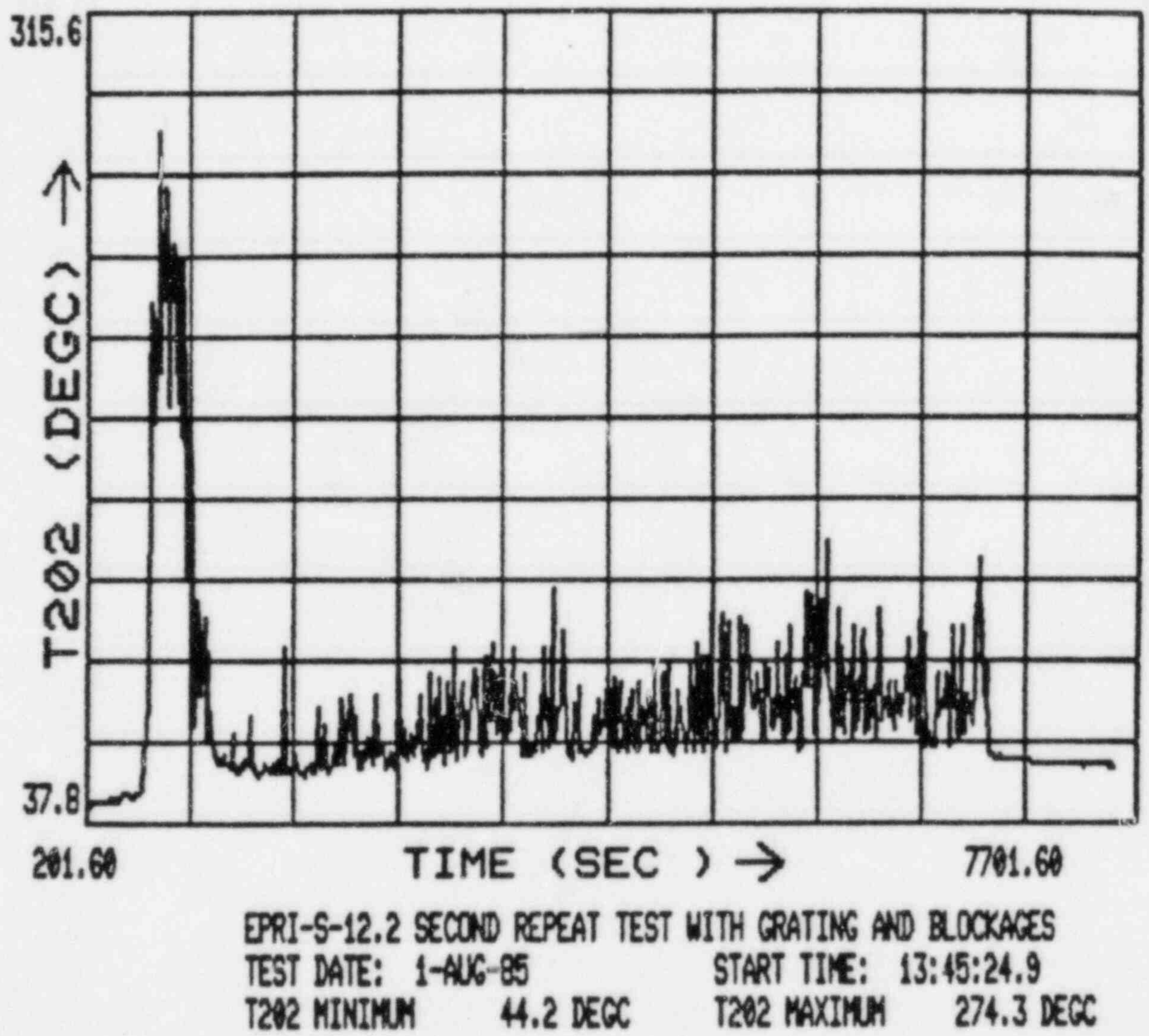
