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Radionuclide Release Calculations for Selected Severe Accident Scenarios

PWR, Large Dry Containment Design

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Battelle's Columbus Division

Prepared for
U.S. Nuclear Regulatory Commission

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ABSTRACT

This report presents results of analyses of the environmental releases of fission products (source terms) for severe accident scenarios in a pressurized water reactor with a large dry containment. The analyses were performed to support the Severe Accident Risk Reduction/Risk Rebaselining Program (SARRP) which is being undertaken for the U.S. Nuclear Regulatory Commission by Sandia National Laboratories. In the SARRP program, risk estimates are being generated for a number of reference plant designs. The Zion plant has been used in this study as an example of a large dry containment PWR design.

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REPORT

on

RADIONUCLIDE RELEASE CALCULATIONS FOR SELECTED SEVERE ACCIDENT SCENARIOS

Volume V
PWR, Large Dry Containment Design

to

U.S. Nuclear Regulatory Commission*

from

BATTELLE
Columbus Division

May 30, 1986

1. INTRODUCTION

This report presents results of analyses of the environmental releases of fission products (source terms) for severe accident scenarios in a pressurized water reactor with a large dry containment. The analyses were performed to support the Severe Accident Risk Reduction/Risk Rebaselining Program (SARRP) which is being undertaken for the U.S. Nuclear Regulatory Commission by Sandia National Laboratories. In the SARRP program, risk estimates are being generated for a number of reference plant designs. The Zion Plant has been used in this study as an example of a large dry containment PWR design.

All of the analyses in this report have been performed with an interim version of the Source Term Code Package(1). These results supplement analyses reported in BMI-2104 Volume VI(2) using essentially the same codes as in the code package but in their stand-alone forms.

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* This work was funded under subcontract to Sandia National Laboratories.

2. GENERAL APPROACH

The accident scenarios analyzed in this report were selected as potential contributors to the risk profile of the Zion plant. Based on the results of these scenarios, source term bins* will be developed by Sandia National Laboratories which describe the timing, quantity, and characteristics of the release of fission products to the environment.

The methods of analysis used to predict fission product release and transport behavior are essentially the same as those presented in NUREG-0956, "Reassessment of the Technical Basis for Estimating Source Terms"[3]. These computer codes have been assembled as a Source Term Code Package which is scheduled for public release in the spring of 1986. An interim version of the code was used in this study.

2.1 Source Term Code Package

A number of changes have been made in the process of integrating the BMI-2104 source term codes into a Source Term Code Package. Many of these changes merely simplify the use of the codes by streamlining and automating the data transfer between codes. Some of the changes, however, involve actual improvements in the models or in the coupling between models.

Figure 2.1 illustrates the manner in which the codes are grouped in the Source Term Code Package. The MARCH 2[4], CORSOR[5], and CORCON-Mod 2[6] codes are now coupled. The CORSOR-M version of the CORSOR code, which uses an Arrhenius form for the empirical correlation, has been incorporated into MARCH. A consistent treatment can now be made of the release of fission products and the transport of sources of decay heat from the fuel. Based on model improvements suggested by ORNL, the release rates of silver and indium from control rods has been reduced substantially from those in the earlier version of CORSOR. Similarly, CORCON-Mod 2 is now used in the code package to

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* Each of the accident scenarios identified by the Accident Sequence Evaluation Program (ASEP) and the Severe Accident Risk Reduction/Risk Rebaselining Program (SARRP) is mapped to one of the source term bins in the process of developing the risk profile for the plant.

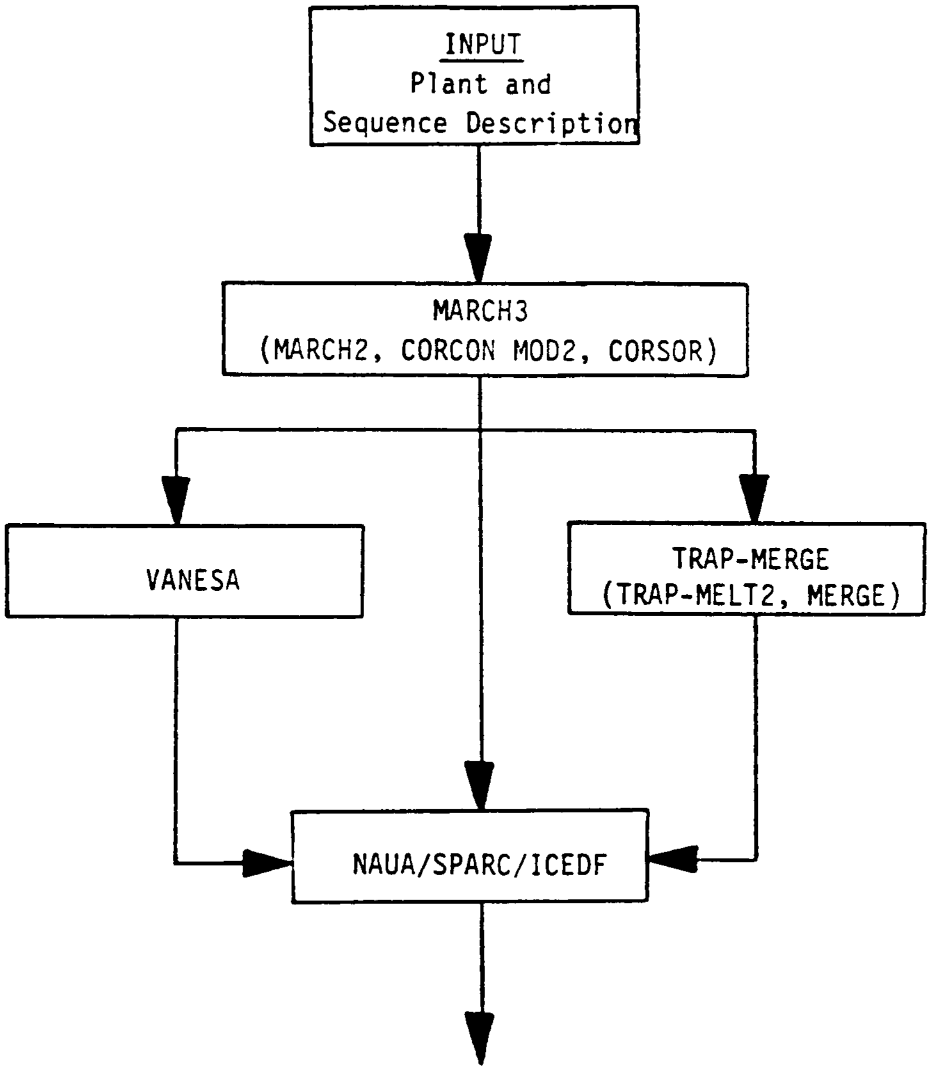

FIGURE 2.1. SOURCE TERM CODE PACKAGE

predict the thermal-hydraulic loads on containment due to core-concrete interactions and as input to the VANESA[7] code to calculate fission product release. In BMI-2104 these processes were treated in a potentially inconsistent manner with two different models, INTER[4] and CORCON-Mod 1[8].

Potentially significant changes also resulted from the intimate coupling of the MERGE[9] and TRAP-MELT[10] codes in the code package. The most important of these are listed below and should be kept in mind when comparing the present results to results presented in BMI-2104 for equivalent accident sequences:

- The decay heat contribution to the thermal hydraulics of the RCS is now considered.
- The fission product transport calculations (TRAP) are nodalized congruently with the thermal hydraulic calculations (MERGE). This includes the use of structures in control volumes that define the boundaries of convective, mixing flow. Previously, distinct structures had to be nodalized as consecutive control volumes.
- Gas properties used in TRAP are those calculated by MERGE and now account for the presence of hydrogen.
- Heat transfer coefficients used in TRAP are supplied by MERGE; mass transfer is based on those using the Chilton-Colburn analogy.
- Aerosol particles are allowed to fall back to upstream volumes if orientation and geometry permit.
- Aerosol particles settling into the melt are instantaneously revaporized by species constituents with condensed vapors revolatilizing as vapors and particles regenerating as particles with nucleation size.
- The treatment of chemisorption on walls now accounts for gas-phase mass transport, which can be limiting for some flows, especially for the highly reactive Te species.

Each of the other codes is run separately in the Code Package. In general, the interfaces between the codes have been automated so that an output file from one code is used as the input file for the next.

2.2 Radionuclide Groups

Initially in the BMI-2104 analyses, four groups of radionuclides were tracked: iodine, cesium, tellurium, and gross aerosols. In order to facilitate ex-plant consequence analyses, the groupings were subsequently changed to the WASH-1400(11) structure: noble gases, iodine, cesium, tellurium, strontium, ruthenium, and lanthanum. In both cases the element named actually represented a group of elements with similar chemical behavior. For the current study, the NRC recommended that two of the WASH-1400 groups (strontium and lanthanum) be further subdivided. Table 2.1 identifies the radionuclide groups used in this study and the additional elements represented by each group. Additionally, the inert aerosols generated in-vessel and those generated ex-vessel are tracked as separate groups. A tracer has also been used in the NAUA(12) calculations to permit a direct heating source term to be assessed at a later date if necessary. A massless source of strength unity is introduced into the containment at the time of vessel failure. The fractional release to the environment of this simulated source is determined as a function of time in the same manner as for the different groups of radionuclides.

TABLE 2.1. RADIONUCLIDE GROUPS

Group	Elements
1	Xe, Kr
2	I, Br
3	Cs, Rb
4	Te, Sb, Se
5	Sr
6	Ru, Rh, Pd, Mo, Tc
7	La, Zr, Nd, Eu, Nb, Pm, Pr, Sm, Y
8	Ce, Pu, Np
9	Ba
10	In-vessel aerosols
11	Ex-vessel aerosols

3. DESCRIPTION OF PLANT AND ACCIDENT SCENARIOS

The representation of the Zion plant for the present analyses was essentially identical to that previously developed in BMI-2104, Volume VI.

3.1 Accident Scenarios Considered

The accident sequences selected for detailed source term calculations were based on preliminary Accident Sequence Evaluation Program (ASEP) results for accident sequence probabilities and preliminary SARRP containment event tree branching probabilities.

The S2DCr sequence is initiated by rupture of the primary coolant pump seals and is accompanied by failure of the emergency core cooling injection as well as containment spray recirculation systems. The containment fan coolers are initially operable, but are assumed to fail at the time of reactor vessel failure. Late overpressure failure has been selected as the containment failure mode of interest for this sequence. The operation of the containment sprays in the injection mode results in a wet reactor cavity in this sequence; the evaporation of this water by the core debris is the major source of long term containment pressurization.

The S2DCirFir sequence is initiated by primary pump seal rupture and is accompanied by failures of emergency core cooling, containment sprays, as well as containment coolers. Two containment failure modes have been selected for analysis for this sequence: an early containment failure due to hydrogen burning and/or direct heating, and a late failure due to a delayed hydrogen burn or overpressurization.

The TMLU sequence is initiated by a transient and is accompanied by the loss of the power conversion, auxiliary feedwater, and emergency core cooling systems; both the containment coolers and sprays are available in this case. The early containment failure mode selected for analysis is the result of direct heating of the containment atmosphere by the core debris.

3.2 Primary System Flowpaths

The most likely small break initiator has been indicated to be rupture of the primary pump seals; this is the failure mode assumed in the present analyses. Figure 3.1 illustrates the flowpaths for fission products within the primary system for the pump seal LOCA scenarios. The TRAP-MERGE control volume breakdown used for these sequences is illustrated in Figure 3.2.

In the TMLU scenario the primary coolant would be boiled off through the pressurizer relief valve. The primary system fission product flowpath for this sequence is illustrated in Figure 3.3. The TRAP-MERGE control volume breakdown is given in Figure 3.4.

3.3 Containment Flowpaths

The Zion reactor building is treated as a single well mixed volume in these analyses. Thus any fission products released to the containment atmosphere are assumed to mix instantaneously with the contents of the containment. After containment failure airborne activity is calculated to leak out of the containment based on orifice flow. After the initial rapid depressurization the leak rate is largely governed by the available driving forces, i.e., gas and vapor generation.

3.4 Containment Failure Mode and Pressure Level

The Zion containment is a pre-stressed concrete design with post tensioning. A number of analyses have been made of the failure pressure including an evaluation in the utility sponsored PRA(13) and by the Los Alamos National Laboratory in support of the Zion/Indian Point Study(14). A value of 149 psia was used as the failure pressure in these analyses. An opening size of 7 ft^2 was assumed in calculating leakage to the environment.

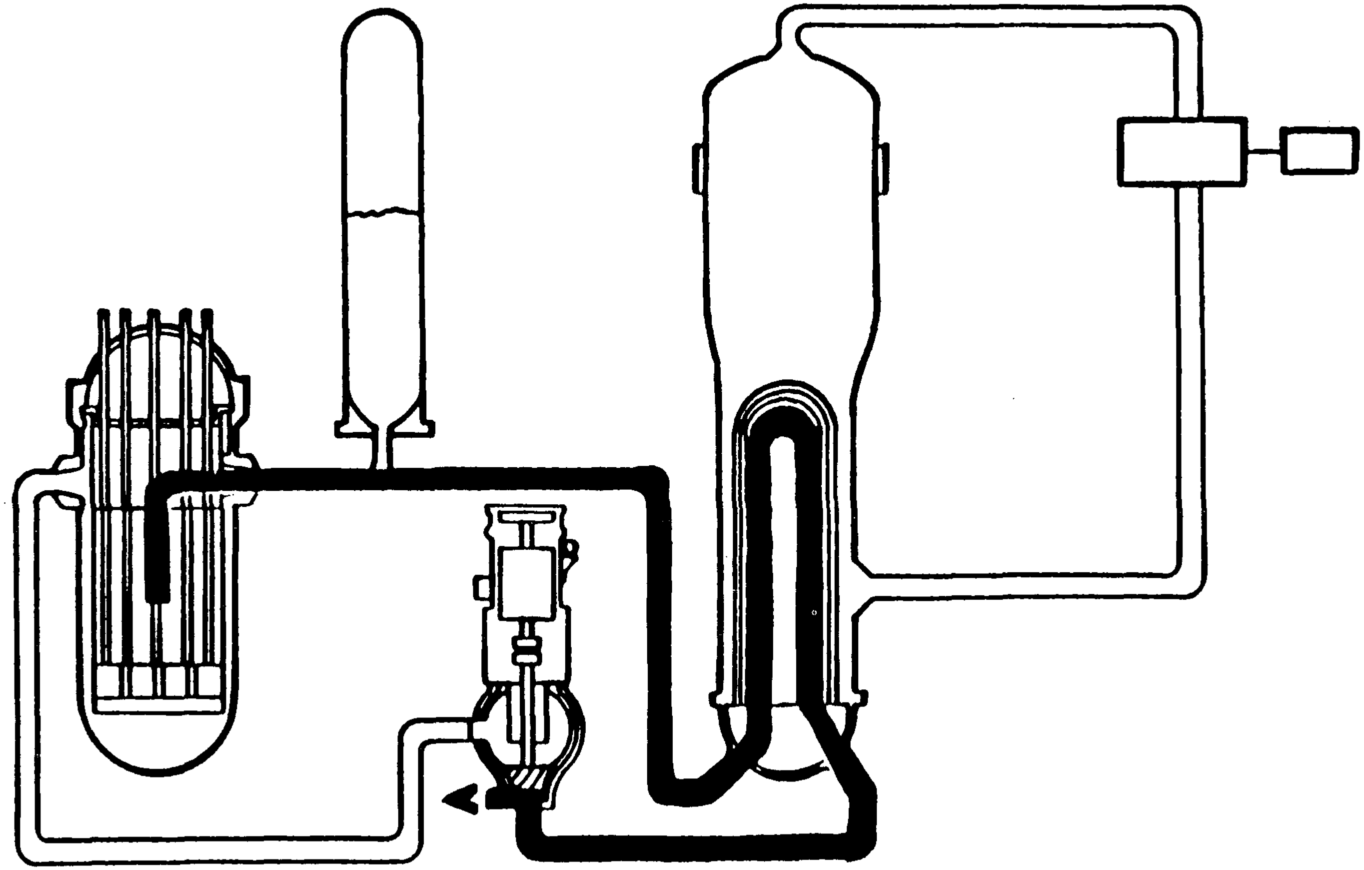

FIGURE 3.1. PRIMARY SYSTEM FLOWPATH FOR SEAL LOCA SEQUENCES

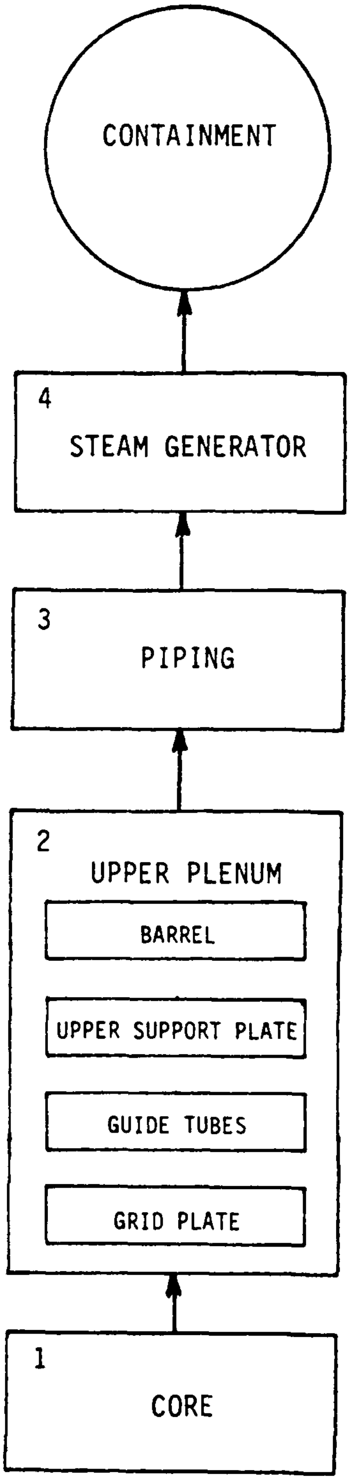

FIGURE 3.2. SCHEMATIC OF TRAP-MERGE CONTROL VOLUMES FOR SEAL LOCA SEQUENCES

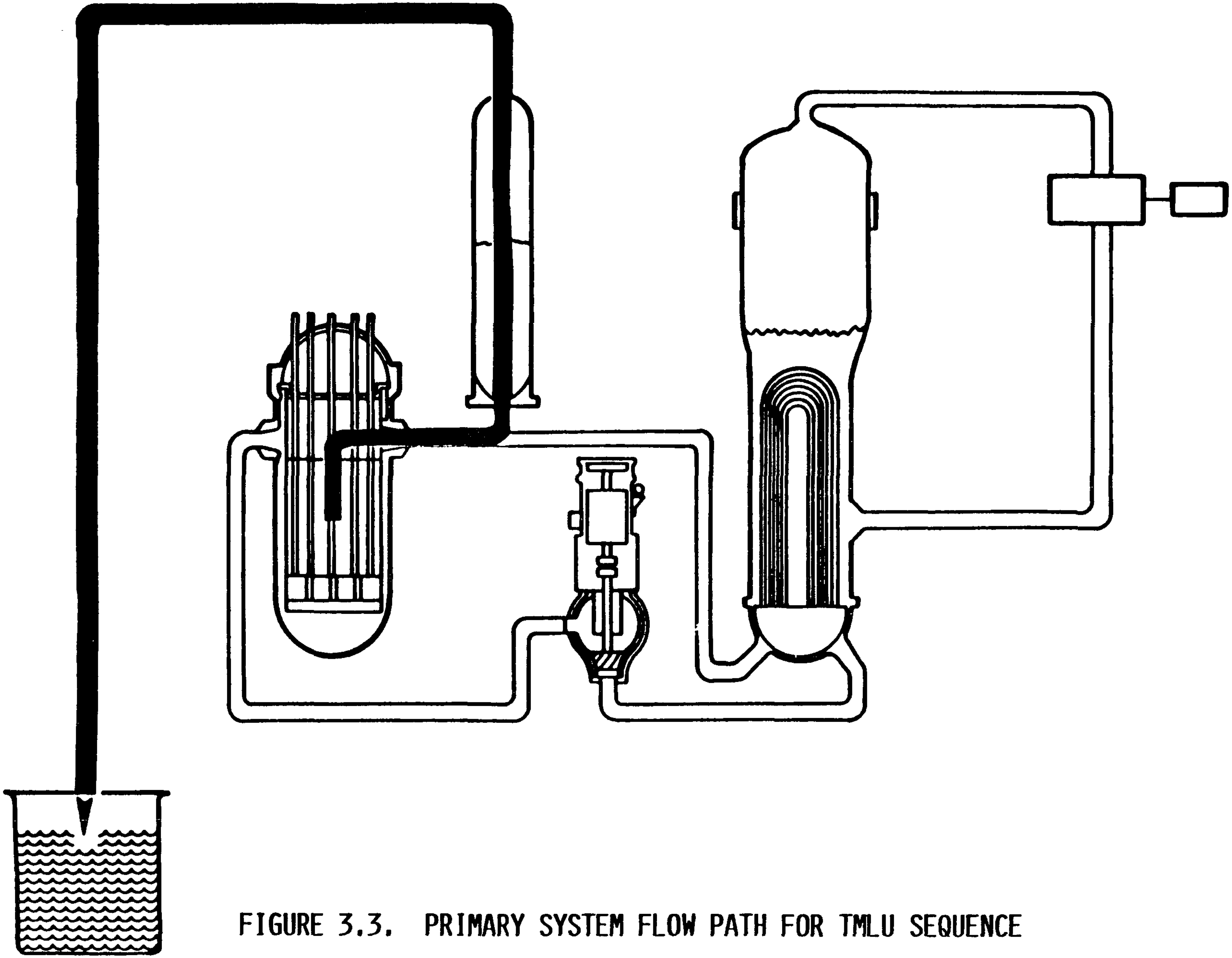

FIGURE 3.3. PRIMARY SYSTEM FLOW PATH FOR TMLU SEQUENCE

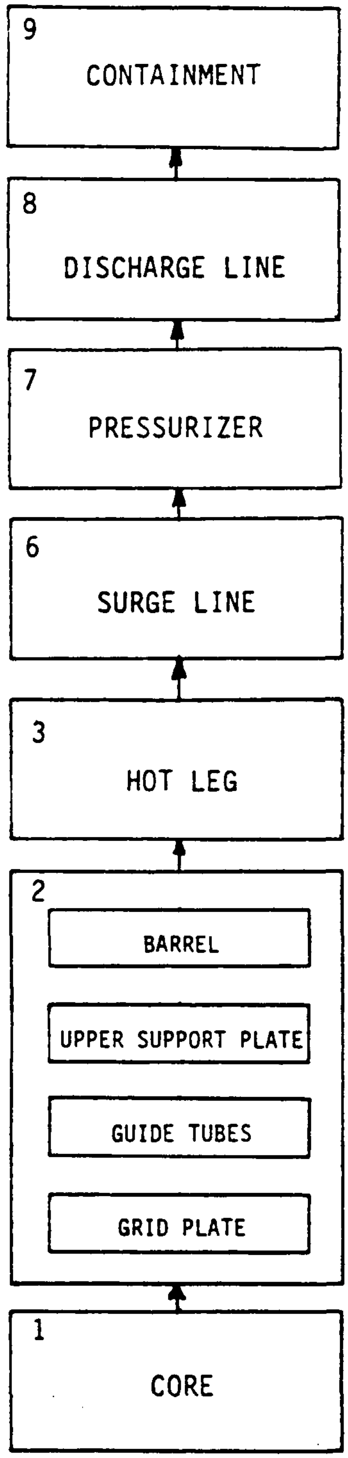

FIGURE 3.4. SCHEMATIC OF TRAP-MERGE CONTROL VOLUMES FOR TMLU SEQUENCE

4. BASES FOR TRANSPORT CALCULATIONS

4.1 Phenomenological Modeling Assumptions

As previously indicated, by far the most likely small break initiator has been identified to be failure of the primary coolant pump seals. Failure of all four pump seals has been predicted to result in a leak rate of 1800 gallons per minute from the primary system. In the MARCH analyses the failed pump seals were represented by a hole 0.0111 square feet in area; this hole size gave the above leak rate of subcooled water at normal reactor operating conditions.

The early containment failure modes identified for source term analyses represent very low probability outcomes for these sequences. The loadings required to fail the Zion containment are considered to be unlikely. However, direct interaction between dispersed hot core debris and the containment atmosphere is believed to be a possible mechanism for achieving such loadings. MARCH 3 does not contain models for the direct interaction of the core debris with the containment atmosphere. In order to calculate containment loads and containment conditions that would be consistent with the postulated failure of the Zion containment, the control parameters for the reactor cavity and hydrogen combustion models in MARCH were selected to enhance hydrogen and steam generation as well as to promote hydrogen combustion. The parameters selected served to approximate the high temperatures and pressures that would be encountered in the event of direct heating; these model input choices should not be construed as being representative of most likely or expected behavior.

4.2 Results of Thermal Hydraulic Analyses

4.2.1 S_2DC_r Sequence

In this sequence, as it has been considered here, the accident is initiated by the failure of the primary coolant pump seals and is accompanied by failure of emergency core cooling injection and containment spray recirculation systems. The containment building coolers are initially

operational but are assumed to fail at the time of reactor vessel failure; the latter would be an accident induced failure. The accident event times as calculated by MARCH 3 are given in Table 4.1. Core and primary system conditions at key times in the accident sequence are presented in Table 4.2; containment conditions are summarized in Table 4.3.

Figure 4.1 illustrates the primary system pressure response for this sequence. The corresponding primary system leak rates and water inventories are given in Figures 4.2 and 4.3, respectively. The primary system pressure drops rapidly from the normal operating level to saturated conditions and is maintained essentially constant at that level as long as the break (pump seal) is water covered. When sufficient inventory is lost to uncover the break the leak flow switches to steam; the latter is clearly reflected by the change in the calculated leak rate. Due to the relatively small opening in the system, the pressure remains at high levels throughout the entire in-vessel portion of the accident. The changes in the leak flow are reflected in the time dependent water inventory illustrated in Figure 4.3.

The maximum and average core temperatures for this sequence are illustrated in Figure 4.4. Initially the core temperatures drop from their operating levels to near the water temperature. At decay heating levels all the heat generation can be removed from the water covered core with only small temperature differences. As the core uncovers the temperatures begin to rise. The maximum temperature in the core is seen to arrest at the input specified effective liquidus temperature, except for brief excursions due to metal-water reactions as molten fuel relocates within the core. The average temperature of the core is seen to increase monotonically up to the point of core collapse. Beyond that point the individual core node temperatures are no longer defined. The fractions of cladding reacted and core melted are illustrated in Figure 4.5.

The average temperature of the gases leaving the core and that leaving the primary system during this sequence as calculated by MARCH 3 are illustrated in Figure 4.6. It is noteworthy that by the time the hot gases reach the break in the primary system and enter the containment their temperature is quite low. The temperature histories of some of the primary system structures are illustrated in Figure 4.7. Based on the MARCH modeling, only the first structure immediately above the core experiences high

TABLE 4.1. TIMING OF KEY EVENTS

Event	Time, Minutes
ZION S_2DCR	
Containment Cooler On	0.0
Core Uncovery	64.9
Start Melt	94.2
Core Slump	108.4
Core Collapse	108.9
Bottom Head Dryout	125.3
Bottom Head Failure	133.0
Containment Cooler Off	133.0
Accumulators Empty	133.0
Start Concrete Attack	133.1
Containment Spray Injection On	133.4
Corium Layers Invert	161.1
Hydrogen Burn	162.1
Containment Spray Injection Off/Recirculation Failure	184.1
Containment Failure	1444.0
End Calculation	1633.1
ZION S_2DCF1	
Core Uncovery	64.9
Start Melt	94.2
Core Slump	108.4
Core Collapse	108.9
Bottom Head Dryout	125.4
Bottom Head Failure	132.8
Accumulators Empty	132.8
Hydrogen Burn	132.8
Containment Failure	133.0
Start Concrete Attack	190.1
Corium Layers Invert	237.1
End Calculation	798.1

TABLE 4.1. TIMING OF KEY EVENTS (Continued)

Event	Time, Minutes
ZION S_2DCF2	
Core Uncovery	64.9
Start Melt	94.2
Core Slump	108.4
Core Collapse	108.9
Bottom Head Dryout	125.4
Bottom Head Failure	132.8
Accumulators Empty	132.8
Start Concrete Attack	132.9
Corium Layers Invert	161.9
Containment Failure	895.9
End Calculation	1357.9
ZION TMLU	
Containment Cooler On	0.0
Steam Generator Dry	93.0
Containment Spray Injection On	101.8
Core Uncovery	124.6
Start Melt	148.4
Spray Recirculation On/Injection Off	151.6
Core Slump	178.2
Core Collapse	179.4
Bottom Head Failure	189.6
Accumulators Empty	189.6
Hydrogen Burn	189.6
Containment Failure	189.7
Cooler and Spray Off	190.1
Start Concrete Attack	253.0
Corium Layers Invert	303.0
End Calculation	861.0

TABLE 4.2. CORE AND PRIMARY SYSTEM RESPONSE

Accident Event	Time, Minutes	Primary System Pressure, psia	Primary System Water Inventory, lbm	Average Core Temperature, F	Peak Core Temperature, F	Fraction Core Melted	Fraction Clad Reacted
			ZION S_2DCR				
Core Uncovery	64.9	1283	1.21×10^5	587	596	0.0	0.0
Start Melt	94.2	1013	8.20×10^4	1850	4130	0.04	0.06
Core Slump	108.4	693	7.49×10^4	3627	4646	0.62	0.41
Core Collapse	108.9	758	7.41×10^4	3835	--	0.69	0.45
Bottom Head Dryout	125.3	1262	2.96×10^4*	3520	--	--	0.47
Bottom Head Failure	133.0	933	2.79×10^4*	3774	--	--	0.47
			ZION S_2DCF				
Core Uncovery	64.9	1283	1.21×10^5	587	596	0.0	0.0
Start Melt	94.2	1013	8.20×10^4	1852	4130	0.04	0.06
Core Slump	108.4	693	7.45×10^4	3629	4752	0.62	0.41
Core Collapse	108.9	750	7.41×10^4	3834	--	0.69	0.45
Bottom Head Dryout	125.4	1253	2.96×10^4*	3526	--	--	0.47
Bottom Head Failure	132.8	939	2.79×10^4*	3772	--	--	0.47

TABLE 4.2. CORE AND PRIMARY SYSTEM RESPONSE (Continued)

Accident Event	Time, Minutes	Primary System Pressure, psia	Primary System Water Inventory, lbm	Average Core Temperature, F	Peak Core Temperature, F	Fraction Core Melted	Fraction Clad Reacted
			<u>ZION TMLU</u>				
Steam Generator Dry	93.0	2376	3.80×10^5	654	660	0.0	0.0
Core Uncovery	124.6	2374	1.01×10^5	669	675	0.0	0.0
Start Melt	148.4	2372	6.74×10^4	1948	4130	0.01	0.06
Core Slump	178.2	2373	6.40×10^4	4456	--	0.57	0.33
Core Collapse	179.4	2374	5.89×10^4	4178	--	0.86	0.50
Bottom Head Failure	189.6	2375	2.50×10^4*	4053	--	--	0.52

* Residual water in low points of primary system piping.

