# APPENDIX A

# LOSS OF COOLANT ACCIDENT ANALYSIS FOR CORE XII OF THE YANKEE NUCLEAR POWER STATION

October 10, 1975

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# APPENDIX B

# ADDITIONAL LOCA ANALYSIS

## Introduction

To determine the sensitivity of the Yankee Rowe LOCA analysis results to the differences between the original YR ECCS evaluation model and the latest H. B. Robinson ECCS evaluation model, the double-ended cold leg guillotine (DECLG) and the double-ended cold leg slot (DECLS) breaks with $C_D$ = 1.0 were run. The Yankee Rowe ECCS model was revised as follows so that it would conform with the H. B. Robinson model:

1. The approved RELAP4/ENC-20 and TOODEE/ENC-13 computer code versions have been used.
2. The phase-separation model in the lower plenum has been deleted and replaced by the homogeneous model.
3. The EOBY definition has been revised to be the time that downcomer flow remains zero rather than the time that break flow reverses.
4. The inlet subcooling of the ECC fluid has been determined by the method discussed in the next section.

## Calculation of Inlet Subcooling

The method proposed by ENC to compute inlet subcooling for use in the FLECHT correlation input to RELAP4-FLOOD and TOODEE2 is detailed in Section 6.0 of Supplement 7 of XN-75-41. NRC has requested that ENC adopt a more conservative approach. A revised conservative method of calculating inlet subcooling is detailed below and justification of the conservatism of the approach is also presented.

During refill, the emergency core cooling water is heated from its injection temperature by mixing with residual coolant in the form of either steam or residual water and by heat transfer from the metal surfaces which contact the ECC water. The difference between the saturation temperature at the existing pressure and the temperature of the ECC water which enters the core at BOCREC is the inlet subcooling temperature, which is an input parameter to the FLECHT heat transfer correlation used in RELAP4-FLOOD and TOODEE2. ENC calculations described below show that highest peak cladding temperatures (PCTs) are associated with highest values of inlet subcooling. Highest inlet subcooling results from minimizing the heat transfer to the ECC water, hence, a conservative value of inlet subcooling results from underestimating the energy transfer to the ECC water.

The assumption of no heat transfer to ECC water is the most conservative, and this assumption may be employed in ENC analysis in the future for plants where energy transfer to the ECC does not greatly increase the temperature. For the Yankee Rowe application, the method for computing the heat transfer from metal surfaces will be as given in Section 6.0 of XN-75-41, Supplement 7, except that the number of heat slabs considered will be reduced and the time for heat transfer will be varied depending on the level of water in the lower plenum, in the following manner:

1) Only heat slabs connected to the intact cold leg and the lower plenum volumes will be considered.

2) The cold leg heat slabs will be assumed to transfer heat from EOBY to BOCREC according to the conduction limited solution as presented in Section 6.0, Supplement 7 to XN-75-41.

3) The heat slabs connected to each of the lower plenum volumes will transfer energy to the ECC water from the time sufficient water has been added to fill one-half of each volume until BOCREC. The cold legs will be filled first and the lower plenum volumes (currently three volumes) will be filled sequentially from the bottom of the lower plenum to the bottom of the core.

4) Energy transferred from the slabs will be summed and added to the water volume needed to fill the cold legs and lower plenum to the bottom of the core. The fluid temperature and inlet subcooling will then be determined.

The above approach is justified in that the peak cladding temperature is highest for high values of inlet subcooling, and high values of inlet subcooling are obtained by conservatively underestimating the energy transferred to the ECC water.

Energy transfer is conservatively estimated by the conduction calculation and the following assumptions:

1) No mixing occurs with steam or residual water.

2) No heat transfer is assumed in the downcomer regions.

Calculations done by ENC show that increasing inlet subcooling increases peak cladding temperatures. These calculations are reported in Section 2.2 of XN-75-41, Supplement 6. Inlet subcooling was increased from 22°F to 127°F, and an overall increase in PCT of 44°F resulted. Two effects were observed with increasing subcooling. First, a slight increase in calculated flooding rates was shown. Second, significantly reduced heat transfer coefficients were calculated, particularly for the first 20-30 seconds of the reflood transient. The principal effect was the reduction in heat transfer coefficients.

This effect was investigated further by assuming a set of representative parameters for the FLECHT correlation with the multipliers as used in the ENC model, and computing heat transfer coefficients as a function of time for various inlet subcooling values. The results of this calculation are shown in Table I. The heat transfer coefficient is determined to be a continuously decreasing function with increasing subcooling over the applicable subcooling range. Thus, the use of a high subcooling value is conservative in that heat transfer coefficients are reduced and higher peak cladding temperature results.

## Results

Figures 1A through 1L illustrate the key parameters for a DECLG break with $C_D$ - 1.0 (the limiting break size previously submitted) and Figures 2A through 2L show the same parameters for a DECLS break with $C_D = 1.0$. The limiting break was the DECLS for which the peak clad temperature was 1883°F at a peak linear heat rate of 9 kw/ft. The DECLS break produced a peak clad temperature only 15°F higher than the peak clad temperature of the DECLG break. This is consistent with the trend predicted for the H. B. Robinson plant in XN-75-57, Revision 1. Those results also showed a trend of decreasing peak clad temperature with decreasing break size for both split and guillotine breaks, a trend which should apply to the Yankee Rowe LOCA analysis as well. Moreover, the trend for Yankee Rowe should show an even larger decrease in peak clad temperature with decreasing break size, since the 1.0 $ft^2$ split break was almost 300°F below the guillotine break of approximately the same size (DECLG with $C_D = 0.4$).

With the results obtained above, the burnup dependent allowable peak linear heat rate curve should be adjusted downward by the ratio of (9/10.45). This approach is appropriate since none of the cladding ruptures during the LOCA and the stored energy of the fuel at the lower peak linear heat follows the same trend with increasing burnup. Furthermore, the lower peak clad temperature at the reduced peak linear heat rate will also reduce the amount of metal-water reaction. Since there is over 310°F margin to the peak clad temperature limit of 2200°F, the operating curve so established will be conservative.

## TABLE I

## EFFECT OF INLET SUBCOOLING ON FLECHT HEAT TRANSFER COEFFICIENTS

| Inlet Subcooling, °F | 22 | 40 | 70 | 100 | 120 | 140 |
|---|---|---|---|---|---|---|
| Time, Sec | | | | | | |
| 0 | 1.693 | 1.693 | 1.693 | 1.693 | 1.693 | 1.693 |
| 6 | 6.184 | 4.804 | 3.175 | 2.408 | 2.165 | 2.030 |
| 10 | 7.602 | 7.043 | 5.529 | 4.097 | 3.447 | 3.013 |
| 16 | 6.700 | 6.589 | 6.235 | 5.564 | 5.027 | 4.535 |
| 20 | 7.551 | 7.494 | 7.290 | 6.919 | 6.560 | 6.162 |
| 100 | 13.593 | 13.292 | 12.669 | 12.361 | 12.266 | 12.212 |

Parameters:

