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April 4, 1984
5211-84-2082

Office of Nuclear Reactor Regulations
Attn: John F. Stolz, Chief
Operating Reactors Branch No. 4
U. S. Nuclear Regulatory Commission
Washington, D.C. 20555

Dear Mr. Stolz:

Three Mile Island Nuclear Station, Unit I, (TMI-1)
Operating License No. DPR-50
Docket No. 50-289
Natural Circulation Cooldown, (GL81-21)

In response to your letter of July 20, 1983 concerning natural circulation cooldown, enclosed please find our analysis to support operating instruction to prevent void formation in the upper head. The analysis discusses the two dimensional model of the TMI-1 Reactor Vessel (RV) head using the HEATING 6 computer code. The calculations were performed to determine the minimum time required to reach Decay Heat Removal (DHR) initiation (325 psig/300°F). In order to start the DHR system, the head fluid temperature must be below the saturation temperature corresponding to the initiation of DHR. The analysis shows that during a natural circulation cooldown of 10°F/hr in the RCS to 300°F with a hold at 375°F, it would require 46 hours to cooldown the RV head without flashing.

The methodology developed in this report allows simulation of upper head cooldown rates for different RCS cooldown rates. Existing natural circulation cooldown procedures will be improved by consideration of this and other methods being developed. The final procedures will be available at TMI-1 for NRC review in June 1984.

Sincerely,
H D Hukill
H. D. Hukill,
Director, TMI-1

HDH:CWS:mle
Attachments

cc: J. Van Vliet
R. Conte

Sworn and Subscribed to
Before me this 4th day
of April, 1984
Darla Jean Berry
DARLA JEAN BERRY
MIDDLETOWN BORO, DAUPHIN COUNTY
MY COMMISSION EXPIRES JUNE 17, 1985
Member, Pennsylvania Association of Notaries

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ENCLOSURE 1

TMI-1 NATURAL CIRCULATION COOLDOWN ANALYSIS

WITHOUT REACTOR VESSEL UPPER HEAD VOID FORMATION

TABLE OF CONTENTS

1.0 INTRODUCTION

1.1 BACKGROUND

On June 11, 1980, the St. Lucie reactor was shutdown due to a loss of component cooling water to the reactor coolant pump seals. This also required shutdown of the reactor coolant pumps and cooldown was accomplished by natural circulation. At approximately four hours into the event, charging flow, which was initially being divided between the cold legs and the auxiliary pressurizer spray, was diverted entirely to the auxiliary spray to enhance the depressurization and reduce the system pressure on the pump seals. At this time, abnormally rapid increases in pressurizer level were observed. Detailed evaluation and follow-up analyses have indicated that a steam void was formed in the upper head region of the reactor vessel and displaced water from the vessel into the pressurizer. The steam void in the upper head region of the vessel was produced when the system pressure dropped below the saturation pressure corresponding to the temperature of the fluid in the upper head. This was a result of the fluid in the upper head being much hotter than the subcooled indications of the hot and cold leg temperatures at the time of voiding. The upper head fluid has the characteristics of being relatively stagnant and in poor communication with the fluid exiting the upper plenum.

1.2 NRC Concerns and Requirements

Because of the unexpected occurrence of the void during the St. Lucie event, and the failure of the operators to immediately recognize the void formation and take corrective action, the question of whether such void formation is properly accounted for in safety analyses has been an area of concern to the NRC. These concerns relate to a) procedures and training to enable operators to avoid void formation (if possible), or recognize and properly react to reactor vessel head voiding during natural circulation cooldown and b) the possibility that significant head voiding increases the susceptibility of the plant to more serious accidents. In particular, these issues are contained in Reference 1 which requests the following information:

1. A detailed description of the natural circulation cooldown procedure and its basis (it should include guidance on possibility, prevention, and mitigation of upper head voiding and natural circulation interruption).

2. Demonstration by analysis or otherwise, that:
   a) Use of this procedure will not result in upper head voiding
   b) If voiding occurs, the procedure will prevent any voiding at the hot leg elevation

1.3 TMI-1 Natural Circulation Cooling Procedure OP 1102-16

Operating procedure 1102-16 addresses RCS natural circulation cooling for TMI-1 in which a cooldown rate not to exceed 10°F/hr is prescribed as a means of preventing upper head voiding. Section A.2.6 and B.2.6 include guidance on possibility and mitigation of upper head voiding as quoted below:

> Voids may occur in the Reactor Vessel head while depressurizing the RCS due to head water temperature being higher than RCS temperature. This condition may be evidenced by a large rapid increase in pressurizer level while reducing RCS pressure even though an adequate saturation margin is indicated between T_h (hot leg temperature) and RCS pressure. Should this condition occur, RCS pressure must be increased to collapse the bubble in the vessel head and return pressure control to the pressurizer. Reference IE Circular 80-15.

In addition, the procedure will prevent any voiding at the hot leg elevation by Steps A.2.5 and B.2.5:

> Voids in the RCS can cause steam to accumulate at the top of the hot legs and interrupt natural circulation. This is prevented by establishing and maintaining at least a 25°F subcooled margin after Reactor Coolant Pump trip.

As a result of the analysis presented in this report, improvements to the procedure have been identified. These improvements are discussed in Section 5 "Operational Guidelines" and are subject to in-house review and verification prior to implementation.

1.4 TMI-1 Natural Circulation Cooldown Analysis without Reactor Vessel Upper Head Void Formation

To determine the procedural requirements to prevent reactor head void formation, an analysis was performed of TMI-1 natural circulation cooldown. A two-dimensional model of the TMI-1 RV upper head was developed for the HEATING6 computer code. HEATING6 is a multi-dimensional, generalized heat conduction code which was used to model the heat transfer processes which govern cool down of the RV upper head under natural circulation conditions.

The calculations were performed to determine the minimum time required to reach the decay heat removal system cut-in point which can be initiated at 325 psig and RCS temperature of 300°F based on the system design. In order to start the decay heat removal system, the vessel head fluid temperature must be below the saturation temperature corresponding to pressure for the cut-in point of the DHR system. The saturation temperature corresponding to 325 psig is 429°F; the results of the analysis indicate that it would take 46 hours to cool the head to this temperature, based on an RCS cooldown rate of 10°F/hr (this includes a 15 hour 'hold' period at 375°F).

2.0 TMI-1 REACTOR VESSEL UPPER HEAD COOLDOWN MECHANISMS

During natural circulation, the fluid in the RV upper head is relatively stagnant since the reactor coolant system loop flow rates are significantly smaller than during forced circulation. This can be seen on Figure 2-1, which shows the structural components of the TMI-1 upper head, where the plenum cover acts as a barrier which tends to isolate the RV head fluid from the rest of the RCS. Flow into the head region is through the CRD guide tubes which extend approximately one foot above the plenum cover. Under natural circulation, fluid flow through the CRD guide tubes is at low velocity. Consequently, this fluid is not expected to mix with the majority of fluid in the RV head dome. The cool down of the head metal and fluid is a slow process which is governed by the heat transfer mechanisms described below, and the small amount of coolant that flows over the plenum cover. Figure 2-2 illustrates qualitatively the heat transfer mechanisms associated with RV upper head cool down, while Figure 2-3 depicts anticipated fluid circulation patterns present in the upper head water.

The head cooling mechanisms are:

- o Heat transfer from the insulation exterior to containment is considered to occur by convective processes and by radiative heat transfer.

- o Conduction heat transfer across the three (3) inch thick insulation is the predominant heat transfer mechanism.

- Convection and radiative heat transfer to the inside surface of the insulation occurs from the air space located between the vessel and insulation.

- Heat from the vessel walls is transferred into the air space by convective and radiative heat transfer. In addition, heat will be conducted along the metal walls toward the CRDM nozzles located in the vessel head.

- Heat from the upper head wall is conducted along the steel vessel wall toward the inlet coolant located in the annulus between the vessel walls and the core thermal shield and from the vessel walls to the nozzle regions which will be cooled by the loop flows.

- Heat from the air space is convected to the CRDM nozzles located at the top of the vessel head.

- Circulation patterns in the upper head water promotes heat transfer to the vessel walls by convection. In addition, heat is removed from the upper head water by means of convective heat transfer between the water, CRDM nozzles and lead screws.