TABLE 4.3. CONTAINMENT RESPONSE

Accident Event	Time, Minutes	Containment Pressure, psia	Containment Temperature, F	RWST Water Mass, lbm	Sump Water Mass, lbm	Sump Water Temp., F	Reactor Cavity Water Mass, lbm	Reactor Cavity Water Temp., F	Steam Condensation on Walls, lbm/min
				ZION S_2DCR					
Containment Cooler On	0.0	14.7	110	3.2×10^{6}	0.0	--	0.0	--	0
Core Uncovery	64.9	22.2	174	3.2×10^{6}	3.03×10^{5}	174	4.90×10^{4}	174	445
Start Melt	94.2	21.1	169	3.2×10^{6}	3.04×10^{5}	166	1.04×10^{5}	166	239
Core Slump	108.4	20.6	164	3.2×10^{6}	3.05×10^{5}	161	1.22×10^{5}	161	101
Core Collapse	108.9	20.6	164	3.2×10^{6}	3.05×10^{5}	160	1.22×10^{5}	160	97
Bottom Head Dryout	125.3	21.7	170	3.2×10^{6}	3.05×10^{5}	160	1.39×10^{5}	160	231
Bottom Head Failure/ Containment Cooler Off	133.0	27.1	192	3.2×10^{6}	3.05×10^{5}	160	1.50×10^{5}	160	2303
Accumulators Empty/Start Concrete Attack	133.1	27.9	195	3.2×10^{6}	3.06×10^{5}	160	3.52×10^{5}	140	4336
Containment Spray Injection On	133.4	27.7	194	--	3.05×10^{5}	161	3.55×10^{5}	150	3666
Hydrogen Burn	162.1	53.2	861	1.4×10^{6}	1.90×10^{6}	141	5.65×10^{5}	225	0
Spray Injection Off/ Recirculation Failure	184.1	21.1	164	0.0	3.37×10^{6}	157	5.63×10^{5}	231	0
Containment Failure	1444.0	149.0	344	0.0	2.85×10^{6}	157	5.25×10^{5}	358	253
End Calculation	1633.1	15.0	272	0.0	2.62×10^{6}	174	5.68×10^{5}	213	0

TABLE 4.3. CONTAINMENT RESPONSE
(Continued)

Accident Event	Time, Minutes	Containment Pressure psia	Containment Temperature, F	RWST Water Mass, lbm	Sump Water Mass lbm	Sump Water Temp., F	Reactor Cavity Water Mass, lbm	Reactor Cavity Water Temp., F	Steam Condensation on Walls, lbm/min
				ZION S_2DCF1					
Core Uncovery	64.9	32.5	220	3.2×10^6	2.92×10^5	209	0.0	--	1063
Start Melt	94.2	36.1	230	3.2×10^6	2.99×10^5	210	2.06×10^4	210	756
Core Slump	108.4	37.3	233	3.2×10^6	2.99×10^5	211	2.94×10^4	210	392
Core Collapse	108.9	37.4	233	3.2×10^6	2.99×10^5	211	2.97×10^4	210	374
Bottom Head Dryout	125.4	40.7	240	3.2×10^6	2.99×10^5	211	3.49×10^4	210	322
Bottom Head Failure	132.8	47.9	249	3.2×10^6	2.99×10^5	211	3.74×10^4	210	3170
Accumulators Empty	132.8	48.1	249	3.2×10^6	3.0×10^5	212	2.39×10^5	154	3572
Hydrogen Burn	132.8	57.2	295	3.2×10^6	3.0×10^5	212	1.97×10^5	290	4895
Containment Failure	133.0	149.0	1210	3.2×10^6	3.0×10^5	212	1.06×10^5	316	0
Start Concrete Attack	190.1	14.7	258	3.2×10^6	2.95×10^5	194	9.45×10^4	212	0
End Calculation	798.1	14.8	216	3.2×10^6	2.93×10^5	187	1.88×10^2	210	0

TABLE 4.3. CONTAINMENT RESPONSE
(Continued)

Accident Event	Time, Minutes	Containment Pressure, psia	Containment Temperature, F	RWST Water Mass, lbm	Sump Water Mass, lbm	Sump Water Temp., F	Reactor Cavity Water Mass, lbm	Reactor Cavity Water Temp., F	Steam Condensation on Walls, lbm/min
				ZION S_2DCF2					
Core Uncovery	64.9	32.5	220	$3.2x10^6$	$2.92x10^5$	209	0.0	--	1063
Start Melt	94.2	36.1	230	$3.2x10^6$	$2.99x10^5$	210	$2.06x10^4$	210	756
Core Slump	108.4	37.3	233	$3.2x10^6$	$2.99x10^5$	211	$2.94x10^4$	210	392
Core Collapse	108.9	37.4	233	$3.2x10^6$	$2.99x10^5$	211	$2.97x10^4$	210	374
Bottom Head Dryout	125.4	40.7	240	$3.2x10^6$	$2.99x10^5$	211	$3.49x10^4$	210	322
Bottom Head Failure	132.8	47.9	249	$3.2x10^6$	$2.99x10^5$	211	$3.74x10^4$	210	3170
Accumulators Empty	132.8	48.1	249	$3.2x10^6$	$3.0 x10^5$	212	$2.39x10^5$	138	3585
Start Concrete Attack	132.9	48.1	249	$3.2x10^6$	$3.0 x10^5$	212	$2.39x10^5$	138	3547
Containment Failure	895.9	149.0	342	$3.2x10^6$	100.0	342	$8.50x10^4$	358	346
End Calculation	1357.9	14.8	272	$3.2x10^6$	98.0	212	128	219	0

TABLE 4.3. CONTAINMENT RESPONSE (Continued)

Accident Event	Time, Minutes	Containment Pressure psia	Containment Temperature, F	RWST Water Mass, lbm	Sump Water Mass lbm	Sump Water Temp., F	Reactor Cavity Water Mass, lbm	Reactor Cavity Water Temp., F	Steam Condensation on Walls, lbm/min
ZION TMLU									
Containment Cooler On	0.0	13.7	110	3.2×10^6	0.0	--	0.0	--	0
Steam Generator Dry	93.0	17.6	139	3.2×10^6	7.44×10^4	140	0.0	--	527
Containment Spray/ Injection On	101.8	25.5	191	3.2×10^6	1.63×10^5	178	0.0	--	2728
Core Uncovery	124.6	18.8	149	1.8×10^6	1.76×10^6	169	0.0	--	30
Start Melt	148.4	16.5	123	2.1×10^5	3.34×10^6	145	0.0	--	0
Containment Spray/ Recirculation On	151.6	16.4	121	1.7×10^4	3.57×10^6	142	0.0	--	0
Core Slump	178.2	17.8	137	1.7×10^4	3.58×10^6	135	0.0	--	100
Core Collapse	179.4	19.3	150	1.7×10^4	3.58×10^6	135	0.0	--	814
Bottom Head Failure	189.6	33.3	213	1.7×10^4	3.60×10^6	138	0.0	--	8158
Accumulators Empty	189.6	33.3	213	1.7×10^4	3.61×10^6	139	2.02×10^5	143	8227
Hydrogen Burn	189.6	59.8	510	1.7×10^4	3.61×10^6	139	1.53×10^5	287	0
Containment Failure	189.7	149.0	1264	1.7×10^4	3.60×10^6	139	4.73×10^4	307	0
Cooler/Spray Off	190.1	99.7	652	1.7×10^4	3.59×10^6	139	4.73×10^4	307	0
Start Concrete Attack	253.0	14.7	201	1.7×10^4	3.60×10^6	139	4.28×10^4	212	241
End Calculation	861.0	15.0	209	1.7×10^4	2.75×10^6	143	5.68×10^5	213	5

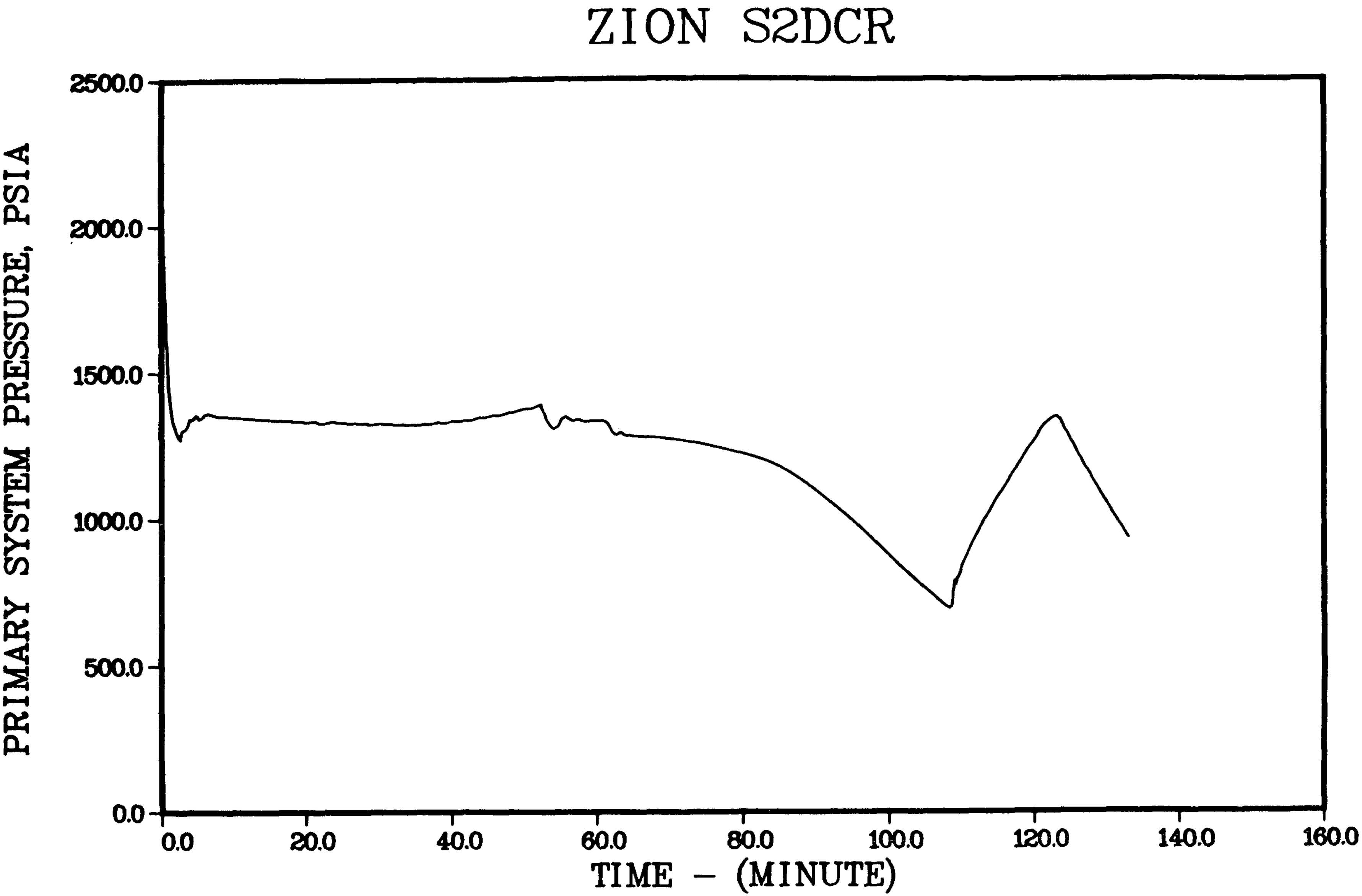

FIGURE 4.1. PRIMARY SYSTEM PRESSURE RESPONSE FOR S_2DC_R SEQUENCE

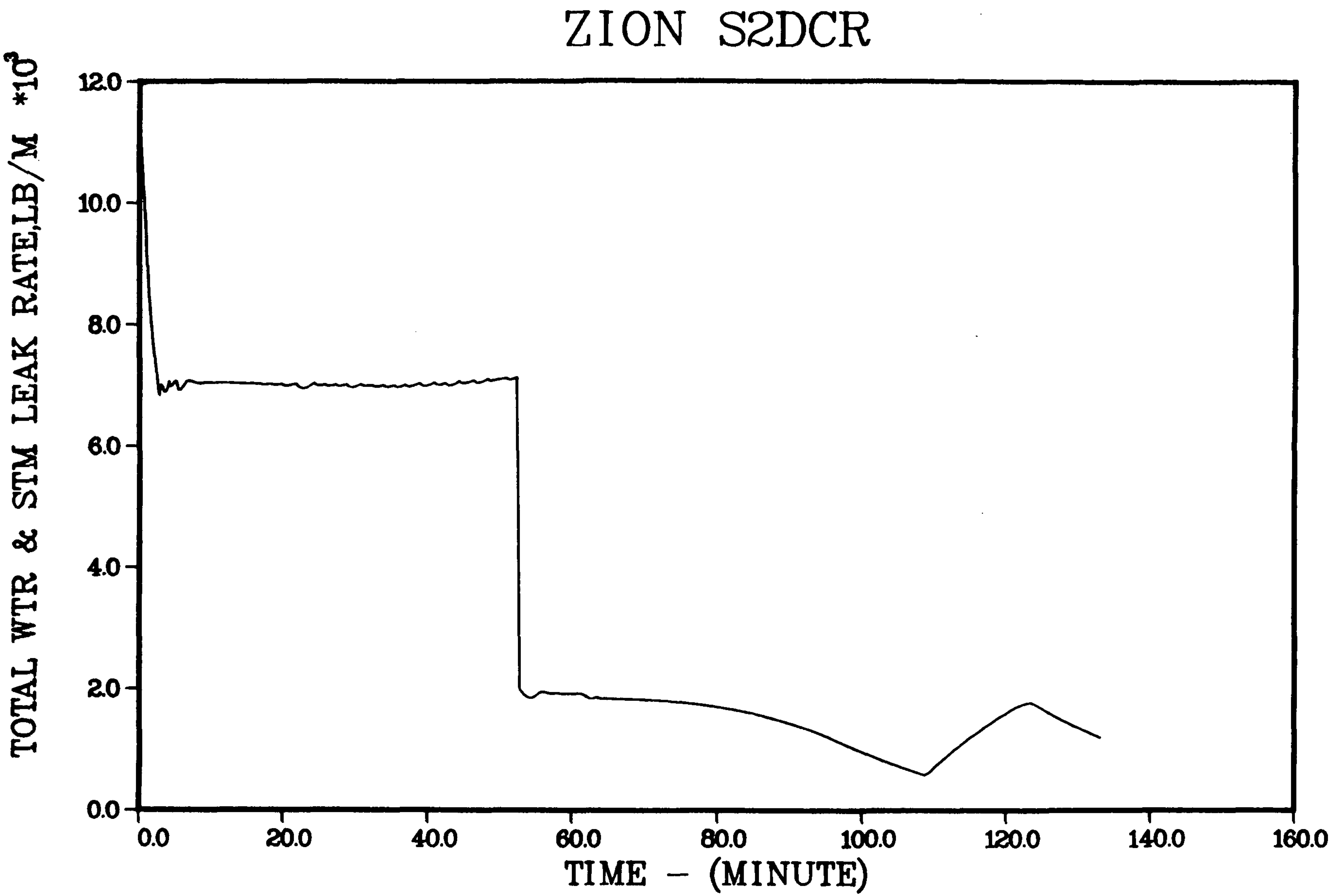

FIGURE 4.2. PRIMARY SYSTEM LEAK RATES FOR S_2DC_R SEQUENCE

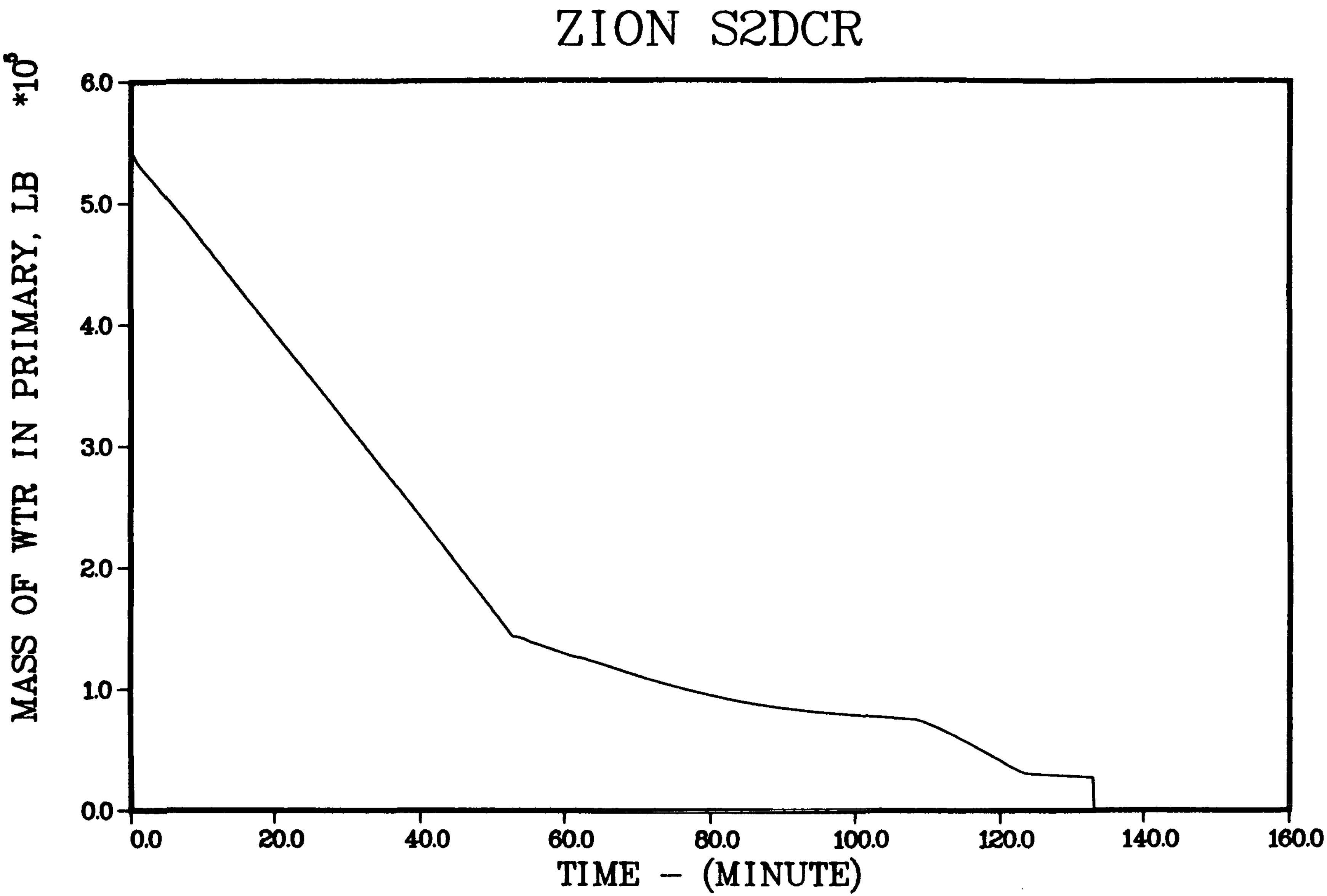

FIGURE 4.3. PRIMARY SYSTEM WATER INVENTORY FOR S_2DC_R SEQUENCE

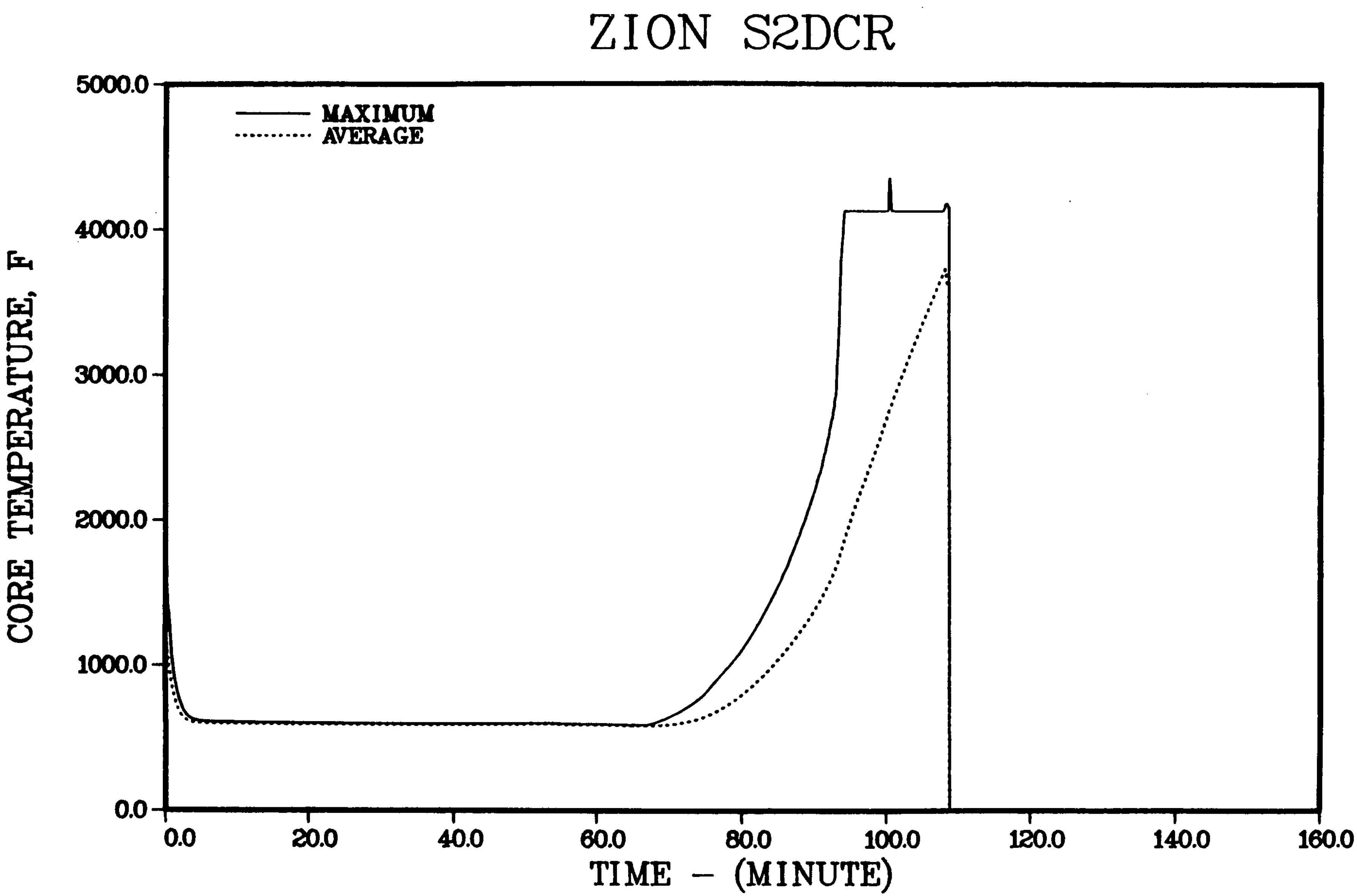

FIGURE 4.4. MAXIMUM AND AVERAGE CORE TEMPERATURES FOR S_2DC_R SEQUENCE

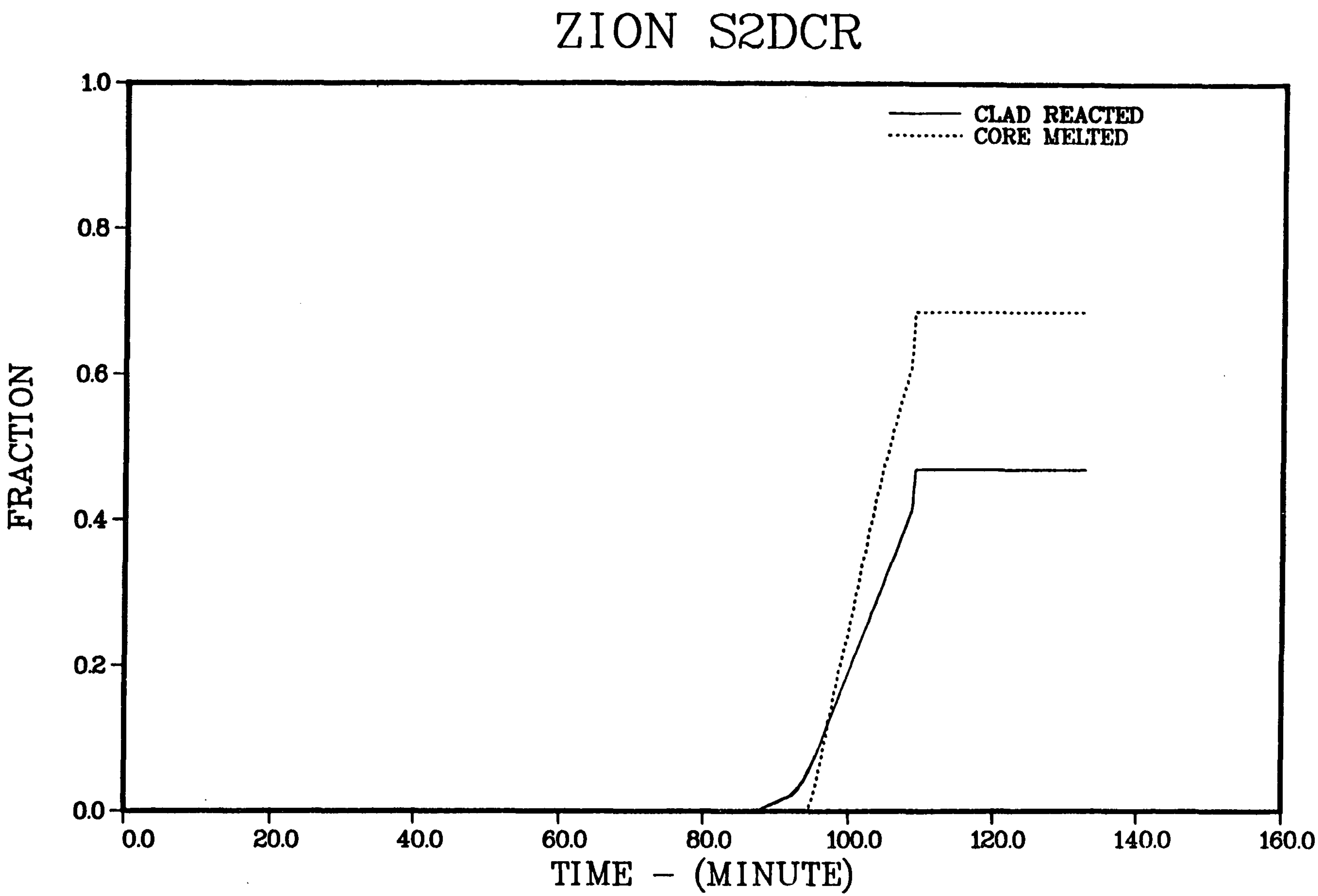

FIGURE 4.5. FRACTIONS OF CLADDING REACTED AND CORE MELTED FOR S_2DC_R SEQUENCE

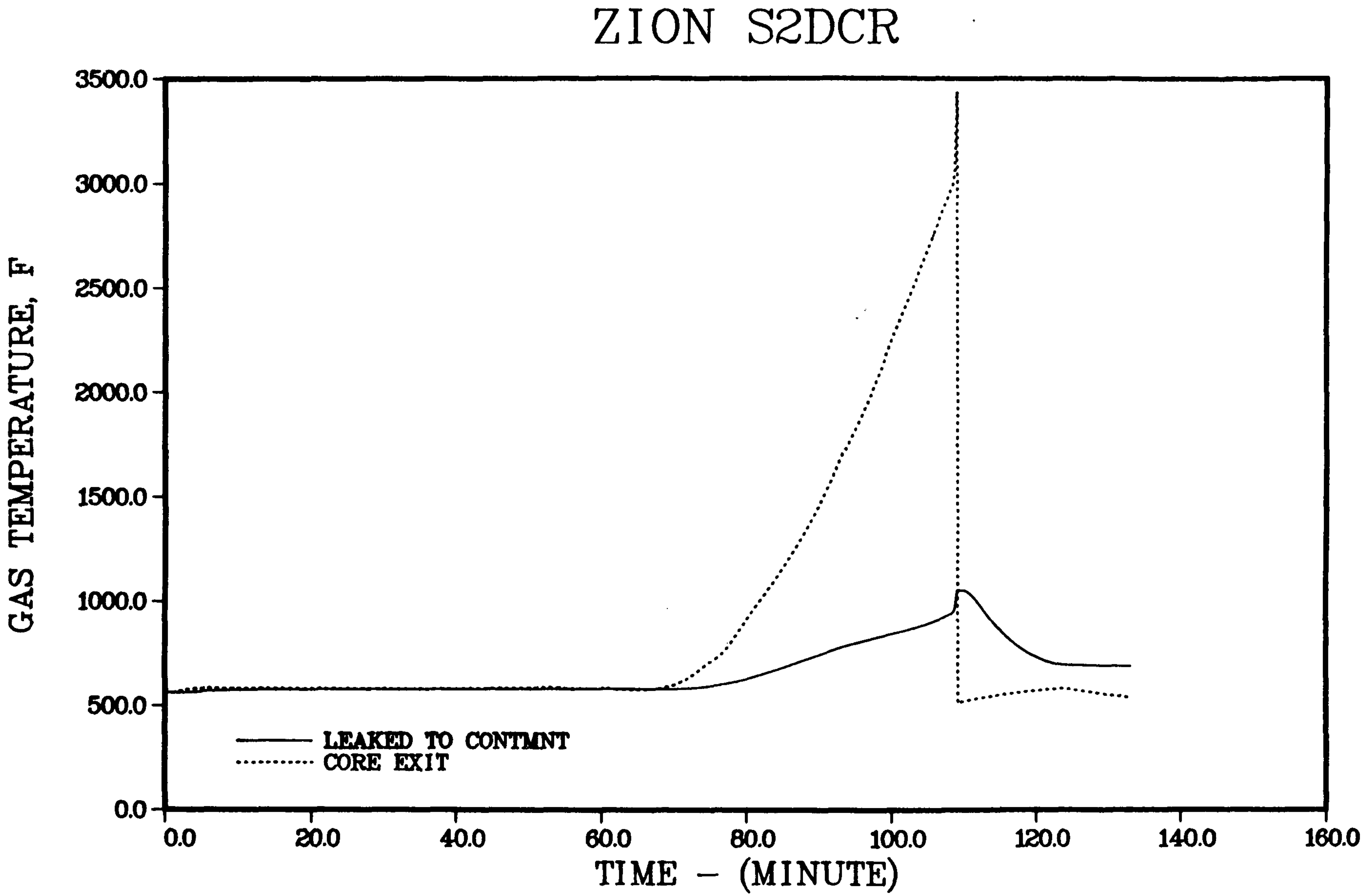

FIGURE 4.6. TEMPERATURES OF THE GASES LEAVING THE CORE AND LEAKING TO CONTAINMENT FOR S_2DC_R

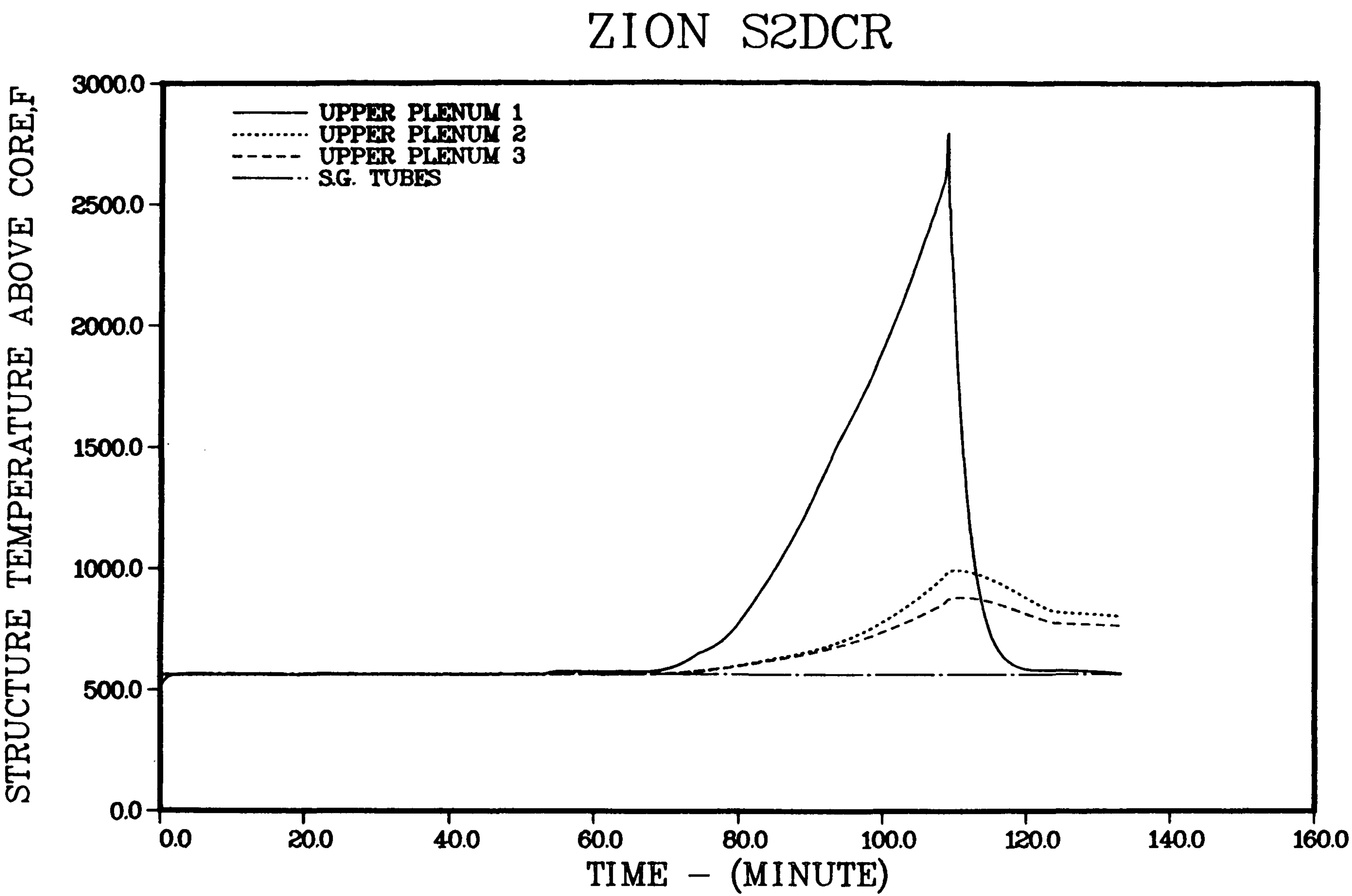

FIGURE 4.7 PRIMARY SYSTEM STRUCTURE TEMPERATURES FOR S_2DC_R

temperatures, with structures further downstream of the core experiencing only modest heating. The steam generator tubes in this sequence remain water filled and do not see any temperature increase. The MARCH 3 modeling of the primary system is based on once-through flow of gases and does not attempt to take into account possible recirculation of hot gases within the primary system. While such recirculation has been postulated to be important in certain transient events, it is doubtful that such recirculation flows could be established in this scenario with its continuing blowdown of the primary system inventory.

The containment pressure and temperature responses for this sequence are illustrated in Figures 4.8 and 4.9; the containment sump and reactor cavity water inventories and temperatures are given in Figures 4.10 and 4.11, respectively. The initial operation of the containment coolers in this sequence maintains the containment pressure below the assumed spray initiation setpoint of 25 psia until the time of vessel failure. Vessel failure is followed by the assumed failure of the building coolers and the initiation of the containment sprays. Thus only a small containment pressure rise is predicted immediately after vessel failure. A subsequent larger pressure excursion is predicted due to hydrogen combustion, but this pressure increase is quickly reduced by the containment sprays. The operation of the containment sprays is also reflected in the containment sump and reactor cavity water inventories illustrated in Figure 4.10.