System Pressure = 39 psia

Initial Temp. = 1600°F

Power at 6' elevation = .66 kW/ft

Flood Rate = 1.0 in/sec

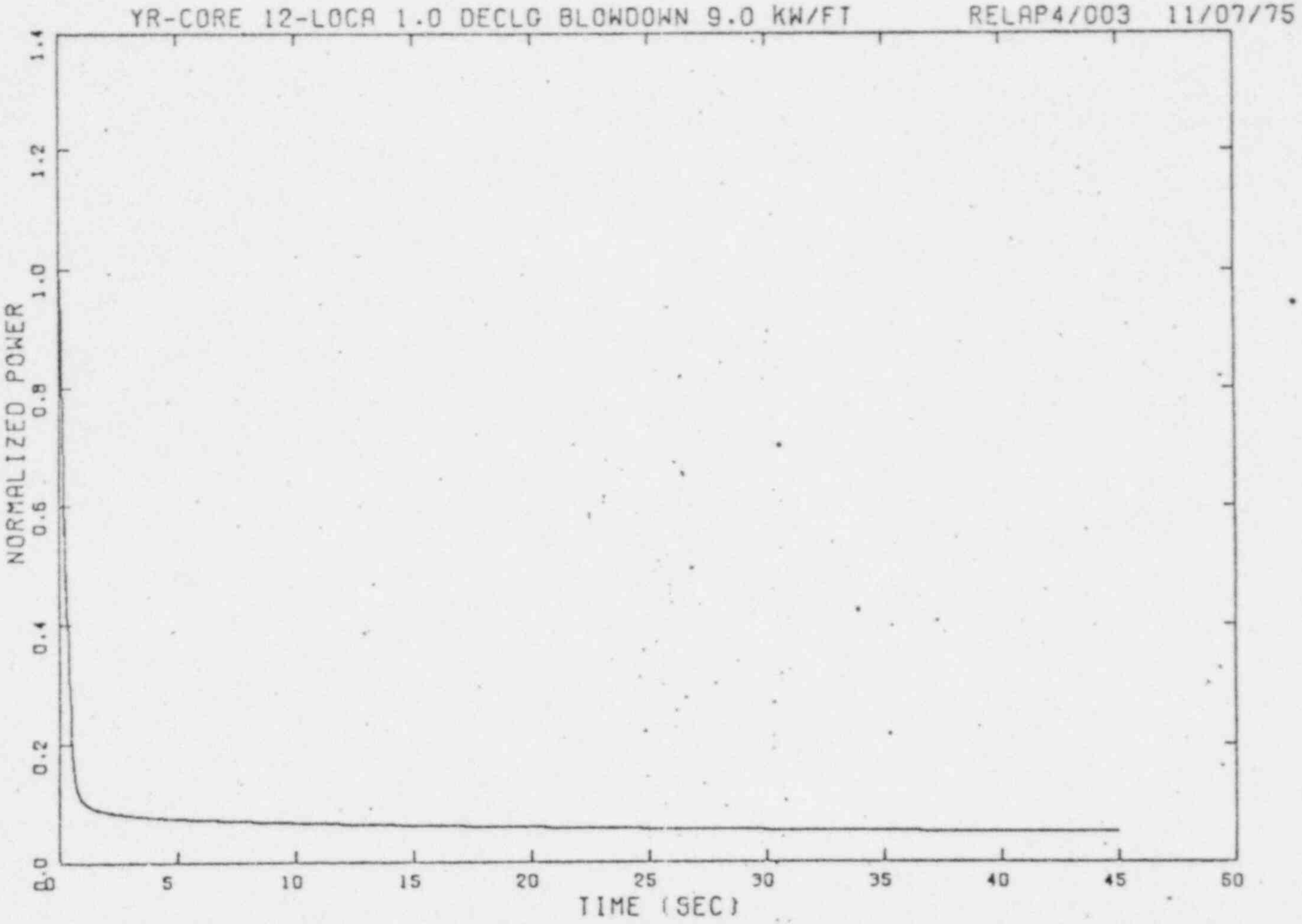


FIGURE 1A NORMALIZED CORE POWER FOR
DECLG BREAK WITH CD = 1.0

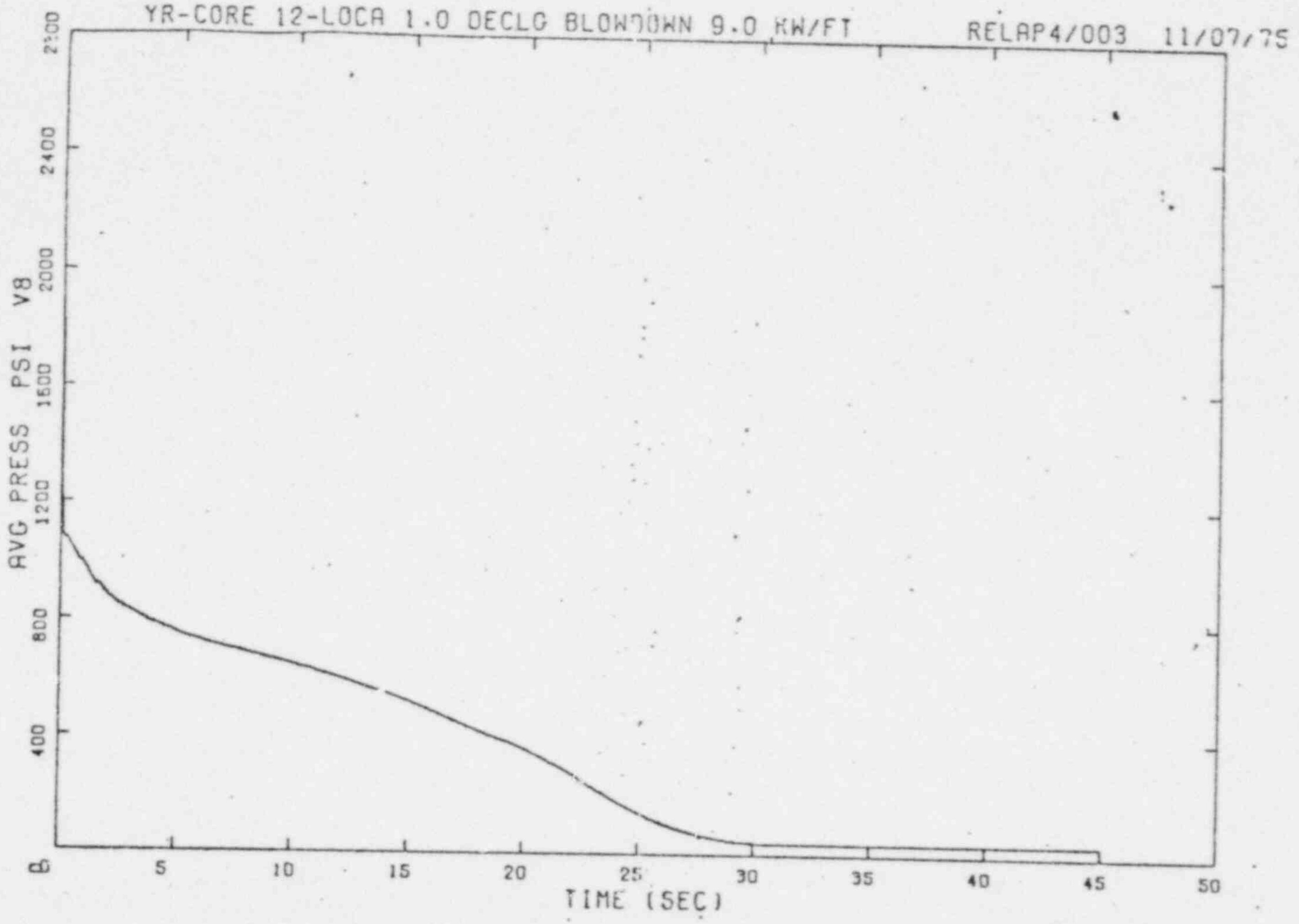


FIGURE 1B REACTOR VESSEL PRESSURE FOR DECLG BREAK WITH CD = 1.0

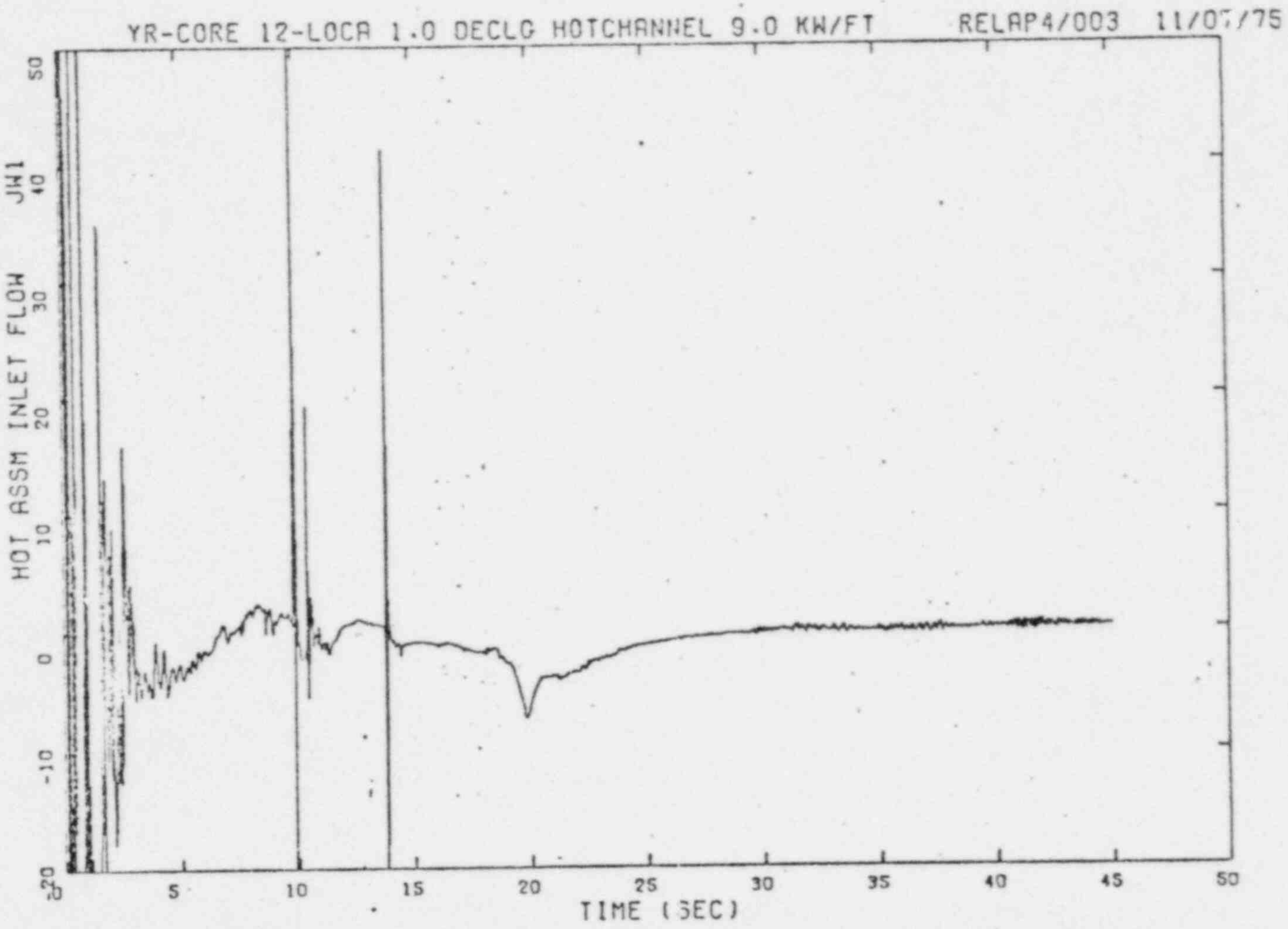


FIGURE 1C HOT ASSEMBLY INLET FLOW FOR DECLG BREAK WITH CD = 1.0

