TENNESSEE VALLEY AUTHORITY
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400 Chestnut Street Tower II

December 18, 1981

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US NUCLEAR REGULATORY COMMISSION
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Director of Nuclear Reactor Regulation
Attention: Ms. E. Adensam, Chief
Licensing Branch No. 4
Division of Licensing
U.S. Nuclear Regulatory Commission
Washington, DC 20555

Dear Ms. Adensam:

In the Matter of) Docket Nos. 50-327
Tennessee Valley Authority) 50-328

The Sequoyah Nuclear Plant unit 2 operating license (DPR-79) condition 2.C(16).n requires TVA to submit the analysis performed by the Westinghouse Owners Group (WOG) addressing void formation in Westinghouse-designed nuclear steam supply systems during natural circulation/depressurization transients. Enclosed is a copy of a letter submitted to Paul S. Check, NRC, on April 20, 1981 from Robert W. Jurgensen, chairman of the WOG. The information provided by the April 20, 1981 letter is applicable to TVA's Sequoyah Nuclear Plant. This submittal satisfies the unit 2 operating license condition 2.C(16).n.

In addition, the Westinghouse Owners Group is currently developing appropriate modifications to the Westinghouse Owners Group Reference Operating Instructions to take the results of the study into account so as to preclude void formation in the upper head region during natural circulation cooldown/depressurization transients and to specify those conditions under which upper head voiding may occur. TVA will consider the generic guidance developed by the Westinghouse Owners Group in the development of the Sequoyah operating procedures. TVA submitted a response to NRC's Generic Letter 81-21 (Natural Circulation Cooldown) which contained the WOG description of the Westinghouse analysis on natural circulation cooldown.

Very truly yours,

TENNESSEE VALLEY AUTHORITY

L. M. Mills

L. M. Mills, Manager
Nuclear Regulation and Safety

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Sworn to and subscribed before me
this 18th day of Dec., 1981
Bryant M. Lowery
Notary Public
My Commission Expires 4/4/82

Enclosure

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PDR ADOCK 05000327
P PDR

AMERICAN ELECTRIC POWER *Service Corporation*

AEP

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(212) 440-3000

April 20, 1981
OG-57

Mr. Paul S. Check
Assistant Director for Plant Systems
Division of Systems Integration
U.S. Nuclear Regulatory Commission
7920 Norfolk Avenue
Bethesda, Maryland 20014

Dear Mr. Check:

ST. LUCIE COOLDOWN EVENT REPORT

On June 11, 1980, a total loss of component cooling water flow to the reactor coolant pumps occurred at the St. Lucie Unit 1 plant. When the cooling flow could not be restored in the time limit specified by the plants Technical Specifications, the reactor was manually tripped. Within two minutes after the reactor trip, the reactor coolant pumps were also manually tripped. Approximately 27 minutes later natural circulation cooldown was initiated.

It is evident that void formation occurred in the upper head region of the reactor vessel during the natural circulation cooldown at St. Lucie. Apparently, the fluid in the upper head was much hotter than the rest of the primary system. It is postulated that the steam bubble in the upper head area was produced when the system pressure dropped below the saturation pressure corresponding to the temperature of the fluid in the upper head.

After the St. Lucie incident, the NRC recommended various action items for power reactor licensee consideration. These items are listed in IE Circular 80-15 and include establishing a natural circulation cooldown/depressurization rate envelope to preclude void formation. Subsequent to this, the Westinghouse Owners Group undertook a study with Westinghouse to ascertain the potential for void formation in Westinghouse designed NSSS's during natural circulation cooldown/depressurization transients and to develop appropriate modifications to Westinghouse Owners Group Reference Operating Instructions. A description of the study, including major assumptions and results, is attached. The Westinghouse Owners Group Reference Abnormal Operating Instructions are being modified to take the results of the study into account so as to preclude void formation in the upper head region during natural circulation cooldown/depressurization transients, and to specify those conditions under which upper head voiding may occur.

Very truly yours,

Robert W. Jurgensen

Robert W. Jurgensen, Chairman
Westinghouse Owners Group

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Attachment

I. INTRODUCTION

On June 11, 1980, a total loss of component cooling water flow to the reactor coolant pumps occurred at the St. Lucie Unit 1 plant. An electrical short across a solenoid valve terminal board caused one of the two series containment isolation valves in the component cooling water return from all reactor coolant pumps to fail shut. When the cooling flow could not be restored in the time limit specified by the plants Technical Specifications, the reactor was manually tripped. Within two minutes after the reactor trip, the reactor coolant pumps were also manually tripped. Approximately 27 minutes later natural circulation cooldown was initiated.

Based on pressurizer level and primary system pressure response it is evident that void formation occurred in the upper head region during the natural circulation cooldown. At St. Lucie, the measured hot and cold leg temperatures at the time of voiding were highly subcooled. It appears that the fluid in the upper head was much hotter, relatively stagnant and in poor communication with the rest of the primary system. It is postulated that the steam bubble in the upper head area was produced when the system pressure dropped below the saturation pressure corresponding to the temperature of the fluid in the upper head.

The objectives of this study are twofold. First, the potential for void formation in Westinghouse designed NSSS's during natural circulation cooldown/depressurization transients and the conditions under which such voiding (if any) can occur is to be established. Second, potential modifications to Westinghouse Owners' Group Reference Operating Instructions are to be developed; if appropriate.

The results of the analysis are applicable to all 2, 3 and 4 loop Westinghouse plants. Previous analyses performed for preparation of reference emergency operating guidelines and safety analyses reported in plant licensing documentation explicitly account for void formation in the upper head region if it is calculated to occur. The results of the previous analyses indicate no safety concerns are associated with this possibility since voids generated in the upper head would be collapsed when they are brought in contact with the subcooled region of the system. Furthermore, actual events which necessitated cooldown on natural circulation have shown no real safety issues attributable to any upper head flashing phenomenon.

II. METHOD OF ANALYSIS

A. Parameters Governing Void Formation

There are several parameters which can have a significant effect on the formation of voids in the upper head region during natural circulation cooldown/depressurization transients. One such parameter is the magnitude of the flow communication between the upper downcomer and the upper head. This flow is at a temperature equivalent to that of the cold leg fluid. Hence, this flow directly affects the steady state upper head fluid temperature, which is a second factor which has an effect on the formation of voids in the upper head region. Most currently operating Westinghouse plants have an amount of flow into the upper head region which results in an upper head fluid temperature between the cold leg temperature (T_{COLD}) and the core outlet temperature (T_{HOT}). In the analysis described in this study the initial upper head temperature for these plants is conservatively chosen as T_{HOT}. Other Westinghouse plants operate with sufficient flow from the upper downcomer to the upper head region to make the upper head fluid temperature equal to the cold leg fluid temperature (T_{COLD}). Both types of plants are analyzed in this study.

Another parameter affecting void formation in the upper head which is analyzed in the study is the cooldown/depressurization rate of the primary system.

A final parameter important in the formation of voids in the upper head is the heat removal rate from the upper head. The two primary means of heat loss are ambient heat losses and heat removal by the control rod drive mechanism (CRDM) fans.

The CRDM cooling system consists of fans which maintain a suitable atmosphere within the CRDM shroud to protect and prolong the life of the CRDM motors. The system induces cooler containment air into the CRDM shroud and exhausts through the fans.

The effect of ambient heat losses through the reactor vessel on upper head temperature is small compared to the effect of the CRDM fans and is neglected in this study. The cooloff rate of the upper head due to ambient heat losses is less than $1^{o}F/hr$.

Metal heat addition to the upper head area from the reactor vessel and upper internals is taken into account.

B. Major Assumptions

The WFLASH code (references 1 and 2) is used in the analysis. WFLASH permits a detailed spatial representation of the primary system with the system nodalized into volumes interconnected by flow paths. The transient behavior of the system is determined from conservation equations of mass, energy and momentum applied throughout the system. The WFLASH code has two phase capability and can track void propagation if it occurs.

A 4-loop plant with a core thermal power of 3411 MW is used. Since the analysis is not a design basis analysis, the transient response of the primary system is based upon the conditions more likely to occur during the event; i.e., a best estimate model is employed.

For the best estimate model, several changes were made in order to approach more realistic assumptions and more likely conditions during the cooldown transient than are presently found in the Appendix K model. The principal differences between the best estimate and Appendix K models are listed in Table 1.

An inverted top hat upper support plate design is assumed since it results in a larger upper head volume and hence more total heat in the upper head area initially. This design would offer the maximum thermal inertia for cooling of the upper head region.

The reactor and the reactor coolant pumps are assumed to be tripped at the initiation of the transient (at 2.0 seconds in WFLASH). The pumps are tripped at the start of the transient to conservatively keep the upper head temperature higher by minimizing the flow communication between the upper head and the rest of the system.

The primary system pressure is maintained at approximately 2250 psia prior to initiation of natural circulation cooldown. Natural circulation cooldown rates of 25^{o}F/hr and 50^{o}F/hr are analyzed. These rates are in the range of typical plant cooldown rates.

While the analysis is based on a 4-loop plant, the results and conclusions of the anlysis are applicable to 2 and 3-loop plants. The power level to core/upper plenum volume ratio is essentially the same for 2, 3 and 4-loop plants (1.97, 1.75 and 1.8 for typical 2, 3 and 4-loop plants with inverted top hat upper support plates). Thus the downcomer density to core/upper plenum density ratio remains essentially the same for 2, 3 and 4-loop plants. As discussed in Section III.B, the driving force for the guide tube/spray nozzle flow is the downcomer density being greater than the core density.

A comparison of the guide tube/spray nozzle flow path resistance between 2, 3 and 4-loop plants can be gained from the percent of total plant flow passing through the spray nozzles. The minimum percentage of total flow going through the spray nozzles for 2 and 3-loop plants (0.27% for a 2-loop plant and 0.17% for a 3 loop plant) is greater than that used in this analysis for 4-loop plants (0.15% for T_{HOT} upper head).

The ratio of upper head heat removal by the CRDM fans to upper head total energy is essentially the same for 2 and 3 loop plants (1.05 $\frac{kw}{ft3}$ and 1.02 $\frac{kw}{ft3}$ for typical 2 and 3-loop) as for 4-loop plants (0.92 $\frac{kw}{ft3}$). Thus the cooldown rates given above for the CRDM fans are applicable to 2 and 3 loop plants as well as 4 loop plants.

Since (1) the driving force for the guide tube/spray nozzle flow is essentially the same for 2, 3 and 4-loop plants, (2) the resistance to guide tube/spray nozzle flow is less for 2 and 3-loop plants than 4-loop plants and (3) the cooldown rate of the upper head by the CRDM fans is effectively the same for 2, 3 and 4-loop plants, the results and conclusions reached in this analysis are valid for 2, 3 and 4-loop plants.

III. RESULTS

A. Establishing Natural Circulation

With the input as described in the previous section; WFLASH is run until steady state natural circulation is established in the plant. This occurred prior to 720 seconds into the transient. In this analysis, natural circulation cooldown is assumed to be initiated at 720 seconds into the transient. The primary plant conditions at this time are listed in Table 2. At 720 seconds the difference between the hot and cold leg temperatures is approximately 30°F, the primary system loop flow is approximately 500 lb/sec, and the reactor power (due to decay heat) is 2.3% of full power (nominal). The loop flow rate of 500 lb/sec is approximately 5% of full power loop flow. Natural circulation flow is observed to be 4.5% to 5.0% of full power flow at 2.3% of nominal power (see Figure 1) for a Westinghouse 4-loop plant based on 4-loop calculations and tests.

With forced flow (i.e., with the reactor coolant pumps running) the flow goes from the upper downcomer through the upper head spray nozzles into the upper head region. From the upper head region the flow goes down through the guide tubes into the upper plenum/core region. With the reactor coolant pumps running the vessel pressure distribution is such that flow is forced up the upper head spray nozzles. Within 2 to 4 minutes after the reactor coolant pumps are tripped this flow reverses and goes up the guide tubes into the upper head region and down through the upper head spray nozzles into the upper downcomer. This flow reversal occurs due to the downcomer density being greater than the upper plenum/core density, and the upper plenum/core density being greater than the upper head density. This density variation forces flow up the guide tubes.

With the exception of the pressurizer, the primary system is subcooled when the natural circulation cooldown is initiated.

B. T_{COLD} Plants

Some Westinghouse PWR's (referred to as T_{COLD} plants) have sufficient bypass flow from the upper downcomer through the spray nozzles into the upper head area to keep the upper head fluid temperature equal to the cold leg fluid temperature during normal power operation of the plant. Table 3 gives the initial upper head spray nozzle flow rate, 609 lb/sec, and other pertinent data regarding the initial upper head flow for a T_{COLD} plant.

Westinghouse plants with the upper head injection (UHI) system are T_{COLD} plants. Thus, the results and conclusions reached in this study for T_{COLD} plants are valid for these units.

Two natural circulation cooldown rates are analyzed: 25°F/hr and 50°F/hr. An update was made to WFLASH which permits the secondary side temperature as a function of time to be input specified. If a cooldown rate of 25°F/hr is prescribed for the secondary system, the primary system in natural circulation will follow this cooldown rate. For both cooldown rates natural circulation cooldown is initiated at 720 seconds.

The core inlet, hot leg and cold leg temperature transients are shown in Figures 2 through 7. For both cooldown rates, the transient is carried out until the hot leg temperature reaches 350°F, which is the temperature at which the Residual Heat Removal System (RHRS) could be employed for further cooldown.

Consistent with normal plant operations, charging flow is added to the primary system at a rate sufficient to keep the pressurizer mixture level relatively constant during the cooldown transient (Figures 8 and 9). The primary system pressure response is shown in Figures 10 and 11. Some depressurization occurs initially due to system shrinkage caused by the cooldown. Further depressurization results from the cooling of the pressurizer due to the addition of colder water from the hot leg to the pressurizer in the latter part of the transient. Pressurizer heaters were not modelled for the analysis.

The upper head pressure transient is given in Figures 12 and 13. A sensitivity study, discussed in Section III.C, verifies that the primary system depressurization rate effect on the upper head temperature is insignificant.

The hot leg and cold leg mass flow rate transients are given in Figures 14 through 17.

The upper head spray nozzle flow is initially from the upper downcomer through the upper head spray nozzles into the upper head area, and from the upper head area down through the guide tubes into the upper plenum/core area. In the first 2 to 4 minutes of the transient, this flow reverses (see Figures 18 and 19) due to the density in the downcomer being greater than the core density, and the reactor coolant pumps being tripped at the start of the transient.

Because of this flow reversal, upper head temperature rises early in the transient (see Figures 20 and 21). The upper head temperature is initially equivalent to the cold leg temperature. When the spray nozzle/guide tube flow reversal (discussed in the previous paragraph) occurs, hotter water from the core is introduced into the upper head area and causes the upper head temperature rise. After this early increase, the upper head temperature steadily decreases.

From the upper head temperature transients, the upper head saturation pressure transients (see Figures 22 and 23) are determined. As shown, the upper head saturation pressure is well below the primary system pressure (Figures 11 and 12) at any given time during the calculated transient.

When the primary system temperature reaches 500°F during the cooldown transient the upper head temperature and corresponding saturation pressure are as given in Table 4 for both cooldown rates.

The same information is listed in Table 4 for a primary system temperature of 350°F. If, for example, during the cooldown of the plant, the operator wanted the primary system pressure to be less than 1500 psia when the primary system temperature is 500°F, then the upper head saturation pressure for either cooldown rate is well below 1500 psia and there would be no void formation in the upper head area. If a second condition for the plants cooldown is that the primary system pressure be less than 400 psia when the primary system temperature is 350°F (conditions under which the RHRS could be used), then the upper head saturation pressure for either cooldown rate is well below 400 psia and no voids would be formed in the upper head.

In effect, the analysis shows that formation of a steam bubble in the upper head area is avoided when cooling down at 25°F/hr because the primary system pressure can easily be maintained above the upper head saturation pressure shown in Figure 22 at any specific time by maintaining 50°F subcooling in the hot leg. For the 50°F/hr cooldown rate the primary system pressure is shown to remain above the upper head saturation curve on Figure 23 if the hot leg is maintained 100°F subcooled.

It should be noted that no credit is taken for the effect on the upper head temperature of ambient heat losses for the reactor vessel or heat removal from the upper head area by the control rod drive mechanism (CRDM) fans in the analysis of T_{COLD} plants. As described in section III.D, the CRDM fans could considerably increase the upper head cooldown rate for a given RCS cooldown rate.

C. T_{HOT} Plants

Some Westinghouse PWR's have a bypass flow path characteristic from the upper downcomer through the spray nozzles into the upper head area which results in an upper head fluid temperature between the RCS cold leg temperature and the core outlet temperature. In this study the initial upper head temperature for these plants (referred to as T_{HOT} plants) is conservatively assumed to be equal to the core outlet temperature. Table 5 gives the initial upper head spray nozzle flow rate, 59.2 lb/sec, and other pertinent data regarding the initial upper head flow for a T_{HOT} plant.

Natural circulation cooldown rates of $25^{o}F/hr$ and $50^{o}F/hr$ are analyzed for T_{HOT} plants with the cooldown initiated at 720 seconds following plant trip for both cooldown rates.

The core inlet, hot leg and cold leg temperature transients are shown in Figures 24 through 29. For both cooldown rates, the primary system is cooled down via natural circulation until the hot leg temperature reaches $350^{o}F$, which is the temperature at which the RHRS could be employed for further cooldown.

Charging flow is added to the primary system at a rate sufficient to keep the pressurizer mixture level relatively constant during the cooldown transient (Figures 30 and 31). The primary system pressure response is shown in Figures 32 and 33. Depressurization of the primary system occurs for the same reasons as stated for the T_{COLD} plants (see Section III.B). A sensitivity study was made to verify that the primary system depressurization rate has an insignificant effect on the upper head temperature. Table 6 shows that for two significantly different primary system depressurization rates, the upper head temperature is essentially equal at any given time.

The upper head pressure transient is given in Figures 34 and 35 for each cooldown rate. The hot leg and cold leg mass flow rate transients are given in Figures 36 through 39.

As for the T_{COLD} plants the spray nozzle flow is initially from the upper downcomer through the spray nozzles into the upper head area, and from the upper head area down through the guide tubes into the upper plenum/core area. Approximately 2 minutes into the transient, this flow reverses (Figures 40 and 41) due to the density in the downcomer being greater than the core density and the reactor coolant pumps being tripped at the start of the transient. The resulting upper head temperature transients are given in Figures 42 and 43. From the upper head temperature transients, the upper head saturation pressure transients (Figures 44 and 45) are determined.

When the primary system reaches 500°F during the cooldown transient the upper head temperature and corresponding saturation pressure are as shown in Table 7 for both cooldown rates. The same information is listed in Table 7 for a primary system temperature of 350°F. If, for example, during the cooldown of the plant, it was desired to have the primary system pressure less than 1500 psia when the primary system temperature is 500°F, then the upper head saturation pressure for the 25°F/hr cooldown rate is below 1500 psia and there would be no void formation in the upper head area. However, for the 50°F/hr cooldown rate, some upper head void formation may occur at these conditions since the upper head saturation pressure is slightly above 1500 psia when the hot leg temperature reaches 500°F.

A second condition for the plant cooldown might be that the primary system pressure be 400 psia or less when the primary system temperature is 350°F (conditions which would permit use of the RHRS). From Table 7 it is seen that the upper head saturation pressure is well above 400 psia for either cooldown rate when the hot leg temperature reaches 350°F. To prevent void formation in the upper head area the natural circulation cooldown and depressurization should be terminated when the hot leg temperature reaches approximately 350°F to allow the upper head to cool off.

In determining the upper head cool off due to conduction through the 1.0 foot thick stainless steel upper support plate, the primary system is assumed to stay at 350°F since the heat added from the upper head during the cool off period is small compared to the total heat in the primary system. A window mode hand calculation of the conduction was performed which utilized the initial upper head temperature at the time the primary system reached 350°F. From the time the hot leg temperature reaches 350°F, it would require approximately 20 hours to reach an upper head saturation pressure of 400 psia for the 25°F/hr cooldown transient. The corresponding upper head cool off period to reach a saturation pressure of 400 psia for the 50°F/hr cooldown transient is approximately 27 hours. At this point the rest of the primary system could be depressurized to 400 psia and the RHRS employed for any further cooldown.

In the analysis of T_{HOT} plants described above no credit is taken for ambient heat losses through the reactor vessel or heat removal from the upper head area by the CRDM fans. As described in Section III.D, the effect of the CRDM fans could significantly increase the upper head cooldown rate for a given primary system cooldown rate.

D. Effect of CRDM Fans

For the 4 loop plant evaluated here, the CRDM fans remove 780 KW at full power. This translates to a cooldown rate of 32°F/hr for the upper head fluid when the upper head fluid temperature is 600°F. If it is assumed that the heat removal capacity of the fans is proportional to the ΔT between the upper head metal temperature and the containment temperature (assumed to be 100°F), then the CRDM fans cooldown the upper head fluid at a rate of 17°F/hr with the upper head fluid at 350°F.

For T_{COLD} plants the upper head cooldown rate due to the CRDM fans varies from 30°F/hr (when the upper head temperature is at its highest temperature - 572°F) to 17°F/hr when the upper head temperature is 350°F.

cooldown, a T_{HOT} plant could be cooled at a natural circulation cooldown rate of 25°F/hr to the point where the RHRS could be used for further cooldown with no void formation occurring in the upper head area. The operator should maintain 50°F subcooling during the depressurization.

Without the CRDM fans a T_{HOT} plant can be cooled down to RHRS conditions at a natural circulation cooldown rate of 25°F/hr with no void formation occurring in the upper head with appropriate precautions being taken by the operators. The operator should maintain 50°F subcooling until the primary system pressure reaches 1900 psia. After the automatic safety injection signals are blocked, the operator should establish 200°F subcooling (approximately 430°F in the hot leg) and maintain 200°F subcooling (or the Technical Specification limit if it is more restrictive) to a primary system pressure of 1200 psia (see Figure 47). The depressurization should be stopped at 1200 psia and the cooldown continued until the primary system temperature is less than 350°F. At this point the operator must wait for approximately 20 hours to allow the upper head to cool off to a temperature corresponding to a saturation pressure of 400 psia. For plants with upper head thermocouples, they can provide further verification of the upper head temperature for guidance. Finally the primary system should be depressurized to 400 psia and the RHRS used for any further cooldown.

C. Summary of Conclusions

Table 8 summarizes the recommended maximum natural circulation cooldown rates and primary system subcooling requirements for T_{HOT} and T_{COLD} plants with and without fans. The limits noted provide appropriate and conservative margin to the calculated limits.

IV. CONCLUSIONS

A. T_{COLD} Plants

The average cooldown rate of the upper head fluid due to a 50°F/hr natural circulation cooldown rate is about 34°F/hr for a T_{COLD} plant. The total upper head cooldown rate due to both natural circulation cooldown and the CRDM fans varies from a maximum of 64°F/hr to around 51°F/hr when the upper head temperature is cooled to 350°F. Thus, with the CRDM fans operating during the cooldown, a T_{COLD} plant could be cooled at a natural circulation cooldown rate of 50°F/hr to the point where the RHRS could be employed for further cooldown without void formation occurring in the upper head area. The operator should maintain 50°F subcooling during the depressurization.

Adding the cooldown rate due to the CRDM fans to that from the natural circulation cooldown is conservative since the additional cooling due to the fans will enhance the density effect (discussed in Section III.A) which in turn increases the guide tube/spray nozzle flow rate.

With the CRDM fans not available, a T_{COLD} plant can be cooled down to RHRS conditions at a natural circulation cooldown rate of 50°F/hr with no void formation in the upper head area if the operator maintains 100°F subcooling during the depressurization (see Figure 46).

B. T_{HOT} Plants

The average cooldown rate of the upper head fluid due to the 25°F/hr natural circulation cooldown rate is about 10°F/hr for a T_{HOT} plant. The total upper head cooldown rate due to both the natural circulation cooldown and the CRDM fans varies from 42°F/hr initially to around 27°F/hr when the upper head temperature is cooled to 350°F. Thus, with the CRDM fans operating during the

REFERENCES

1. Porsching, T. A., Murphy, J. H., Redfield, J. A., and Davis, V. C., "FLASH-4: A Fully Implicit FORTRAN-IV Program for the Digital Simulation of Transients in a Reactor Plant," WAPD-TM-840; Bettis Atomic Power Laboratory.

2. Esposito, V. J., Kesavan, K. and Maul, B. A., "WFLASH-A FORTRAN-IV Computer Program for Simulation of Transients in a Multi-Loop PWR," WCAP-8200, Revision 2, July, 1974 (Proprietary) and WCAP-8261, Revision 1, July, 1974 (Non-Proprietary).

