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Davis Besse
Continuous RV
Head Vent
Design Evaluation
Report

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1.0 Introduction

A continuous reactor vessel head vent design was suggested for the Toledo Edison, Davis Besse Plant as a possible alternative to a RV head level measurement system and the more standard type vent to the reactor building atmosphere. A passive vent path from the reactor vessel upper head region to the top of the steam generator (SG) would act to transfer non-condensible gases and/or steam, which could accumulate in the RV head to the upper region of one of the two hot legs. In the hot leg, the non-condensible gases, and the steam which was not condensed in the flow stream, could be observed and monitored utilizing the full range hot leg level monitoring system. The non-condensible gases could then be vented from the RCS through the hot leg vents.

If the RV head vent line is sized with adequate flow capacity, steam and non-condensible gas accumulations in the RV head would be minimized. Such a continuous vent system would seem to obviate the need for a RV head level measurement system since any steam and non-condensible gases which did form would be quickly and effectively moved to the hot leg region.

In addition to the benefits described above, a continuous RV head vent system could greatly enhance the cooldown of the reactor vessel head. During natural circulation flow conditions, the expected flow and mixing in the RV head are substantially reduced from that during forced flow resulting in the hot stagnant fluid collecting in the upper regions of the RV head. This upper head trapped fluid can inhibit a normal natural circulation cooldown by flashing during RCS depressurization to the decay heat system cut-in pressure and thereby interfering with the normal pressurizer pressure control. A continuous RV head vent will promote increased flow and mixing of the RV head fluid, and should yield a more uniform cooldown of the RV head metal. This will not only allow a more rapid natural circulation depressurization under normal conditions, but

will also provide a means for effectively removing and condensing the steam bubble which could form in the head during a controlled rapid cooldown and depressurization (e.g. following the steam generator tube rupture ATOG procedure).

This document summarizes the results of an evaluation to quantify the operational benefits of a continuous RV head vent design concept. In particular, the following aspects of this design are addressed:

- Vent line flow rates during forced flow and natural circulation conditions, and non-condensible gas bubble removal rates.

- RV head liquid cooling during normal natural circulation.

- RV head steam bubble generation and removal rate during a controlled rapid RCS depressurization and cooldown.

- Preliminary evaluation of potential impact on FSAR accident analyses.

2.0 Summary

An evaluation was performed of a RV head vent design concept which would provide a continuous flow path from the RV head to the hot leg flow stream at the SG upper plenum. The evaluation focused on the functional characteristics of this design with the intent of quantifying the operational benefits and identifying any potentially significant concerns associated with its implementation.

The results of the analyses performed to evaluate the functional aspects of the continuous RV head vent design were compared to pre-established functional design criteria. All of these design criteria were met, as described below, for a RV head vent line of 2-1/2 inch SCH 160 piping.

- Vent line flowrates during a normal natural circulation cooldown are sufficient to allow cooldown of the fluid in the RV head, assuming reasonable mixing, to below the saturation temperature at the Decay Heat Removal System (DHRS) cut-in pressure in approximately 12 hours without steam formation in the RV head. This easily satisfies the 36 hour criterion for this type of cooldown.

- Vent line flowrates during a controlled rapid RCS depressurization and cooldown with natural circulation flow are sufficient to permit cooldown and depressurization from post trip RCS conditions to approximately 1000 psig and 500°F in less than 30 minutes without the steam bubble expanding out of the RV head. The steam bubble, which did form during the final depressurization phase, was smaller than that which occured with no RV head vent, and was effectively dissipated through the vent after the depressurization was terminated. The primary acceptance criteria for this event was easily satisfied since the RV head steam bubble did not progress out the RV outlet nozzles.

- An RV head volume of non-condensible gas can be vented to the upper hot leg region within 10 minutes, which is well within the 30 minute target time criterion.

The Davis Besse Chapter 15 FSAR analyses were reviewed as part of the evaluation effort to identify the potential impact of a continuous RV head vent design on these events. No significant impact is anticipated. Although the addition of the vent may affect the timing of events during certain small break LOCA's which result in interruption of natural circulation, the basic results and their acceptability should not be significantly impacted. These effects can be quantitatively addressed when plant specific analyses are performed in accordance with NUREG-0737, Section II.K.3.31.

This design evaluation effort has shown that a continuous RV head vent design as proposed for Davis Besse provides many desirable operational features.

- It is passive and requires no operator action to place it in service.

- Its steam flow capacity will help minimize bubble accumulation in the RV head region by venting it to the hot leg flow stream where the steam can be condensed.

- Non-condensible gases will be quickly and effectively transferred to the upper hot leg where they can be vented from the RCS through the hot leg vents.

- RV head cooling during natural circulation flow conditions will be markedly improved without losing RCS inventory.

In summary, the continuous RV head vent design concept has considerable advantage over a conventional type vent to the reactor building atmosphere. In addition, its non-condensible gas and steam flow capacity is such that significant bubble accumulation would not be expected in the RV head for any substantial period of time. An RV head level measurement should, therefore, not be needed if this continuous RV head vent design is implemented.

3.0 Design Criteria for Continuous RV Head Vent Line

The following general and functional design criteria were developed for the continuous RV head vent line design concept. The general design criteria provide basic RV head vent system design requirements. The functional design criteria are the primary performance criteria for judging the acceptability of the design and defining some of the key hardware design specifications (e.g., minimum line size). Also identified in the functional design criteria are limitations regarding the effect of the RV head vent on Chapter 15 accident analyses.

An evaluation of the continous RV head vent design concept with respect to the functional design criteria is the scope of this document.

3.1 General Design Criteria

A. The addition of an RV head vent shall not increase the probability of interrupting natural circulation flow in both hot legs. The vent line will be connected to the loop with the pressurizer to satisfy this criterion.

B. The RV head vent shall be designed to accommodate flow in either direction.

C. RV head vent system connections to the RCS shall use existing penetrations.

D. Pipe routing from the RV head vent shall, to the maximum extent possible, be sloped continuously upward to prevent the formation of traps.

E. All pressure boundary RV head vent piping shall be designed to ASME Section III, Class 1 criteria and be supported in such a manner that any stress due to weight, thermal transients, internal piping conditions and external environment will be within the maximum allowable stresses at the existing vent nozzles. In addition, the line shall be routed and supported to avoid

significant subsequent impairment of the intended design functions of essential systems and components from pipe whip, jet impingement, and missiles following a postulated RV head vent line break.

F. RV head vent piping shall be thermally insulated to:

a. Provide piping protection
b. Reduce heat losses
c. Minimize piping stresses
d. Provide personnel protection
e. Increase driving head for vent flow

The insulation shall be sufficient to ensure that ambient losses to the reactor building during natural circulation will not adversely affect vent line performance.

G. The RV head vent line shall be designed for convenient dismantling during refueling.

H. Vent Piping shall be designed for 2500 psig and 650°F and any gaskets or seals shall be compatible with all anticipated fluids and gases. This includes RCS water, saturated steam, steam water mixture, superheated steam, fission product gases, helium, nitrogen and hydrogen.

3.2 Functional Design Criteria

o The RV head vent system design shall have sufficient liquid flow capability through the RV upper head region during a normal RCS natural circulation cooldown that such a cooldown can be achieved within 36 hours without steam formation in the RV head.

- The RV head vent system design shall have sufficient steam flow capability during a rapid RCS cooldown/depressurization that the RCS can be depressurized to 1000 psig within approximately 15 minutes without the steam bubble in the RV head expanding to the level of the hot leg nozzles. This assumes a controlled transient consistent with ATOG guidelines for SG tube rupture with no RC pumps operating.

- The RV head vent system design shall have sufficient noncondensible gas flow capability that an assumed RV head volume of gas can be vented to the upper hot leg region within 30 minutes.

- The addition of an RV head vent shall not significantly affect Chapter 15 accident analysis results to where resubmittal of any of these analyses would be required.

4.0 Analysis Methods, Assumptions and Results

4.1 Continuous RV Head Vent Line Flow

4.1.1 Vent Line System Description

The continuous RV head vent line design evaluated for Davis Besse is shown in Figure 1. A currently unused control rod drive (CRD) mounting nozzle would serve as the connection point on the RV head. This CRD nozzle is located 27.2 inches from the center nozzle. From the CRD mounting flange, a 4 inch ID pipe was assumed for the vent path to just above the top of the service structure. From this point, vent line sizes of 1-1/2 and 2-1/2 inch schedule 160 pipe were evaluated to the hot leg flow stream connnection at the upper plenum of the steam generator. The connection at the steam generator would be at an existing 5 inch diameter inspection port. This location was selected because:

- It can accommodate a large vent line without adding significantly to the flow path resistance,

- It is available and accessible,

- Its elevation will provide for a good driving head for flow,

- Its location below the top of the hot leg should help preclude steam collecting in the top of the hot leg by providing significant condensation of any steam from the RV head vent line by the hot leg subcooled flow stream, and

- A new cover flange with the vent line connection can be manufactured in the shop.

4.1.2 Vent Line Flow Analysis Methods

The flow resistance through the RV vent line path to the steam generator upper plenum was calculated using standard engineering techniques for 1-1/2 inch and 2-1/2 inch schedule 160 vent line piping. The piping lengths and elbows were determined from preliminary piping layout sketches. Since most of the vent line flow resistance was due to frictional loss in the vent piping and elbows, this resistance was calculated as a function of Reynolds number.

Flowrates through the RV head vent line were determined for forced RCS flow conditions, and for natural circulation flow conditions. During forced flow conditions, the temperature of the fluid in the RV head would be at the same temperature as that in the hot leg. The driving pressure for flow through the vent line would be the unrecoverable pressure drop from the RV head to the SG upper plenum. This pressure drop is dependent on the hot leg flowrate.

During natural circulation flow conditions, the unrecoverable pressure drop from the RV head to the SG upper plenum is small. Under these conditions, the flowrate in the vent line would be mainly governed by the density difference between the fluid (or gas) in the RV head and that in the hot leg.

4.1.3 Vent Line Flow Results

The vent line flow resistance coefficient as a function of Reynolds number is shown on Figure 2 in terms of velocity heads in the vent line pipe. This variation with Reynolds number is important only for liquid flow through the vent line during

natural circulation flow conditions when low vent line flowrates (< 20 gpm) could occur. During forced flow conditions, or with steam flowing to hot leg during natural circulation, the Reynolds number is very near to or within the complete turbulence zone for the vent line pipe sizes considered.

Using the flow resistance coefficient from Figure 2, the flowrates through the RV head vent line during natural circulation conditions were calculated as a function of the density difference between the hot leg fluid and the RV head fluid (or steam) using the formula:

$$w\ (\text{lbm/s}) = \left[\frac{2g\Delta L\rho\ \Delta\rho}{(K/A^2)}\right]^{1/2} \qquad (3\text{-}1)$$

where: g = gravitational constant, ft/s^2

ΔL = elevation difference between vent line entrance and exit, 50.28 ft

ρ = density of fluid in RV head, lbm/ft^3

Δρ = hot leg fluid density minus RV head fluid density, lbm/ft^3

K = flow resistance coefficient, dimensionless

A = vent line piping area, ft^2

The predicted vent line flowrates using the above formula are shown in Figure 3 for both the 1-1/2 inch and 2-1/2 inch schedule 160 vent piping. These same vent line flowrates are shown in Figure 4 as a function of the temperature difference between the RV head fluid and the hot leg fluid.

Saturated steam flowrates for the two vent line sizes are shown in Figure 5 as a function of RV head pressure. These flowrates were calculated assuming natural circulation conditions with the hot leg fluid 20°F subcooled.

The time needed to vent an assumed entire RV head volume (512 ft^3) of non-condensible gas during natural circulation is given in Table 4-1 below for the two RV head vent line sizes considered. Equation (3-1) was used to calculate the non-condensible gas flowrate assuming a hot leg fluid density of 43.1 lbm/ft^3, and a gas temperature of 600°F at a pressure of 2200 psia.

Table 4-1: RV Head Vent Line Performance for Non-Condensible Gas

Vent Piping	Flowrate, ft^3/min		Time to Vent Head Volume of Gas, min.	
	H_2	N_2	H_2	N_2
1-1/2" SCH 160	71	19	7.2	27.6
2-1/2" SCH 160	219	56	2.3	9.1

During forced flow conditions, the vent line flowrates are a function of the mass flowrate in the hot leg loop to which the vent line is connected. The expected RV head vent flowrate is given in Table 4-2 as a function of the operating RC pump combination. The vent line flowrates are less than 0.15% of the hot leg flowrates.

Table 4-2: RV Head Vent Flowrates During Forced Flow Conditions

RC Pump Combination	Vent Line Flowrate, lbm/s 1-1/2"SCH 160 Vent Line	 2-1/2" SCH 160 Vent Line
2/2	6.9	21.4
2/1	7.3	22.5
1/2	3.0	9.4
2/0	7.5	23.2
0/2 (Reverse Flow)	-1.2	-3.8
1/1	3.4	10.4
1/0	3.6	11.0
0/1 (Reverse Flow)	-0.6	-1.7

4.2 Normal Natural Circulation Cooldown

4.2.1 Model Description and Analysis Assumptions

A finite difference heat transfer model was developed to investigate the thermal response of the reactor vessel head fluid and metal under natural circulation conditions. The model consists of nodes representing the coolant, plenum cover, vessel wall, insulation, and the air trapped between the insulation and metal. Conduction, convection, and radiation heat transfer were considered in addition to the convective transport of heat due to the vent flow and natural circulation. Figure 6 shows the heat transfer paths and mechanisms. The flow through the upper head region due to natural circulation was derived from previous hydraulics calculations; Figure 7 shows these flow paths.

Some of the important assumptions used in this model and analyses are listed below:

1. At the start of the cooldown transient, the RV head metal, vent, and fluid temperatures are 608°F, which is approximately the hot leg temperature at 100 percent full power.

2. The natural circulation flow rate is constant at 3 percent of full flow for the entire cooldown. This is considered acceptable for this analysis since with no RV head vent, there is little flow into and mixing within the RV upper head to aid the RV head cooldown.

3. The ambient (reactor building) temperature is 120°F.

4. The circulatory coolant (hot leg) is assumed to start at an initial temperature of 585°F. Where 585°F = 548°F (saturation temp. at 1015 psig: ADV setpoint) + 37°F ($\sim\Delta T$ for max. decay heat at 2 minutes after reactor trip).

5. The natural circulation cooldown transient assumed a cooldown rate of 75°F/hr to 350°F followed by a 2°F/hr rate to the DHR cut-in temperature (280°F). These cooldown rates are not design criteria but rather rates felt to be reasonably achievable.

6. Vent line flowrate was varied as a function of the temperature difference between the RV upper head fluid and the hot leg fluid. Algorithms were developed from the vent line hydraulics calculations.

7. The plenum cover was treated as a solid stainless steel plate from a heat capacity point of view, yet flow was allowed to pass through it.

8. The control rod drive mechanisms were modeled as infinitely long heat fins such that all the heat passing through the CRDM cross-sectional area at the vessel head (fin base) was lost to the reactor building.

9. Conduction between two dissimilar materials was modeled using the average conductivity of the two materials.

10. The radiative heat transfer has a minor effect relative to the other heat transfer mechanisms.

11. The coolant/metal interface temperatures used in the convective heat transfer equations were calculated using a first order approximation based on the average metal volume temperature.

12. Stagnant fluid regions were allowed to mix whenever cold fluid above hot fluid layering occurred.

4.2.2 Base Cases Analyzed

The finite difference RV head model was used to determine the RV head fluid cooldown for the cases of no vent, 1-1/2 inch vent line, and 2-1/2 inch vent line. Figure 8 shows the flow path model for the no vent case. In the vent line cases, the flow in the upper head region (see Figure 9) was determined by distributing the vent flow equally into each of the seven radial regions.

Figure 10 shows the temperature of the hottest head fluid volume as a function of time. This hot volume was typically that at the top of the RV head where there was assumed to be no vent related flow (refer to Figure 9). During the cooldown, the RV head fluid cooldown rate of the hottest model fluid volume reached approximately 1-1/2°F/hr in the case with no RV head vent. With an RV head vent, the cooldown rate increased to a maximum of about 18°F/hr for a 1-1/2 inch vent line, and to 22°F/hr for the 2-1/2 inch vent line case. Figure 11 shows the calculated cooldown rate versus time for the 2-1/2 inch vent line case.

As mentioned previously, the hottest model fluid volume was typically the assumed stagnant volume at the top of the RV head region. This liquid volume is cooled primarily by the interfacing RV head metal. These interfacing RV head metal volumes are cooled by conduction to their adjacent metal volumes which are cooled by the vent flow. The temperature response of the metal volume at the top of the RV head is shown in Figure 10 for both the no vent and 2-1/2 inch vent line case. The average temperature of this metal volume closely follows that of the hottest fluid volume.

The cooldown results show that with the assumed vent flow distribution in the RV head, the RV head fluid can be cooled to below the saturation temperature corresponding to the decay heat cut-in pressure (290 psig) in 12 hours for a 2-1/2 inch RV head vent line. For a 1-1/2 inch vent line, it would take about 15 hours. Both of these cases easily satisfy the 36 hour criteria established for this natural circulation cooldown transient. Also, a continuous RV head vent would promote a more uniform cooldown of the RV head metal by enhancing the flow and mixing of the RV head fluid.

The following additional results are also provided for the natural circulation cooldown with a 2-1/2 inch RV vent line:

- RV head fluid cooldown vs. time out to 20 hours (Figure 12)

- RV head fluid saturation pressure vs. time (Figure 13)

- RV head vent flowrate vs. time (Figure 14)

Figure 12 also shows the temperature of the RV head vent fluid during the cooldown. The temperature of the vent fluid will be measured, and by maintaining it subcooled, an operator can avoid forming a large steam bubble in the RV head during a natural circulation cooldown.

