INCORPORATION OF THE WESTINGHOUSE MODEL FOR UPPER PLENUM INJECTION IN THE 1981 EVALUATION MODEL WREFLOOD CODE

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1. INTRODUCTION.

The original design of Westinghouse two-loop plants included both high head ECC injection into the hot legs and high or low head injection into the cold legs, so that no single failure could defeat the ECC injection. Later, the hot leg injection was deleted and lines were re-routed to direct low head injection flow into the upper plenum, due to the possibility that steam generated in the core might entrain ECC water injected into the hot leg. The Westinghouse ECCS evaluation model for two-loop plants equipped with UPI originally assumed that water injected into the upper plenum did not interact with steam and entrained water rising from the core; the UPI water was therefore modeled as if delivered through a cold leg injection location. A more elaborate model for upper plenum injection has been described in the letter NS-TMA-2172 (Reference 1), which forms the basis for the results reported here.

2. SUMMARY OF MODEL.

The model and associated FORTRAN coding for upper plenum injection described in the letter NS-TMA-2172 account for the following physical phenomena:

Metal-water heat transfer in the upper plenum,
Core heat transfer and steam generation,
Steam condensation,
Entrainment (horizontal and vertical).

The metal heat release to UPI water from the upper plenum metal structures is calculated using a lumped thermal capacitance model for the metal structures.

The core heat transfer model assumes that the core is divided into two distinct regions, one region covered uniformly by UPI water and the other having no contact with UPI water. In the region covered by UPI water, the heat transfer is calculated based on decay heat removal above the top quench front, and decay heat plus stored energy removal in the unquenched portion of the core. The standard WREFLOOD heat transfer calculations are performed for the region of the core not covered by UPI water.

The steam generation rate from bottom reflood is calculated by adding the core heat release in the non-UPI region to the carryover from bottom reflood.

If any subcooling remains in the UPI water after core heat is added, it is used to condense steam generated from the water entering through the bottom of the core. Water falling into the core consists of steam condensed, plus any water entrained by this steam. The amount of condensation is limited to the total bottom steam flow in the UPI covered region, i.e., the UPI water is assumed not to interact with bottom steam in the region of the core not covered by UPI water.

The amount of water entrained vertically by the steam generated from the UPI water is calculated using a correlation based on the injection flow and steam generation rate; horizontal entrainment is assumed to be a constant 1.67 percent of the injected flow. The total steam generation due to upper plenum injection consists of steam generation due to UPI water-core interaction plus vertical and horizontal entrainment.

The UPI water which is not lost due to steam generation or entrainment is assumed to fall directly to the lower plenum.

A more detailed discussion of the UPI model utilized in this analysis is presented in Reference 1.

3. SUMMARY OF RESULTS.

The Westinghouse upper plenum injection (UPI) model and FORTRAN coding described in letter NS-TMA-2172 (Reference 1) was incorporated in the 1981 Model version of the WREFLOOD code (References 2 and 3). This UPI model is intrinsically based on the mass and energy core model described in the same letter. The results reported here are also based on the 1981 Model Version COCO, SATAN and LOCTA codes (References 2, 4, 5 and 6).

The 1981 evaluation model modified in this manner for upper plenum injection was used to analyze the effects of UPI on the 0.4 DECLG LOCA blowdown transient for Point Beach Unit 1. Only the 0.4 CD break results are considered since this case has historically been limiting for two-loop plants and since the discharge coefficient should not greatly influence the comparison of upper plenum injection results with standard results.

3.1 Base case and non-UPI.

The results of this analysis for the base case (upper plenum coverage of 30%) are shown in Tables 1-3 and Figures 1-12. A comparison of these results with those of the 1981 ECCS model (unmodified for upper plenum injection) for the same conditions (shown in Tables 1-3 and Figures 1-12), shows that the UPI version predicts a considerable benefit in flooding rate. Despite a 1.63 second penalty in the UPI case BOC time due to the assumption in the model of not adding top-injected water to the lower plenum during refill, the 1981 Model version with the UPI modeled predicts a 151 F benefit in PCT in comparison with results of the non-UPI case.

3.2 Coverage sensitivities.

The NS-TMA-2172 model was also run for core coverages of 50%, 70% and 100% to determine the sensitivity of the model to core coverage. These results, shown in Tables 4-5 and Figures 13-19, predict an increase in PCT with increasing core coverage. Both the 50% and 70% core coverage cases still show a benefit in calculated PCT in comparison with the non-UPI case (146F and 60F benefits, respectively), while the 100% coverage case shows a 130F penalty.

4. CONCLUSIONS

The NS-TMA-2172 model for upper plenum injection provides a benefit in calculated flooding rate and PCT when analyzing a minimum safeguards condition with 30% core coverage. In modeling UPI an important beneficial effect is the calculation of steam condensation, while a flooding rate penalty is the result of calculated steam generation. Steam generation is predominant during the early part of the transient; as the core cools, the UPI water subcooling is available to condense steam and steam condensation becomes more influential during the latter part of the transient. Increasing the core coverage accentuates the effect of steam generation and hence produces lower average flooding rates. NS-TMA-2172 concluded on the basis of test results that 30% coverage is an upper bound for core coverage.

5. REFERENCES

1. Anderson, T. M., "Modifications to the W ECCS evaluation model (February 1978 version) for two-loop upper plenum injection plants", NS-TMA-2172, December 6, 1979.

2. "Westinghouse ECCS Evaluation Model, 1981 Version", WCAP-9220-P-A (Proprietary version), and WCAP-9221-P-A (Non-proprietary version), Revision 1, 1982.

3. Kelly, R.D., et al., "Calculational Model for Core Reflooding after a Loss-of-Coolant Accident (WREFLOOD Code)". WCAP-8170 (Proprietary Version), WCAP-8171 (Non-Proprietary Version), June 1974.

4. Bordelon, F.M., and Murphy E.T., "Containment Presure Analysis Code (COCO)", WCAP-8327 (Proprietary Version), WCAP-8326 (Non-Proprietary Version), June 1974.

5. Bordelon, F.M., et al., "SATAN-VI Program: Comprehensive Space-Time Dependent Analysis of Loss-of-Coolant". WCAP-8302 (Proprietary Version), WCAP-8306 (Non-Proprietray Version), June 1974.

6. Bordelon, F.M., et al., "LOCTA-IV Program: Loss-of-Coolant Transient Analysis", WCAP-8301 (Proprietary Version), WCAP-8305 (Non-Proprietary Version), June 1974.

6. LIST OF TABLES AND FIGURES

6.1 BASE CASE (30% coverage) AND NON-UPI

TABLES

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6.2 COVERAGE SENSITIVITIES

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5. Cladding parameters, 50% 70% and 100% coverage.

FIGURES

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a. 50% b. 70% c. 100%

14. Fluid quality.
a. 50% b. 70% c. 100%

15. Mass velocity.
a. 50% b. 70% c. 100%

16. Core and downcomer water levels.
a. 50% b. 70% c. 100%

17. Flooding rate.
a. 50% b. 70% c. 100%

18. Peak cladding temperature.
a. 50% b. 70% c. 100%

19. Heat transfer coefficient.
a. 50% b. 70% c. 100%

TABLE 1

TIME SEQUENCE OF EVENTS -- DECLG CD = 0.4

	UPI	non-UPI
Start	0.0	0.0
Rx trip signal	0.420	0.420
S. I. signal	0.81	0.81
Acc. injection	8.57	8.57
End of bypass	20.3	20.3
End of blowdown	23.3	23.3
Pump injection	25.81	25.81
Bottom of core recovery (BOC)	40.258	38.63
Acc. empty	55.9	55.9

TABLE 2

CLADDING PARAMETERS

	UPI	non-UPI
Peak clad temp, F	1787	1938
PCT location, ft	7.25	7.5
Local Zr/H2O reaction (max), %	1.510	3.503
Location of max reaction, ft	7.25	7.5
Total Zr/H2O reaction, %	<0.3	<0.3
Hot rod burst time, sec	49.6	55.6
Hot rod burst location, ft	6.0	6.0

TABLE 3

CALCULATION ASSUMPTIONS

NSSS power, MWt, 102% of	1518.5
Peak linear power, kw/ft, 102% of	12.60
Peaking factor	2.21
Acc. water volume, per tank, cubic feet	1100
Acc. pressure, psia	700
Number of SI trains operating	1
Steam generator tube plugging	14%

TABLE 4

TIME SEQUENCE OF EVENTS — DECLG CD = 0.4

	50% coverage	70%	100%
Start	0.0 sec	0.0	0.0
Rx trip signal	0.420	0.420	0.420
S. I. signal	0.810	0.810	0.810
Acc. injection	8.57	8.57	8.57
End of bypass	20.33	20.33	20.33
End of blowdown	23.33	23.33	23.33
Pump injection	25.81	25.81	25.81
Bottom of core recovery (BOC)	40.26	40.26	40.26
Acc. empty	55.91	55.91	55.91

TABLE 5

CLADDING PARAMETERS

	50% Coverage	70%	100%
Peak clad temp, F	1792.	1878.	2068.
PCT location, ft	7.25	7.25	7.25
Local Zr/H20 reaction (max), %	1.47	1.93	3.66
Location of max reaction, ft	6.0	6.00	7.25
Total Zr/H20 reaction, %	<0.3	<0.3	<0.3
Hot rod burst time, sec	49.20	49.20	49.20
Hot rod burst location, ft	6.00	6.00	6.00