TABLE 1

BEST ESTIMATE WFLASH INPUT

	T_{HOT} Plant	T_{COLD} Plant	Appendix K
A. PLANT PARAMETERS			
1. Primary Hot Leg Nodes Modeled	Yes	Yes	No
2. Continuous flow paths for crossover and hot legs	Yes	Yes	No
3. Power Level	100%	100%(1)	102%
4. Pressure drops	Best Estimate	Thermal Design	Thermal Design
5. Flow rates	Best Estimate	Thermal Design	Thermal Design
B. REACTOR			
1. Decay heat-ANS infinite	Nominal	Nominal	120%
2. Axial power shape	BOL, First Core B.E.	BOL, First Core B.E.	Worst Case Envelope
3. Reactor trip, sec.	2.0	2.0	Low RCS Pressure Signal
4. Reactor coolant pump trip, sec.	2.0	2.0	Reactor Trip Signal
C. PRESSURIZER			
1. Non-equilibrium pressurizer model	Yes	Yes	No

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(1) Pressure drops enthalpies flow rates and steam generator heat loads based on 102% power.

TABLE 2

PLANT CONDITIONS AT TIME NATURAL CIRCULATION COOLDOWN IS INITIATED (720 SECONDS)

Primary system pressure, psia	2245
Secondary system pressure, psia	1106
Hot leg temperature, °F	586
Cold leg temperature, °F	557
RCS loop flow, lb/sec	506(1)
Reactor power, % of nominal	2.3

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(1) Loop flow is 490 lb/sec for T_{COLD} plants at 720 seconds.

TABLE 3

UPPER HEAD FLOW - T_{COLD} PLANT

Spray nozzle flow area, ft^2	0.192
Primary system loop flow, lb/sec	9757
Percent of total flow passing through spray nozzles	1.56
Initial spray nozzle flow, lb/sec	609

TABLE 4

UPPER HEAD P_{SAT} FOR T_{COLD} PLANT

Cooldown Rate (°F/hr)	Temperature (°F) Primary System	Temperature (°F) Upper Head	P_{SAT} for Upper Head Temperature (psia)
50	500	529	878
25	500	516	785
50	350	426	329
25	350	372	178

TABLE 5

UPPER HEAD FLOW - T_{HOT} PLANT

Spray nozzle flow area, ft^2	0.0167
Primary system loop flow, lb/sec	9868
Percent of flow passing through spray nozzles	0.15
Initial spray nozzle flow, lb/sec	59.2

TABLE 6

DEPRESSURIZATION RATE EFFECT ON UPPER HEAD TEMPERATURE

	Depressurization Rate 1		Depressurization Rate 2	
Time (sec)	Primary System Pressure (psi)	Upper Head Temp. (°F)	Primary System Pressure (psi)	Upper Head Temp. (°F)
1810	2060	612.0	2063	612.0
5085	1912	605.4	2014	605.9
7560	1819	602.3	1975	602.5
10440	1708	597.1	1909	597.5

TABLE 7

UPPER HEAD P_{SAT} FOR T_{HOT} PLANT

	Temperature (°F)		
Cooldown Rate (°F)/Hr)	Primary System	Upper Head	P_{SAT} for Upper Head Temperature (psia)
50	500	599	1531
25	500	585	1382
50	350	549	1035
25	350	513	761

TABLE 8

MAXIMUM RECOMMENDED NATURAL CIRCULATION COOLDOWN RATES

Upper Head	CRDM Fans	Maximum Cooldown Rate ($^{o}F/Hr$)	Required Hot Leg Subcooling* (^{o}F)
T_{COLD}	Yes	50	50
T_{COLD}	No	50	100
T_{HOT}	Yes	25	50
T_{HOT}	No	25	200**

* Required hot leg subcooling to avoid reaching saturation pressure in the upper head.

** Use Tech Spec limit if it is more restrictive. Also, 200°F subcooling required only between hot leg temperature of 350°F to 430°F.