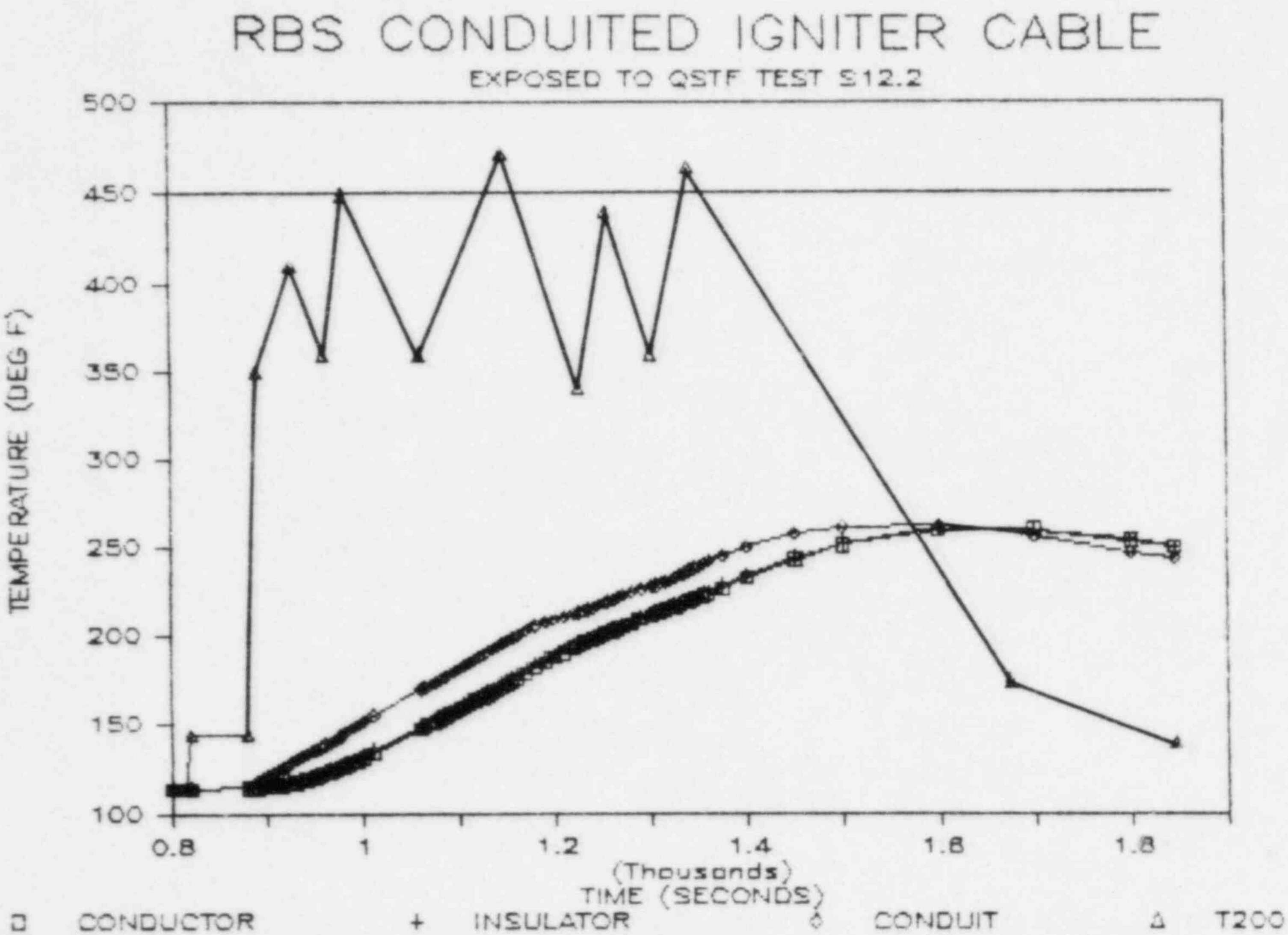