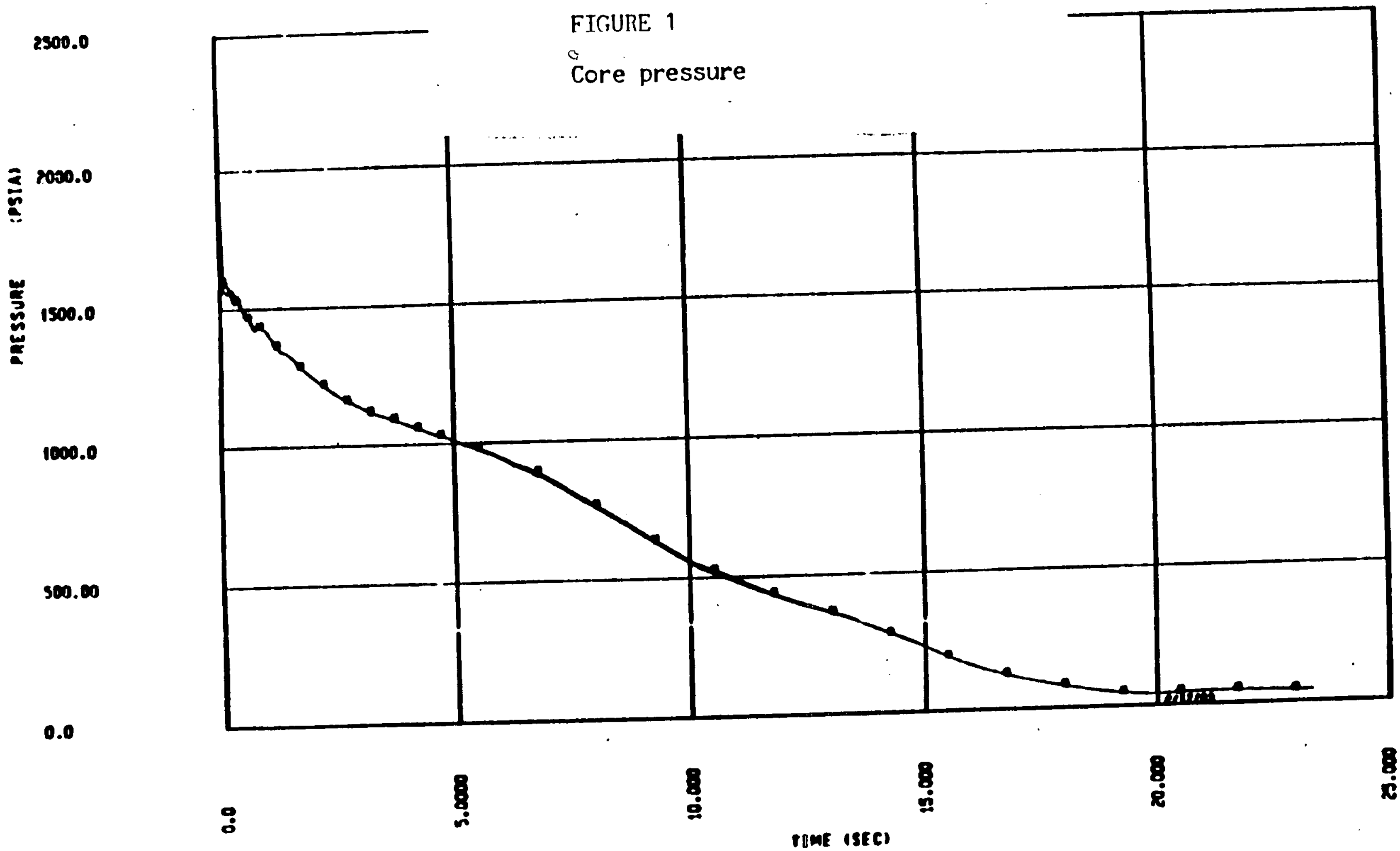


FIGURE 1

Core pressure

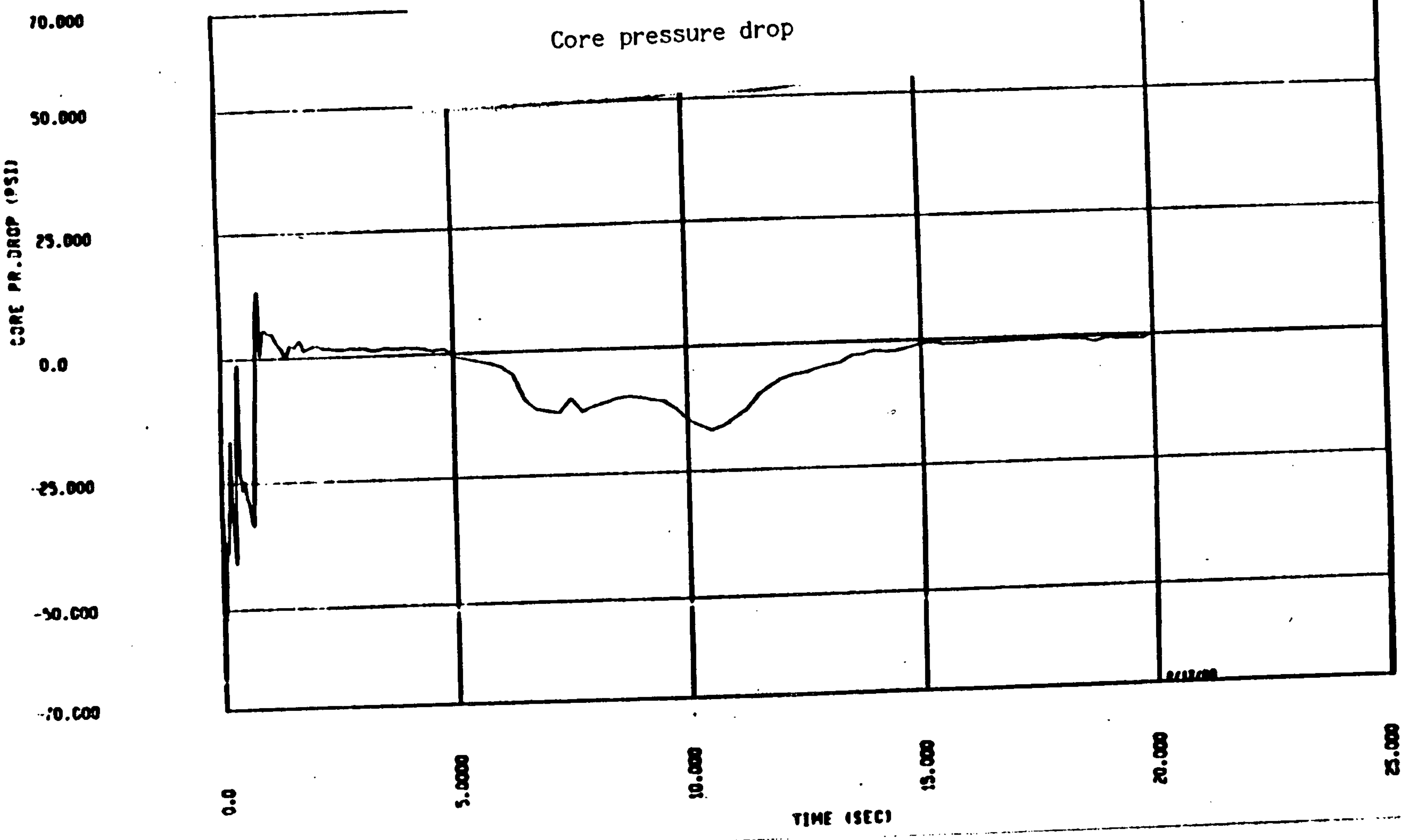


FIGURE 2

Core pressure drop

FIGURE 3

Core flow, top and bottom

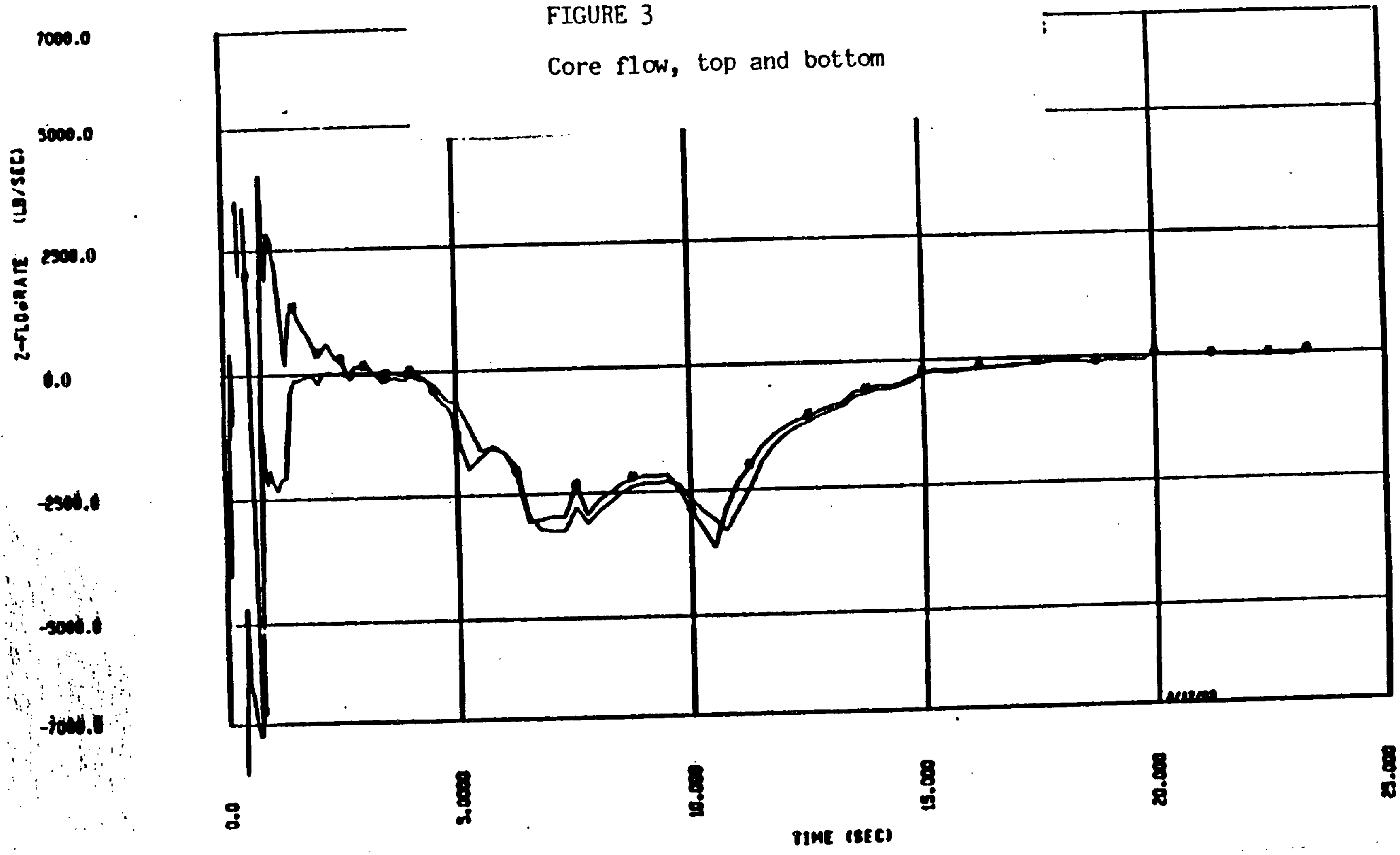


FIGURE 4

Break flow rate

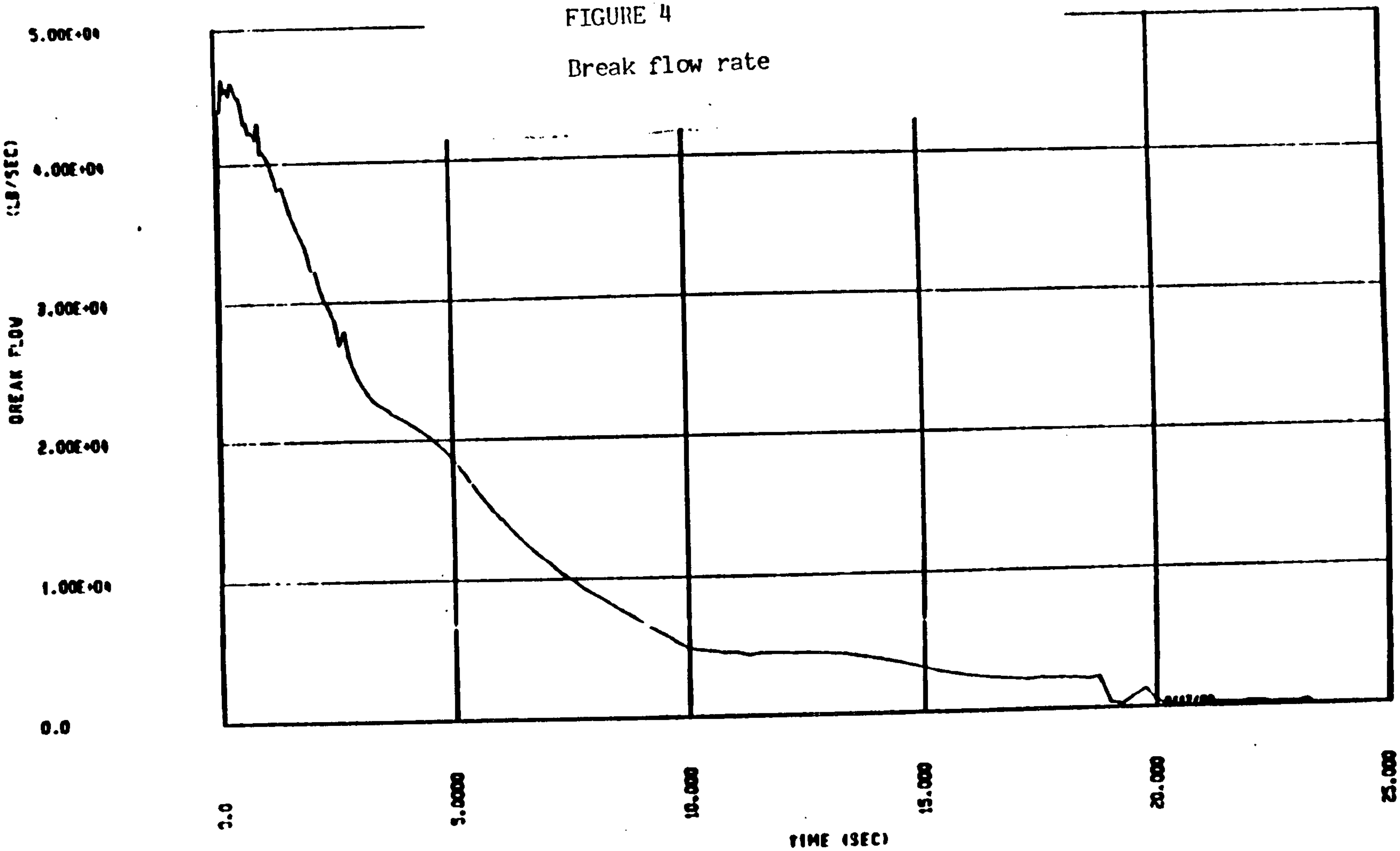


FIGURE 5
Accumulator flow (during blowdown)

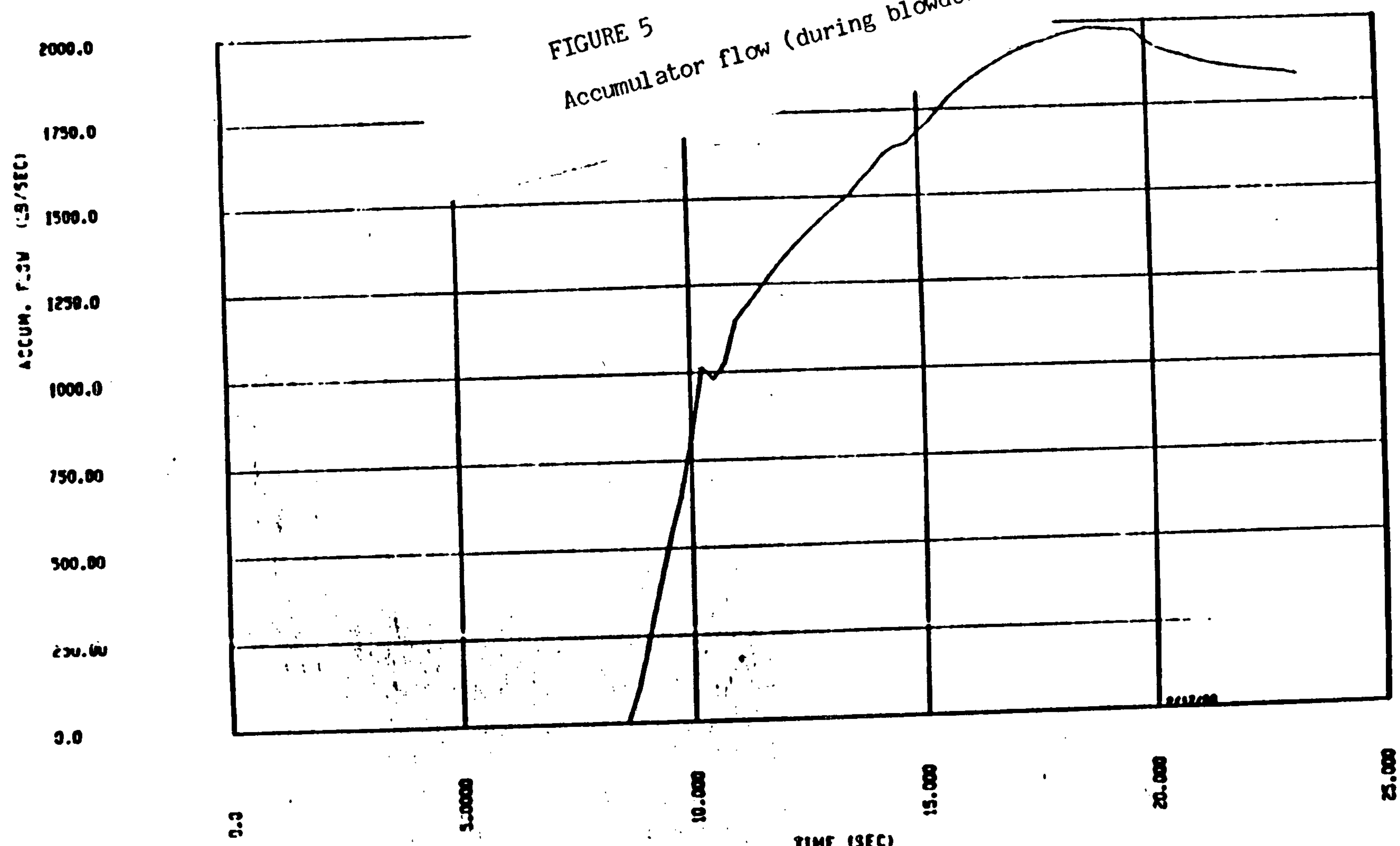


FIGURE 6A

Fluid temperature, UPI

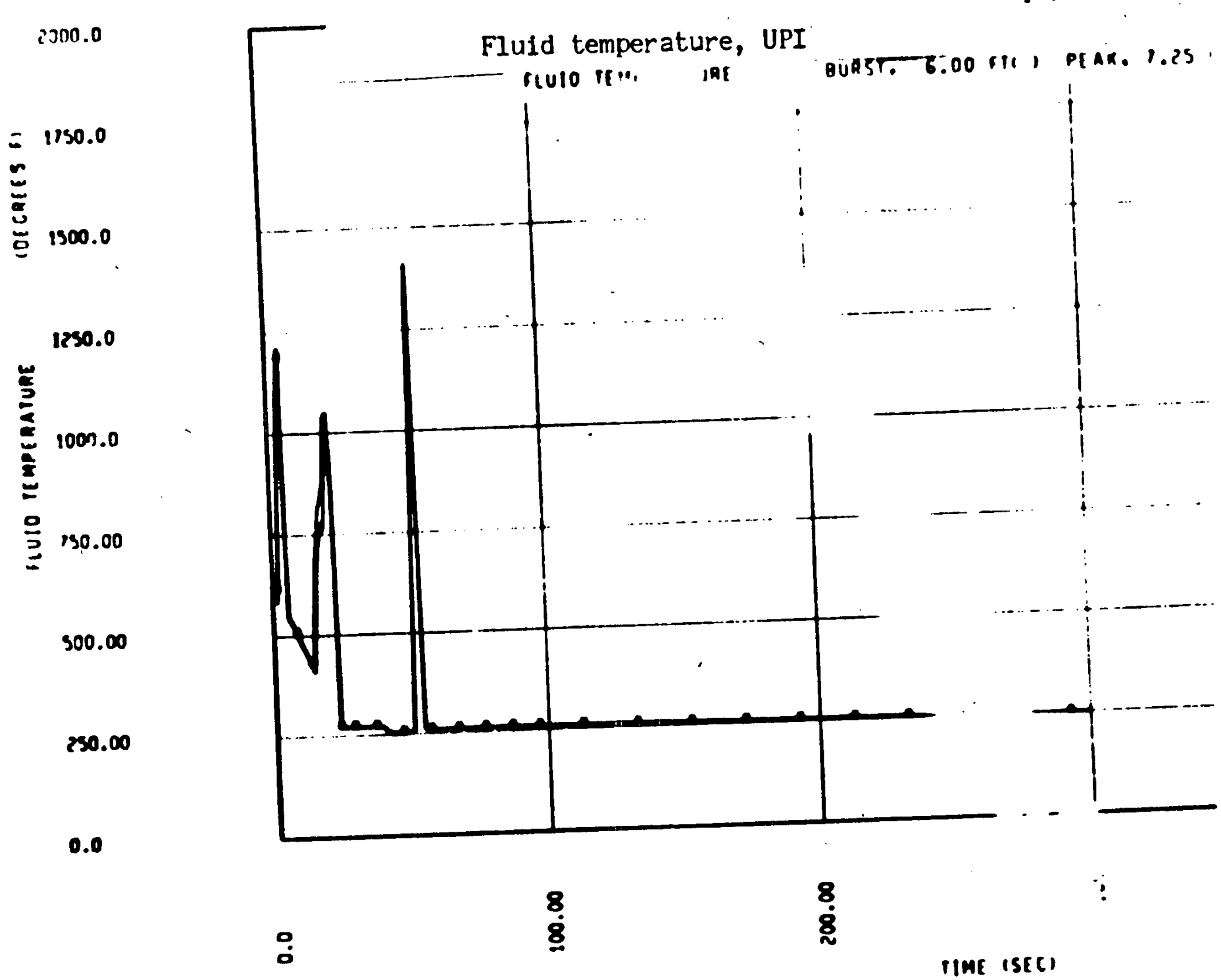


FIGURE 6B

Fluid temperature, non-UPI

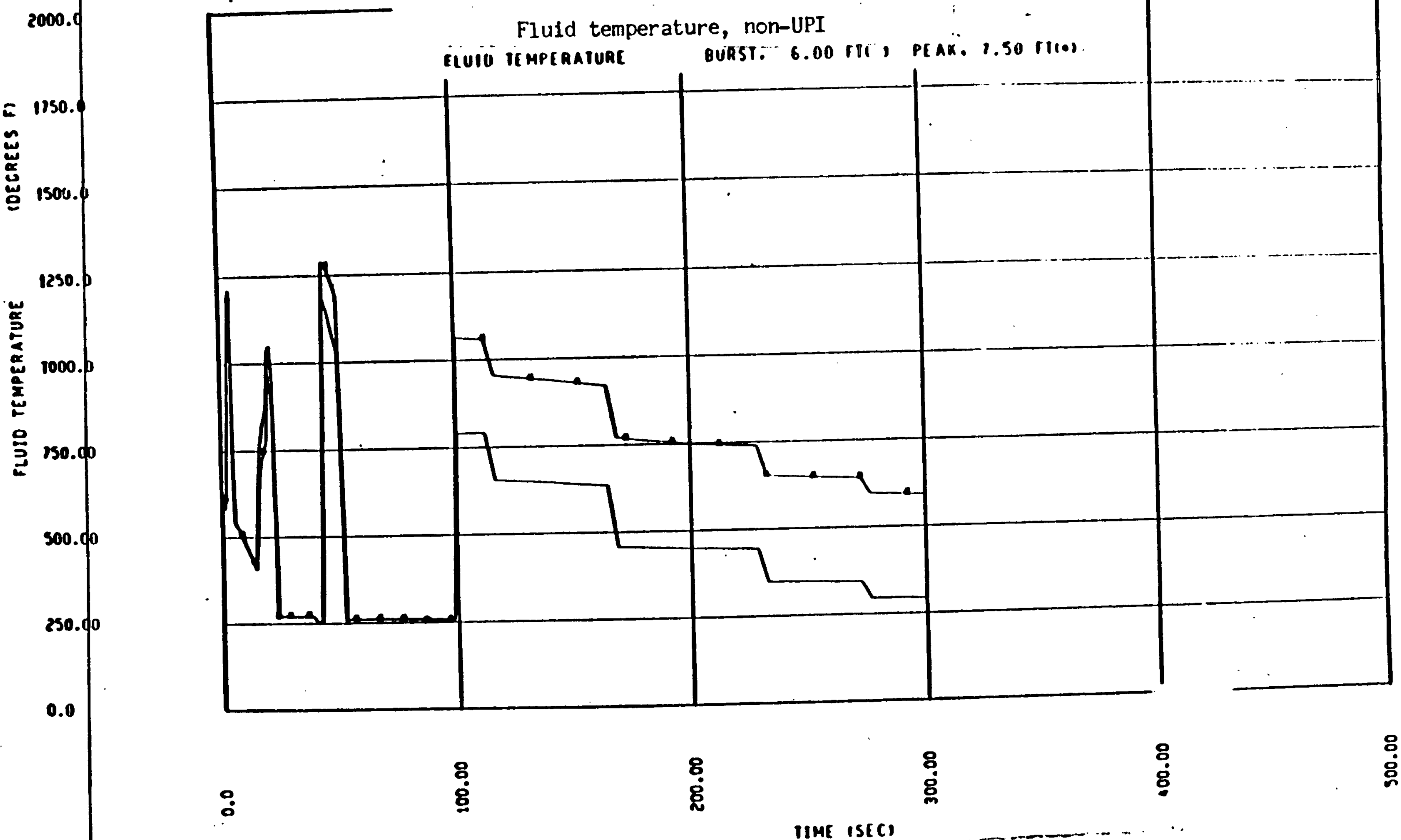


FIGURE 7A

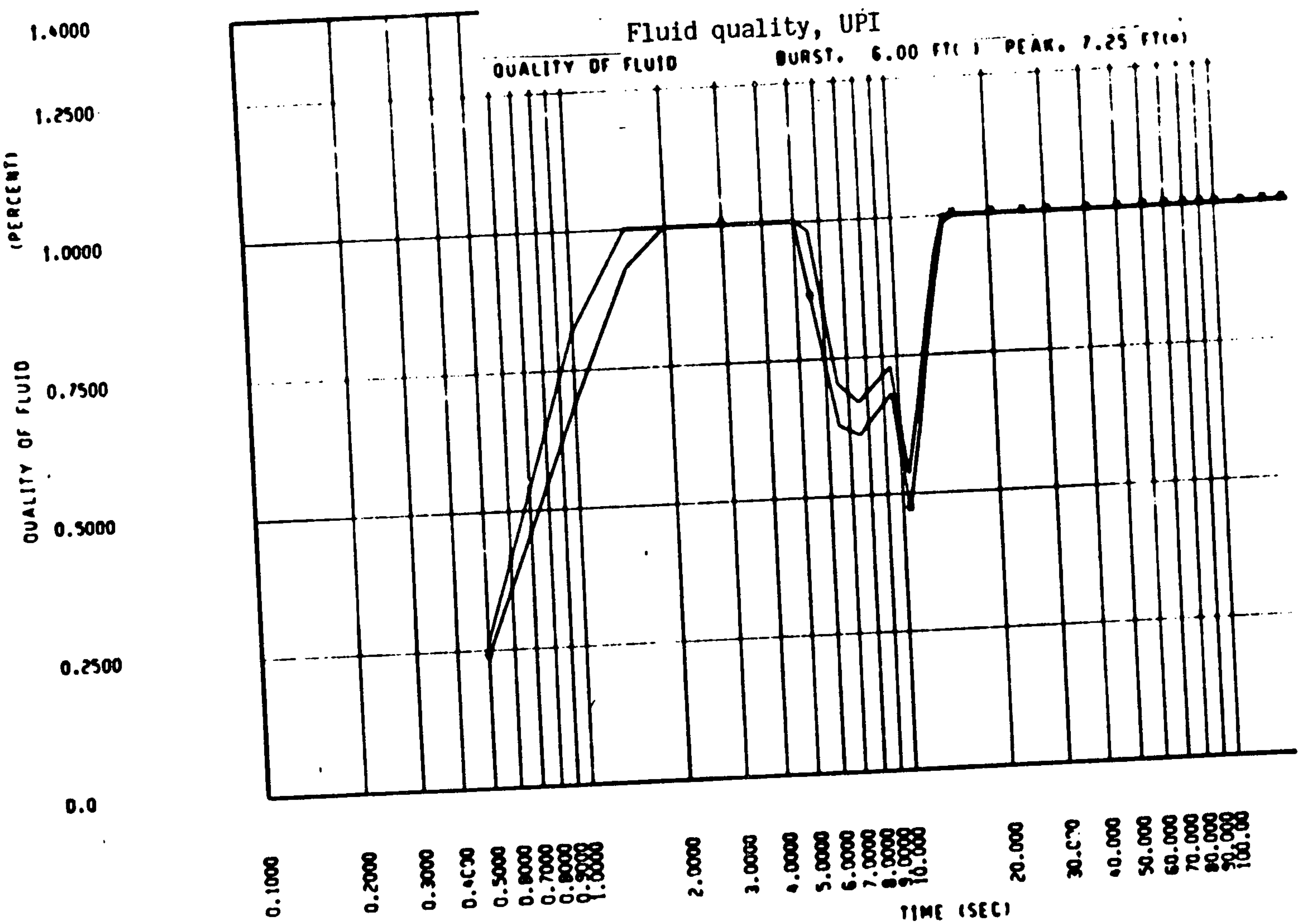

Fluid quality, UPI
QUALITY OF FLUID
BURST, 6.00 FT( ) PEAK, 7.25 FT(a)
QUALITY OF FLUID (PERCENT)
1.4000
1.2500
1.0000
0.7500
0.5000
0.2500
0.0
0.1000
0.2000
0.3000
0.5000
0.6000
0.7000
0.8000
1.0000
2.0000
3.0000
4.0000
5.0000
6.0000
7.0000
8.0000
20.000
40.000
50.000
60.000
70.000
80.000
100.00
TIME (SEC)