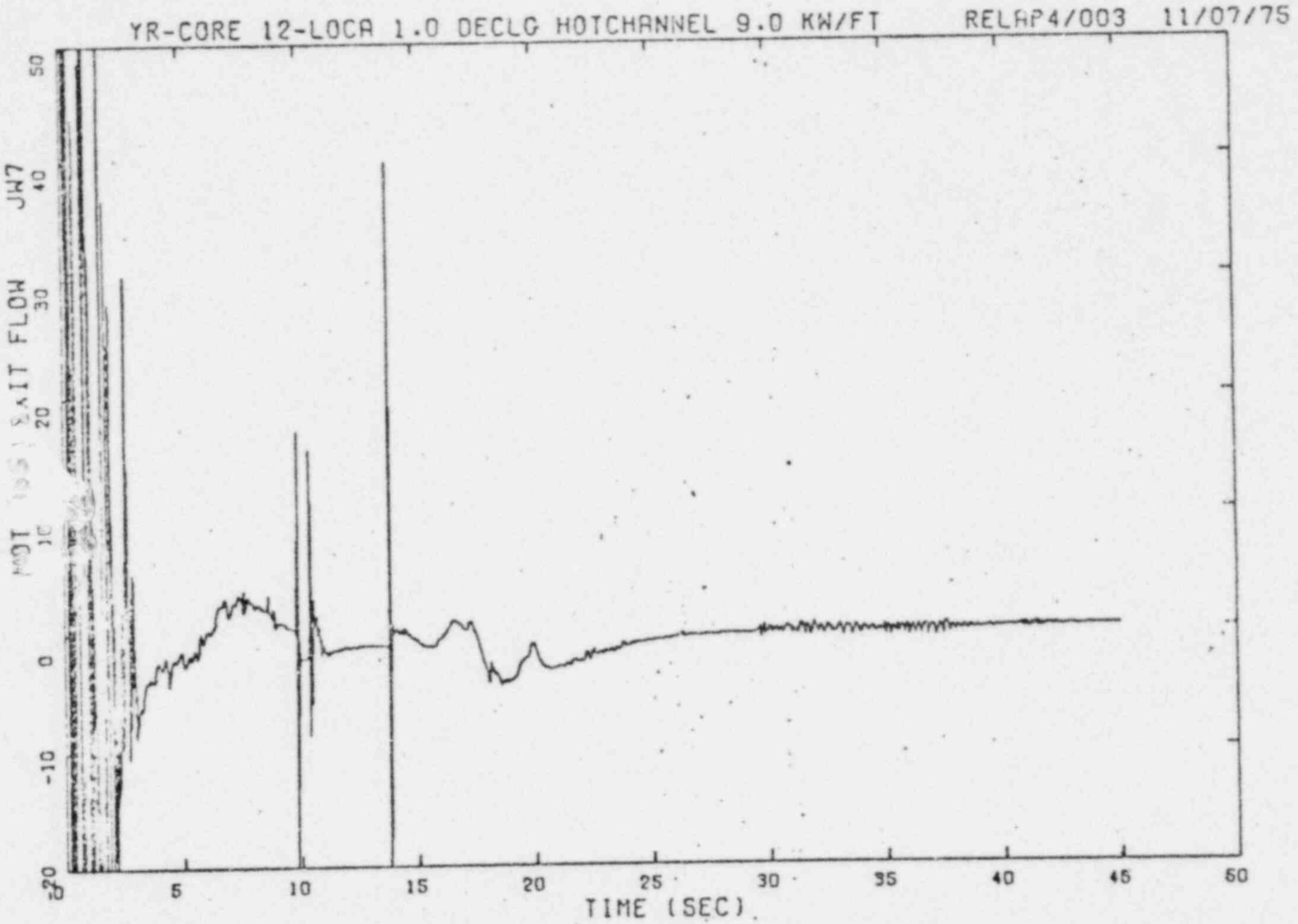


FIGURE 1D HOT ASSEMBLY EXIT FLOW FOR DECLG BREAK WITH CD = 1.0

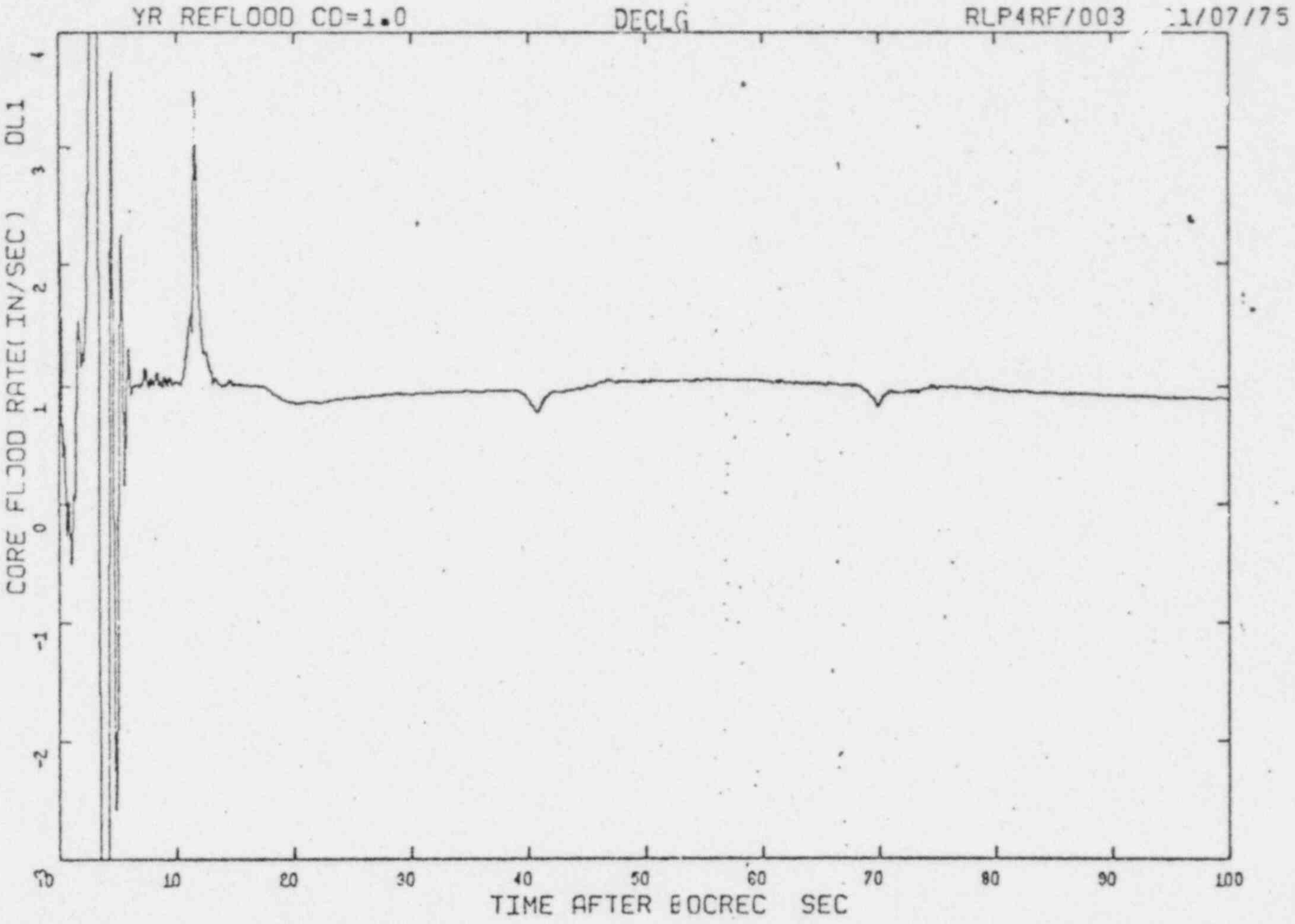


FIGURE 1E CORE FLOODING RATE FOR DECLG BREAK WITH CD = 1.0

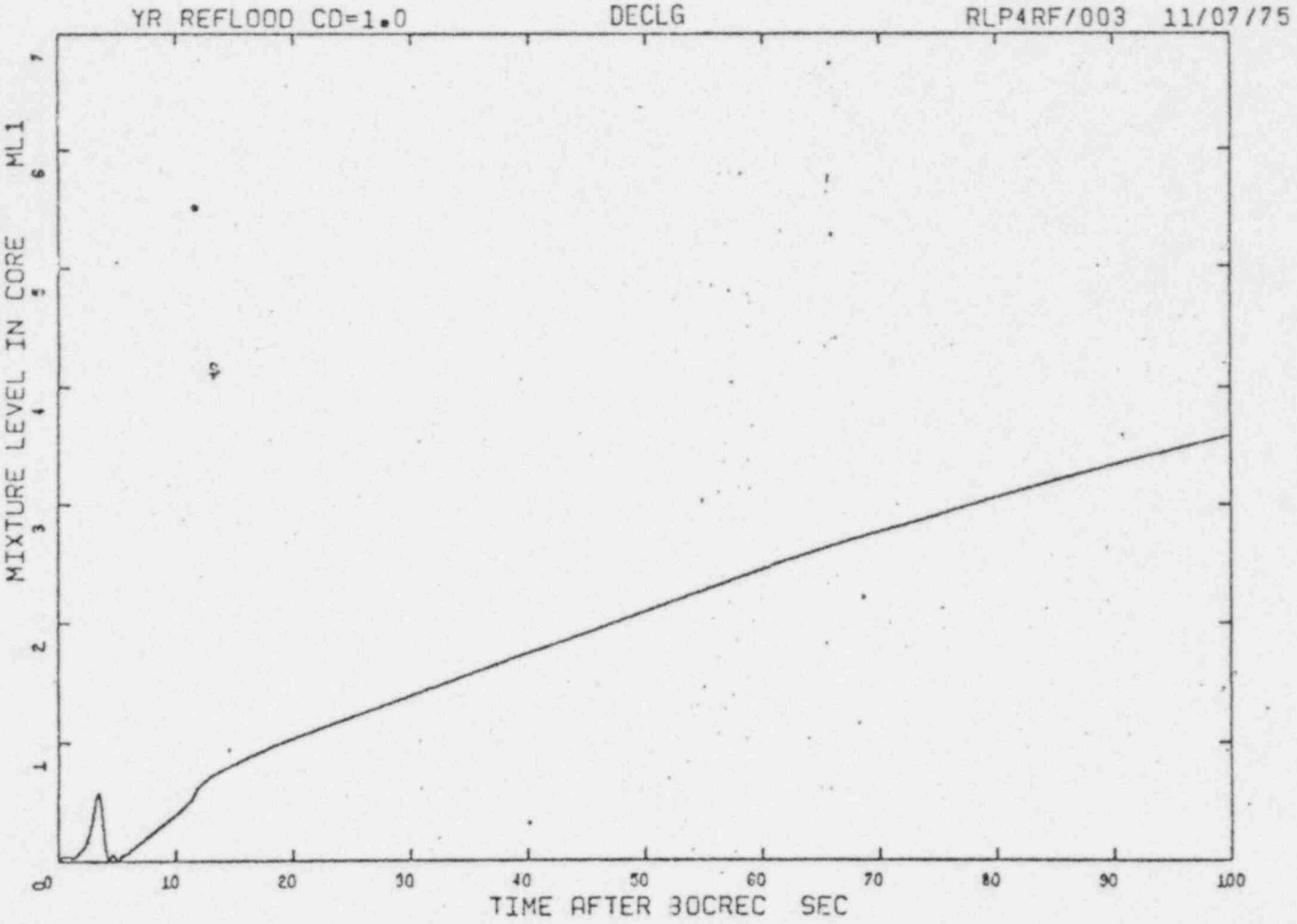


FIGURE 1F CORE MIXTURE LEVEL FOR DECLG BREAK WITH CD = 1.0

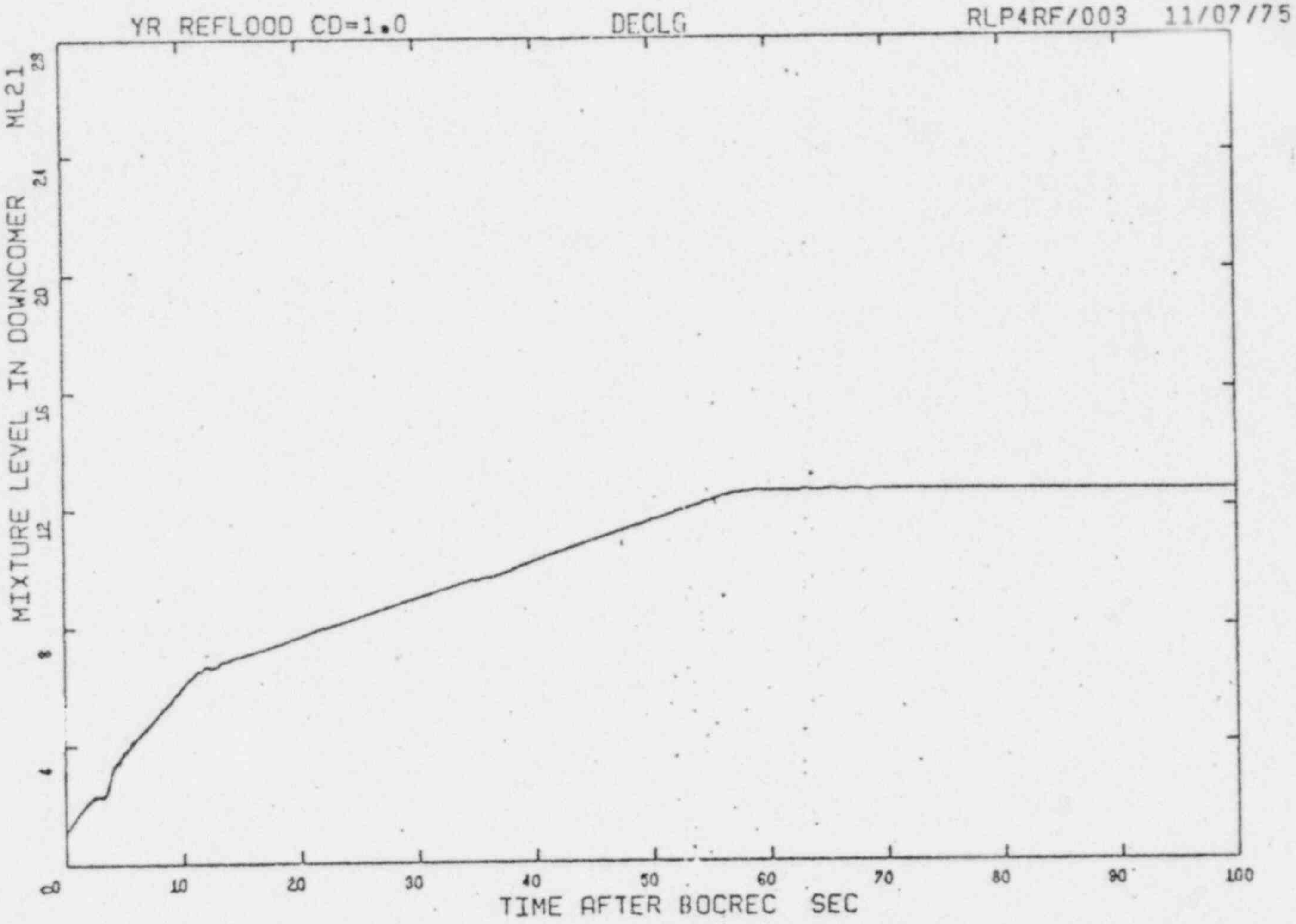
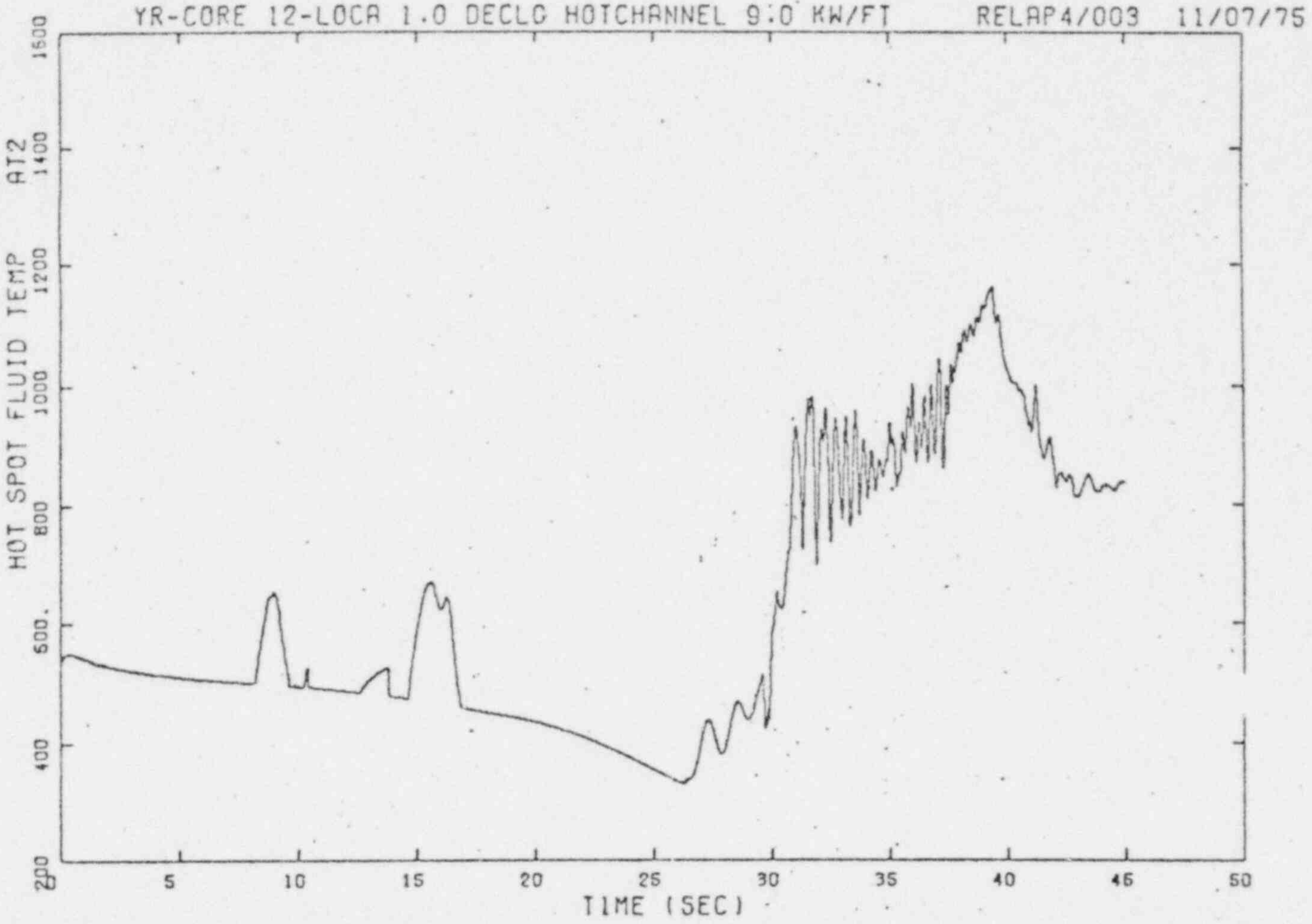