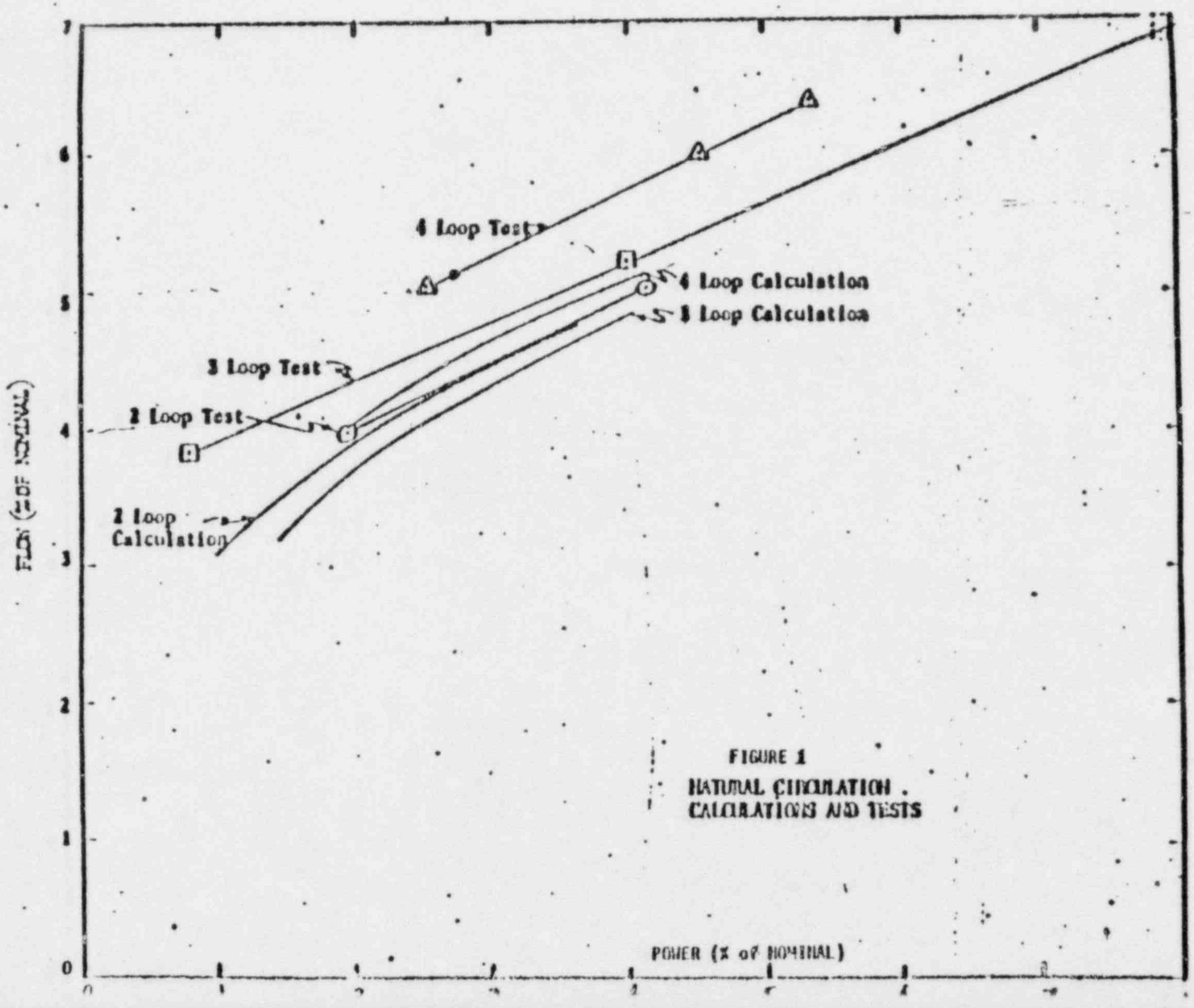


FIGURE 1
NATURAL CIRCULATION
CALCULATIONS AND TESTS

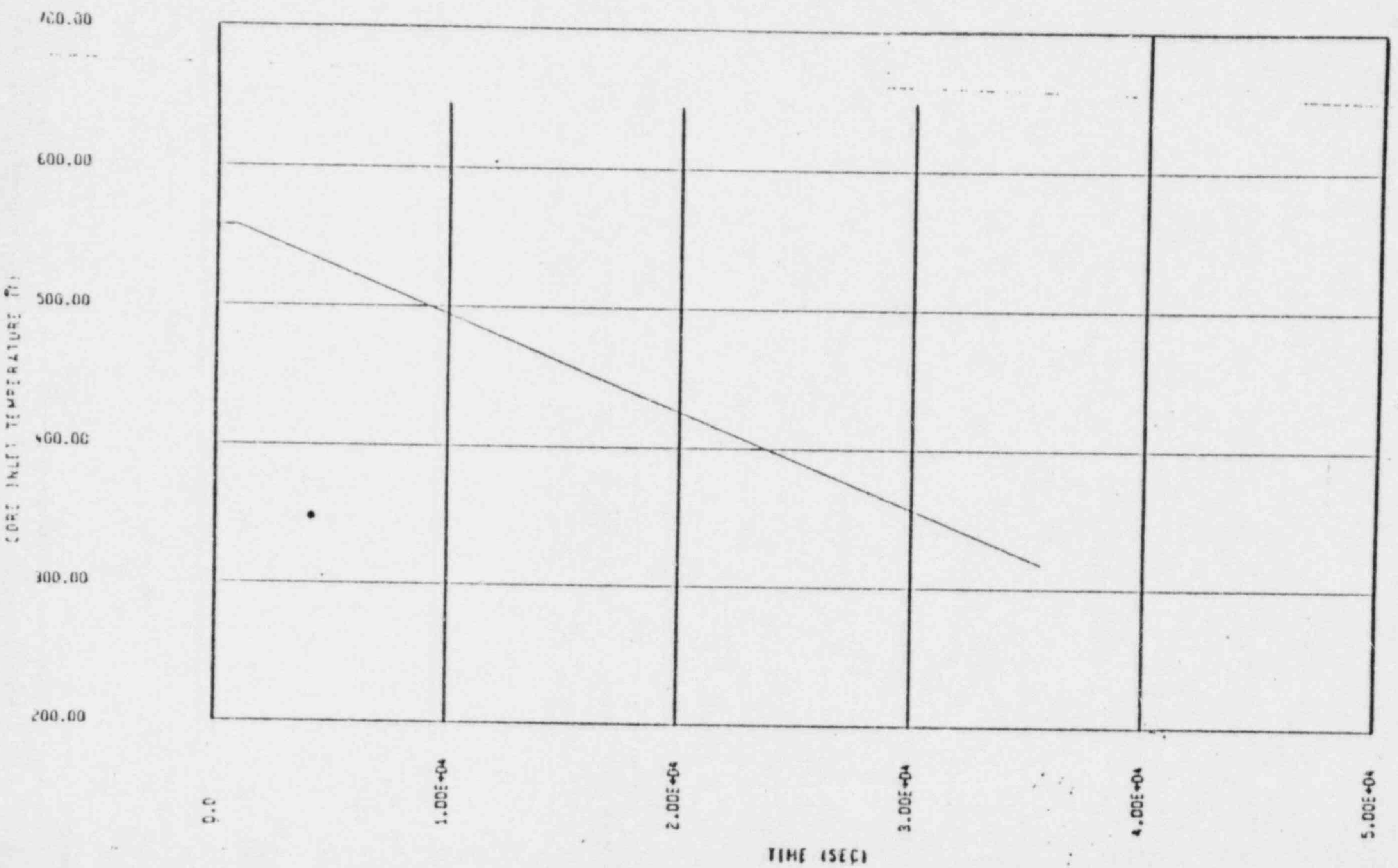


FIGURE 2

CORE INLET TEMPERATURE
T_{COLD} - 25°F/HR COOLDOWN

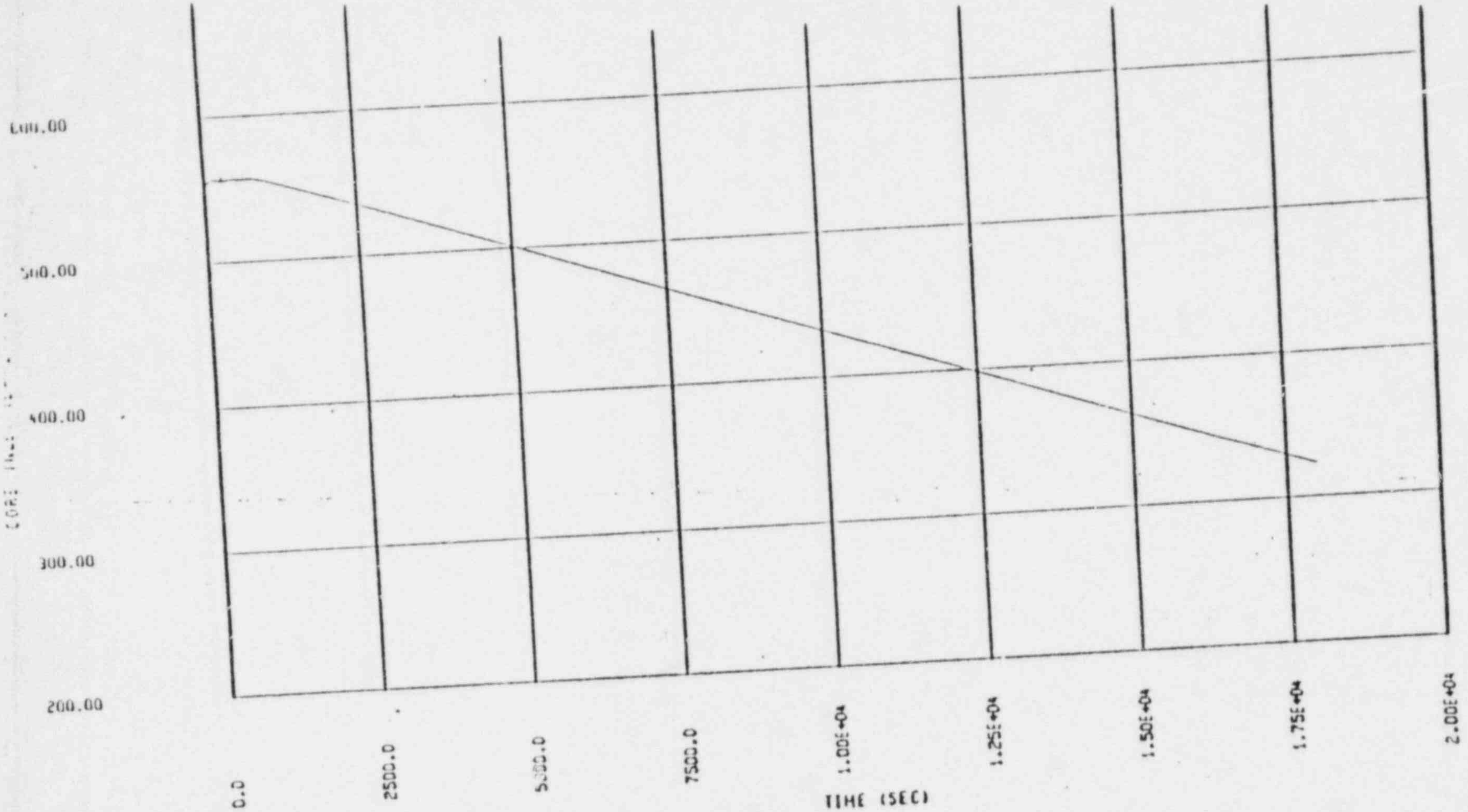


FIGURE 3

CORE INLET TEMPERATURE
T_{COLD} - 50°F/HR COOLDOWN

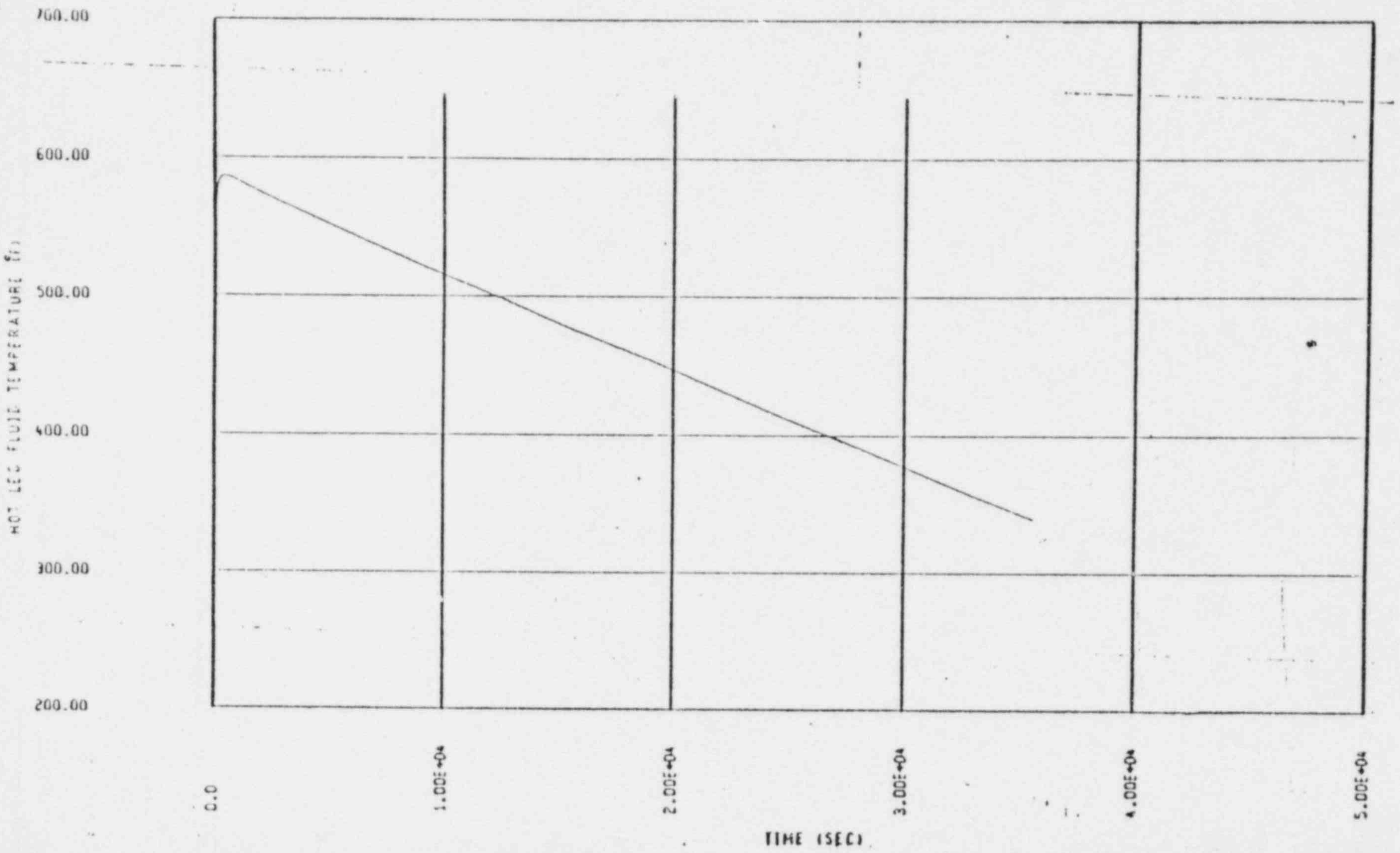


FIGURE 4

HOT LEG FLUID TEMPERATURE
T_{COLD} - 25°F/HR COOLDOWN

Figure 24
Core Inlet Temperature
T_{Hot} - 25°F/HR Cooldown

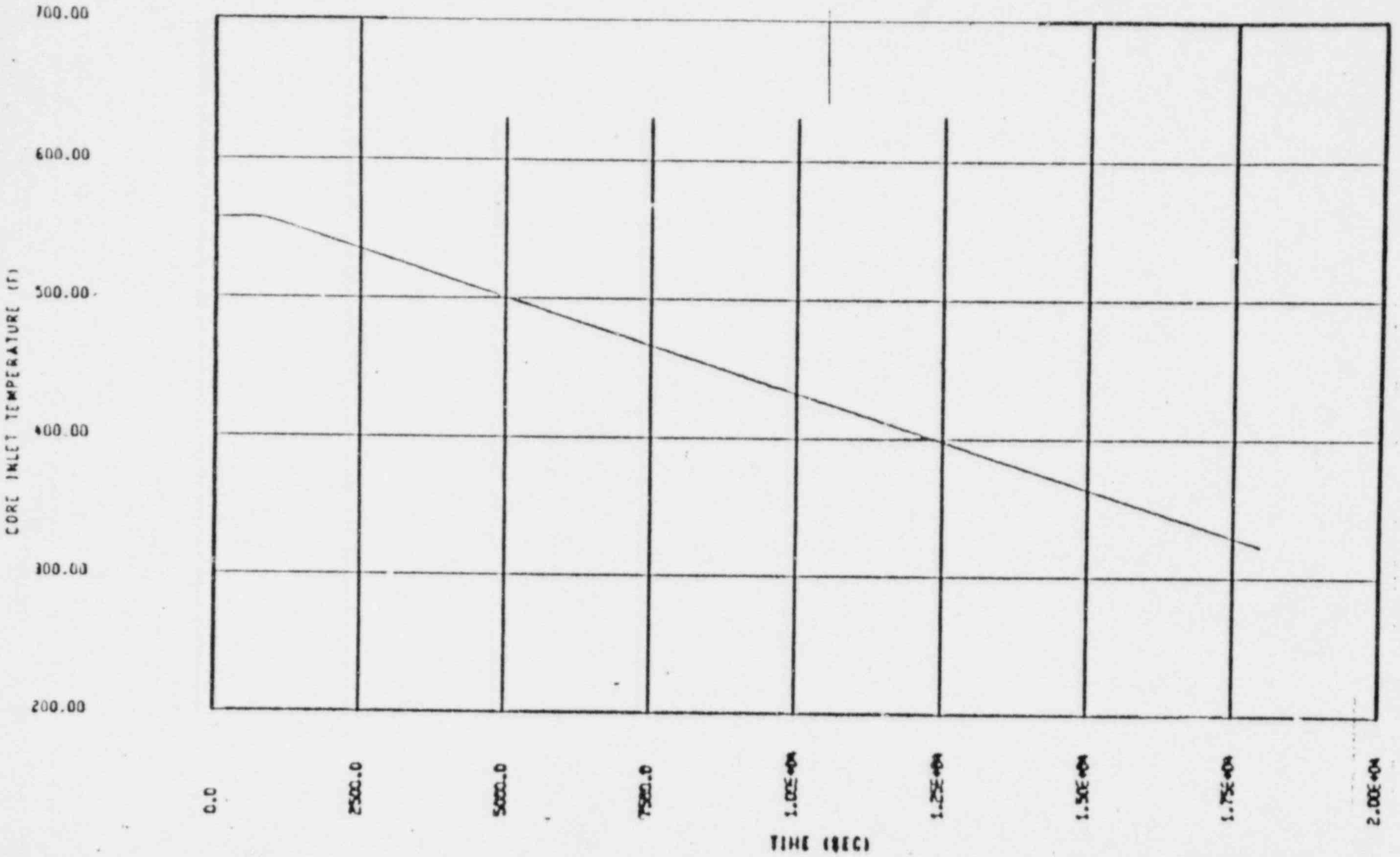


Figure 25

Core Inlet Temperature

T_{Hot} - 50°F/Hr Cooldown

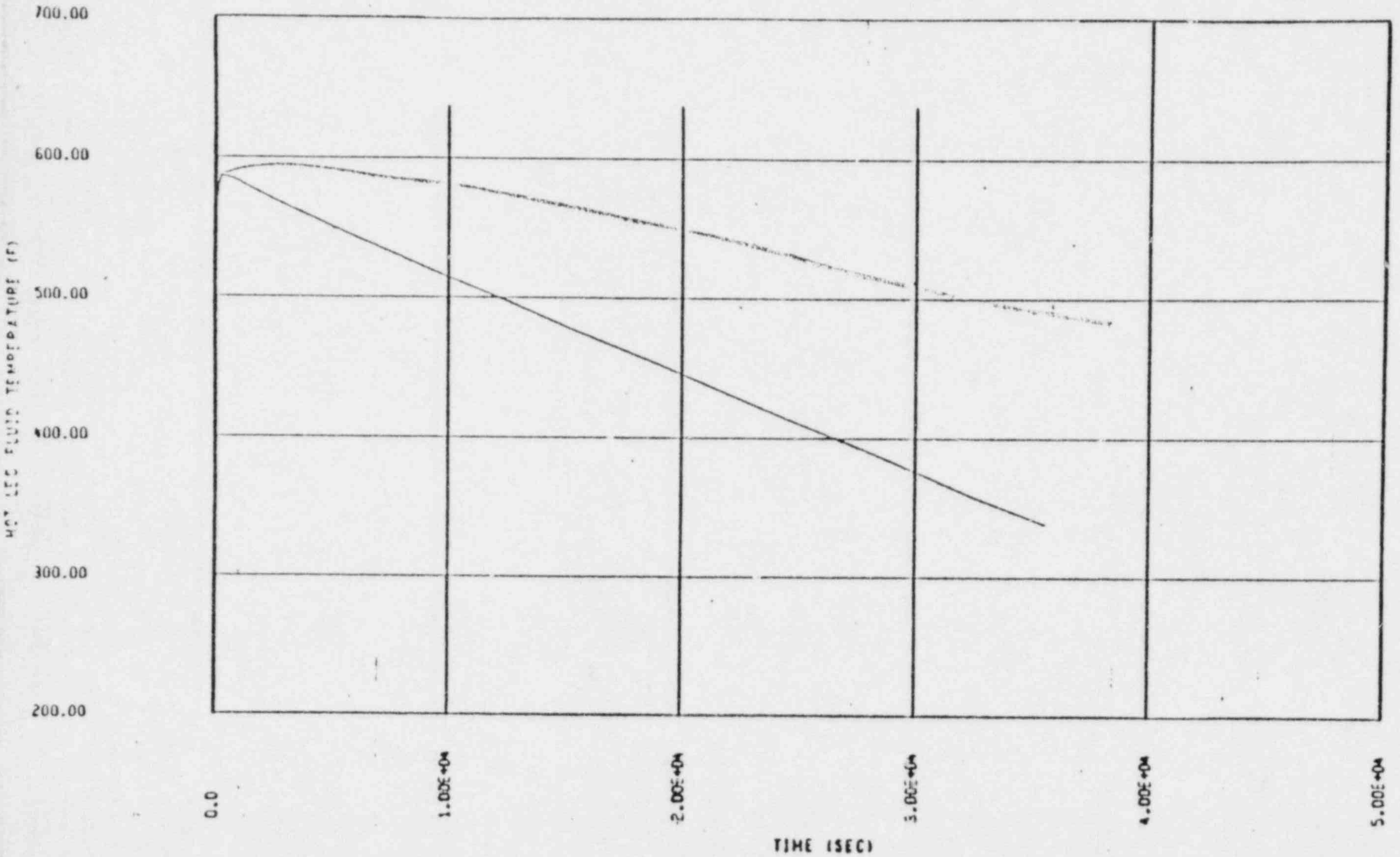


Figure 26

Hot Leg Fluid Temperature

T,, . - 25°F/HR Cooldown

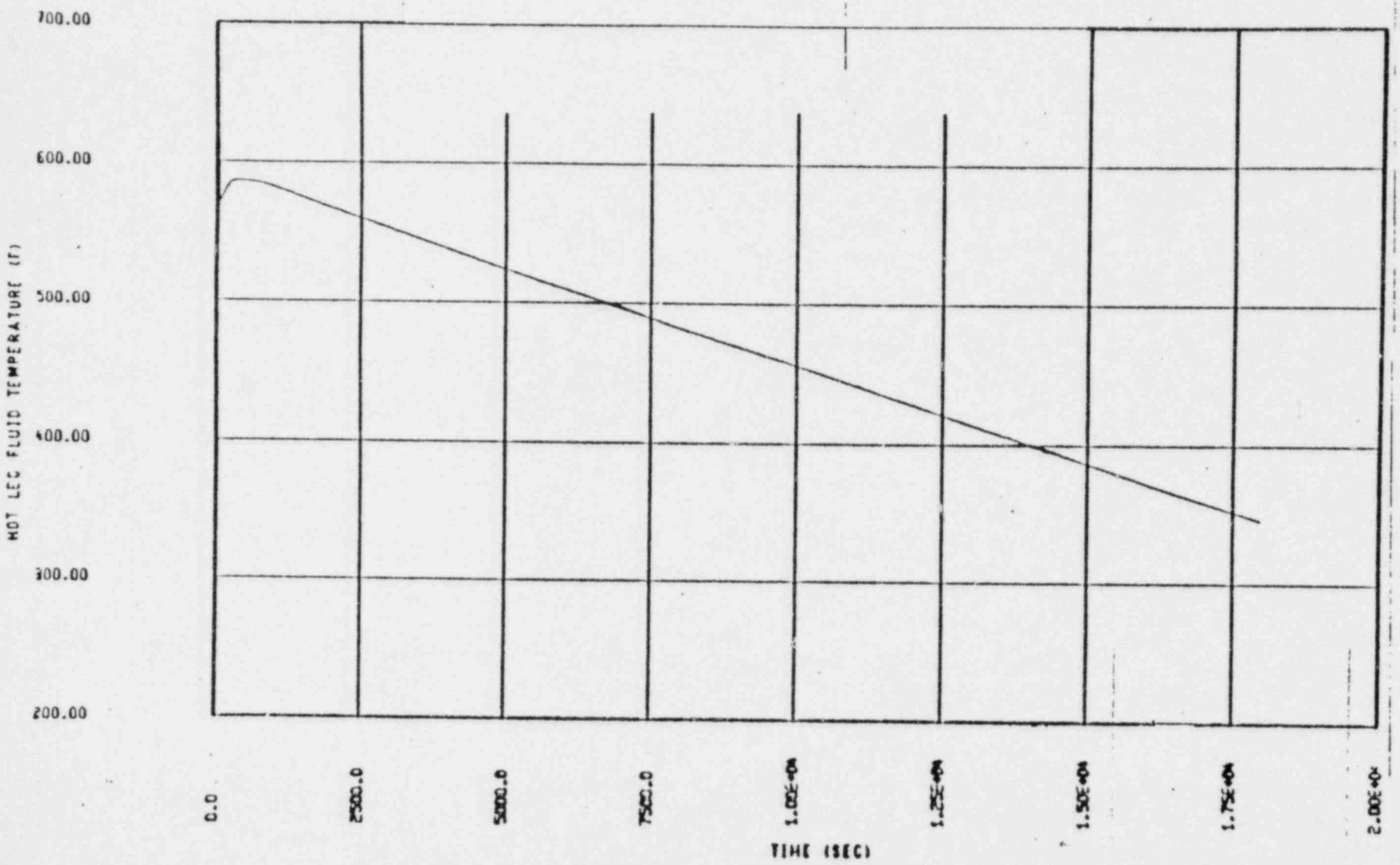


Figure 27
Hot Leg Fluid Temperature
T_{Hot} - 50°F/HR Cooldown

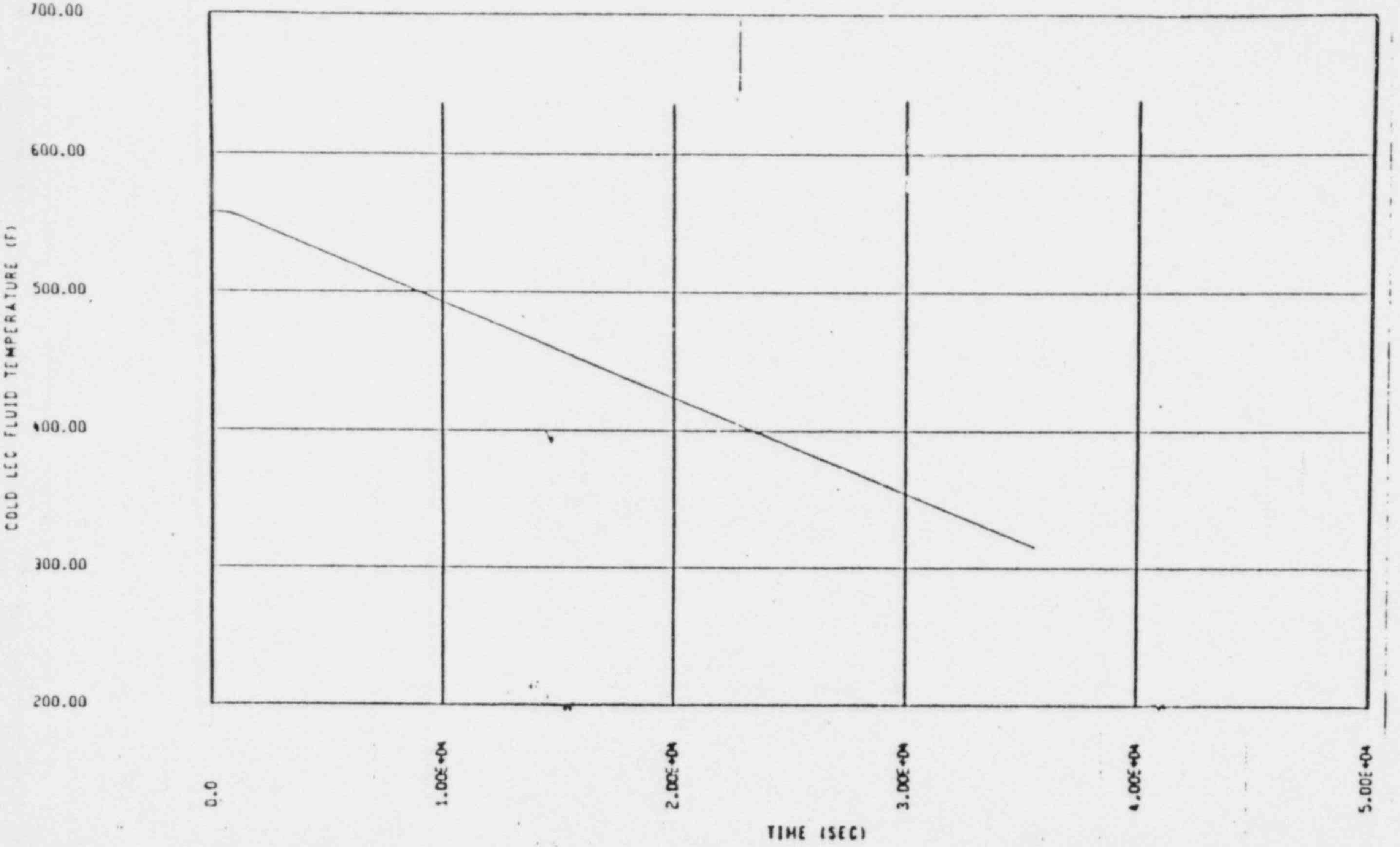


Figure 20
Cold Leg Fluid Temperature
T_{hot} - 25°F/HR Cooldown

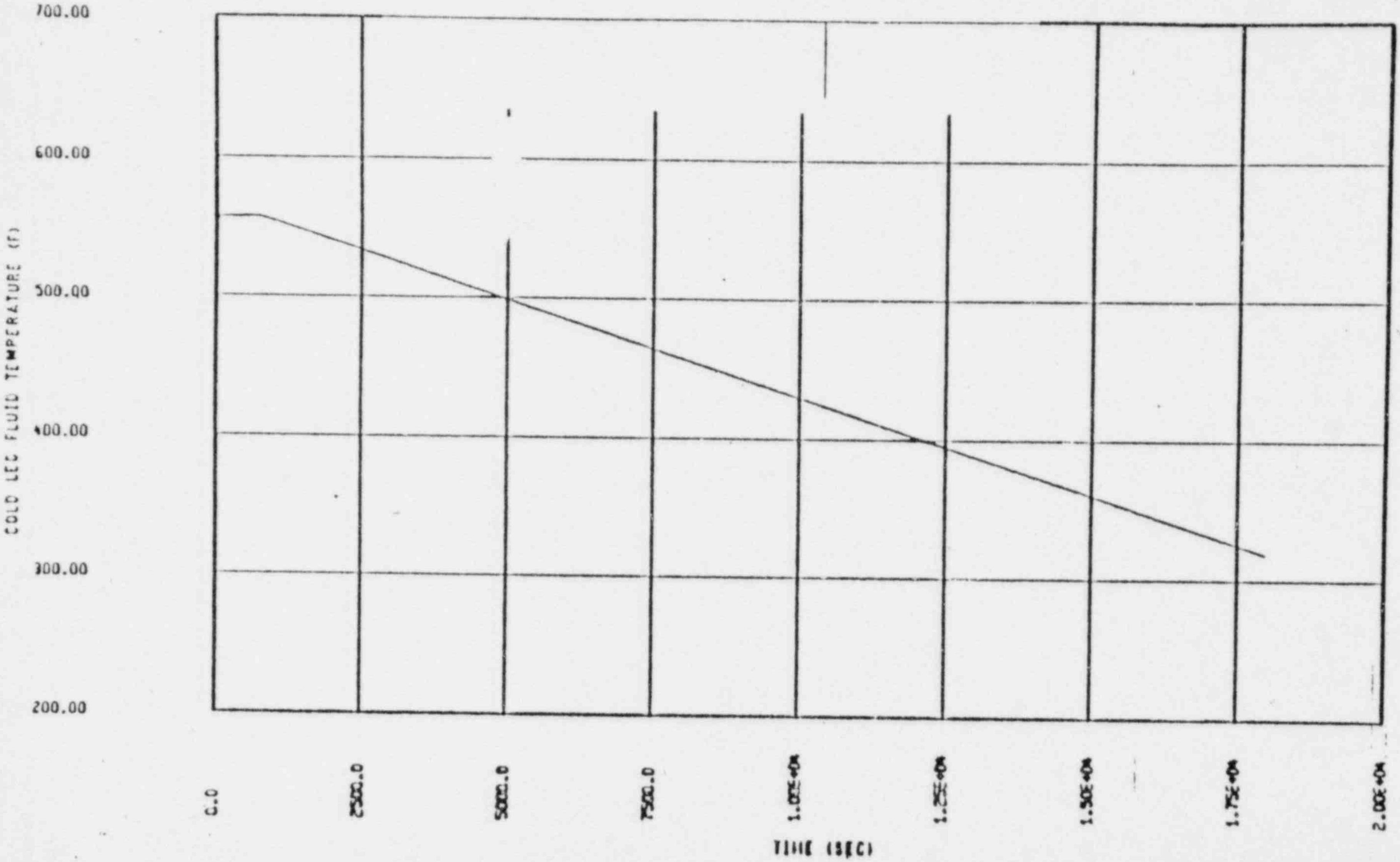


Figure 29

