WESTINGHOUSE INADEQUATE CORE COOLING ANALYSIS PERFORMED TO MEET THE REQUIREMENTS SET FORTH IN NUREG-0578

Introduction

NUREG-0578 (Section 2.1.9) outlines the scope and requirements for Inadequate Core Cooling (ICC) Analyses. Furthermore, NUREG-0578 and IE Bulletin 79-06C establish a schedule of 10/31/79 for performing these analyses. In order to meet the 10/31/79 deadline the Westinghouse Owners Group adopted a very limited program of analysis, as opposed to the original plan proposed at a meeting held with the NRC Staff on August 30, 1979. A single scenario with different failures was analyzed using a Westinghouse 412 (4 loop) plant. This report covers these analyses and shows that core exit thermocouples can be used for detection of ICC. These analyses also serve as the basis for a preliminary set of guidelines describing necessary operator actions for the detection and mitigation of ICC.

Models For ICC

The W-FLASH[1] computer code was used in performing these analyses with some modifications to remove the traditional Appendix K conservatisms and to include some better estimate models for two-phase flow behavior.

The normal Appendix K input was modified to have:

1. Best estimate RCS flows and enthalpies
2. 100% vs 102% core power
3. Best estimate safety injection
4. Best estimate discharge coefficient for break flow
5. Best estimate auxiliary feedwater

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1. Esposito, V. J., et al., "W-FLASH -- A FORTRAN IV Computer Program for Simulation of Transients in a Multi-Loop PWR," WCAP-8220 Revision 2, (Proprietary Version), WCAP-8261 Revision 1, (Non-Proprietary Version), June 1974.

6. Best estimate reactor trip and reactor protection signals
7. Nodes to represent the hot legs (see Figure 1)
8. Best estimate decay heat
9. Continuous flowpath model in the hot legs and pump suction legs.

These changes give a better estimate of the small break transient phenomena in response to NUREG-0578.

ANALYSES

Base Case

A two inch diameter cold leg break was analyzed assuming no equipment failures and minimum operator action as outlined in Chapter 6 of WCAP-9600. This will serve as the base case and Figures 2 through 44 depict this transient. The figures show no core uncovery and a rapid cool down due to the increased (best estimate) safety injection and auxiliary feedwater. In contrast, an Appendix K analysis of the same break would have shown a long period where RCS pressure would have been above steam generator secondary pressure and a slight amount of core uncovery would have occurred. The Appendix K case was presented in volume 1 of WCAP-9600, Section 3.1.

Inadequate Core Cooling Analyses

Two cases (2 inch cold leg break) having different failures were analyzed to achieve an inadequate core cooling condition and to show the differences in symptoms that can exist between transients in which core uncovery occurs.

No High Pressure Injection

The first case was the obvious case of no high pressure safety injection. This case assumes the loss of all the high pressure safety injection pumps; it is, therefore, unrealistic in the mechanistic sense in that multiple failures would have to occur.

A complete uncovery of the core occurs leading to clear indications of inadequate core cooling. Figures 45 through 86 show the detailed results for this transient. In particular Figures 60 and 61* show the fluid enthalpy entering the hot legs while Figure 66 gives the broken loop hot leg temperature.

These figures show that core exit thermocouples or hot leg temperature sensors could be used to detect inadequate core cooling. Application of hot leg temperature sensors to infer inadequate core cooling would be difficult since Figures 60 and 61 show only one of four loops as having a positive indication of inadequate core cooling. Thus, the use of hot leg temperature sensors would require operator action based on only one indication. Therefore, core exit thermocouples seem to be more desirable since several thermocouples would be showing indications of inadequate core cooling.

Figure 50 shows the downcomer mixture level which closely follows the core mixture level during the final core uncovery (i.e., 2000-4000 seconds). Downcomer differential pressure may be a possible new instrument to help in determining core uncovery. Many more analyses are necessary to determine if downcomer mixture level can be used as a reliable measure of core mixture level or impending core uncovery, and in which cases it may be applicable.

Table 1 gives a list of the indications available to the operator that are also obtainable from the W-FLASH code. This tables shows that only the hot leg temperature and the core exit thermocouples are responding in a mode which would indicate inadequate core cooling.

In summary, the obvious case of no safety injection gives strong symptoms of inadequate core cooling that could be detected by either core exit thermocouples or hot leg temperature sensors.

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*Figure 61 and subsequent Figure 103 are also core exit enthalpy when the core is uncovered.

One High Pressure Safety Injection Pump Is Operating

One other case, which was believed to develop inadequate core cooling, was analyzed This was a case in which offsite power would be lost and a diesel plus one high pressure pump would fail to start. This leaves only one high pressure safety injection pump operating for a transient where high pressure injection is necessary if the core is to remain covered.

Figures 87 through 128 depict this transient and show a long period where the top of the core is uncovered (Figure 90). Figures 102, 103, and 108 show the hot leg fluid enthalpies and the hot leg temperature respectively. The indications available from either core exit thermocouples or hot leg temperature sensors would not warrant operator action. The downcomer level transient (see Figure 92) is also not as pronounced as the no SI case but does show a transient similiar to that of the core. A LOCTA[2] analysis shows the peak clad temperature to be 1207°F and no clad damage to occur. Therefore, this case is not an inadequate core cooling case but one in which the core exit thermocouples would show some assemblies with fluid temperatures greater than 700°F and thus the existence of an uncovered core. Based on this analysis, the only reliable indication of an uncovered core are the core exit thermocouples.

Table 2 gives a list of the indications available to the operator that are also obtainable from the W-FLASH computer code. None of these indication provides a strong signal that would indicate core uncovery. The core exit enthalpy is indicative of the average assembly exit fluid temperature (590-600°F) which would be substantially less than the temperature for the hottest assembly. Thus, some of the core exit thermocouples would give readings greater than those indicated in Figure 103.

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

In summary, the analysis for one high head safety injection pump operating does show core uncovery but a LOCTA analysis of the hot assembly clad temperature transient shows peak clad temperatures that are low (1207°F) and does not predict clad damage. Thus, this case is not an inadequate core cooling case from the standpoint of fuel damage. Furthermore, this case shows that (a) hot leg temperatures are not always a reliable predictor of core uncovery, and (b) the core recovered without the need for operator action.

Conclusion Of Inadequate Core Cooling Analyses

Two transients were analyzed for a 412 (4 loop) Westinghouse plant having a 2 inch diameter cold leg break. The first transient was the case of no safety injection which obviously leads to ICC conditions, and concluded that the core exit thermocouples or hot leg temperature sensors could be used for determining core uncovery and inadequate core cooling. The second case assumed that only one high pressure safety injection pump was operating and concluded that only core exit thermocouples were reliable indicators of core uncovery and therefore inadequate core cooling. Thus based on these analyses the core exit thermocouples can be a reliable indicator of inadequate core cooling.

Future Efforts On Inadequate Core Cooling

Originally, the Westinghouse Owners Group proposed a program of inadequate core cooling analysis that would have used the NOTRUMP computer code and investigated several scenarios and subsequent operator actions. The schedule for completion of this program was to have been 1/1/80. Due to the existing schedule in NUREG-0578 the original program was delayed and the program of analyses presented above was undertaken so that the October 31 deadline could be met. However, as part of Westinghouse's future efforts, the original program of analyses will be performed but with a completion date late in the first quarter of 1980. The Owners Group feels that completion of the original program is important since more scenarios will be covered and the information obtainable

from NOTRUMP is more realistic than that obtainable from W-FLASH. Also, the possibility of using excore detectors (source range) for inferring an uncovered core will be investigated. This should lead to a better understanding of ICC and additional guidance to the operator.

TABLE 1

INADEQUATE CORE COOLING STUDY
NO HIGH PRESSURE SAFETY INJECTION

2 INCH DIAMETER COLD LEG BREAK

INDICATION	STATUS DURING CORE UNCOVERY	W-FLASH FIGURE NUMBER
RCS Pressure	Approx 1000 psia	45
Presz Water Level	Empty	51
Hot Leg Temp.	Increasing	66
Cold Leg Temp.	Stable at 560°F	67
SI Flow	None	59
Auxiliary Feedwater Flow	OFF (S.G. is full)	--
Steam Generator Secondary Mixture Level	Stable at about 45 Ft	54
Core Exit Enthalpy	Increasing	61

TABLE 2

INADEQUATE CORE COOLING STUDY
ONE HIGH PRESSURE SAFETY INJECTION
PUMP IS OPERATING

2 INCH DIAMETER COLD LEG BREAK

INDICATION	STATUS DURING CORE UNCOVERY	W-FLASH FIGURE NUMBER
RCS Pressure	Approx 1000 psia	87
Presz Water Level	Empty	93
Hot Leg Temp.	Slight Increase	108
Cold Leg Temp.	Stable at 550oF	109
SI Flow	30 to 40 lmb/sec	101
Auxiliary Feedwater Flow	OFF (S.G. is full)	--
Steam Generator Secondary Mixture Level	Stable at about 45 Ft	89
Core Exit Enthalpy	Slight Increase	103

APPENDIX A

INSTRUCTIONS TO RESTORE CORE COOLING DURING A SMALL LOCA

The Instructions presented below have been developed using the analytical results presented in this report and some of the results presented in WCAP-9600. These Instructions focus upon inadequate core cooling scenarios which can potentially result from a small LOCA.

Several other facets of the issues related to inadequate core cooling are to be addressed later. The need for additional Instructions may be identified as these issues are analysed and resolved. The schedule for preparation of any additional Instructions will be determined in conjunction with the corresponding analytical program.

INSTRUCTION TO RESTORE CORE COOLING DURING A SMALL LOCA

A. PURPOSE

To specify precautions and operator actions aimed at restoring a condition of core cooling during a small LOCA.

B. ACTIONS

1. Throughout this Instruction, continue efforts to provide safety injection and/or charging flow to the RCS and/or feedwater flow to the steam generators. Attempt to operate equipment manually locally, if possible.

2. Continue monitoring of core exit thermocouples to determine effectiveness of subsequent actions.

3. Depressurize the RCS by:

   a. Dumping steam to the condenser, or,

   b. If the condenser is not available dumping steam through the atmospheric relief valves, or,

   CAUTION: Depressurization through use of the steam generators should only be attempted if there is an effective water level and auxiliary or main feedwater is available.

   c. Open the Pressurizer PORV's only if:

      1. SIS or charging is available to deliver to the RCS.

      2. RCS depressurization cannot be accomplished by steam relief from the steam generators.

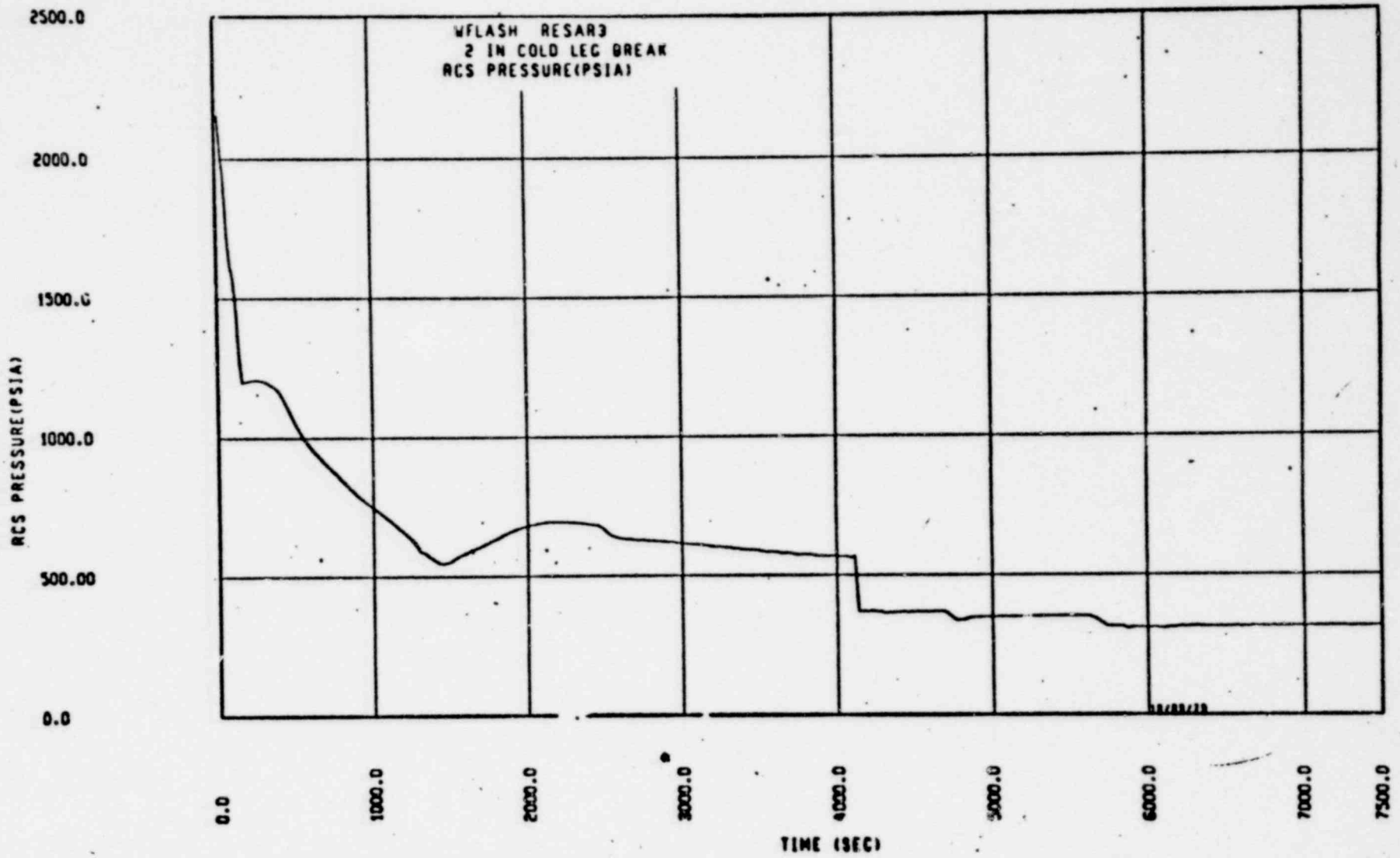
      3. Feedwater is not available to maintain the steam generator secondary water level at an effective level.

4. If no means for RCS depressurization are available, or if the depressurization did not result in decreasing core exit thermocouple temperatures, then start a reactor coolant pump, if possible.

CAUTION: During the conduct of this instruction, the RWST level should be monitored for switchover to cold leg recirculation, if required. Then the procedures already presented in Table E-1.1 (pg. E-1 (HP)-12) should be followed. Also, the precautions given in steps 9, 10 and 11 of E-1 should still be consulted.

(A,C)

Figure 1



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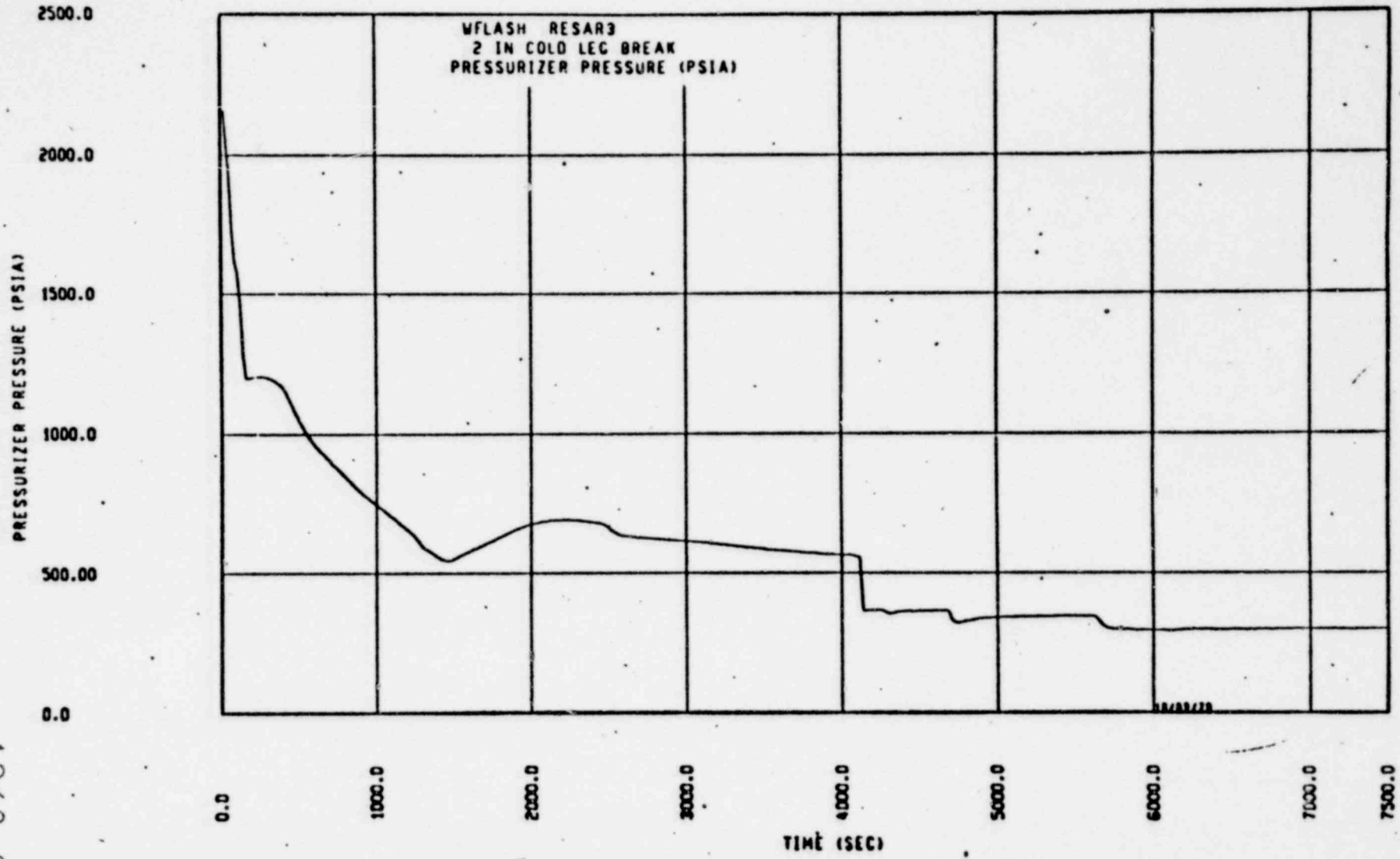

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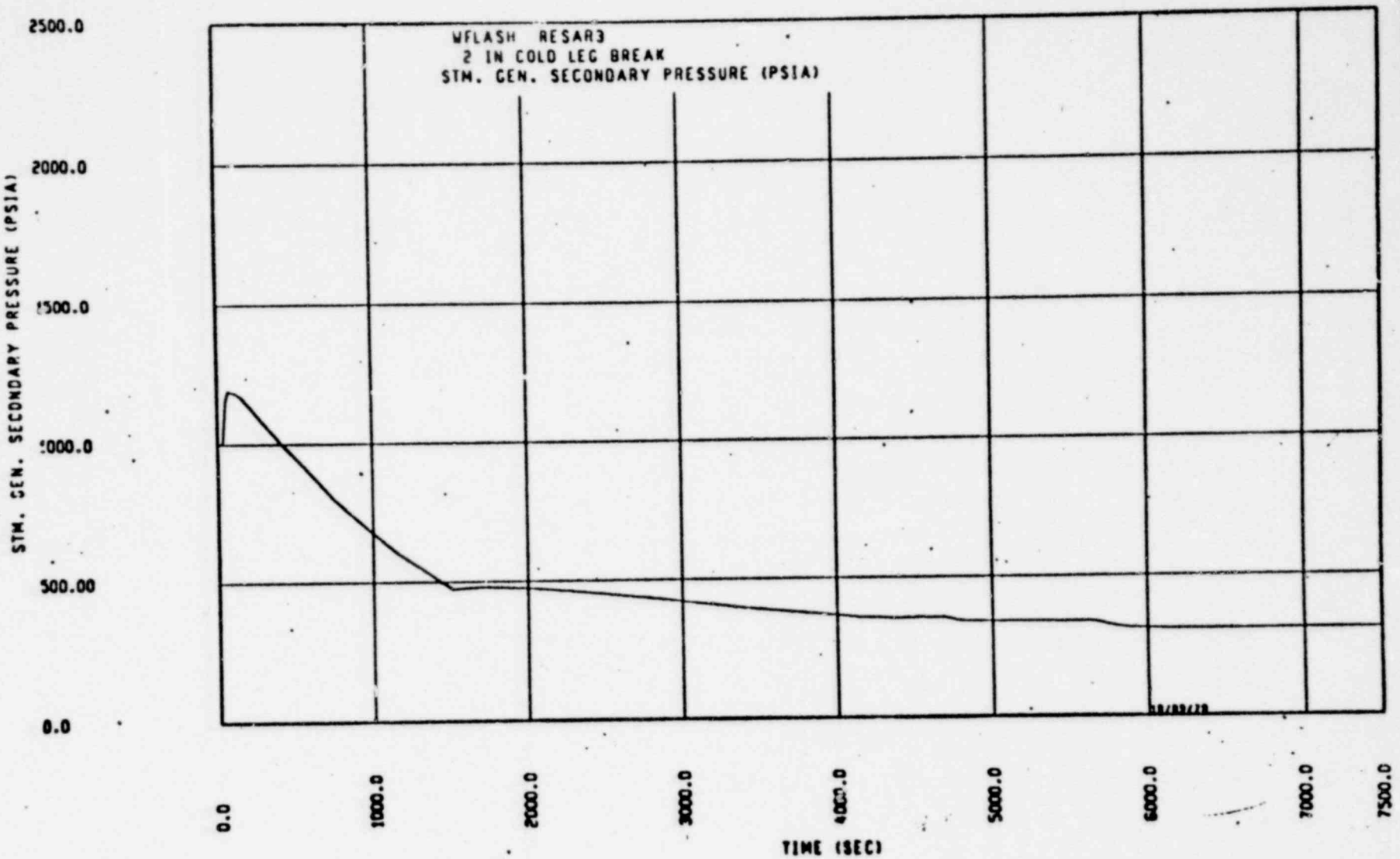
Figure 3



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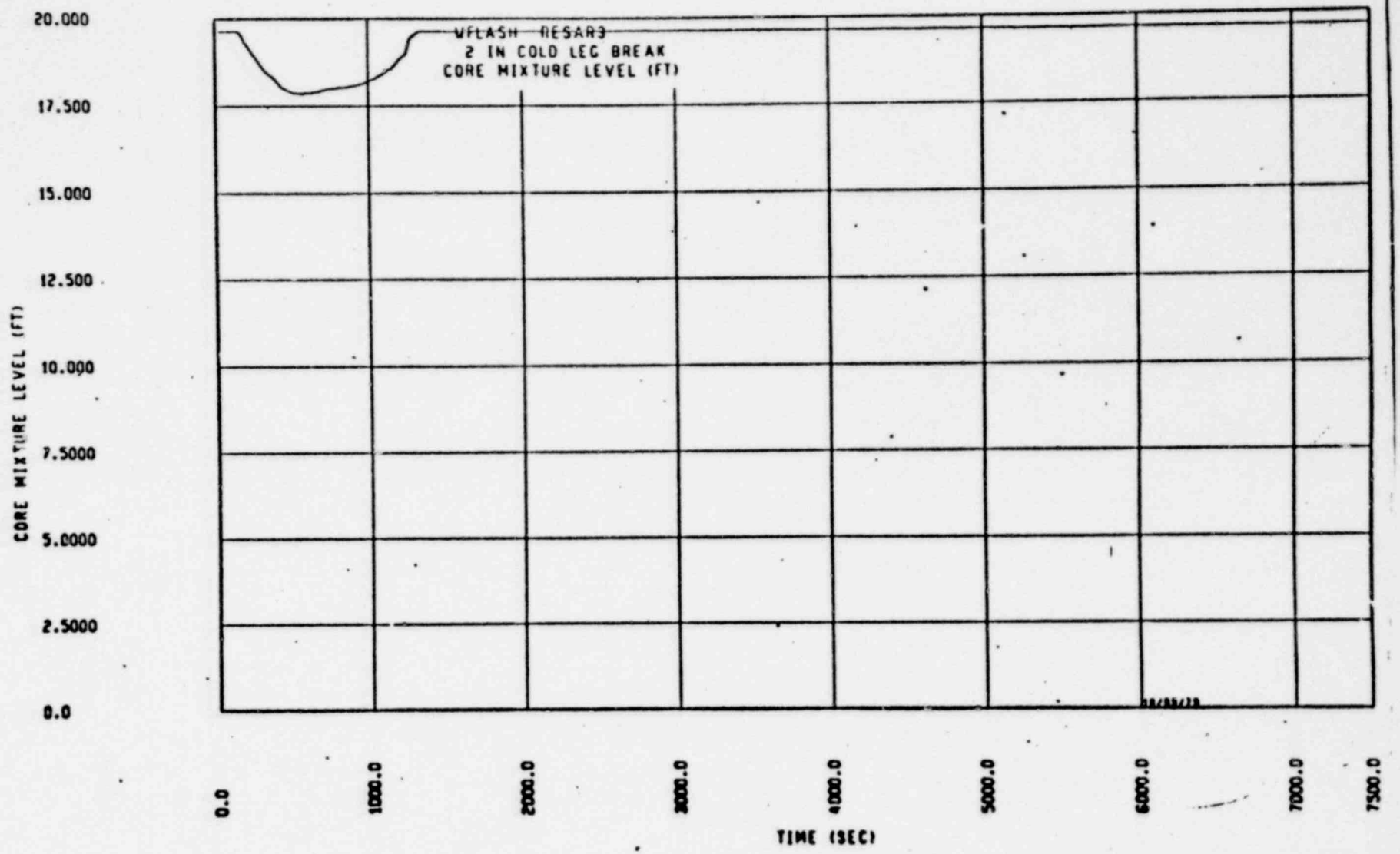

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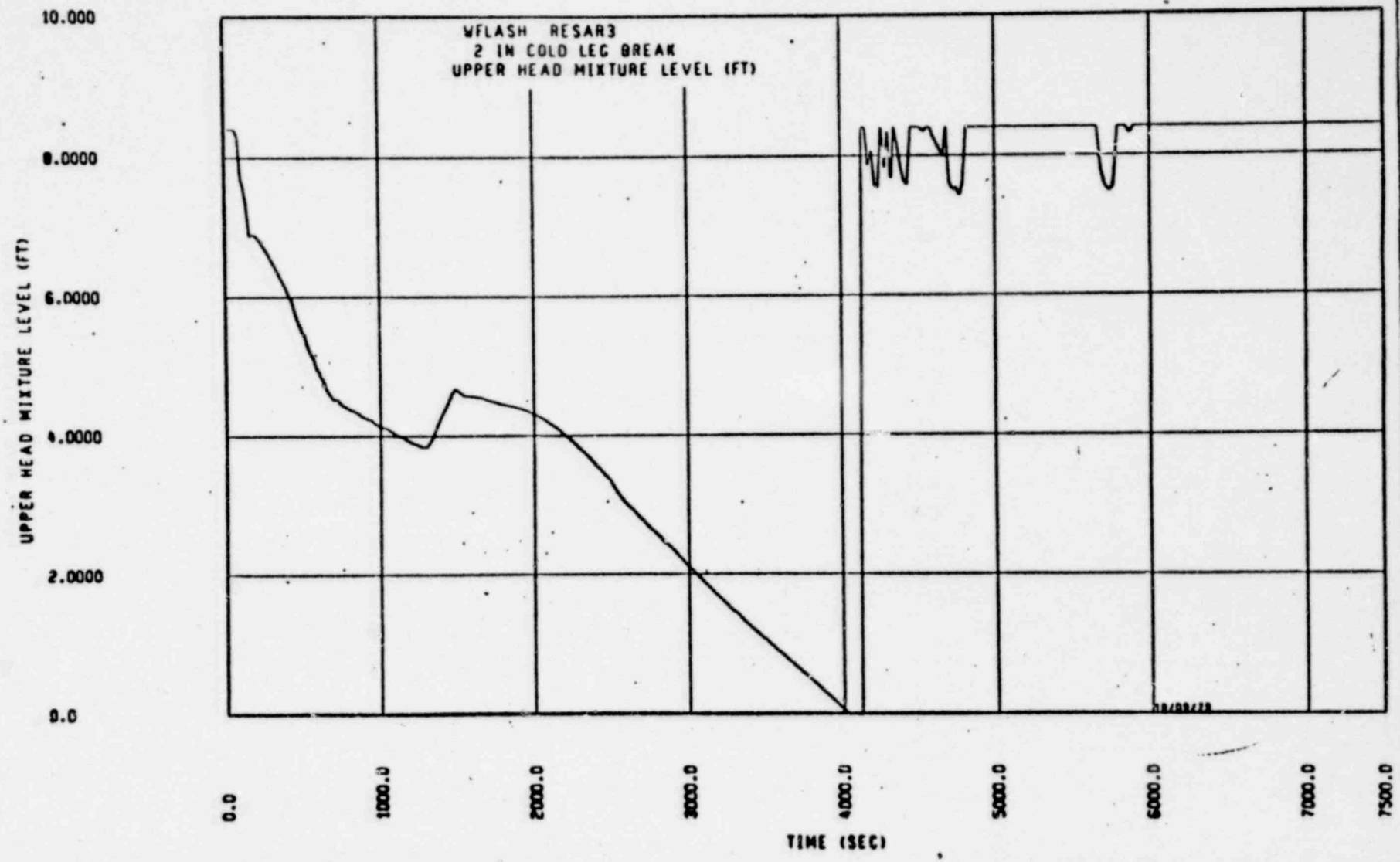

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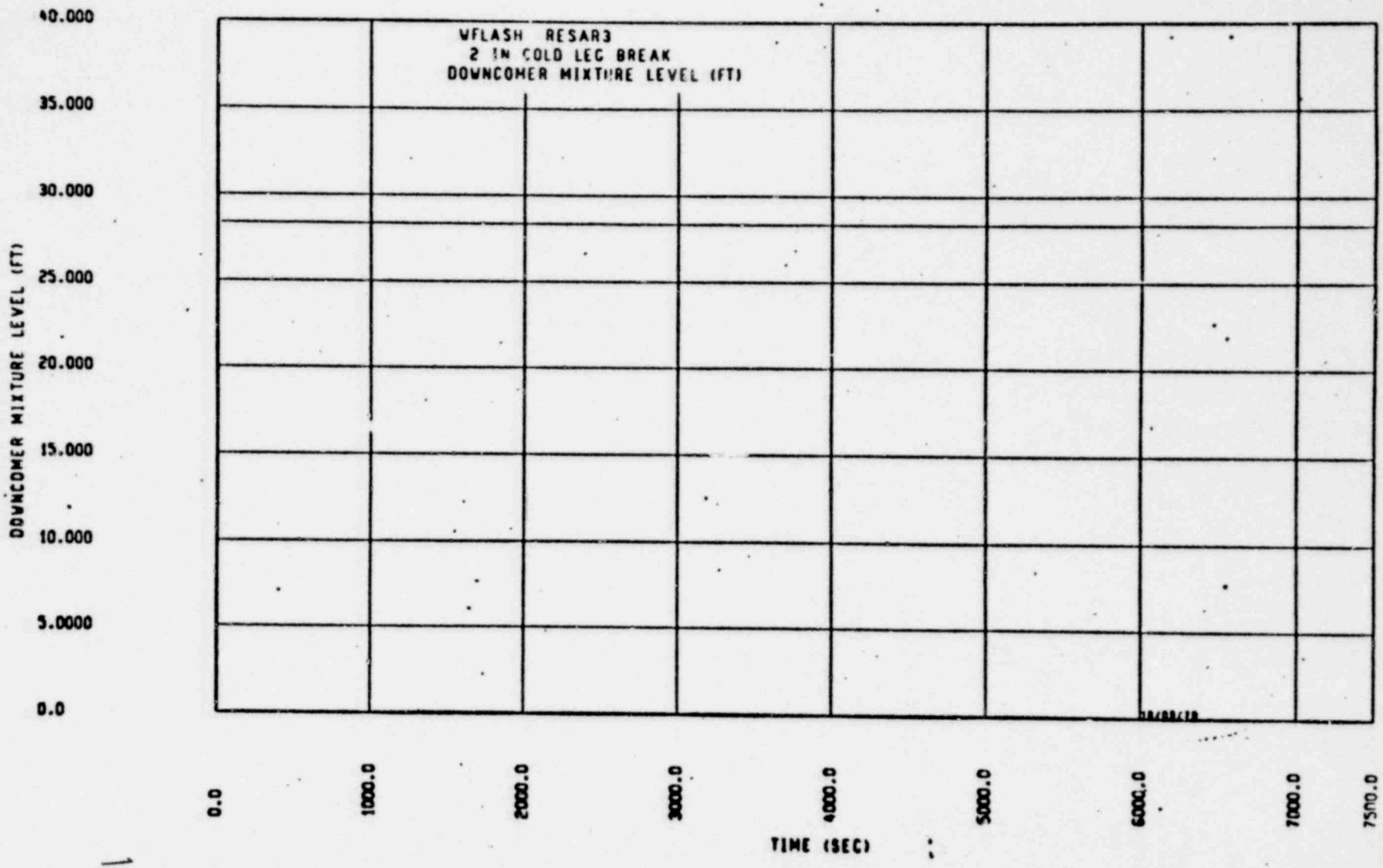

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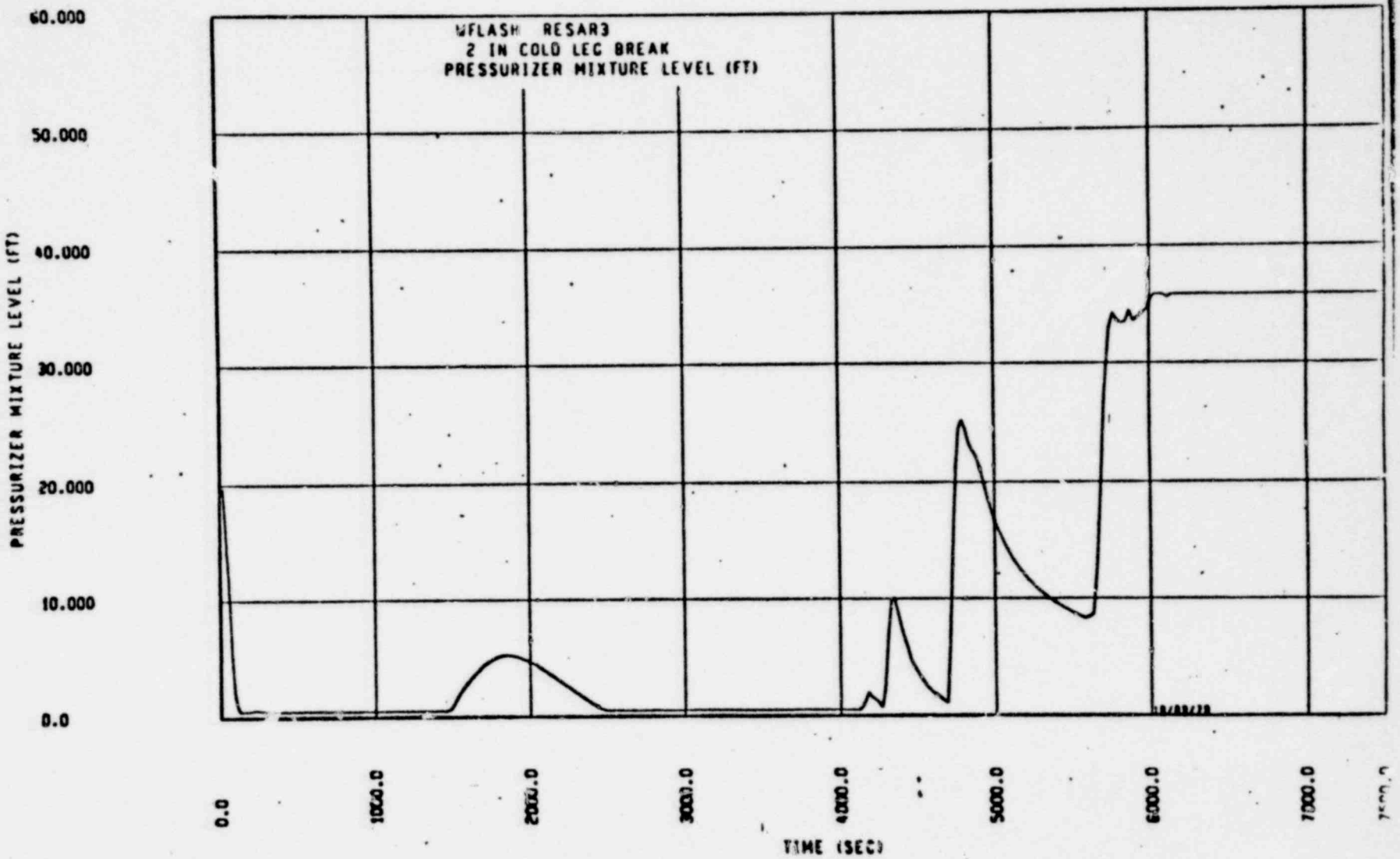

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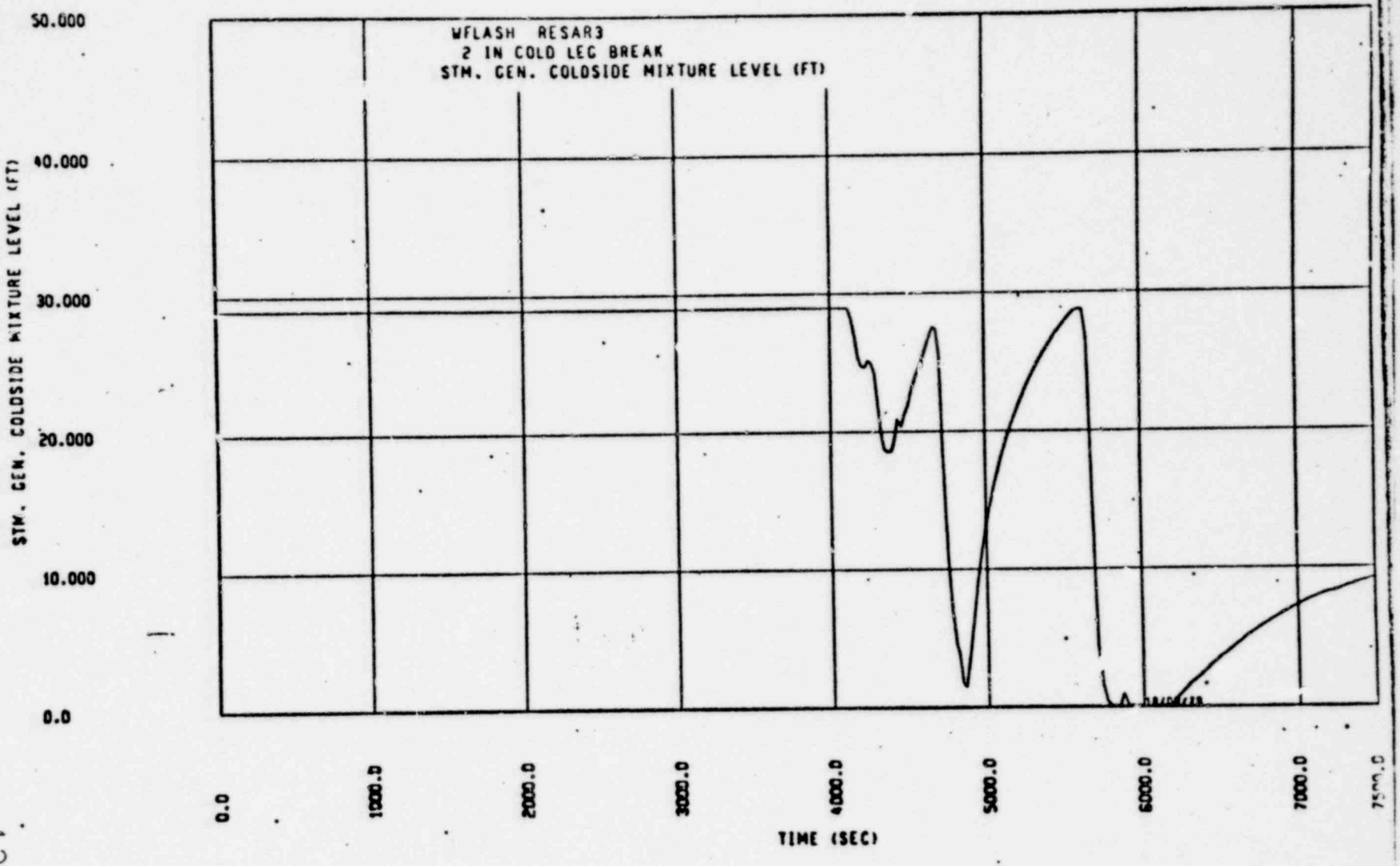

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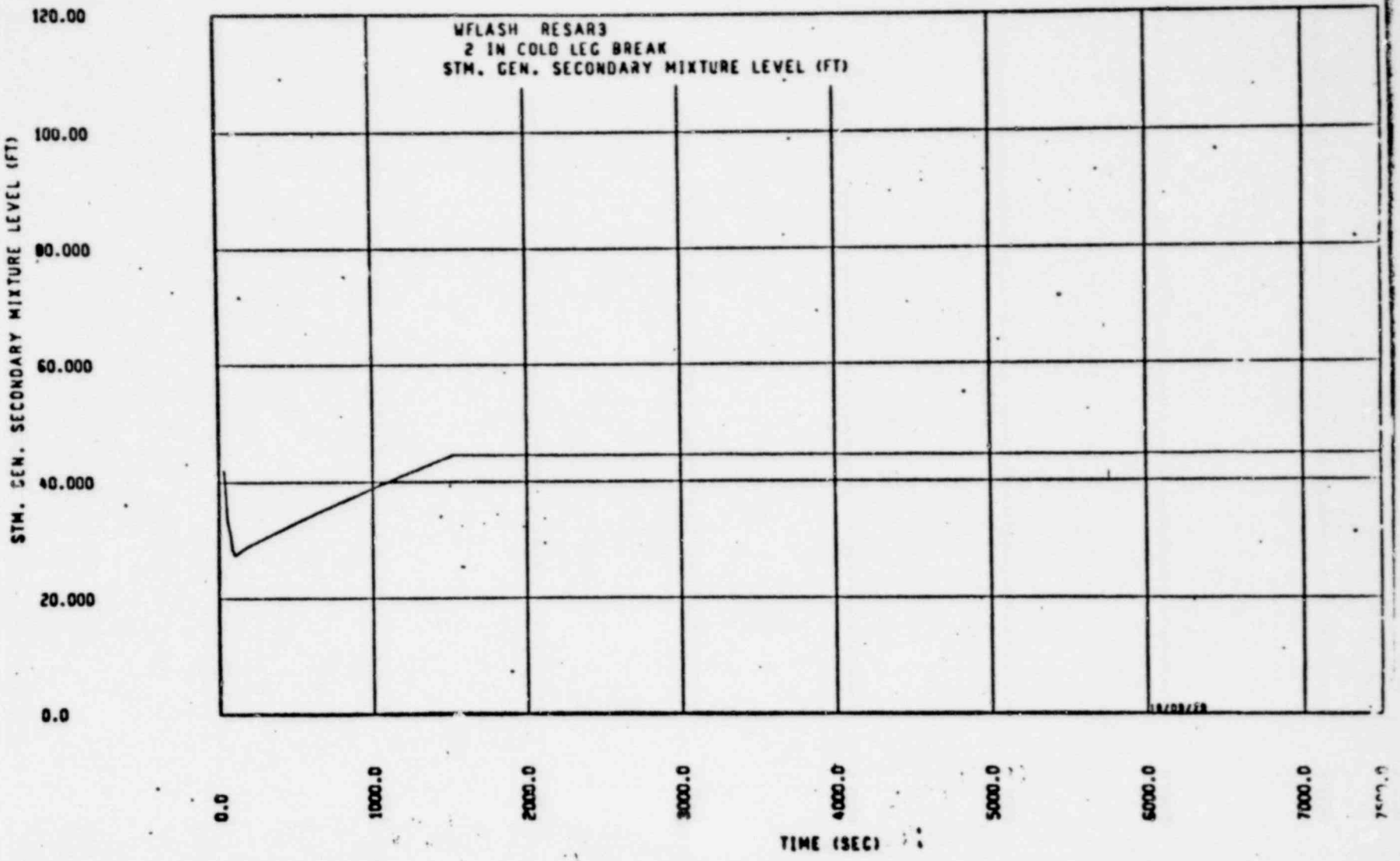

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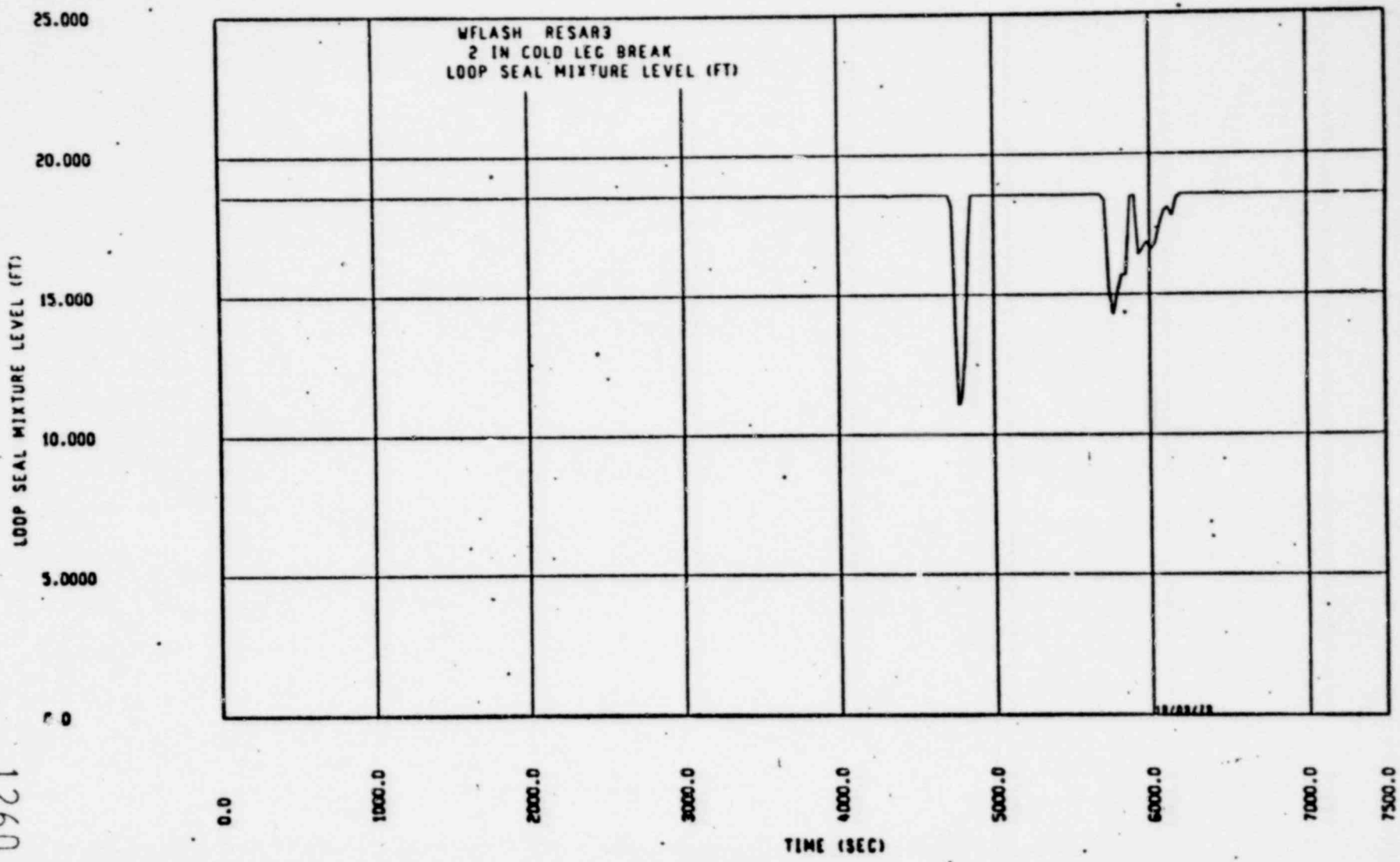

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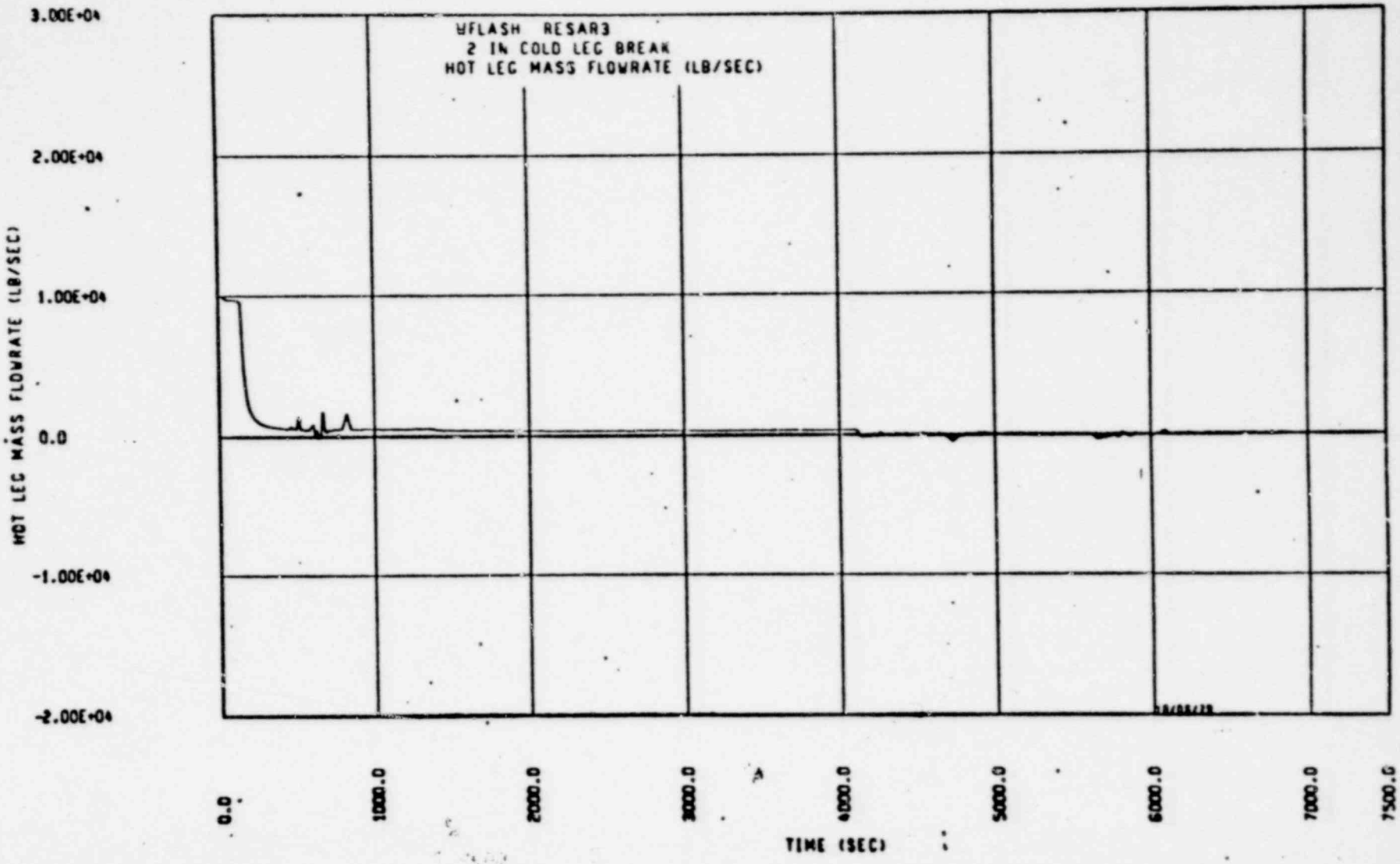

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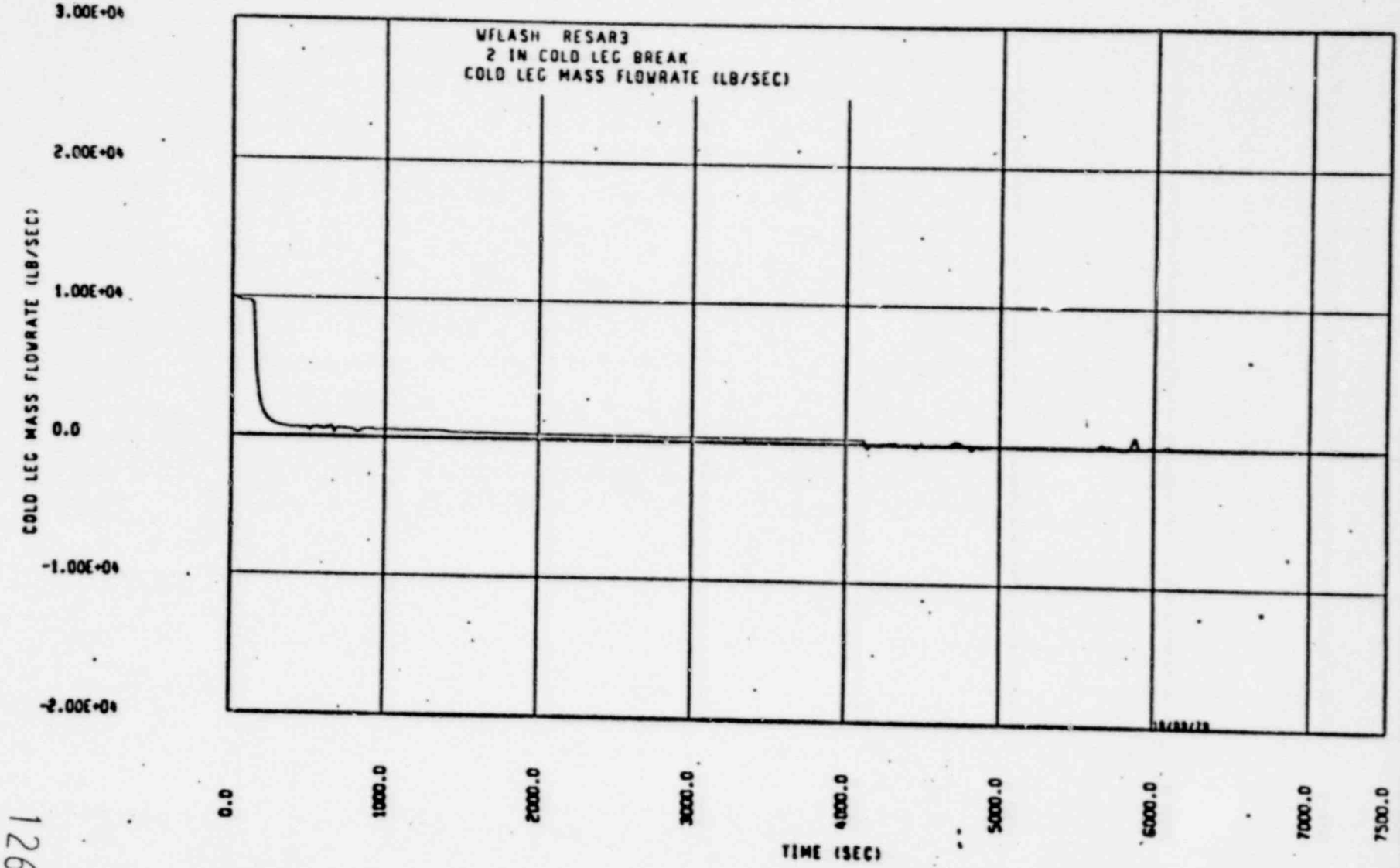

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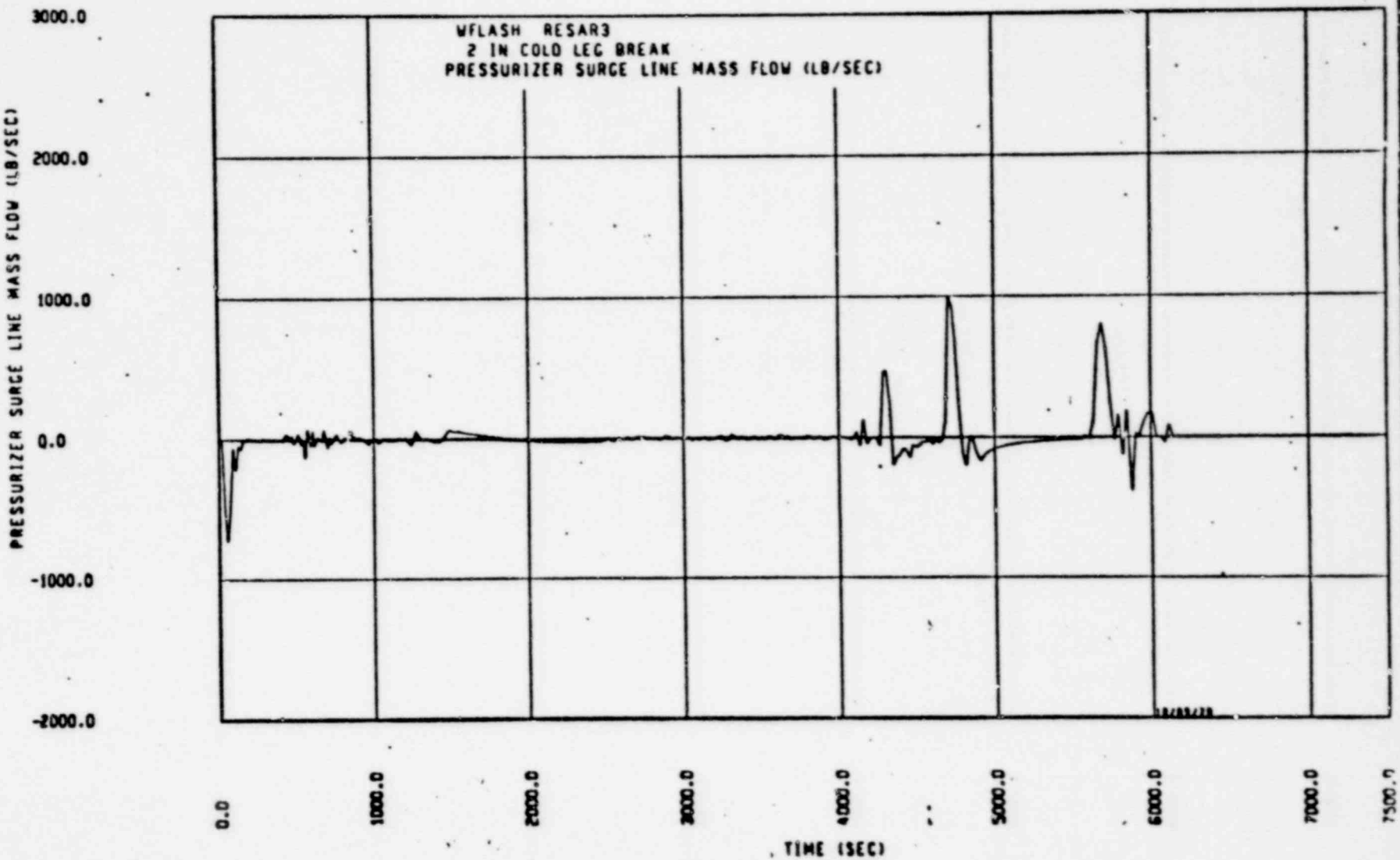