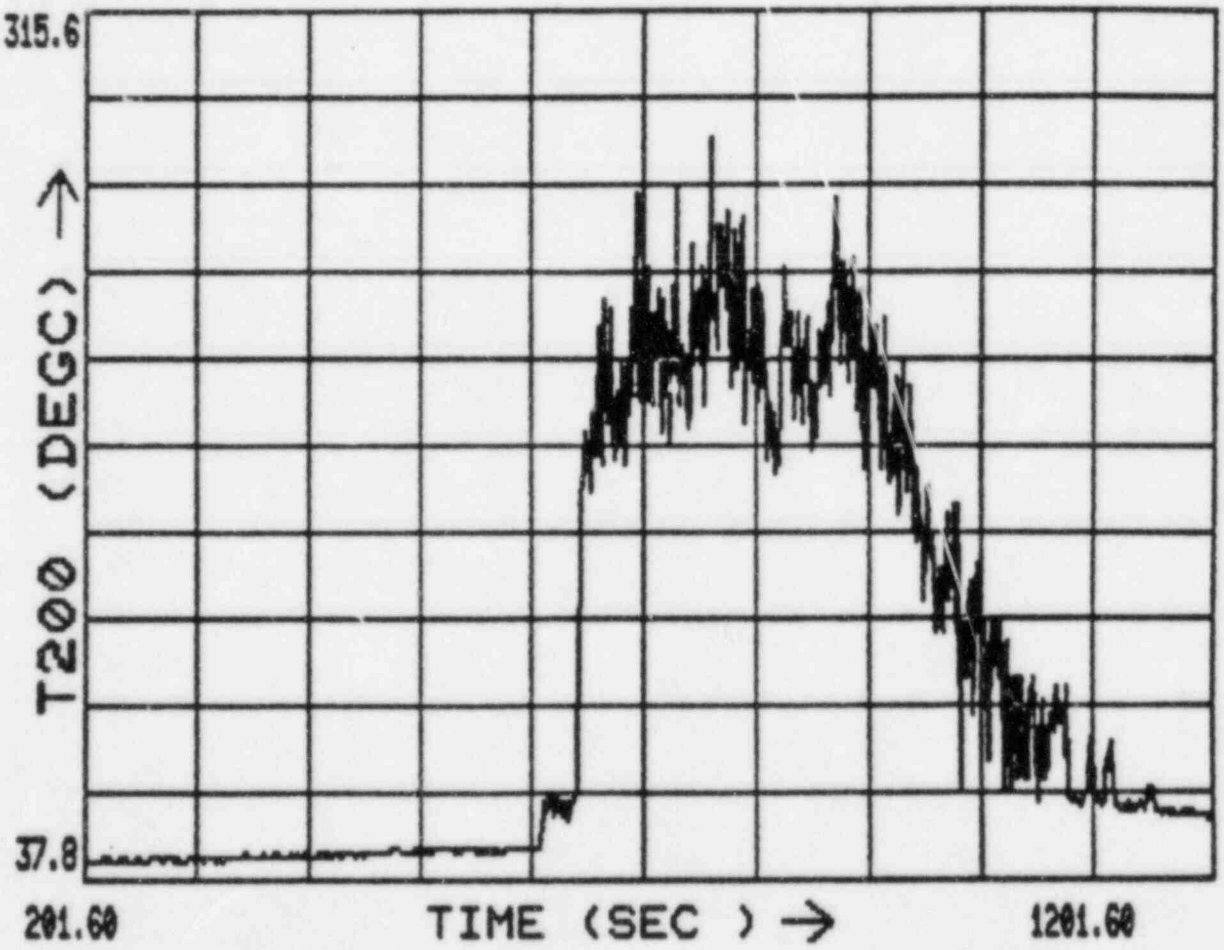


