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April 30, 1985

Mr. Mark A. Cunningham
U. S. Nuclear Regulatory Commission
Nicholson Lane Building
Mail Stop 1130SS
5650 Nicholson Lane
Rockville, Maryland 20852

Dear Mark:

Enclosed for your information and use is our report on "MARCH-MAAP Comparison Calculations". The subject document completes the reporting requirements of Task 2 under Contract NRC-04-84-127.

Sincerely,

Peter Cybulskis

PC/dem

enclosures (4)

cc: Sharon Wollett, NRC

#1

REPORT

on

MARCH-MAAP COMPARISON CALCULATIONS

to

U. S. NUCLEAR REGULATORY COMMISSION

April 29, 1985

by

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#2

MARCH-MAAP COMPARISON CALCULATIONS

INTRODUCTION

In order to provide a meaningful basis of comparison of the results of the Industry Degraded Core Rulemaking (IDCOR) program and the NRC's Accident Source Term Program, a number of code comparison calculations are being performed. This report addresses the comparisons between the NRC's MARCH code predictions and those of the IDCOR-developed MAAP code. The two codes are used to describe the overall accident progression and related thermal hydraulic conditions in the respective programs and thus serve as the drivers for most of the subsequent fission product release and transport calculations. This report deals only with the comparison of accident progression and related thermal hydraulic conditions.

The MARCH-MAAP comparison calculations involved analyses of the following specific plants and accident sequences:

Zion TMLB'

Sequoyah TML and S2HF

Grand Gulf TQUV and TC

Peach Bottom TW.

These plant and accident sequence combinations were selected through discussions involving NRC, IDCOR, and Battelle's Columbus Laboratories. Each of the above accident sequences had been previously analyzed by Battelle as input into the Accident Source Term Program; the results of those analyses are given in BMI-2104[1]. The bases and input assumptions for the former analyses, however, were not necessarily consistent with the approaches adopted by IDCOR.

APPROACH

The code utilized for these comparison calculations is the MARCH 2 version[2] recently completed by Battelle and used in the NRC's Accident Source Term Program. The MARCH results are to be compared to the MAAP results provided by IDCOR. In order to focus the comparisons on differences in modeling assumptions, the attempt has been made to use comparable inputs for describing the physical details of the plants and accident sequence definitions. This has been accomplished by utilizing, to the extent possible, the IDCOR data files as the basis for the MARCH input. The parameter files given in IDCOR Technical Report 16.2-3, MAAP, Modular Accident Analysis Program User's Manual - Vol. I, August 1983,[3] were the source of most of the initial MARCH input data. Some additional information was obtained through discussions with E. Fuller of IDCOR. Most recently, further discussions were held with IDCOR and FAI representatives to resolve questions arising out of the results of the initial comparisons. The results in this report reflect input changes resulting from the latter discussions. In some instances it was not possible to use identical inputs due to differences in the modeling approaches used by the developers of the two codes.

For the MARCH analyses the choices of modeling options used in BMI-2104 were largely adopted for these comparison calculations. In particular, the calculations described here utilized the gradual slumping model with continued metal-water reaction after the onset of melting. Particular aspects of the calculations were tailored to mimic the IDCOR approaches in situations where we were familiar with what has been done in their program. For example, for high pressure meltdown cases we tried to model failure of the vessel head as a small opening, rather than gross melting.

The expected basis of comparison between the MARCH and MAAP calculational results are the predicted times of occurrence of key events, containment pressure histories, times of containment failure, etc. There is considerable difficulty, however, in any comparison since all the events of interest do not necessarily have the same definition or meaning in the two programs. The time of core uncovery is a fairly straightforward point of comparison. The start of core melting, on the other hand, is not directly comparable in the two programs. MARCH utilizes a single effective melting

temperature for the combined fuel and cladding, with the actual value used being between the melting point of the cladding and that of the fuel; thus the start of melting in MARCH corresponds to the first node reaching this effective melting temperature. MAAP separates the fuel and the cladding, with a distinct melting temperature for each; the start of melting apparently corresponds to reaching the melting of pure uranium dioxide. The situation gets even more complicated when the timing of core slumping and collapse are considered. With the gradual slumping model and related input assumptions in MARCH as used in this study, start of core slumping occurs when the lowest node in a radial region becomes molten; the collapse of the remainder of the core into the bottom head is typically assumed when 75 percent of the core is molten. Frequently the start of slumping and collapse of the core are predicted to take place very closely together. In the MARCH analyses vessel head heatup is not started until the entire core has collapsed into the bottom head. In the MAAP calculations, as we understand them, core slumping takes place when a preselected fraction of the core is molten; this molten portion of the core falls immediately to the bottom of the reactor vessel and leads to head failure via a small opening in a preprogrammed time interval. The remainder of the core slumps as it reaches melting, with major portions of the core slumping after vessel head failure. The above differences should be kept in mind in comparing the results of the two sets of calculations.

RESULTS

Zion Large Dry PWR

For the MARCH analyses the Zion large dry containment was modeled as a single compartment; this is at variance with the IDCOR approach of using a multi-compartment treatment. The MARCH analyses did take into account the proper relationship between the water in the reactor cavity and that in the containment sump. As will be noted below, an alternate representation was also considered in order to approximate certain aspects of the IDCOR treatment of the transient sequence considered. The MARCH analyses used ten radial and twenty axial zones to represent the core; the MAAP parameter file used only seven radial and ten axial core nodes. The MARCH input duplicated the radial and axial power distribution given in the MAAP parameter file. There were also some differences in the representations of upper plenum structures, primary piping, and the steam generators; these are the result of inherent assumptions in the two codes with respect to the modeling of these structures. In other respects the MARCH input attempted to duplicate that used in the MAAP analyses, as we understood them.

Results for Zion TMLB

Two variations of the Zion TMLB sequence were initially considered for the MARCH analysis. In the first case the water in the containment sump would not overflow into the reactor cavity until the level on the floor exceeded 6 inches, corresponding to the height of the lip around the cavity. This is our understanding of the physical layout of the plant. The results for this case indicated that the reactor cavity would be dry at the time of vessel head failure; thus the containment pressurization following the evaporation of the accumulator water would be governed by the rate of concrete attack. In the second case, it was assumed that the water in the containment sump would come into contact with the core debris. This is intended to approximate the case where some of the core debris are expelled from the reactor cavity and thus come into contact with the sump water; this is the situation treated in the IDCOR MAAP analyses. Since MARCH does not model the expulsion of the core from the reactor cavity, this second case was

actually set up as if all the water in the containment sump could flow into the reactor cavity following the onset of concrete attack.

The second approach to treating debris-water interactions was chosen as the basis for comparison with MAAP results. The MARCH results for this case are summarized in Table 1. The calculated containment pressure and temperature responses are illustrated in Figures 1 and 2. With the assumed contact between the core debris and sump water, the containment pressure increases steadily until all the water is evaporated; after that, continued pressurization is due to concrete decomposition. Containment failure is predicted at about 24 hours after the start of the accident. The predicted progression of concrete attack is illustrated in Figure 3.

Comparison of the MARCH predictions with the MAAP results taken from IDCOR Technical Report 23.1, Zion Nuclear Generating Station Integrated Containment Analyses[4], is given in Table 2 and shows somewhat shorter times to steam generator dryout, core uncovery, start of melting, and reactor vessel failure for MARCH than predicted by MARCH. As was noted previously, there are inherent differences in primary system nodalization and distribution of structures between MARCH and MAAP; thus the input to the two codes could not be completely reconciled. These differences appear to lead to the differences in predicted times of steam generator dryout and core uncovery. The predicted differences in start of melting, core slump, etc., are at least in part due to the differences in the definitions of these events in the two codes, as noted previously. The MARCH calculations predict more extensive hydrogen generation than does MAAP; in particular, during the in-vessel phase of the accident MARCH predicts about 900 lb of hydrogen to be generated, versus 300 lb for MAAP. The MARCH modeling assumptions utilized for these analyses include radiation from the core to water below it to generate steam, permit continued metal-water reaction in the molten nodes, and consider continued clad oxidation during the core slumping process. The predicted fraction of cladding reacted as a function of time is illustrated in Figure 4; the corresponding hydrogen generation is given in Figure 5. In the MAAP analysis a cutoff temperature of 3680 F (2300 C) is used to terminate cladding oxidation prior to, as well as after, core melting, there is no radiation from the core to the water below, and initial fuel slumping is assumed to lead to immediate bottom head failure. The MARCH results in Figure 4 show that substantial cladding oxidation is predicted just prior to and during the core

slumping process. The MAAP analysis fails the head and thus effectively terminates in-vessel hydrogen generation at 40-50 percent core melting. The combination of the above differences leads to the substantial differences in the predicted in-vessel hydrogen generation.

For reasons noted previously, in the MARCH analyses, the entire core was assumed to be in contact with the sump water while at the same time attacking concrete. In the MAAP analyses approximately half the core was expelled from the reactor cavity and came into contact with the sump water; the remainder of the core attacked the concrete in the reactor cavity. The difference in the predicted times to containment failure for the two codes appears to be consistent with these differences in modeling.

THE REACTOR IS A PWR

CONTAINMENT COOLED BY COOLERS

THE ACCIDENT IS A NORMAL TRANSIENT

CONTAINMENT SPRAY DOES NOT WORK

ECI SYSTEM WORKS

HYDROGEN BURNS ARE ACCOUNTED FOR STARTING WITH START OF PROBLEM
HYDROGEN BURNS ARE ADIABATIC ONLY

OUTPUT IS IN AMERICAN ENGINEERING UNITS

TABLE 1. SUMMARY OF MARCH RESULTS FOR ZION TMLB

EVENT	TIME (MIN)	PRIMARY PRESSURE	CONTMNT PRESSURE	DEBRIS MASS	DEBRIS TEMP	FRACTION OF ZIRC REACTED	SUMP MASS	SUMP TEMP	REACTOR CAVITY MASS	REACTOR CAVITY TEMP
STM GEN DRY	81.50	2522.437	17.809				5.7442E+04	155.8	.0000E+00	100.0
CORE UNCOVER	107.75	2537.157	32.457				2.2156E+05	197.8	.0000E+00	100.0
START MELT	126.75	2537.170	32.470		4130.0	.0477	2.4924E+05	200.7	.0000E+00	100.0
CORE SLUMP FRACTION CORE MELTED	145.75	2526.035	30.981	5.6479E-01	5369.2	.2514	2.6418E+05	201.7	.0000E+00	100.0
CORE COLLAPSE	147.25									
START HEAD HEATUP	147.50	2536.610	32.012	2.6823E+05	5265.6	.4629	2.6600E+05	201.9	.0000E+00	100.0
BOTTOM HEAD FAIL	158.50		48.674	2.7289E+05	5243.5	.4629	2.9186E+05	203.7	2.0362E+05	125.0
HOTDRP, WRC = 0	213.69		68.458	2.7328E+05	409.9	.4857	3.7613E+05	221.6	.0000E+00	301.4
END HOTDRP	258.69		65.087	2.7324E+05	2595.3	.4857	3.9785E+05	224.8	.0000E+00	301.4
INTER	258.69		65.087	2.7327E+05	2594.6	.4857	3.9785E+05	224.8	.0000E+00	301.4
R.C. WALL MELT	259.79		65.023				1.0000E+02	224.8	3.9731E+05	225.8
METAL IS FROZEN	259.95		65.024	2.7426E+05	2572.2	.4857	1.0000E+02	247.6	3.9739E+05	225.8
OXIDE IS MOLTEN	329.46		62.959	2.8740E+05	4338.2	.4857	1.0000E+02	274.4	4.1424E+05	295.8
LAYERS INVERT	383.75		67.874	3.2071E+05	4077.6	.4857	1.0000E+02	280.1	3.8919E+05	300.8
OXIDE IS FROZEN	573.32		93.039	4.1454E+05	2543.1	.4857	1.0000E+02	305.0	2.4242E+05	322.6
INTER	618.82		97.296	4.2954E+05	2579.8	.4857	1.0000E+02	308.2	2.2340E+05	325.5
INTER	978.22		132.365	5.5439E+05	2540.6	.4857	1.0000E+02	333.5	4.4235E+04	348.4
INTER	1339.53		144.591	6.7298E+05	2623.5	.4857	1.0000E+02	338.6	4.6539E+02	351.8