- Heat transfer occurs between layers of upper head water at different temperatures by means of convective mixing.

- Heat is convected from the upper head water to the CRD lead screws. Two boundary temperature conditions were applied to the lead screw. Above the plenum cover, the lead screw temperature at the top of the CRD guide tube was taken to be the temperature of the fluid in the guide tube. At the CRD nozzle mating flange, the lead screw temperature was calculated based on a heat transfer analysis performed on the CRD lead screw.

- In the short period of time following the 4 RCP trip, heat is convected from the plenum cover and structural members below to the plenum coolant. During the remaining cooldown period, plenum coolant which enters the upper head via CRD guide tubes mixes with water in the lower region of the upper head.

- Energy is transported from the upper head by means of effluent water which passes through the annulus to the hot leg. Water which exits the upper head is replaced by water from the CRD guide tubes which forms a boundary temperature equal to the system temperature shortly into the transient.

FIGURE 2-1: REACTOR VESSEL UPPER HEAD COMPONENTS

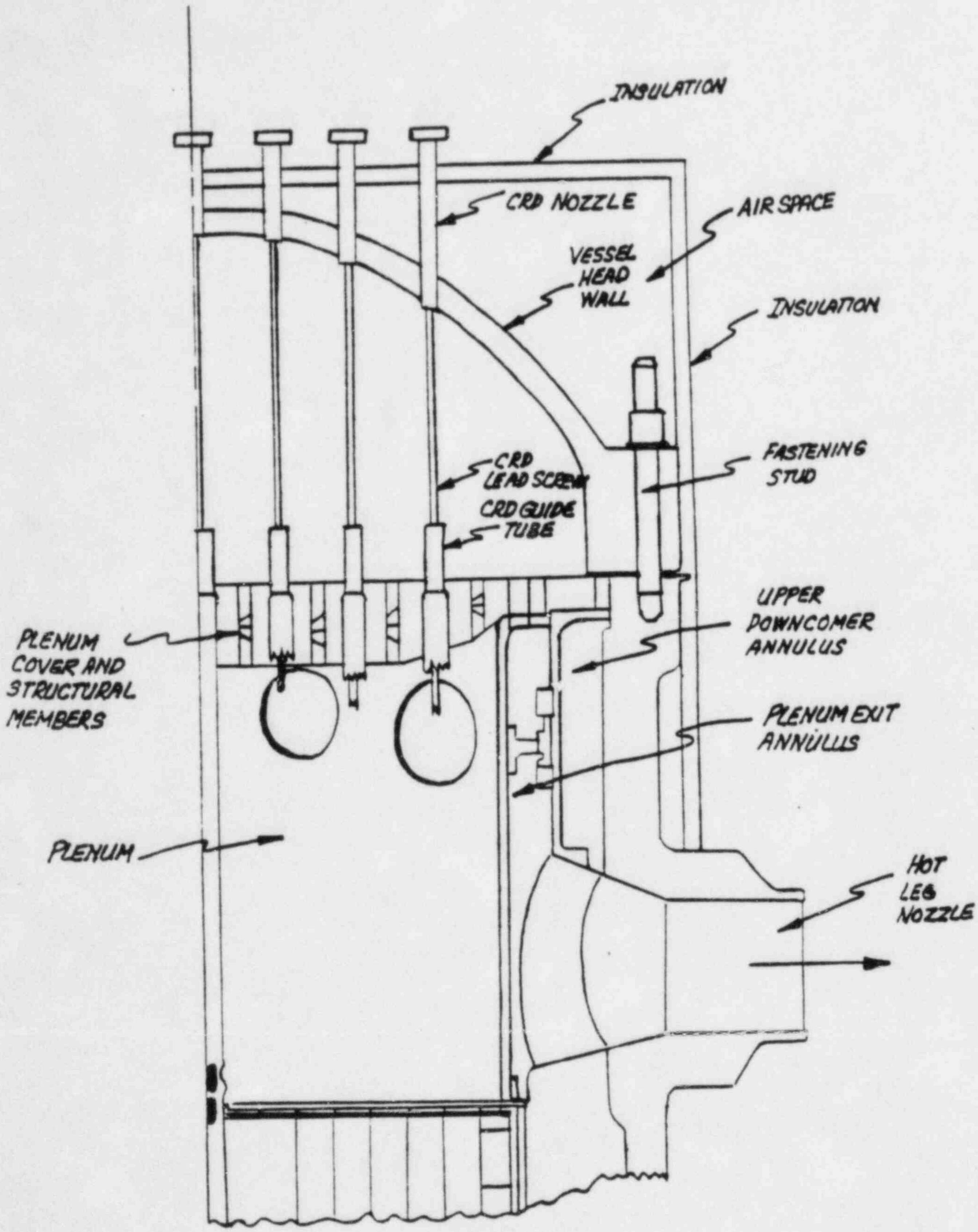


FIGURE 2-2: REACTOR VESSEL UPPER HEAD HEAT TRANSFER MECHANISMS

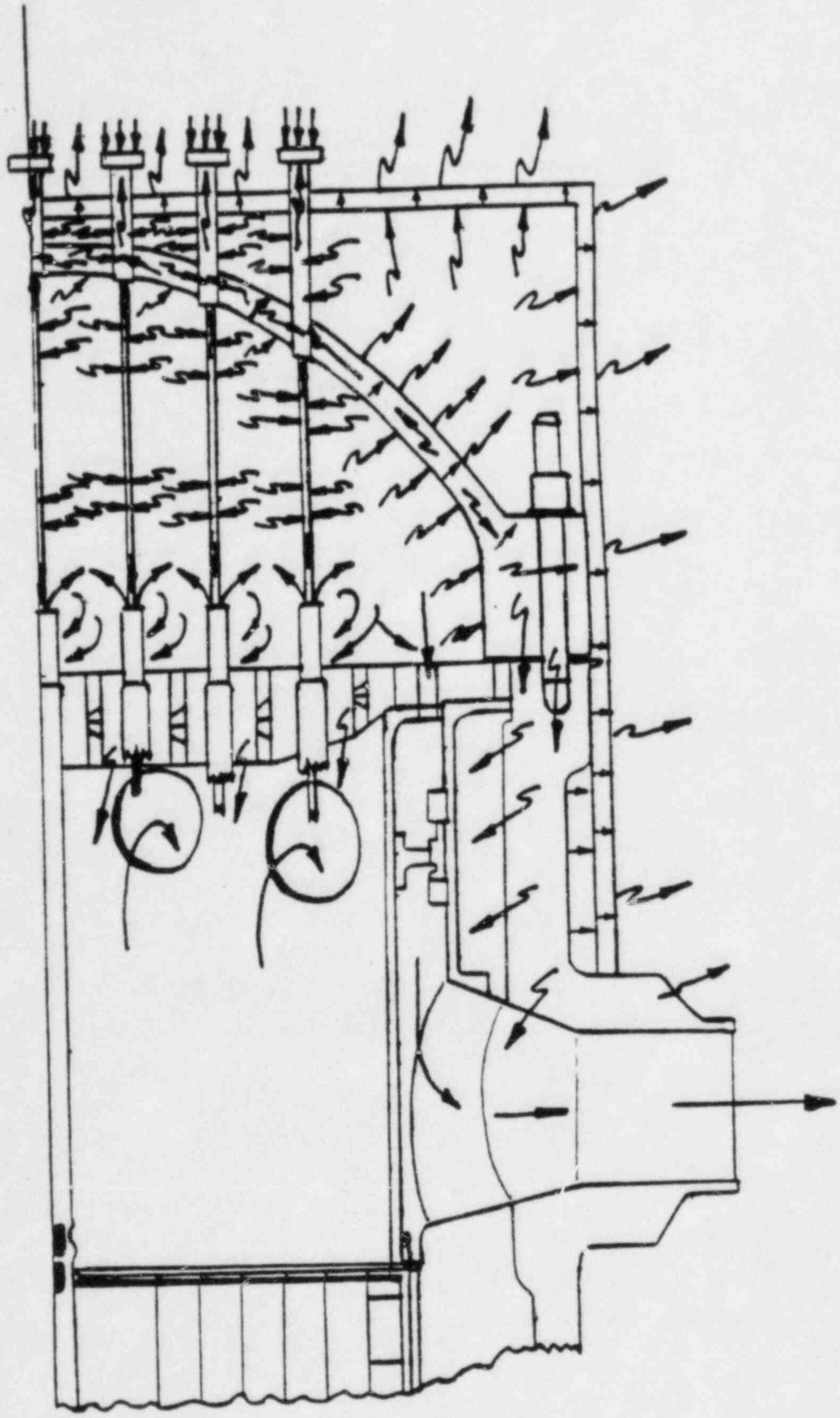
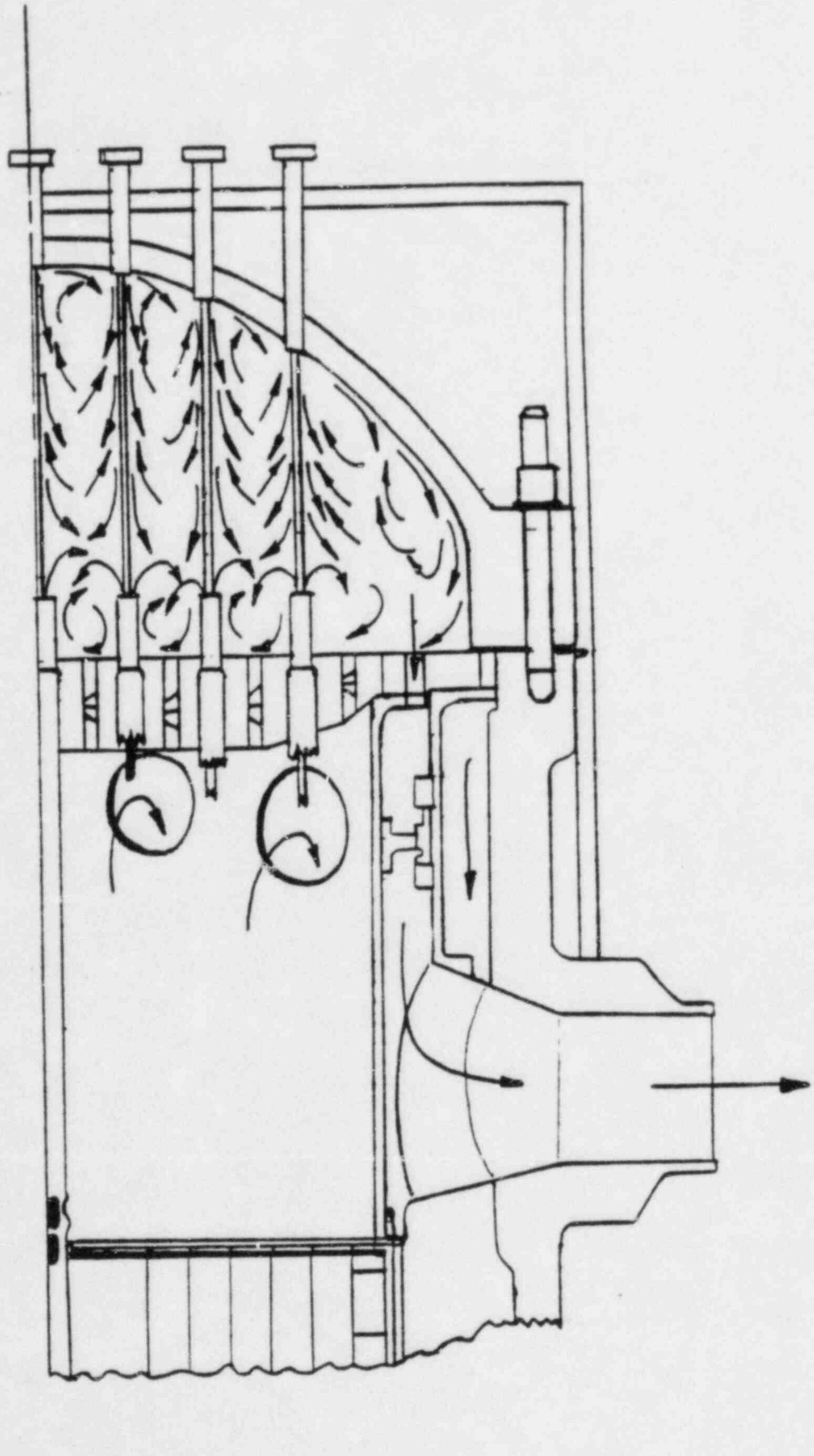


FIGURE 2-3: UPPER HEAD CIRCULATION PATTERNS



3.0 HEATING6 MODEL OF TMI-1 UPPER HEAD

3.1 HEATING6 Code

HEATING6 is a multi-dimensional, generalized heat conduction code which may be applied to problems which require steady state and/or transient solutions[2]. Various material thermophysical properties may be taken to be anisotropic or temperature or time dependent. Boundary conditions may be applied by means of the following:

- o Coefficients for convective heat transfer
  - natural convection
  - forced convection
- o Coefficients for radiative heat transfer
- o Temperature
- o Heat flux

User supplied subroutines allow flexibility in the manner in which the foregoing may be developed. Both explicit and implicit finite difference methods of solution are available to the user.

3.2 Upper Head Model

The HEATING6 model of the TMI upper head was developed in two dimensional R-Z geometry making use of the vessel symmetry about the center control rod drive. In developing the model, care was taken to account for the heat transfer paths and mechanisms associated with the cooldown of the upper head as discussed in the previous section. The primary components of the model are the plenum cover, the upper head water mass, the vessel walls, the vessel head, and the vessel insulation. Vessel component dimensions were obtained from construction drawings. Ninety-one regions and 2003 nodes were used to describe the head in detail. Figures 3-1 and 3-2 show the regions and materials of the HEATING6 RV upper head model, which are discussed in detail below.