Figure 4-2.
Temperature Profile for 45° Chimney above the HCU floor - Test S.12.2

Figure 4-3.



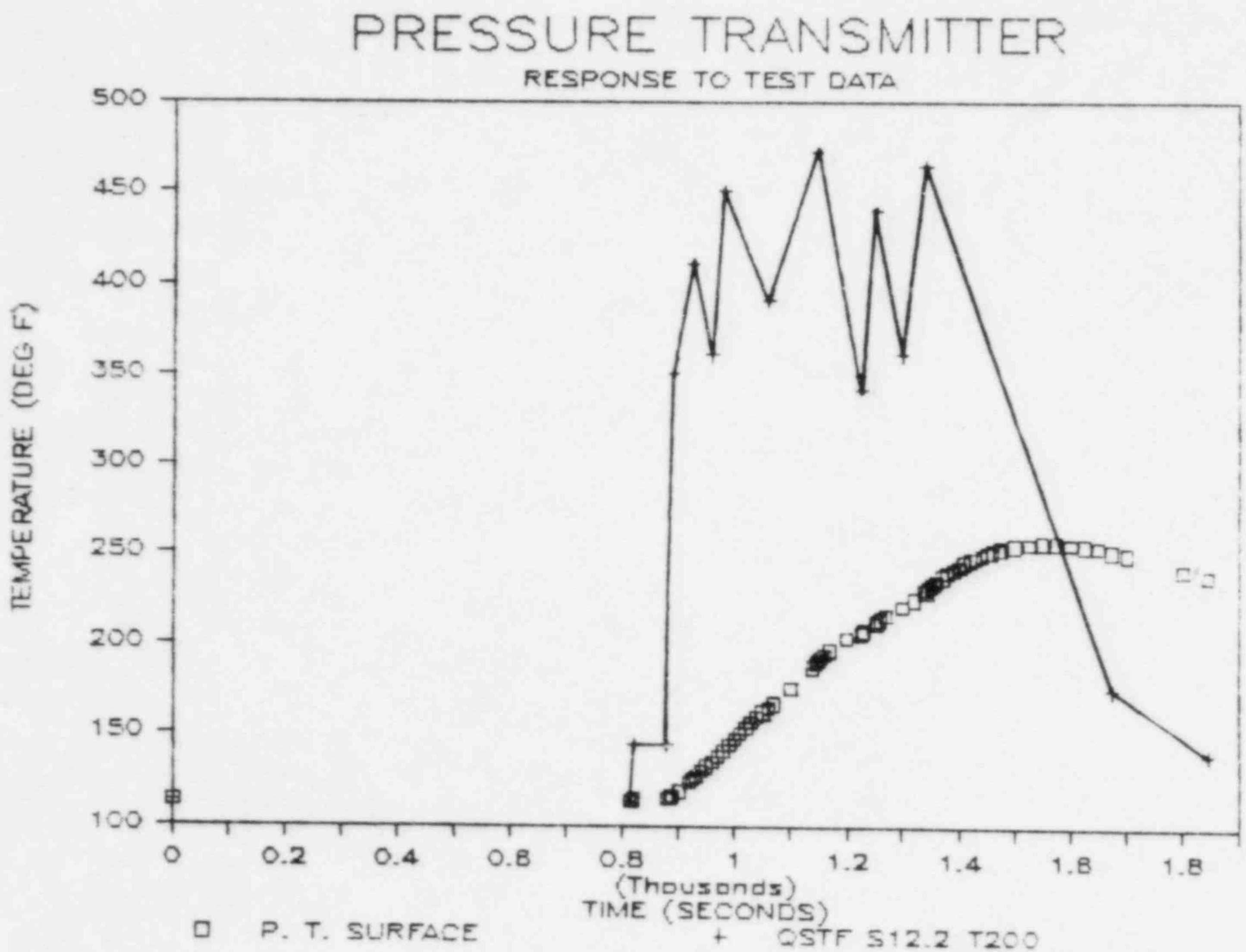
RBS CONDUITED IGNITER CABLE
EXPOSED TO QSTF TEST S12.2
TEMPERATURE (DEG F)
500
450
400
350
300
250
200
150
100
0.8
1
1.2
1.4
1.6
1.8
(Thousands)
TIME (SECONDS)
CONDUCTOR
INSULATOR
CONDUIT
T200



EPRI-S-12.2 SECOND REPEAT TEST WITH GRATING AND BLOCKAGES
TEST DATE: 1-AUG-85 START TIME: 13:45:24.9
T200 MINIMUM 43.8 DEGC T200 MAXIMUM 275.3 DEGC

Figure 4-4.
Temperature Profile for 45° Chimney above the HCU floor - Test S.12.2

Figure 4-5.


