TMBDB SODIUM-CONCRETE PENETRATION MARGINS ASSESSMENT FOR THE CRBRP

by

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INTRODUCTION

Experiments (References 1 and 2) have indicated that sodium-concrete reactions tend to be self-limiting with limestone concrete under conditions prevailing during a postulated TMBDB scenario in CRBRP. The sodium-concrete penetration was represented in the base case CACECO analysis as a constant reaction penetration of 0.5 inch per hour for a period of 4 hours (Reference 3). Sensitivity studies (Reference 3) show that a reaction penetration rate of 1 inch per hour for 12 hours (12 inches total penetration versus 2 inches in the base case) can be accommodated by the TMBDB containment features based on their design requirements.

Some sodium-concrete experiments have exhibited considerably higher penetration rates (up to approximately 0.2 inches per minute) for short periods of time (References 4 and 5). For all tests that had an excess of sodium, the rapid reaction penetration was not sustained for more than a few minutes. Apparently the reaction penetration was self-limiting after a short period of rapid penetration. In other tests, where only a limited amount of sodium was used, the available sodium was all consumed in a short time if rapid penetration occurred (in many tests virtually no penetration at all occurred, and very little sodium was consumed). In all tests to date, the total sodium reaction penetration has not exceeded the energy and hydrogen releases associated with the 1 inch per hour for 12 hours used in the sensitivity calculations. From the large body of available data, Reference 6 states that sodium-concrete reaction penetration into horizontal surfaces appears to progress in three stages, each characterized by successively decreasing rates of penetration. These three stages and the recommended upper bound rates and durations are as follows:

A. An initial rapid penetration probably due to spallation and breakup of the surface layer of concrete. The upper bound rate and duration of this stage is 7 inches per hour for 20 minutes.

B. An intermediate stage where spallation is no longer occurring but the concrete surface is not fully protected by the developing layer of reaction products. The upper bound for this stage is 1 inch per hour for 3 hours.

C. In the longer term (the third stage) the rate of penetration is much slower and decreases with time because of a continually growing layer of reaction products which inhibits transport of unreacted sodium to the unreacted concrete surface. Upper bound-0.1 inch/hour indefinitely.

Based on the above mentioned analysis of the data and the analyses of TMBDB sequences in Reference 3, it is apparent that the sensitivity analyses adequately cover the range of data observed to date. It is also apparent that considerable margin exists in TMBDB analyses for accommodating higher sodium-concrete reactions at the expense of vent time (less than the base case 36 hours). With a view to assessing the margins available in the current CRBRP design relative to assumed variations in the sodium-concrete penetration rate, a margin study was conducted. In assessing the margins available in the design, two distinct considerations emerge:

A. If there were no requirement to maintain containment integrity for a fixed time without venting, what range of reaction rates could be accommodated by the design?

B. There must be some period of time allowed for venting decisions, activation of emergency plans, etc. How early could venting reasonably be assumed, and would such an assumption give sufficient margin to cover any remaining uncertainties regarding sodium-concrete reactions?

To assess these considerations a study was initiated with following objectives:

A. Artificially contrive a sodium-concrete reaction scenario which would so far exceed any observed in tests to date so as to result in a need

to vent containment in 10 hours. (This is compatible with evacuation times quoted in Chapter 13 of the PSAR.)

B. Assess the capability of the design to accommodate such a scenario.

This report documents the analysis of this margins assessment which is a scenario with an initial sodium concrete penetration rate of 7 inches/hour for 3 hours, followed by a rate of 1 inch/hour. For this case, no credit is taken for the reaction inhibiting effects of the reaction product layer, such that the 1 inch/hour reaction was assumed to continue until all sodium was consumed. It is emphasized that this artificially contrived case does not represent test data, but is simply a margin study to assess the design capability.

MODEL AND ASSUMPTIONS

The CACECO code model defined in Reference 3 (Appendix C.1) was modified to perform this sensitivity study. The model used in the base case includes a sodium-concrete reaction rate of 0.5 inches per hour for 4 hours, starting at the time of reactor cavity liner failure (assumed to be at the time of penetration of the reactor vessel and guard vessel). To calculate the containment conditions for the penetration margins assessment, the CACECO model had to be modified to include the more severe reactions associated with the margins assessment case. The criteria for venting were similar to those for the base case scenario and, as in the base case, the RCB hydrogen concentration was the limiting factor on vent time. Other design requirements (heat load to the confinement building, venting rates, aerosol discharge to the cleanup system, etc.) were not imposed on the assumption that the TMBDB features external to the RCB could be enhanced, if necessary, to accommodate greater operational loads. Other variations from the base case scenario included were: 1) the sodium-concrete penetration rate for the pipeway floor concrete is the same as for the RC floor (with the exception that the reaction occurs only when a sodium pool exists; 2) initiation of the RCB annulus cooling system at 10 hours; 3) increasing the thermal conductivity of the concrete nodes as the assumed penetration front moved past the node to simulate movement of the sodium boundary (the node thickness

used in the region of concrete penetration was two inches); 4) consumption of sodium by reaction with the concrete residue (0.38 ft^3 sodium per ft^3 concrete) in addition to reactions with the water and carbon dioxide driven off from the concrete. (In the base case TMBDB, the reaction energy 331 Btu/lb concrete, was accounted for, but sodium consumption from this source was ignored due to the small amount of concrete involved); and 5) RCB purge initiated at 13.5 hours (immediately after blowdown to atmospheric pressure).

RESULTS

The results confirm that with an initial sodium concrete penetration rate into the reactor cavity floor of seven inches per hour for the first three hours and 1 inch per hour thereafter, RCB venting would be required at 10 hours.

Considerations which are important during the TMBDB scenario inlcude the consequences from the initial hydrogen ignition, conditions which cause the initiation of RCB venting, and long term or maximum RCB conditions during venting. These results are summarized in Table I. Due to the additional energy from the more severe sodium-concrete reactions causing the sodium pool to heat up faster and allowing sodium vapor to enter containment sooner, the criteria for initial hydrogen ignition are met at 1.4 hours as compared to 10 hours in the base case. The corresponding hydrogen build-up in containment prior to ignition is less than in the base case (2.5% versus 4.5%). Upon ignition, the containment responses would be less severe. The resulting containment temperature and pressure would be 570°F and 13.9 psig as compared to 845°F and 22.4 psig for the base case.

The initiation of RCB venting is the next important consideration. The criteria that can dictate venting are excessive RCB pressure and steel shell temperature, or excessive hydrogen buildup. In this case the hydrogen buildup was the limiting condition causing venting to occur at 10 hours. With the sodium and hydrogen rates into containment averaging about 4000 lb/hr and 350 lb/hr, respectively, over the first ten hours, the containment oxygen was depleted to below 8% due to the chemical reactions. After the oxygen is depleted to below 8% in containment (8.5 hours) the hydrogen is

predicted to accumulate due to incomplete burning. As in the base case TMBDB sequence, venting would be initiated well in advance of reaching the hydrogen limit because the depressurization of containment results in hydrogen flowing up from the reactor cavity, which in turn causes the hydrogen concentration to increase during the blowdown period before purging can be initiated. (For purging, the RCB must be at a negative pressure.) In the base case the resulting peak hydrogen concentration is 4.5%, well below the objective maximum of 6.0%. In this case the calculated hydrogen concentration has reached 2.6% at 10 hours when venting is initiated. The blowdown excursion exceeded 6% for approximately 2 hours. (The peak was 8.7% at 13.5 hours.) During the time hydrogen was above 6%, the oxygen was below 5% so that the mixture in containment would not be flammable (calculationally, the reason the hydrogen exceeded 6% was because there is not enough oxygen to meet burning criteria). This short excursion beyond 6% hydrogen is considered acceptable for this margins assessment case since it occurs at a time when RCB oxygen has been depleted. Shortly after purging was initiated, the incoming air raised the oxygen concentration to 5% at which time the hydrogen in excess of 4% burned with acceptable consequences to containment conditions. Figure 1 shows the hydrogen and oxygen concentrations as a function of time. The peak containment pressure was higher at venting than the base case (18.7 versus 13.1 psig), but well within the ultimate pressure capability of the steel shell (Reference 3). The reactor cavity and containment atmosphere temperatures are shown in Figure 2. The containment temperature is several hundred degrees higher than the base case due to the increased rate of sodium burning. The higher containment atmosphere temperature also results in a higher steel shell temperature than in the base case (490°F versus 400°F based on the one-dimensional CACECO calculations). The steel temperature is shown on Figure 2. Figure 3 shows the reactor containment pressure which is higher than found in the base case because of the increased sodium burning and more energetic concrete reactions. Additionally, the heat loads to the RCB steel shell for the base case and for the margins assessment case are shown on Figure 4. While the peak flux to the steel shell is not significantly different from that observed for the base case, it occurs earlier in time and is sustained for a longer period. Sodium boildry occurs at 51 hours for this case as compared to 133 hours for the base case. The amounts of sodium aerosols ingested into the cleanup

system are discussed in the Radiological and Aerosol Consequences section below.

Figures 5 to 15 show structural temperatures for the various cavity and pipeway floors and walls. The total penetration of sodium into the reactor cavity floor is 5.7 feet while the pipeway floor is penetrated approximately 2 feet. These temperatures are used in Appendix B to assess the integrity of the structures. The effects of the heat loads on the steel containment shell and concrete confinement structure were assessed and the results are shown in Appendix A.

RADIOLOGICAL AND AEROSOL CONSEQUENCES

2 Hour Exclusion Boundary Doses

The doses resulting from the margins assessment case (10 hour vent) scenario are compared with the TMBDB base case (36 hour vent) doses in Table 2.* The penetration margins assessment scenario produces a higher RCB pressure for the first 2 hours resulting in a greater release rate of the initially suspended 1000 lbs. of sodium and noble gases. The larger leakage during this time interval produces the higher 2 hour Exclusion Boundary doses for the margins assessment case compared to the base case.

30 Day Low Population Zone Doses

The majority (>99%) of the 30 day Low Population Zone (LPZ) bone dose comes from plutonium sparging following boildry. Sparging remains unchanged so the bone dose increased very little. The whole body dose is largely dependent on external gamma exposure from the released noble gases. The higher RCB pressure and early vent time releases more of these gases early in the event, when the calculated radiological impact is greater. The result is an LPZ dose about 4 times greater than the base case. The second significant change is in the thyroid dose which decreases from 99.2 rem in the base case to 94.7

*This comparison used Case 2 from Table 4-3 of Reference 3 as the base case.

rem for the penetration margins assessment case. This decrease is attributed to the fact that this case has higher aerosol concentrations, resulting in greater overall agglomeration and fallout than the base case. The lung dose is heavily dependent on the solid fission products which are not released early in the event during more radiologically significant time intervals. However, the greater suspended aerosol concentrations produce a higher RCB agglomeration and fallout rate with less release to the environment. Consequently, the net effect on the lung dose is very small and it is essentially the same as the base case dose.

The higher aerosol concentrations in the penetration margins assessment case result in greater aerosol depletion and somewhat less aerosol discharge to the RCB clean-up system. Table 1 provides a comparison of the total aerosol transported into the clean-up system and the rate of transport.

STRUCTURAL CONSEQUENCES

The consequences of the penetration margins assessment case on containment and confinement structures have been assessed and the details are presented in Appendix B. The results indicate that design changes would be required in two areas of the structures to accommodate the margins assessment case. The required modifications are:

A. Reactor Cavity Floor

(1) Extend the wall liner to 6.5 feet into the floor structural concrete.

(2) Eliminate the construction joint at Elevation 733 and rearrange the rebar in the floor.

(3) Provide a design feature on the RC floor liner near the wall to inhibit the spreading of the duel debris to the region of the wall-floor junction.

B. Pipeway Cell Floors

(1) Provide a second layer of insulating concrete below the second liner which separates the two layers of structural concrete.

(2) Increase the thickness of the floor by the thickness of the second layer of insulating concrete (lower bottom).

These modifications are not considered major changes and would, in conjunction with other existing TMBDB features, result in acceptable TMBDB margins to accommodate the margins assessment case.

CONCLUSIONS

Base on this margins assessment, the following conclusions have been reached:

A. The sodium-concrete penetration rate for the margins assessment case, which is 7 inches/hr for 3 hours followed by 1 inch/hr thereafter until sodium boildry, could be accommodated by venting the containment at about 10 hours.

B. Hydrogen ignition would occur earlier and would result in less severe containment conditions following rapid burning.

C. The clean-up system peak flow rate is somewhat higher than the base case, but below the design basis value for the system. The total aerosol loading would be less than the base case.

D. The sodium boildry time is reduced to 51 hours compared to 133 hours in the base case.

E. With modest design modifications in two areas (the Reactor Cavity floor and the pipeway cell floors) the margins assessment scenario would result in acceptable containment and confinement structural margins.

F. Radiological doses are comparable to the base case except the 30 day LPZ whole body dose which is greater than the base case due to the earlier venting, but still within the guideline values for this beyond design base event.

REFERENCES

1. J. A. Hassberger, R. K. Hilliard and L. D. Muhlestein, "Sodium Concrete Reactions Tests," HEDL-TME-74-36, June 1974

2. J. A. Hassberger, "Intermediate Scale Sodium-Concrete Reaction Tests," HEDL-TME-77-99, March 1978

3. CRBRP-3, Volume 2, "Hypothetical Core Disruptive Accident Considerations in CRBRP, Volume 2 Assessment of Thermal Margin Beyond the Design Base," March 1980

4. B. M. Butcher, et al., "Sodium Containment and Structural Integrity," NUREG-0181-3, Advanced Safety Research Program Quarterly Report, April-June, 1977, SAND 77-1134 Sandia National Laboratories, Albuquerque, NM, pp. 145-156, November 1977

5. D. A. Dahlgren, et al., "Sodium Containment and Structural Integrity," Advanced Reactor Safety Research Program Quarterly Report, July-September, 1977, SAND 77-1975 Sandia National Laboratories, Albuquerque, NM, pp. 111-118, May 1978

6. HEDL-TME 82-15, L. D. Muhlstein and A. K. Postma, "Sodium-Concrete Reaction Executive Summary Report: Application to Limestone Concrete," June 1982

TABLE 1

SUMMARY OF RESULTS WITH INITIAL SODIUM-CONCRETE PENETRATION OF SEVEN INCHES PER HOUR

	Base Case	Penetration Margin Assessment
Initial Hydrogen Ignition		
Time (hrs.)	10.0	1.4
RCB Atmosphere Temperature (°F) (before/after)	120/845	145/570
RCB Pressure (psig) (before/after)	2.2/22.4	2.4/13.9
Hydrogen Concentration (Vol.%) (before/after)	4.5/0.0	2.5/0.0
Initiation of RCB Venting		
Time (hrs.)	36	10
RCB Atmosphere Temperature (°F)	617	710
RCB Steel Shell Temperature (°F)	400	390
RCB Pressure (psig)	13.1	18.7
RCB Hydrogen Concentration (%)	0.0	2.6
RCB Oxygen Concentration (%)	8.4	7.4
Maximum Conditions During Venting		
Maximum Venting Rate (ACFM)	24,000	27,500
Purge Rate Assumed (SCFM)	8000	8000
Peak Hydrogen Concentration (Vol.%)/Time (hr.)	4.0/40	8.7/13.5
RCB Atmosphere Temperature (°F)/Time (hr.)	915/40	1020/14.6
Aerosol Comparisons		
Maximum Rate to the RCB Cleanup System (lb/hr)	4400	5100
Total Aerosols to the RCB Cleanup System to Boildry (lb)	260,000	167,000

TABLE 2

COMPARISON OF RADIOLOGICAL CONSEQUENCES

2 Hour EB Doses (rem)

Organ	36 Hour Vent Base Case	10 Hour Vent Penetration Margin Assessment
Bone	0.028	0.44
Lung	0.0055	0.082
Thyroid	0.0096	0.023
Whole Body	0.16	1.9

30 Day LPZ Doses (rem)

Organ	36 Hour Vent Base Case	10 Hour Vent Penetration Margin Assessment
Bone	55.1	55.2
Lung	3.96	3.91
Thyroid	99.2	94.7
Whole Body	3.5	13.0