4.2.3 Parametric Studies to Evaluate Model Sensitivity

Two studies were performed to evaluate the sensitivity of the cooldown results to key assumptions and approximations used in the analyses. One was to investigate the effect of the assumed vent flow distribution through the RV upper head region on the cooldown of the RV head fluid. The other was to evaluate the sensitivity of the results to the heat transfer at the fluid/metal interface.

As discussed in section 4.2.2, the base analyses assumed the vent flow was equally distributed to each of the seven radial regions just above the plenum cover. For convenience, this base distribution will be called Type A. The two other vent flow distribution assumptions evaluated were:

o Type B - Vent flow was distributed uniformly according to the relative flow area of each of the annular regions.

$$\text{Vent Flow Fraction} = \frac{A(I)}{A_{total}} * (\text{Total Vent Flow})$$

where A(I) = annular flow area of one of the 7 regions.

- Type C - The vent flow distribution was skewed towards the center of the RV head. In this distribution, the three center radial regions each received 30% of the vent flow, and the remaining four regions received 4%, 3%, 2% and 1% respectively proceeding outward.

The cooldown results for the hottest RV head fluid volume are shown in Figure 15 for the three vent line flow distributions with a 2-1/2 inch vent line. The results for the type B flow distribution (probably the most realistic) compares favorably with the base, type A, distribution. Although the predicted cooldown with the type C distribution is significantly slower than that with the base distribution, it still appears adequate to satisfy the 36 hour cooldown criteria.

In the base analyses, the fluid/metal interface temperature were calculated based on a first order approximation. The surface metal temperature for the heat flux calculation was determined from the average metal temperature of the volume assuming a linear temperature profile. Since the actual temperature profile may not be linear, the sensitivity of the cooldown results to this assumption was also investigated. This was done by multiplying the heat flux in the convective heat transfer equations inside the RV head by factors of 0.5 and 2.0. The results given in Figure 16 show that the thermal response of the hottest fluid volume is relatively insensitive to this assumption.

4.3 Rapid RCS Depressurization and Cooldown

4.3.1 Model Description and Analysis Assumptions

The rapid RCS depressurization and cooldown transient was modelled and evaluated using RELAP4, Mod 6, version 1. The base model used was a single combined loop natural circulation model of the Davis Besse plant primary and partial secondary side configuration. This base model was originally developed to benchmark RELAP4 to the 1978 natural circulation tests at Davis Besse.

The volume and junction diagram for the model used in the rapid RCS depressurization and cooldown analysis is shown in Figure 17. Although the steam generator primary side was modelled as two parallel paths, there was no distinction made in these analyses with respect to heat transfer performance in the two paths. Several features were, however, added to the base model to better similate the transient of interest.

- o Core power was input as a time history to represent the decay heat curve.
- o A heat slab was added to the RV head volume to simulate the stored energy of the RV head metal.
- o Makeup capability was included to help maintain pressurizer level.
- o A 2-1/2 inch RV head vent line was modelled (vent line case only).

The purpose of the RELAP4 analyses was to evaluate the effectiveness of a continuous RV head vent in dispersing the steam which would form in the RV head region during a

controlled, rapid depressurization and cooldown. Of particular concern was the potential for the steam bubble to expand out of the RV head into the hot leg where it could interfere with natural circulation flow. Cases with and without the RV head vent were run for comparison.

The transient steps analyzed are described below. They are compatible with the procedure given in the Abnormal Transient Operating Guidelines (ATOG) for a SG tube rupture with no RC pumps operating.

Step (1): Open the pressurizer PORV and depressurize RCS to a pressure corresponding to a saturation temperature equal to the hot leg temperature plus approximately 20°F subcooling margin. A close PORV setpoint of 1530 psia was used in the analyses.

Step (2): Close the PORV and use the atmosphere dump valves (ADV's) to cool down the RCS at a rate not to exceed 240°F/hr. The ATOG procedure calls for several cooldown/depressurization steps, after the step (1) depressurization, to reach RCS conditions of approximately 1000 psig and a hot leg temperature of 500°F. For simplicity, the analyses assumed a single cooldown phase to reduce the hot leg temperature to about 500°F. This was followed by the step (3) depressurization.

Step (3): Close the ADV's and open the PORV until the RCS depressurizes to 1000 psig.

Some of the important initial conditions and analysis assumptions are listed below:

1. The primary RCS initial conditions were taken from the base RELAP4 model which reflected steady state natural circulation conditions.

Core Power	-	108 Mwt (3.9% FP)
RCS Core Outlet Pressure	-	2211 psia
Hot Leg Temperature	-	585°F
Cold Leg Temperature	-	536°F
SG Collapsed Liquid Level	-	9.1 ft
SG Secondary Pressure	-	916 psia

2. The initial RV head fluid temperature was assumed to be 608°F which corresponds to the hot leg temperature at 100% full power.

3. The initial AFW flow was zero. In the analyses, AFW control was modelled using SG inventory control limits which corresponded to on/off level setpoints of 38 inches and 50 inches above the lower tubesheet.

4. Heat loss rate from the RV head insulation to the ambient air was assumed to be 70 Btu/ft^2-hr.

5. RCS cooldown rate was controlled by adjusting the total effective ADV flow area. Achieving the desired cooldown rate (~ 240°F/hr) in the analysis was found to be difficult due to the effects of decreasing core decay heat, decreasing ADV flow with decreasing secondary pressure, and relatively long loop transit time.

6. During the cooldown phase, the makeup flowrate was estimated to try to offset the RCS fluid contraction rate. The primary concern was to ensure that the pressurizer did not fill or empty during the rapid depressurization and cooldown transient.

4.3.2 Analysis Results and Discussion

4.3.2.1 No RV Head Vent Case

The results of the rapid depressurization and cooldown transient for the case with no RV head vent are shown in Figures 18 to 20. An explanation of the key responses observed is given below for each of the three phases of this transient.

o Initial Depressurization (No Vent)

- When the RCS pressure dropped below the saturation pressure of the hot fluid in the RV head steam flashing occurred and a steam bubble formed. (Note that because of the spherical shape of the top portion of the RV head, the level versus volume change is not linear. The actual relationship is shown in Figure 21.)

- The RV head fluid temperature dropped about 8°F due to the steam flashing as it approached the saturation temperature corresponding to the new RCS pressure.

- The pressurizer level increased primarily due to the steam bubble in the RV head.

- The RCS cold leg temperature increased as the secondary pressure increased to the relief valve setpoint.

o <u>Cooldown (No Vent)</u>

- At 150 seconds, the RCS cooldown phase was started by opening the atmospheric dump valves. The effect was quickly seen on the cold leg temperature. The hot leg temperature responded later due to the loop transit time.

- The pressurizer level and the RV head level both decreased during the first 450 seconds of the cooldown phase because the RCS contraction rate exceeded the makeup flowrate used during this period. This also resulted in the decrease seen in RCS pressure which caused additional steam flashing to occur in the RV head causing an increase in the steam bubble.

- At 600 seconds, the makeup flowrate was increased to stop the decreasing RCS pressure and restore the pressurizer inventory to its initial level. The steam bubble in the RV head started to condense due to the uniform mixing of the hot RV head fluid with the colder hot leg fluid which entered because of the excessive makeup flow. [RELAP4 allows fluid temperature stratification only in non-equilibrium volumes (e.g. pressurizer); the RV head was not modelled with a non-equilibrium volume]. In reality, steam bubble condensation at this rate would not be expected to occur because of the fluid temperature stratification.

- Restoration of the pressurizer level was slowed until after the condensation of the steam bubble in the RV head.

- At about 400 seconds, the SG level reached the low inventory setpoint and the AFW began cycling on and off to maintain the SG inventory within the control limits. This AFW cycling, and the ADV cycling which began at about 800 seconds, caused the secondary pressure fluctuations seen on Figure 19.

- Starting at 1000 seconds, primary pressure was limited in the calculations by the PORV with a tight control band. Notice that the RV head liquid temperature did not change after the primary pressure was stabilized.

- Near the end of the cooldown phase (at 1290 seconds), the makeup flowrate was reduced since the pressurizer level had increased beyond its initial value. This reduction in makeup flowrate significantly slowed the rate of pressurizer level increase.

o <u>Final Depressurization (No Vent)</u>

- The RCS depressurization was started at 1390 seconds by opening the PORV. Steam flashing occurred when the pressure dropped below the saturation pressure of the hot fluid in the RV head. This large depressurization step resulted in the formation of a large steam bubble which reduced the RV head liquid level to less than 2 inches.

- The RV head liquid temperature decreased to the saturation temperature corresponding to the new RCS pressure.

- The pressurizer level increased in response to the RV head steam bubble formation.

- After this depressurization step was completed, the RV head steam bubble began to condense very slowly. This was due to the increasing RCS pressure resulting from the increase in makeup flowrate, and the uniform mixing of the fluid in the RV head assumed in RELAP4.

4.3.2.2 <u>2-1/2 Inch RV Head Vent Case</u>

The controlled rapid depressurization and cooldown transient results for the case which includes a 2-1/2 inch continuous RV head vent are shown in Figures 22 to 25. This case was run from the same initial conditions as the no vent case, and used similar transient control variables (e.g. pressure control setpoints, makeup flowrates, etc.) and timing.

An explanation of the key responses observed is given below for each of the three key phases of this transient.

o <u>Initial Depressurization (2-1/2 Inch RV Head Vent)</u>

- When the RCS pressure dropped below the saturation pressure of the hot fluid in the RV head, steam flashing occurred and a steam bubble formed.

- The RV head liquid temperature dropped about 8°F due to the steam flashing as it approached the saturation temperature corresponding to the new RCS pressure.

- The pressurizer level increased primarily due to the steam bubble in the RV head.

- RCS cold leg temperature increased as the secondary pressure increased to the ADV setpoint.

o <u>Cooldown (2-1/2 Inch RV Head Vent)</u>

- At 150 seconds, the RCS cooldown phase was started by opening the atmospheric dump valves. The effect was quickly seen on the cold leg temperature. The hot leg temperature responded later due to the loop transit time.

- The pressurizer level decreased during the first 450 seconds of the cooldown phase because the RCS contraction rate exceeded the makeup flowrate used during this period. This also resulted in a decrease in RCS pressure.

- When the rapid depressurization stopped at 150 seconds, the steam bubble in the RV head started to dissipate via the RV head vent even though the decreasing RCS pressure was causing additional steam flashing. This decrease in the steam bubble size was reversed momentarily when the steam

flashing rate exceeded the steam flowrate through the RV head vent line. The momentary increase in the RCS depressurization was caused by the AFW cycling on to maintain SG inventory.

- At 600 seconds, the makeup flowrate was increased to stop the decreasing RCS pressure and restore the pressurizer inventory to its initial level. The RV head vent flow (Figure 25) served to dissipate the steam bubble very quickly after the RCS depressurization (and resultant RV head steam flashing) stopped, and then to continue to cool the RV head fluid.

- At about 350 seconds, the SG level reached the low inventory control setpoint and AFW began cycling on and off to maintain the SG inventory within the control limits. This AFW cycling, and the ADV cycling which began at about 800 seconds, caused the secondary pressure fluctuations seen on Figure 22.

- Starting at about 900 seconds, the primary pressure oscillations were due to PORV operation.

- Near the end of the cooldown phase (at 1290 seconds), the makeup flowrate was reduced since the pressurizer level had increased beyond its initial value. This slowed the rate of pressurizer level increase.

o <u>Final Depressurization (2-1/2 Inch RV Head Vent)</u>

  - At 1390 seconds, the PORV was opened which started the RCS depressurization to 1000 psig. Steam flashing occurred when the pressure dropped below the saturation pressure of the hot fluid in the RV

head. Because of the large depressurization step, a large RV head steam bubble formed and the RV head liquid level dropped to about 7 inches.

- The RV head liquid temperature decreased to the saturation temperature corresponding to the new RCS pressure.

- The pressurizer level increased in response to the RV head steam bubble formation.

- After the depressurization step was completed, the RV head steam bubble began to dissipate due to the flow through the RV head vent. This recovery was slowed to some extent due to the continued slow decrease in RCS pressure. The steam vented to the SG upper plenum was condensed by the hot leg fluid. This would be expected since the steam mass flowrate was less than 0.2% of the hot leg flowrate.

4.3.2.3 Comparison of Results and Limitations of Analyses

The size of the steam bubble formed during the controlled rapid depressurization and cooldown analyses is shown in Figure 26 for both the no vent and 2-1/2 inch RV head vent line cases. From this comparison, one can see the benefits of a continuous RV head vent for dissipating an RV head steam bubble after a rapid depressurization event, and for limiting the size of the steam bubble which may form during a slow depressurization event.

In examining this comparison, one should also be cognizant of the limitations of the analytical model and the analyses which may have significantly affected the results. These key limitations and their expected effect on the results are discussed below.

o <u>No Temperature Stratificatior In RV Head Fluid</u>

The volume representing the RV head region allowed for phase separation, but not temperature stratification in the fluid. This meant that all the fluid and any steam in this volume had to be at the same temperature. For decreasing pressure situations, this representation was acceptable, and the calculated steam bubble sizes formed should be reasonable. When the pressure increased, however, the code did the following to decrease the temperature of all of the RV head liquid and steam to the new equilibrium temperature:

- Uniformly mixed all fluid entering the head region with the hotter fluid already there, and

- Condensed as much steam as needed.

The overall impact of this limitation was, therefore, a steam condensation rate in the RV head region which was much too high.

For the no vent case, this resulted in the unrealistic condensing of the steam bubble during those times when the RCS pressure increased. If fluid temperature stratification had been allowed in this model volume, the steam bubble formed during the initial depressurization phase would not have condensed, but instead would have been added to that formed during the final depressurization phase.

For the case with a continuous RV head vent, the steam bubble dissipation was due to a combination of condensation, and steam flow out the vent line. Better fluid mixing would be expected for this arrangement due to the higher flow into the RV head

as the steam exits through the vent. Therefore, although the calculated steam condensation rate for this case was also probably too high, it was more realistic than for the no vent case, and was not the primary cause for the steam bubble dissipation.

- <u>No RCS Pressure or Pressurizer Level Control</u>

  The RELAP model did not include a positive means to control RCS pressure or pressurizer level during the cooldown. In the analyses, the makeup flowrate was used to try to offset the effects of the RCS contraction and the RV head steam bubble. This coarse control resulted in the inability to maintain a constant RCS pressure during the cooldown. During a realistic rapid cooldown transient, the plant operator would typically have pressurizer level controlling the makeup, and the pressurizer heaters to maintain RCS pressure.

- <u>Pancaking in RV Head Vent Line</u>

  The RV head vent steam flow rates that were calculated by RELAP4 were observed to be approximately a factor of three lower than expected. This was caused by the model not allowing the saturated liquid in the vent line volume to slip by the steam and drain into the RV head volume once the steam started flowing through the junction path connecting these two volumes. This significantly affected the steam flowrate since during natural circulation the main driving head for flow is the density difference between the fluid in the hot leg and that in the RV head vent line.

This model limitation obviously had a substantial effect on the calculated steam bubble dissipation time. The steam bubble should have dissipated approximately three times faster than shown in the RELAP results for the vent line case.

o <u>Large Final Depressurization Step</u>

As mentioned previously, the ATOG rapid depressurization and cooldown procedure was simplied in the RELAP analyses. After the initial depressurization phase, the ATOG procedure recommends several small cooldown/depressurization steps to get to the desired RCS conditions of 1000 psig and approximately 500°F hot leg temperature. In the analyses, one large cooldown and depressurization step was used.

For the case with no vent and a more realistic steam condensation rate, the size of the final steam bubble in the head would not be significantly affected by the number of cooldown/depressurization steps taken. This is because very little steam condensation would be expected during the cooldown phases.

With a continuous RV head vent, however, the steam bubble formed during each depressurization step would be expected to be dissipated during the following cooldown step. Thus the maximum size of the RV head steam bubble formed during this controlled rapid cooldown/depressurization transient could be limited by the size of each of the depressurization steps.

In summary, the previously described code and analysis limitations lead to the conclusion that the actual performance benefits of a continuous RV head vent design would be substantially greater than shown in the RELAP

analysis results. If these code and analysis limitations did not exist, the estimated steam bubble size and time to disipate would be as shown in Figure 27 for both the no vent and the 2-1/2" vent cases. This still assumes a single large cooldown/depressurization step. By following the recommended ATOG procedure with several small cooldown/depressurization steps, this evaluation shows that the RCS can obviously be quickly cooled and depressurized to the desired conditions without a large steam bubble forming in the RV head if the continous RV head vent design is implemented.

4.4 Evaluation of Potential Impact on FSAR Accident Analysis Results

A qualitative review of the accident analyses in Chapter 15 of the Davis Besse FSAR was made to evaluate the potential impact of a continuous RV head vent system on these results. Most of the Chapter 15 events can easily be eliminated from the review by first considering the following operational features of the continuous RV head vent design.

- For events which maintain some forced circulation and a subcooled margin throughout the RCS, the RV head vent will simply flow hot leg temperature liquid like a parallel hot leg flow path. The presence of the continuous RV head vent will, therefore, have no affect on these types of events.

- For events which result in a natural circulation flow condition but maintain a subcooled margin throughout the RCS, the RV head vent will flow liquid with a temperature probably slightly higher than that in the hot leg. Because the vent flowrate is so small in comparison to that in the hot leg ($< 0.15\%$), it will have an insignificant affect on these types of events.

Based on the above operational considerations, the only types of events which could be affected by a continuous RV head vent are those where RCS subcooling margin is lost. This can occur for severe overcooling transients and loss of coolant accidents (LOCA's).

The most severe overcooling transient considered in the Davis Besse FSAR analyses is a steam line break. This event does not result in a loss of subcooling margin in the RCS. The operator, therefore, would not trip the RC pumps. The RV head region would thus remain adequately subcooled by the forced flow. If the RC pumps were tripped, the RV head vent would help minimize the formation of any steam bubbles in the RV head by providing increased flow and mixing to cool the RV head, and a vent path to remove any steam bubble formation.

Large break LOCA's result in a rapid depressurization and loss of subcooling in the RCS. A continuous RV head vent will have no significant affect on these events.