FIGURE 1G DOWNCOMER WATER LEVEL FOR DECLG BREAK WITH CD = 1.0



<u>FIGURE 1H</u> HOT SPOT FLUID TEMPERATURE FOR DECLG BREAK WITH CD = 1.0

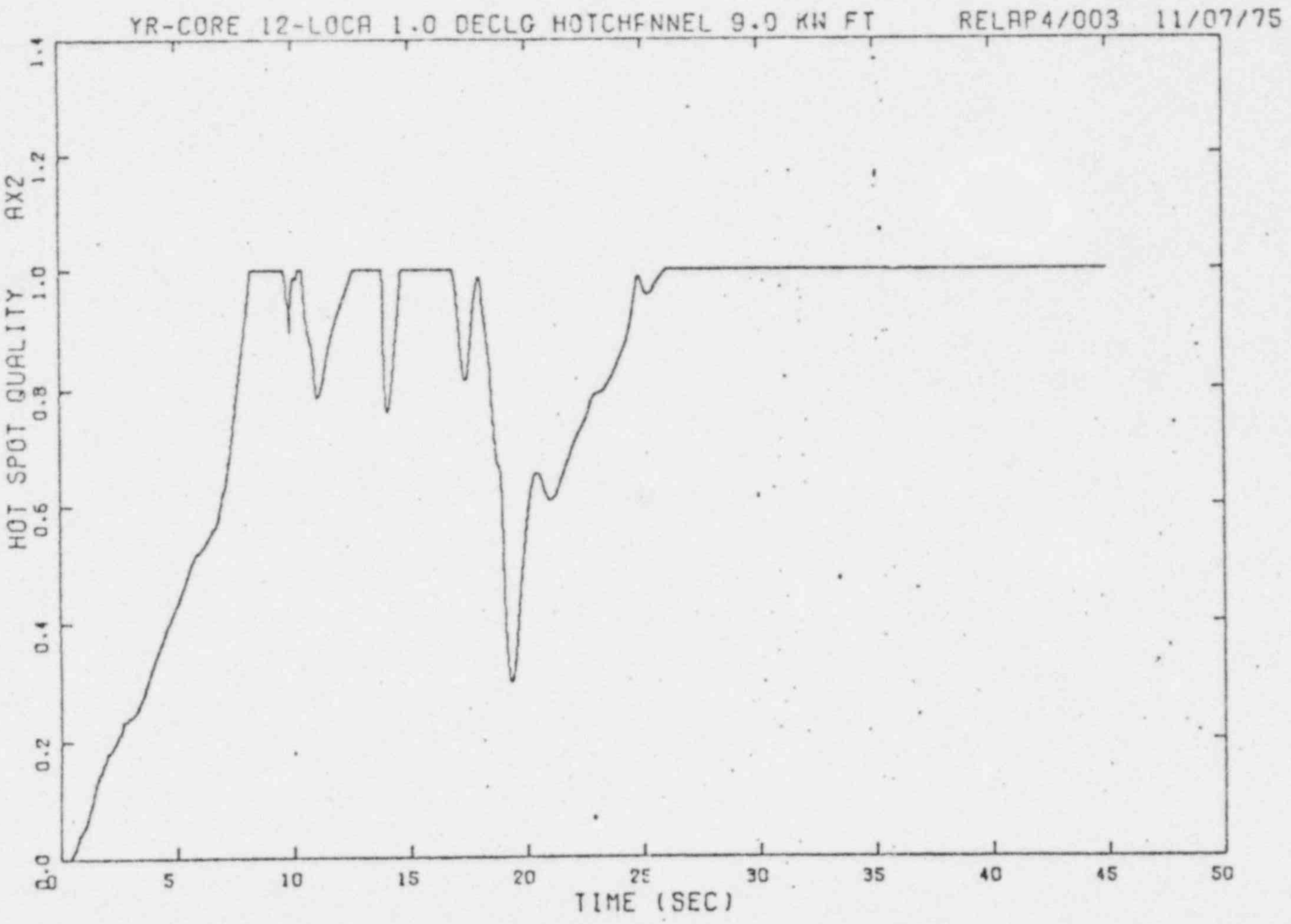


FIGURE 11 HOT SPOT FLUID QUALITY FOR DECLG WITH CD = 1.0

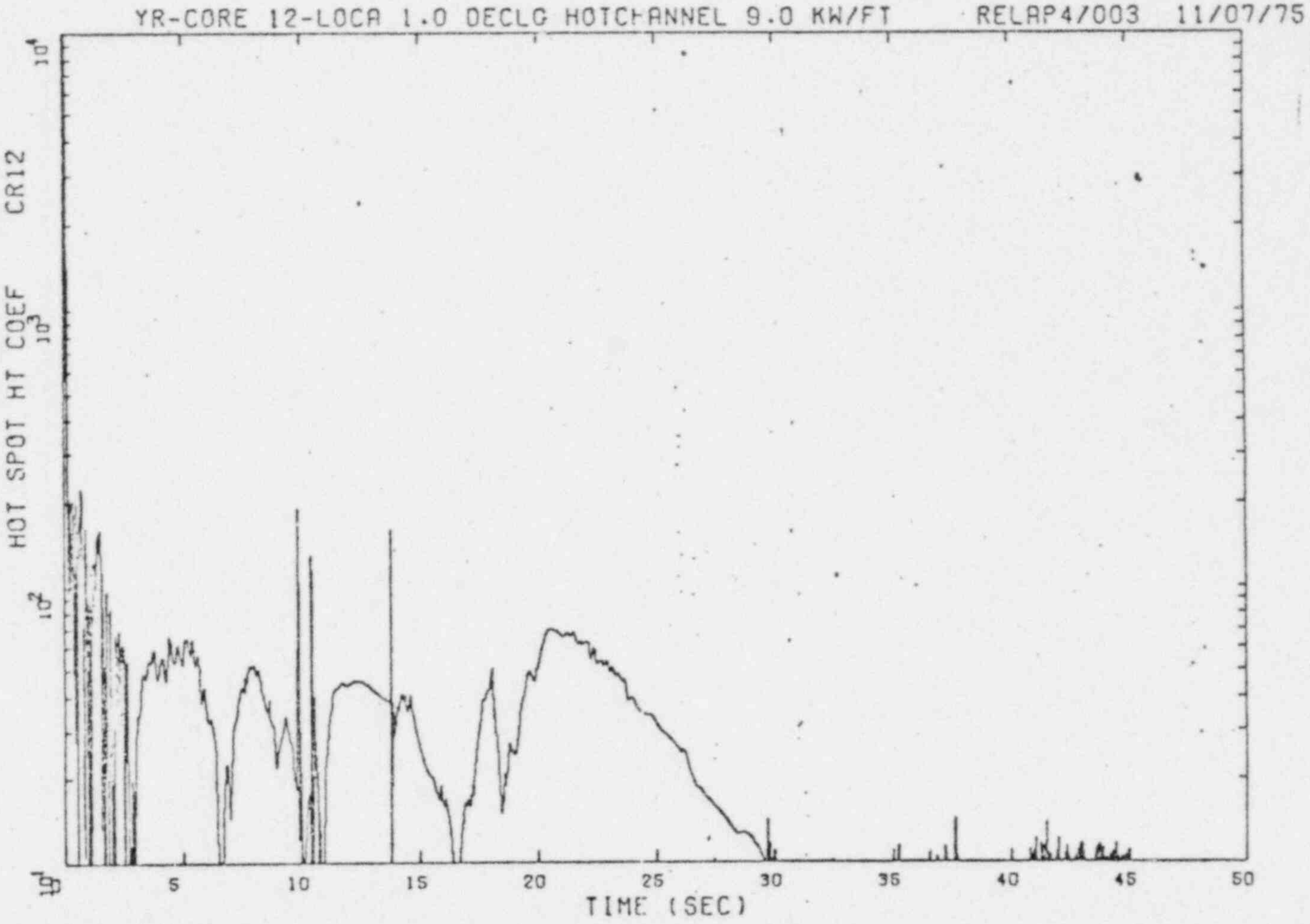


FIGURE 1J HOT SPOT FILM COEFFICIENT FOR DECLG BREAK WITH CD = 1.0