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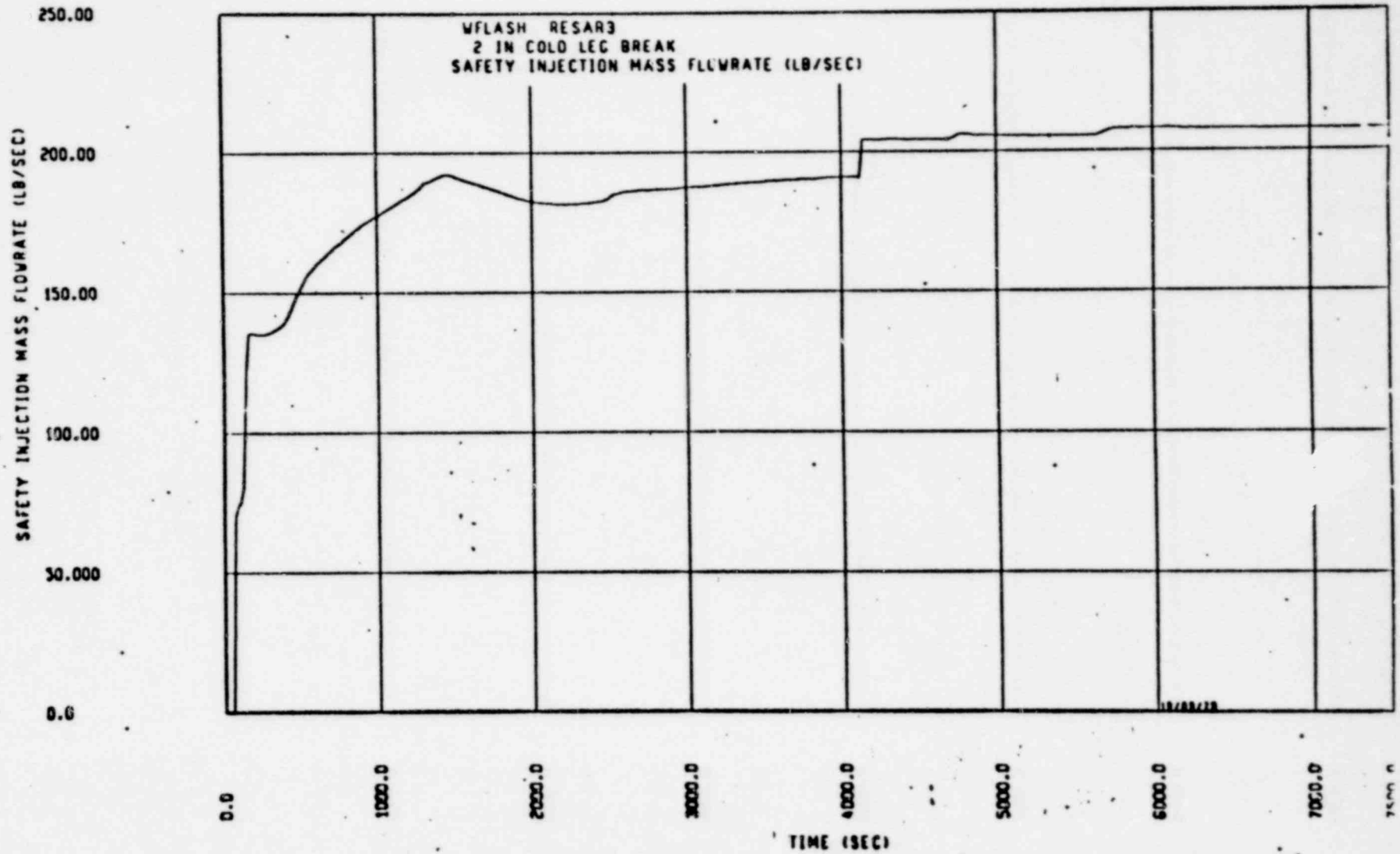

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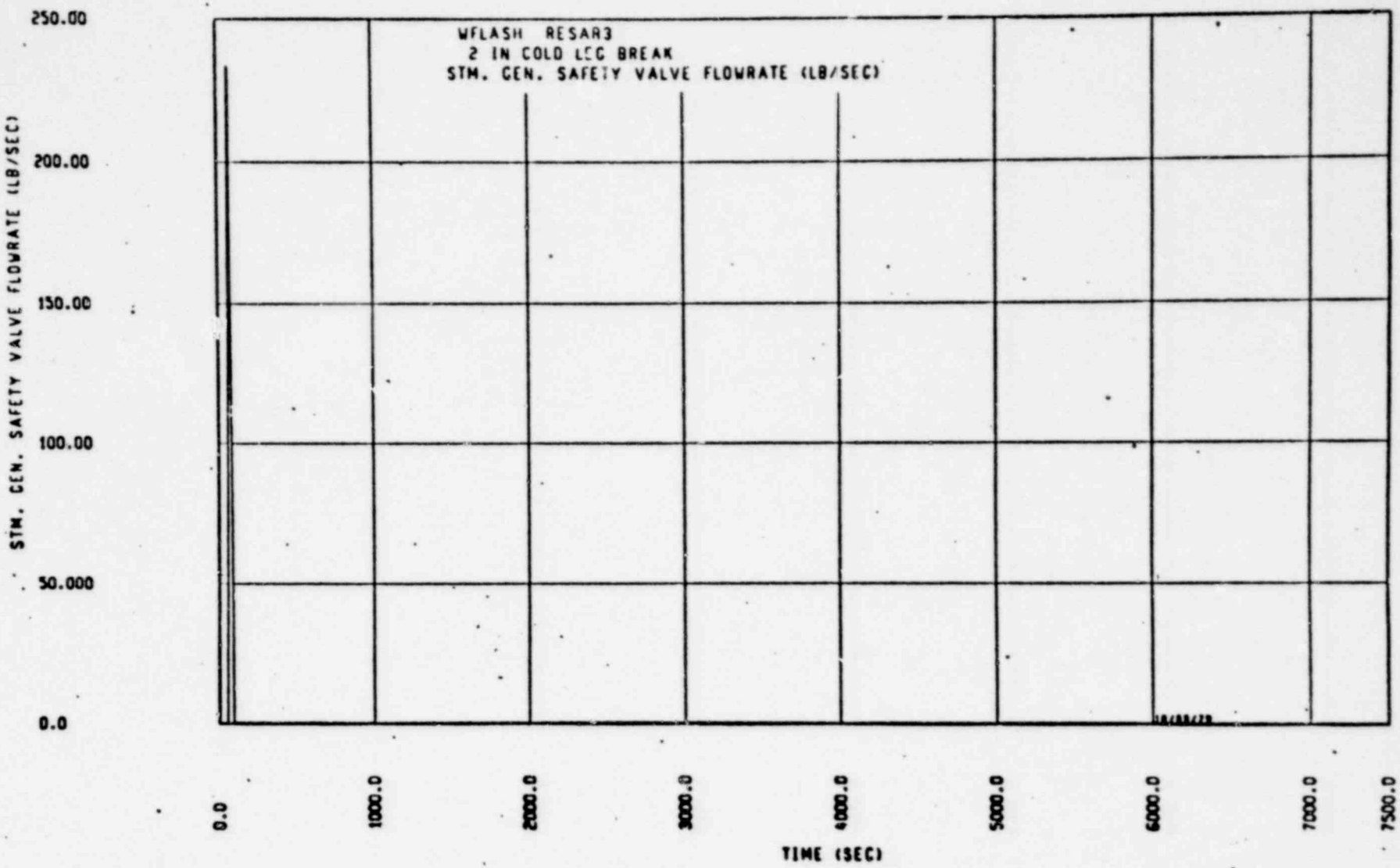

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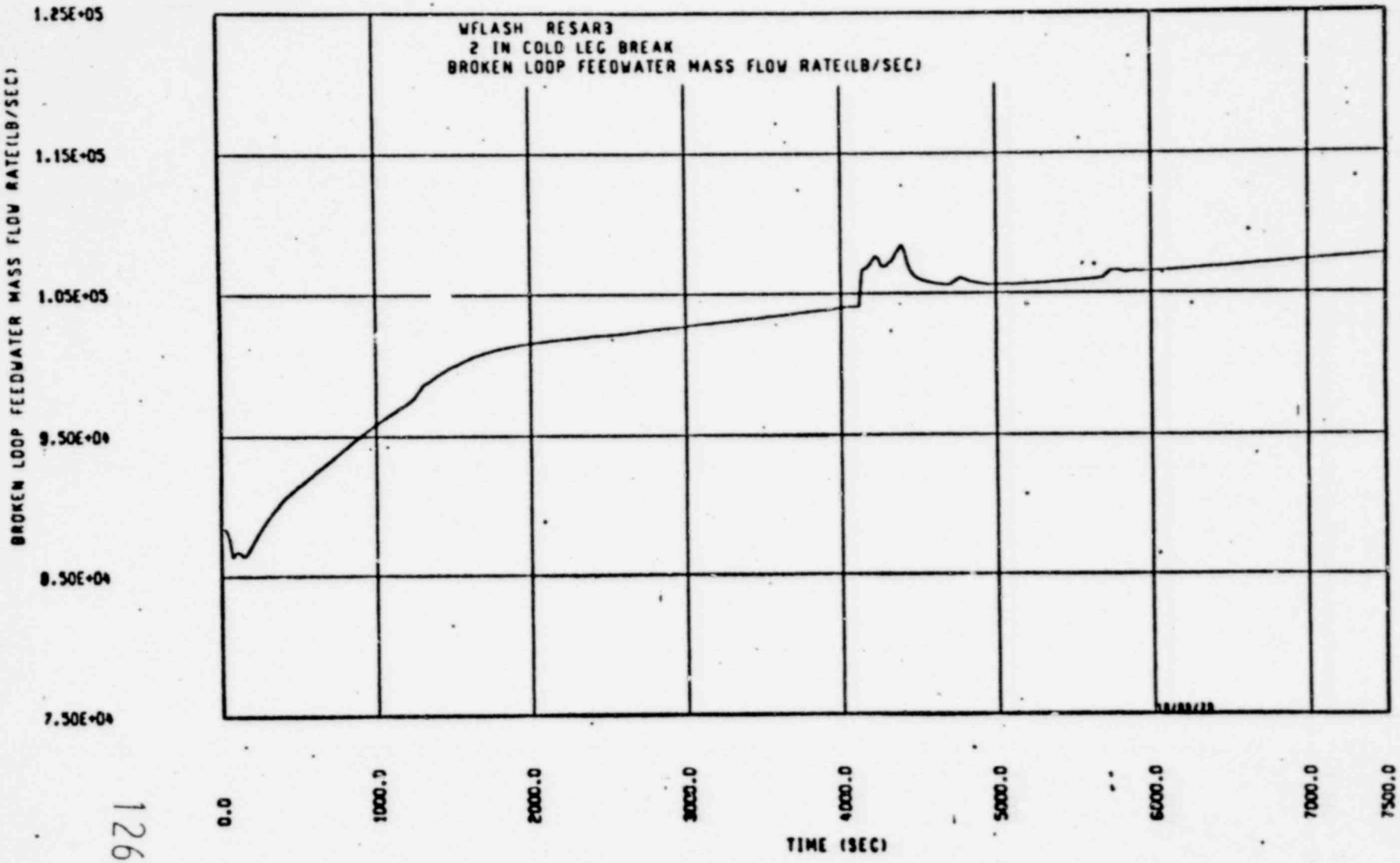

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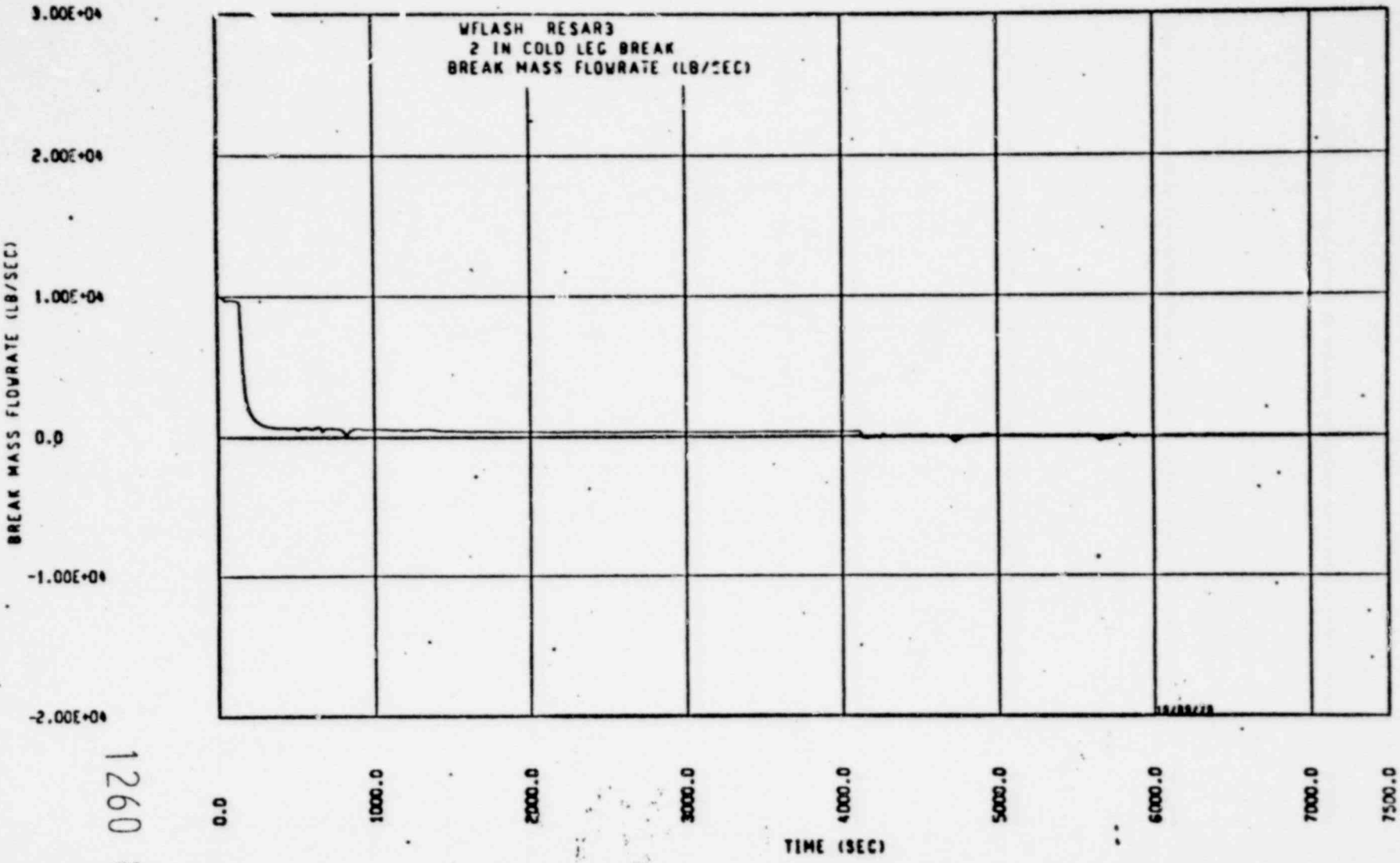

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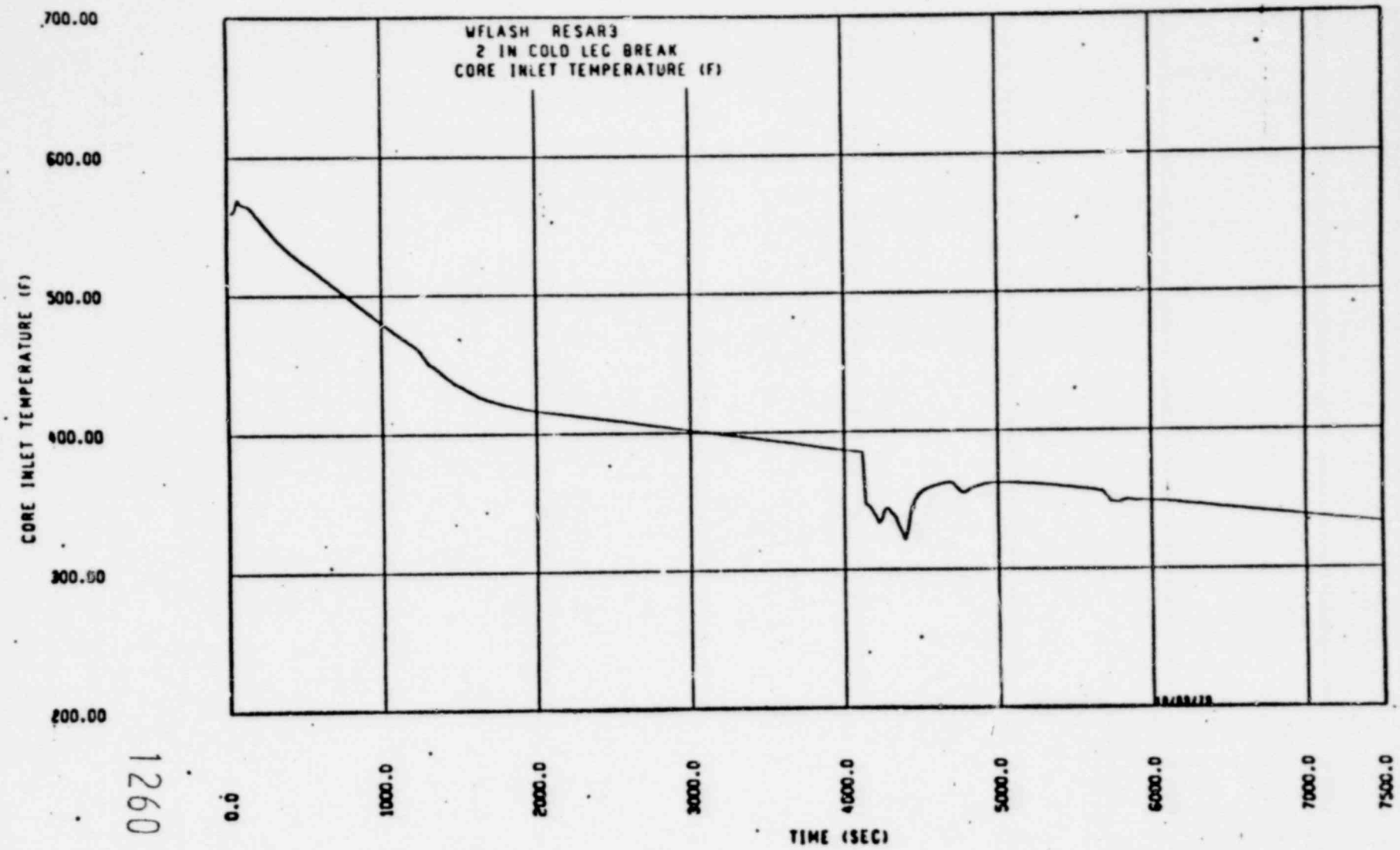

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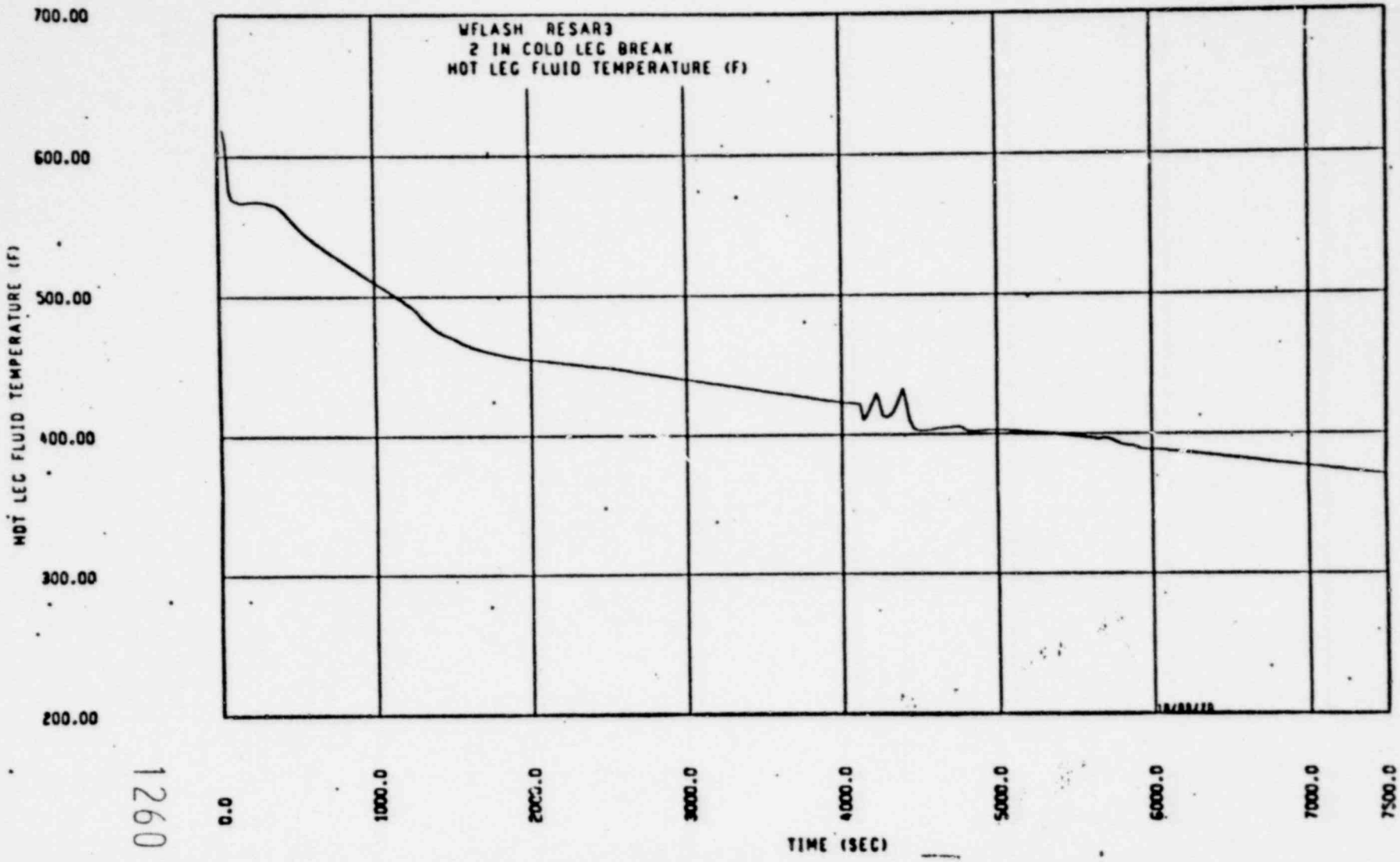

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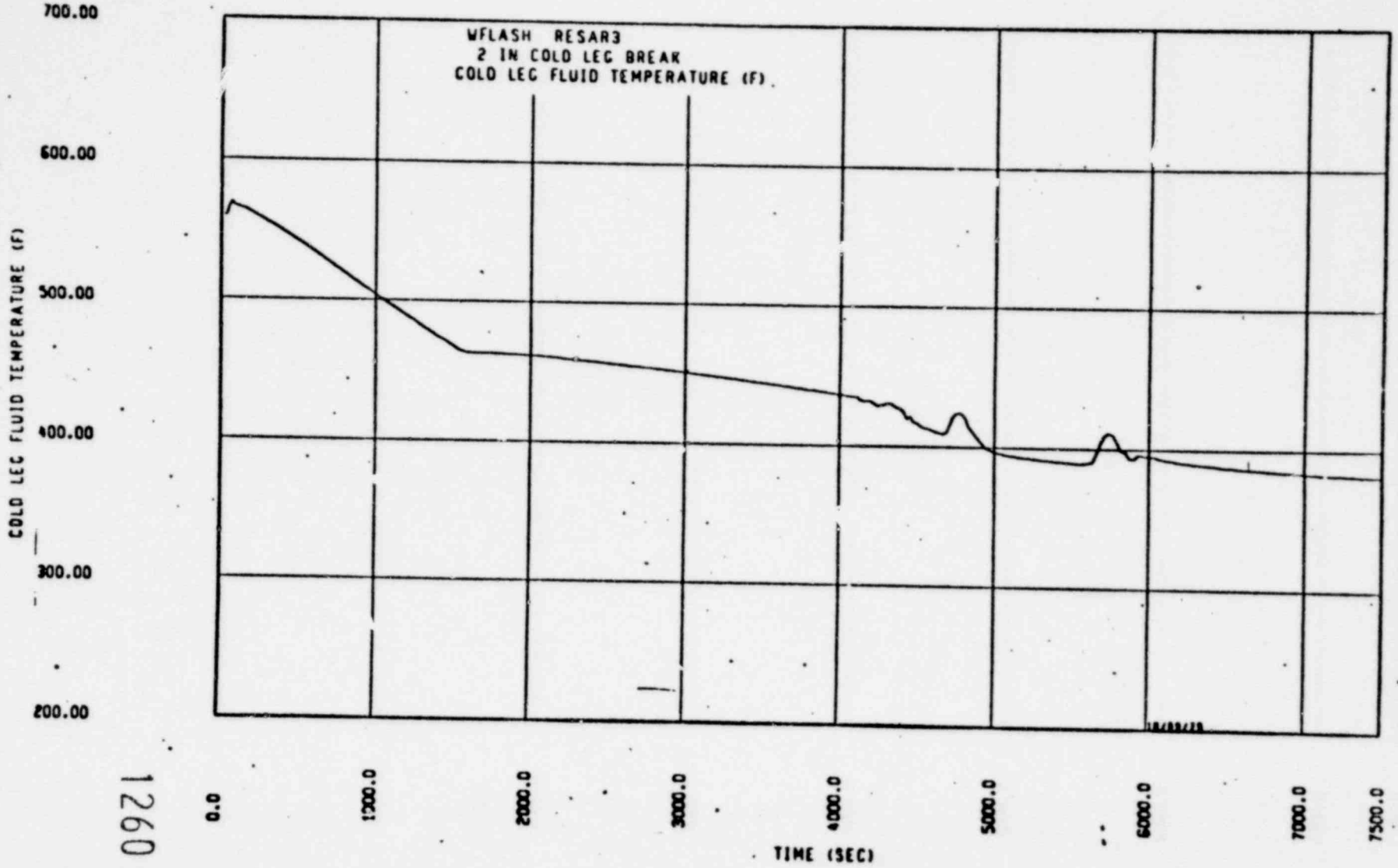

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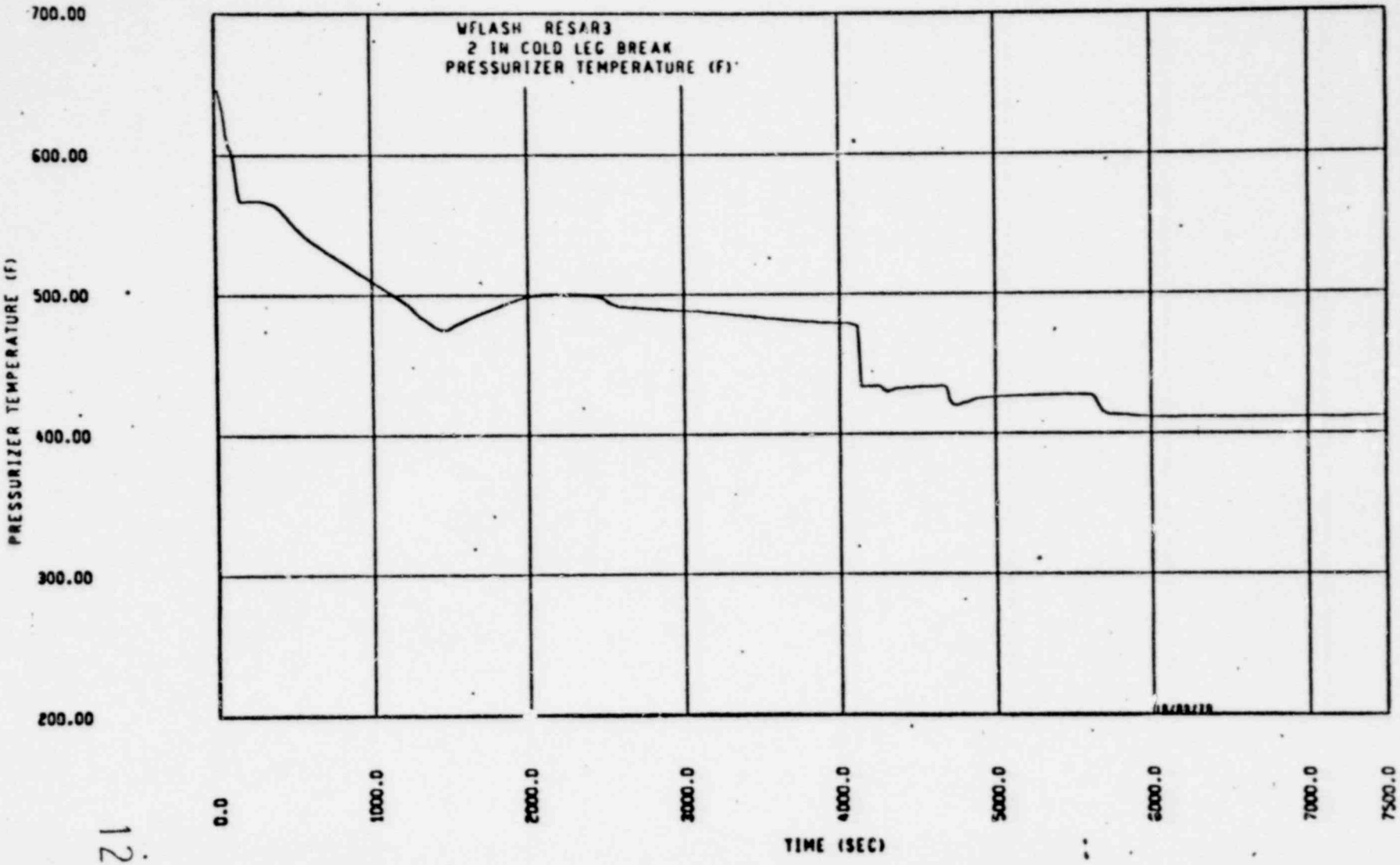

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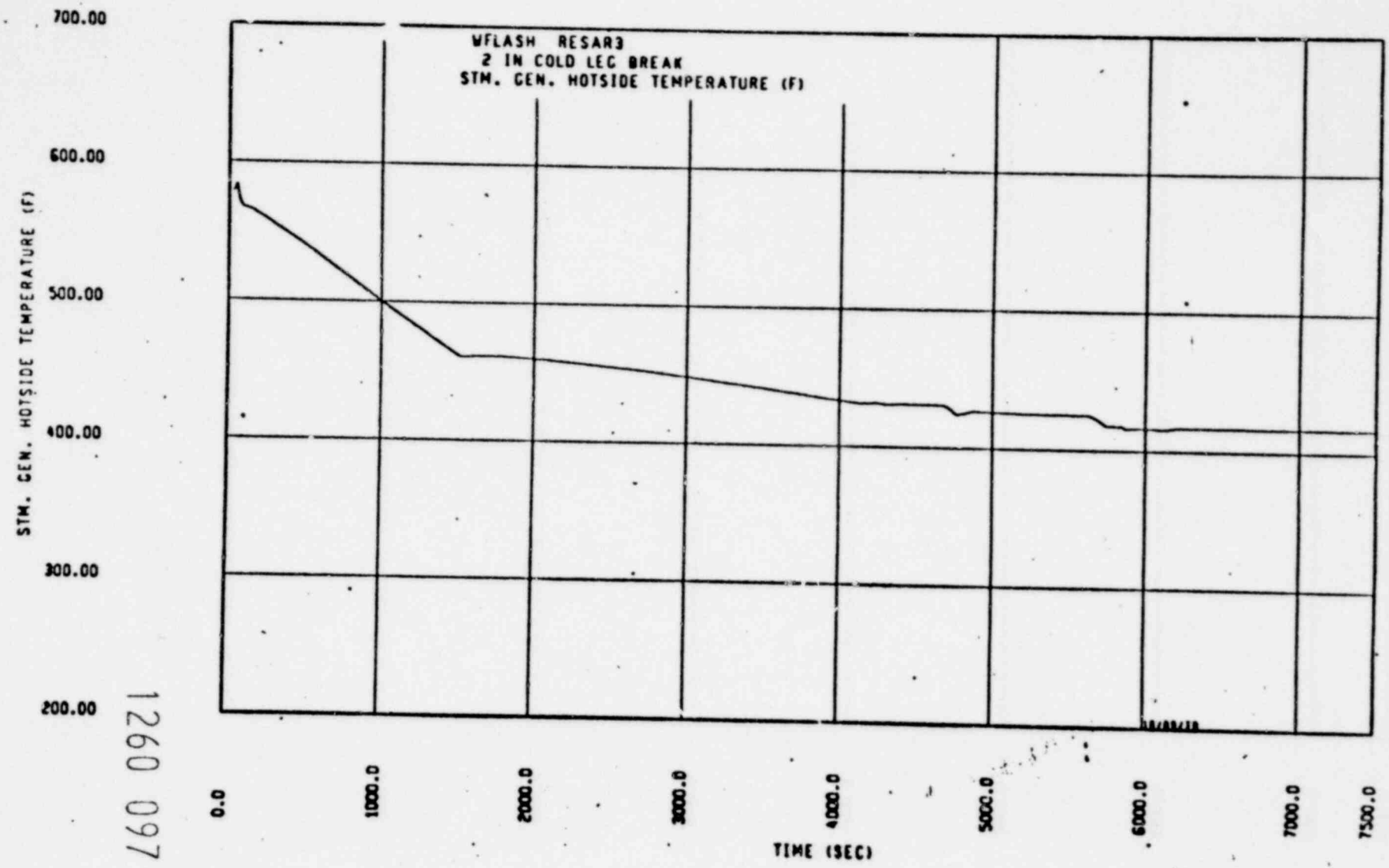

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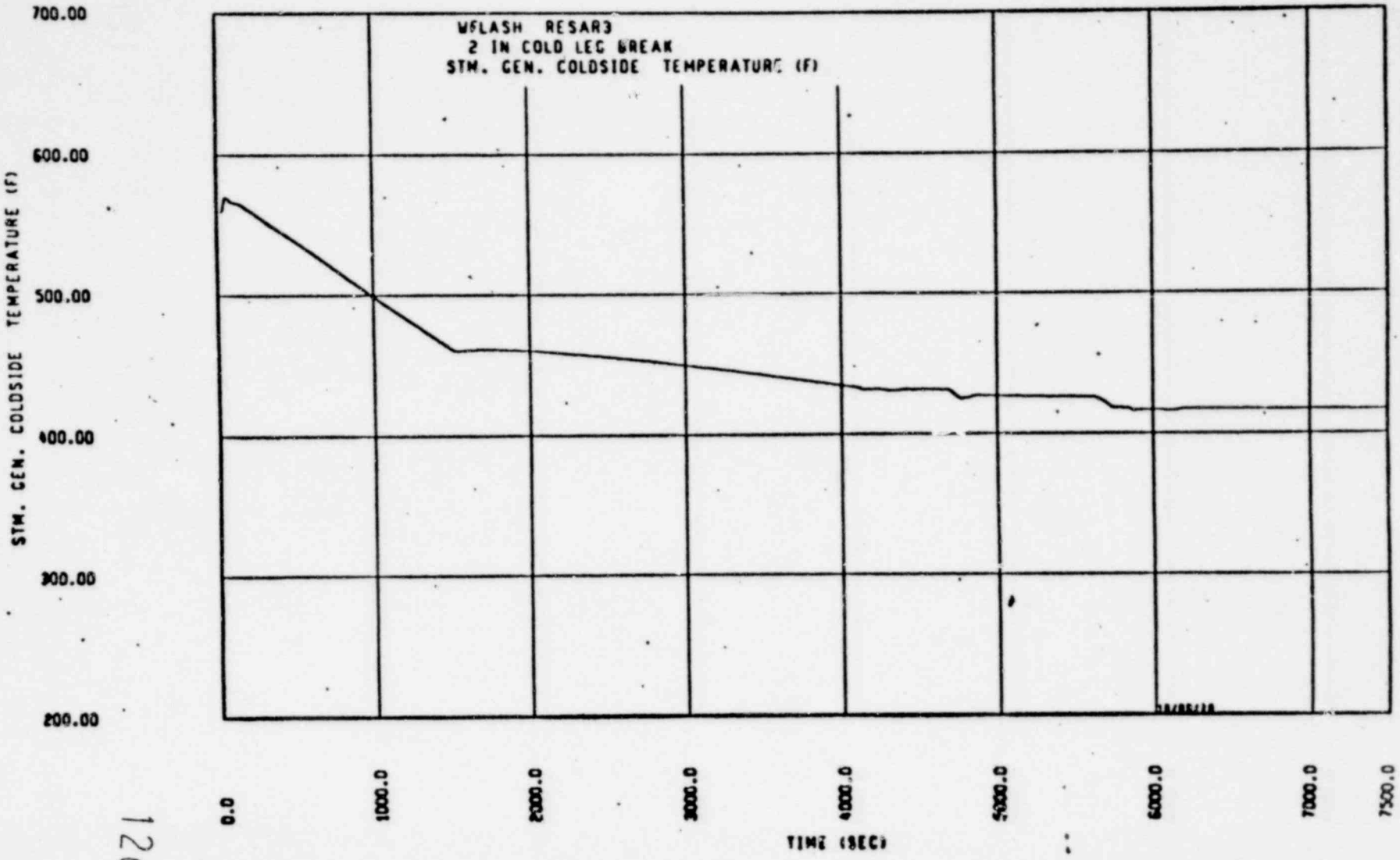

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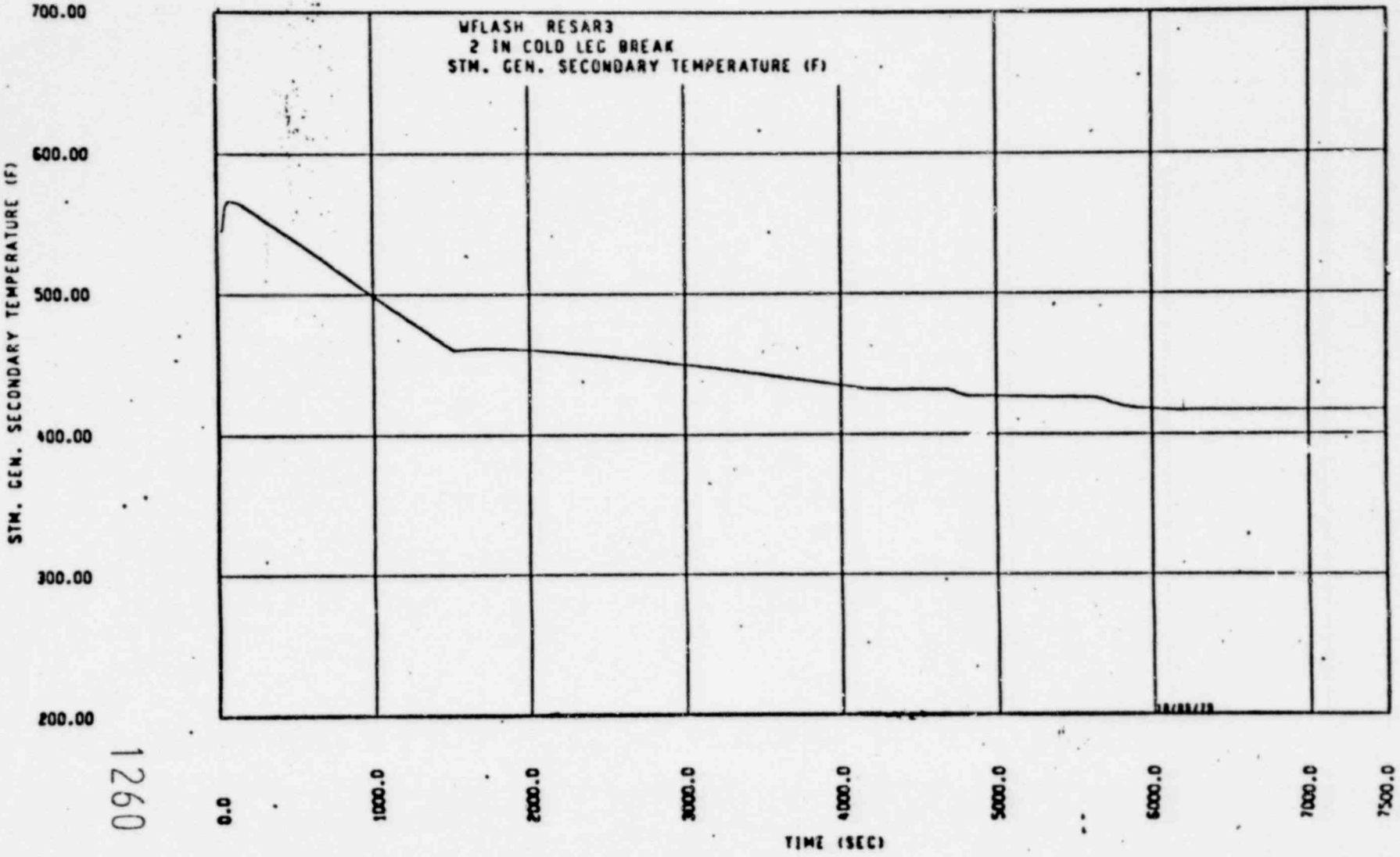

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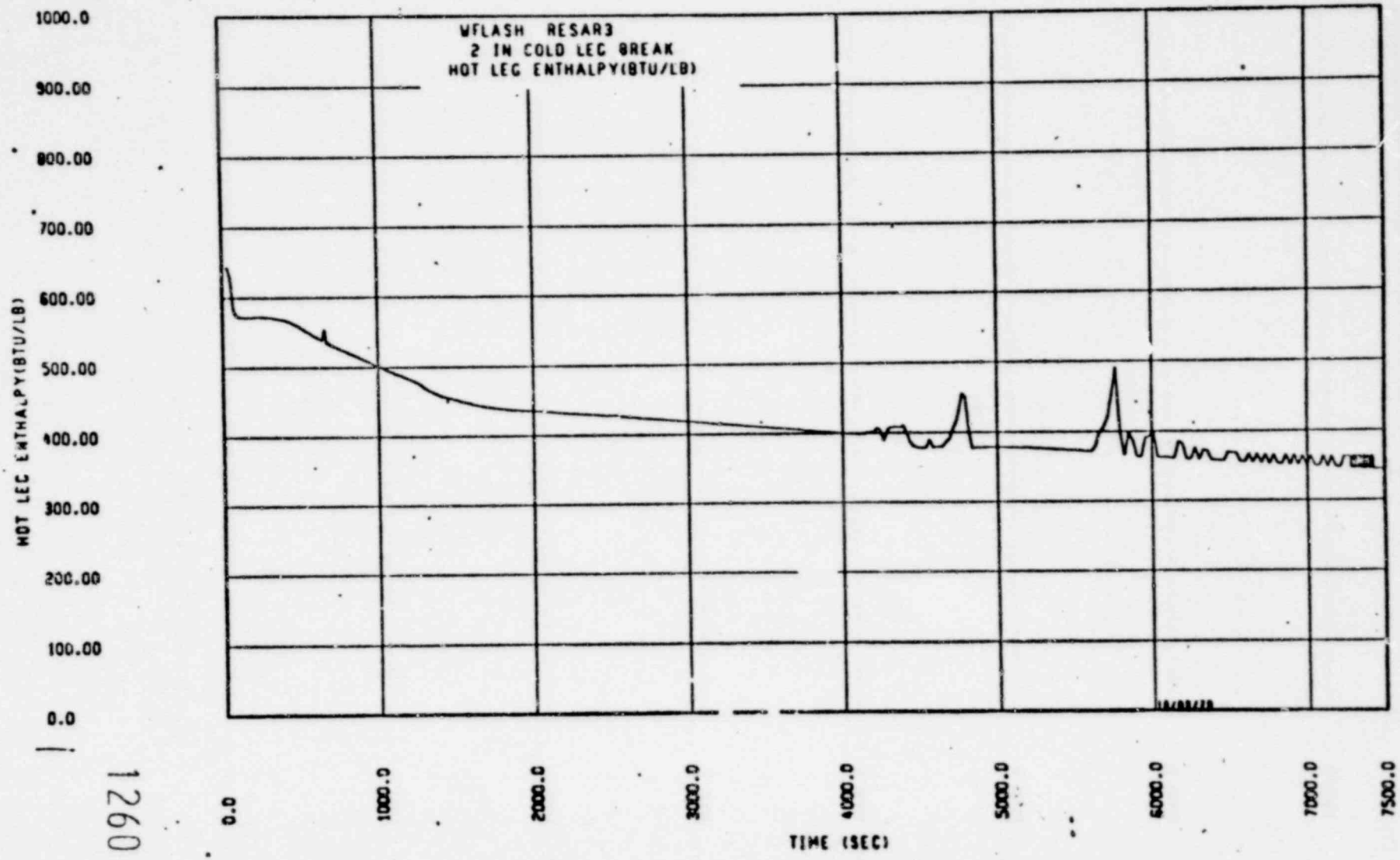

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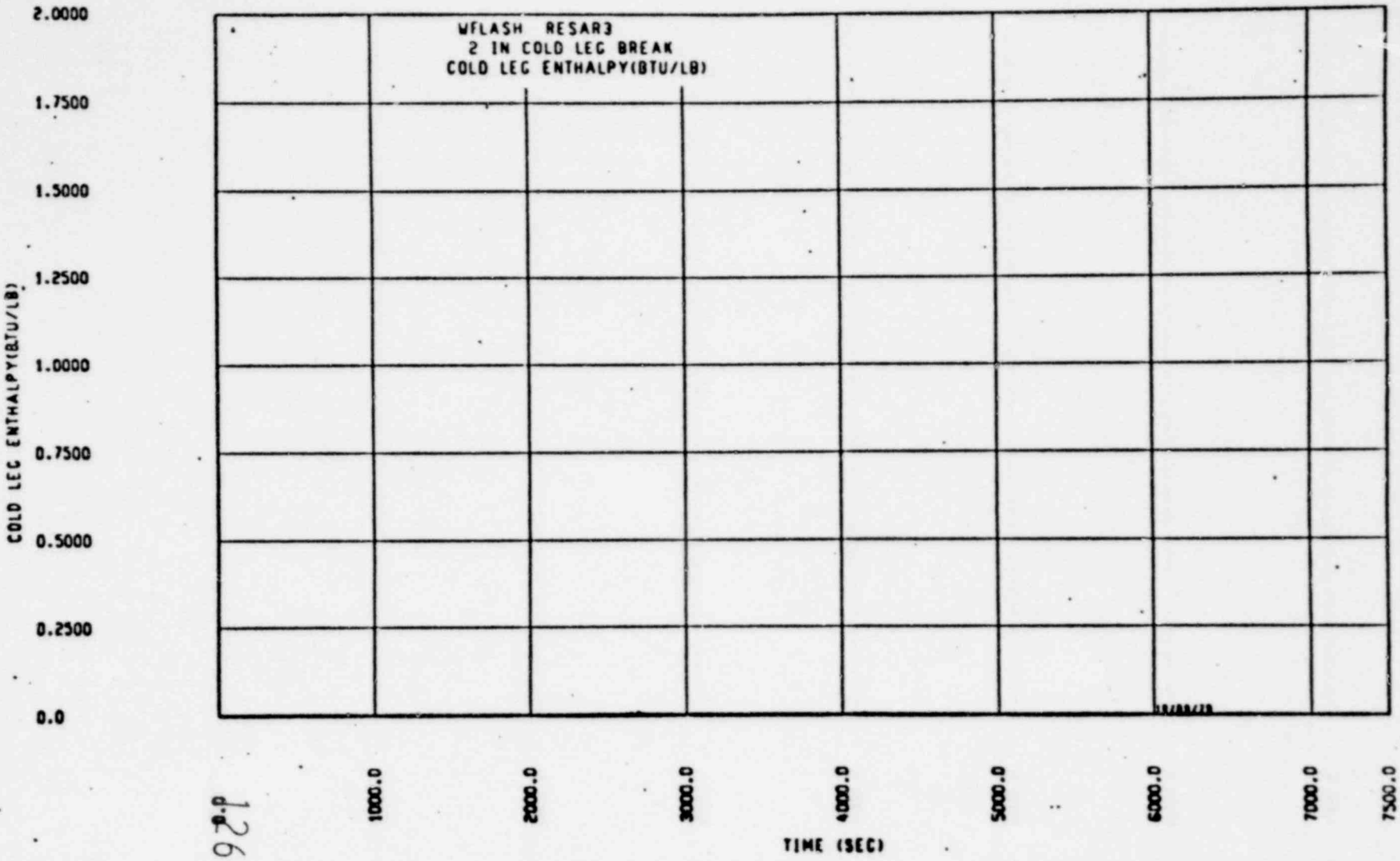
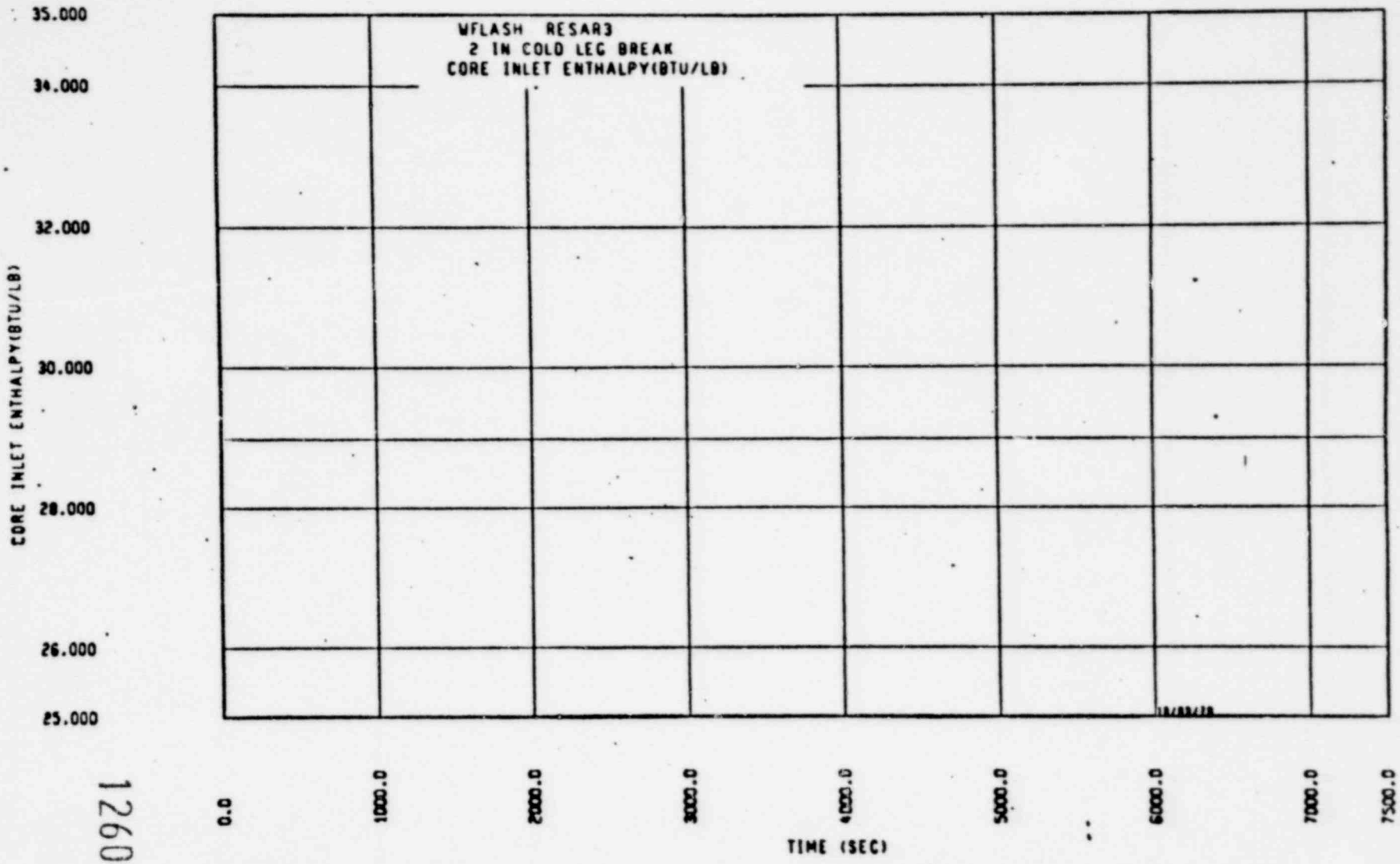

WFLASH RESAR3
2 IN COLD LEG BREAK
COLD LEG ENTHALPY(BTU/LB)
COLD LEG ENTHALPY(BTU/LB)
2.0000
1.7500
1.5000
1.2500
1.0000
0.7500
0.5000
0.2500
0.0
1000.0
2000.0
3000.0
4000.0
5000.0
6000.0
7000.0
7500.0
TIME (SEC)

Figure 27



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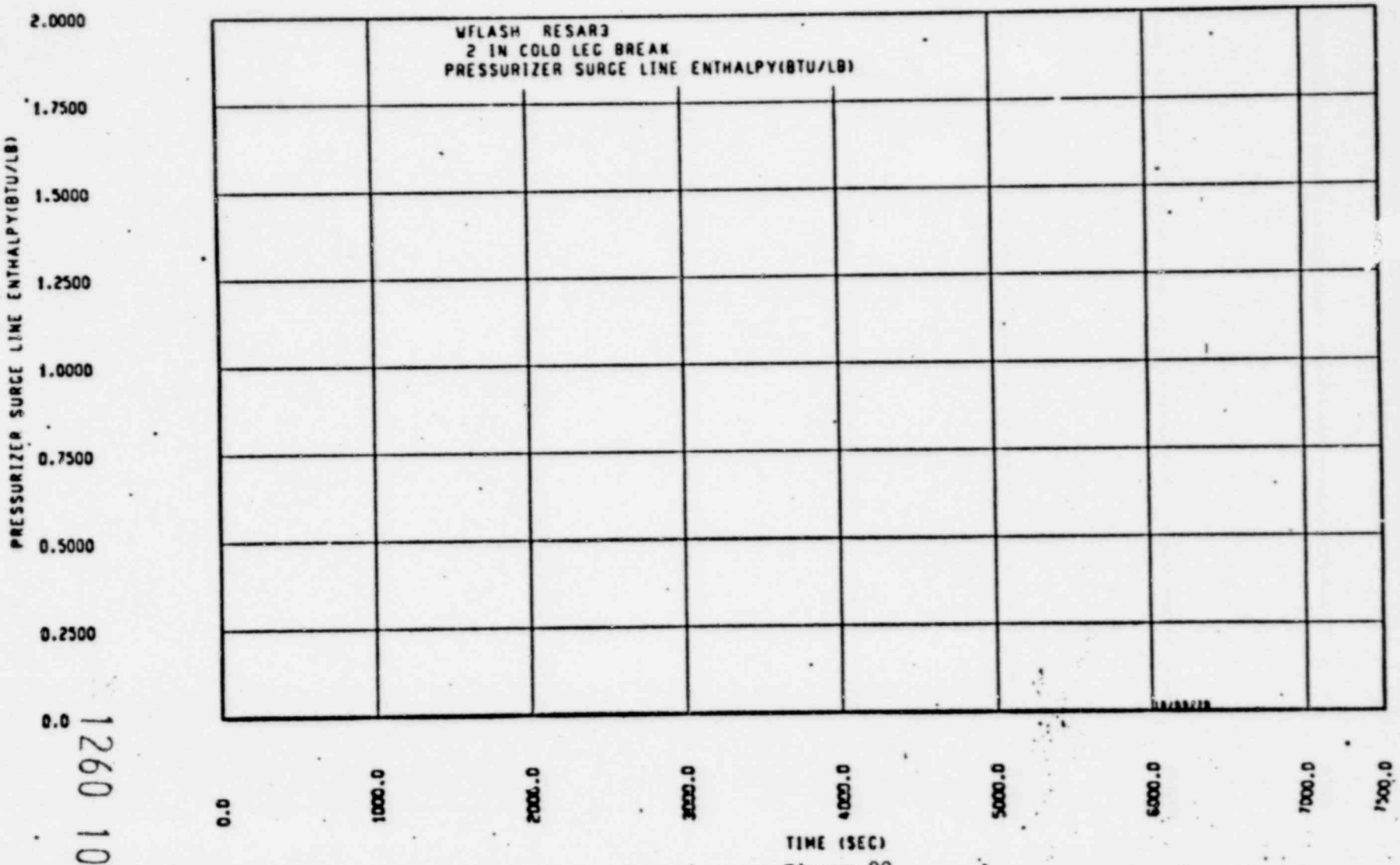

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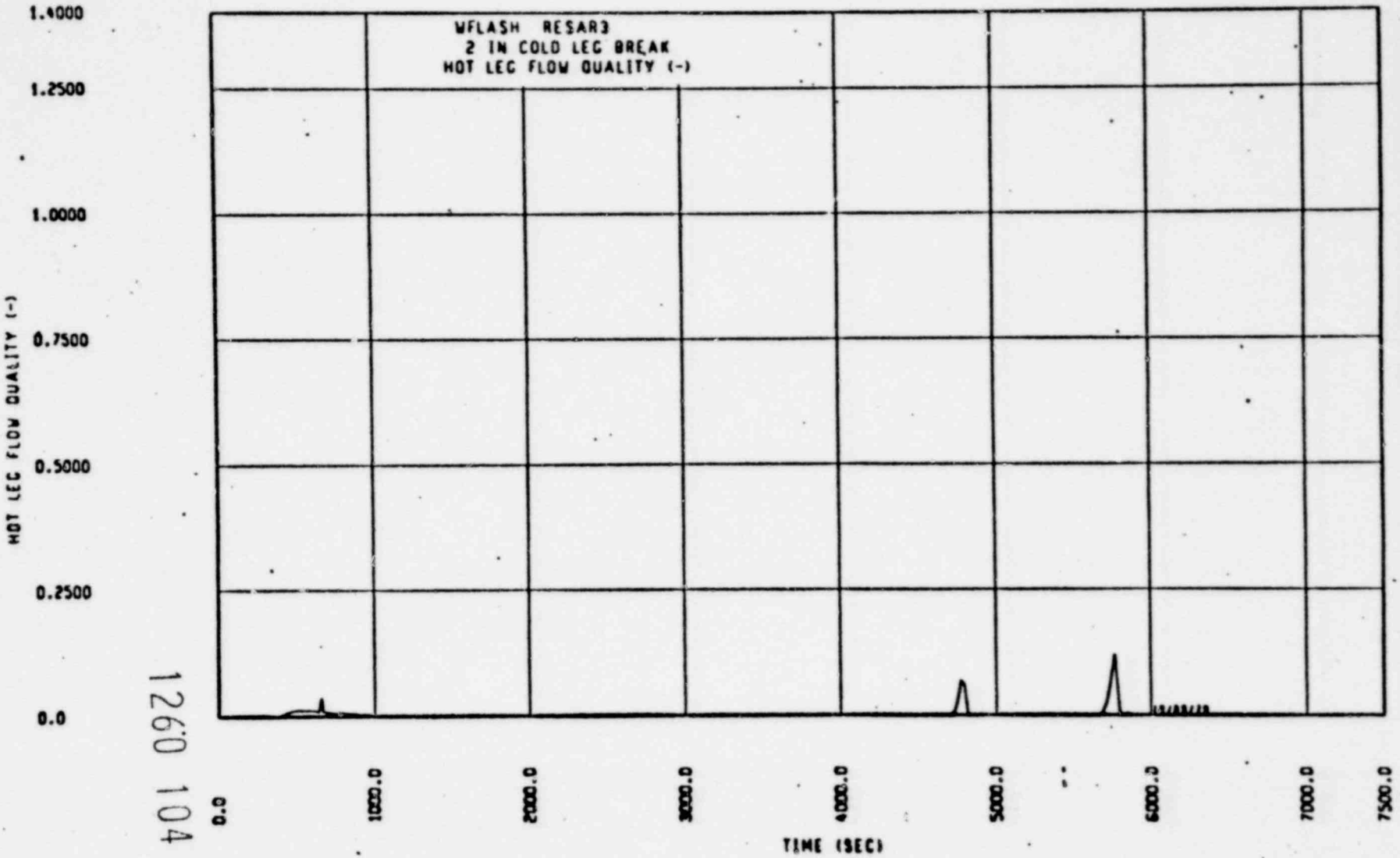

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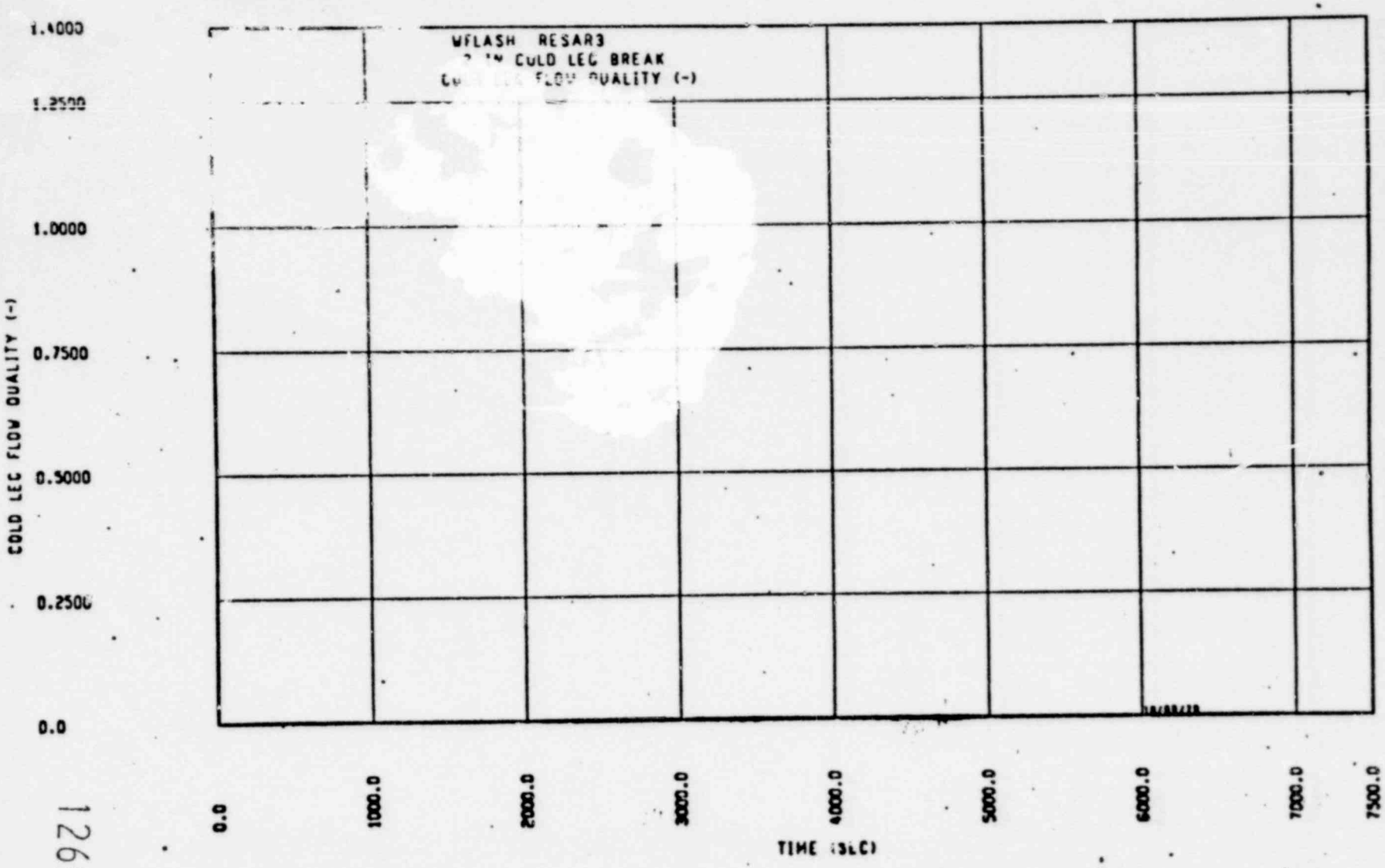