For small break LOCA's, core cooling is maintained by natural circulation flow and cooling via the steam generators or by boiler-condensor mode if natural circulation is interrupted. There exists a range of break sizes around approximately 0.01 ft^2, for which natural circulation is predicted to be interrupted by steam in the top of the hot leg. For these events, the addition of a continuous RV head vent may result in an earlier interruption of natural circulation flow in the loop with the RV head vent connection. However, the natural circulation flow in the other hot leg should not be degraded by steam from the RV head and may be enhanced such that the time to total interruption of natural circulation flow may be increased. In addition, the increased steam volume in the top of the affected hot leg may possibly result in establishing a boiler-condensor cooling surface earlier.

In summary, for a range of small break LOCA's, the addition of a continuous RV head vent may have some affect on the timing of the events. However, this change is not expected to have a significant impact on the basic results of these analyses. The specific effects of this proposed design change, if implemented, can be quantitatively evaluated for these small break events when the plant specific analyses are performed for NUREG-0737, Section II.K.3.31.

5.0 Conclusions

The continuous RV head vent is a viable design configuration which offers many operational benefits. It provides a path for transferring non-condensible gases to the upper hot leg region where they can be monitored via the hot leg level instrumentation, and vented through the hot leg vents. It will allow for steam transfer to, and condensation in the top of the steam generator. Also, for the more probable situations where an RCS cooldown during natural circulation conditions is needed, the continuous RV head vent will provide increased cooling for the RV head region. This will allow for a uniform cooldown of the RV head metal, and a depressurization to the DHRS in a reasonable period of time without forming a steam bubble in the RV head, and without losing RCS inventory.

Of the two vent line sizes evaluated (1-1/2 inch and 2-1/2 inch SCH 160), the 2-1/2 inch line size satisfies all the functional criteria and provides about three times the flow capacity of the smaller size. This difference could be significant particularly with respect to minimizing potential steam and non-condensible gas accumulation in the RV head. Based on the effectiveness of the 2-1/2 inch RV head vent line to limit and dissipate the steam bubble in the RV head during a rapid RCS depressurization; and the small time predicted to vent an assumed instantaneous accumulation of an RV head volume of non-condensible gasses, a RV head level measurement system should not be needed if this RV head vent design is implemented.