FIGURE 7B

Fluid quality, non-UPI

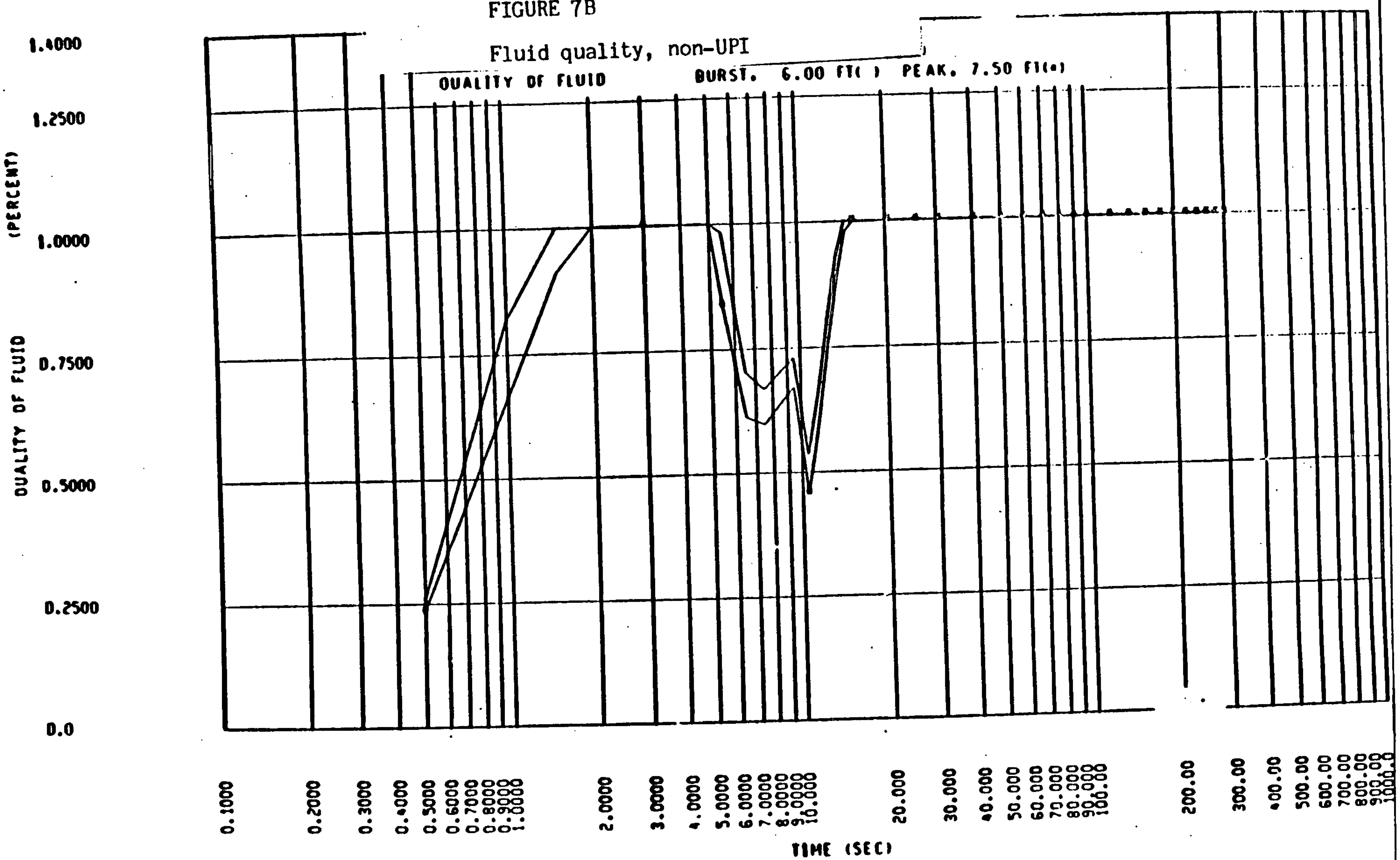


FIGURE 8A

Mass velocity, UPI

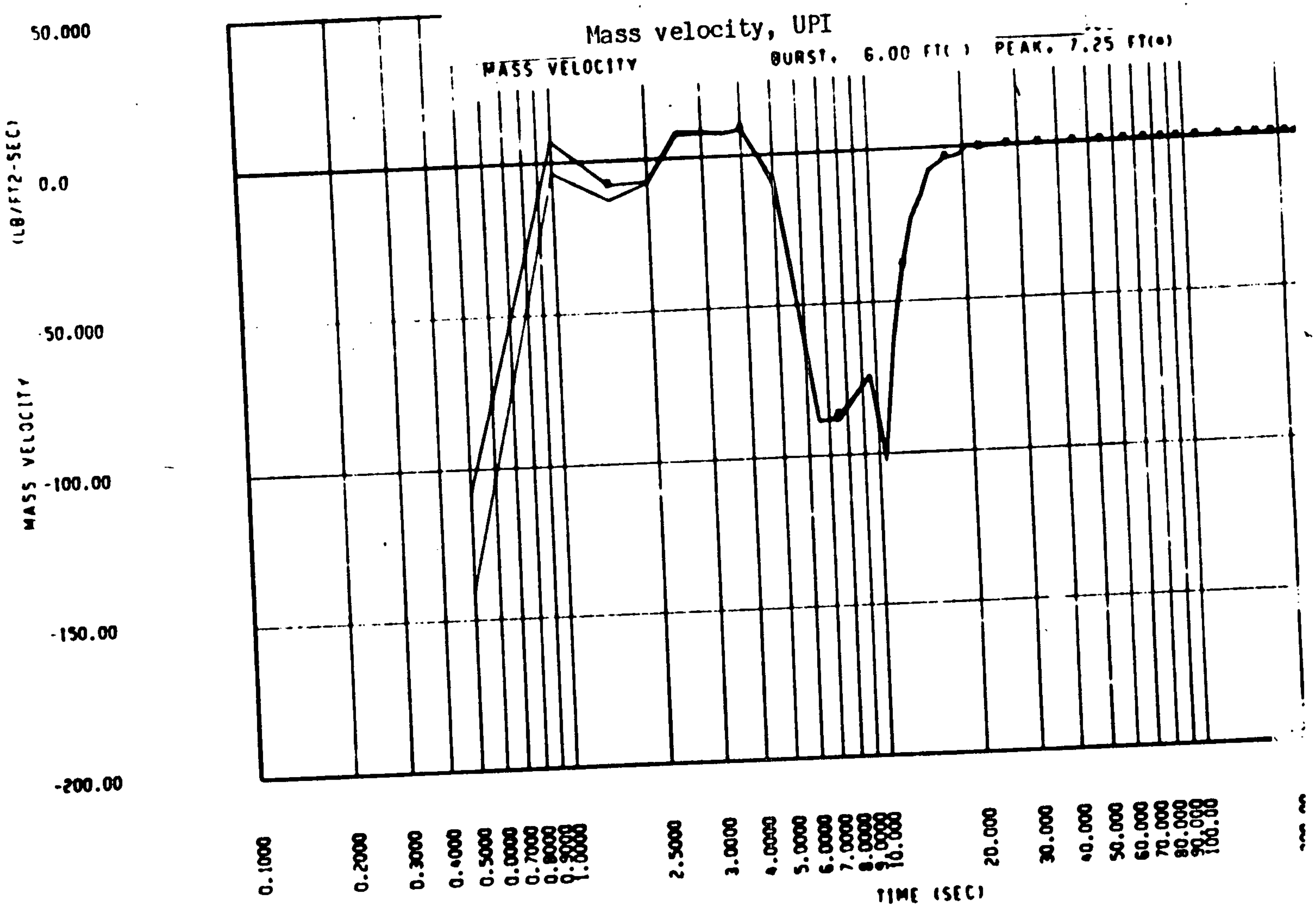


FIGURE 8B

Mass velocity, non-UPI

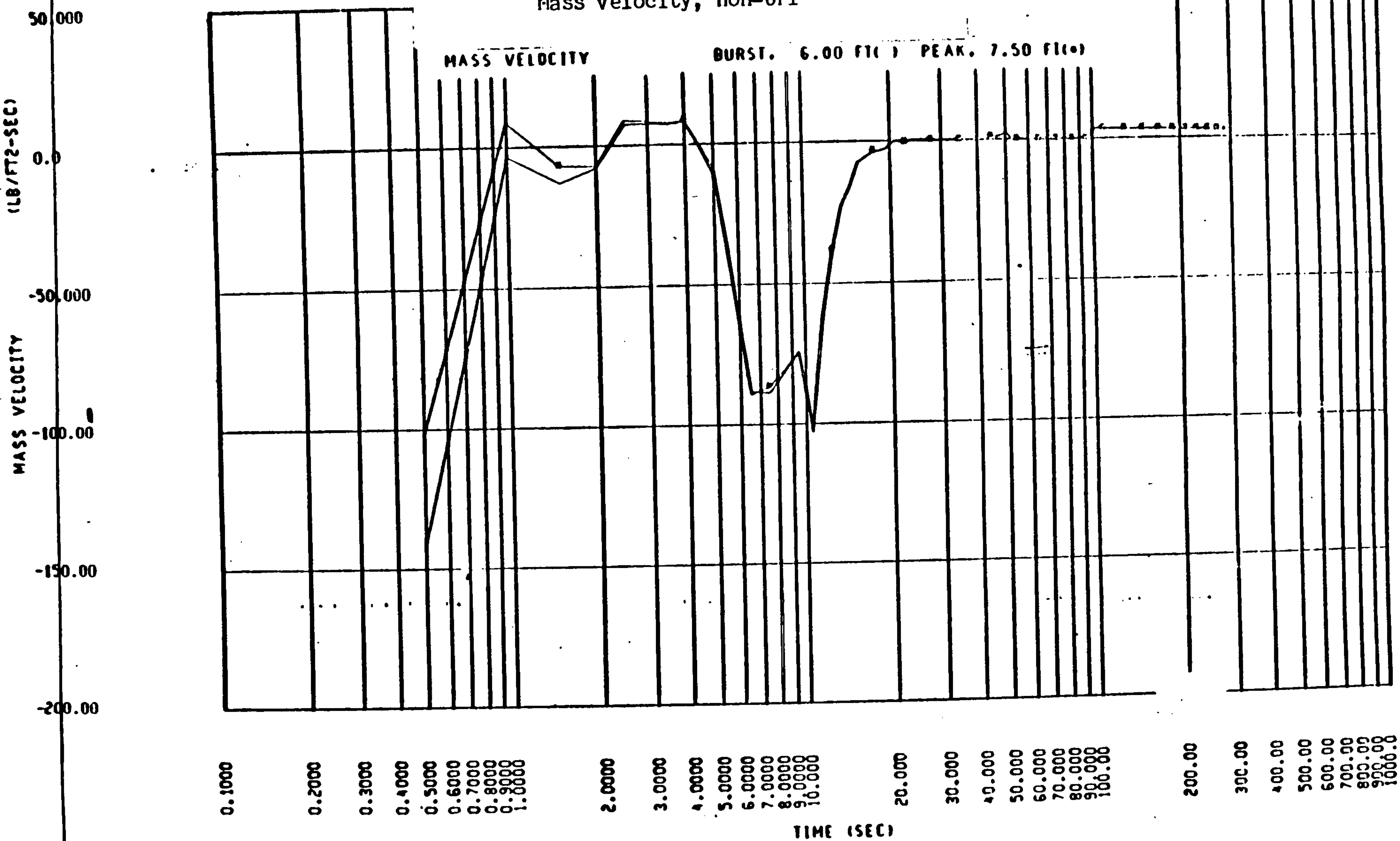


FIGURE 9A

Core and downcomer water levels, UPI

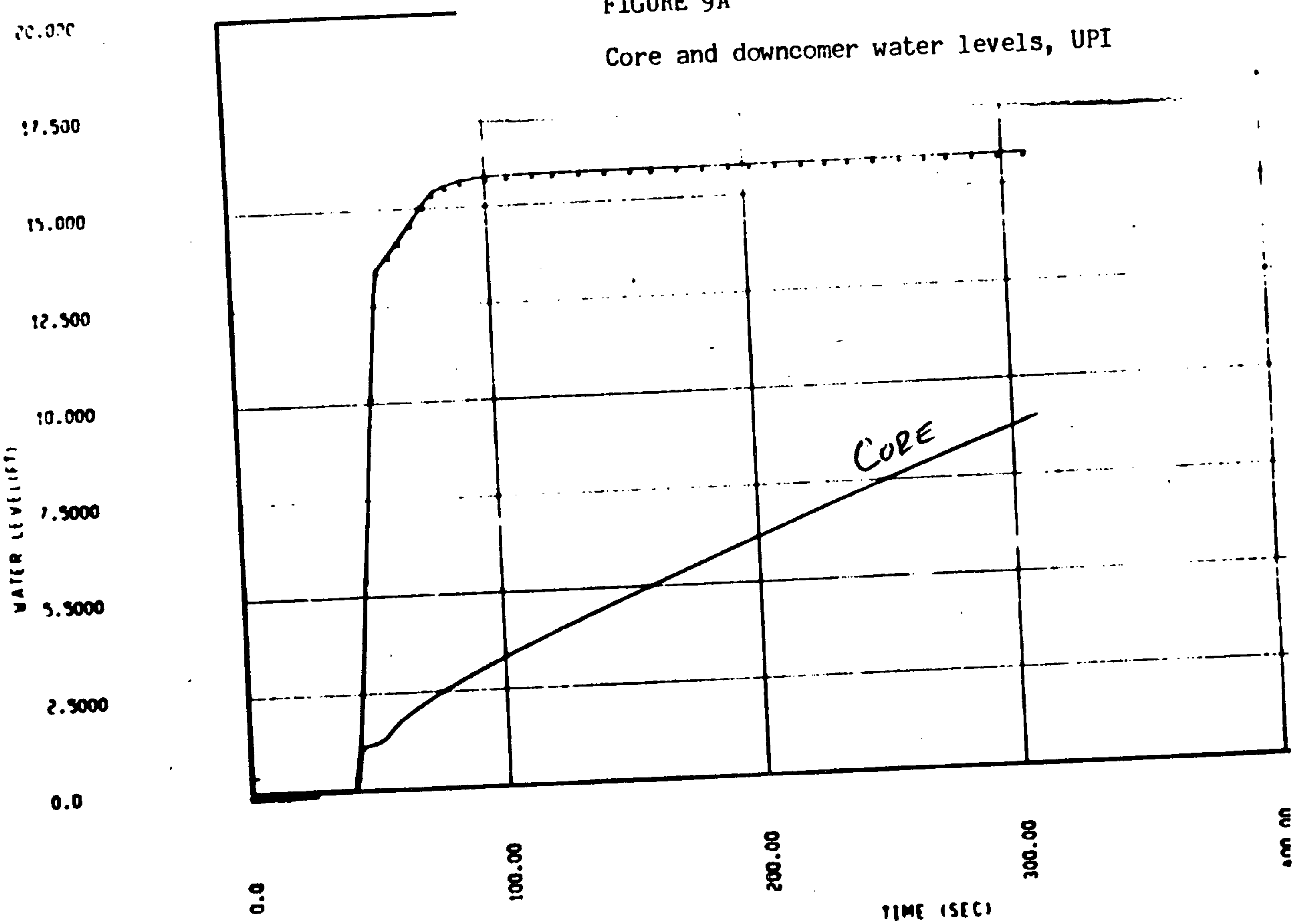


FIGURE 9B

Core and downcomer water levels, non-UPI

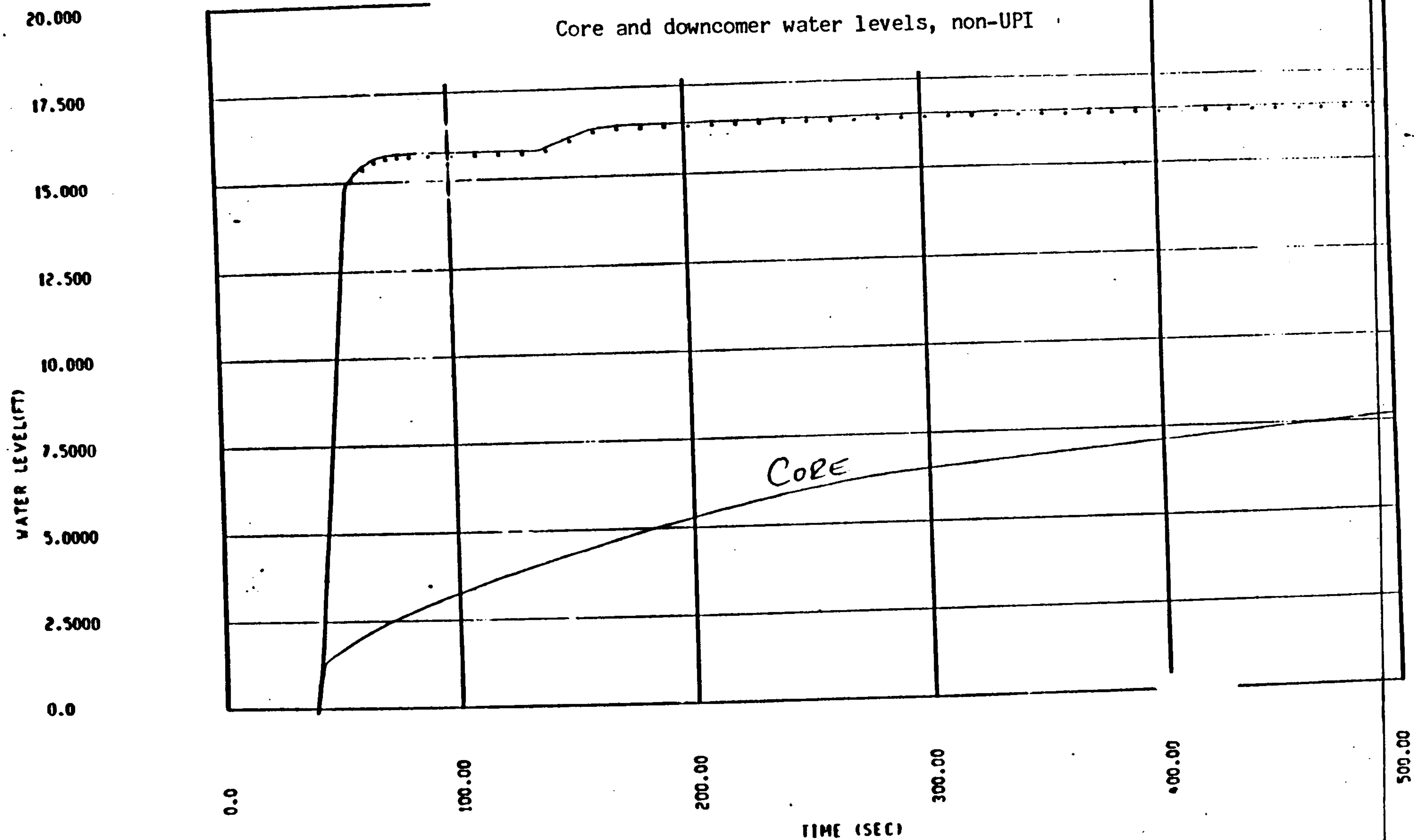


FIGURE 10A

Flooding rate, UPI

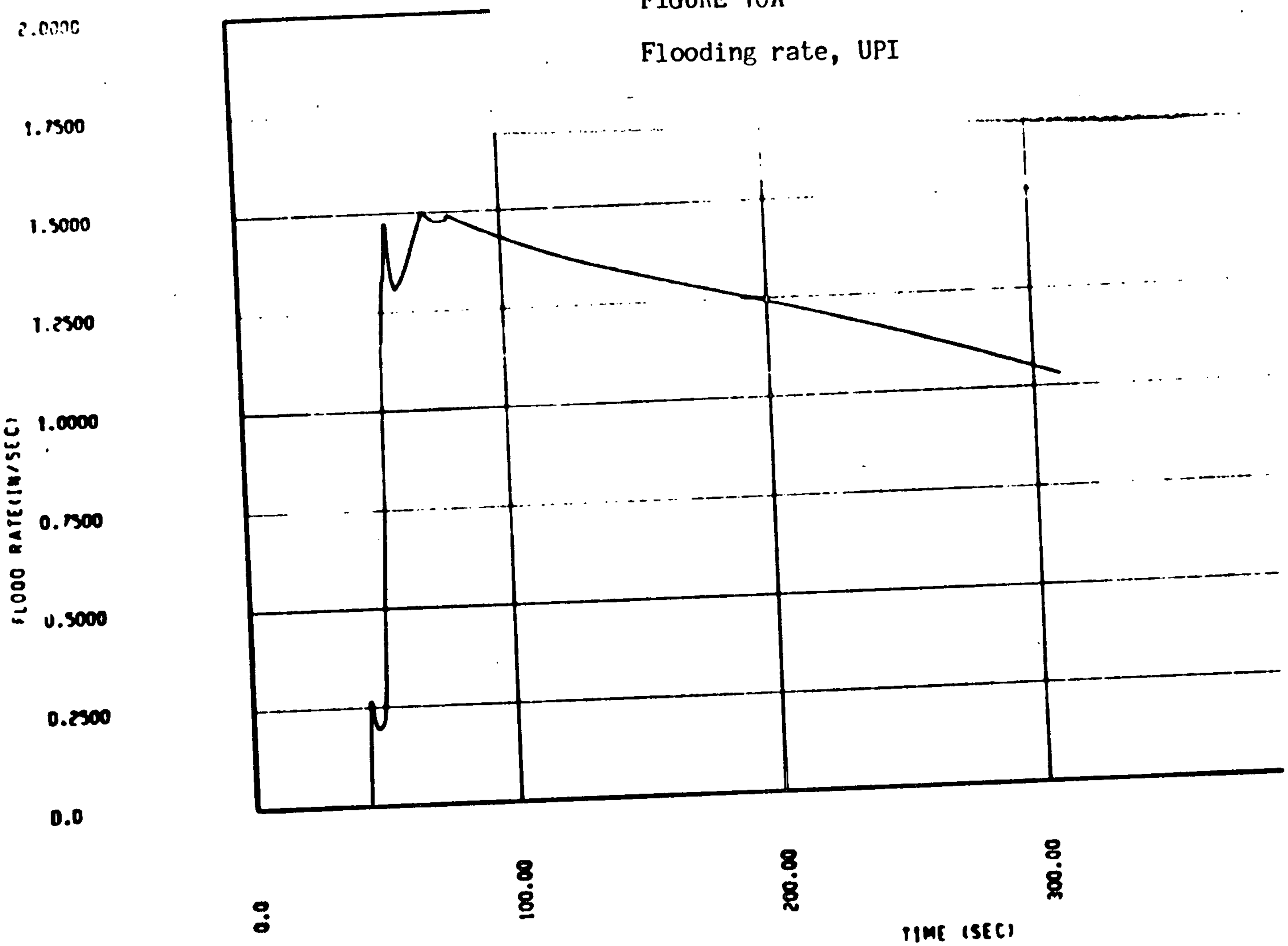