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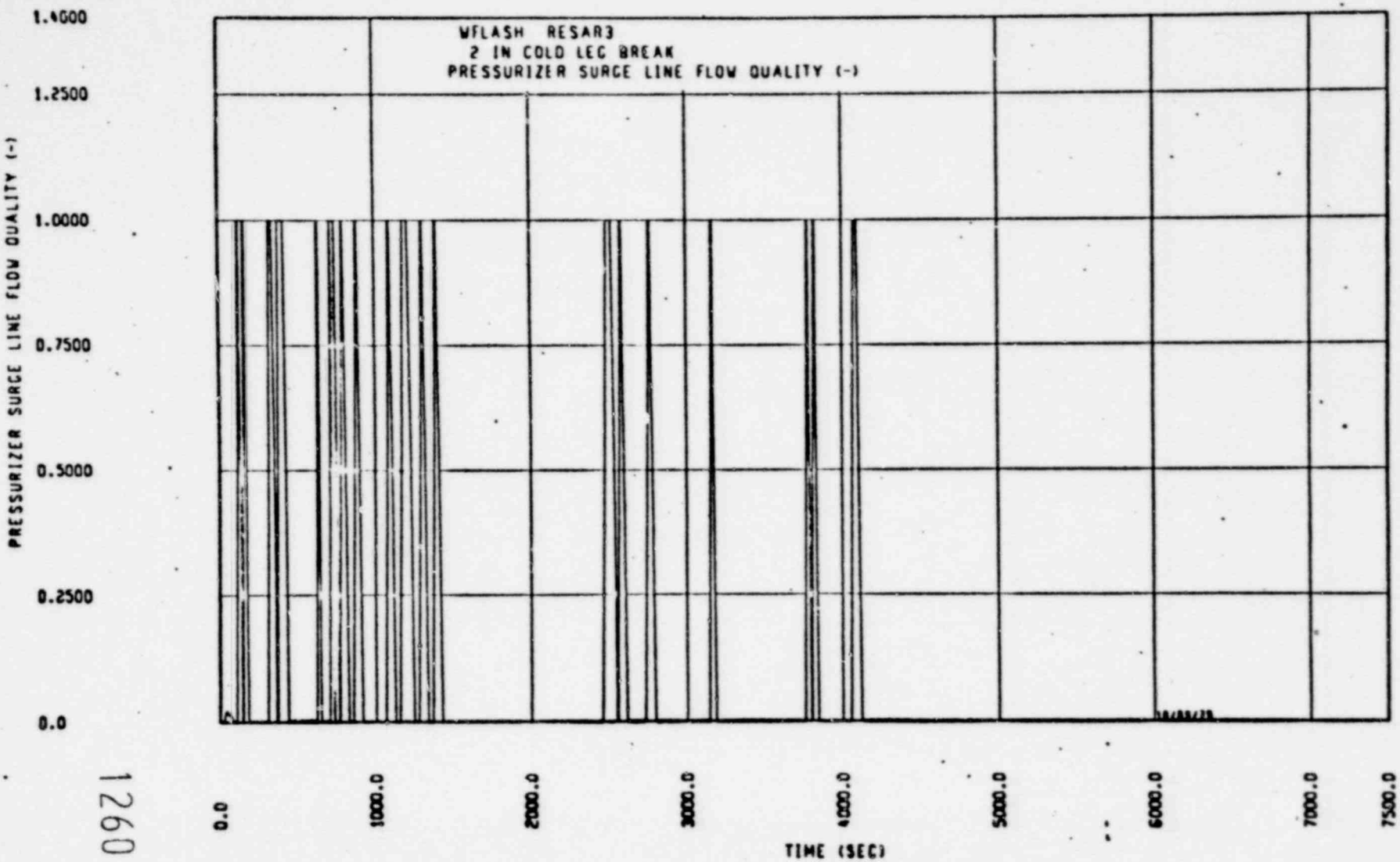

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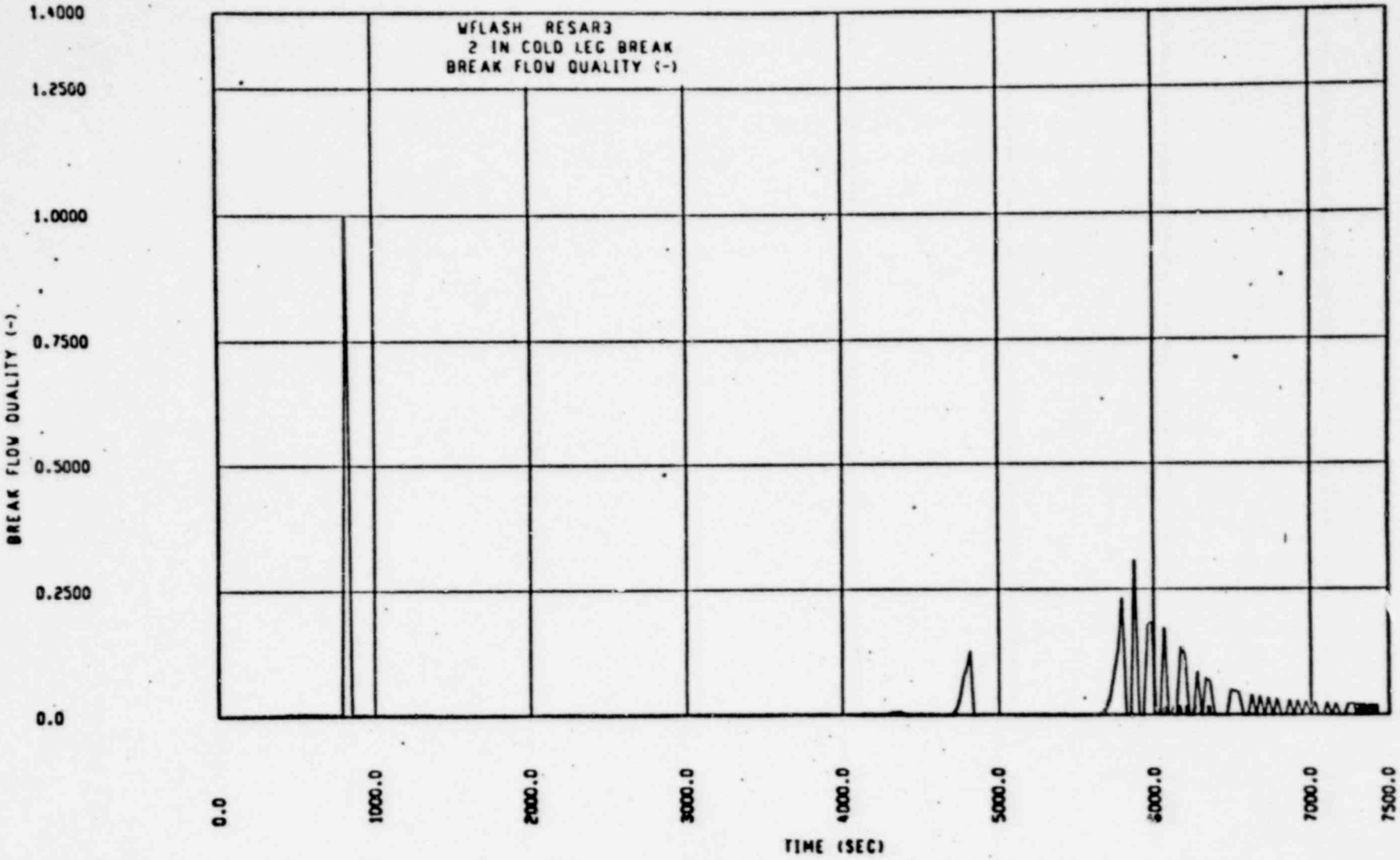

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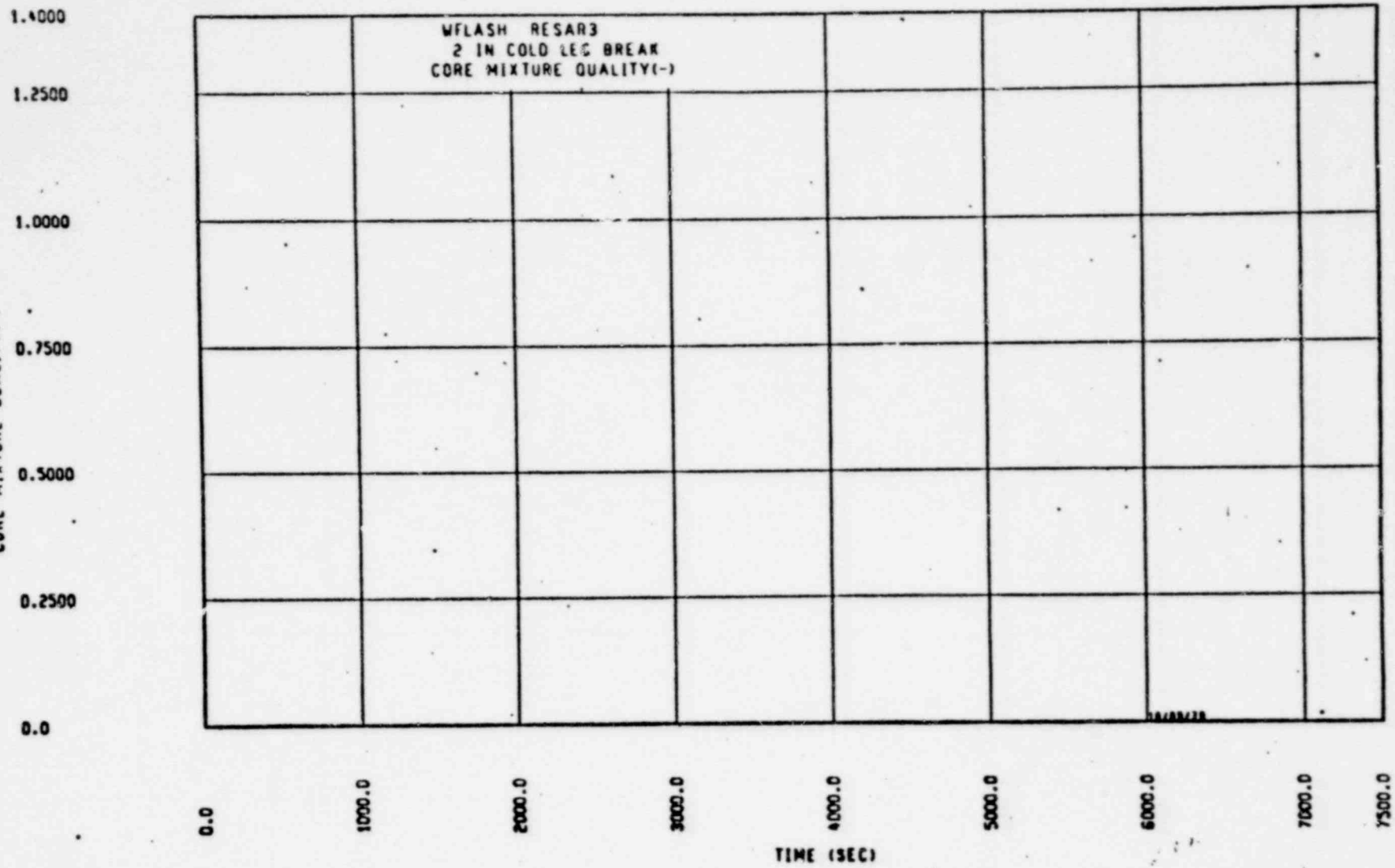

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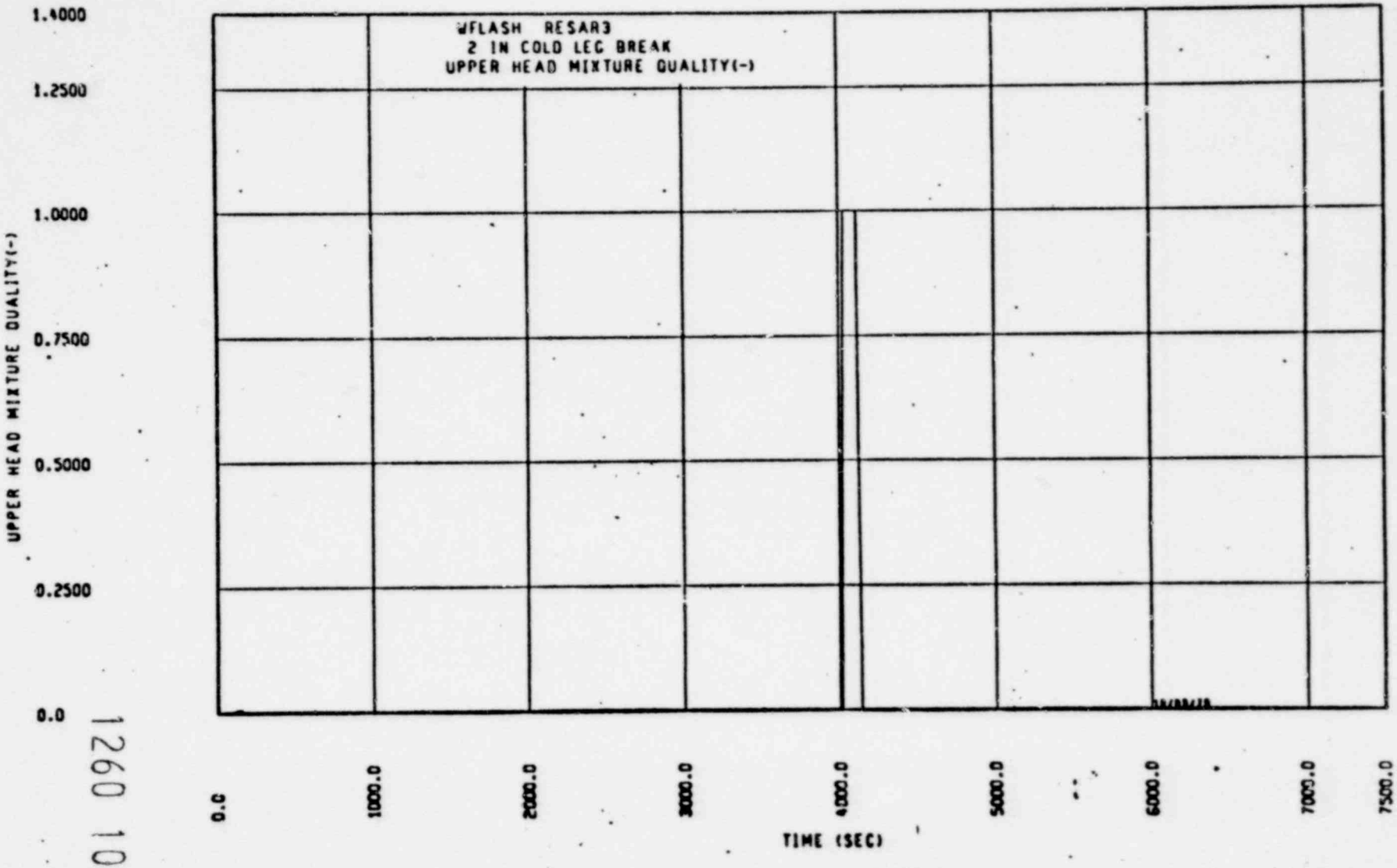

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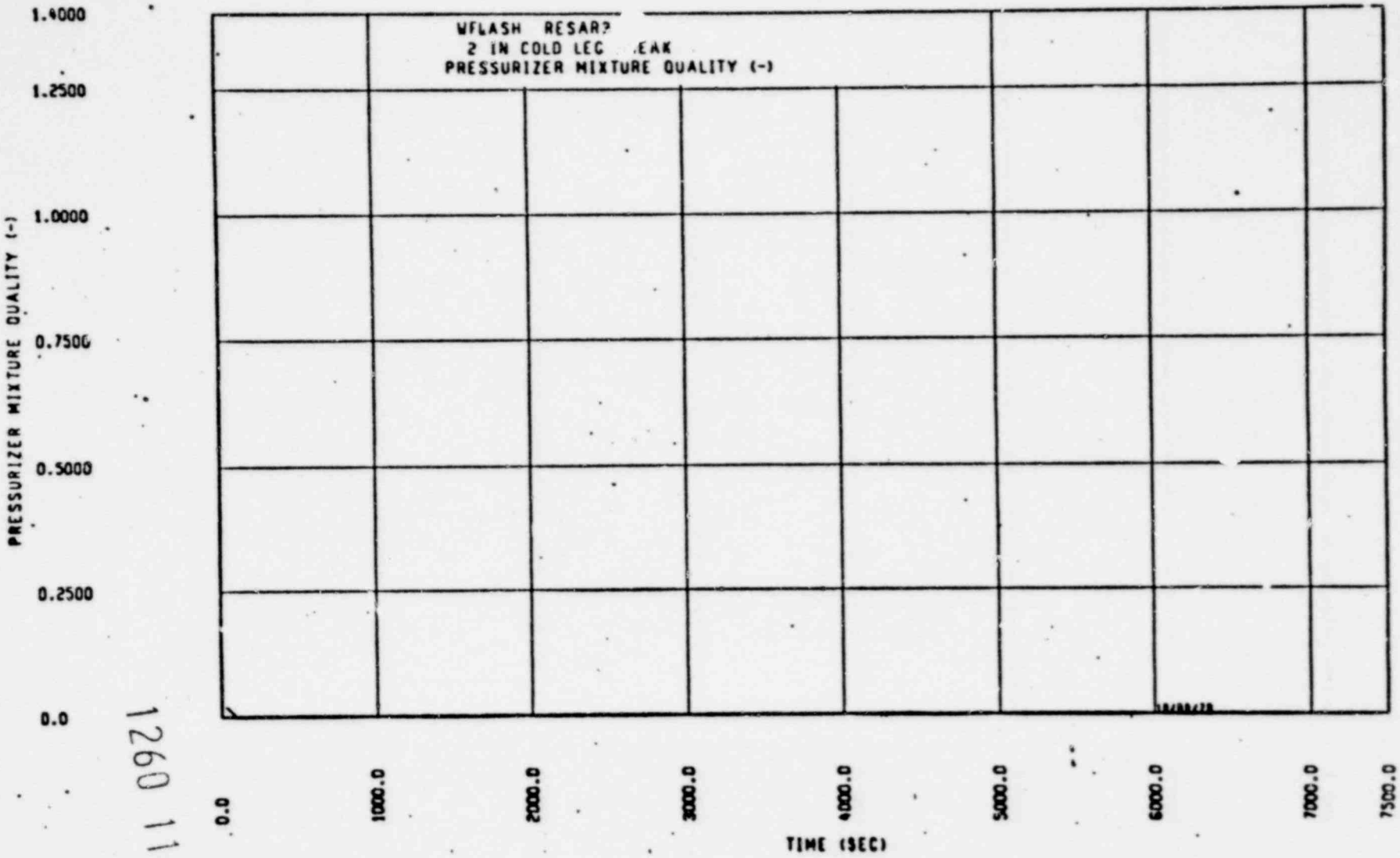

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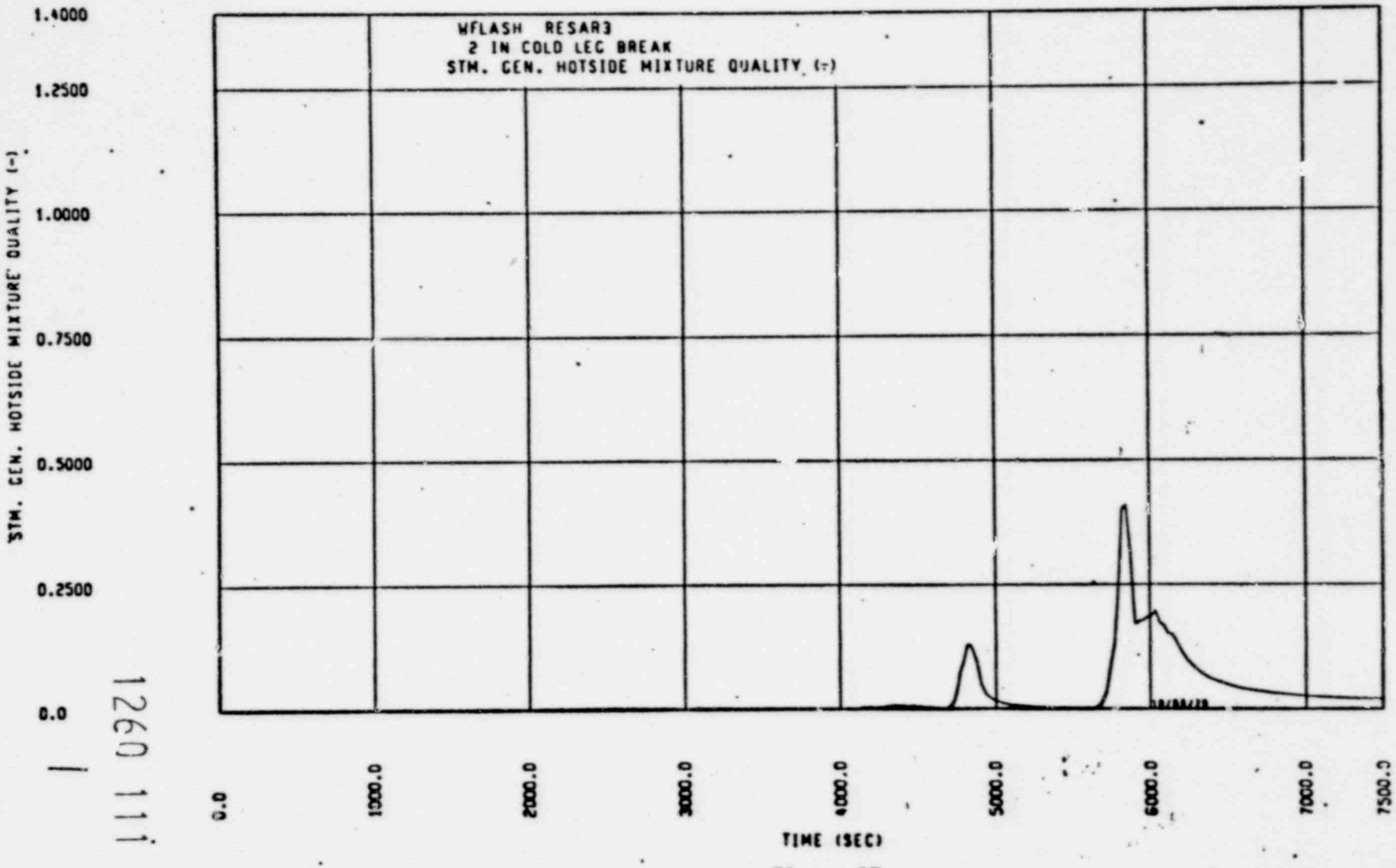
Figure 36



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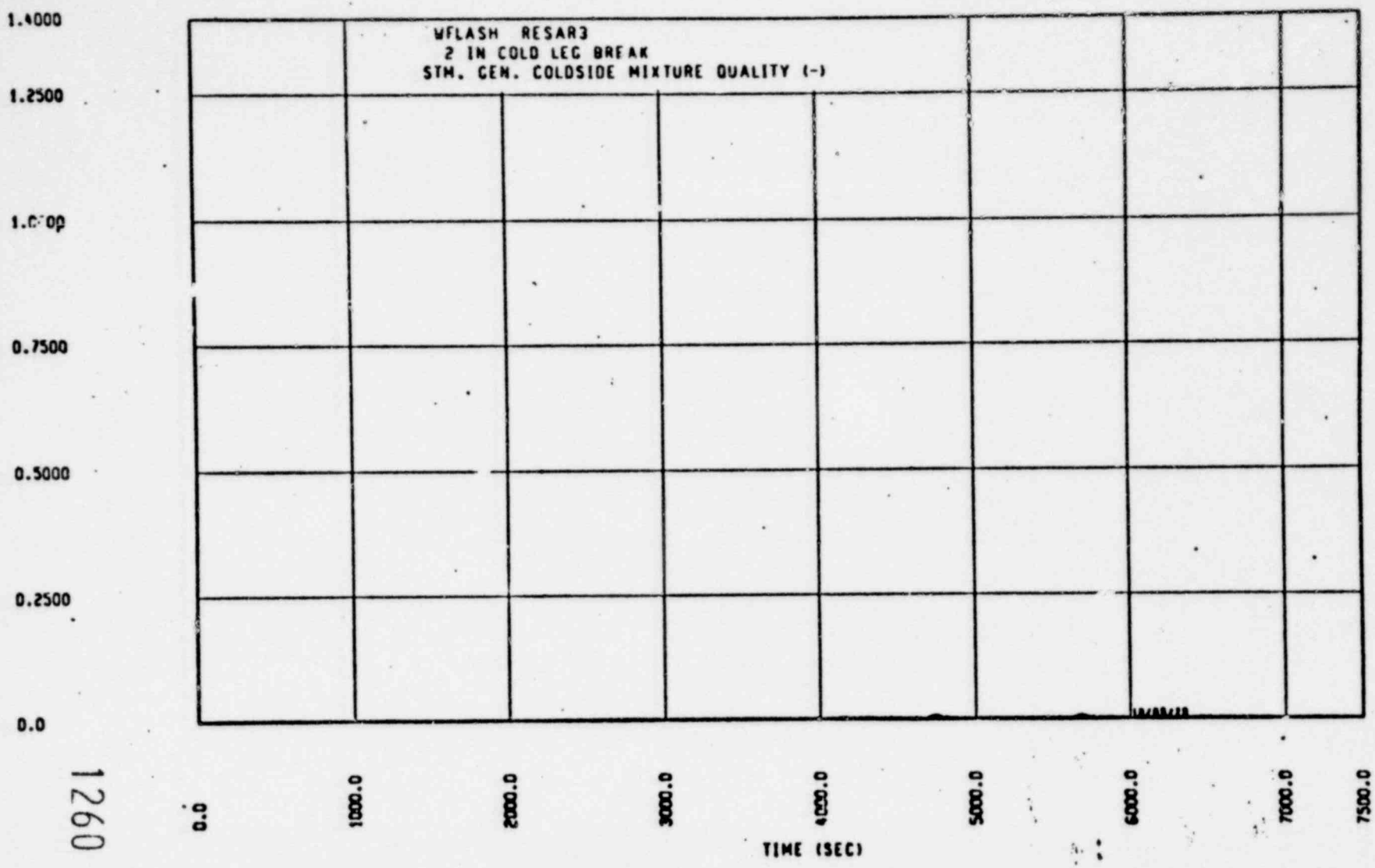

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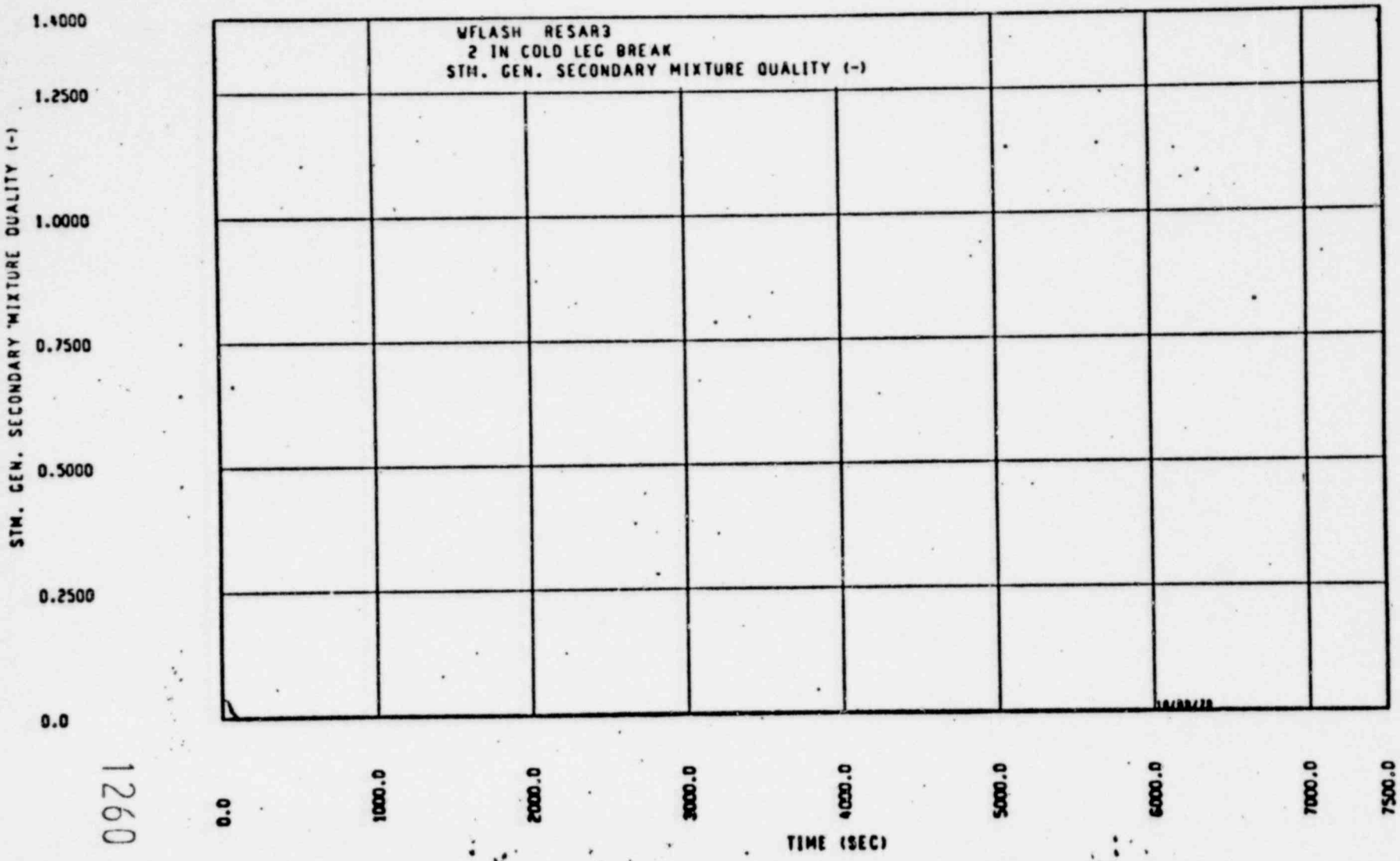

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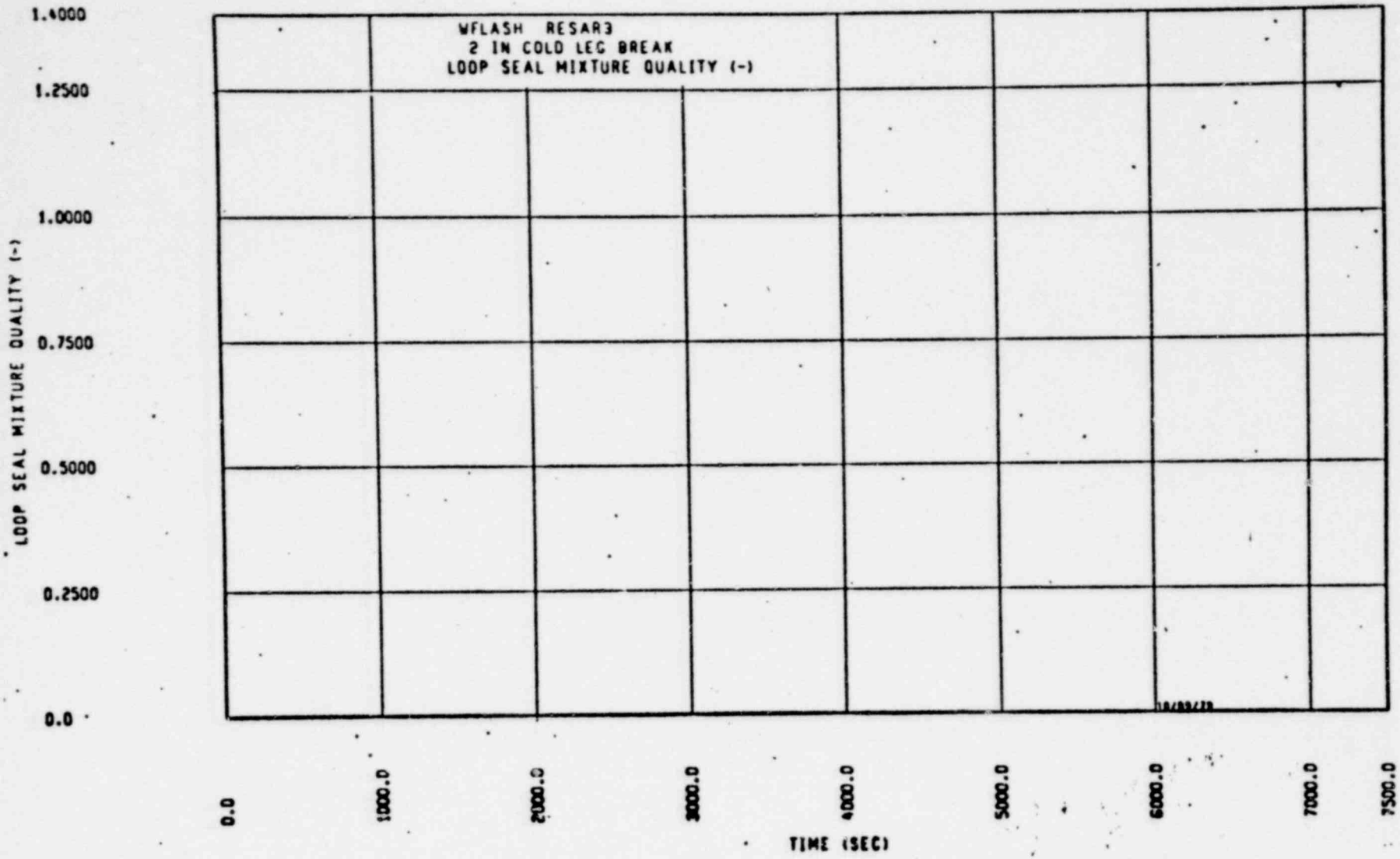