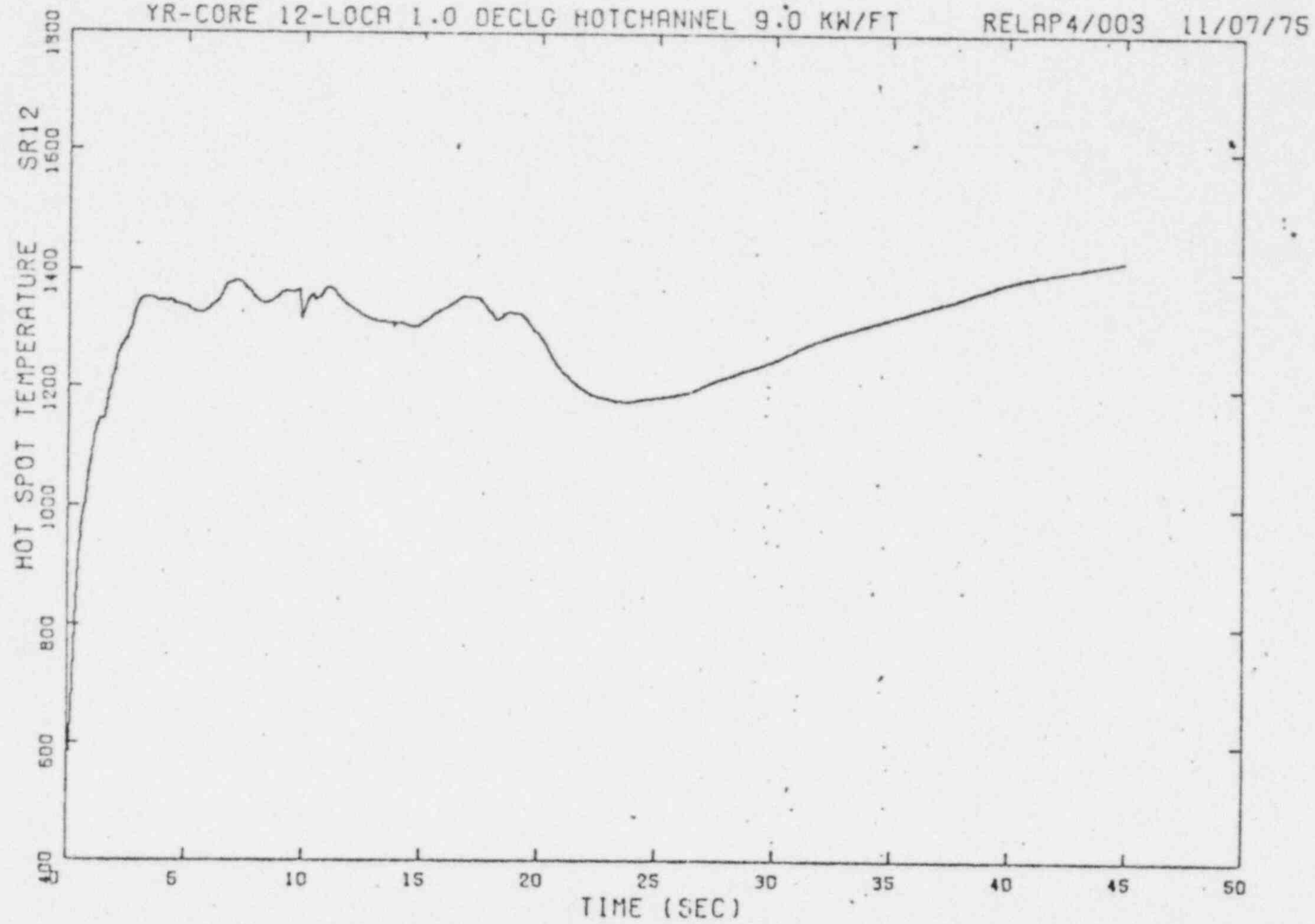


FIGURE 1K HOT SPOT CLAD TEMPERATURE FOR DECLG BREAK WITH CD = 1.0

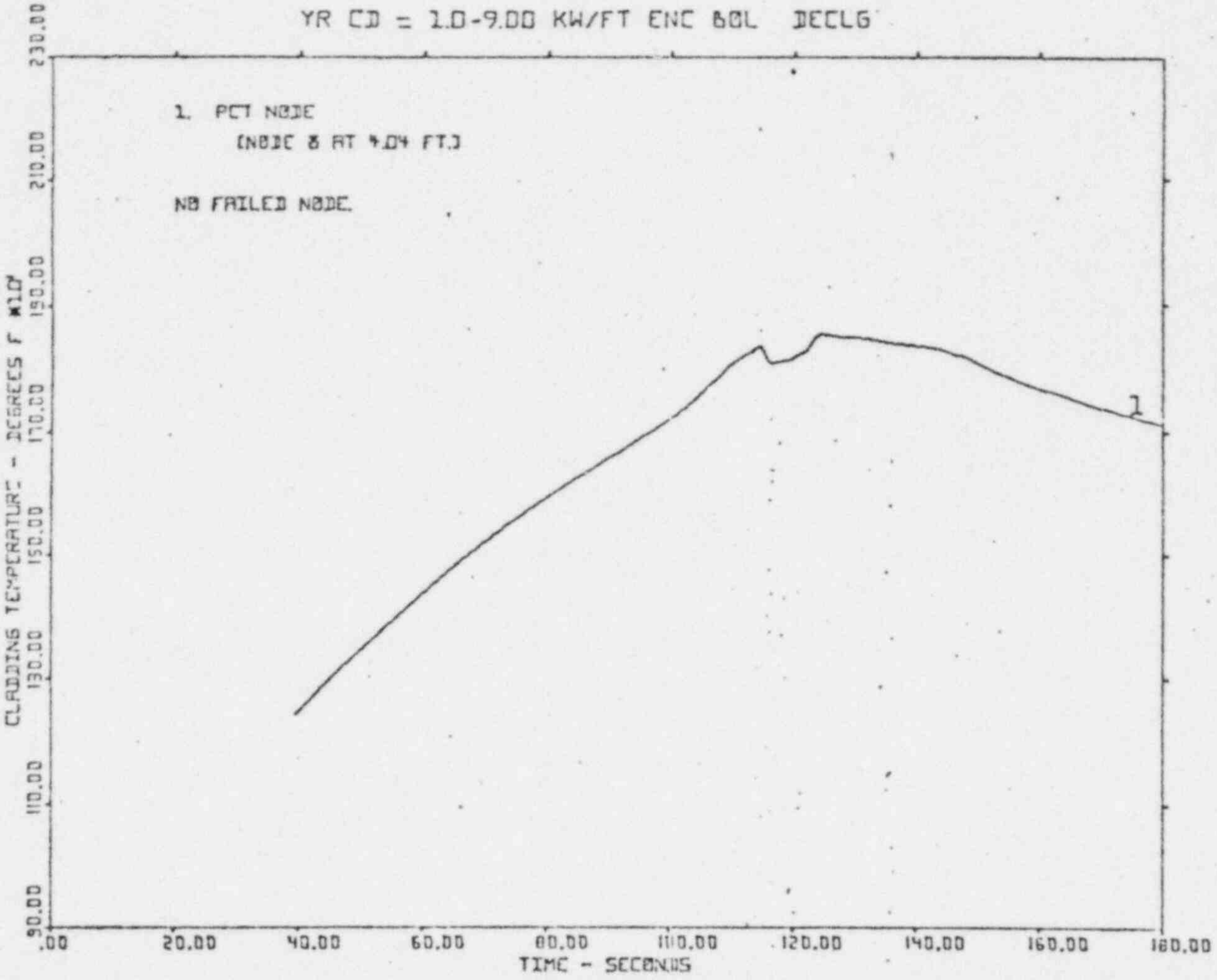


FIGURE 1L PEAK CLAD TEMPERATURE FOR DECLG BREAK WITH CD = 1.0

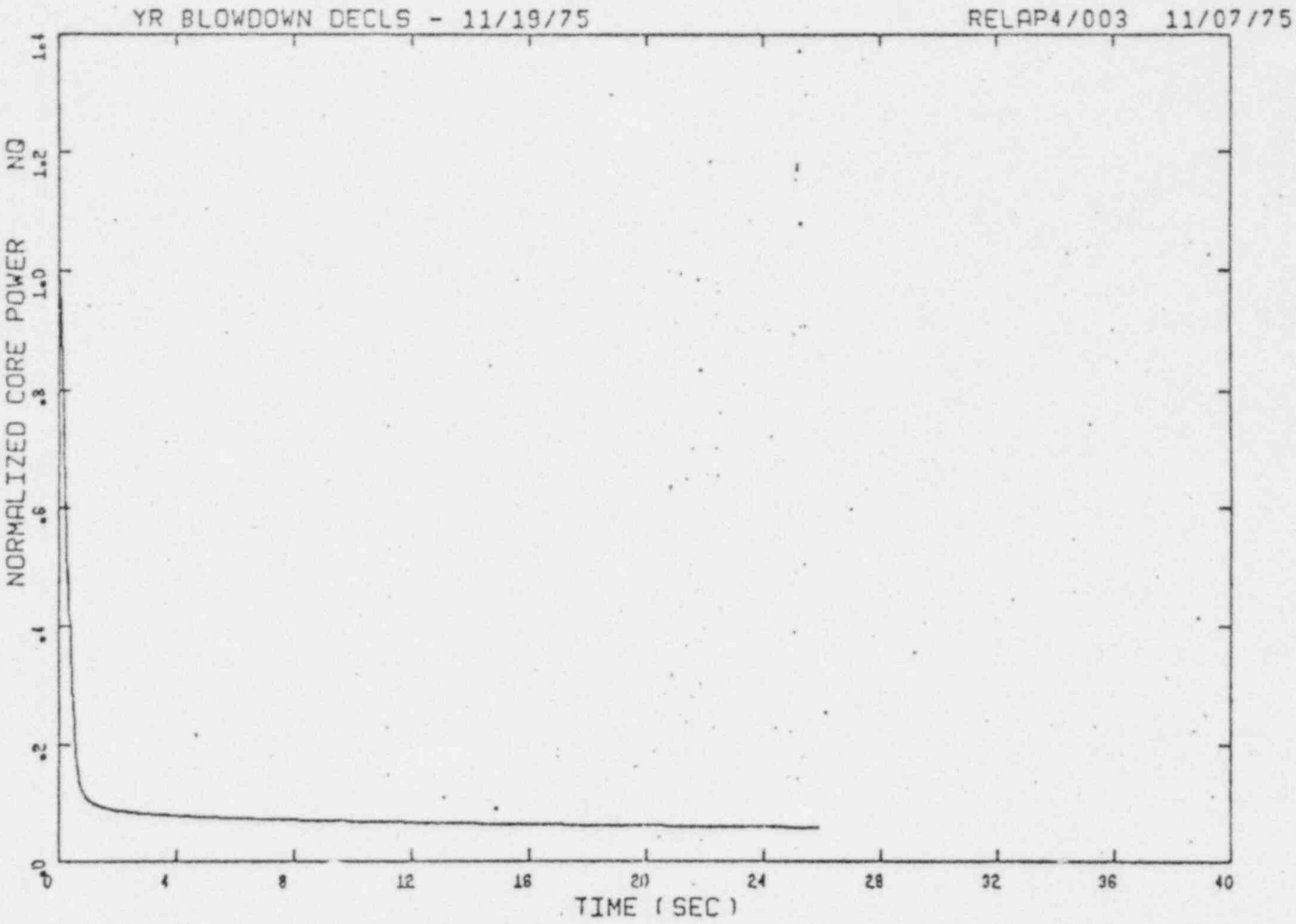


FIGURE 2A NORMALIZED CORE POWER FOR DECLS BREAK

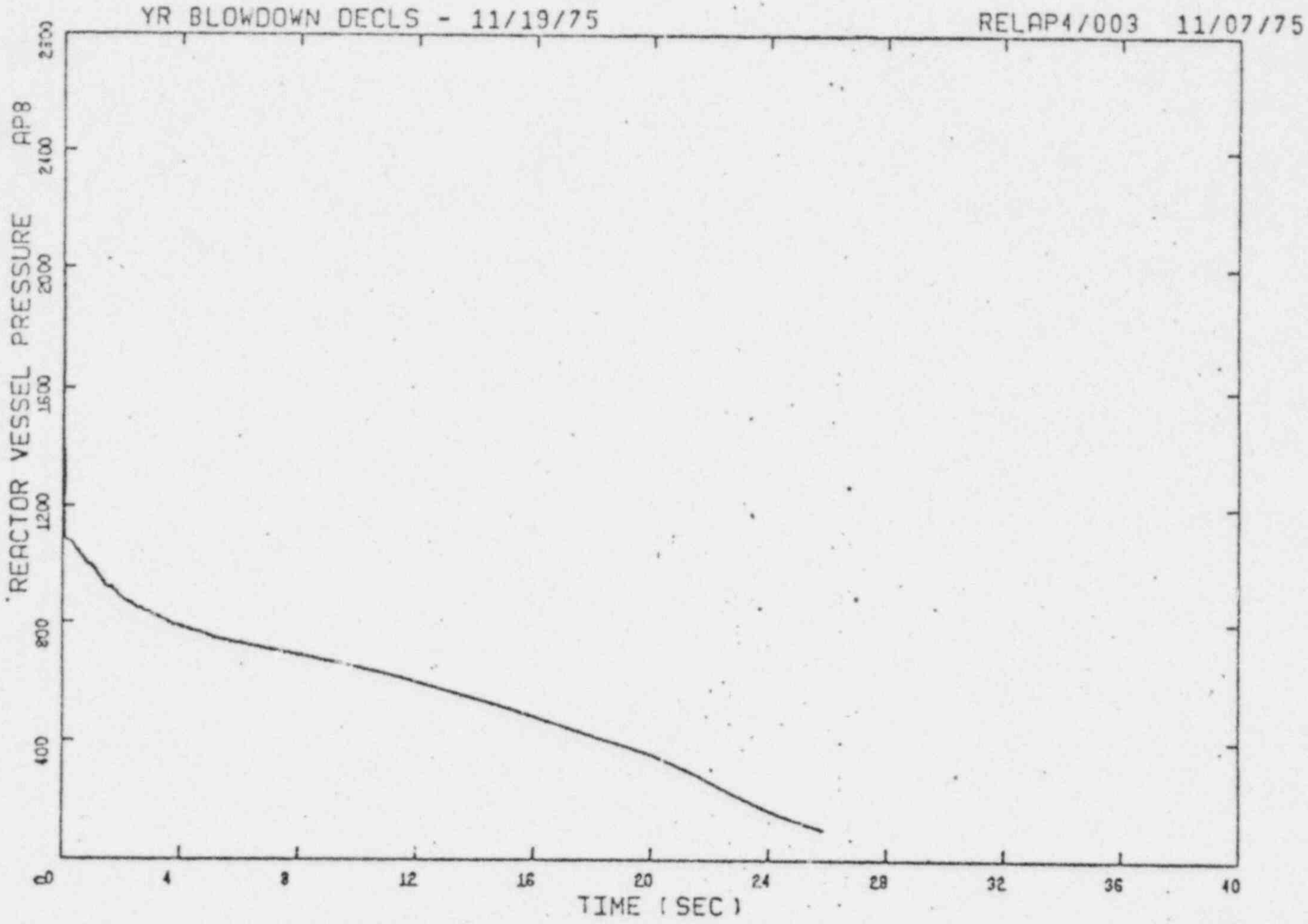