Figure 1

RCB Hydrogen and Oxygen Concentration

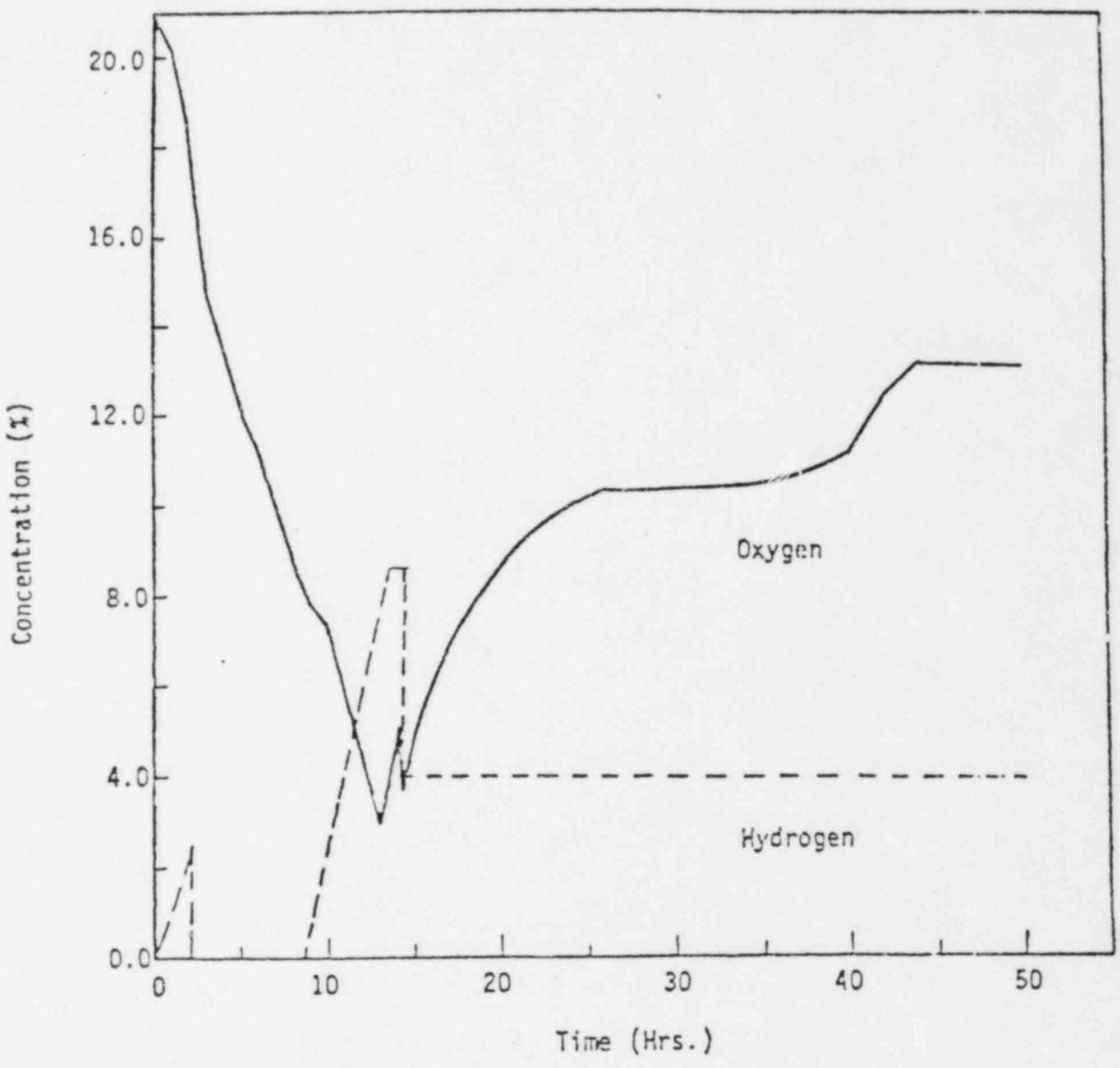


Figure 2

Reactor Cavity and Containment Atmosphere and Containment Steel Dome Temperature

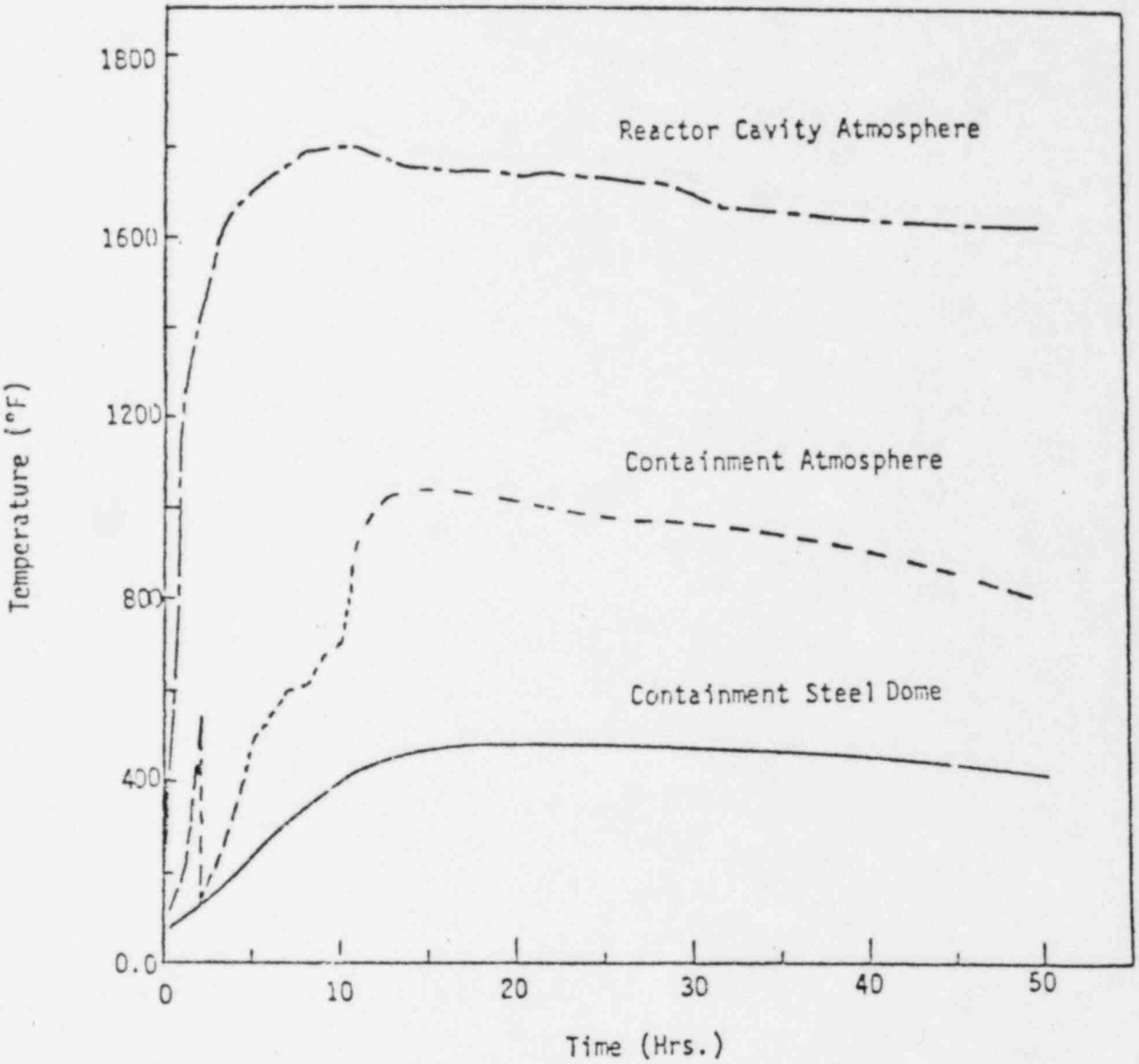


Figure 3

Containment Pressure

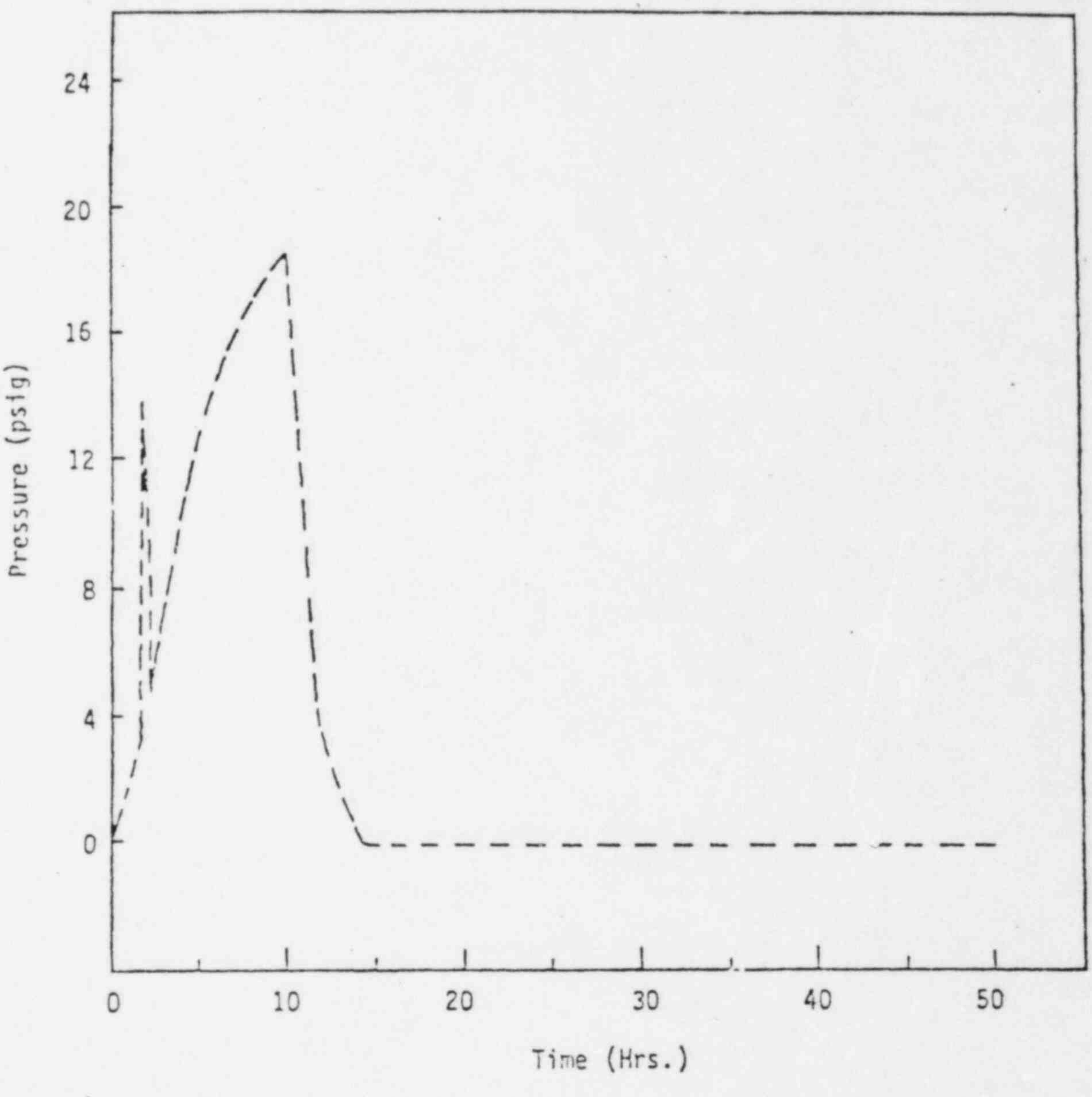
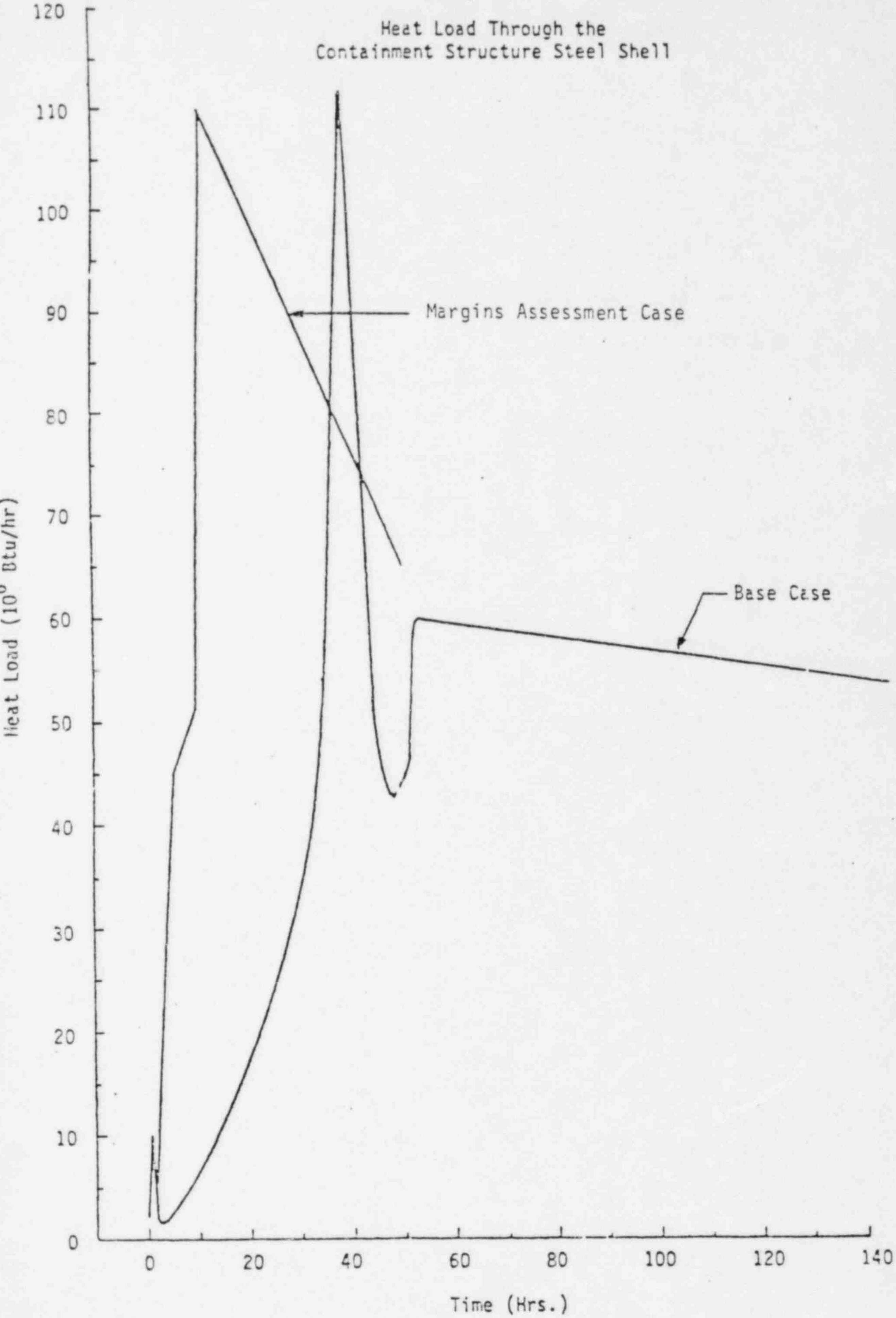


Figure 4



Heat Load Through the
Containment Structure Steel Shell
Margins Assessment Case
Base Case
Heat Load (10^6 Btu/hr)
Time (Hrs.)
0
10
20
30
40
50
60
70
80
90
100
110
120
0
20
40
60
80
100
120
140

Figure 5

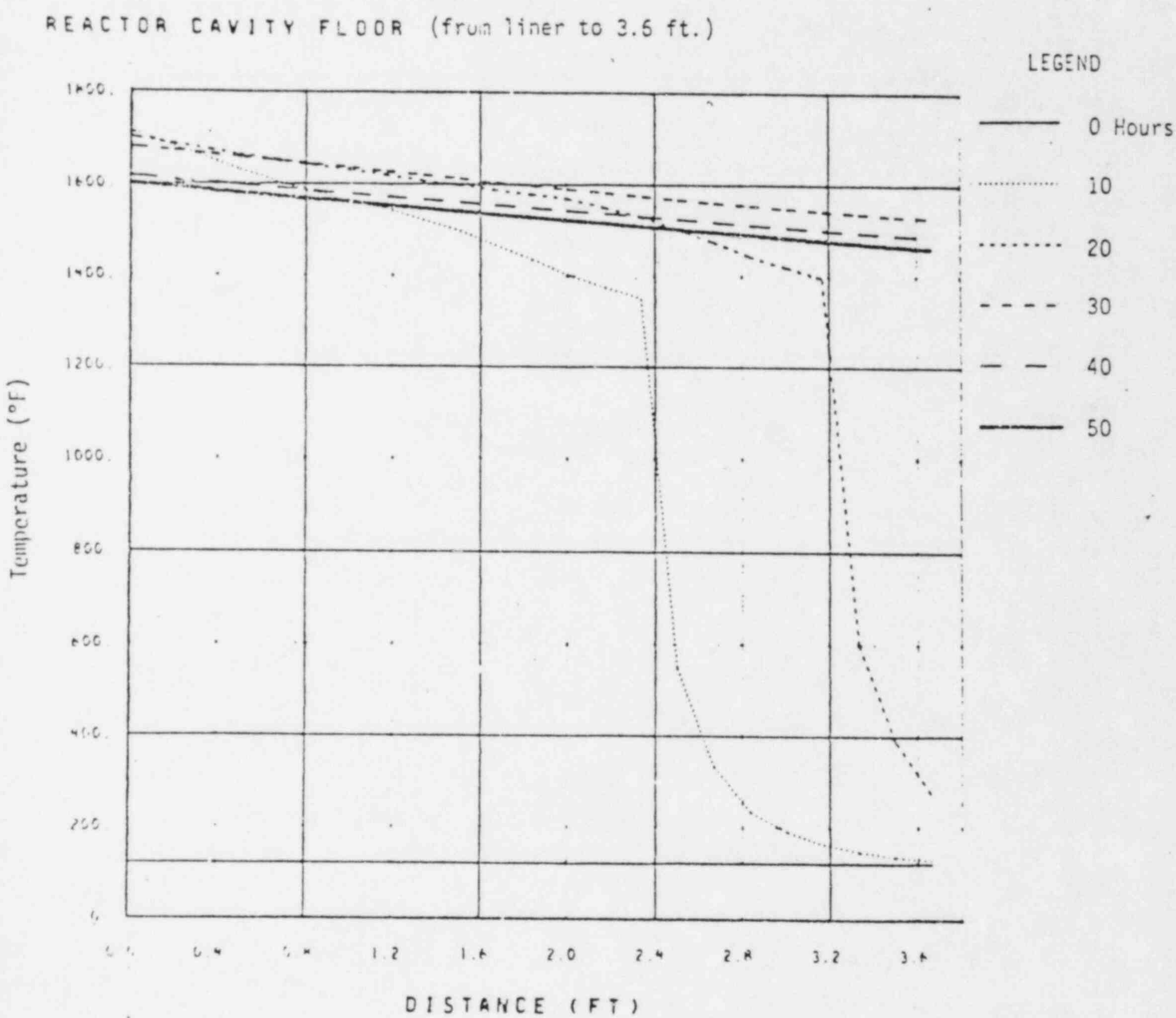
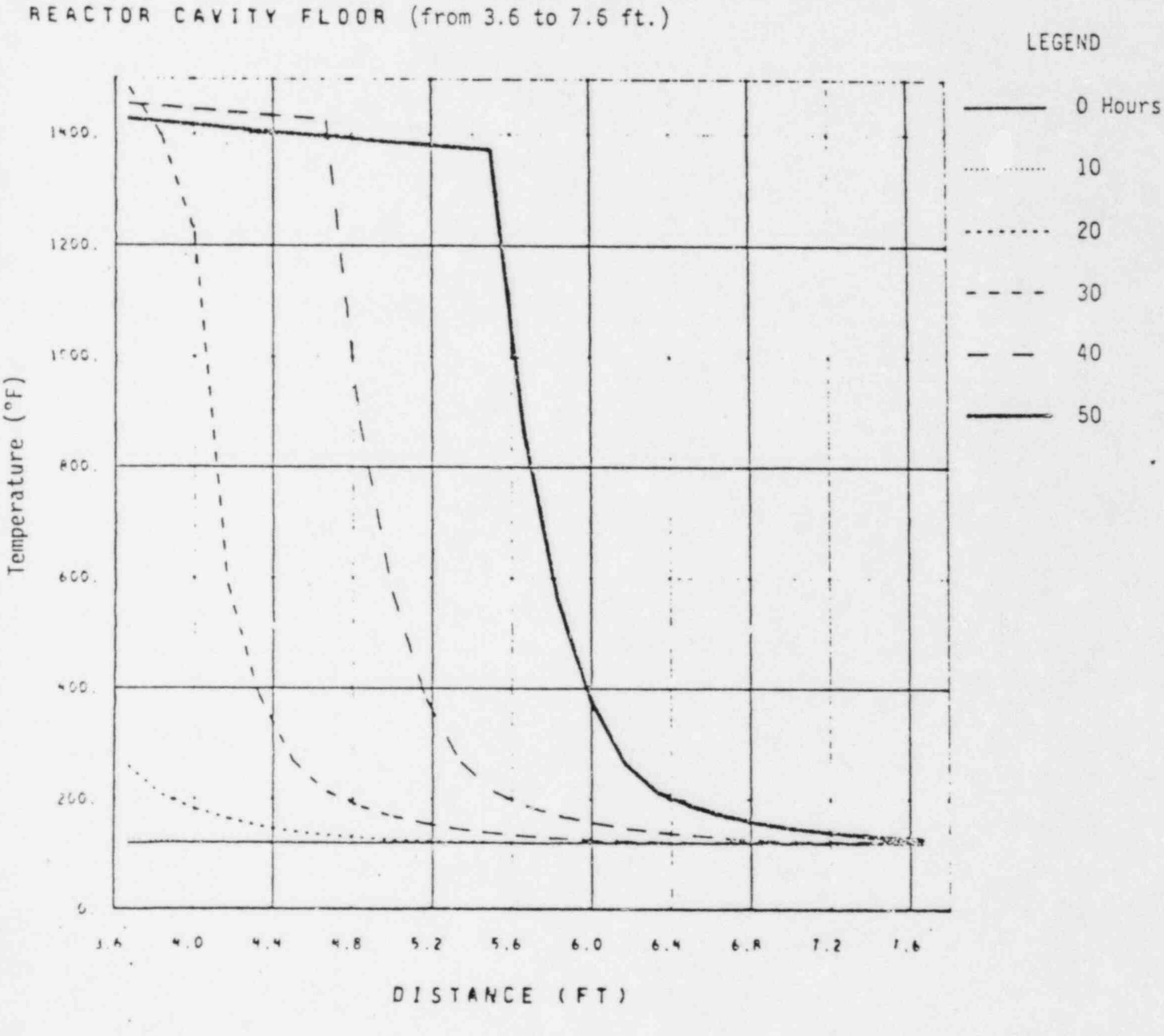

REACTOR CAVITY FLOOR (from liner to 3.6 ft.)
LEGEND
0 Hours
10
20
30
40
50
1800.
1600.
1400.
1200.
1000.
800.
600.
400.
200.
Temperature (°F)
1.2
1.6
2.0
2.4
2.8
3.2
DISTANCE (FT)