Cold Leg Fluid Temperature

T_{Hot} - 50°F/HR Cooldown

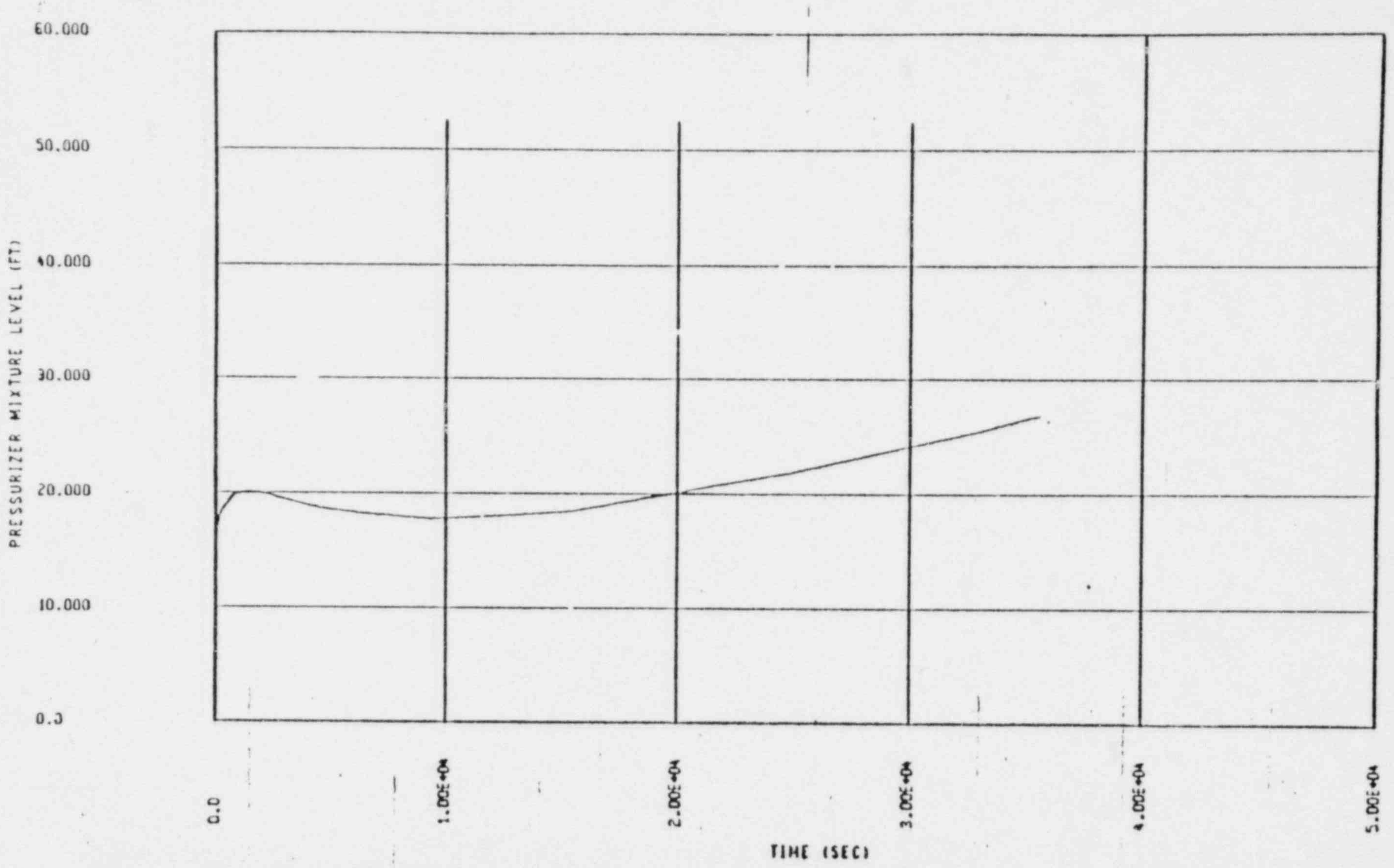


Figure 30

Pressurizer Mixture Level

T_{Hot} - 25°F/Hr Cooldown

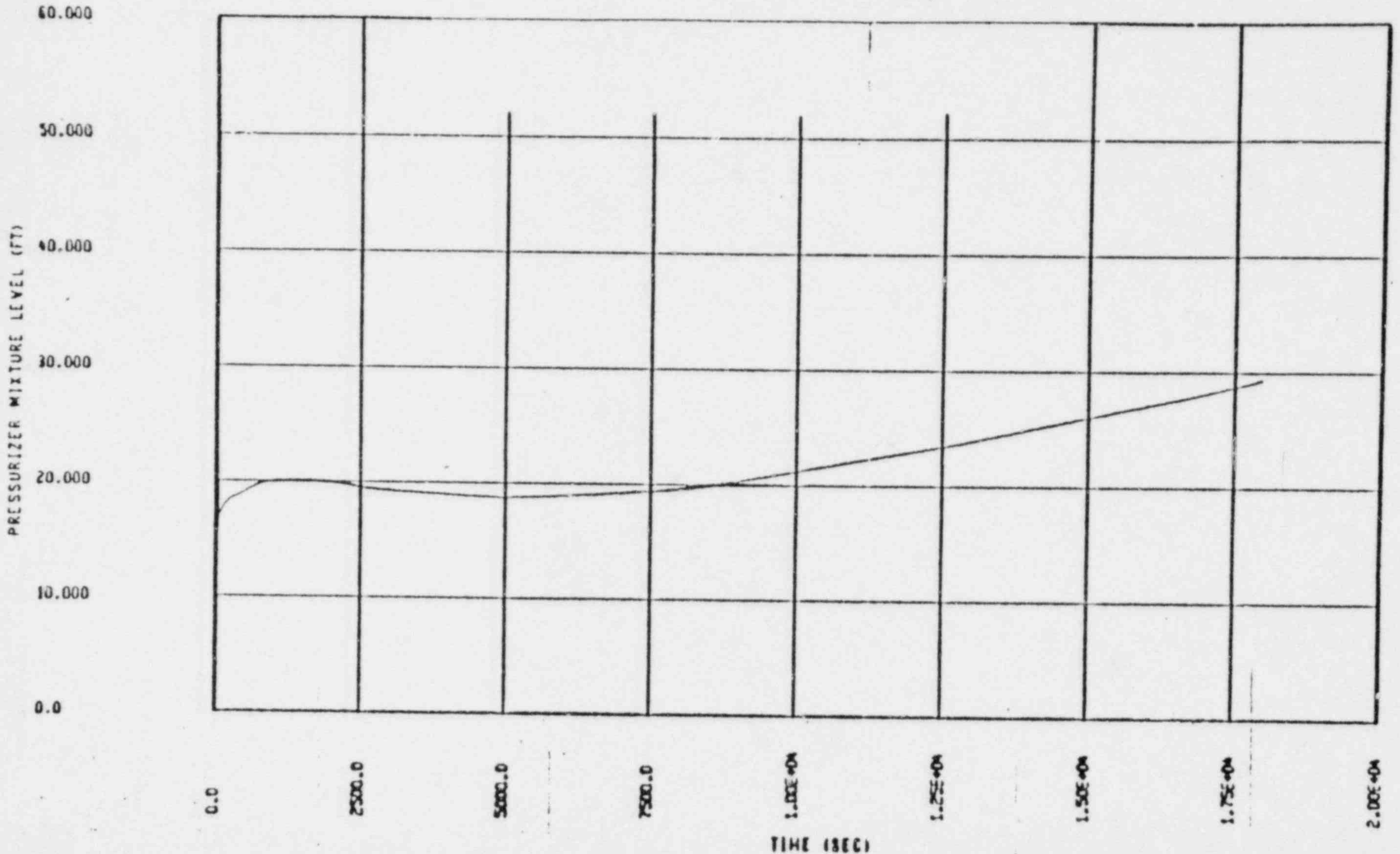


Figure 31

Pressurizer Mixture Level

T_{Hot} - 50°F/Hr Cooldown

Figure 32

Primary System Pressure

T_{Hot} - 25°F/Hr Cooldown

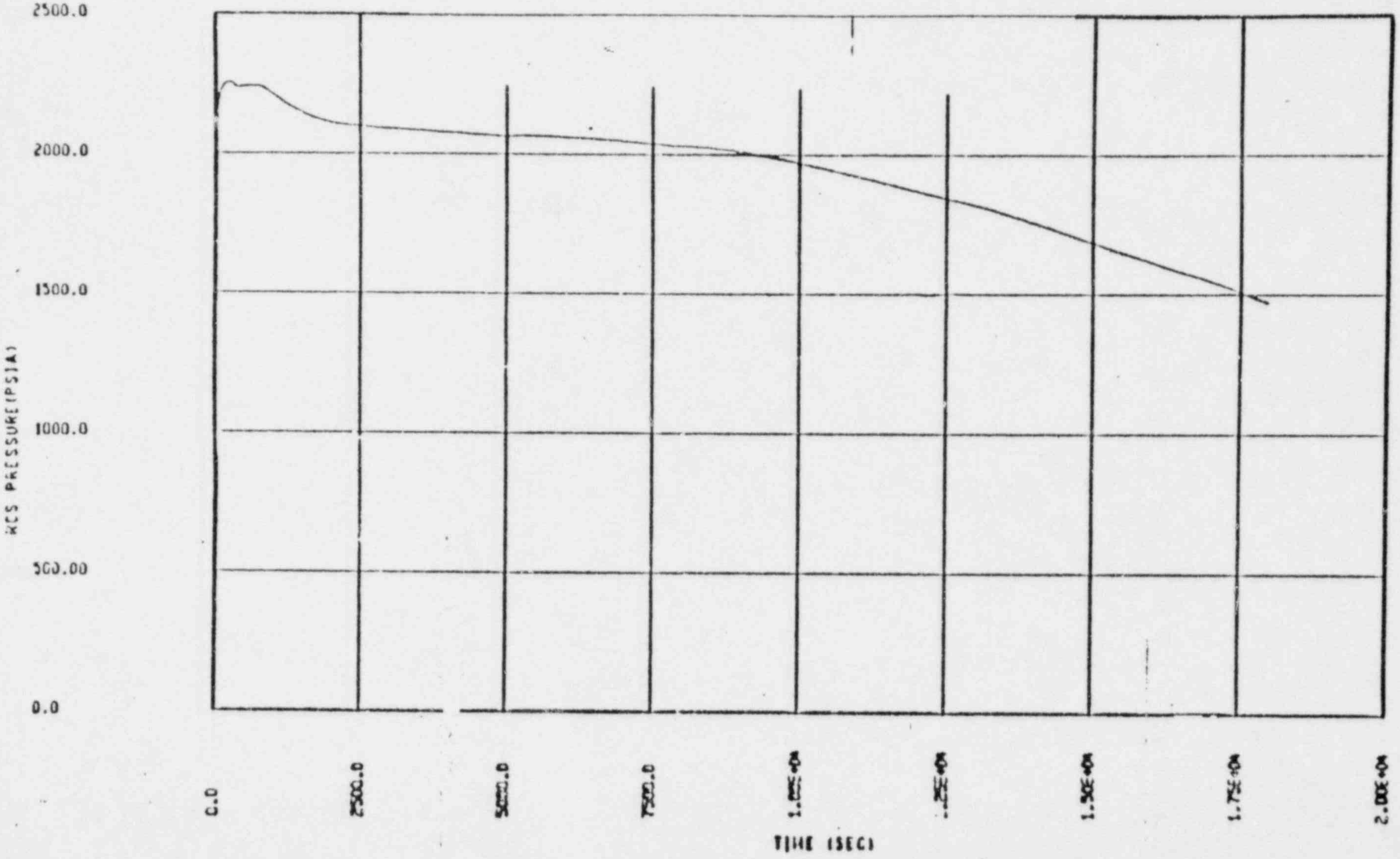


Figure 33

Primary System Pressure

T_{Hot} - 50°F/Hr Cooldown

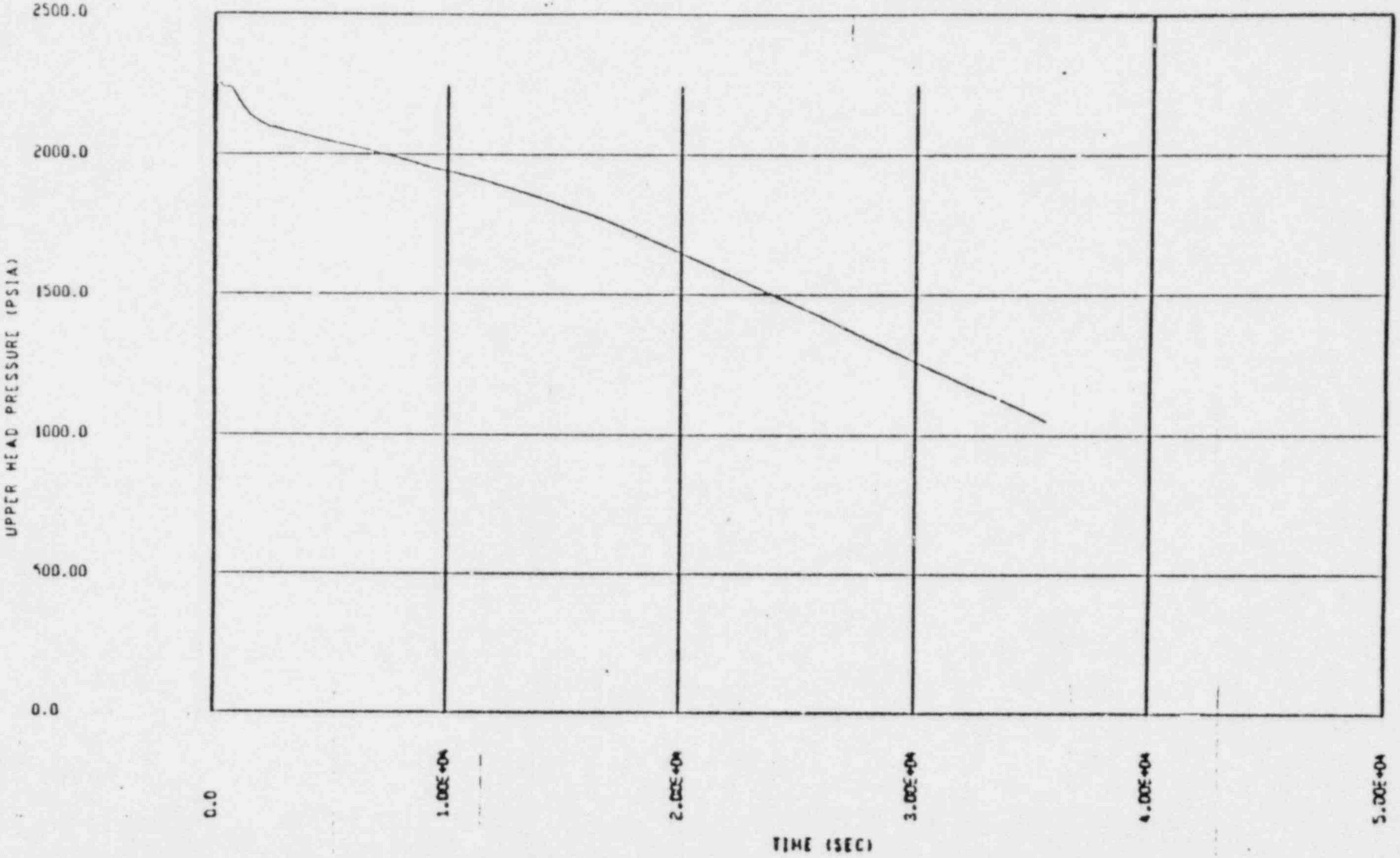


Figure 34
Upper Head Pressure
T_{Hot} - 25°F/Hr Cooldown

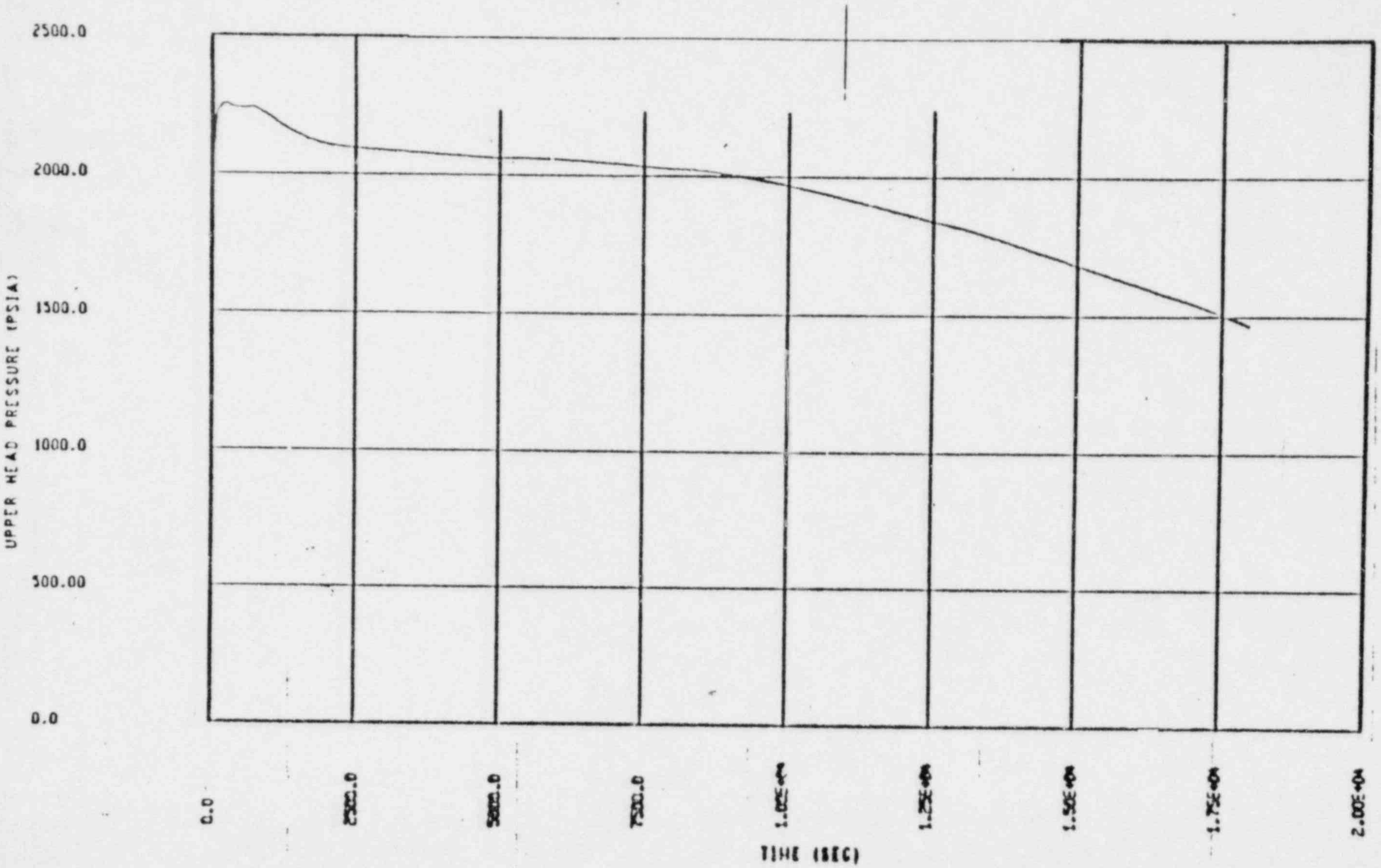


Figure 35

Upper Head Pressure

T_{Hot} - 50°F/Hr Cooldown

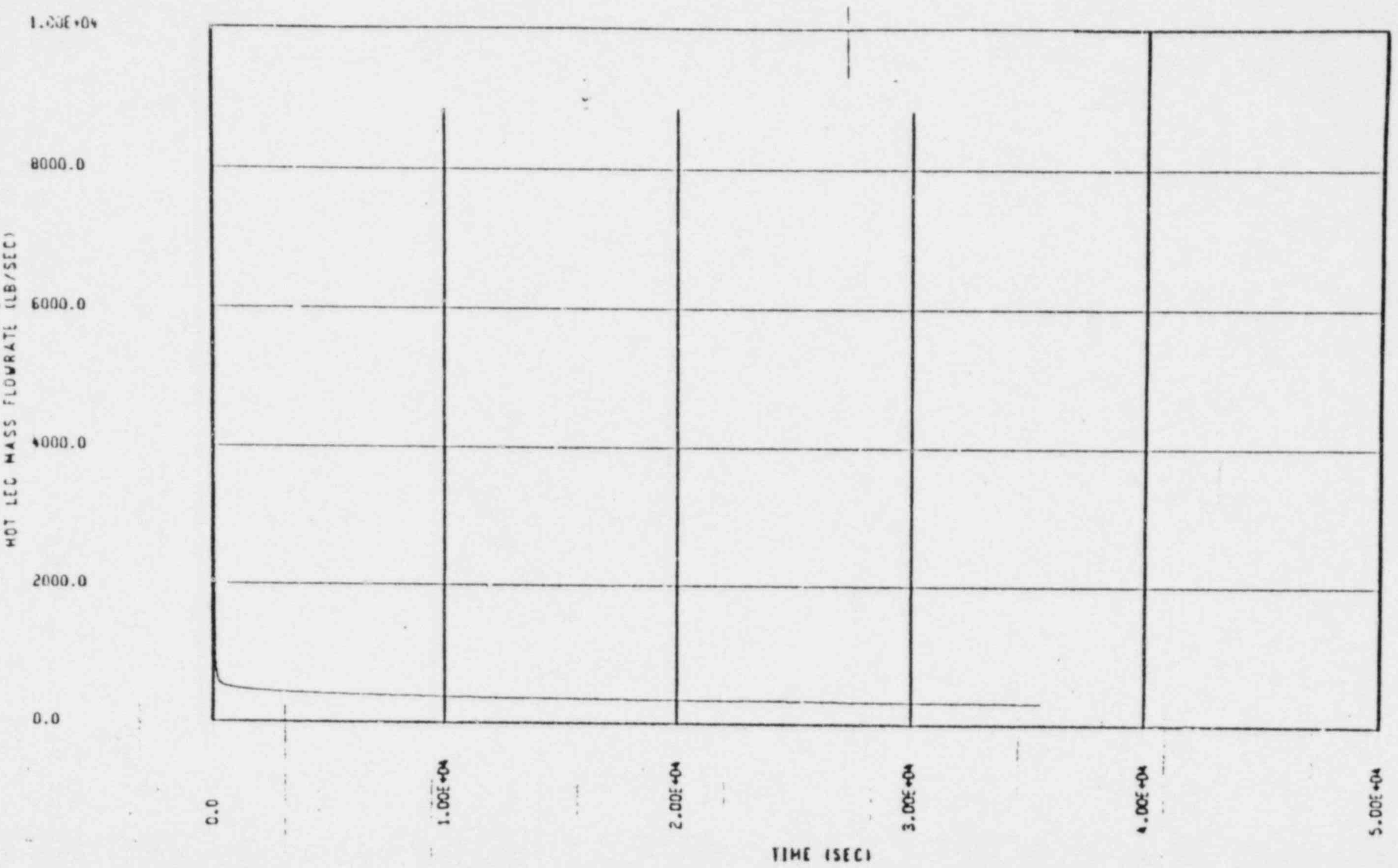


Figure 36

Hot Leg Mass Flow Rate

T_{Hot} - 25°F/Hr Cooldown

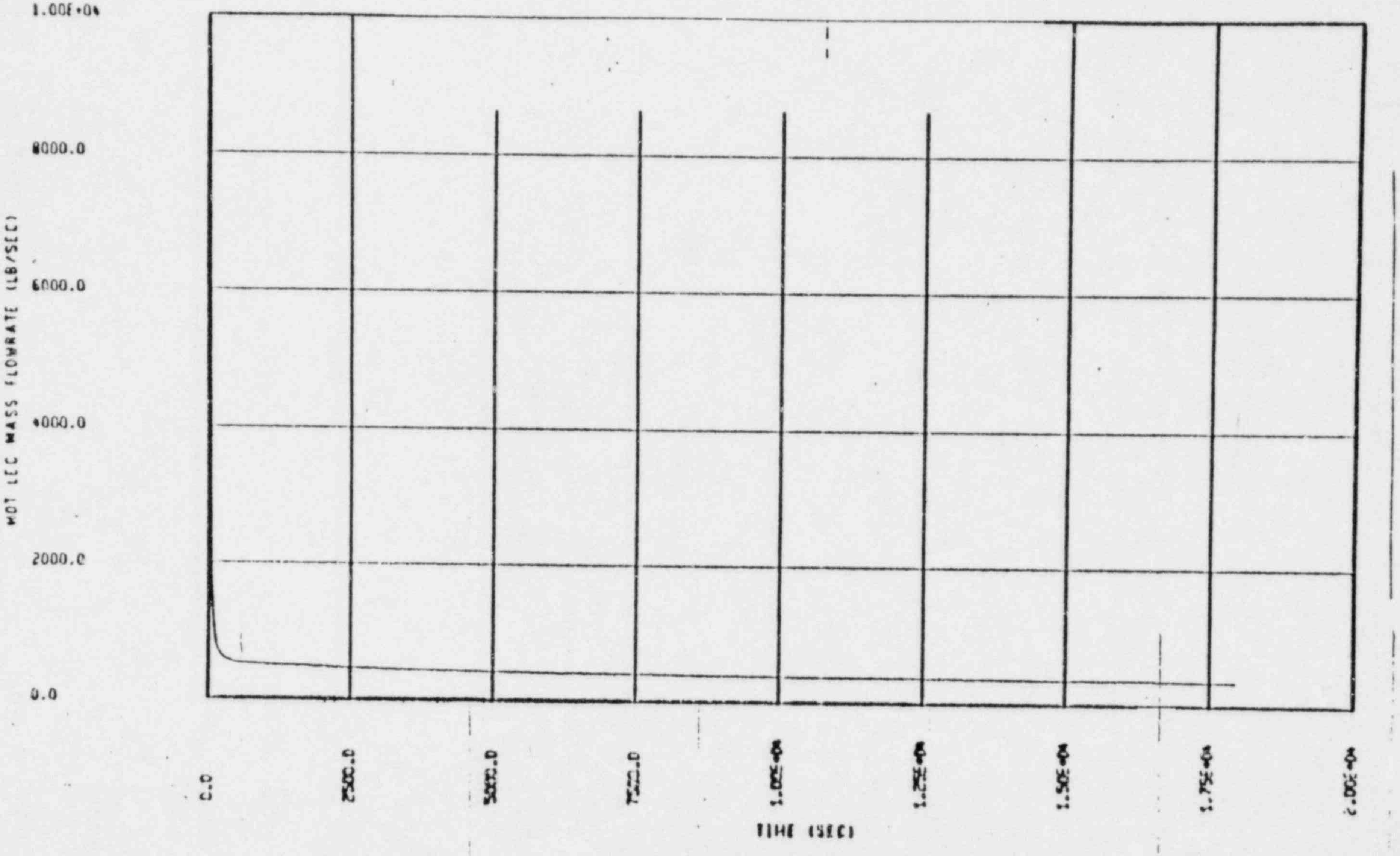


Figure 37

Hot Leg Mass Flowrate

T_{Hot} - 50°F/Hr Cooldown

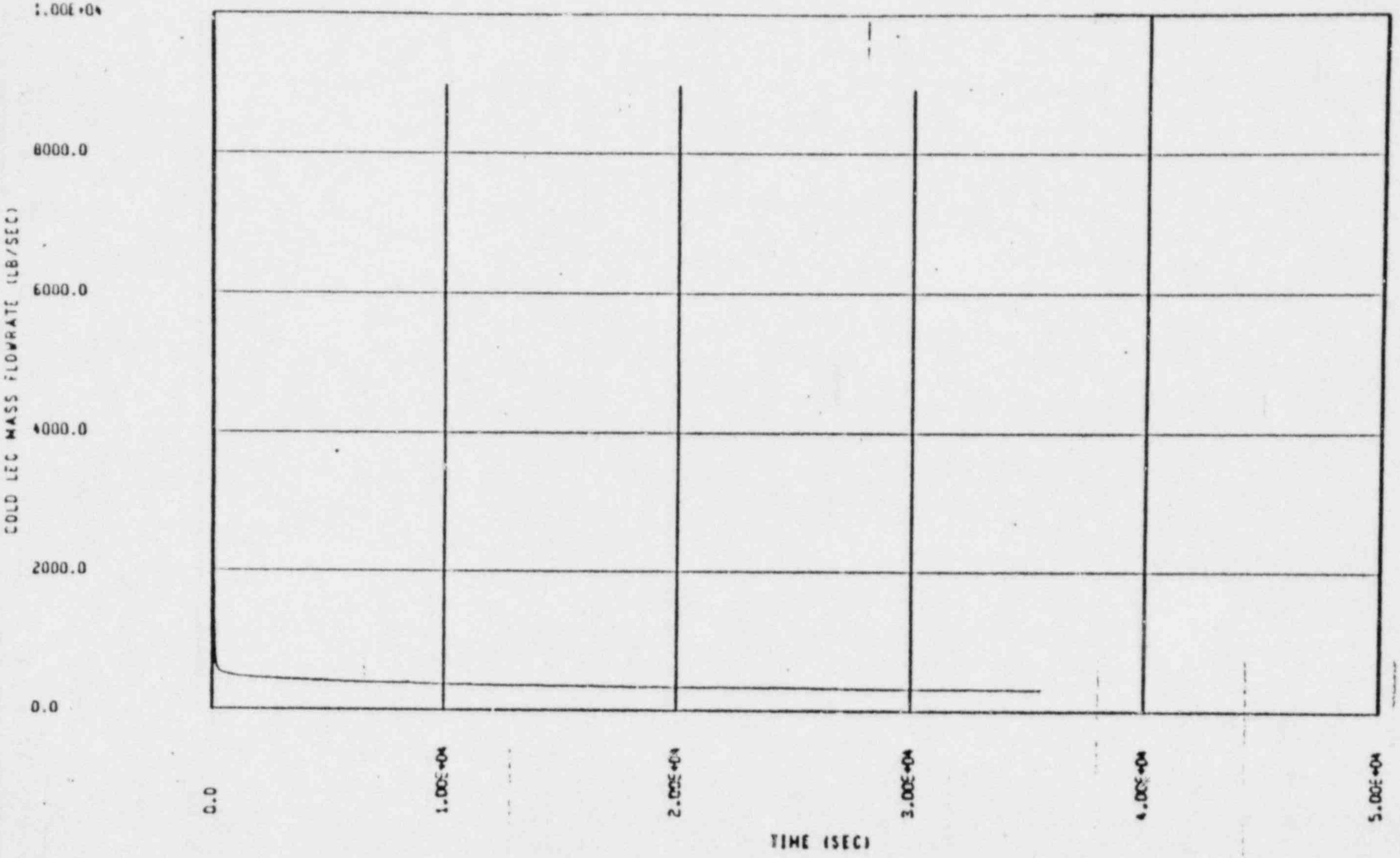


Figure 38

Cold Leg Mass Flowrate

T.. . - 25°F/Hr Cooldown