1 NORMAL EXIT MARCH1 ETMRE >= RPST

NUMBER OF BOIL TIMESTEPS = 391 NUMBER OF MACE TIMESTEPS = 1609

63 INFORMATORY INP1 NO DEFAULT FILE AVAILABLE

DEFAULT FILE AVAILABLE

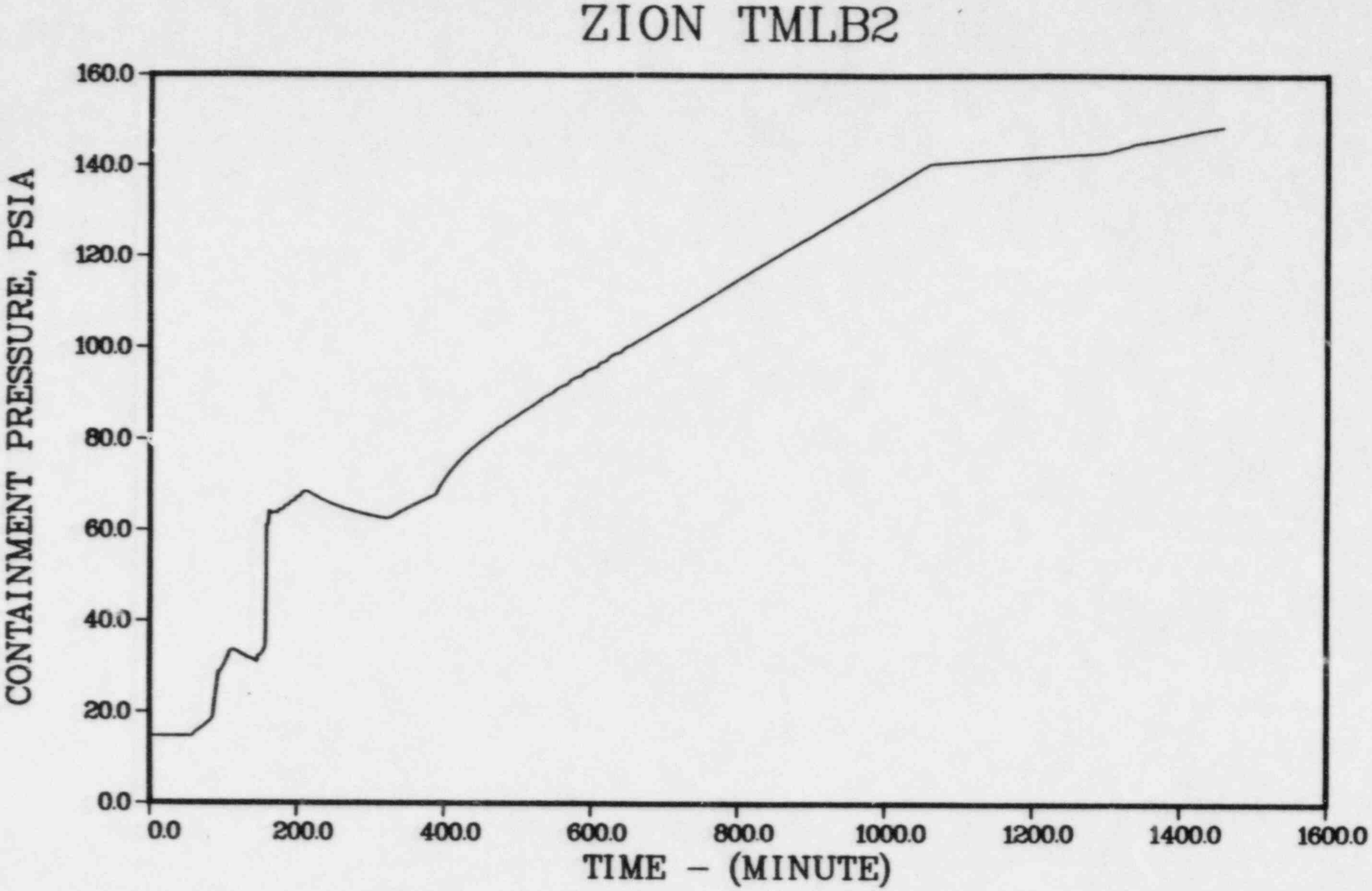

FIGURE 1. CONTAINMENT PRESSURE RESPONSE FOR ZION TMLB

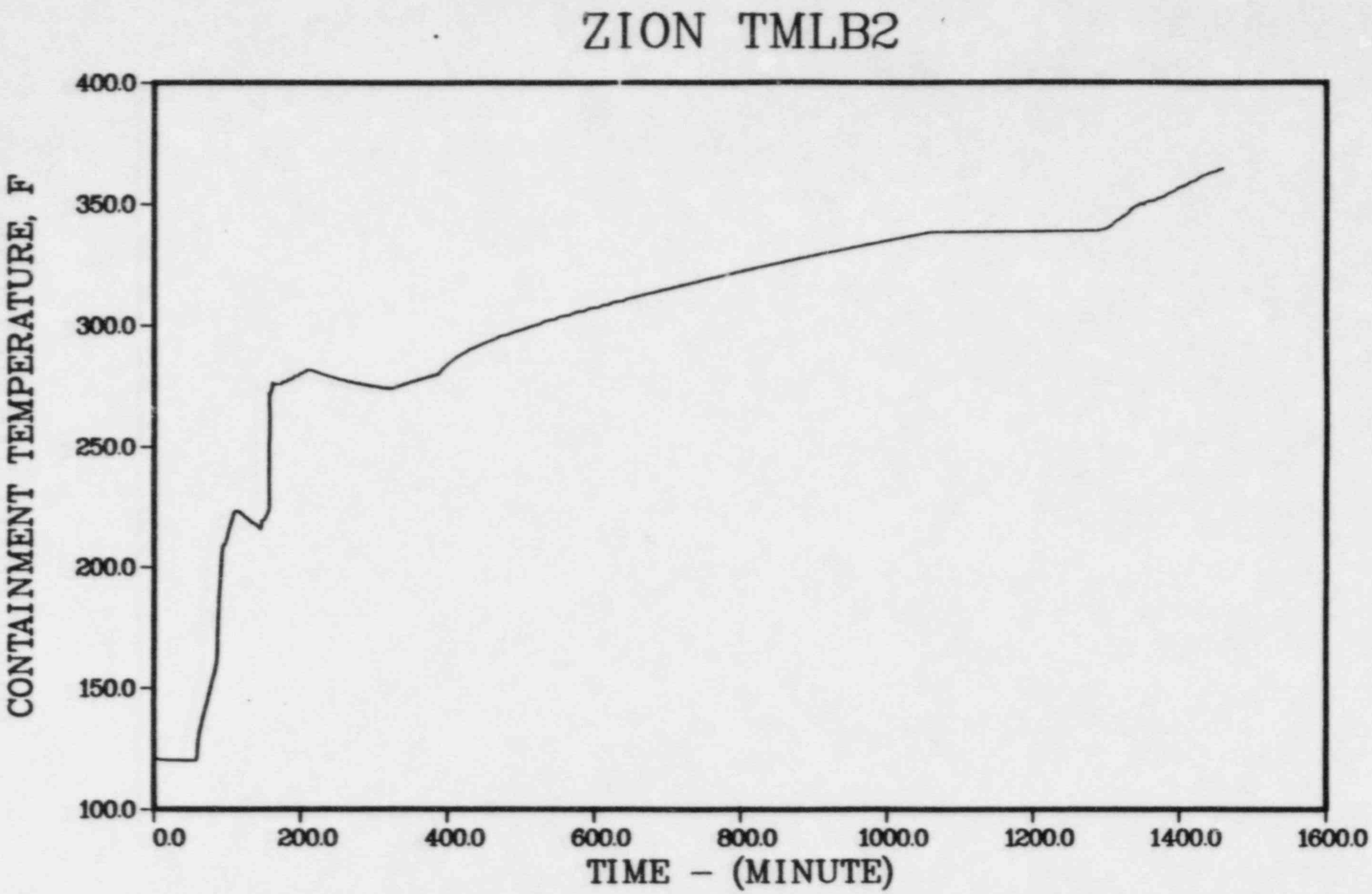

FIGURE 2. CONTAINMENT TEMPERATURE RESPONSE FOR ZION TMLB

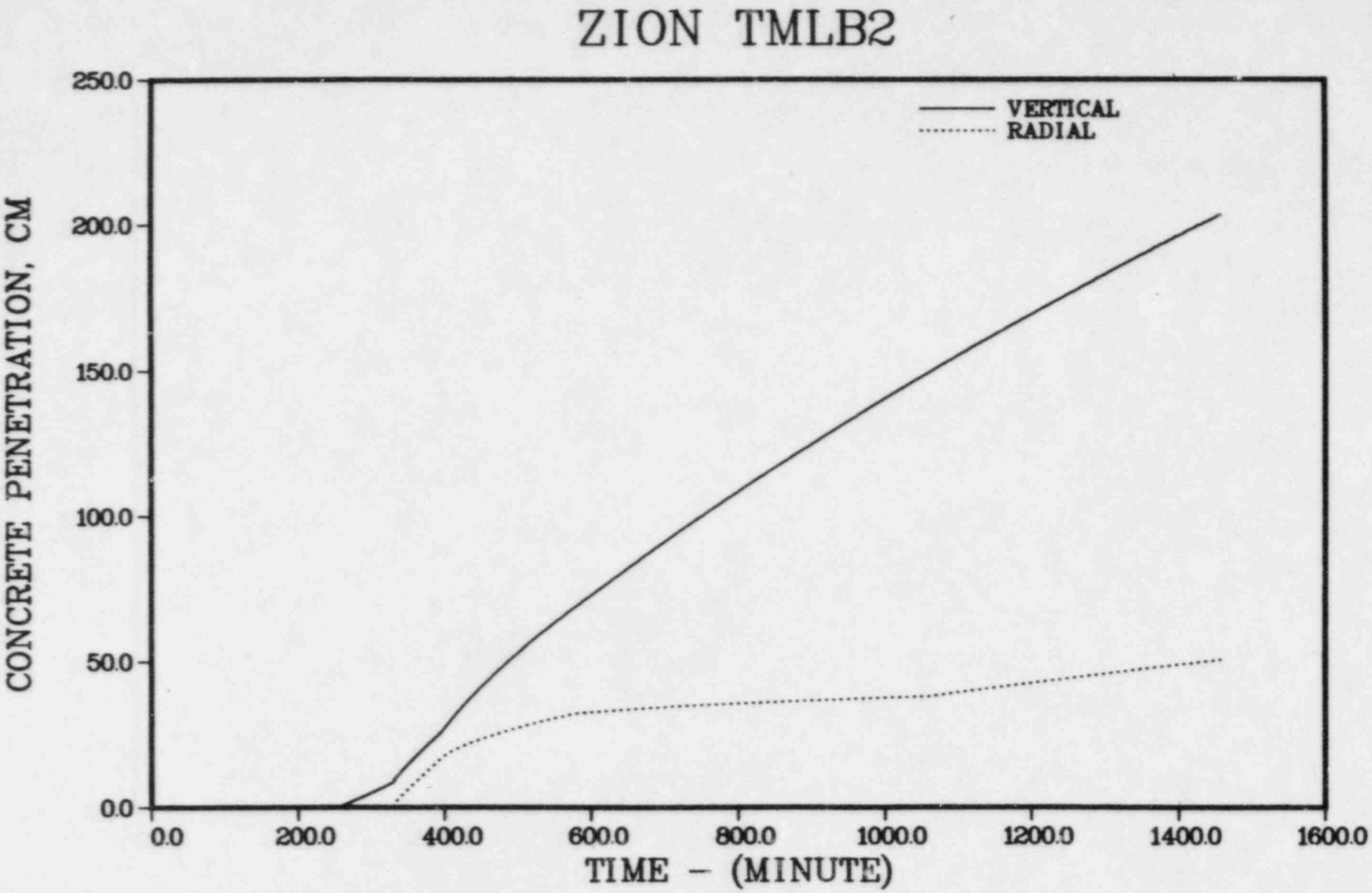

FIGURE 3. CONCRETE PENETRATION FOR ZION TMLB

TABLE 2. MARCH/MAAP COMPARISON FOR ZION TMLB

	MARCH	MAAP
STEAM GENERATOR DRY (HR)	1.36	1.76
CORE UNCOVER (HR)	1.80	2.26
START MELT (HR)	2.11	3.1
50% CORE MELT (HR)	2.37	3.9
CORE SLUMP (HR)	2.43	3.9
CORE COLLAPSE (HR)	2.45	
VESSEL FAIL (HR)	2.64	4.0
CONTAINMENT FAIL (HR)	24.38	32.
IN-VESSEL HYDROGEN (LB)	900	300

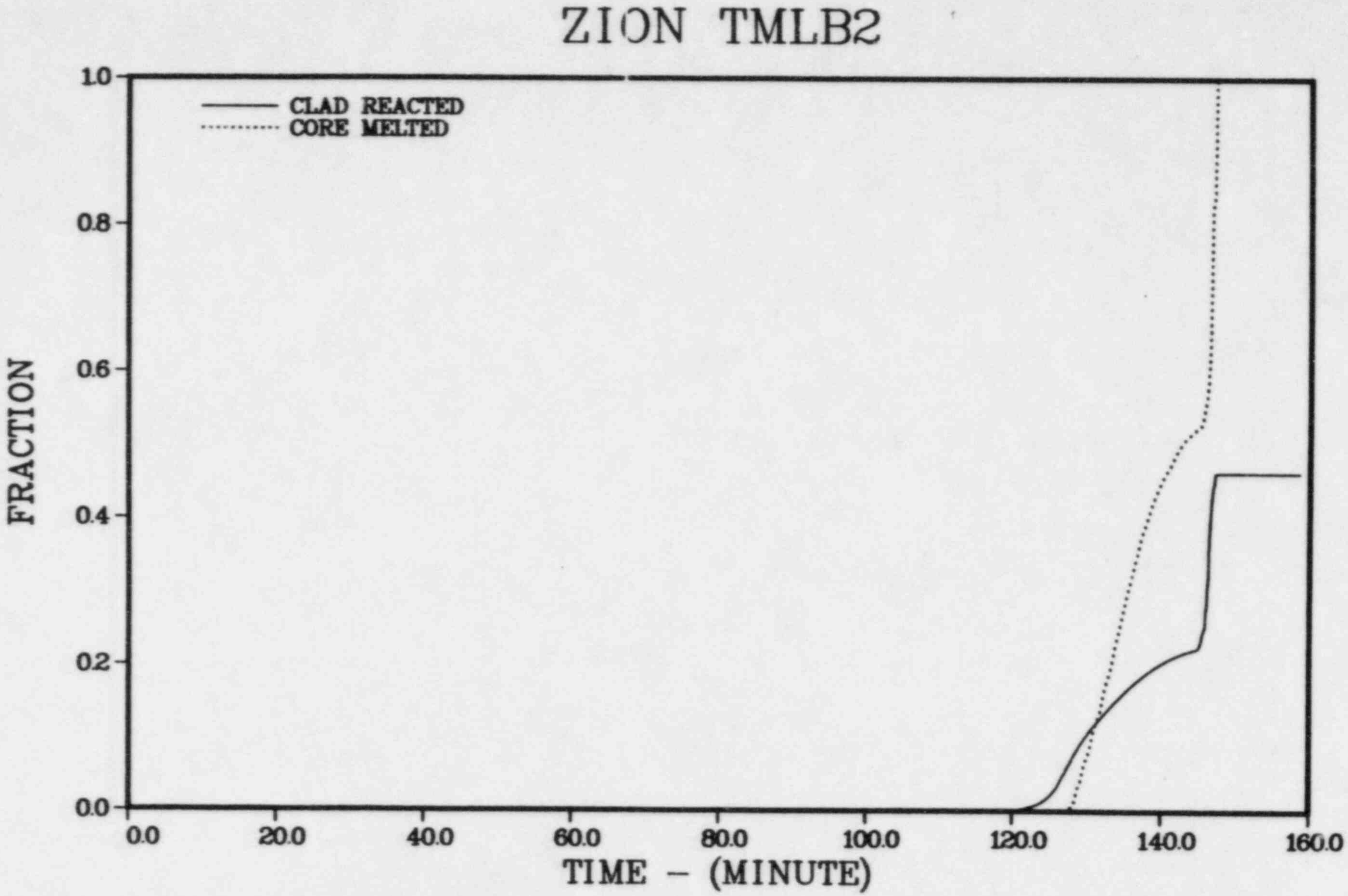

FIGURE 4. CLADDING OXIDATION FOR ZION TMLB

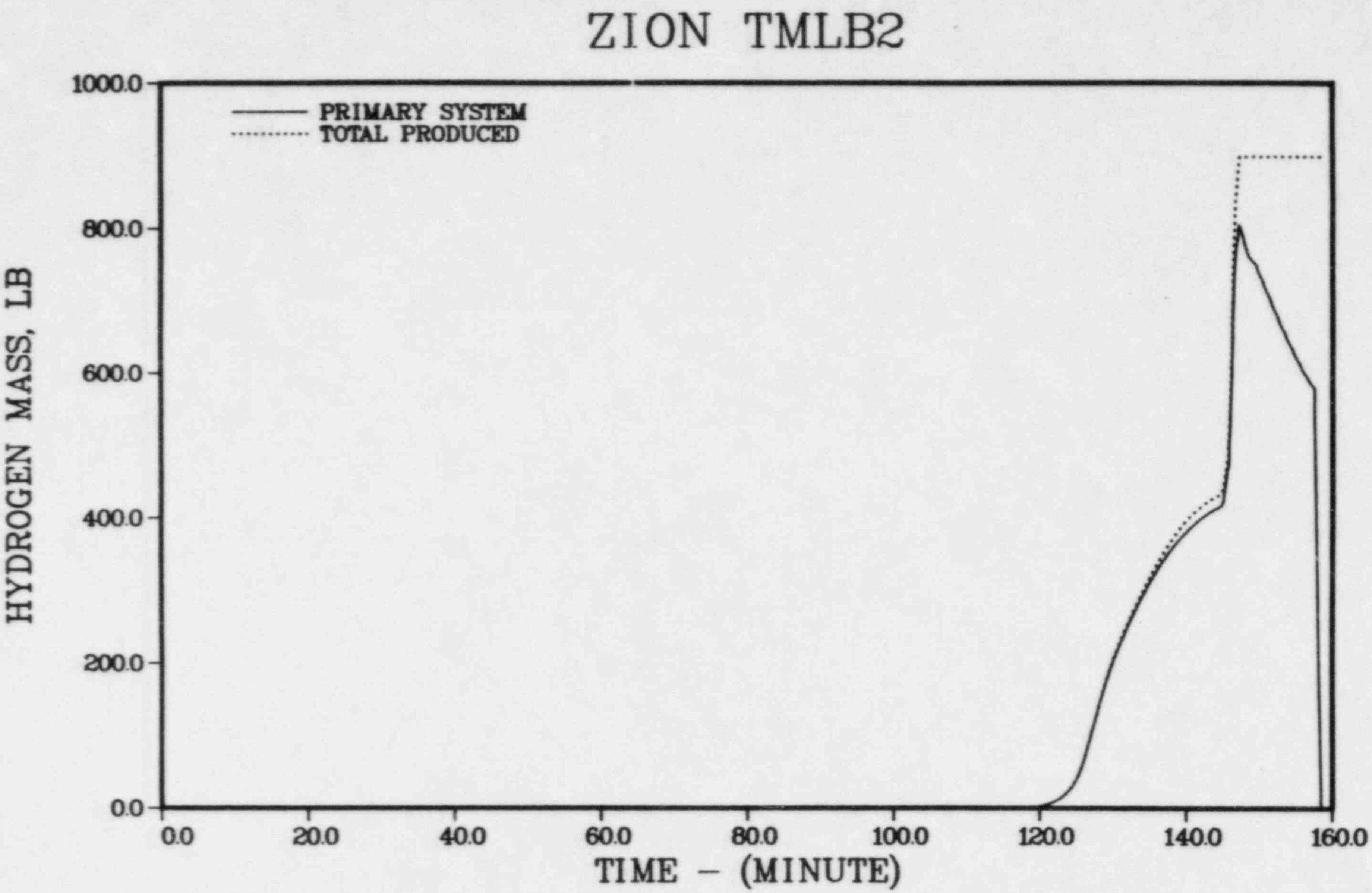

FIGURE 5. HYDROGEN GENERATION FOR ZION TMLB

Sequoyah Ice Condenser PWR

The MARCH analyses for the Sequoyah plant modeled the ice condenser containment as a two compartment system, with the ice condenser treated as being in the junction between the two compartments, This is typical of other MARCH analyses for this type of containment, though we have used more compartments in some of our analyses. The MAAP analyses used finer compartmentalization, with explicit modeling of the ice condenser. The MARCH and MAAP representation of the sump water communication with the reactor cavity are believed to be similar. The MARCH analysis used ten radial and twenty axial regions to represent the core; the MAAP parameter file shows seven radial and ten axial core nodes. The same axial and radial power peaking factors were used in the two calculations. As was the case with the Zion input, there are some differences in the representation of upper plenum, primary piping and steam generator structures.