At early times in the sequence the inventory of water in the sump originates from blowdown water from the primary system and condensate from the containment coolers. As the water on the containment floor builds up it begins to overflow into the reactor cavity, but up to the time of vessel failure the total quantity of water in the containment is limited. The actuation of the containment sprays following vessel failure together with the accumulator discharge result in the flooding of the reactor cavity and a rapid increase in the quantity of water on the containment floor. The sprays fail upon switchover to the recirculation mode. As the water in the reactor cavity is boiled off by the core debris, the reactor cavity is kept full by overflow from the containment sump; this is illustrated by the continuing decrease in the sump inventory following spray failure. As can be seen in Figure 4.11, the sump water remains relatively cold while that in the reactor cavity is

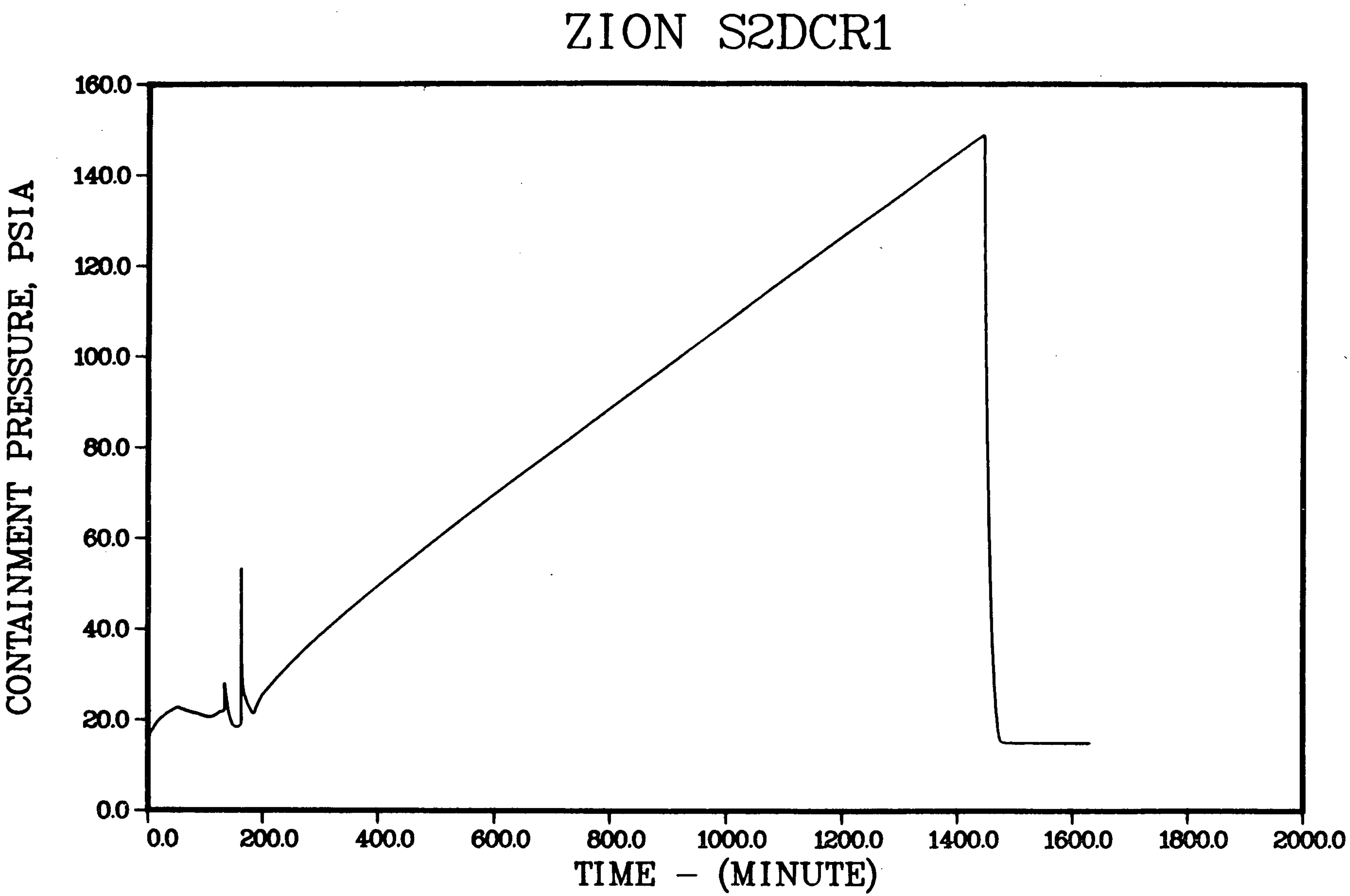

FIGURE 4.8. CONTAINMENT PRESSURE RESPONSE FOR S_2DC_R SEQUENCE

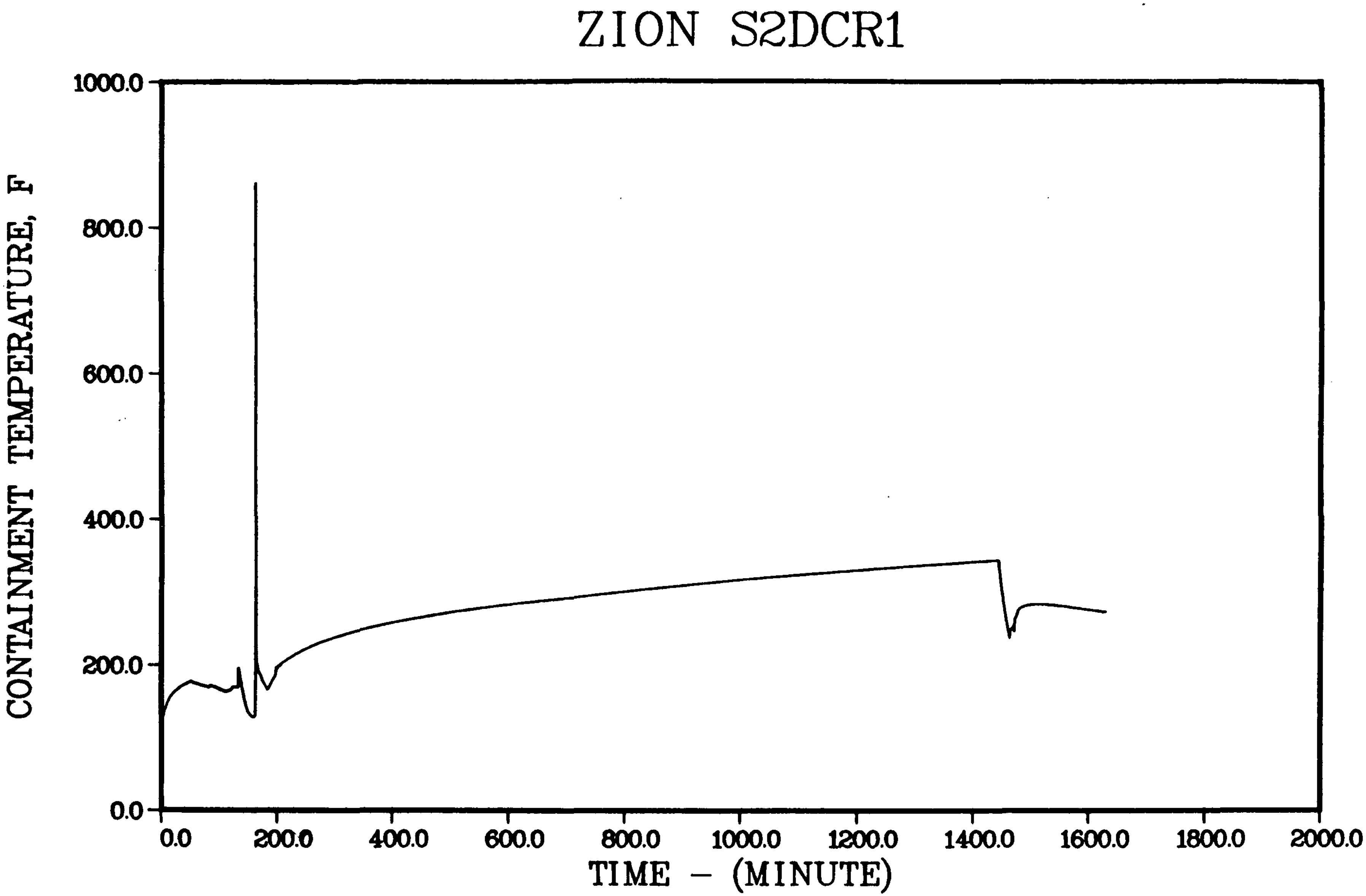

FIGURE 4.9. CONTAINMENT TEMPERATURE RESPONSE FOR S_2DC_R SEQUENCE

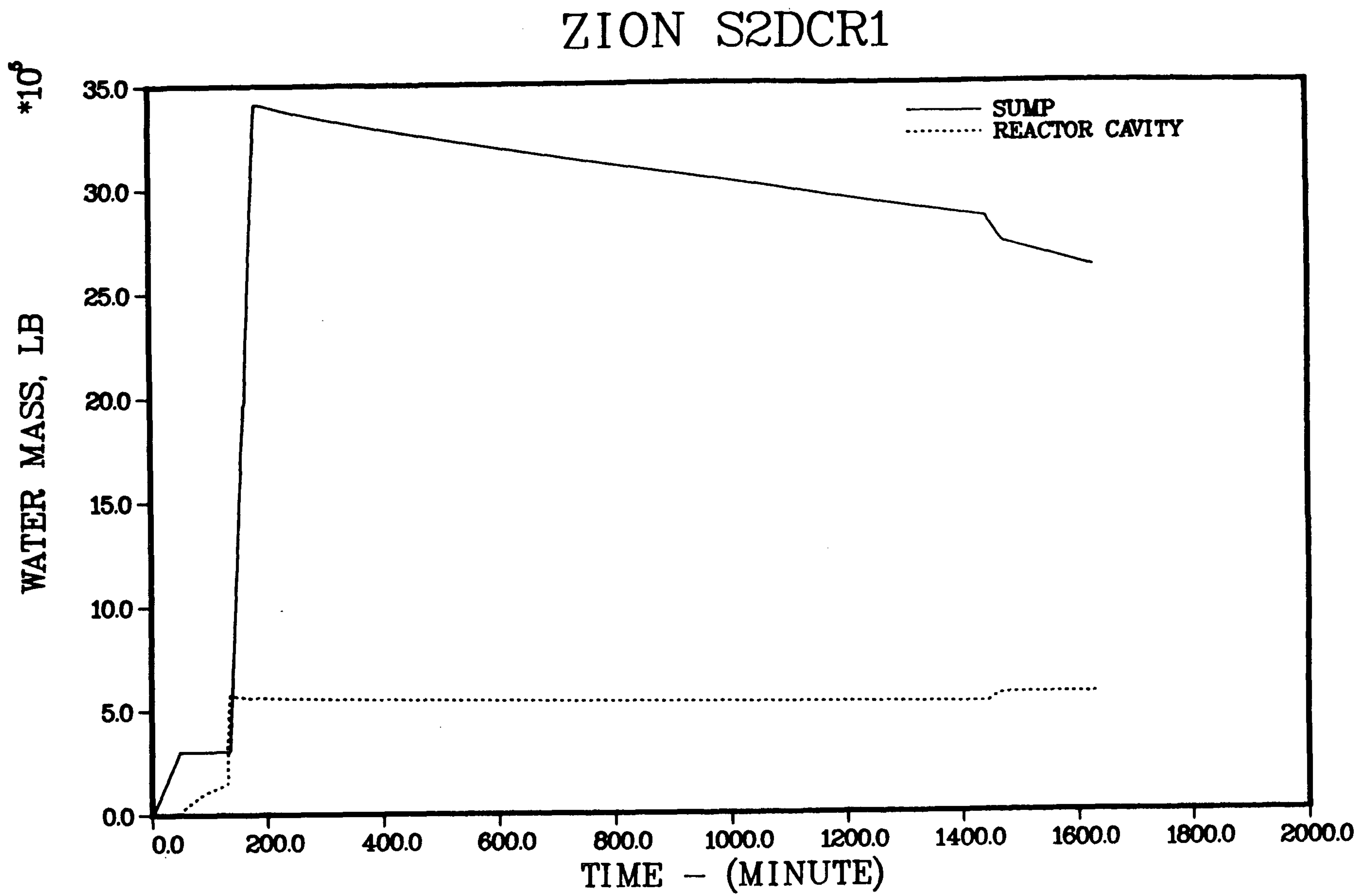

FIGURE 4.10. CONTAINMENT SUMP AND REACTOR CAVITY WATER INVENTORIES FOR S_2DC_R SEQUENCE

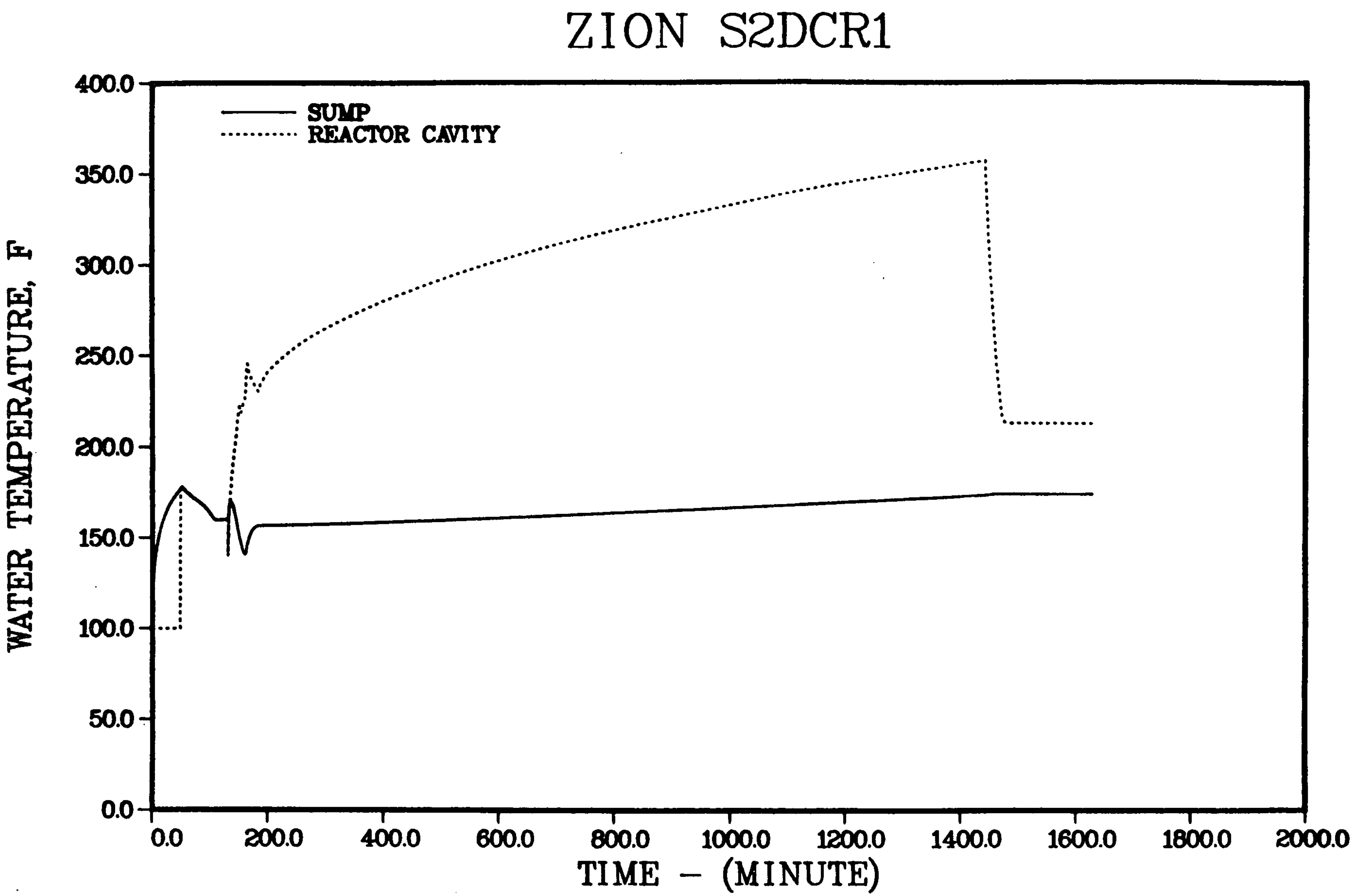

FIGURE 4.11. CONTAINMENT SUMP AND REACTOR CAVITY WATER TEMPERATURES FOR S_2DC_R SEQUENCE

heated to saturation. Following containment failure the cavity water temperature decreases due to flashing.

The predicted progression of concrete attack is illustrated in Figure 4.12. The total volume of gases leaked from the containment is illustrated in Figure 4.13. The time dependent containment leak rates used as input in the NAUA analyses of containment fission product transport are given in Table 4.4. The MARCH 3 calculated distribution of the noble gases during this sequence is illustrated in Figure 4.14.

4.2.2 $S_2DC_{ir}F_{ir}$ Sequence

The $S_2DC_{ir}F_{ir}$ sequence is initiated by the failure of the primary coolant pump seals and is accompanied by failures of emergency core cooling injection and both the containment sprays and coolers. The primary system behavior for this sequence is identical to that of the preceding S_2DC_r sequence and the discussion will not be repeated. Two containment failure modes have been examined for this sequence; these are described below.

The early containment failure considered for this sequence (designated by S_2DCF_1) is assumed to be the consequence of a combination of hydrogen combustion and direct heating of the containment atmosphere by the core debris. The accident event times for this scenario are summarized in Table 4.1. Core and primary system conditions at key times can be found in Table 4.2, and containment conditions are summarized in Table 4.3.

Since MARCH 3 does not have explicit modeling of the direct interaction of the core debris with the containment atmosphere, the conditions arising from such interactions were approximated by use of existing debris-water interaction and hydrogen combustion models, notably by inputs to these models designed to enhance containment pressure generation. Specifically, a very small debris particle size was used for the debris-water interaction in the reactor cavity, and the steam inerting criterion for hydrogen-oxygen recombination in the containment atmosphere was removed. The results of these input choices are conceptually consistent with those expected from the dispersal of a large fraction of the core into the containment atmosphere. While attack of the concrete has been assumed in these analyses, it is also

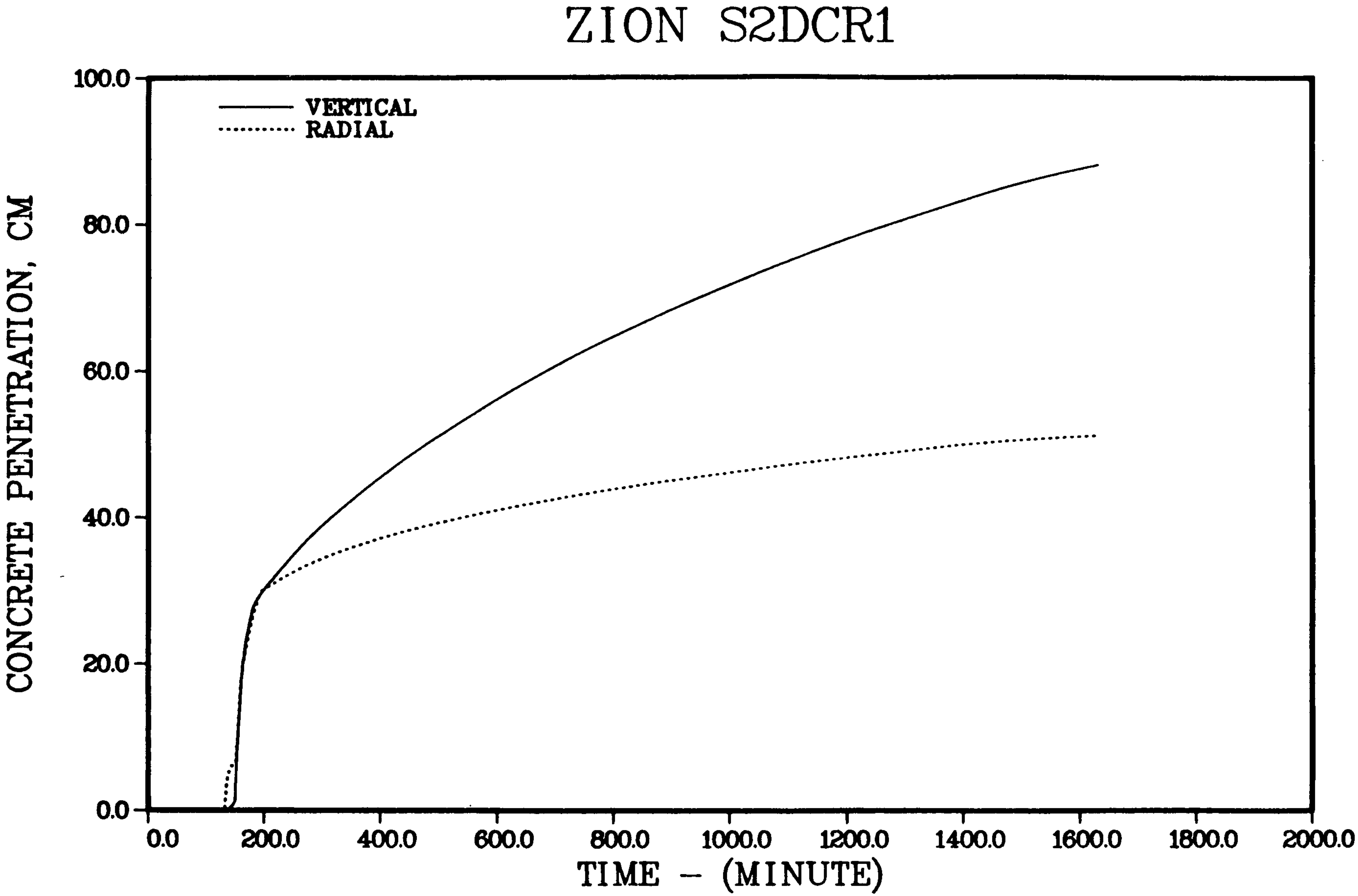

FIGURE 4.12. PROGRESSION OF CONCRETE ATTACK FOR S_2DC_R SEQUENCE

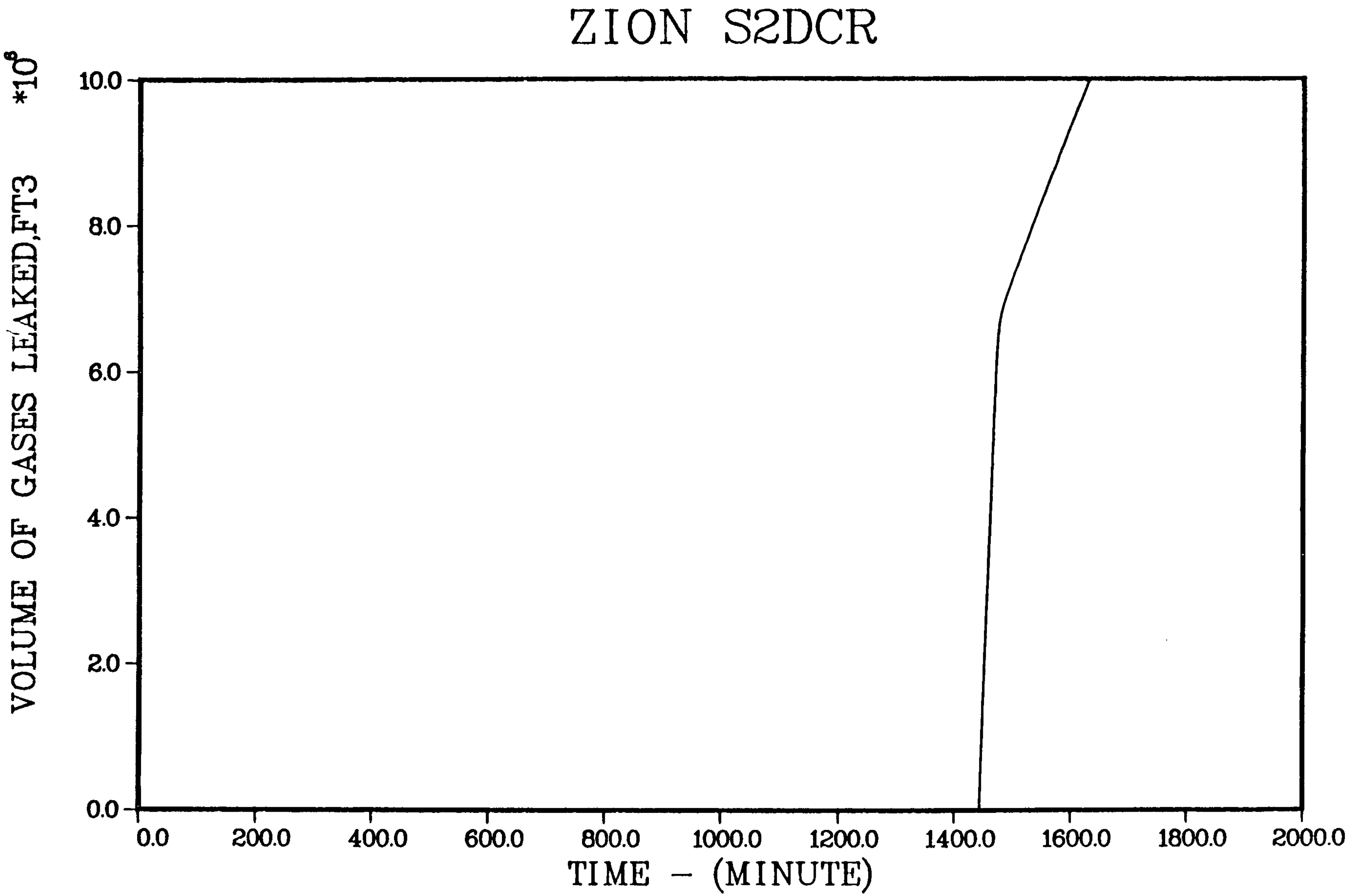

FIGURE 4.13. TOTAL VOLUME OF GASES LEAKED FOR S_2DC_R SEQUENCE

TABLE 4.4. CONTAINMENT LEAK RATES

Subsequence	CSIS Start, min.	CSIS End, min.	CSRS Start, min.	CSRS End, min.	Leakage Time Interval, min.	Leak Rate,[a] v/hr	Pressure MPa	Pressure psia	Temp. F	Temp. C	Remarks
S_2DCR	133.4	184.1	--	--	0.0 - 64.9	4×10^{-5}	0.14	21	162	72	Initial Heatup
					64.9 - 94.2	4×10^{-5}	0.15	22	171	77	Core Uncovers
					94.2 - 108.4	4×10^{-5}	0.14	21	167	75	Core Melts
					108.4 - 108.9	4×10^{-5}	0.14	21	164	73	Core Slumps and Collapses
					108.9 - 125.3	4×10^{-5}	0.14	21	165	74	Dryout of Vessel Head
					125.3 - 133.0	4×10^{-5}	0.15	22	170	77	Vessel Head Heats
					133.0	4×10^{-5}	0.19	27	192	89	Vessel Head Fails
					133.0 - 133.4	4×10^{-5}	0.19	28	195	90	Concrete Decomposition
					133.4 - 162.1	4×10^{-5}	0.14	20	147	64	Concrete Decomposition
					162.1 - 162.2	4×10^{-5}	0.22	32	356	180	Hydrogen Burns
					162.2 - 184.1	4×10^{-5}	0.17	24	186	85	Concrete Decomposition
					184.1 - 253.1	4×10^{-5}	0.19	28	204	96	Concrete Decomposition
					253.1 - 373.1	4×10^{-5}	0.28	40	240	116	Concrete Decomposition
					373.1 - 493.1	4×10^{-5}	0.37	53	263	128	Concrete Decomposition
					493.1 - 613.1	4×10^{-5}	0.45	65	278	137	Concrete Decomposition
					613.1 - 853.1	6×10^{-5}	0.57	82	295	146	Concrete Decomposition
					853.1 - 1273.1	8×10^{-5}	0.79	114	321	160	Concrete Decomposition
					1273.1 - 1444.0	9×10^{-5}	0.97	141	339	171	Concrete Decomposition
					1444.0	1×10^{-4}	1.03	149	344	173	Containment Fails
					1444.0 - 1453.1	5.1	0.68	98	312	156	Concrete Decomposition
					1453.1 - 1573.1	1.2	0.12	18	277	136	Concrete Decomposition
					1573.1 - 1633.1	0.4	0.10	15	275	135	Concrete Decomposition

(a) Normalized to a containment-free volume of 2.715×10^6 ft^3. Units are volume fractions per hour. Leakage is to the environment.

TABLE 4.4. CONTAINMENT LEAK RATES (Continued)

Subsequence	CSIS		CSRS		Leakage						Remarks
	Start, min.	End, min.	Start, min.	End, min.	Time Interval, min.	Leak Rate,[a] v/hr	Pressure MPa	Pressure psia	Temp. F	Temp. C	
S_2DCF1	--	--	--	--	0.0 - 64.9	4×10^{-5}	0.17	25	184	84	Initial Heatup
					64.9 - 94.2	4×10^{-5}	0.23	34	225	108	Core Uncovers
					94.2 - 108.4	4×10^{-5}	0.26	37	232	111	Core Melts
					108.4 - 108.9	4×10^{-5}	0.26	37	233	112	Core Slumps and Collapses
					108.9 - 125.4	4×10^{-5}	0.27	39	236	113	Dryout of Vessel Head
					125.4 - 132.8	4×10^{-5}	0.29	42	242	116	Vessel Head Heats
					132.8	4×10^{-5}	0.33	48	249	121	Vessel Head Fails
					132.8 - 133.0	8×10^{-5}	0.85	123	862	461	Hydrogen Burns
					133.0	1×10^{-4}	1.03	149	1210	654	Containment Fails
					133.0 - 134.4	6.3	0.73	106	776	414	Reactor Cavity Debris-Water Interacts
					134.4 - 160.1	3.6	0.20	29	347	175	Reactor Cavity Debris-Water Interacts
					160.1 - 190.1	4×10^{-5}	0.10	15	274	134	Reactor Cavity Debris-Water Interacts
					190.1 - 237.1	0.6	0.10	15	241	116	Concrete Decomposition
					237.1 - 370.1	0.4	0.10	15	226	108	Concrete Decomposition
					370.1 - 550.1	0.1	0.10	15	220	105	Concrete Decomposition
					550.1 - 730.1	0.1	0.10	15	217	103	Concrete Decomposition
					730.1 - 798.1	0.1	0.10	15	216	102	Concrete Decomposition

(a) Normalized to a containment-free volume of 2.715×10^6 ft^3. Units are volume fractions per hour. Leakage is to the environment.

TABLE 4.4. CONTAINMENT LEAK RATES (Continued)

Subsequence	CSIS		CSRS		Leakage						Remarks
	Start, min.	End, min.	Start, min.	End, min.	Time Interval, min.	Leak Rate,[a] v/hr	Pressure MPa	Pressure psia	Temp. F	Temp. C	
S_2DCF2	--	--	--	--	0.0 - 64.9	4×10^{-5}	0.17	25	184	85	Initial Heatup
					64.9 - 94.2	4×10^{-5}	0.23	34	225	108	Core Uncovers
					94.2 - 108.4	4×10^{-5}	0.26	37	232	111	Core Melts
					108.4 - 108.9	4×10^{-5}	0.26	37	233	112	Core Slumps and Collapses
					108.9 - 125.4	4×10^{-5}	0.27	39	236	113	Vessel Head Dryout
					125.4 - 132.8	4×10^{-5}	0.29	42	242	116	Vessel Head Heats
					132.8	4×10^{-5}	0.33	48	249	121	Vessel Head Fails
					132.8 - 161.9	4×10^{-5}	0.34	49	254	123	Concrete Decomposition
					161.9 - 192.9	4×10^{-5}	0.37	54	263	128	Concrete Decomposition
					192.9 - 312.9	4×10^{-5}	0.46	67	279	137	Concrete Decomposition
					312.9 - 492.9	6×10^{-5}	0.60	87	297	147	Concrete Decomposition
					492.9 - 672.9	7×10^{-5}	0.76	110	316	158	Concrete Decomposition
					672.9 - 895.9	9×10^{-5}	0.93	135	334	168	Concrete Decomposition
					895.9	1×10^{-4}	1.03	149	342	172	Containment Fails
					895.9 - 912.9	5.1	0.50	73	286	142	Concrete Decomposition
					912.9 - 1032.9	0.8	0.11	16	273	134	Concrete Decomposition
					1032.9 - 1357.9	0.1	0.10	15	275	135	Concrete Decomposition

(a) Normalized to a containment-free volume of 2.715×10^6 ft^3. Units are volume fractions per hour. Leakage is to the environment.

TABLE 4.4. CONTAINMENT LEAK RATES (Continued)

Subsequence	CSIS		CSRS		Leakage						Remarks
	Start, min.	End, min.	Start, min.	End, min.	Time Interval, min.	Leak Rate,[a] v/hr	Pressure MPa	Pressure psia	Temp. F	Temp. C	
TMLU	101.8	151.6	151.6	190.1	0.0 - 93.0	$4x10^{-5}$	0.10	15	103	40	Initial Heatup/Coolers On
					93.0 - 101.8	$4x10^{-5}$	0.14	21	162	72	S.G. Dry/Core Heats
					101.8 - 124.6	$4x10^{-5}$	0.15	22	168	76	Containment Spray Operable
					124.6 - 184.4	$4x10^{-5}$	0.12	17	134	57	Core Uncovers
					148.4 - 178.2	$4x10^{-5}$	0.12	18	134	57	Core Melts
					178.2 - 179.4	$4x10^{-5}$	0.13	19	145	63	Core Slumps and Collapses
					179.4 - 189.6	$4x10^{-5}$	0.14	21	156	69	Vessel Head Heats
					189.6	$4x10^{-5}$	0.23	33	213	101	Vessel Head Fails
					189.6 - 189.7	$7x10^{-5}$	0.77	111	799	426	Hydrogen Burns
					189.7	$1x10^{-4}$	1.03	149	1264	684	Containment Fails
					189.7 - 190.7	6.1	0.68	99	673	356	Concrete Decomposition
					190.7 - 200.2	5.0	0.32	46	307	153	Concrete Decomposition
					200.2 - 253.0	0.6	0.10	15	208	98	Concrete Decomposition
					253.0 - 313.0	$1x10^{-2}$	0.10	15	197	92	Concrete Decomposition
					313.0 - 433.0	0.5	0.10	15	203	95	Concrete Decomposition
					433.0 - 861.0	0.4	0.10	15	211	100	Concrete Decomposition

(a) Normalized to a containment-free volume of 2.715×10^6 ft^3. Units are volume fractions per hour. Leakage is to the environment.

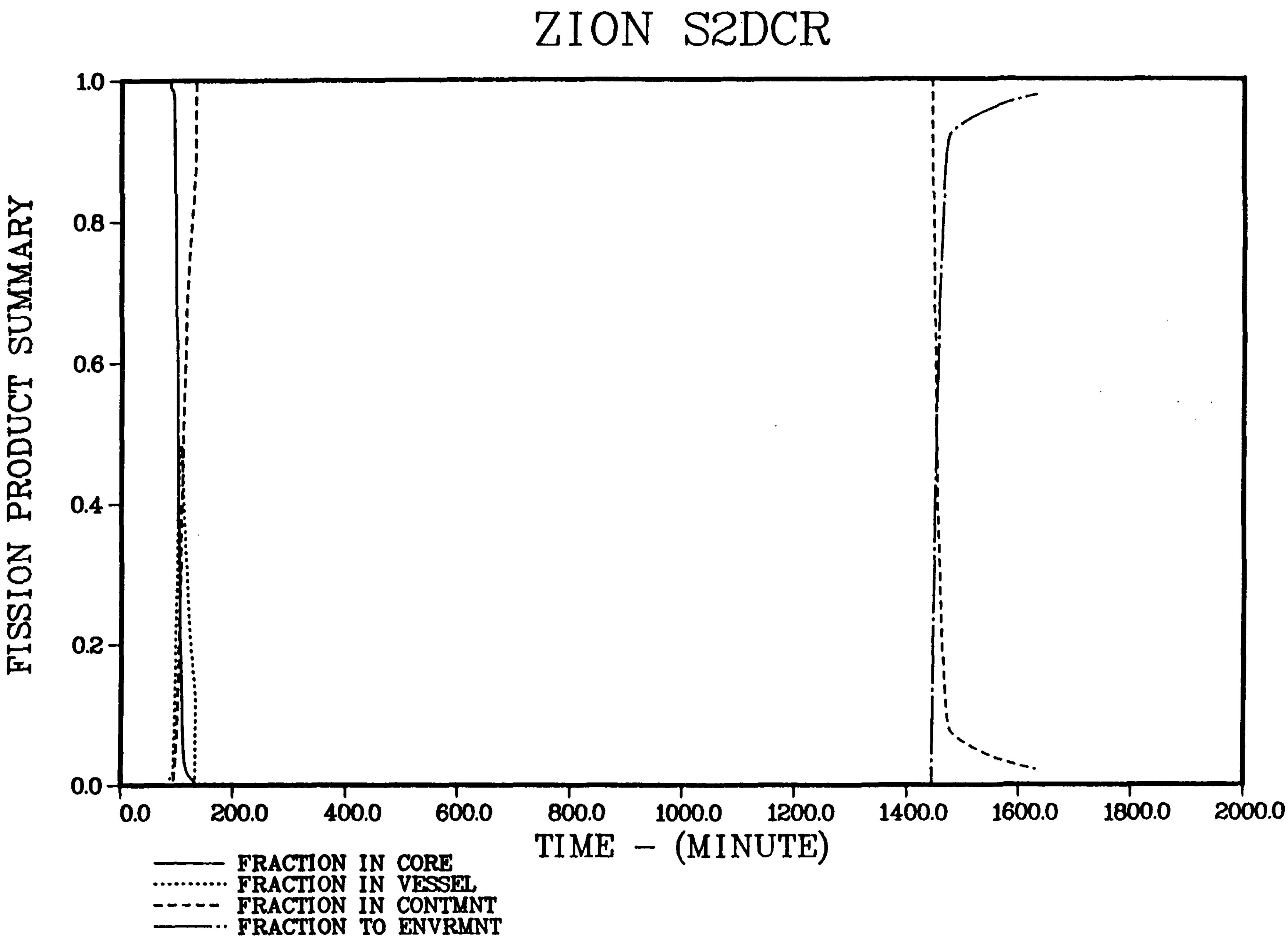

FIGURE 4.14. NOBLE GAS DISTRIBUTIONS FOR S_2DC_R SEQUENCE

possible that the widespread dispersal of the core debris throughout the containment implied for this scenario would preclude significant corium-concrete interactions.