Figure 6



REACTOR CAVITY FLOOR (from 3.6 to 7.6 ft.)
LEGEND
0 Hours
10
20
30
40
50
Temperature (°F)
1400.
1200.
1000.
800.
600.
400.
200.
0.
3.6
4.0
4.4
4.8
5.2
5.6
6.0
6.4
6.8
7.2
7.6
DISTANCE (FT)

Figure 7

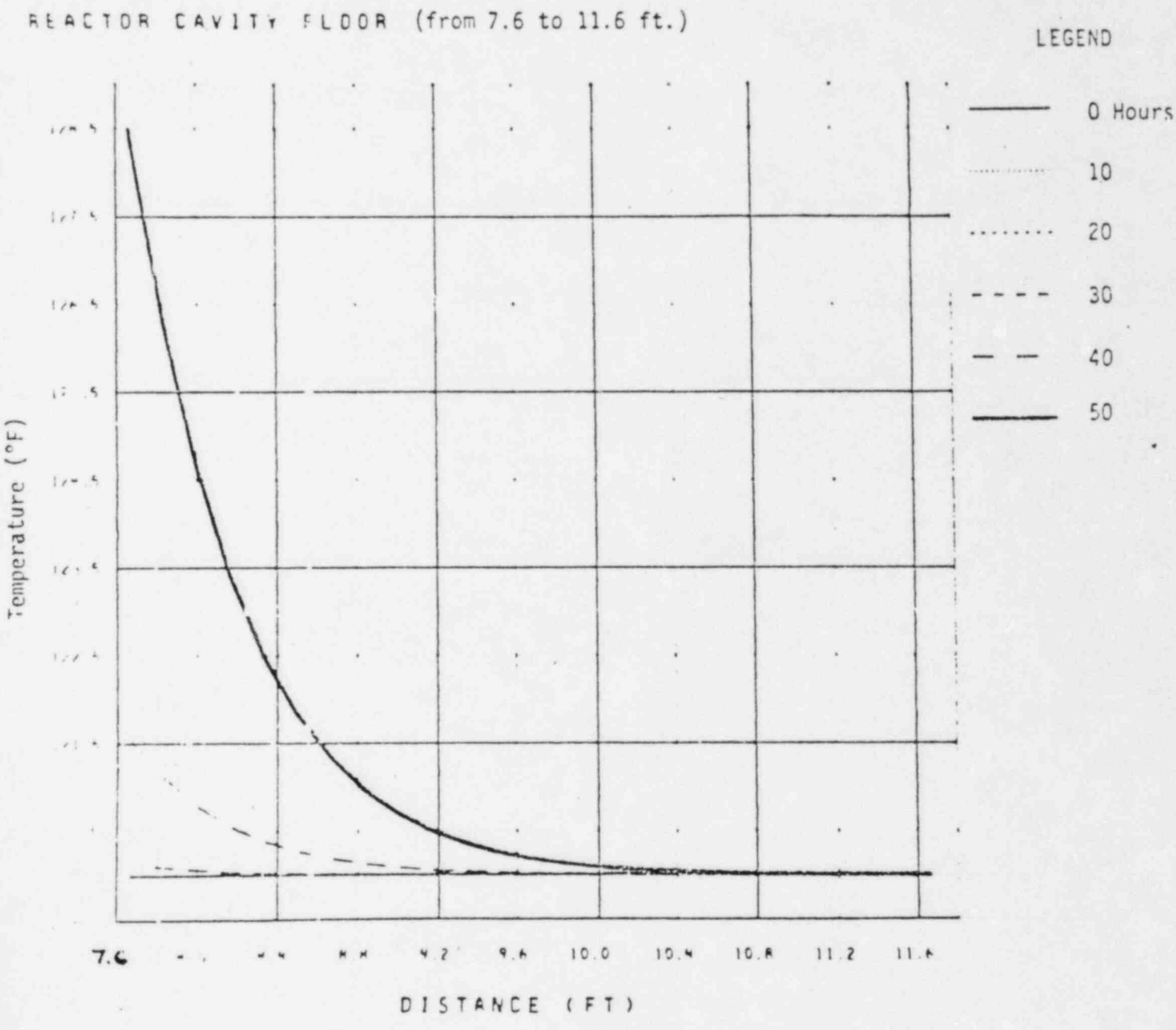
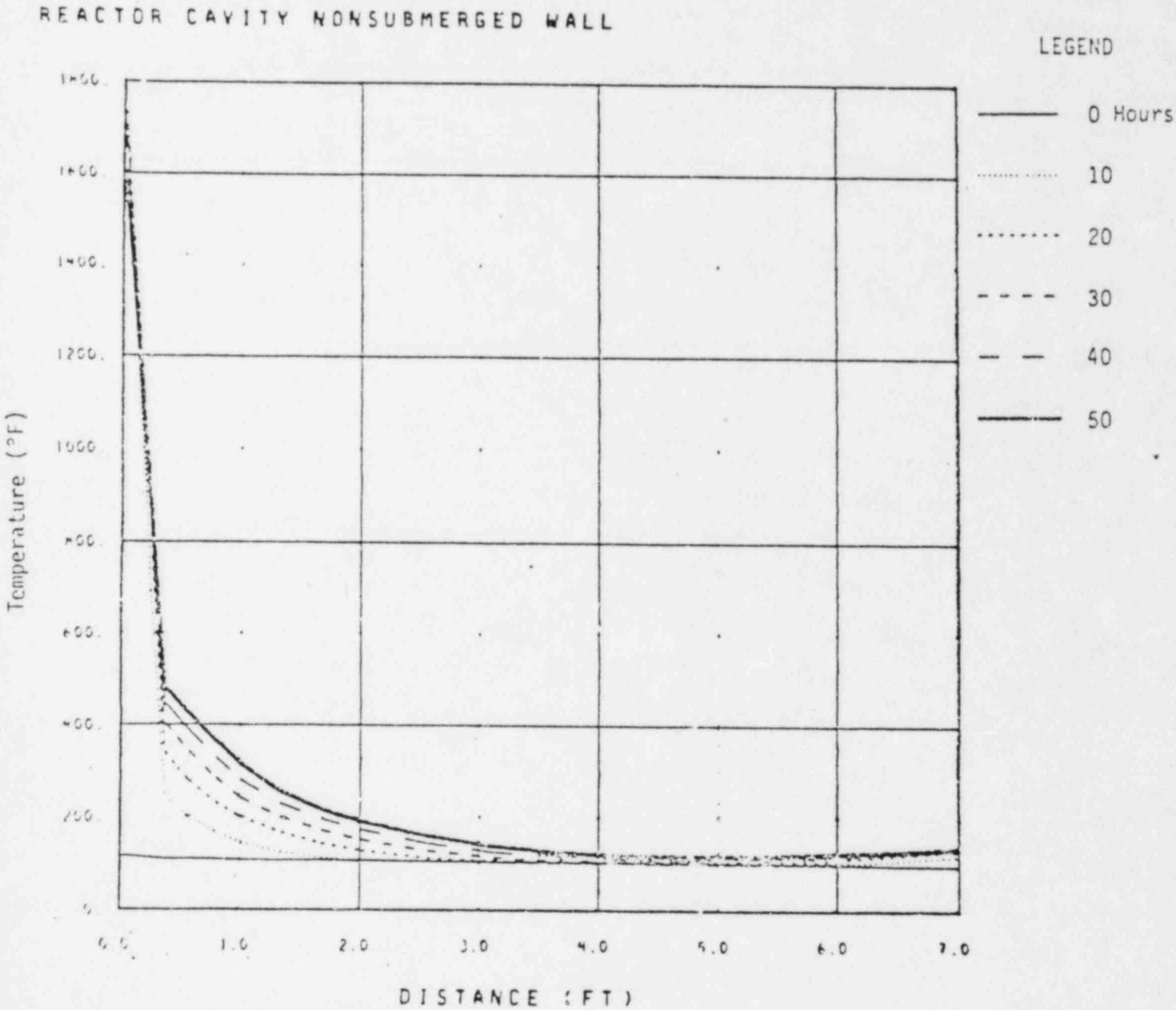

REACTOR CAVITY FLOOR (from 7.6 to 11.6 ft.)
LEGEND
0 Hours
10
20
30
40
50
Temperature (°F)
7.6
9.2
10.0
10.4
10.8
11.2
DISTANCE (FT)

Figure 8



REACTOR CAVITY NONSUBMERGED WALL
LEGEND
0 Hours
10
20
30
40
50
Temperature (°F)
1800.
1600.
1400.
1200.
1000.
800.
600.
400.
200.
0.
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
DISTANCE (FT)

Figure 9

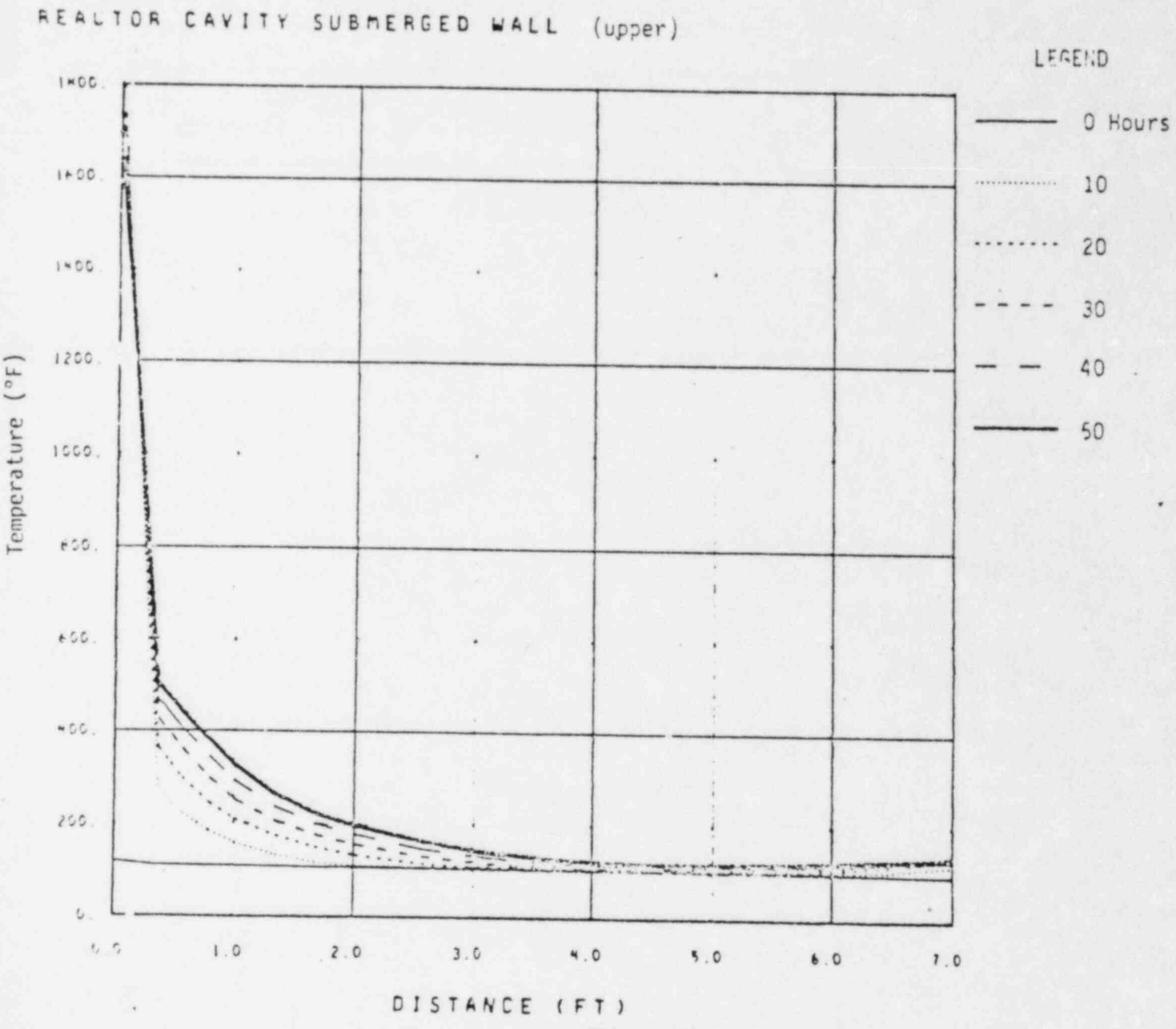
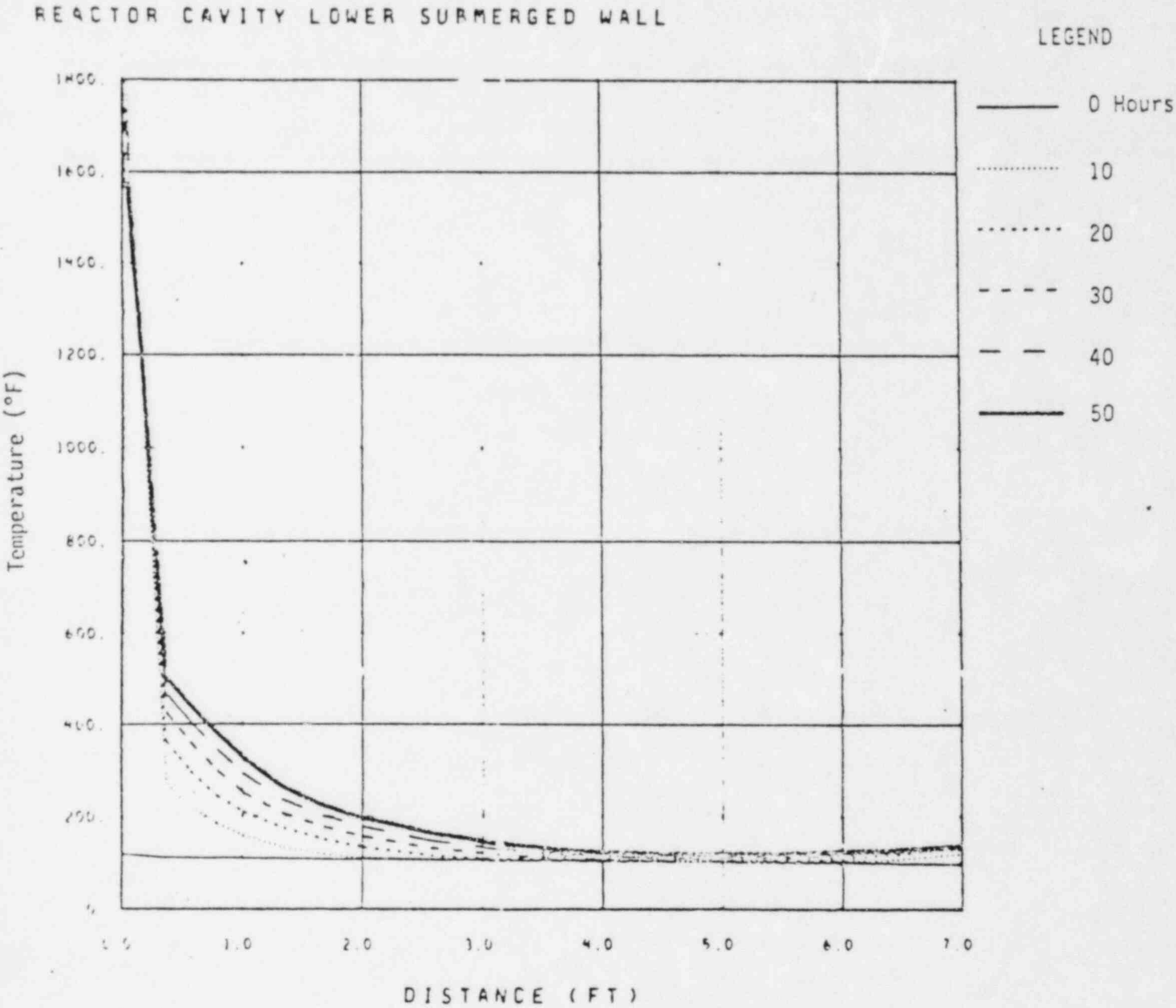
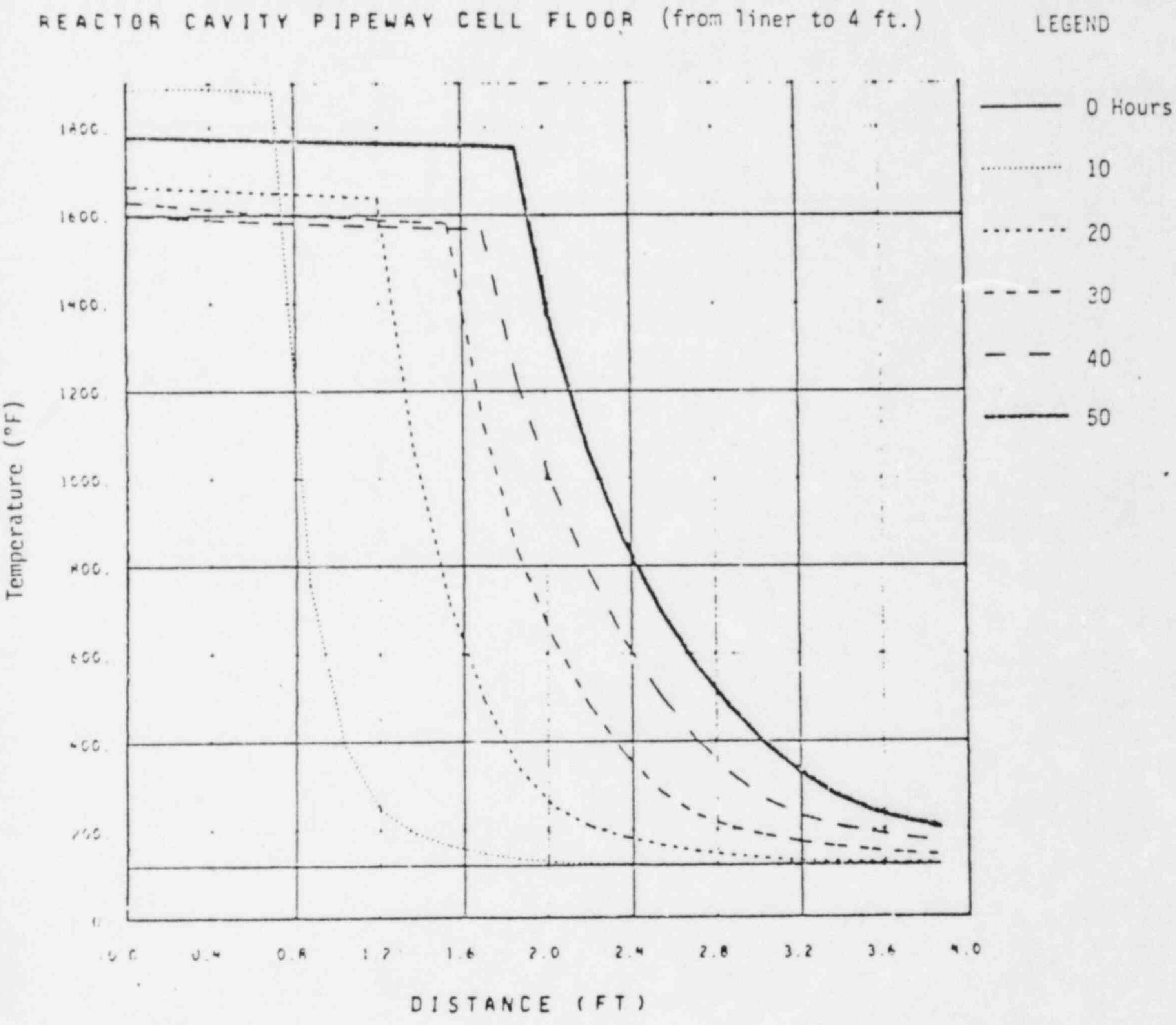

REACTOR CAVITY SUBMERGED WALL (upper)
LEGEND
0 Hours
10
20
30
40
50
Temperature (°F)
DISTANCE (FT)
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
200.
400.
600.
800.
1000.
1200.
1400.
1600.
1800.