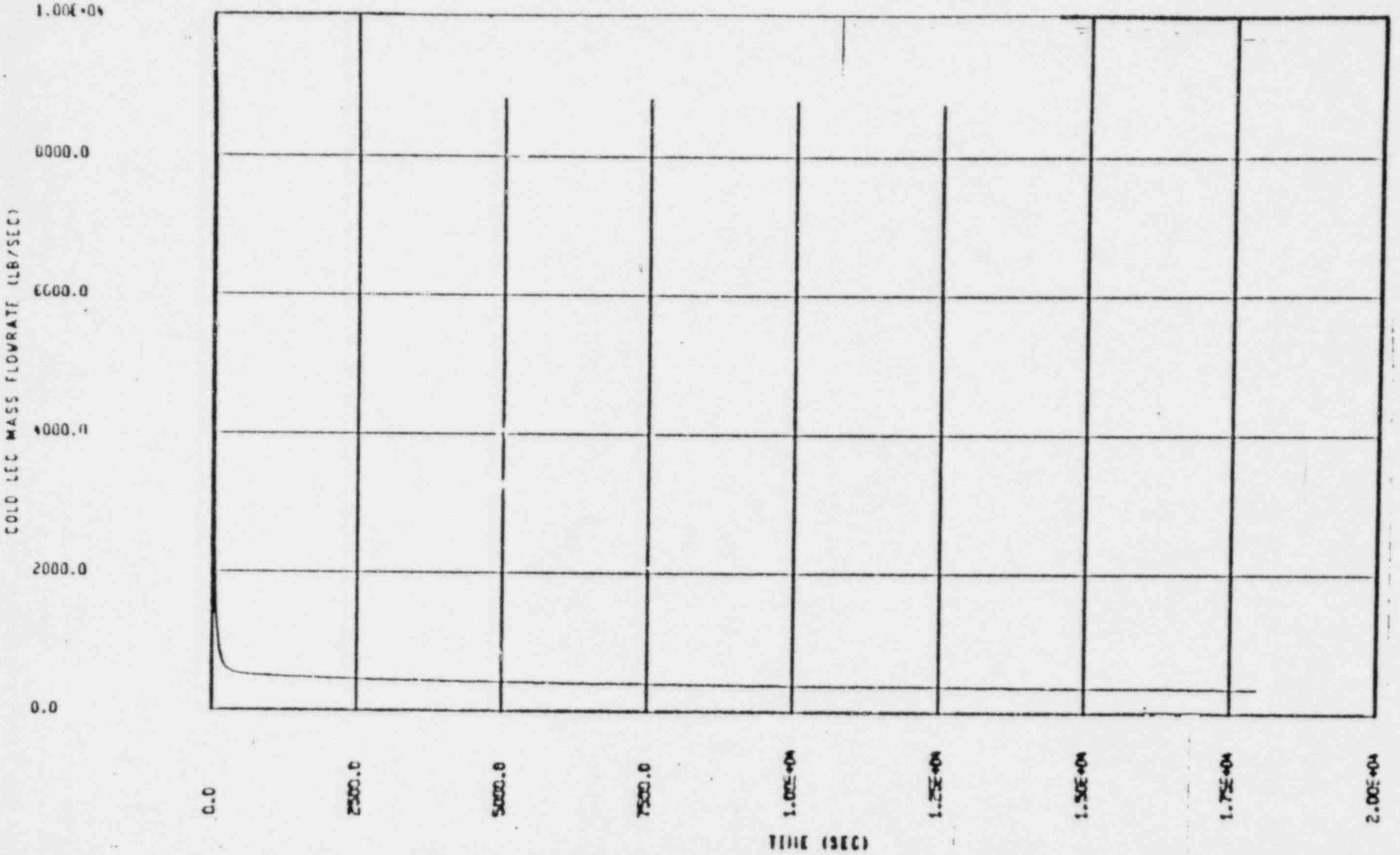


Figure 39

Cold Leg Mass Flowrate
T_{Hot} - 50°F/Hr Cooldown

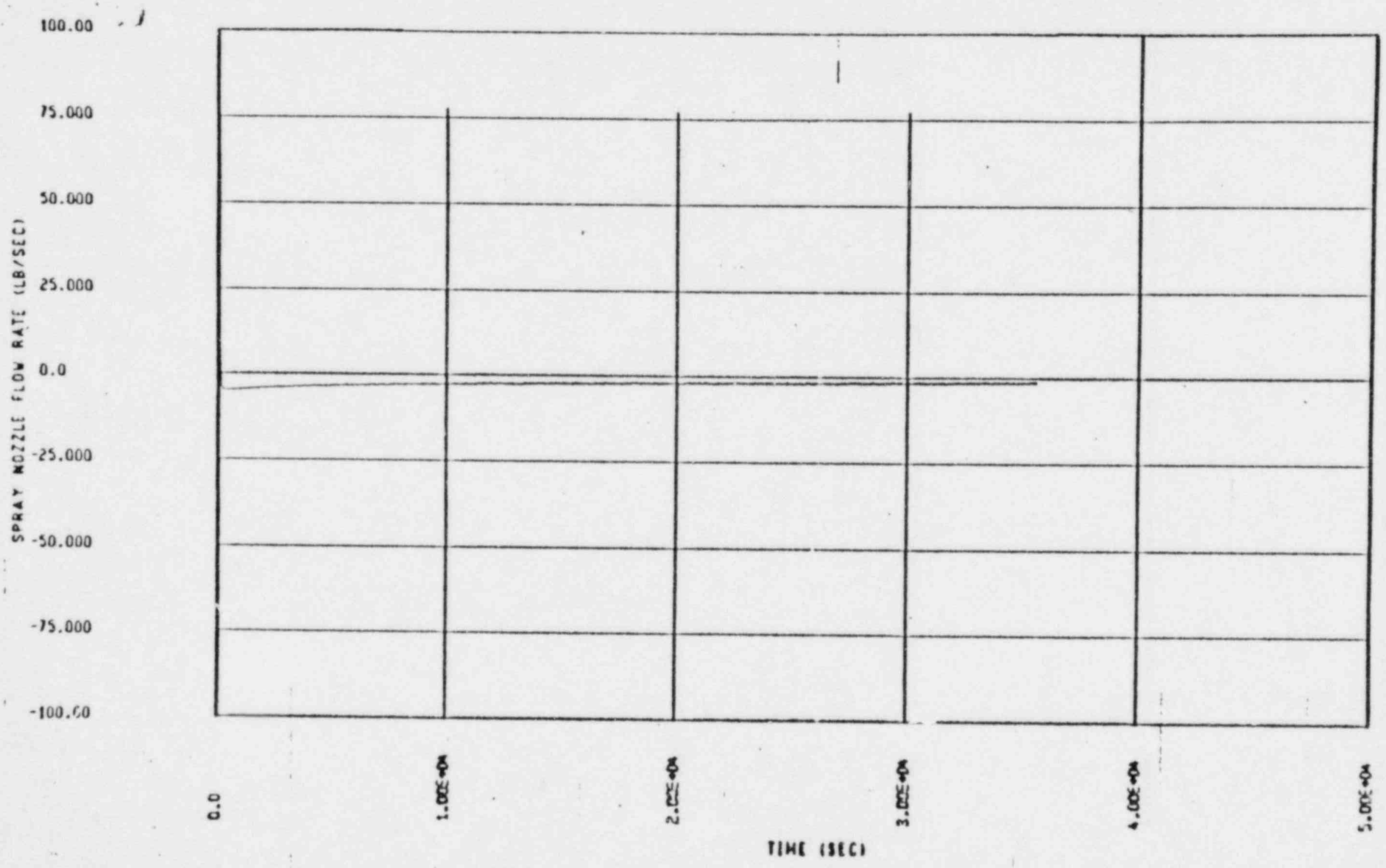


Figure 40

Spray Nozzle Flowrate

T_{Hot} - 25°F/Hr Cooldown

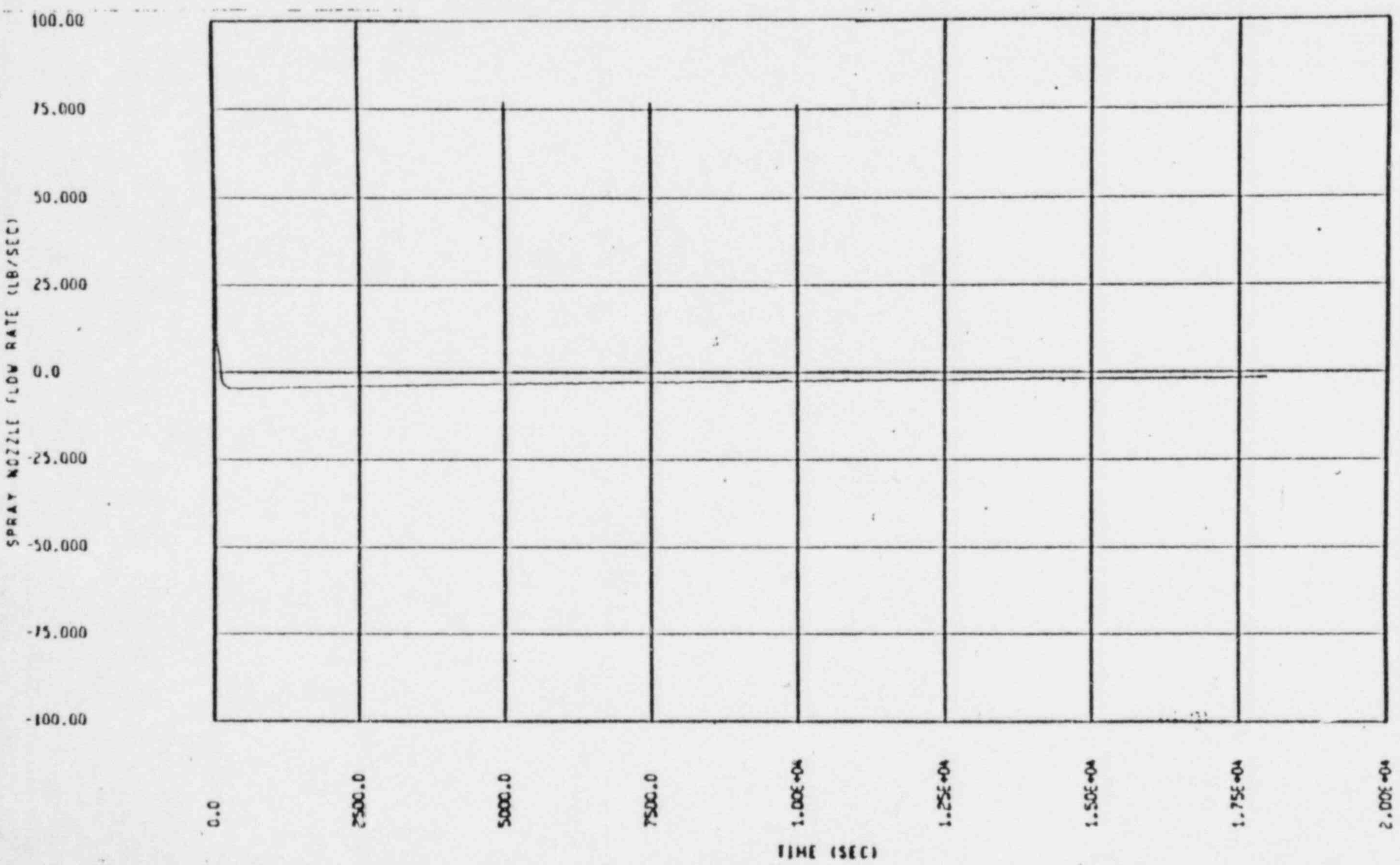


Figure 41
Spray Nozzle Flow Rate
T_{Hot} - 50°F/Hr Cooldown

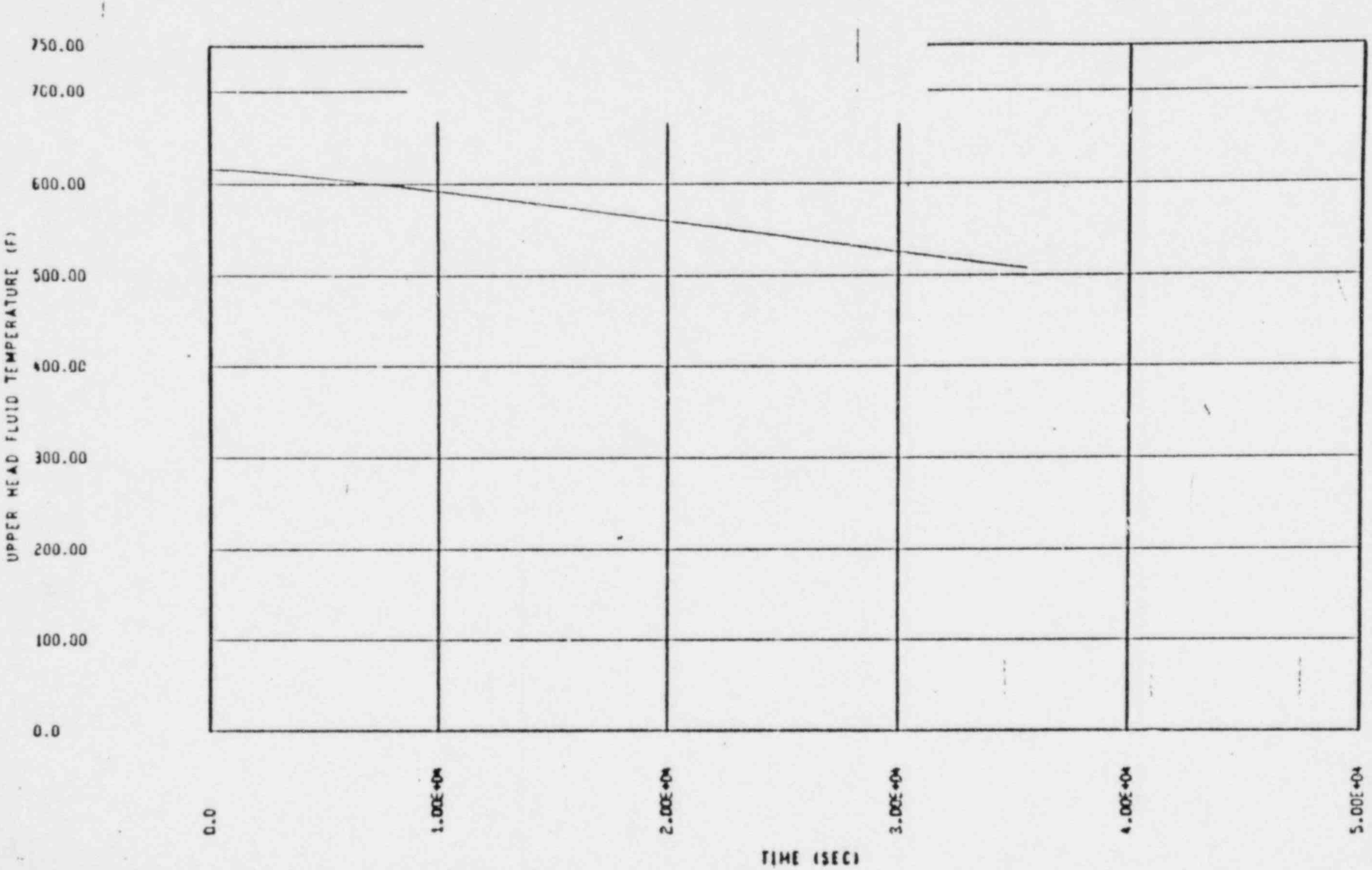


Figure 42

Upper Head Fluid Temperature

T_{Hot} - 25^{0}F/Hr - Cooldown

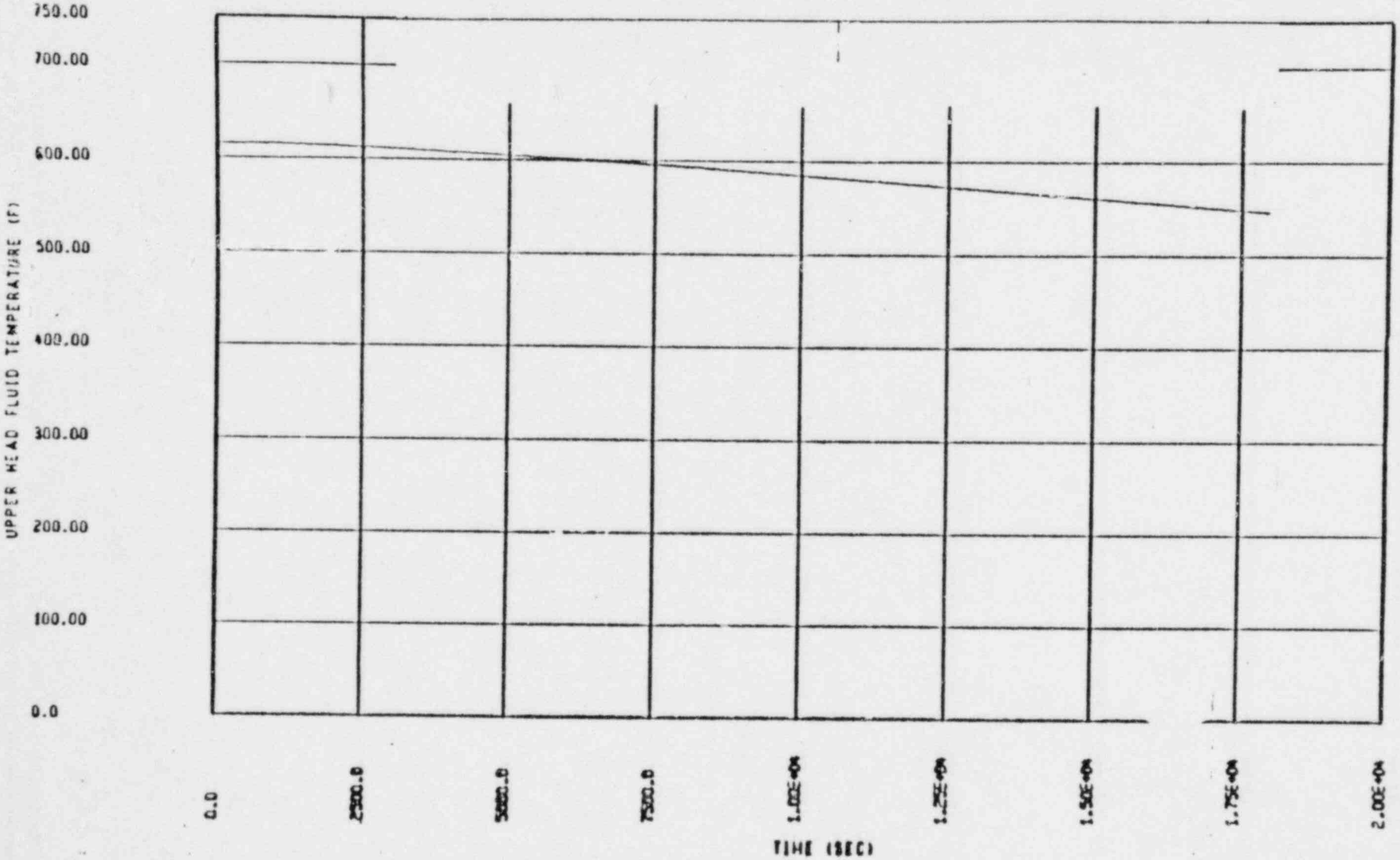
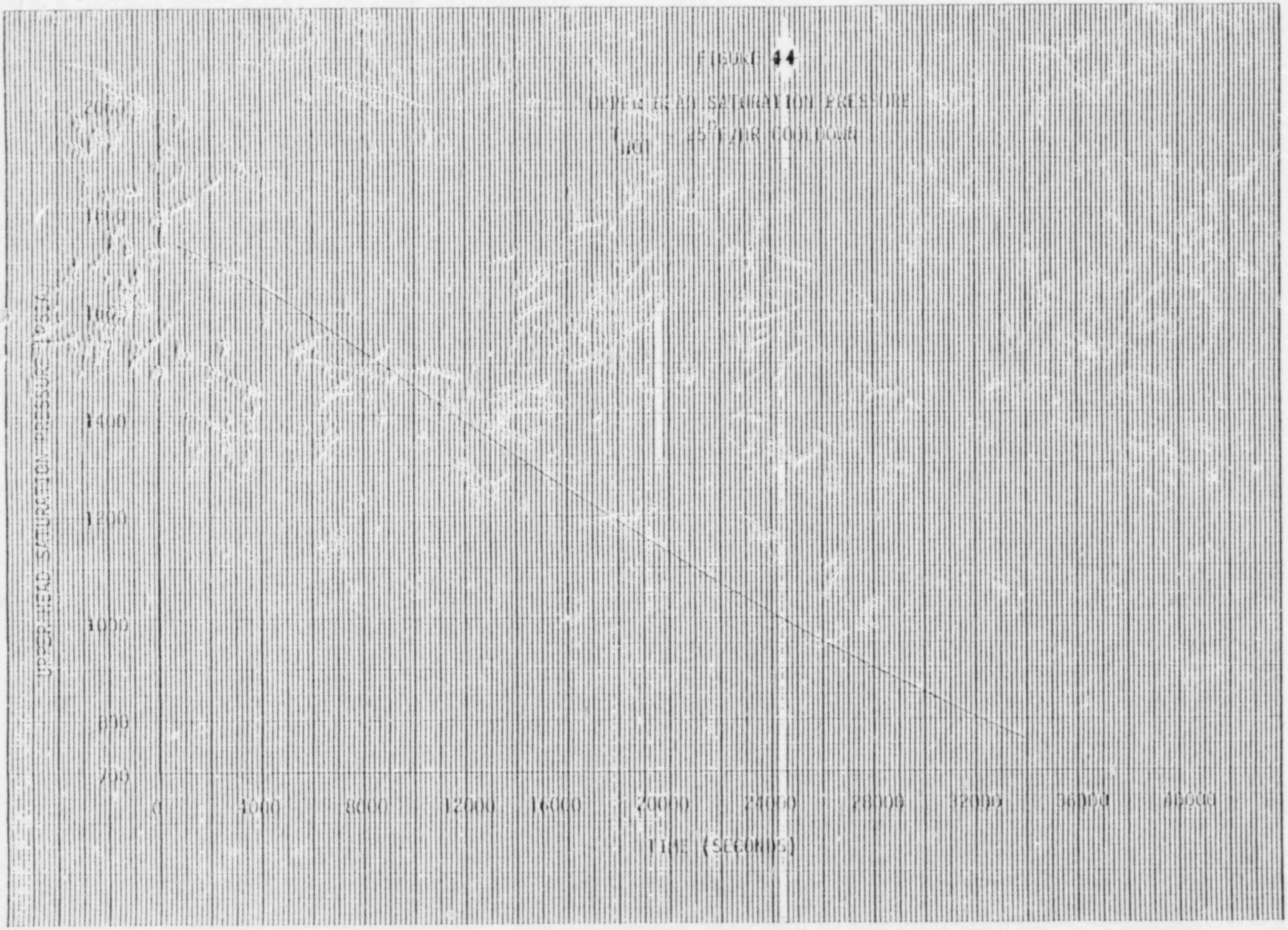


Figure 43

Upper Head Fluid Temperature
T_{Hot} - 50°F/Hr Cooldown

FIGURE 44

UPPER HEAD SATURATION PRESSURE
(25°F/HR COOLDOWN)



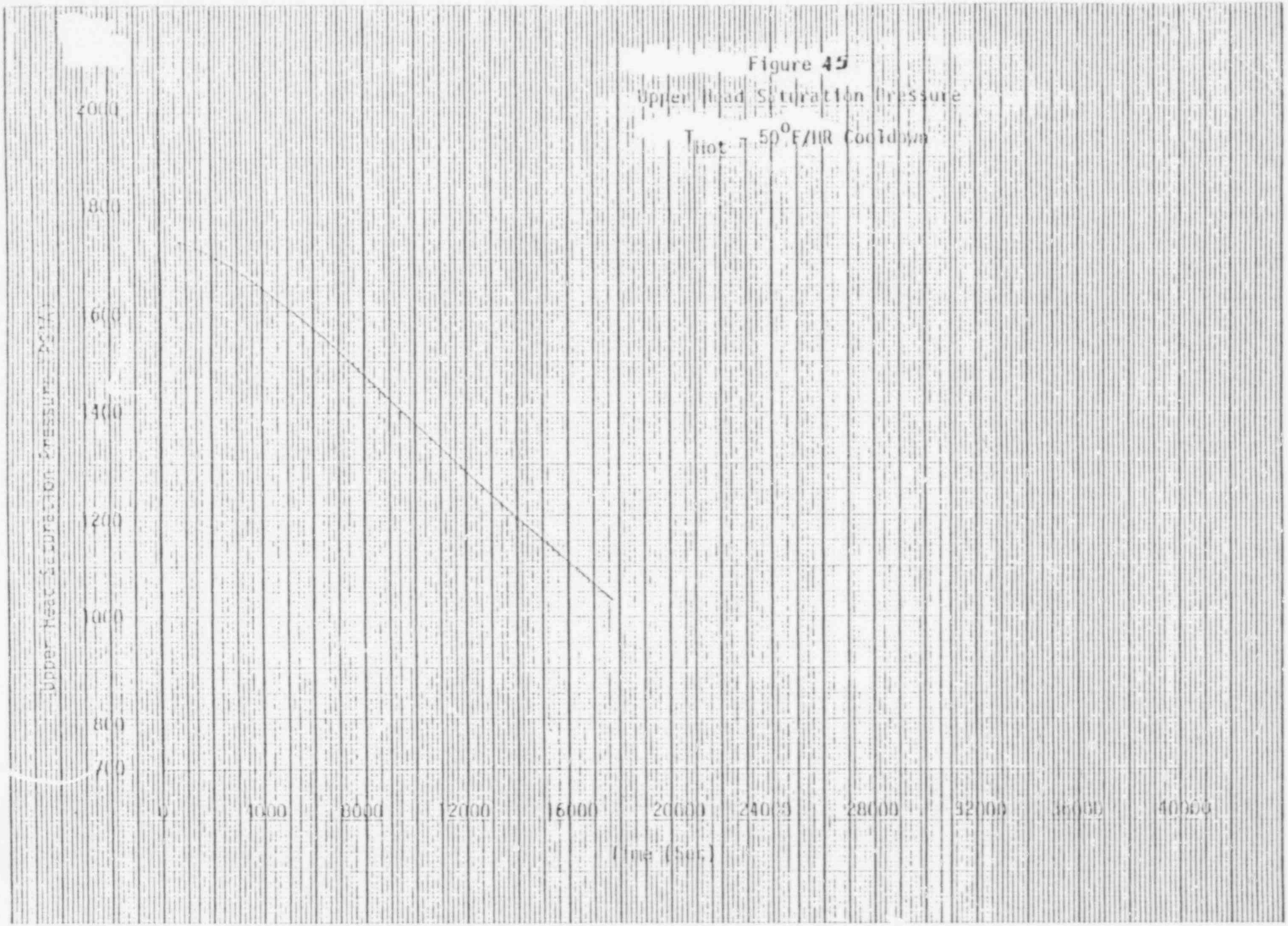


Figure 45

Upper Head Saturation Pressure

T_{hot} = 50°F/HR Cooldown

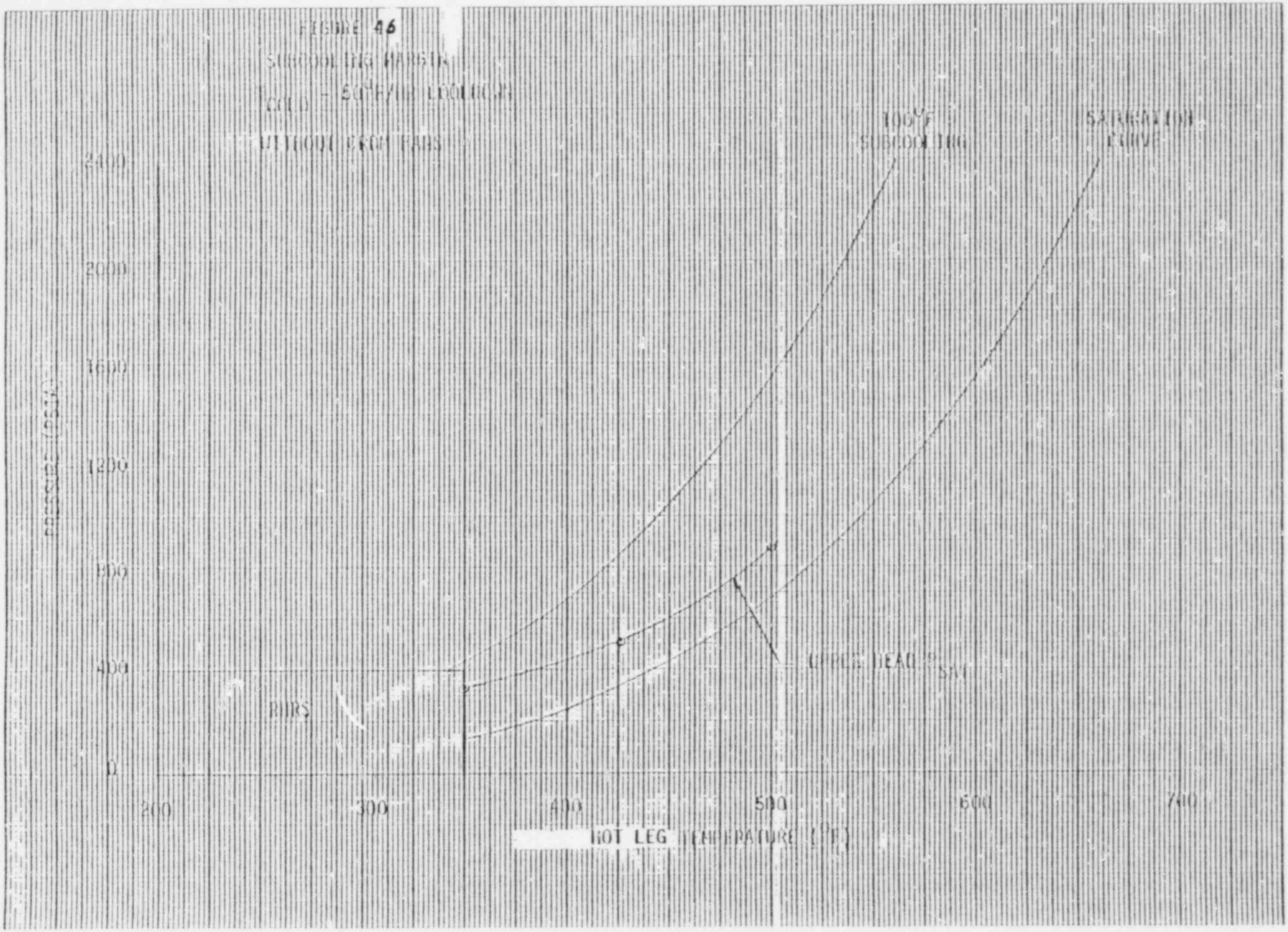


FIGURE 46
SUBCOOLING MARGIN
COLD - 50°F/HR COOLDOWN
WITHOUT CRDM FANS

K-E 10 X 10 TO THE CENTIMETER 18 X 25 CM
KEUFFEL & ESSER CO. MADE IN U.S.A.