The carbon steel vessel walls were modeled from the mating surface down to a point just above the hot leg nozzle. The cold leg water between the vessel wall and the core thermal shield was also included. The plenum stainless steel cylinder was included for several inches to account for it as a conduction path. The plenum cover and structure were also modeled. Above the plenum cover to the top of the CRD guide tubes is an area of mixed water (i.e. flow through the CRD guide tubes mixed with upper head water). Above this point, upper head water (designated as H2OHIK on Figure 3-2) is present. In this region, an effective thermal conductivity of water was employed to account for natural convection heat transfer between nodes and fluid layer mixing.

The CRD leadscrews, guide tubes, and nozzles were modeled in a similar fashion. The 69 CRD mechanisms were lumped into four concentric cylinders. The leadscrew cylinders were distributed radially along with the nozzle and guide tube cylinders. Each guide tube and nozzle cylinder is located next to a leadscrew cylinder.

The head was modeled using a "stair-step" approximation to the spherical shape. The flange of the head is modeled as a cylinder with another cylinder on top of it, and finally with a disk to represent the top of the head.

The insulation is modeled as a cylinder with an outer radius of 103 inches. The top of the insulation is modeled as a disk. The insulation was placed at an average distance above the head since its distance from the head actually varies with the radius of the head.

3.3 Assumptions

The following modeling assumptions were used in the analysis:

1. The spherical head was approximated as a disk on top of two cylinders.

2. The resistance to heat transfer offered by the 0.125" stainless steel cladding on the interior of the vessel was assumed to be negligible.

3. Mixing of the upper head water immediately above the plenum cover and the RCS water coming through the plenum cover was assumed based on an energy balance. This energy balance produced a temperature for the boundary condition at the top of the CRD guide tubes.

4. Flow into the upper head region from below the plenum cover was assumed to mix only in the first 20.50 inches above the plenum cover. No penetration of this flow beyond the top of the CRD guide tubes was assumed.

5. Heat transfer from below the plenum cover was conservatively based on a forced convection heat transfer coefficient for flow over a flat plate.

6. Except for the boundary condition below the plate, heat transfer by means of natural convection was assumed to occur at all metal - water interfaces in the upper head.

7. The CRD convective heat losses (to the service structure region and ambient containment conditions) were not accounted for. Instead, a CRD temperature of a 120°F was maintained at 3 1/2 feet above the RV head based on a simplified heat transfer analysis performed on the CRD lead screw.