FIGURE 2B REACTOR VESSEL PRESSURE FOR DECLS BREAK

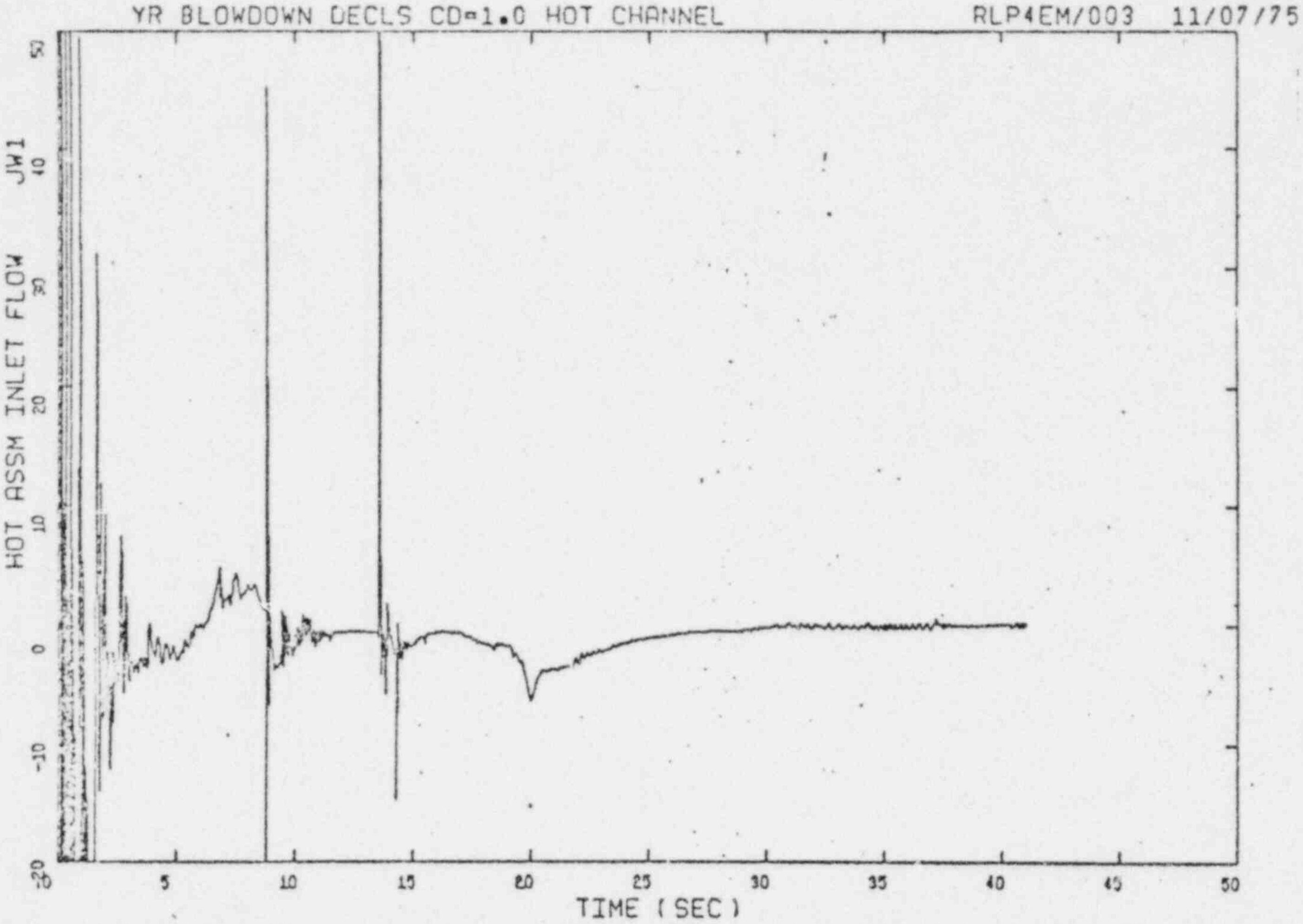


FIGURE 2C HOT ASSEMBLY INLET FLOW
FOR DECLS BREAK

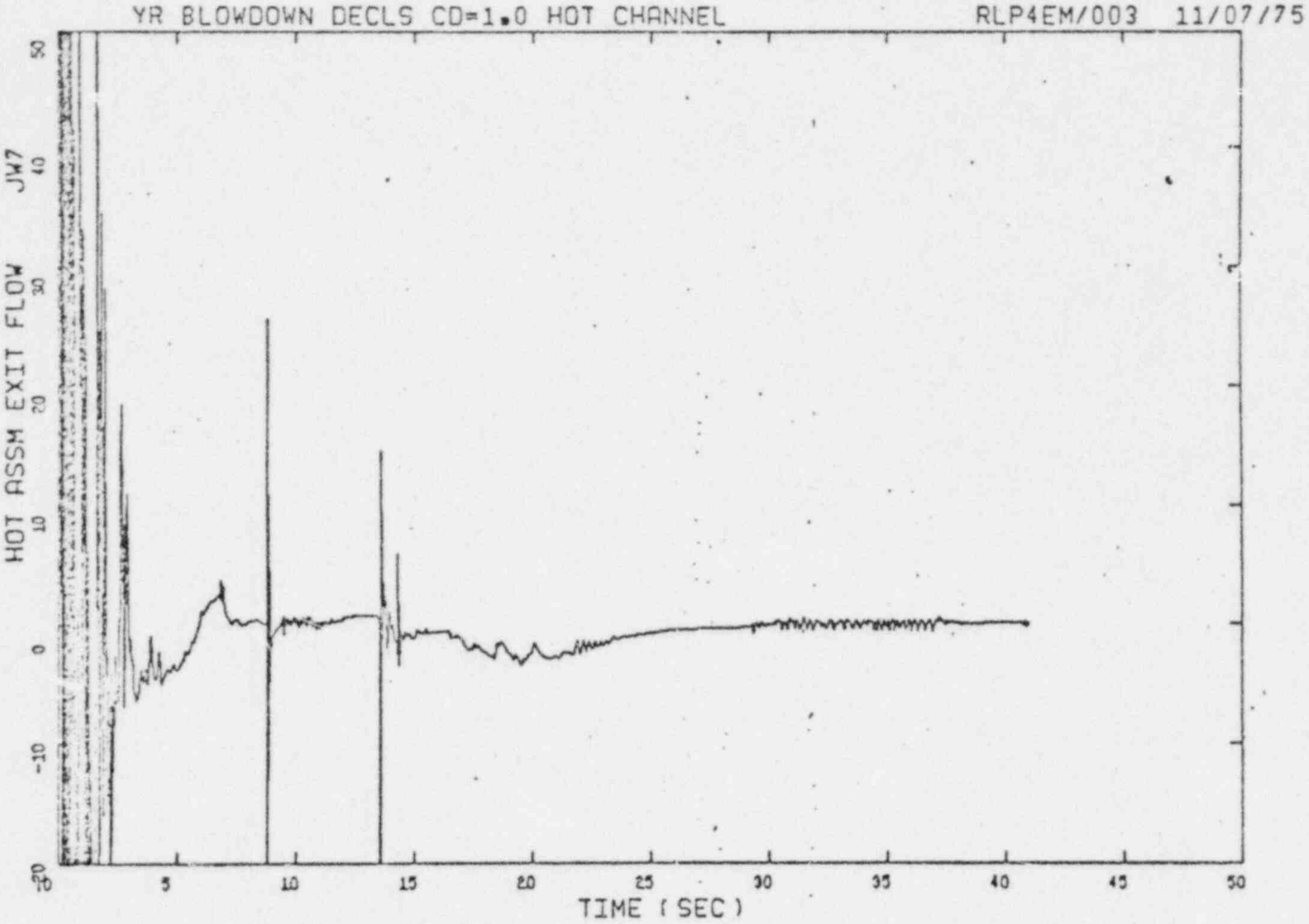


FIGURE 2D HOT ASSEMBLY EXIT FLOW
FOR DECLS BREAK

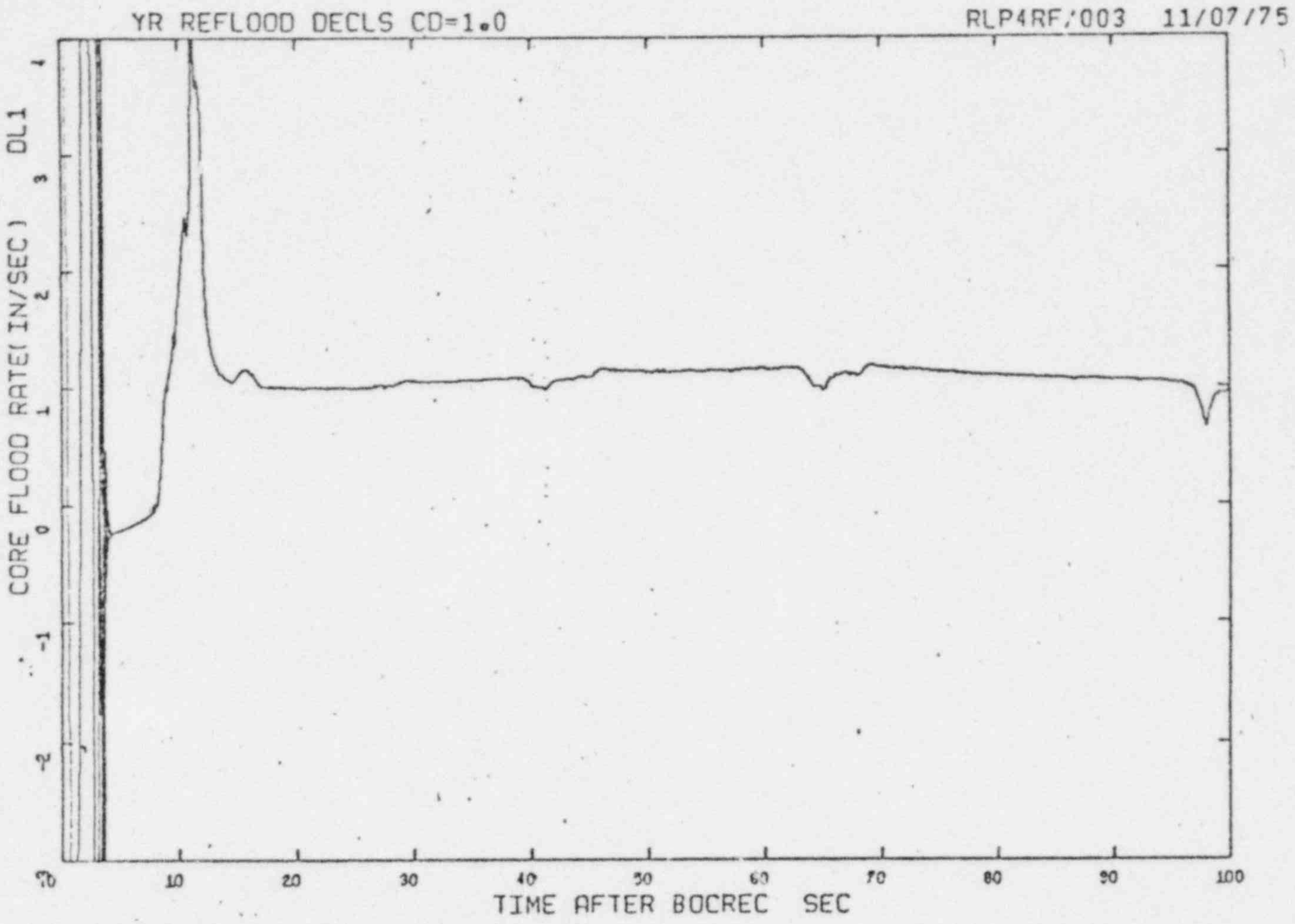


FIGURE 2E CORE FLOODING RATE
FOR DECLS BREAK