Figure 40

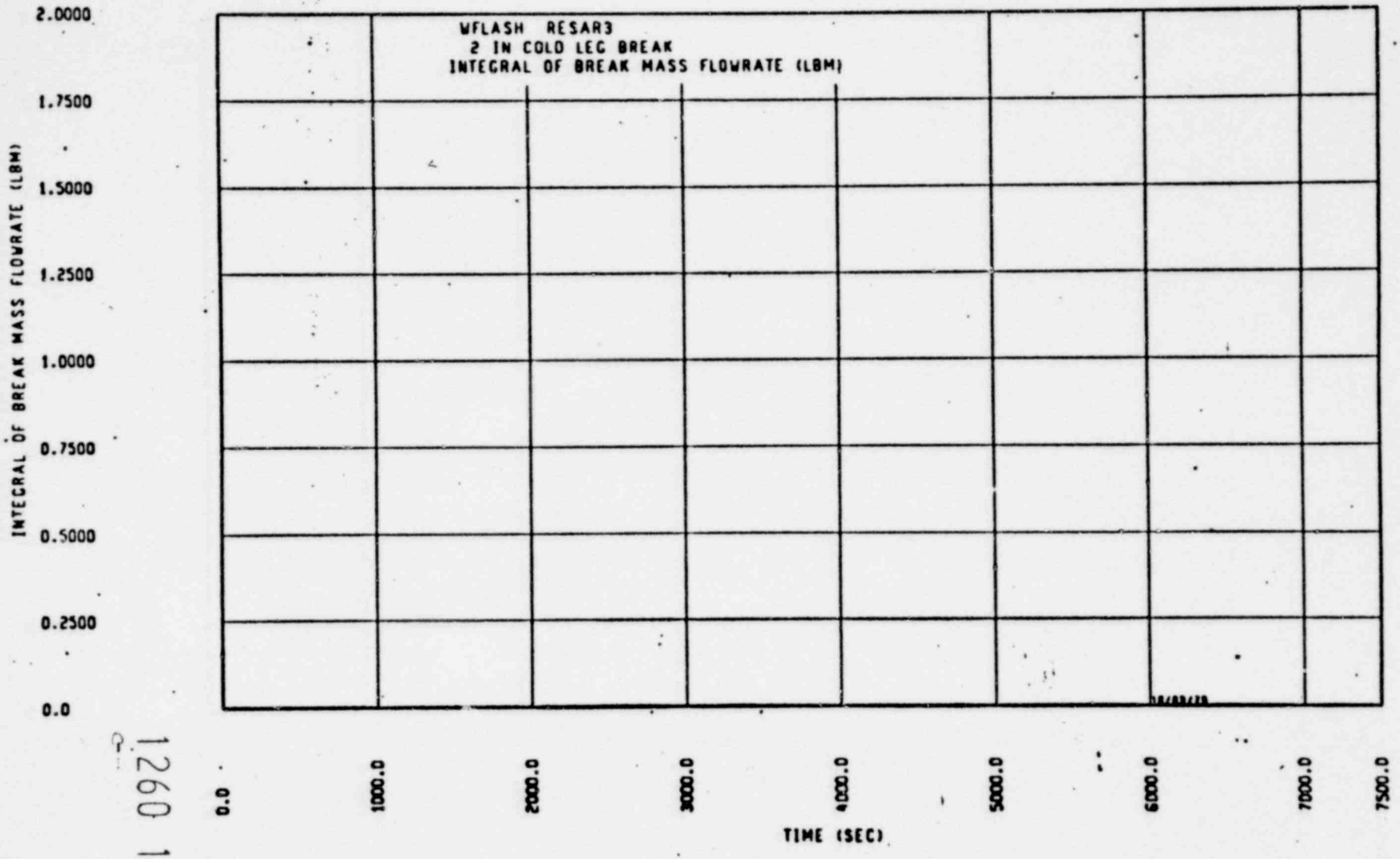


Figure 41

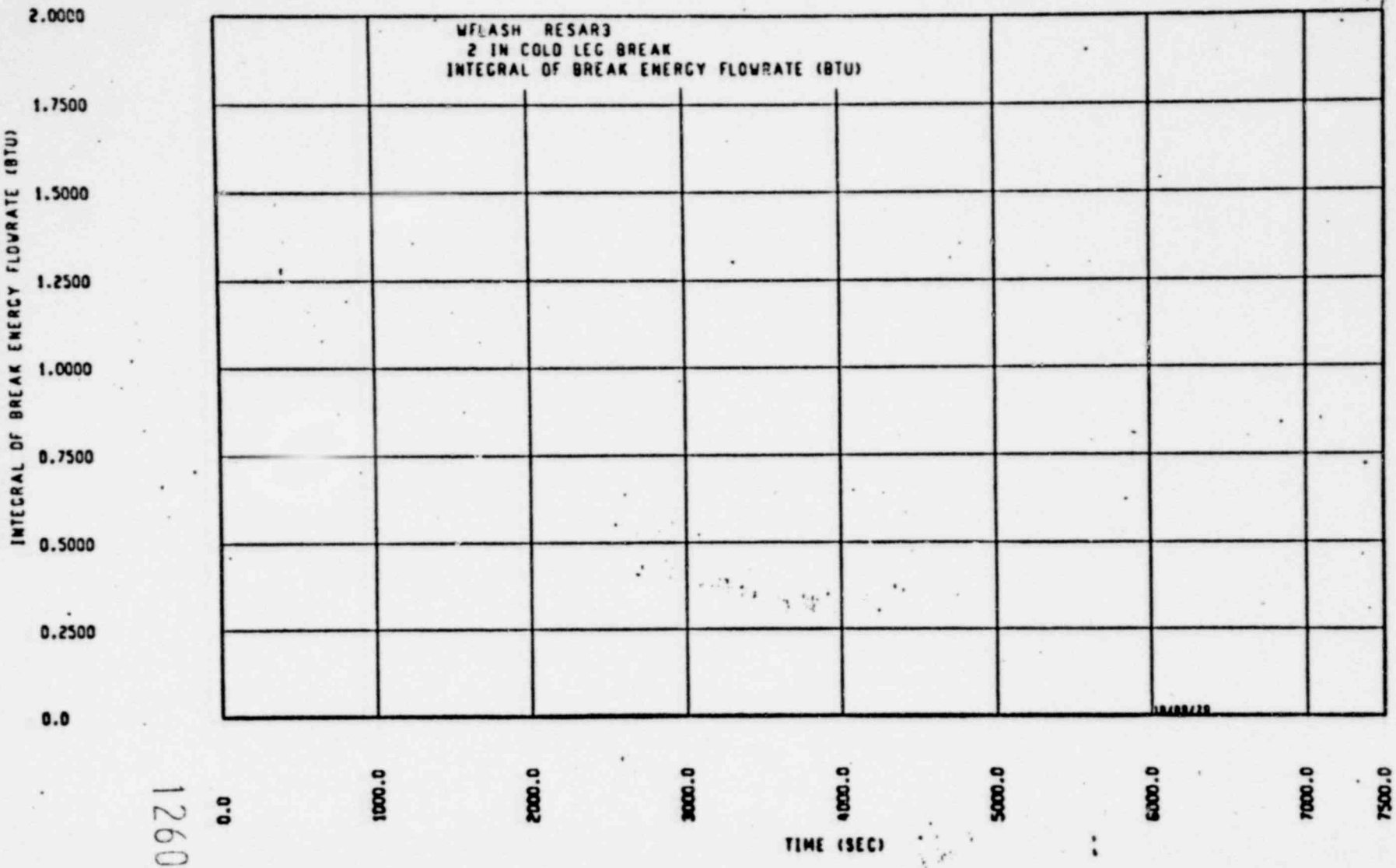


Figure 42

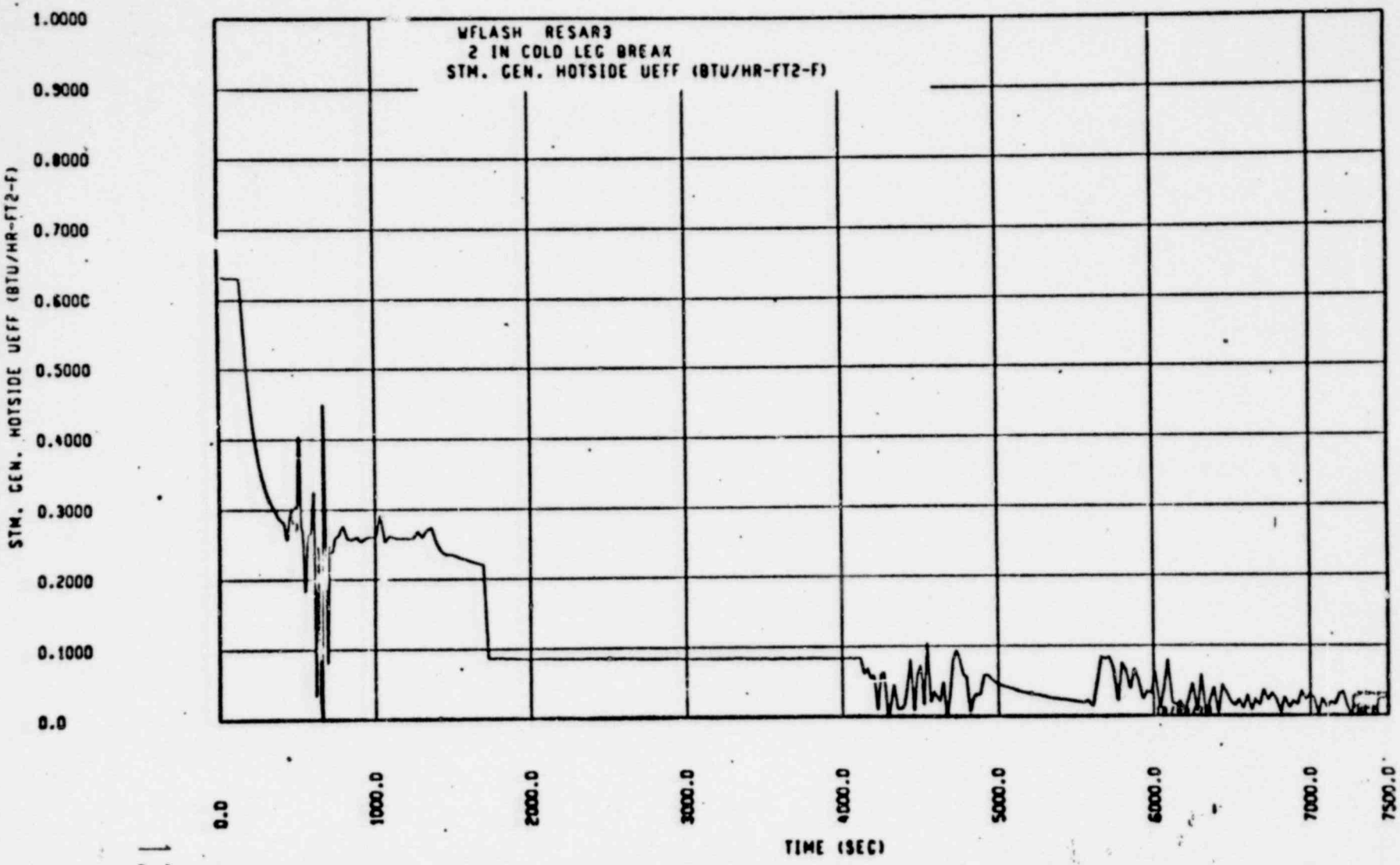


Figure 43

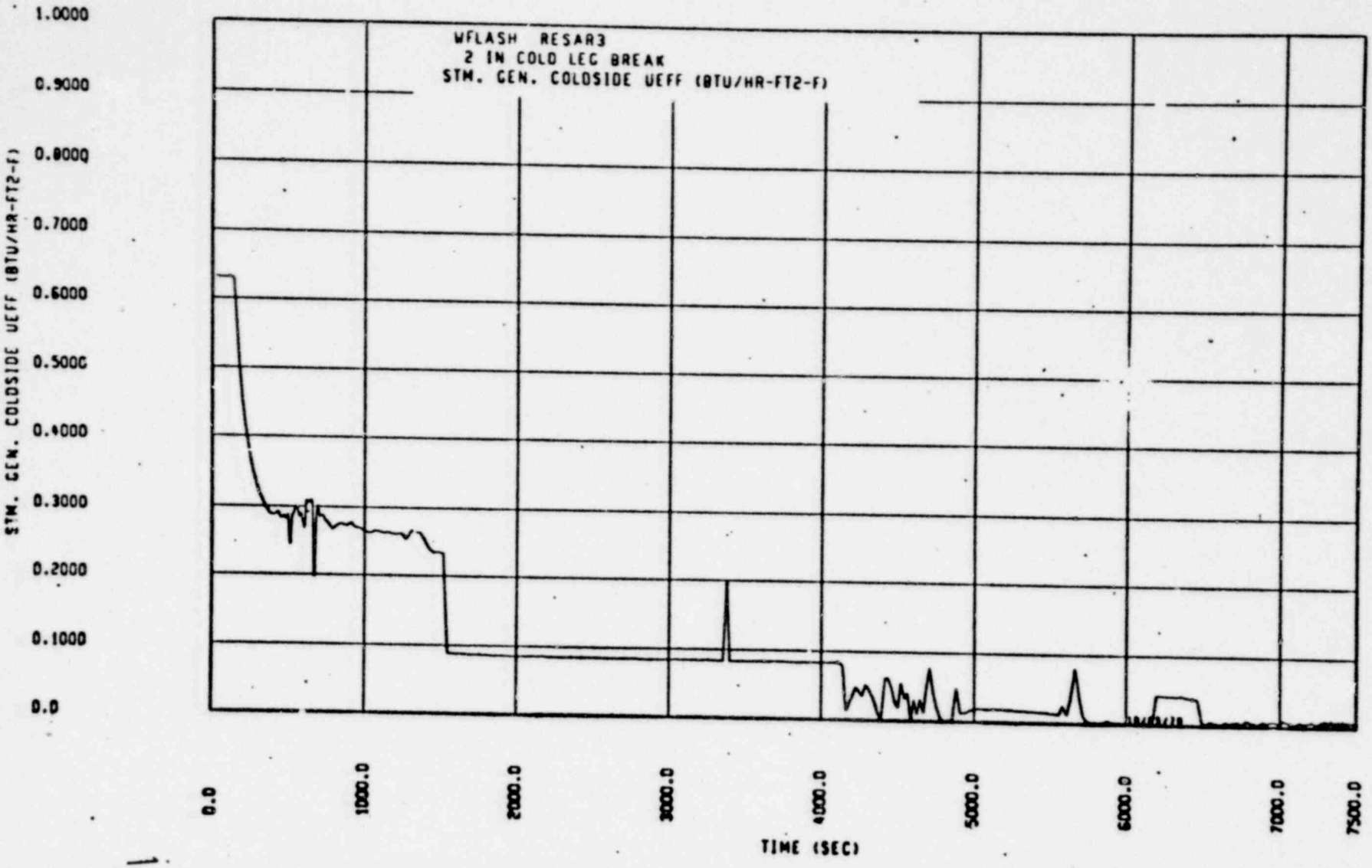


Figure 44

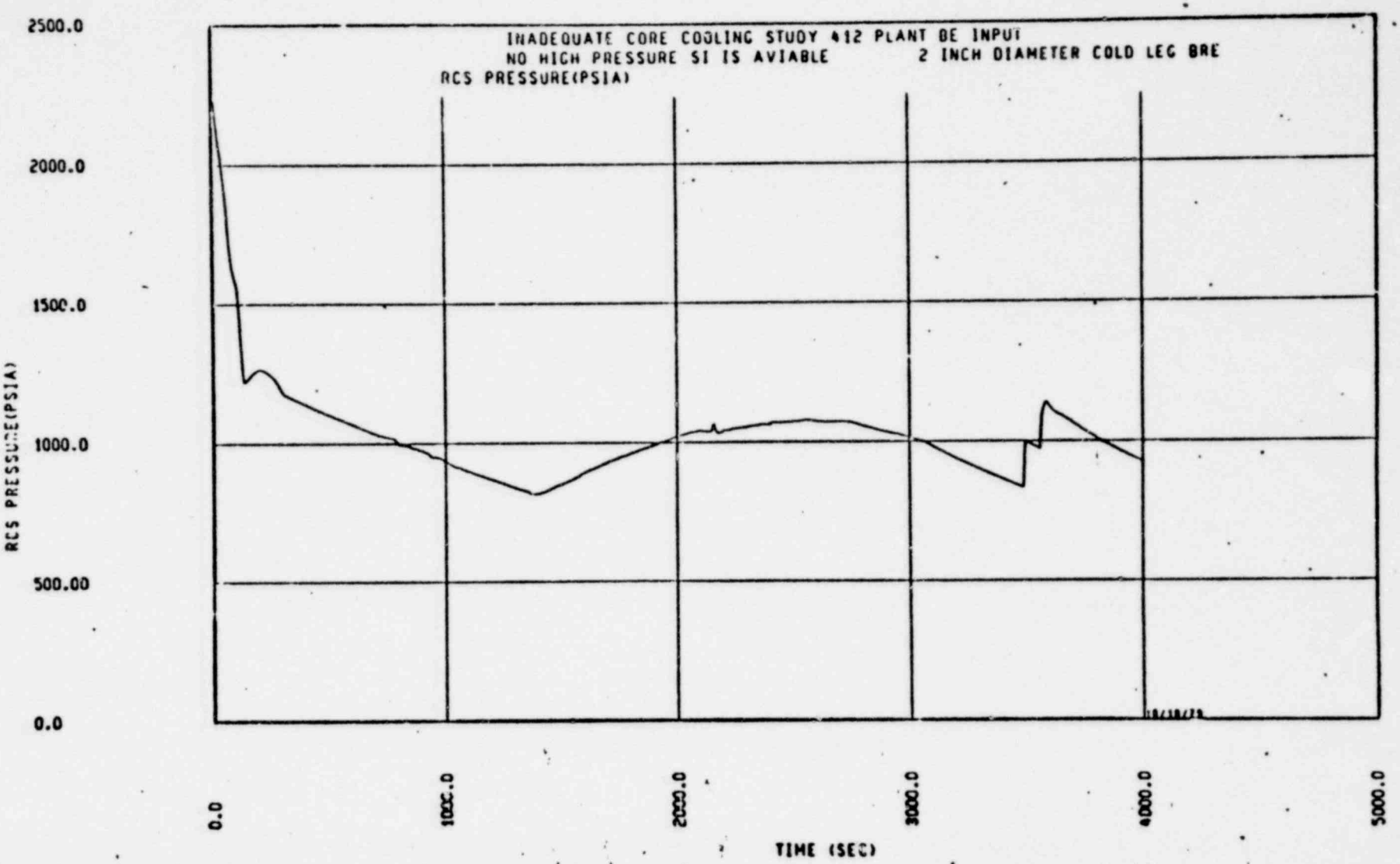


Figure 45

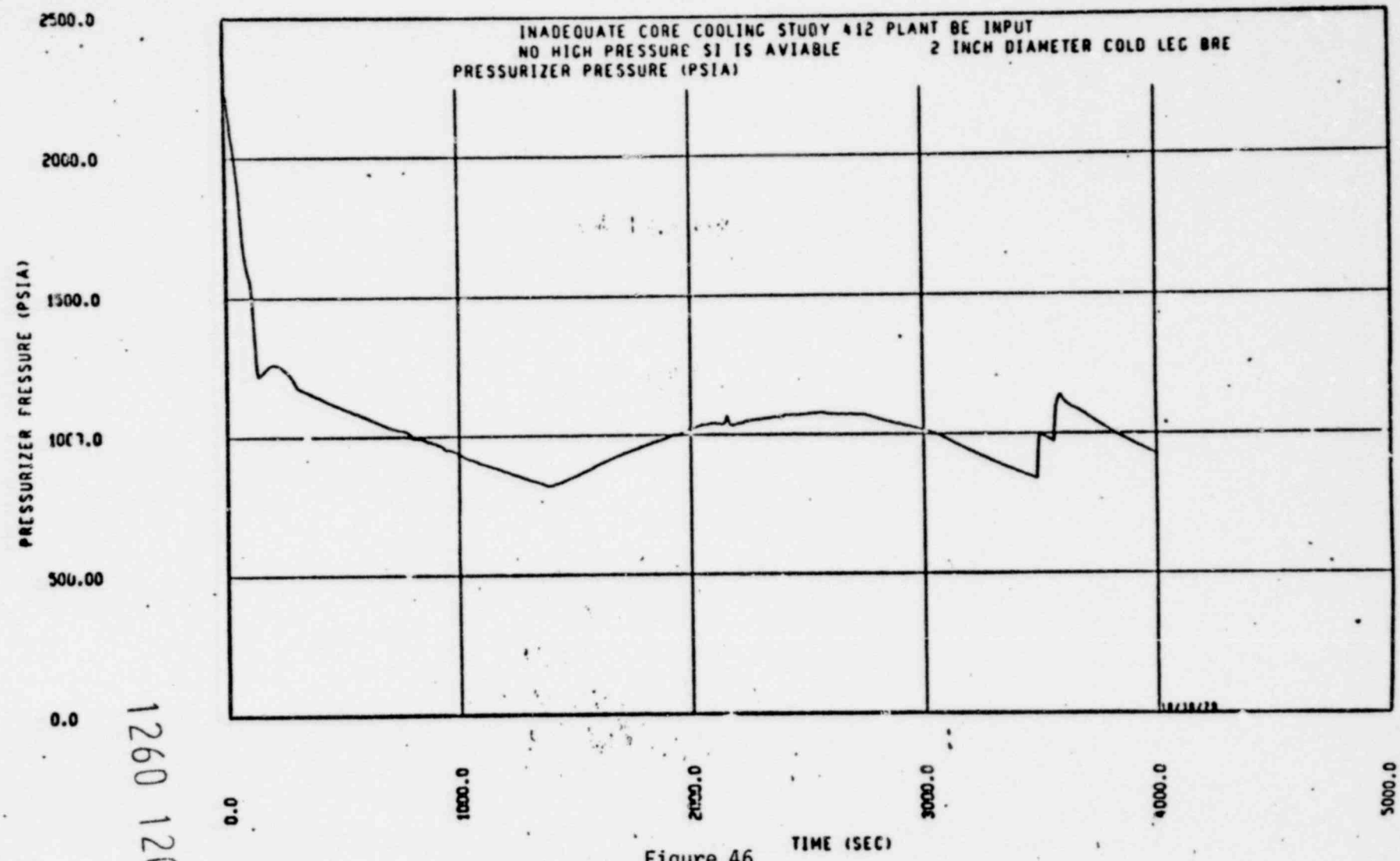


Figure 46

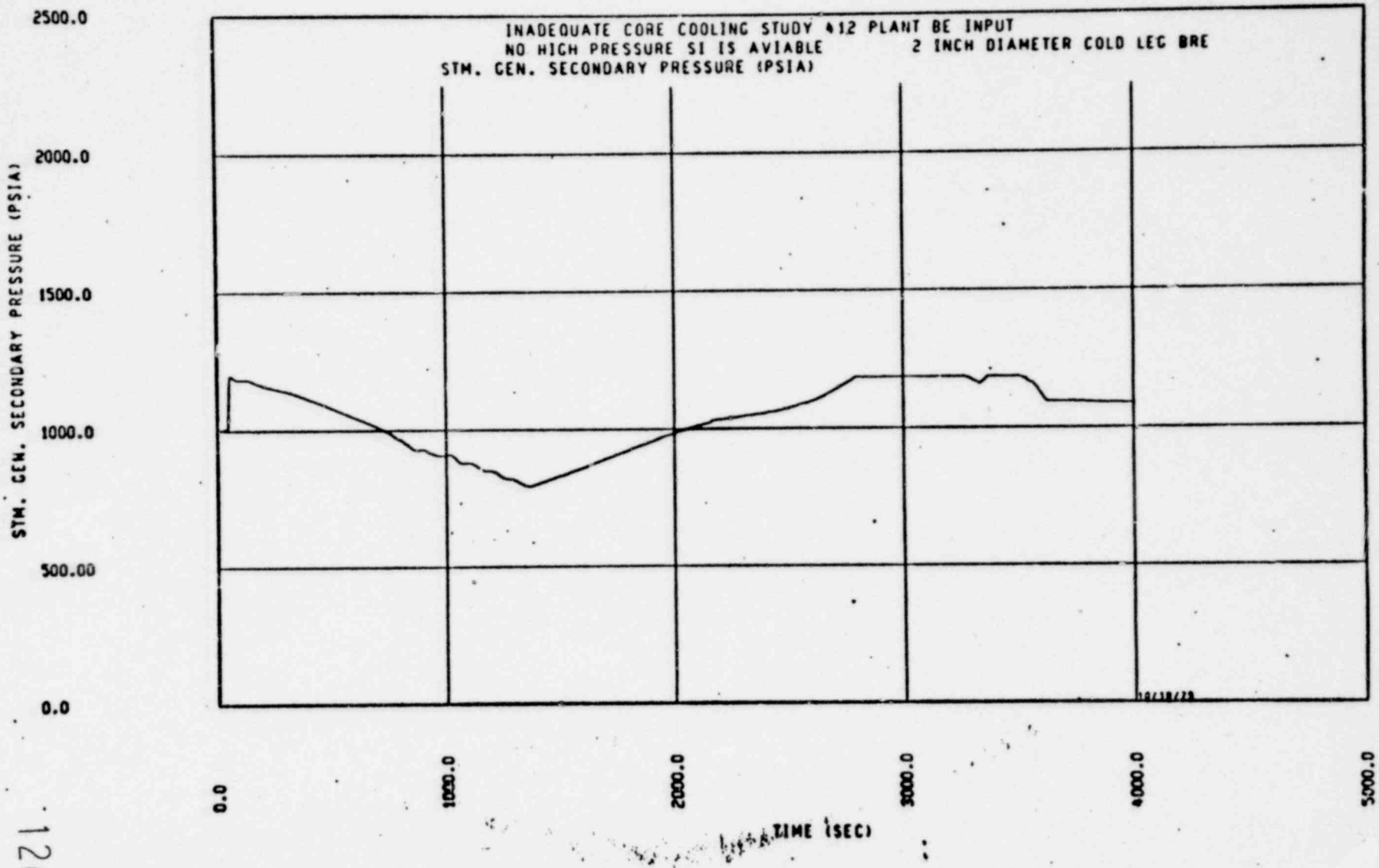


Figure 47

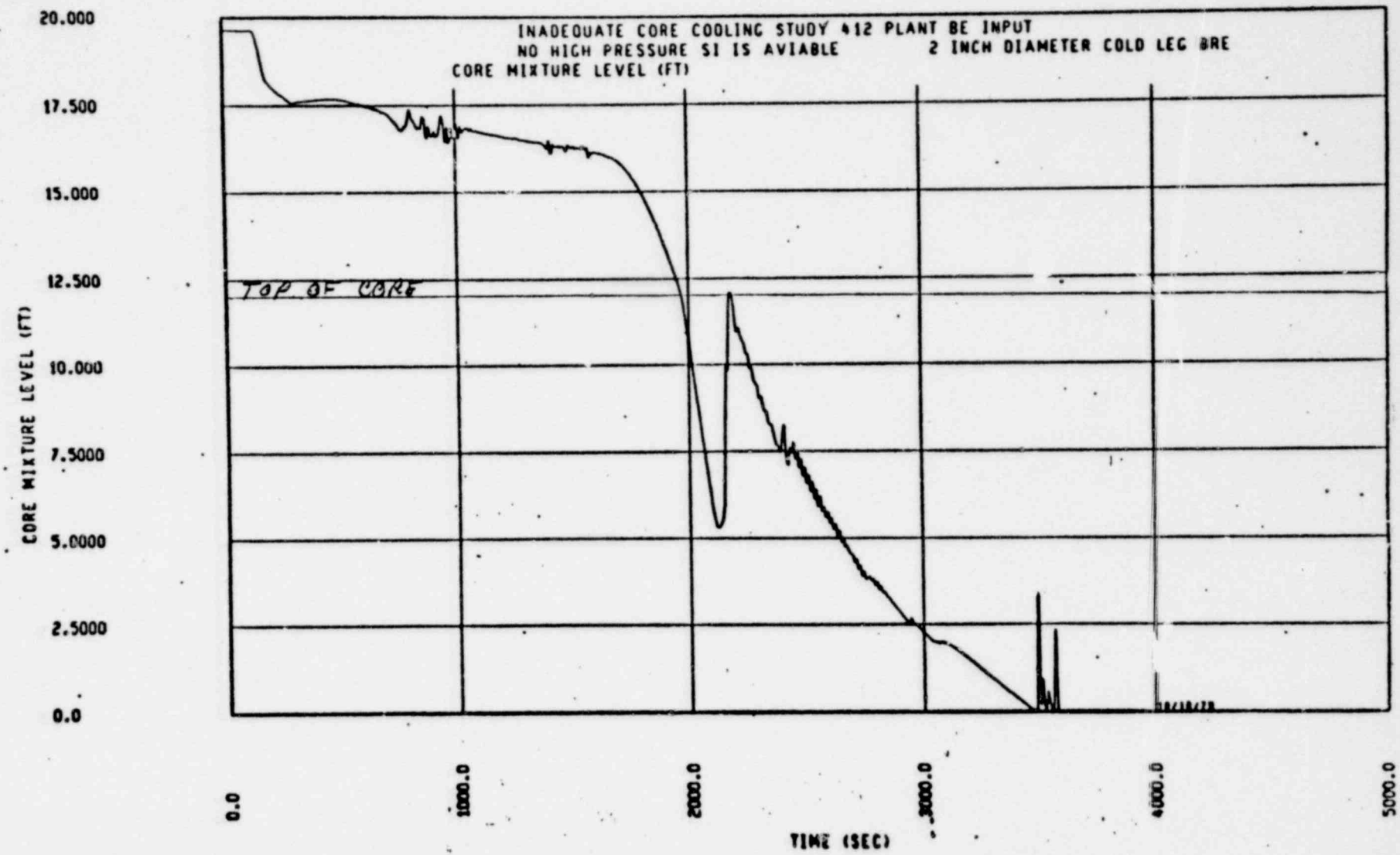


Figure 48

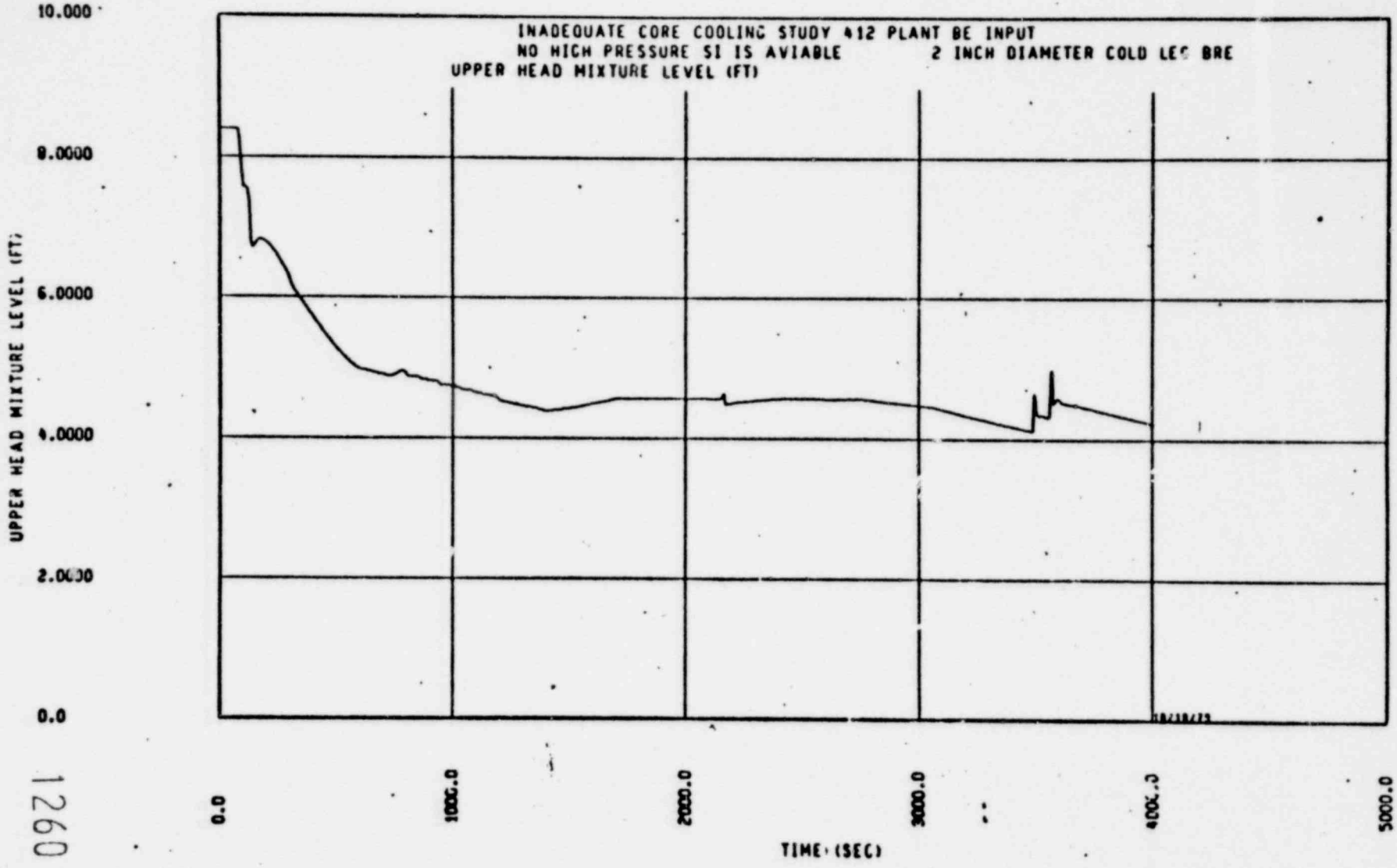


Figure 49

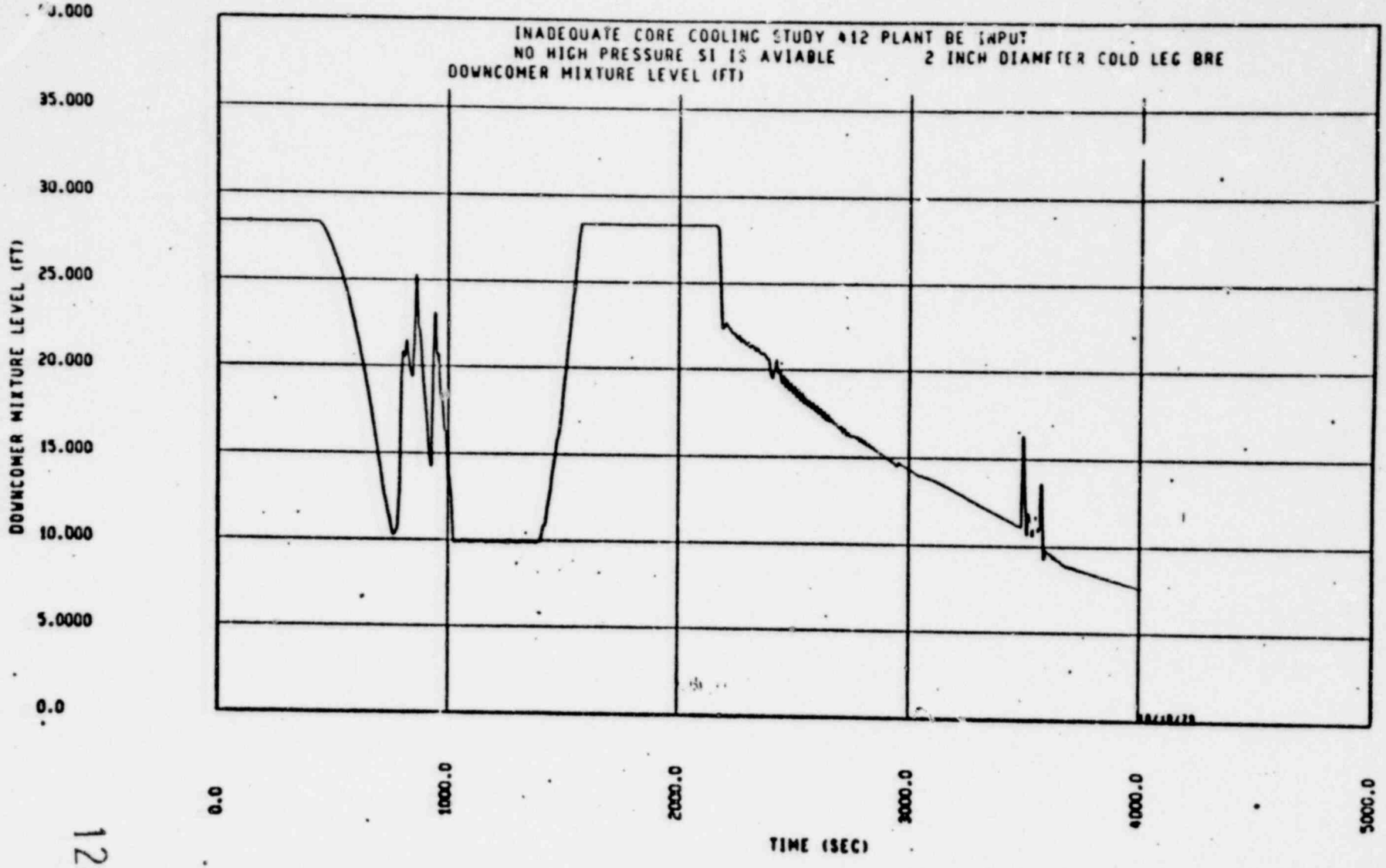


Figure 50

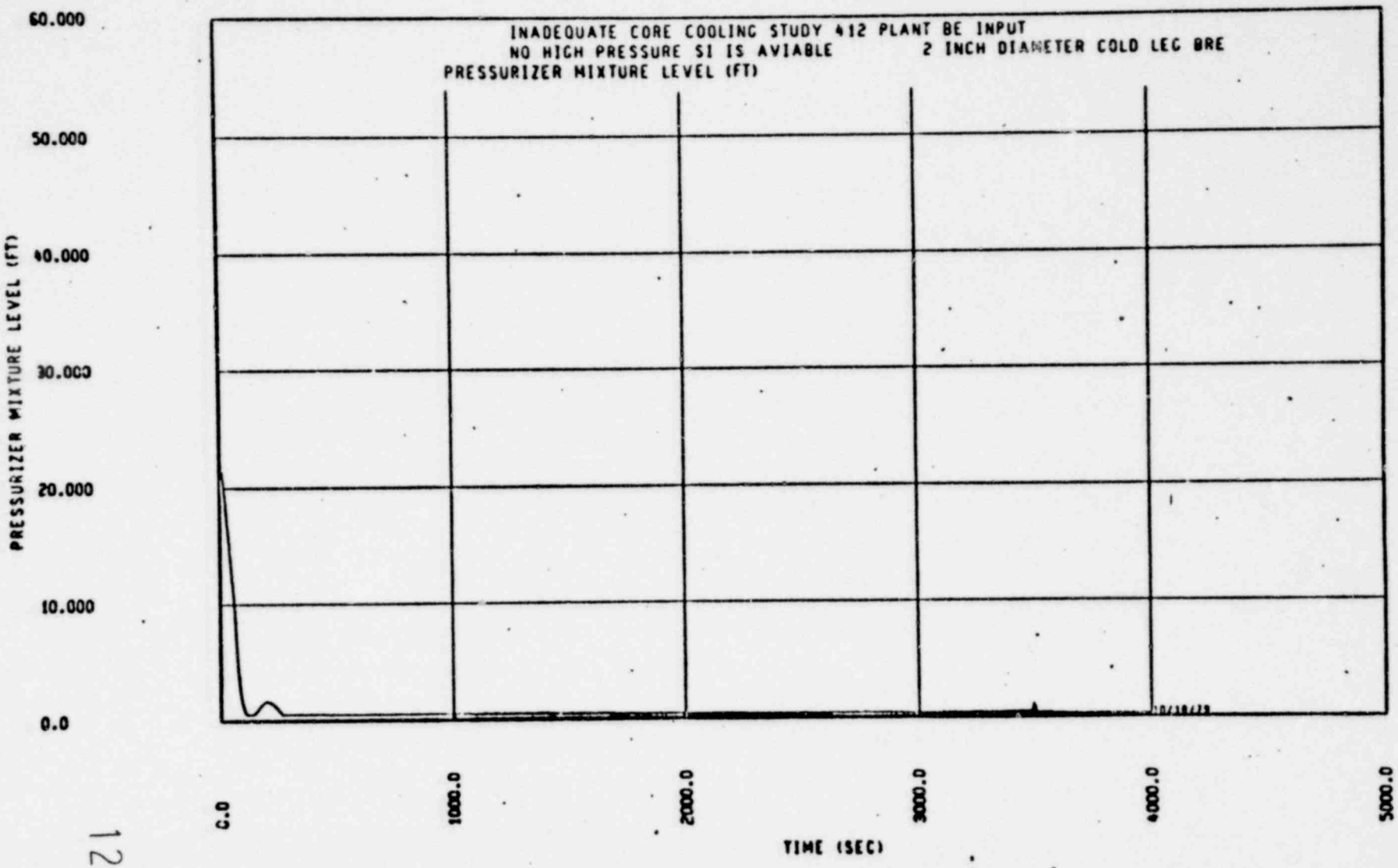


Figure 51

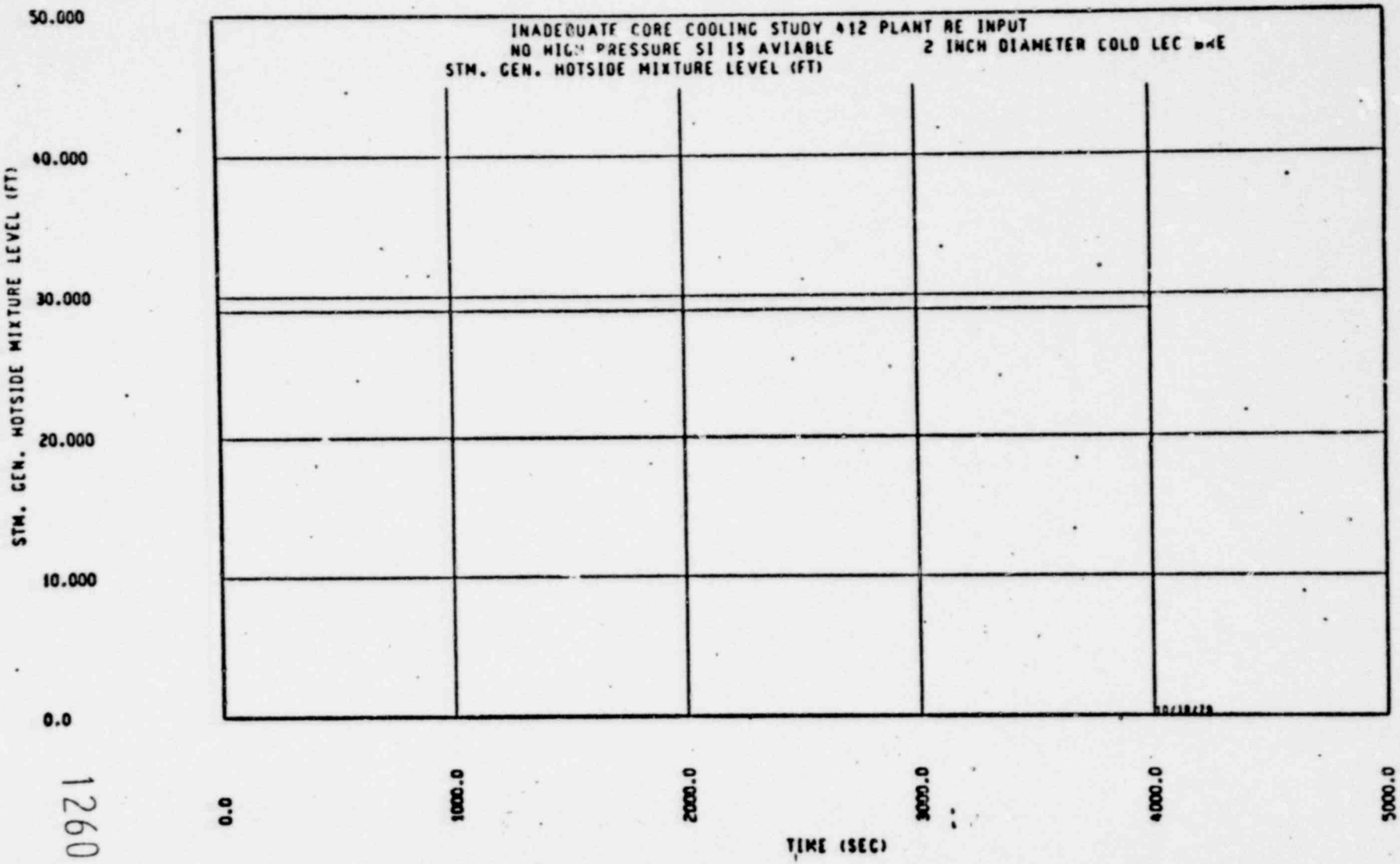
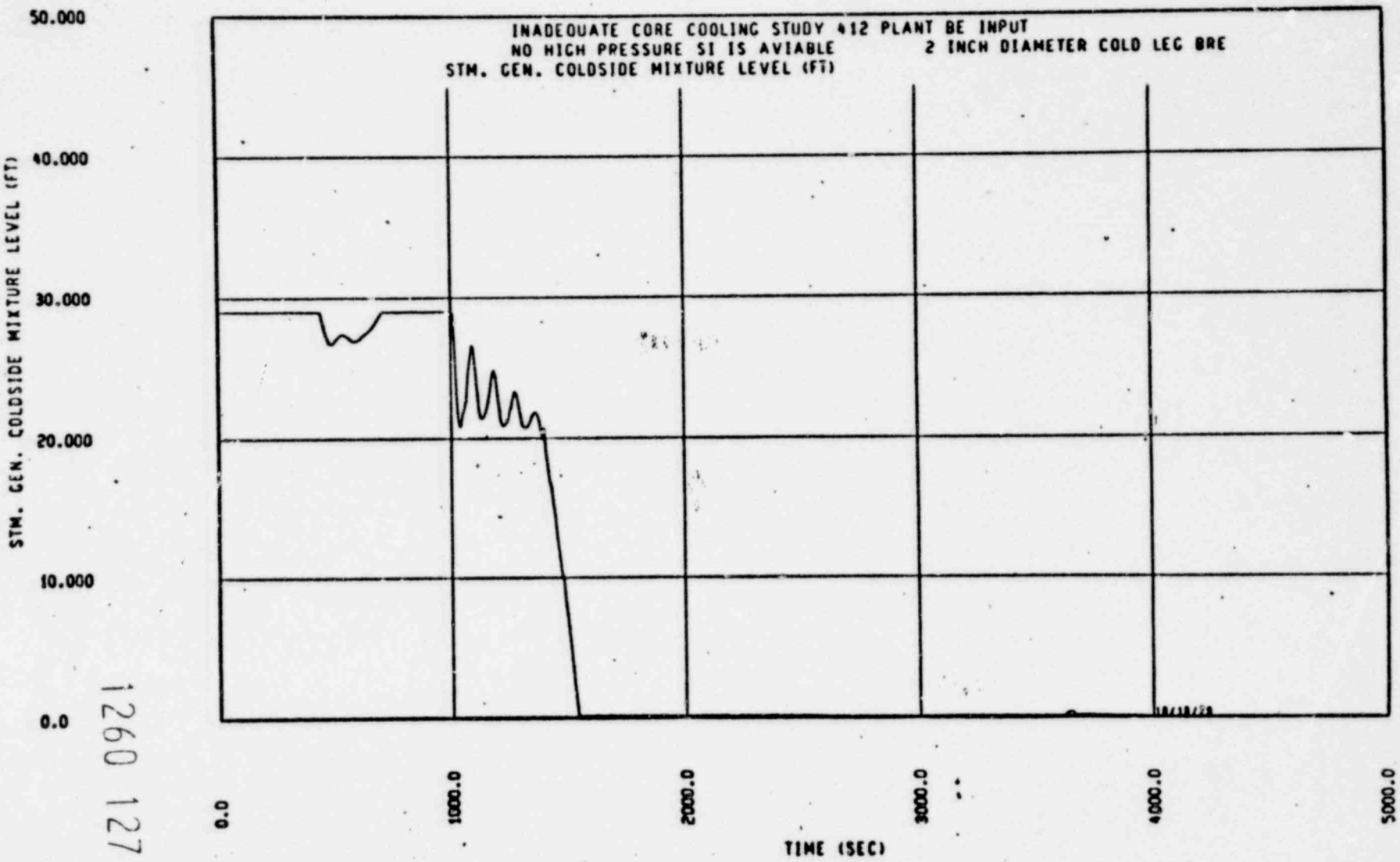


Figure 52



1260 127

Figure 53

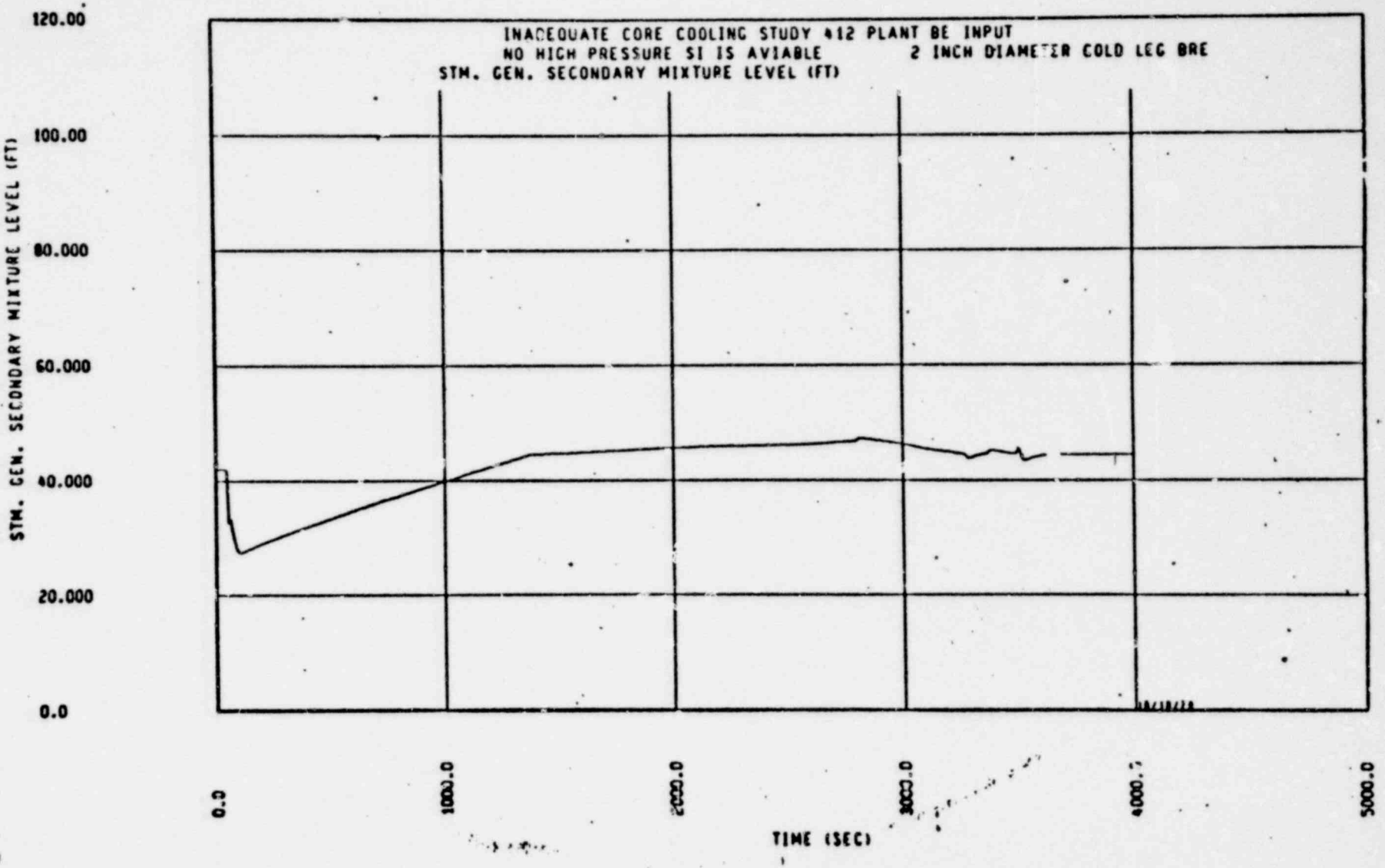


Figure 54

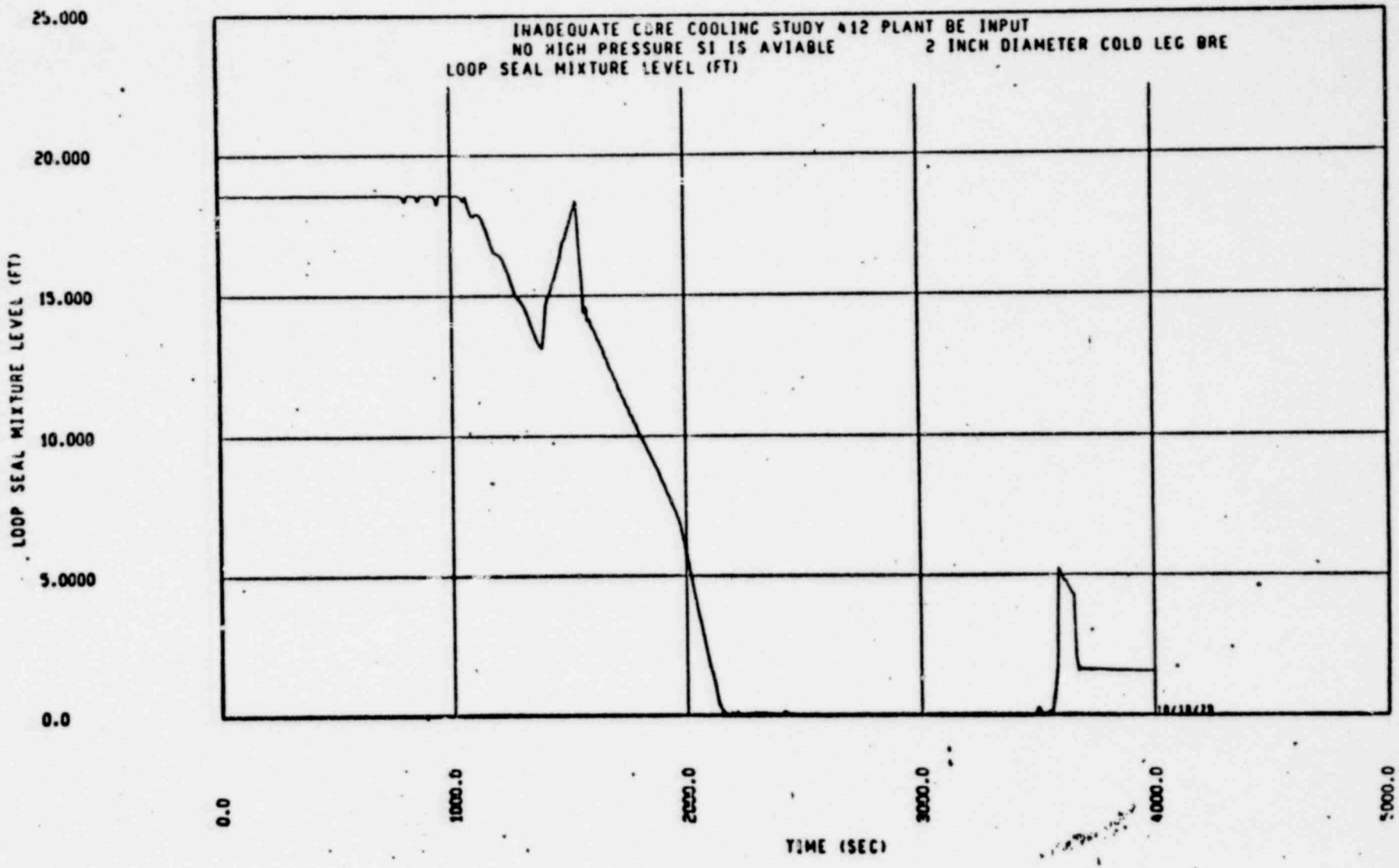


Figure 5.

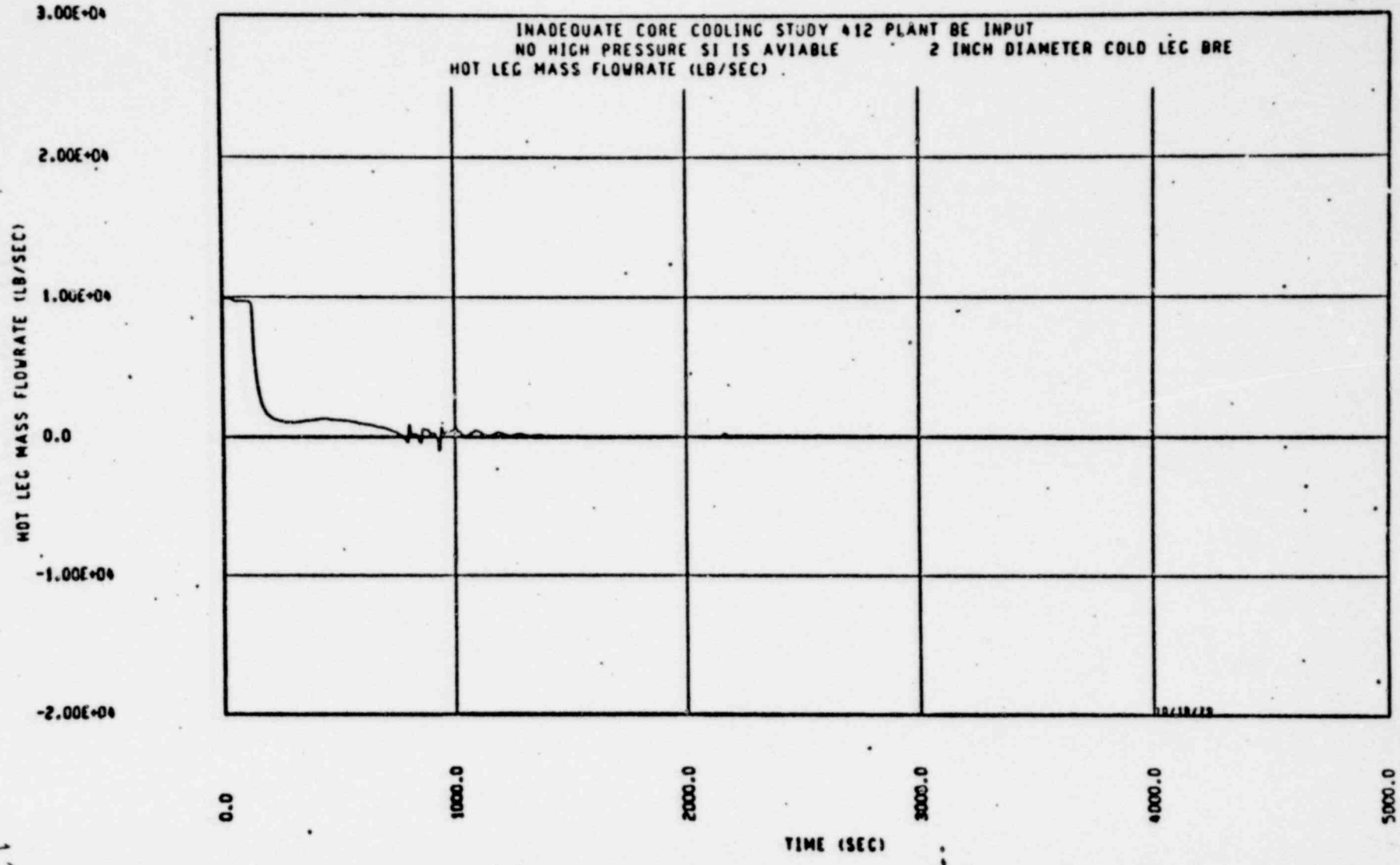


Figure 56

1260 130

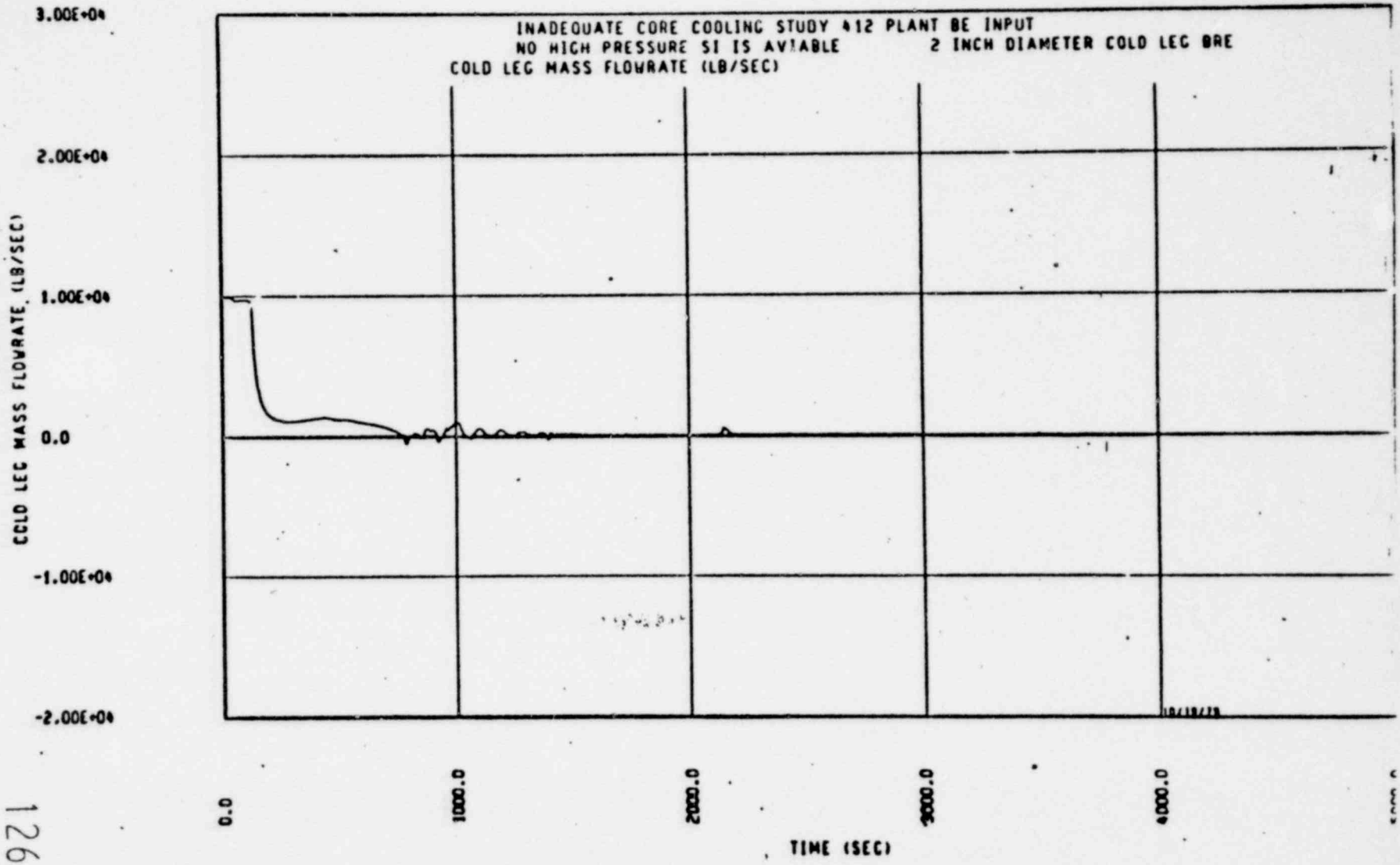

INADEQUATE CORE COOLING STUDY 412 PLANT BE INPUT
NO HIGH PRESSURE SI IS AVIABLE
2 INCH DIAMETER COLD LEG BRE
COLD LEG MASS FLOWRATE (LB/SEC)
3.00E+04
2.00E+04
1.00E+04
0.0
-1.00E+04
-2.00E+04
COLD LEG MASS FLOWRATE (LB/SEC)
0.0
1000.0
2000.0
3000.0
4000.0
TIME (SEC)