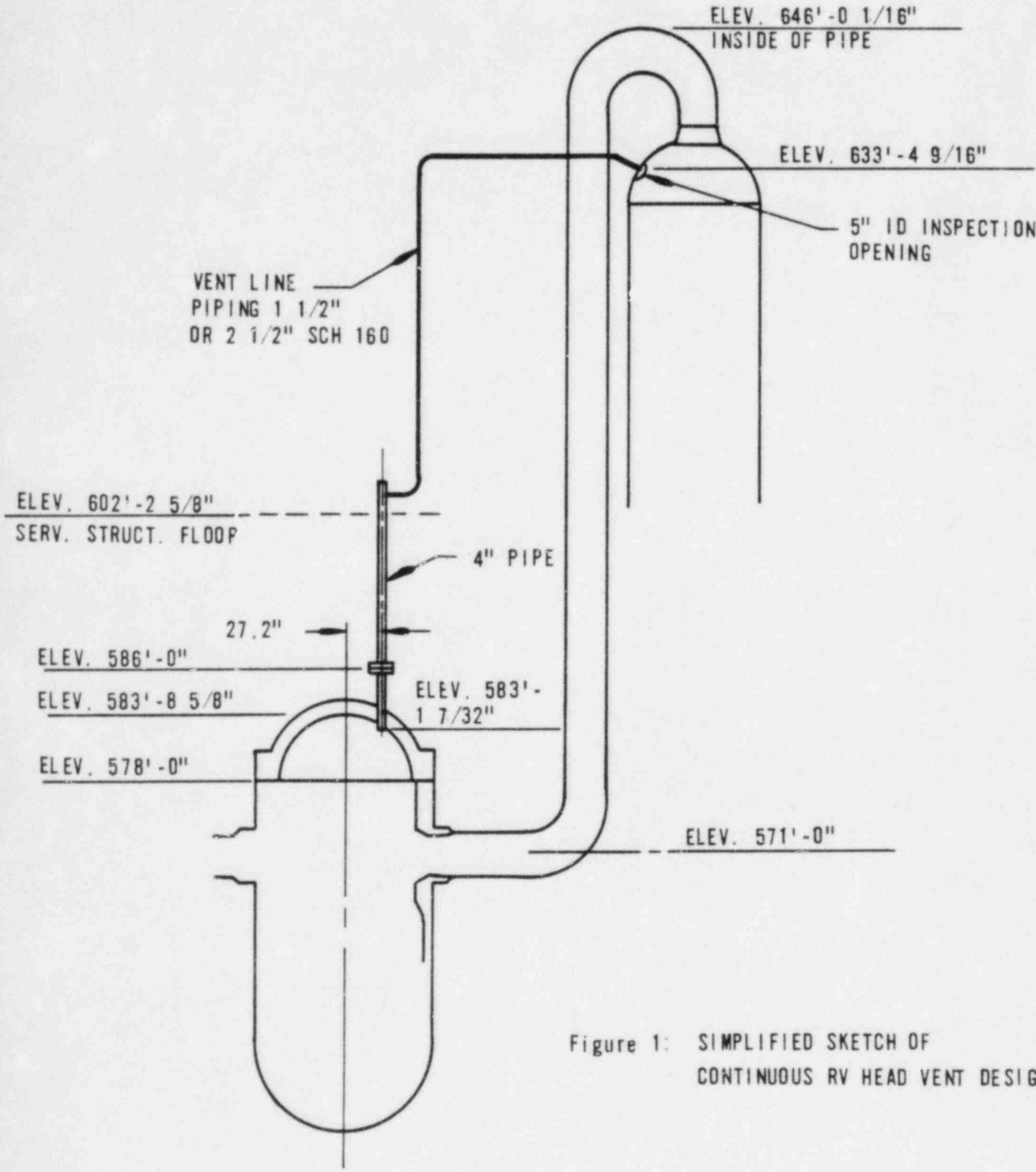


Figure 1: SIMPLIFIED SKETCH OF CONTINUOUS RV HEAD VENT DESIGN

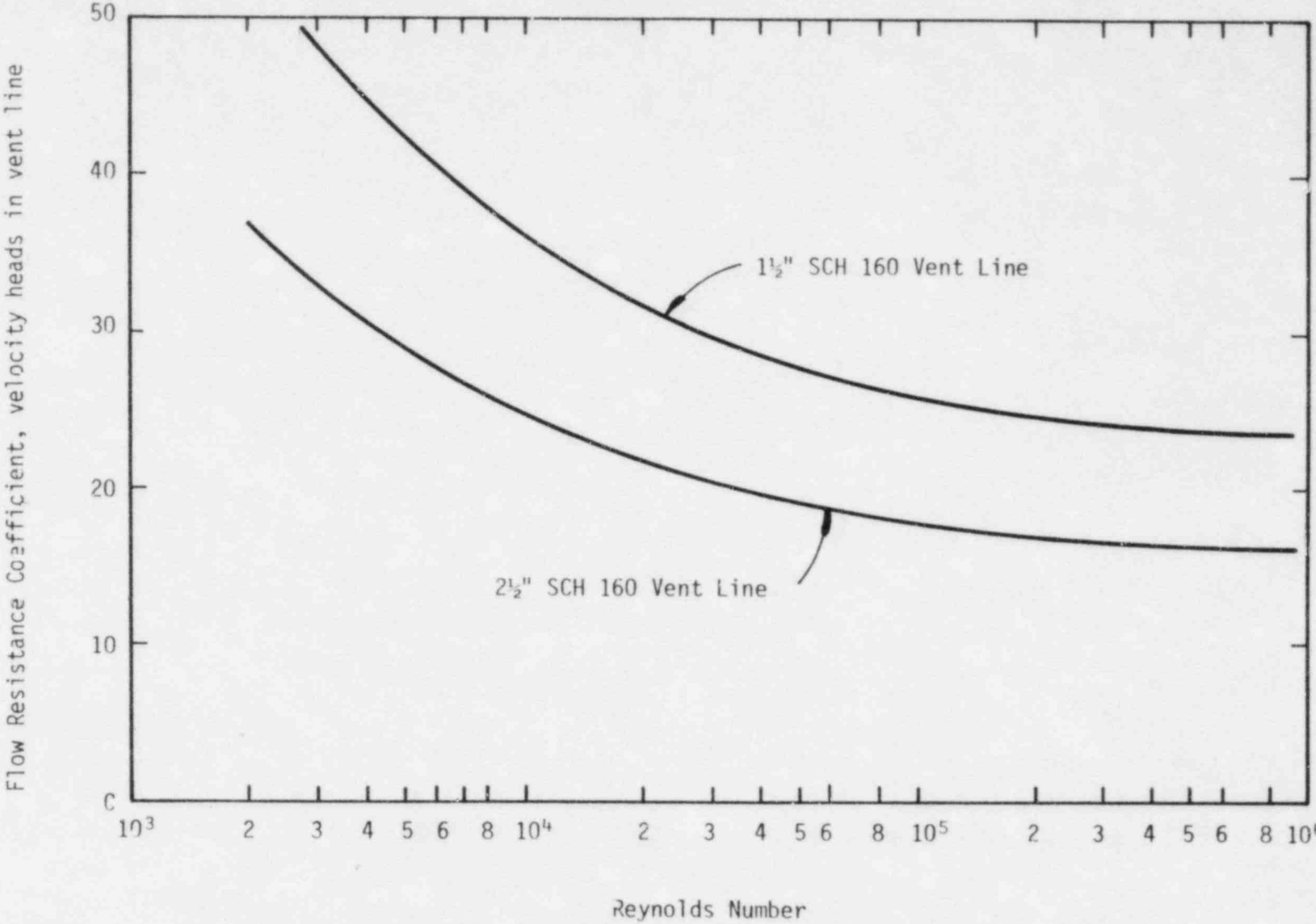


FIGURE 2: RV Head Vent Line Flow Resistance Coefficient vs. Reynolds Number

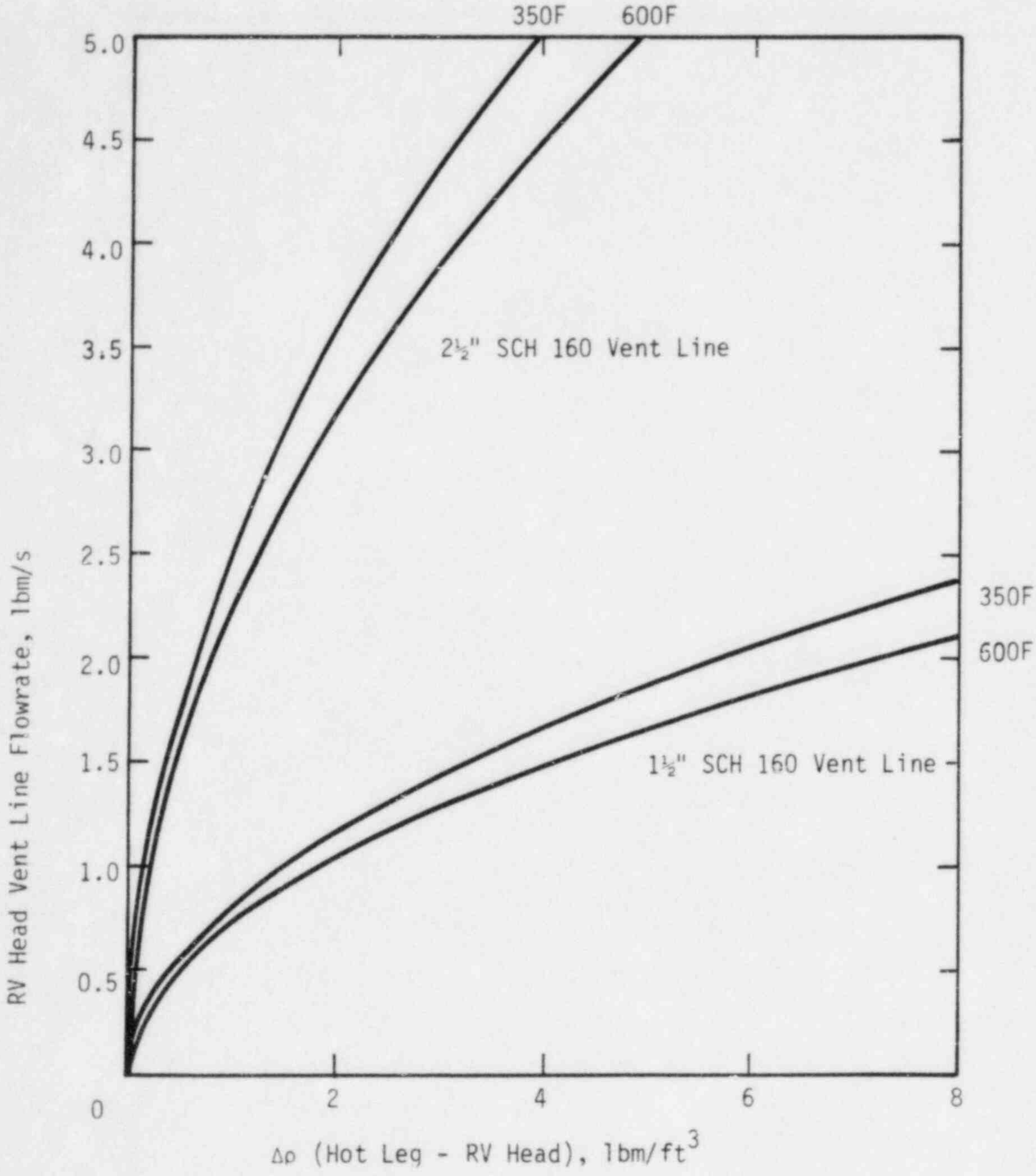


FIGURE 3: Vent Line Flowrate Vs. Δρ for indicated RV Head Fluid Temperature

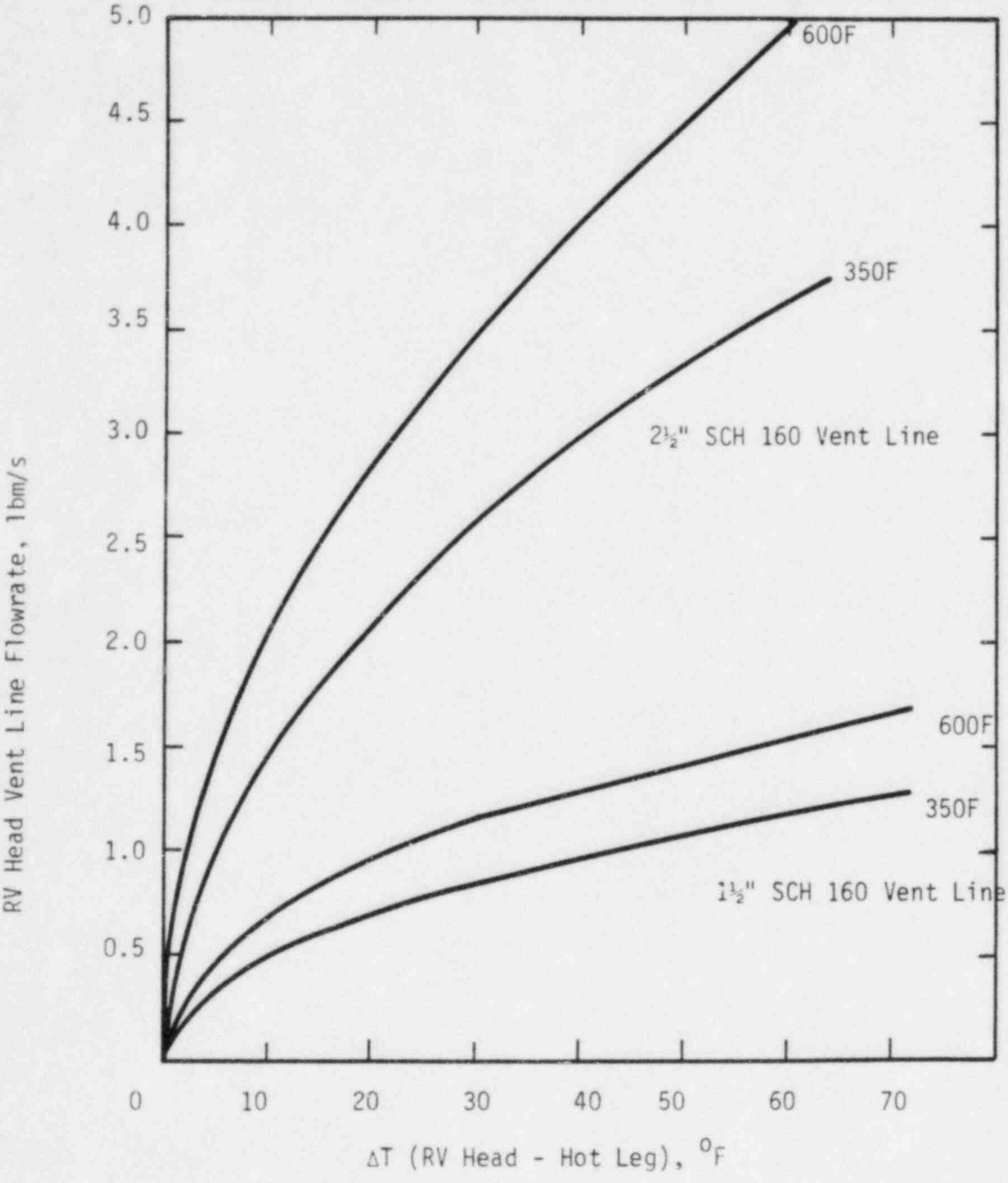


FIGURE 4: Vent Line Flowrate Vs. ΔT for indicated RV Head Fluid Temperature

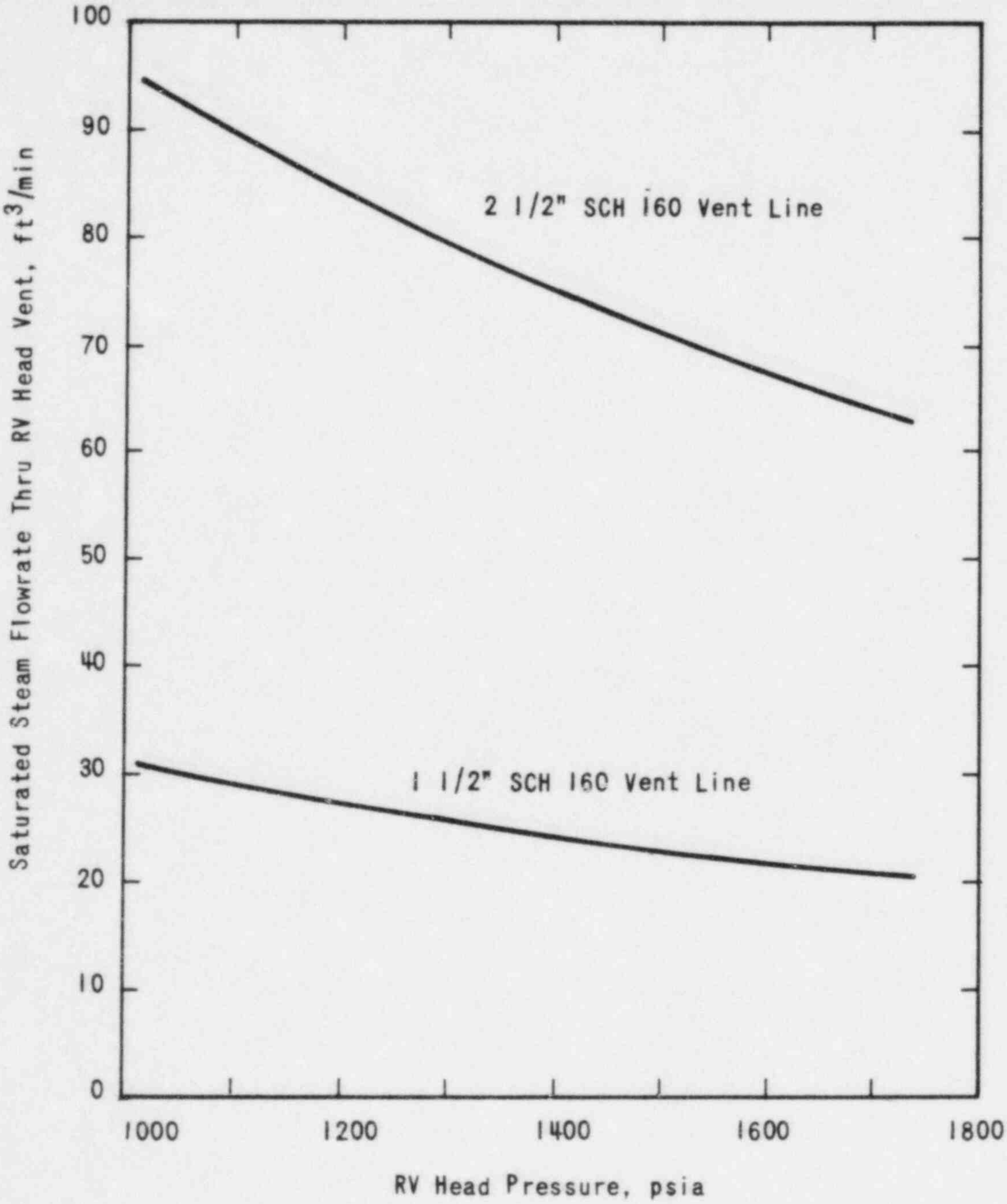
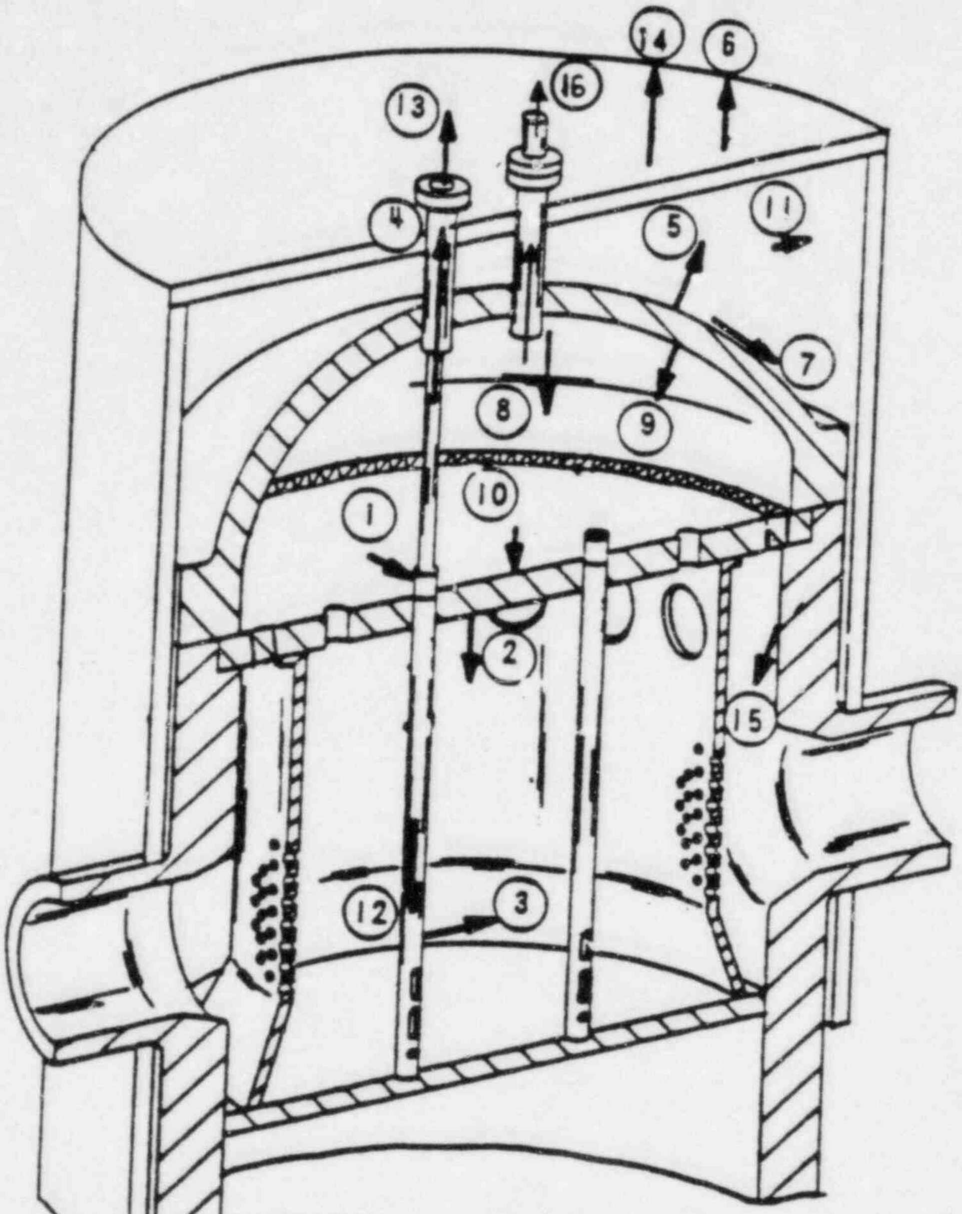


Figure 5. SATURATED STEAM FLOWRATE THROUGH RV HEAD VENT TO 20°F SUBCOOLED HOT LEG



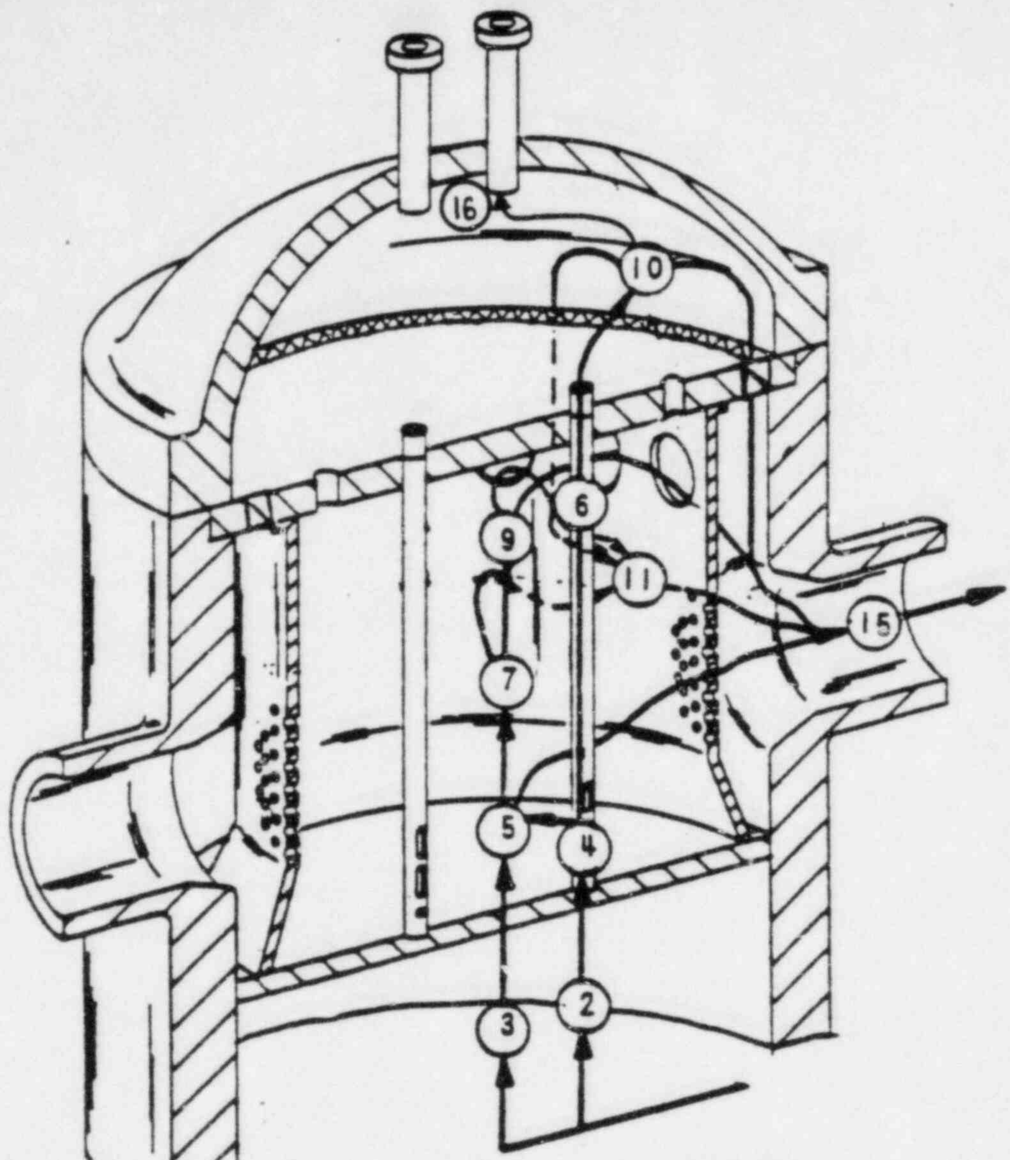
Node Number		Description
1	(a)	Upper Head Coolant to Lead Screw
2	(a)	Plenum Cover to Upper Plenum
3	(b)	Column Weldment to Upper Plenum
4	(b)	Up CRD Nozzle
5	(a)	RV Head to Air Under Insulation
6	(c)	Insulation to Containment
7	(b)	RV Head to Plenum Cover
8	(b)	From Hotter to Cooler Coolant Nodes
9	(a)	RV Head to Coolant in Upper Head
10	(a)	Upper Head Coolant to Plenum Cover
11	(a)	Air Under Insulation to Insulation
12	(b)	From Hotter to Cooler Nodes of Column Weldment
13	(b)	CRD Nozzle to Containment
14	(a)	Insulation to Containment
15	(a)	RV Wall to Upper Plenum Coolant
16		From Head to Hot Leg (via RV Head Vent)

(a) Convection

(b) Conduction

(c) Radiation

FIGURE 6: Heat Transfer Model



From Node	To Node	Path Description
2	4	Thru Fuel Assembly upper and fitting (UEF) into column weldment (CW)
3	5	Thru Fuel Assembly UEF into plenum open area
4	5	From inside CW to plenum open area thru lower exit ports
4	6	Up full column weldment
5	7	Axial flow in plenum open area
5	15	Thru 3-inch holes in plenum cyl. to outlet nozzle
7	9	Axial flow in plenum open area
7	11	Thru 22- and 34-inch holes in plenum cyl. to plenum cyl. outer annulus
9	11	Thru 34-inch holes in plenum cyl. to plenum cyl. outer annulus
9	15	Thru 34-inch holes in plenum cyl. to outlet nozzle
6	10	Thru CW top caps to upper head
10	11	Thru plenum cover annulus to plenum cyl. outer
10	15	Thru plenum cover annulus to outlet nozzle
11	15	Plenum cyl. outer annulus to outlet nozzle
10	16	From upper head to RV hood vent