Figure 10



REACTOR CAVITY LOWER SUBMERGED WALL
LEGEND
0 Hours
10
20
30
40
50
1800.
1600.
1400.
1200.
1000.
800.
600.
400.
200.
Temperature (°F)
1.0
2.0
3.0
4.0
5.0
6.0
7.0
DISTANCE (FT)

Figure 11



REACTOR CAVITY PIPEWAY CELL FLOOR (from liner to 4 ft.)
LEGEND
0 Hours
10
20
30
40
50
Temperature (°F)
DISTANCE (FT)

Figure 12

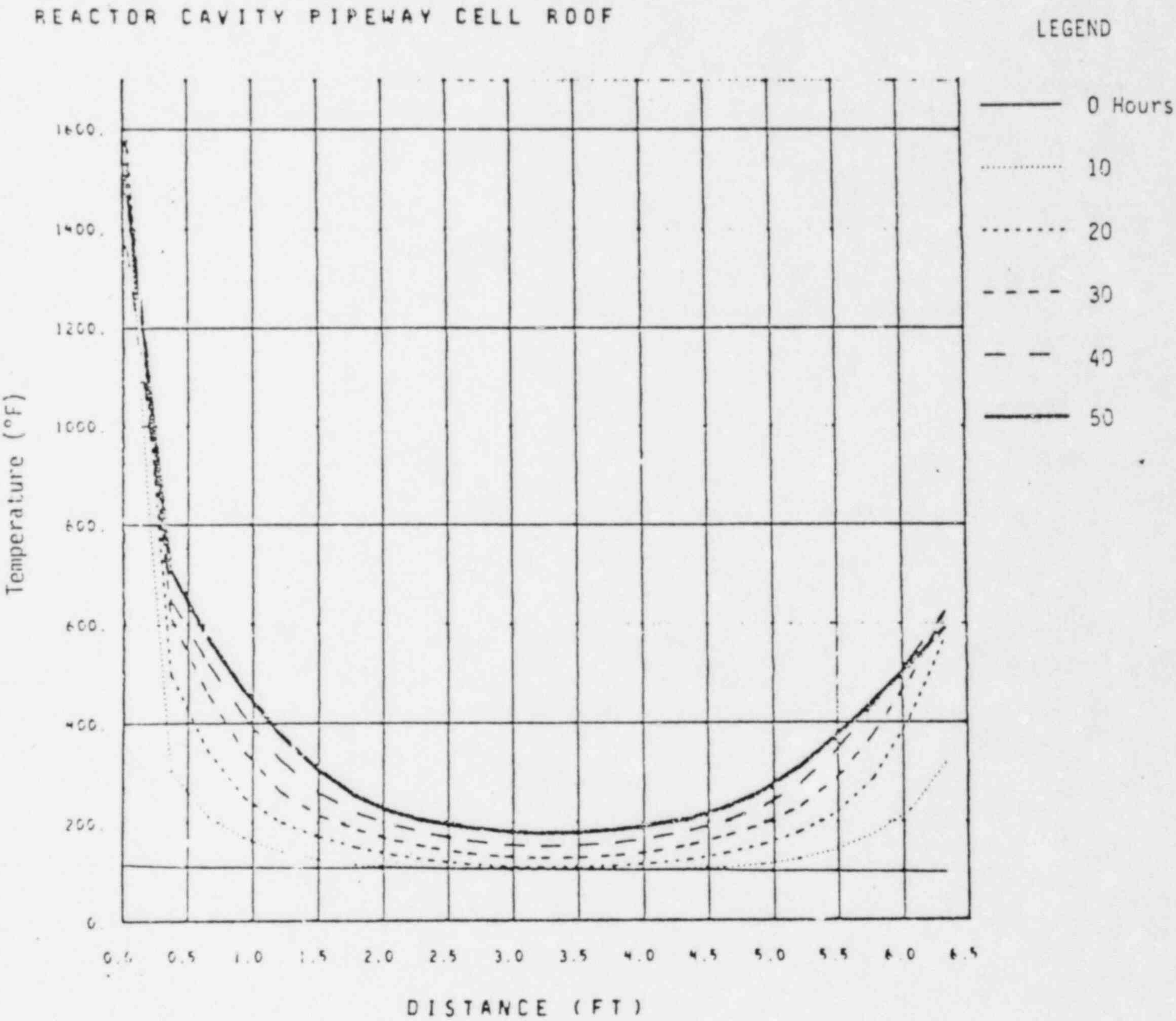
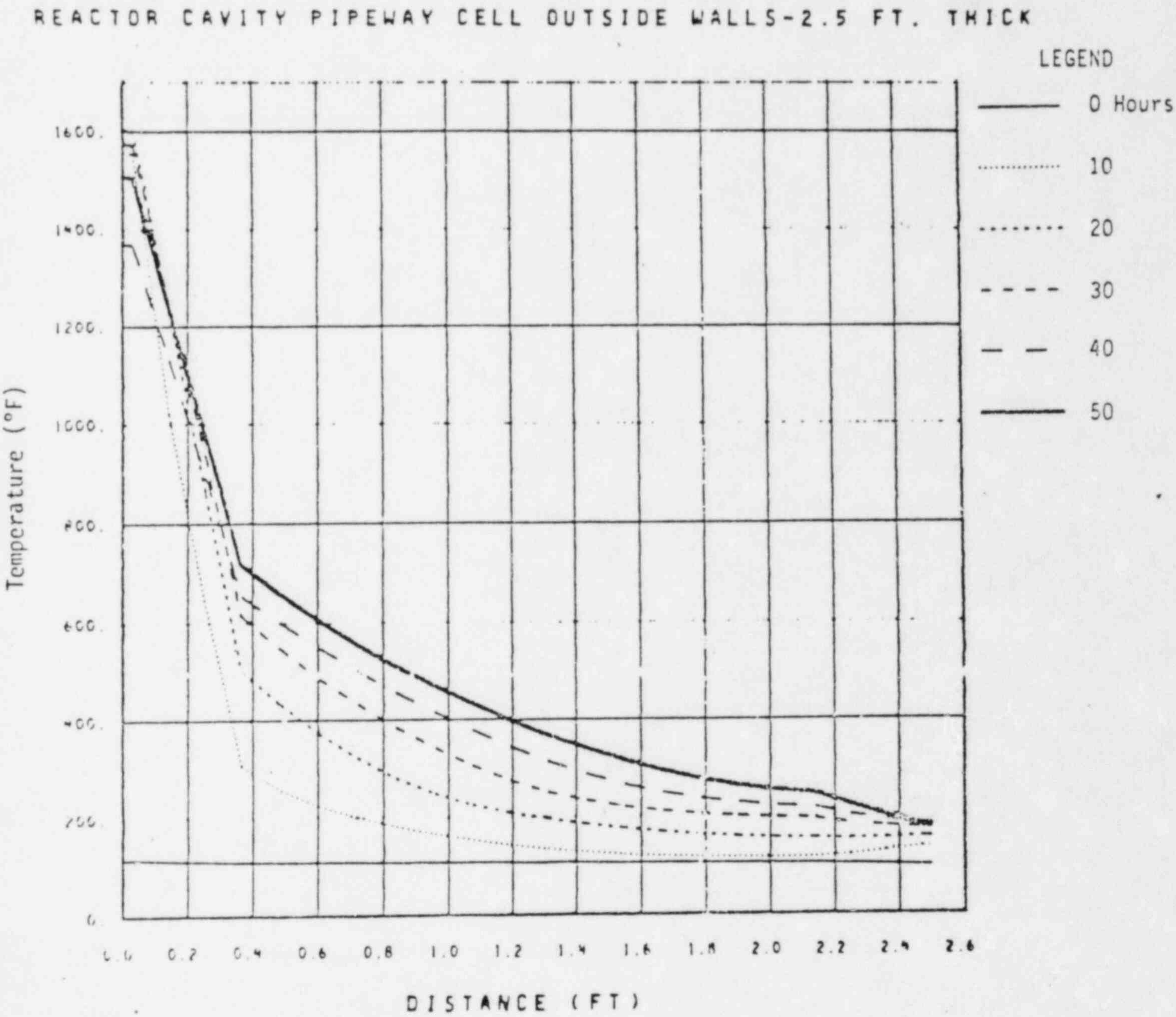

REACTOR CAVITY PIPEWAY CELL ROOF
LEGEND
0 Hours
10
20
30
40
50
Temperature (°F)
1600.
1400.
1200.
1000.
800.
600.
400.
200.
0.
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
DISTANCE (FT)

Figure 13



REACTOR CAVITY PIPEWAY CELL OUTSIDE WALLS-2.5 FT. THICK
LEGEND
0 Hours
10
20
30
40
50
Temperature (°F)
1600.
1400.
1200.
1000.
800.
600.
400.
200.
0.
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
DISTANCE (FT)

Figure 14

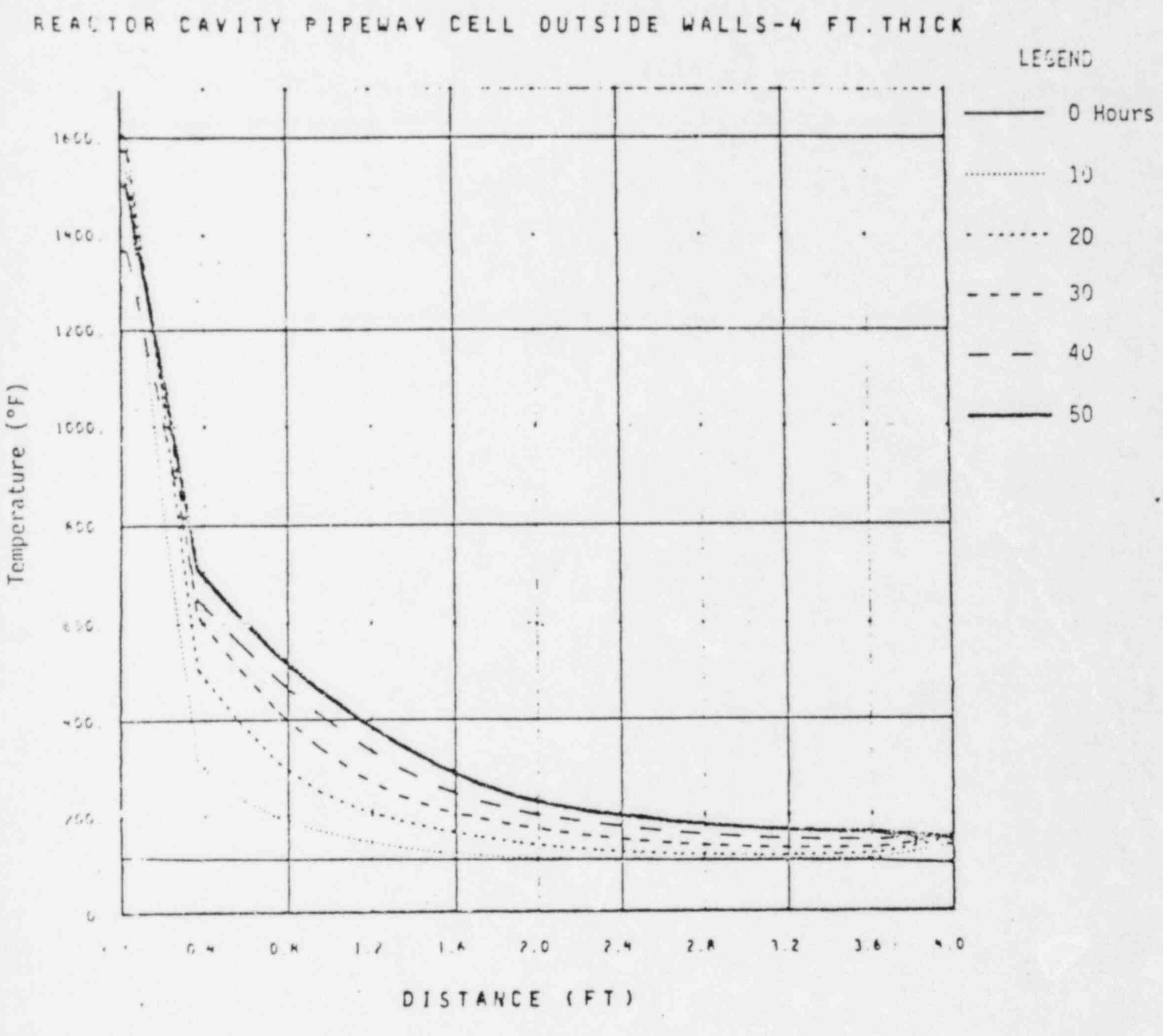
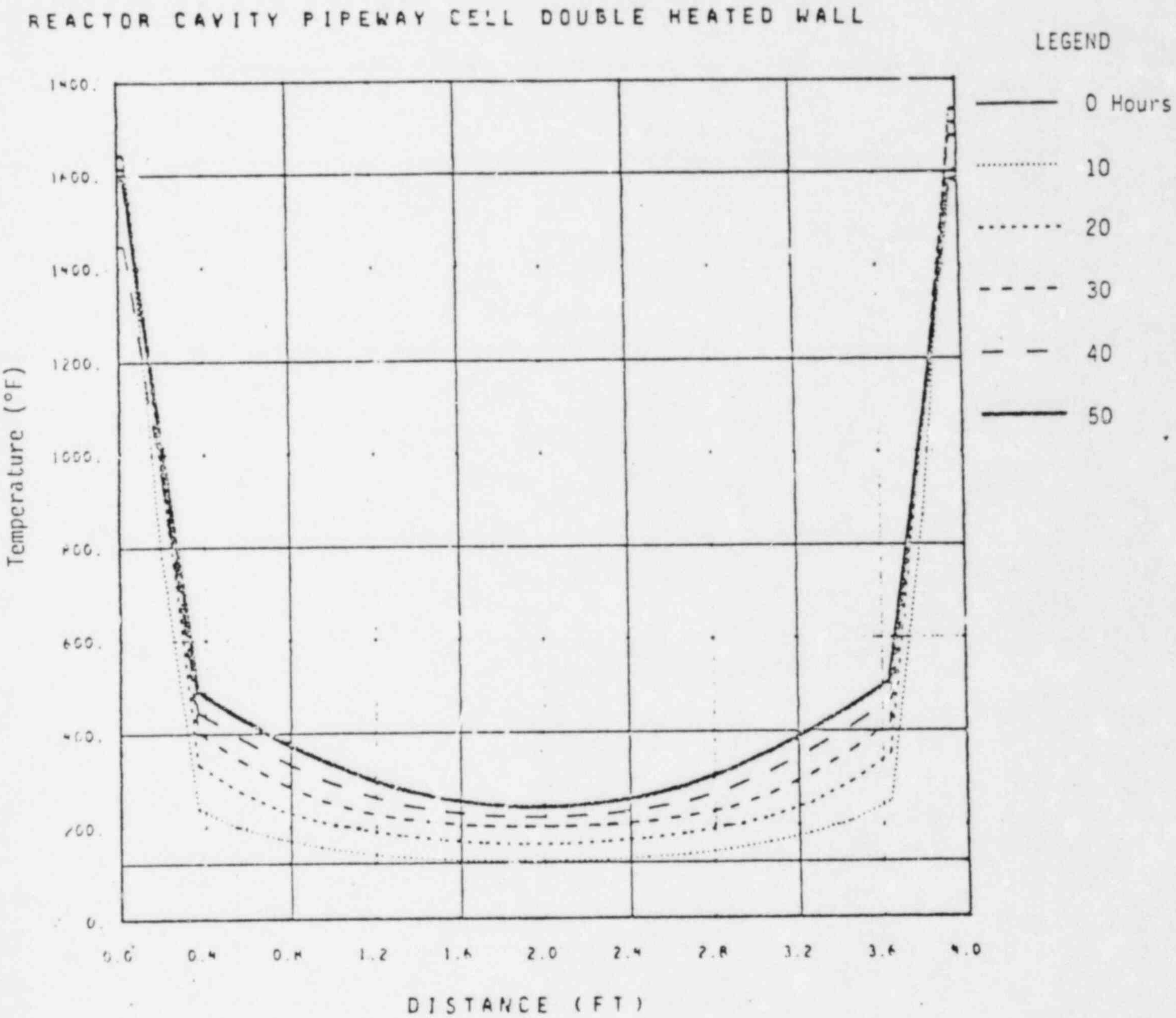

REACTOR CAVITY PIPEWAY CELL OUTSIDE WALLS-4 FT.THICK
LEGEND
0 Hours
10
20
30
40
50
Temperature (°F)
1600.
1400.
1200.
1000.
400.
0.4
0.8
1.2
2.0
2.4
3.2
4.0
DISTANCE (FT)

Figure 15



REACTOR CAVITY PIPEWAY CELL DOUBLE HEATED WALL
LEGEND
0 Hours
10
20
30
40
50
Temperature (°F)
DISTANCE (FT)

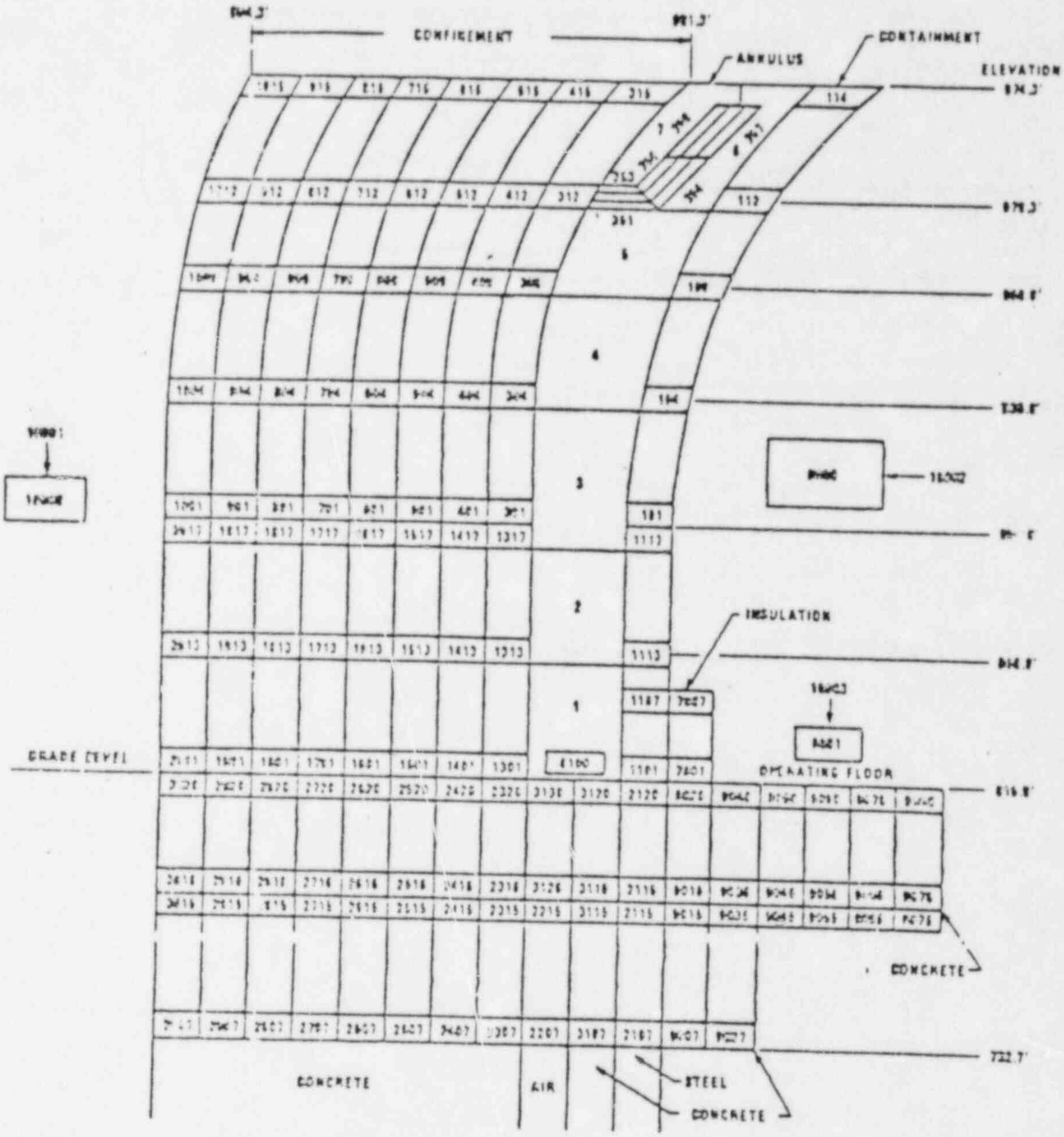
APPENDIX A

SODIUM-CONCRETE PENETRATION MARGINS ASSESSMENT ANNULUS COOLING ANALYSIS

The penetration margins assessment case heat loads to the containment steel shell as a function of time were used as input to a detailed thermal calculation using the TRUMP computer code. The thermal model was identical to that of Reference 3, except an updated model was used in the vicinity of the annulus cooling outlet structures. The nodal arrangement of the thermal model is shown in Figure A1. An annulus cooling system flow of 400,000 SCFM was used as was in the base case.