FIGURE 10B

Flooding rate, non-UPI

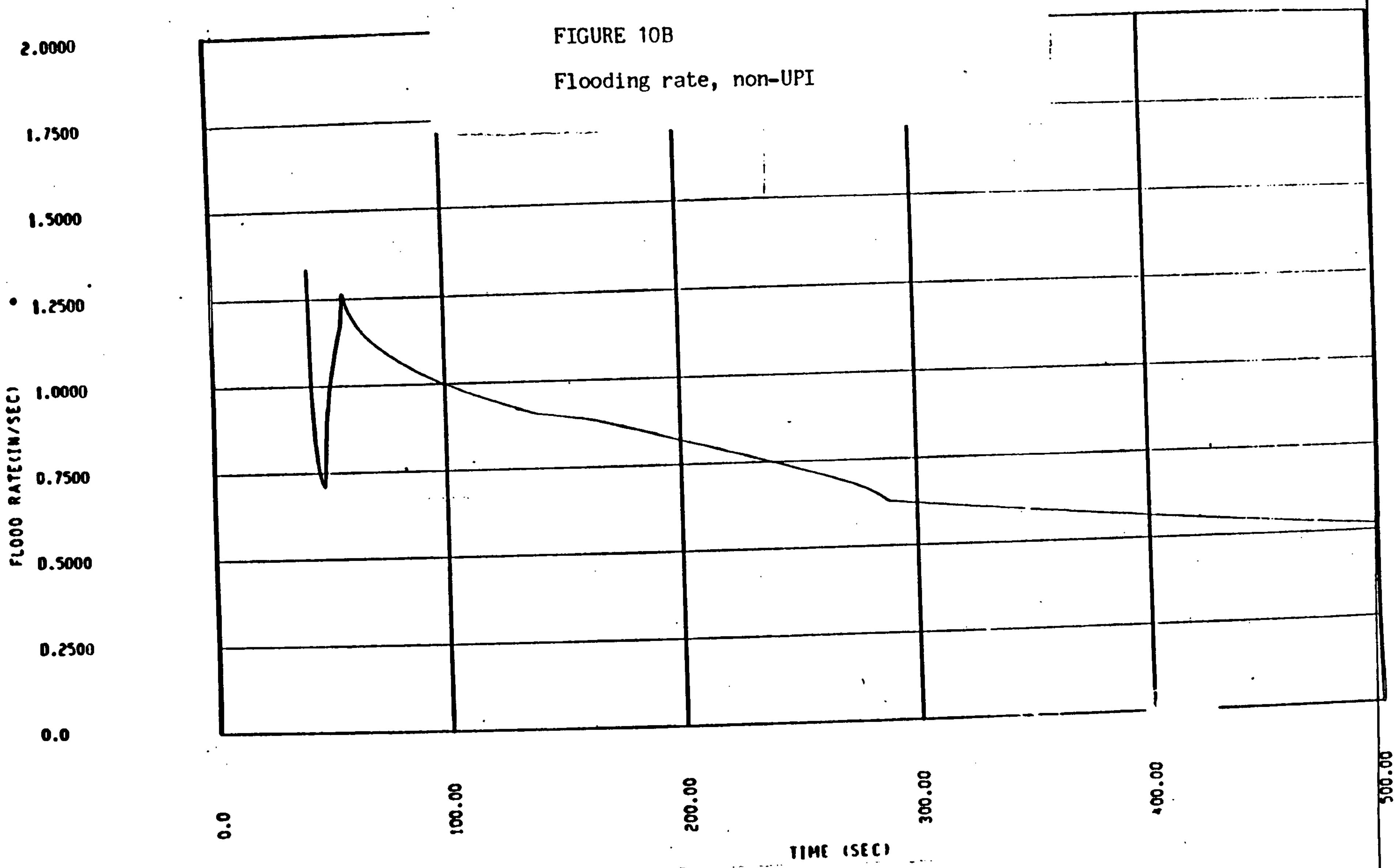


FIGURE 11A

Peak clad temperature, UPI

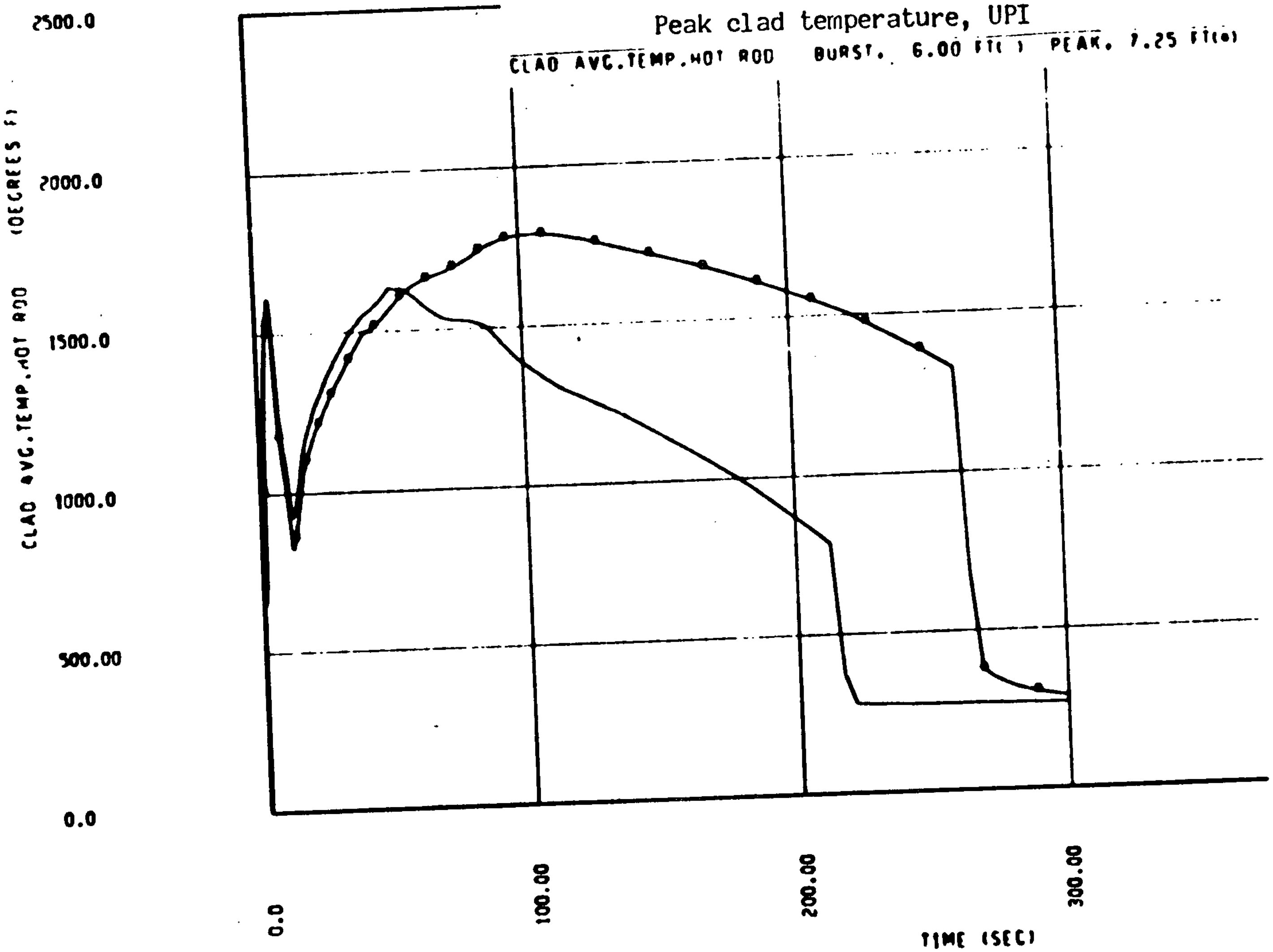


FIGURE 11B

Peak clad temperature, non-UPI

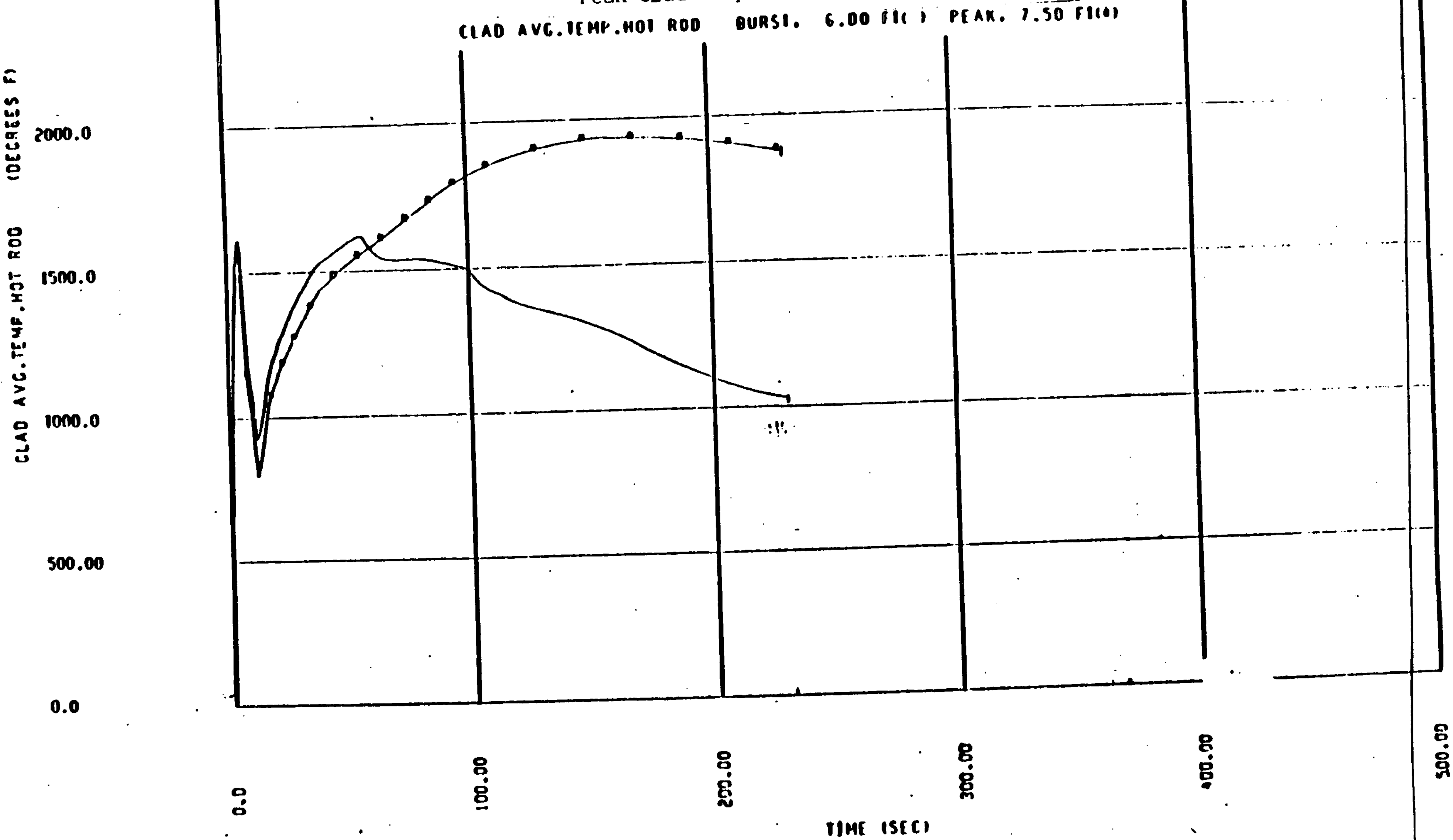


FIGURE 12A

Heat transfer coefficient, UPI

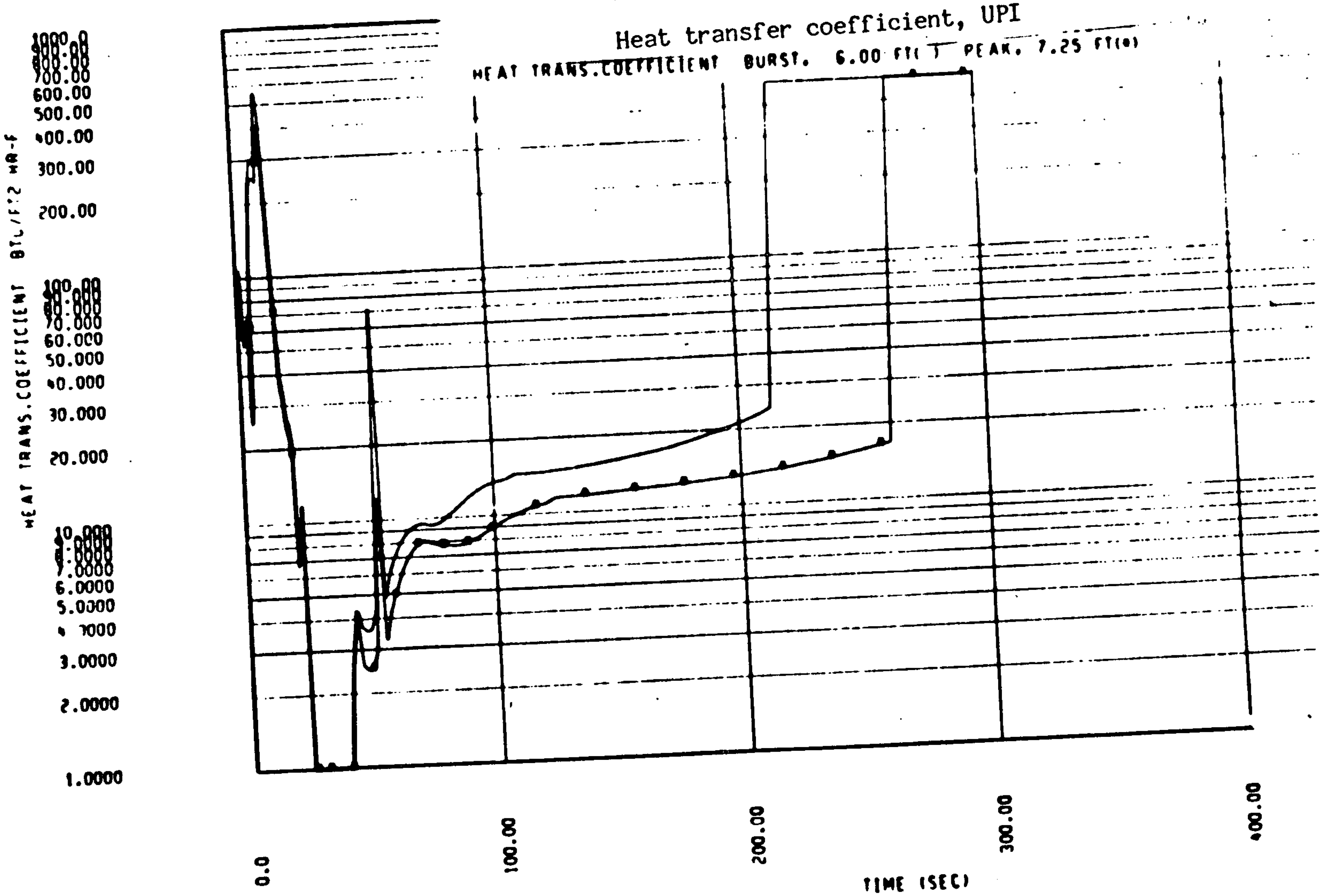


FIGURE 12B

Heat transfer coefficient, non-UPI

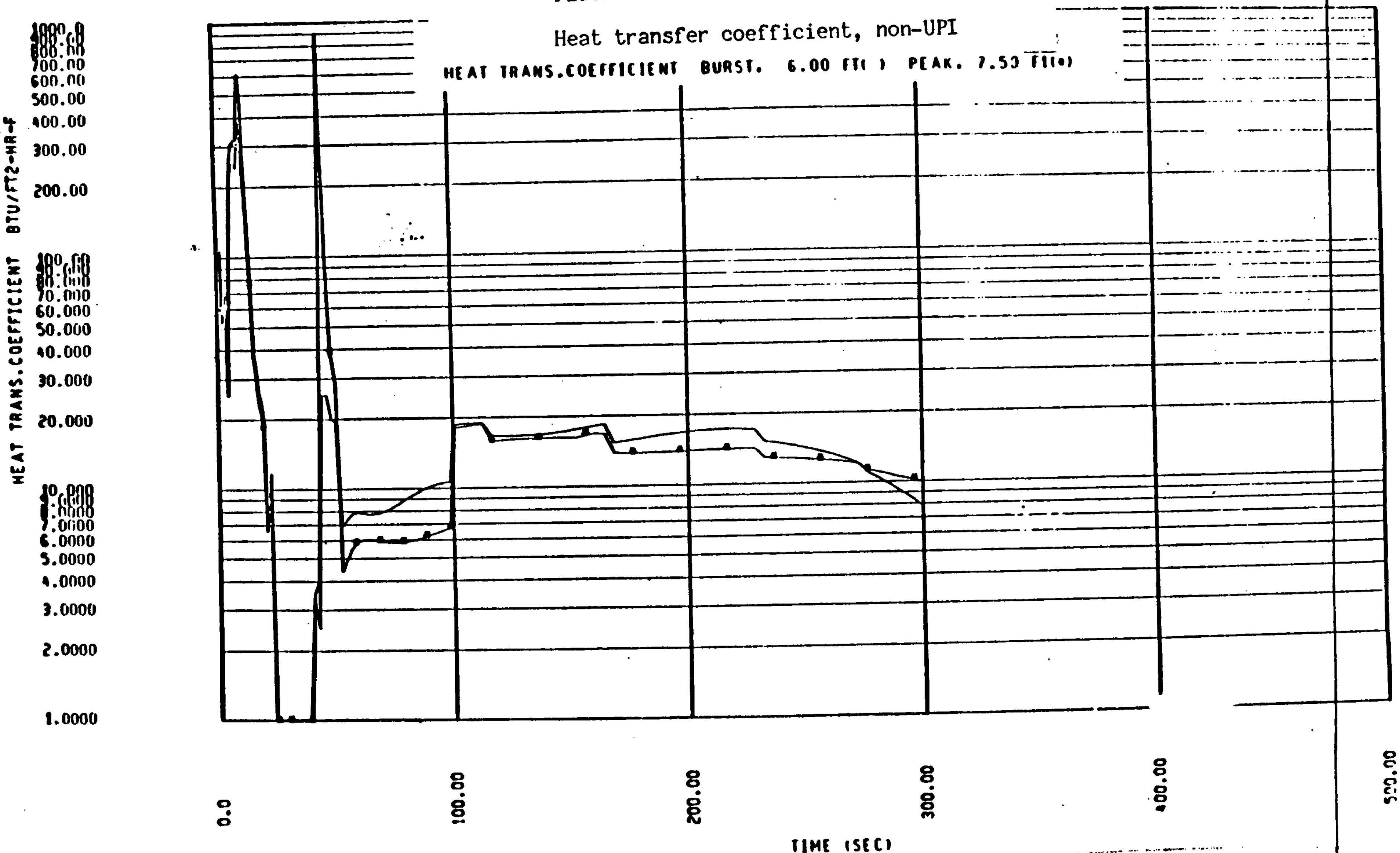


FIGURE 13A
Fluid temperature, 50%