FIGURE 7: Upper Plenum and RV Head Mass Transfer Model

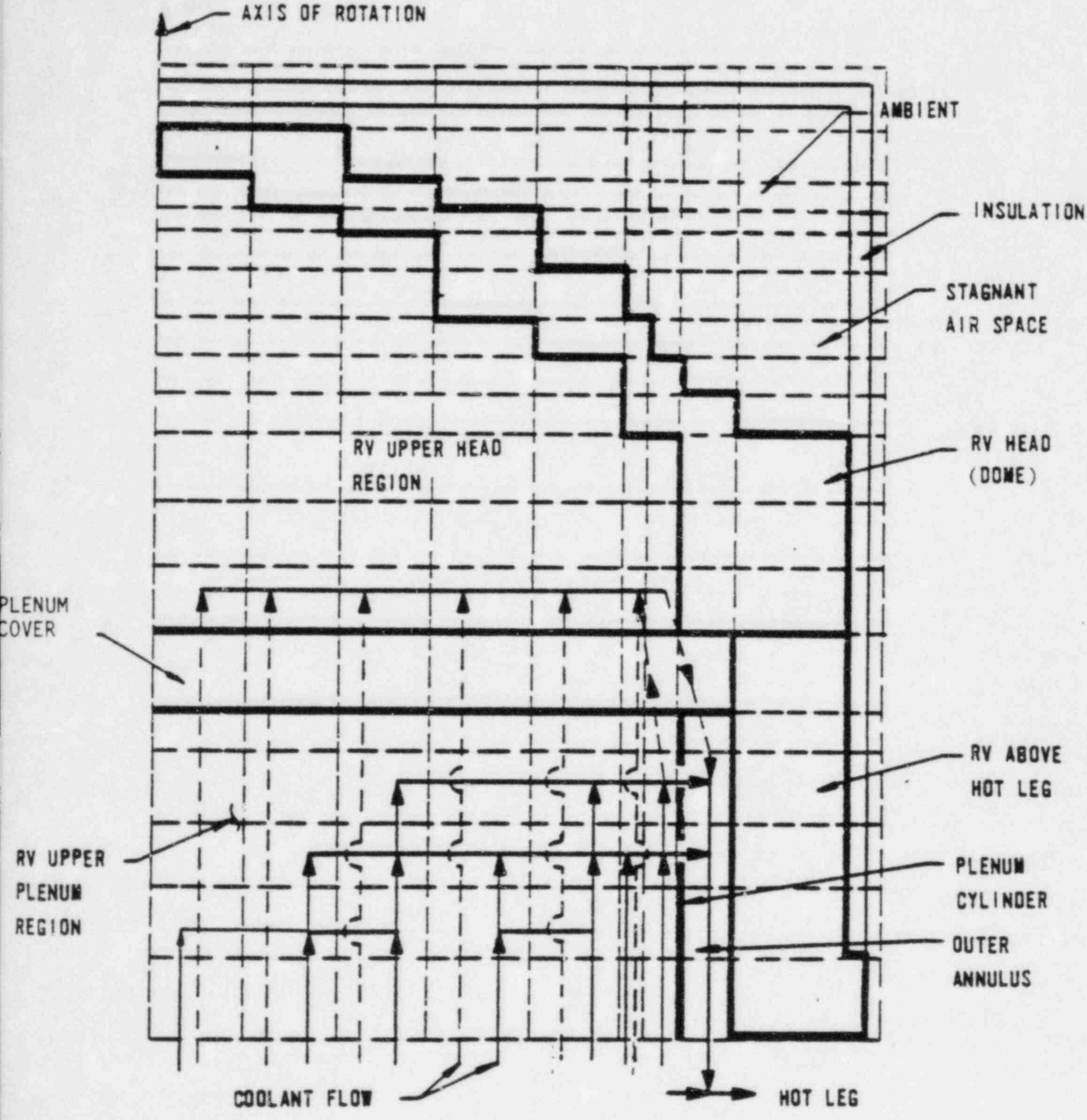


FIGURE 8: Flow Path Model Without Head Vent

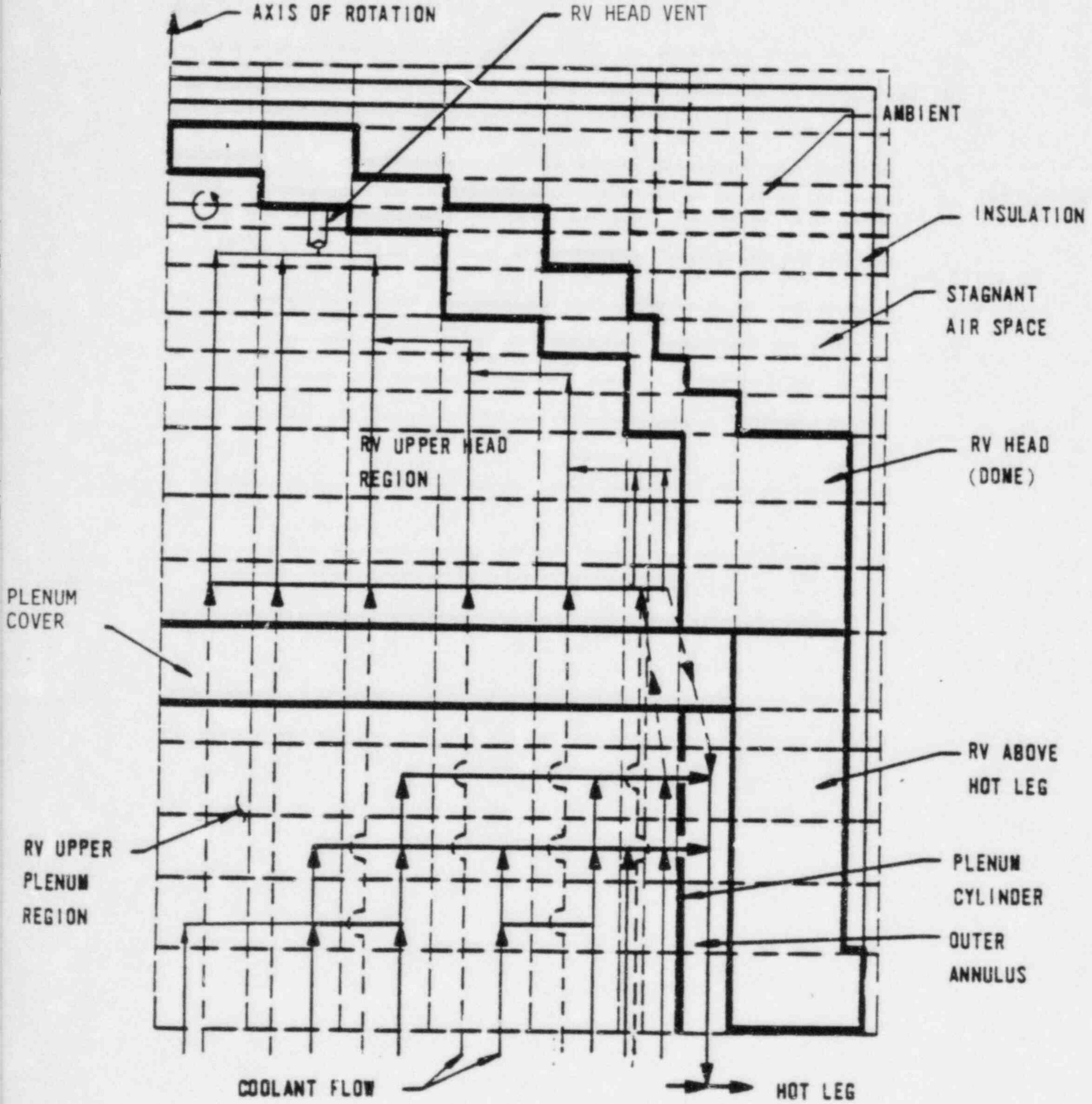


FIGURE 9: Flow Path Model With Head Vent

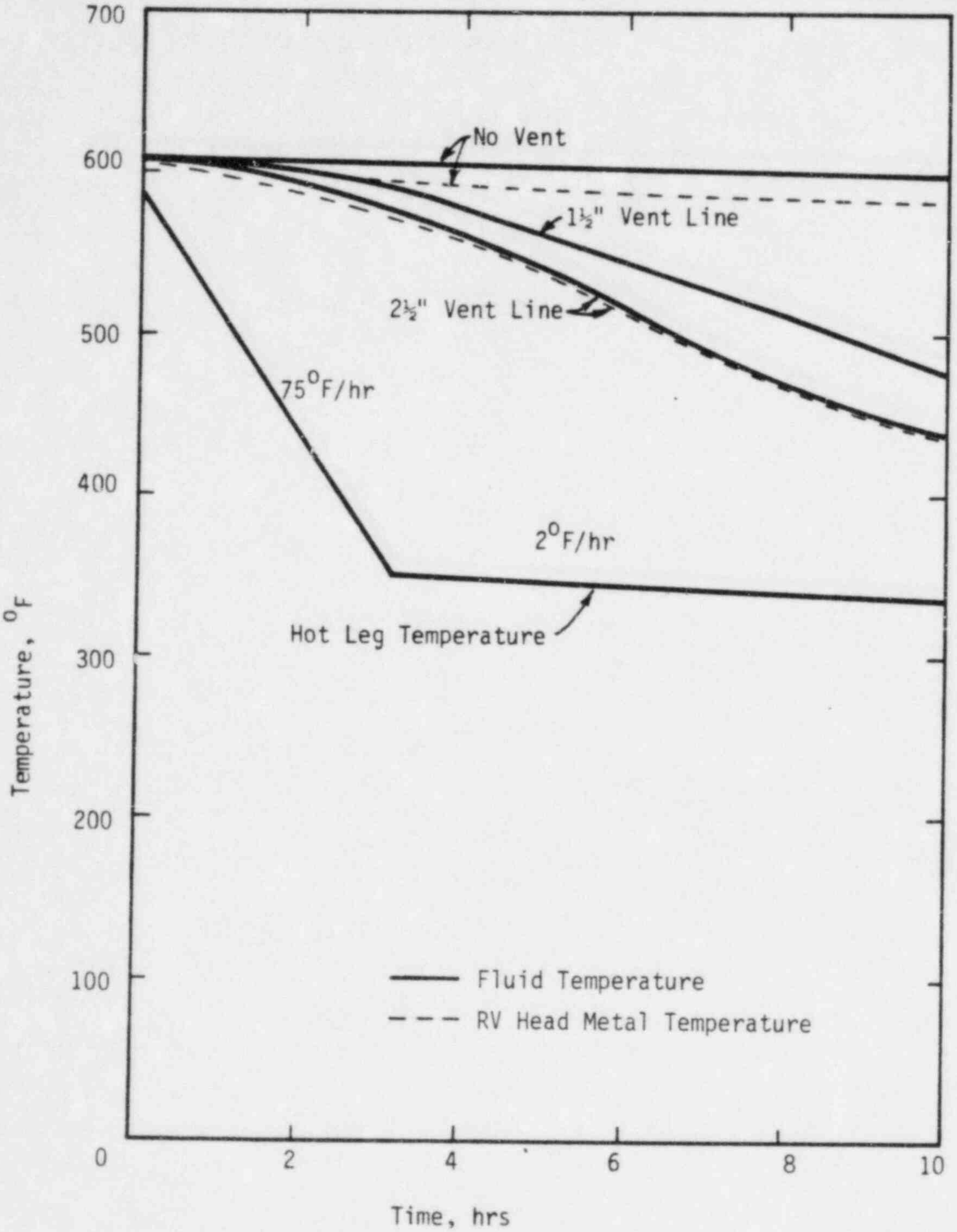


FIGURE 10: Cooldown Response of Hottest RV Head Fluid Volume - Base Cases Analyzed