Figure 57

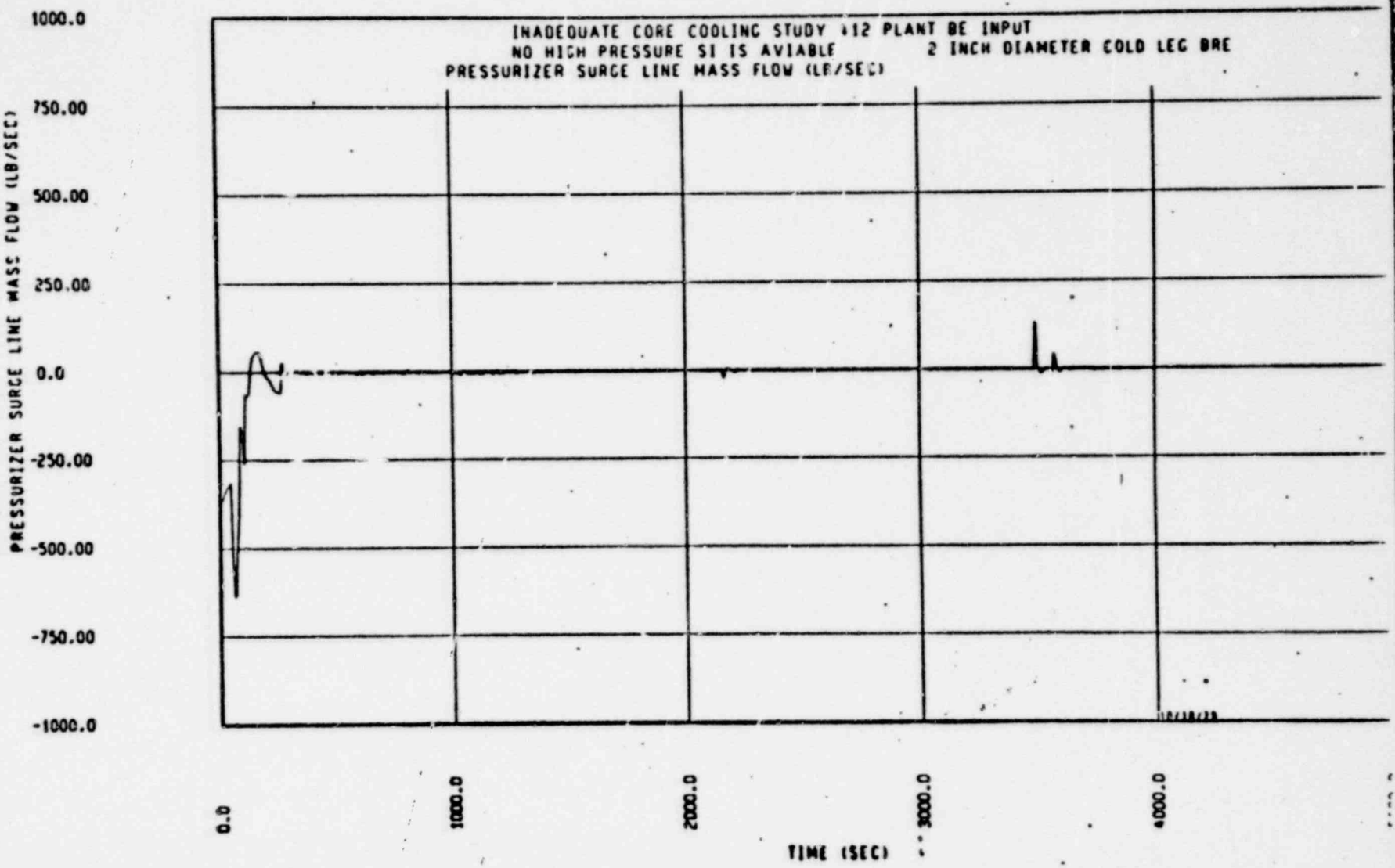


Figure 58

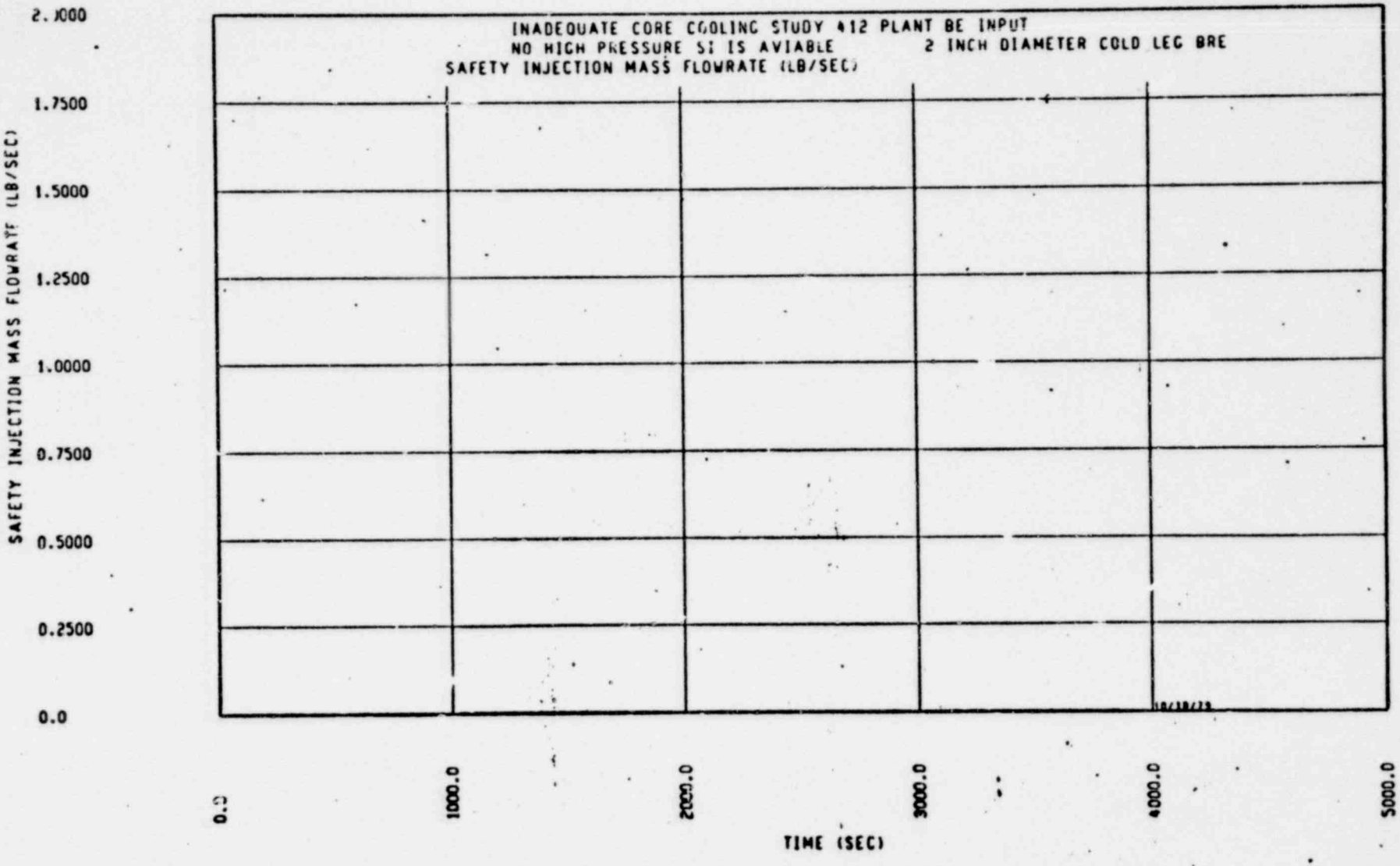


Figure 59

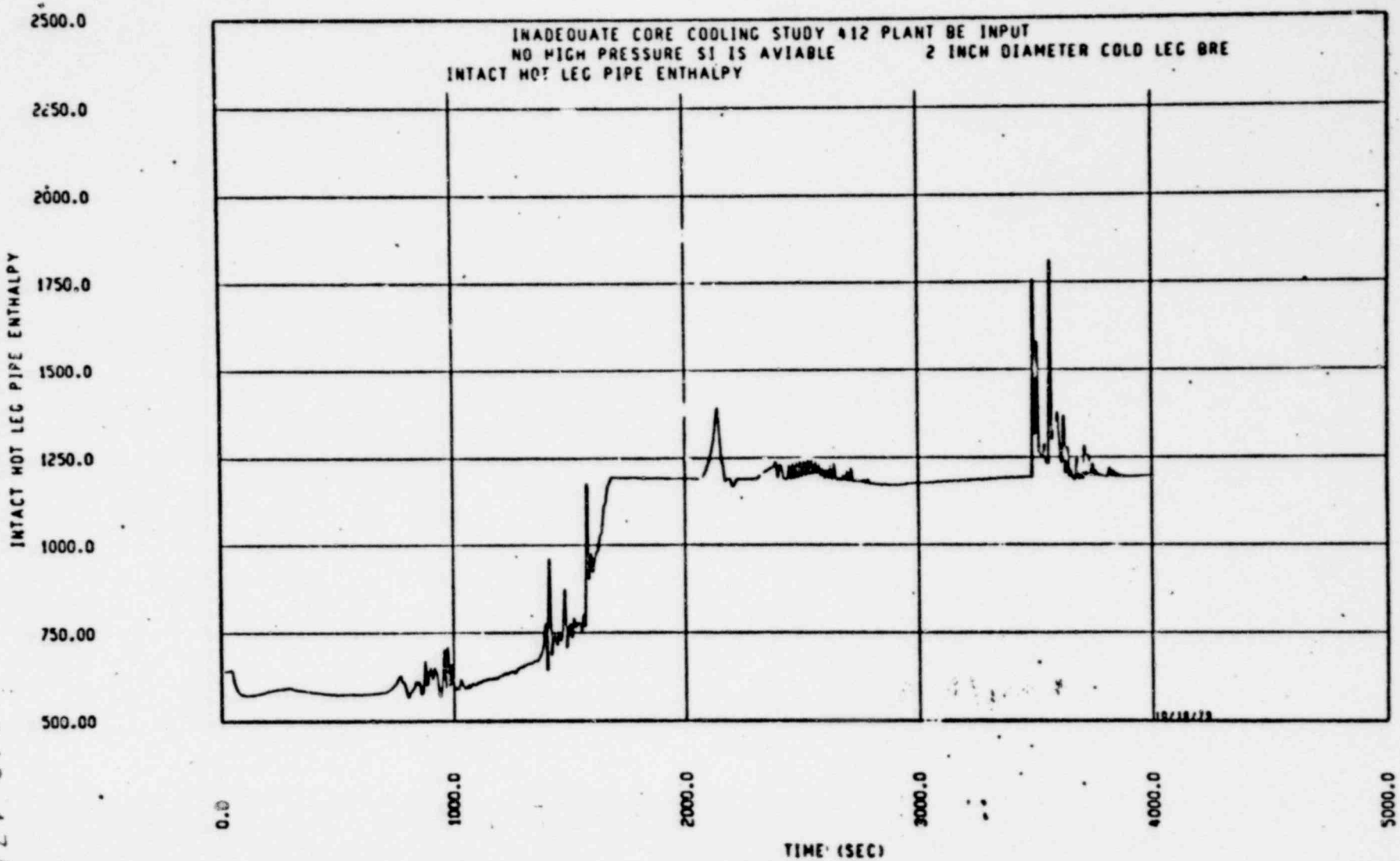


Figure 60

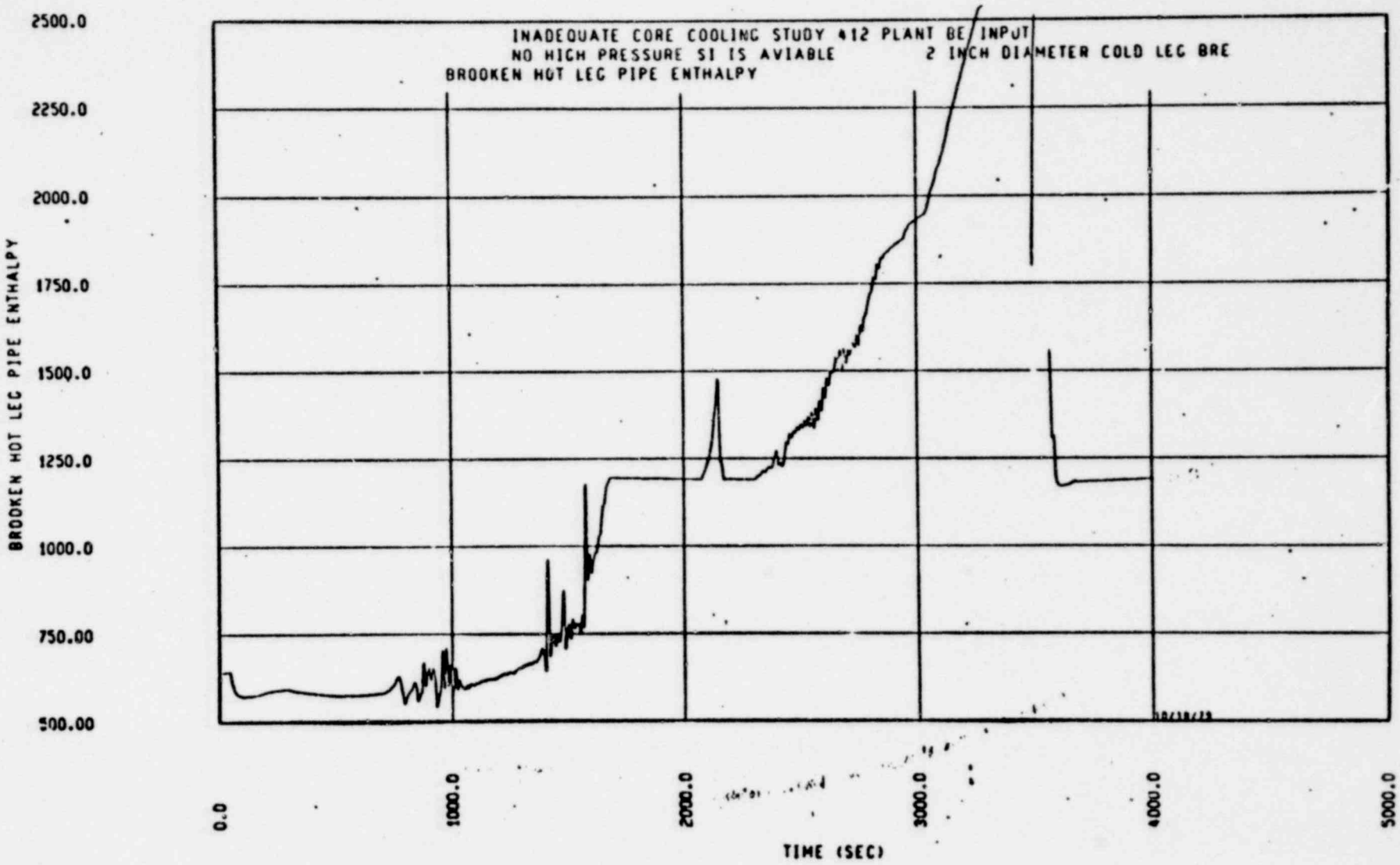


Figure 61

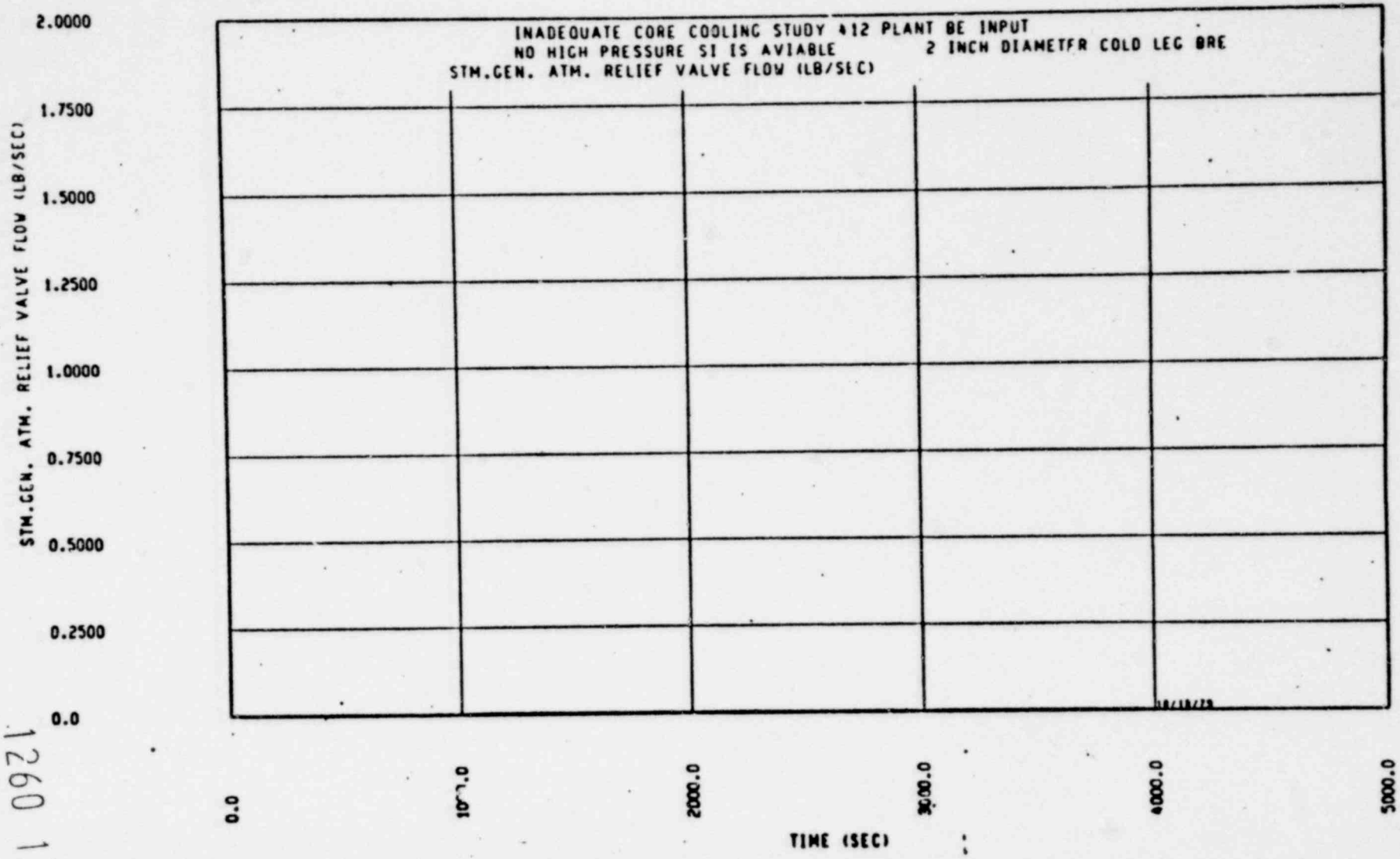


Figure 62

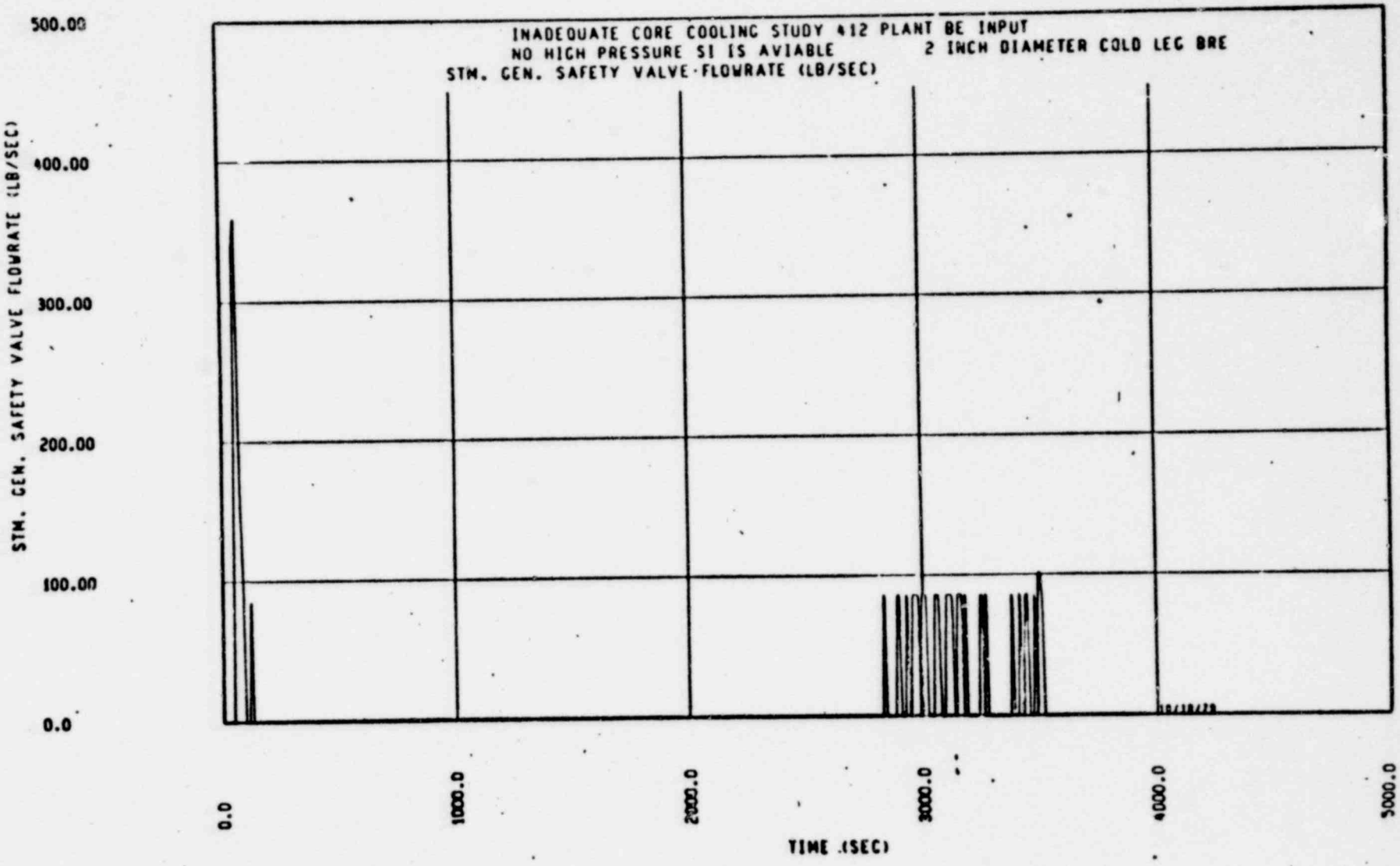


Figure 63

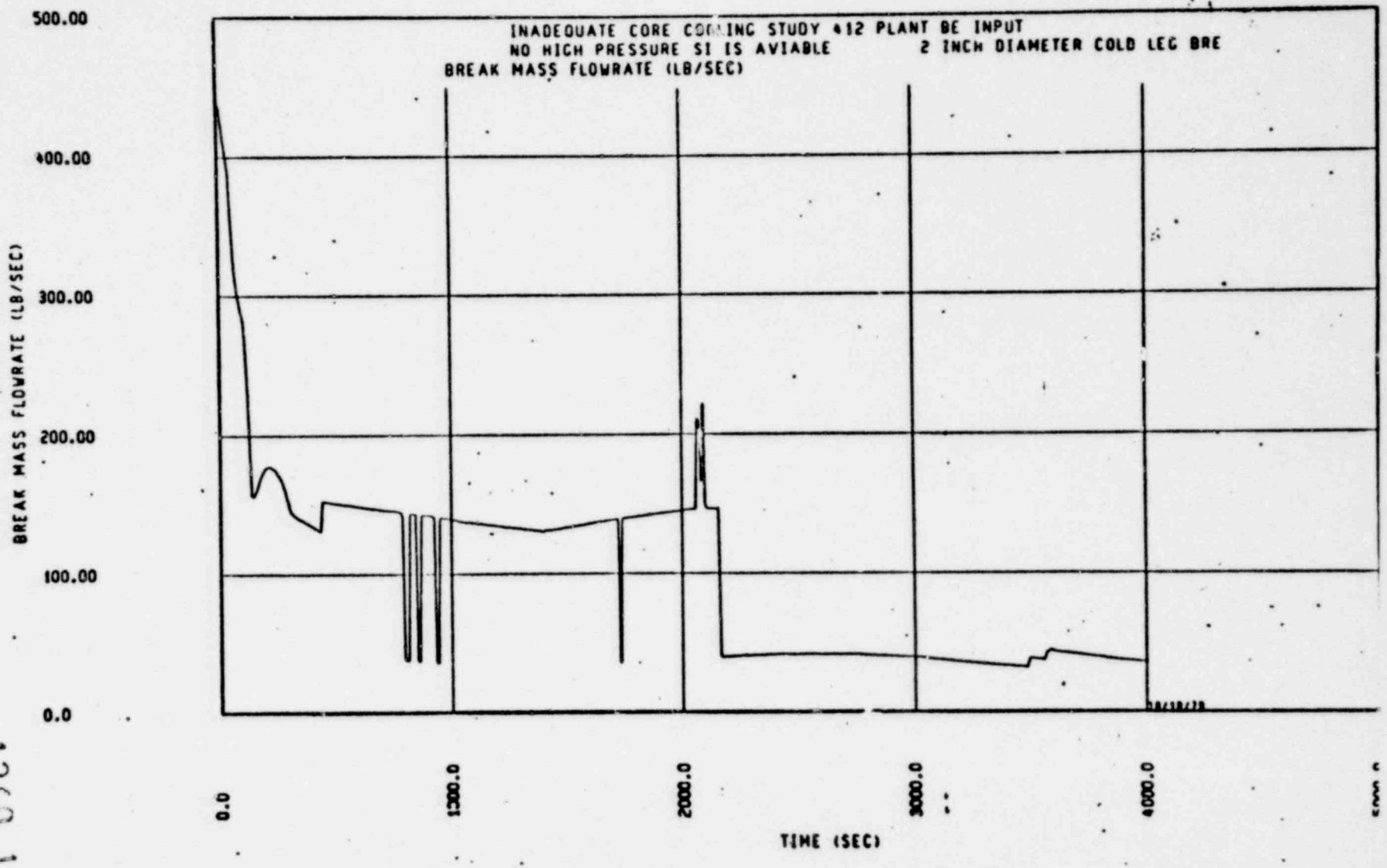


Figure 64

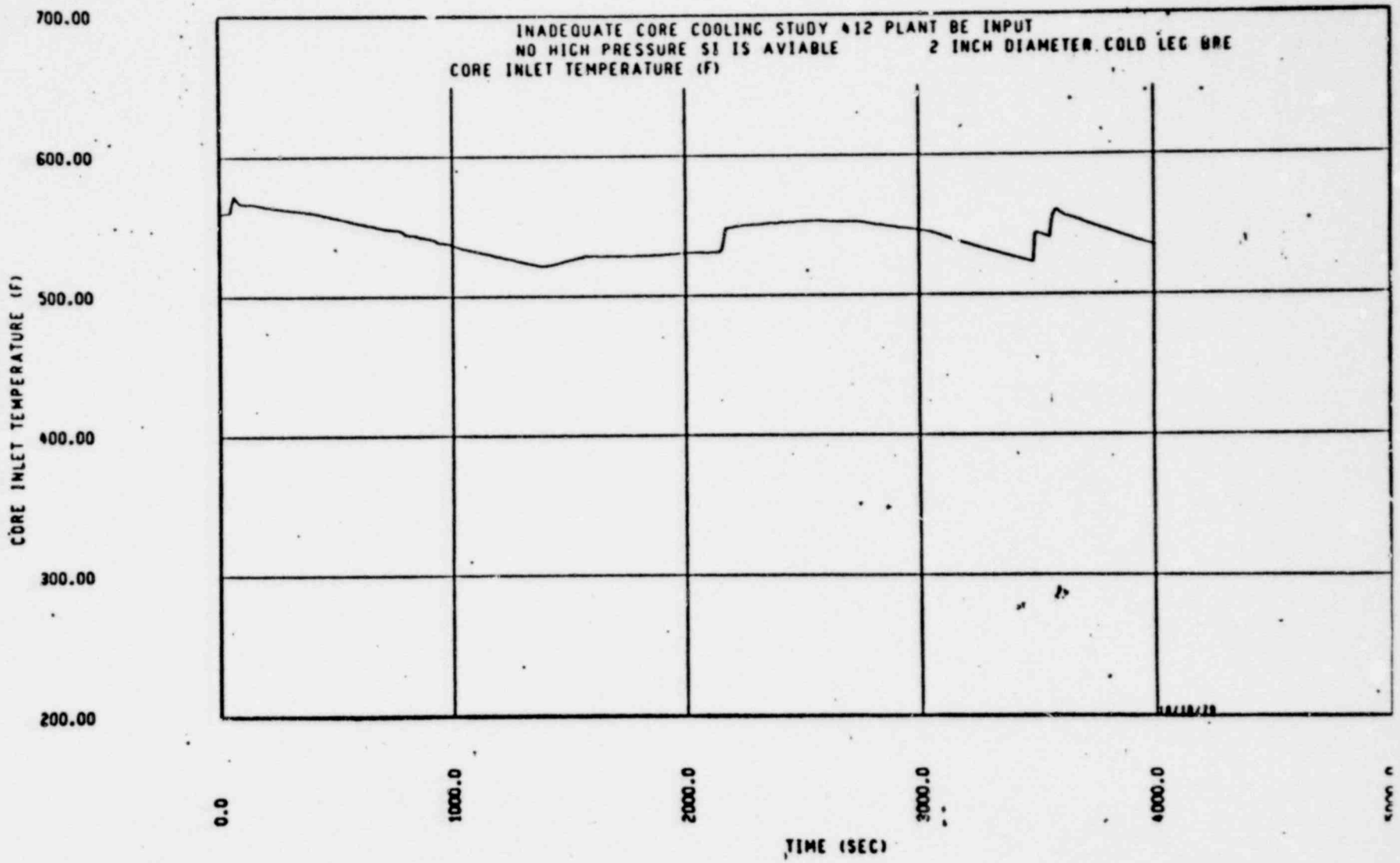


Figure 65

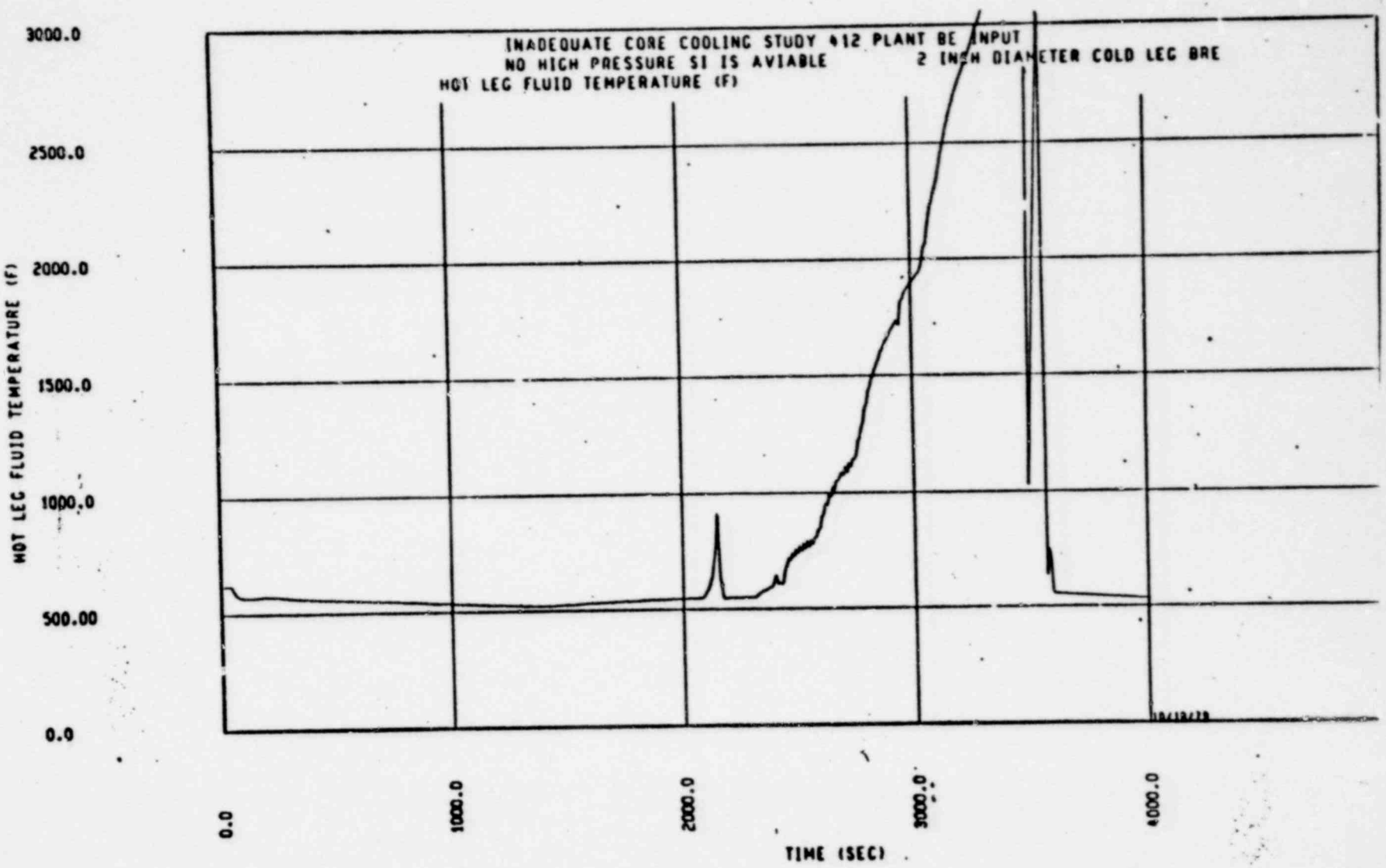


Figure 66

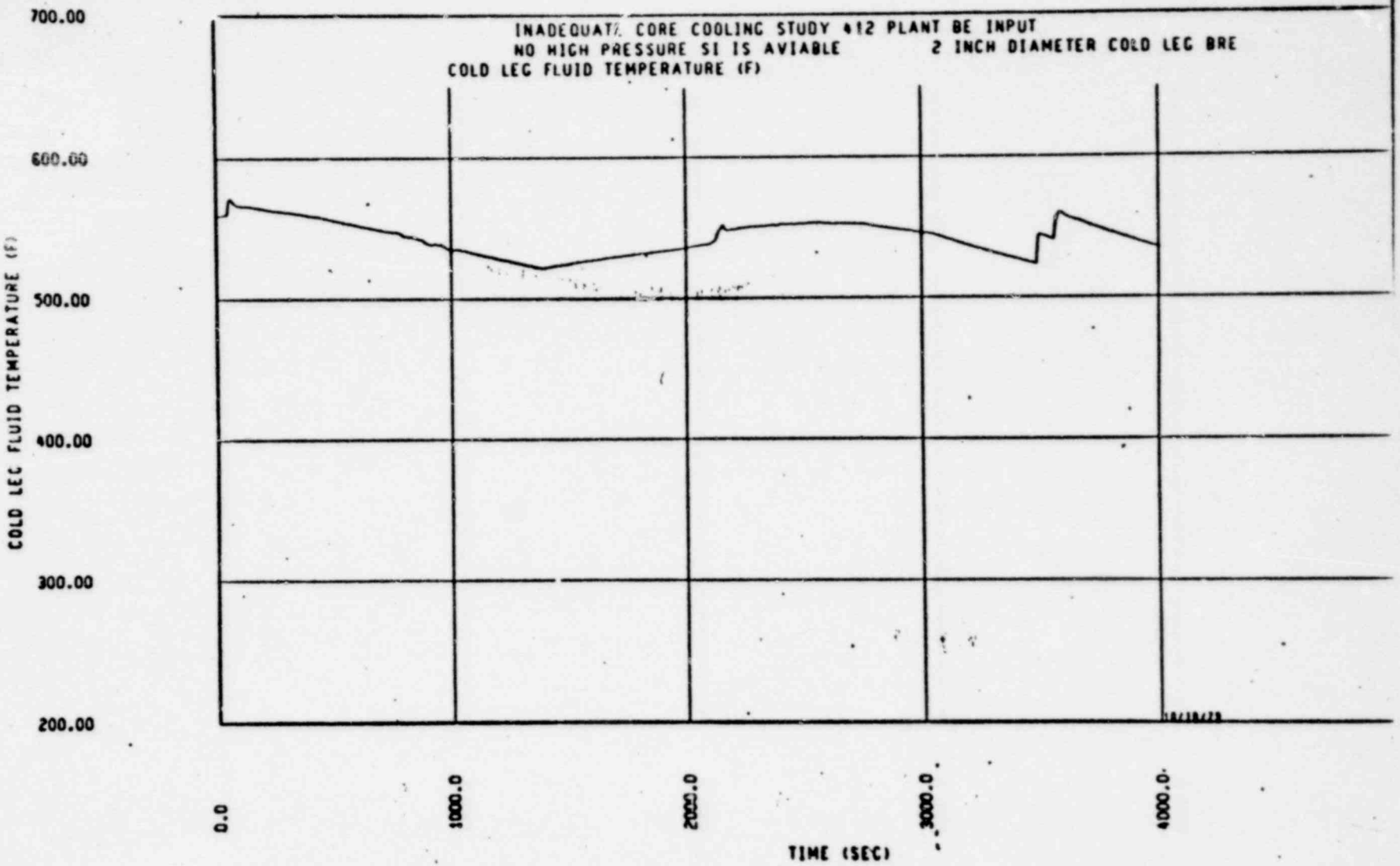


Figure 67

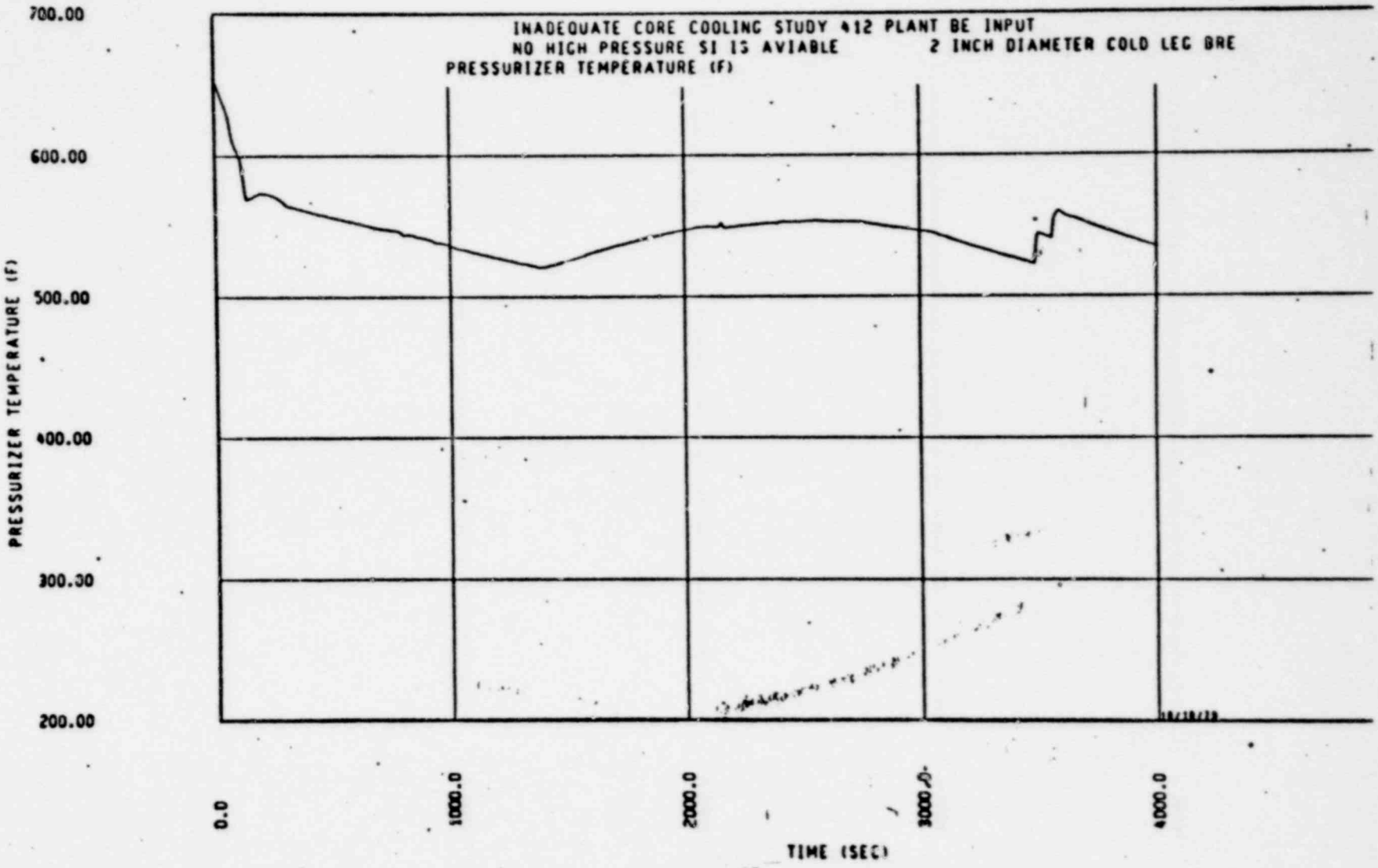


Figure 68

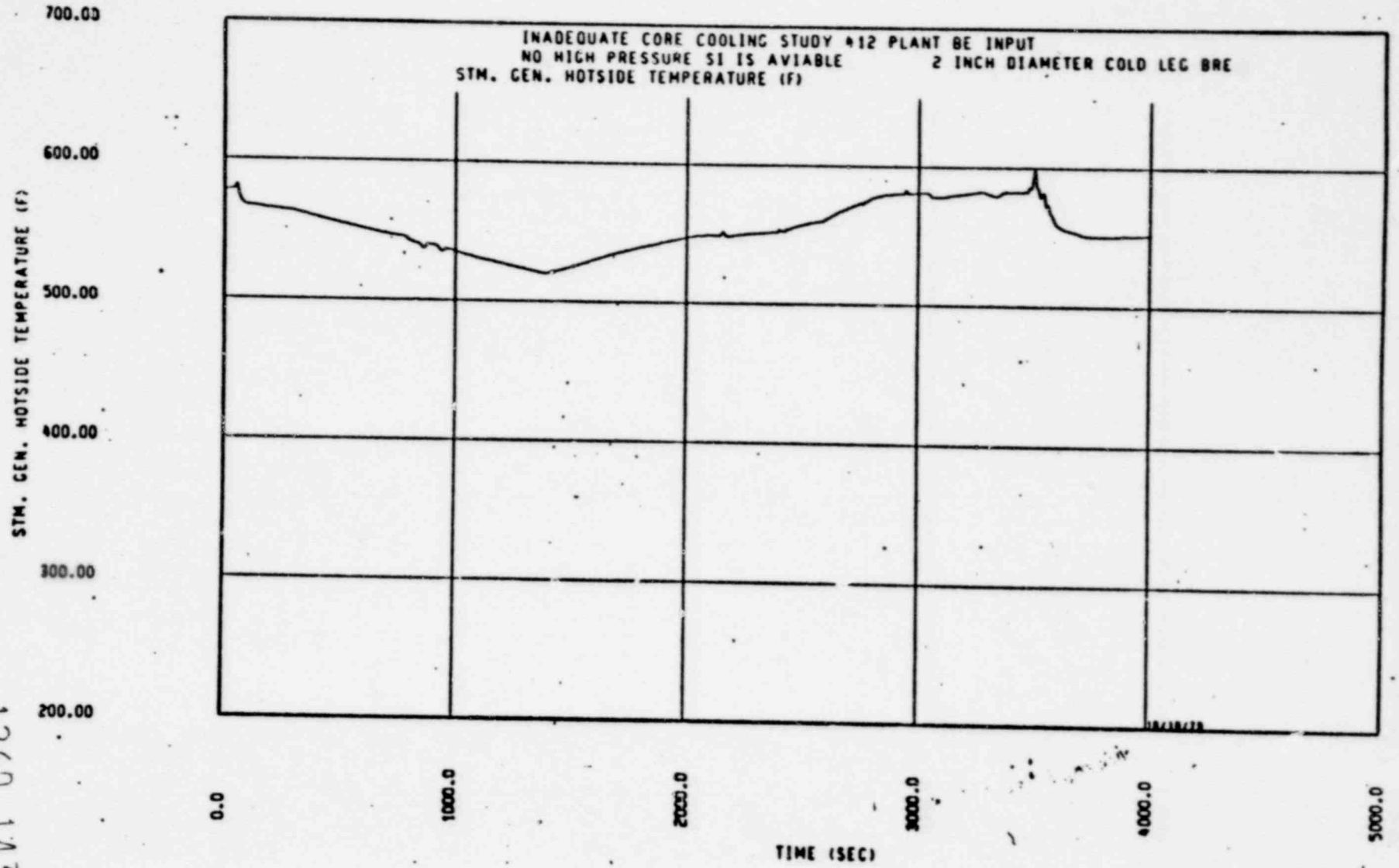


Figure 69

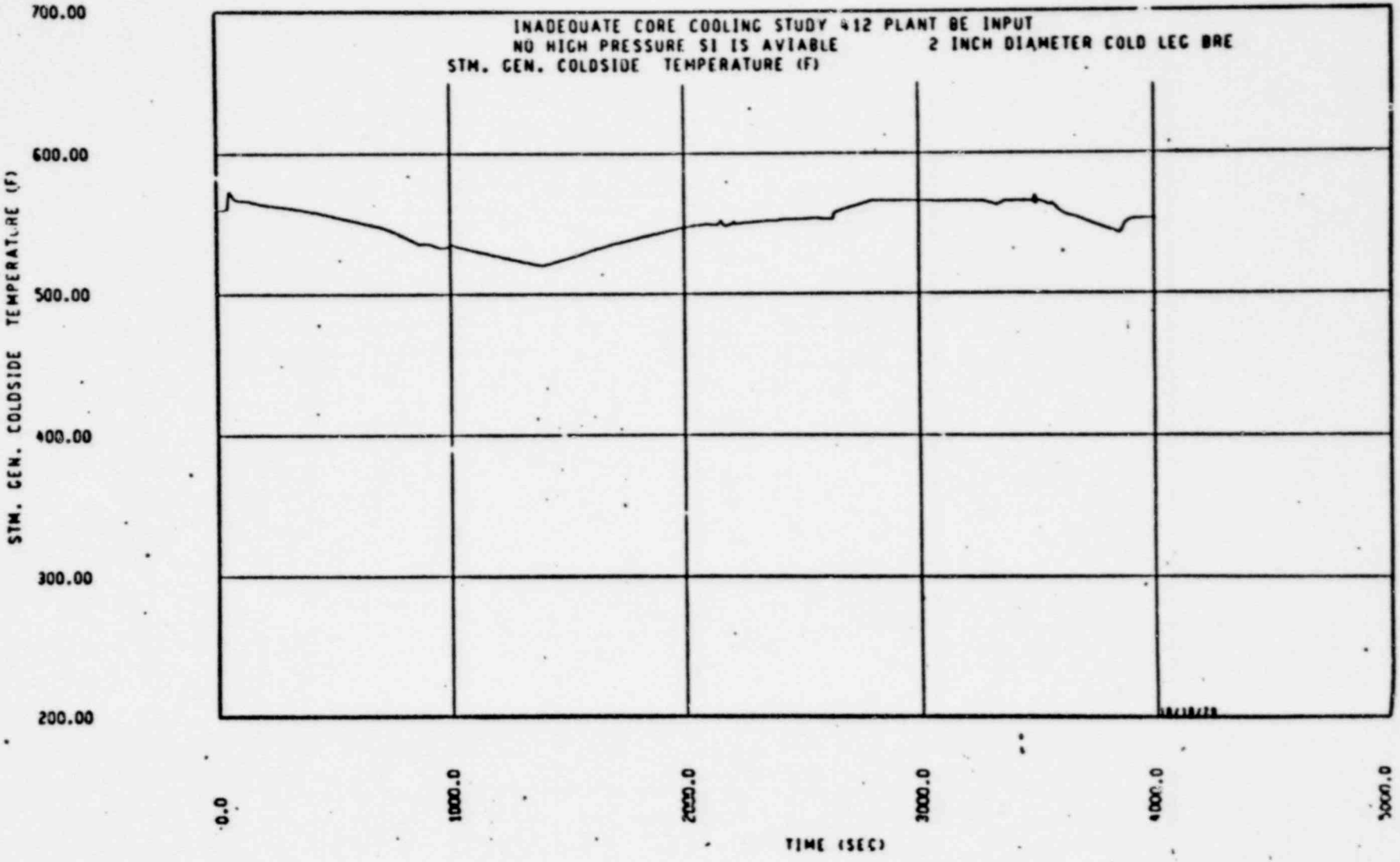


Figure 70

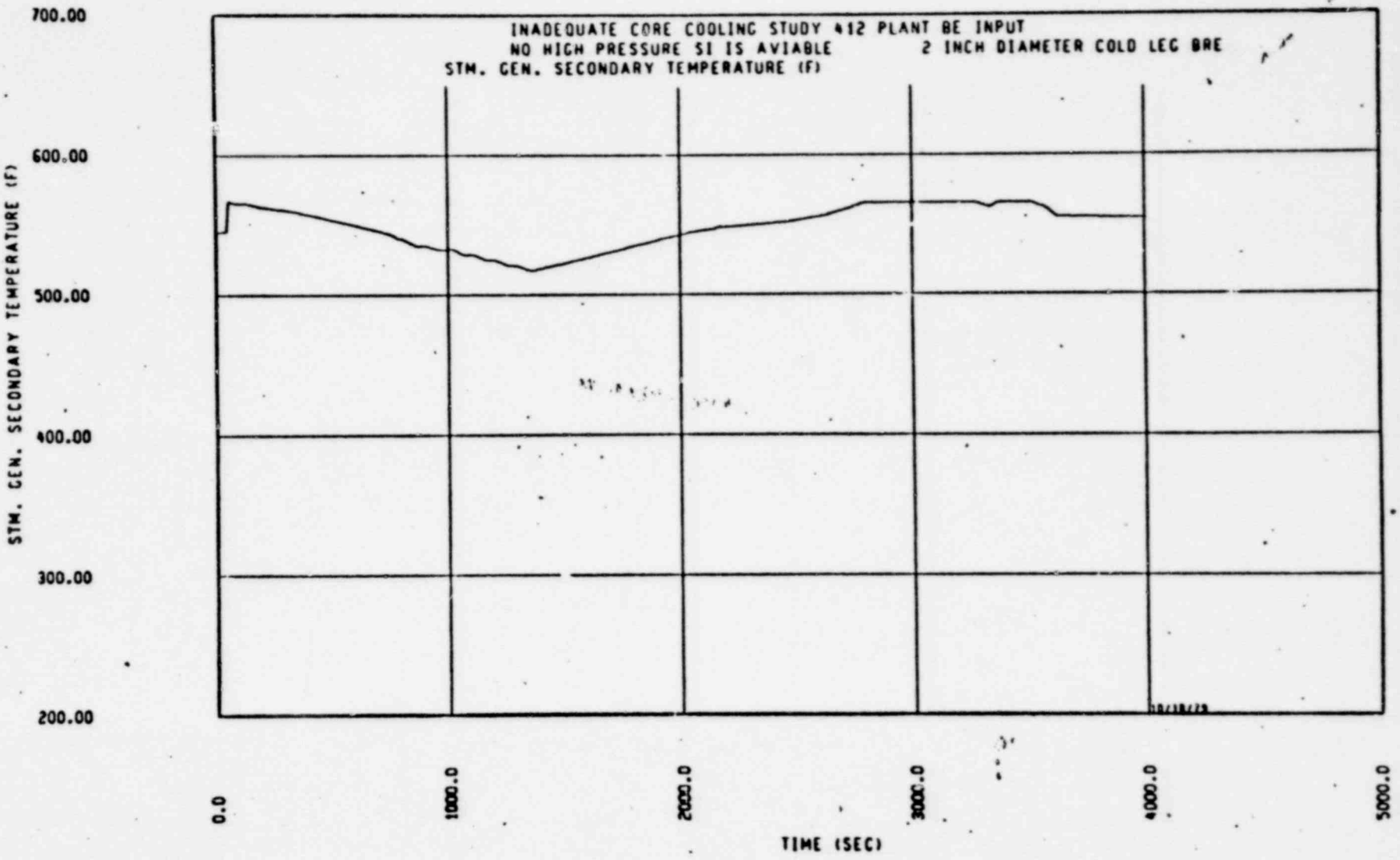


Figure 71

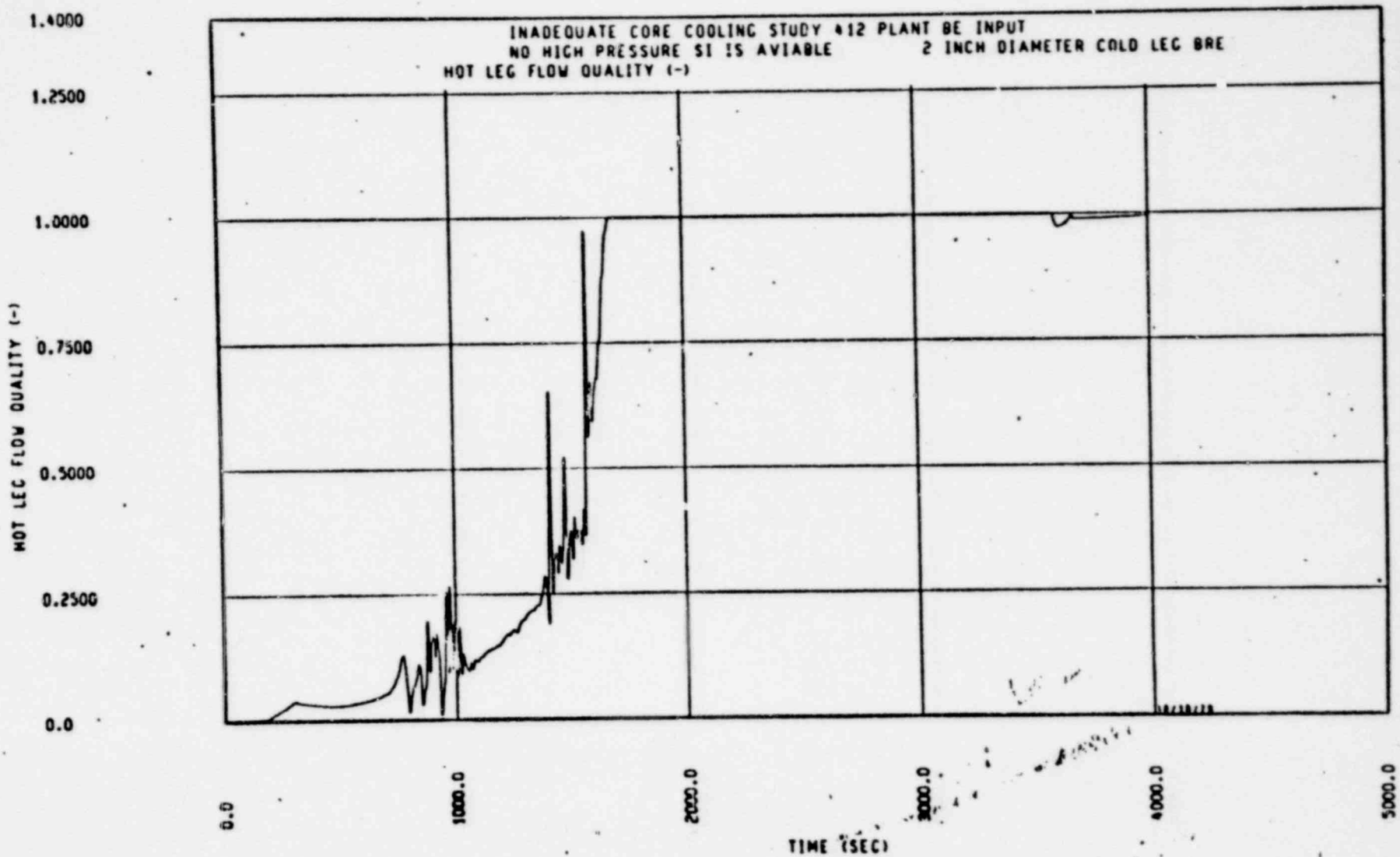


Figure 72

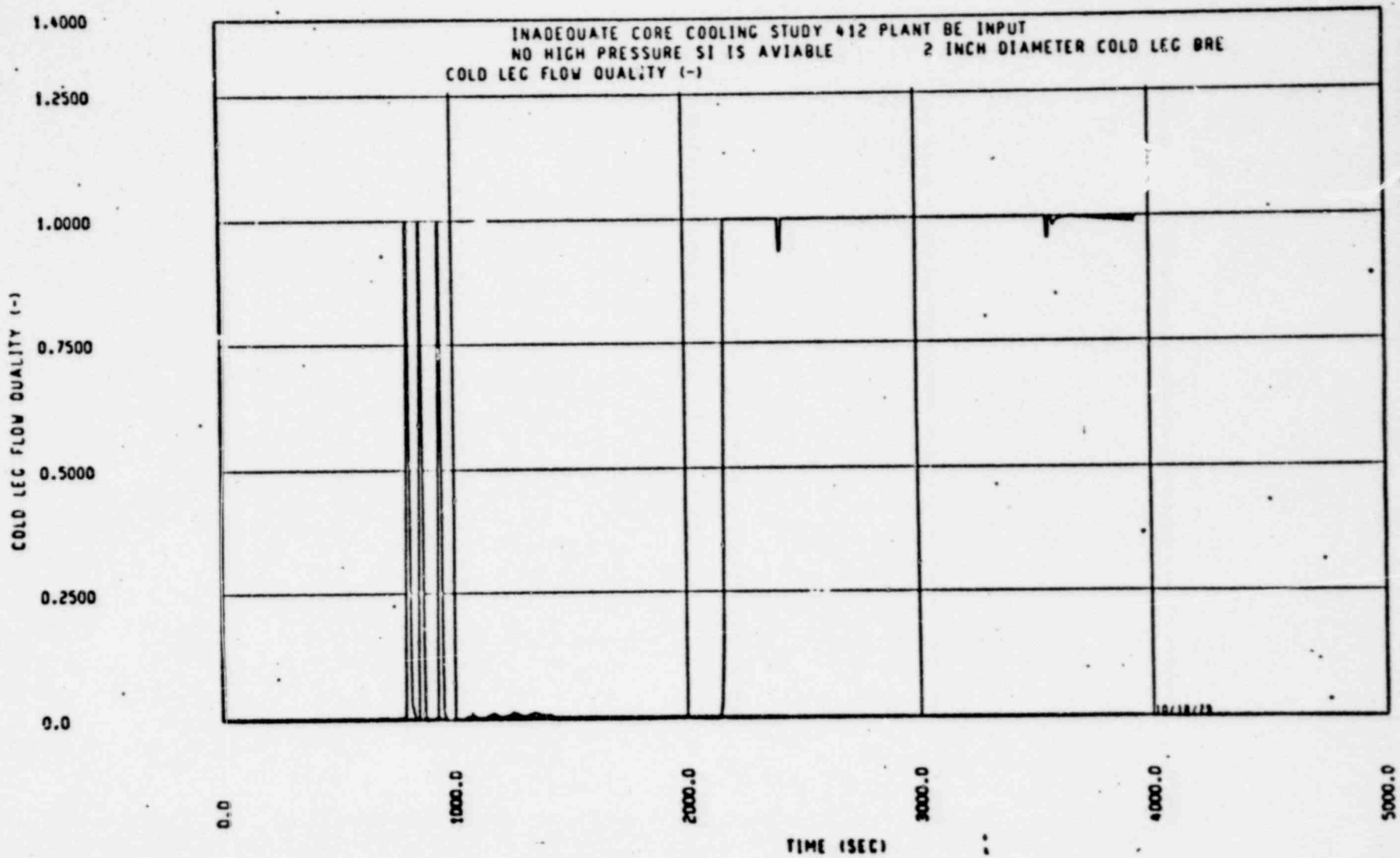


Figure 73

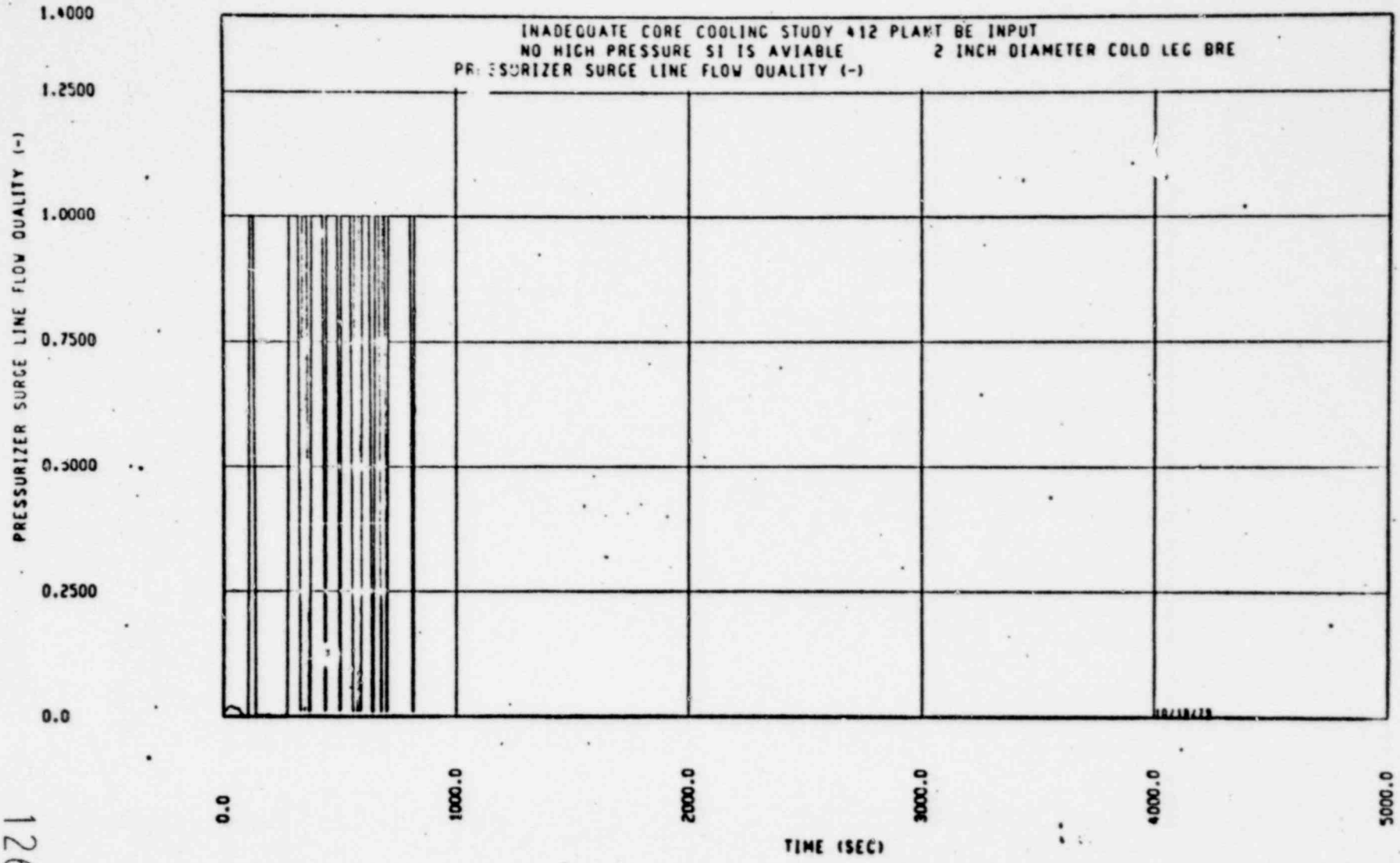


Figure 74

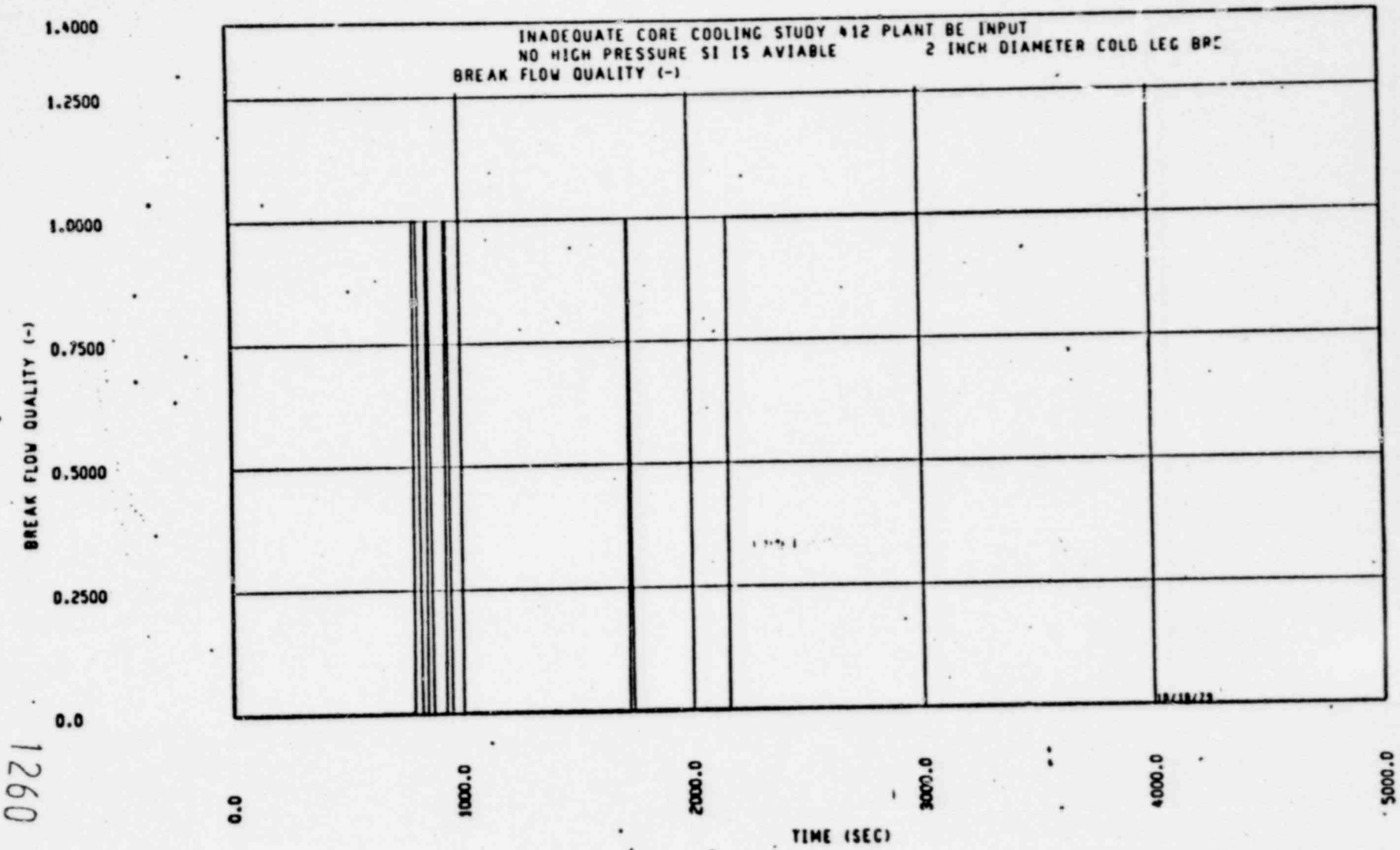


Figure 75