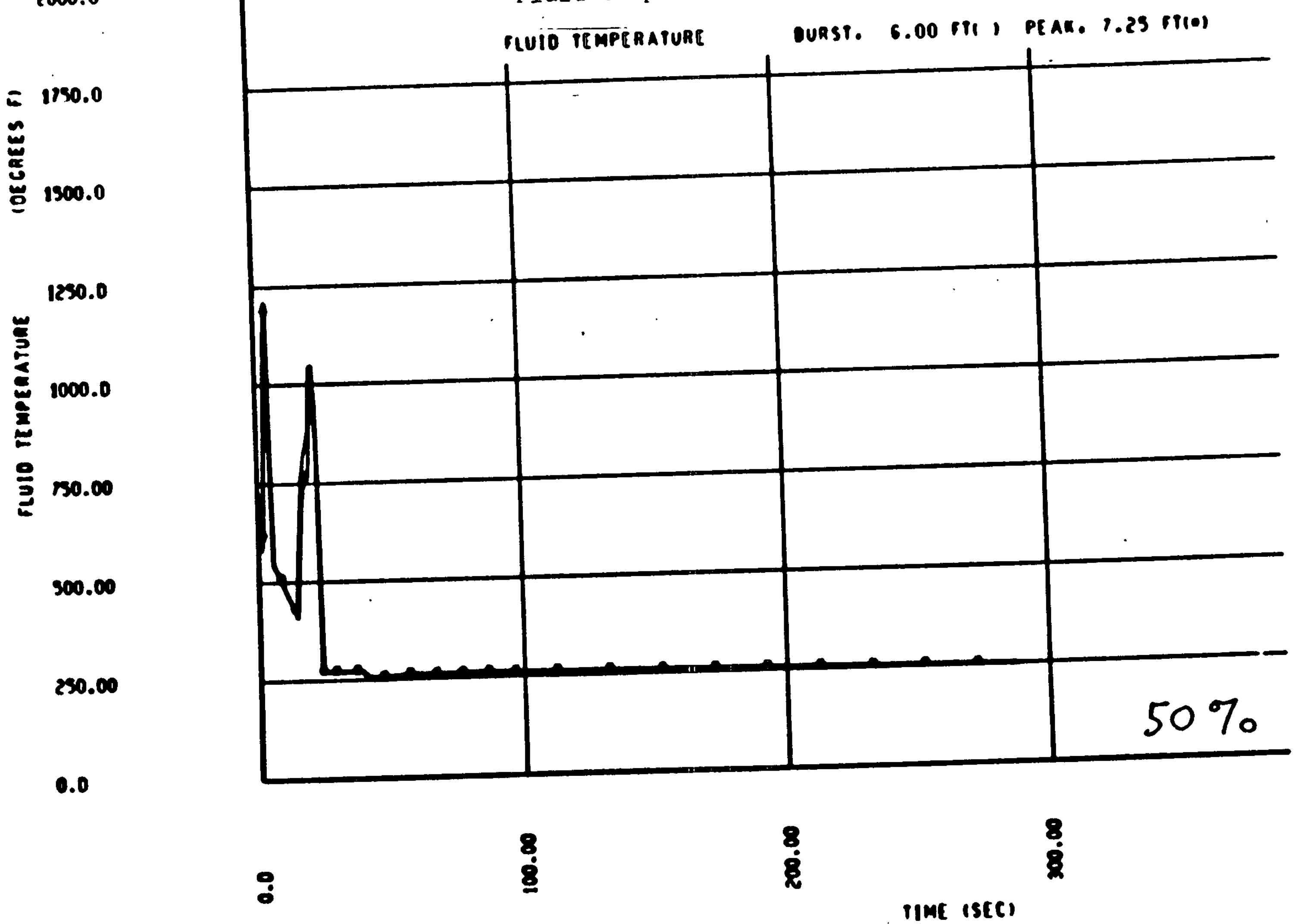


FIGURE 13B
Fluid temperature, 70%

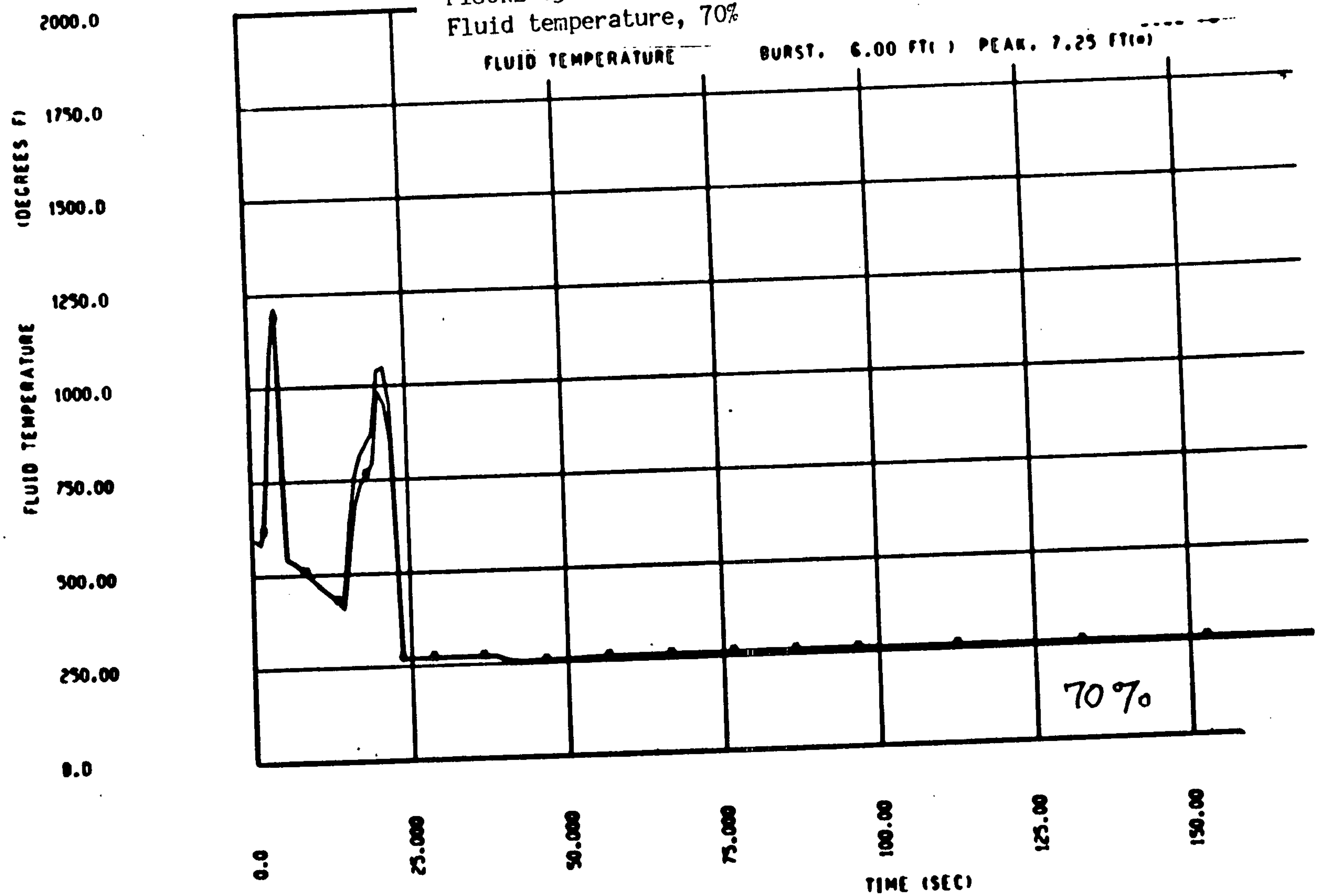


FIGURE 13C
Fluid temperature, 100%

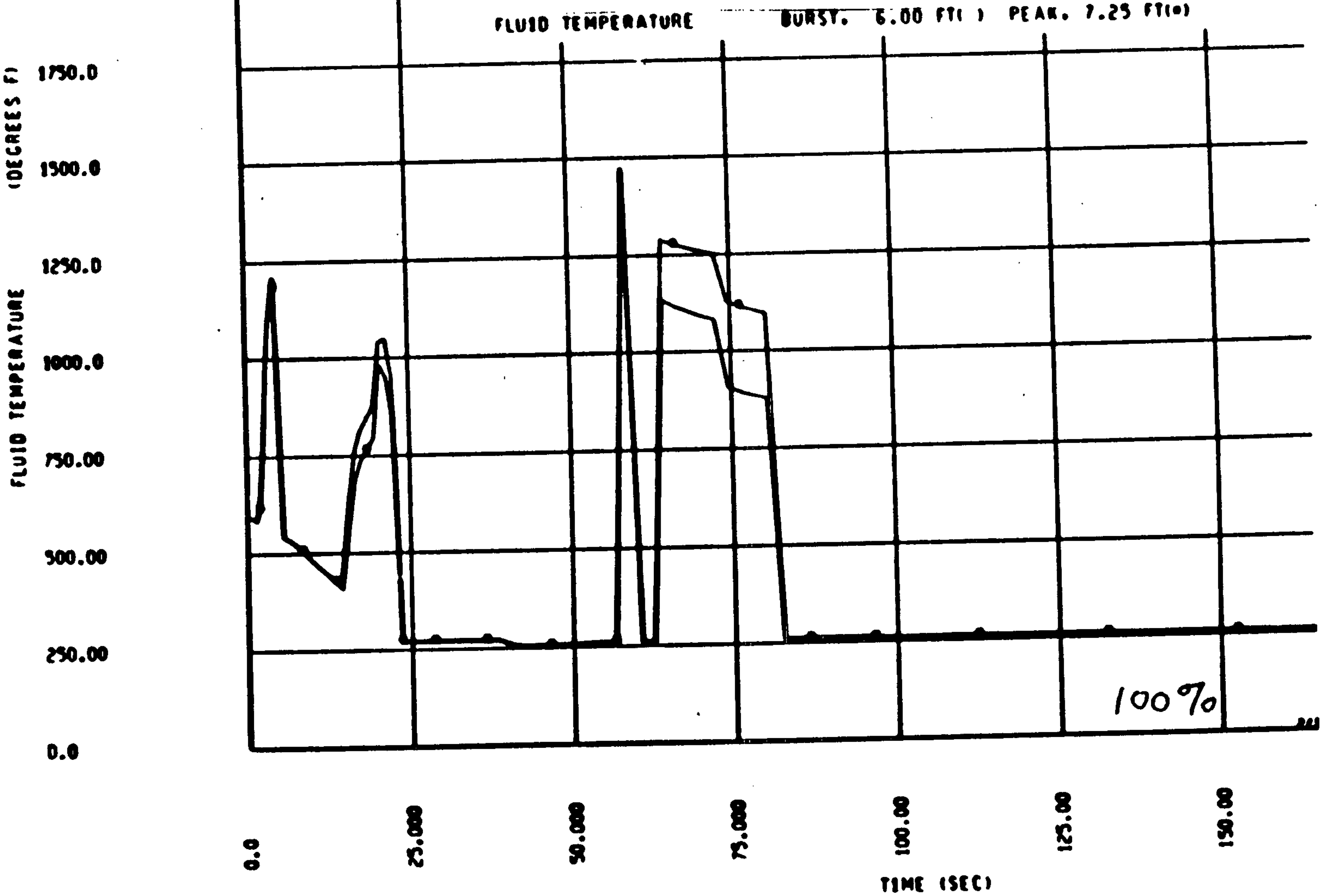


FIGURE 14A
Fluid quality, 50%

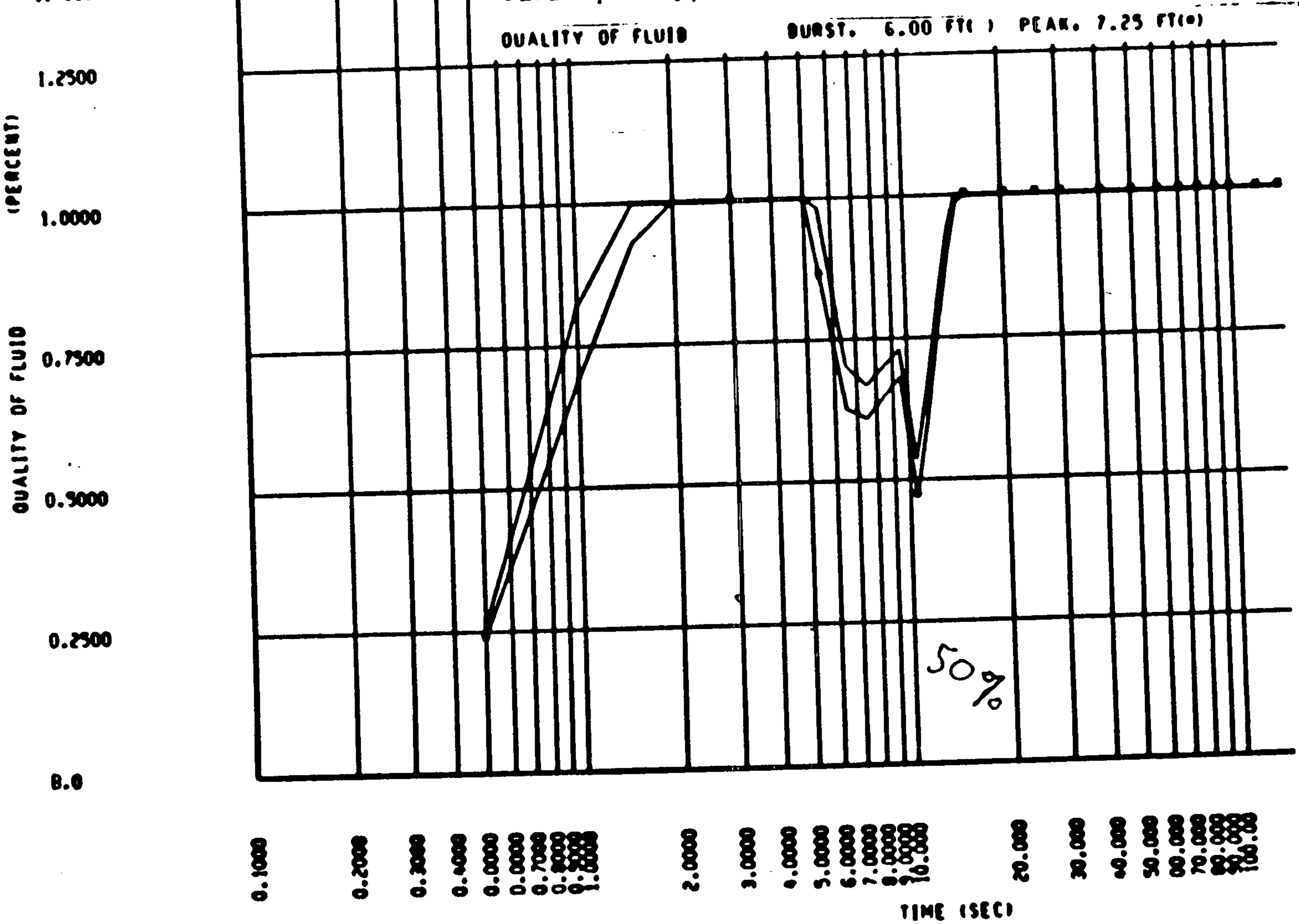


FIGURE 14B
Fluid quality, 70%

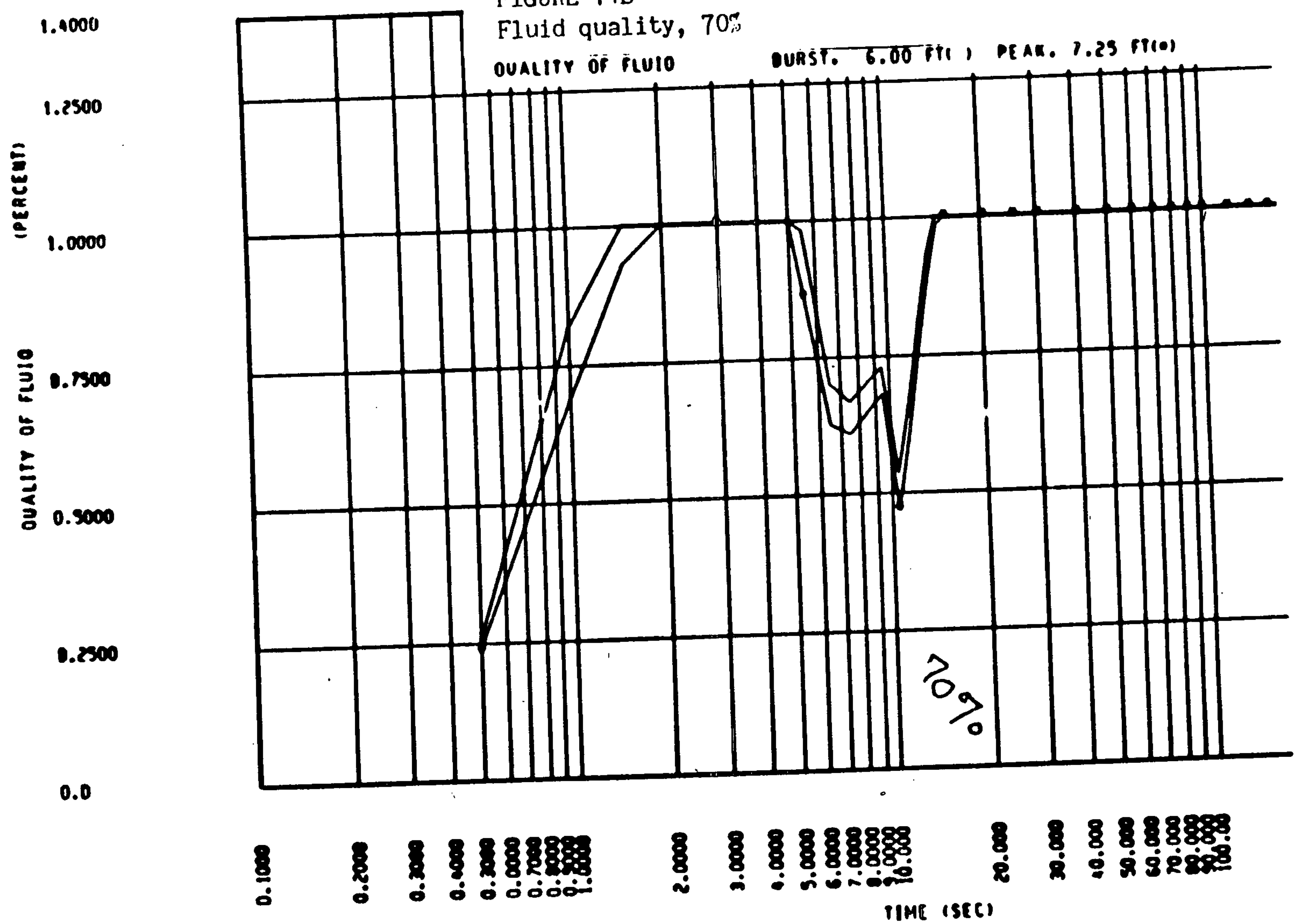


FIGURE 14C
Fluid quality, 100%

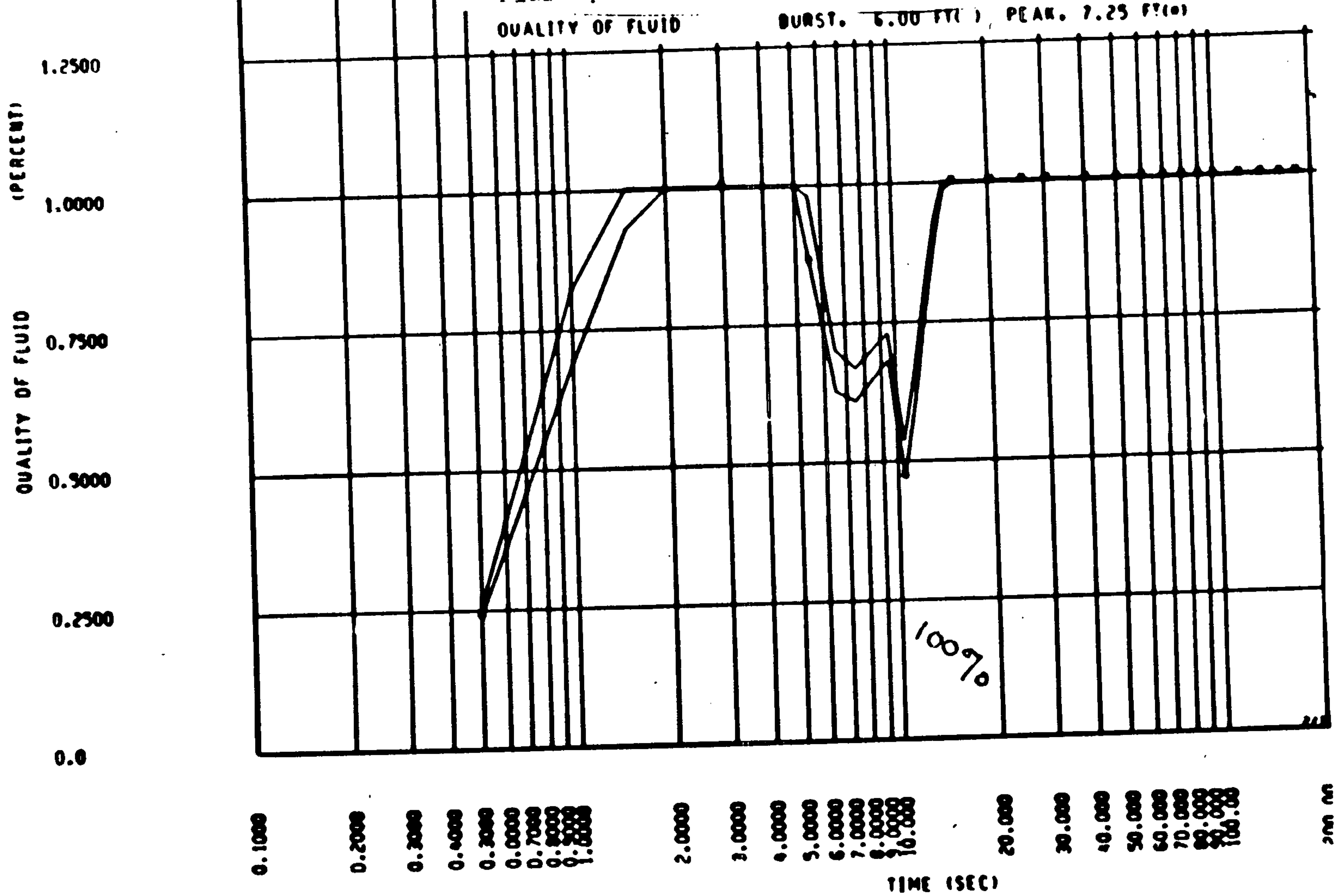


FIGURE 15A
Mass velocity, 50%