The calculated containment pressure and temperature responses associated with early containment failure for this sequence are illustrated in Figures 4.15 and 4.16. The combination of a large steam spike together with hydrogen-oxygen recombination raises the containment pressure beyond the nominal failure level.

The containment sump and reactor cavity water inventories and temperatures are illustrated in Figures 4.17 and 4.18. Because of the inoperability of both the emergency core cooling as well as spray injection systems in this scenario the total quantity of water in the containment is limited to that initially in the primary system and the accumulators. Up to the time of reactor vessel failure the amount of water in the reactor cavity is quite limited. Accumulator discharge following head failure leads to a rapid increase in reactor cavity water, but most of this water is evaporated in the ensuing interaction with the core debris. The quantity of water evaporated rapidly is limited by the stored energy in the core debris, and complete boiloff of cavity water is delayed until the debris reheat. Similarly, the attack of the concrete is delayed until the debris reheat, as is illustrated in Figure 4.19.

The total volume of gases leaked from the containment for this scenario is illustrated in Figure 4.20. The time dependent leak rates used as input to the containment fission product transport analyses are given in Table 4.4. The MARCH 3 calculated noble gas distributions are illustrated in Figure 4.21.

The late containment failure mode initially selected for analysis for the $S_2DC_{ir}F_{ir}$ sequence (designated as S_2DCF_l) was based on the assumption of a late hydrogen burn. The latter presupposed buildup of a high concentration of hydrogen and the condensation of sufficient steam to permit combustion late in the accident sequence. Initial MARCH 3 analyses of such a scenario did not support the hypothesis of a large delayed hydrogen burn, indicating that combustion would be precluded by continuing high partial pressures of steam. As the steam in the containment atmosphere condensed on containment structures it would run down to the containment sump. Since the

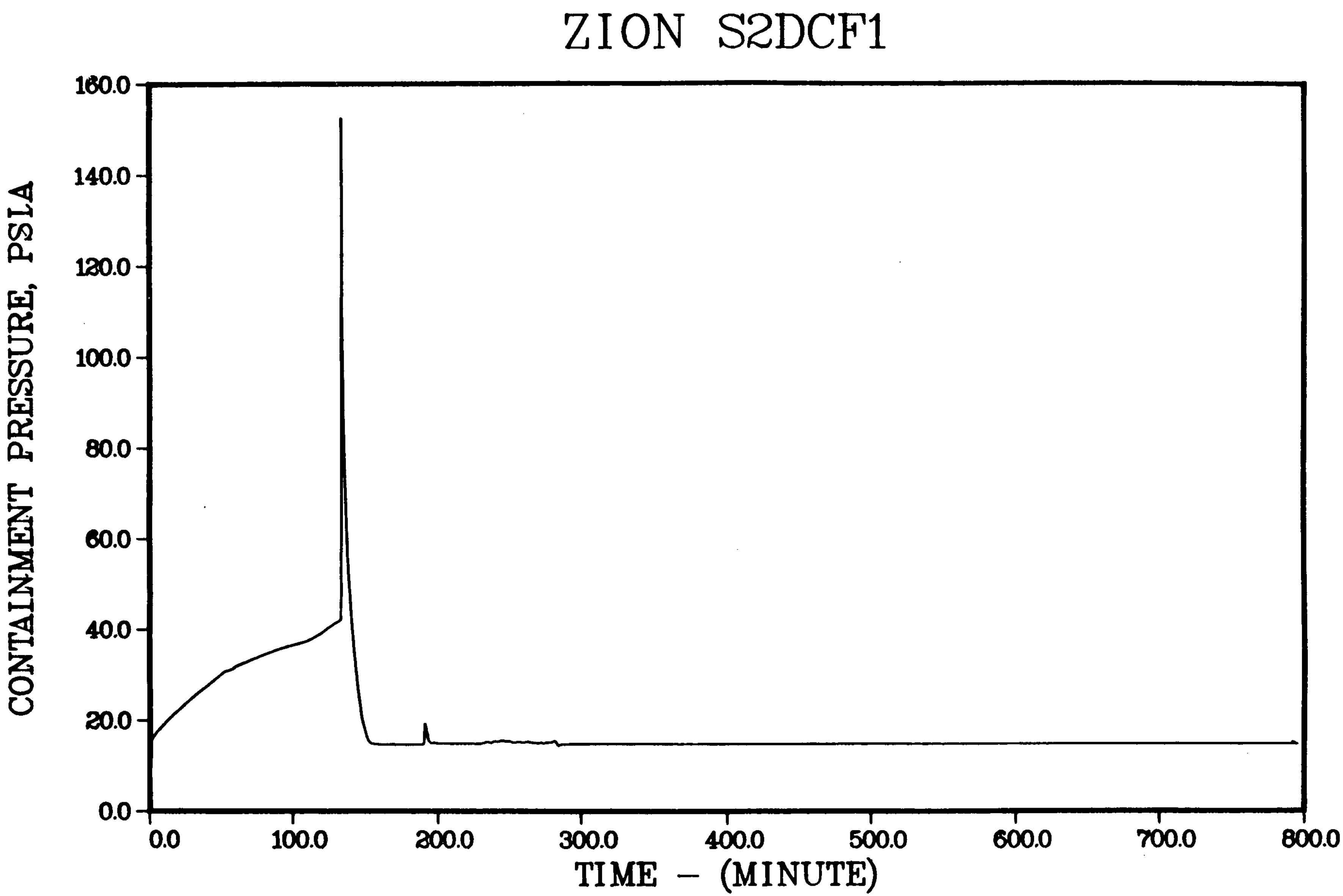

FIGURE 4.15. CONTAINMENT PRESSURE RESPONSE FOR S_2DCF SEQUENCE WITH EARLY CONTAINMENT FAILURE

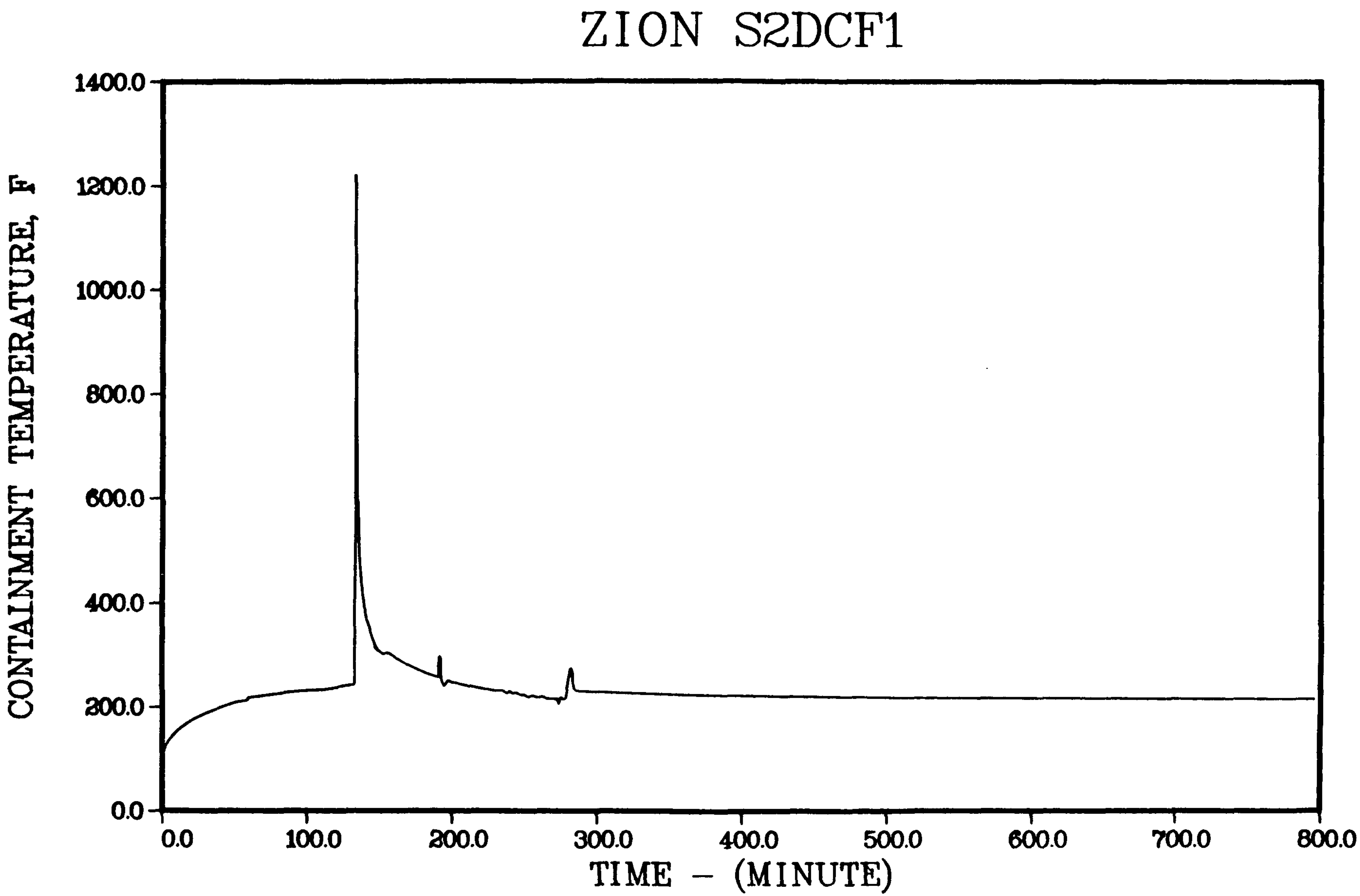

FIGURE 4.16. CONTAINMENT TEMPERATURE RESPONSE FOR S_2DCF SEQUENCE WITH EARLY CONTAINMENT FAILURE

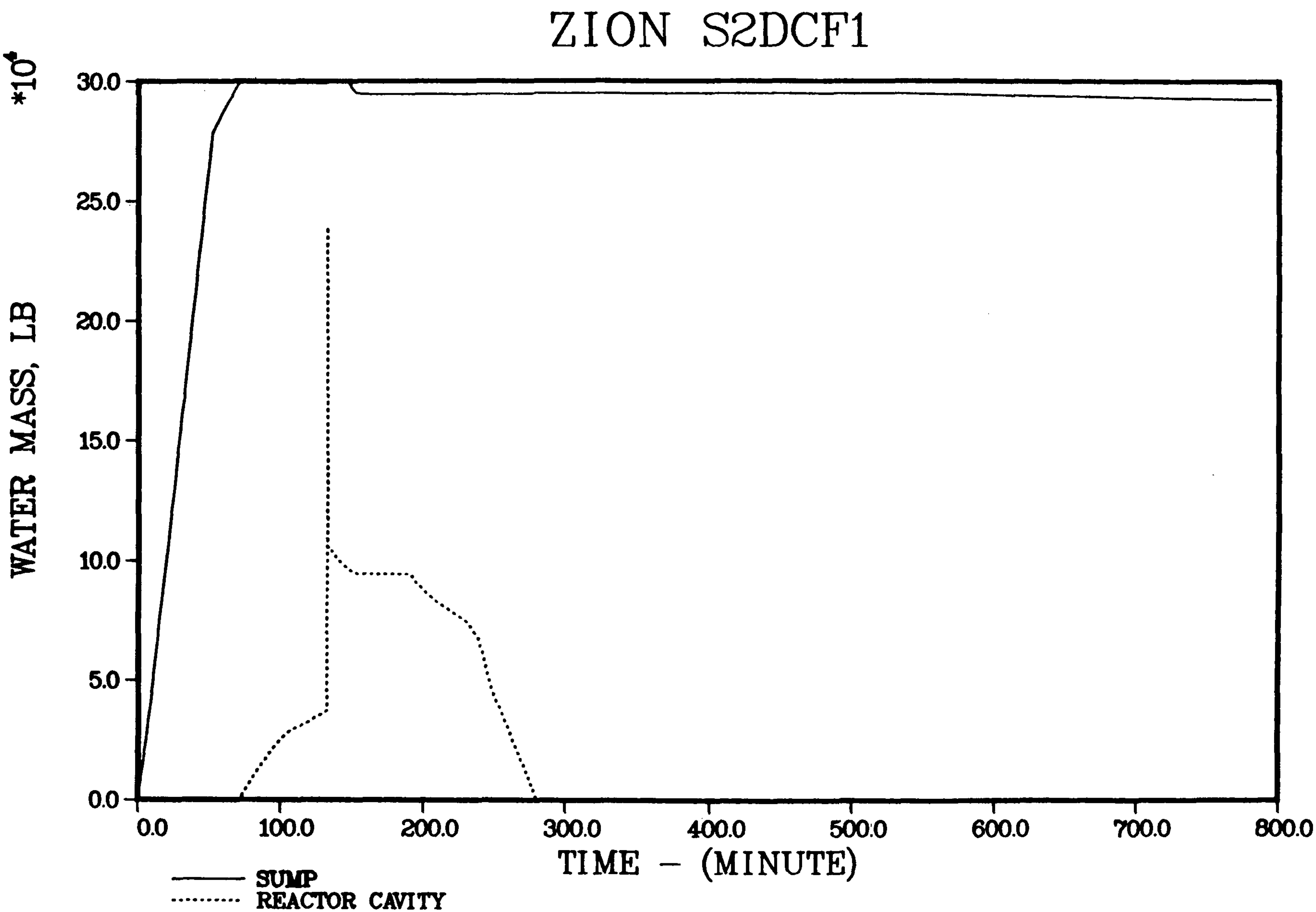

FIGURE 4.17. CONTAINMENT SUMP AND REACTOR CAVITY WATER INVENTORIES FOR S_2DCF SEQUENCE WITH EARLY CONTAINMENT FAILURE

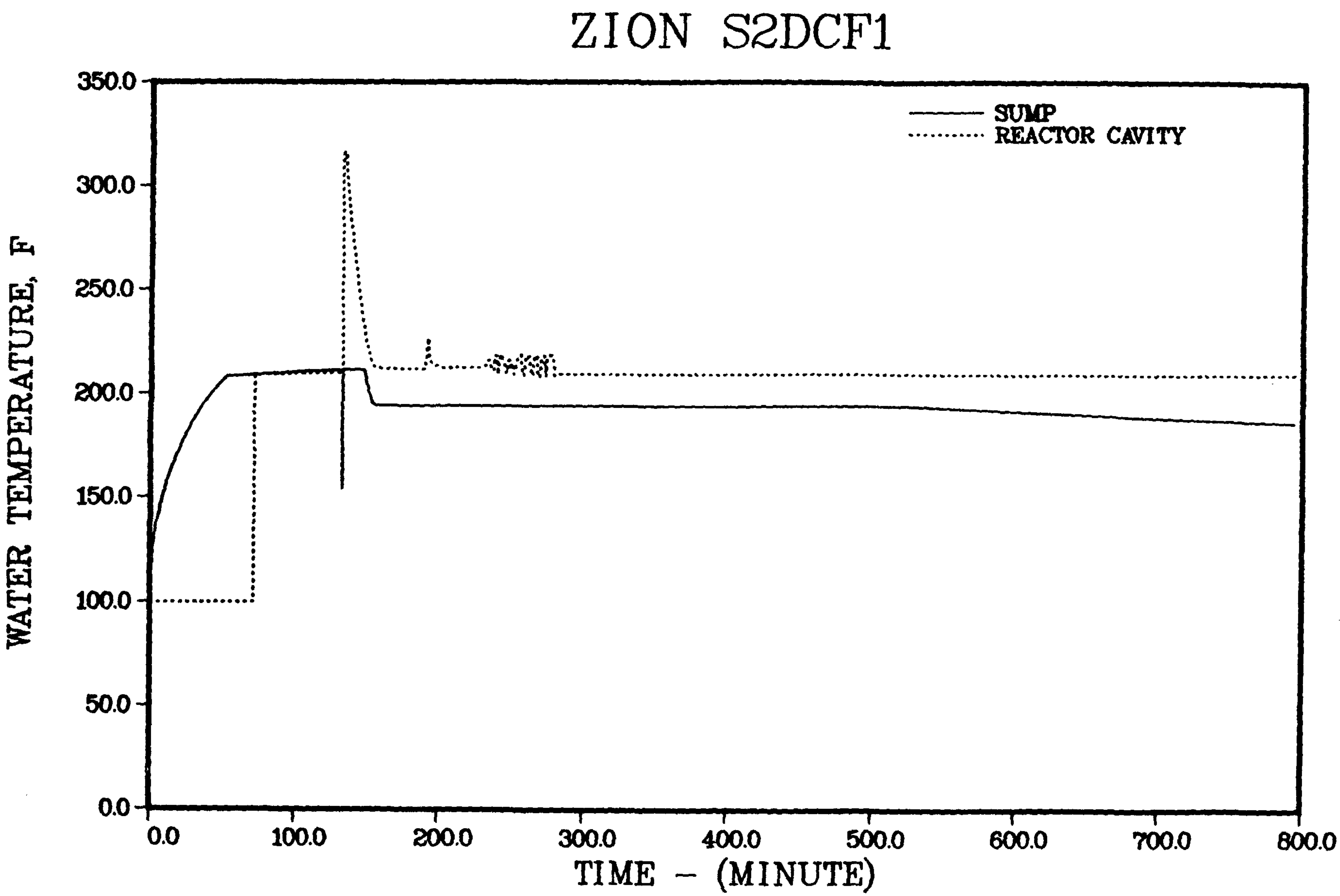

FIGURE 4.18. CONTAINMENT SUMP AND REACTOR CAVITY WATER TEMPERATURES FOR S_2DCF SEQUENCE WITH EARLY CONTAINMENT FAILURE

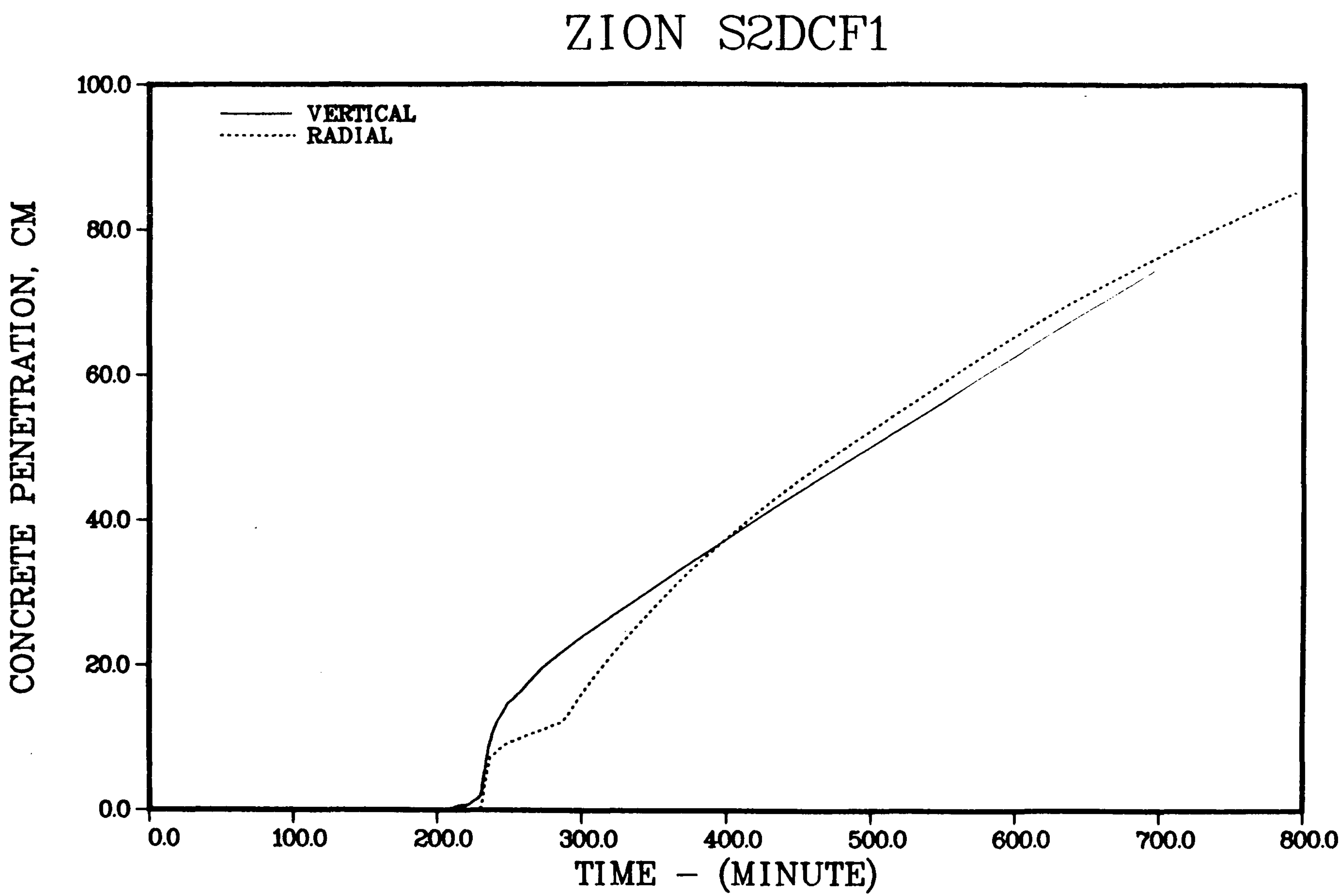

FIGURE 4.19. PROGRESSION OF CONCRETE ATTACK FOR S_2DCF SEQUENCE WITH EARLY CONTAINMENT FAILURE

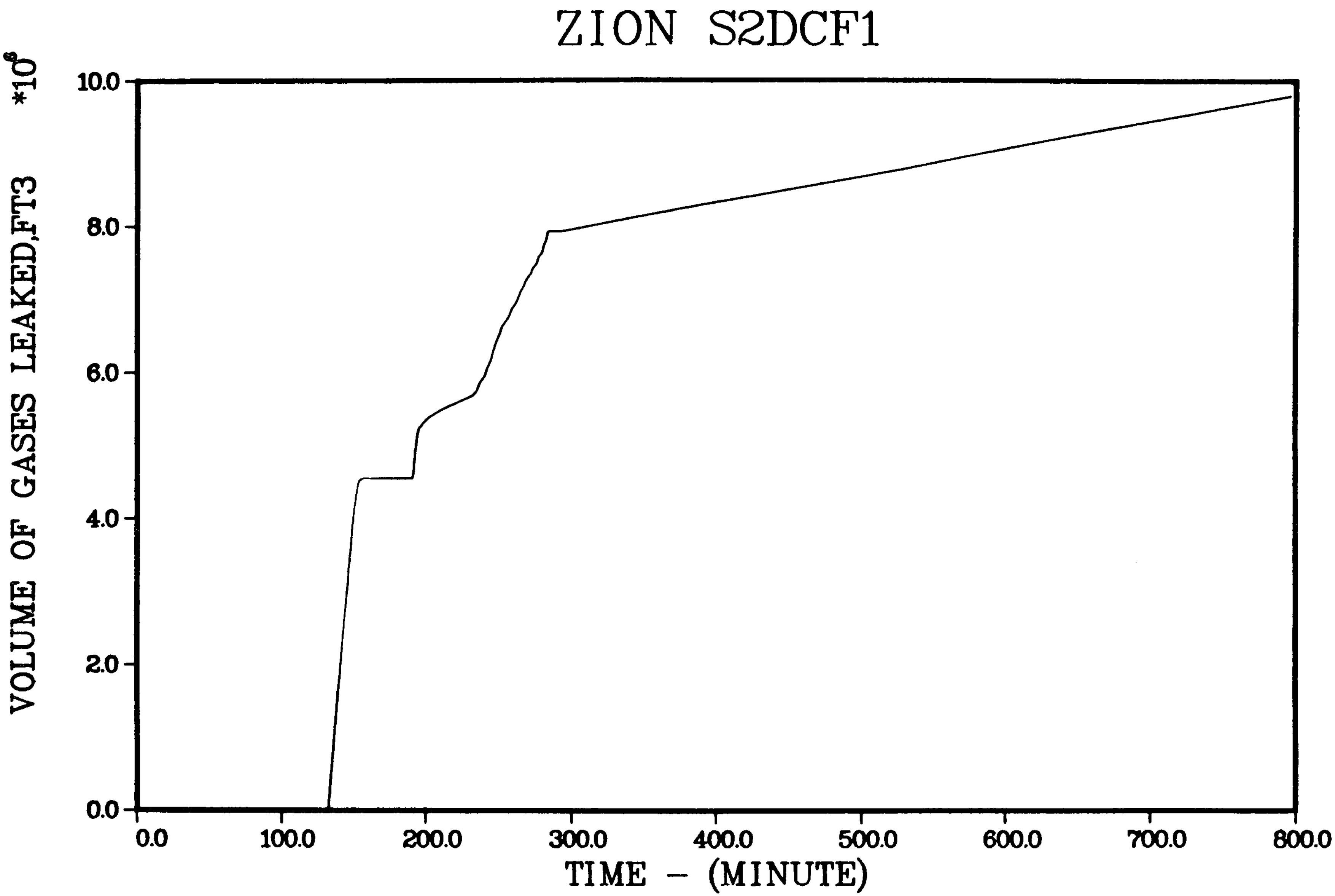

FIGURE 4.20. TOTAL VOLUME OF GASES LEAKED FOR S_2DCF SEQUENCE WITH EARLY CONTAINMENT FAILURE

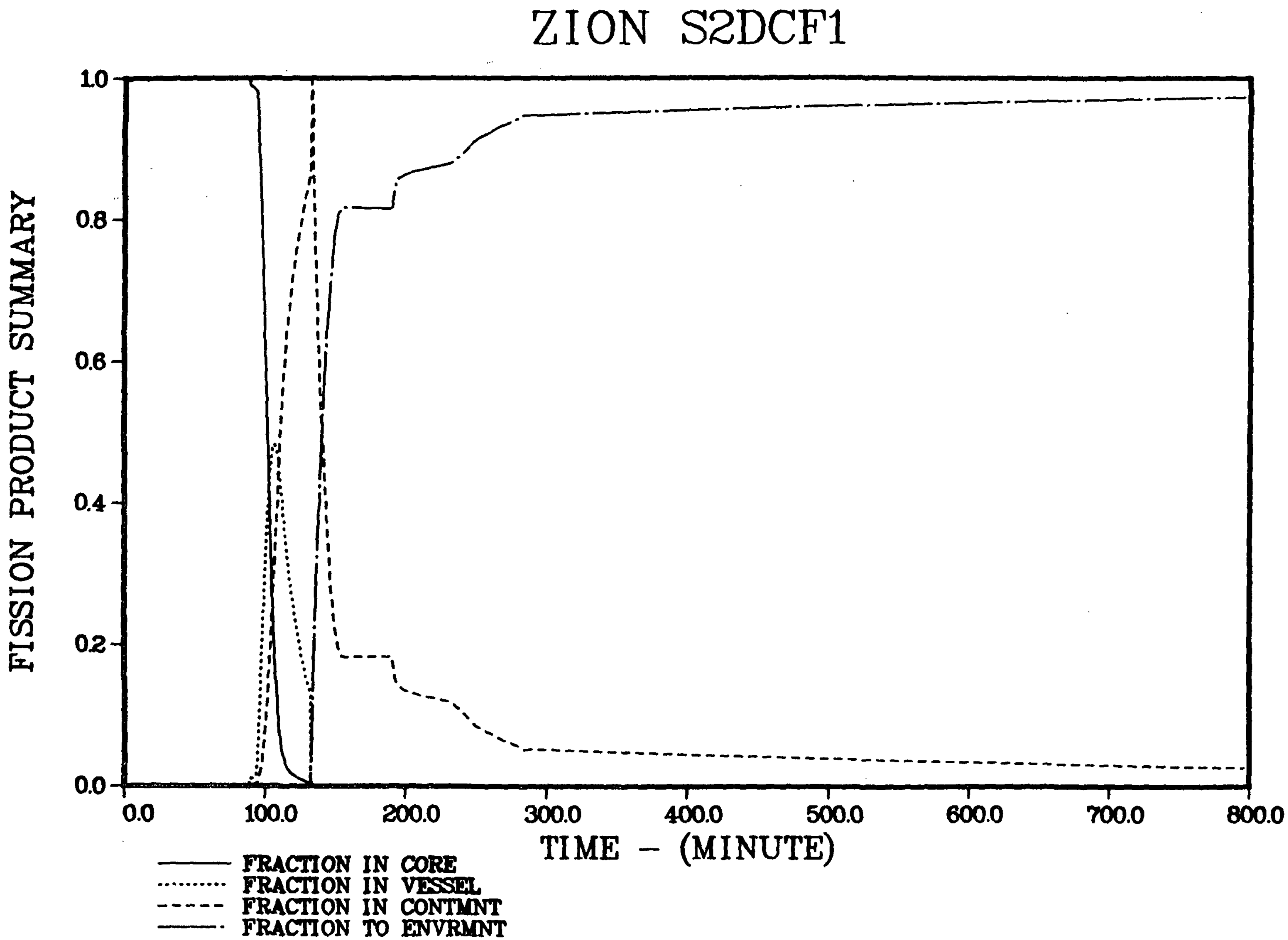

FIGURE 4.21. NOBLE GAS DISTRIBUTIONS FOR S_2DCF SEQUENCE WITH EARLY CONTAINMENT FAILURE

containment floor, including the sump, can only hold a limited quantity of water without overflow into the reactor cavity, some of the condensed water would return to the cavity to be reevaporated. Thus a high partial pressure of steam in the containment atmosphere was indicated for prolonged periods of time. Also, since all the water in the containment did not come into contact with the core debris in the reactor cavity, not all of it could be evaporated. Thus the predicted pressure rise in the containment was limited to well below the nominal failure level for this containment for an extended period of accident time. This conclusion is quite consistent with the results for the TMLB scenario in BMI-2104.

To satisfy the identified need for a late containment failure for this sequence the MARCH 3 calculation was set up assuming that all the water on the containment floor could enter the reactor cavity. This may be regarded as an approximation of the situation in which a significant fraction of the core debris is expelled from the reactor cavity and can thus boil the water on the containment floor. It will be recalled that MARCH does not provide a capability for explicitly distributing the core debris to various parts of the containment. Another way of achieving the desired late containment failure would have been to assume that the containment sprays or coolers were recovered at some time late in the accident; the condensation of steam by sprays or coolers would have brought the containment atmosphere into the flammable range.

The accident event times for the late containment failure scenario as described above are given in Table 4.1. Core and primary system conditions are again the same as for S_2DC_r and are given in Table 4.2. The containment conditions at key times during the accident sequence are summarized in Table 4.3.