Results for Sequoyah TML

In the TML sequence as considered here all coolant makeup to the secondary side of the steam generators as well as the primary system is lost. After the dryout of the steam generators, boiloff of the primary coolant inventory takes place through the pressurizer relief valve. The containmnet safety systems, consisting of the ice condenser, sprays, air return fans, and hydrogen igniters are available during this sequence. The summary of the MARCH results for the Sequoyah TML sequence is given in Table 3. For the calculation presented here the core debris as assumed to be uncoolable even though there was a continuing supply of water to the reactor cavity; if a coolable debris bed were to form in the reactor cavity the accident would be terminated at that point. The latter situation was treated in the MAAP analyses. The containment pressure and temperature responses are illustrated in Figures 6 and 7. The mass of ice in the icebed as a function of time is given in Figure 8. In the present analyses an ignition threshold for the hydrogen igniters of 6 volume percent hydrogen was assumed. Within these assumptions hydrogen burning was not predicted to lead to containment failure, though several large pressure rises are predicted. The prediction of the pressure loads due to hydrogen burning is known to be dependent on the

ignition threshold, containment compartmentalization, and related assumptions. In the MARCH treatment hydrogen burning takes place in discrete burns, with the hydrogen concentration building up to the ignition threshold and then being burned to an internally calculated lower limit. With large rapid releases of hydrogen to the containment, the preselected ignition concentration can be exceeded, leading to large predicted pressure increases. Large pressure increases can also result if the burning is predicted to propagate into the upper compartment of the ice condenser containment. Examination of Figure 9 indicates that most of the in-vessel hydrogen generation is retained within the primary system until the time of core slumping, to be released rapidly to the containment. The containment temperatures in Figure 7 indicate that the large burns are predicted to propagate into the upper compartment. Both of these factors contribute to the high containment pressures calculated.

The pressure history in Figure 6 illustrates that over the time scale explicitly considered containment failure would not be reached; extrapolation of the results indicate failure at about 25 hours after the start of the accident. Containment overpressurization would be due to the long-term buildup of noncondensibles from the attack of the concrete by the core debris. Figure 10 shows the predicted progression of concrete attack.

Comparison of the MARCH results with the corresponding MAAP calculations[5] as given in Table 4 indicates a fairly consistent predictions for the occurrence of the key accident events. It must again be remembered that the start of melting, core slump, etc., are conceptually different in the two codes; thus the predicted times for these events should not be expected to be comparable. The time of ice melting differs considerably; this is obviously due to the substantial difference in the amount of hydrogen produced as well as in the hydrogen burning models.

Results for Sequoyah S2HF

In this sequence both the emergency core cooling and containment spray recirculation systems are assumed to fail due to the drains between the upper and lower compartments of the containments being closed. In this situation the water sprayed into the upper compartment cannot return to the containment sump to be recirculated and the sump eventually runs dry, with

subsequent failure of the pumps. The MARCH results for this sequence are summarized in Table 5. The predicted core heatup for this case includes several cycles of start of core melting and refreezing due to accumulator discharge. Considerable hydrogen generation is associated with each one of these cycles. The accumulators are predicted to be emptied at about 220 minutes, with the final core overheating following thereafter. For the particular set of assumptions utilized, the ice is predicted to be melted at about 180 minutes. Thus, the containment would be expected to be vulnerable to subsequent hydrogen burns. With the repeated core overheating, together with the particular modeling assumptions utilized, about 80 per cent of the cladding is predicted to be oxidized during the in-vessel phase of the accident. The large amount of hydrogen released to the containment leads to the prediction of containment failure during slumping of the core into the vessel head.

The MAAP results for the Sequoyah S2HF sequence[5] differ significantly from the MARCH results discussed above. The key accident event times as predicted in the two sets of calculations are summarized in Table 6. In the MARCH analysis, emergency core cooling recirculation failure was modeled as being due to sump water depletion; thus, emergency core cooling recirculation operated successfully initially, but failed eventually because the spray water could not drain back to the sump from the upper compartment. In the MAAP analyses, the emergency core cooling system was apparently assumed to fail immediately upon switching to the recirculation mode. Thus, the times for subsequent events are different in the two analyses. This difference in the timing of emergency core cooling system failure, together with other differences in the modeling of in-vessel hydrogen generation as well as its subsequent combustion, make a comparison between the two analyses difficult. The large in-vessel hydrogen generation calculated by MARCH and its subsequent burning lead to early ice depletion and the prediction of early containment failure. In the MAAP analyses, less hydrogen is generated and it is burned in a more continuous manner. Containment failure in the MAAP analysis is predicted much later in time and is apparently due to the generation of noncondensable gases.

THE REACTOR IS A PWR WITH ICE CONDENSER CONTAINMENT

THE ACCIDENT IS A NORMAL TRANSIENT

CONTAINMENT SPRAY WORKS

ECC SYSTEM WORKS

HYDROGEN BURNS ARE ACCOUNTED FOR STARTING WITH START OF PROBLEM

OUTPUT IS IN AMERICAN ENGINEERING UNITS

TABLE 3. SUMMARY OF MARCH RESULTS FOR SEQUOYAH TML

EVENT	TIME (MIN)	PRIMARY PRESSURE	CONTMNT PRESSURE	DEBRIS MASS	DEBRIS TEMP	FRACTION OF ZIRC REACTED	SUMP MASS	SUMP TEMP	REACTOR CAVITY MASS	REACTOR CAVITY TEMP
FAN ON	55.94		17.512				2.4587E+04	150.1	.0000E+00	100.0
SPRAY ON	56.45		17.502				2.9249E+04	151.3	.0000E+00	100.0
STM GEN DRY	61.00	2386.953	17.914				1.9892E+05	113.1	.0000E+00	100.0
CORE UNCOVER	99.50	2388.672	18.672				2.2532E+06	117.8	1.8311E+05	118.1
START MELT	109.75	2386.693	16.683		4130.0	.0360	2.4135E+06	111.7	9.6348E+05	116.1
SPRAY RECIRC. ON	130.75		16.088				3.2602E+06	106.6	9.6348E+05	116.1
CORE SLUMP	139.25	2387.302	17.302	6.4833E-01	5276.1	.3998	3.2696E+06	105.6	9.6348E+05	116.1
FRACTION CORE MELTED										
CORE COLLAPSE	141.									
START HEAD HEATUP	141.25	2388.318	18.644	3.0339E+05	3811.2	.5924	3.3111E+06	105.7	9.6348E+05	116.1
BOTTOM HEAD FAIL	143.25		57.101	3.9839E+05	3797.7	.5924	3.7346E+06	108.2	1.3410E+06	113.2
END HOTPP	146.26		56.335	4.2089E+05	3558.1	.5924	4.1175E+06	109.0	9.6337E+05	121.2
INTER	146.27		56.335	4.2089E+05	3586.7	.5924	4.1175E+06	109.0	9.6337E+05	121.2
OXIDE IS MOLTEN	163.11		16.083	4.2785E+05	3828.9	.5924	4.3119E+06	113.5	9.5116E+05	161.3
OXIDE IS FROZEN	183.12		16.083	4.2787E+05	3206.6	.5924	4.3118 06	113.5	9.5116E+05	161.3
LAYERS INVERT	267.42		18.162	4.6691E+05	3124.0	.6458	4.5316E+06	115.3	9.2731E+05	222.1
INTER	384.28		21.561	5.1914E+05	2929.2	.7175	4.9246E+06	112.9	9.2432E+05	231.7
ICE MELT COMPLETE	443.53		24.086				5.0455E+06	111.8	9.2257E+05	237.3
INTER	625.40		32.866	6.3563E+05	2276.3	.9014	5.0339E+06	128.5	9.1801E+05	255.0
METAL IS FROZEN	797.65		39.580	7.2840E+05	2027.4	1.0000	5.0412E+06	128.6	9.0969E+05	266.4
INTER	968.34		38.991	7.4105E+05	2108.1	1.0000	5.0443E+06	125.0	9.1010E+05	265.5
INTER	1193.32		41.664	7.8108E+05	2409.3	1.0000	5.0499E+06	116.0	9.0525E+05	269.5
INTER	1348.31		44.736	8.2443E+05	2476.1	1.0000	5.0560E+06	114.2	9.0623E+05	273.8