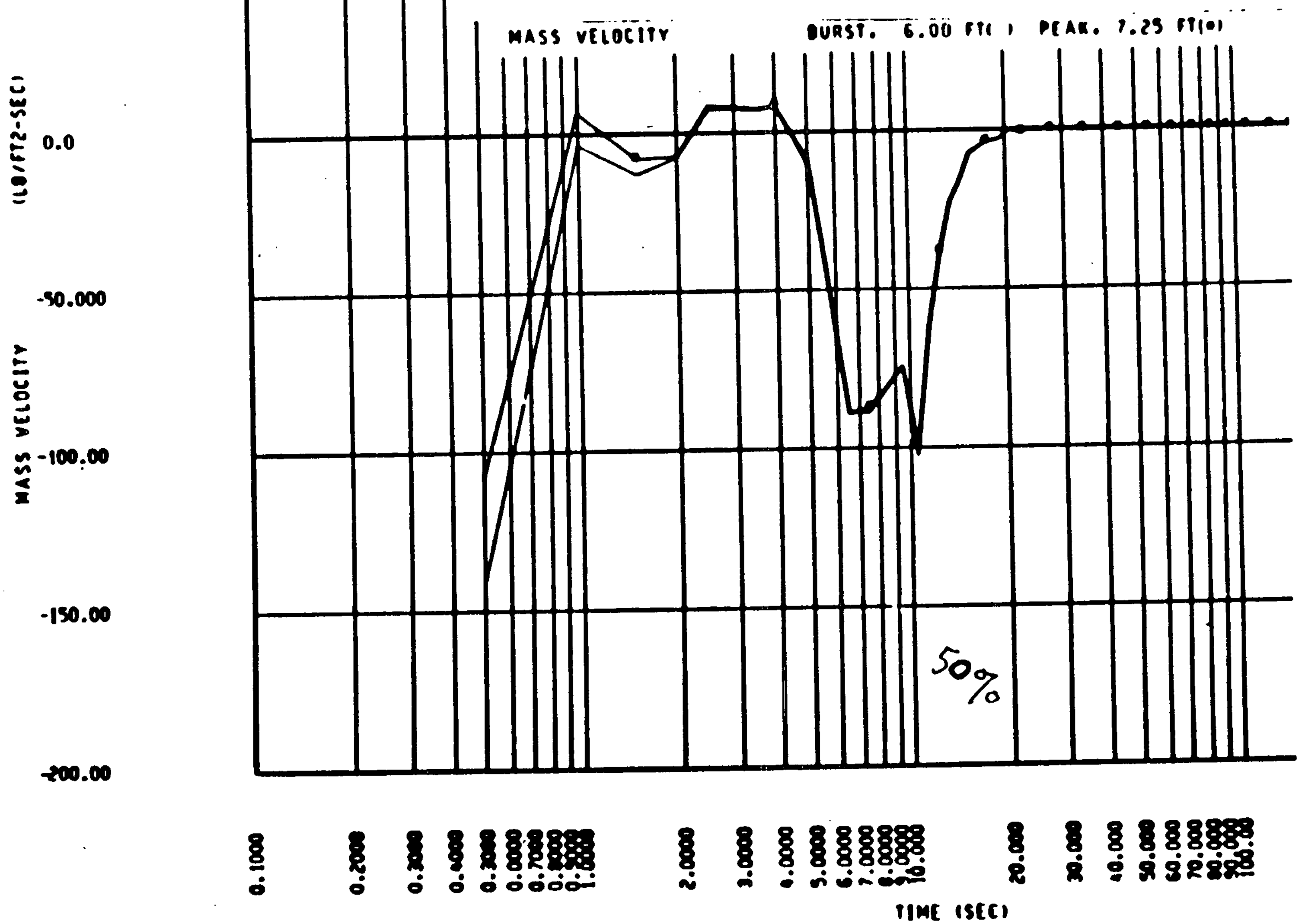


FIGURE 15B
Mass velocity, 70%

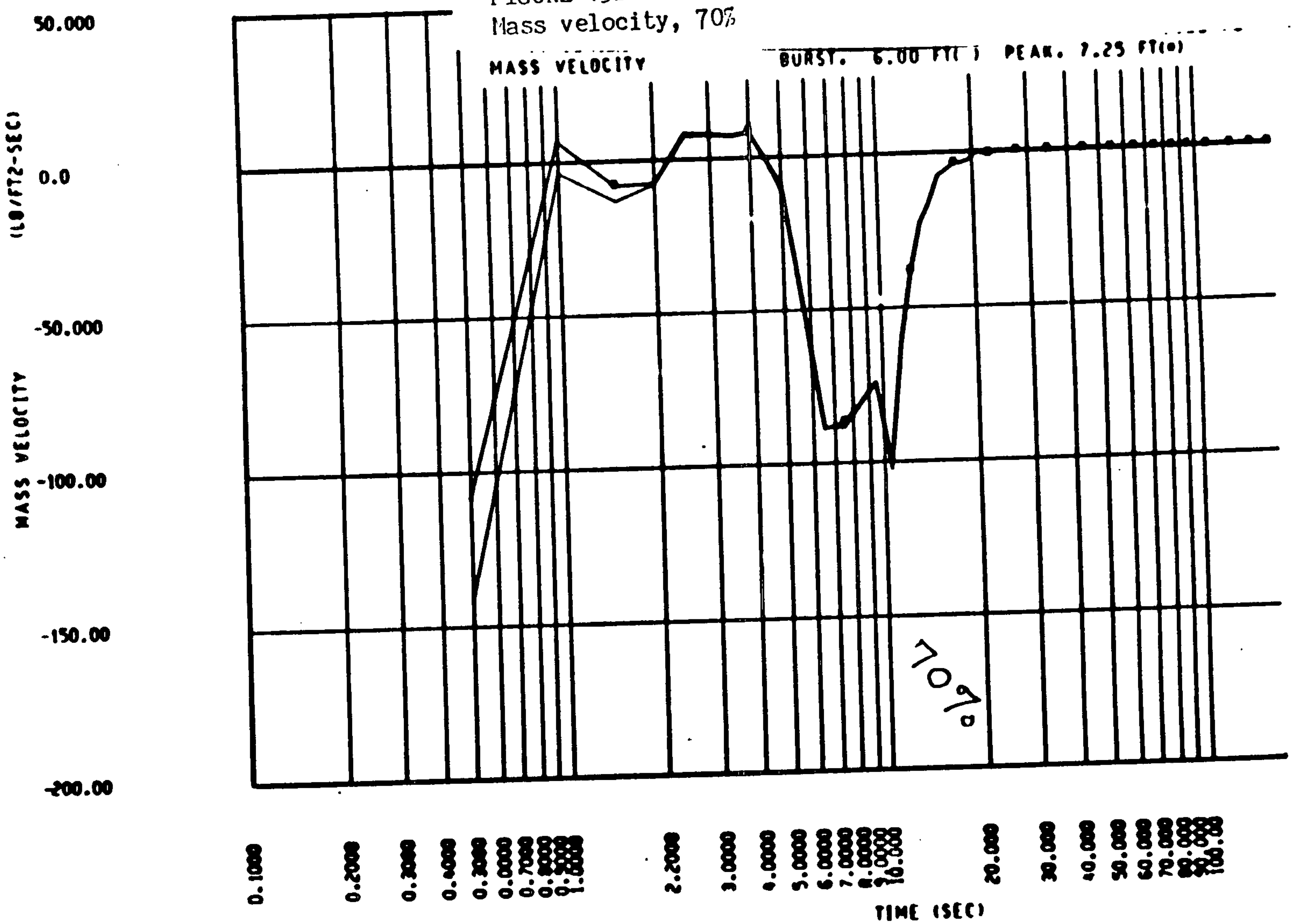


FIGURE 15C
Mass velocity, 100%

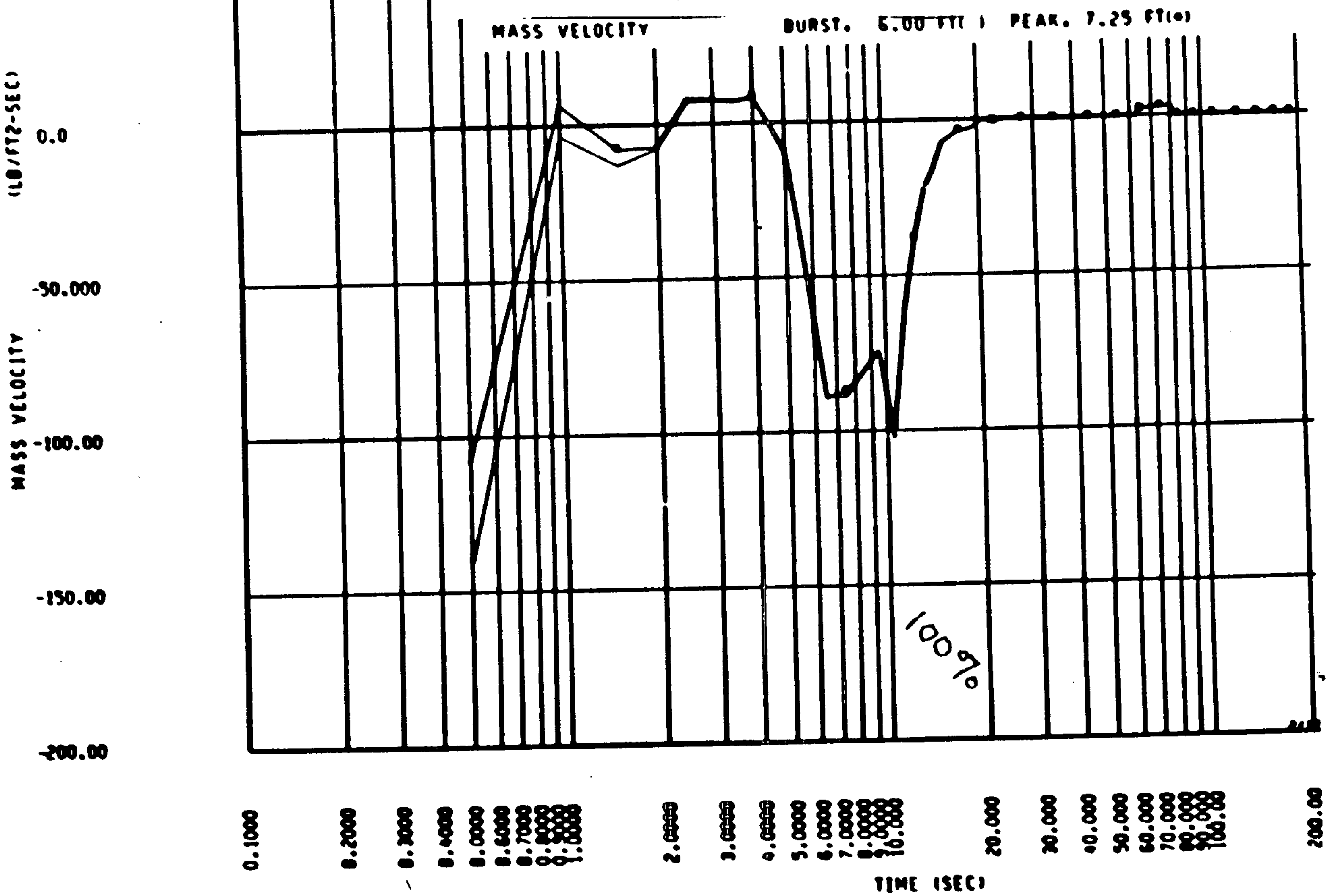


FIGURE 16A
Core/downcomer water levels, 50%

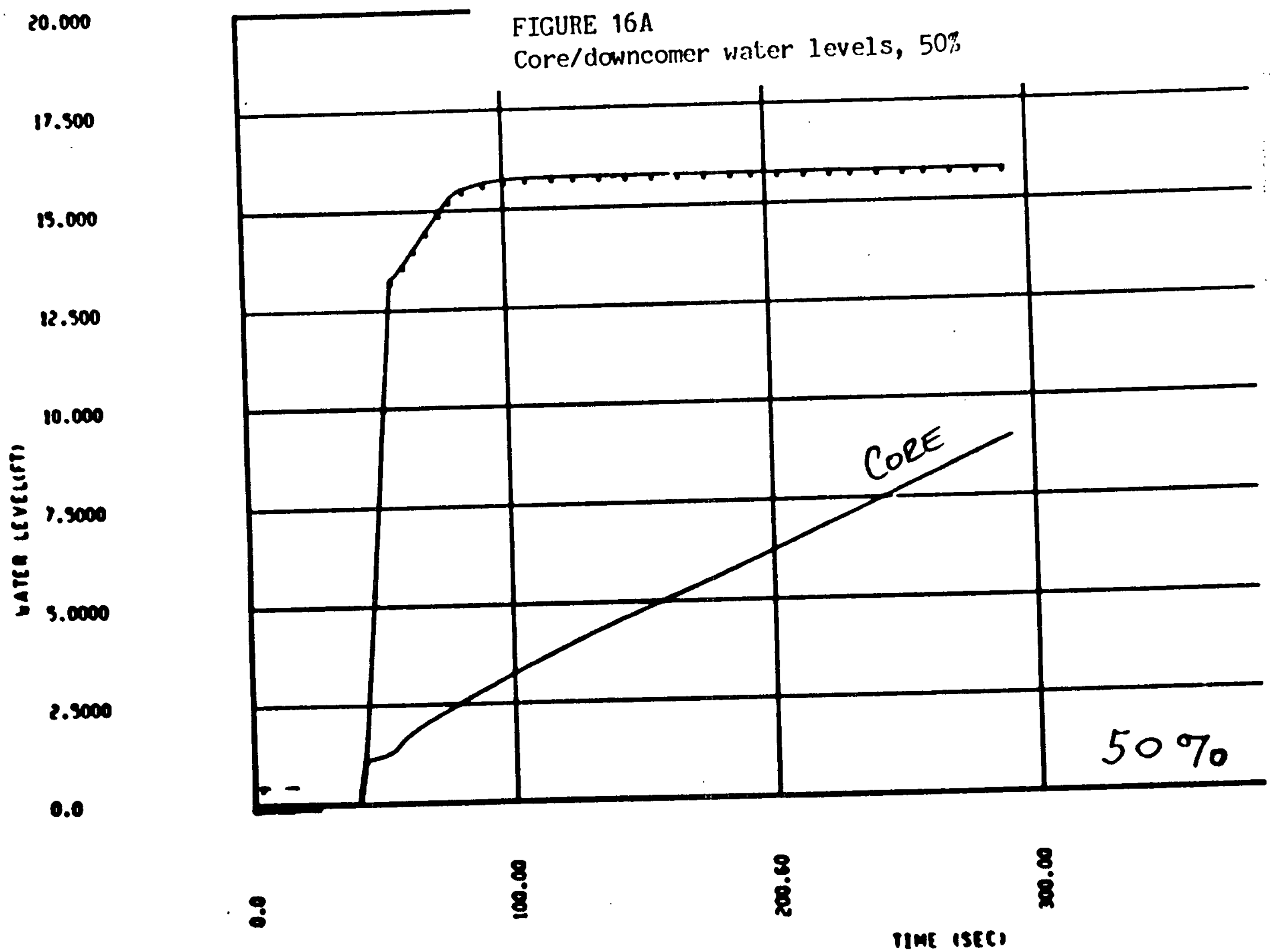


FIGURE 16B
Core/downcomer water levels, 70%

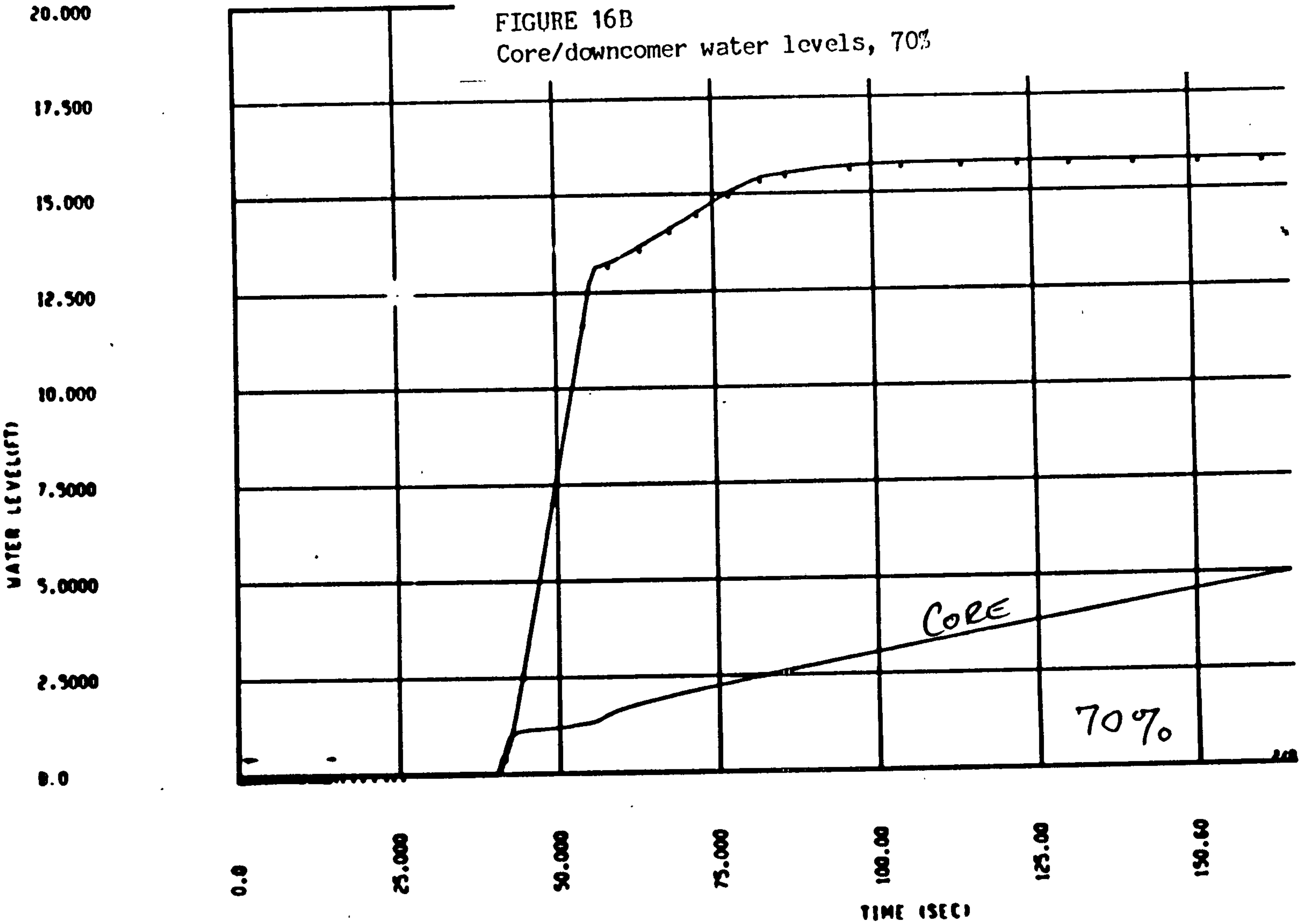


FIGURE 16C
Core/downcomer water levels, 100%

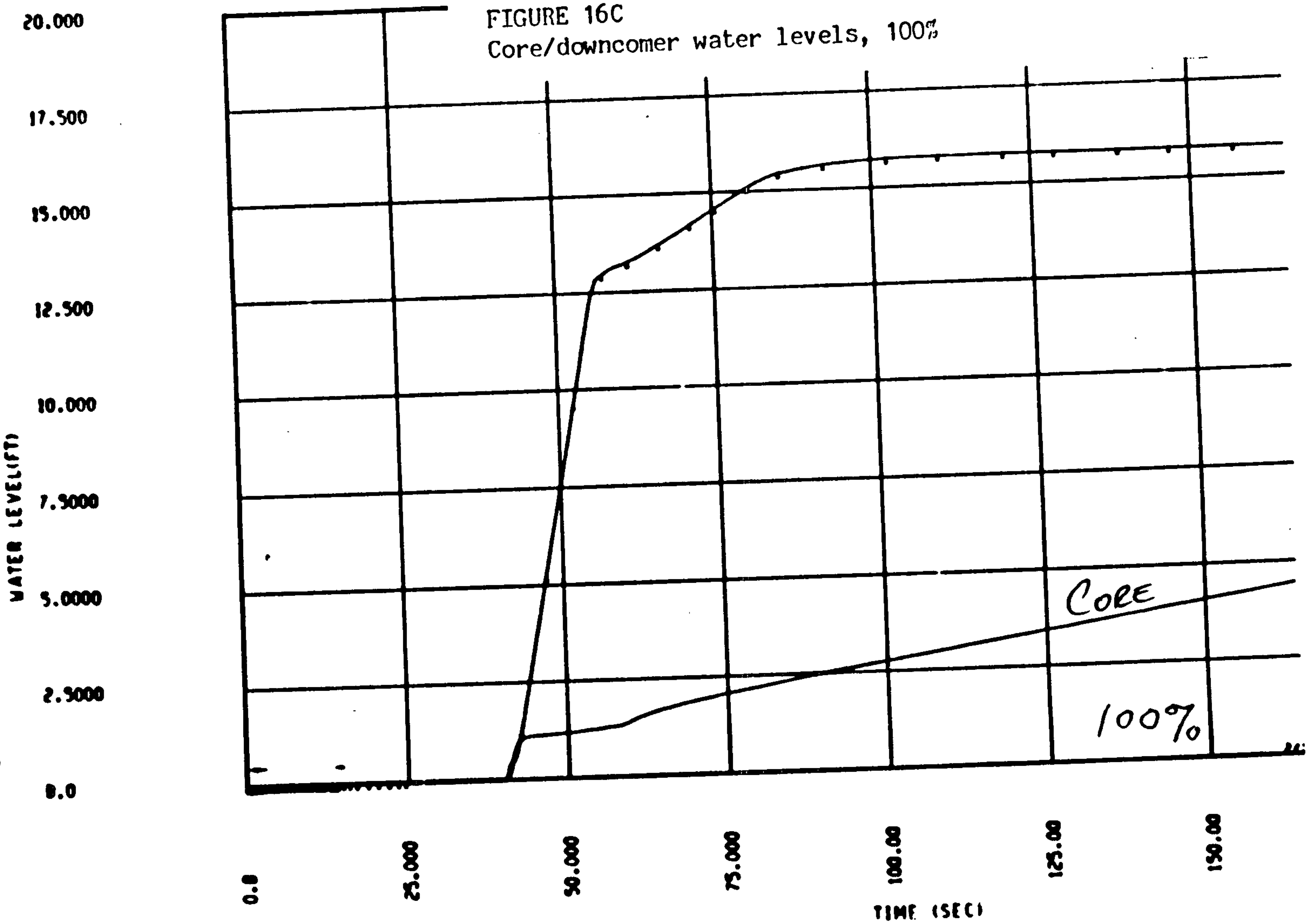
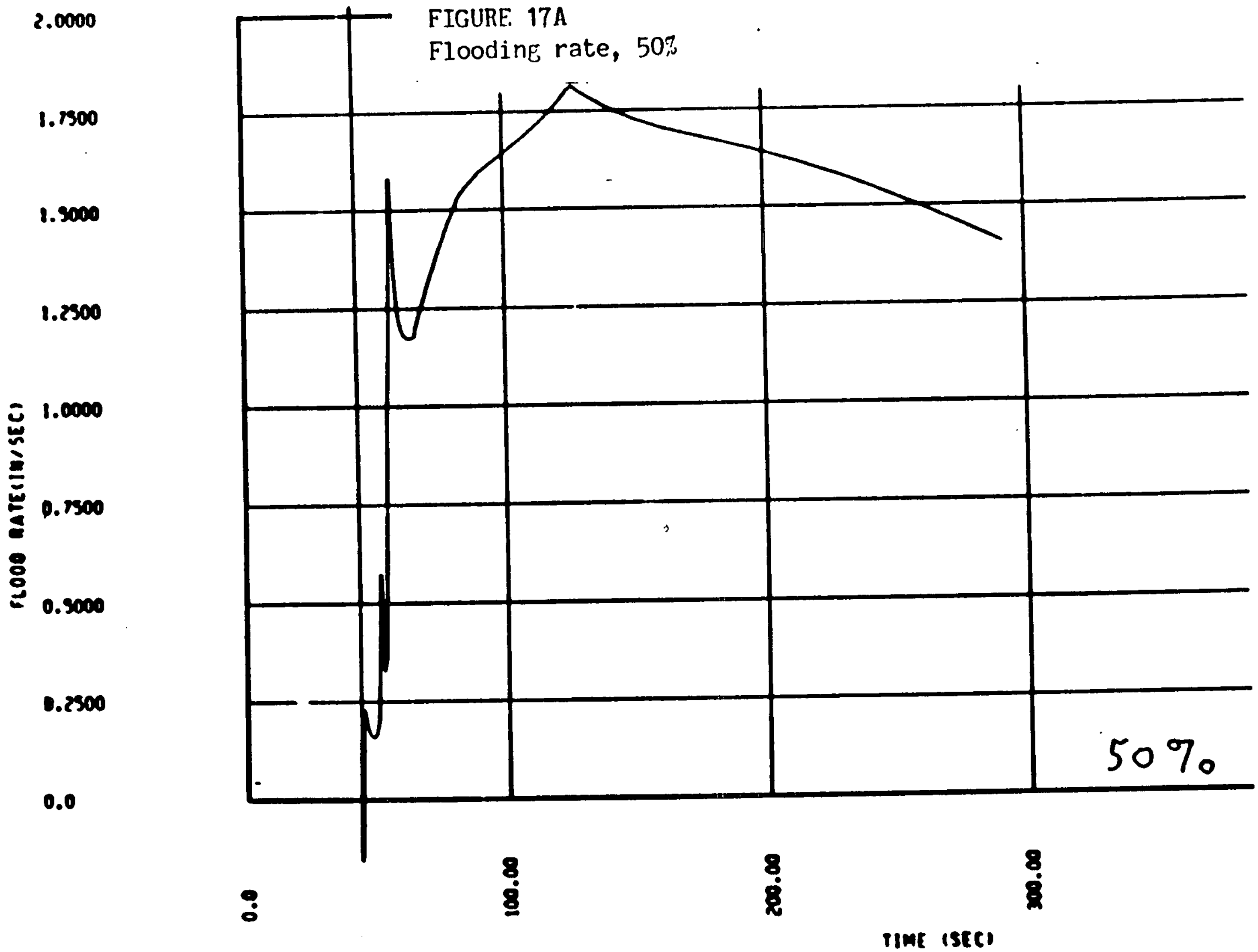