46 1510

FIGURE 47

SUBCOOLING MARGIN

ΔT = 25°F/HR COOLDOWN

(1000 GPM BREAK)

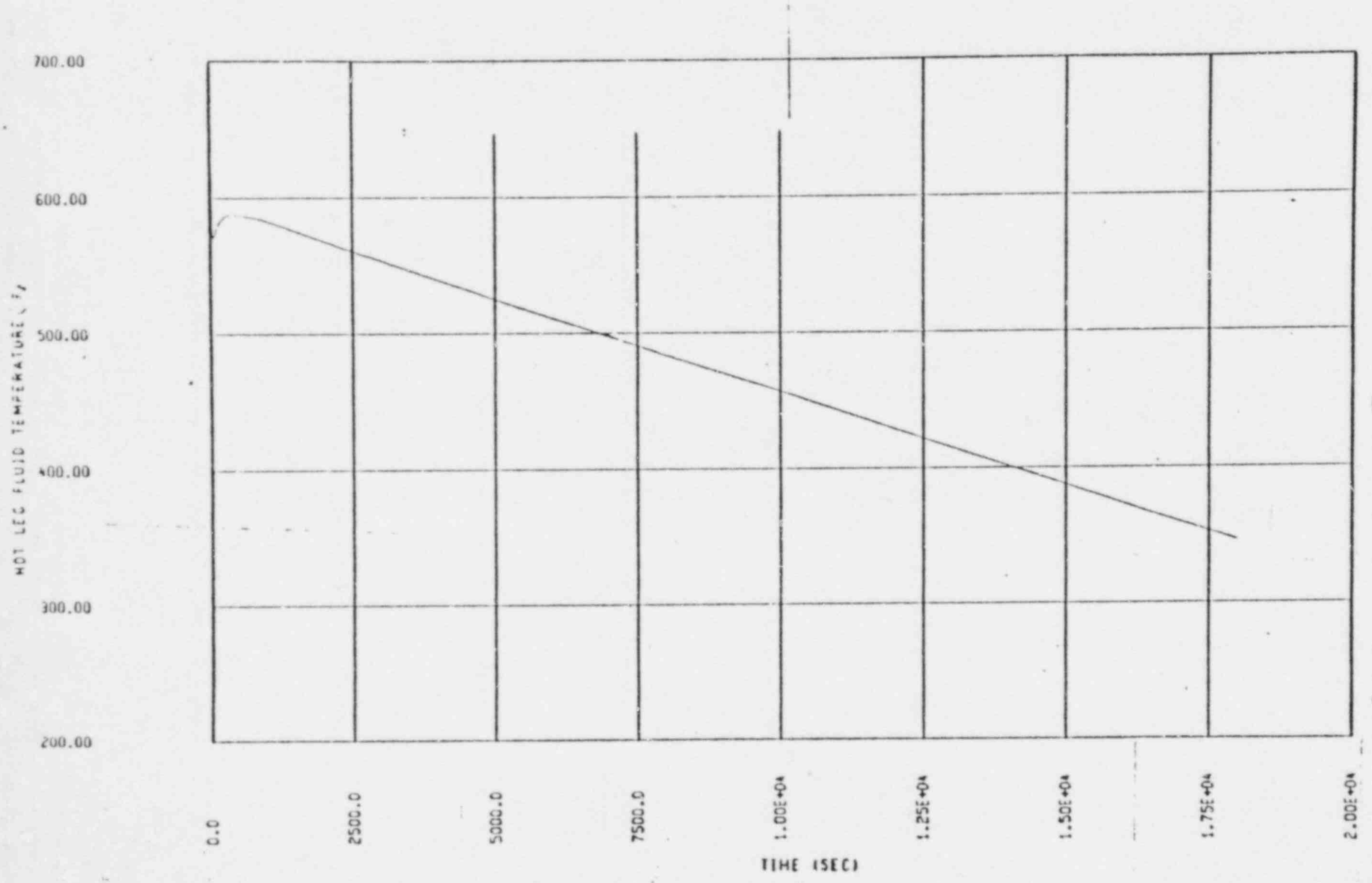


FIGURE 5

HOT LEG FLUID TEMPERATURE
T_{COLD} - 50°F/HR COOLDOWN

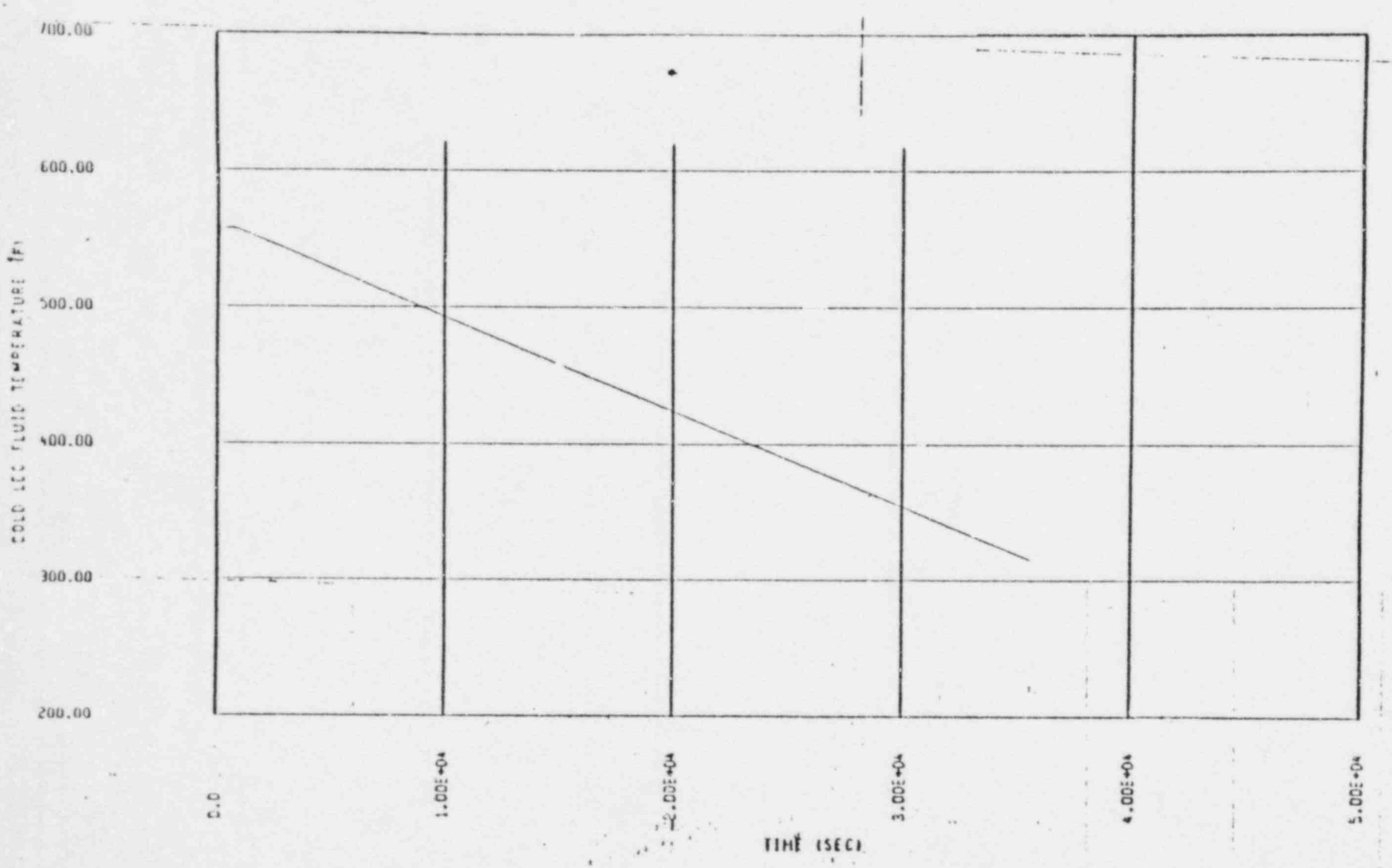


FIGURE 6

COLD LEG FLUID TEMPERATURE

T_{COLD} - 25°F/HR COOLDOWN

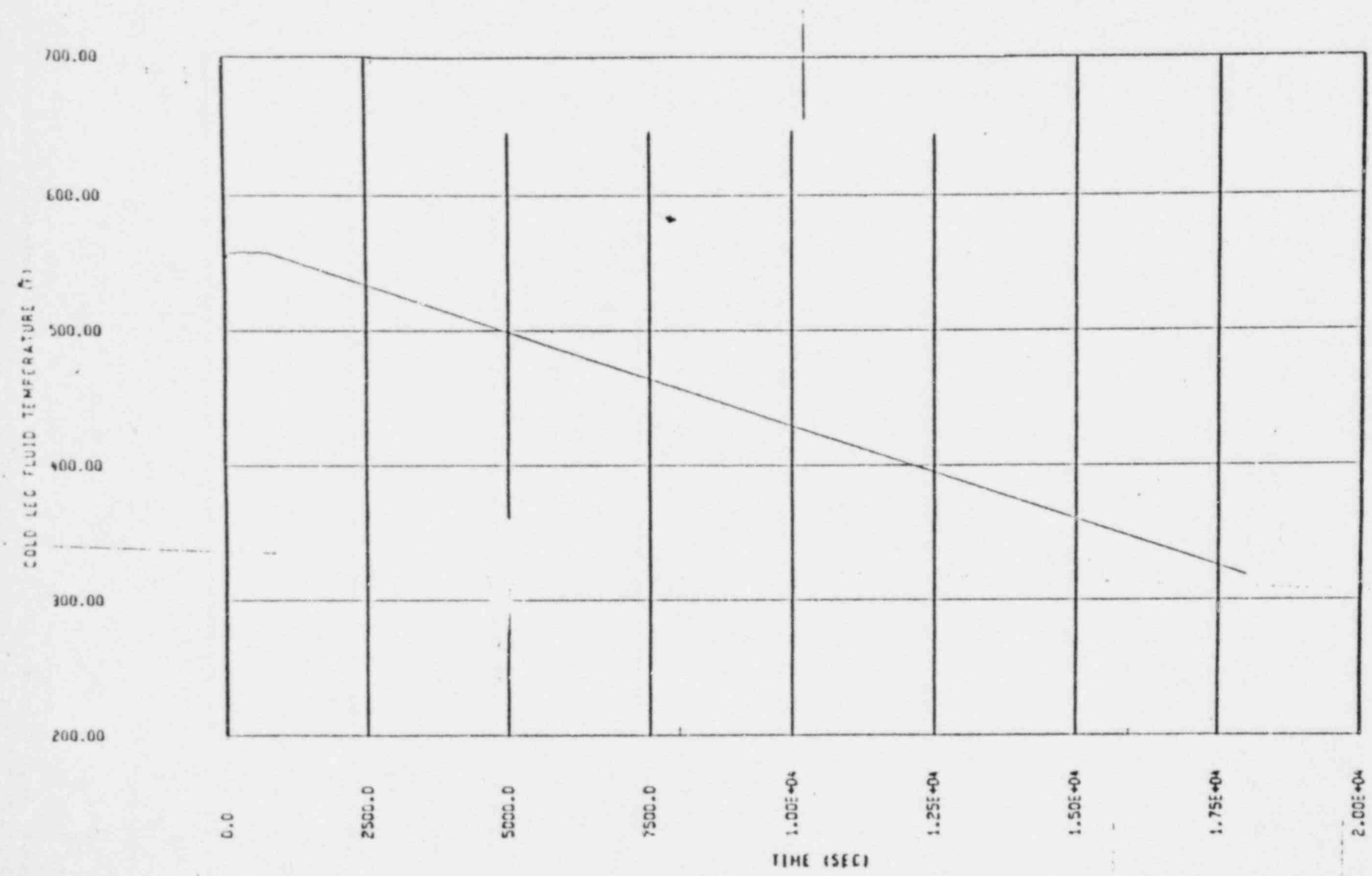


FIGURE 7

COLD LEG FLUID TEMPERATURE

T_{COLD} - 50°F/HR COOLDOWN

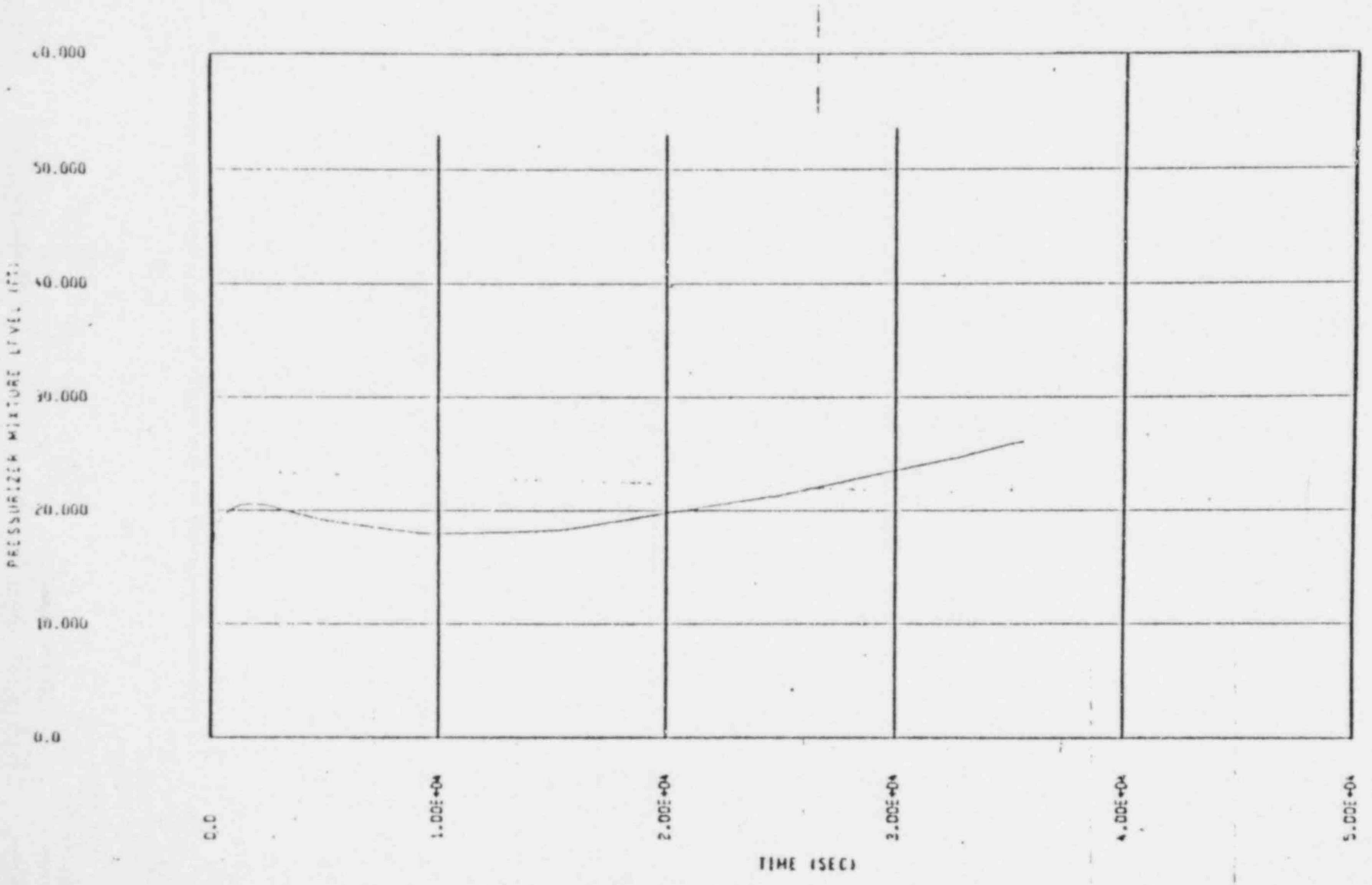


FIGURE 8

PRESSURIZER MIXTURE LEVEL
T_{COLD} - 25°F/HR COOLDOWN

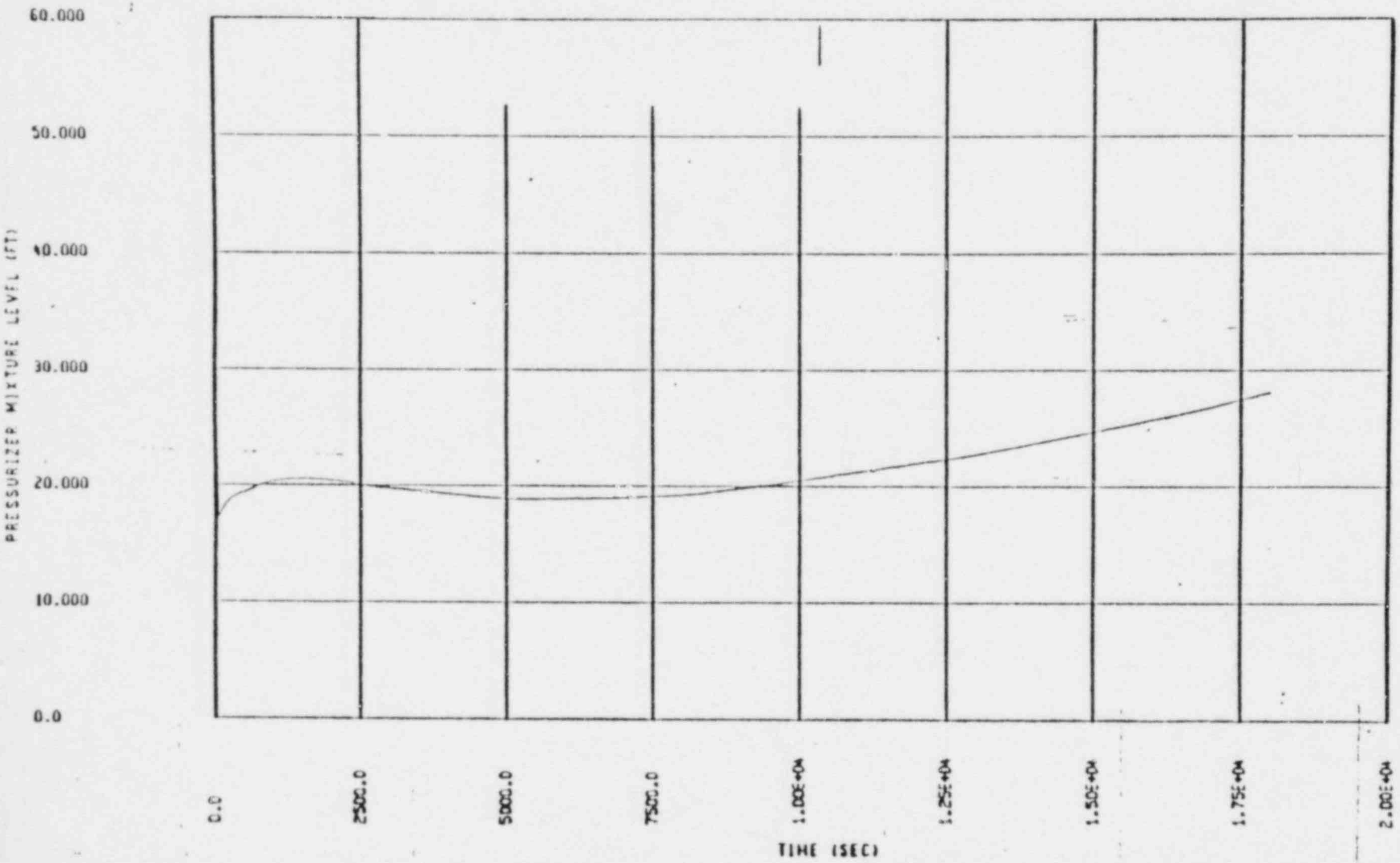


FIGURE 9

PRESSURIZER MIXTURE LEVEL
T_{cold} - 50°F/HR COOLDOWN

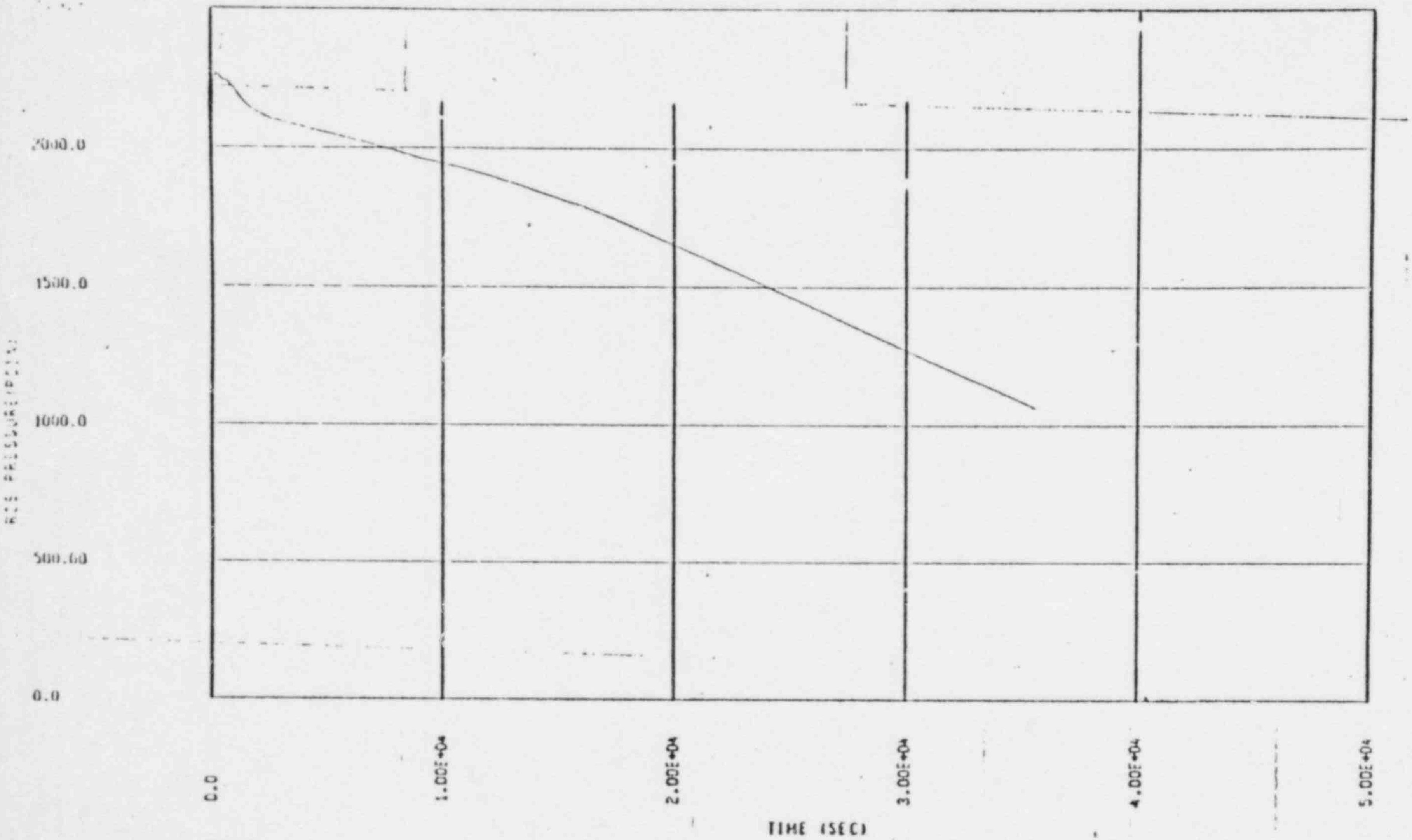


FIGURE 1D

PRIMARY SYSTEM PRESSURE
T_{COLD} - 25°F/HR COOLDOWN