35 NORMAL EXIT INTER: TIME > TF

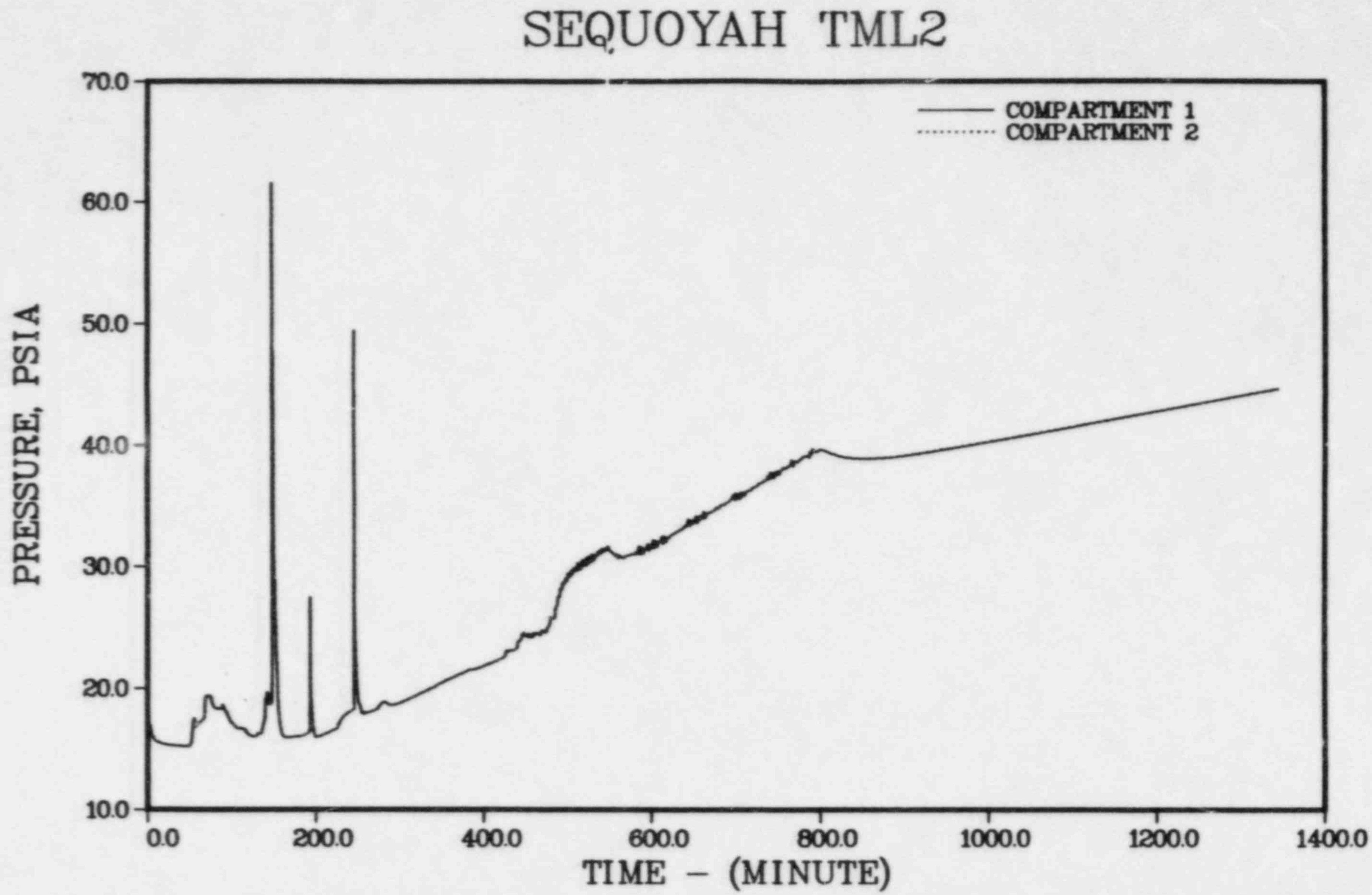

FIGURE 6. CONTAINMENT PRESSURE RESPONSE FOR SEQUOYAH TML

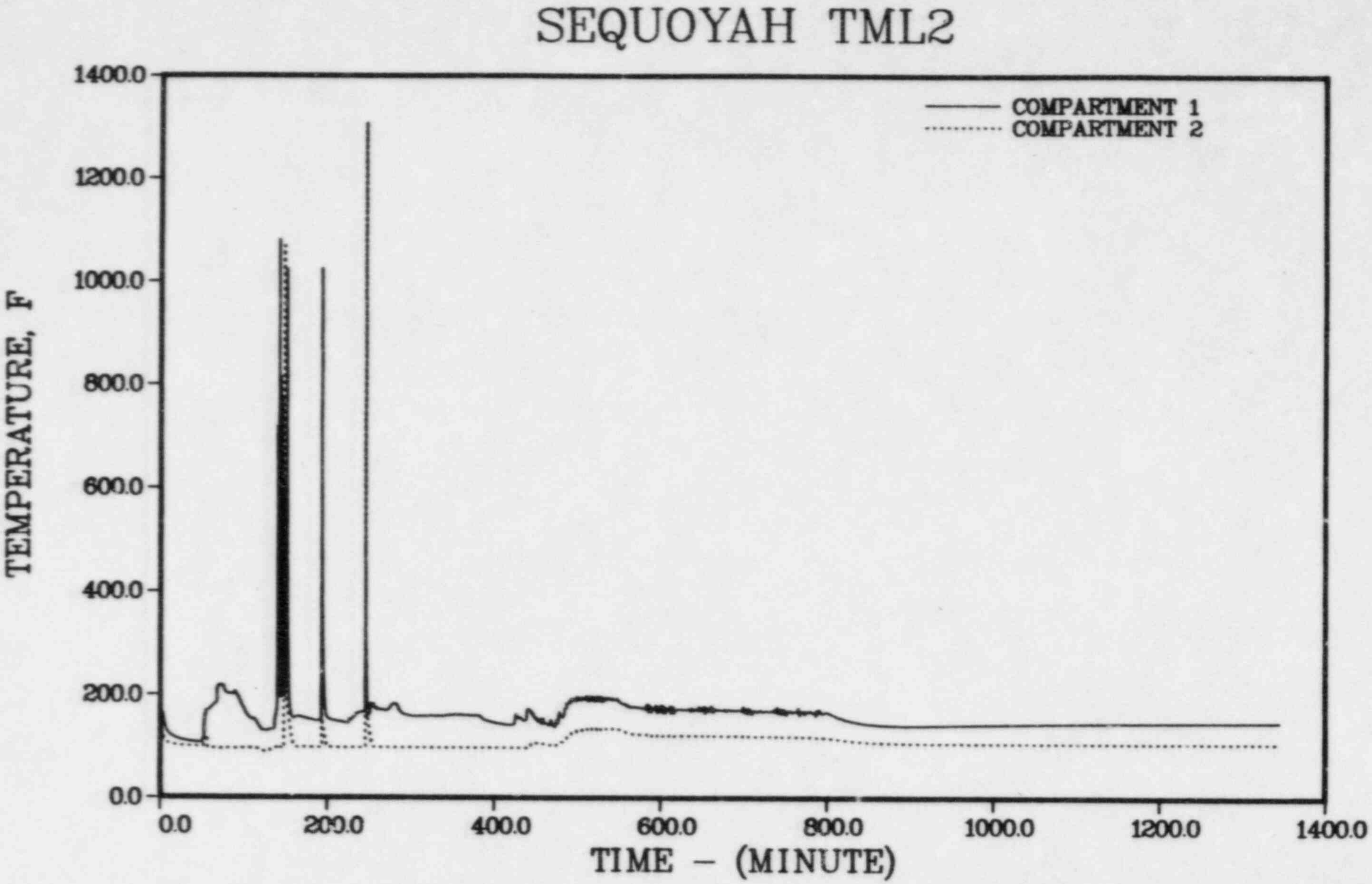

FIGURE 7. CONTAINMENT TEMPERATURE RESPONSE FOR SEQUOYAH TML

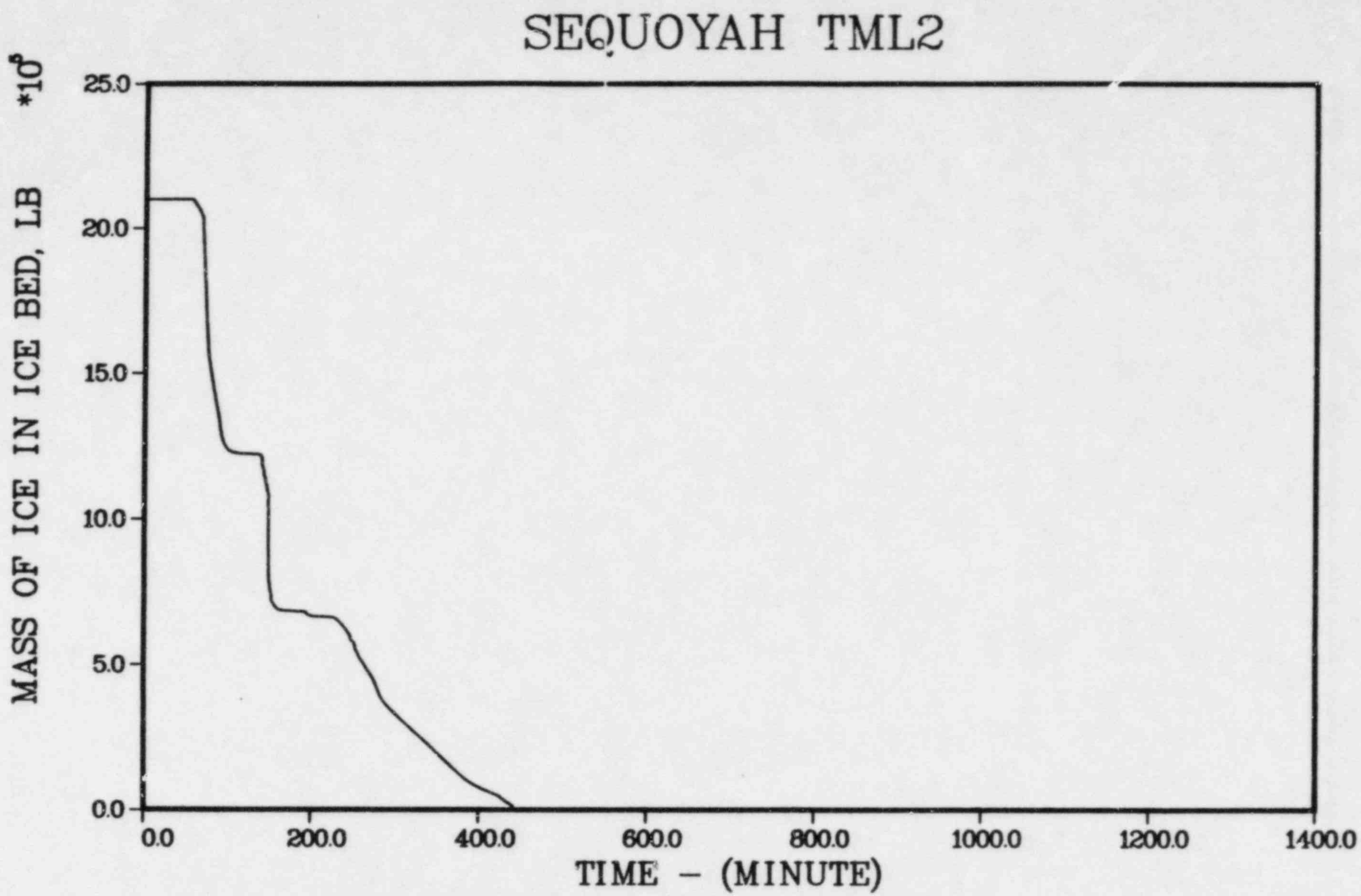

FIGURE 8. ICE MELTING FOR SEQUOYAH TML

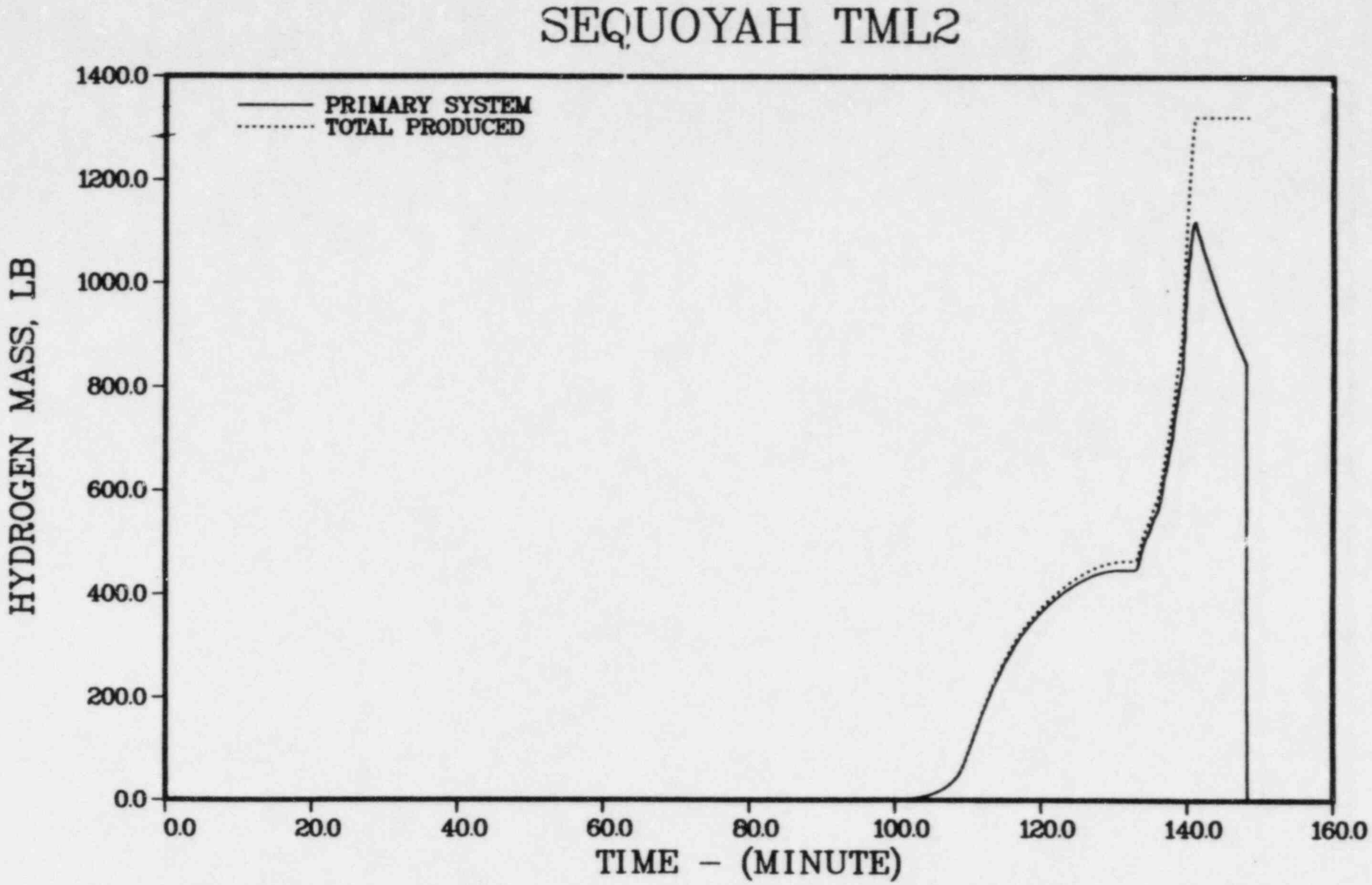

FIGURE 9. HYDROGEN GENERATION FOR SEQUOYAH TML

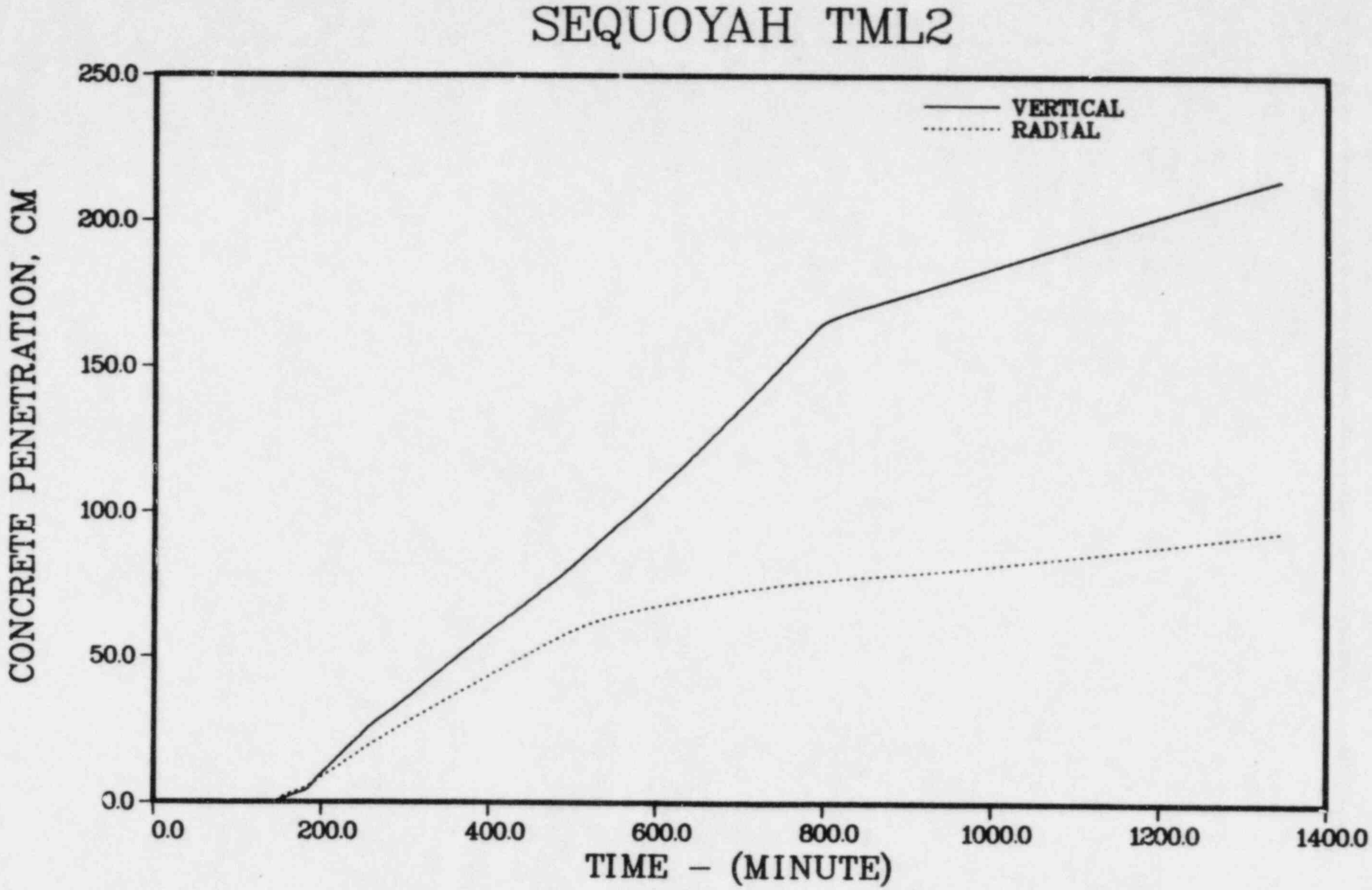

FIGURE 10. CONCRETE PENETRATION FOR SEQUOYAH TML

TABLE 4. MARCH/MAAP COMPARISON FOR SEQUOYAH TML

	MARCH	MAAP
STEAM GENERATOR DRY (HR)	1.02	0.95
CORE UNCOVER (HR)	1.49	1.50
START MELT (HR)	1.83	1.74
CORE SLUMP (HR)	2.32	2.98
CORE COLLAPSE (HR)	2.35	
VESSEL FAIL (HR)	2.47	3.00
ICE MELTED (HR)	7.40	5.30
IN-VESSEL HYDROGEN (LB)	1330	772

SUMMARY OF RESULTS   MARCH 2 VERSION 152   SEQUOYAH S2HF DELTA: MARCH/MAAP COMPARISON: REVISED 1/85

TABLE 5. SUMMARY OF MARCH RESULTS FOR SEQUOYAH S2HF

THE REACTOR IS A PWR WITH ICE CONDENSER CONTAINMENT

THE ACCIDENT IS A NORMAL TRANSIENT

CONTAINMENT SPRAY WORKS

ECC SYSTEM WORKS

HYDROGEN BURNS ARE ACCOUNTED FOR STARTING WITH START OF PROBLEM

OUTPUT IS IN AMERICAN ENGINEERING UNITS

				DEBRIS		FRACTION	SUMP		REACTOR CAVITY	
EVENT	TIME (MIN)	PRIMARY PRESSURE	CONTMNT PRESSURE	MASS	TEMP	OF ZIRC REACTED	MASS	TEMP	MASS	TEMP
FAN ON	.77		17.516				8.8565E+03	178.3	.0000E+00	100.0
SPRAY ON	1.28		18.056				1.8474E+04	176.5	.0000E+00	100.0
ECC RECIRC. ON	38.50	1233.305	19.417				1.0638E+06	157.6	.0000E+00	100.0
SPRAY RECIRC. ON	38.50		19.417				1.0638E+06	157.6	.0000E+00	100.0
ECC R PUMP OFF	55.43		20.523				8.3775E+04	158.4	.0000E+00	100.0
SPRAY R PUMP OFF	55.43						8.3775E+04	158.4	.0000E+00	100.0
CORE UNCOVER	74.66	975.129	18.983				3.3259E+05	143.4	.0000E+00	100.0
START MELT	97.16	541.081	19.489		4130.0	.0316	6.2274E+05	137.6	.0000E+00	100.0
START MELT	142.91	536.166	19.553		4130.0	.1533	1.1864E+06	138.1	.0000E+00	100.0
ICE MELT COMPLETE	181.18		20.547				1.5948E+06	140.7	.0000E+00	100.0
START MELT	217.04	233.611	34.994		4130.0	.3629	1.5968E+06	144.5	.0000E+00	100.0
ECC OFF	218.79	208.467	35.128				1.6056E+06	144.5	.0000E+00	100.0
CORE SLUMP FRACTION CORE MELTED	243.23	73.324	47.067	4.9520E-01	2407.9	.6168	1.6066E+06	146.9	.0000E+00	100.0
CONTMNT FAIL	263.61	1187.796	65.000				1.6066E+06	148.9	.0000E+00	100.0
START HEAD HEATUP	271.86	975.204	58.984	3.0749E+05	2199.0	.8220	1.6066E+06	149.7	.0000E+00	100.0
BOTTOM HEAD FAIL	386.62		14.842	4.4826E+05	4883.1	.8220	1.6066E+06	160.0	.0000E+00	100.0
END HOTDRP	386.66		14.870	4.7076E+05	4130.0	.8220	1.6066E+06	160.0	.0000E+00	100.0
INTER	386.67		14.870	4.7076E+05	4128.9	.8220	1.6066E+06	160.0	.0000E+00	100.0
OXIDE IS MOLTEN	414.57		14.949	4.7797E+05	4524.2	.8220	1.6066E+06	162.4	.0000E+00	100.0
OXIDE IS FROZEN	414.63		14.949	4.7804E+05	4292.8	.8221	1.6066E+06	162.4	.0000E+00	100.0
LAYERS INVERT	500.20		15.339	5.2141E+05	3673.3	.8506	1.6010E+06	165.9	.0000E+00	100.0

TABLE 6. MARCH/MAAP COMPARISON FOR SEQUOYAH S2HF

	MARCH	MAAP
ECCS FAILS (HR)	0.92	0.37
CORE UNCOVER (HR)	1.24	1.19
START MELT (HR)	1.62, 2.38, 3.63	
ICE MELTED (HR)	3.02	3.43
ACCUMULATORS EMPTY (HR)	3.65	2.80
CORE SLUMP (HR)	4.05	2.75
CONTAINMENT FAIL (HR)	4.39	23.68
CORE COLLAPSE (HR)	4.53	
VESSEL FAIL (HR)	6.44	2.77
IN-VESSEL HYDROGEN (LB)	1835	890

Grand Gulf Mark III BWR

In the MARCH analyses the Mark III pressure suppression containment was modeled as a two compartment system, typical of our other analyses for this containment. The MAAP analyses used more compartmentalization in their modeling of the containment. The MARCH representation of the core used ten radial and twenty axial nodes, whereas the MAAP parameter file uses only six radial and ten axial nodes. The core power distributions in the two sets of analyses were the same. In other respects the representations of the system are believed to be similar.