8. When cold fluid was located on top of hot fluid, mixing was assumed to occur.

9. Mixing was assumed to occur radially when a temperature difference existed.

10. The thermophysical properties of the stainless steel mirror insulation were estimated from its thermal conductivity and knowledge of its construction.

11. An initial temperature of 604°F was assumed throughout most of the RV head. This temperature includes measurement uncertainty[3], and is approximately the hot leg temperature for 100% power, and maximizes the energy in the RV head.

12. Subsequent to the 4 RCP trip, the flow coastdown results in natural circulation flow which stabilizes at 3% of the RCS flow with 4 RCPs running.

13. Coolant flow into the upper head through the CRD guide tubes was assumed to be 8% of the RCS flow at any given time [4].

14. A four pump coastdown was conservatively assumed to be coincident with the reactor trip. Operation of the RCPs after a reactor trip will reduce the RV upper head temperature from the full-power hot leg temperature to the lower post-trip hot leg temperature, since the RV head region temperature follows the hot leg temperature during forced flow conditions in the RCS. The amount of upper head temperature reduction will be dependent upon the length of RCP operation assumed after the reactor trip and the post-trip decrease in hot leg temperature.

15. The ambient (reactor building) temperature was assumed constant at 120°F.

3.4 Initial Conditions

Initial conditions which were imposed on the thermal model of the RV upper head are shown in Figure 3-3 and explained below:

- o The plant was assumed to be at 100% operating power.
- o Upper head metal and water were assumed to be at 604°F.
- o The insulation and cold leg were taken to be at 333°F and 555°F respectively.
- o Containment air temperature was taken to be 120°F and assumed to be invariant throughout the cooldown period.

At time (t=0+), the transient was initiated with the following events imposed:

- o Reactor trip with insertion of control rods achieved.
- o Coincident with the reactor trip, 4 RCPs are tripped.
- o Following the 4 RCP trip, RCS flow was taken to decay with pump coastdown.

3.5 Boundary Conditions

Various boundary conditions were applied to components of the upper vessel head model. The types that were used are delineated below and illustrated on Figure 3-4.

3.5.1 Specified Temperature

As explained in Section 3.3, a constant temperature (120°F) boundary condition was maintained at the top of the CRD leadscrews and nozzles (BC5). A time dependent temperature (which is a function of the cooldown rate) was applied at the lower surface of the lower plenum and hot leg metal interface (BC2).

A time dependent boundary temperature was defined at the interface between the RCS coolant and upper head water located above the plenum cover.

This temperature was based on the mixing of water from the CRD guide tubes with the water on top of the plenum cover. The flow rate leaving the upper plenum cover was equal to the flow rate of the water coming in through the CRD guide tubes. The boundary temperature closely follows the RCS hot leg temperature.

3.5.2 Convective Heat Transfer

Natural convection heat transfer coefficients were applied at the lower boundary of the upper head water and at the top of the plenum cover (BC1 and BC6), to provide a conservative heat transfer margin.

Similarly, a natural convection heat transfer coefficient was applied to the annulus between the vessel wall and the core thermal shield through which RCS coolant from the steam generators is directed to the core (BC9).

In the upper head, a natural convection heat transfer coefficient was applied at the interface between all metal surfaces and water (BC7 and BC8).

Natural convection coefficients were also applied to the following model components:

- To the outside surface of the insulation (BC4)
- To the air space between the vessel head and the inside surface of the insulation (BC3)

The coefficients were calculated by means of an iterative procedure performed on the conduction and convection heat transfer relationships. A known steady state heat flux across the insulation was used in the procedure to predict temperatures on the interior and exterior surfaces of the insulation. Subsequently, the temperatures were used to predict suitable convective coefficients. It should be noted that the convective coefficient that was used between the vessel wall and the inside surface of the insulation is assumed to include radiative heat transfer effects. Since it was difficult to determine an appropriate radiative heat transfer coefficient for the complex geometry of the air space, the lumped convective coefficient was adopted and the air space was modeled as an area devoid of material.

FIGURE 3-1: HEATING6 MODEL OF TMI-1 UPPER HEAD

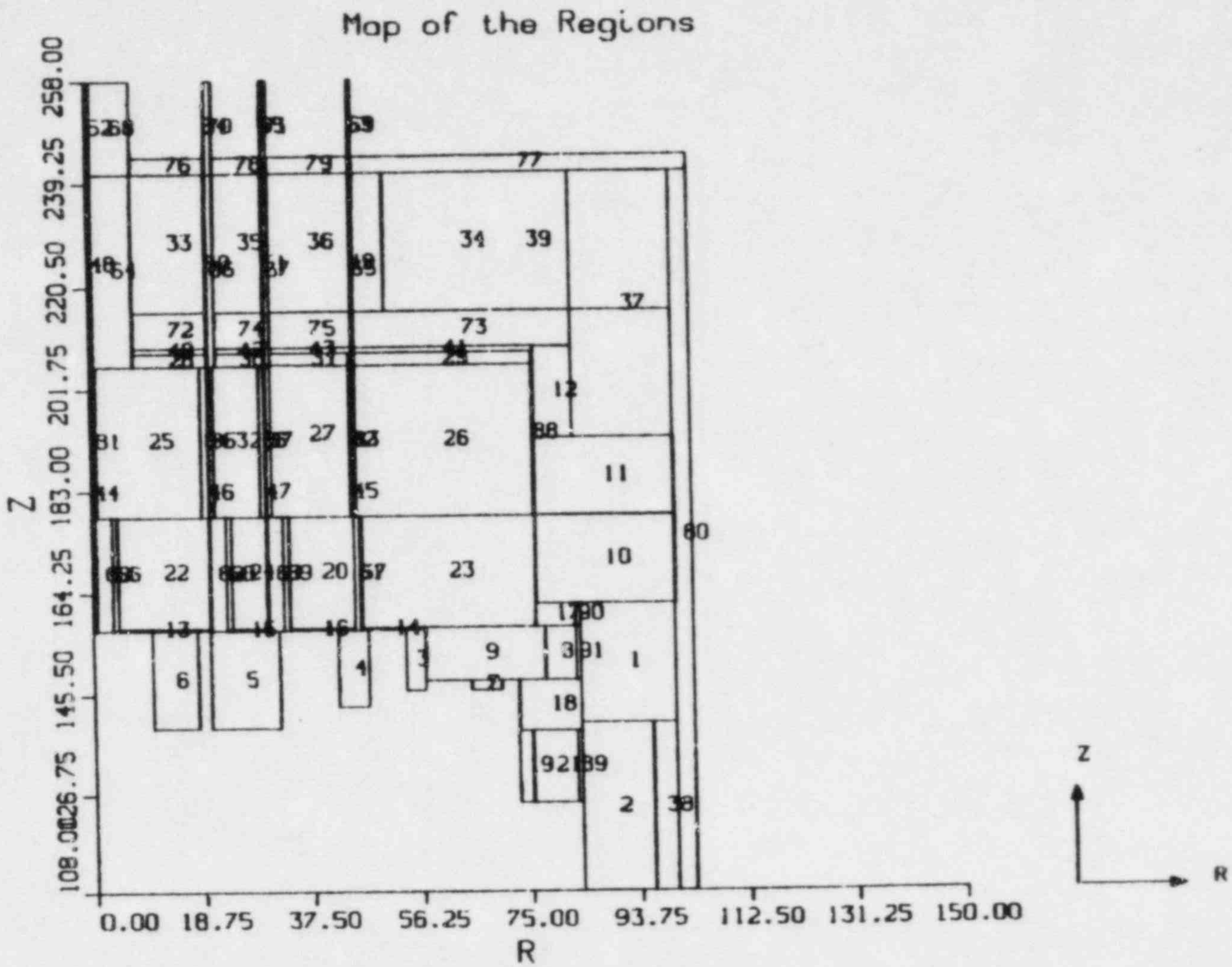
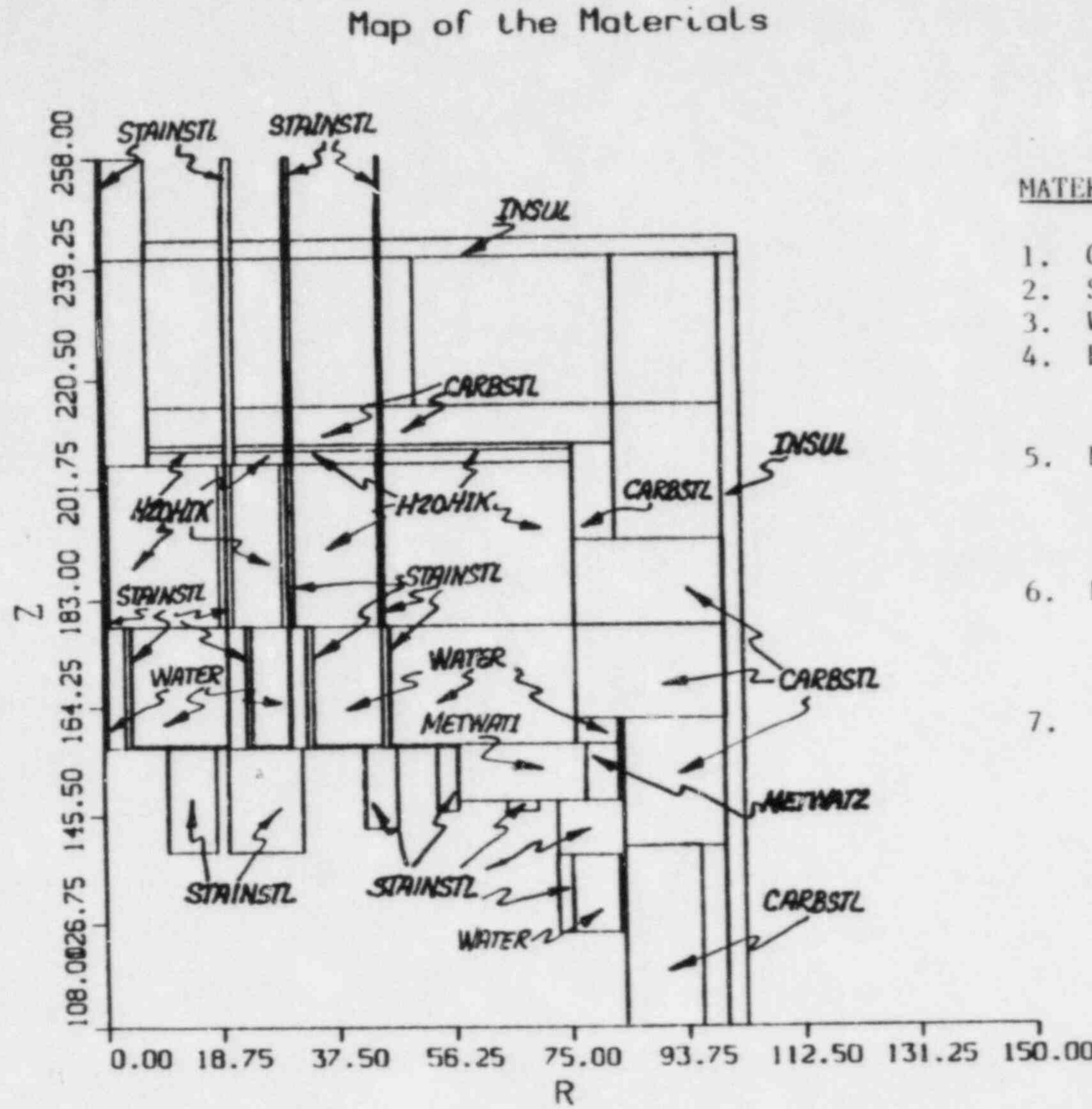