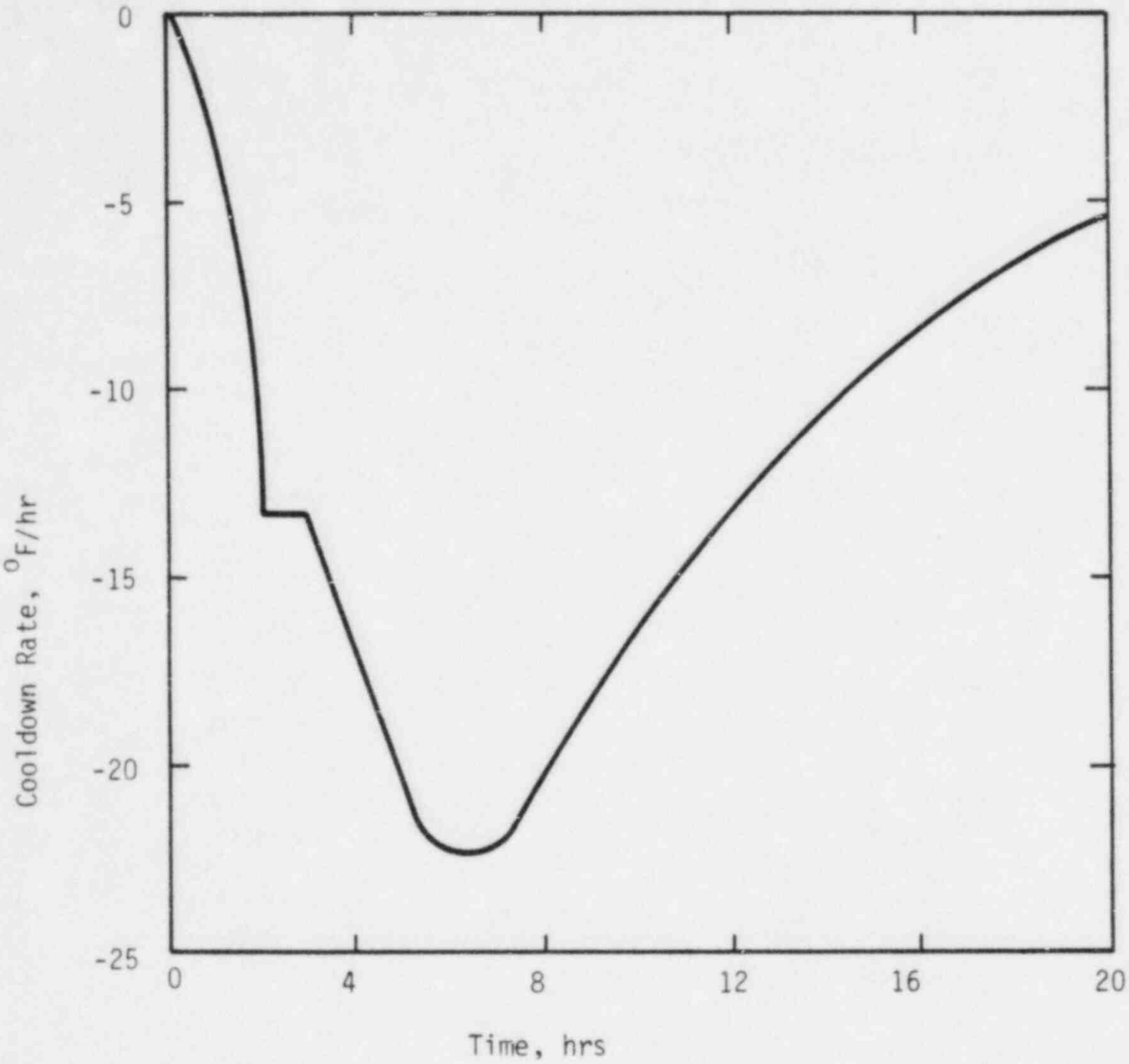


FIGURE 11: Cooldown Rate of Hottest RV Head Fluid Volume - 2½" Vent Line

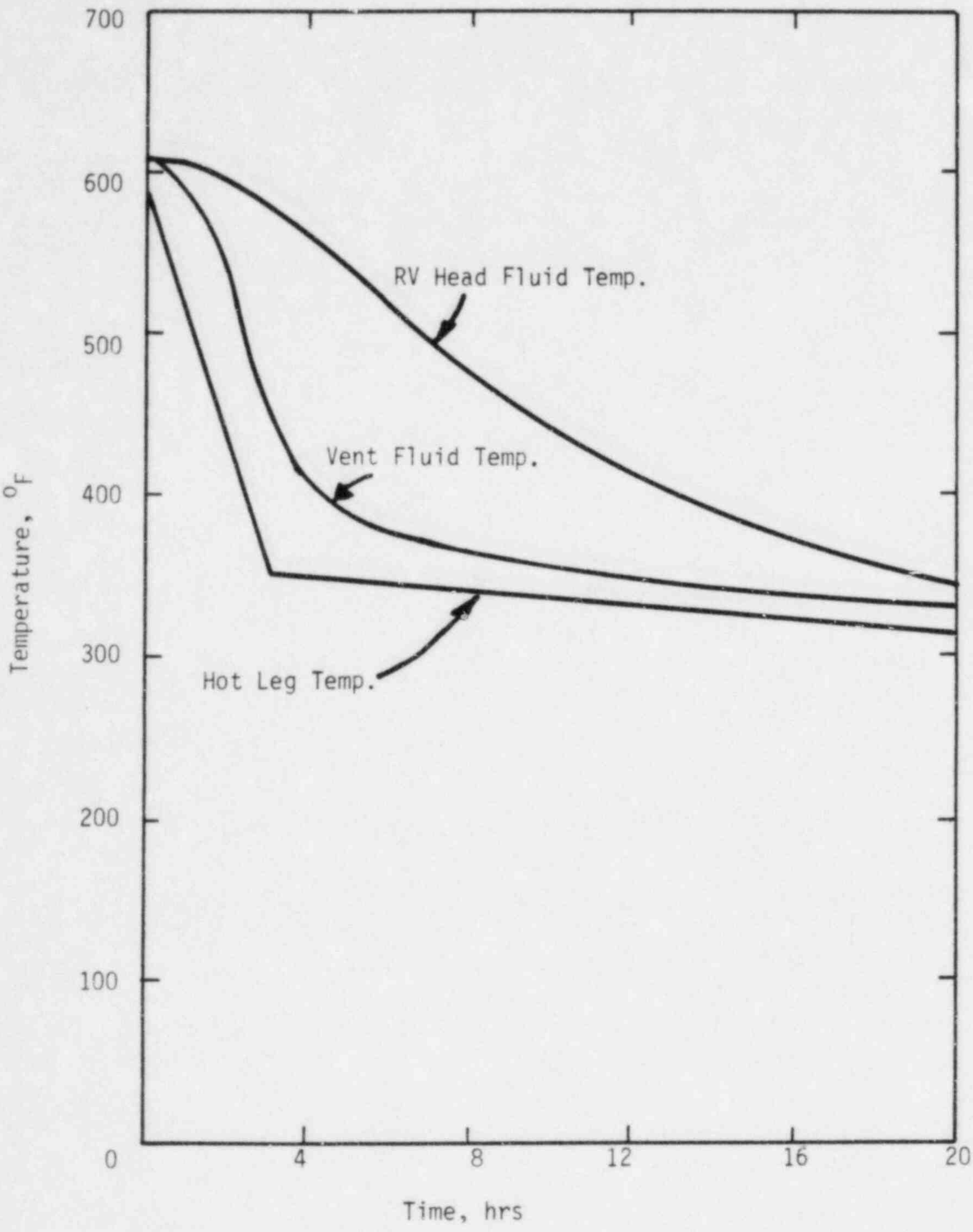


FIGURE 12: Cooldown Response of Hottest RV Head Fluid Volume - 2½" Vent Line

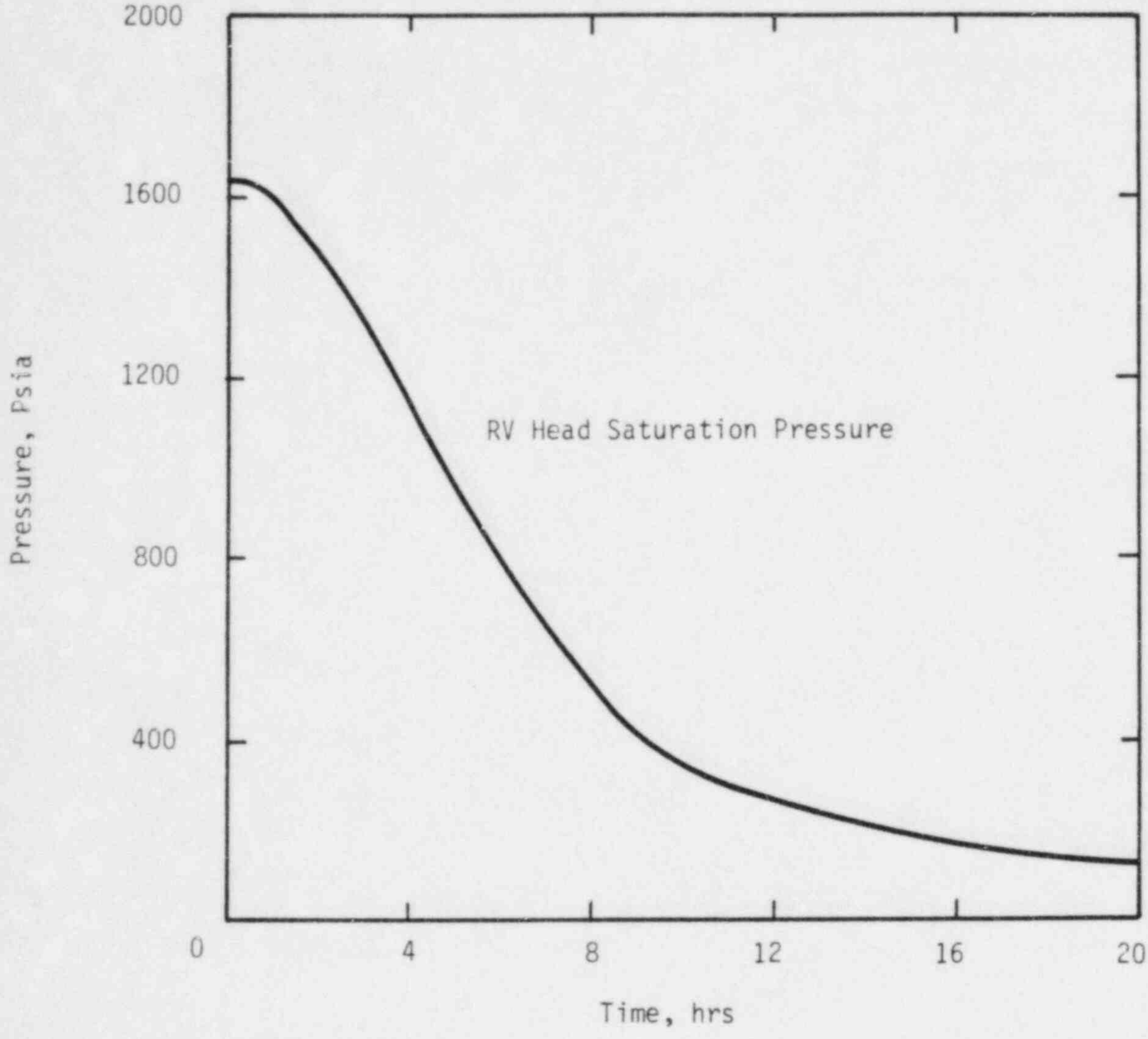


FIGURE 13 - RV Head Fluid Saturation Pressure vs. Time - 2 1/2 inch Vent Line

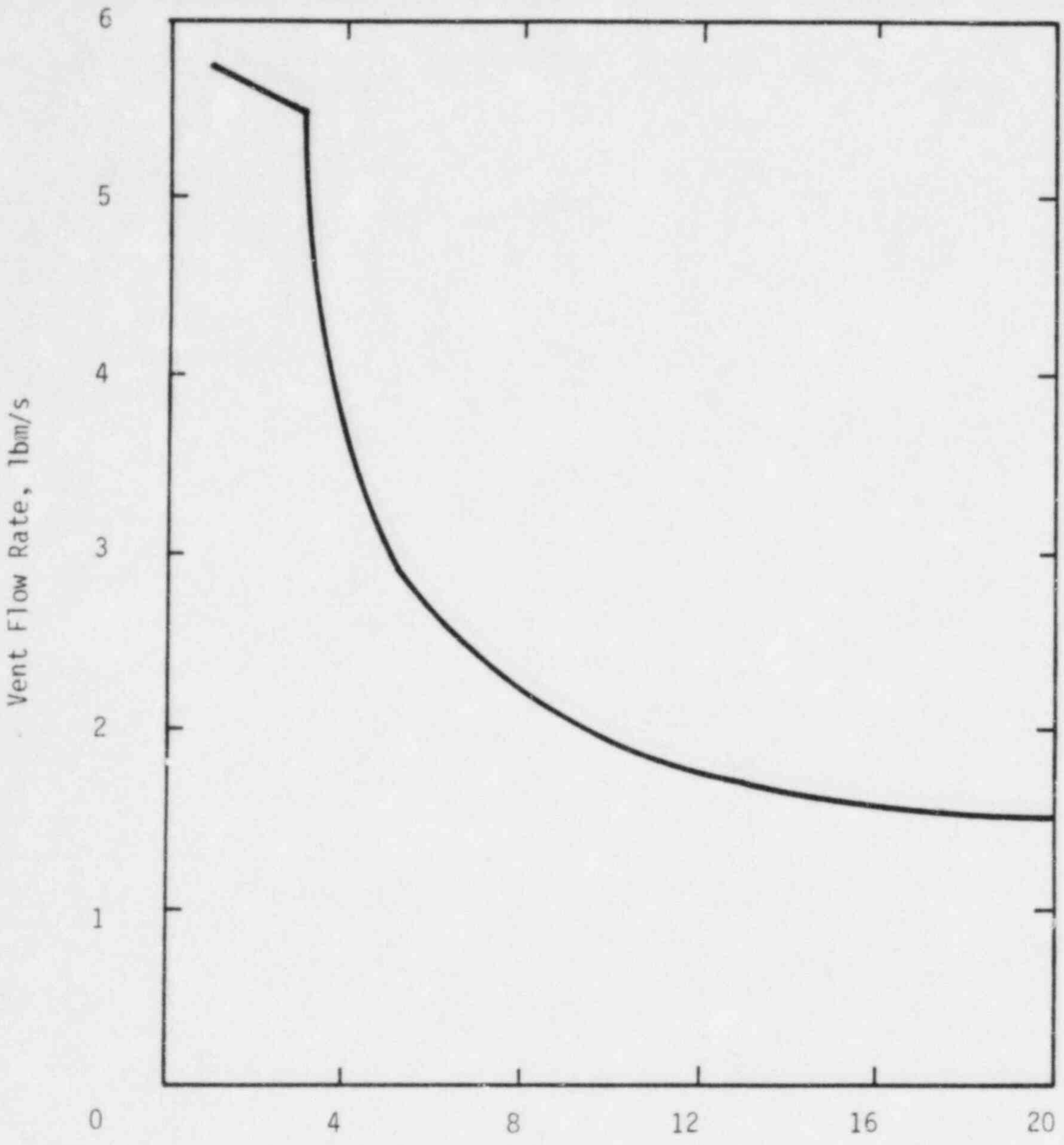


FIGURE 14 - Vent Flow Rate vs. Time - 2 1/2 inch Vent Line

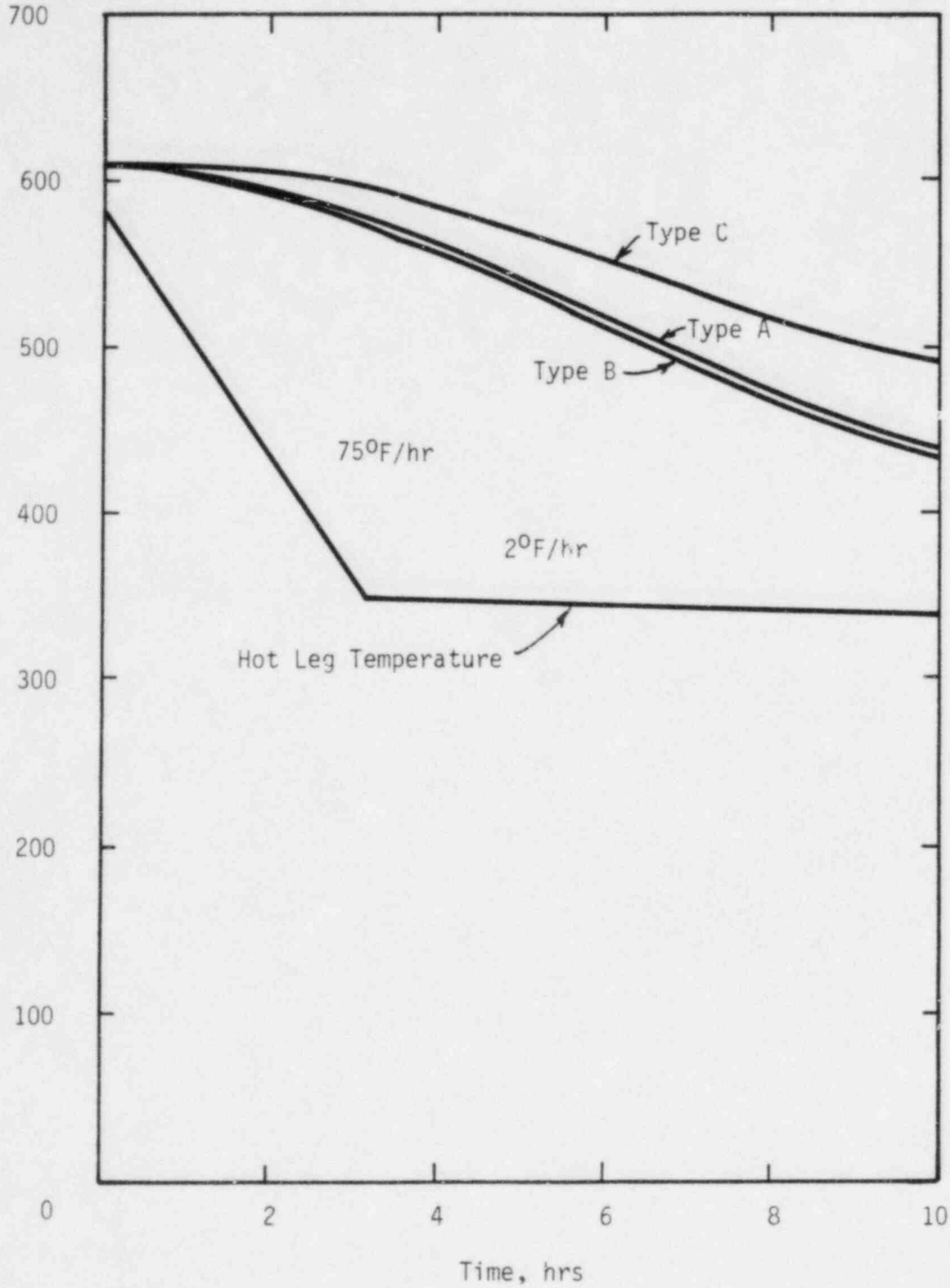


FIGURE 15 - Sensitivity of RV Head Fluid Cooldown to Vent Flow Distribution - 2 1/2" Vent Line

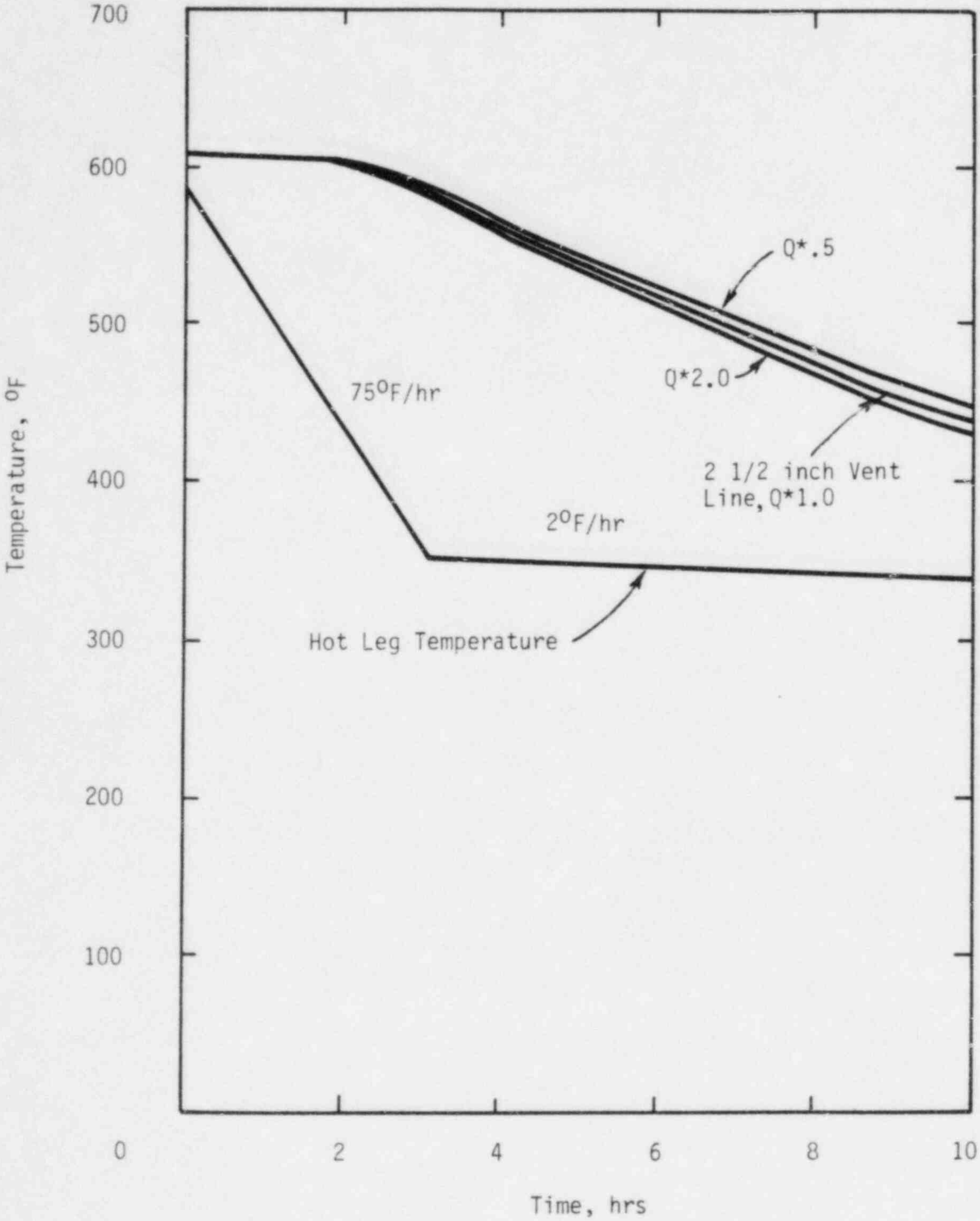


FIGURE 16 - Sensitivity of RV Head Fluid Cooldown to Interface Heat Transfer - 2 1/2" Vent Line