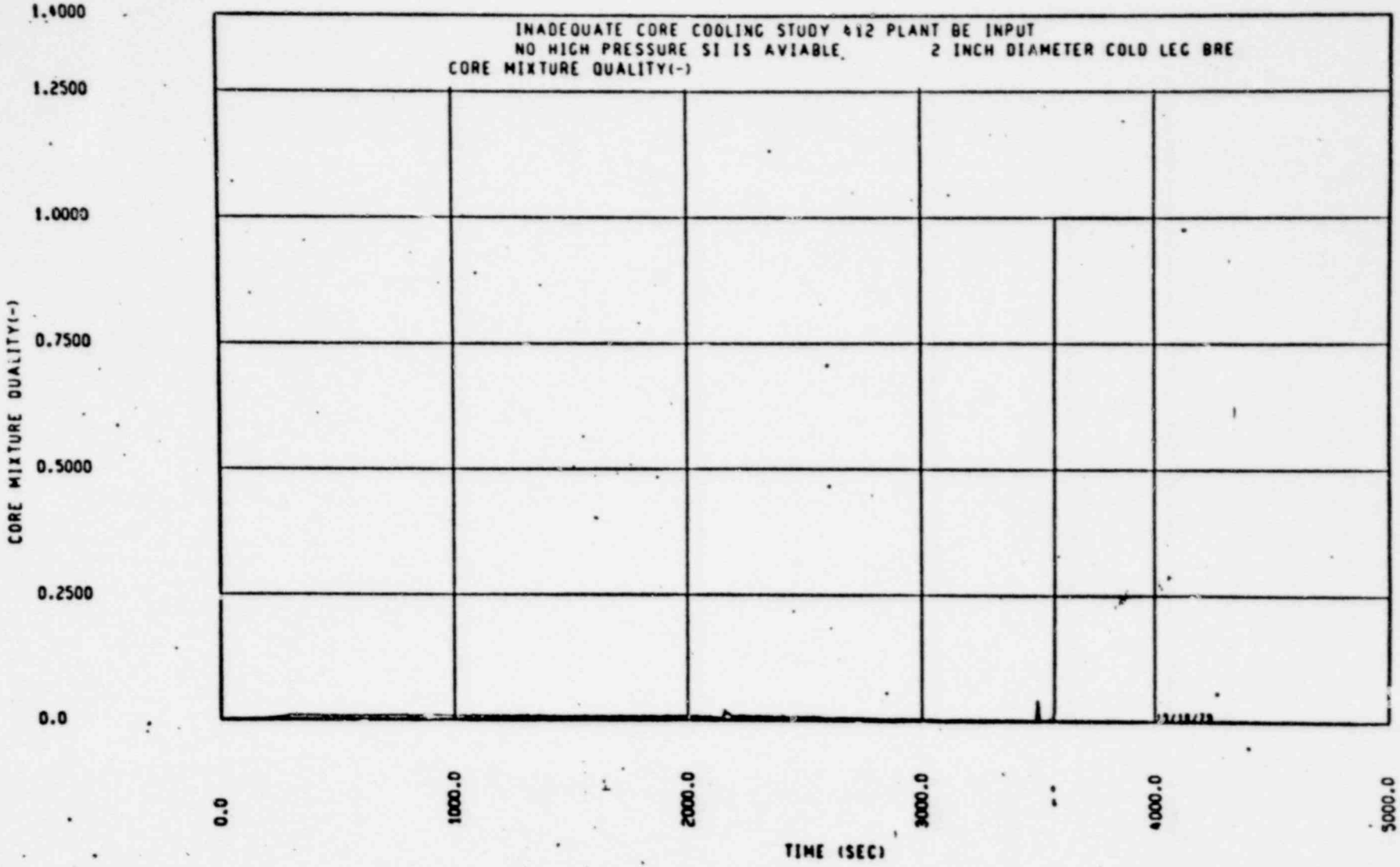


Figure 76

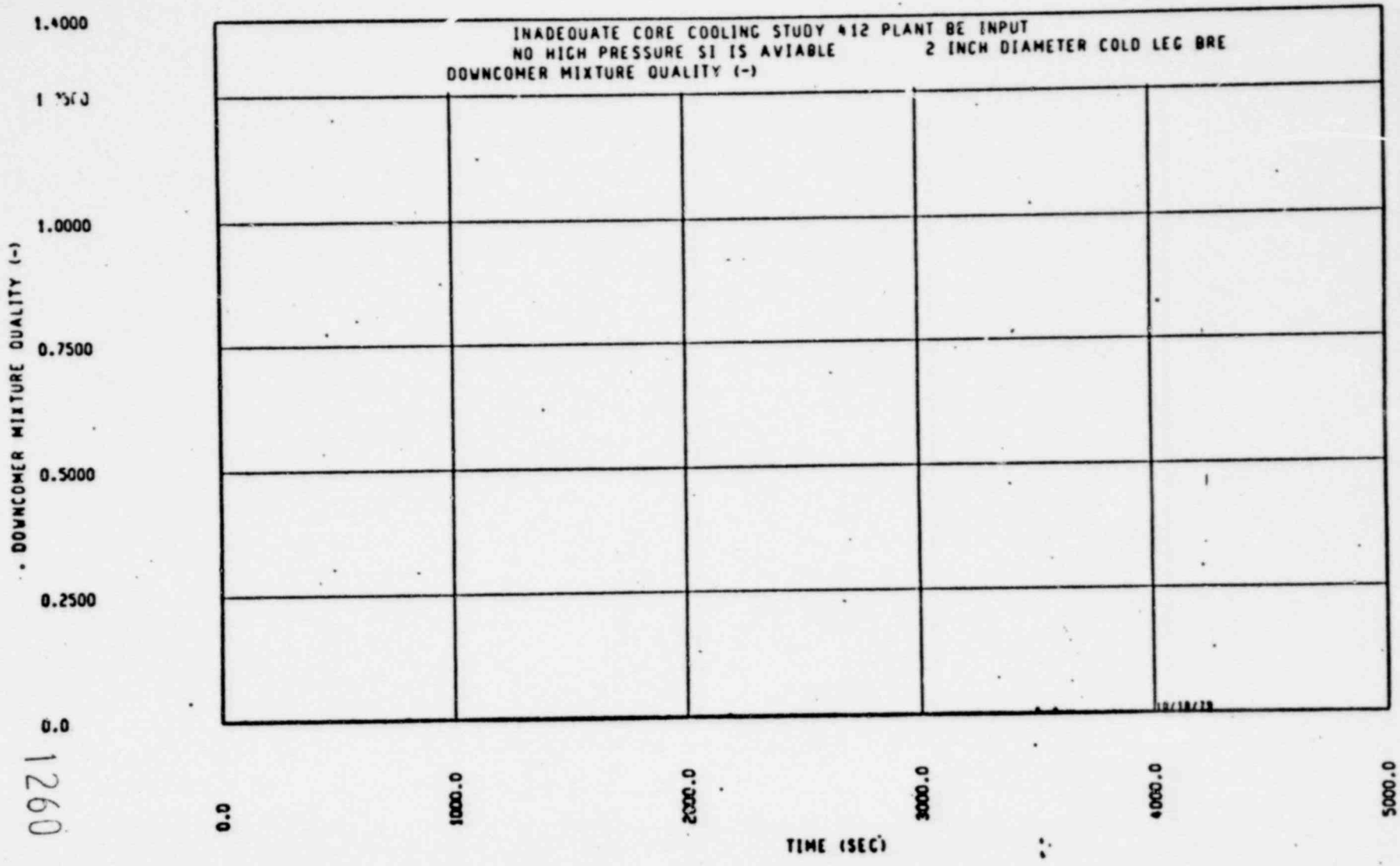


Figure 77

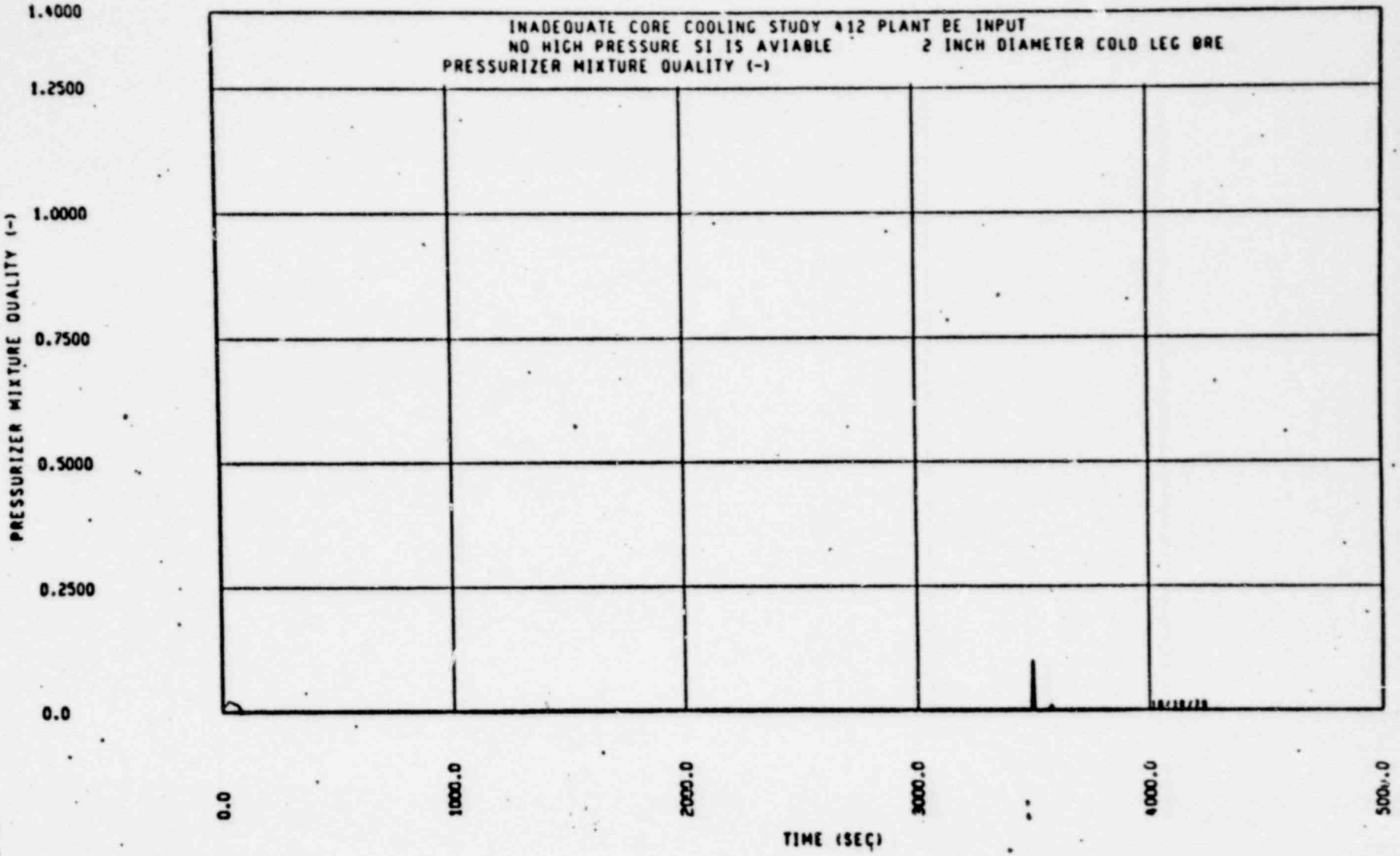


Figure 78

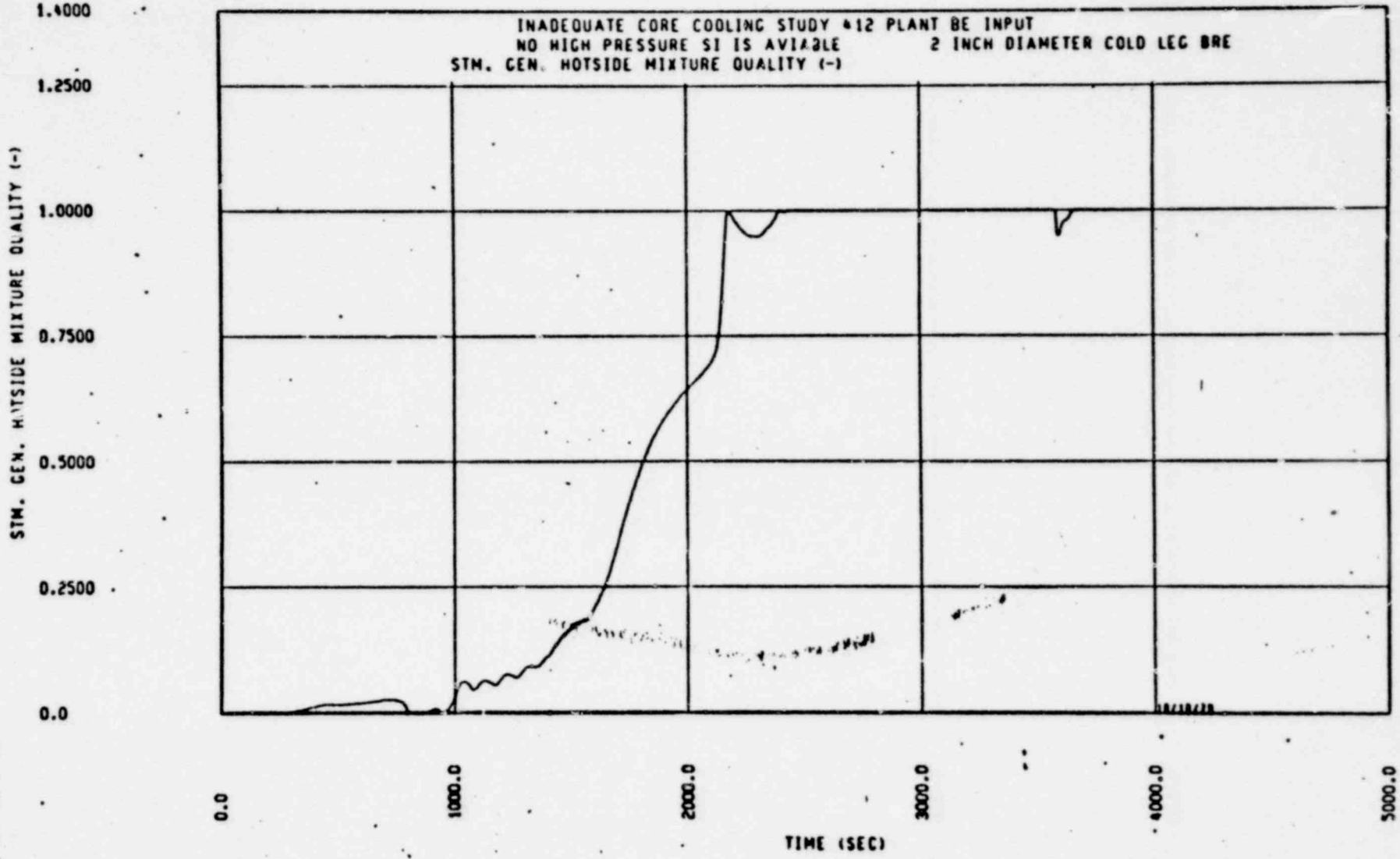


Figure 79

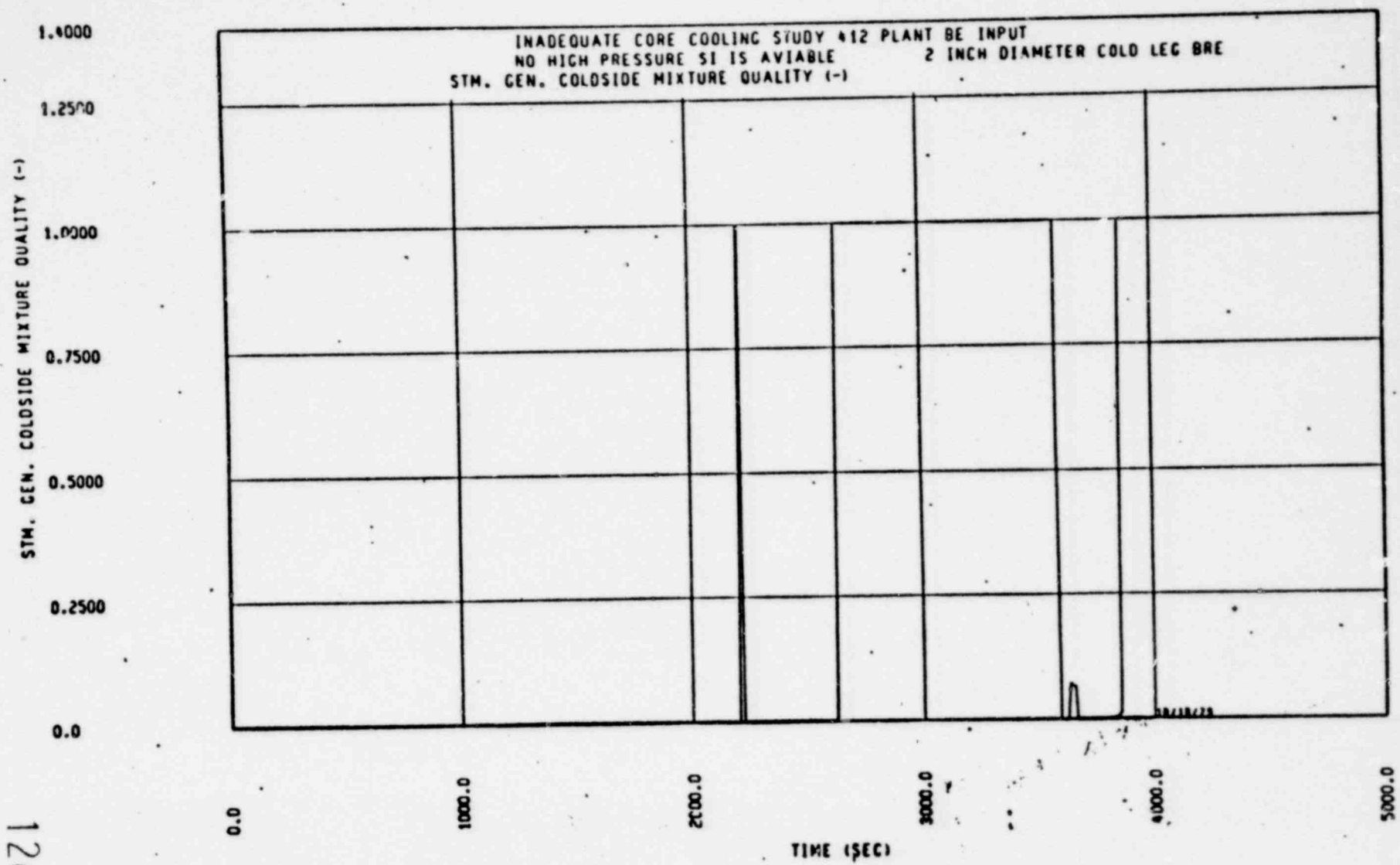


Figure 80

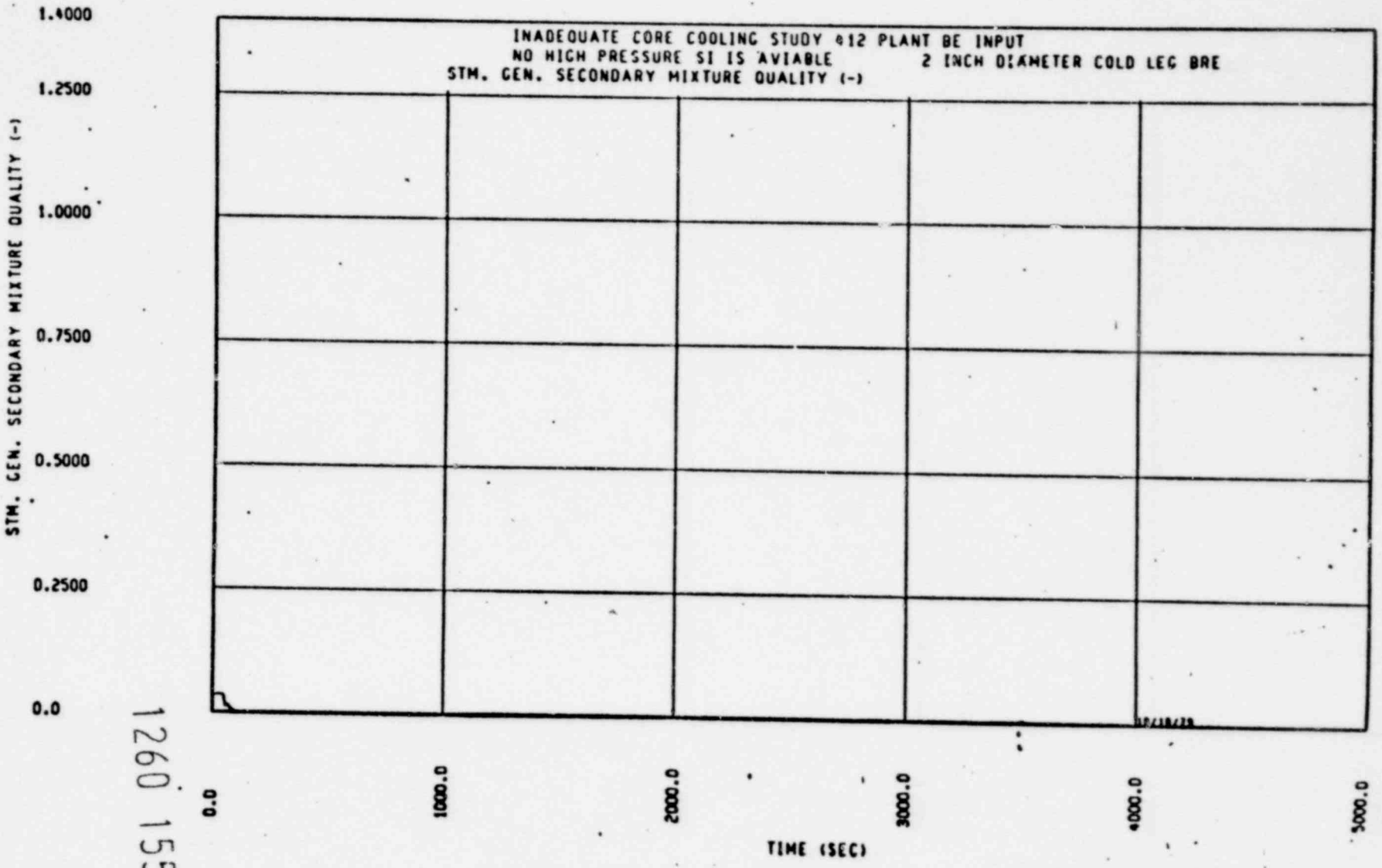


Figure 81

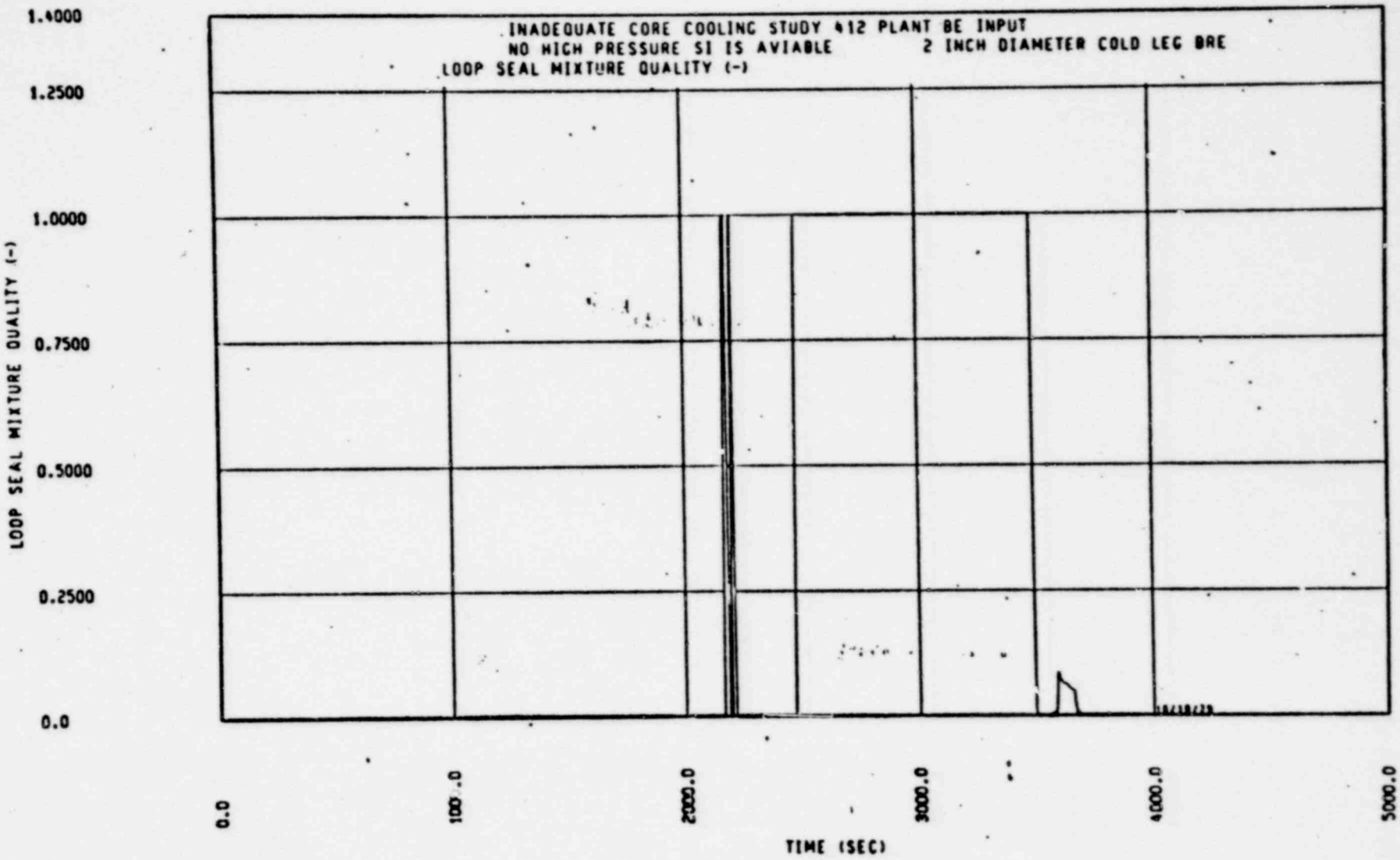


Figure 82

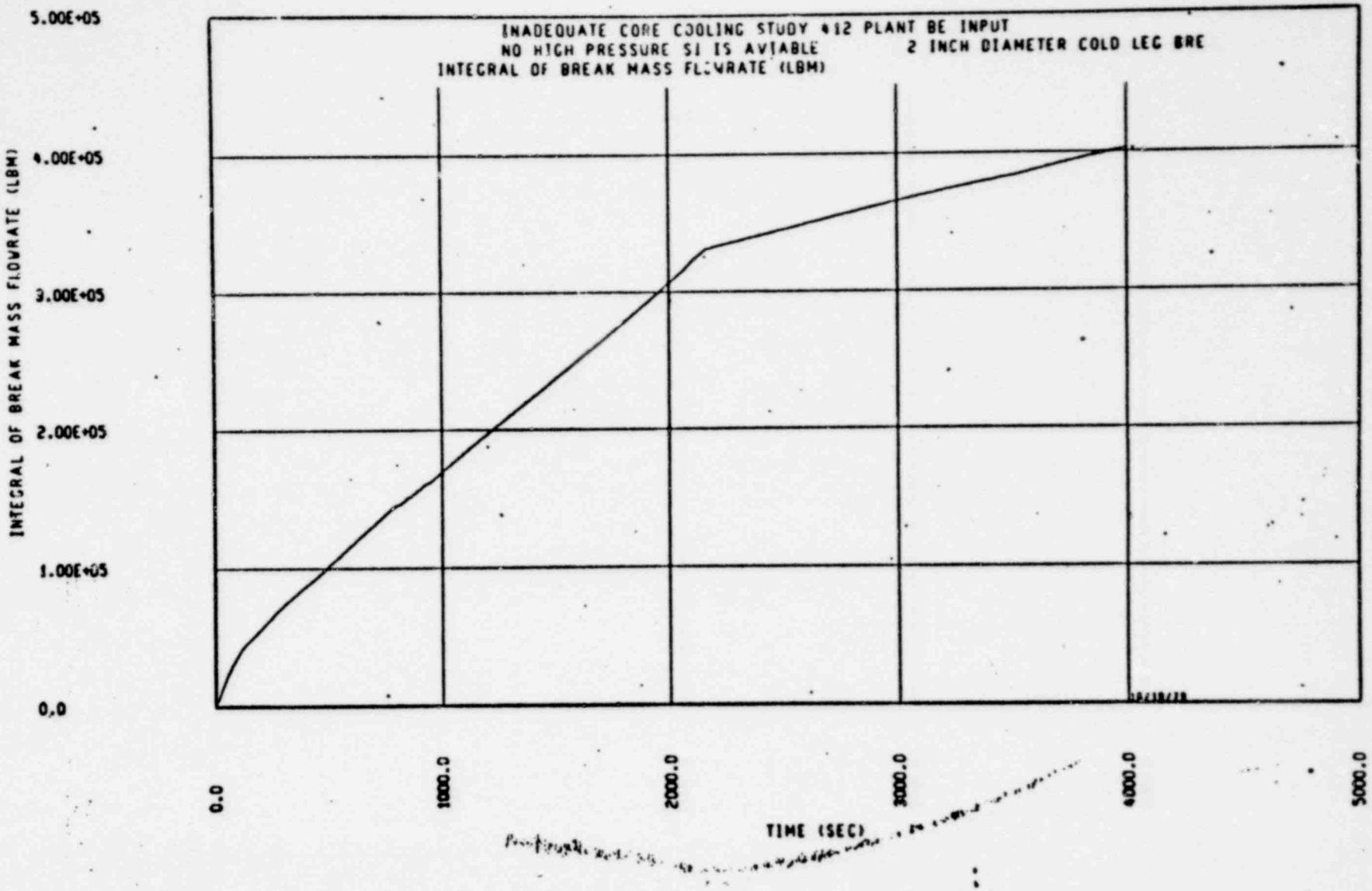


Figure 83

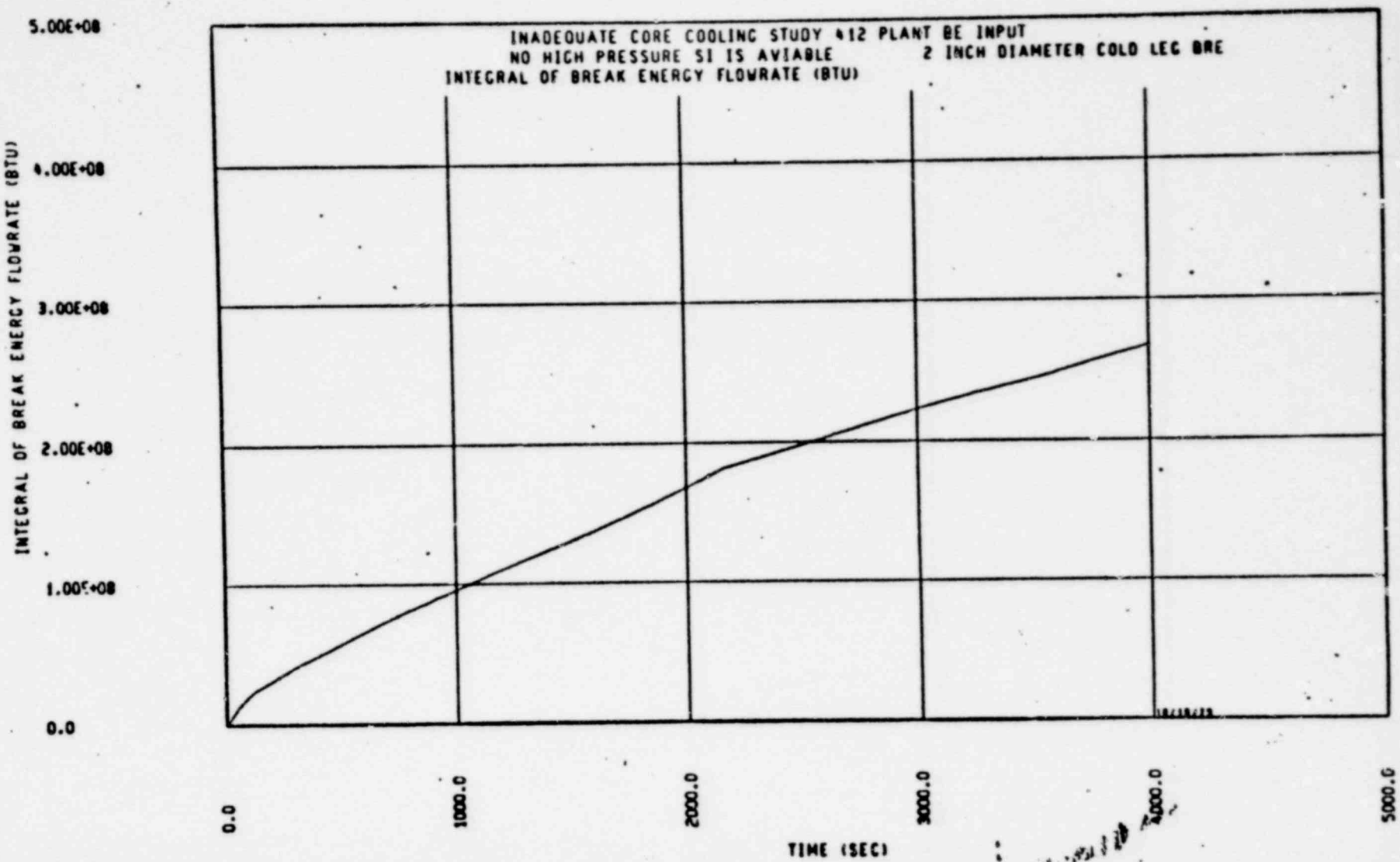


Figure 84

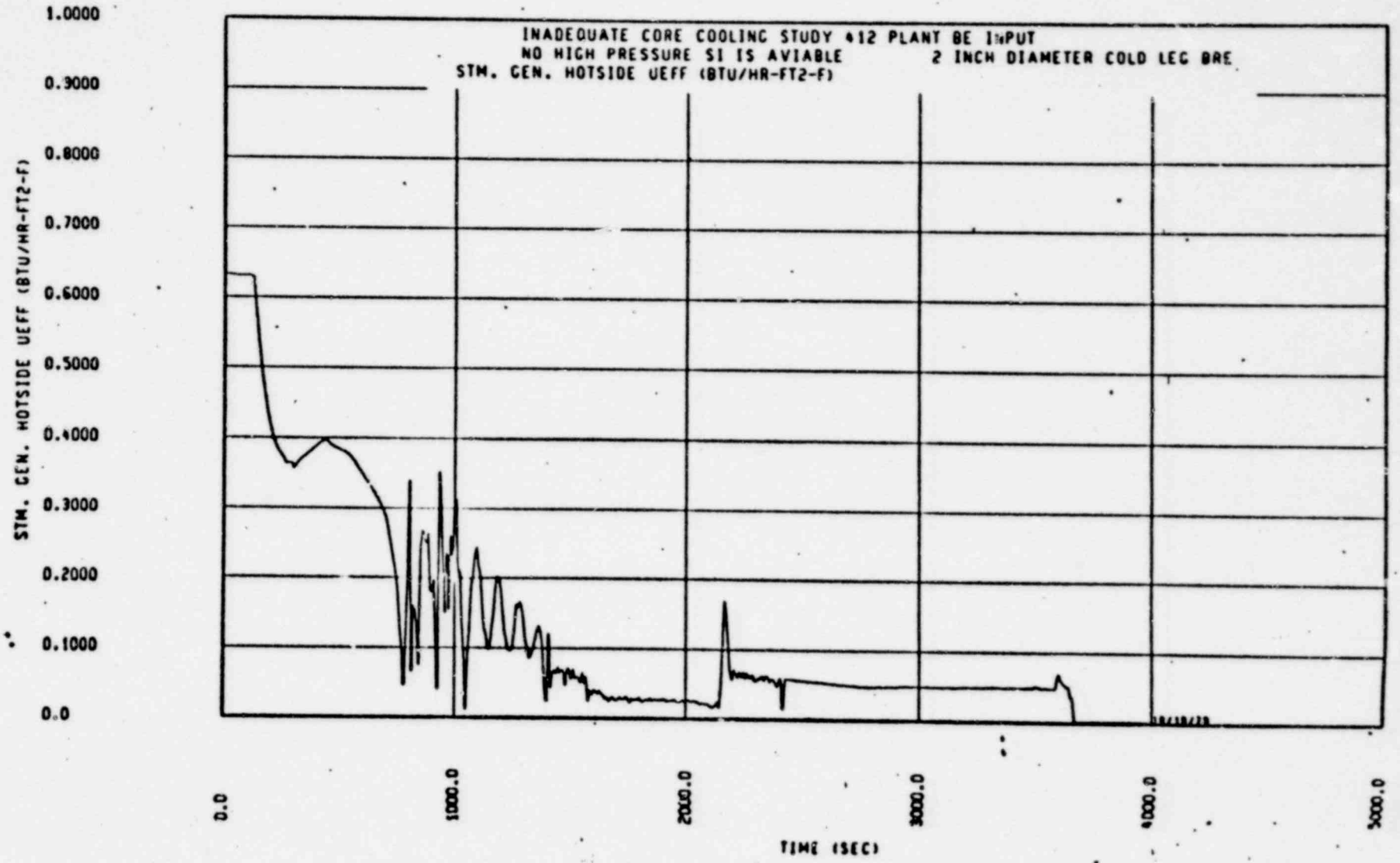


Figure 85

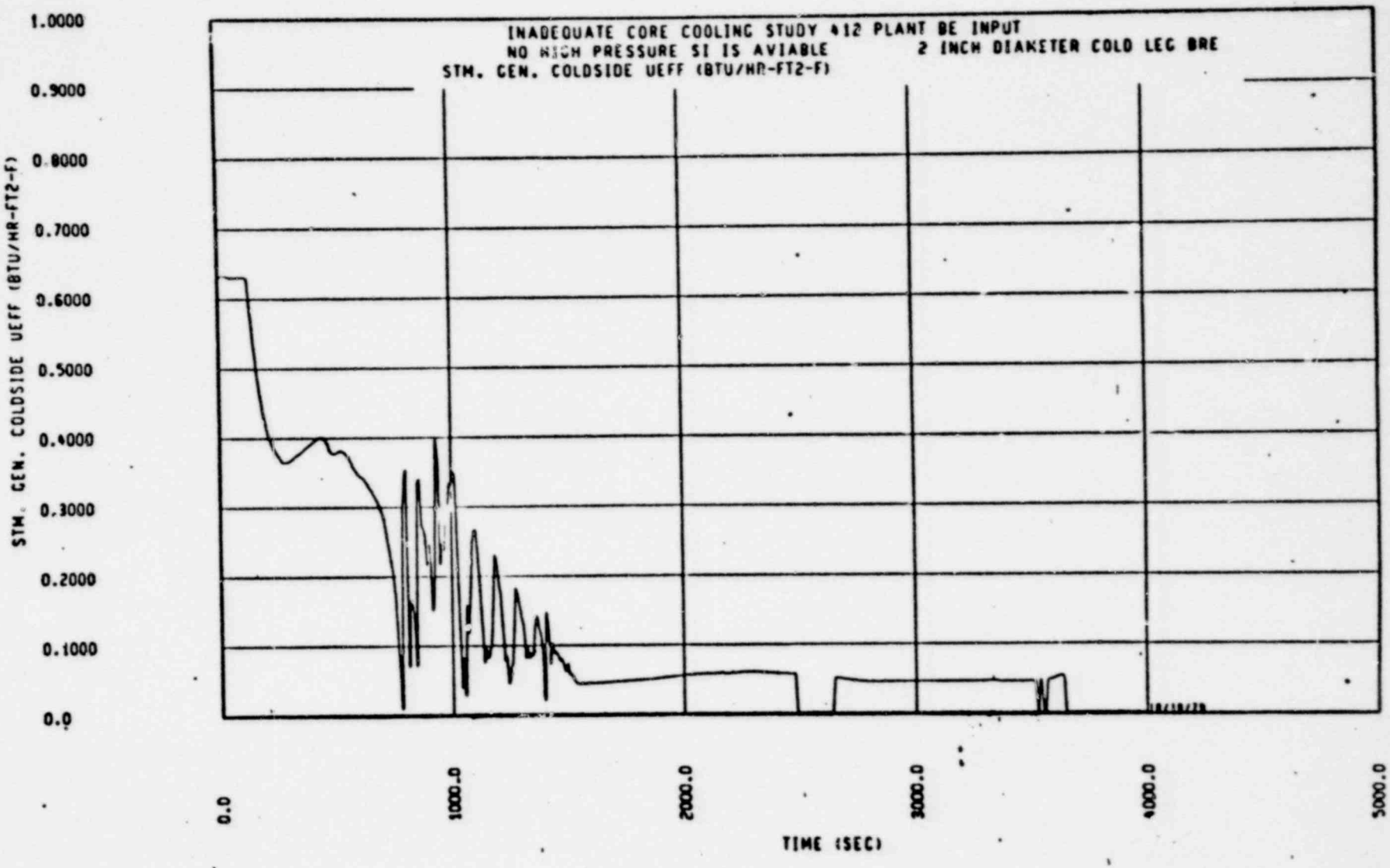


Figure 86

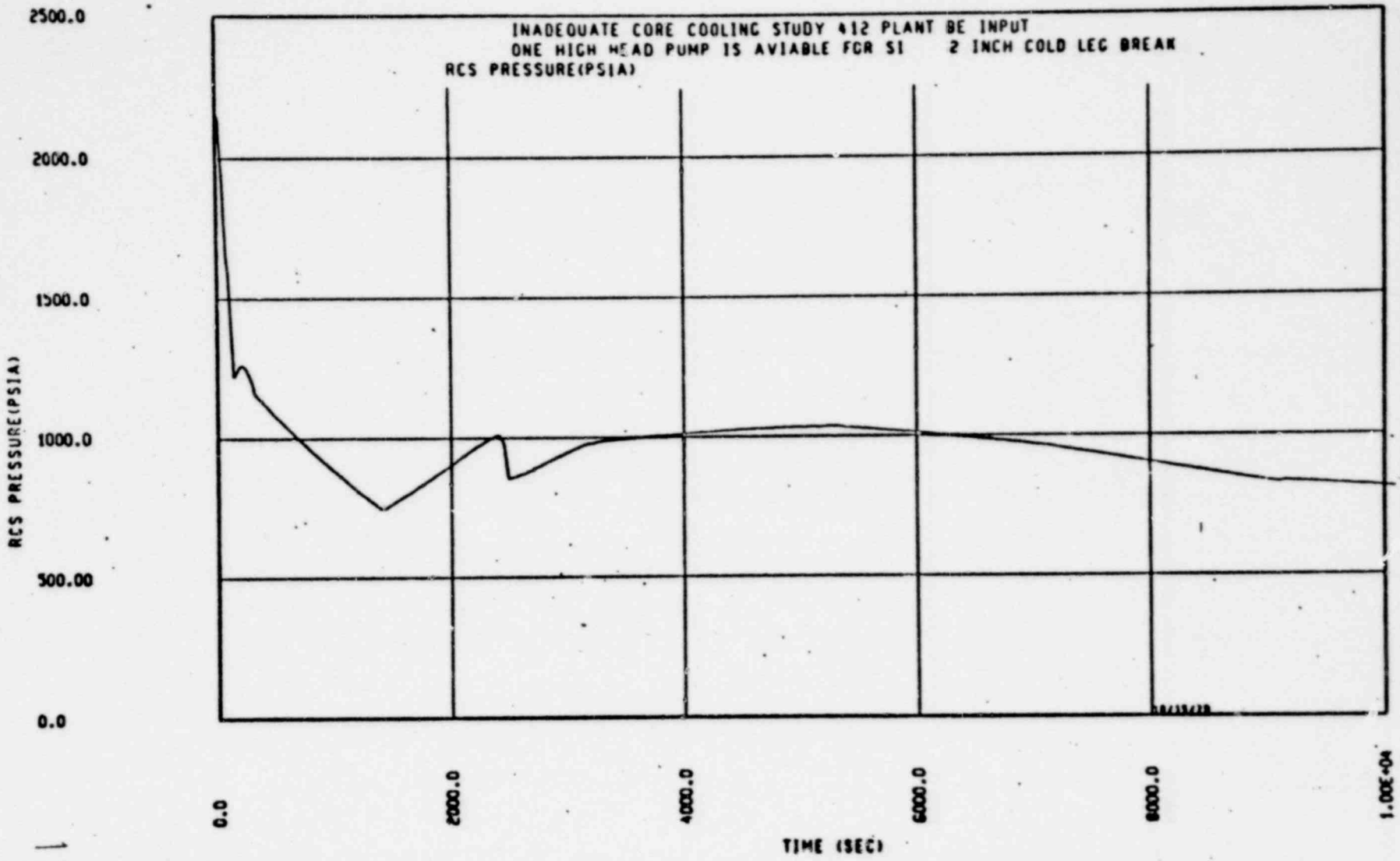


Figure 87

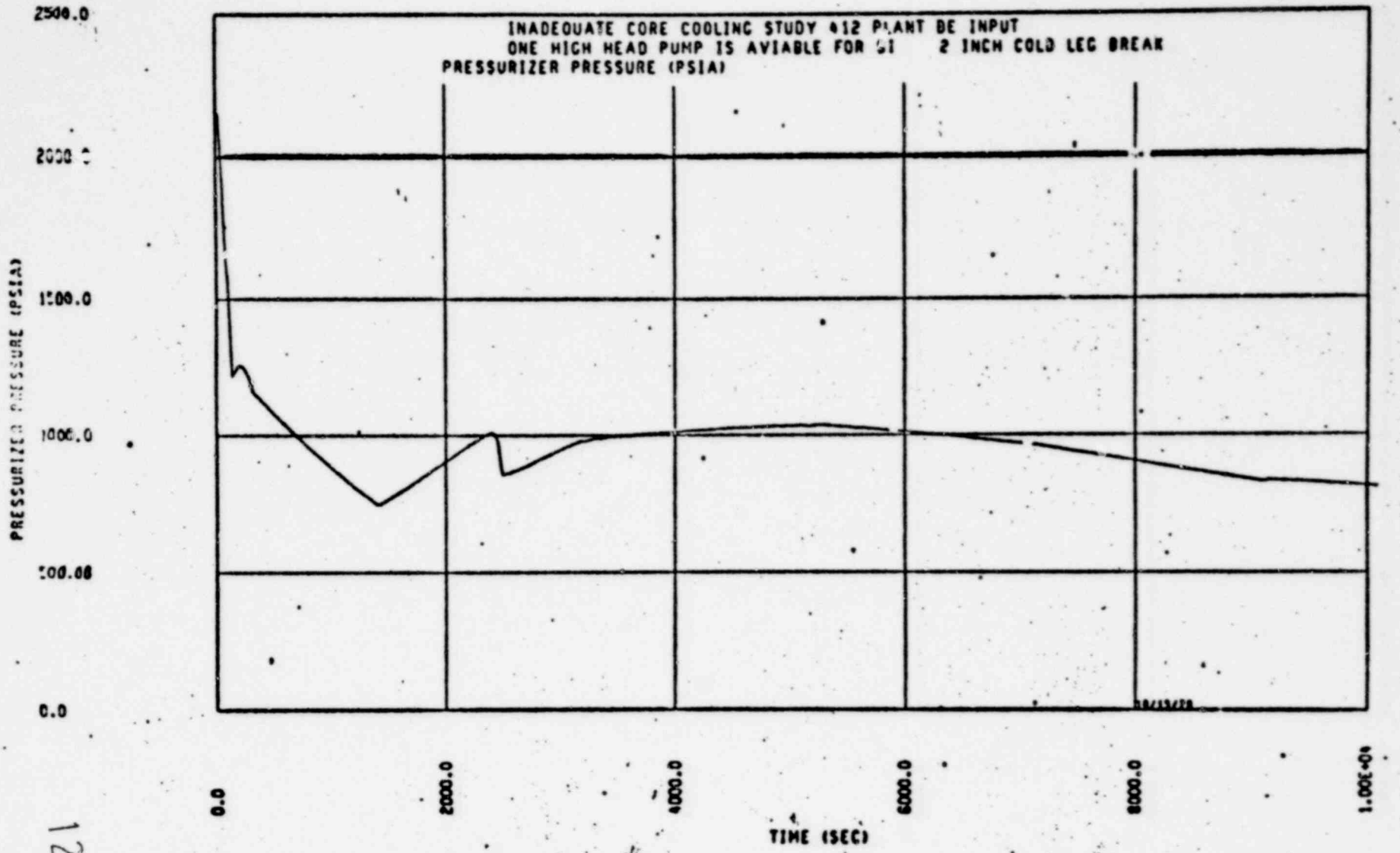


Figure 88

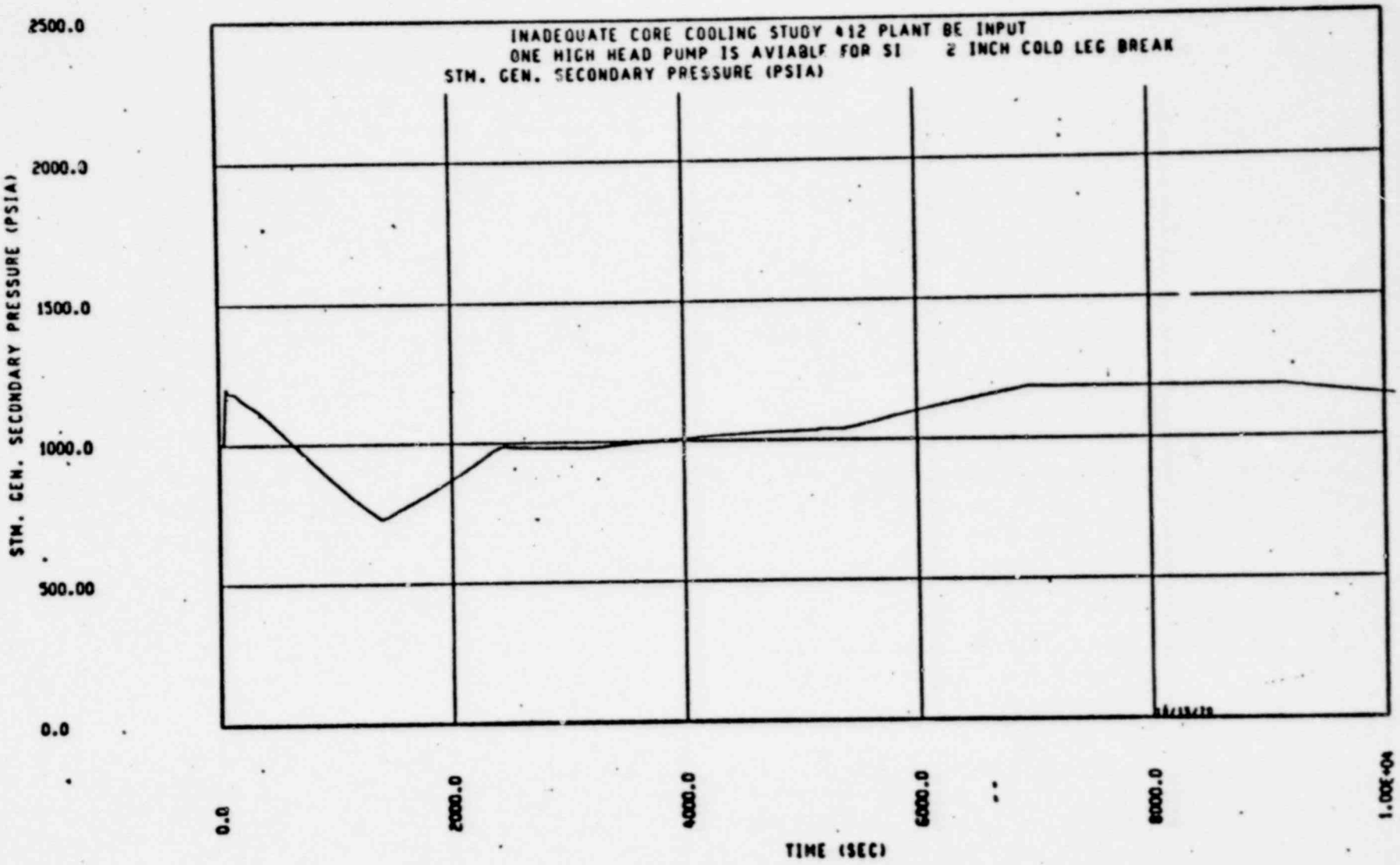

INADEQUATE CORE COOLING STUDY 412 PLANT BE INPUT
ONE HIGH HEAD PUMP IS AVIABLE FOR SI 2 INCH COLD LEG BREAK
STM. GEN. SECONDARY PRESSURE (PSIA)
STM. GEN. SECONDARY PRESSURE (PSIA)
2500.0
2000.0
1500.0
1000.0
500.00
0.0
0.0
2000.0
4000.0
6000.0
8000.0
1.00E+04
TIME (SEC)