Results for Grand Gulf TC

In the TC sequence failure of the control rods to insert and shut down the reactor leads to the reactor power equilibrating at a level consistent with the primary coolant makeup by the emergency core cooling systems. This power level is well above the capacity of the residual heat removal system and results in the heatup of the suppression pool and the associated pressurization of the containment. Failure of the containment is assumed to lead to the failure of the emergency core cooling pumps. Thus subsequent core overheating and melting take place within a failed containment. The MARCH results for this sequence are summarized in Table 7. The MARCH-calculated power history for this sequence is illustrated in Figure 11. Continued operation of the emergency core cooling system keeps the core covered and the power at the equilibrium level until after containment failure. Core uncovery following emergency core cooling system failure leads to shutdown of the reactor. In the MARCH calculation actuation of the Automatic Depressurization System (ADS) was assumed at initial core uncovery, or relatively early in the sequence. The containment pressure and temperature responses are illustrated in Figures 12 and 13. The slow decay in the pressure following containment failure is due to flashing of the hot suppression pool water and the finite opening in the containment associated with the failure. The predicted progression of concrete attack following vessel failure is illustrated in Figure 14.

The comparison of predicted times of key accident events as calculated by MAAP[6] and MARCH is given in Table 8. The two predictions of

time to containment failure are essentially identical; the times for core uncovery differ only slightly. As noted previously, start of melt, core slump, etc., differ conceptually in the two codes and are thus not expected to be comparable. The substantial difference in predicted in-vessel hydrogen generation is discussed below.

As in the PWR analyses, the MARCH modeling included radiation from the core to water below it, continued metal-water reactions in the melted nodes, consideration of continued cladding oxidation during the core slumping process. In the Grand Gulf TC sequence as described in the MAAP parameter file, and modeled in the present MARCH analysis, the emergency core cooling pumps fail at the time of containment failure but the CRD flow into the vessel continues. This CRD flow is not sufficient by itself to cool the core and in the MARCH analyses acts primarily to supply steam for reaction with the cladding. More significantly, the CRD flow keeps the lowest portions of the core cooled and thus delays the onset of fuel slumping. Figure 15 illustrates the predicted extent of cladding reaction as a function of time. In the MAAP analyses there is no radiation from the core to the water below, and a cutoff temperature of 3680 F (2300 C) is used to terminate cladding oxidation. Of greater significance for this case, fuel slumping followed by vessel failure is assumed when twenty percent of the core is molten; thus initial fuel slumping effectively terminates in-vessel hydrogen generation. If core slumping were assumed at twenty percent core melting in the MARCH analysis, considerably less in-vessel hydrogen production would have been calculated. These differences in the treatment of in-vessel phenomena appear to be the reason for the widely varying predictions of hydrogen generation.

<u>Results for Grand Gulf TQUV</u>

In the TQUV sequence all means of supplying makeup water to the primary system are assumed to be lost. The reactor shuts down but due to decay heating the primary system inventory is boiled off through the relief/safety valves. The operator would be expected to manually actuate the Automatic Depressurization System (ADS) in an effort to maintain core cooling. In the MARCH analysis it was assumed that the ADS was actuated at the time of core uncovery. The MARCH predictions for this sequence are summarized in Table 9. It can be seen that the primary system depressurizes rapidly, being

essentially at the containment pressure at the predicted start of core melting. The predicted containment pressure and temperature responses are illustrated in Figures 16 and 17. The large pressure increase is due to a hydrogen burn at the time of core slumping and collapse. The steam generated by the core collapse sweeps much of the hydrogen into the main containment where it burns. As can be seen from the temperature histories in Figure 17, the burning takes place largely in the main containment. The progression of the attack of the concrete following vessel failure is illustrated in Figure 18.

The predictions of MARCH and MAAP[6] for the Grand Gulf TQUV sequence are summarized in Table 10. The difference in the predicted time to core uncovery is believed to be due to differences in the actuation of the ADS. The onset of core melt, collapse, etc., are again conceptually somewhat different and cannot be directly compared. A major difference is once again seen in the predicted amounts of in-vessel hydrogen generation. The reasons for this difference have been previously noted.

SUMMARY OF RESULTS   MARCH 2 VERSION 152   MARCH/MAAP: GRAND GULF TC,CASE=2(CRD FLOW=90 GPM) REVISED 01/85   GGTC2

THE REACTOR IS A BWR

THE ACCIDENT IS A NORMAL TRANSIENT

CONTAINMENT SPRAY WORKS

ECC SYSTEM WORKS

HYDROGEN BURNS ARE ACCOUNTED FOR STARTING WITH START OF PROBLEM
HYDROGEN BURNS ARE ADIABATIC ONLY

OUTPUT IS IN AMERICAN ENGINEERING UNITS

TABLE 7. SUMMARY OF MARCH RESULTS FOR GRAND GULF TC

55gpm @ 1015psi
0 @ 1602psi

EVENT	TIME (MIN)	PRIMARY PRESSURE	CONTMNT PRESSURE	DEBRIS MASS	DEBRIS TEMP	FRACTION OF ZIRC REACTED	SUMP MASS	SUMP TEMP	REACTOR CAVITY MASS	REACTOR CAVITY TEMP
SPRAY ON	10.00		18.787				1.1139E+07	152.3	.0000E+00	100.0
SPRAY RECIRC. ON	10.05		18.804				1.1144E+07	152.5	.0000E+00	100.0
ECC RECIRC. ON	45.20	116.042	45.245				1.2426E+07	251.2	.0000E+00	100.0
CONTMNT FAIL	60.90	187.257	71.300				1.2326E+07	289.5	.0000E+00	100.0
CORE UNCOVER	70.65	138.243	80.024				1.2509E+07	302.6	.0000E+00	100.0
START MELT	119.47	61.169	42.443		4130.0	.0198	1.2369E+07	266.5	.0000E+00	100.0
CORE SLUMP	148.57	56.790	34.482	9.9990E-01	4505.4	.3390	1.2270E+07	247.4	.0000E+00	100.0
FRACTION CORE MELTED										
CORE COLLAPSE	154.0									
START HEAD HEATUP	154.07	75.120	33.556	5.8917E+05	4427.7	.3452	1.2278E+07	247.1	.0000E+00	100.0
BOTTOM HEAD FAIL	169.10		30.601	5.8961E+05	4210.1	.3452	1.2338E+07	242.6	.0000E+00	100.0
END HOTDRP	169.14		30.954	5.8961E+05	4130.0	.3452	1.2338E+07	242.5	.0000E+00	100.0
INTER	169.15		30.954	5.7664E+05	4128.9	.3452	1.2338E+07	242.5	.0000E+00	100.0
OXIDE IS MOLTEN	203.28		21.040	5.9197E+05	4601.3	.3452	1.2281E+07	225.1	.0000E+00	100.0
OXIDE IS FROZEN	203.43		21.040	5.9217E+05	4407.6	.3453	1.2281E+07	225.1	.0000E+00	100.0
INTER	289.29		14.901	6.6420E+05	3936.9	.3823	1.2237E+07	197.2	.0000E+00	100.0
LAYERS INVERT	337.21		14.891	7.0307E+05	3705.3	.4043	1.2243E+07	186.5	.0000E+00	100.0
INTER	409.28		14.900	7.6608E+05	3480.1	.4412	1.2248E+07	172.8	.0000E+00	100.0
INTER	529.20		14.896	8.7166E+05	3178.7	.5022	1.2254E+07	154.8	.0000E+00	100.0
INTER	649.28		14.914	9.7874E+05	2960.7	.5636	1.2258E+07	141.3	.0000E+00	100.0
INTER	769.20		14.919	1.0912E+06	2810.6	.6289	1.2261E+07	131.3	.0000E+00	100.0