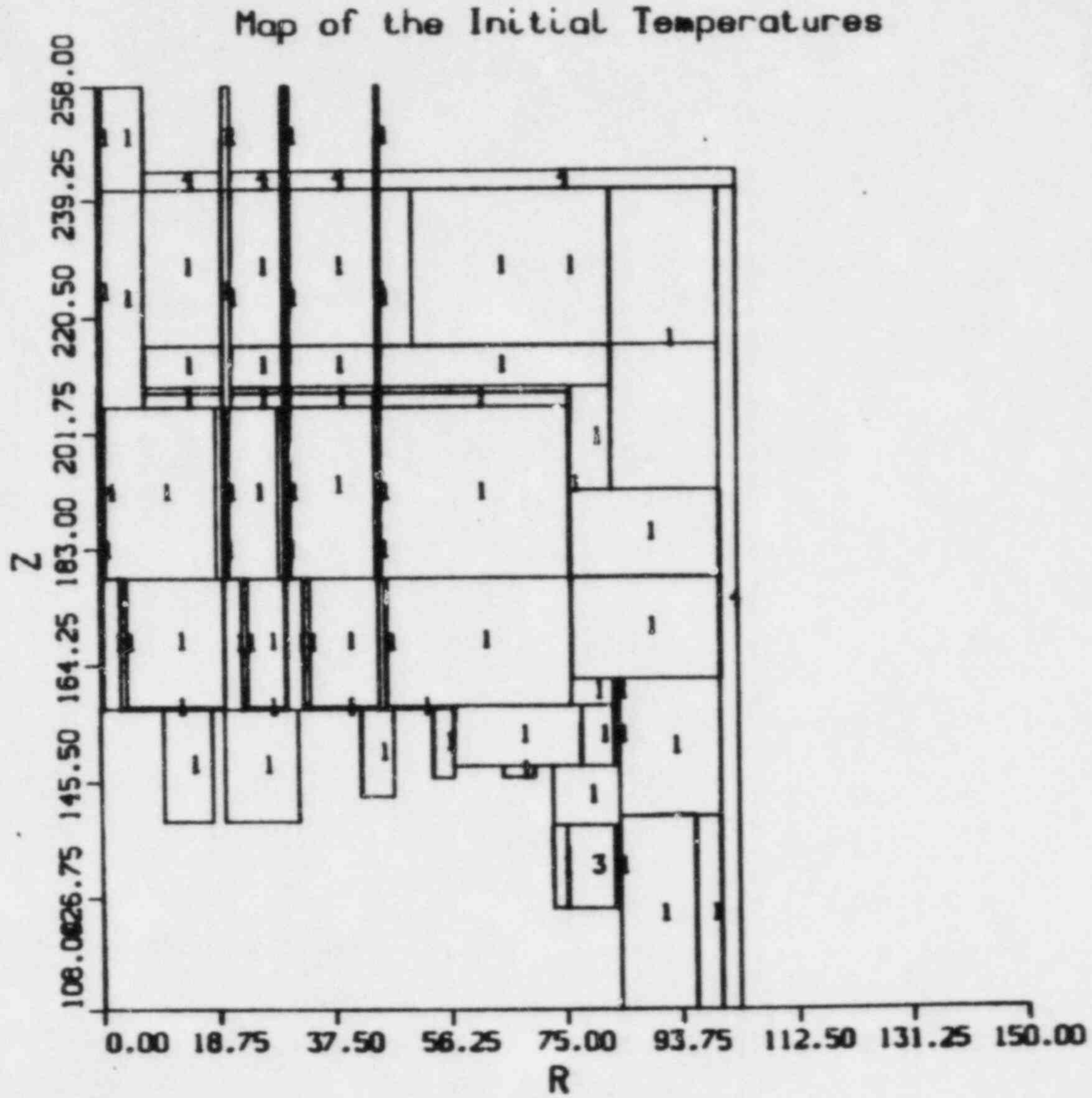
FIGURE 3-2: HEATING6 MODEL OF TMI-1 UPPER HEAD



MATERIAL LEGEND

1. CARBSTL - Carbon Steel
2. STAINSTL - Stainless Steel
3. WATER - Water
4. H2OHIK - Water at an effective thermal conductivity (mixing influenced)
5. METWAT1 - Water and structural members composite in the vicinity of the plenum
6. METWAT2 - Water and structural members composite in the vicinity of the plenum
7. INSUL - Insulation