RESULTS

The temperature versus time plots for key nodes are presented in Figures A2 through A13. The structural consequences of these temperatures are described in Appendix B.



NOTES:
(1) NODES 1 THRU 7 REPRESENT AIR FLOW.
(2) NODE 8184 IS SOURCE NODE FOR AIR FLOW.
(3) NODE 8100 IS SOURCE NODE FOR HEAT LOAD TO STEEL CONTAINMENT.
(4) NODE 8201 IS SOURCE NODE FOR HEAT LOAD TO CONCRETE OPERATING FLOOR.
(5) NODE 16000 IS AMBIENT AIR.
(6) NODES 16001, 16002 AND 16003 ARE BOUNDARY NODES.

Figure A1 Annulus Cooling System Thermal Model

3659-1

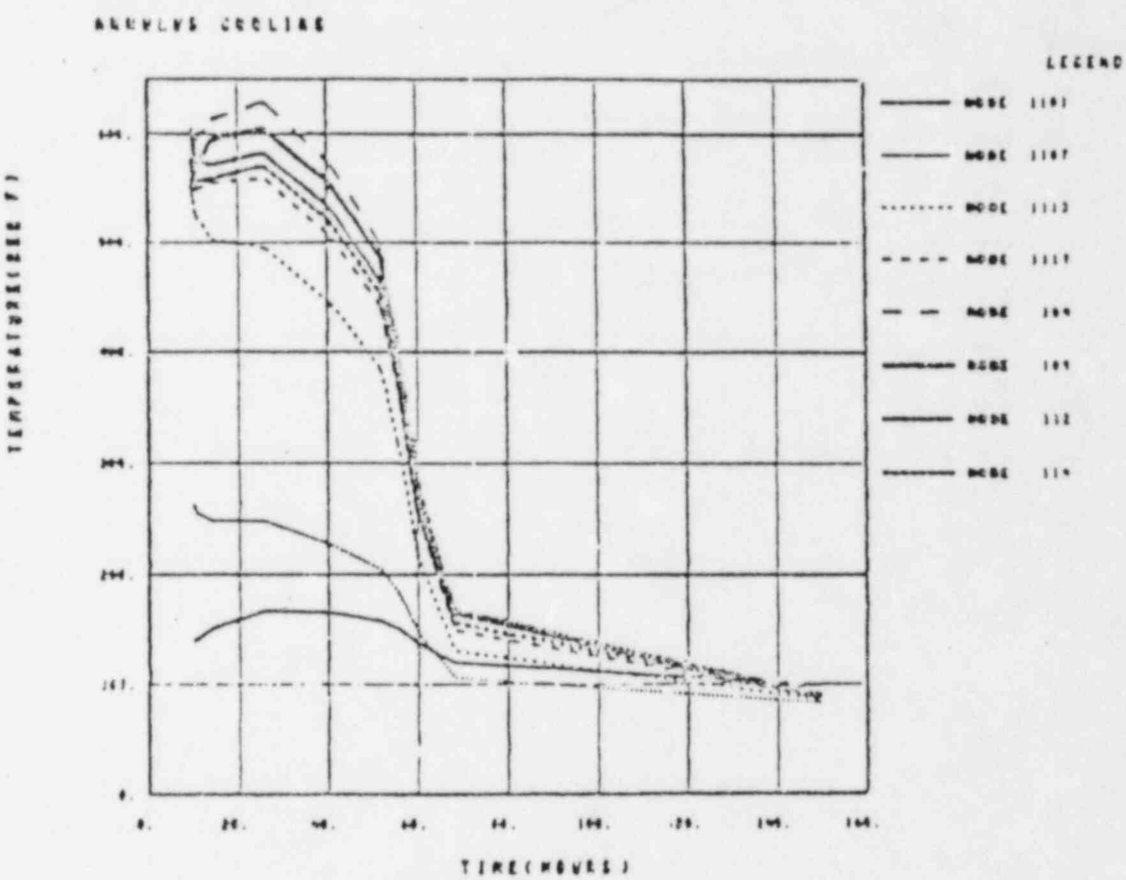


Figure A2

Steel Nodes

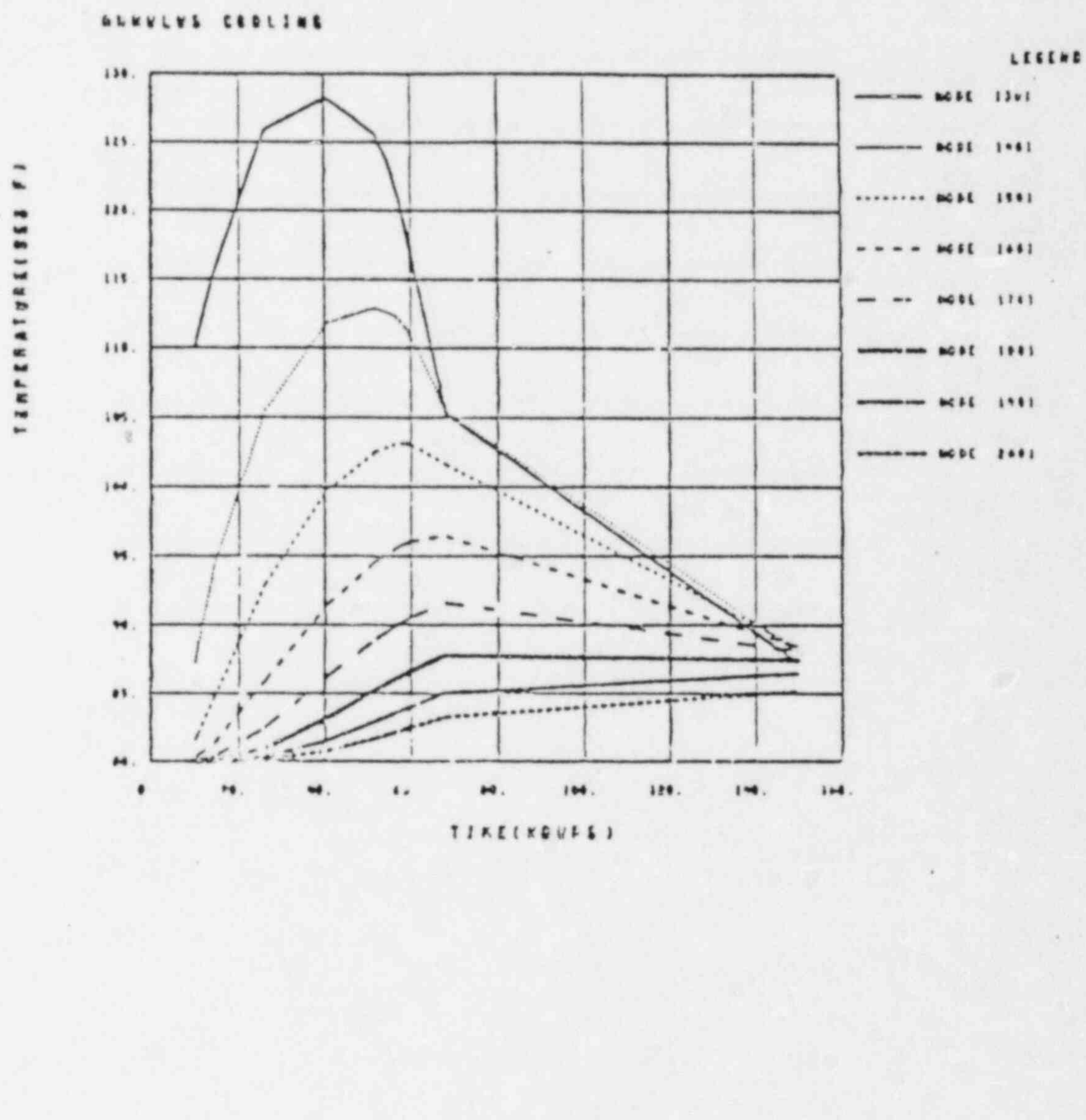


Figure A3

Nodes 1301-2001

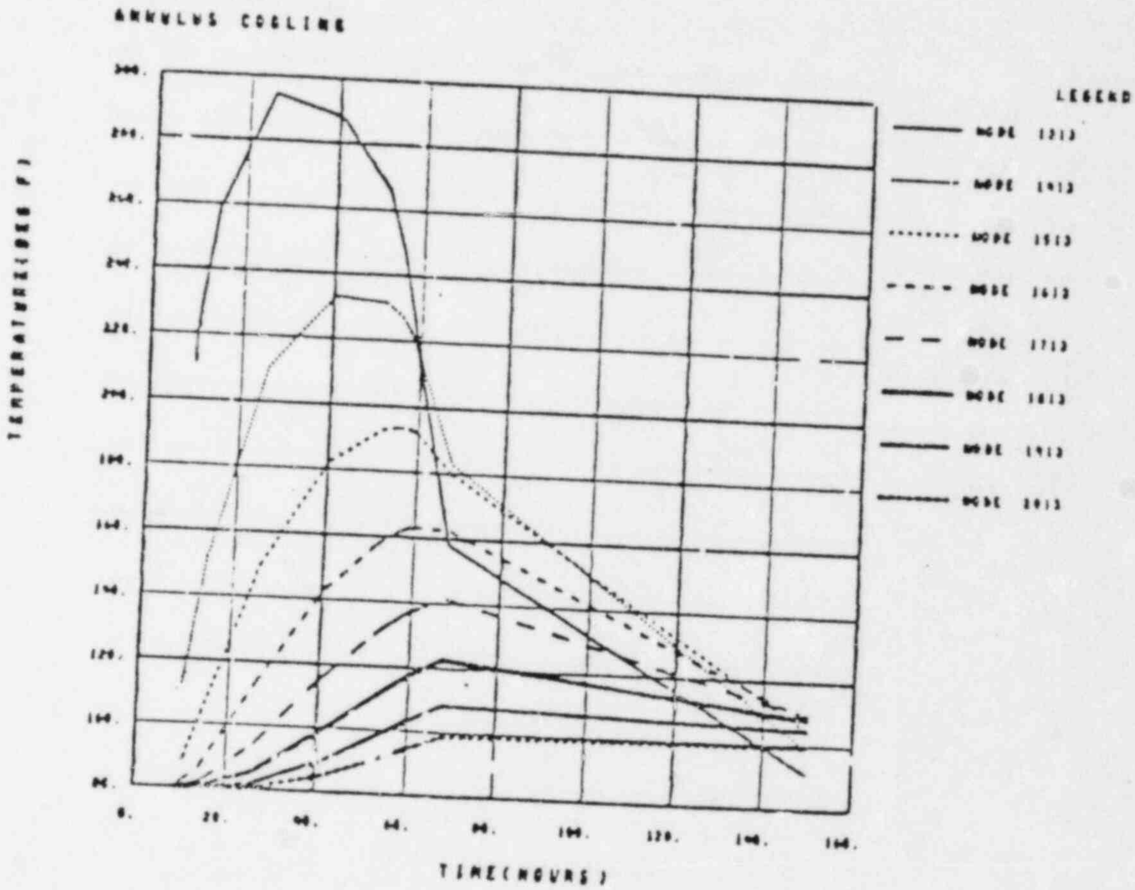


Figure A4

Nodes 1313-2013

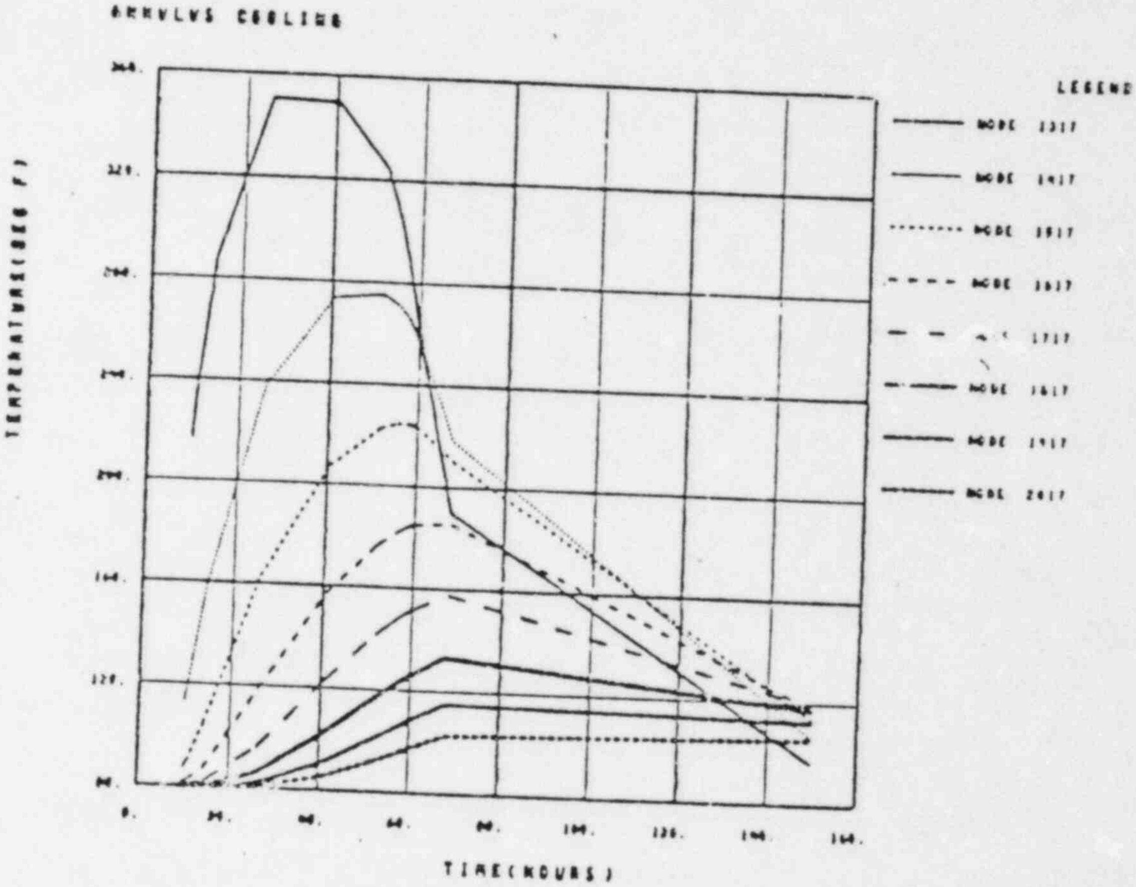


Figure A5

Nodes 1317-2017

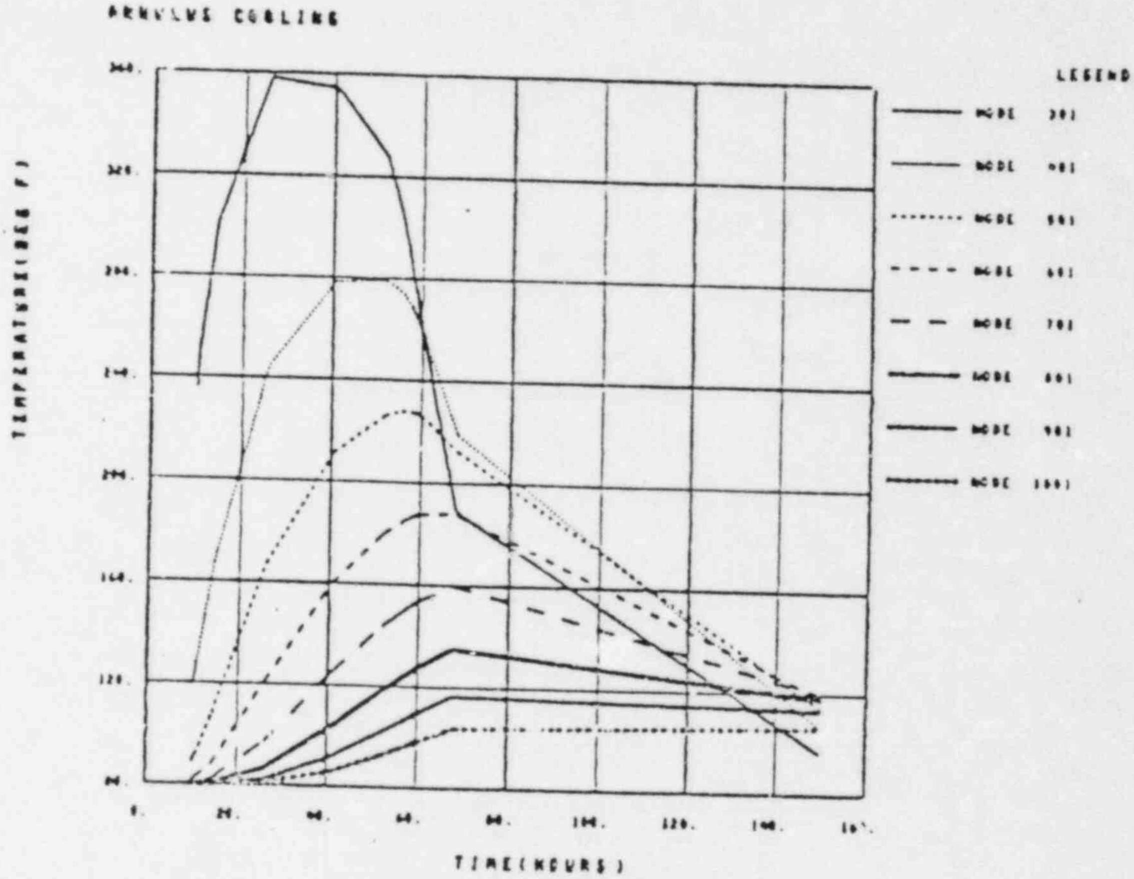


Figure A6

Nodes 301-1001

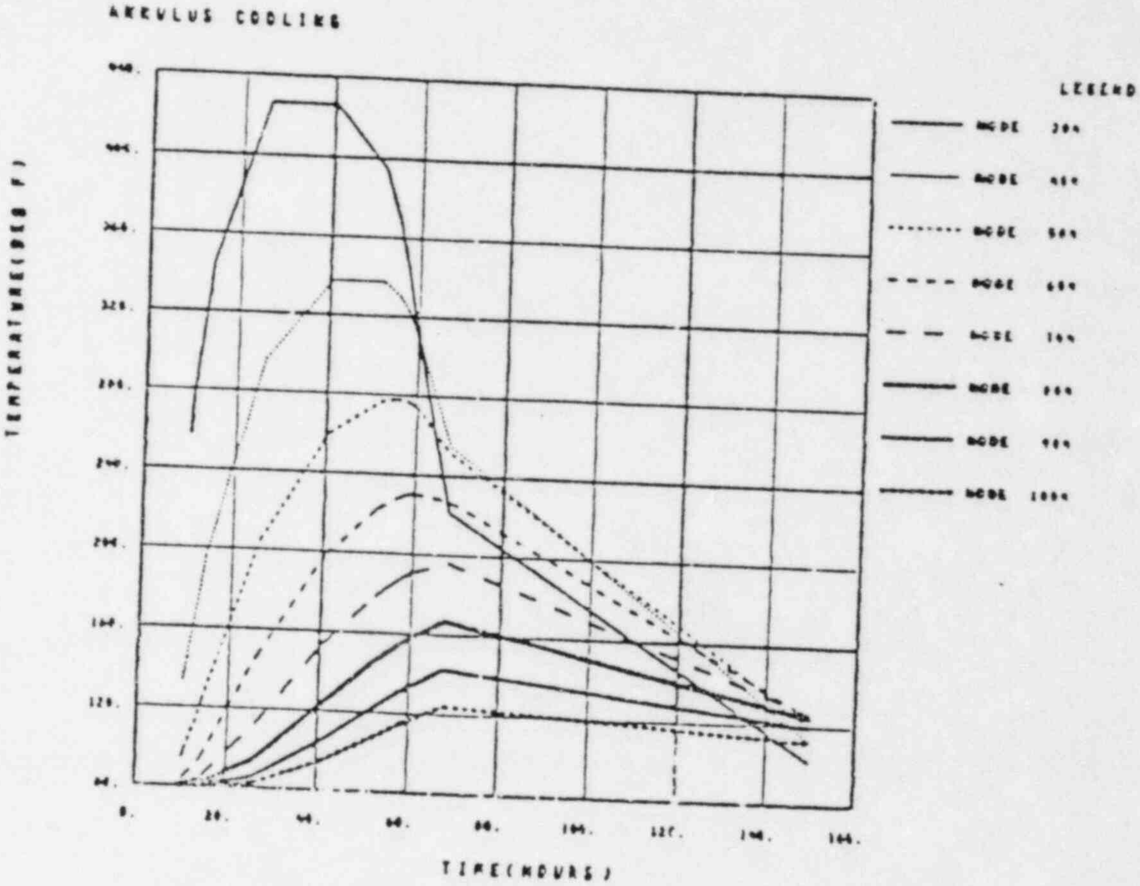


Figure A7

Nodes 304-1004

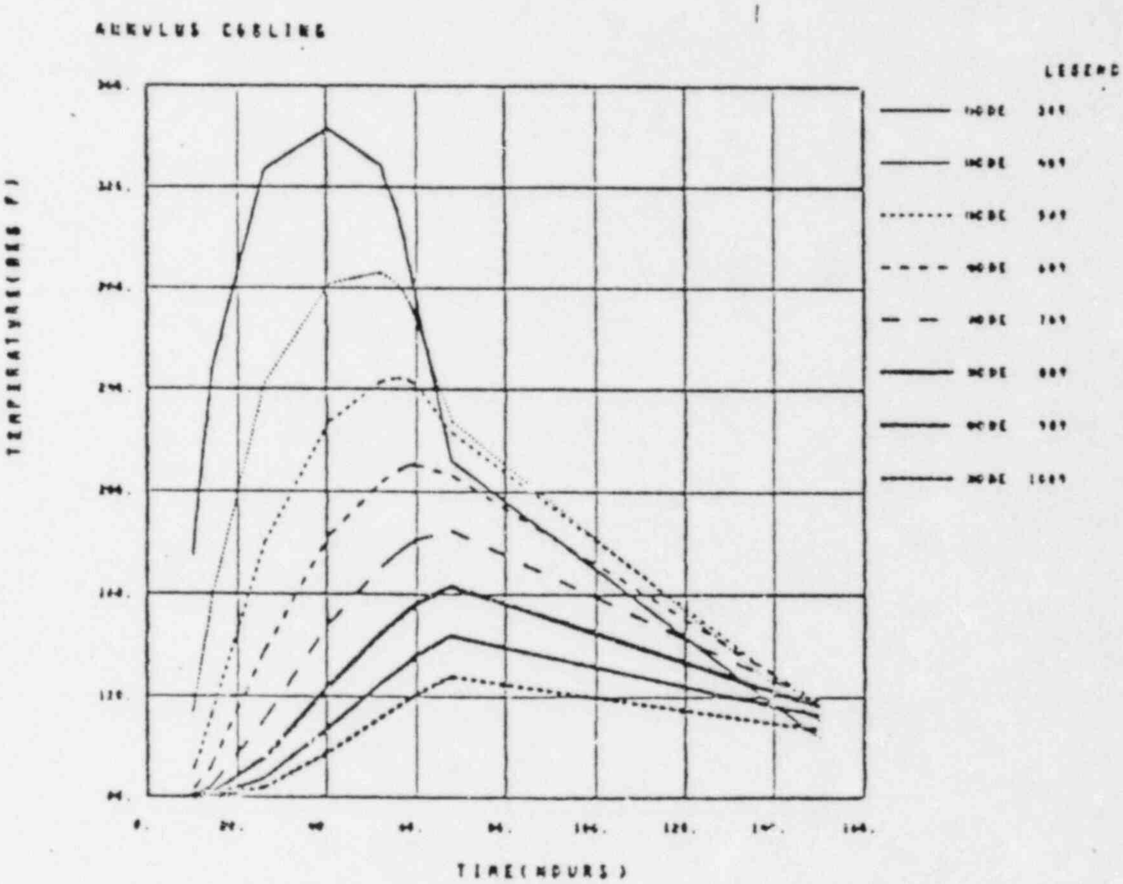