Figure 89

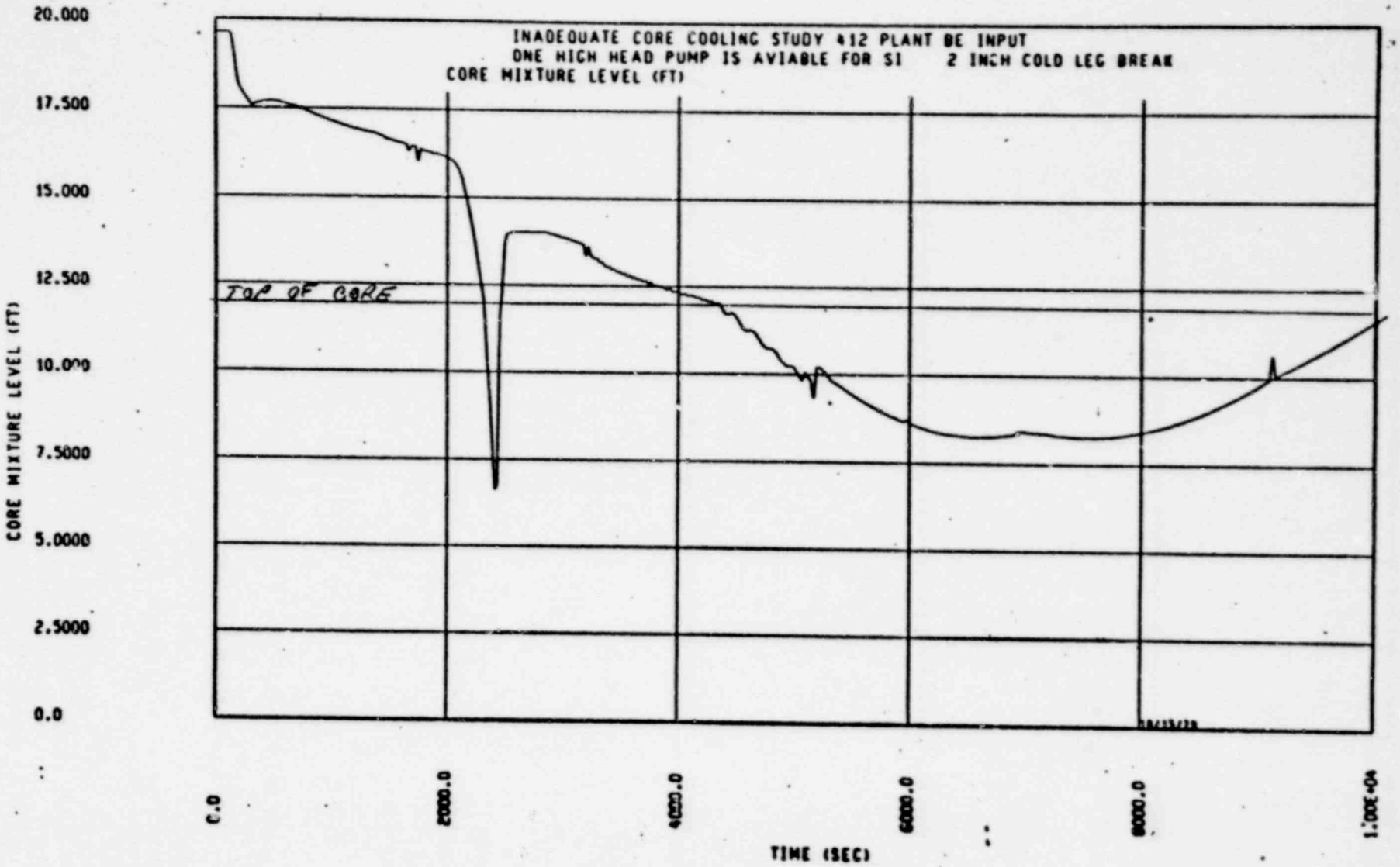


Figure 90

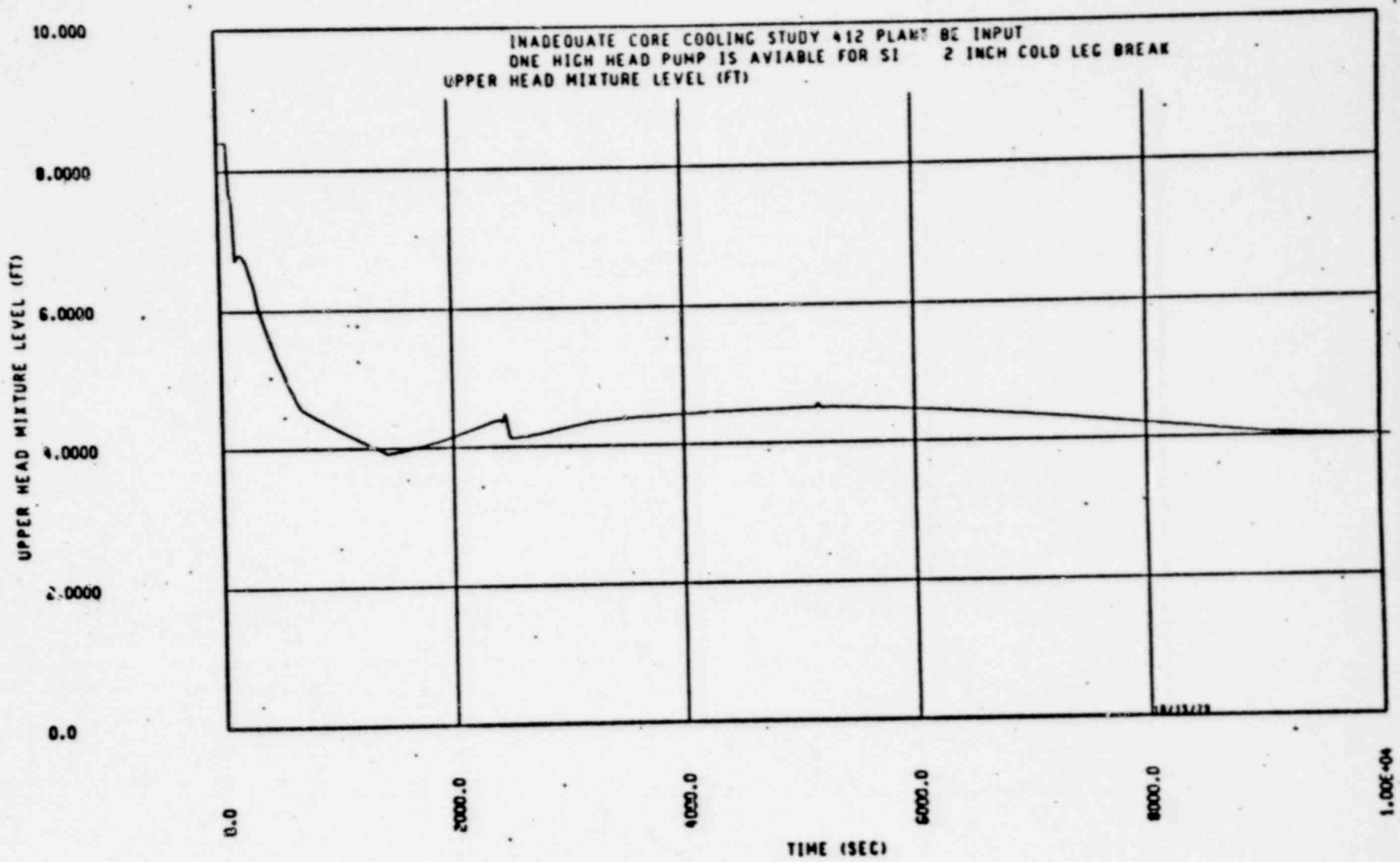


Figure 91

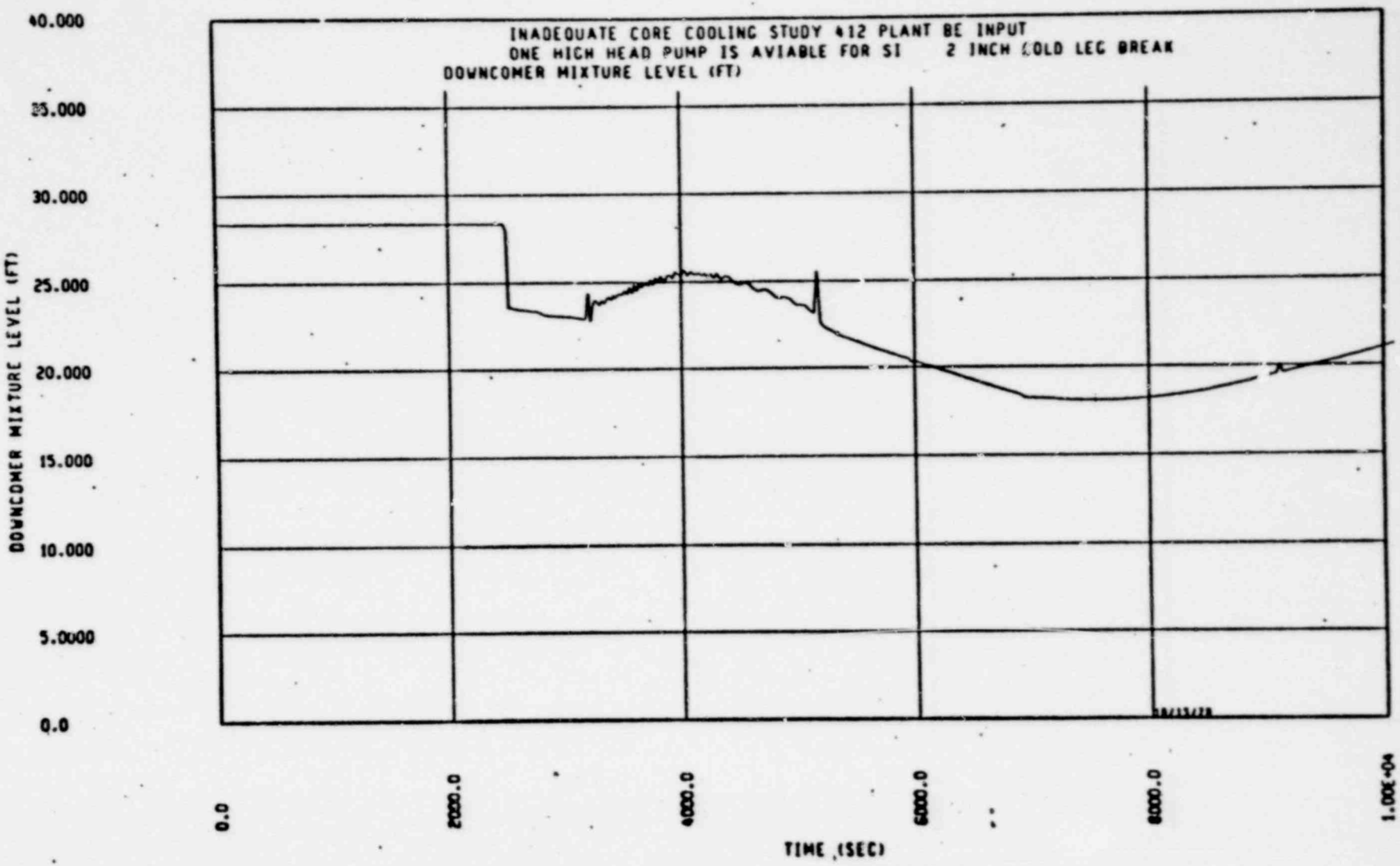


Figure 92

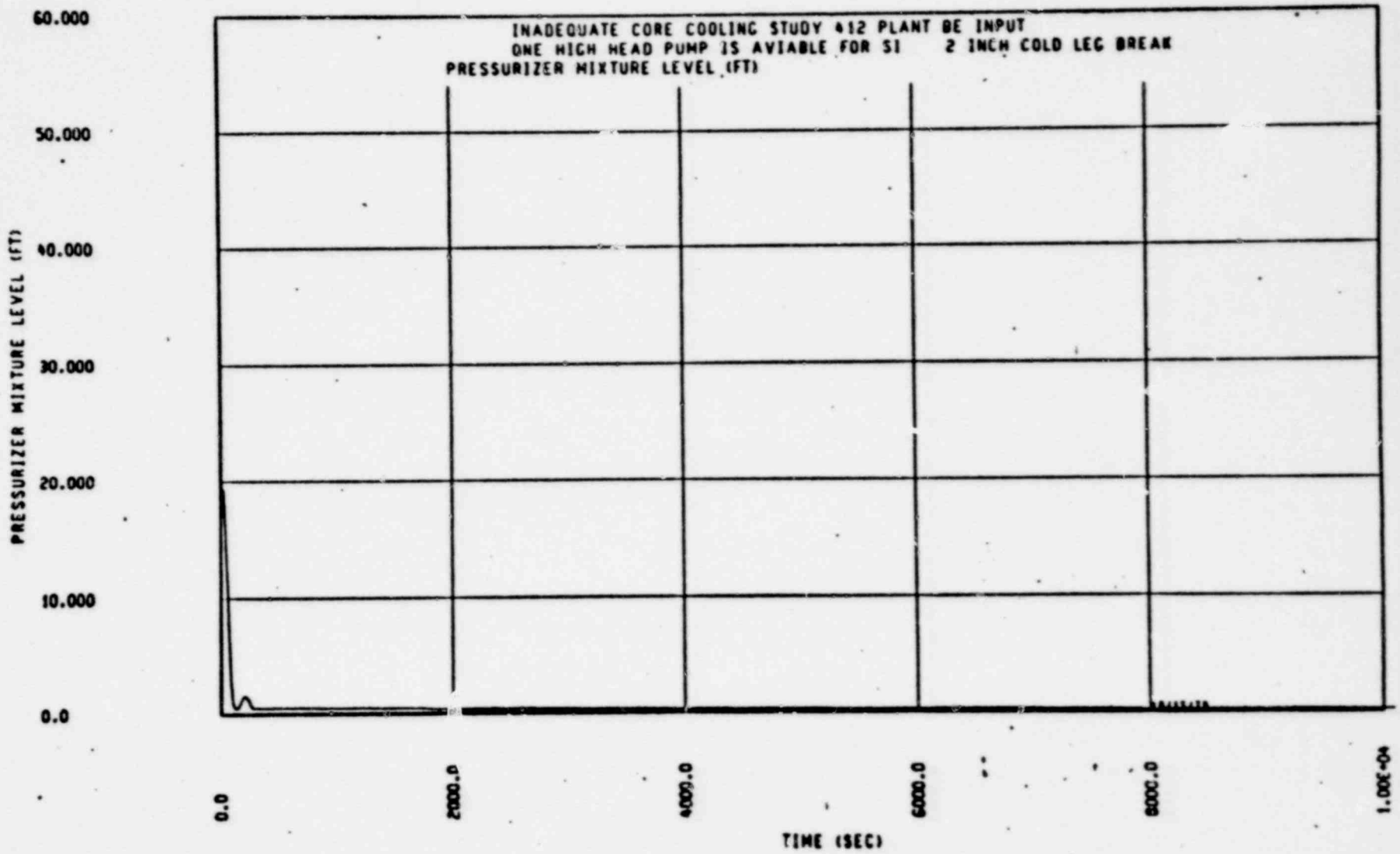


Figure 93

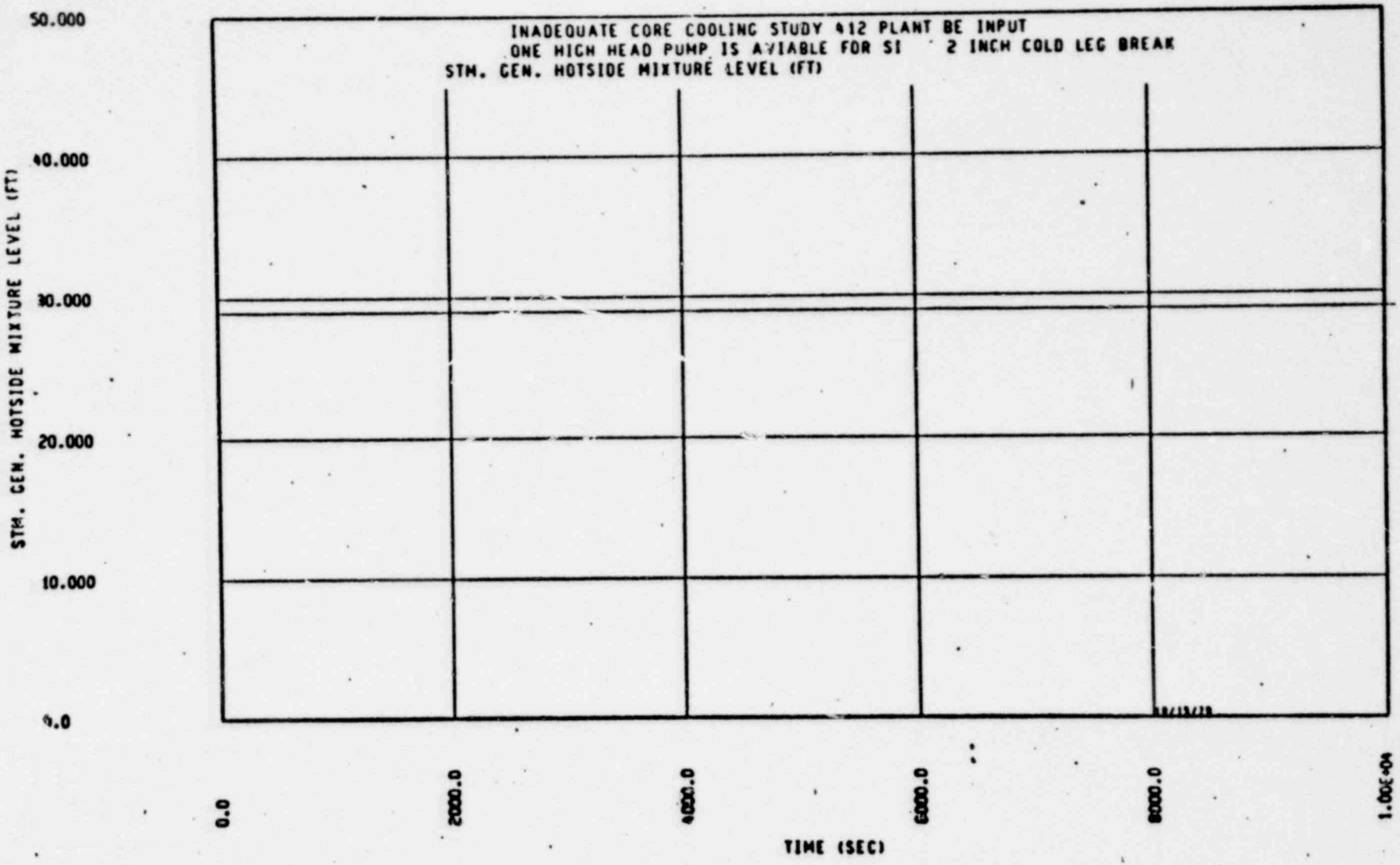


Figure 94

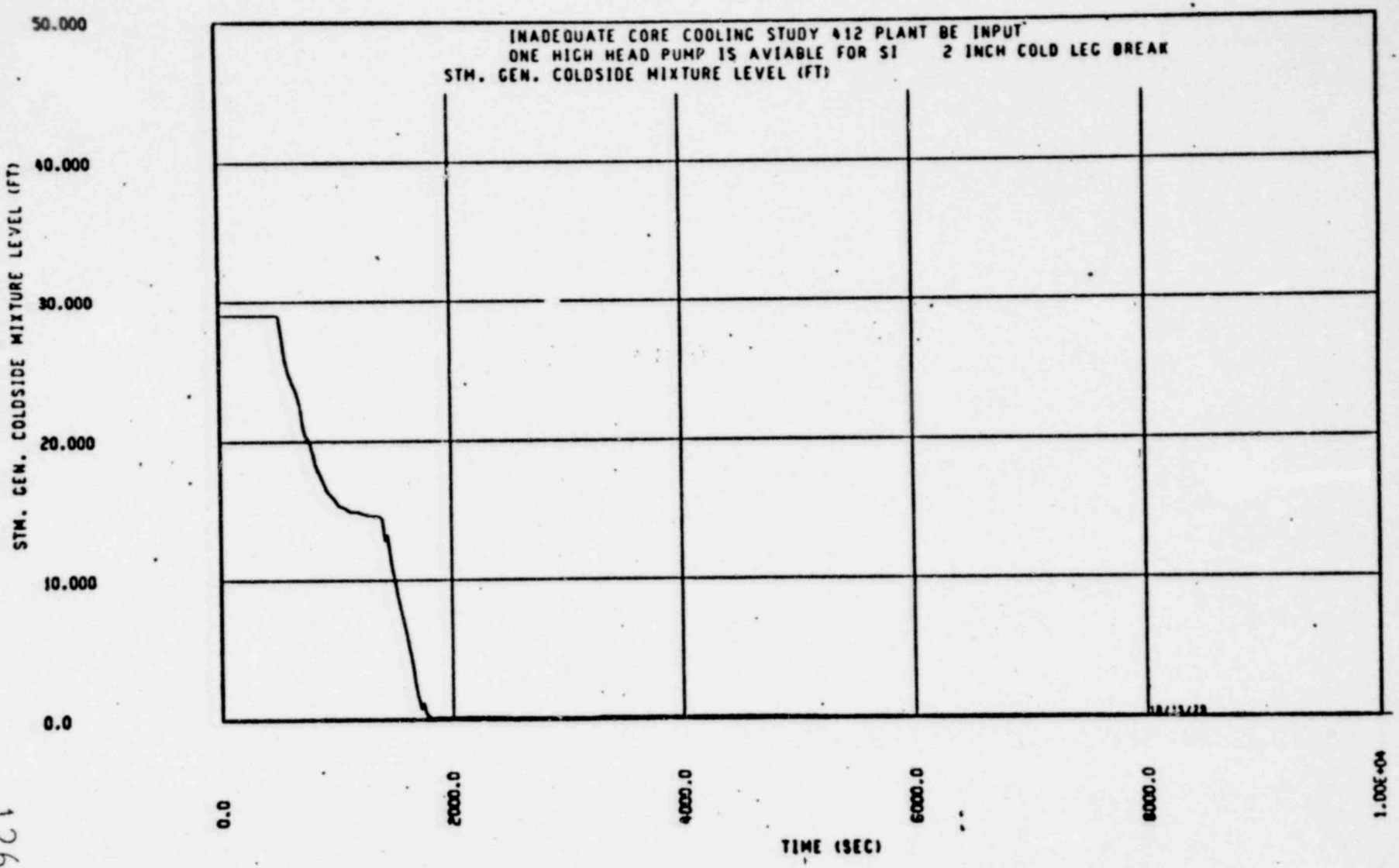


Figure 95

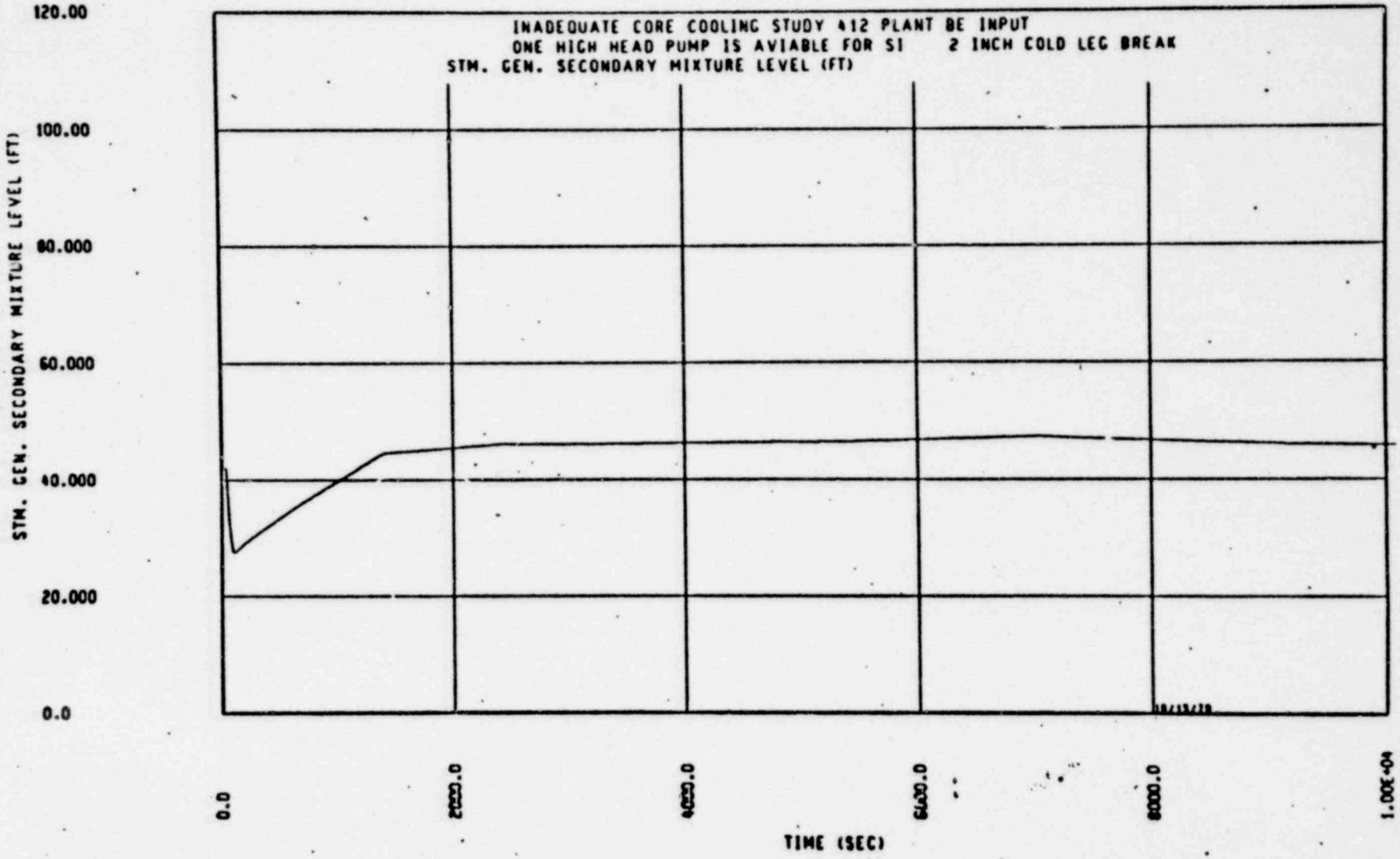


Figure 96

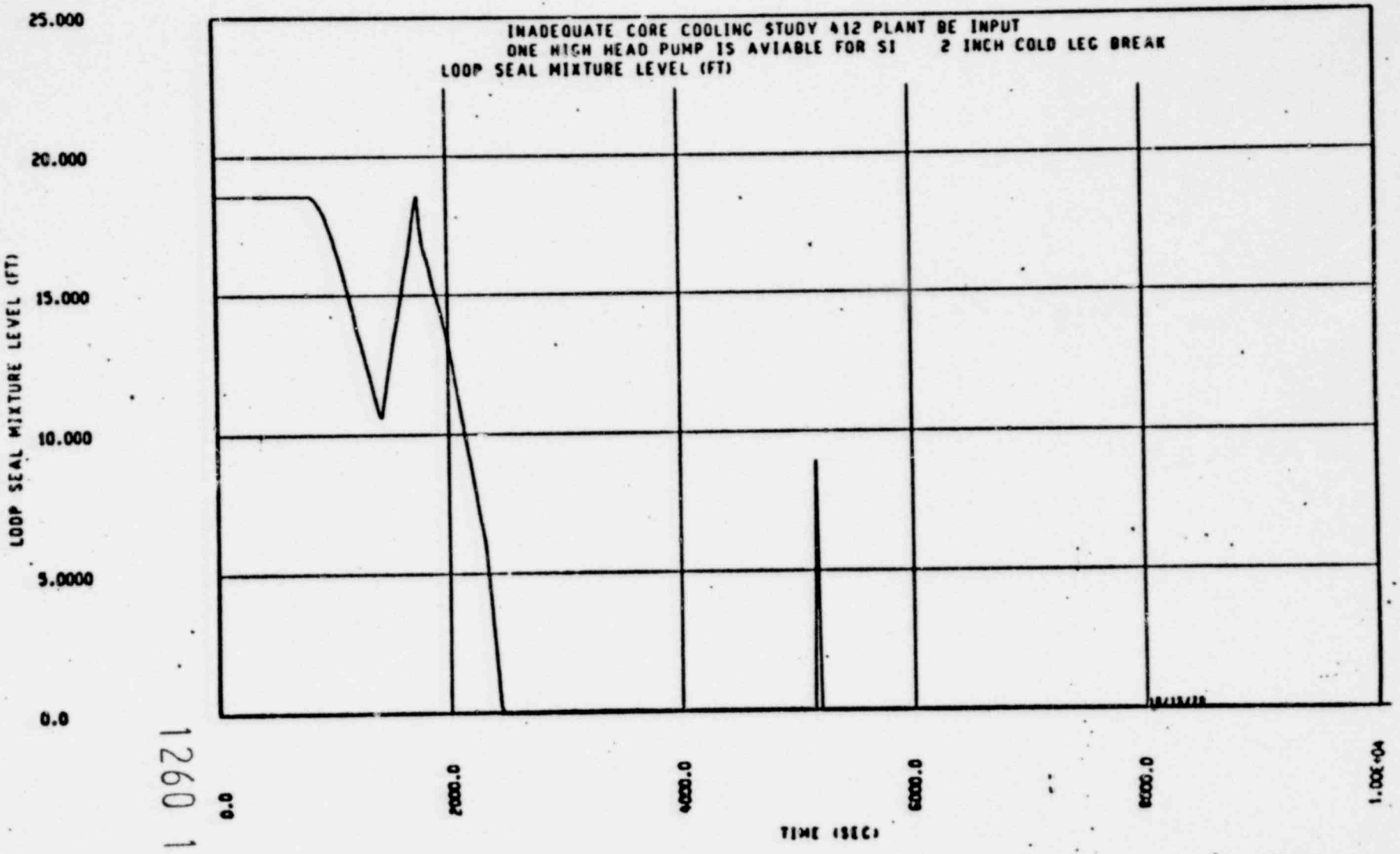


Figure 97

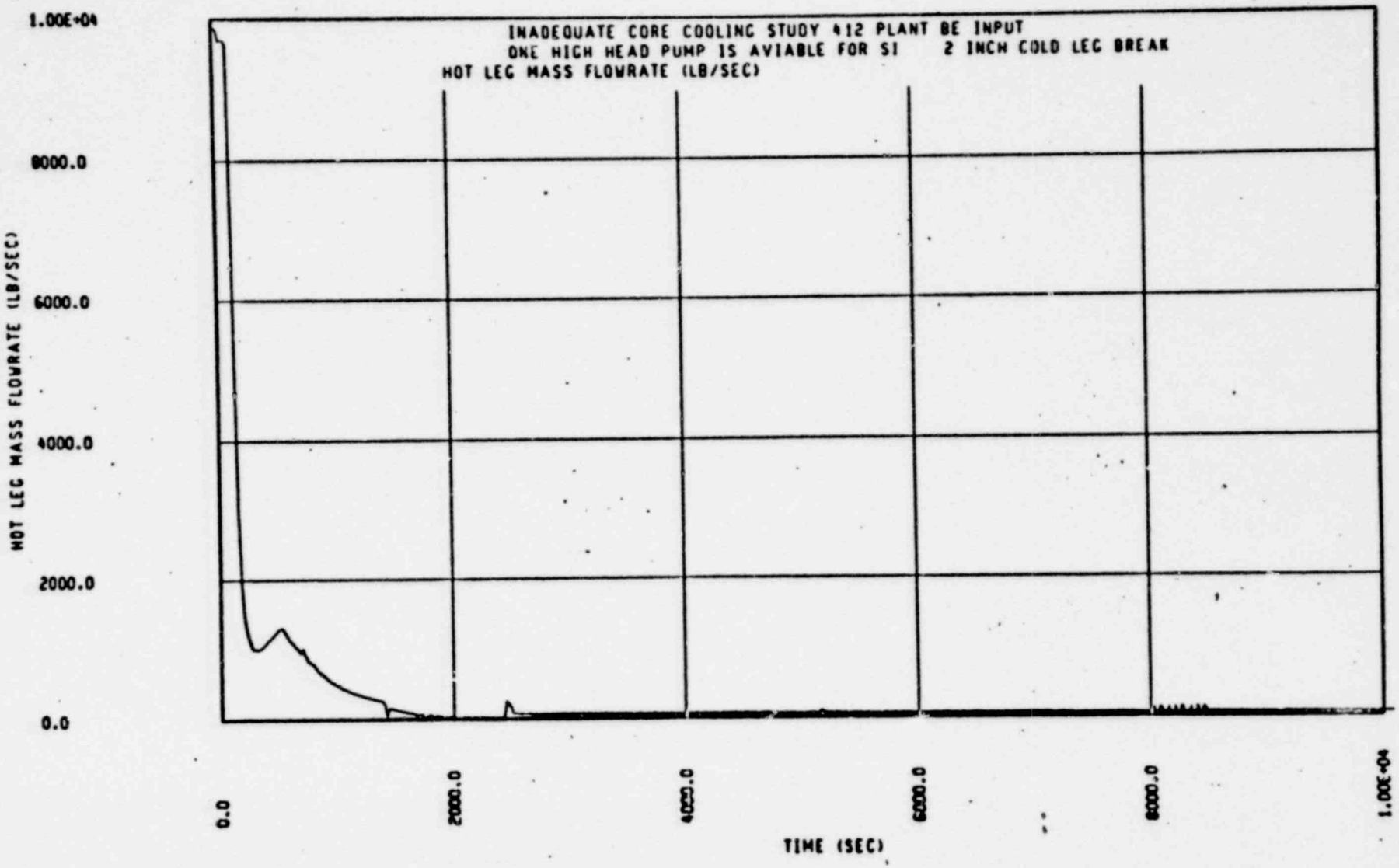


Figure 98

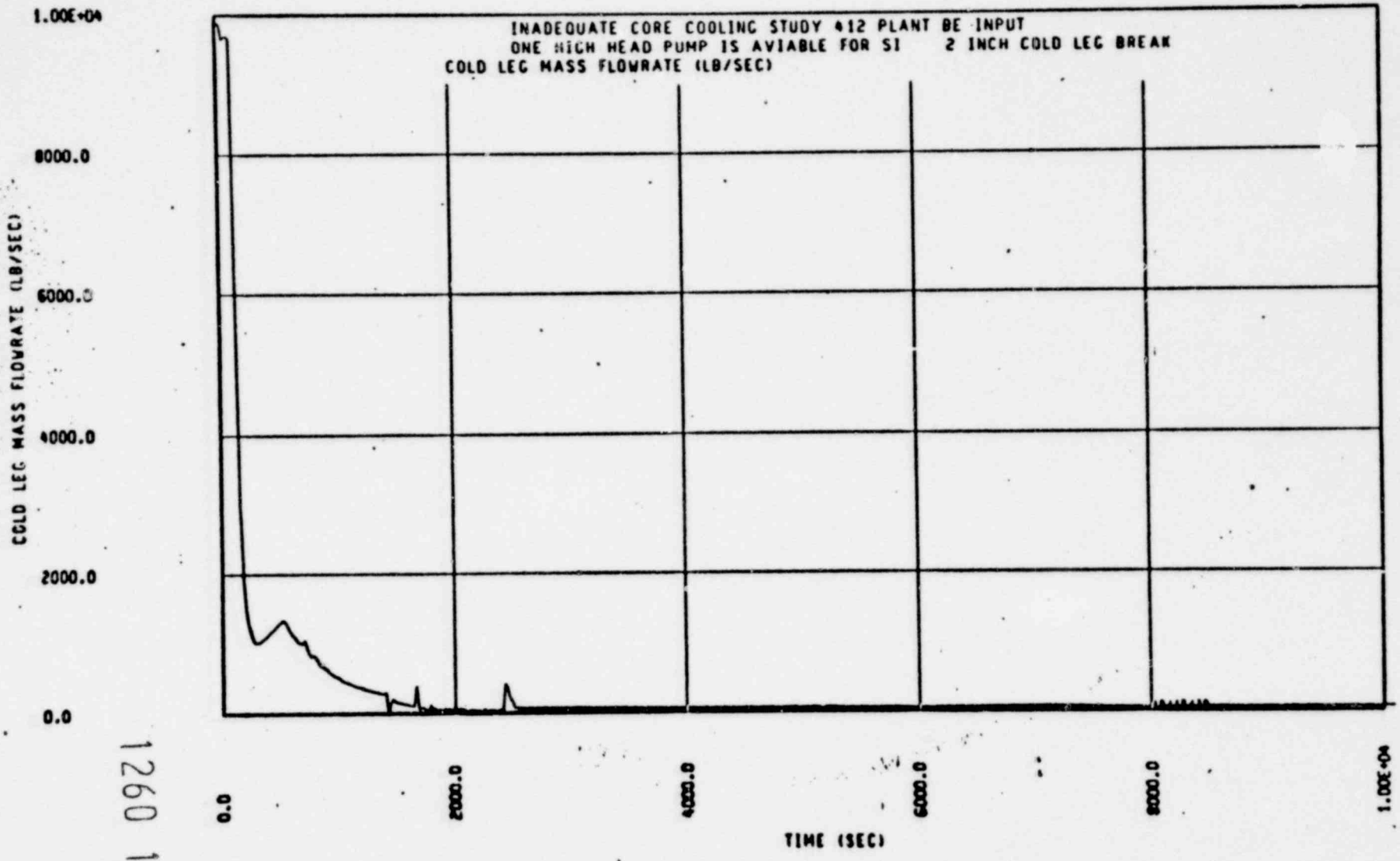


Figure 99

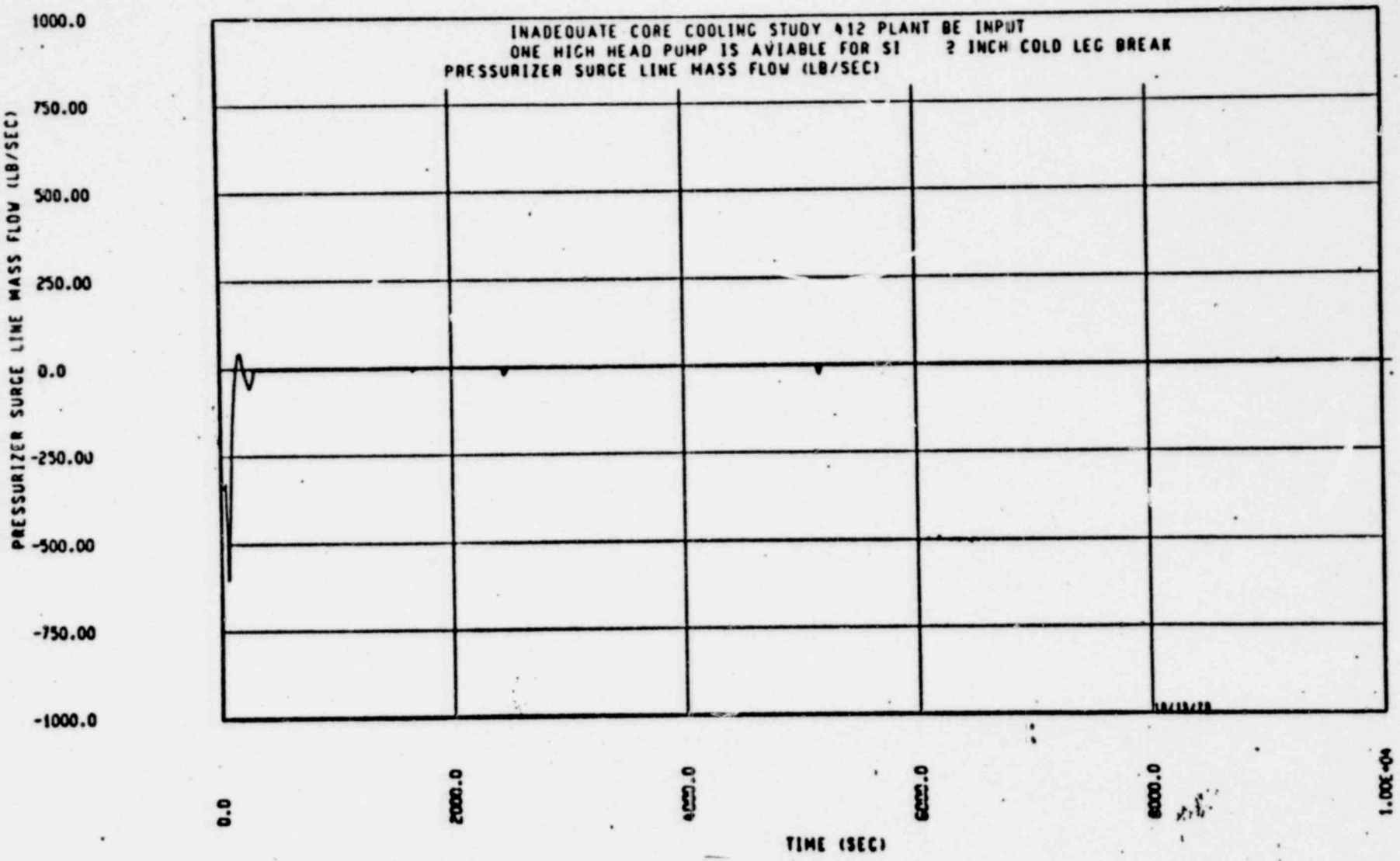


Figure 100

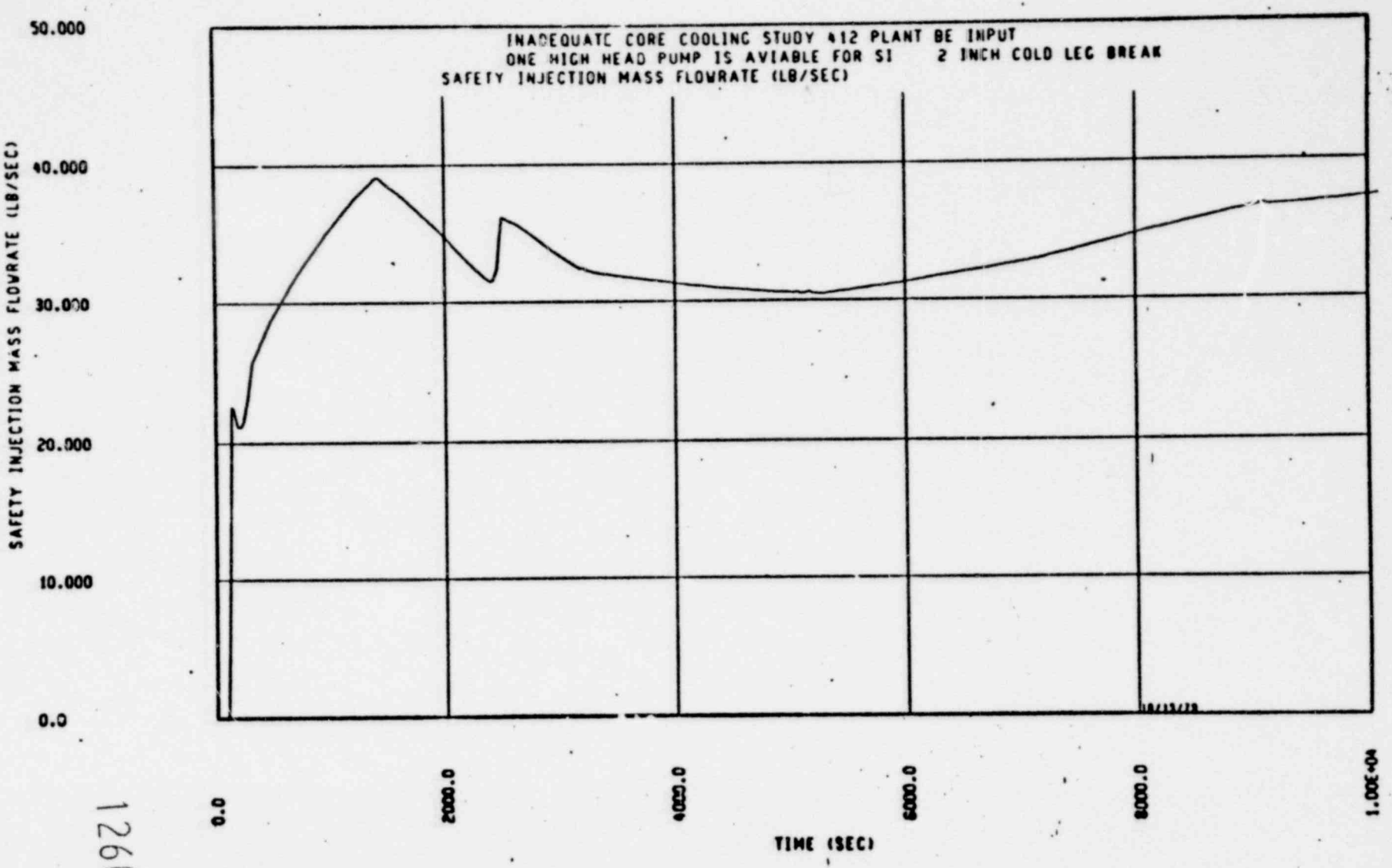


Figure 101

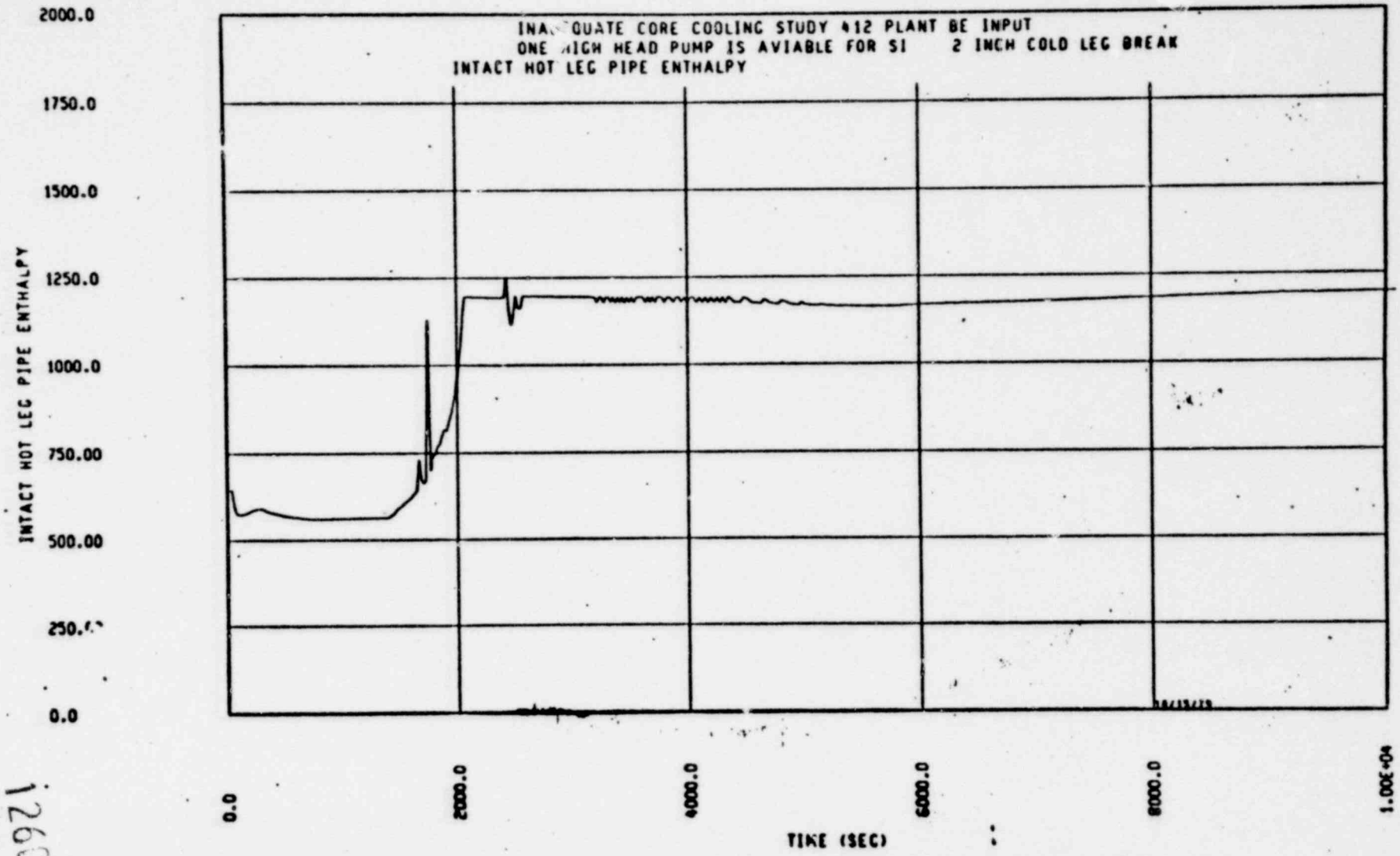


Figure 102

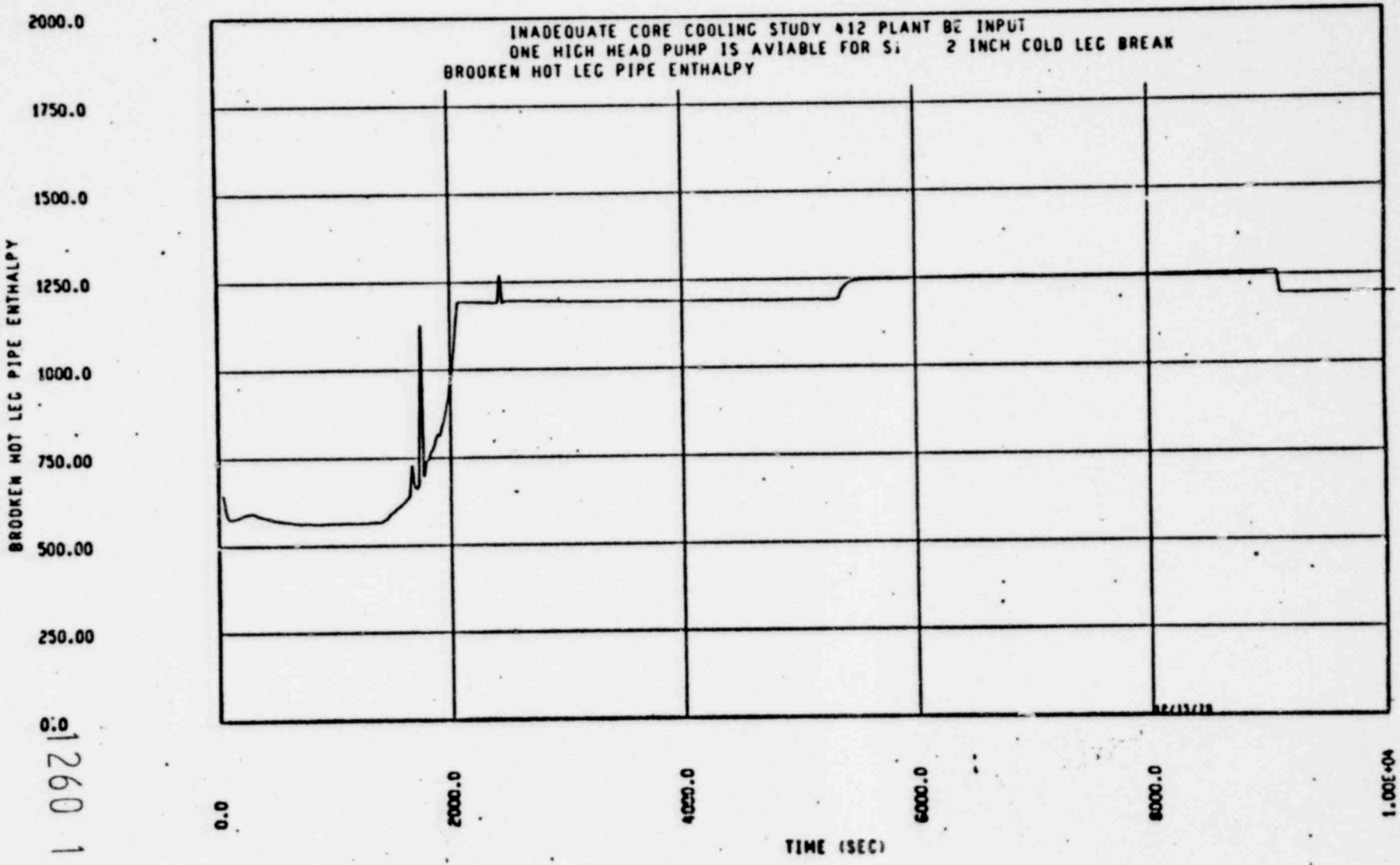


Figure 103

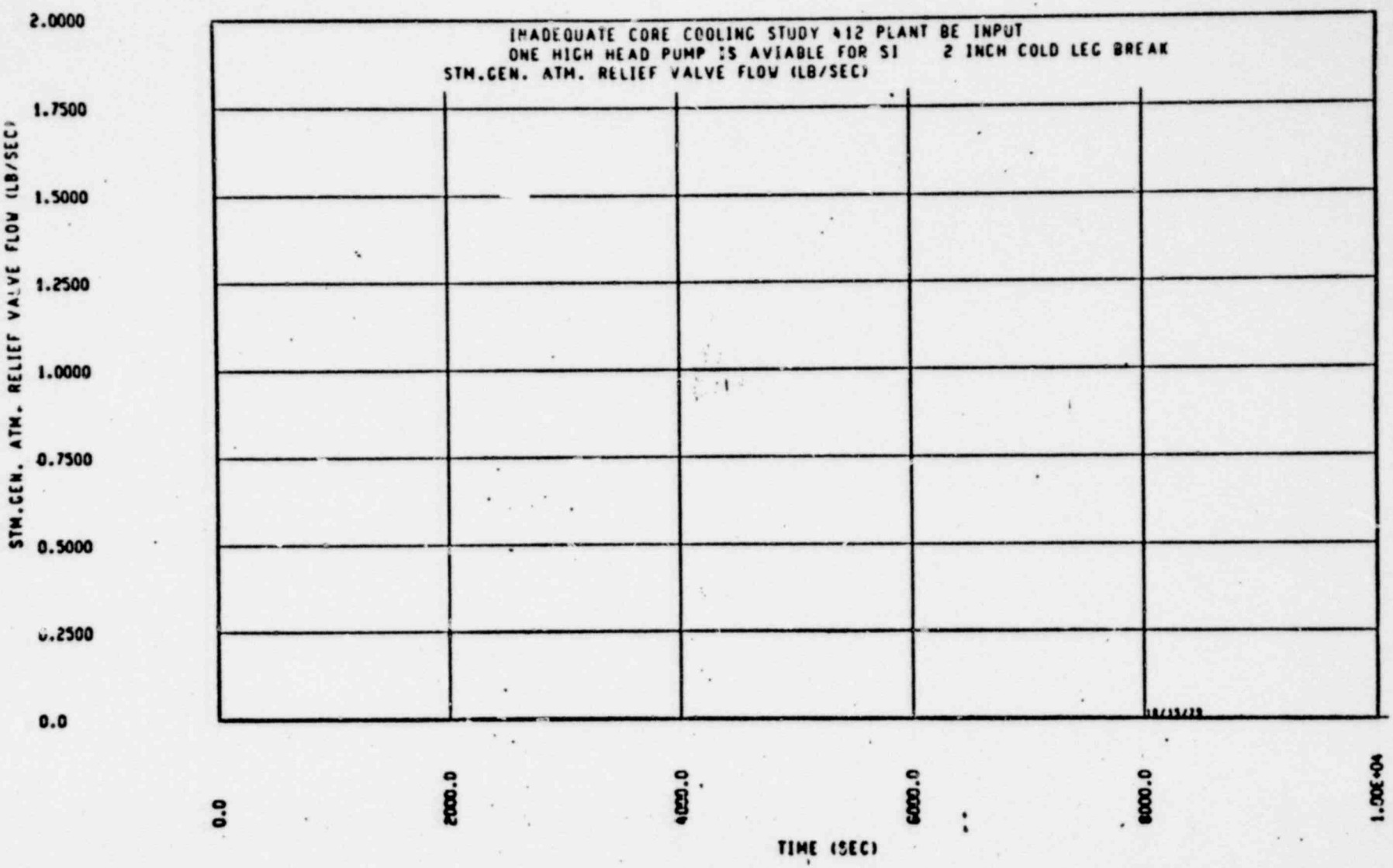


Figure 104

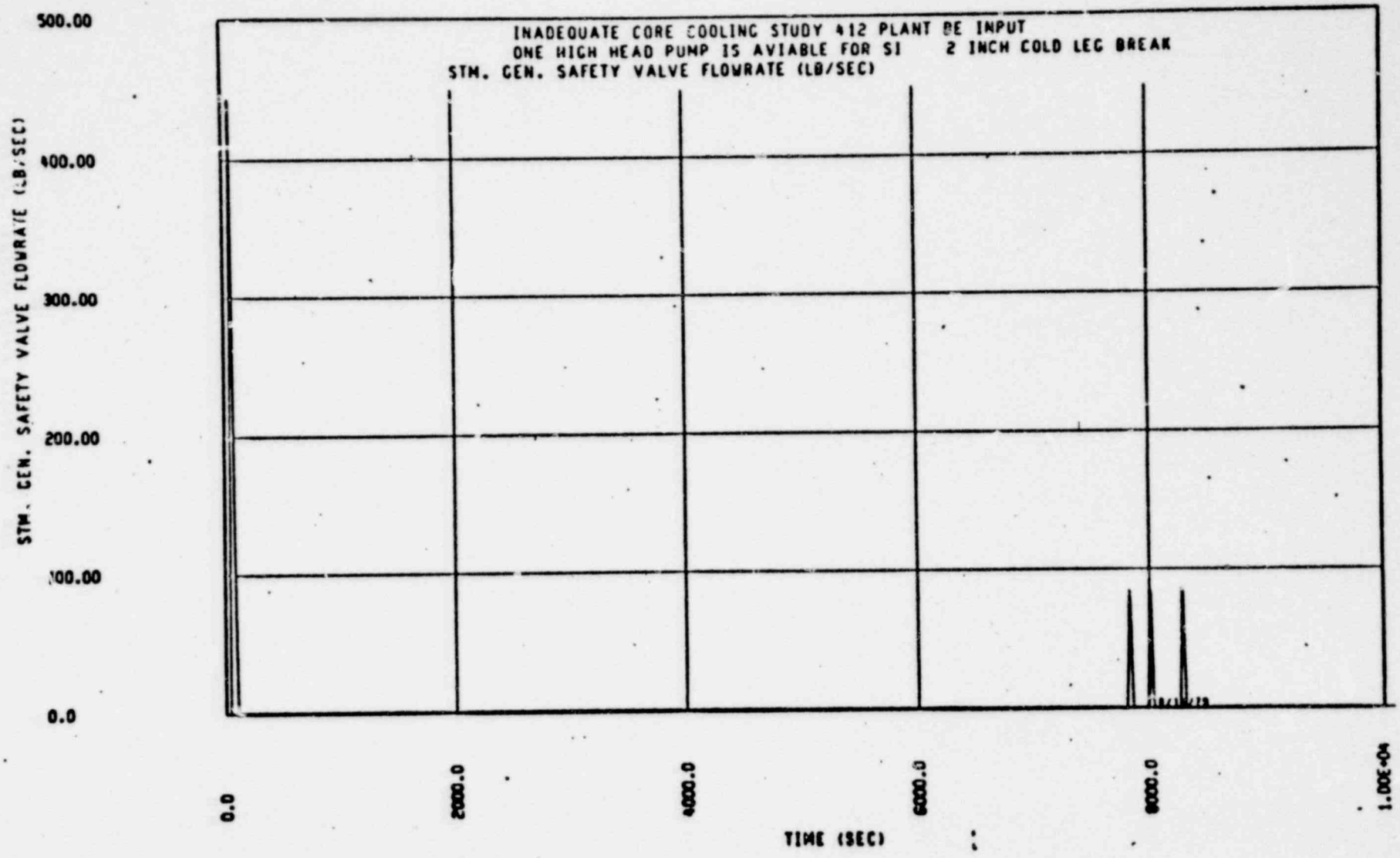


Figure 105

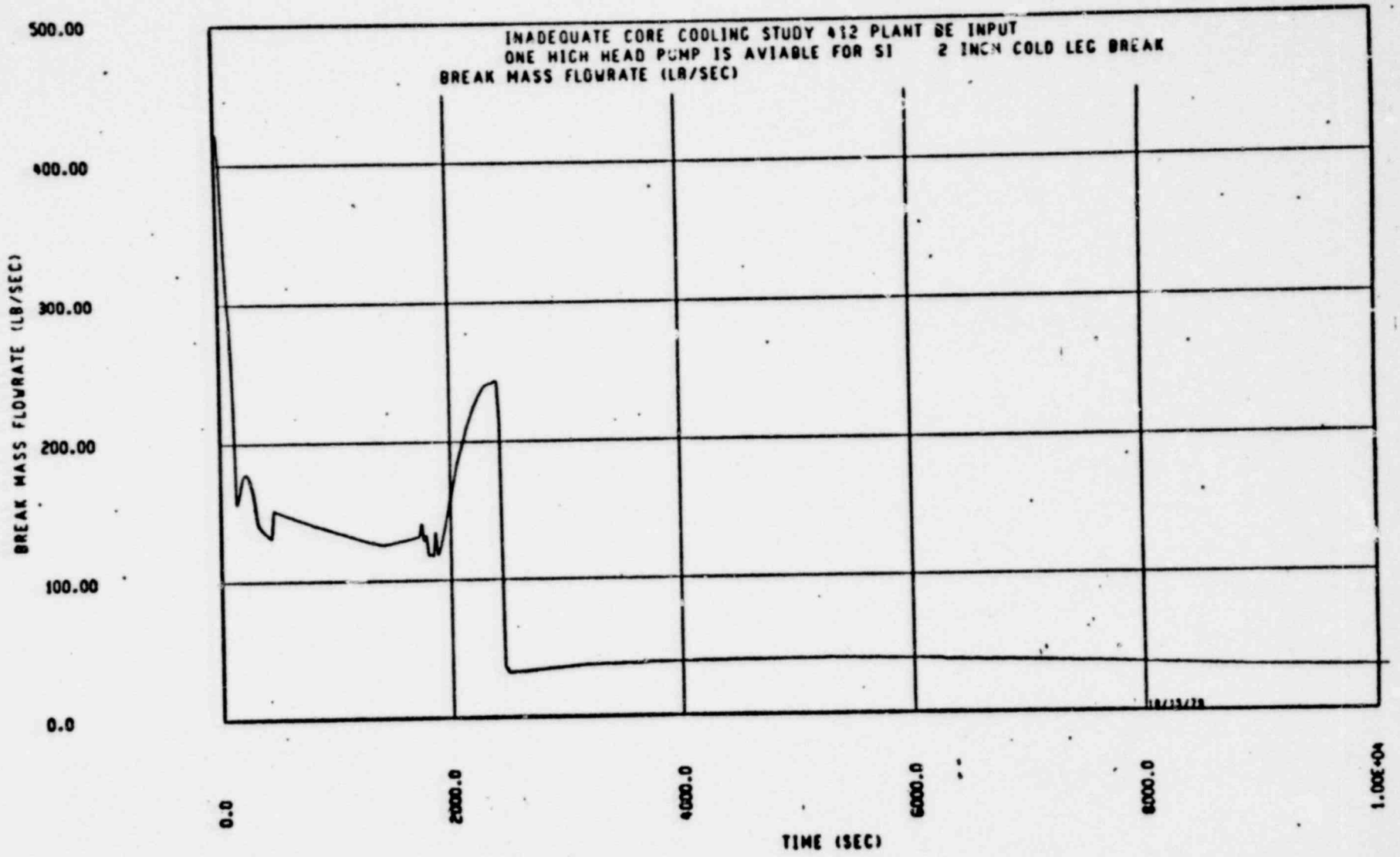


Figure 106

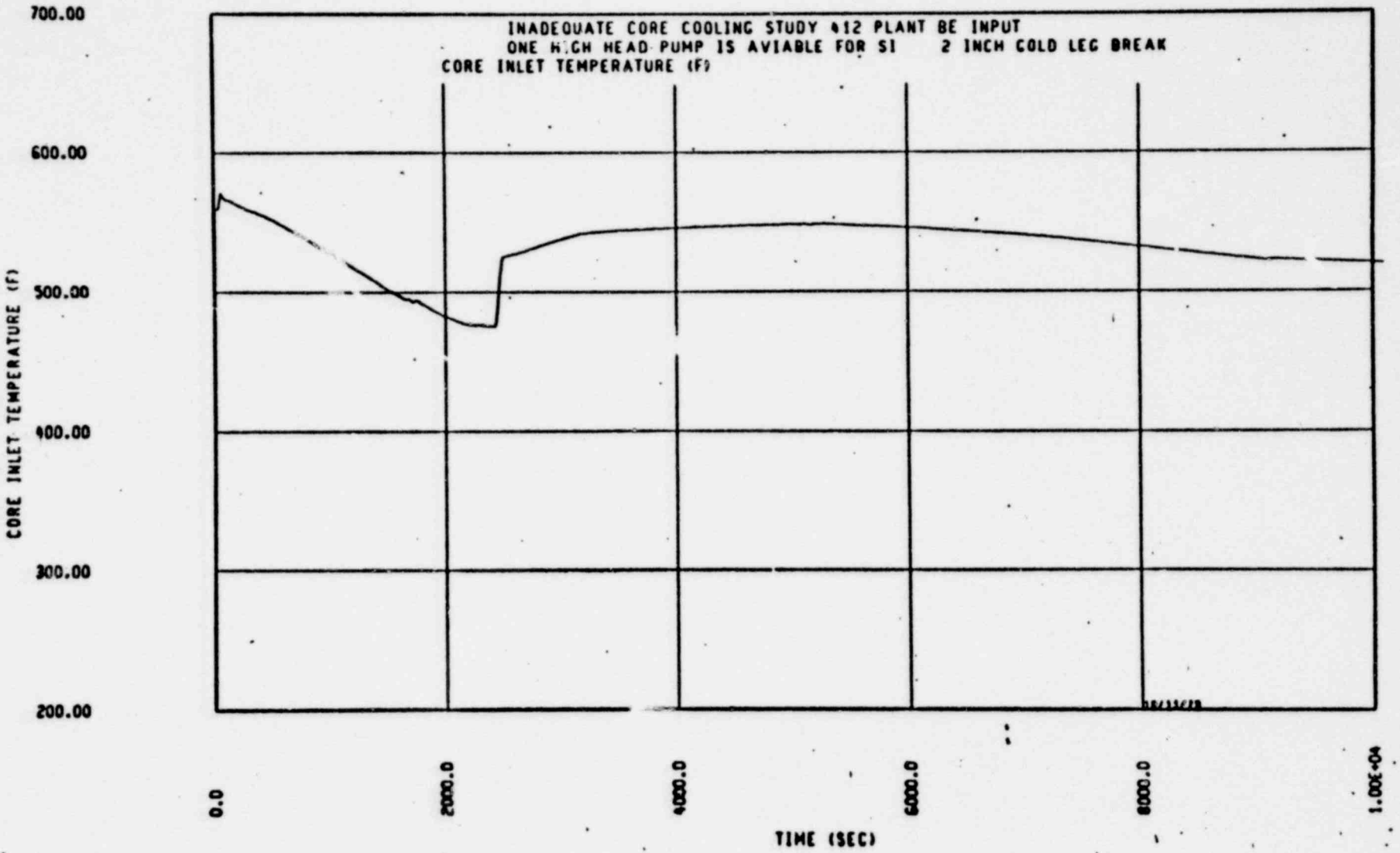


Figure 107

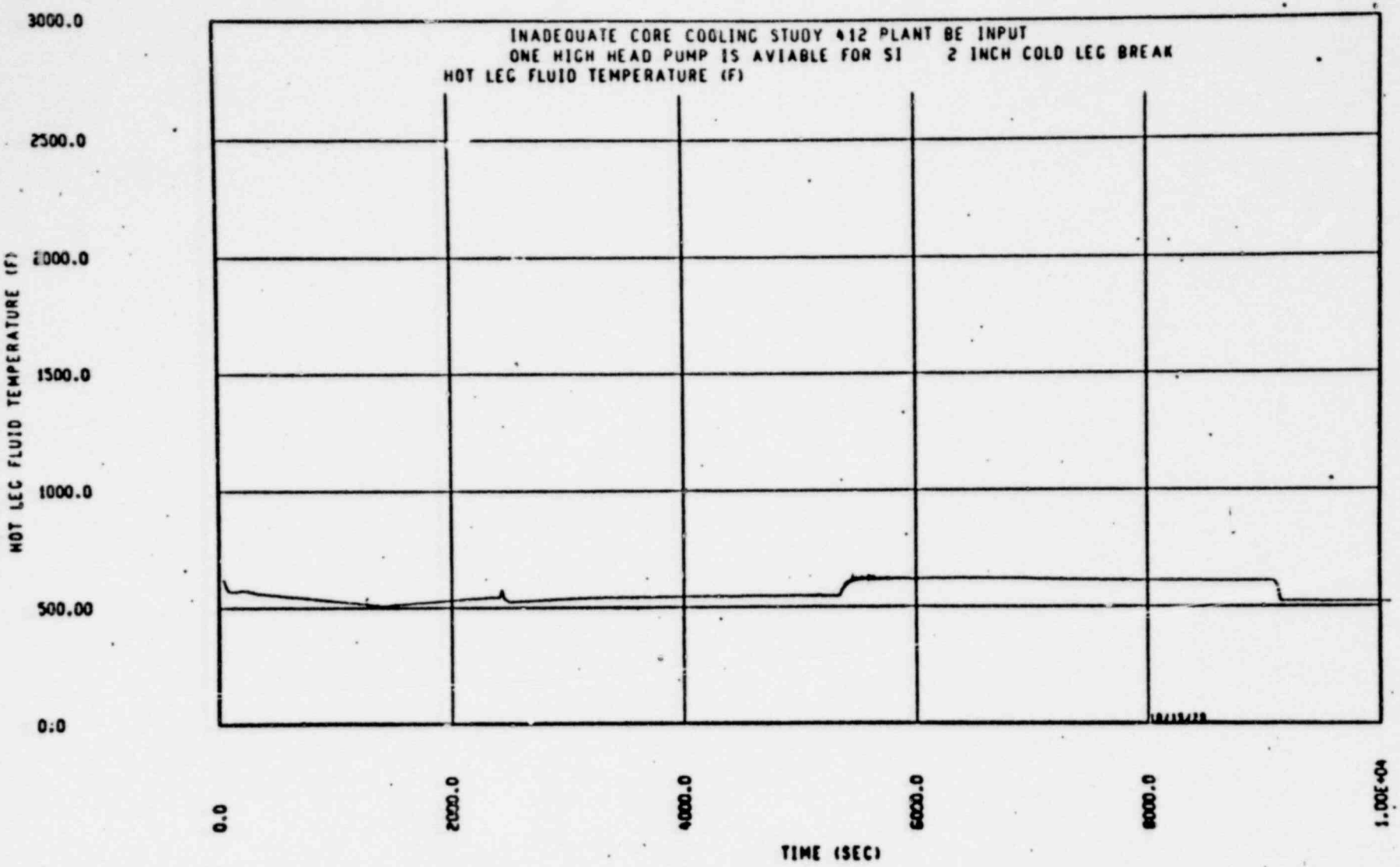


Figure 108

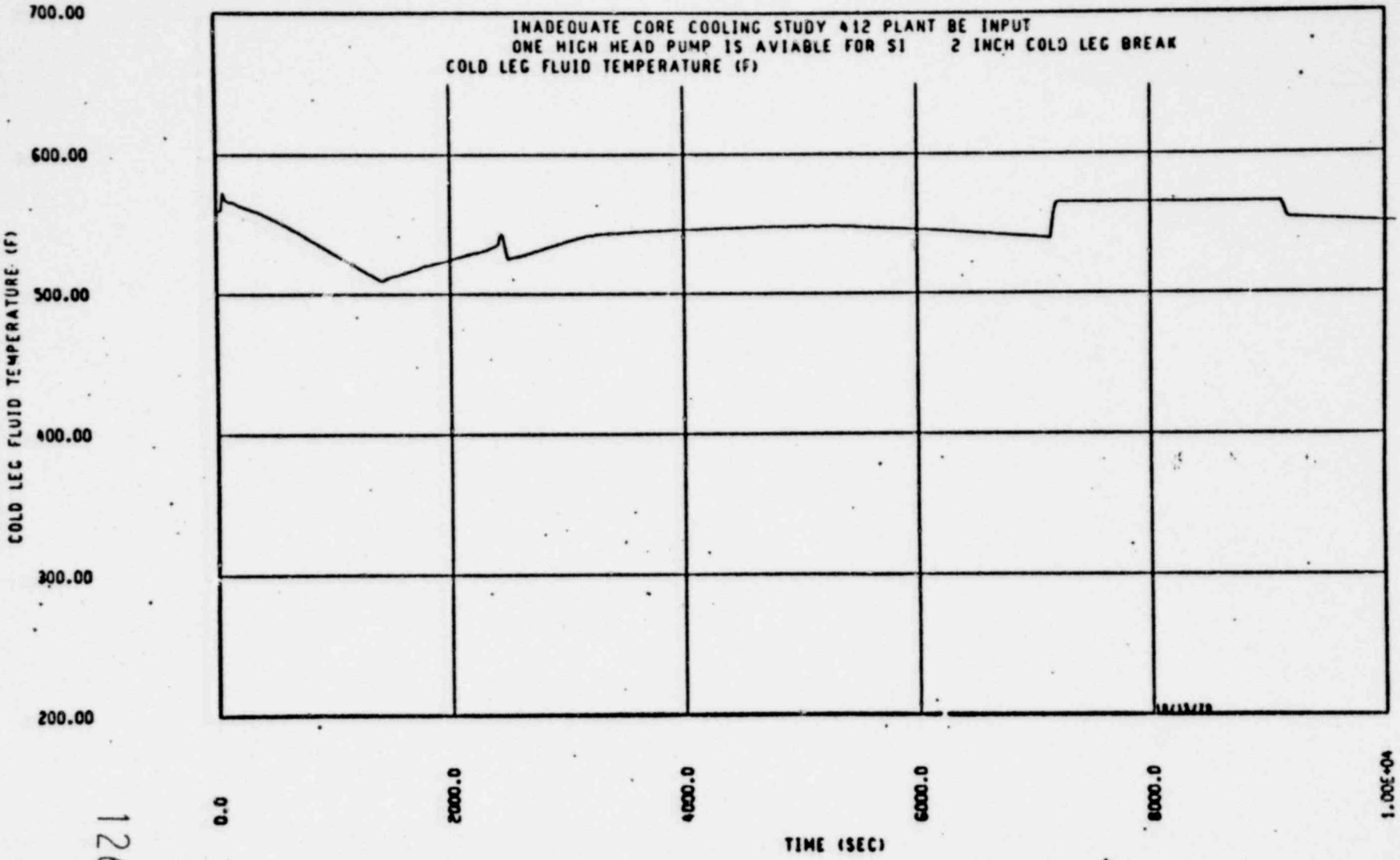


Figure 109

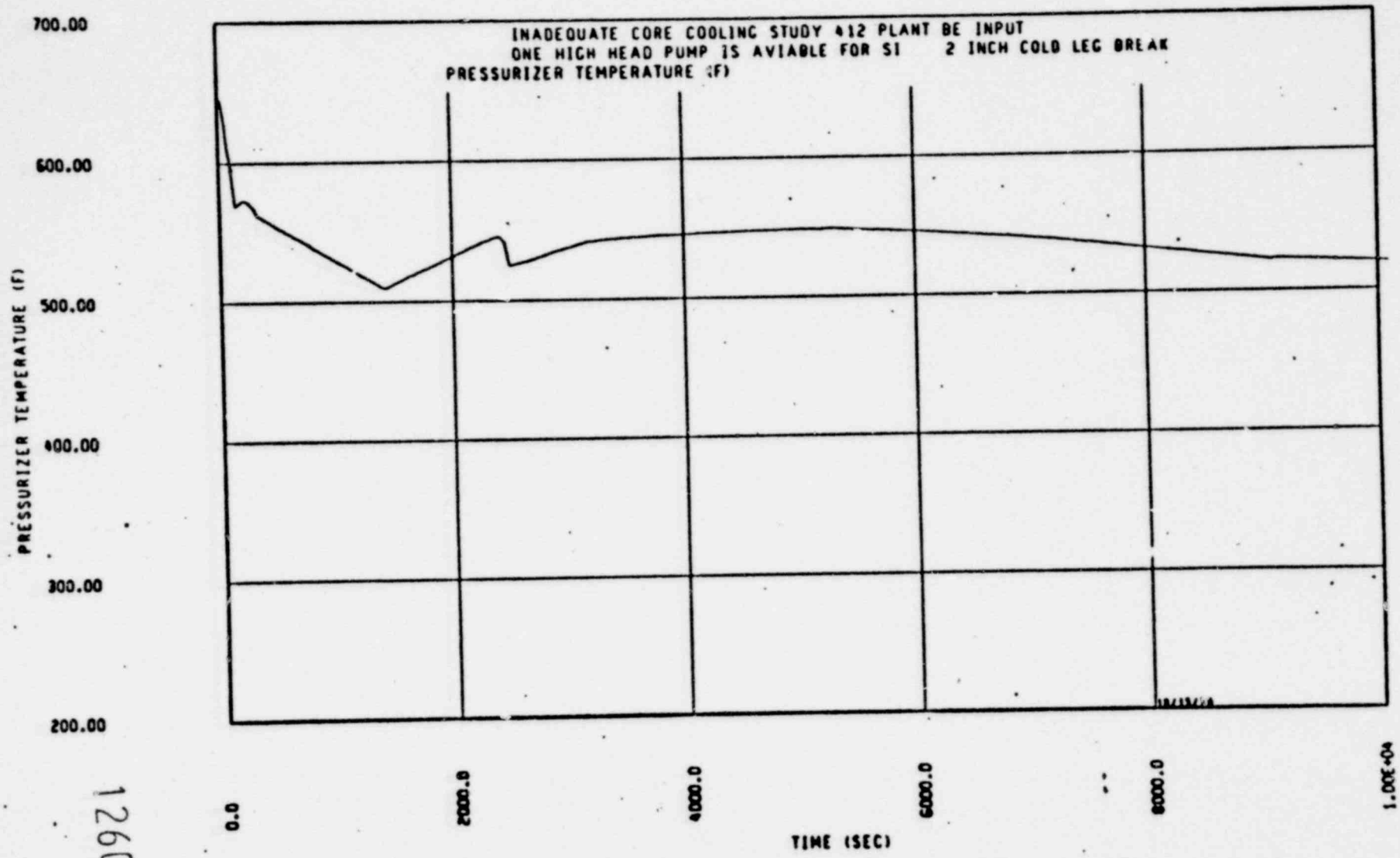


Figure 110

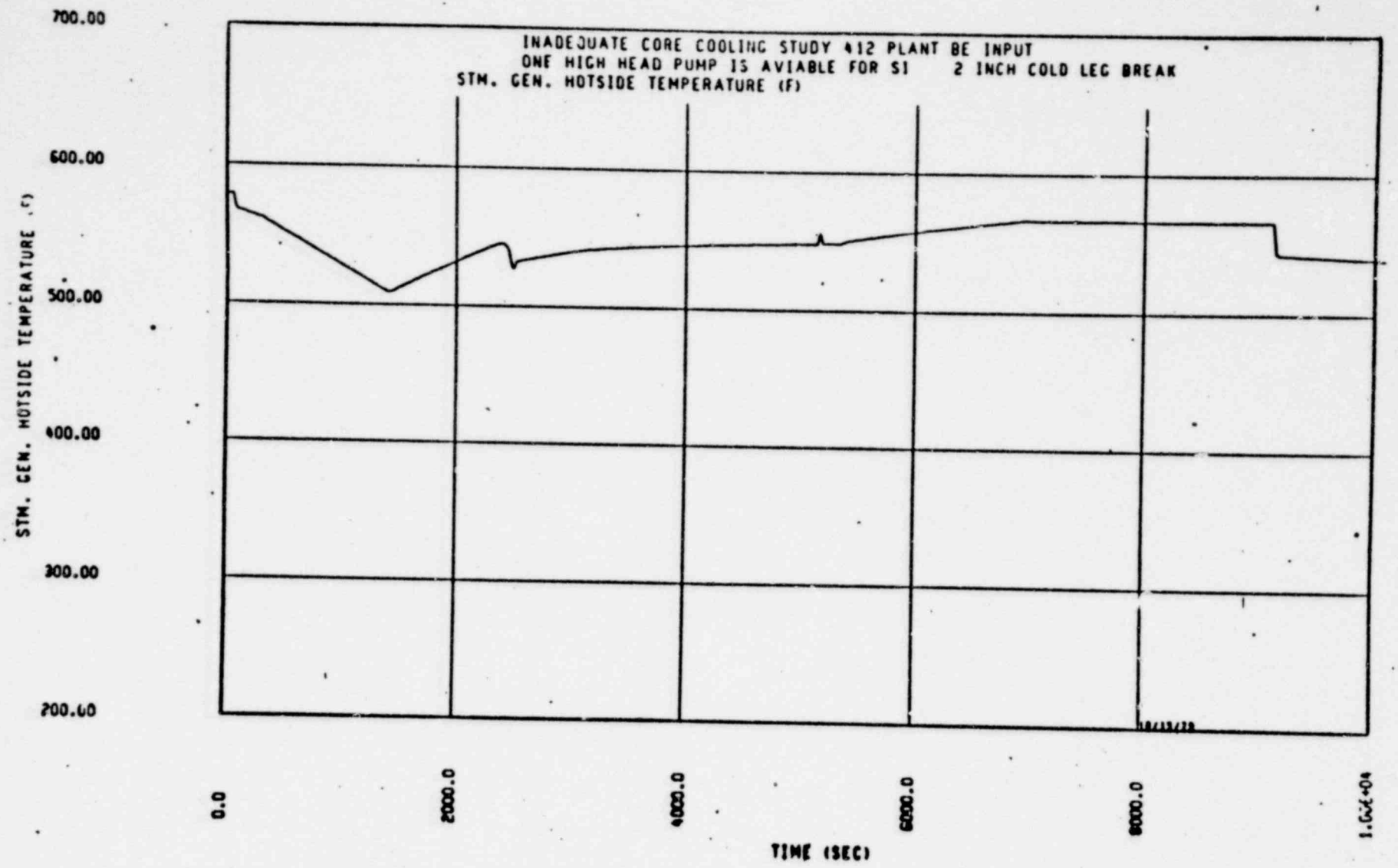