The predicted containment pressure and temperature responses for the $S_2DC_{ir}F_{ir}$ sequence with late containment failure are illustrated in Figures 4.22 and 4.23. The containment sump and reactor cavity water inventories and water temperatures are given in Figures 4.24 and 4.25, respectively. As noted above, for the time period after reactor vessel failure it was assumed that the core debris would come into contact with all the water on the containment floor; this is reflected in Figure 4.24 as the sump water flowing into the reactor cavity. The essentially constant decrease in the containment water

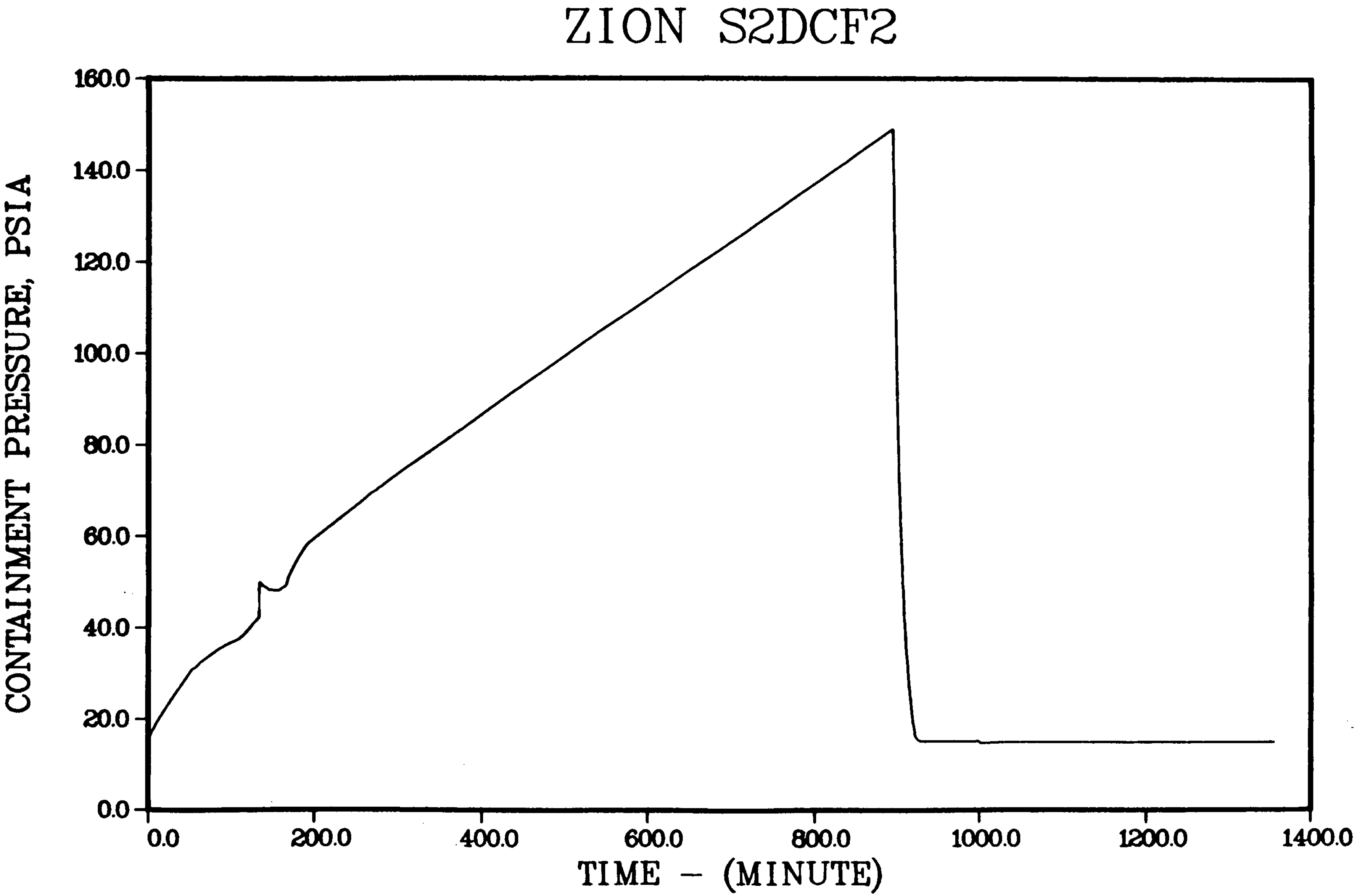

FIGURE 4.22. CONTAINMENT PRESSURE RESPONSE FOR S_2DCF SEQUENCE WITH LATE CONTAINMENT FAILURE

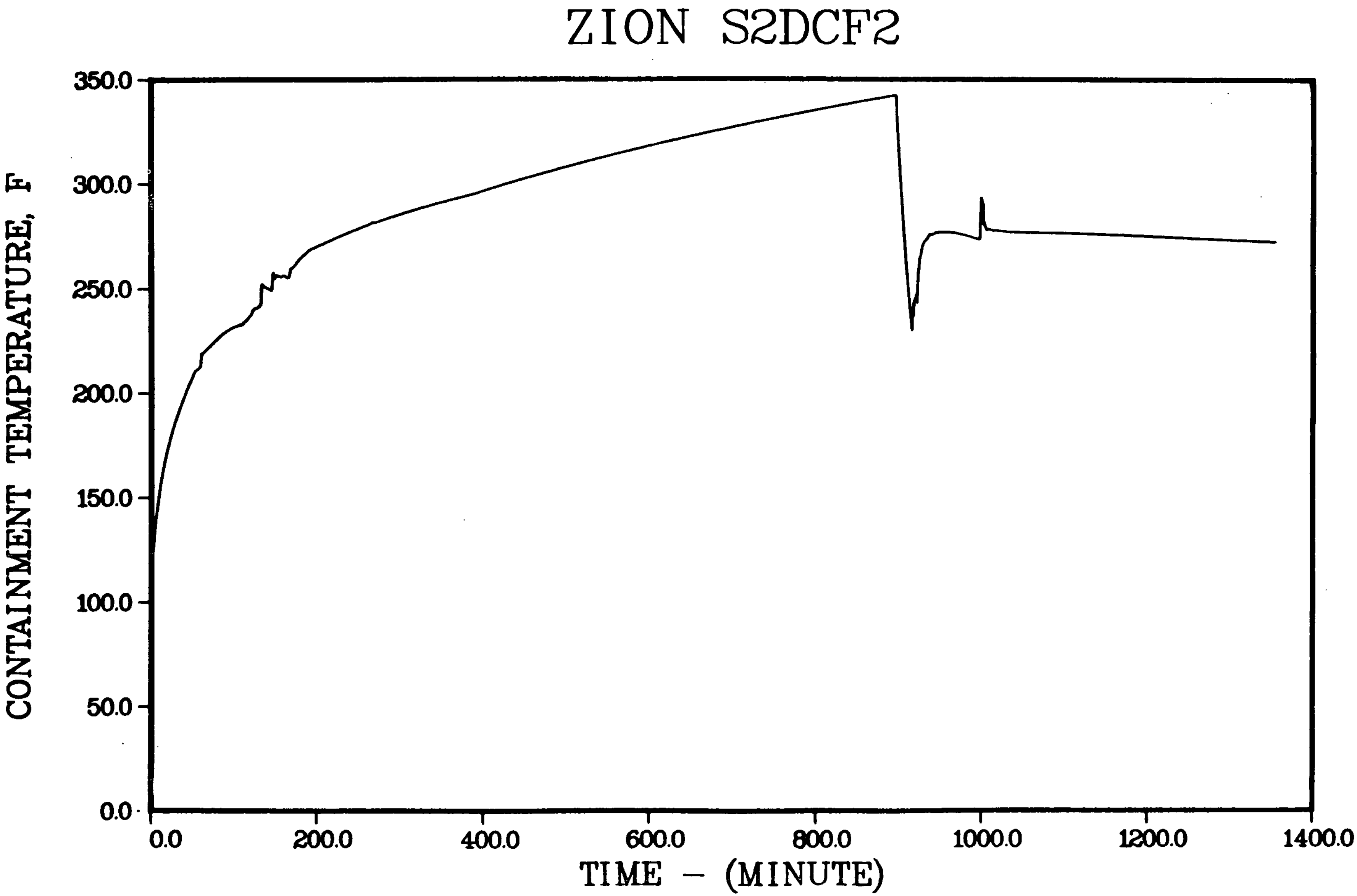

FIGURE 4.23. CONTAINMENT TEMPERATURE RESPONSE FOR S_2DCF SEQUENCE WITH LATE CONTAINMENT FAILURE

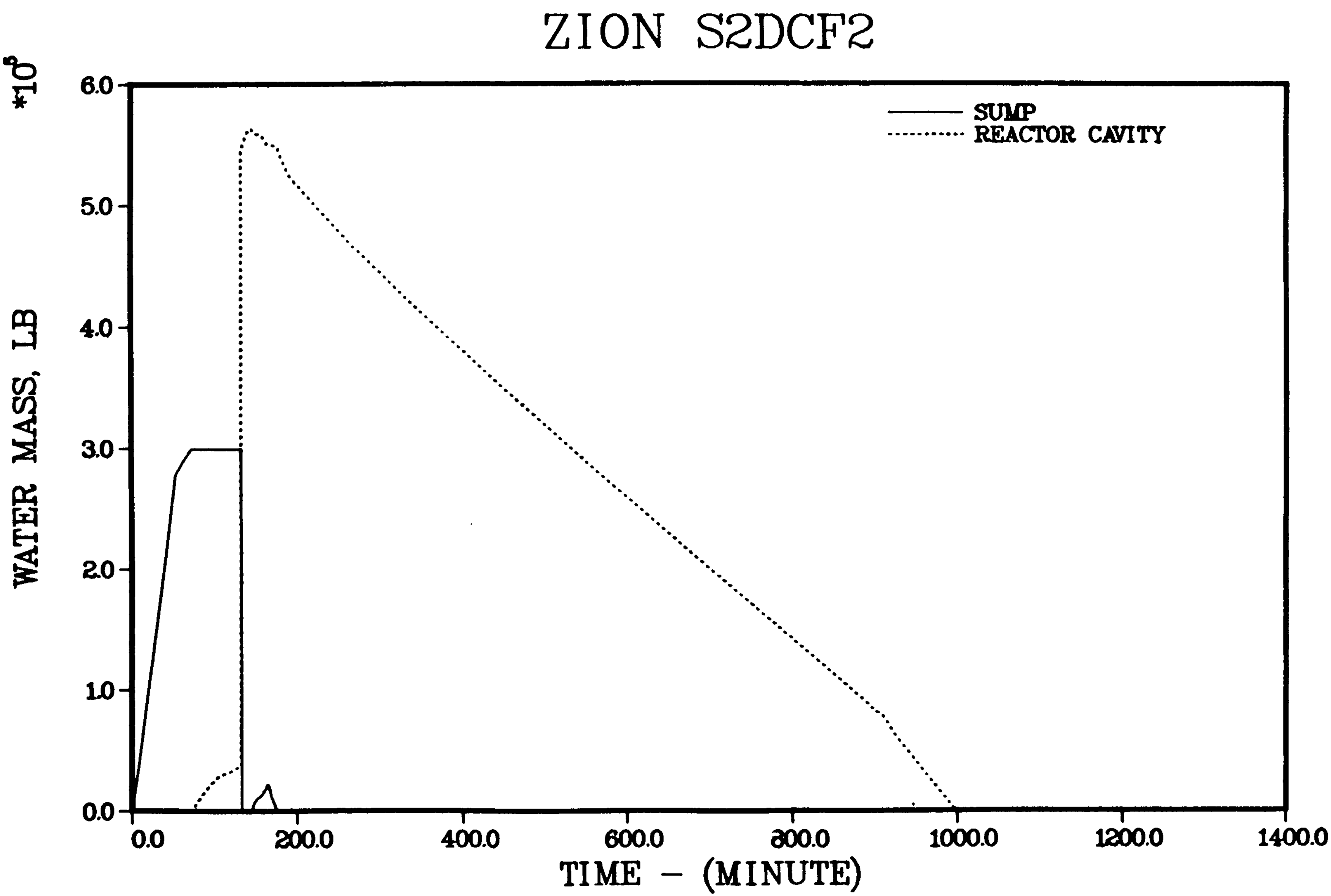

FIGURE 4.24. CONTAINMENT SUMP AND REACTOR CAVITY WATER INVENTORIES FOR S_2DCF SEQUENCE WITH LATE CONTAINMENT FAILURE

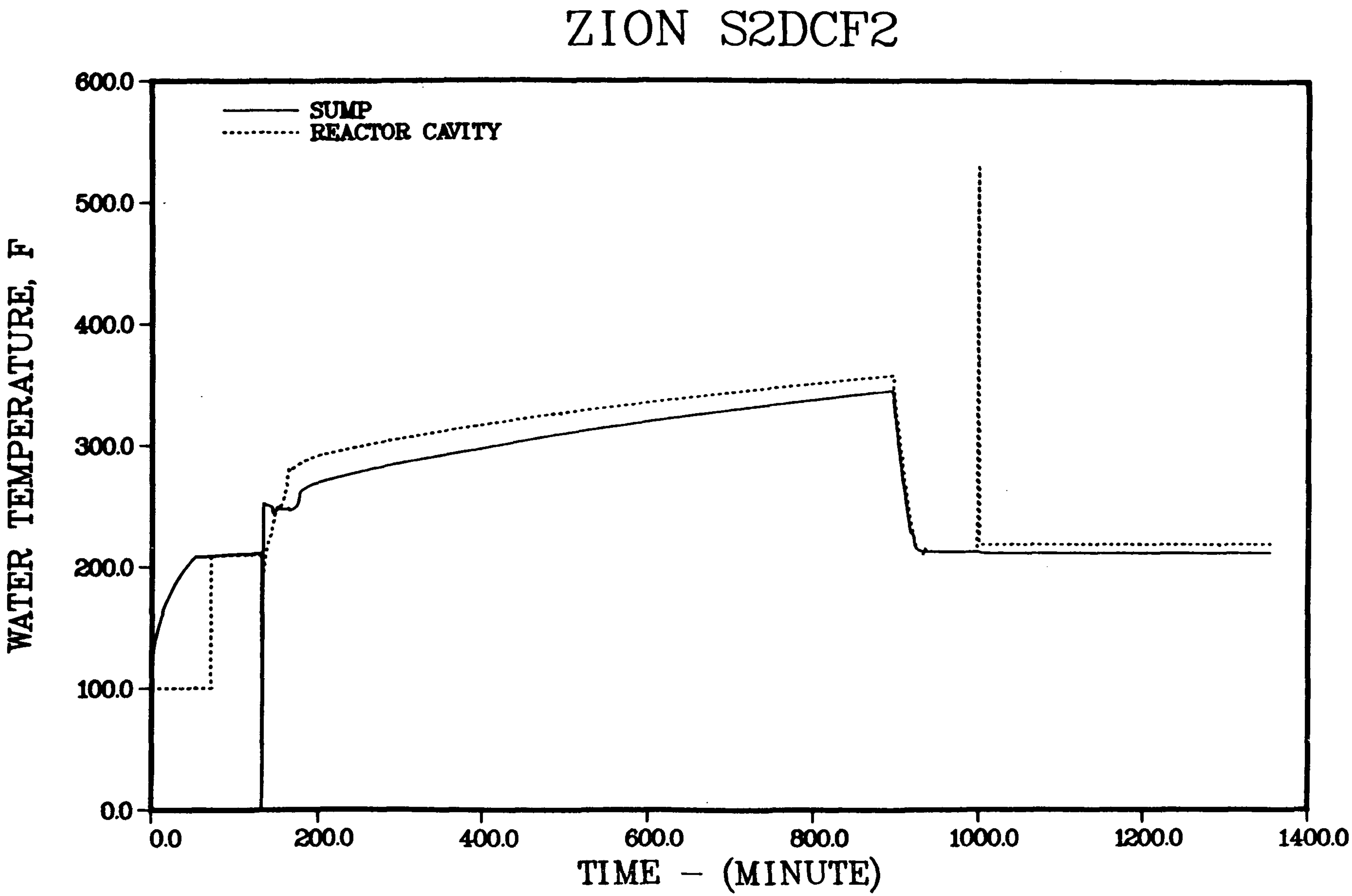

FIGURE 4.25. CONTAINMENT SUMP AND REACTOR CAVITY WATER TEMPERATURES FOR S_2DCF SEQUENCE WITH LATE CONTAINMENT FAILURE

inventory is manifested as essentially a constant rate of containment pressure increase up to the assumed failure level. All the water on the containment floor is predicted to be boiled off about an hour after containment failure. The time required to boil off all this water can be quite variable and would depend, among other factors, on the fraction of the core which comes into contact with the water. In the present analyses the entire core was assumed to simultaneously attack the concrete basemat as well as boiling water at the top surface. The rate of heat loss to the water was limited by film boiling and radiation from a flat surface. If less than the entire core comes into contact with the water in the containment, (is expelled from the cavity) the rate of boiloff could be slower. On the other hand, fragmentation of the core debris upon contact with water could result in more rapid boiloff. If the core debris should form a coolable bed on the containment floor the attack of the concrete could be delayed until after the time that all the water is boiled off.

The predicted progression of concrete attack is illustrated in Figure 4.26. It should again be recognized that these results are based on the simultaneous attack of the concrete and boiloff of water by the entire mass of the core debris, with no substantial initial quenching of the debris by the water in the cavity.

The total volume of gases leaked from the containment for this scenario is illustrated in Figure 4.27. The time dependent leak rates used as input to the containment fission product transport analyses are given in Table 4.4. The MARCH 3 calculated distributions of the noble gases are illustrated in Figure 4.28.

4.2.3 TMLU Sequence

The TMLU sequence is initiated by a transient and is accompanied by the failures of the power conversion, auxiliary feedwater, and emergency core cooling systems. Both the containment coolers and sprays are available during this sequence.

The early containment failure mode selected for analyses for this sequence is a very low probability outcome and is based on the assumption of the direct interaction between the core debris and the containment atmosphere. As noted previously, MARCH does not have explicit models for treating direct

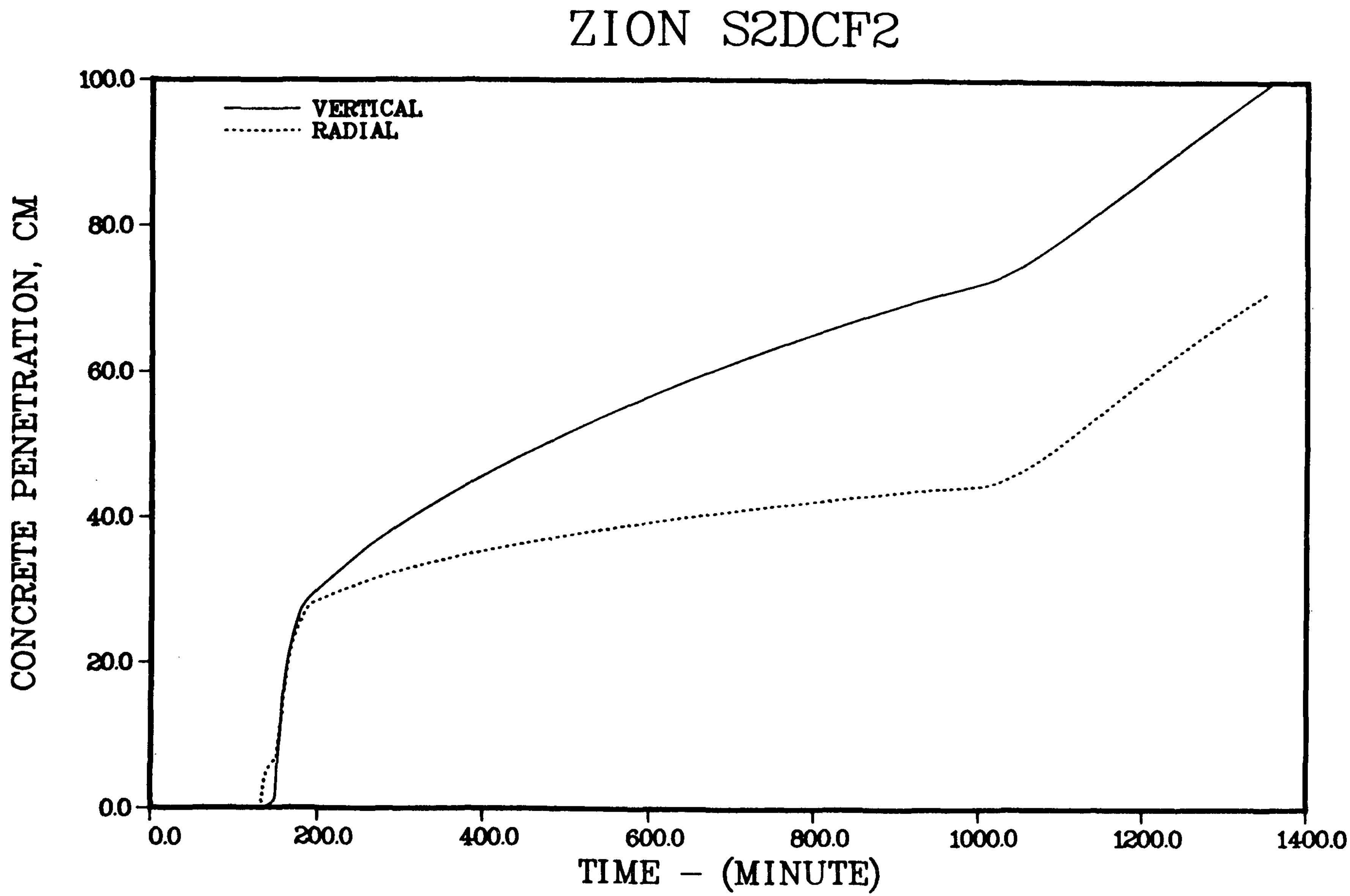

FIGURE 4.26. PROGRESSION OF CONCRETE ATTACK FOR S_2DCF SEQUENCE WITH LATE CONTAINMENT FAILURE

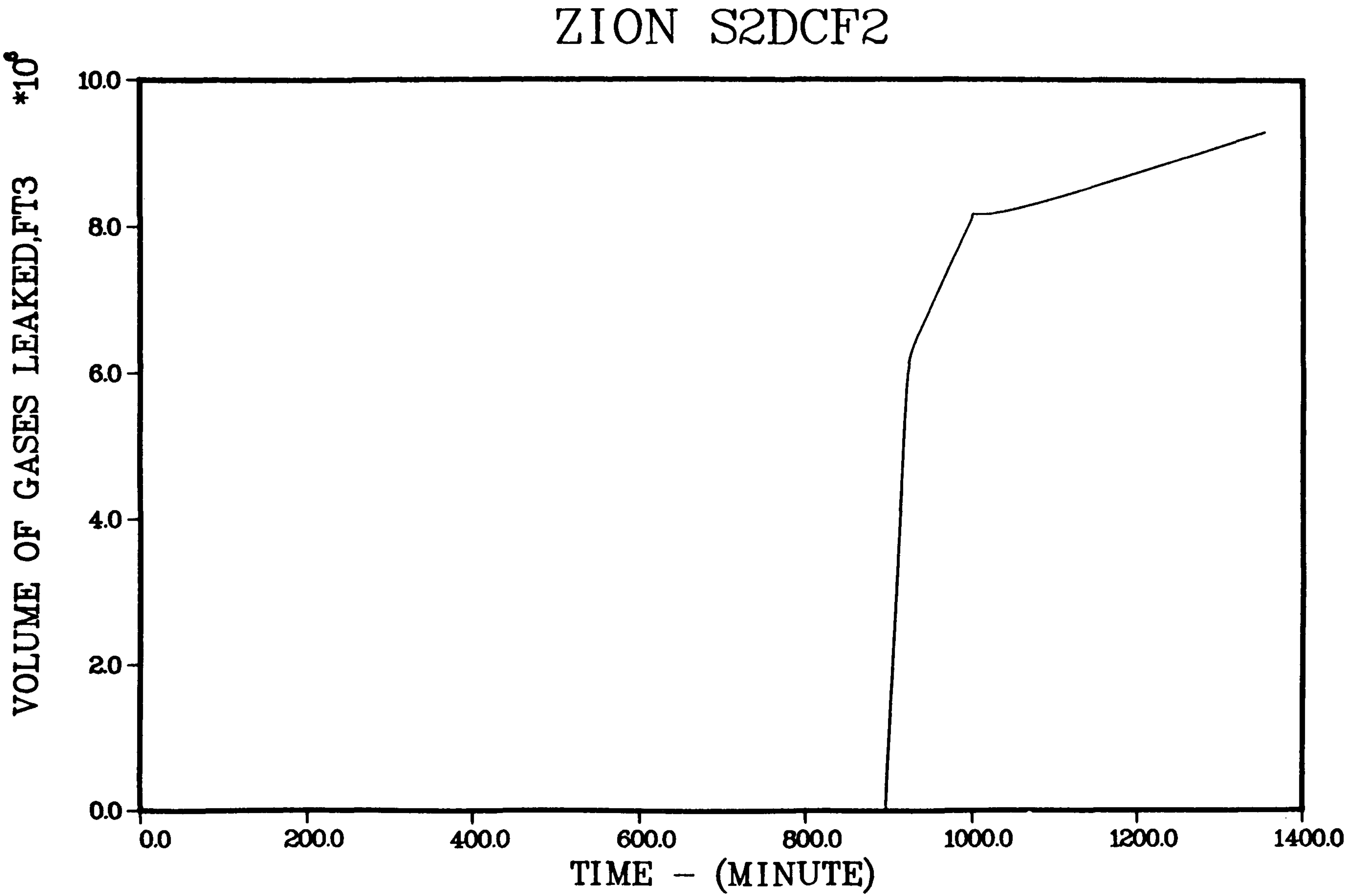

FIGURE 4.27. TOTAL VOLUME OF GASES LEAKED FOR S_2DCF SEQUENCE
WITH LATE CONTAINMENT FAILURE

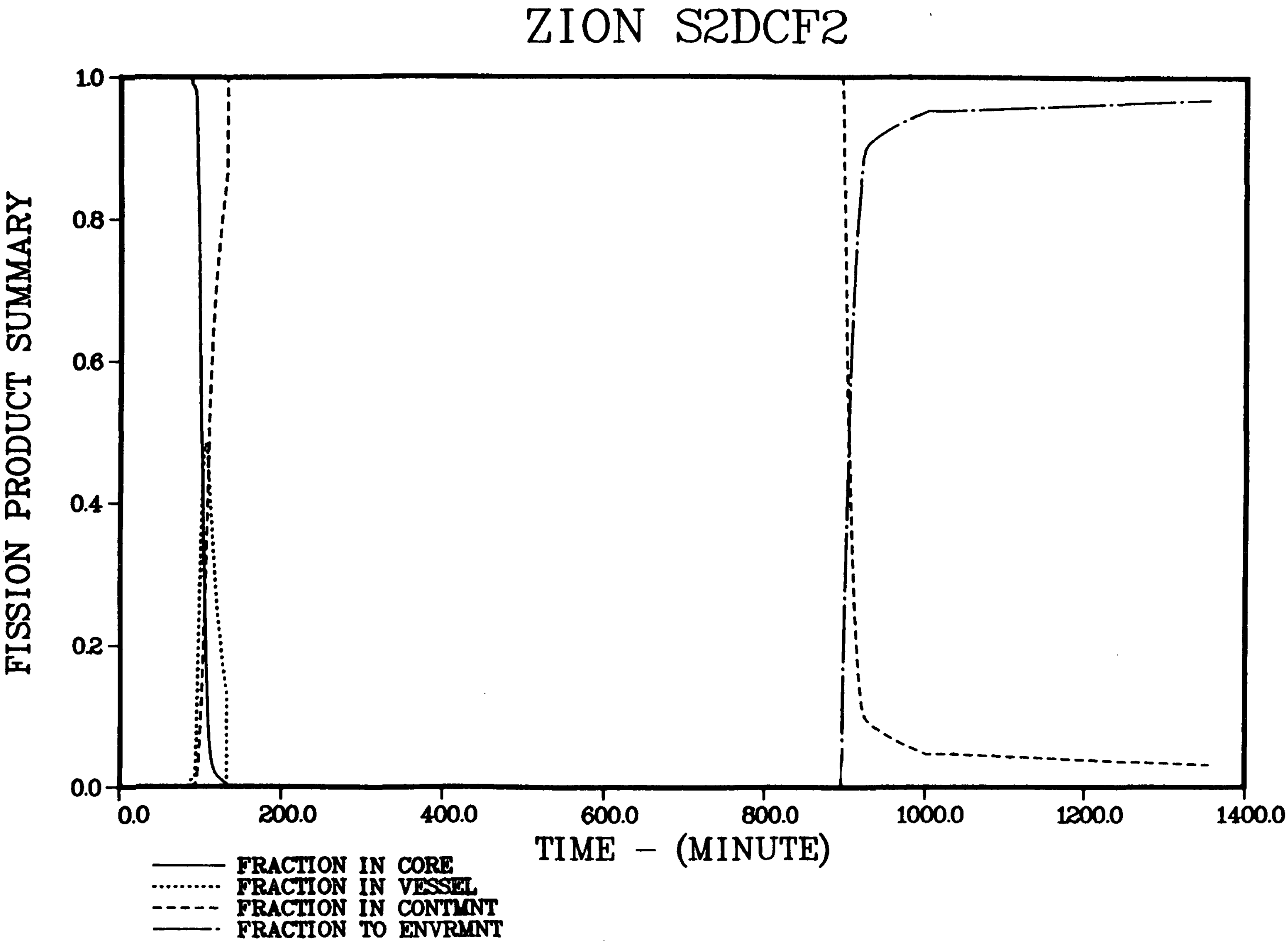

FIGURE 4.28. NOBLE GAS DISTRIBUTIONS FOR S_2DCF SEQUENCE WITH LATE CONTAINMENT FAILURE

heating; as before, the loadings and containment conditions that would be associated with such phenomena were simulated by selected choice of inputs to the debris-water interaction and hydrogen combustion models.

The accident event times for the TMLU sequence are again summarized in Table 4.1. The core and primary system conditions at key times during the sequence are summarized in Table 4.2; containment conditions are given in Table 4.3.

Figure 4.29 illustrates the predicted primary system response for this sequence. During the initial portion of the transient, while the steam generators are providing an effective heat sink, the primary system pressure is reduced below normal operating levels. As the steam generators begin to dry out and lose their effectiveness, the primary system pressure rises to the safety/relief valve setpoint. The steam generator secondary side water inventory is illustrated in Figure 4.30. The combined steam and water leak rates from the primary system are illustrated in Figure 4.31, with the primary system water inventory shown in Figure 4.32. After the initial transient which results in the expulsion of a small amount of the primary coolant inventory through the pressurizer relief valve, all the decay heat is removed through the steam generators. As the steam generators approach dryout the primary system pressure rises and expulsion of primary coolant starts at about 65 minutes. The rate of primary coolant loss is nearly constant until the inventory becomes saturated; at that point the rate of coolant loss increases significantly, as can be seen in Figure 4.31. The uncovery of the pressurizer surge line at about 105 minutes changes the leak flow from liquid to steam, with a substantial decrease in the rate of coolant loss. The steam boiloff rate remains relatively constant until the time of core uncovery; from there the rate of boiloff decreases. The final rapid increase in coolant boiloff is associated with the collapse of the core into the vessel head. The maximum and average core temperatures for this scenario are illustrated in Figure 4.33. The fractions of cladding reacted and core melted are illustrated in Figure 4.34. The behavior illustrated is typical of what has been seen for a variety of accident scenarios.

The temperatures of the gases leaving the top of the core and leaking to containment are illustrated in Figure 4.35. The abrupt drop in the core exit temperatures is not real but correspond to a period of no flow