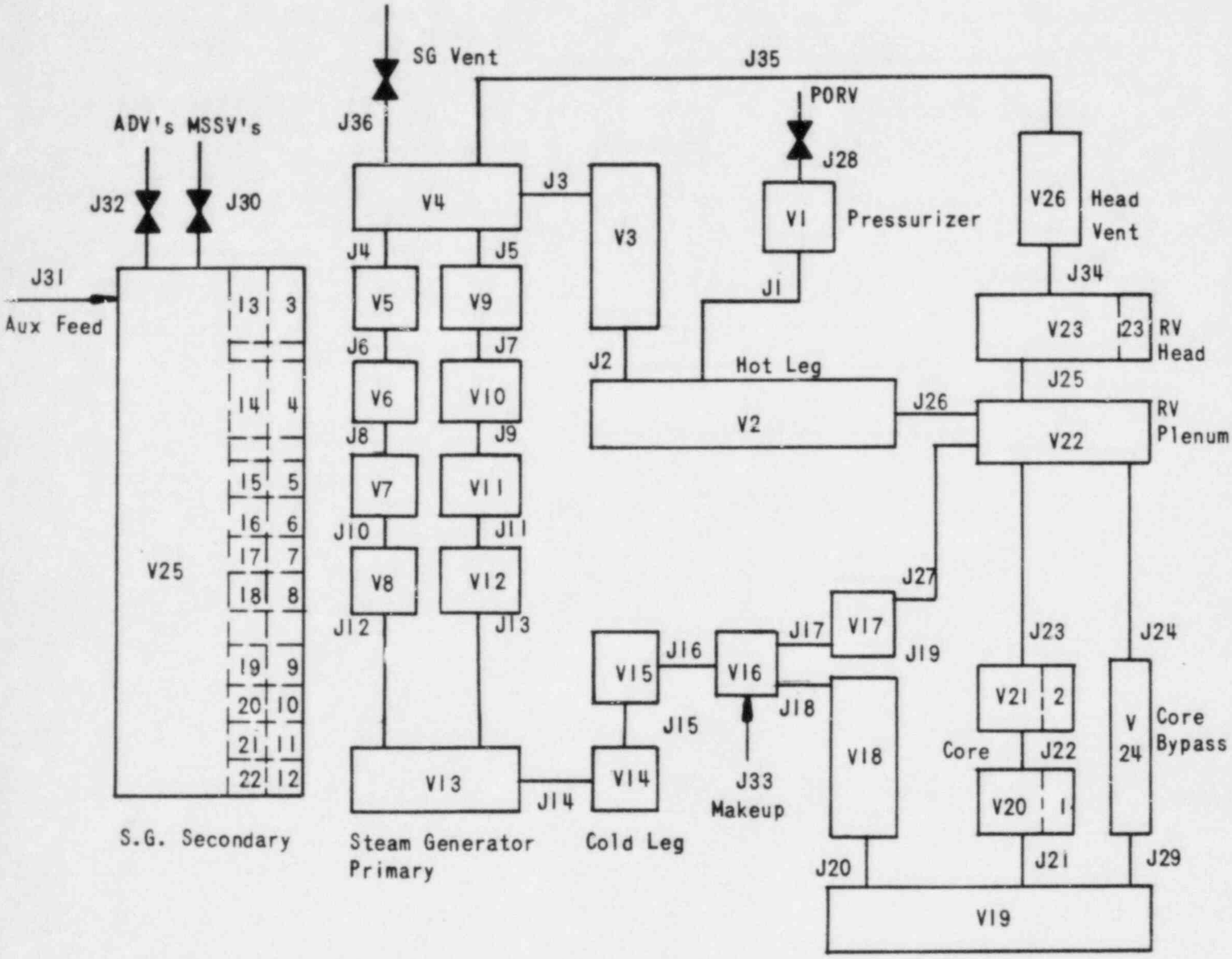


Figure 17: RELAP-4 Model For Rapid Depressurization and Cooldown Analyses

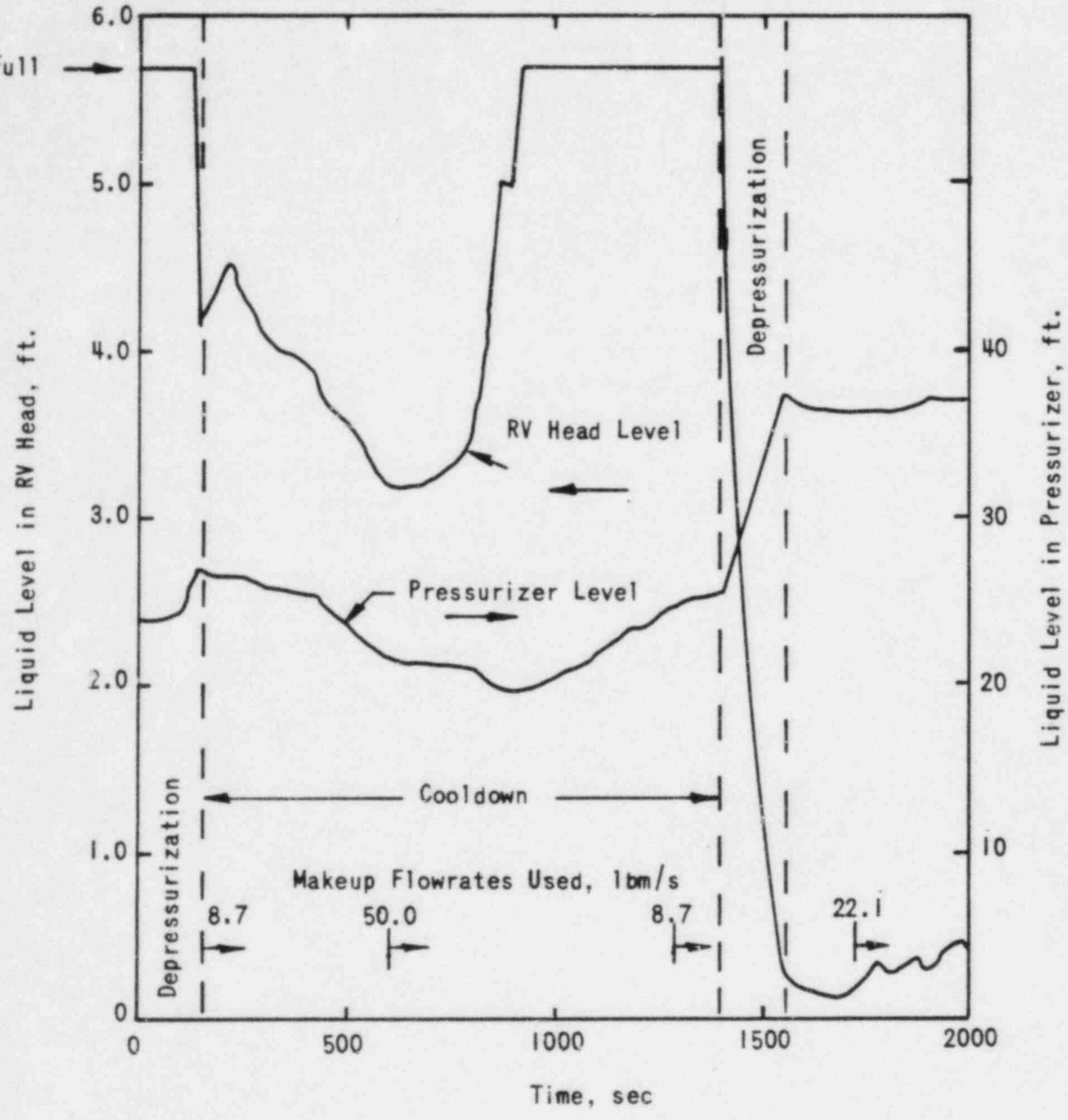


Figure 18. RV HEAD AND PRESSURIZER FLUID LEVEL RESPONSE - NO VENT

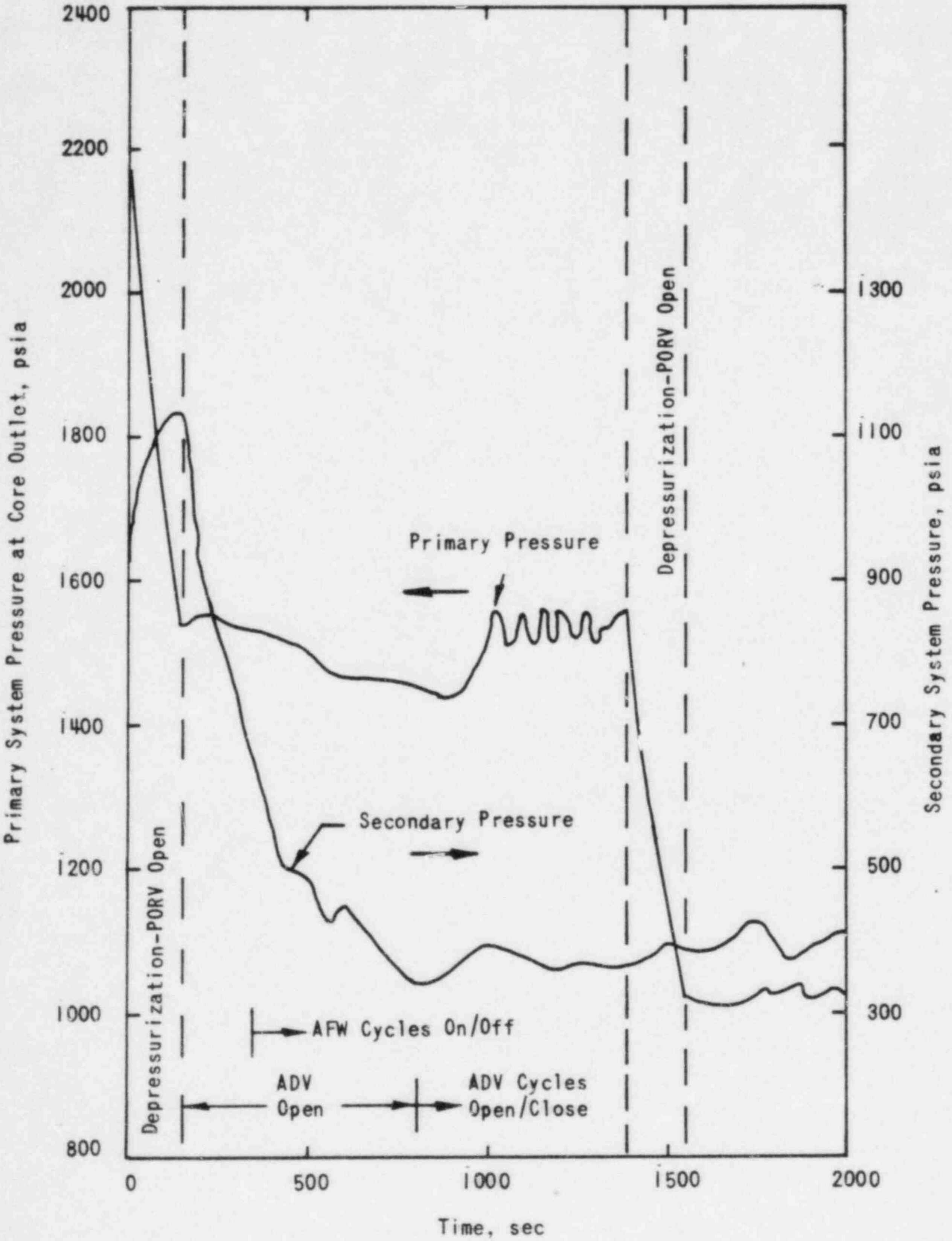


Figure 19: PRIMARY AND SECONDARY PRESSURE - NO VENT

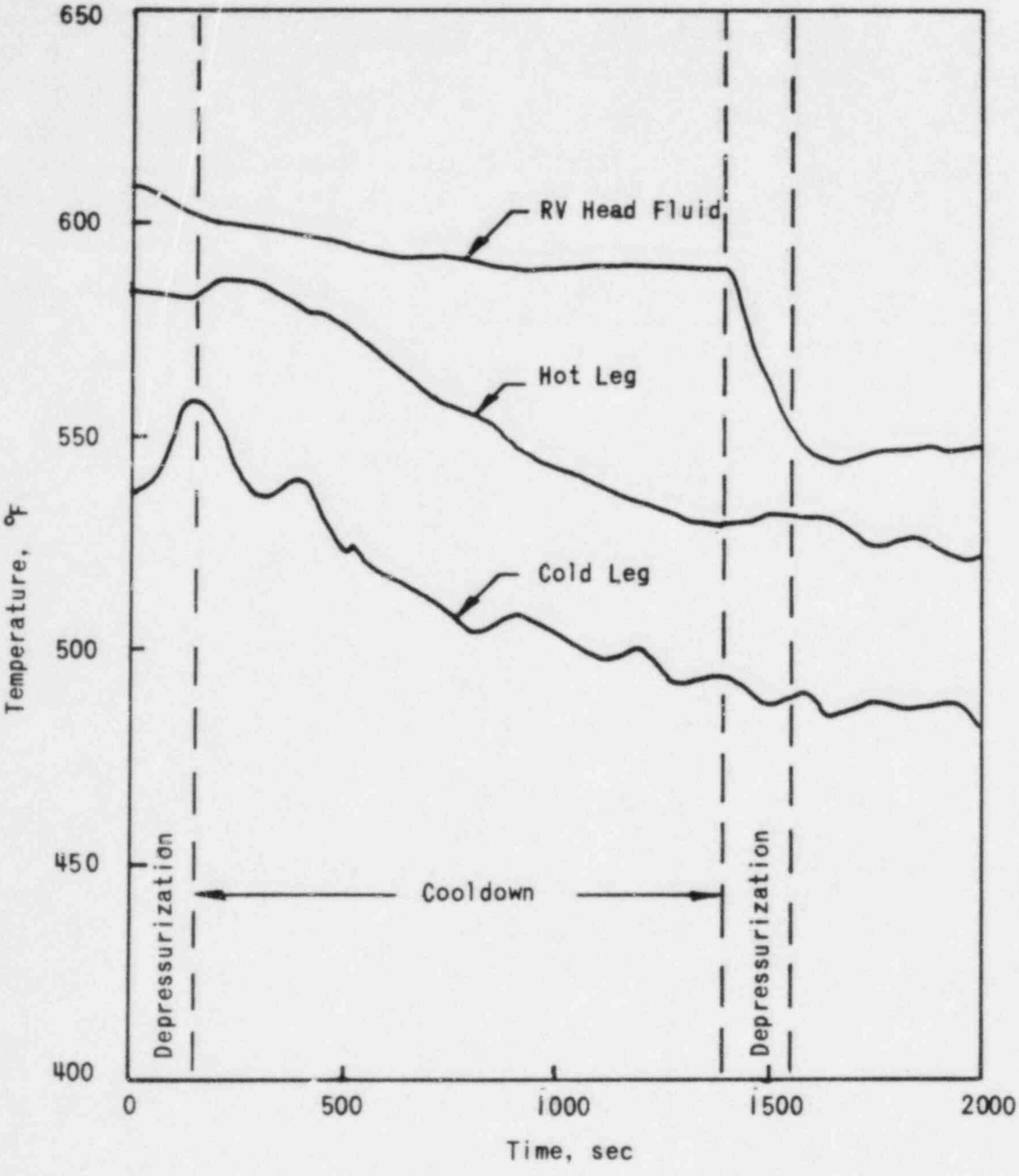


Figure 20. HOT LEG, COLD LEG AND RV HEAD FLUID TEMPERATURE RESPONSE - NO VENT

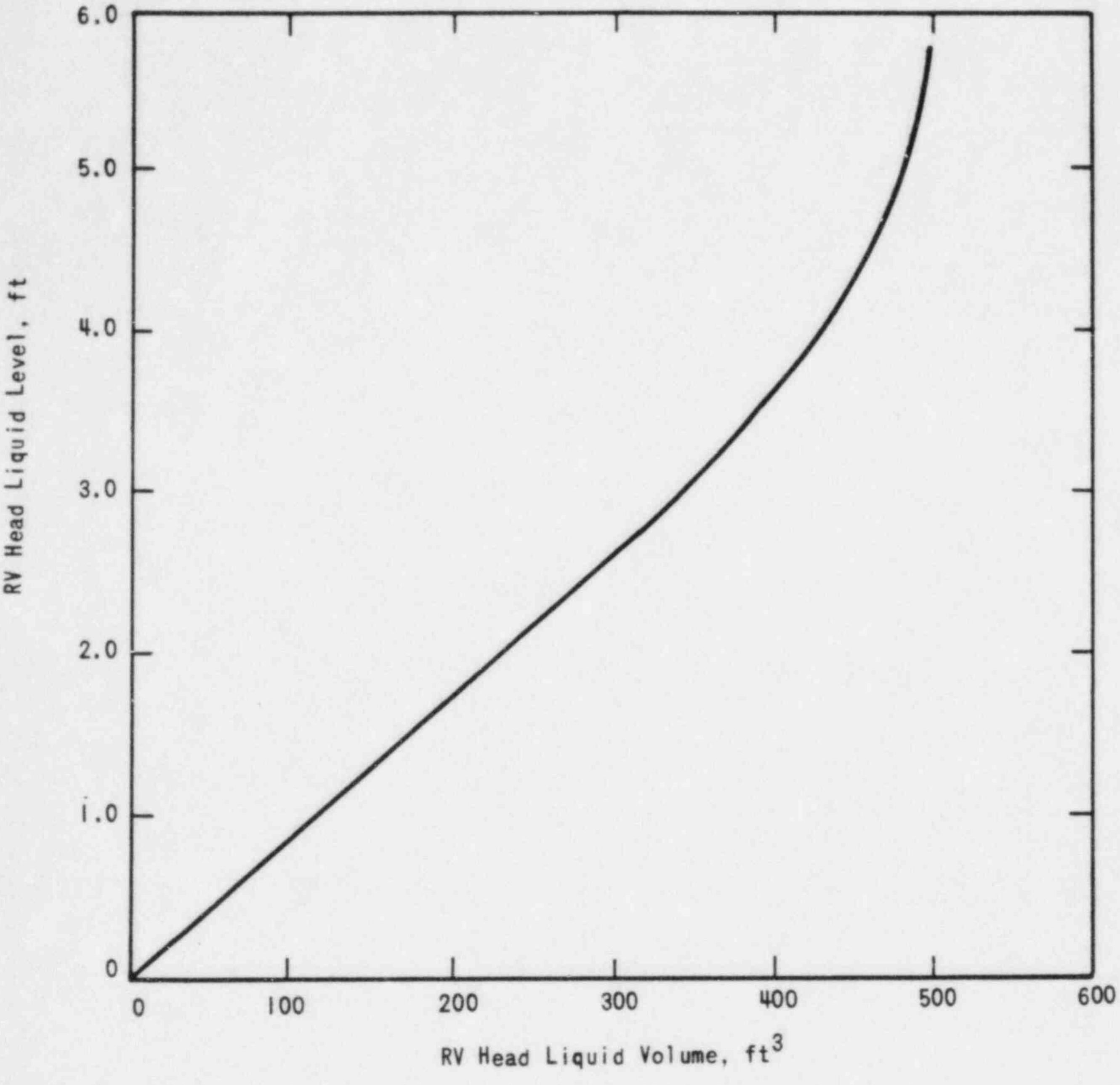


Figure 21. RV Head Level Versus Volume Relationship

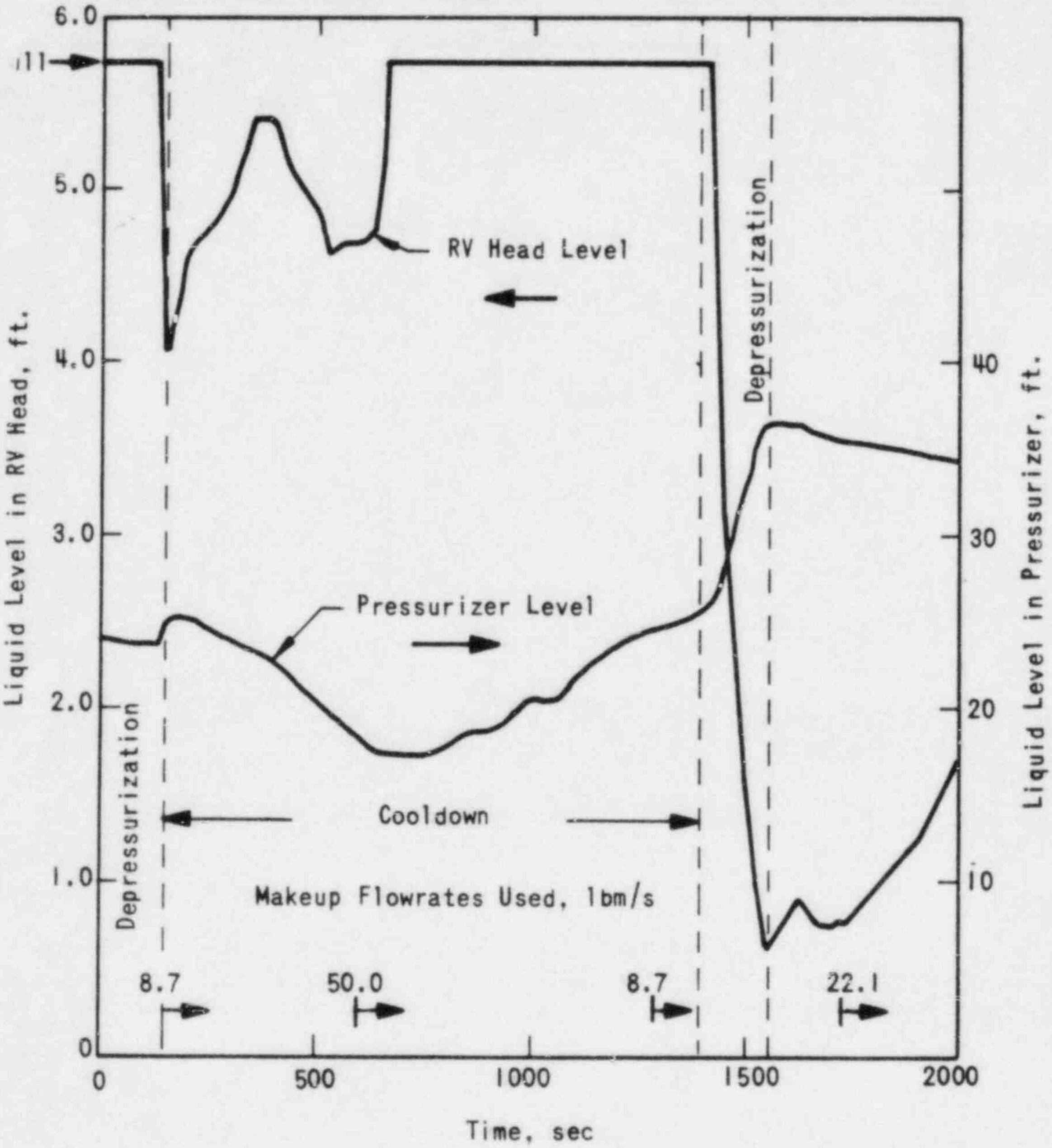


Figure 22. RV HEAD AND PRESSURIZER FLUID LEVEL RESPONSE - 2 1/2" VENT