35 NORMAL EXIT   INTER: TIME > TF

NUMBER OF BOIL TIMESTEPS = 2840   NUMBER OF MACE TIMESTEPS = 3749

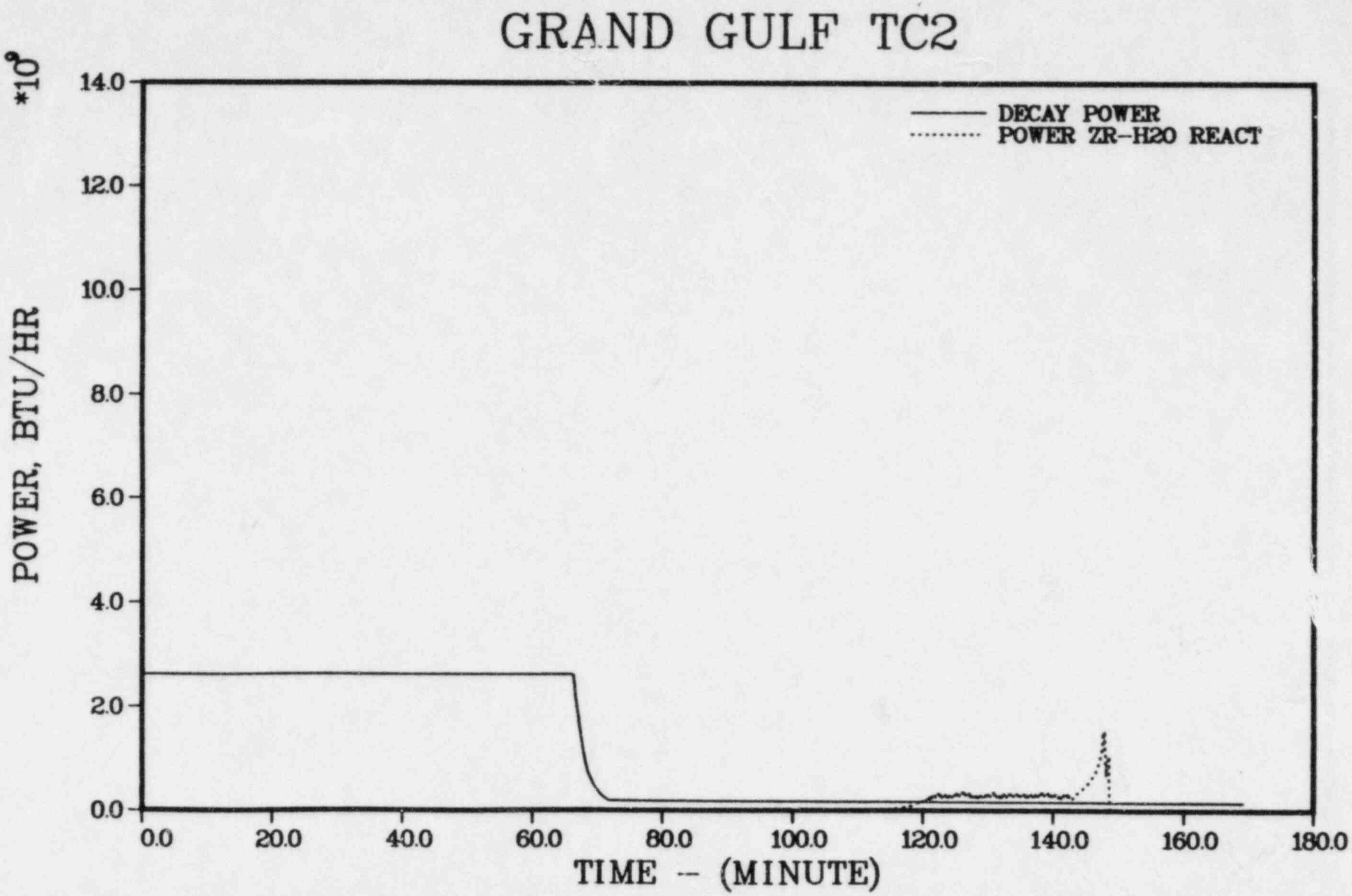

FIGURE 11. POWER HISTORY FOR GRAND GULF TC

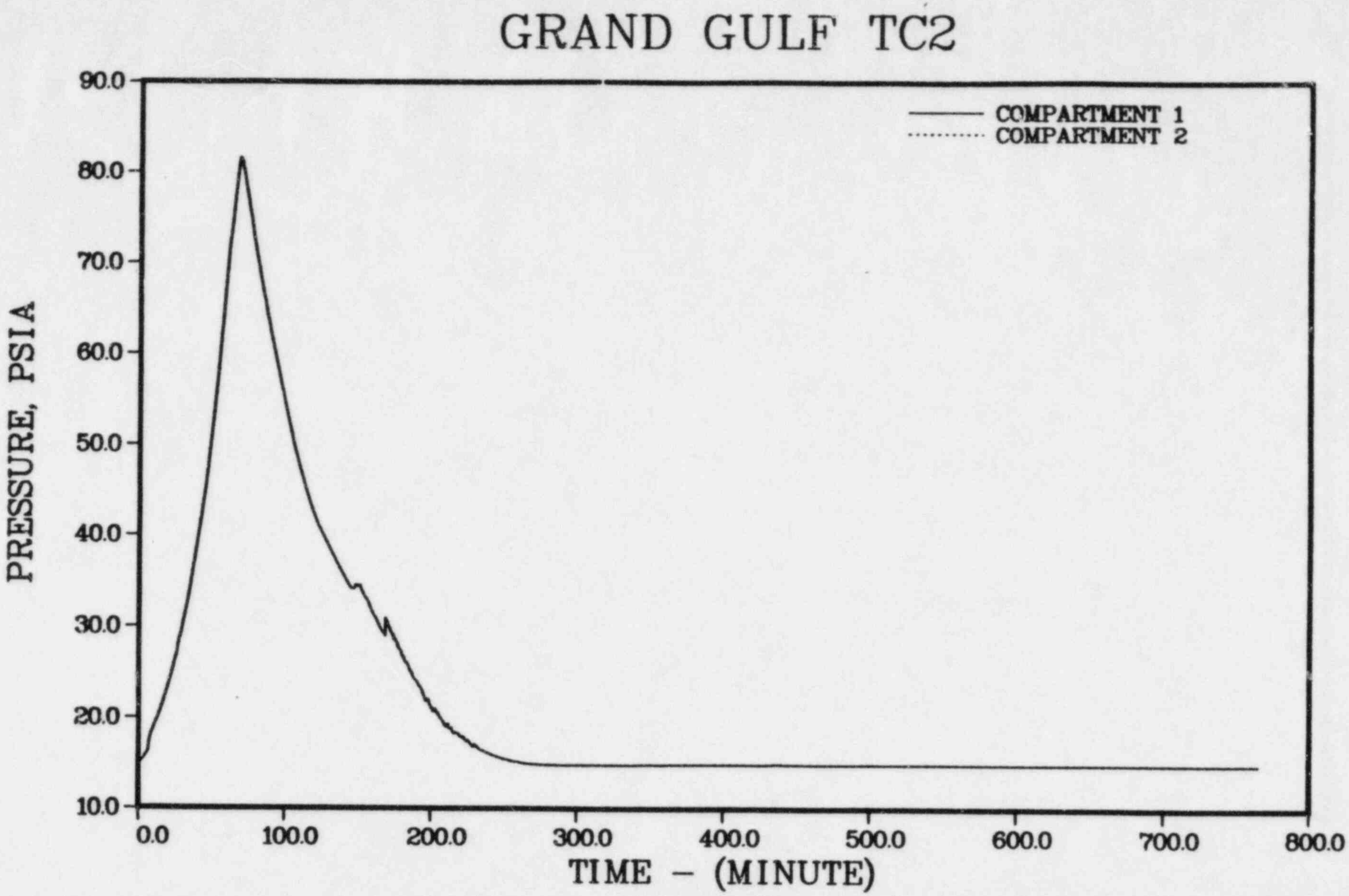

FIGURE 12. CONTAINMENT PRESSURE RESPONSE FOR GRAND GULF TC

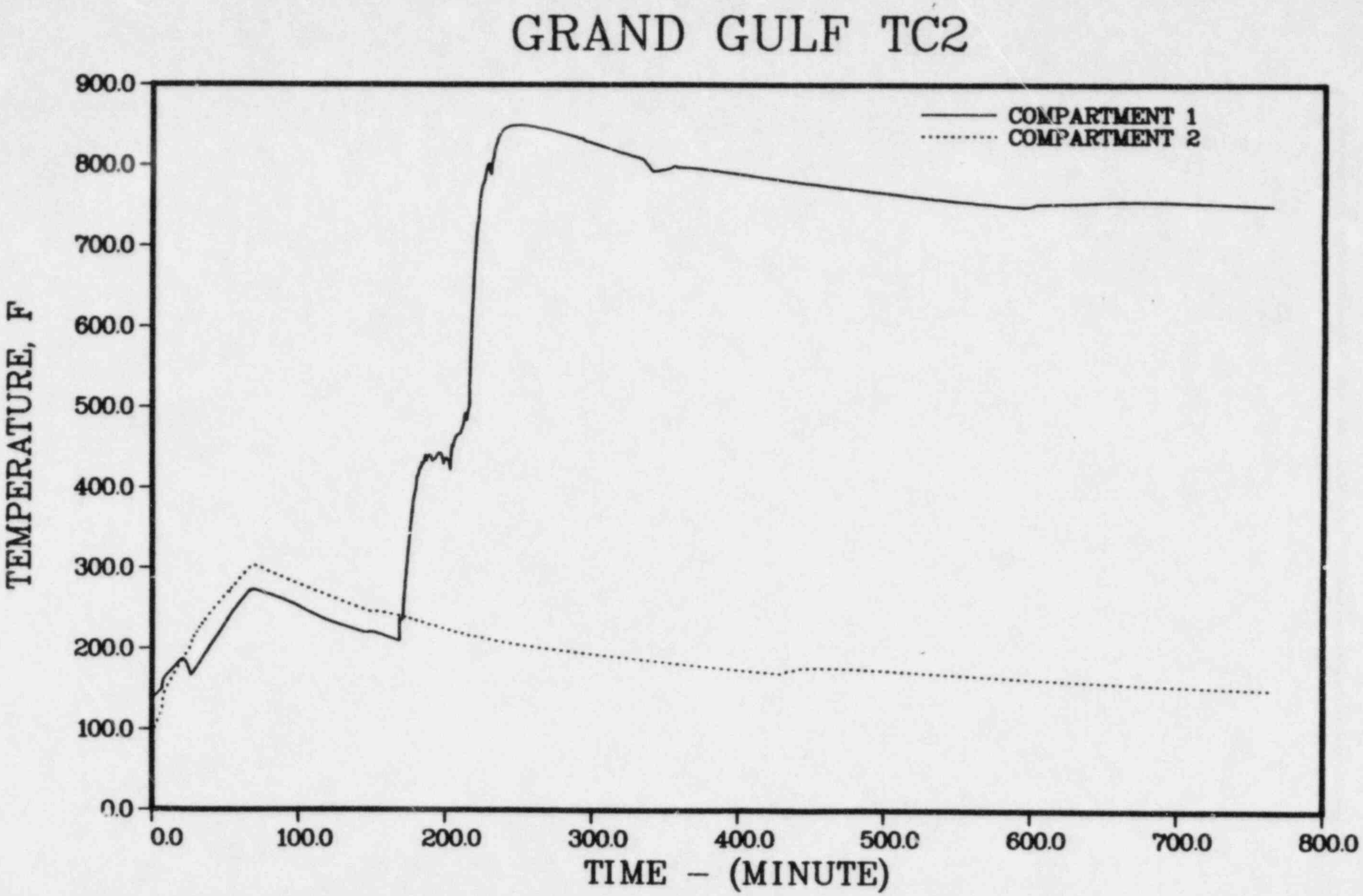

FIGURE 13. CONTAINMENT TEMPERATURE RESPONSE FOR GRAND GULF TC

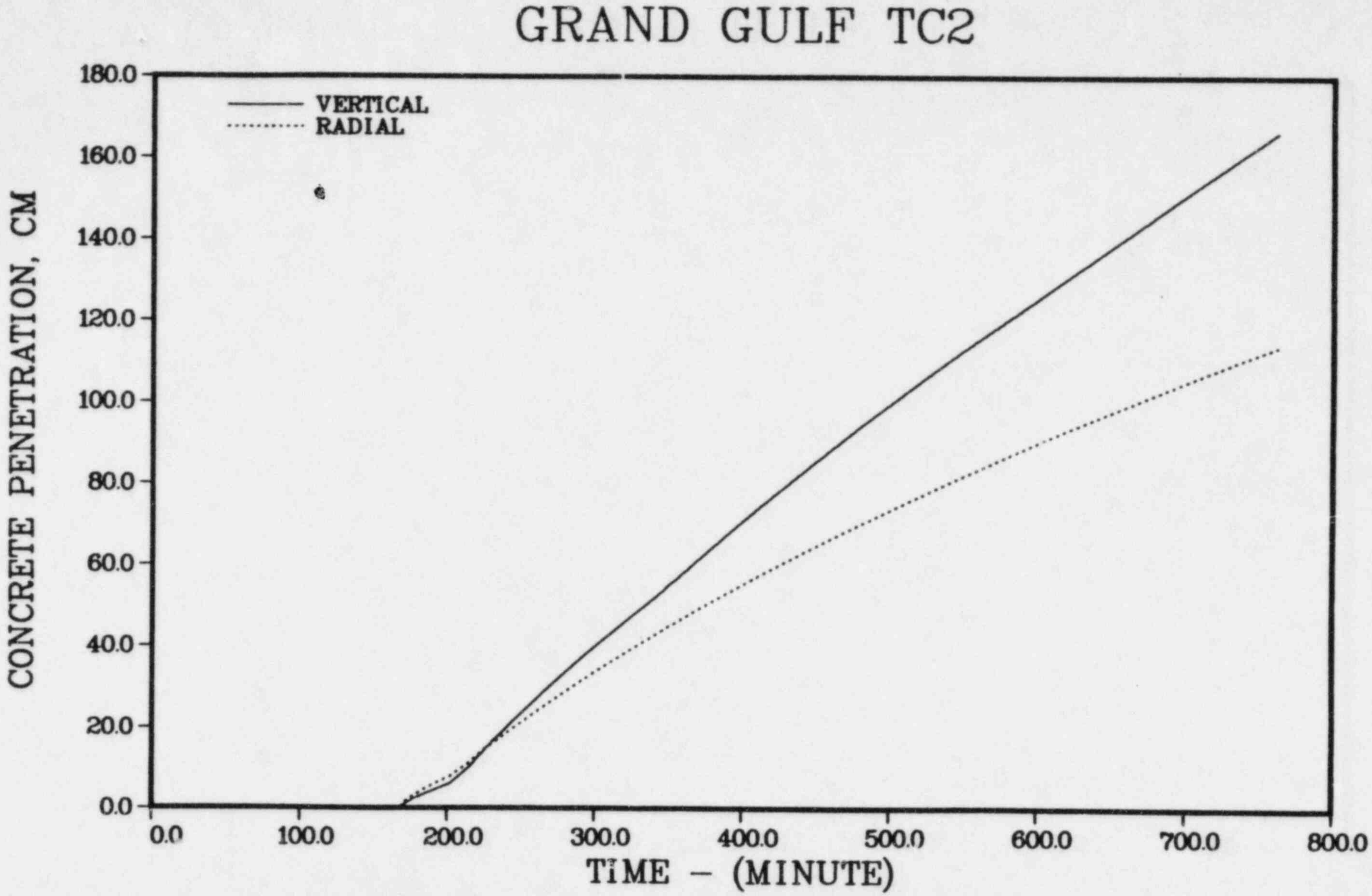

FIGURE 14. CONCRETE PENETRATION FOR GRAND GULF TC

TABLE 8. MARCH/MAAP COMPARISON FOR GRAND GULF TC

	MARCH	MAAP
CONTAINMENT FAIL (HR)	1.02	1.0
CORE UNCOVER (HR)	1.18	1.3
START MELT (HR)	1.99	3.0
20% CORE MELT (HR)	2.13	3.8
CORE SLUMP (HR)	2.48	3.8
CORE COLLAPSE (HR)	2.57	
VESSEL FAIL (HR)	2.82	3.8
IN-VESSEL HYDROGEN (LB)	2950	530

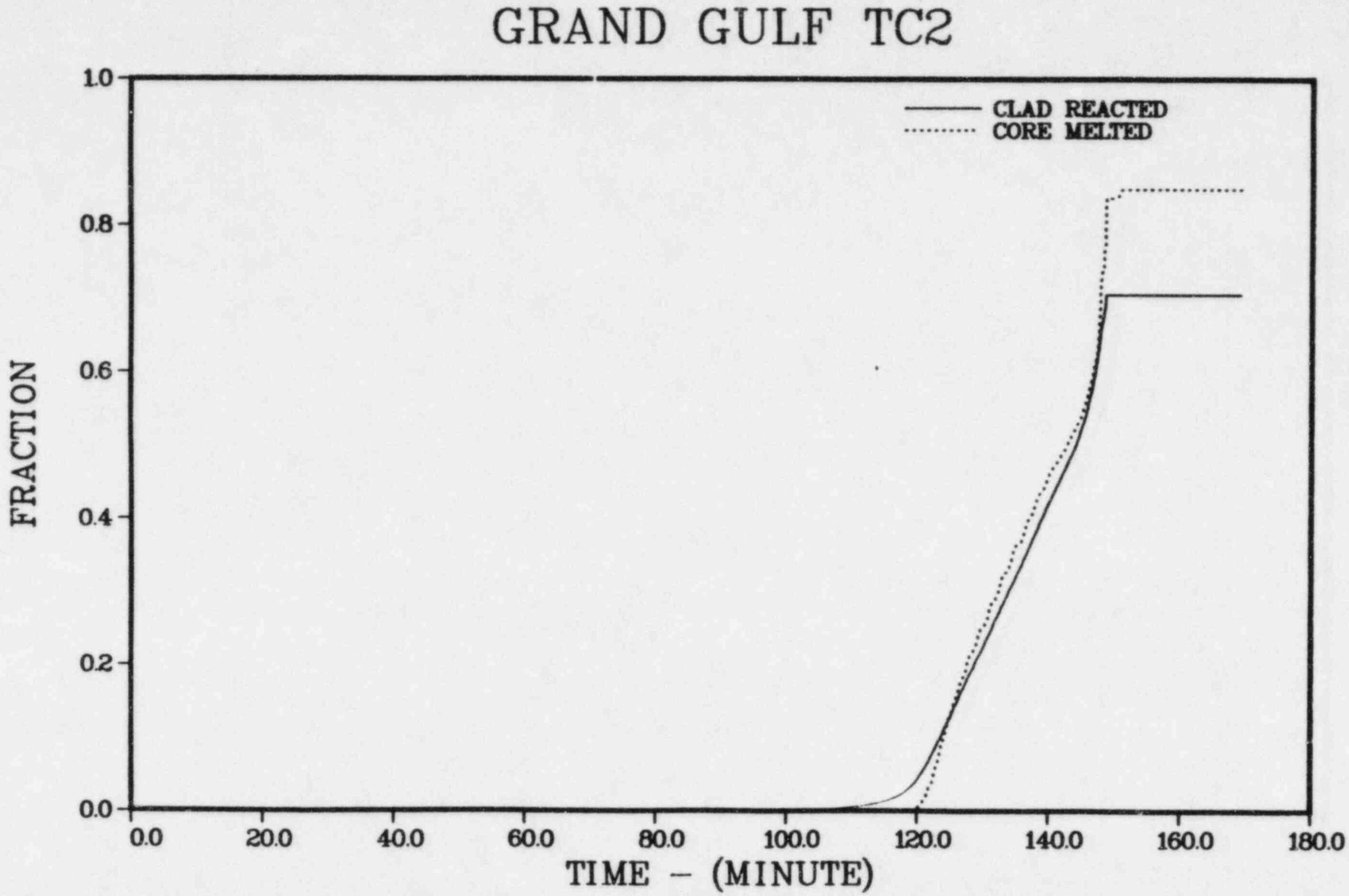

FIGURE 15. CLADDING OXIDATION AND CORE MELTING FOR GRAND GULF TC

SUMMARY OF RESULTS MARCH 2 VERSION 152 MARCH/MAAP COMPARISON: GRAND GULF TQUV, CASE=3 W/ADS, REVISED 1/85

TABLE 9. SUMMARY OF MARCH RESULTS FOR GRAND GULF TQUV

THE REACTOR IS A BWR

THE ACCIDENT IS A NORMAL TRANSIENT

CONTAINMENT SPRAY WORKS

ECC SYSTEM WORKS

HYDROGEN BURNS ARE ACCOUNTED FOR STARTING WITH START OF PROBLEM

OUTPUT IS IN AMERICAN ENGINEERING UNITS

				DEBRIS		FRACTION	SUMP		REACTOR CAVITY	
EVENT	TIME (MIN)	PRIMARY PRESSURE	CONTMNT PRESSURE	MASS	TEMP	OF ZIRC REACTED	MASS	TEMP	MASS	TEMP
SPRAY ON	10.00		15.175				1.0674E+07	105.4	.0000E+00	100.0
SPRAY RECIRC. ON	11.00		15.218				1.0744E+07	106.4	.0000E+00	100.0
CORE UNCOVER	41.01	1108.840	16.381				1.0949E+07	124.4	.0000E+00	100.0
START MELT	76.01	25.186	20.657		4130.0	.0375	1.1117E+07	136.0	.0000E+00	100.0
CORE SLUMP	109.01	26.860	22.742	3.5273E-01	5453.7	.0795	1.1118E+07	132.2	.0000E+00	100.0
FRACTION CORE MELTED										
CORE COLLAPSE	118.8	81.97	46.49	0.810						
START HEAD HEATUP	118.89	79.724	46.807	5.7910E+05	4736.9	.1933	1.1118E+07	131.5	.0000E+00	100.0
BOTTOM HEAD FAIL	133.71		30.075	5.7954E+05	4500.2	.1933	1.1203E+07	136.3	.0000E+00	100.0
END HOTDRP	133.75		30.011	5.7954E+05	4130.0	.1933	1.1203E+07	136.3	.0000E+00	100.0
INTER	133.76		30.011	5.6658E+05	4126.9	.1933	1.1203E+07	136.3	.0000E+00	100.0
OXIDE IS MOLTEN	168.96		25.855	5.8314E+05	4615.6	.1933	1.1212E+07	134.0	.0000E+00	100.0
OXIDE IS FROZEN	169.11		25.855	5.8336E+05	4416.2	.1934	1.1212E+07	134.0	.0000E+00	100.0
INTER	253.82		36.418	6.7521E+05	3654.9	.2419	1.1223E+07	129.2	.0000E+00	100.0
LAYERS INVERT	274.14		38.442	6.9804E+05	3493.7	.2541	1.1224E+07	128.2	.0000E+00	100.0
INTER	373.92		35.998	8.1952E+05	3012.0	.3243	1.1231E+07	123.5	.0000E+00	100.0
METAL IS FROZEN	491.08		42.137	9.6829E+05	2705.6	.4110	1.1236E+07	118.9	.0000E+00	100.0
INTER	493.77		42.222	9.7064E+05	2700.5	.4110	1.1236E+07	118.7	.0000E+00	100.0
INTER	613.78		43.641	1.0291E+06	2885.9	.4110	1.1236E+07	114.3	.0000E+00	100.0
INTER	733.79		45.713	1.0816E+06	3156.1	.4110	1.1241E+07	111.1	.0000E+00	100.0