PRESSURE TRANSMITTER
RESPONSE TO TEST DATA
TEMPERATURE (DEG F)
500
450
400
350
300
250
200
150
100
0
0.2
0.4
0.8
0.8
1
1.2
1.4
1.8
1.8
(Thousands)
TIME (SECONDS)
□ P. T. SURFACE
+ QSTF S12.2 T200

5.0 Conclusions

The CLASIX-3 code has been used to date for purposes of assessing equipment's ability to survive hydrogen combustion in the form of deflagrations. Very conservative assumptions have been used in completing the CLASIX-3 analysis. This has resulted in very conservative predictions of both the peak pressure produced by hydrogen combustion in the Mark III containment, and the temperature environment to which equipment would be exposed during hydrogen generation events. Although test S.08 did not involve total hydrogen injection equivalent to 75% MWR, the ECCS reflood transient and the sustained, low hydrogen production of 0.07 lbm/sec are directly comparable to the hydrogen release rates used in the CLASIX-3 analysis. The comparison provided in section two clearly demonstrates that the CLASIX-3 thermal profiles are extremely conservative in comparison with the temperatures measured during 1/4 scale testing. In addition, as discussed previously, the comparison of 1/4 scale pressures with pressures predicted by CLASIX-3 reinforces the conclusion that CLASIX-3 is overly conservative.

Several key assumptions used in the CLASIX-3 analysis appear to be excessively conservative. The 1/4 scale tests have demonstrated that combustion will be initiated well before global hydrogen concentration reaches 5%. In fact, the tests have demonstrated that the hydrogen concentration does not exceed 6% for all tests completed to date. The testing to date has demonstrated that steady diffusion flames can exist on the suppression pool surface for hydrogen flow rates of 0.14 lbm/sec for all simulations of degraded core accident hydrogen production.

When hydrogen flow rates are below the threshold for steady diffusion flames, repeated deflagrations are not observed. The only deflagration resembling the deflagrations predicted by CLASIX-3 is the initial lightoff deflagration. When diffusion flames are reignited after extinguishing themselves, the deflagration which reestablishes the diffusion flame is virtually imperceptible on the infrared camera videotapes. This further emphasizes the conservatism of the CLASIX-3 predictions of thermal environments associated with hydrogen combustion in the Mark III containment.

Gulf States Utilities is a member of the HCOG. HCOG has a long term program of analysis and testing in progress to assure resolution of issues associated with degraded core hydrogen control. This program will result in complete definition of the thermal environments produced by hydrogen combustion including definition of thermal environments produced by steady diffusion flames, and by deflagrations. For the purpose of initial plant licensing, Gulf States Utilities has submitted plant specific analyses of containment response and equipment survivability. These analyses have demonstrated that the containment structure will survive the peak pressure produced by hydrogen combustion without failure. The analyses have also demonstrated that with the extremely conservative thermal environments predicted by the CLASIX-3 computer program, selected components may reach or exceed their equipment qualification temperature. Based on the information available from the 1/4 scale test program and additional analyses of equipment response to diffusion flame thermal environments defined from 1/4 scale data, Gulf States Utilities concludes that the long term program of analysis and testing currently in progress through HCOG will result in demonstration of equipment survivability. Accordingly, Gulf States Utilities considers it evident that sufficient information has been presented to warrant licensing of the River Bend Station with a license condition to complete the HCOG generic program of analysis and testing.

References

1. 1/20 Scale Final Test Report submitted to the NRC staff by letter HGN-014 dated February 9, 1984

2. Report on 1/4 Scale Scoping Test Results submitted to the NRC staff by letter HGN-053 dated August 1, 1985

3. Final Scoping Test Hydrogen Release Histories submitted to the NRC staff by letter HGN-031 dated March 13, 1985

4. Preliminary Equipment Survivability Report Supplement Three submitted to the NRC staff by letter RBG-21,912 dated August 22, 1985