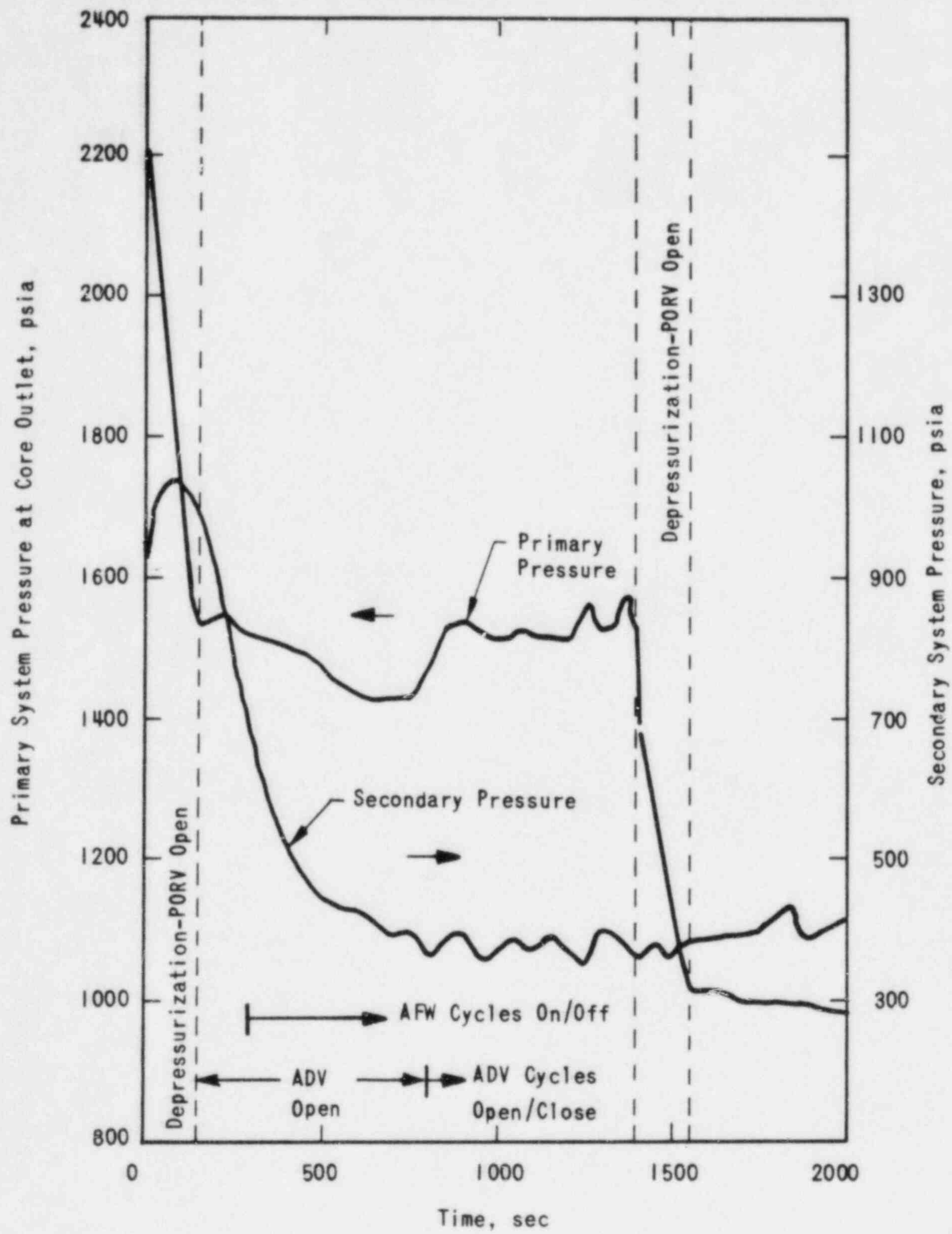


Figure 23. PRIMARY AND SECONDARY PRESSURE - 2 1/2" VENT

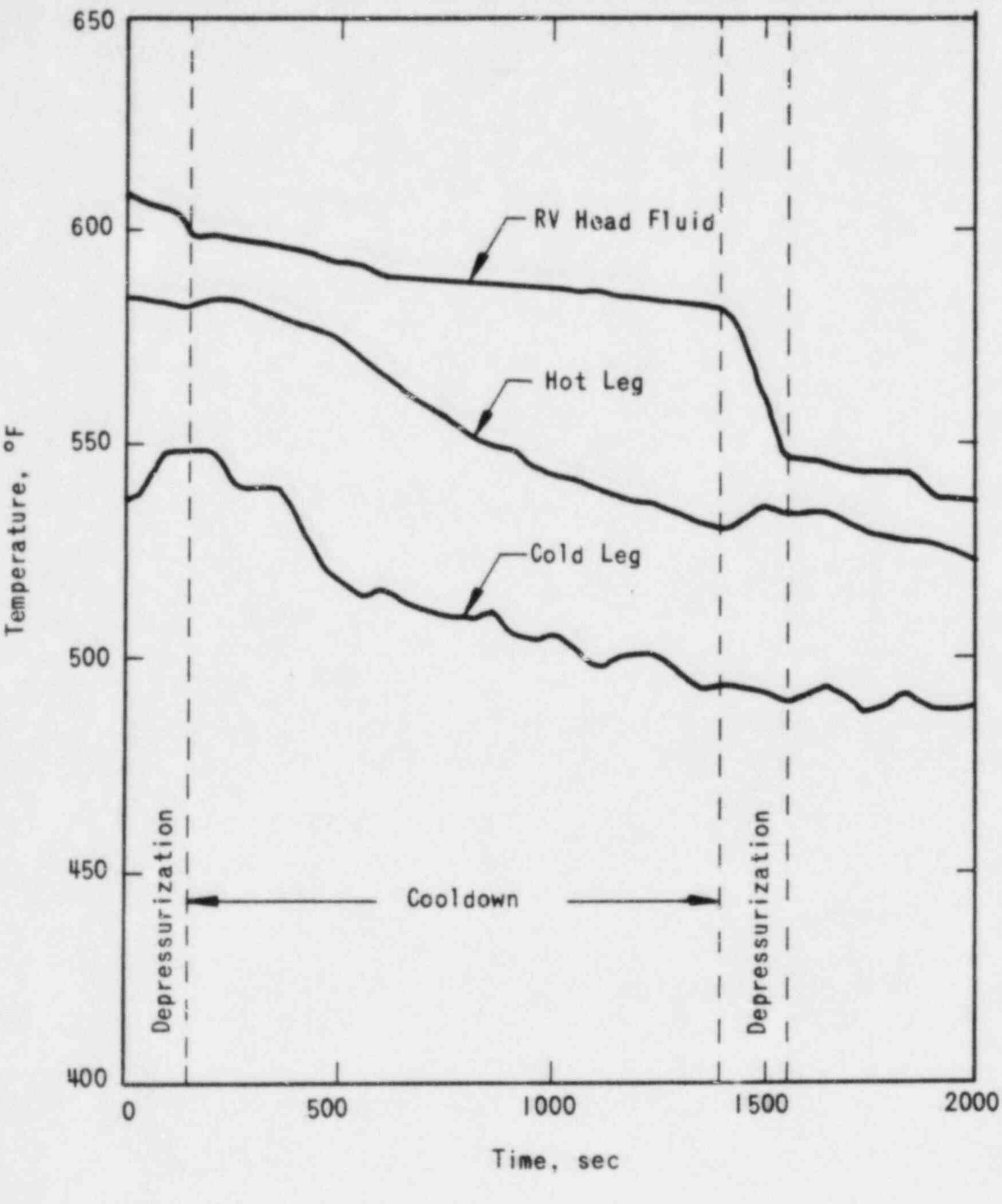


Figure 24. HOT LEG, COLD LEG AND RV HEAD FLUID TEMPERATURE RESPONSE - 2 1/2" VENT

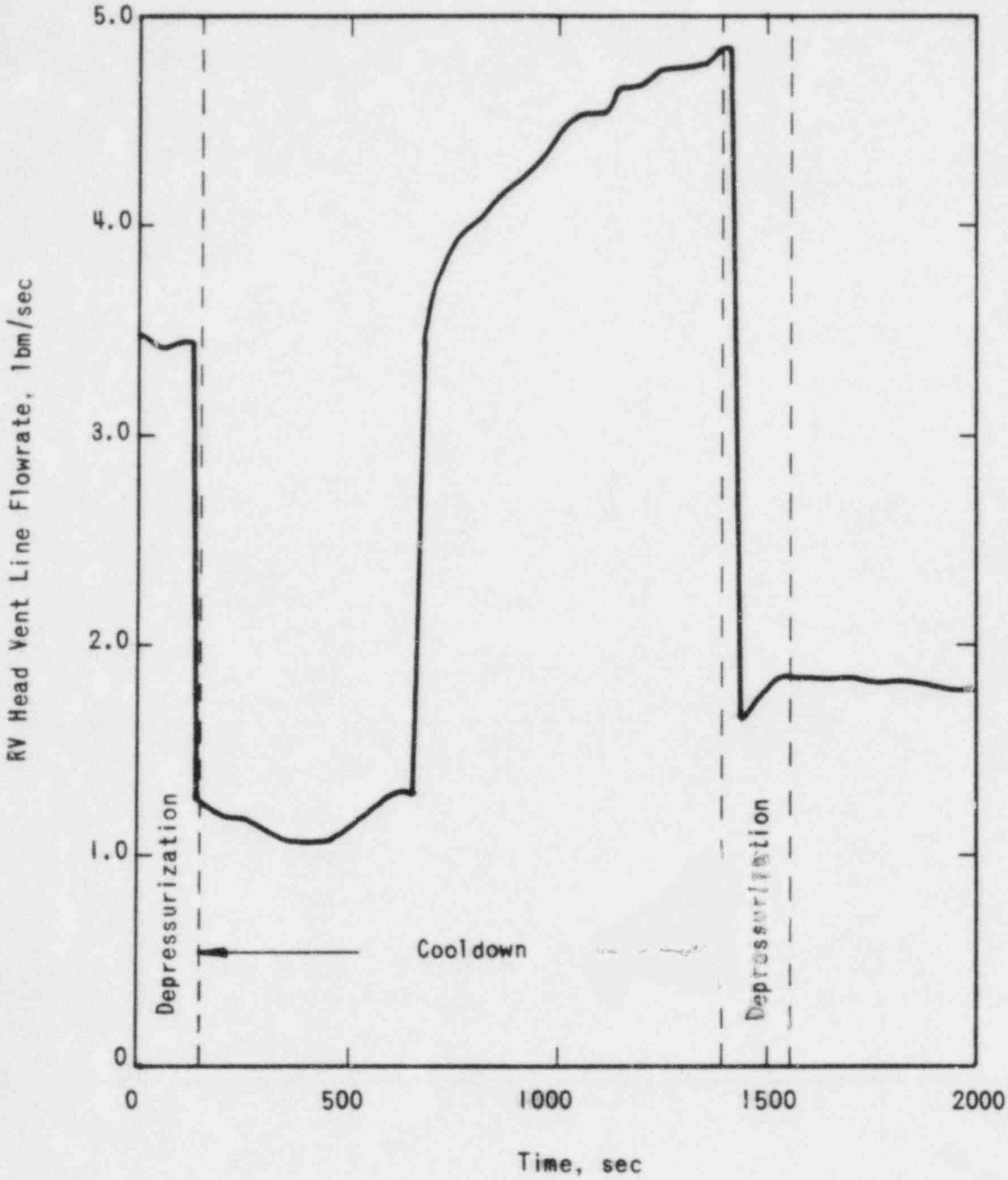


Figure 25. RV HEAD VENT LINE MASS FLOWRATE

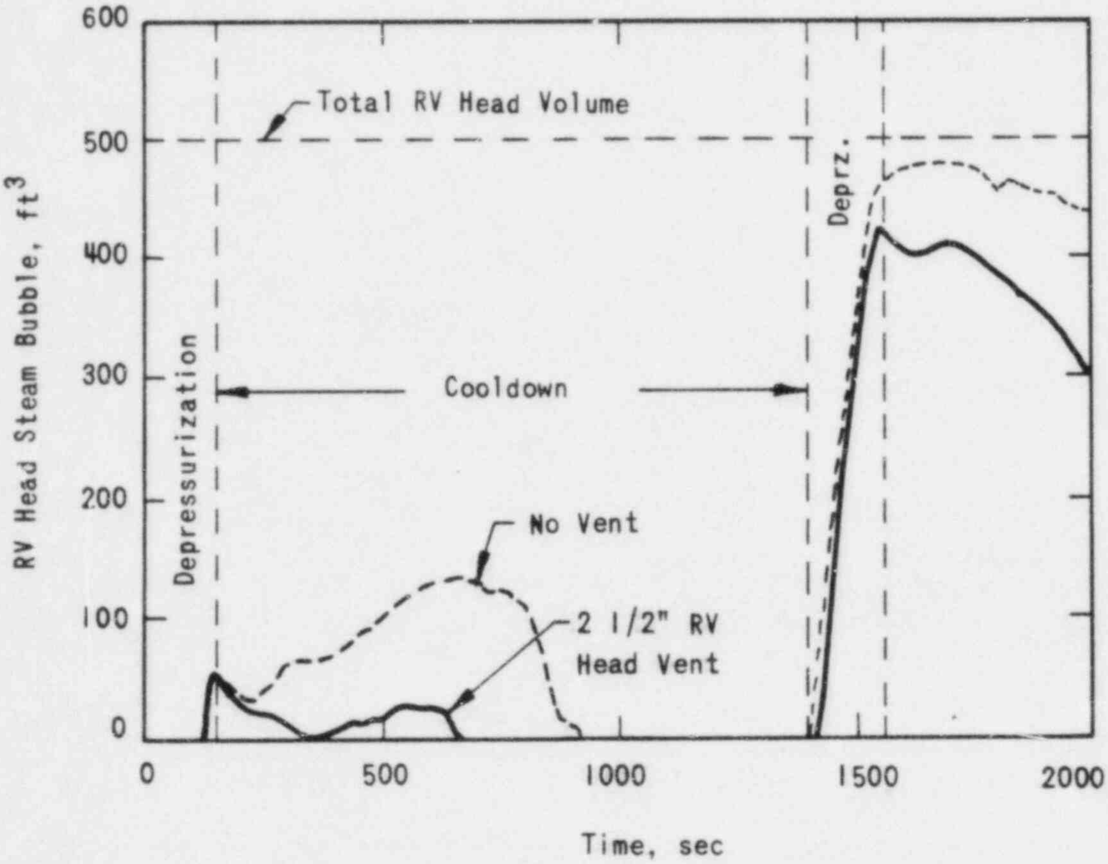


Figure 26. COMPARISON OF RV HEAD STEAM BUBBLE SIZE FOR NO VENT AND 2 1/2" VENT CASES

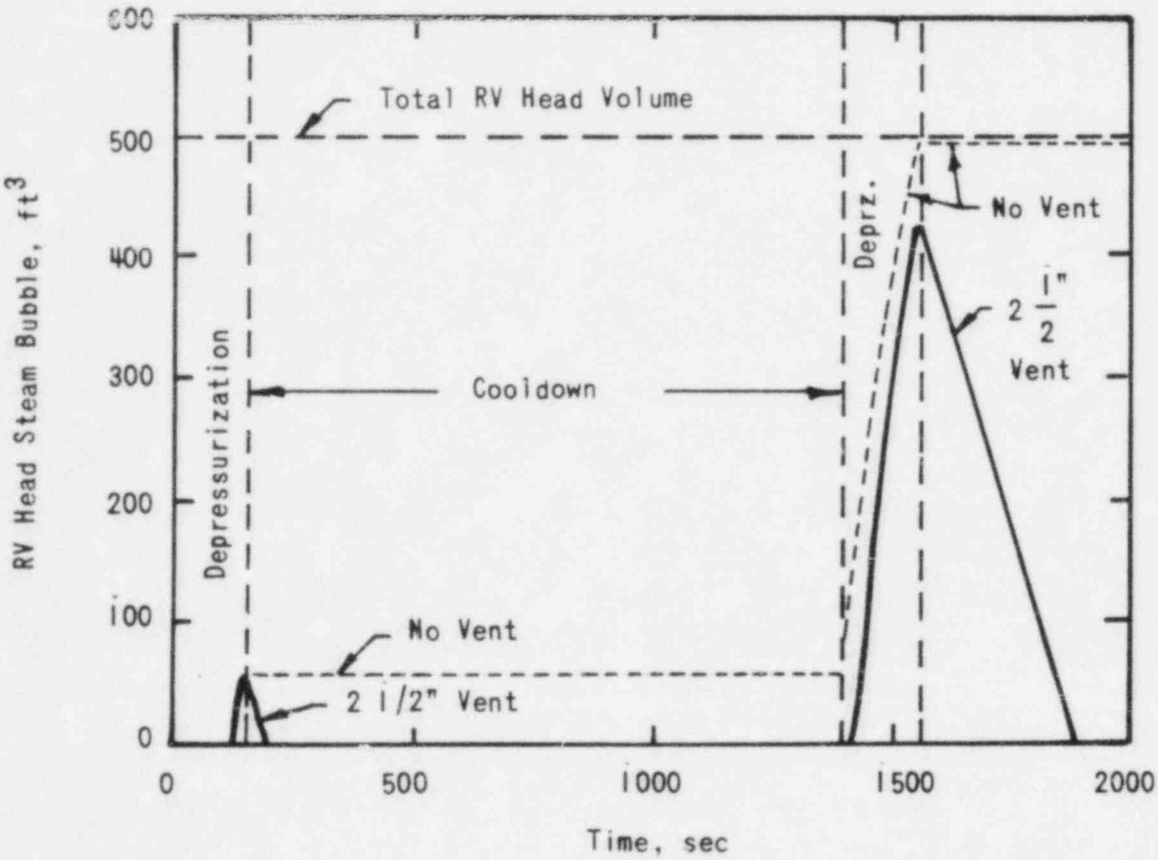


Figure 27: ESTIMATED STEAM BUBBLE SIZE FOR NO VENT AND 2 1/2" VENT LINE CASES (WITHOUT EFFECTS OF ANALYTICAL LIMITATIONS)