FIGURE 3-3: HEATING6 MODEL OF TMI-1 UPPER HEAD



INITIAL TEMPERATURE LEGEND

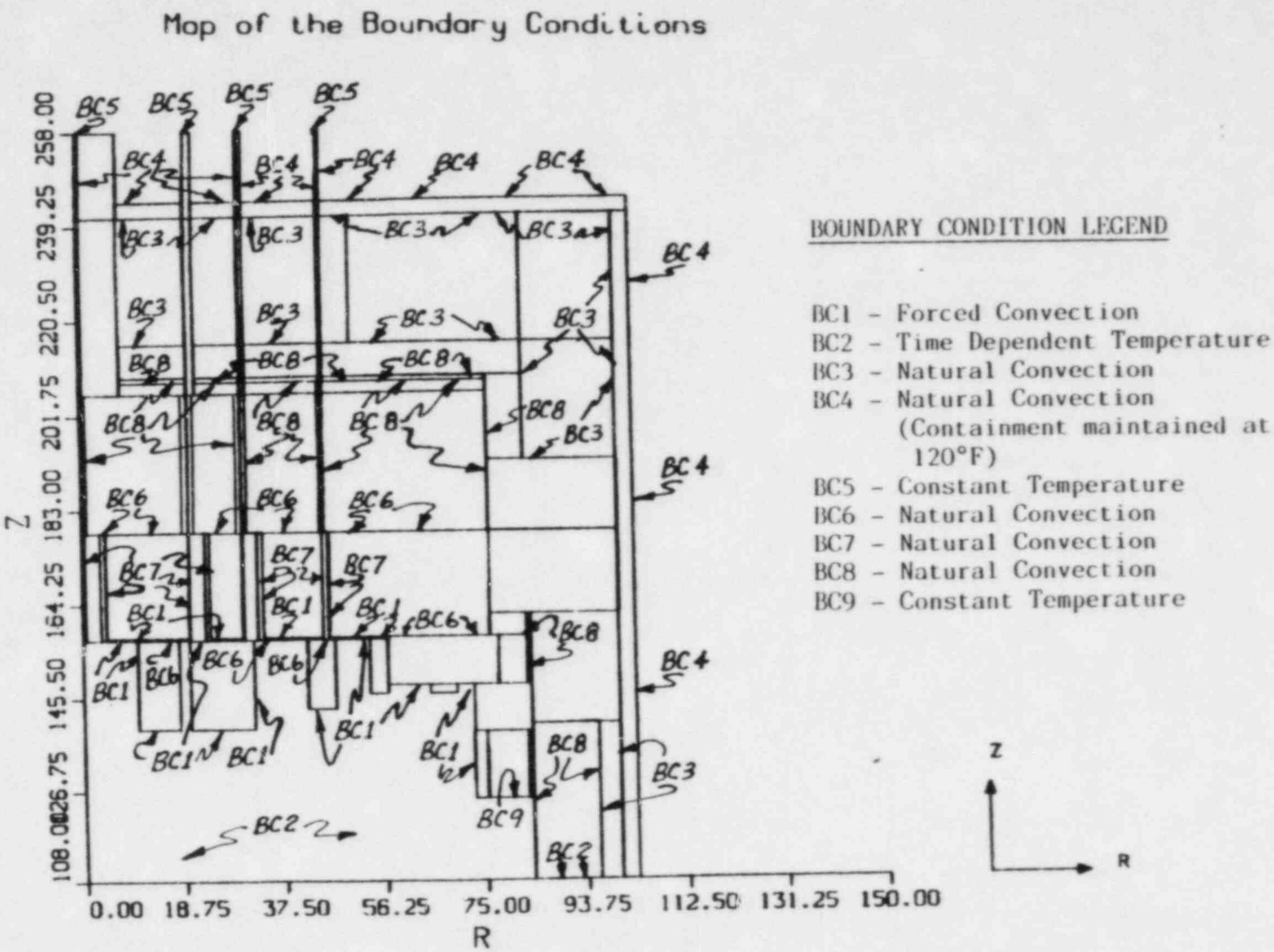
1. TØ = 604.0°F

2. TØ = 604.0°F

3. TØ = 555.0°F

4. TØ = 333.4°F

FIGURE 3-4: HEATING6 MODEL OF TMI-1 UPPER HEAD



4.0 ANALYSIS RESULTS

The RV head cooldown analysis was performed for a RCS cooldown rate of 10°F/hr. The results are shown on Figures 4-1 and 4-2 and are discussed in detail below.

The analysis was carried out to the cut-in point of the decay heat removal system (325 psig and RCS temperature of 300°F). In order to start the decay heat removal system, the head fluid temperature must be below the saturation temperature corresponding to the cut-in point, which is 429°F. A volume average temperature in the top foot of the vessel head was used as representative of the overall upper head temperature as explained below.

4.1 Volume Averaging of the Top Foot of the Vessel Head

Heat transfer by means of natural convection is a complex process which involves mass and energy transport at relatively low fluid velocities. Fluid circulation in natural convection is attributable to buoyant forces which arise from temperature variations in the fluid. Consequently, free convective flow is compressible flow. In this process, the convective heat transfer coefficient is characterized by the product of the Prandtl and Grashof numbers, the Grashof number being proportional to the ratio of buoyant to viscous forces.

In the model of the TMI-1 vessel head, circulation patterns are expected to develop as shown on Figure 2-3. The patterns account for cooling of the CRD lead screws via heat transfer to the environment beyond the insulation. In addition, it is reasonable to expect energy transport to occur by means of mixing which may take place between fluid layers at different temperatures.

HEATING6 is a heat conduction computer code and is, therefore, limited by the following:

- The mesh applied over the geometry of interest is fixed in size. The mass which occupies each unit component is assumed to be concentrated at the geometric center.

- If each unit mesh is considered an elemental control volume, then its thermodynamic equivalent is the system. Consequently, mass transport across control surfaces is non-existent.

- In HEATING6, the variation of material density as a function of temperature does not satisfy the conservation of mass in this code. Consequently, the density of water for the TMI-1 upper head cooldown problem was assumed to be 51.84 lbms/ft^3. This value tends to bias the heat capacitance term of the hotter nodes to slightly higher values.

- o Accountability for mass transport across a unit mesh and thermodynamic mixing within the mesh must be related to the material thermal conductivity by means of an effective thermal conductivity.

It is expected that the upper head water will establish circulation patterns toward and away from the CRD lead screws throughout the vessel cooldown. Consequently, it is not unreasonable to expect the water temperature in close proximity to the CRD lead screws to be at a nearly uniform temperature. Further, only four CRD lead screws were accounted for in the upper head model. The cooling influence of additional lead screws in close proximity were not considered. Given the computer code limitations and the modeling assumptions, the use of an average temperature in the top foot of the upper head is a reasonable yet conservative representation of the fluid conditions in the RV head.

4.2 <u>RCS Cooldown at 10°F/HR</u>

Figure 4-1 shows the RCS cooling down from 604°F to 375°F in 23 hours. Subsequently, the plant is assumed to be in a 'soak' or 'holding' period at 375°F for 15 hours followed by a cooldown to 30[illegible]°F at 10°F/hr.