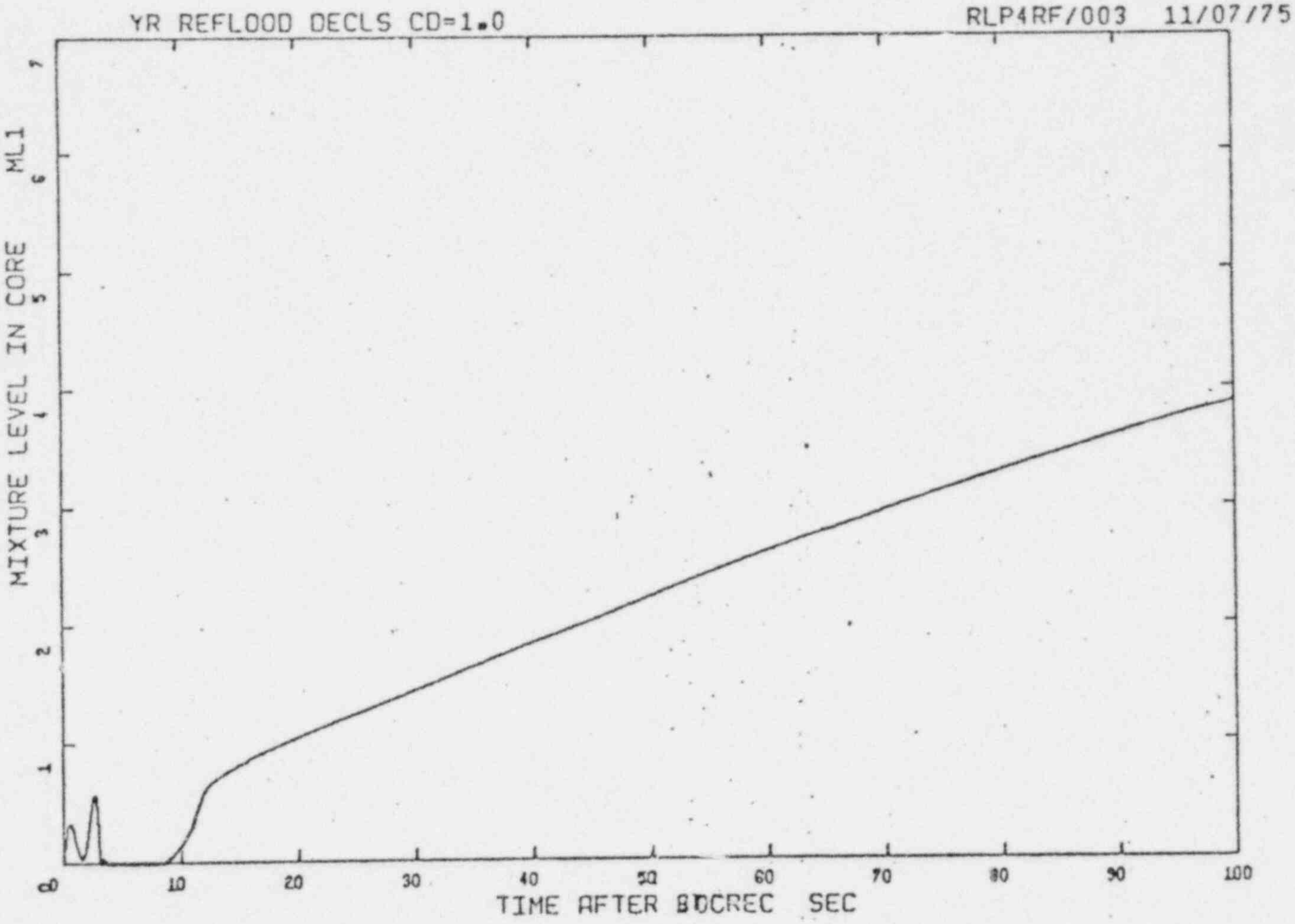


FIGURE 2F CORE MIXTURE LEVEL
FOR DECLS BREAK

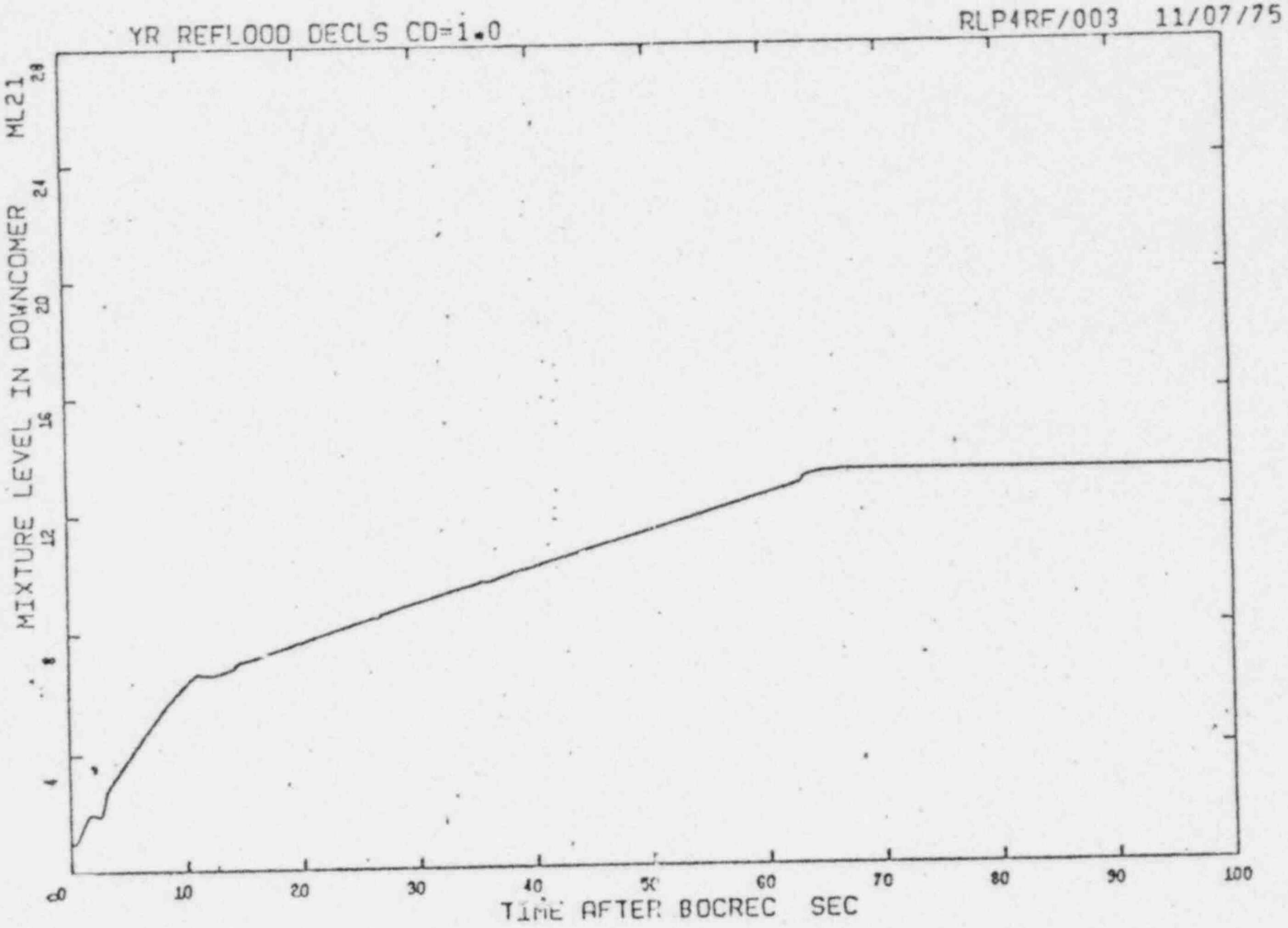


FIGURE 2G DOWCOMER WATER LEVEL FOR DECLS BREAK

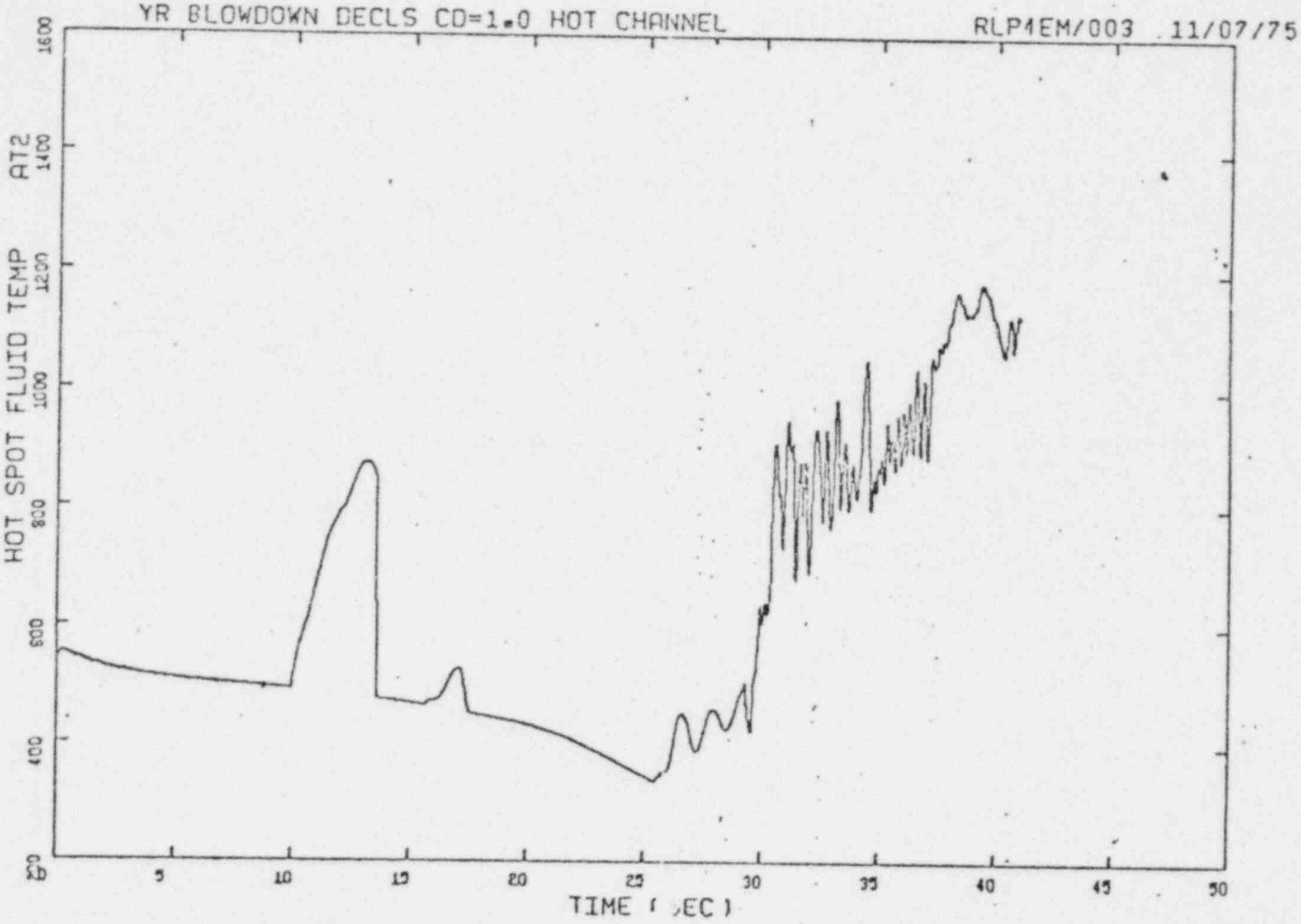


FIGURE 2H HOT SPOT FLUID TEMPERATURE FOR DECLS BREAK

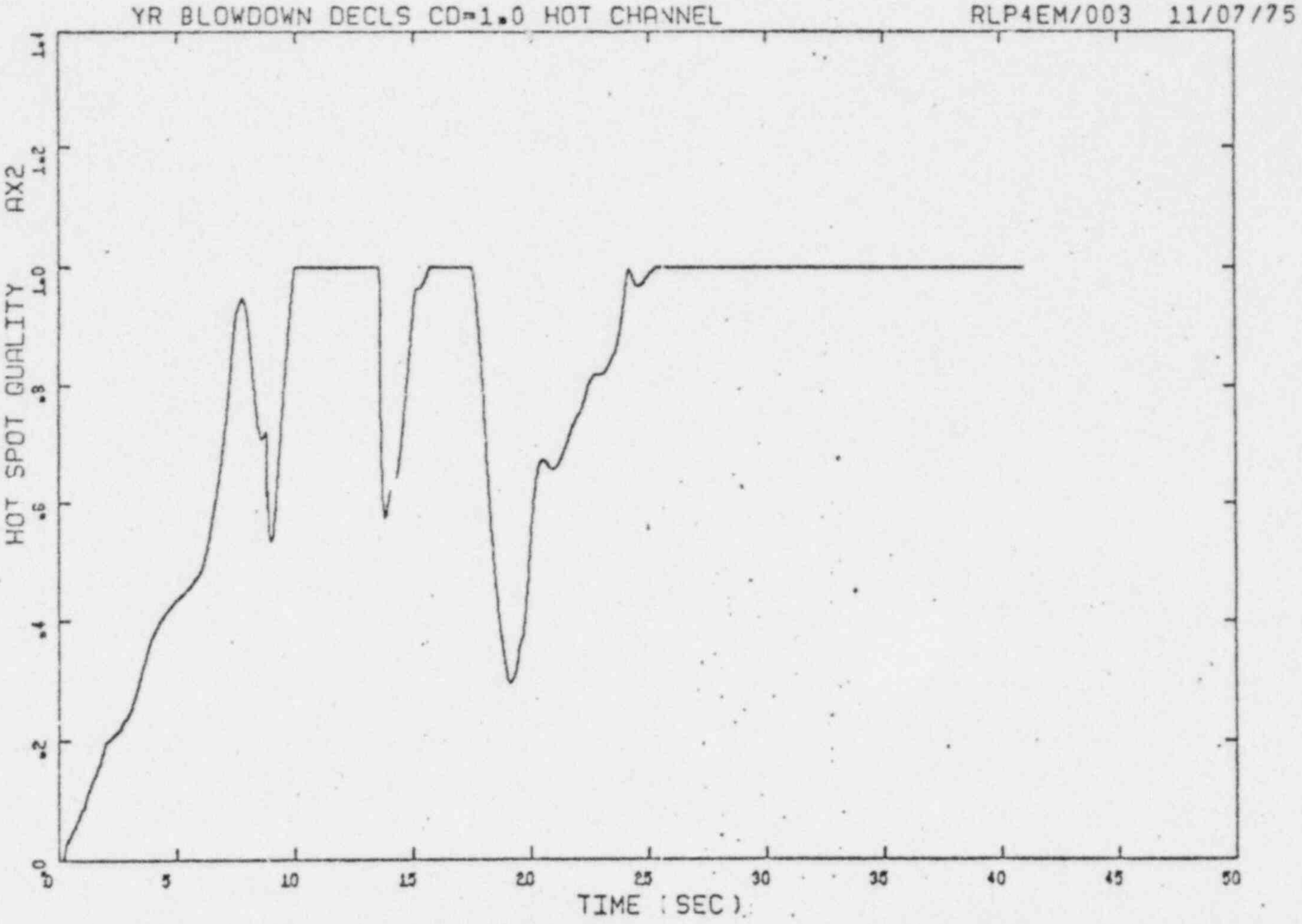


FIGURE 21 HOT SPOT FLUID QUALITY