Figure 111

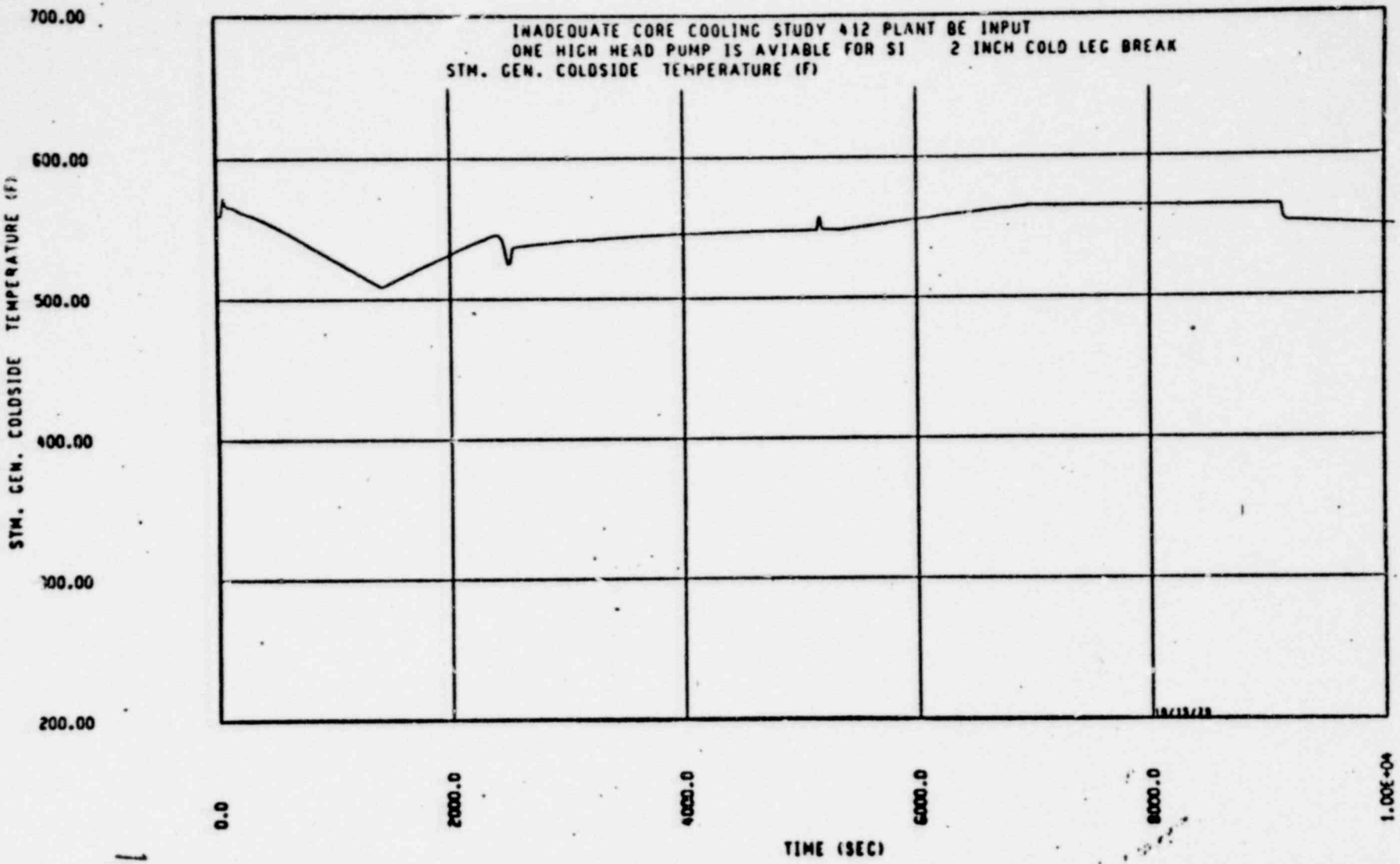


Figure 112

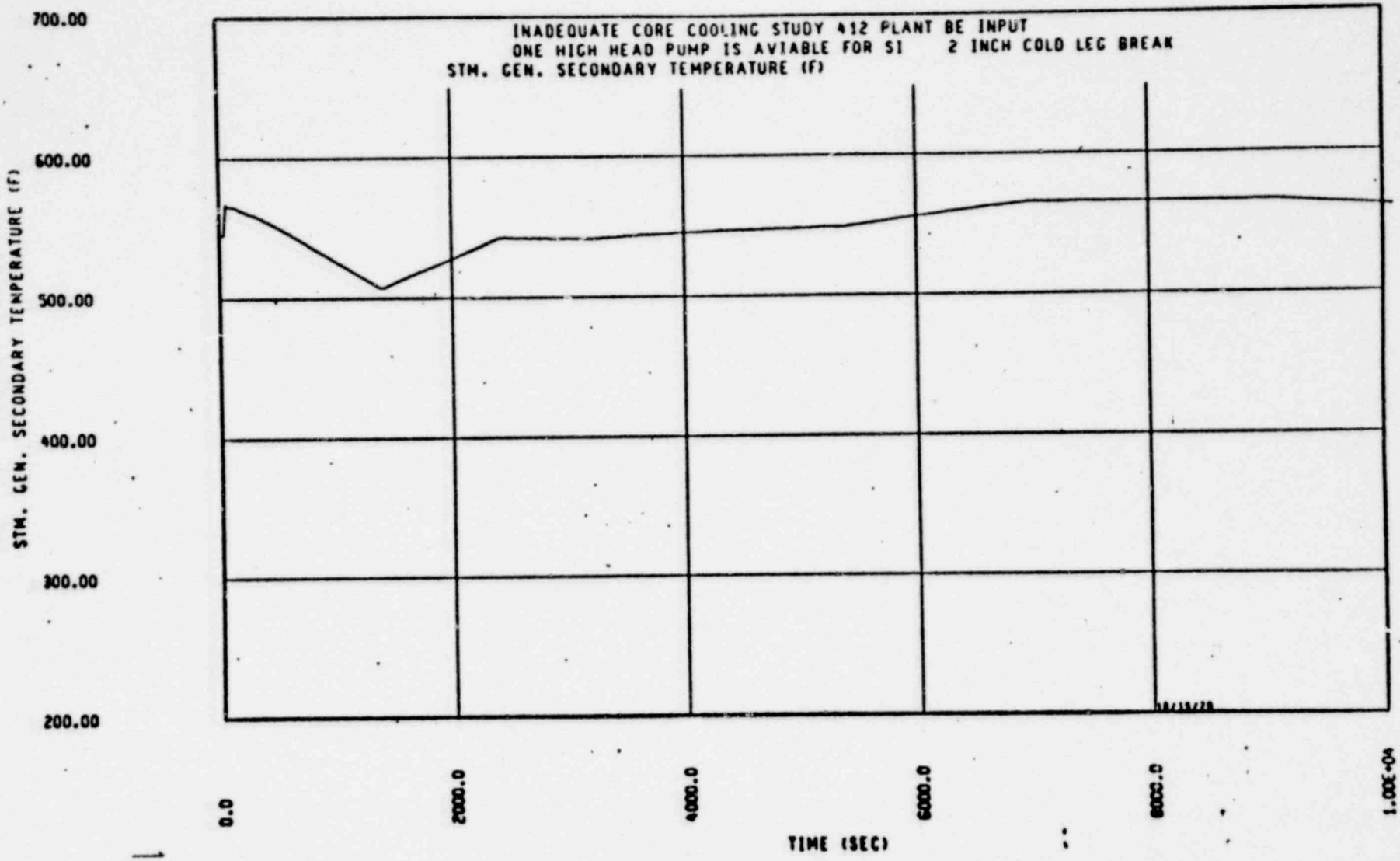


Figure 113

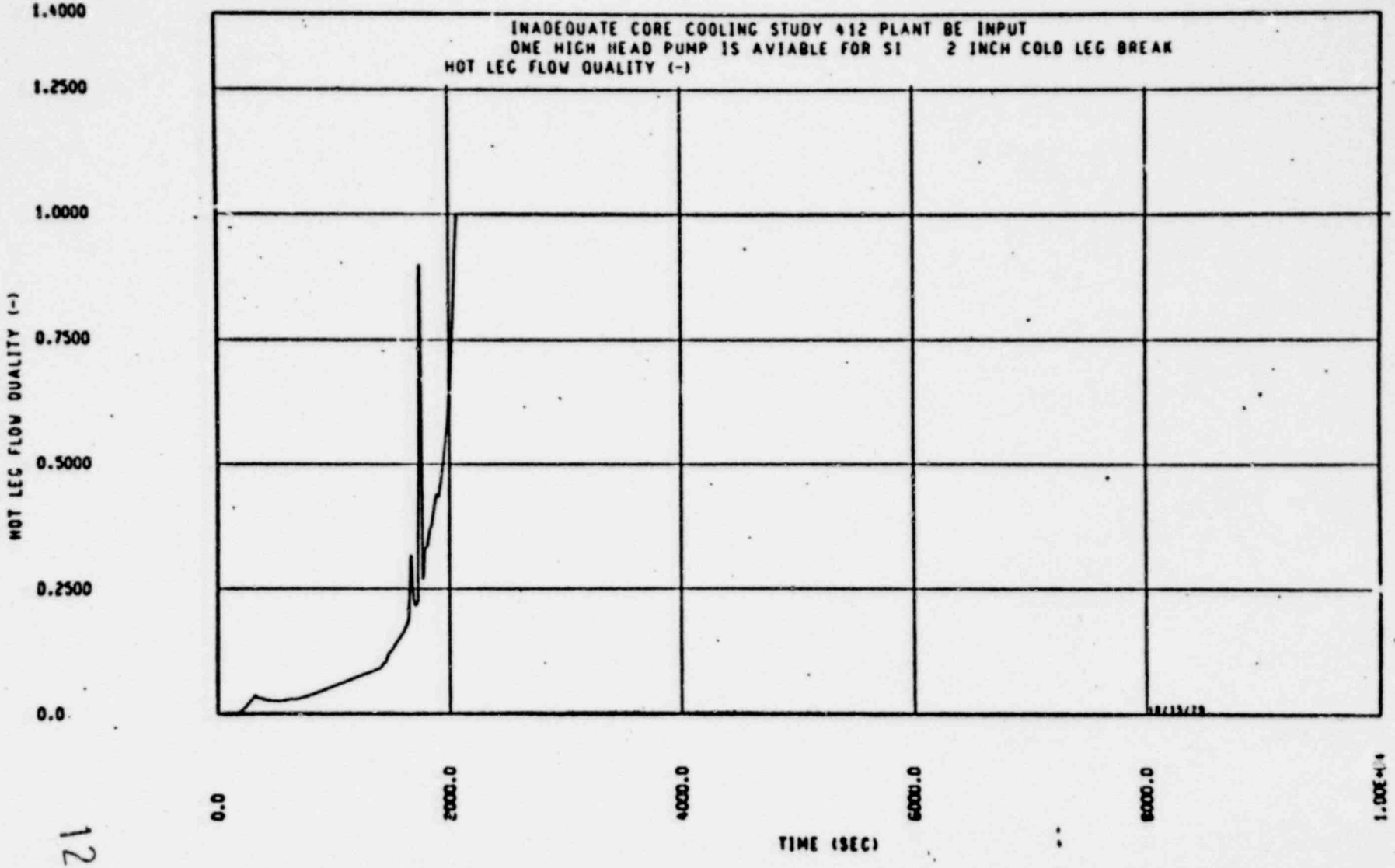


Figure 114

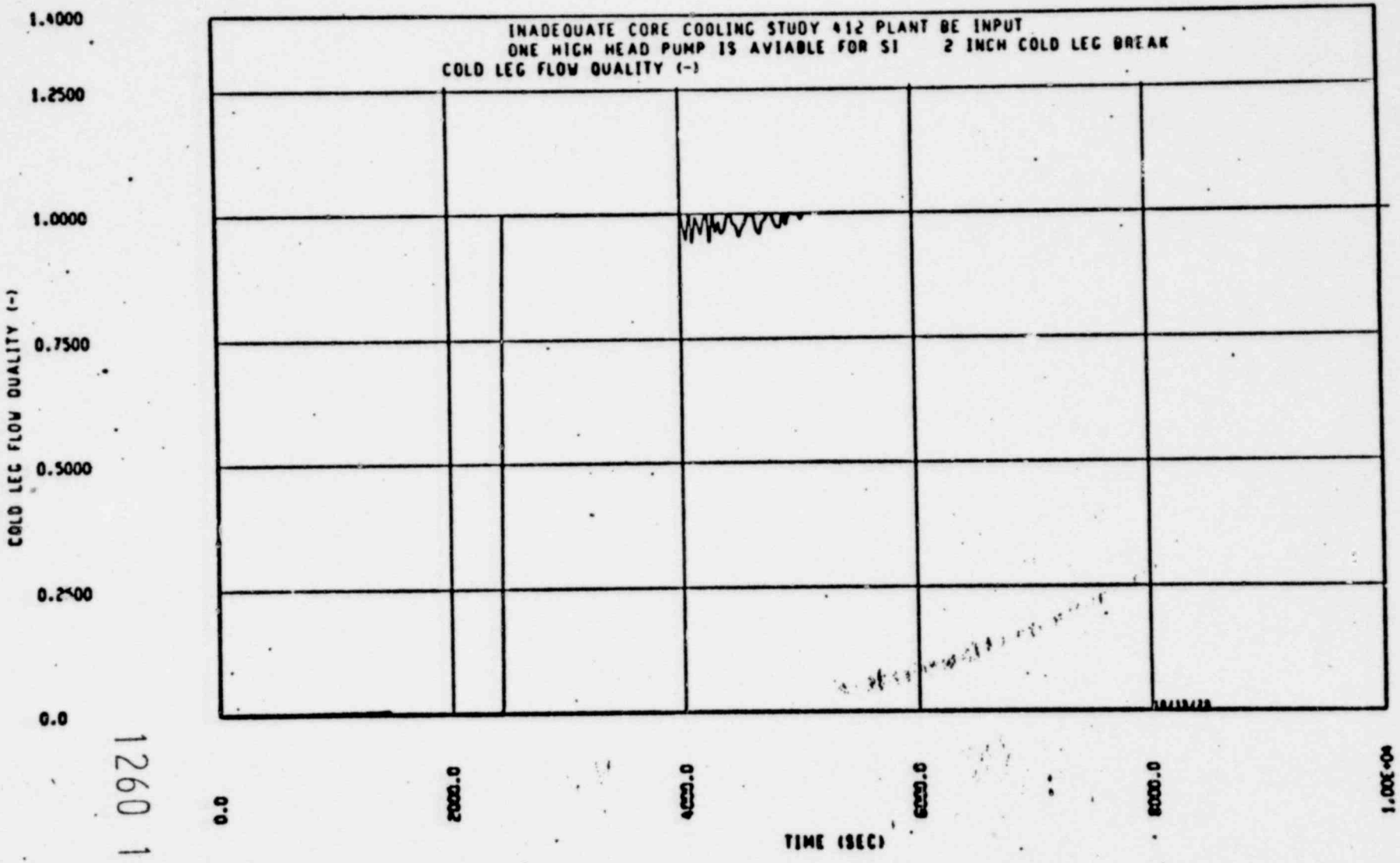


Figure 115

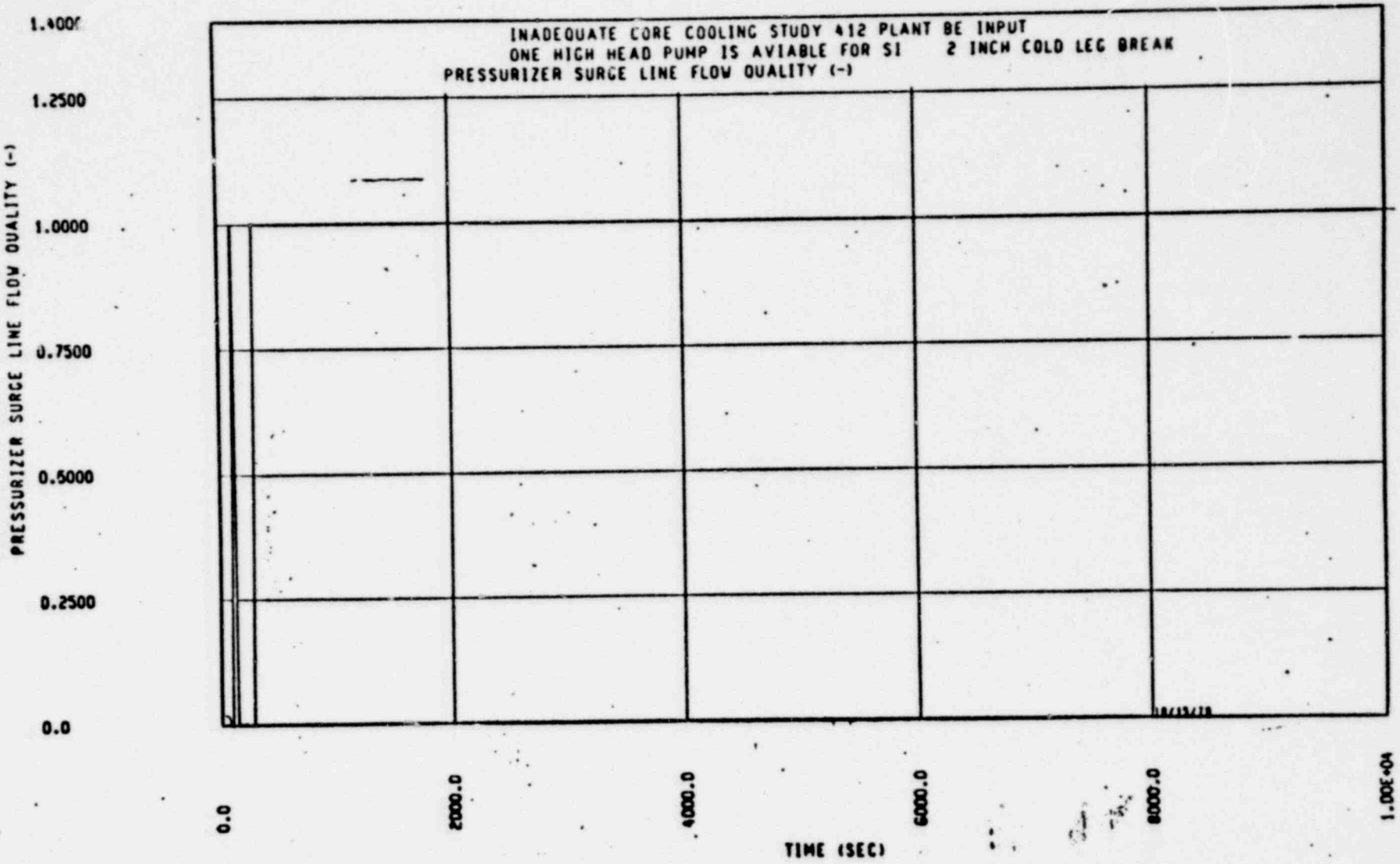


Figure 116

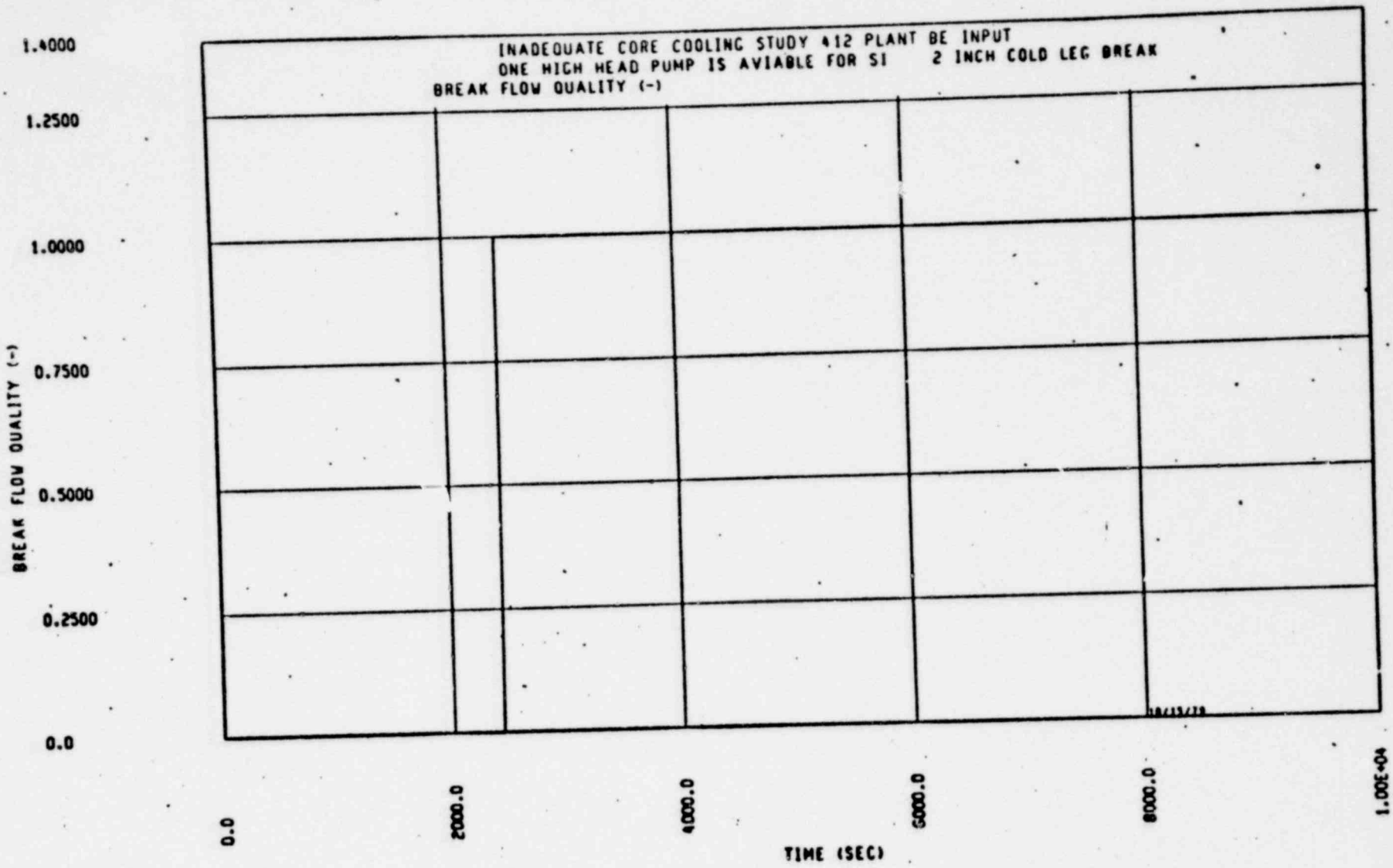

INADEQUATE CORE COOLING STUDY 412 PLANT BE INPUT
ONE HIGH HEAD PUMP IS AVIABLE FOR SI 2 INCH COLD LEG BREAK
BREAK FLOW QUALITY (-)
1.4000
1.2500
1.0000
0.7500
0.5000
0.2500
0.0
BREAK FLOW QUALITY (-)
0.0
2000.0
4000.0
6000.0
8000.0
1.00E+04
TIME (SEC)

Figure 117

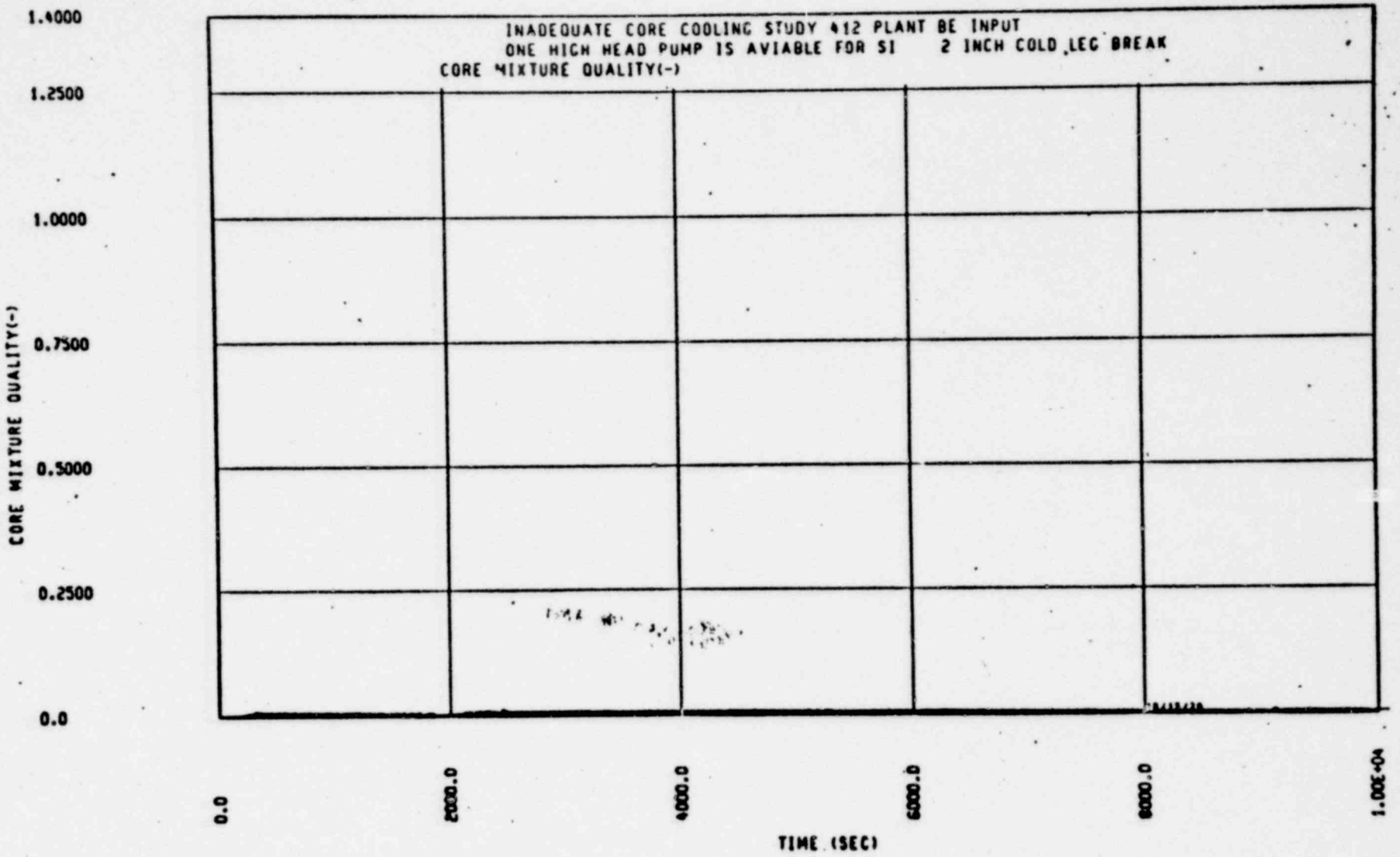
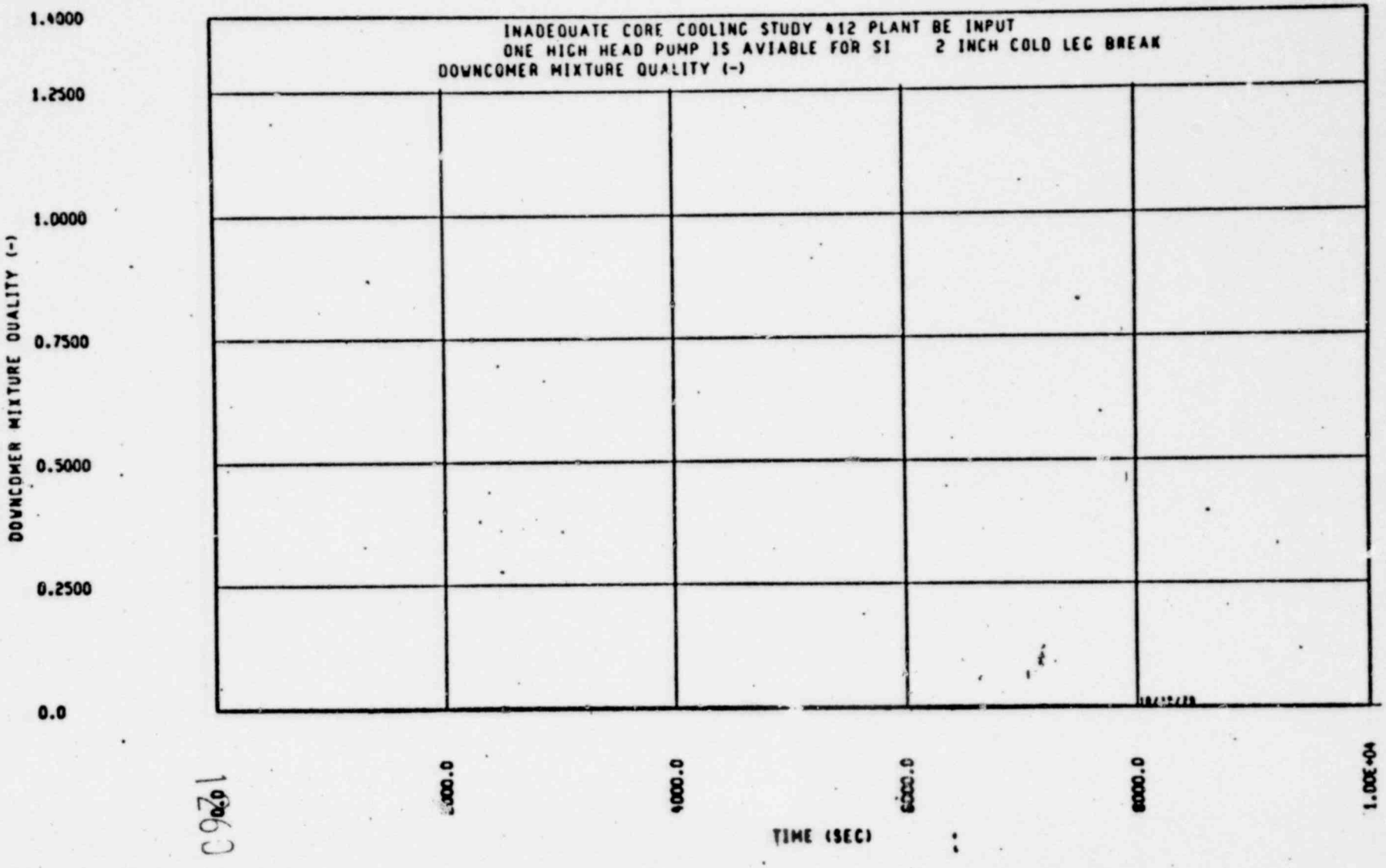


Figure 118



1960 193

Figure 119

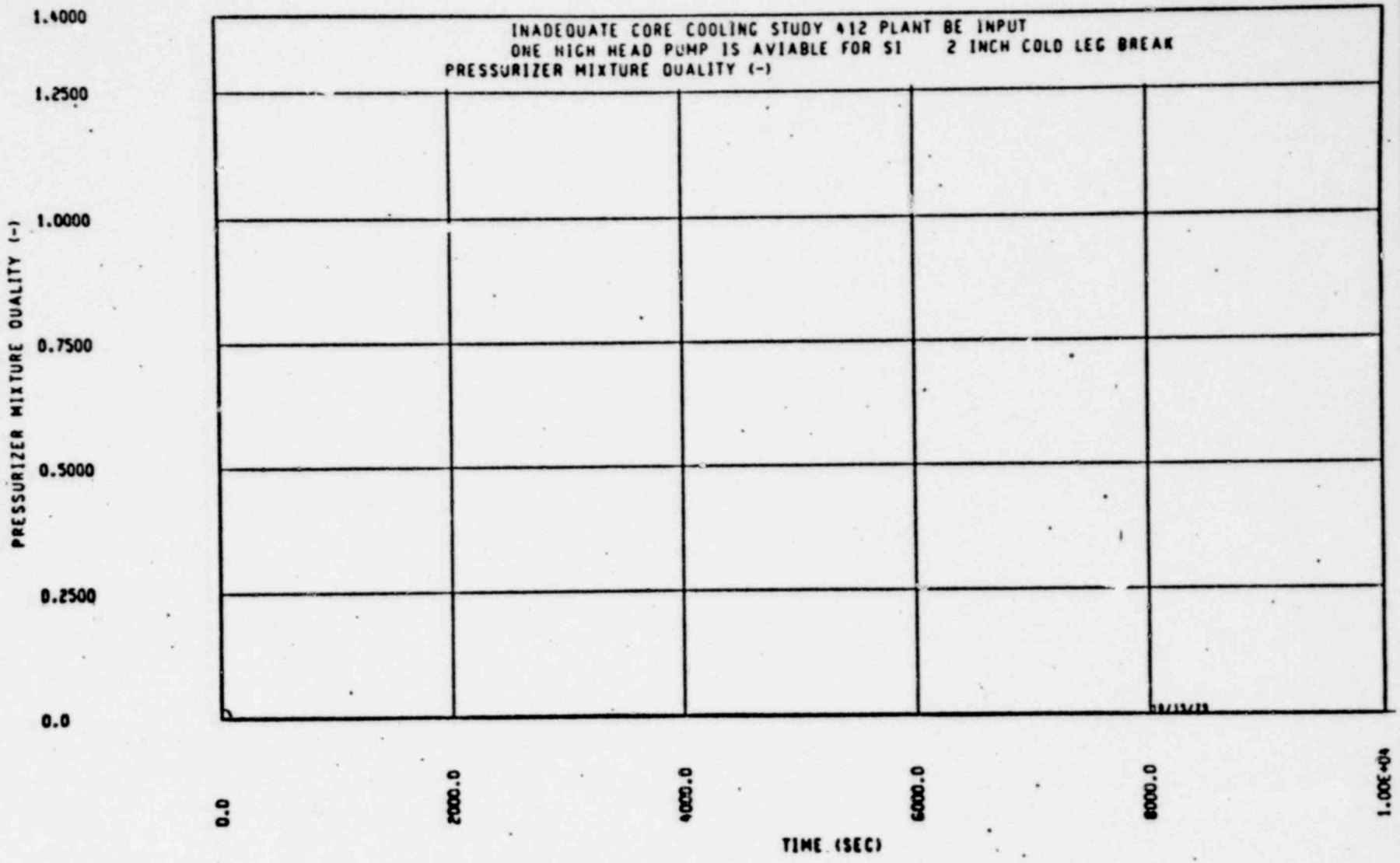


Figure 120

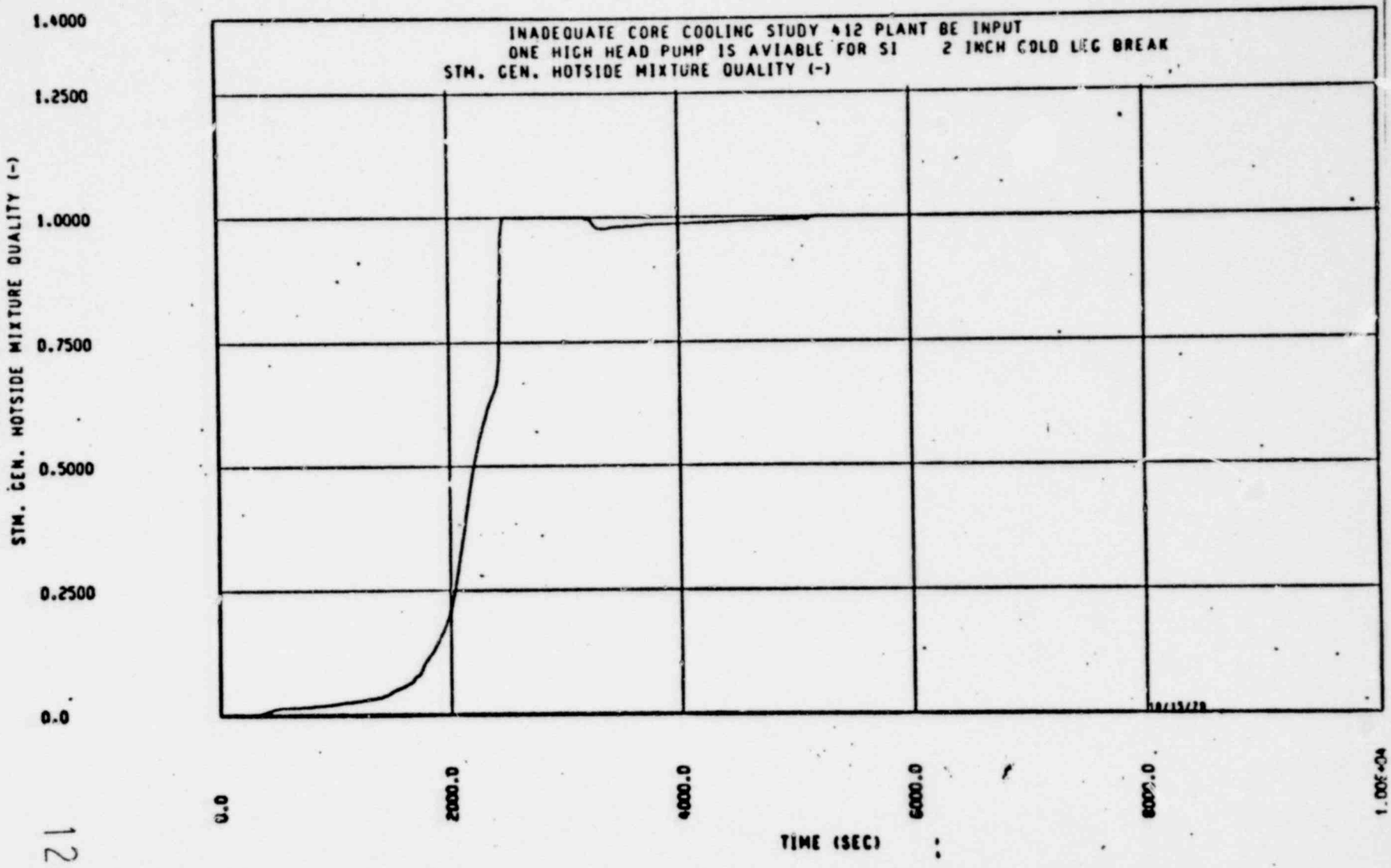


Figure 121

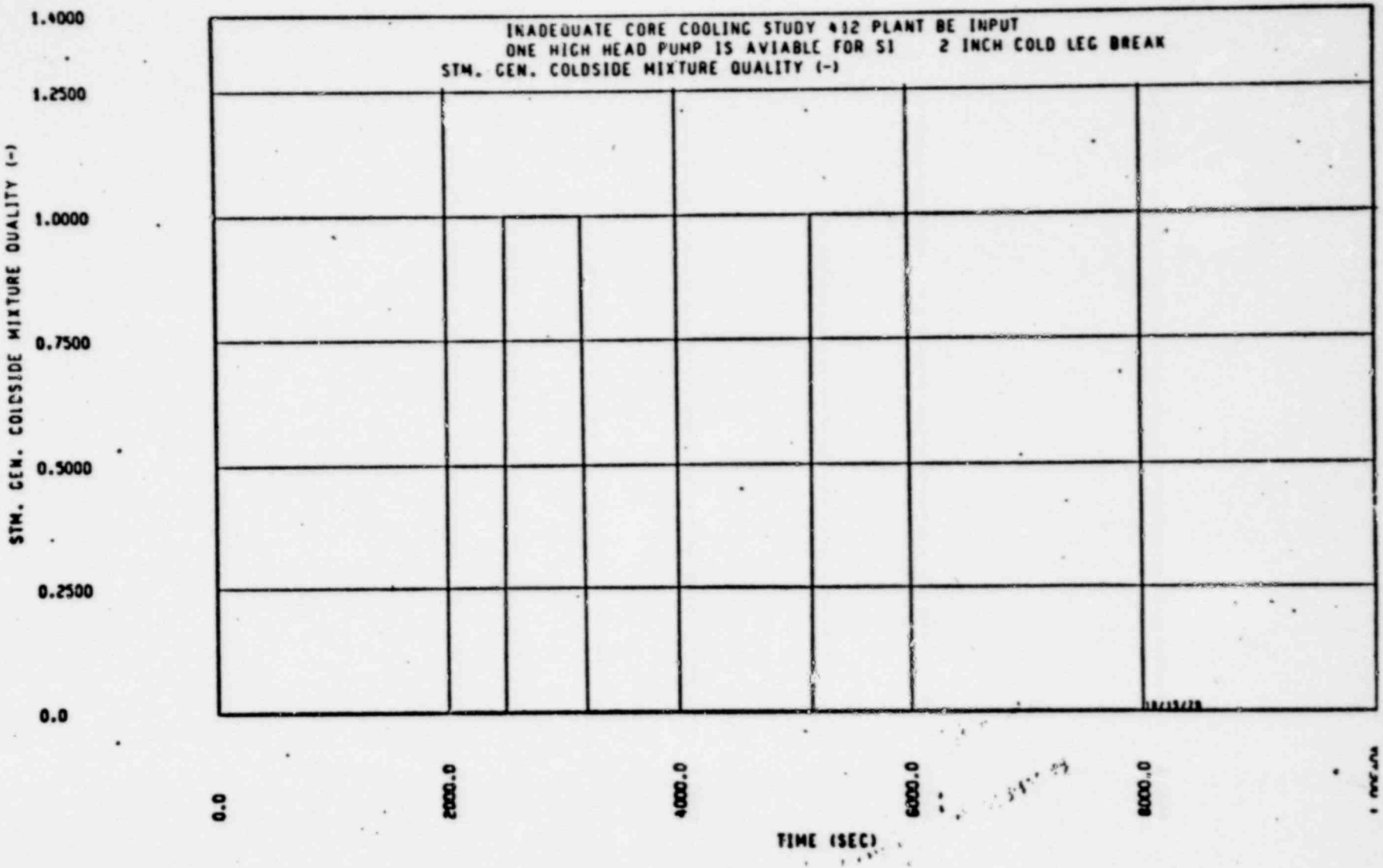


Figure 122

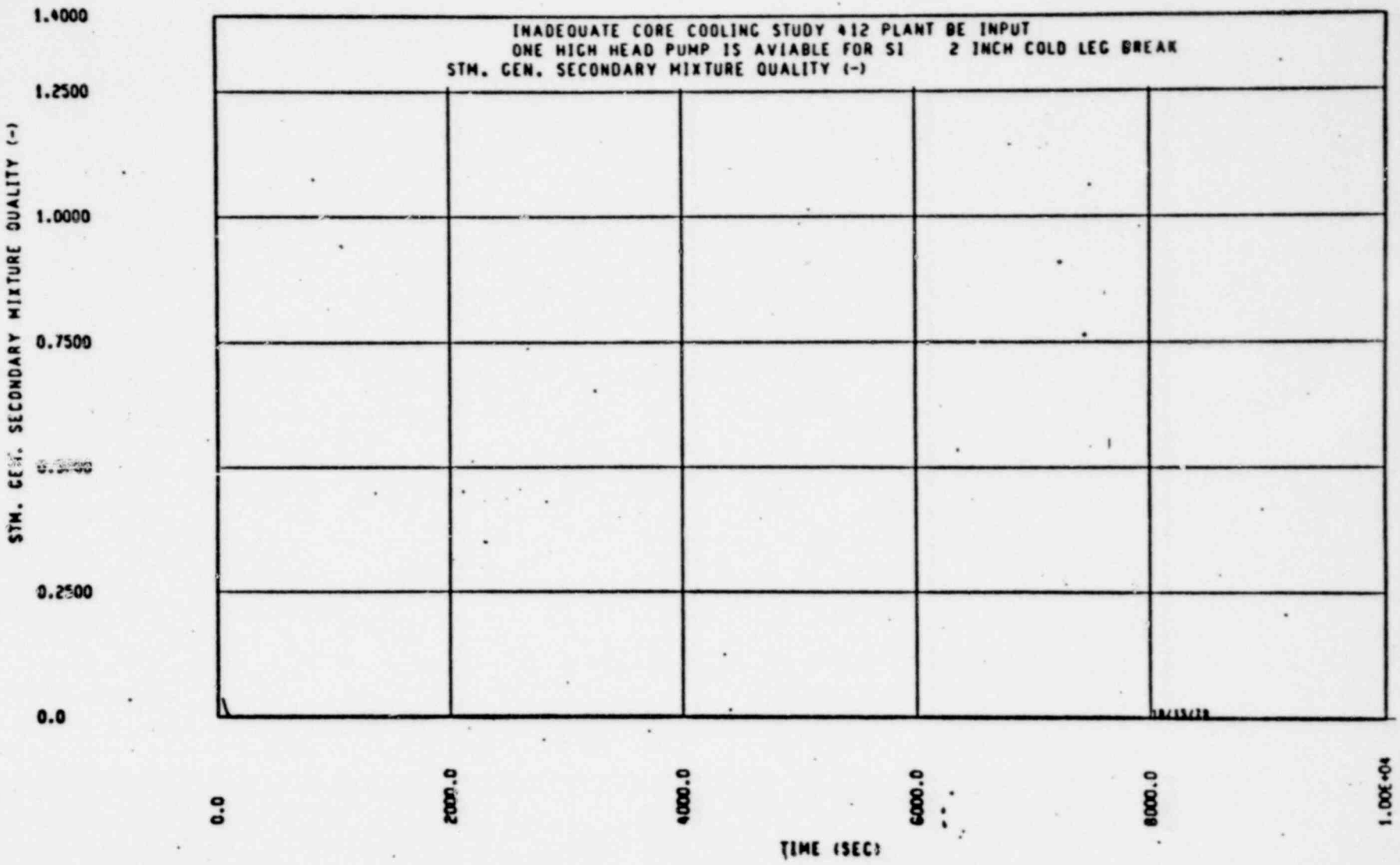


Figure 123

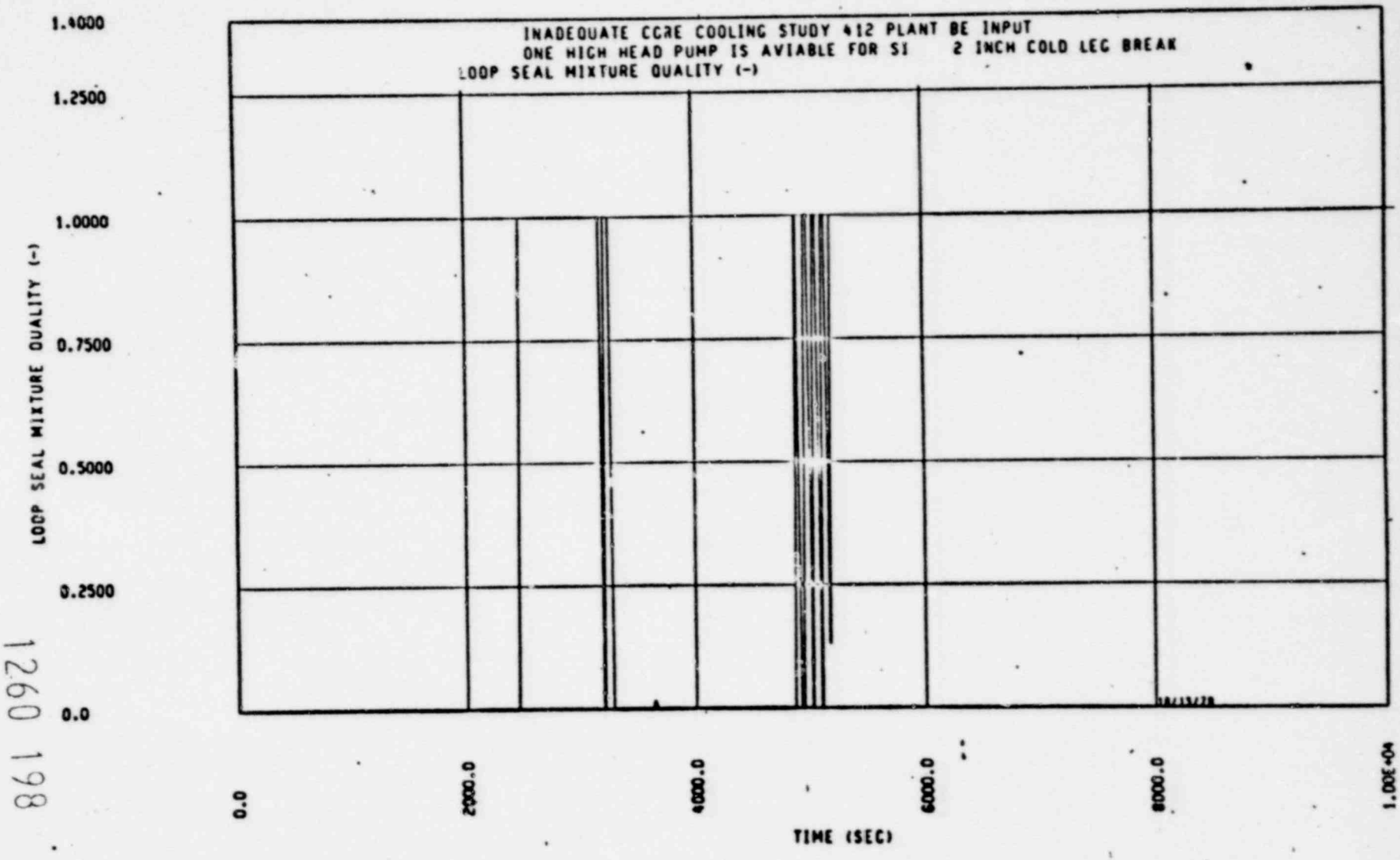


Figure 124

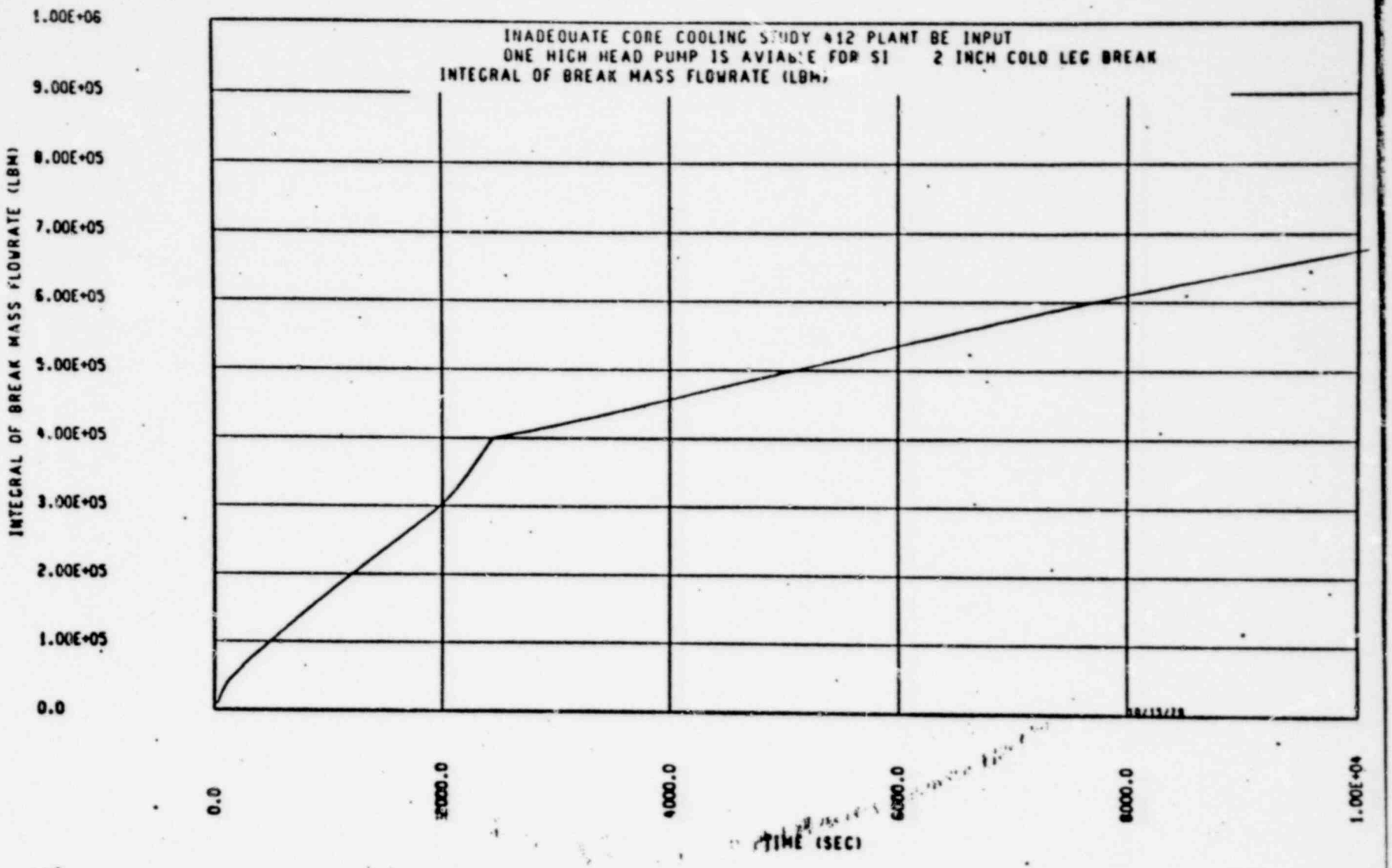


Figure 125

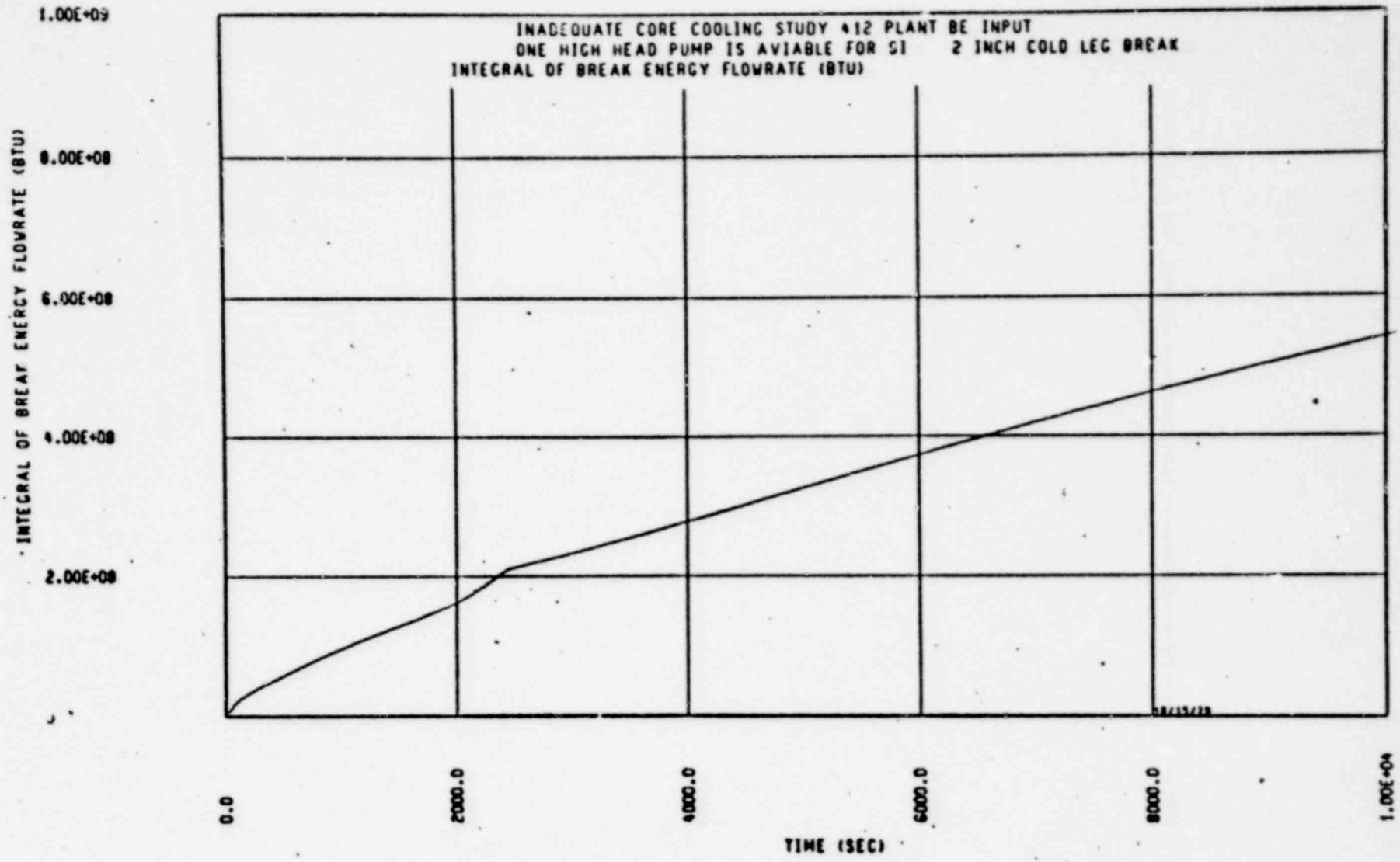


Figure 126

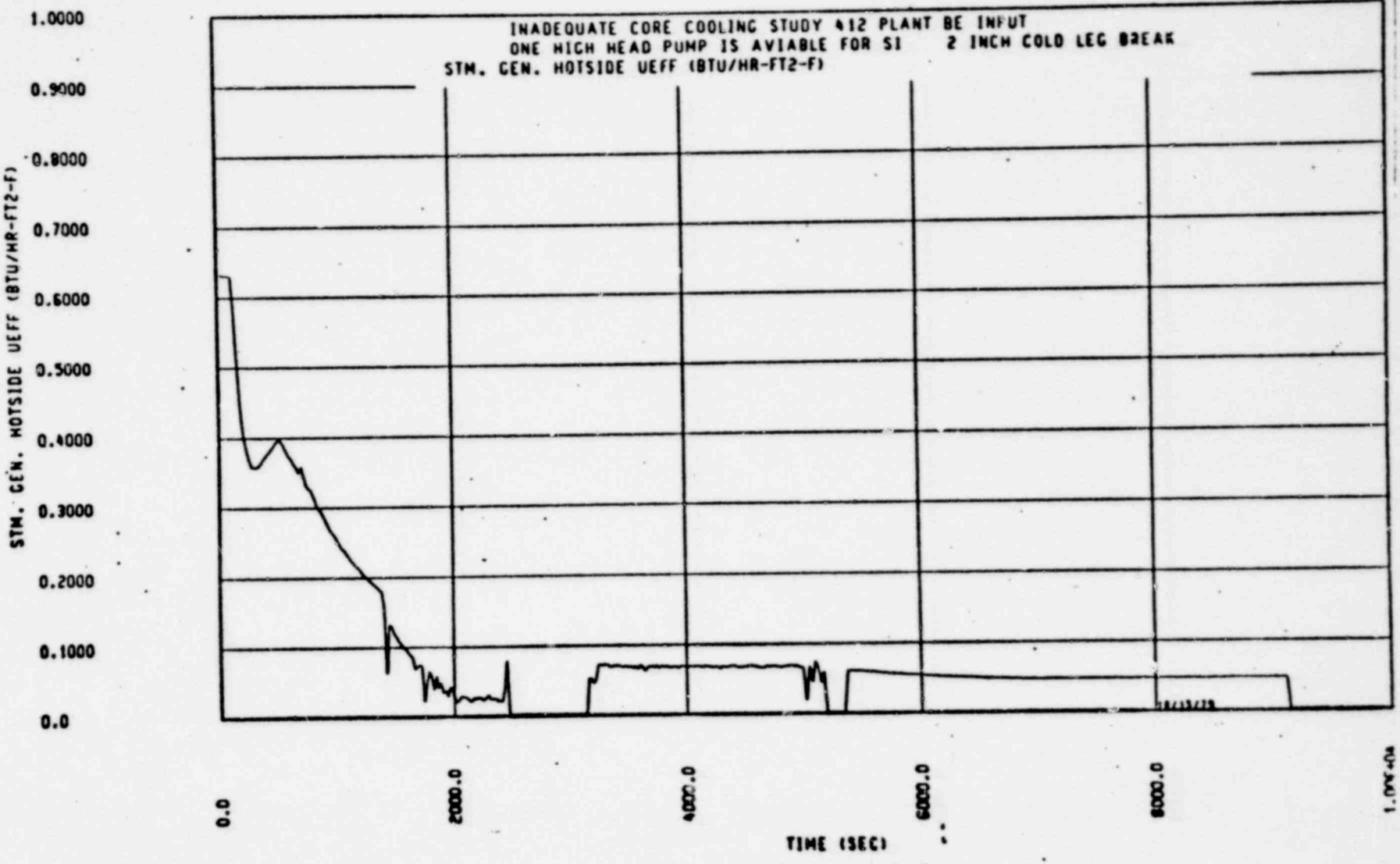


Figure 127

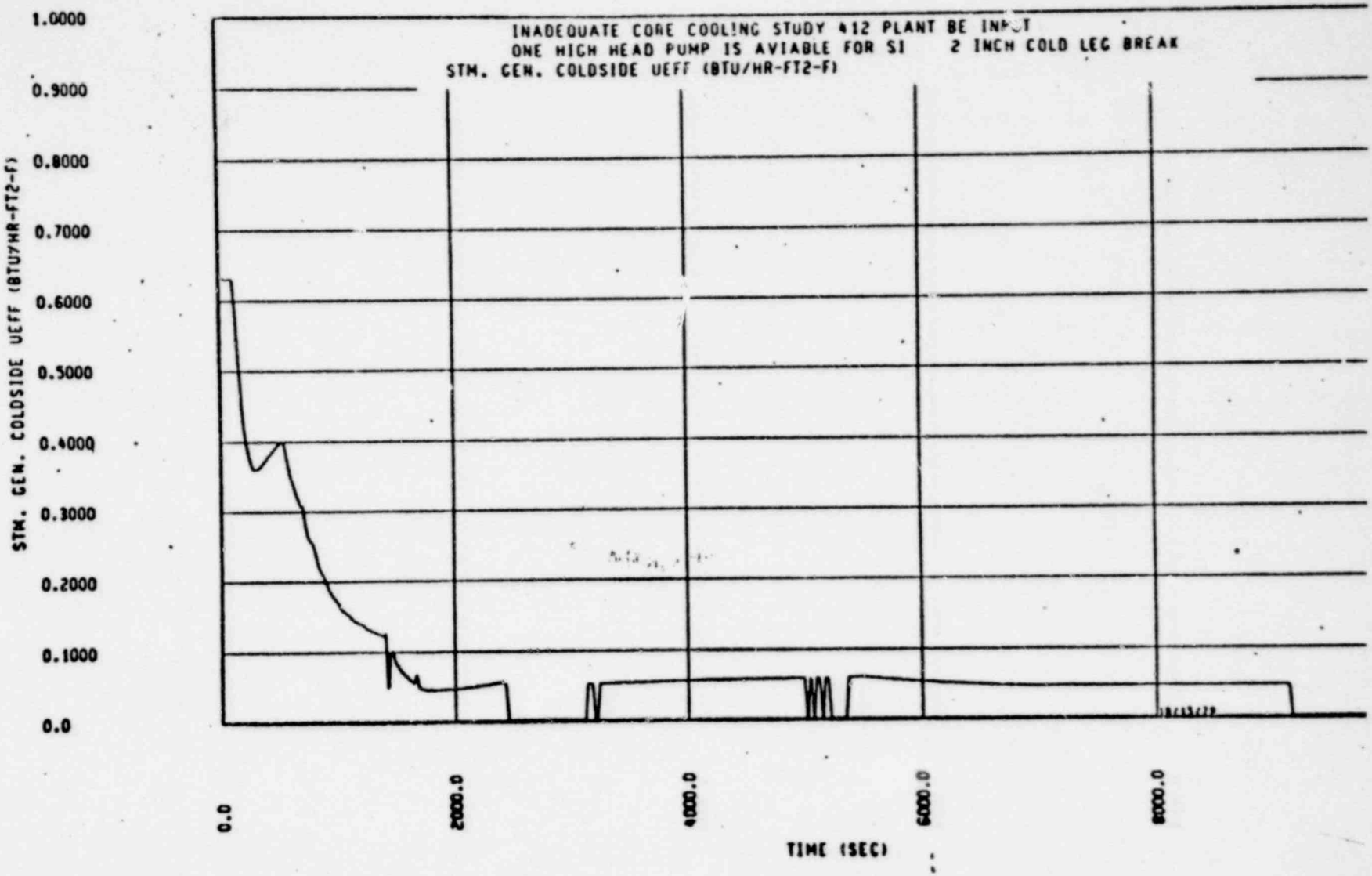


Figure 128