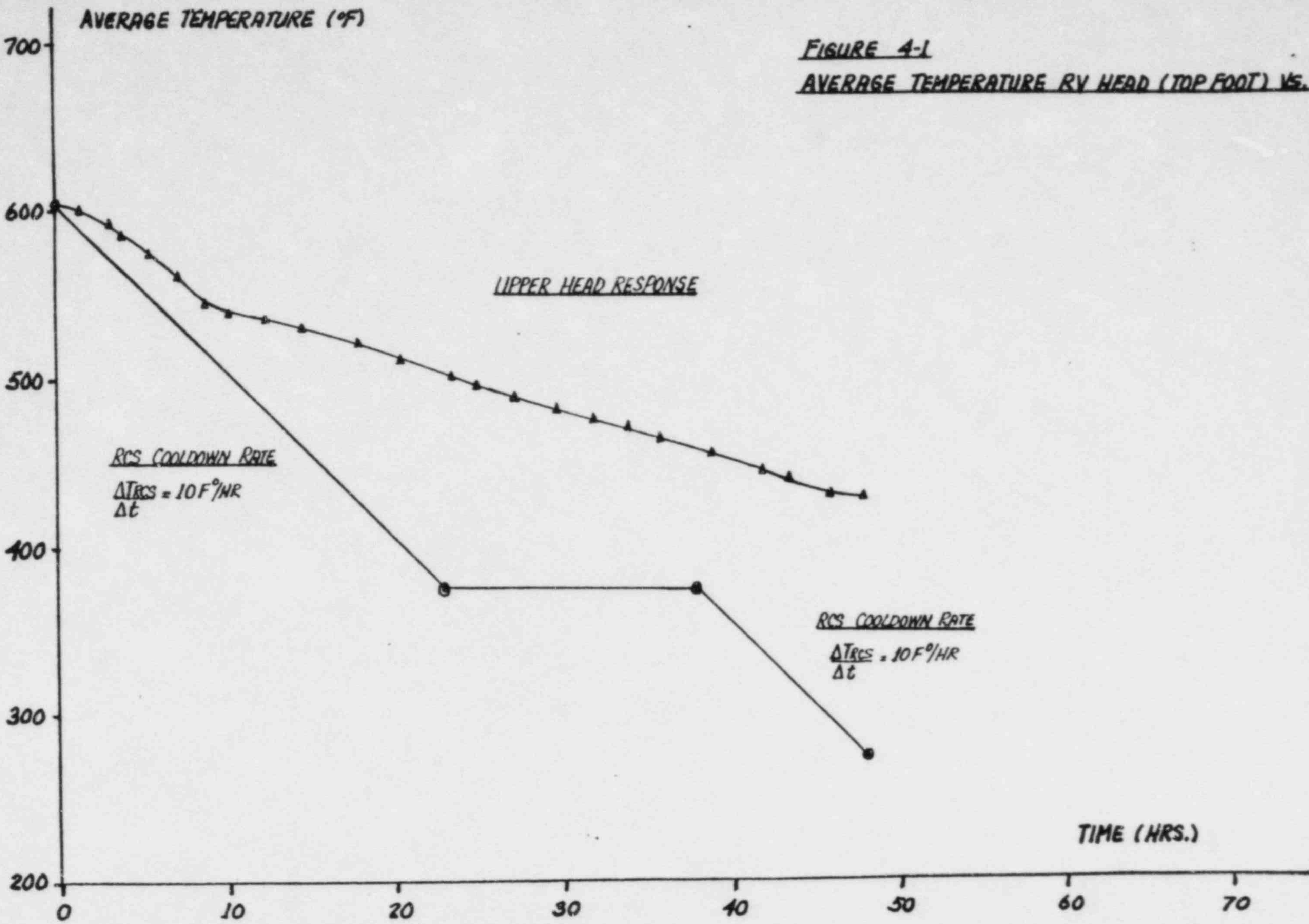
Also included on Figure 4-1 is the temperature of the volume average of the top foot of the RV head. The results show that the average temperature of the RV head decreases at an average rate of approximately 4F°/hr.

The analysis conservatively assumed that the flow up through the plenum cover mixed with the water up to the top of the CRD housings. These nodes cool down at the same rate as the RCS (10°F/hr) and influence the cool down of the hotter regions of the RV head through the various heat transfer mechanisms previously defined.

Figure 4-2 shows the saturation pressure corresponding to the volume averaged temperature of the top foot of the RV head during the cooldown as a function of time. An RCS cooldown rate of 10F°/hr with an intermediate soak for 15 hours at 375°F would take the head about 46 hours to cool to the DHR cut-in point without flashing.

FIGURE 4-1

AVERAGE TEMPERATURE RV HEAD (TOP FOOT) VS. TIME



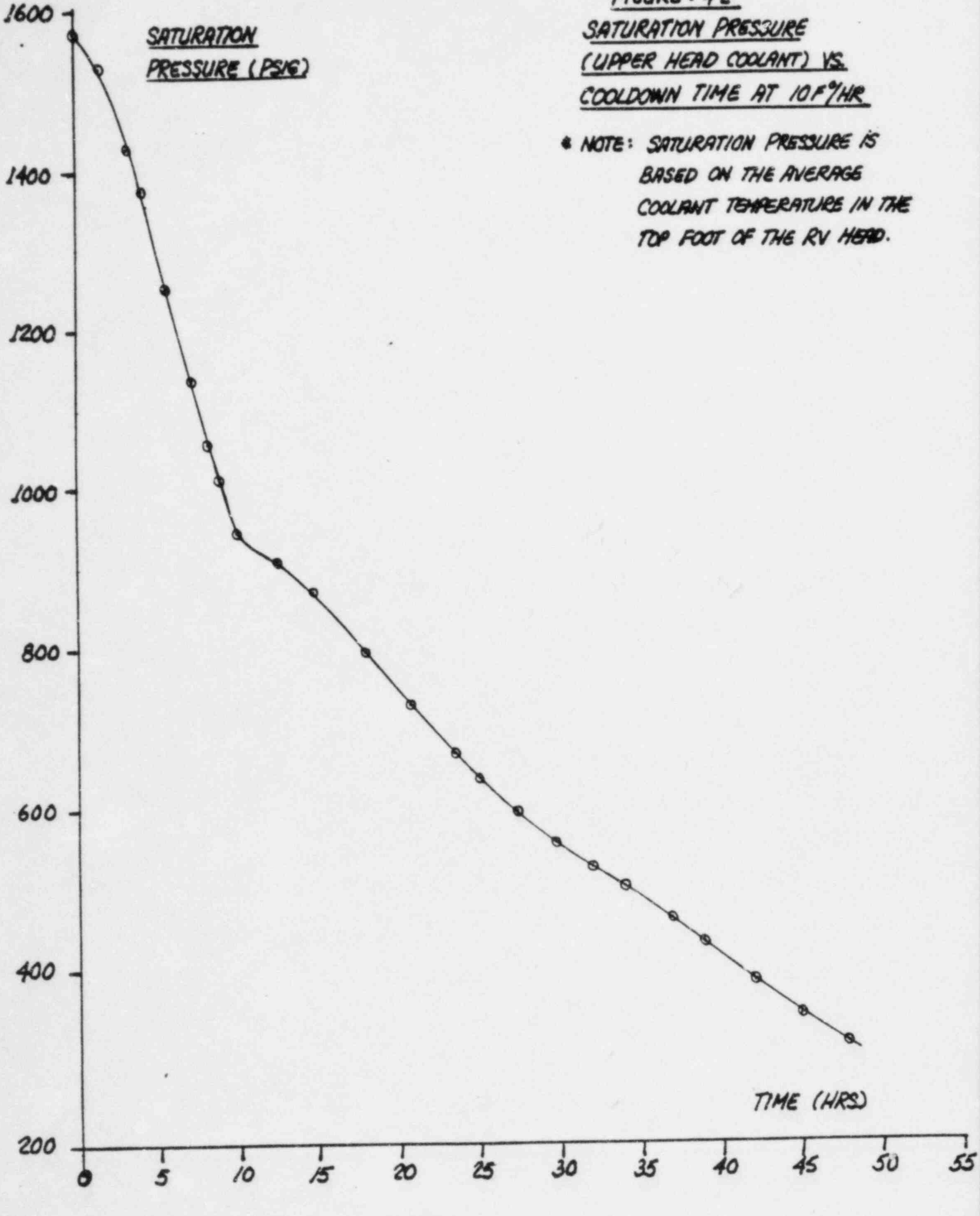


FIGURE: 4-2
SATURATION PRESSURE (UPPER HEAD COOLANT) VS. COOLDOWN TIME AT 10F°/HR
* NOTE: SATURATION PRESSURE IS BASED ON THE AVERAGE COOLANT TEMPERATURE IN THE TOP FOOT OF THE RV HEAD.
SATURATION PRESSURE (PSIG)
TIME (HRS)
1600
1400
1200
1000
800
600
400
200
0
5
10
15
20
25
30
35
40
45
50
55

5.0 OPERATION GUIDELINES

The application of the method developed in the previous sections form the basis for operational guidelines for a natural circulation cooldown.

While it is desirable to avoid reactor vessel upper head voiding in non-emergency cooldown situations, the following should be noted to keep this phenomenon in perspective:

1. A natural circulation cooldown is an unlikely occurrence
   The two most likely reasons in which the RCPs will not be available are loss of power to the RCP motors and loss of services (cooling water and seal injection) to the RCPs. Experience has shown that both of these are unlikely for an extended time.