Figure A8

Nodes 309-1009

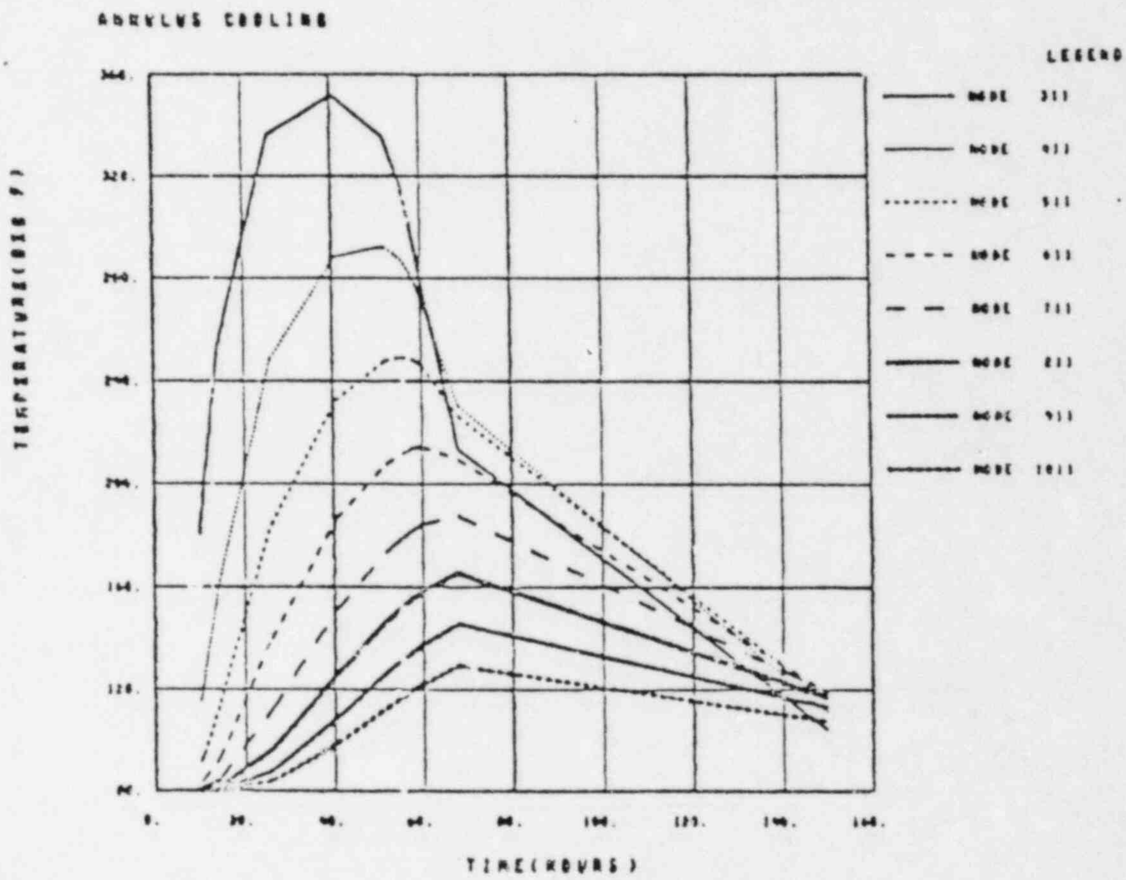


Figure A9

Nodes 311-1011

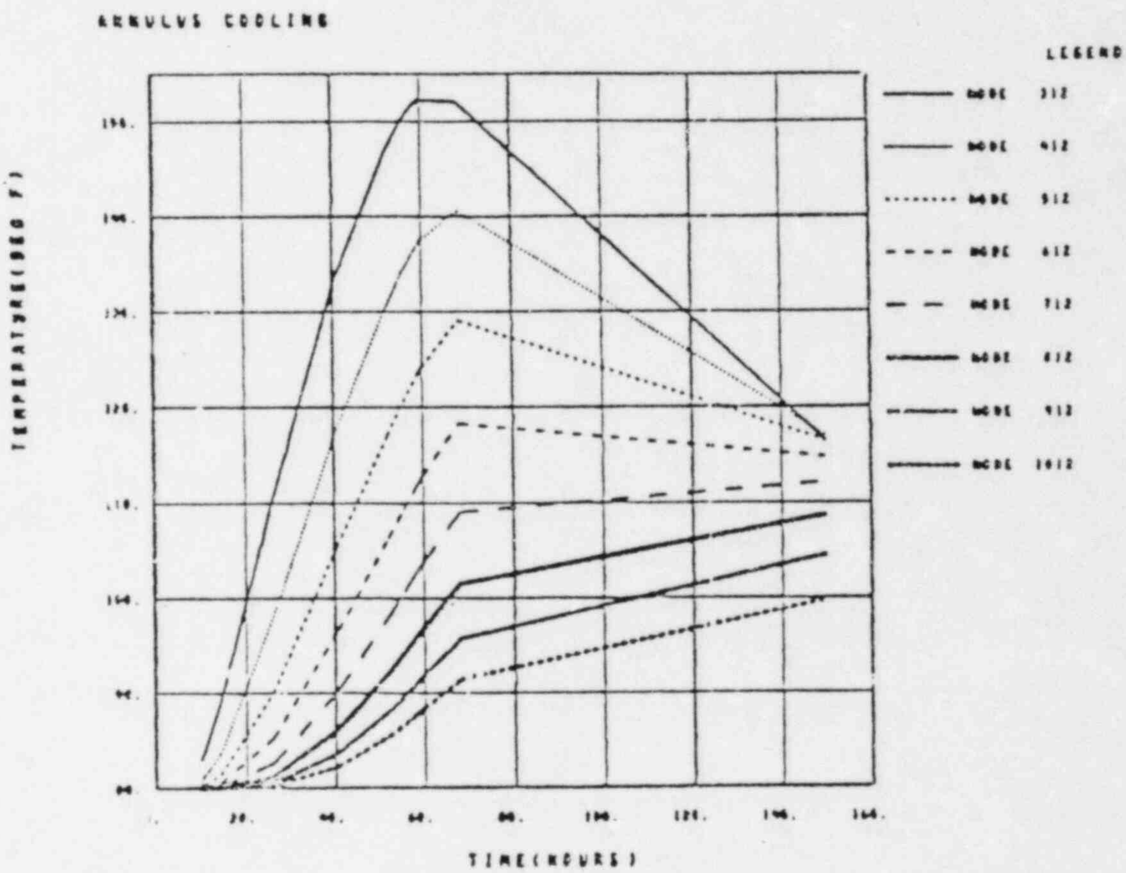


Figure A10

Nodes 312-1012

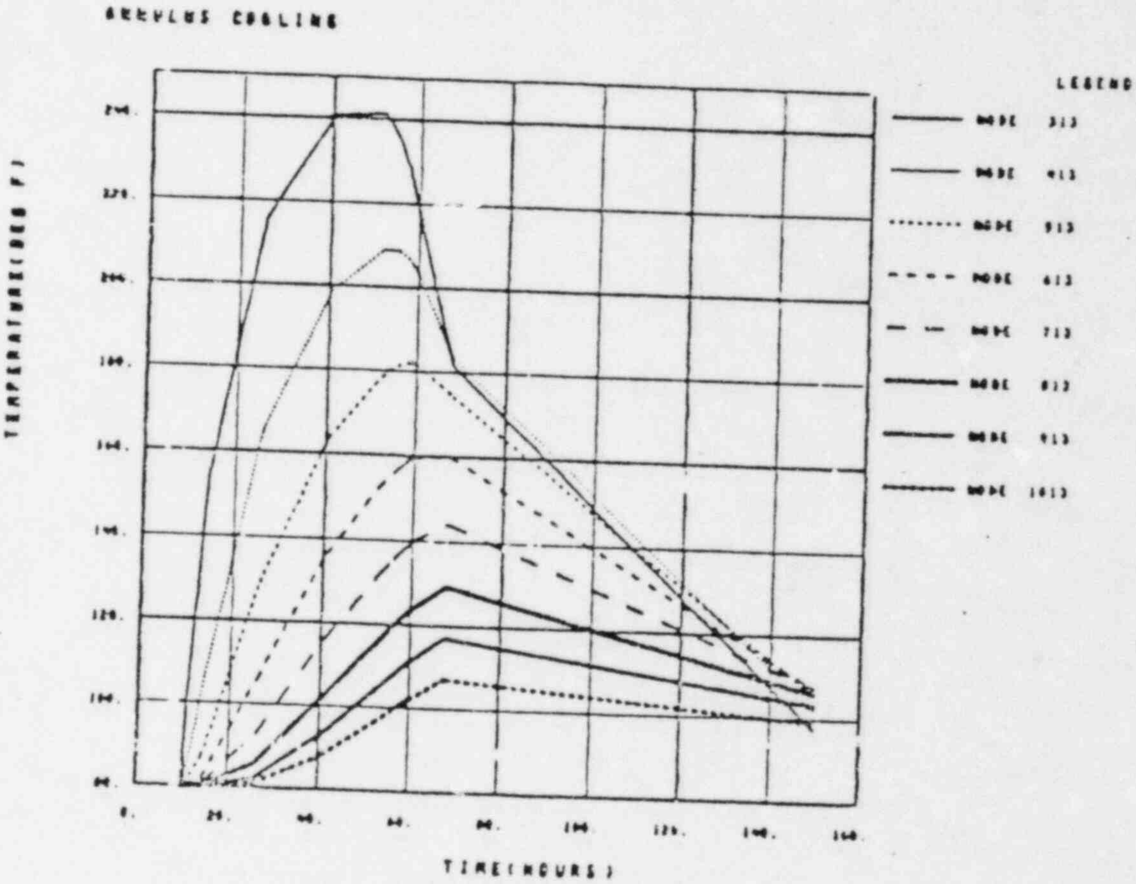


Figure A11

Nodes 313-1013

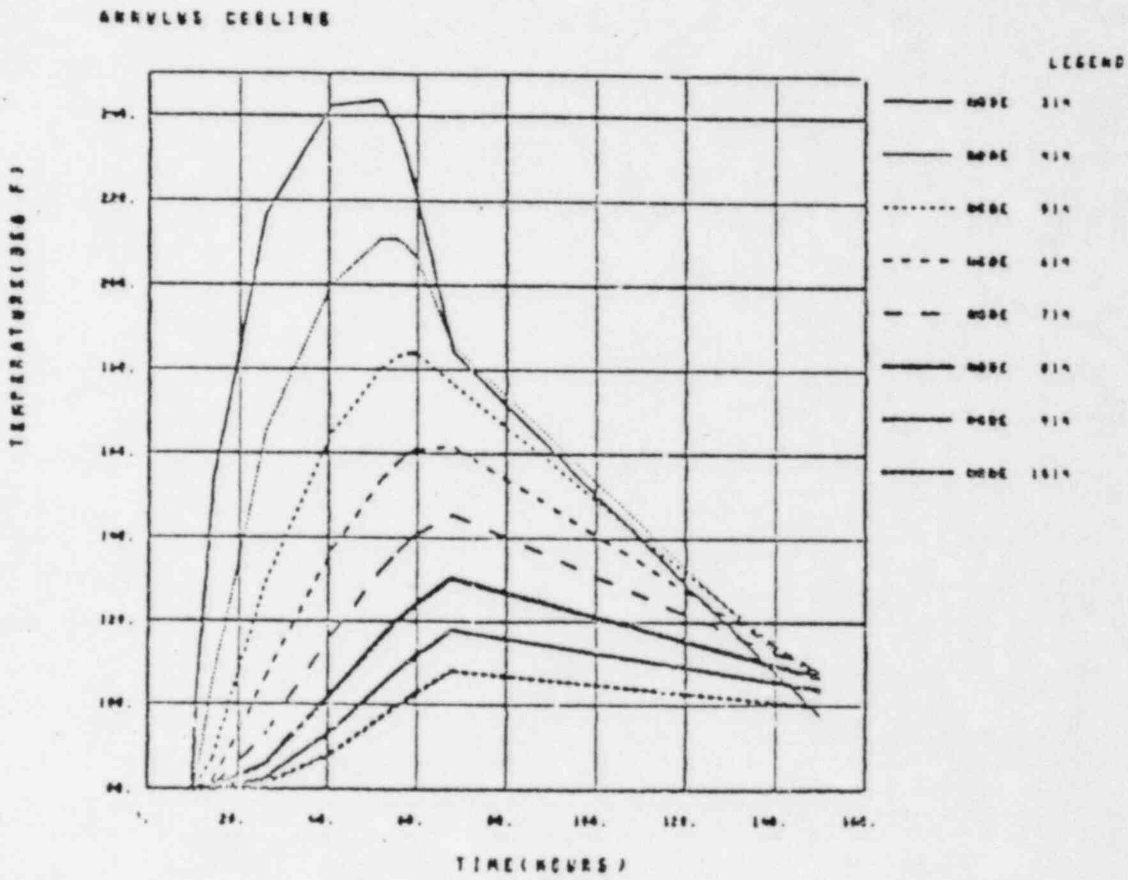


Figure A12

Nodes 314-1014

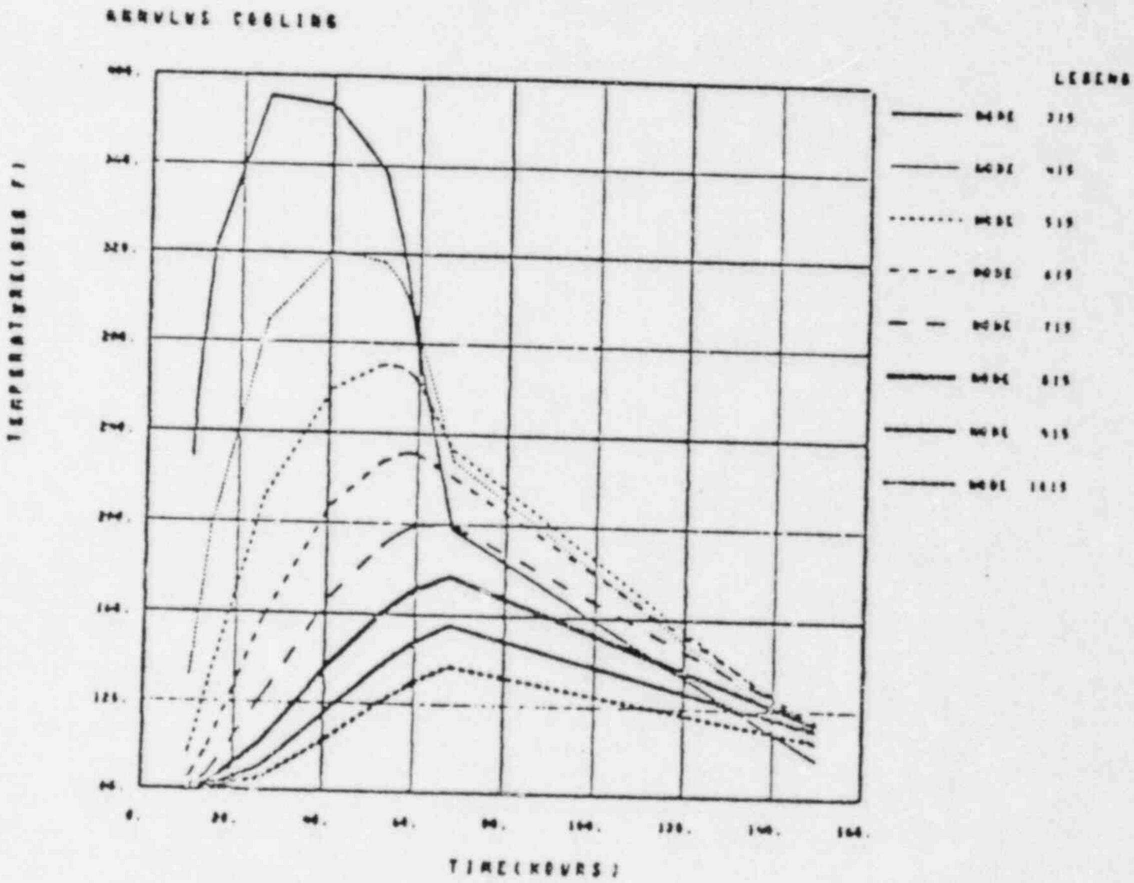


Figure A13

Nodes 315-1015

APPENDIX B

TMBDB SODIUM-CONCRETE PENETRATION MARGINS STRUCTURAL ASSESSMENTS

The sodium-concrete penetration margins assessment case considers penetration rates of sodium into concrete of 7 inches per hour for 3 hours and 1 inch per hour thereafter. The temperature transients for this case are shown in Figures 5 through 15. The structural requirements are as follows:

A. Wall liners in the Reactor Cavity to maintain integrity until boildry time (50 hours). While this is not a base case TMBDB requirement, it is imposed here to preclude extreme penetration into the RC walls concurrently with extreme penetration into the floor.