FOR DECLS BREAK

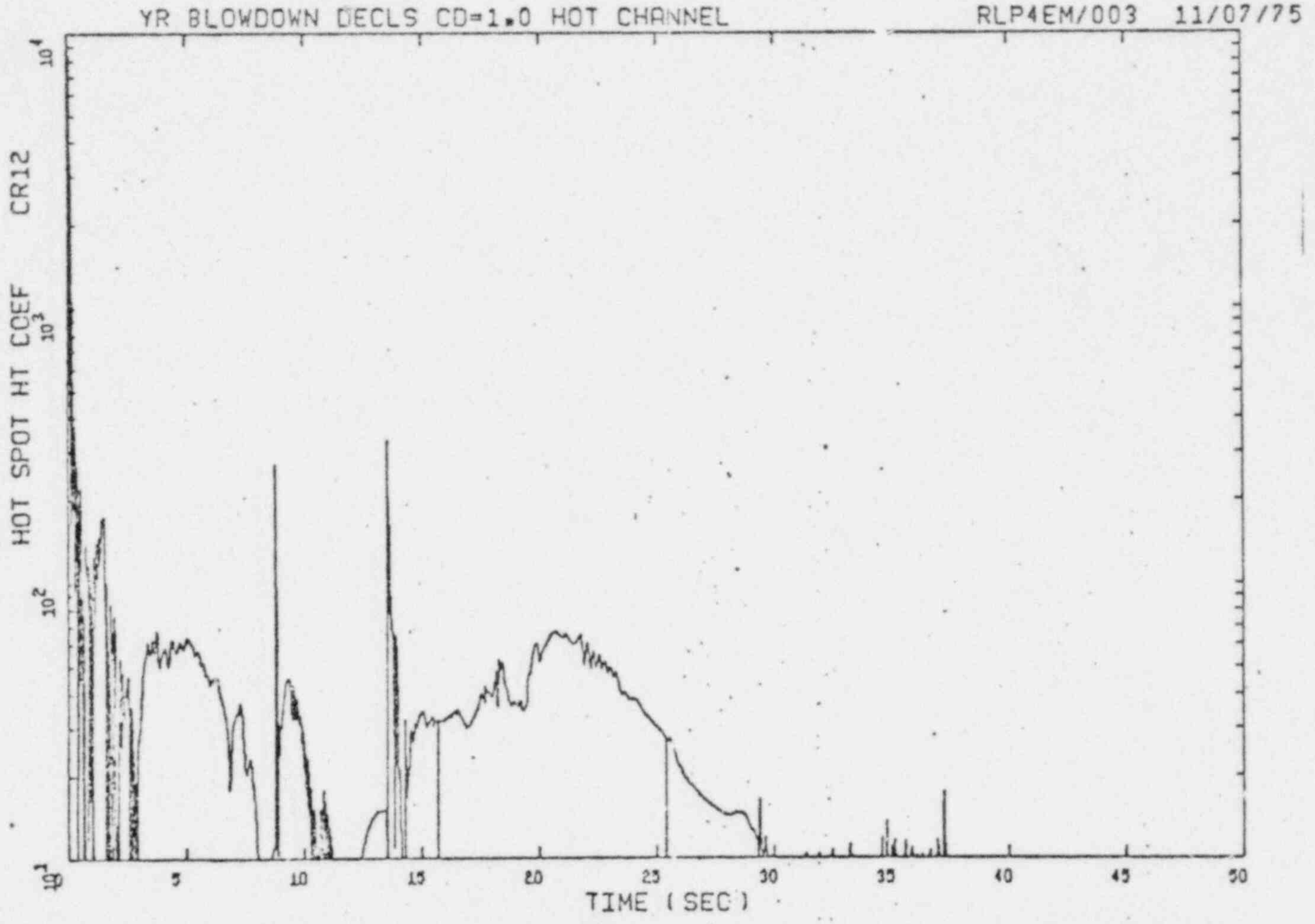


FIGURE 2J HOT SPOT FILM COEFFICIENT FOR DECLS BREAK

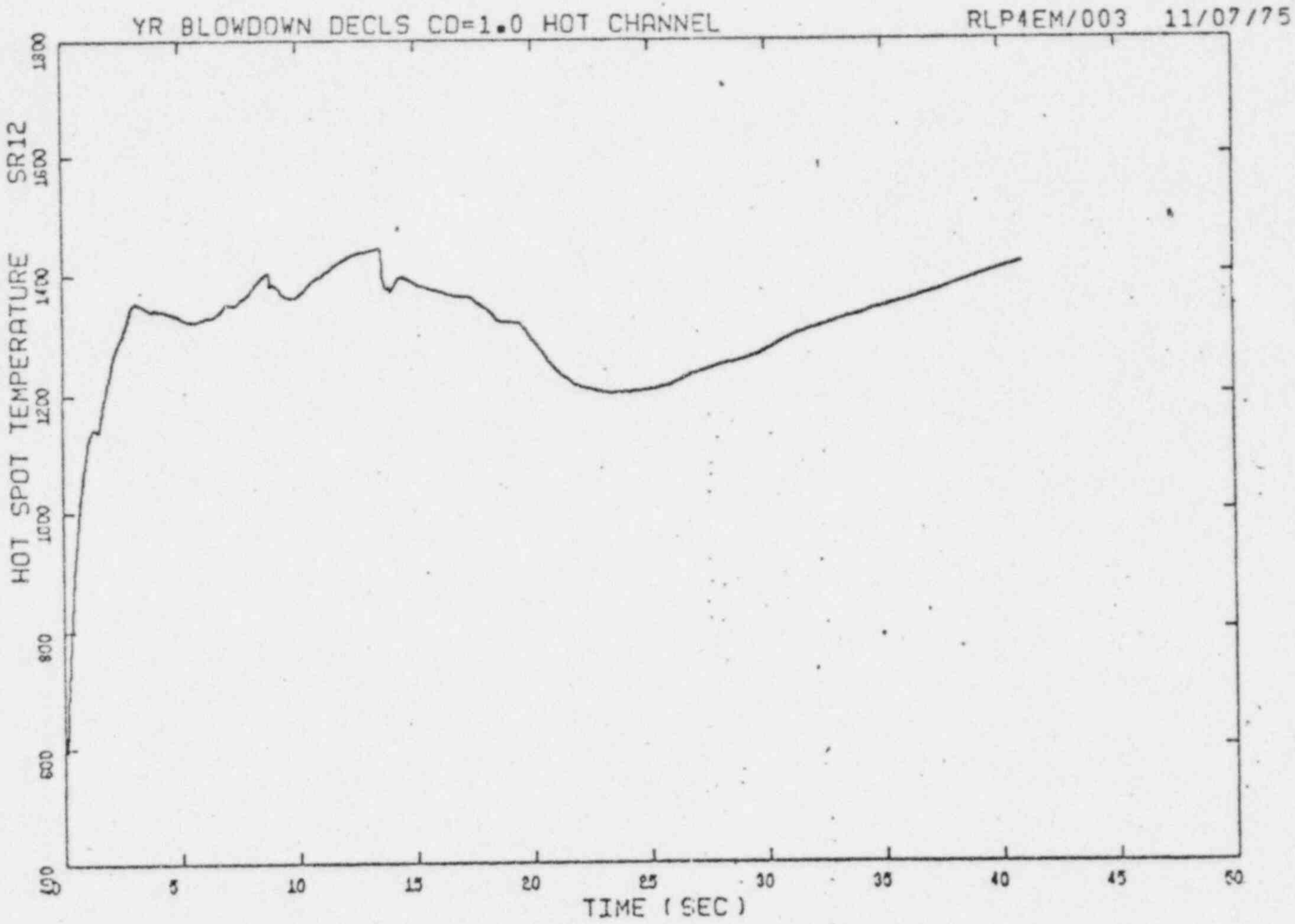


FIGURE 2K HOT SPOT CLAD TEMPERATURE
FOR DECLS BREAK

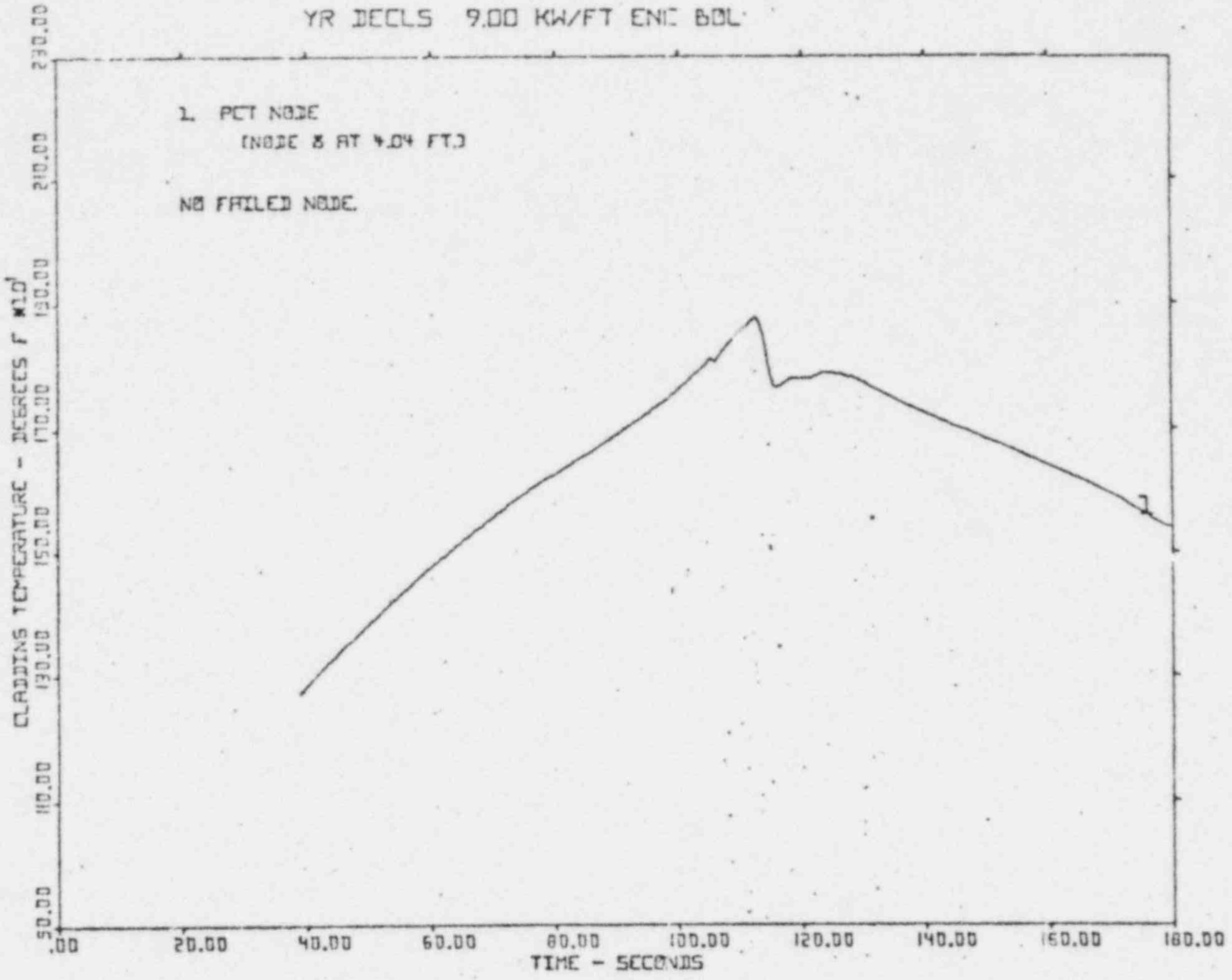


FIGURE 2L PEAK CLAD TEMPERATURE FOR DECLS BREAK

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