FIGURE 17A
Flooding rate, 50%



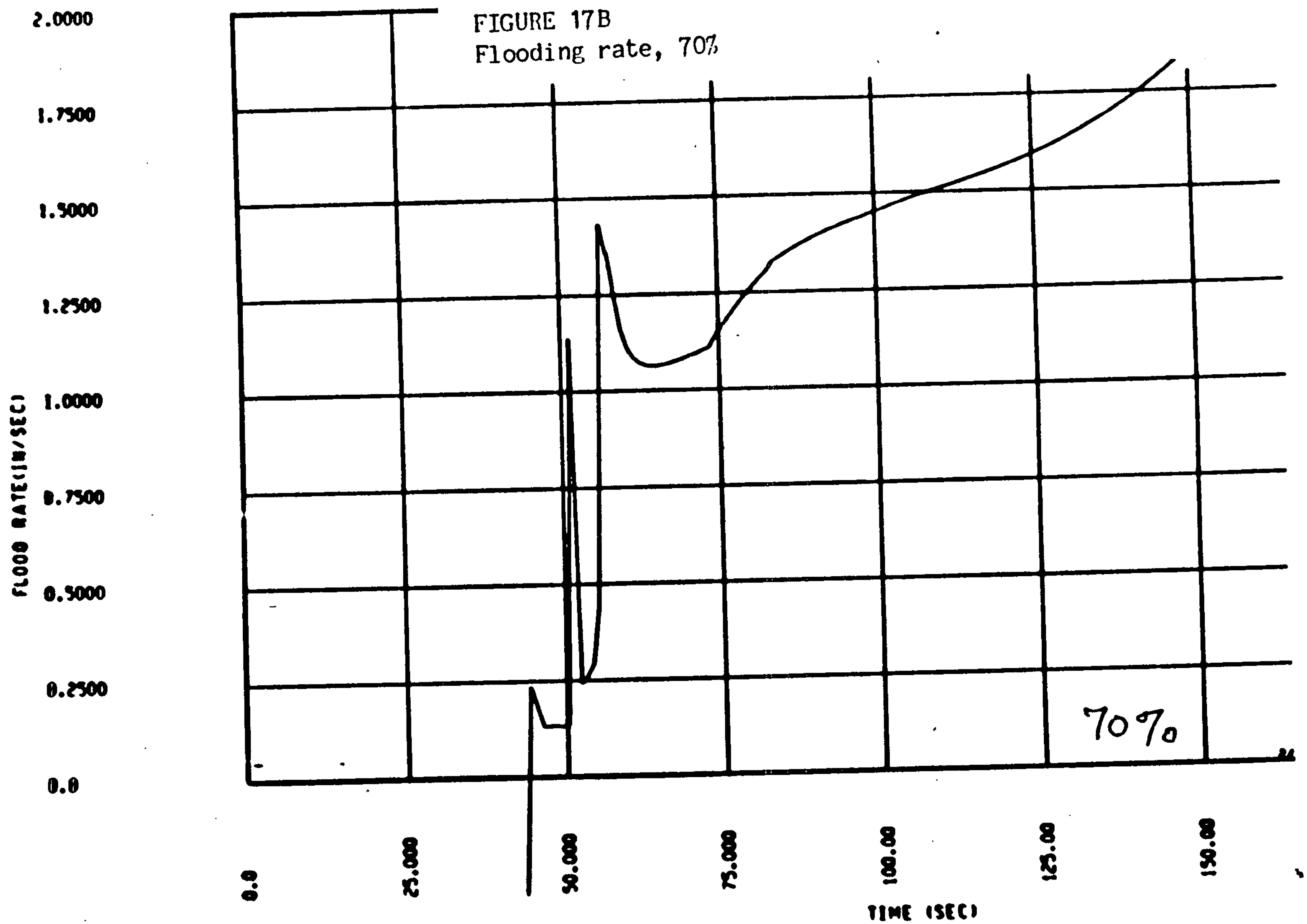


FIGURE 17B
Flooding rate, 70%
2.0000
1.7500
1.5000
1.2500
1.0000
0.7500
0.5000
0.2500
0.0
FLOOD RATE(IN/SEC)
0.0
25.000
50.000
75.000
100.00
125.00
150.00
TIME (SEC)
70%

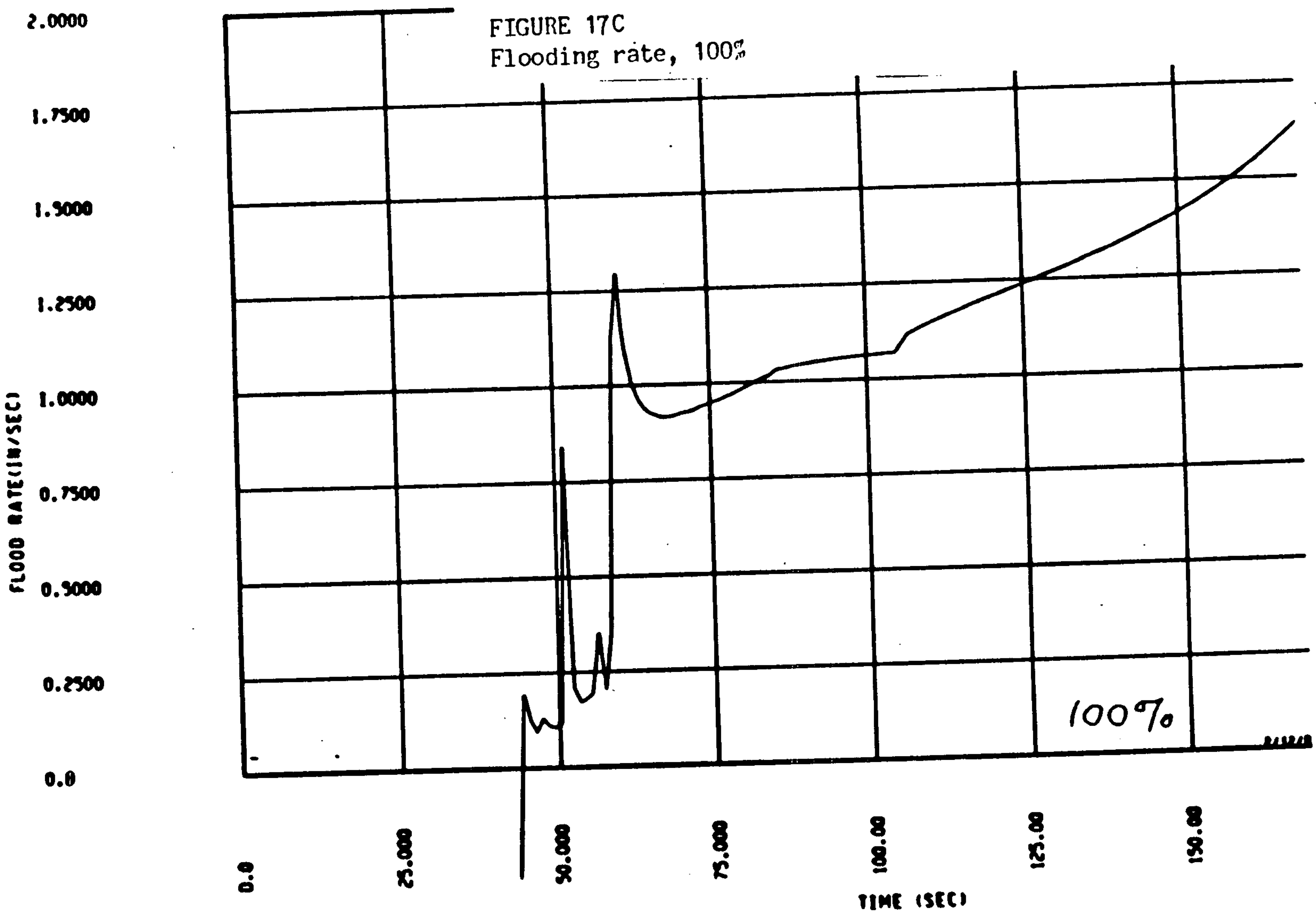


FIGURE 17C
Flooding rate, 100%
2.0000
1.7500
1.5000
1.2500
1.0000
0.7500
0.5000
0.2500
0.0
FLOOD RATE(IN/SEC)
0.0
25.000
50.000
75.000
100.00
125.00
150.00
TIME (SEC)
100%