B. Pipeway cell wall integrity to be maintained as follows:
Wall between RC and pipeway cell (double heated wall) - 50 hours
All others - 30 hours

C. The Reactor Cavity floor and Pipeway Cell floor to prevent sodium leakage to Cell 105 until boildry time.

D. Containment and Confinement integrity to be maintained for long term.

The structural assessments for the sodium-concrete penetration margins assessment case include the Reactor Cavity, Pipeway Cells, and the Confinement structure and containment shell above the operating floor. The containment and confinement below the operating floor are not subjected to any significant temperatures in the short term, and long term effects are not expected to be different than the base case.

The purpose of the structural assessments was to evaluate whether the structures, as designed, can withstand the imposed conditions, and if not, to determine what modifications would be necessary to accomplish that. Due to the scoping nature of the work the assessments are based on simplified computer models and/or comparisons with the base case structural evaluations, the material properties and criteria are as described in Appendix C.3 of

CRBRP-3 (Reference B1).

A brief summary of the evaluations is given below.

REACTOR CAVITY AND LINER

The Reactor Cavity wall above the floor is subjected to temperature transients (Figures 8 through 10) which are about the same as in the base case, since the surface temperature is governed by the sodium boiling temperature which is independent of sodium-concrete penetration rate. Integrity for the Reactor Cavity wall and liner in the base case has been demonstrated for 50 hours and longer, so the 50 hours (boildry time) integrity requirement in the margins assessment case is met.

The Reactor Cavity floor liner is assumed to fail at the onset of the accident as in the base case. The Reactor Cavity floor thermal transients of Figure B1 indicate that 5.5 to 6.0 feet of concrete would be totally degraded by the penetration of sodium and heat and this would leave only about 2 feet of concrete to the floor fill construction joint (Figure B2) which is not adequate to prevent sodium leakage through the construction joint. Further, if the sodium penetration extends radially into the wall, the base of the wall would be undermined and leakage to the adjacent cell 105 might occur.

In order to meet the scenario requirements it would be necessary to introduce modifications in the floor of the Reactor Cavity and the junction with the wall. The basic modifications, in the conceptual stage, consist of the following (Figure B3):

A. The wall liner would be extended to 6.5 feet into the structural concrete.

B. The construction joint at Elevation 733 would be eliminated and the floor rebar rearranged.

C. Provide a design feature on the RC floor near the wall to inhibit the spreading of the fuel debris to the region of the floor wall junction.

Evaluations were performed to determine the adequacy of the concrete below the reactor cavity floor under the temperature transient at boildry time (50 hours). In these evaluations the undergraded portion of the floor was represented by the axisymmetric restrained section in Figure B4 and the stress analysis was performed using elastic procedures and the computer program ANSYS (Reference B2). The behavior was bracketed by two extreme conditions of no radial restraint and full radial restraint. Capacity calculations were performed using the computer program MPHI (Reference B3). The results of the analyses demonstrate that the floor can withstand the imposed temperatures with sufficient margin.

PIPEWAY CELL WALLS

In the base case, integrity for the wall and liner between the Reactor Cavity and the pipeway cells has been demonstrated for 70 hours. For the penetration margins assessment case, the wall liner is subjected to the same temperatures as in the base case and the concrete wall at boildry (50 hours) is subjected to temperatures which are lower than the base case 70 hour temperature (Figure B5). It may be concluded that this concrete wall and wall liner meet the margin assessment case requirements.

In the base case, integrity of the pipeway cell walls and wall liners (other than the liner between the RC and the pipeway cell) has been demonstrated for 40 hours, at which time the liners may fail, but collapse of the walls is not expected until after the 133 hour sodium boildry time. In the penetration margins assessment case, the wall liners are subjected to the same temperatures as in the base case. A comparison of the penetration margins assessment case transient with the base case transient (Figure B6) indicates that the pipeway cell wall temperatures at 30 hours are somewhat lower than the 40 hour base case transients. It may be concluded from this that the pipeway cell liners meet the penetration margin assessment requirements. Because of the much shorter boildry time, the wall temperatures are less severe at boildry (50 hours) in the margins assessment case, so that the concrete walls also meet the requirements for the penetration margins assessment case.

PIPEWAY CELL FLOOR AND LINER

The penetration margins assessment case considers that the pipeway cell floor experiences the same penetration rate in the reaction as the reactor cavity so there is substantial sodium penetration. In order to accommodate the temperature transients it is necessary to introduce the following modifications to the present design (Figure B7):

A. Provide a second layer of insulating concrete below the second liner.

B. Increase the thickness of the floor by the thickness of the second layer of insulating concrete (lower bottom).

With the above modifications the temperature transient at 50 hours is as shown in Figure B8. Scoping computer analysis was performed using the programs ANSYS and MPHI, with the floor represented by a restrained section similar to that of the Reactor Cavity floor model described earlier. The results of this analysis indicate that structural integrity of the modified floor would be maintained and leakage to Cell 105 would be prevented for at least 50 hours as required.

CONFINEMENT STRUCTURE

An evaluation was performed to determine whether the confinement structure could sustain the thermal transients of Appendix A with the same annulus cooling as in the base case. The evaluation consisted of computer analysis using simplified models and comparisons with the base case evaluation described in Reference B1. Specifically, analysis was performed using the computer program ANSYS and models of restrained sections similar to that shown in Figure B4 for the RC floor to calculate the thermal moments and forces at various levels. These values were then adjusted based on the results from the base case which considered both restrained sections and the full structure and were compared to allowables from the program MPHI. The results indicate that for the 50 hour transients integrity will be maintained. The results also indicate that the worst conditions, from the

structural standpoint, occur at 50 hours or earlier. As shown in Appendix A, the temperatures decrease after the 50 hour sodium boildry time.

CONTAINMENT STEEL SHELL

The temperature transients in the steel shell are shown in Appendix A, with the annulus cooling activated at 10 hours. The peak temperatures prior to venting (when the peak pressure of 18.7 psig occurred) were about 600°F. Reference B1 gives a pressure capability of the steel shell of over 34 psig at 600°F so there is no significant threat to the steel shell as a result of the penetration margins assessment case. Also, the peak temperature at the steel shell-grade level intersection was about 170°F, well below the 240°F critical buckling temperature of Reference B1. It is concluded that the margins assessment case does not present a significant challenge to the steel shell.

REFERENCES

B1 CRBRP-3, Volume 2, Assessment of Thermal Margin Beyond the Design Base

B2 Computer Program ANSYS, Revision 3, Swanson Analysis Systems Inc., Houston, Pennsylvania