2. A steam bubble in the RV upper head is not a safety problem
   A steam bubble in the RV upper head is not in itself a safety problem, but a plant control problem for the op[illegible]or. The expansion of the void into the hot leg to interrupt natural

circulation is unlikely since the regions below the upper head are subcooled, and expansion of the void into these regions would result in condensation, thus restricting the void to the upper head region only.

3. Controlled transition to natural circulation or intermittent operation of RCPs

In the highly likely event of a controlled transition to natural circulation, operating the RCPs after a reactor trip will reduce the RV upper head temperature from the full-power hot leg temperature toward the lower post-trip hot leg temperature. RCP operation for several minutes beyond the reactor trip is effective in reducing the RV upper head temperature and thus reducing the RCS pressure for voiding in the upper head during NC cooldown. In addition, either intermittent operation or 'bumping' of one or more RCPs during natural circulation will result in mixing of the colder RCS water with hotter upper head water due to the increased flow to the head region, and lower the RCS pressure at which voiding would occur.

Figure 4-1 of the previous section showed the RV head response resulting from a 10F°/hr cooldown of the RCS. The RCS could be cooled down at any rate between 10F°/hr and 100F°/hr, and a higher than 10°F/hr RCS cooldown rate would result in a faster cooldown of the RV head.

The curve on Figure 5-1 represents the minimum pressure to prevent flashing in the RV upper head. This curve was developed by combining the RC temperature of Figure 4-1 and the saturation pressure of Figure 4-2, and including instrument errors of 50 psig and 12°F. To prevent flashing in the head, the RCS fluid conditions must be maintained above and to the left of this curve. Note that above 750 psig, RCS pressure limits are controlled by the fuel compression limits. Until this point, the operator can cool the plant at any rate between 10°F and 100F°/hr following existing plant limits without drawing a head bubble.

A 'hold' or 'soak' is designated on this figure at 750 psig so that system pressure and temperature will be maintained constant for 15 hours. A subsequent RCS cooldown to 300°F at 10°F/hr would result in a head temperature which would be below saturation for the indicated RCS pressure. In actuality, further operating flexibility is available as shown on Figure 4-2, where RCS pressure could be decreasing during the 15 hour soak so long as it is maintained above the RV head saturation pressure.

As a result of the analysis of Section 4.0, improvements have been identified to the TMI-1 Natural Circulation Cocling Procedure OP 1102-16. In general, these improvements will:

1. Modify existing cooldown procedure to include a curve depicting minimum pressure to prevent flashing in the RV upper head. This will be based upon the upper head cooldown simulations consistent for a given RCS cooldown rate.

2. Instructions for collapsing the steam bubble, should void formation occur in the RV head.

3. Instructions to re-establish natural circulation should it be interrupted.

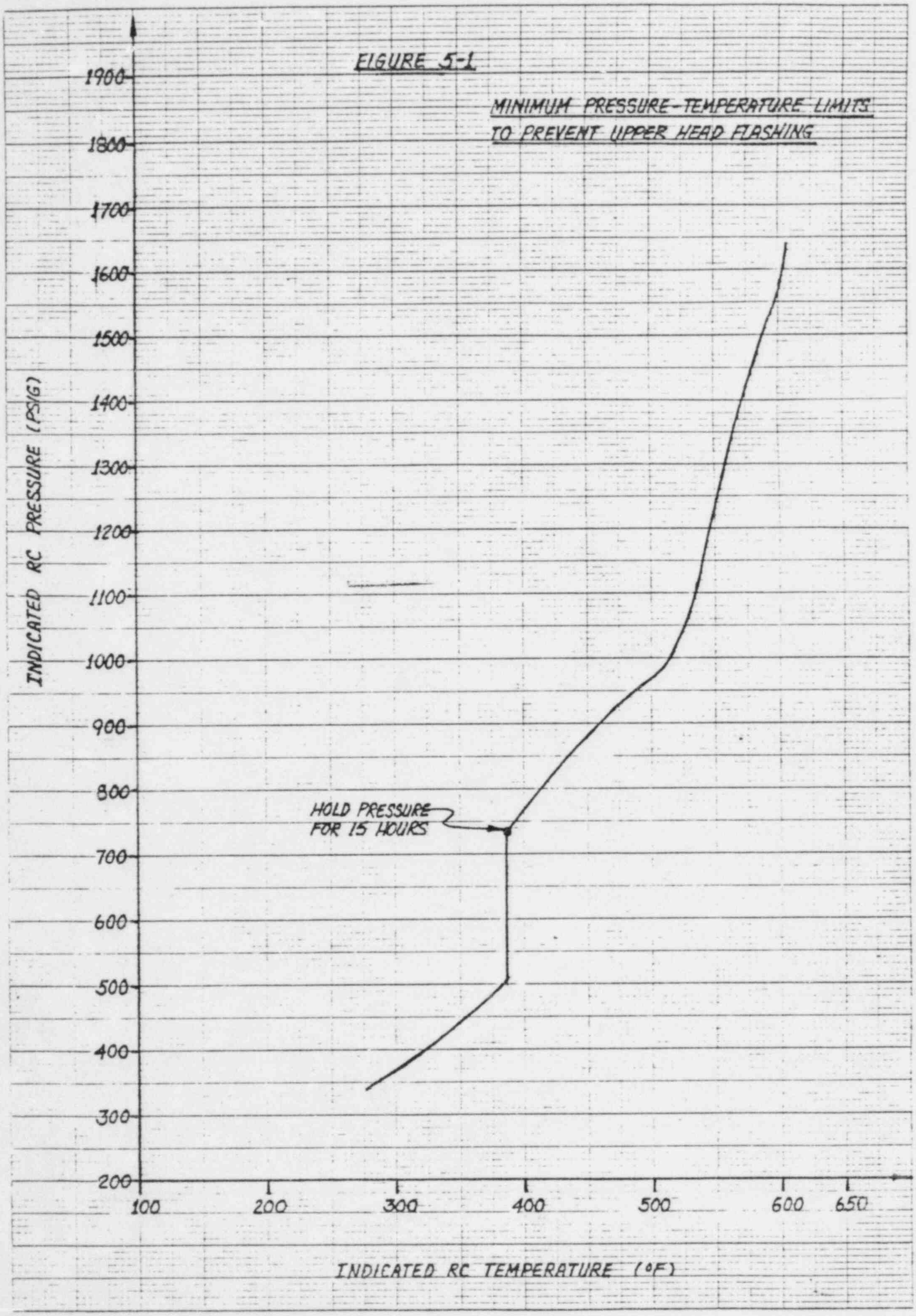


FIGURE 5-1
MINIMUM PRESSURE-TEMPERATURE LIMITS TO PREVENT UPPER HEAD FLASHING
HOLD PRESSURE FOR 15 HOURS
INDICATED RC PRESSURE (PSIG)
1900
1800
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
200
300
400
500
600
650
INDICATED RC TEMPERATURE (°F)

6.0 CONCLUSIONS

Important conclusions of this report are:

- During natural circulation with an RCS cooldown rate of at least 10°F/hr to 375°F and then a 'hold' at 375°F for 15 hours followed by a cool down to 300°F at 10°F/hr, it would require 46 hours for the RV head to cool down without flashing to DHR system entry conditions of 325 psig and 300°F.

- Cooldown rates greater than 10°F/hr with RCS pressure controlled can be achieved without creating a head bubble.

- As a result of the analysis presented in this report, improvements to the existing RCS Natural Circulation Cooling procedure have been identified.

7.0 REFERENCES

1.0 NRC Letter, J. F. Stolz to H. D. Hukill, Request for Additional Information, Natural Circulation Cooldown (GL 81-21), July 20, 1983.

2.0 HEATING6: A Multi-Dimensional Heat Conduction Analysis with the Finite-Difference Formulation, RSIC # RSR-199.

3.0 TMI-1 FSAR, Updated Version, Volume 2, Chapter 4.

4.0 J. Smotrel, RV Internal Flow Velocity, B&W Document # 51-1146582-01, August 31, 1983.