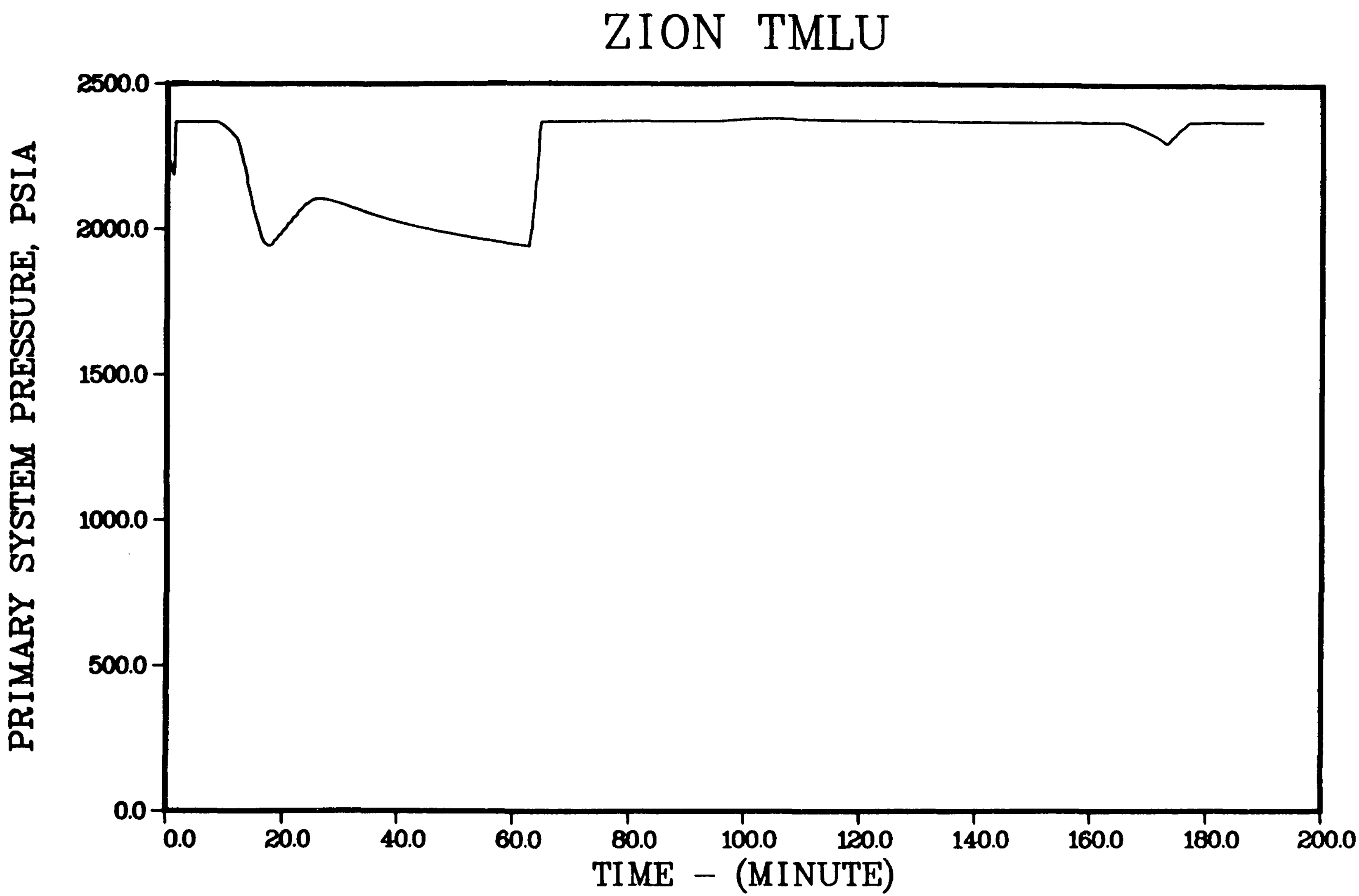

FIGURE 4.29. PRIMARY SYSTEM PRESSURE RESPONSE FOR TMLU SEQUENCE

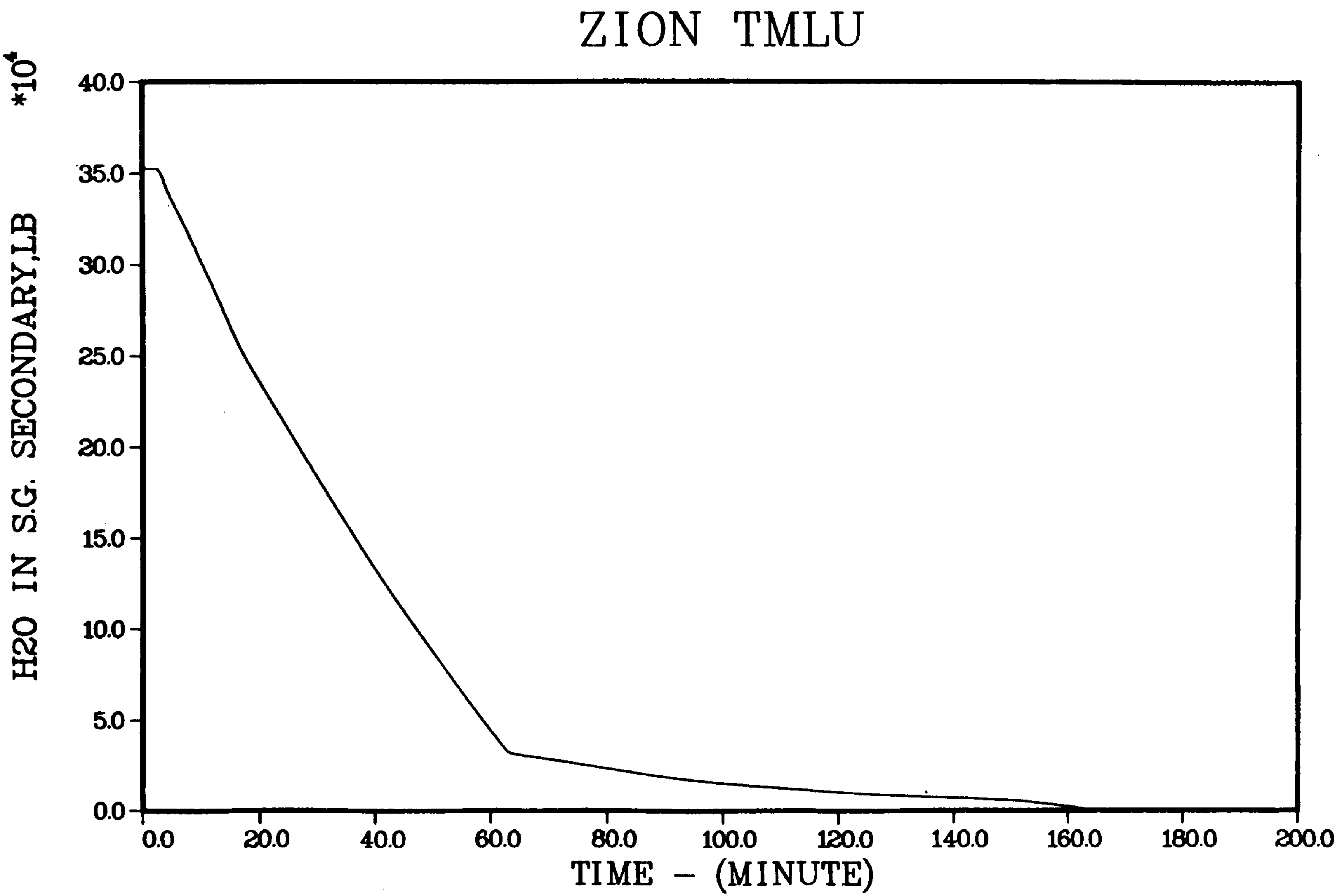

FIGURE 4.30. STEAM GENERATOR WATER INVENTORY FOR TMLU SEQUENCE

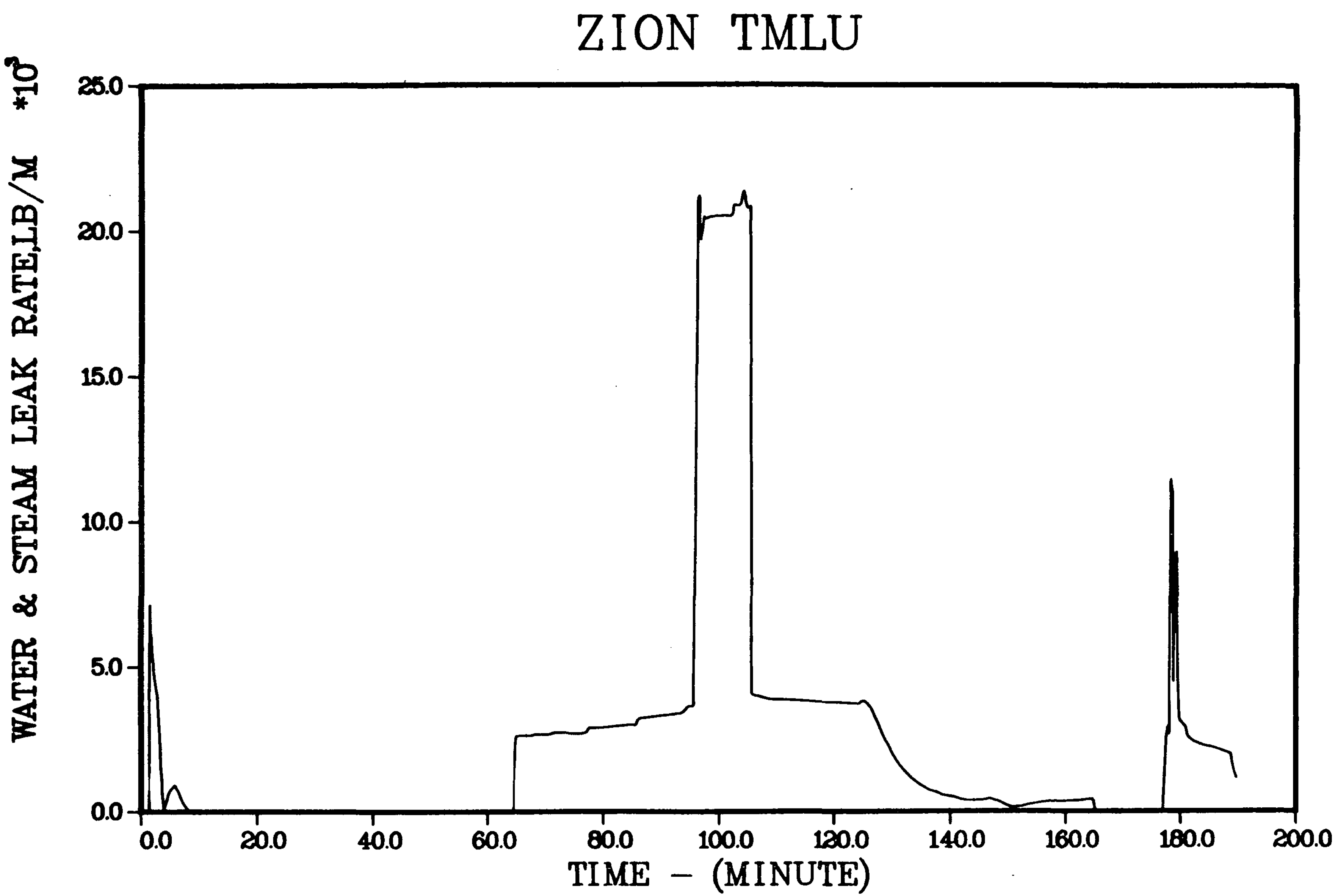

FIGURE 4.31. PRIMARY SYSTEM LEAK RATES FOR TMLU SEQUENCE

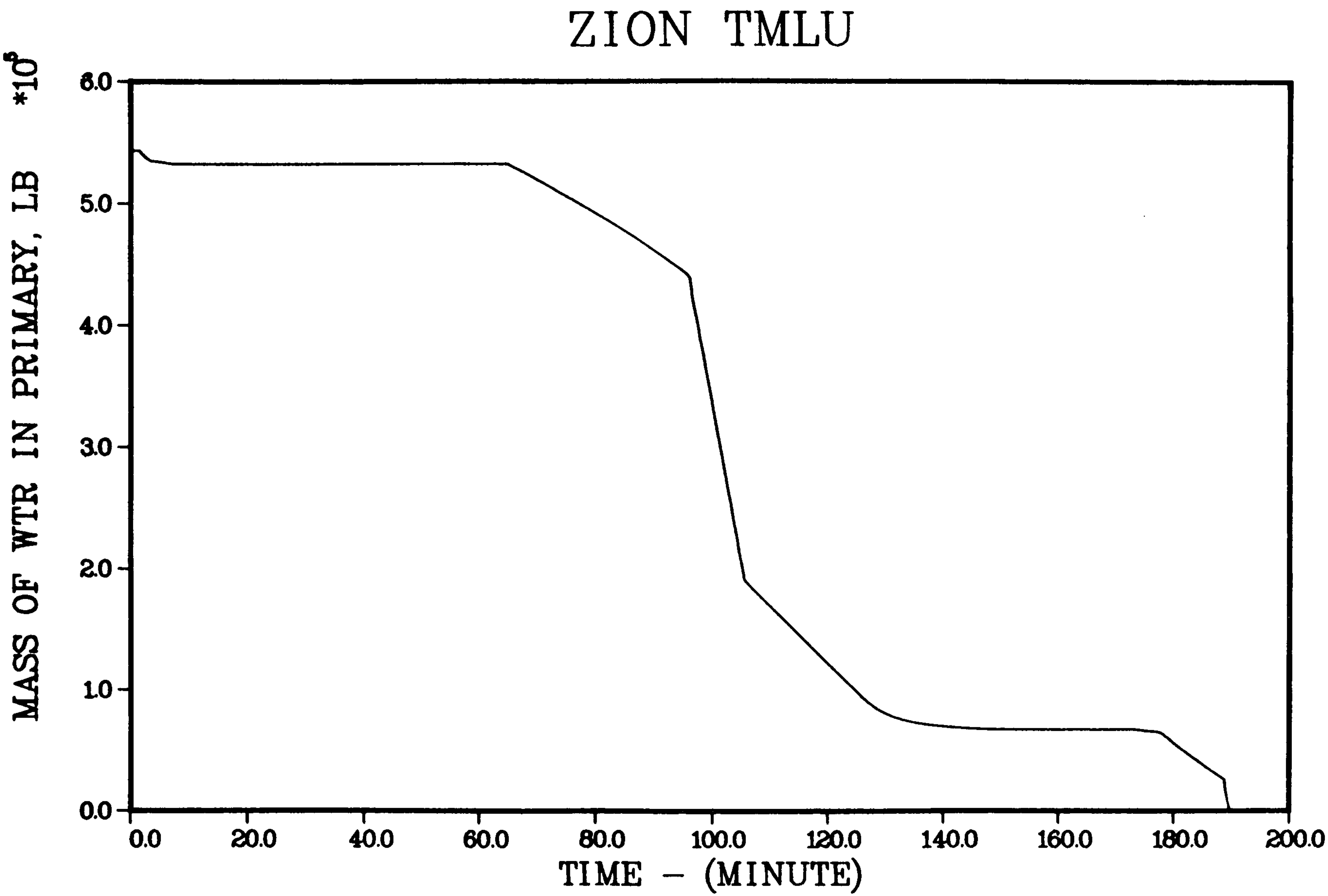

FIGURE 4.32. PRIMARY SYSTEM WATER INVENTORY FOR TMLU SEQUENCE

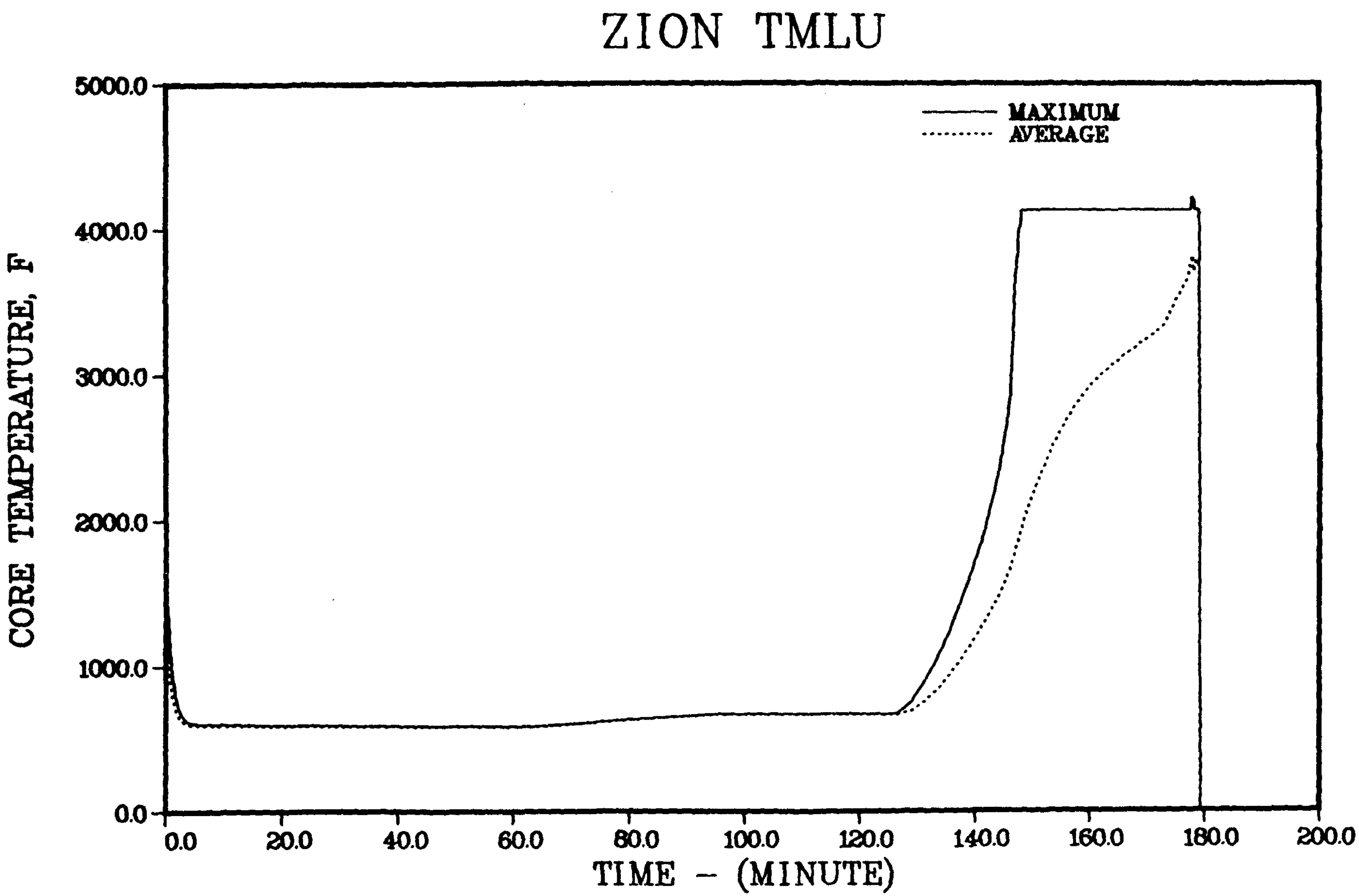

FIGURE 4.33. MAXIMUM AND AVERAGE CORE TEMPERATURES FOR TMLU SEQUENCE

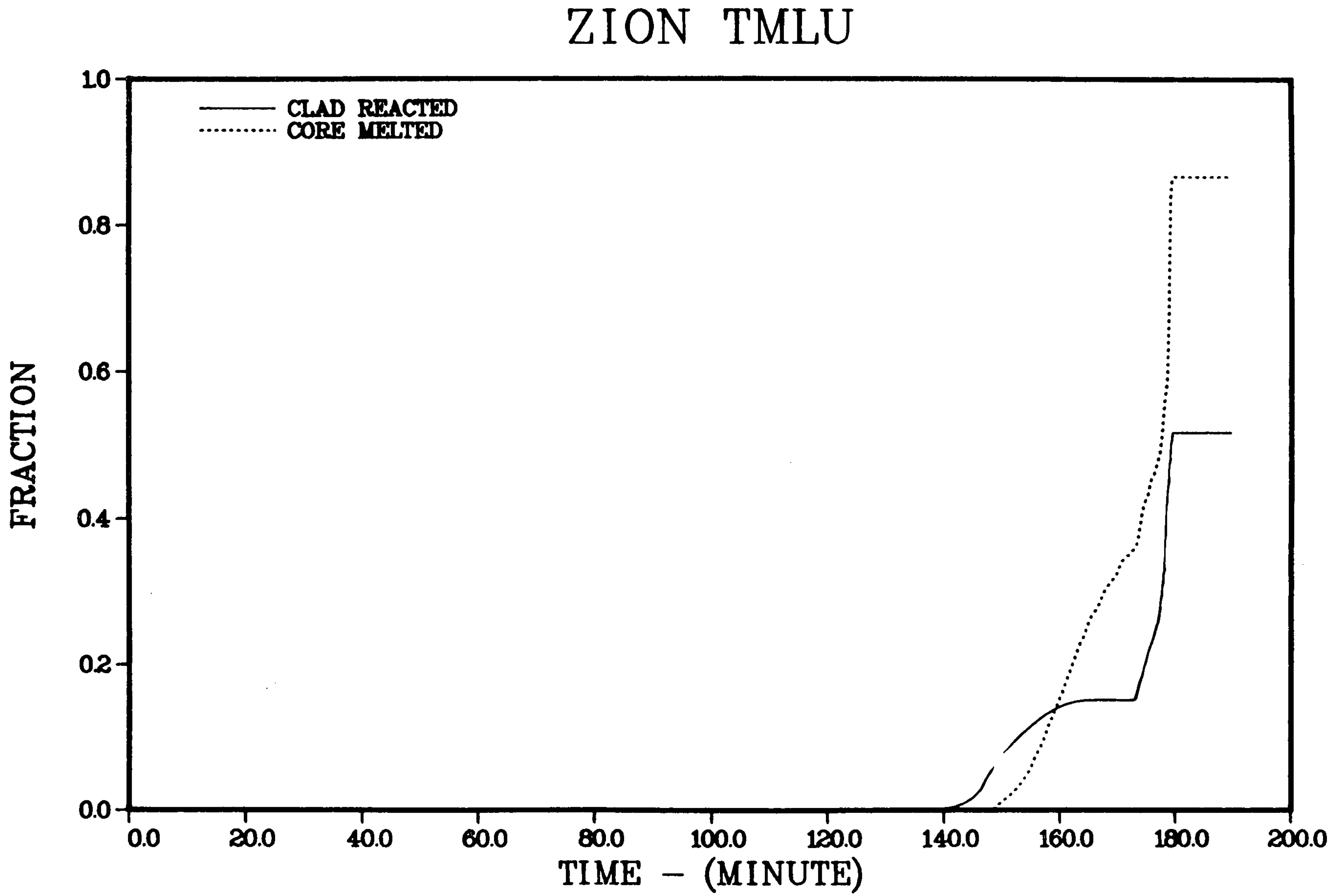

FIGURE 4.34. FRACTIONS OF CORE MELTED AND CLADDING REACTED FOR TMLU SEQUENCE

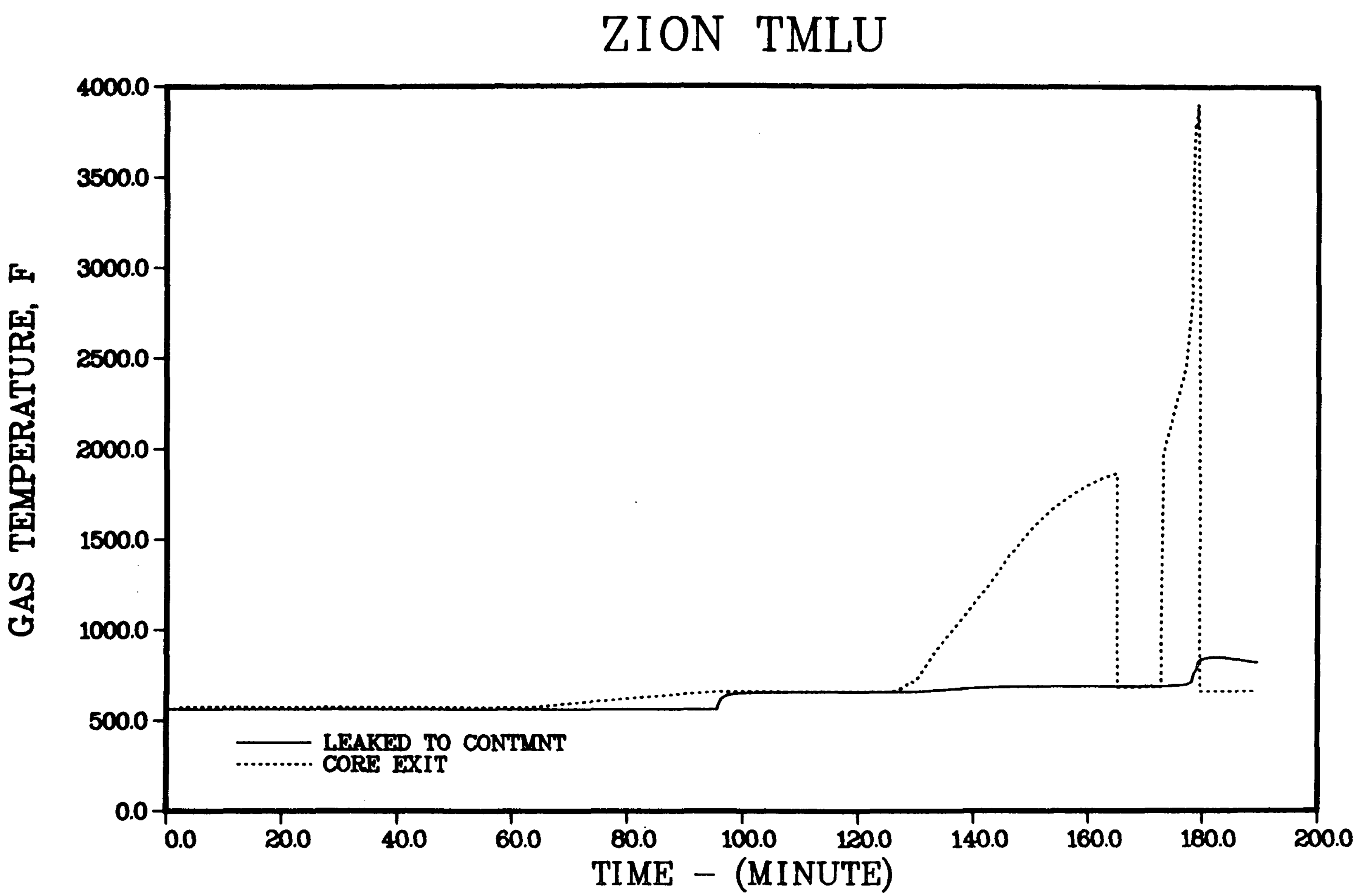

FIGURE 4.35. TEMPERATURES OF GASES LEAVING THE CORE AND LEAKING TO THE CONTAINMENT FOR TMLU SEQUENCE

through the core. As in similar cases, it is noteworthy that while very high temperatures are predicted at the top of the core, the temperature of the gases leaving the primary system is relatively low. The temperatures of some of the primary system structures are illustrated in Figure 4.36. Again it is interesting to note that only the first structure immediately above the core is predicted to experience very high temperatures; structures further downstream experience only limited heating. It should be noted that these results are based on the once-through flow of the gases from the core to where they exit to the containment. There is no provision in MARCH to model the internal recirculation of hot gases within the primary system; the latter have been postulated to have potentially significant effects on the course of accidents like the sequence considered here.

The predicted containment pressure and temperature responses for the TMLU scenario with early containment failure are illustrated in Figures 4.37 and 4.38. The rapid pressure increase to the containment failure level immediately after reactor vessel failure was based on a very small particle size in the debris-water interaction model as well the removal of the steam inerting inhibition to hydrogen-oxygen recombination in the containment atmosphere. These selected inputs were used as a simulation for the conditions that may result from the direct interaction of the core debris with the containment atmosphere.

Since the containment sprays are operating in this sequence there is a large quantity of water potentially available for interaction in the reactor cavity; if all the water is included in the interaction, the core debris would be quenched with minimal steam production. As part of the simulation of direct heating, the amount of water that was assumed to participate in the debris-water interaction in the reactor cavity was restricted to that in the accumulators. The containment sump and reactor cavity water inventories and temperatures are illustrated in Figures 4.39 and 4.40, respectively. The reactor cavity is kept filled by overflow from the containment sump. The cavity water is continually boiled off and thus maintained at the saturation temperature while the sump water remains relatively cold.

The predicted progression of concrete attack for this sequence is illustrated in Figure 4.41. These results are based on the assumption that concrete attack is initiated as soon as the debris reheat after the initial quenching, and that concrete attack and boiloff of cavity water occur