B3 Computer Program MPHI, Burns and Roe, Inc., Oradell, NJ

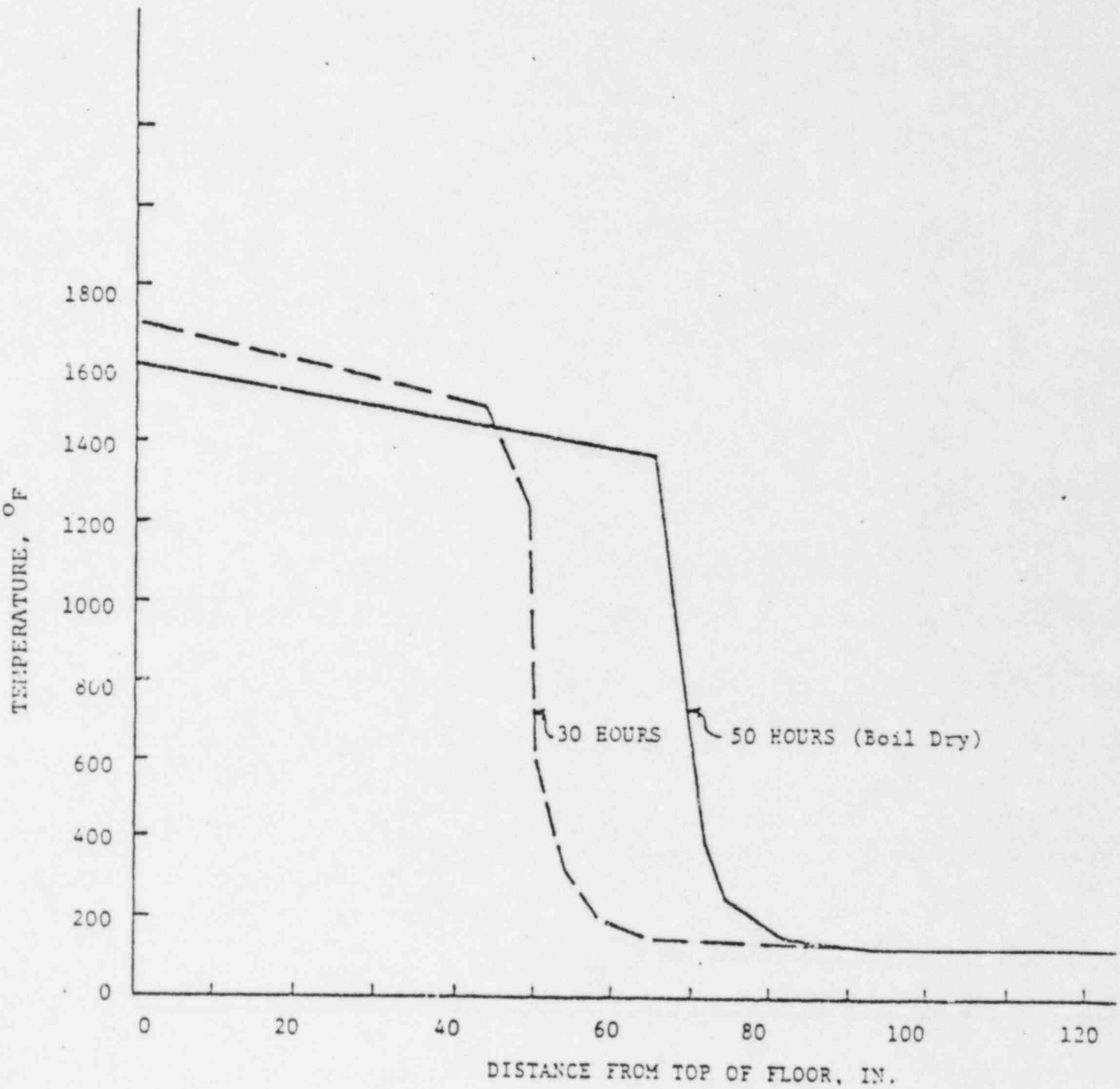


FIGURE B1

REACTOR CAVITY FLOOR - TEMPERATURE TRANSIENTS

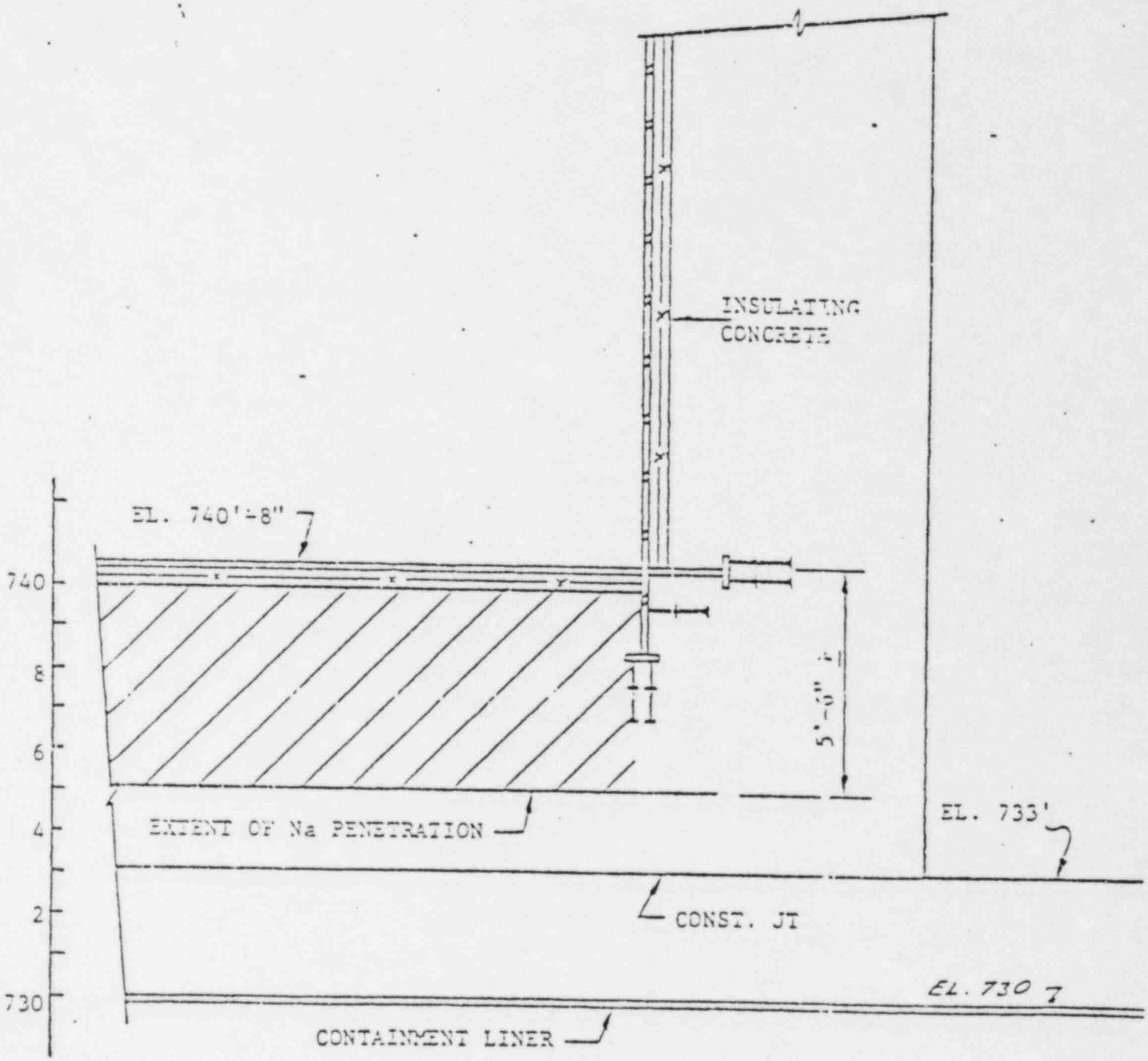


FIGURE B2
SECTION - REACTOR CAVITY AND WALL
CURRENT DESIGN AND EXTENT OF Na PENETRATION

PENETRATION MARGIN ASSESSMENT

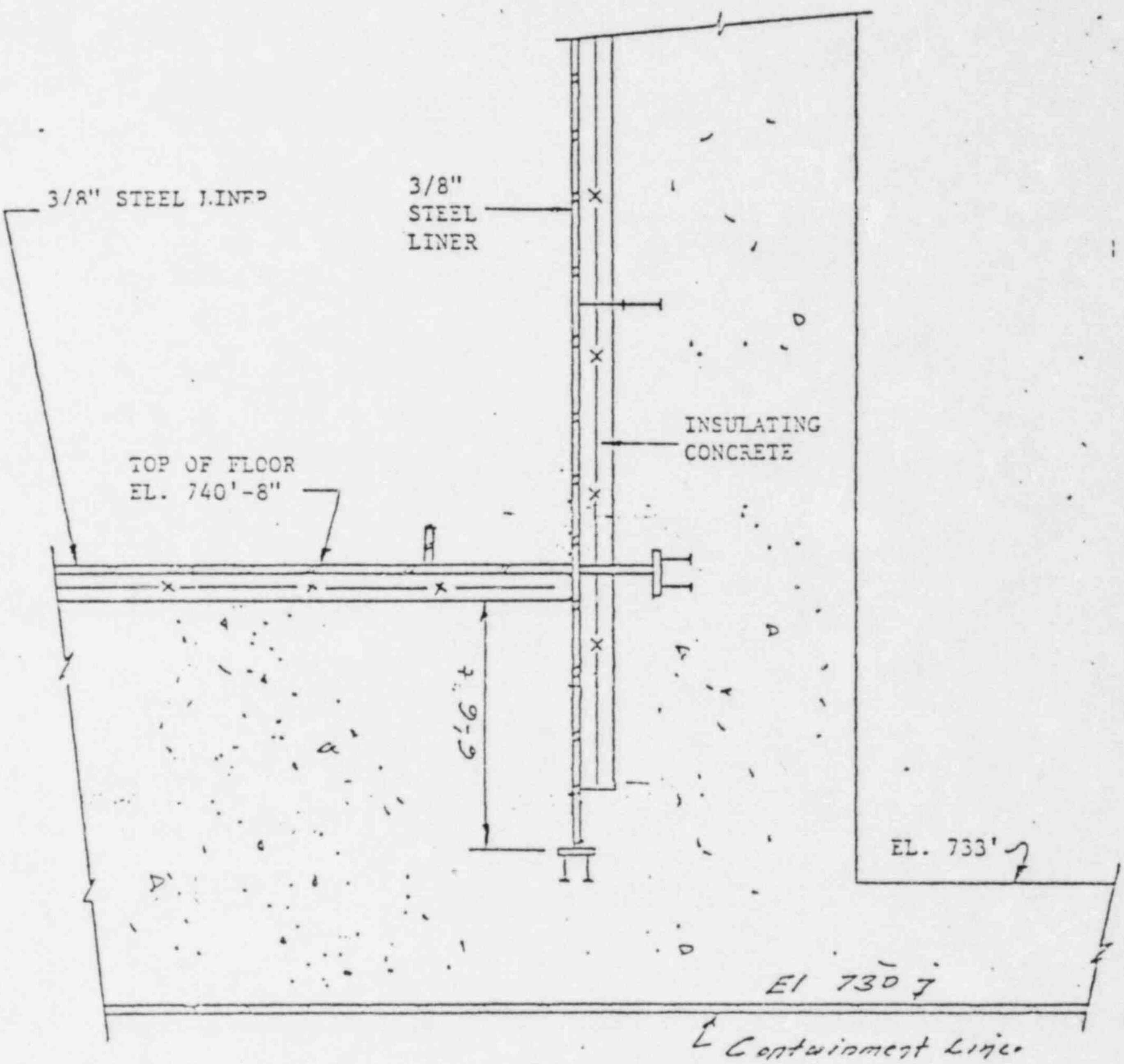


FIGURE B3

SECTION - REACTOR CAVITY FLOOR AND WALL
MODIFIED DESIGN

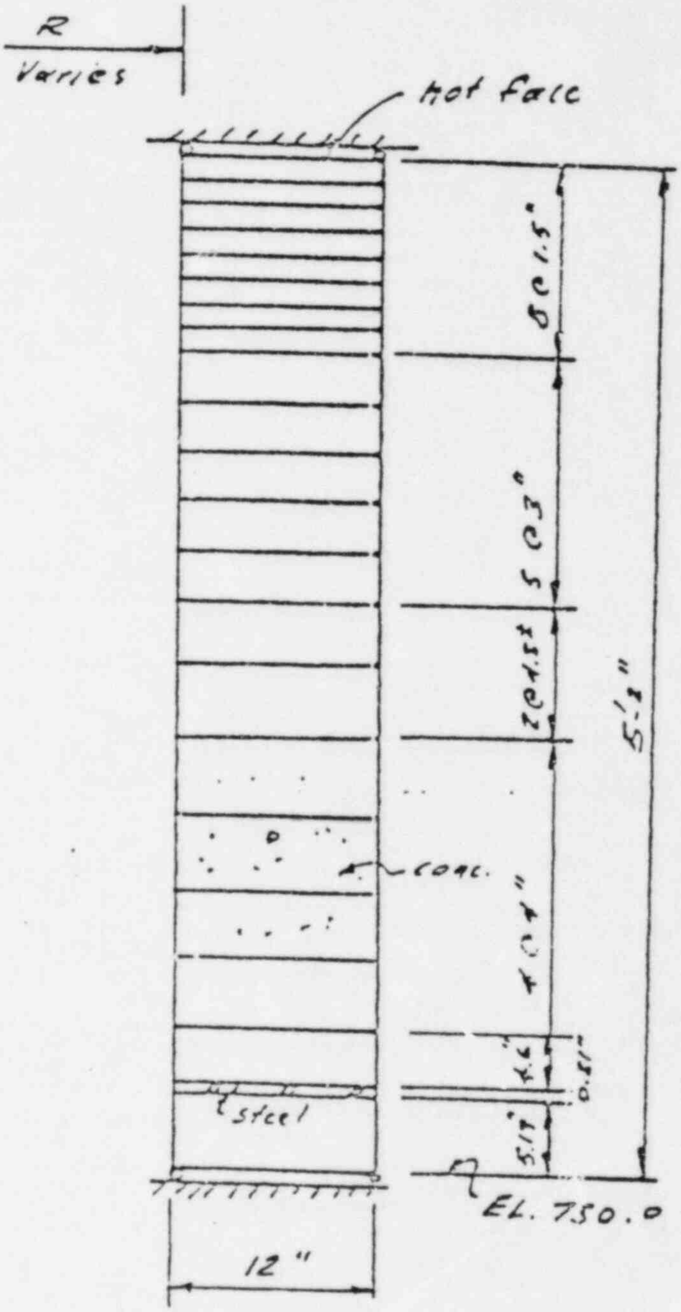
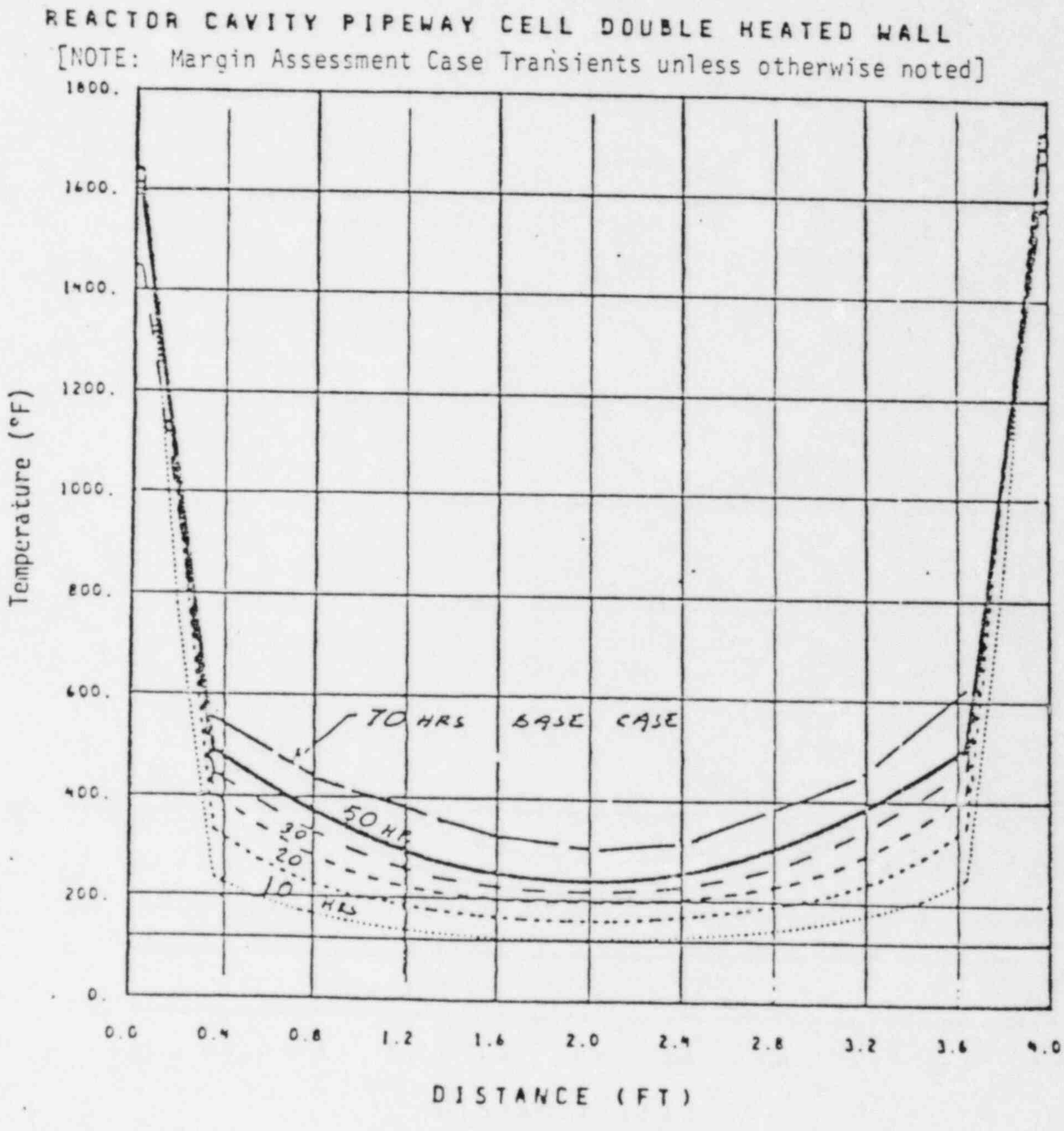


FIGURE B4

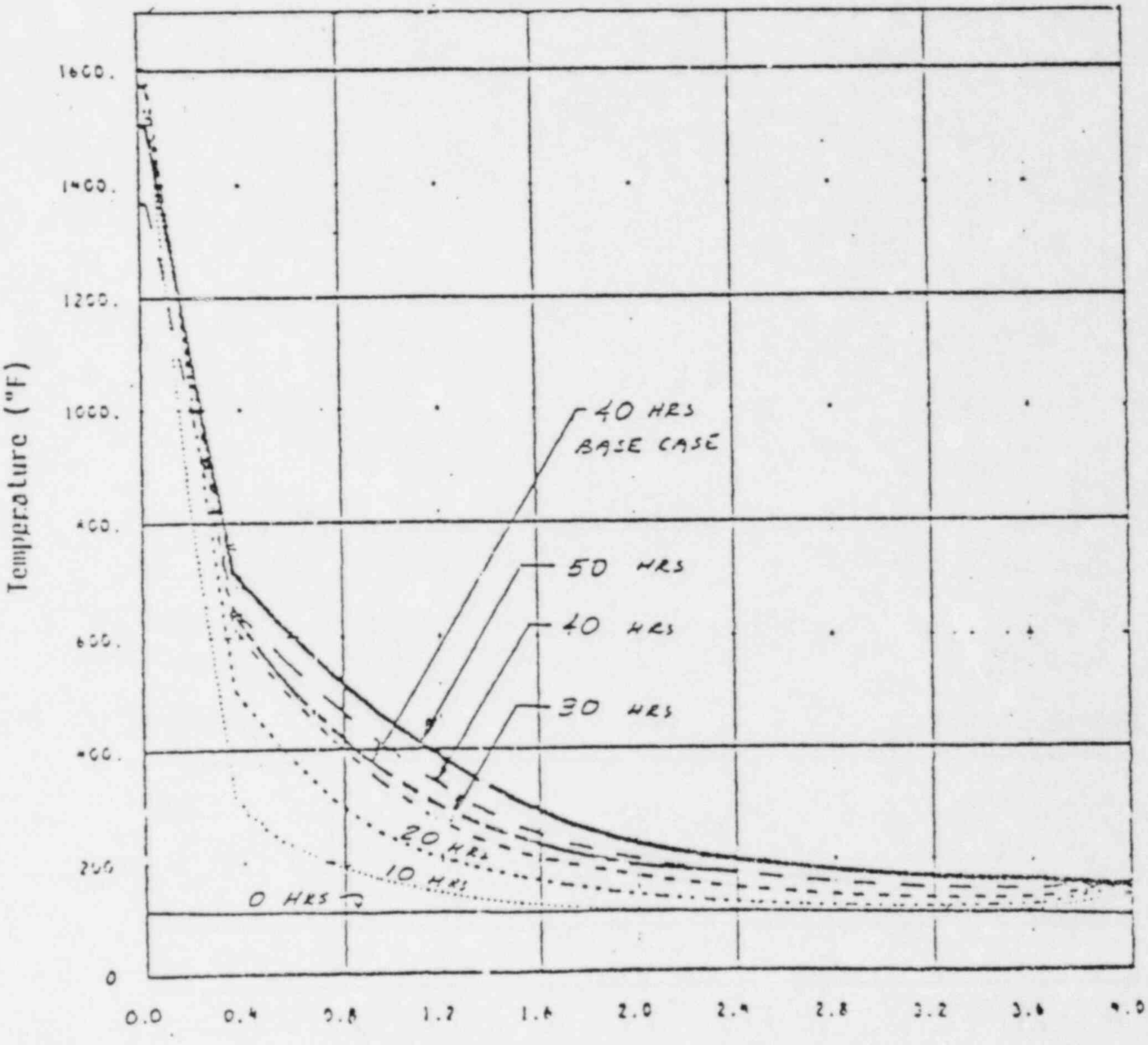
AXISYMMETRICAL MODEL FOR RC FLOOR



REACTOR CAVITY PIPEWAY CELL DOUBLE HEATED WALL
[NOTE: Margin Assessment Case Transients unless otherwise noted]
1800.
1600.
1400.
1200.
1000.
800.
600.
400.
200.
0.
Temperature (°F)
70 HRS BASE CASE
50 HR
30
20
10
HRS
0.0
0.4
0.8
1.2
1.6
2.0
2.4
2.8
3.2
3.6
4.0
DISTANCE (FT)

Figure B5

PIPEWAY CELL OUTSIDE WALLS-4 FT.THICK



NOTE: Penetration Margins Assessment
Transients unless noted otherwise

FIGURE B5

PIPEWAY CELL WALL TEMPERATURES - PENETRATION MARGINS ASSESSMENT AND BASE CASE

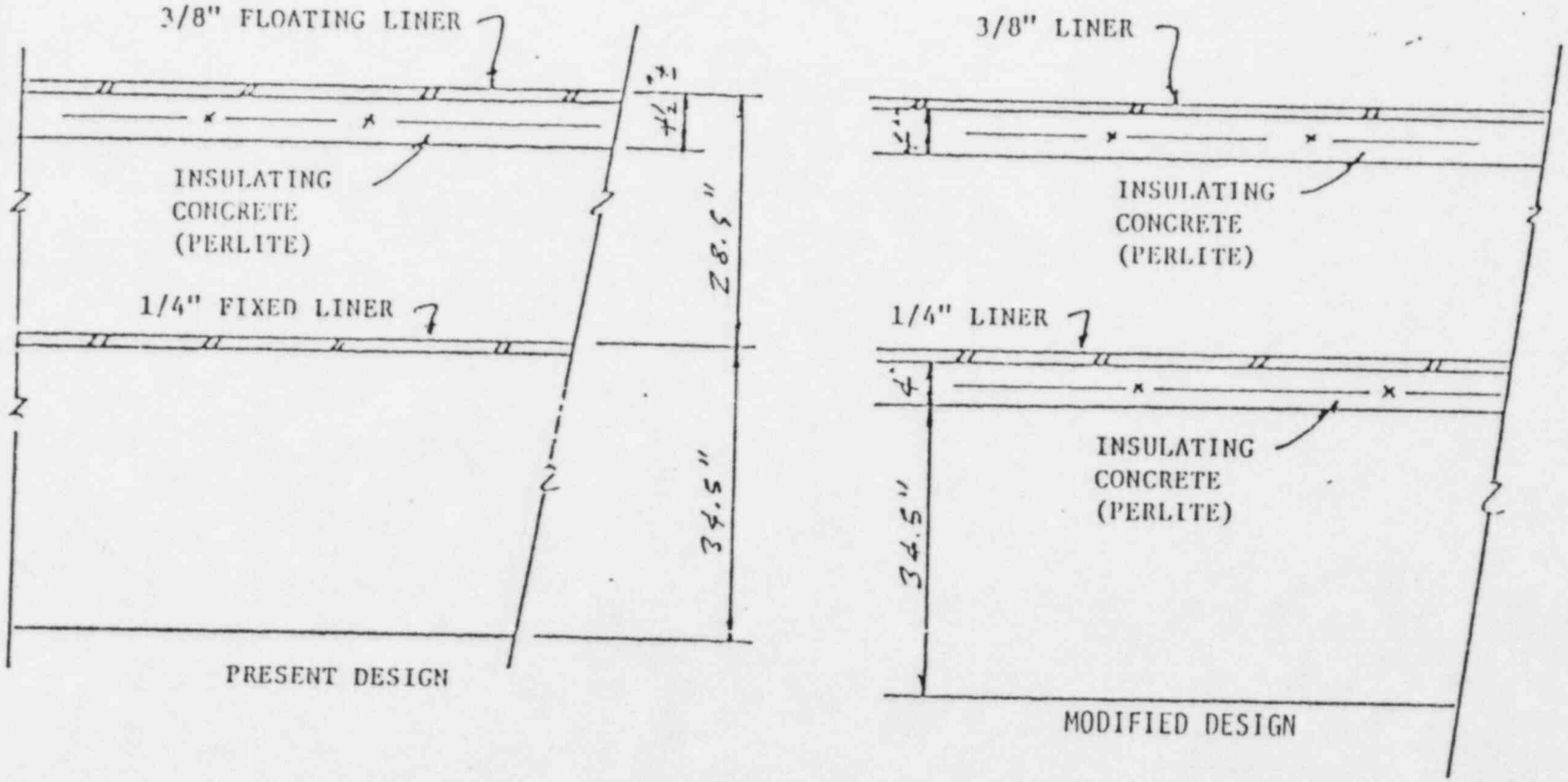


FIGURE B7

PIPEWAY CELL FLOOR CROSS SECTION

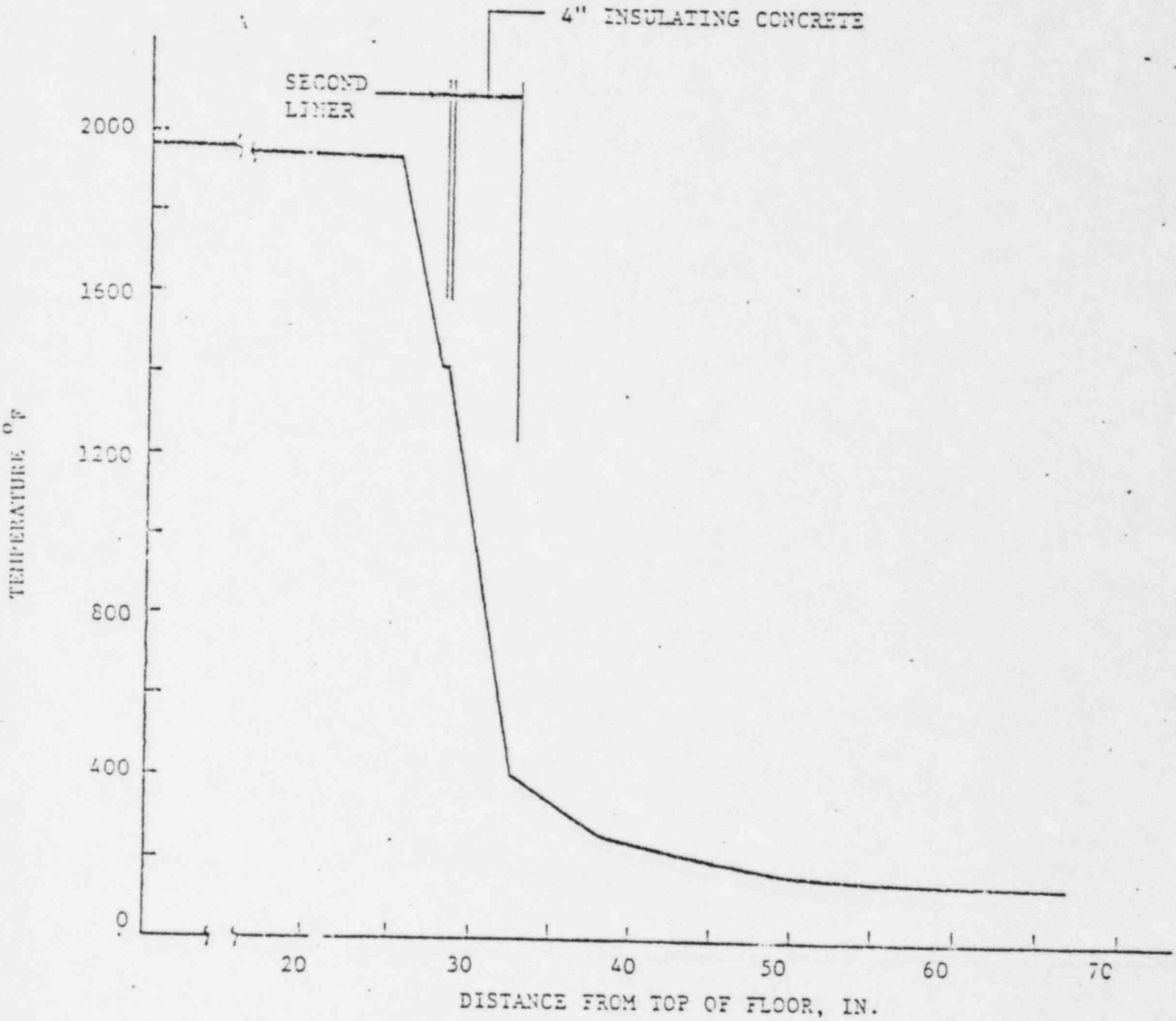


FIGURE B8

PIPEWAY CELL FLOOR - THERMAL TRANSIENTS