36 NORMAL EXIT INTER: TIME > TF

NUMBER OF BOIL TIMESTEPS = 676 NUMBER OF MACE TIMESTEPS = 1430

62 INFORMATORY INP: NO DEFAULT FILE AVAILABLE

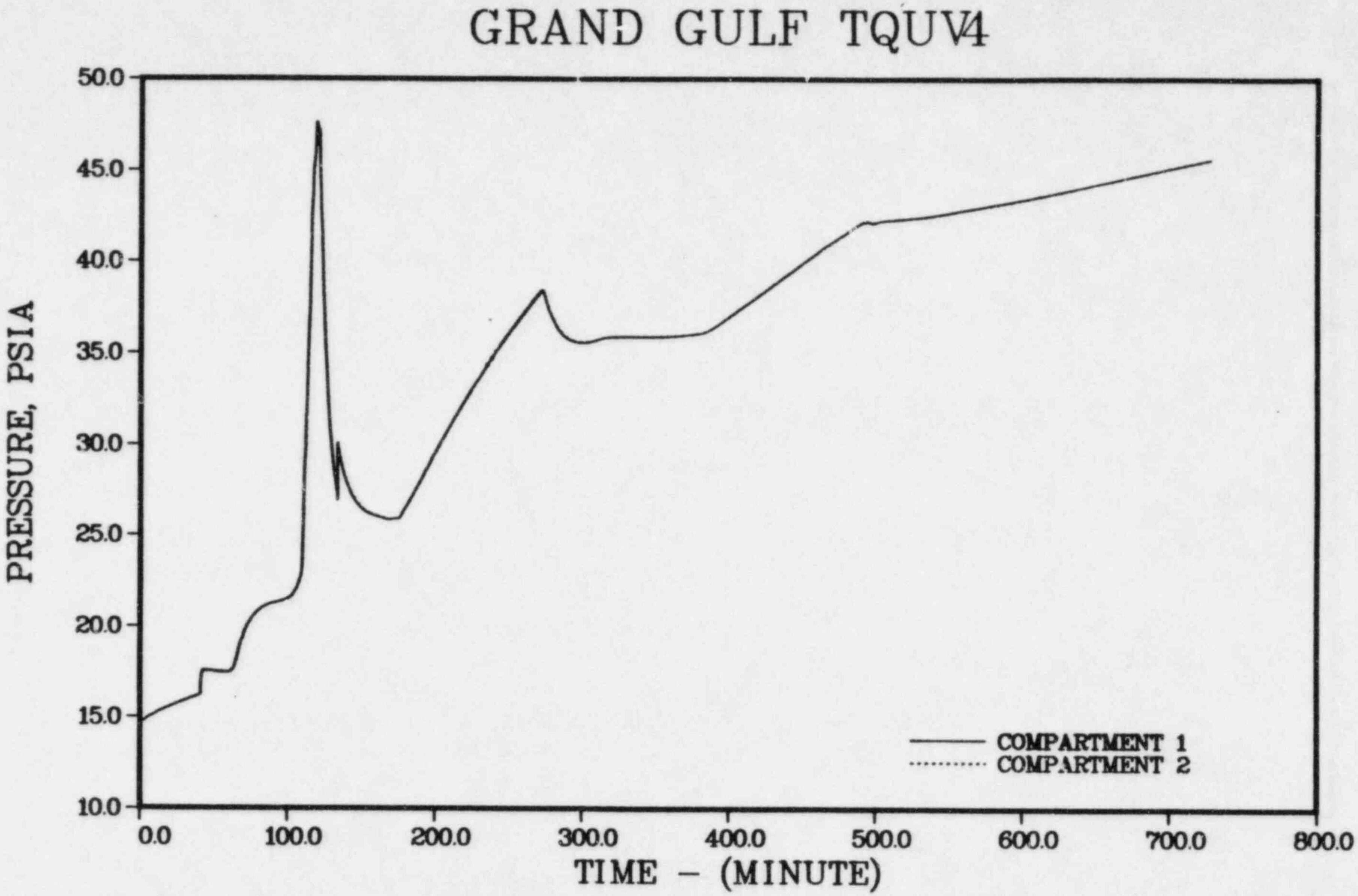

FIGURE 16. CONTAINMENT PRESSURE RESPONSE FOR GRAND GULF TQUV

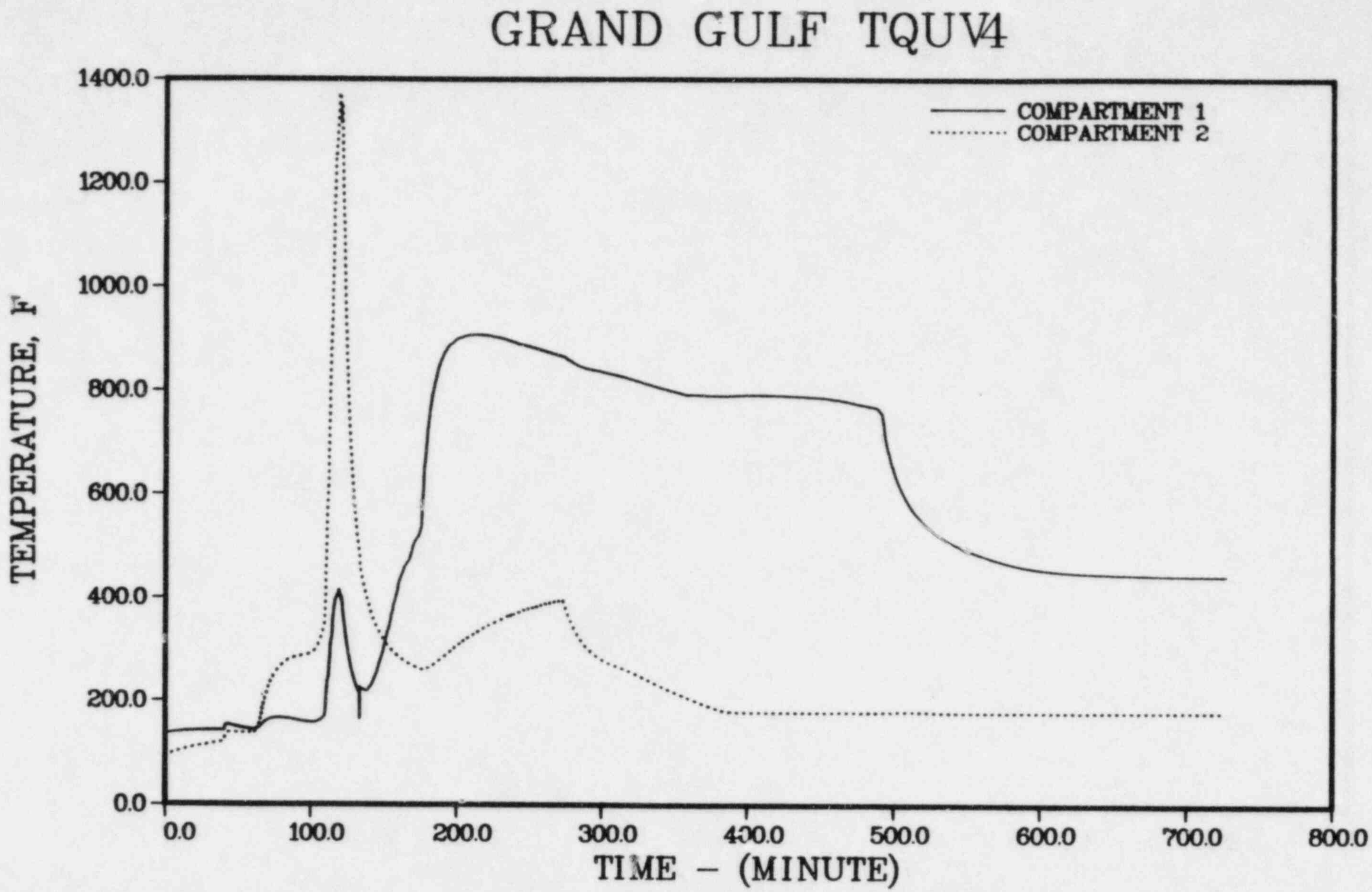

FIGURE 17. CONTAINMENT TEMPERATURE RESPONSE FOR GRAND GULF TQUV

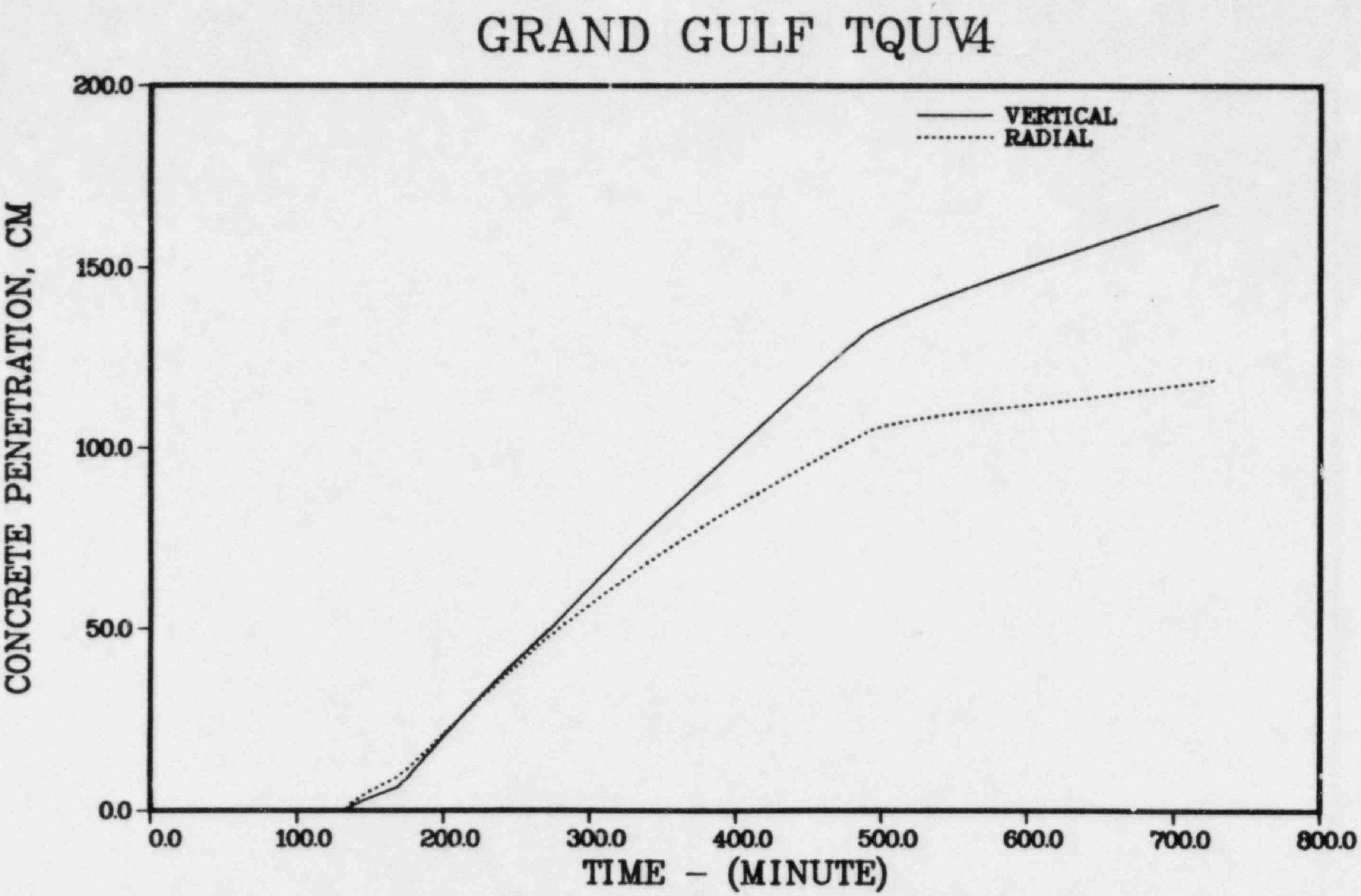

FIGURE 18. CONCRETE PENETRATION FOR GRAND GULF TQUV

TABLE 10. MARCH/MAAP COMPARISON FOR GRAND GULF TQUV

	MARCH	MAAP
CORE UNCOVER (HR)	0.68	0.47
START MELT (HR)	1.30	2.0
20% CORE MELT (HR)	1.70	2.35
CORE SLUMP (HR)	1.82	2.35
CORE COLLAPSE (HR)	1.98	
VESSEL FAIL (HR)	2.23	2.35
CONTAINMENT FAIL (HR)	38	47.
IN-VESSEL HYDROGEN (LB)	1635	100

Peach Bottom Mark I BWR

The MARCH analyses represented the Mark I pressure suppression containment as a two compartment system; the secondary containment was represented as a third compartment. The MAAP analyses generally use finer compartmentalization of the containment. The core was represented in MARCH by nine radial and twenty axial regions; the MAAP parameter file for this plant contains three radial and ten axial core zones. The core power distributions were the same in both sets of analyses.

Results for Peach Bottom TW

In the TW sequence all safety features except the containment heat removal are operable. In the absence of containment heat removal the suppression pool heats up and the containment pressure increases until the failure level is reached. Containment failure is followed by the failure of the emergency core cooling pumps. Since the large volume of water in the suppression pool is being heated only by fission product decay heat, an extremely long time is required to reach the containment failure level. The MARCH results for this sequence are summarized in Table 11. Containment pressure and temperature histories are illustrated in Figures 19 and 20. In the MARCH analyses actuation of the ADS was assumed at the time of initial core uncovery. The actuation of the ADS is seen to increase the containment pressure above the failure level. The relatively small containment hole size used to characterize failure does not permit rapid depressurization. Another, even larger, containment repressurization is associated with the start of core slumping. The secondary containment shows no perceptible pressurization; the temperature of the secondary containment is seen to rise gradually to about 200 F following primary containment failure.

Table 12 gives the comparison between the MARCH and MAAP[7] predictions of accident event times. The excellent agreement in the time to containment failure can be viewed as indicative of reasonable energy balances in both calculations. The time of core uncovery for the two calculations are also in good agreement. Subsequent events are conceptually different and predicted timings for them diverge somewhat.

SUMMARY OF RESULTS MARCH 2 VERSION 152 PBTW2:MARCH/MAAP-ADS ON/FAN ON(UNCOVER/CNMT FAIL): REVISED 1/85

TABLE 11. SUMMARY OF MARCH RESULTS FOR PEACH BOTTOM TW

THE REACTOR IS A BWR

THE ACCIDENT IS A NORMAL TRANSIENT

CONTAINMENT SPRAY DOES NOT WORK

ECC SYSTEM WORKS

HYDROGEN BURNS ARE ACCOUNTED FOR STARTING WITH START OF PROBLEM
HYDROGEN BURNS ARE ADIABATIC ONLY

OUTPUT IS IN AMERICAN ENGINEERING UNITS

EVENT	TIME (MIN)	PRIMARY PRESSURE	CONTMNT PRESSURE	DEBRIS MASS	DEBRIS TEMP	FRACTION OF ZIRC REACTED	SUMP MASS	SUMP TEMP	REACTOR CAVITY MASS	REACTOR CAVITY TEMP
ECC RECIRC. ON	701.00	1266.609	25.970				8.7298E+06	231.6	.0000E+00	100.0
FAN ON	1925.00		130.430				8.5099E+06	349.4	.0000E+00	100.0
CONTMNT FAIL	1927.16	1267.224	15.200				8.5095E+06	349.3	.0000E+00	100.0
ECC OFF	1928.05	[illegible]	134.903				8.5094E+06	349.2	.0000E+00	100.0
CORE UNCOVER	2041.25	[illegible]	130.744				8.6679E+06	348.5	.0000E+00	100.0
START MELT	2123.56	138.411	135.309		4130.0	.0371	8.8142E+06	349.8	.0000E+00	100.0
CORE SLUMP FRACTION CORE MELTED	2159.76	137.203	131.319	1.1050E-01	913.1	.0919	8.8166E+06	344.6	.0000E+00	100.0
CORE COLLAPSE	2509.0									
START HEAD HEATUP	2509.26	102.675	101.967	5.7701E+05	3191.5	.6210	8.9374E+06	329.4	.0000E+00	100.0
BOTTOM HEAD FAIL	2558.06		97.407	6.8324E+05	3492.8	.6210	8.9522E+06	325.5	.0000E+00	100.0
END MCTDRP	2558.10		98.607	7.1155E+05	3347.4	.6210	8.9520E+06	325.5	.0000E+00	100.0
INTER	2558.11		98.607	7.1155E+05	3346.5	.6210	8.9520E+06	325.5	.0000E+00	100.0
INTER	2678.15		87.850	7.4211E+05	3128.7	.6210	8.9740E+06	319.2	.0000E+00	100.0
METAL IS FROZEN	2729.18		84.422	7.5212E+05	3540.8	.6210	8.9765E+06	316.4	.0000E+00	100.0
METAL IS MOLTEN	2730.02		84.439	7.5215E+05	3476.2	.6210	8.9765E+06	316.3	.0000E+00	100.0
OXIDE IS MOLTEN	2733.53		84.069	7.5239E+05	3762.9	.6210	8.9764E+06	316.1	.0000E+00	100.0
OXIDE IS FROZEN	2734.37		85.005	7.5271E+05	3557.3	.6210	8.9766E+06	316.1	.0000E+00	100.0
INTER	2798.13		80.433	7.7082E+05	3493.1	.6210	8.9812E+06	313.0	.0000E+00	100.0
LAYERS INVERT	2827.12		79.567	7.8281E+05	3444.0	.6216	8.9859E+06	311.9	.0000E+00	100.0
INTER	2918.10		82.871	8.8294E+05	2791.7	.6855	9.0034E+06	311.0	.0000E+00	100.0
INTER	3038.16		80.243	1.0339E+06	2530.5	.7902	9.0103E+06	310.0	.0000E+00	100.0
INTER	[illegible]		77.018	1.1831E+06	2253.8	.8963	9.0110E+06	[illegible]	[illegible]	[illegible]