FIGURE 18A
Peak cladding temperature, 50%

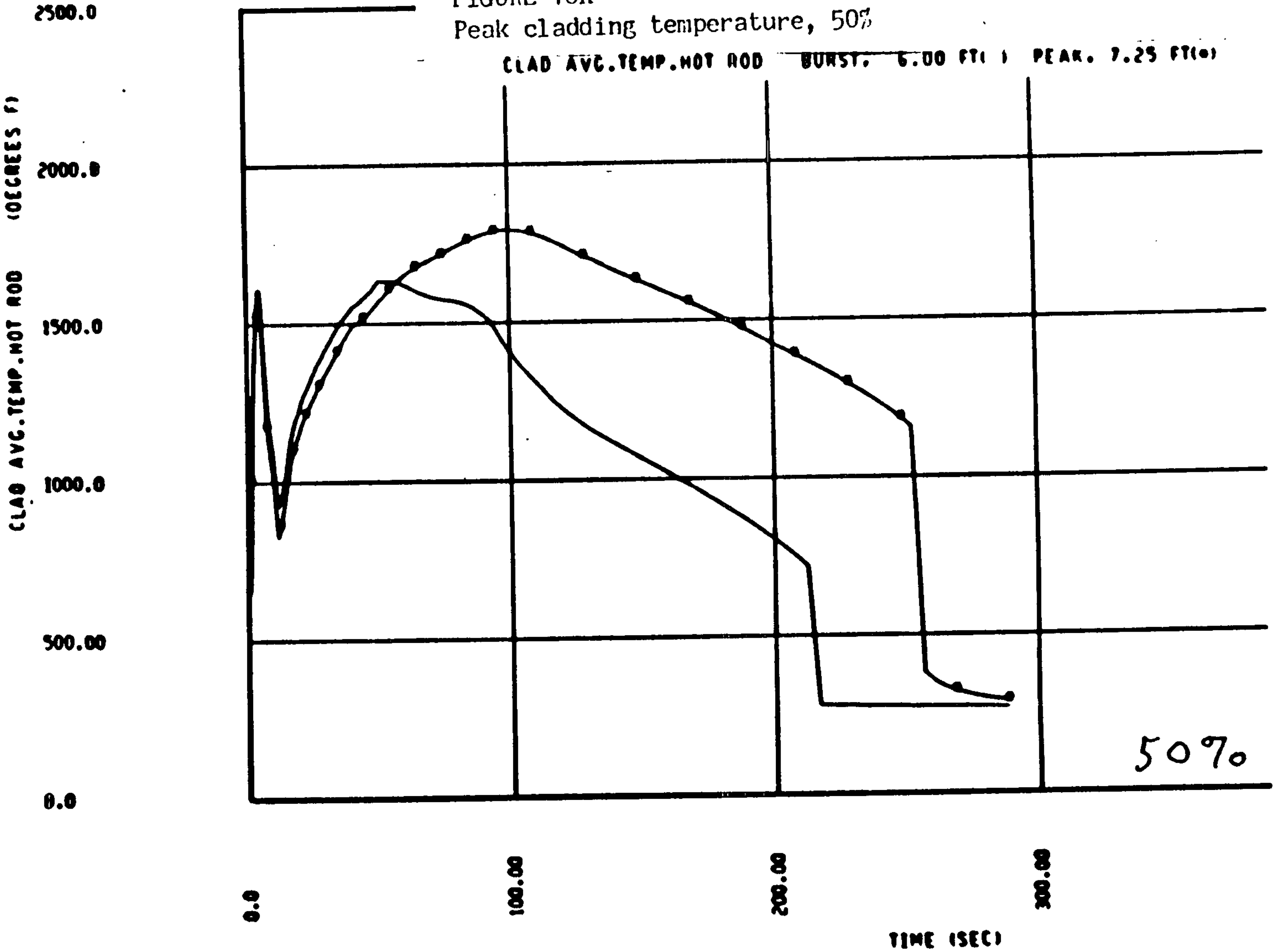


FIGURE 18B
Peak cladding temperature, 70%

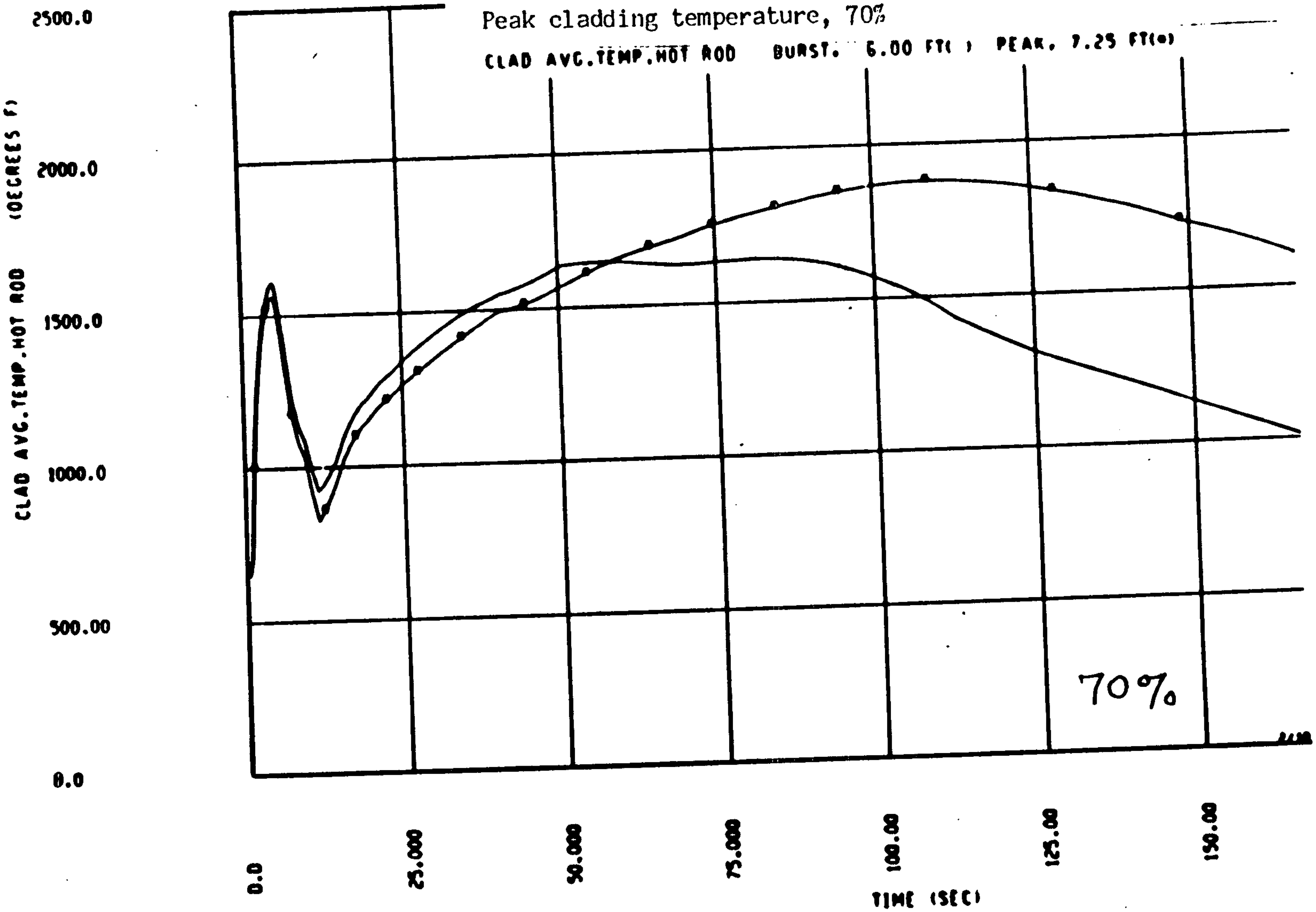


FIGURE 18C
Peak cladding temperature, 100%

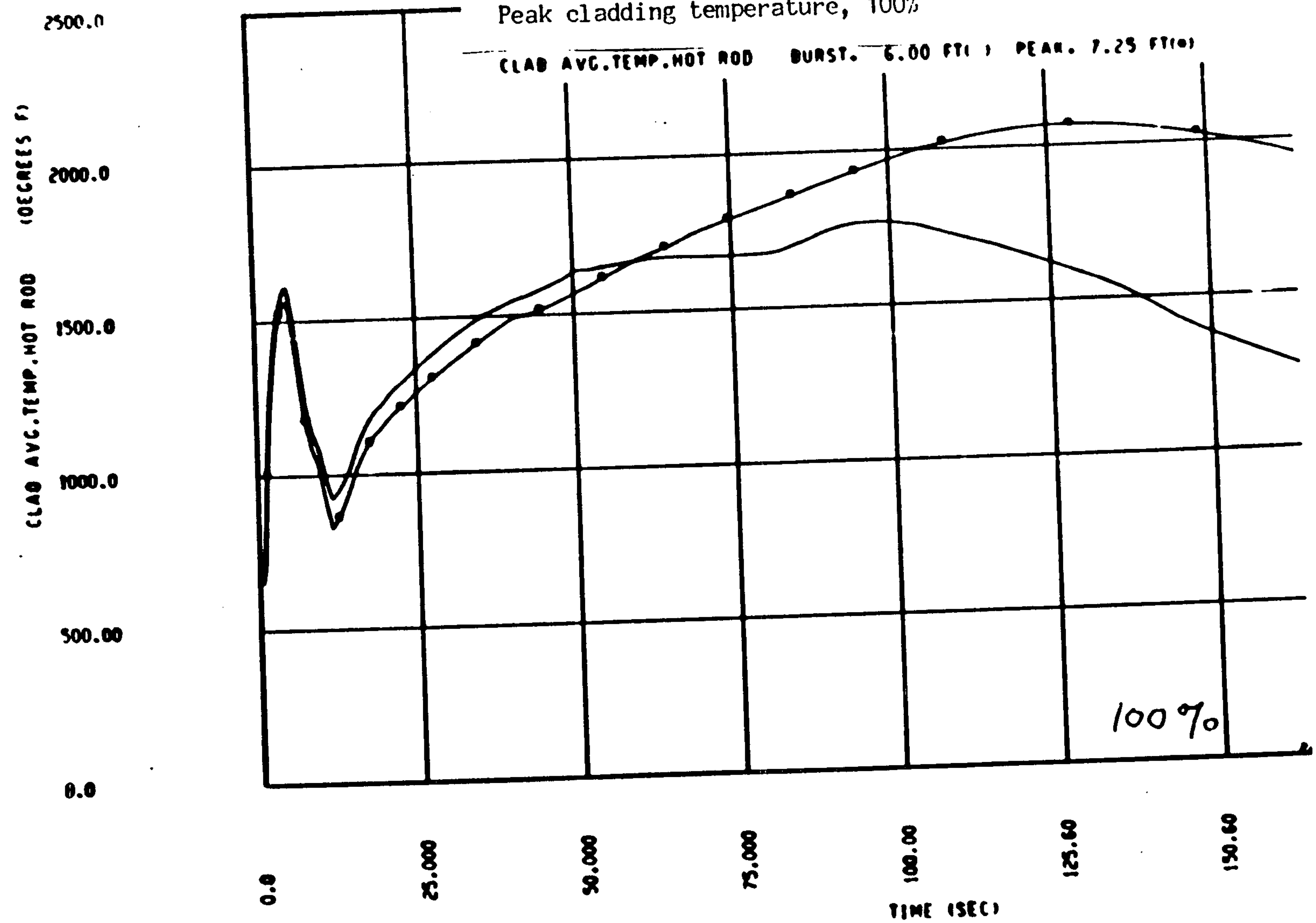


FIGURE 19A

Heat trans. coeff., 50%

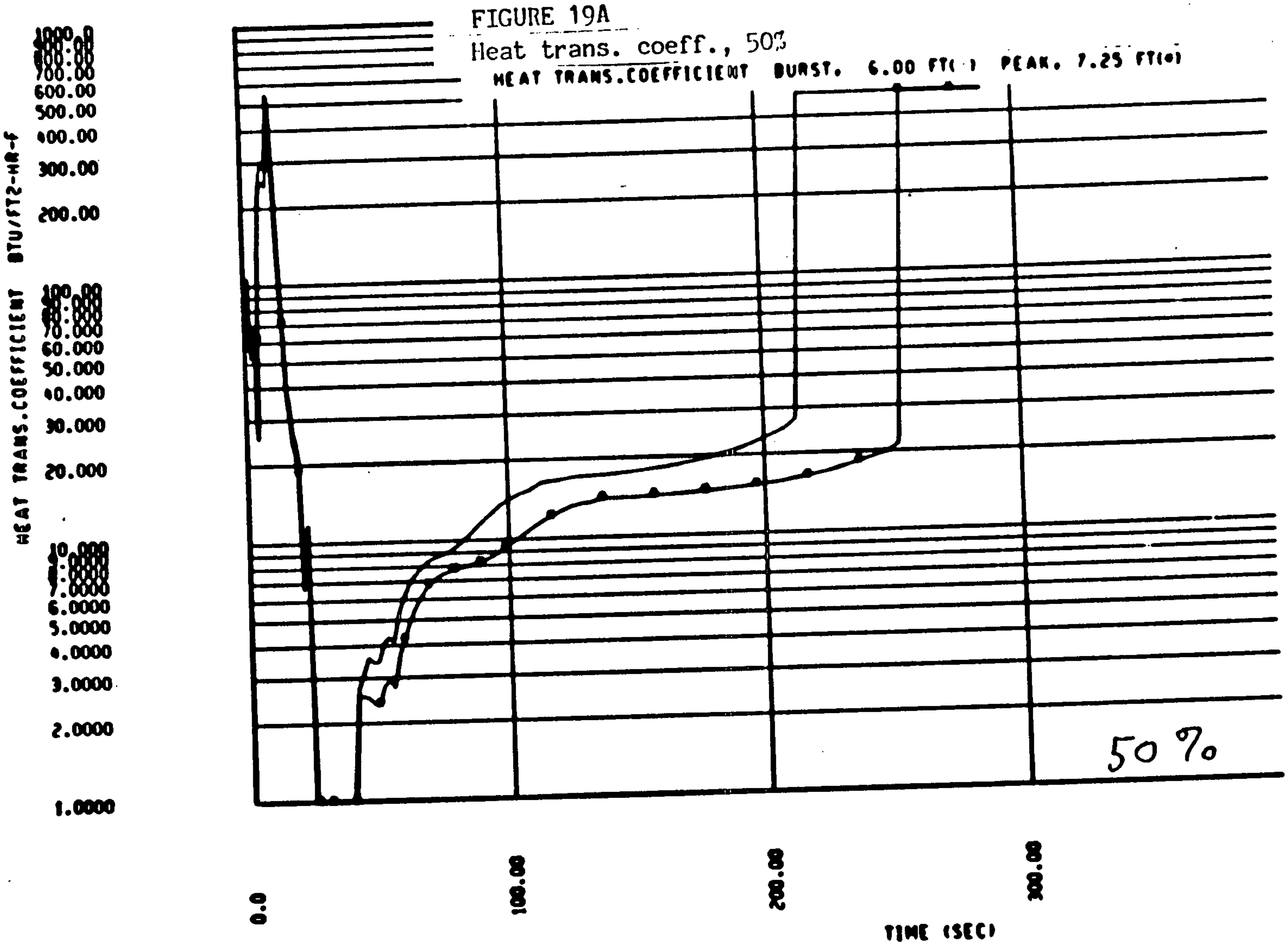


FIGURE 19B
Heat trans. coeff., 70%

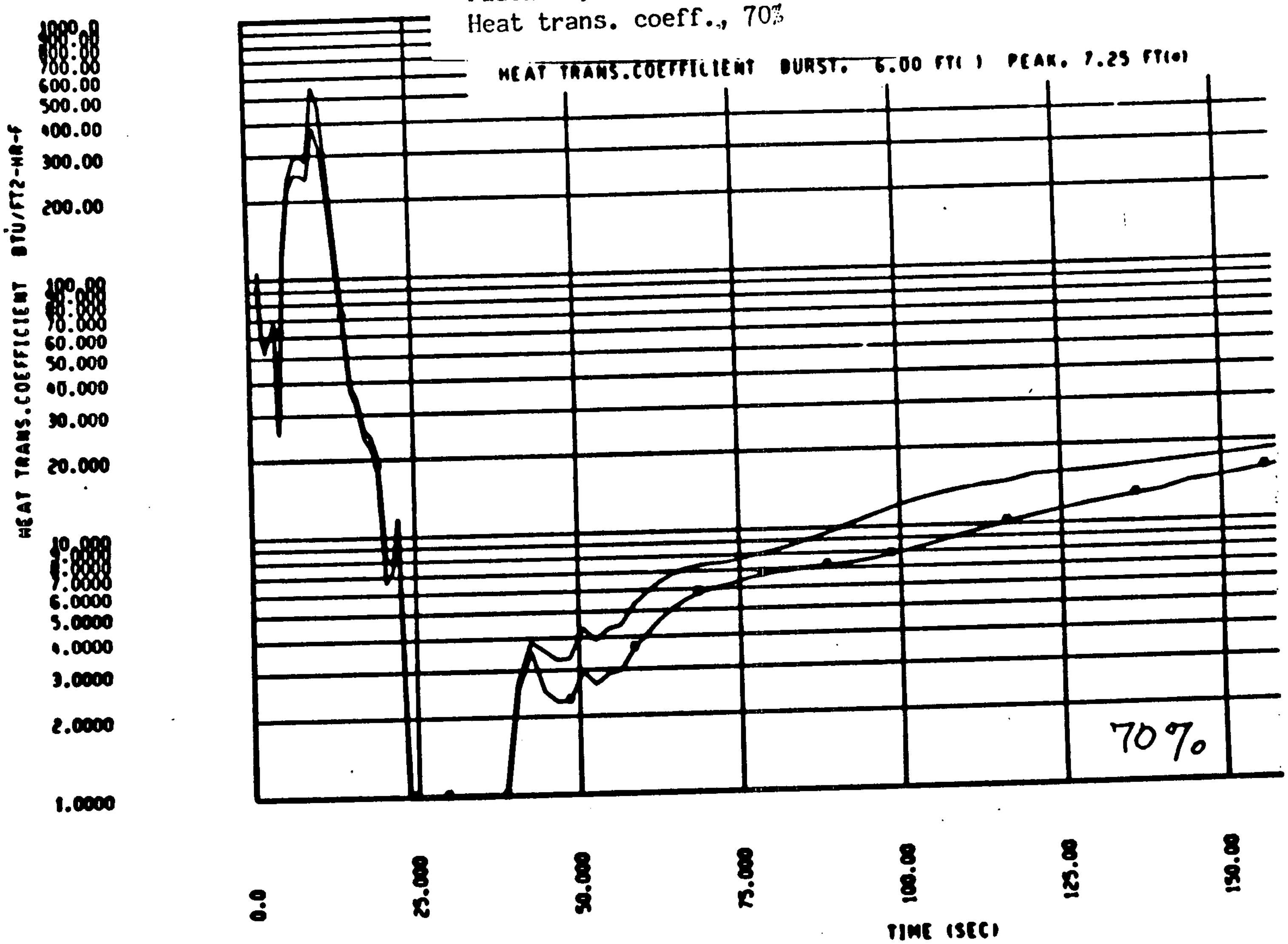


FIGURE 19C
Heat trans. coeff., 100%