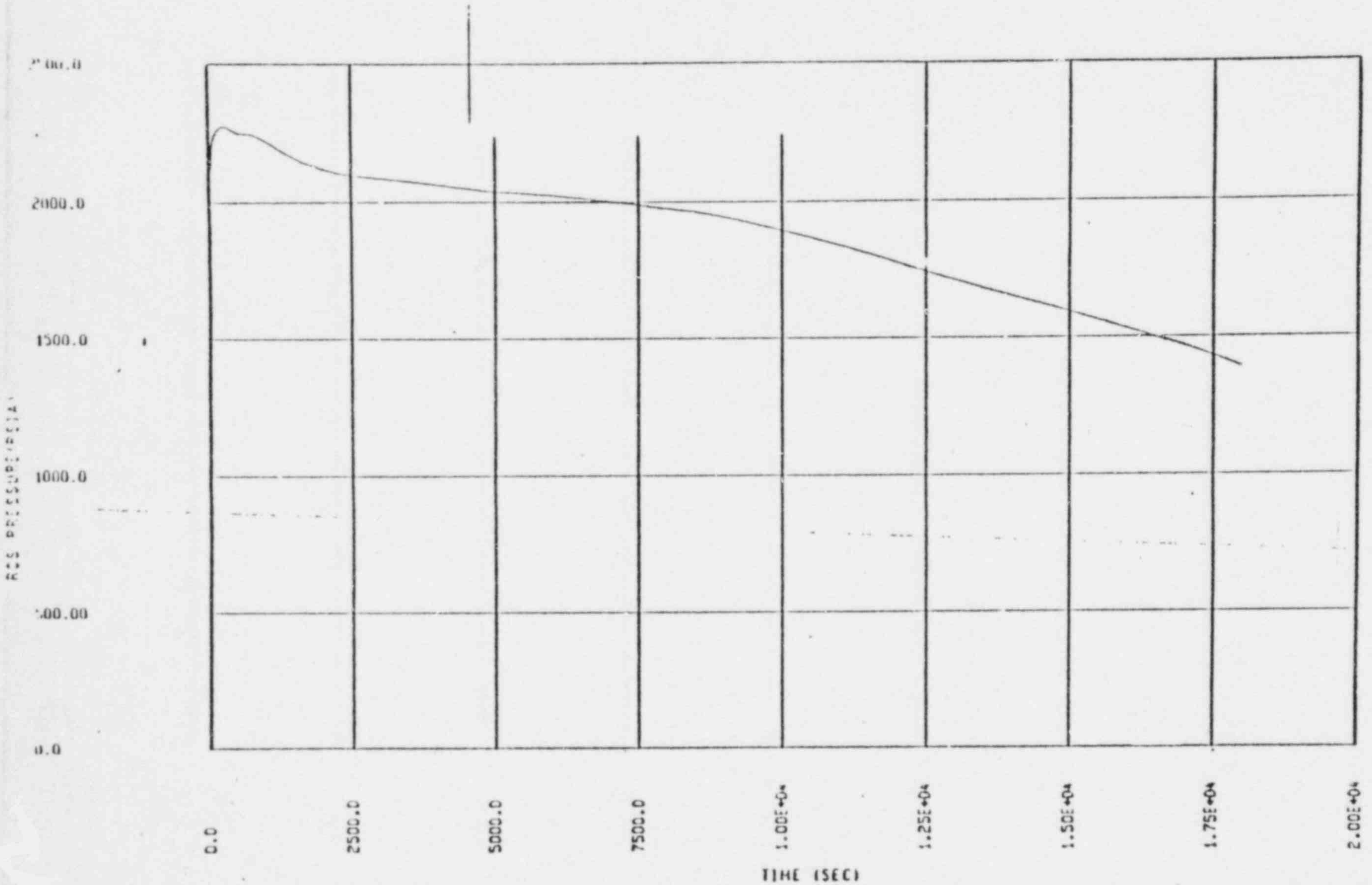


FIGURE 11

PRIMARY SYSTEM PRESSURE
T_{COLD} - 50°F/HR COOLDOWN

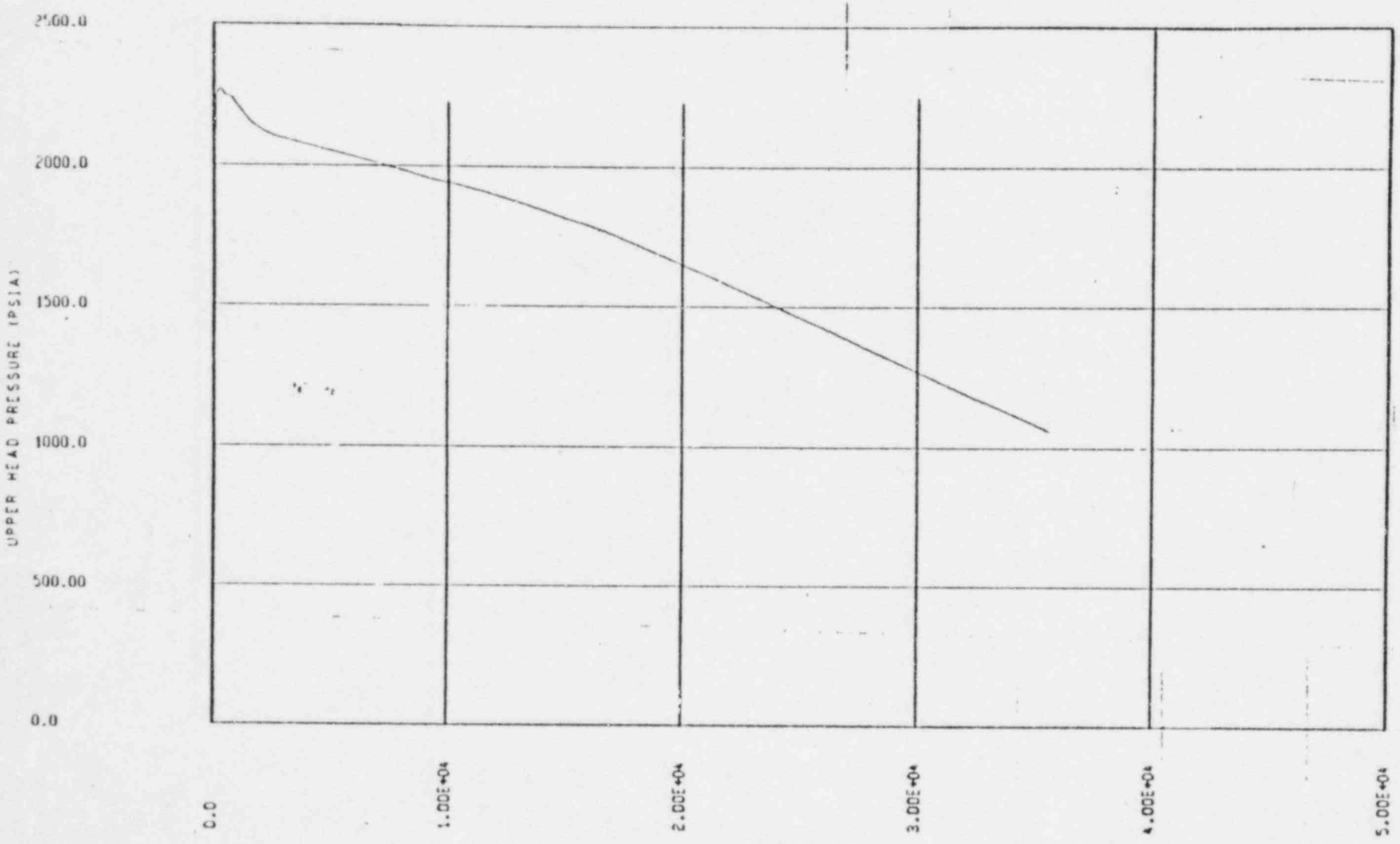


FIGURE 12

UPPER HEAD PRESSURE
T_{COLD} - 25°F/HR COOLDOWN

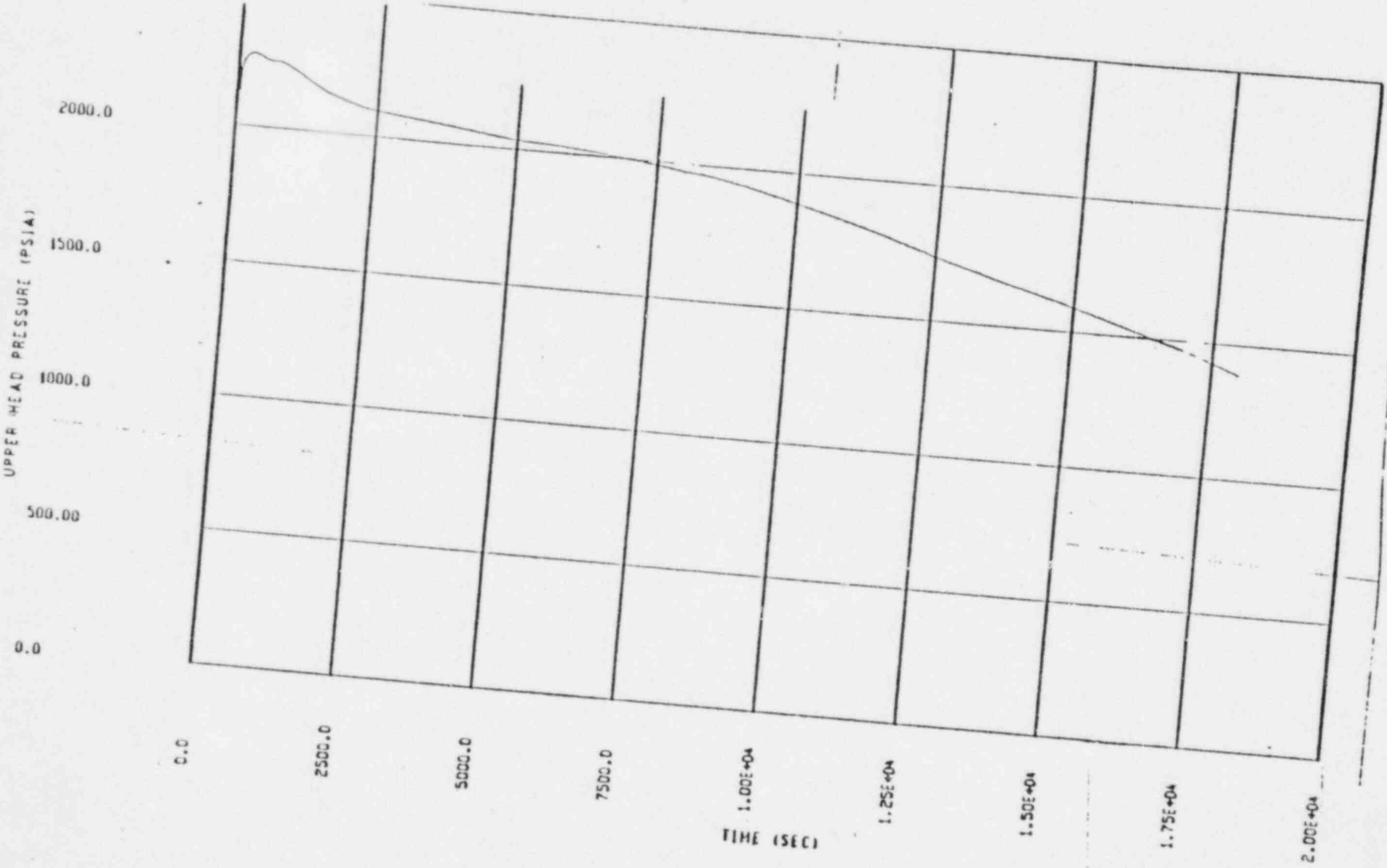


FIGURE 13

UPPER HEAD PRESSURE
T_{COLD} - 50°F/HR COOLDOWN

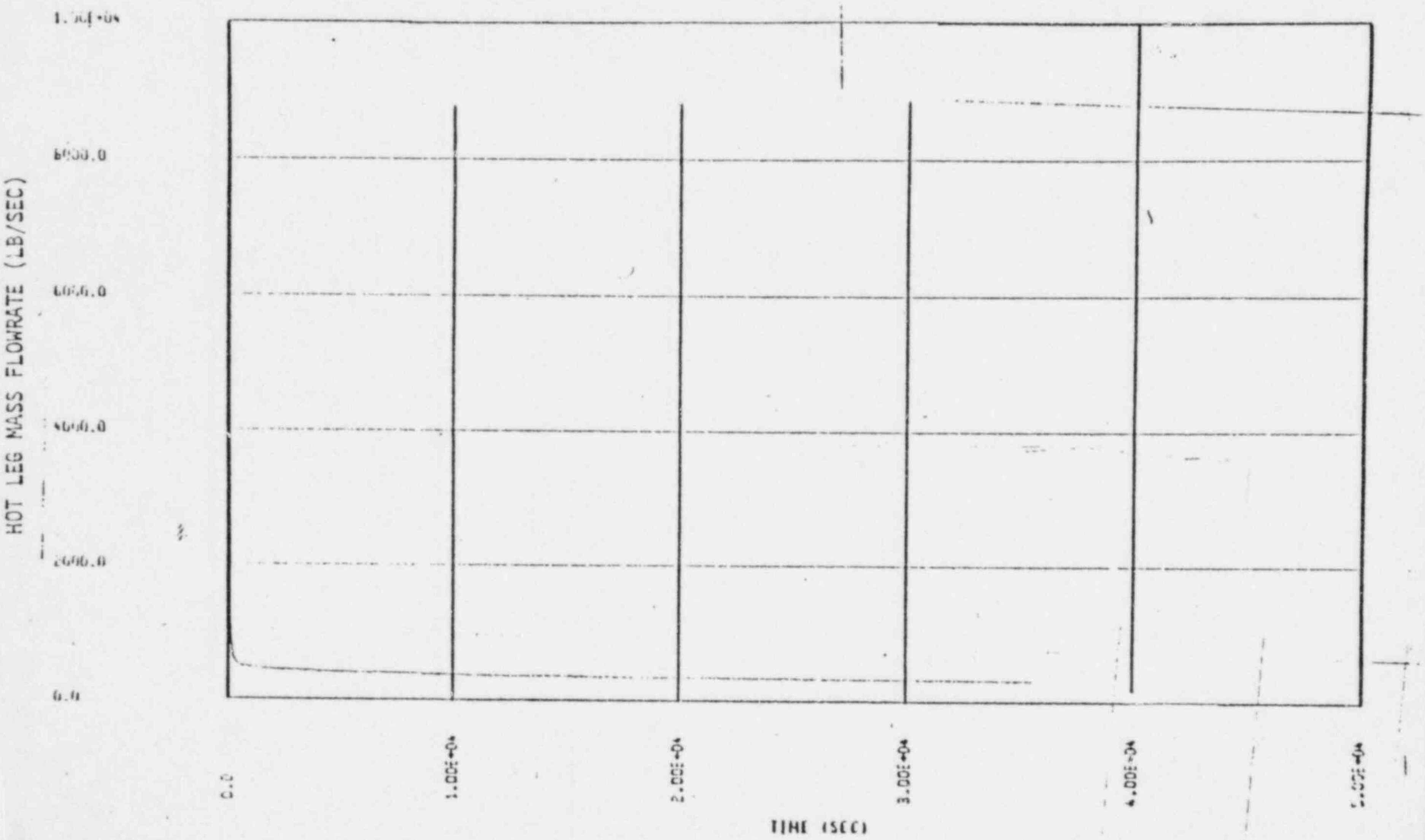


FIGURE 14

HOT LEG MASS FLOWRATE
T_{COLD} - 25°F/HR COOLDOWN

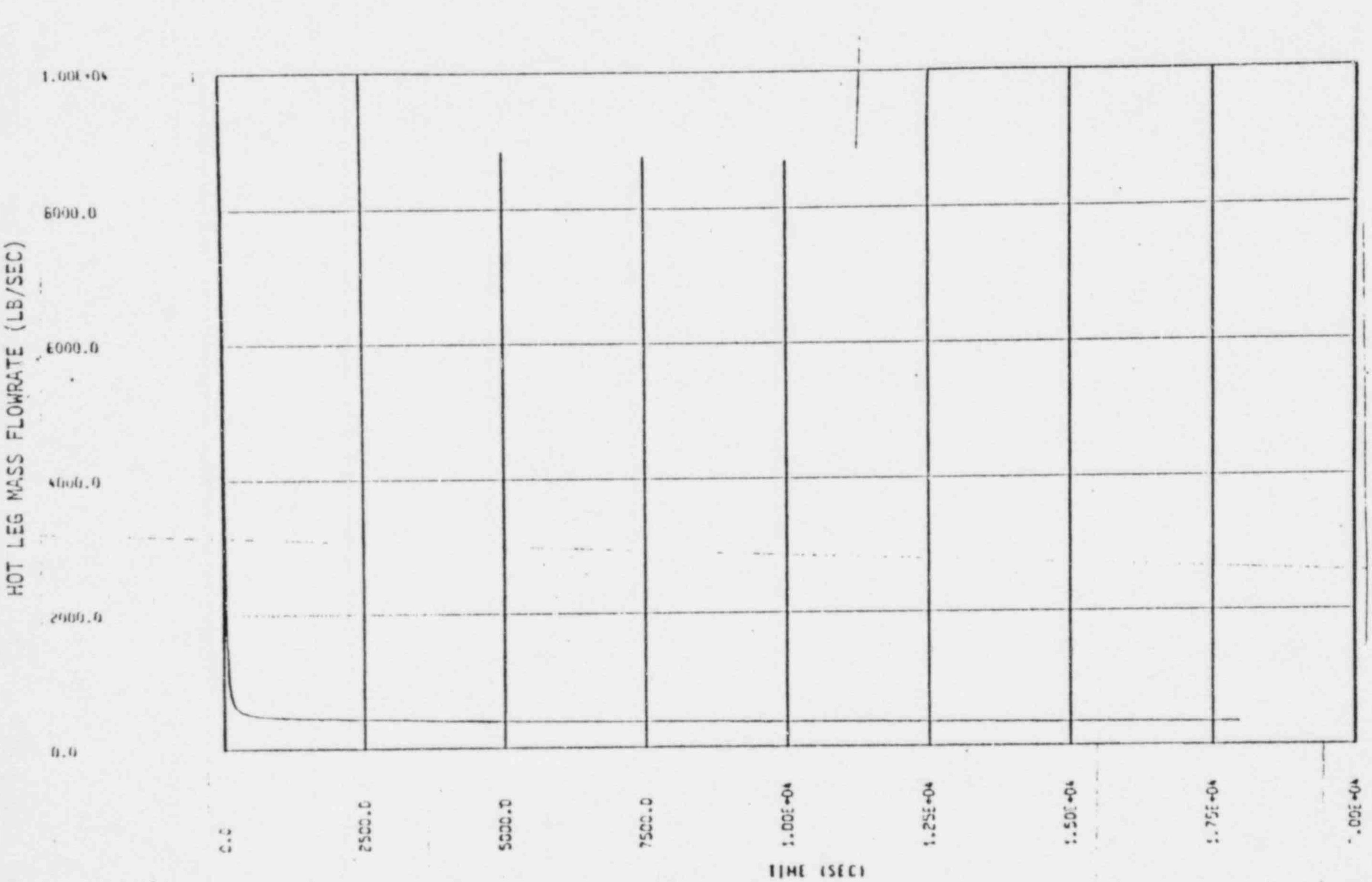


FIGURE 15

HOT LEG MASS FLOWRATE
T_{COLD} - 50°F/HR COOLDOWN

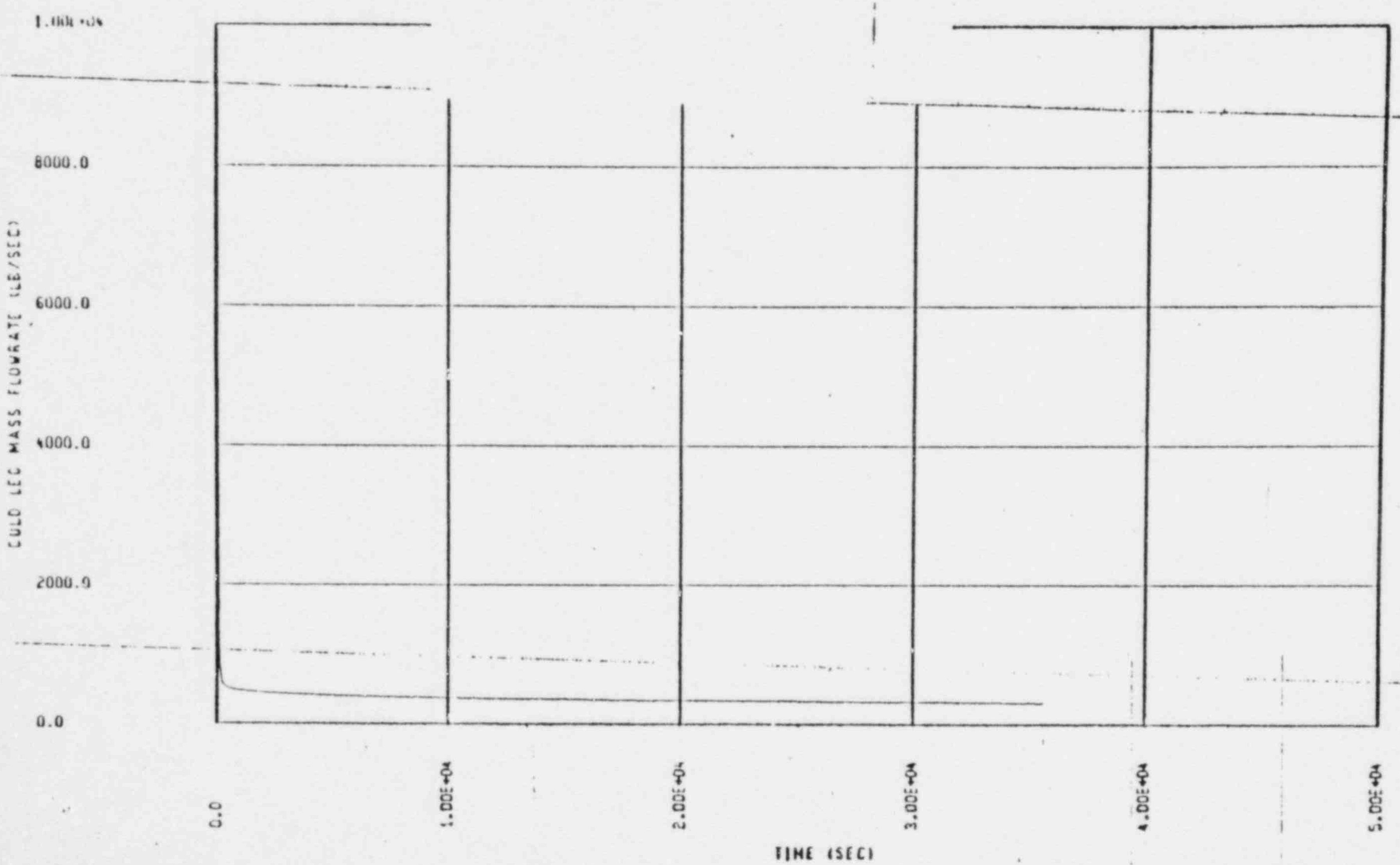


FIGURE 16

COLD LEG MASS FLOWRATE
T_{COLD} - 25°F/HR COOLDOWN

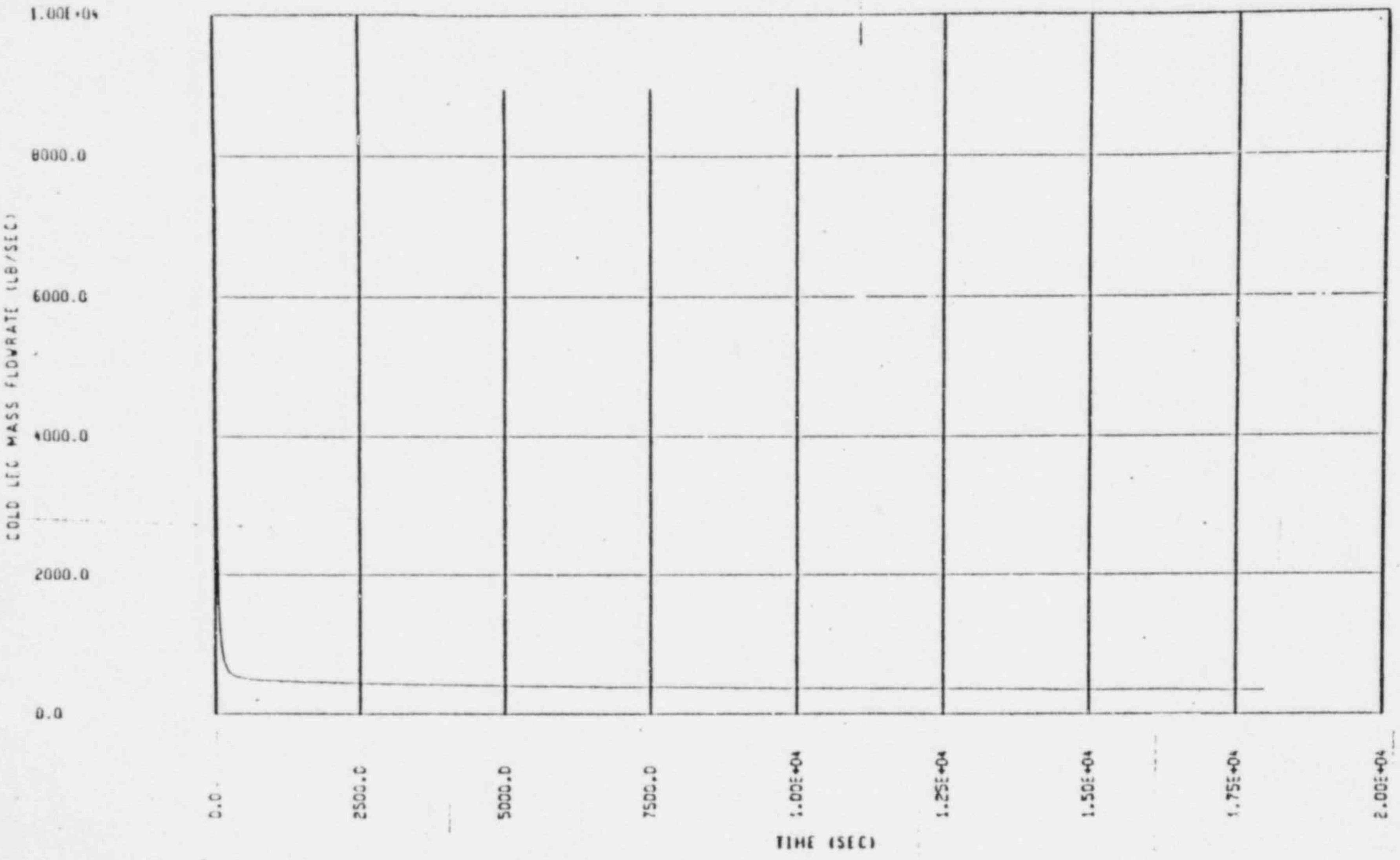


FIGURE 17

COLD LEG MASS FLOWRATE
T_{COLD} - 50°F/HR COOLDOWN