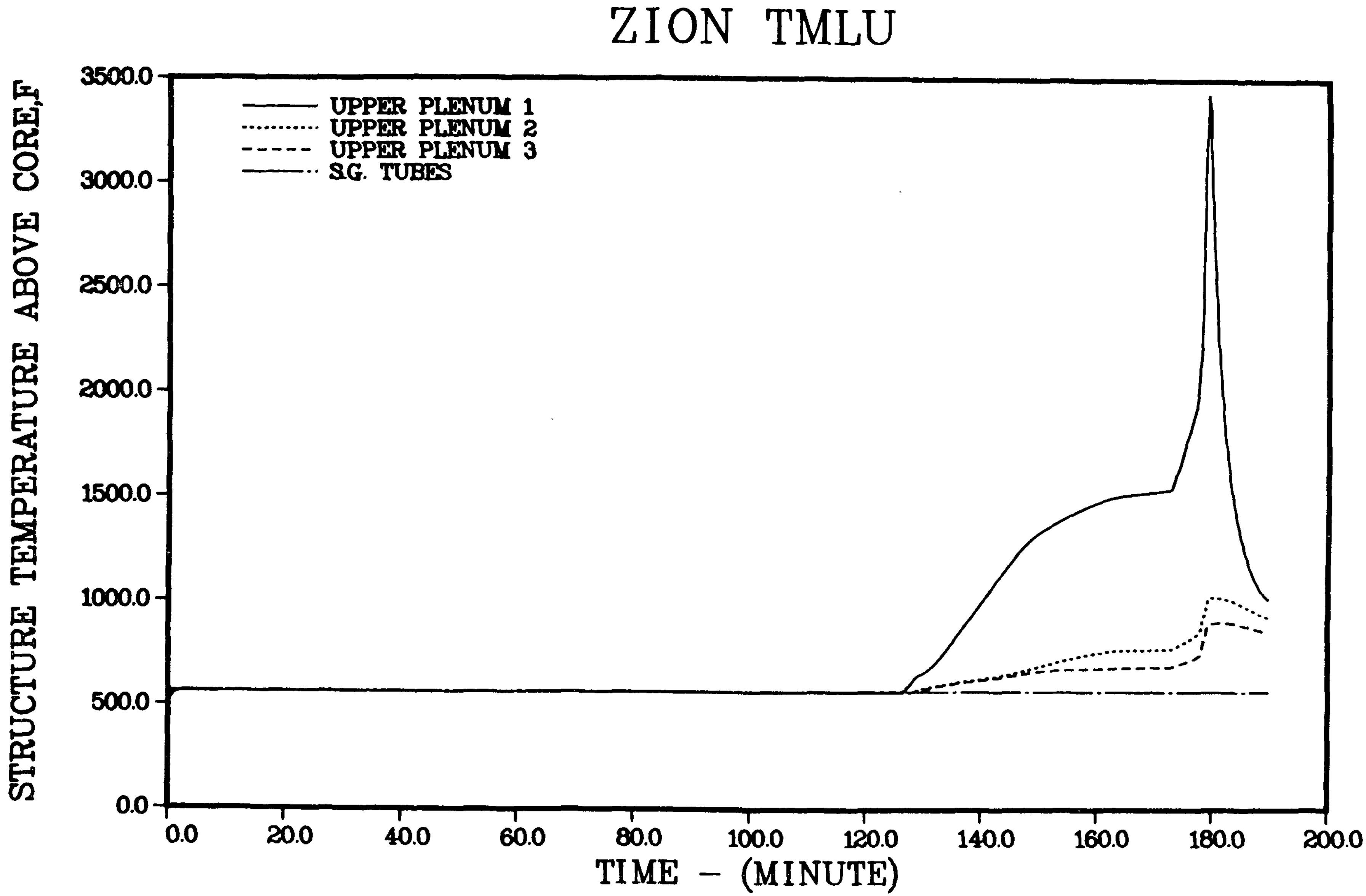

FIGURE 4.36. PRIMARY SYSTEM STRUCTURE TEMPERATURES FOR TMLU SEQUENCE

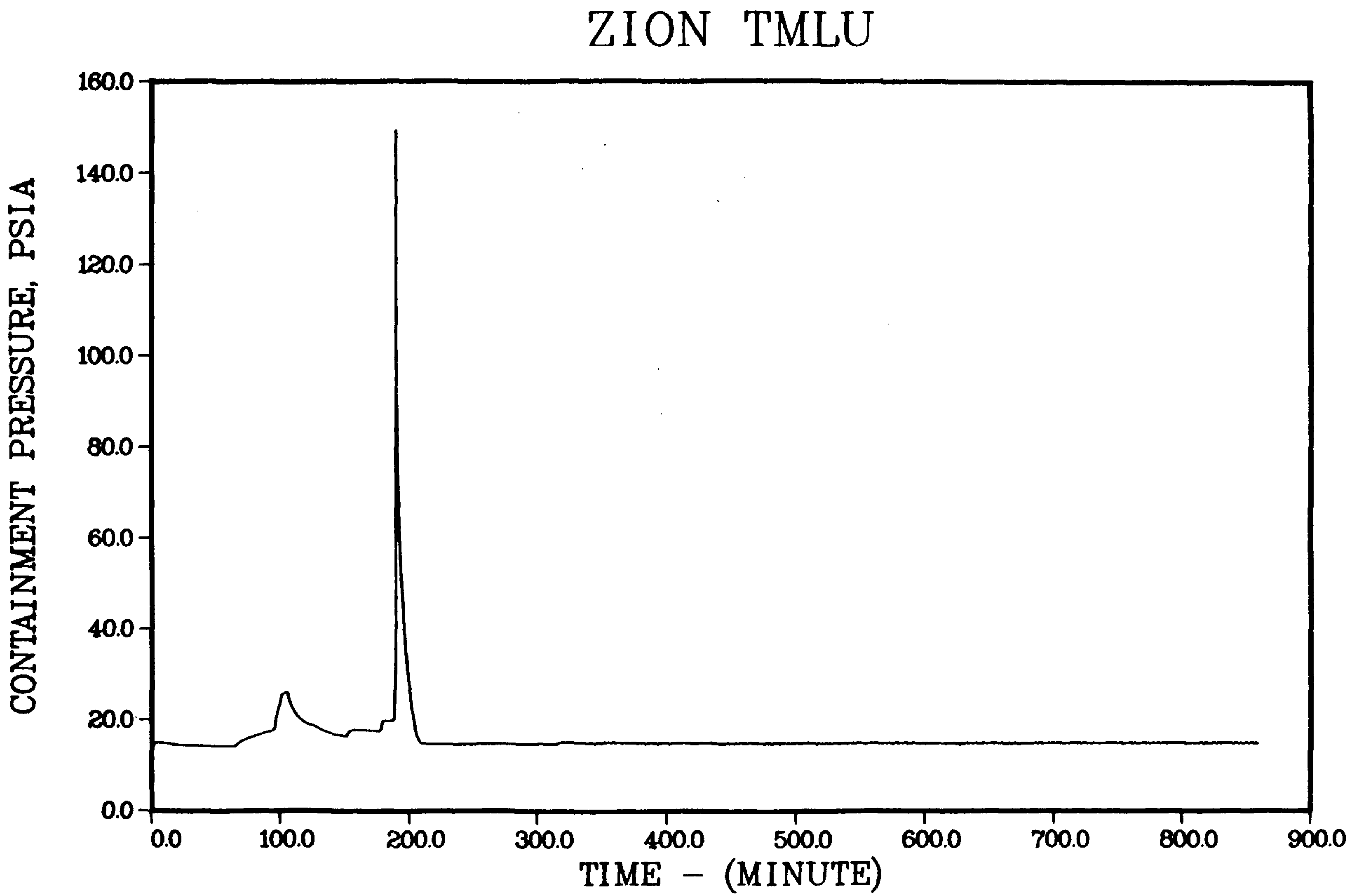

FIGURE 4.37. CONTAINMENT PRESSURE RESPONSE FOR TMLU SEQUENCE

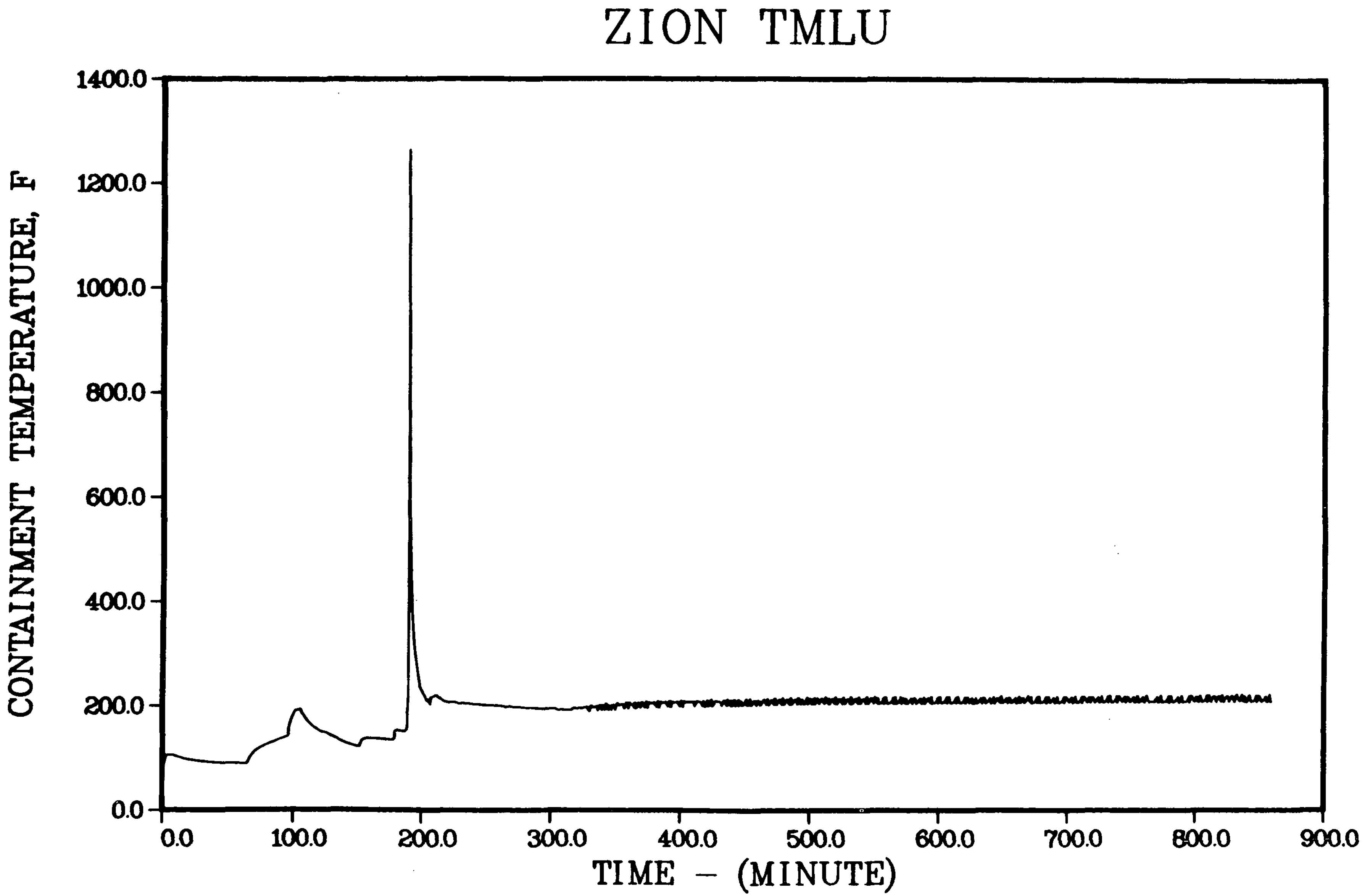

FIGURE 4.38. CONTAINMENT TEMPERATURE RESPONSE FOR TMLU SEQUENCE

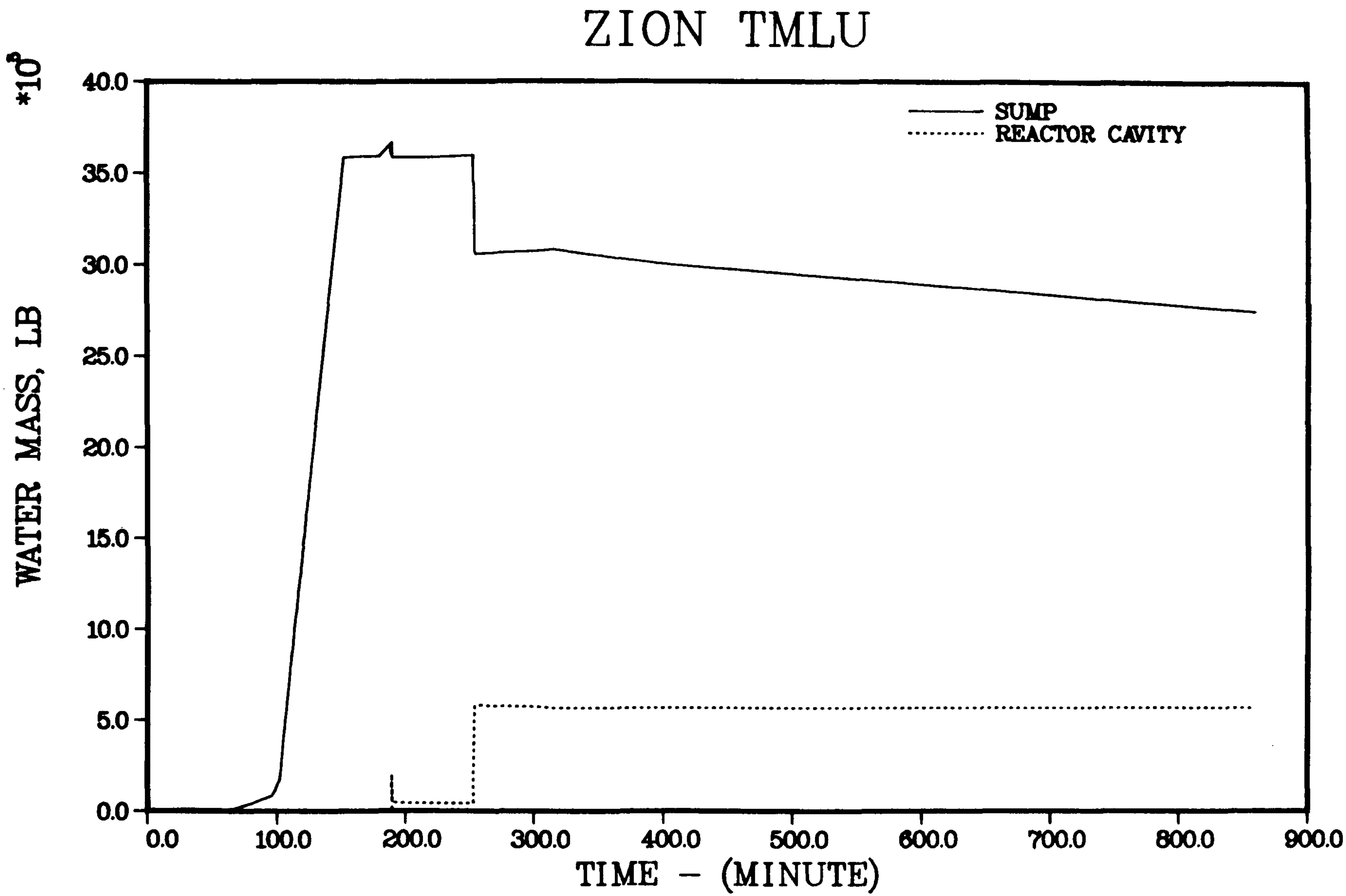

FIGURE 4.39. CONTAINMENT SUMP AND REACTOR CAVITY WATER INVENTORIES FOR TMLU SEQUENCE

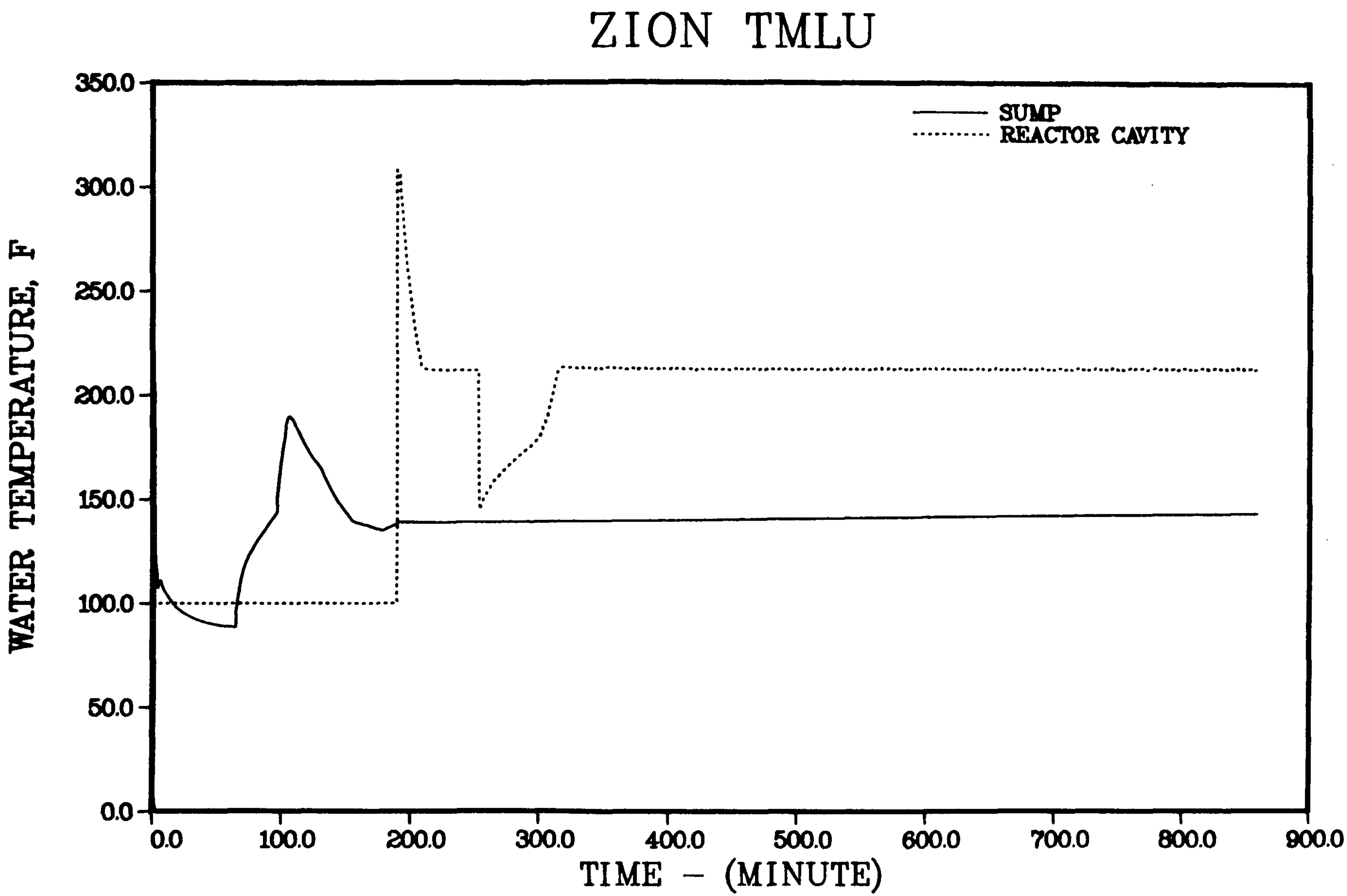

FIGURE 4.40. CONTAINMENT SUMP AND REACTOR CAVITY WATER TEMPERATURES FOR TMLU SEQUENCE

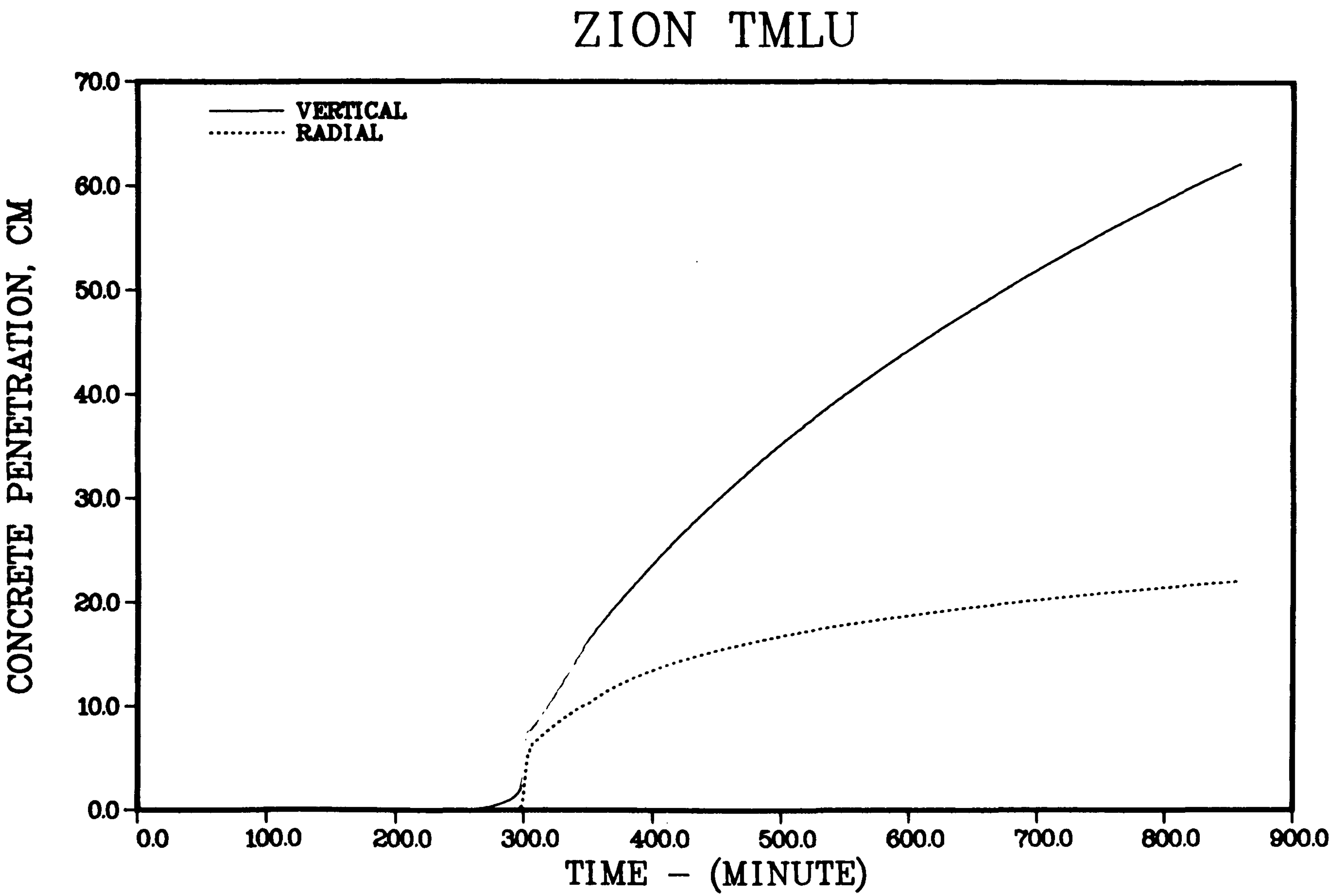

FIGURE 4.41, PROGRESSION OF CONCRETE PENETRATION FOR TMLU SEQUENCE

simultaneously. Several other courses are also possible for the scenario being considered. In view of the direct containment heating assumption, it is possible that the debris could be sufficiently dispersed to preclude significant concrete attack. Or, the debris could form a coolable bed and remain quenched as long as there is water on the containment floor.

The total volume of gases leaked from the containment is illustrated in Figure 4.42. The time dependent leak rates used as input to the containment fission product transport analyses are given in Table 4.4. The MARCH calculated noble gas distributions for this sequence are illustrated in Figure 4.43.

4.3 Radionuclide Sources

4.3.1 Source Within Pressure Vessel

The inventory of fission products used for these analyses is the same as in Volume VI of BMI-2104. Table 4.5 provides the inventories for each of the key fission product, actinide, and structural elements. These values are based on ORIGEN calculations for a PWR reactor with a three region model in which the maximum burnup corresponds to 33,000 MW days/tonne. In Table 4.6 these elements are collected into the elemental groups used in this study.

4.3.2 Sources Within the Containment

Release from Reactor Coolant System

Radionuclides enter the containment as they are transported through the primary system. After melt-through of the reactor pressure vessel, material still suspended in the RCS is assumed to be transported into the containment as the RPV and containment pressures are equalized.

Release from Core-Concrete Interaction

The VANESA code was used to predict aerosol and gas release rates and compositions as functions of time. Composition of the core materials contacting the concrete was determined with the CORSOR module. These compositions for the various sequences are given in Table 4.7. The concrete

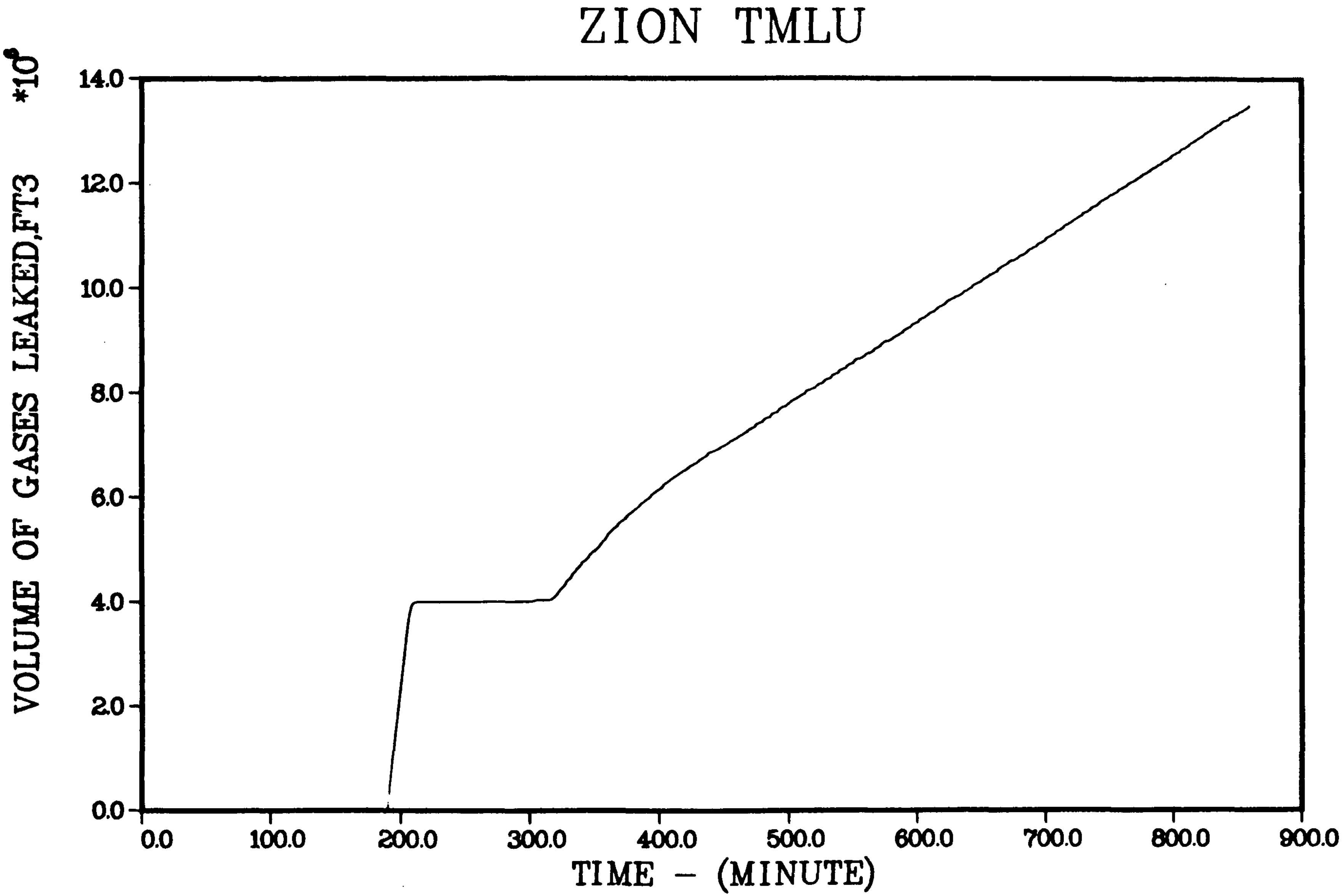

FIGURE 4.42. TOTAL VOLUME OF GASES LEAKED FOR TMLU SEQUENCE

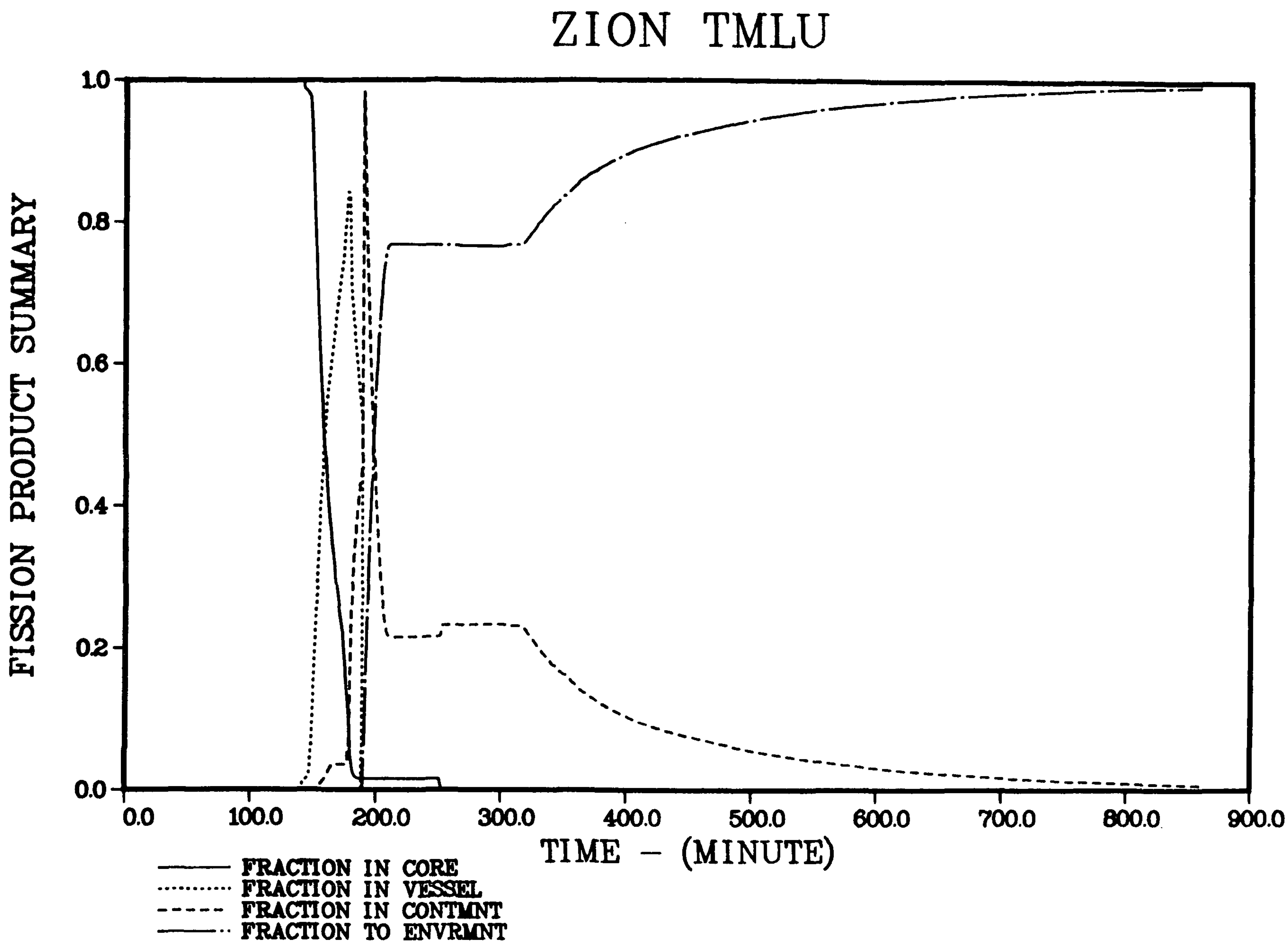

FIGURE 4.43. NOBLE GAS DISTRIBUTIONS FOR TMLU SEQUENCE

TABLE 4.5. INVENTORIES OF RADIONUCLIDES AND STRUCTURAL MATERIALS

Fission Products		Actinides/Structural	
Element	Mass (kg)	Element	Mass (kg)
Kr	16.5	U	86,600
Rb	18.1	Pu	578
Sr	59.1	Cr	1,210
Y	28.2	Mn	0
Zr	220	Fe	4,850
Mo	191	Ni	674
Tc	45.8	Zr	20,200
Ru	128	Sn	347
Rh	25.8	Gd	0
Pd	64.8		
Te	30.8		
I	14.8		
Xe	320		
Cs	161		
Ba	75.4		
La	76.8		
Ce	162		
Pr	62.6		
Nd	210		
Sm	41.9		
Eu	11.0		
Nb	3.4		
Np	32.0		
Pm	8.9		

TABLE 4.6. INVENTORY BY GROUP

Group	Elements	Total Mass (kg)
1	Xe, Kr	336.5
2	I, Br	14.8
3	Cs, Rb	179
4	Te, Sb, Se	30.8
5	Sr	59.1
6	Ru, Rh, Pd, Mo, Tc	455
7	La, Zr, Nd, Eu, Nb, Pm, Pr, Sm, Y	663
8	Ce, Pu, Np	772
9	Ba	75.4

TABLE 4.7. INVENTORY OF MELT AT THE TIME OF VESSEL FAILURE FOR ZION (kg)

	S_2DCF1	S_2DCF2	S_2DC_r	TMLU
Cs	0.61	0.61	0.60	0.163
I	0.058	0.058	0.056	0.015
Xe	1.23	1.24	1.21	0.325
Kr	0.064	0.064	0.062	0.017
Te	18.6	18.7	17.5	14.3
Ag (FP)	0	0	0	0
Sb	0	0	0	0
Ba	74.8	74.8	74.8	73.9
Sn	328	328	328	310
Tc	45.8	45.8	45.8	45.8
UO_2	98,200	98,200	98,200	98,200
Zr (struct)	3400	10,600	10,590	0
Zr (FP)	37.0	116	115	0
Fe	11,800	21,000	21,000	10,200
Mo	191	191	191	191
Sr	59.1	59.1	59.1	59.0
Cr	5240	5240	5240	5240
Ni	2910	2910	2910	2910
Mn	0	0	0	0
La	76.8	76.8	76.8	76.8
Ag (struct)	2232	2230	2232	2232
Cd	140	140	140	140
In	419	419	419	419
Ce	162	162	162	162
Rb	0.107	0.11	0.104	0.0048
Br	0	0	0	0
Ru	128	128	128	128

TABLE 4.7. INVENTORY OF MELT AT THE TIME OF VESSEL FAILURE FOR ZION (kg) (Continued)

	S_2DCF1	S_2DCF2	S_2DC_r	TMLU
Rh	25.8	25.8	25.8	25.8
Pd	64.8	64.8	64.8	64.8
Nd	210	210	210	210
Eu	11.0	11.0	11.0	11.0
Gd	0	0	0	0
Nb	3.4	3.4	3.4	3.4
Pm	8.9	8.9	8.9	8.9
Pr	62.6	62.6	62.6	62.6
Sm	41.9	41.9	41.9	41.9
Y	28.2	28.2	28.2	28.2
Np	32.0	32.0	32.0	32.0
Pu	578	578	578	578
Se	0	0	0	0
FeO	0	0	0	0
ZrO_2*	22,700	12,800	12,800	27,300

* 1.08% of the ZrO_2 is fission product Zr.

was taken to be a basaltic concrete and the initial temperature of the molten material was as calculated with the MARCH module. The total release rates and composition of the release are given in Tables 4.8 through 4.10.

TABLE 4.8. AEROSOL RELEASE DURING CONCRETE ATTACK FOR S_2DC_r

SPECIES	TIME .0	1200.0	2400.0	3600.0	4800.0	6000.0	7200.0	8400.0
FEO	.1788E-11	.3298E-01	.3915E-01	.4020E-01	.3042E-01	.8788E-01	.1292	.1842
CR2O3	.5527E-18	.2888E-18	.1185E-19	.2205E-01	.4877E-02	.7908E-03	.6890E-03	.6140E-03
NI	.7839	.1467	.4554E-02	.5284E-01	.4175E-01	.3699E-01	.3402E-01	.3150E-01
MO	.7574E-08	.5835E-07	.8337E-10	.5894E-05	.1614E-03	.1041E-01	.1093E-01	.1124E-01
RU	.5350E-05	.4194E-08	.4858E-09	.2045E-08	.1178E-08	.8876E-09	.7200E-09	.5944E-09
SN	1.438	.4779	.2612	9.458	11.51	15.17	15.58	15.91
SB	0.	0.	0.	0.	0.	0.	0.	0.
TE	1.260	.5527	.5268	17.89	19.93	19.89	20.59	21.45
AG	30.40	20.64	3.595	71.58	67.08	61.74	60.40	59.17
MN	0.	0.	0.	0.	0.	0.	0.	0.
CAO	0.	24.41	15.99	.4846	.7073	1.253	1.266	1.275
AL2O3	0.	.2827	.1169E-03	.1371E-05	.1843E-05	.1980E-05	.2209E-05	.2438E-05
NA2O	0.	0.	0.	0.	0.	0.	0.	0.
K2O	0.	0.	0.	0.	0.	0.	0.	0.
SIO2	0.	26.07	78.48	.1876	.5556E-01	.1520E-01	.1322E-01	.1171E-01
UO2	.6729	.8525E-01	.1047E-02	.1207	.2898	1.236	1.186	1.133
ZRO2	.7659E-02	.7235E-03	.2047E-04	.9244E-03	.1113E-02	.1134E-02	.1206E-02	.1279E-02
CS2O	.1552	.1049	0.	0.	0.	0.	0.	0.
BAO	6.678	2.637	.3850	.1548	.3423	.7692	.7848	.7965
SRO	9.708	2.752	.7170	.4906E-02	.8247E-02	.1842E-01	.1826E-01	.1806E-01
LA2O3	.8685	.1005	.4184E-08	.1741E-04	.2098E-04	.2135E-04	.2275E-04	.2408E-04
CEO2	3.409	.4246	.3305E-02	.2995E-04	.3605E-04	.3873E-04	.3914E-04	.4142E-04
NB2O5	12.53	0.	0.	0.	0.	0.	0.	0.
CSI	.6174	.3204E-04	.1933E-14	.8042E-13	.9681E-13	.9865E-13	.1051E-12	.1112E-12
CD	31.47	21.27	0.	0.	0.	0.	0.	0.
OXIDE MELT TEMP(K)	2353.	2200.	1766.	1665.	1636.	1623.	1612.	1603.
SOURCE RATE(GM/S)	121.1	582.9	104.2	.4745	.1897	.1642	.1415	.1188
AEROSOL DENSITY(GM/CM3)	4.980	3.436	2.504	7.821	7.658	7.481	7.430	7.383
AEROSOL SIZE(MICRON)	.8201	1.009	.6194	.1108	.1022	.1011	.9813E-01	.9551E-01

TABLE 4.8. AEROSOL RELEASE DURING CONCRETE ATTACK FOR S_2DC_r (Continued)

SPECIES	TIME 9600.0	10800.0	12000.0	13200.0	14400.0	15600.0	16800.0	18000.0
FEO	.2324	.2745	.3131	.3487	.3817	.4124	.4408	.4673
CR203	.5536E-03	.1365E-03	.1426E-03	.1481E-03	.1532E-03	.1577E-03	.1619E-03	.1657E-03
NI	.2921E-01	.2728E-01	.2584E-01	.2421E-01	.2297E-01	.2168E-01	.2091E-01	.2005E-01
MO	.1154E-01	.1180E-01	.1203E-01	.1225E-01	.1244E-01	.1262E-01	.1278E-01	.1294E-01
RU	.4931E-09	.4165E-09	.3572E-09	.3104E-09	.2727E-09	.2420E-09	.2167E-09	.1954E-09
SN	16.28	16.59	16.89	17.18	17.45	17.71	17.95	18.19
SB	0.	0.	0.	0.	0.	0.	0.	0.
TE	22.30	23.08	23.79	24.44	25.04	25.60	26.12	26.60
AG	57.95	56.84	55.81	54.85	53.97	53.15	52.38	51.66
MN	0.	0.	0.	0.	0.	0.	0.	0.
CAO	1.282	1.287	1.290	1.292	1.293	1.294	1.293	1.292
AL203	.2676E-05	.2906E-05	.3128E-05	.3342E-05	.3549E-05	.3747E-05	.3938E-05	.4122E-05
NA20	0.	0.	0.	0.	0.	0.	0.	0.
K20	0.	0.	0.	0.	0.	0.	0.	0.
SIO2	.1044E-01	.9438E-02	.8634E-02	.7980E-02	.7442E-02	.6995E-02	.6620E-02	.6303E-02
UO2	1.090	1.053	1.019	.9888	.9610	.9353	.9115	.8894
ZRO2	.1353E-02	.1422E-02	.1485E-02	.1543E-02	.1595E-02	.1643E-02	.1686E-02	.1726E-02
CS20	0.	0.	0.	0.	0.	0.	0.	0.
BAO	.8079	.8192	.8281	.8349	.8399	.8435	.8458	.8471
SRO	.1790E-01	.1774E-01	.1756E-01	.1737E-01	.1718E-01	.1698E-01	.1677E-01	.1657E-01
LA203	.2548E-04	.2678E-04	.2797E-04	.2905E-04	.3004E-04	.3094E-04	.3176E-04	.3250E-04
CEO2	.4383E-04	.4607E-04	.4812E-04	.4998E-04	.5168E-04	.5322E-04	.5463E-04	.5591E-04
NB205	0.	0.	0.	0.	0.	0.	0.	0.
CSI	.1177E-12	.1237E-12	.1292E-12	.1342E-12	.1388E-12	.1429E-12	.1467E-12	.1501E-12
CD	0.	0.	0.	0.	0.	0.	0.	0.
OXIDE MELT TEMP(K)	1593.	1585.	1578.	1571.	1565.	1559.	1554.	1549.
SOURCE RATE(GM/S)	.9975E-01	.8859E-01	.7979E-01	.7252E-01	.6642E-01	.6125E-01	.5681E-01	.5297E-01
AEROSOL DENSITY(GM/CM3)	7.338	7.297	7.260	7.227	7.196	7.168	7.142	7.117
AEROSOL SIZE(MICRON)	.9305E-01	.9092E-01	.8907E-01	.8744E-01	.8600E-01	.8472E-01	.8357E-01	.8254E-01

TABLE 4.8. AEROSOL RELEASE DURING CONCRETE ATTACK FOR S_2DC_r (Continued)

SPECIES	TIME 19200.0	20400.0	21600.0	22800.0	24000.0	25200.0	26400.0	27600.0
FEO	.4921	.5152	.5369	.5572	.5763	.5943	.6112	.6271
CR2O3	.1692E-03	.1723E-03	.1752E-03	.1778E-03	.1802E-03	.1823E-03	.1843E-03	.1860E-03
NI	.1927E-01	.1857E-01	.1794E-01	.1736E-01	.1683E-01	.1634E-01	.1589E-01	.1547E-01
MO	.1308E-01	.1321E-01	.1334E-01	.1346E-01	.1357E-01	.1367E-01	.1377E-01	.1387E-01
RU	.1775E-09	.1622E-09	.1490E-09	.1376E-09	.1275E-09	.1187E-09	.1109E-09	.1040E-09
SN	18.41	18.63	18.83	19.03	19.23	19.41	19.60	19.77
SB	0.	0.	0.	0.	0.	0.	0.	0.
TE	27.04	27.46	27.85	28.22	28.56	28.89	29.19	29.48
AG	50.99	50.36	49.76	49.19	48.66	48.15	47.67	47.21
MN	0.	0.	0.	0.	0.	0.	0.	0.
CAO	1.290	1.288	1.285	1.282	1.279	1.276	1.272	1.268
AL2O3	.4298E-05	.4467E-05	.4630E-05	.4787E-05	.4938E-05	.5083E-05	.5222E-05	.5356E-05
NA2O	0.	0.	0.	0.	0.	0.	0.	0.
K2O	0.	0.	0.	0.	0.	0.	0.	0.
SIO2	.6033E-02	.5800E-02	.5600E-02	.5425E-02	.5273E-02	.5140E-02	.5022E-02	.4918E-02
UO2	.8687	.8493	.8310	.8138	.7974	.7819	.7671	.7531
ZRO2	.1762E-02	.1795E-02	.1824E-02	.1852E-02	.1876E-02	.1899E-02	.1919E-02	.1937E-02
CS2O	0.	0.	0.	0.	0.	0.	0.	0.
BAO	.8475	.8471	.8461	.8445	.8424	.8399	.8370	.8339
SRO	.1636E-01	.1616E-01	.1596E-01	.1576E-01	.1557E-01	.1537E-01	.1519E-01	.1500E-01
LA2O3	.3318E-04	.3380E-04	.3436E-04	.3487E-04	.3533E-04	.3576E-04	.3614E-04	.3649E-04
CEO2	.5708E-04	.5814E-04	.5911E-04	.5999E-04	.6078E-04	.6151E-04	.6217E-04	.6277E-04
NB2O5	0.	0.	0.	0.	0.	0.	0.	0.
CSI	.1533E-12	.1561E-12	.1587E-12	.1611E-12	.1632E-12	1652E-12	.1670E-12	.1686E-12
CD	0.	0.	0.	0.	0.	0.	0.	0.
OXIDE MELT TEMP(K)	1545.	1541.	1537.	1533.	1530.	1527.	1524.	1521.
SOURCE RATE(GM/S)	.4963E-01	.4672E-01	.4415E-01	.4187E-01	.3983E-01	.3800E-01	.3635E-01	.3484E-01
AEROSOL DENSITY(GM/CM3)	7.095	7.074	7.055	7.037	7.020	7.004	6.989	6.975
AEROSOL SIZE(MICRON)	.8160E-01	.8075E-01	.7997E-01	.7926E-01	.7861E-01	.7800E-01	.7744E-01	.7692E-01

TABLE 4.8. AEROSOL RELEASE DURING CONCRETE ATTACK FOR S_2DC_r (Continued)