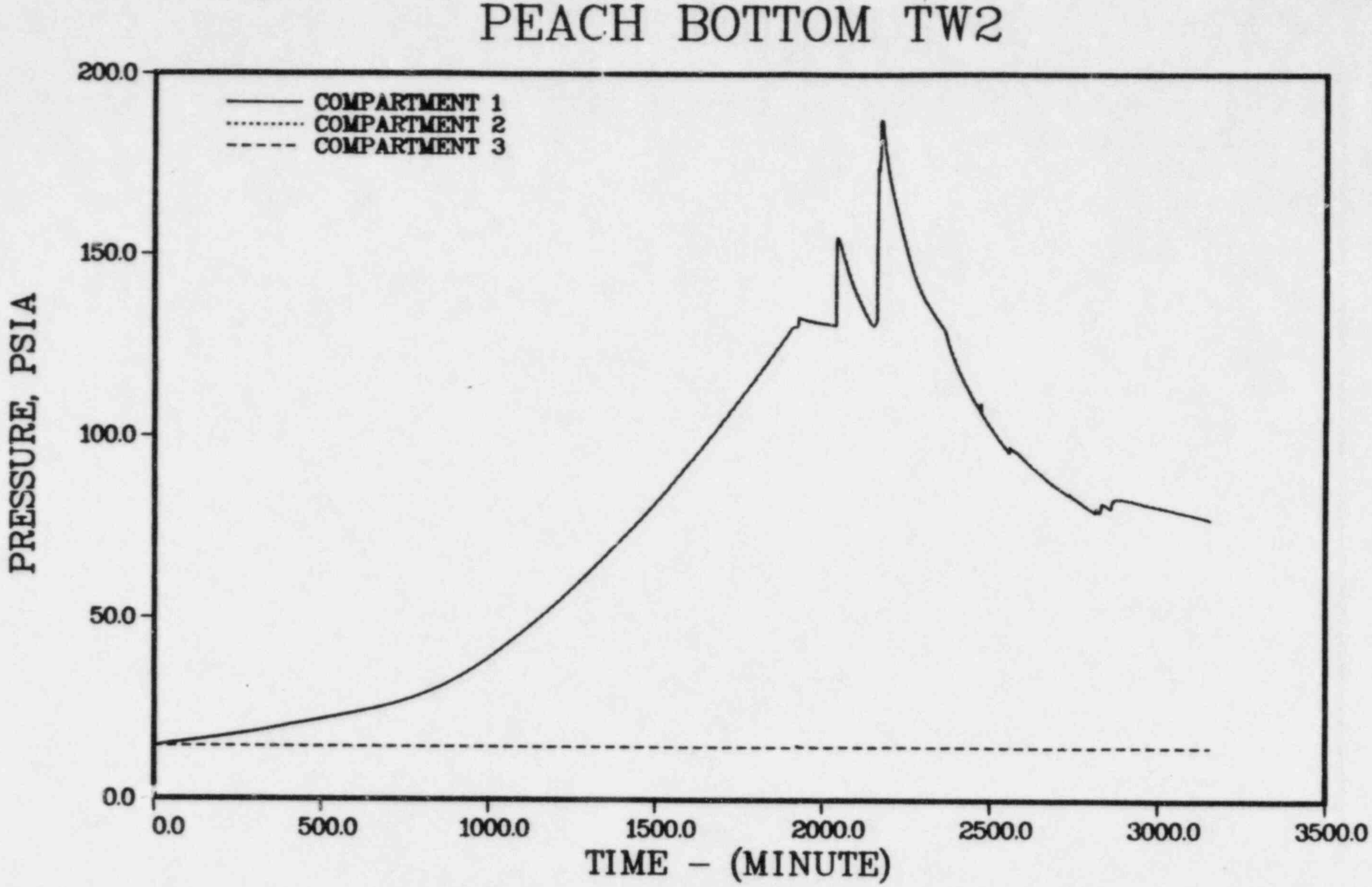

FIGURE 19. CONTAINMENT PRESSURE RESPONSE FOR PEACH BOTTOM TW

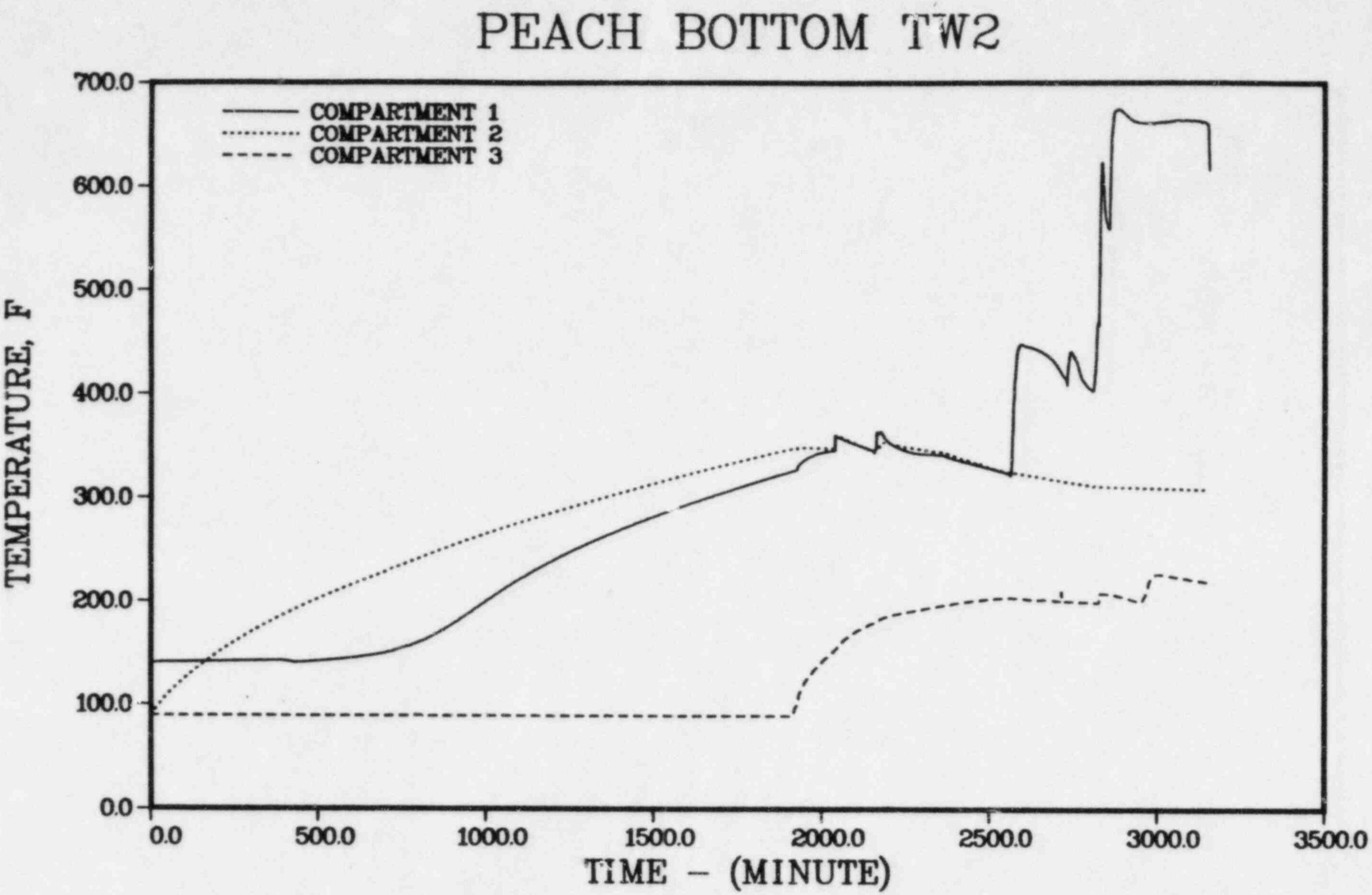

FIGURE 20. CONTAINMENT TEMPERATURE RESPONSE FOR PEACH BOTTOM TW

TABLE 12. MARCH/MAAP COMPARISON FOR PEACH BOTTOM TW

	MARCH	MAAP
CONTAINMENT FAIL (HR)	32.1	32.
CORE UNCOVER (HR)	34.0	34.
START MELT (HR)	35.4	39.
CORE SLUMP (HR)	36.0	40.
20% CORE MELT (HR)	36.1	40.
CORE COLLAPSE (HR)	41.8	
VESSEL FAIL (HR)	42.6	40.

DISCUSSION

The MARCH/MAAP comparison calculations described above were aimed at highlighting the differences in modeling assumptions between the two codes. For this purpose, the attempt was made to use a common data base for the input. Specifically, the MAAP input files were selected as the source of MARCH input data. Even with the MAAP input as a point of departure, considerable difficulty was encountered in achieving completely comparable inputs for the two codes. Part of the difficulty was due to inherent differences in the two codes in how they described various aspects of the reactor systems considered, part of it was due to differences in nomenclature; still others were due to differences in the capabilities and limitations of the two codes. Not to be completely overlooked is the very limited effort that could be allotted to this activity. Obviously, the availability of greater resources could have eliminated many of the differences encountered. It may be further noted that the MARCH analysts did not have the opportunity for any hands-on exposure to the MAAP code.

The above difficulties at arriving at a common point of departure notwithstanding, for most of the accident sequences considered it was possible to generate comparable results with the two codes. A notable difference was the S2HF sequence for Sequoyah, where differences in the accident sequence definition together with modeling differences, precluded a completely meaningful comparison between the predictions of the two codes. There were some very significant and persistent differences between the predictions; the reasons for these are believed to be understood and will be discussed later.

In the MARCH calculations, finer core nodalization was generally utilized than was the case in MAAP. The motivation for this was the concern that the relatively coarse nodalization given in the MAAP parameter files may not be adequate for the treatment of metal-water reactions and the description of fuel slumping. The choice of nodalization for the MARCH calculations was in keeping with other recent MARCH analyses. The MAAP power distributions were maintained in MARCH.

MARCH is limited to a single volume for describing the reactor primary system, whereas MAAP is able to accommodate a finer primary system breakdown. This difference in modeling also contributed to some differences

in the representation of the major components of the primary system such as the steam generators. These system nodalization differences are believed to be responsible for at least some of the differences in the predicted timing of events such as steam generator dryout and the onset of core uncovery.

As was noted earlier, there are some inherent differences in the meaning of such events as start of core melting, core slump, core collapse, etc., between the two codes; thus the differences in the predicted timing of these events must be viewed with these conceptual differences in mind. The differences in the core nodalization can also contribute to differences in the predicted timing of some of these events.

The remarkably good agreement obtained for certain of the comparisons, notably the Grand Gulf TC and Peach Bottom TW sequences, can be viewed as being indicative of consistency in the basic energy balances in the two codes. In both of these cases, however, the predicted timing of containment failure is insensitive to the treatment of in-vessel phenomena. The differences in core melt progression and in-vessel hydrogen generation appear in all cases and are attributable in part to inherent modeling differences and in part to user selected choices to drive the models in each of the two codes.

The MARCH analyses assume that metal-water reactions continue after core melting (liquefaction), that core slumps into the bottom head of the reactor vessel in a region-wise or piece-meal fashion, complete collapse of the entire core into the bottom head requires that seventy-five percent of the core be molten, core debris fragment upon contact with the water in the bottom head, and attack of the vessel head is only initiated after the entire core has collapsed. The temperature of the fuel and the cladding is the same in the lumped parameter approximation used in MARCH; the value of the effective melting temperature assumed (4130 F) is between the melting points of the Zircaloy cladding and that of the uranium dioxide fuel. All of the above assumptions are not hard-wired into MARCH, but represent the currently preferred model options as they were used for the BMI-2104 analyses.

In the MAAP analyses, cladding oxidation is stopped by an input cutoff temperature which corresponds approximately to the melting point of the Zircaloy cladding. Alternatively, a blockage temperature can also be used to terminate further cladding oxidation in the molten region and/or above it.

There is no implicit or explicit consideration of material relocation within the core. When the fraction of the core melted reaches a user input value, the molten fraction of the core is assumed to fall to the bottom of the reactor vessel, without breakup on contact with the water, and immediately attack the vessel head. Vessel failure via a small hole is prescribed immediately after initial fuel slumping. The remainder of the fuel reaches melting and falls out of the vessel after vessel failure. The fuel melting temperature utilized corresponds to that of uranium dioxide. Core melt fractions for fuel slumping of 40 to 50 percent have been used in the PWR analyses, and 20 percent for BWR's. It is understood that the cutoff and blockage temperatures as well as fraction core melted for slumping are user inputs to MAAP and can be changed if desired.

The predicted differences in melt progression and in-vessel hydrogen generation were not surprising and had been fully anticipated on the basis of the several technical exchange meetings between the NRC and IDCOR. The reasons for these differences in predictions were believed to be understood. In order to confirm and highlight these reasons, a few MARCH calculations were performed which attempted to mimic insofar as possible the types of input and modeling assumptions utilized by IDCOR in the MAAP analyses. The approach and results of one particular set of such calculations are discussed below.

The MARCH input for the Sequoyah TML sequence, whose predicted results were described earlier, was chosen to try to mimic the MAAP modeling and user selected input choices. The changes to the previously developed MARCH input included:

- use of the MARCH 1.1 rather than the MARCH 2 model of radiation heat transfer from the core to water below,
- use of a 3380 F cutoff temperature for cladding oxidation rather than permitting it to continue even after melting,
- a fuel melting temperature of 5130 F instead of the previous value of 4130F,
- no fuel movement out of the core until forty percent of the core has melted,
- no consideration of cladding oxidation in the bottom head.

The results of this particular MARCH calculation are compared with the other

results in Table 13; it is interesting to note that in this case, MARCH predicts even less hydrogen generation than MAAP. There are shifts in the predicted timing of events, illustrating the interdependence among the phenomena; e.g., shutoff of the metal-water reaction delays the predicted start of core melting. The comparison is complicated by built-in differences in the two codes regarding energy redistribution within the core, as well as possible differences in the treatment of steam bypass around molten regions. This comparison does illustrate the sensitivity of the predicted core melt progression on assumptions regarding cladding oxidation.

CONCLUSIONS

This report has described the attempt to reproduce by means of the MARCH code analyses conducted with the IDCOR MAAP code using common input insofar as possible. From the evaluation of the results of the comparison calculations, it may be concluded that:

1) The overall treatments of mass and energy balances in the two approaches appear to be consistent.
2) Major differences exist in the course of melt progression and in-vessel hydrogen generation as currently predicted by the two codes.
3) There are significant differences in the treatment of hydrogen combustion in the containment between the two codes.
4) The differences in the treatment of in-vessel hydrogen generation and its combustion in the containment lead, in some cases, to substantially different views on the timing of containment failure.
5) While some of the predicted differences in the course of in-vessel melt progression are due to inherent differences in the two codes, many are due to user selected input or model parameters; by proper choice of inputs, it is possible to get very similar predictions by the two codes.

Due to large inherent uncertainties in the treatment of severe accident phenomena, it is not possible to determine that one set of predictions, or one set of user preferred modeling options, is better than the other. In the present state of knowledge both appproaches must at least be considered as plausible. The effort described here has served to highlight the differences in the approach preferred by IDCOR and the NRC.

TABLE 13. MARCH SIMULATION OF MAAP FOR SEQUOYAH TML

	MARCH	MAAP	MARCH(MOD)
STEAM GENERATOR DRY (HR)	1.02	0.95	1.o2
CORE UNCOVER (HR)	1.49	1.50	1.49
START MELT (HR)	1.83	1.74	2.07
40% CORE MELT (HR)	2.17	2.98	2.38
CORE SLUMP (HR)	2.32	2.98	2.38
CORE COLLAPSE (HR)	2.35		2.40
VESSEL FAIL (HR)	2.47	3.00	2.53
ICE MELTED (HR)	7.40	5.30	
IN-VESSEL HYDROGEN (LB)	1330	772	510

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