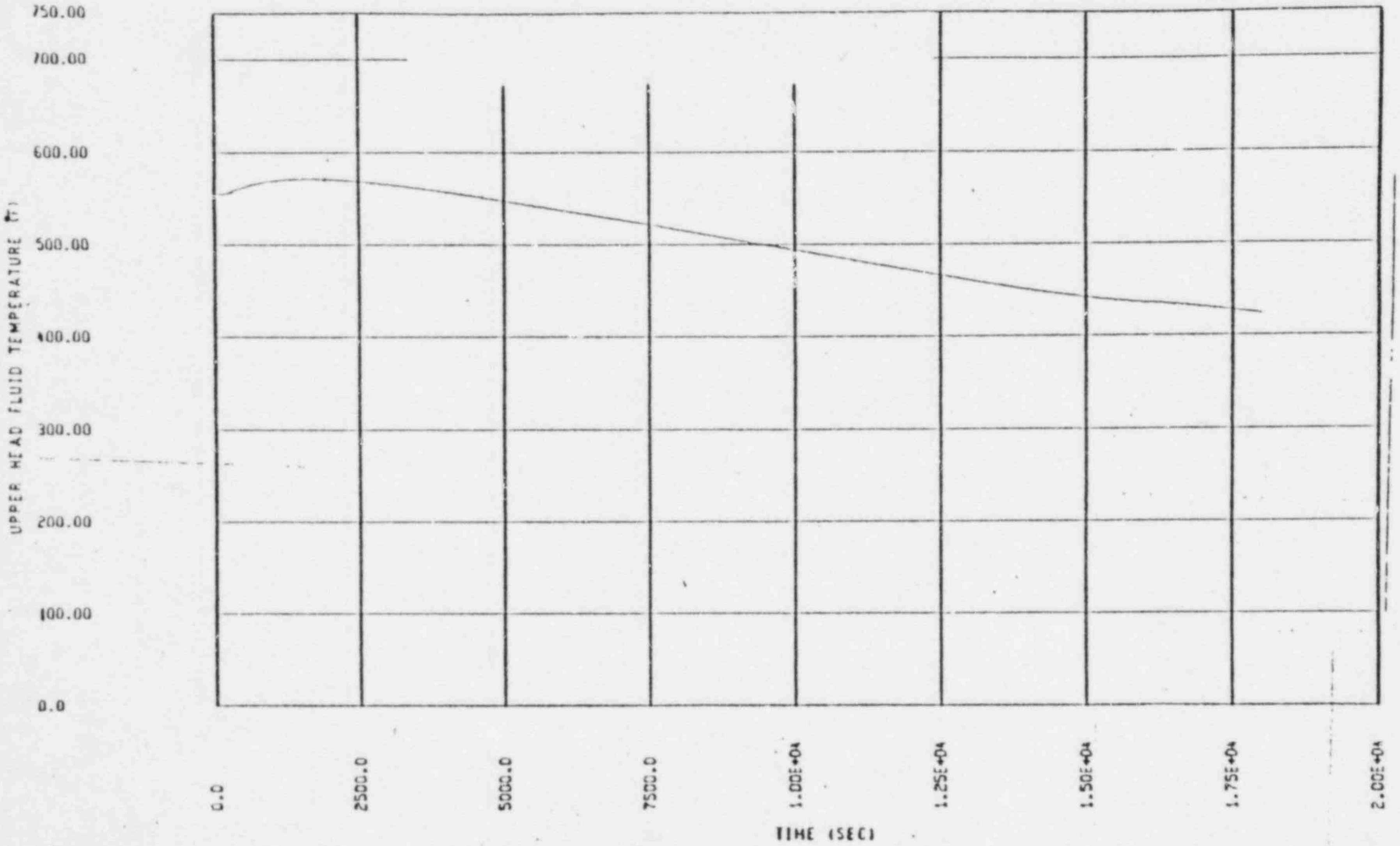


FIGURE 21

UPPER HEAD FLUID TEMPERATURE
T_{COLD} - 50°F/HR COOLDOWN

K+E 10 X 10 TO THE CENTIMETER 18 X 25 CM
KEUFFEL & ESSER CO. MADE IN U.S.A.

461510

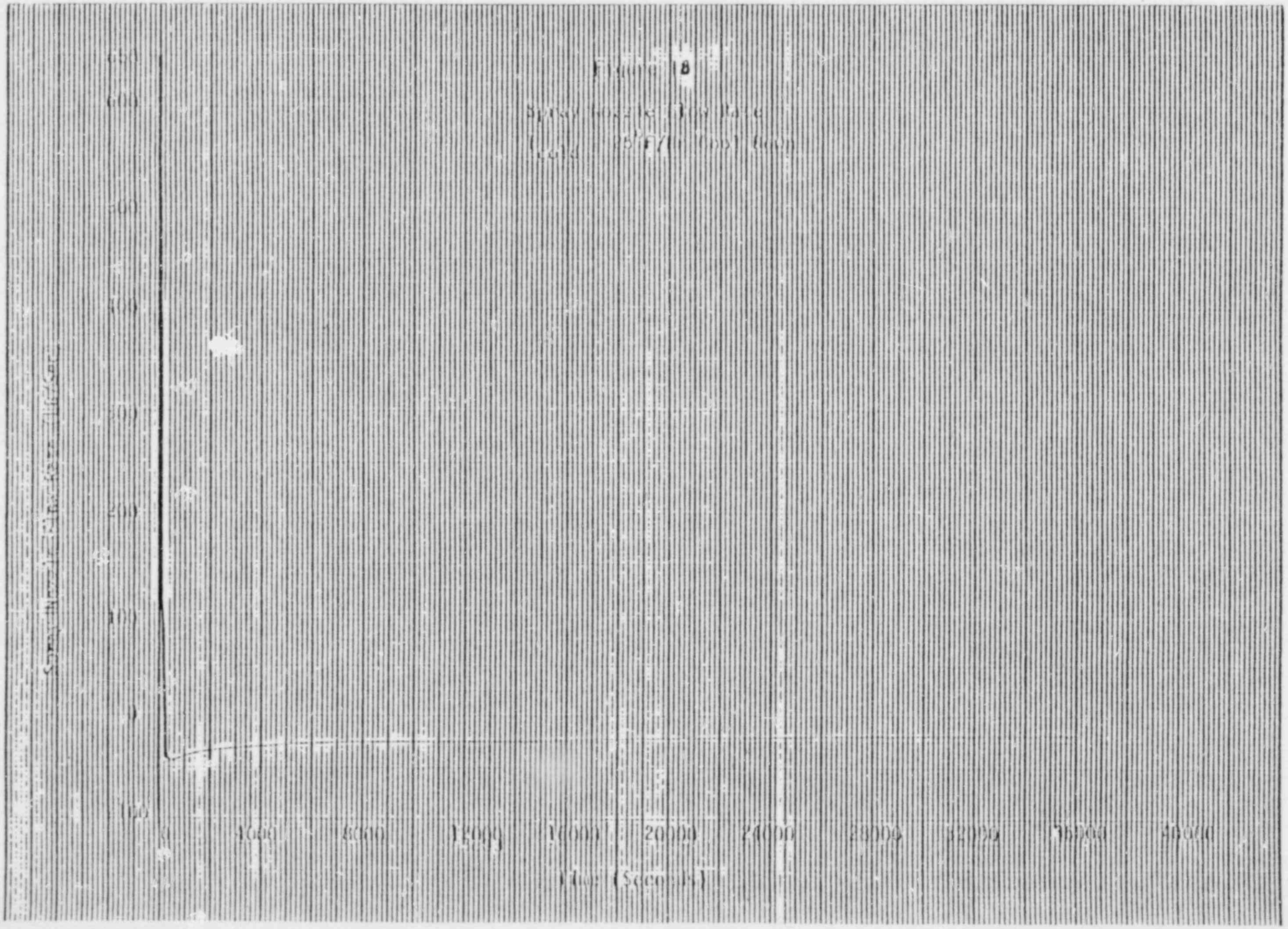


Figure 18

Spray Nozzle Flow Rate

(Cold 25°F/hr Cool Down)

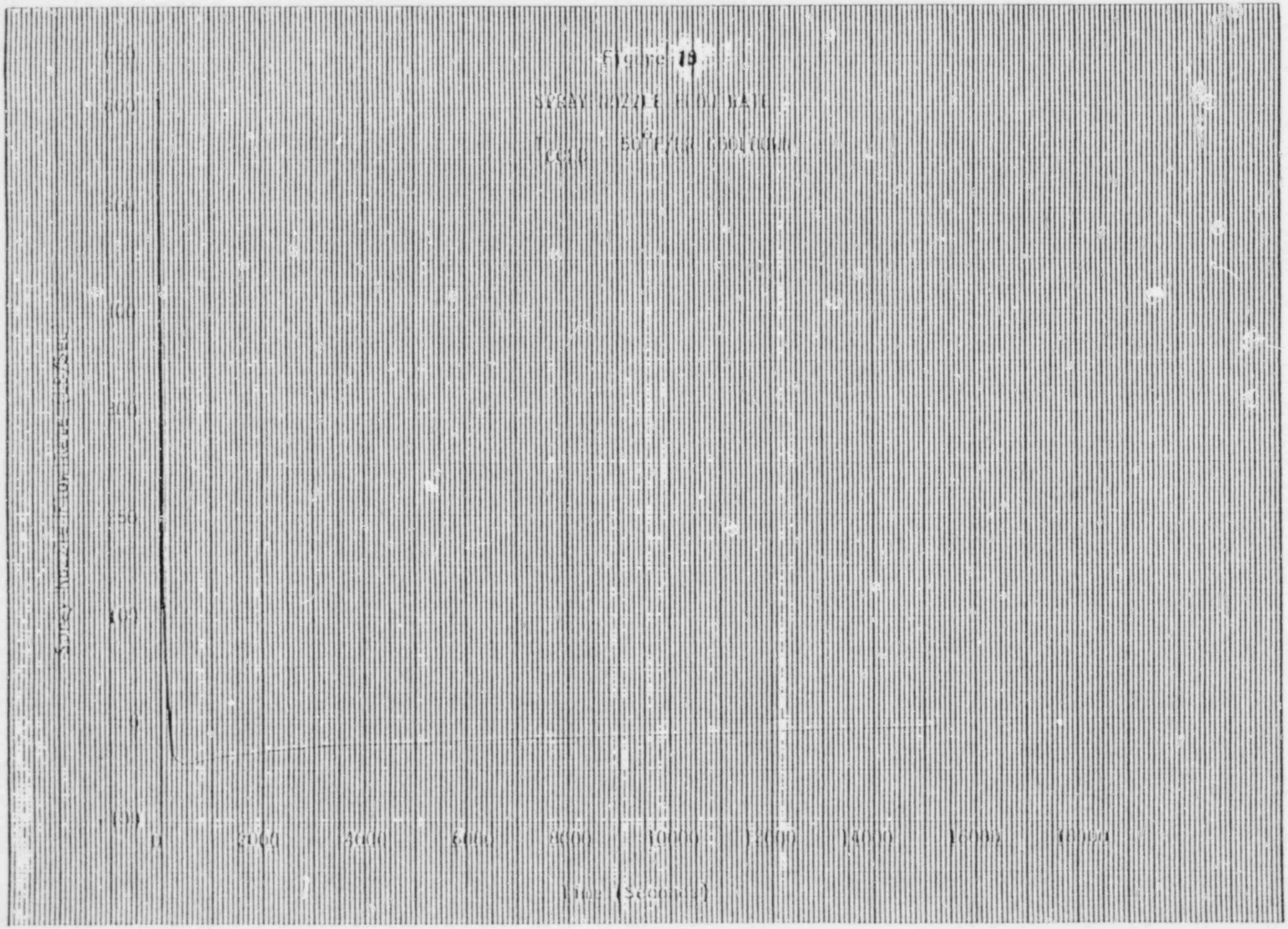


Figure 19

SPRAY NOZZLE FLOW RATE

LOCA [illegible]

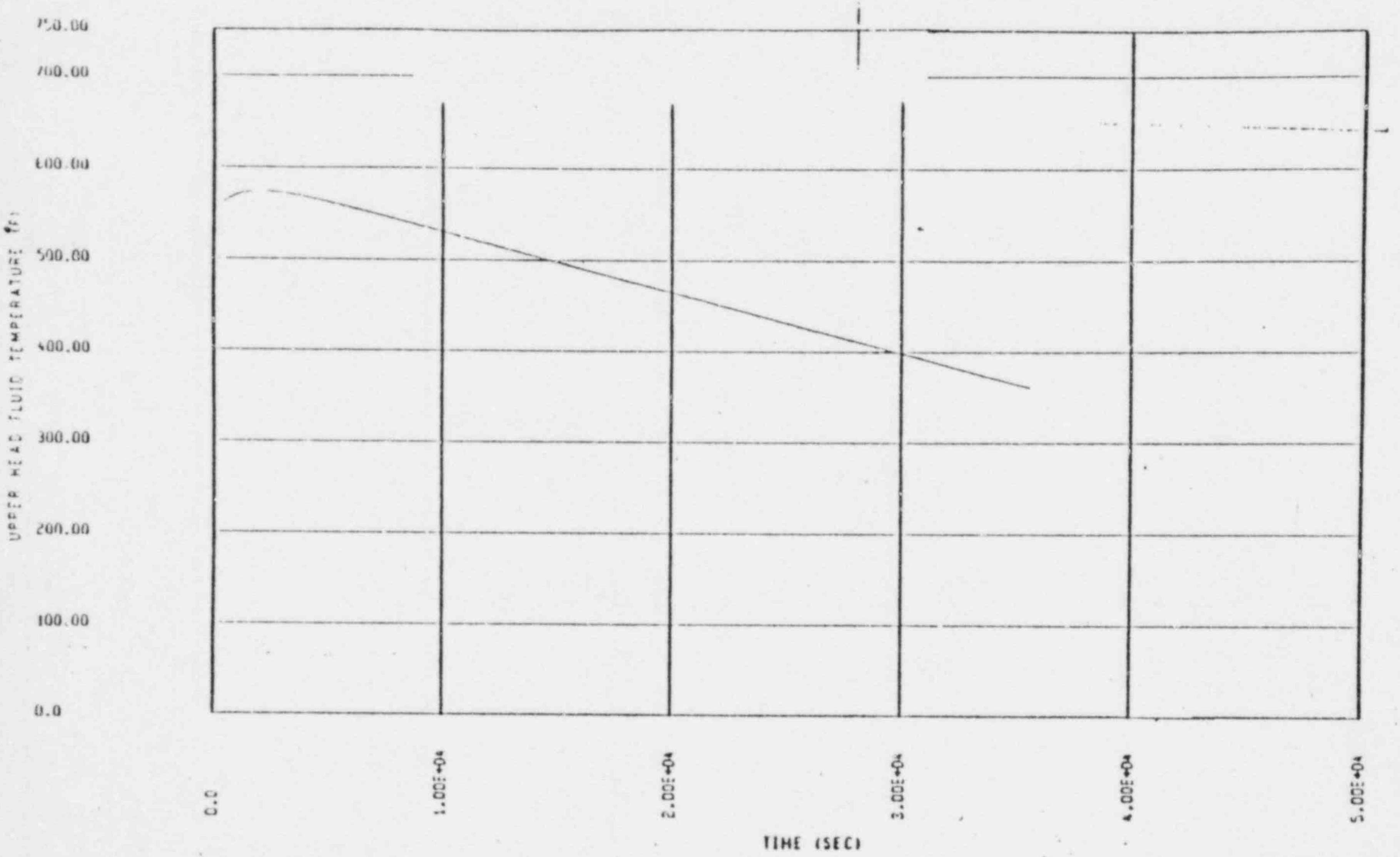


FIGURE 20

UPPER HEAD FLUID TEMPERATURE

T_{COLD} - 25°F/HR COOLDOWN

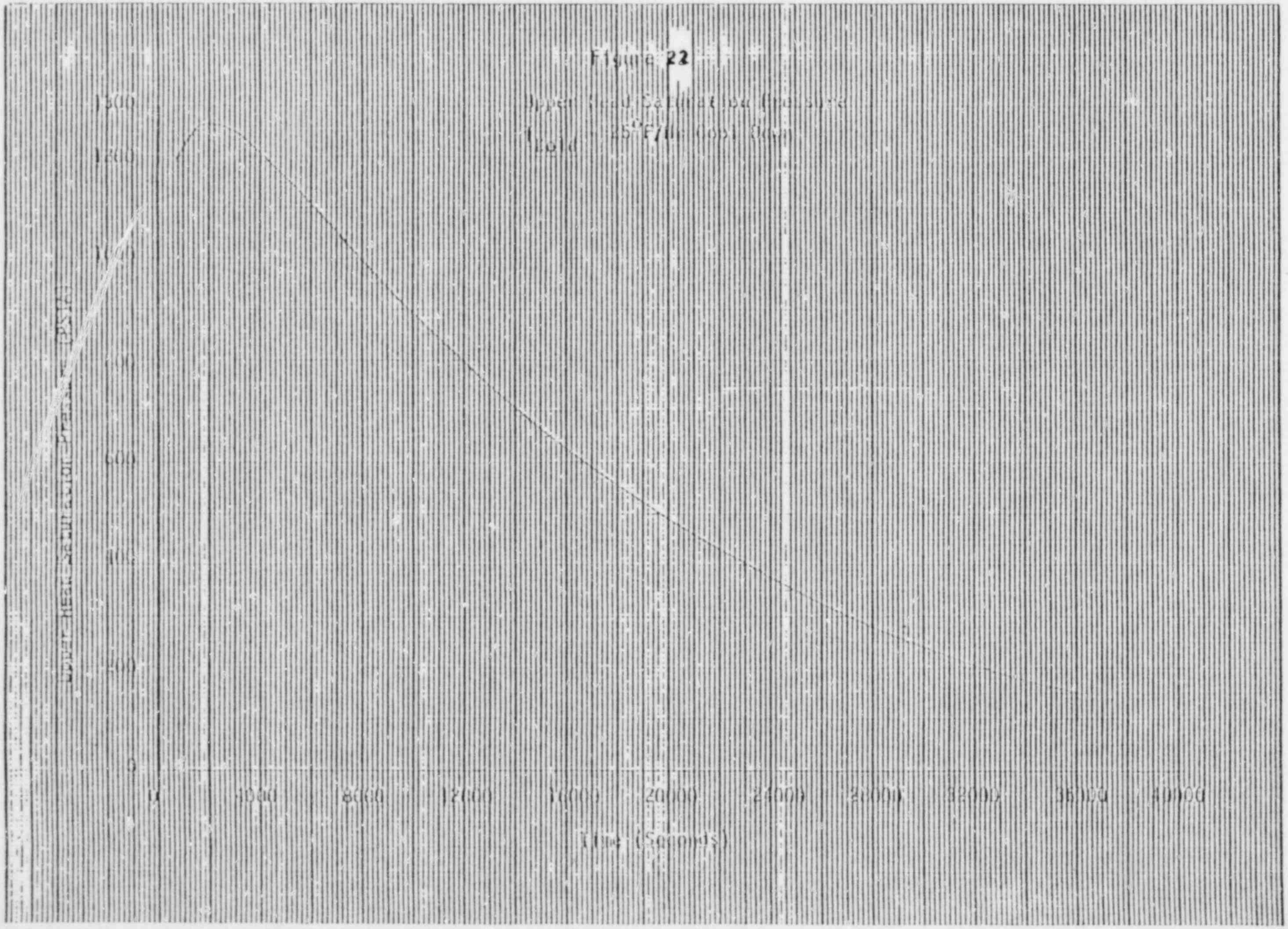


Figure 22

Upper Head Saturation Pressure

(T_cold = 25°F/hr Cool Down)

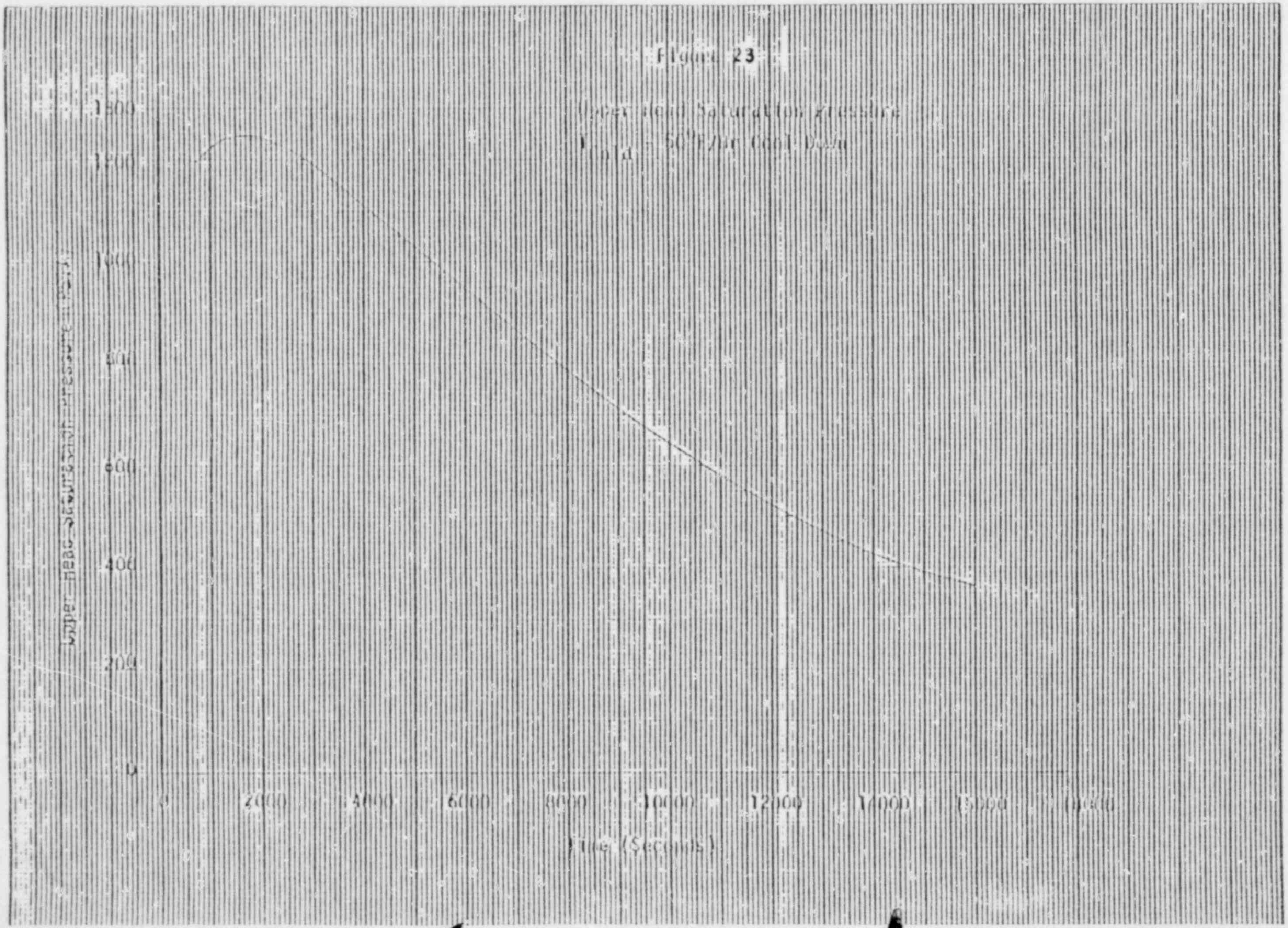


Figure 23

Upper Head Saturation Pressure

Mode A - 50°F/hr Cool Down