SPECIES	TIME	28800.0	30000.0	31200.0	32400.0	33600.0	34800.0	36000.0	37200.0
FEO		.6421	.6563	.6697	.6823	.6943	.7041	.7146	.7249
CR2O3		.1876E-03	.1891E-03	.1903E-03	.1915E-03	.1925E-03	.1934E-03	.1942E-03	.1949E-03
NI		.1509E-01	.1473E-01	.1439E-01	.1408E-01	.1378E-01	.1351E-01	.1325E-01	.1301E-01
MO		.1396E-01	.1404E-01	.1413E-01	.1421E-01	.1428E-01	.1435E-01	.1442E-01	.1449E-01
RU		.9780E-10	.9224E-10	.8723E-10	.8269E-10	.7858E-10	.7483E-10	.7141E-10	.6828E-10
SN		19.94	20.11	20.27	20.43	20.58	20.73	20.88	21.03
SB		0.	0.	0.	0.	0.	0.	0.	0.
TE		29.76	30.01	30.26	30.49	30.71	30.92	31.11	31.30
AG		46.77	46.36	45.96	45.58	45.21	44.86	44.53	44.21
MN		0.	0.	0.	0.	0.	0.	0.	0.
CAO		1.265	1.261	1.256	1.252	1.248	1.243	1.239	1.235
AL2O3		.5485E-05	.5609E-05	.5728E-05	.5843E-05	.5953E-05	.6058E-05	.6160E-05	.6257E-05
NA2O		0.	0.	0.	0.	0.	0.	0.	0.
K2O		0.	0.	0.	0.	0.	0.	0.	0.
SIO2		.4826E-02	.4744E-02	.4671E-02	.4605E-02	.4546E-02	.4494E-02	.4446E-02	.4403E-02
UO2		.7396	.7268	.7145	.7027	.6914	.6805	.6701	.6600
ZRO2		.1954E-02	.1969E-02	.1982E-02	.1994E-02	.2005E-02	.2014E-02	.2022E-02	.2029E-02
CS2O		0.	0.	0.	0.	0.	0.	0.	0.
BAO		.8304	.8267	.8228	.8187	.8145	.8102	.8058	.7971
SRO		.1482E-01	.1464E-01	.1446E-01	.1429E-01	.1412E-01	.1396E-01	.1380E-01	.1364E-01
LA2O3		.3680E-04	.3708E-04	.3733E-04	.3755E-04	.3775E-04	.3793E-04	.3808E-04	.3822E-04
CEO2		.6330E-04	.6379E-04	.6422E-04	.6461E-04	.6495E-04	.6525E-04	.6552E-04	.6575E-04
NB2O5		0.	0.	0.	0.	0.	0.	0.	0.
CSI		.1700E-12	.1713E-12	.1725E-12	.1735E-12	.1744E-12	.1752E-12	.1759E-12	.1766E-12
CD		0.	0.	0.	0.	0.	0.	0.	0.
OXIDE MELT TEMP(K)		1518.	1516.	1514.	1511.	1509.	1507.	1505.	1503.
SOURCE RATE(GM/S)		.3346E-01	.3219E-01	.3102E-01	.2994E-01	.2893E-01	.2799E-01	.2711E-01	.2629E-01
AEROSOL DENSITY(GM/CM3)		6.961	6.949	6.937	6.925	6.915	6.904	6.895	6.885
AEROSOL SIZE(MICRON)		.7644E-01	.7600E-01	.7558E-01	.7519E-01	.7483E-01	.7449E-01	.7418E-01	.7388E-01

TABLE 4.8. AEROSOL RELEASE DURING CONCRETE ATTACK FOR S_2DC_r (Continued)

SPECIES TIME	38400.0	39600.0	40800.0	42000.0	43200.0	44400.0	45600.0	46800.0
FEO	.7344	.7435	.7520	.7601	.7678	.7751	.7820	.7885
CR203	.1955E-03	.1959E-03	.1964E-03	.1967E-03	.1970E-03	.1972E-03	.1974E-03	.1973E-03
NI	.1276E-01	.1256E-01	.1236E-01	.1216E-01	.1198E-01	.1180E-01	.1163E-01	.1148E-01
MO	.1456E-01	.1462E-01	.1468E-01	.1474E-01	.1480E-01	.1485E-01	.1491E-01	.1496E-01
RU	.6540E-10	.6275E-10	.6031E-10	.5804E-10	.5594E-10	.5395E-10	.5211E-10	.5047E-10
SN	21.17	21.30	21.44	21.57	21.70	21.83	21.95	22.08
SB	0.	0.	0.	0.	0.	0.	0.	0.
TE	31.48	31.65	31.81	31.97	32.11	32.26	32.39	32.51
AG	43.90	43.60	43.31	43.04	42.77	42.51	42.26	42.03
MN	0.	0.	0.	0.	0.	0.	0.	0.
CAO	1.230	1.226	1.221	1.216	1.212	1.207	1.203	1.198
AL203	.6351E-05	.6441E-05	.6527E-05	.6609E-05	.6689E-05	.6767E-05	.6841E-05	.6908E-05
NA20	0.	0.	0.	0.	0.	0.	0.	0.
K20	0.	0.	0.	0.	0.	0.	0.	0.
SIO2	.4364E-02	.4328E-02	.4295E-02	.4266E-02	.4238E-02	.2487E-02	.2513E-02	.2537E-02
UO2	.6503	.6410	.6320	.6233	.6149	.6067	.5988	.5911
ZRO2	.2035E-02	.2041E-02	.2045E-02	.2048E-02	.2051E-02	.2054E-02	.2055E-02	.2055E-02
CS20	0.	0.	0.	0.	0.	0.	0.	0.
BAO	.7926	.7880	.7834	.7787	.7740	.7694	.7647	.7598
SRO	.1349E-01	.1334E-01	.1319E-01	.1304E-01	.1290E-01	.1277E-01	.1263E-01	.1250E-01
LA203	.3833E-04	.3843E-04	.3851E-04	.3858E-04	.3863E-04	.3868E-04	.3871E-04	.3870E-04
CEO2	.6594E-04	.6611E-04	.6625E-04	.6636E-04	.6645E-04	.6654E-04	.6659E-04	.6658E-04
NB205	0.	0.	0.	0.	0.	0.	0.	0.
CSI	.1771E-12	.1775E-12	.1779E-12	.1782E-12	.1785E-12	.1787E-12	.1788E-12	.1788E-12
CD	0.	0.	0.	0.	0.	0.	0.	0.
OXIDE MELT TEMP(K)	1501.	1500.	1498.	1496.	1495.	1493.	1492.	1491.
SOURCE RATE(GM/S)	.2553E-01	.2481E-01	.2414E-01	.2351E-01	.2293E-01	.2241E-01	.2190E-01	.2145E-01
AEROSOL DENSITY(GM/CM3)	6.877	6.868	6.860	6.852	6.845	6.838	6.831	6.825
AEROSOL SIZE(MICRON)	.7360E-01	.7334E-01	.7310E-01	.7287E-01	.7265E-01	.7245E-01	.7225E-01	.7208E-01

TABLE 4.8. AEROSOL RELEASE DURING CONCRETE ATTACK FOR S_2DC_r (Continued)

SPECIES TIME	48000.0	49200.0	50400.0	51600.0	52800.0	54000.0	55200.0	56400.0
FEO	.7946	.8005	.8061	.8114	.8164	.8212	.8257	.8299
CR2O3	.1972E-03	.1972E-03	.1972E-03	.1971E-03	.1969E-03	.1968E-03	.1965E-03	.1963E-03
NI	.1134E-01	.1119E-01	.1105E-01	.1092E-01	.1079E-01	.1067E-01	.1055E-01	.1043E-01
MO	.1501E-01	.1506E-01	.1511E-01	.1516E-01	.1520E-01	.1525E-01	.1529E-01	.1534E-01
RU	.4896E-10	.4745E-10	.4603E-10	.4470E-10	.4344E-10	.4225E-10	.4113E-10	.4008E-10
SN	22.19	22.31	22.43	22.55	22.66	22.78	22.89	23.00
SB	0.	0.	0.	0.	0.	0.	0.	0.
TE	32.62	32.74	32.85	32.96	33.07	33.16	33.26	33.35
AG	41.81	41.58	41.36	41.15	40.95	40.74	40.55	40.36
MN	0.	0.	0.	0.	0.	0.	0.	0.
CAO	1.194	1.189	1.185	1.180	1.175	1.171	1.166	1.162
AL2O3	.6971E-05	.7036E-05	.7099E-05	.7160E-05	.7218E-05	.7274E-05	.7327E-05	.7379E-05
NA2O	0.	0.	0.	0.	0.	0.	0.	0.
K2O	0.	0.	0.	0.	0.	0.	0.	0.
SIO2	.2560E-02	.2583E-02	.2606E-02	.2628E-02	.2648E-02	.2669E-02	.2688E-02	.2706E-02
UO2	.5837	.5765	.5694	.5626	.5560	.5496	.5433	.5372
ZRO2	.2054E-02	.2054E-02	.2053E-02	.2052E-02	.2051E-02	.2049E-02	.2047E-02	.2044E-02
CS2O	0.	0.	0.	0.	0.	0.	0.	0.
BAO	.7547	.7500	.7453	.7406	.7359	.7313	.7267	.7221
SRO	.1237E-01	.1224E-01	.1211E-01	.1199E-01	.1187E-01	.1176E-01	.1164E-01	.1153E-01
LA2O3	.3868E-04	.3868E-04	.3867E-04	.3865E-04	.3862E-04	.3859E-04	.3855E-04	.3850E-04
CEO2	.6654E-04	.6654E-04	.6652E-04	.6649E-04	.6644E-04	.6638E-04	.6631E-04	.6623E-04
NB2O5	0.	0.	0.	0.	0.	0.	0.	0.
CSI	.1787E-12	.1787E-12	.1786E-12	.1785E-12	.1784E-12	.1783E-12	.1781E-12	.1779E-12
CD	0.	0.	0.	0.	0.	0.	0.	0.
OXIDE MELT TEMP(K)	1489.	1488.	1487.	1486.	1485.	1484.	1483.	1481.
SOURCE RATE(GM/S)	.2104E-01	.2059E-01	.2015E-01	.1974E-01	.1934E-01	.1896E-01	.1860E-01	.1825E-01
AEROSOL DENSITY(GM/CM3)	6.819	6.813	6.807	6.801	6.796	6.791	6.786	6.781
AEROSOL SIZE(MICRON)	.7193E-01	.7177E-01	.7162E-01	.7147E-01	.7134E-01	.7121E-01	.7109E-01	.7098E-01

TABLE 4.8. AEROSOL RELEASE DURING CONCRETE ATTACK FOR S_2DC_r (Continued)

SPECIES	TIME 57600.0	58800.0	60000.0	61200.0	62400.0	63600.0	64800.0	66000.0
FEO	.8341	.8379	.8414	.8448	.8479	.8508	.8536	.8563
CR2O3	.1963E-03	.1959E-03	.1956E-03	.1951E-03	.1946E-03	.1941E-03	.1936E-03	.1931E-03
NI	.1031E-01	.1021E-01	.1011E-01	.1002E-01	.9932E-02	.9849E-02	.9767E-02	.9687E-02
MO	.1538E-01	.1542E-01	.1547E-01	.1551E-01	.1554E-01	.1558E-01	.1562E-01	.1566E-01
RU	.3895E-10	.3801E-10	.3715E-10	.3633E-10	.3559E-10	.3488E-10	.3419E-10	.3351E-10
SN	23.11	23.22	23.32	23.42	23.52	23.62	23.72	23.82
SB	0.	0.	0.	0.	0.	0.	0.	0.
TE	33.45	33.53	33.61	33.68	33.74	33.80	33.86	33.92
AG	40.15	39.98	39.81	39.65	39.49	39.35	39.20	39.05
MN	0.	0.	0.	0.	0.	0.	0.	0.
CAO	1.157	1.153	1.149	1.144	1.140	1.136	1.131	1.127
AL2O3	.7437E-05	.7484E-05	.7527E-05	.7567E-05	.7604E-05	.7639E-05	.7673E-05	.7707E-05
NA2O	0.	0.	0.	0.	0.	0.	0.	0.
K2O	0.	0.	0.	0.	0.	0.	0.	0.
SIO2	.2727E-02	.2744E-02	.2759E-02	.2773E-02	.2786E-02	.2799E-02	.2811E-02	.2823E-02
UO2	.5313	.5255	.5199	.5144	.5090	.5038	.4987	.4938
ZRO2	.2044E-02	.2041E-02	.2037E-02	.2032E-02	.2027E-02	.2021E-02	.2016E-02	.2011E-02
CS2O	0.	0.	0.	0.	0.	0.	0.	0.
BAO	.7180	.7135	.7089	.7042	.6996	.6949	.6904	.6859
SRO	.1142E-01	.1131E-01	.1121E-01	.1110E-01	.1100E-01	.1090E-01	.1080E-01	.1070E-01
LA2O3	.3849E-04	.3843E-04	.3835E-04	.3827E-04	.3817E-04	.3807E-04	.3796E-04	.3786E-04
CEO2	.6622E-04	.6611E-04	.6598E-04	.6583E-04	.6566E-04	.6548E-04	.6531E-04	.6514E-04
NB2O5	0.	0.	0.	0.	0.	0.	0.	0.
CSI	.1778E-12	.1775E-12	.1772E-12	.1768E-12	.1763E-12	.1759E-12	.1754E-12	.1749E-12
CD	0.	0.	0.	0.	0.	0.	0.	0.
OXIDE MELT TEMP(K)	1480.	1479.	1478.	1478.	1477.	1476.	1475.	1474.
SOURCE RATE(GM/S)	.1789E-01	.1758E-01	.1729E-01	.1702E-01	.1677E-01	.1654E-01	.1631E-01	.1609E-01
AEROSOL DENSITY(GM/CM3)	6.775	6.771	6.767	6.763	6.759	6.755	6.752	6.748
AEROSOL SIZE(MICRON)	.7084E-01	.7074E-01	.7065E-01	.7057E-01	.7050E-01	.7044E-01	.7038E-01	.7032E-01

TABLE 4.8. AEROSOL RELEASE DURING CONCRETE ATTACK FOR S_2DC_r (Continued)

SPECIES	TIME 67200.0	68400.0	69600.0	70800.0	72000.0	73200.0	74400.0	75600.0
FEO	.8588	.8612	.8634	.8655	.8675	.8693	.8710	.8726
CR2O3	.1926E-03	.1921E-03	.1917E-03	.1912E-03	.1906E-03	.1901E-03	.1895E-03	.1890E-03
NI	.9605E-02	.9525E-02	.9449E-02	.9375E-02	.9304E-02	.9235E-02	.9169E-02	.9106E-02
MO	.1569E-01	.1573E-01	.1577E-01	.1580E-01	.1584E-01	.1587E-01	.1591E-01	.1594E-01
RU	.3284E-10	.3219E-10	.3157E-10	.3098E-10	.3042E-10	.2989E-10	.2938E-10	.2889E-10
SN	23.92	24.02	24.11	24.21	24.30	24.40	24.49	24.58
SB	0.	0.	0.	0.	0.	0.	0.	0.
TE	33.99	34.05	34.10	34.16	34.21	34.26	34.30	34.35
AG	38.90	38.76	38.61	38.47	38.34	38.21	38.08	37.96
MN	0.	0.	0.	0.	0.	0.	0.	0.
CAO	1.123	1.119	1.114	1.110	1.106	1.102	1.098	1.094
AL2O3	.7742E-05	.7776E-05	.7808E-05	.7839E-05	.7868E-05	.7895E-05	.7921E-05	.7945E-05
NA2O	0.	0.	0.	0.	0.	0.	0.	0.
K2O	0.	0.	0.	0.	0.	0.	0.	0.
SIO2	.2835E-02	.2847E-02	.2859E-02	.2870E-02	.2880E-02	.2890E-02	.2899E-02	.2907E-02
UO2	.4889	.4841	.4795	.4749	.4704	.4661	.4619	.4577
ZRO2	.2006E-02	.2001E-02	.1996E-02	.1991E-02	.1985E-02	.1980E-02	.1974E-02	.1968E-02
CS2O	0.	0.	0.	0.	0.	0.	0.	0.
BAO	.6816	.6774	.6732	.6690	.6649	.6607	.6567	.6527
SRO	.1061E-01	.1052E-01	.1042E-01	.1033E-01	.1025E-01	.1016E-01	.1008E-01	.9994E-02
LA2O3	.3777E-04	.3768E-04	.3759E-04	.3749E-04	.3739E-04	.3728E-04	.3717E-04	.3706E-04
CEO2	.6498E-04	.6483E-04	.6466E-04	.6449E-04	.6432E-04	.6413E-04	.6395E-04	.6375E-04
NB2O5	0.	0.	0.	0.	0.	0.	0.	0.
CSI	.1745E-12	.1741E-12	.1736E-12	.1732E-12	.1727E-12	.1722E-12	.1717E-12	.1712E-12
CD	0.	0.	0.	0.	0.	0.	0.	0.
OXIDE MELT TEMP(K)	1474.	1473.	1472.	1471.	1471.	1470.	1469.	1469.
SOURCE RATE(GM/S)	.1586E-01	.1564E-01	.1541E-01	.1519E-01	.1495E-01	.1470E-01	.1443E-01	.1416E-01
AEROSOL DENSITY(GM/CM3)	8.745	8.741	8.738	8.734	8.731	8.728	8.725	8.722
AEROSOL SIZE(MICRON)	.7025E-01	.7019E-01	.7013E-01	.7007E-01	.7002E-01	.6998E-01	.6994E-01	.6990E-01

TABLE 4.8. AEROSOL RELEASE DURING CONCRETE ATTACK FOR S_2DC_r (Continued)

SPECIES	TIME 76800.0	78000.0	79200.0	80400.0	81600.0	82800.0	84000.0	85200.0
FEO	.8740	.8754	.8784	.8835	.8849	.8857	.8865	.8872
CR2O3	.1884E-03	.1878E-03	.1901E-03	.1964E-03	.1967E-03	.1962E-03	.1958E-03	.1954E-03
NI	.9045E-02	.8986E-02	.8779E-02	.8383E-02	.8301E-02	.8255E-02	.8212E-02	.8170E-02
MO	.1597E-01	.1601E-01	.1607E-01	.1616E-01	.1619E-01	.1622E-01	.1624E-01	.1627E-01
RU	.2843E-10	.2799E-10	.2644E-10	.2381E-10	.2305E-10	.2275E-10	.2246E-10	.2219E-10
SN	24.67	24.75	24.92	25.18	25.27	25.35	25.42	25.49
SB	0.	0.	0.	0.	0.	0.	0.	0.
TE	34.39	34.43	34.66	35.15	35.23	35.26	35.29	35.32
AG	37.84	37.72	37.33	36.58	36.41	36.31	36.22	36.13
MN	0.	0.	0.	0.	0.	0.	0.	0.
CAO	1.090	1.086	1.081	1.075	1.072	1.068	1.065	1.062
AL2O3	.7968E-05	.7989E-05	.8132E-05	.8447E-05	.8498E-05	.8517E-05	.8535E-05	.8552E-05
NA2O	0.	0.	0.	0.	0.	0.	0.	0.
K2O	0.	0.	0.	0.	0.	0.	0.	0.
SIO2	.2915E-02	.2923E-02	.2975E-02	.3090E-02	.3108E-02	.3115E-02	.3121E-02	.3127E-02
UO2	.4537	.4498	.4458	.4417	.4385	.4355	.4326	.4298
ZRO2	.1962E-02	.1956E-02	.1980E-02	.2046E-02	.2048E-02	.2044E-02	.2039E-02	.2035E-02
CS2O	0.	0.	0.	0.	0.	0.	0.	0.
BAO	.6487	.6448	.6461	.6546	.6526	.6496	.6466	.6438
SRO	.9913E-02	.9834E-02	.9782E-02	.9767E-02	.9707E-02	.9647E-02	.9588E-02	.9530E-02
LA2O3	.3695E-04	.3684E-04	.3726E-04	.3852E-04	.3857E-04	.3849E-04	.3840E-04	.3832E-04
CEO2	.6356E-04	.6337E-04	.6413E-04	.6627E-04	.6636E-04	.6621E-04	.6606E-04	.6592E-04
NB2O5	0.	0.	0.	0.	0.	0.	0.	0.
CSI	.1707E-12	.1702E-12	.1722E-12	.1780E-12	.1782E-12	.1778E-12	.1774E-12	.1770E-12
CD	0.	0.	0.	0.	0.	0.	0.	0.
OXIDE MELT TEMP(K)	1468.	1467.	1465.	1461.	1460.	1459.	1459.	1459.
SOURCE RATE(GM/S)	.1389E-01	.1362E-01	.1255E-01	.1090E-01	.1023E-01	.9989E-02	.9771E-02	.9565E-02
AEROSOL DENSITY(GM/CM3)	6.720	6.717	6.706	6.685	6.680	6.678	6.676	6.674
AEROSOL SIZE(MICRON)	.6987E-01	.6984E-01	.6946E-01	.6862E-01	.6851E-01	.6848E-01	.6845E-01	.6843E-01

TABLE 4.8. AEROSOL RELEASE DURING CONCRETE ATTACK FOR S_2DC_r (Continued)

SPECIES	TIME 86400.0	87600.0	88800.0	90000.0
FEO	.8878	.8884	.8890	.8894
CR2O3	.1949E-03	.1945E-03	.1941E-03	.1937E-03
NI	.8129E-02	.8089E-02	.8051E-02	.8014E-02
MO	.1629E-01	.1631E-01	.1634E-01	.1636E-01
RU	.2192E-10	.2167E-10	.2142E-10	.2119E-10
SN	25.55	25.62	25.68	25.75
SB	0.	0.	0.	0.
TE	35.35	35.38	35.40	35.43
AG	36.04	35.96	35.87	35.79
MN	0.	0.	0.	0.
CAO	1.059	1.056	1.053	1.051
AL2O3	.8568E-05	.8584E-05	.8599E-05	.8613E-05
NA2O	0.	0.	0.	0.
K2O	0.	0.	0.	0.
SIO2	.3133E-02	.3138E-02	.3143E-02	.3148E-02
UO2	.4271	.4245	.4219	.4194
ZRO2	.2030E-02	.2026E-02	.2021E-02	.2017E-02
CS2O	0.	0.	0.	0.
BAO	.6409	.6382	.6355	.6328
SRO	.9474E-02	.9419E-02	.9366E-02	.9314E-02
LA2O3	.3823E-04	.3815E-04	.3807E-04	.3798E-04
CEO2	.6577E-04	.6563E-04	.6548E-04	.6534E-04
NB2O5	0.	0.	0.	0.
CSI	.1766E-12	.1762E-12	.1759E-12	.1755E-12
CD	0.	0.	0.	0.
OXIDE MELT TEMP(K)	1458.	1458.	1457.	1457.
SOURCE RATE(GM/S)	.9344E-02	.9136E-02	.8938E-02	.8834E-02
AEROSOL DENSITY(GM/CM3)	6.672	6.670	6.668	6.667
AEROSOL SIZE(MICRON)	.6841E-01	.6839E-01	.6837E-01	.6835E-01

TABLE 4.9. AEROSOL RELEASE DURING CONCRETE ATTACK FOR S_2DCF_1

SPECIES TIME	.0	1200.0	2400.0	3600.0	4800.0	6000.0	7200.0	8400.0
FEO	.5802E-15	.2324E-04	.2076E-02	.1630E-02	.5930E-02	.5604E-02	.1505E-01	.5187E-01
CR2O3	.5195E-23	.7542E-20	.2273E-17	.4700E-02	.6646E-02	.2996E-02	.3872E-03	.4671E-03
NI	.7635E-03	.8035E-01	.4934	.1319E-01	.1343E-01	.1405E-01	.1756E-01	.2411E-01
MO	.3418E-11	.1091E-07	.3072E-06	.1052E-06	.4973E-06	.4911E-05	.2562E-02	.3929E-02
RU	.2678E-10	.8003E-07	.2188E-05	.2062E-08	.1201E-08	.1005E-08	.1148E-08	.1432E-08
SN	.3419	1.080	1.666	.9698	1.755	2.411	4.569	6.880
SB	0.	0.	0.	0.	0.	0.	0.	0.
TE	.4880	1.205	1.361	1.171	2.092	2.747	3.589	5.359
AG	1.181	20.34	24.51	8.799	12.09	14.25	18.18	26.21
MN	0.	0.	0.	0.	0.	0.	0.	0.
CAO	0.	.9241	17.86	.1330E-01	.3039E-01	.4674E-01	.1316	.2001
AL2O3	0.	.5796E-04	.1386	.9620E-08	.3834E-07	.6319E-07	.9487E-07	.1583E-06
NA2O	0.	0.	0.	0.	0.	0.	0.	0.
K2O	0.	0.	0.	0.	0.	0.	0.	0.
SIO2	0.	24.12	17.45	.3975E-01	.3246E-01	.1889E-01	.4785E-02	.6414E-02
UO2	.2009E-03	.2600E-01	.2083	.1341E-01	.1745E-01	.3263E-01	.2744	.3521
ZRO2	.1603E-04	.1689E-03	.2440E-02	.2690E-04	.5155E-04	.6995E-04	.8873E-04	.1266E-03
CS2O	.4839	.2319	.1277	.4466	.4204	.4029	.3661	.3043
BAO	.3402	2.636	2.776	.6912E-02	.1365E-01	.2657E-01	.1077	.1465
SRO	.9876	2.949	3.544	.4994E-03	.6758E-03	.1046E-02	.3769E-02	.5005E-02
LA2O3	.3647E-06	.2143E-01	.2264	.5076E-06	.9730E-06	.1320E-05	.1675E-05	.2390E-05
CEO2	.8888E-03	.1169	.7632	.8758E-06	.1679E-05	.2278E-05	.2889E-05	.4123E-05
NB2O5	.3442E-08	.2119E-08	3.241	.7047E-09	.1351E-08	.1833E-08	.2326E-08	.3317E-08
CSI	.3993E-01	.1994	.2642	.1962E-14	.3760E-14	.5102E-14	.6471E-14	.9234E-14
CD	96.14	46.08	25.37	86.52	83.52	80.04	72.73	60.45
OXIDE MELT TEMP(K)	1656.	2039.	2274.	1807.	1747.	1725.	1716.	1707.
SOURCE RATE(GM/S)	1.525	7.645	290.8	63.47	10.50	7.410	5.937	3.832
AEROSOL DENSITY(GM/CM3)	3.785	3.710	3.818	3.979	4.092	4.173	4.351	4.700
AEROSOL SIZE(MICRON)	.6364	.8051	.9628	.5353	.3964	.3462	.3078	.2599

TABLE 4.9. AEROSOL RELEASE DURING CONCRETE ATTACK FOR S_2DCF_1 (Continued)

SPECIES	TIME	9800.0	10800.0	12000.0	13200.0	14400.0	15600.0	18800.0	18000.0
FEO		.1197	.2374	.2737	.3017	.3228	.3380	.3481	.3538
CR2O3		.6303E-03	.8583E-03	.7297E-03	.6212E-03	.5287E-03	.4488E-03	.3114E-03	.2855E-03
NI		.3659E-01	.5575E-01	.5326E-01	.5085E-01	.4857E-01	.4634E-01	.4422E-01	.4241E-01
MO		.6550E-02	.1093E-01	.1144E-01	.1201E-01	.1264E-01	.1336E-01	.1418E-01	.1510E-01
RU		.2010E-08	.2848E-08	.2535E-08	.2255E-08	.2009E-08	.1787E-08	.1591E-08	.1435E-08
SN		11.30	18.58	19.14	19.74	20.39	21.09	21.85	22.63
SB		0.	0.	0.	0.	0.	0.	0.	0.
TE		8.886	14.04	14.19	14.33	14.44	14.54	14.62	14.63
AG		41.42	65.49	64.84	64.16	63.46	62.71	61.94	61.22
MN		0.	0.	0.	0.	0.	0.	0.	0.
CAO		.3273	.5298	.5323	.5311	.5265	.5191	.5091	.4967
AL2O3		.2795E-06	.4846E-06	.5195E-06	.5517E-06	.5804E-06	.6064E-06	.6285E-06	.6427E-06
NA2O		0.	0.	0.	0.	0.	0.	0.	0.
K2O		0.	0.	0.	0.	0.	0.	0.	0.
SIO2		.9455E-02	.1387E-01	.1266E-01	.1145E-01	.1030E-01	.9189E-02	.8151E-02	.7251E-02
UO2		.4991	.7117	.6384	.5745	.5187	.4695	.4260	.3879
ZRO2		.1954E-03	.3006E-03	.2892E-03	.2782E-03	.2672E-03	.2566E-03	.2458E-03	.2337E-03
CS2O		.1872	0.	0.	0.	0.	0.	0.	0.
BAO		.2174	.3230	.3011	.2812	.2628	.2460	.2302	.2147
SRO		.7283E-02	.1063E-01	.9730E-02	.8927E-02	.8199E-02	.7540E-02	.6935E-02	.6118E-02
LA2O3		.3688E-05	.5673E-05	.5458E-05	.5251E-05	.5043E-05	.4843E-05	.4640E-05	.4410E-05
CEO2		.6382E-05	.9787E-05	.9417E-05	.9059E-05	.8701E-05	.8355E-05	.8005E-05	.7609E-05
NB2O5		.5119E-08	.7875E-08	.7577E-08	.7289E-08	.7001E-08	.6723E-08	.6441E-08	.6122E-08
CSI		.1426E-13	.2192E-13	.2109E-13	.2029E-13	.1949E-13	.1871E-13	.1793E-13	.1704E-13
CD		37.18	0.	0.	0.	0.	0.	0.	0.
OXIDE MELT TEMP(K)		1699.	1692.	1686.	1679.	1672.	1666.	1659.	1654.
SOURCE RATE(GM/S)		2.341	1.444	1.428	1.414	1.406	1.400	1.389	1.391
AEROSOL DENSITY(GM/CM3)		5.540	7.747	7.725	7.703	7.681	7.658	7.636	7.617
AEROSOL SIZE(MICRON)		.2080	.1577	.1565	.1556	.1548	.1542	.1538	.1539

TABLE 4.9. AEROSOL RELEASE DURING CONCRETE ATTACK FOR S_2DCF_1 (Continued)

SPECIES TIME	19200.0	20400.0	21600.0	22800.0	24000.0	25200.0	26400.0	27600.0
FEO	.3553	.3532	.3483	.3417	.3328	.3221	.3099	.2968
CR2O3	.2259E-03	.1935E-03	.1649E-03	.1361E-03	.1121E-03	.9144E-04	.1414E-04	.1293E-04
NI	.4068E-01	.3935E-01	.3808E-01	.3620E-01	.3454E-01	.3297E-01	.3152E-01	.3021E-01
MO	.1617E-01	.1741E-01	.1894E-01	.2099E-01	.2361E-01	.2713E-01	.3207E-01	.3941E-01
RU	.1296E-08	.1196E-08	.1106E-08	.9787E-09	.8753E-09	.7837E-09	.7045E-09	.6365E-09
SN	23.46	24.31	25.22	26.37	27.59	28.92	30.38	31.98
SB	0.	0.	0.	0.	0.	0.	0.	0.
TE	14.62	14.50	14.35	14.29	14.16	13.98	13.74	13.42
AG	60.46	59.79	59.10	58.07	57.04	55.94	54.78	53.56
MN	0.	0.	0.	0.	0.	0.	0.	0.
CAO	.4826	.4664	.4489	.4305	.4111	.3911	.3707	.3504
AL2O3	.6525E-06	.6514E-06	.6450E-06	.6472E-06	.6410E-06	.6291E-06	.6107E-06	.5858E-06
NA2O	0.	0.	0.	0.	0.	0.	0.	0.
K2O	0.	0.	0.	0.	0.	0.	0.	0.
SIO2	.6416E-02	.5717E-02	.5062E-02	.4315E-02	.3689E-02	.3089E-02	.2572E-02	.2115E-02
UO2	.3543	.3245	.2979	.2730	.2520	.2339	.2188	.2071
ZRO2	.2216E-03	.2074E-03	.1932E-03	.1829E-03	.1714E-03	.1596E-03	.1473E-03	.1347E-03
CS2O	0.	0.	0.	0.	0.	0.	0.	0.
BAO	.2003	.1856	.1717	.1605	.1494	.1384	.1284	.1169
SRO	.5632E-02	.5165E-02	.4730E-02	.4353E-02	.3994E-02	.3660E-02	.3350E-02	.3064E-02
LA2O3	.4183E-05	.3915E-05	.3647E-05	.3462E-05	.3235E-05	.3012E-05	.2780E-05	.2542E-05
CEO2	.7216E-05	.6755E-05	.6293E-05	.5956E-05	.5580E-05	.5196E-05	.4797E-05	.4386E-05
NB2O5	.5807E-08	.5435E-08	.5063E-08	.4793E-08	.4490E-08	.4181E-08	.3880E-08	.3529E-08
CSI	.1616E-13	.1513E-13	.1409E-13	.1334E-13	.1250E-13	.1164E-13	.1074E-13	.9824E-14
CD	0.	0.	0.	0.	0.	0.	0.	0.
OXIDE MELT TEMP(K)	1648.	1644.	1640.	1634.	1628.	1623.	1618.	1613.
SOURCE RATE(GM/S)	1.409	1.454	1.512	1.537	1.576	1.631	1.698	1.786
AEROSOL DENSITY(GM/CM3)	7.597	7.582	7.567	7.542	7.518	7.493	7.468	7.443
AEROSOL SIZE(MICRON)	.1543	.1554	.1569	.1576	.1589	.1607	.1630	.1660

TABLE 4.9. AEROSOL RELEASE DURING CONCRETE ATTACK FOR S_2DCF_1 (Continued)

SPECIES TIME	28800.0	30000.0	31200.0	32400.0	33800.0	34800.0	38000.0
FEO	.2834	.2704	.2590	.2502	.2448	.2369	.1971
CR2O3	.1171E-04	.1051E-04	.9342E-05	.8205E-05	.7113E-05	.5956E-05	.4299E-05
NI	.2903E-01	.2795E-01	.2703E-01	.2647E-01	.2658E-01	.2810E-01	.2997E-01
MO	.5116E-01	.7202E-01	.1147	.2209	.5724	2.272	13.01
RU	.5776E-09	.5236E-09	.4736E-09	.4292E-09	.3876E-09	.3520E-09	.3179E-09
SN	33.73	35.69	37.93	40.53	43.69	47.49	48.59
SB	0.	0.	0.	0.	0.	0.	0.
TE	13.03	12.56	12.00	11.32	10.46	9.168	6.787
AG	52.24	50.76	49.07	47.05	44.37	40.04	30.52
MN	0.	0.	0.	0.	0.	0.	0.
CAO	.3308	.3125	.2965	.2839	.2749	.2605	.2170
AL2O3	.5552E-06	.5206E-06	.4826E-06	.4414E-06	.3979E-06	.3460E-06	.2591E-06
NA2O	0.	0.	0.	0.	0.	0.	0.
K2O	0.	0.	0.	0.	0.	0.	0.
SIO2	.1710E-02	.1345E-02	.1020E-02	.7368E-03	.4963E-03	.3045E-03	.1593E-03
UO2	.1995	.1974	.2038	.2253	.2774	.3930	.5757
ZRO2	.1220E-03	.1095E-03	.9729E-04	.8544E-04	.7407E-04	.6202E-04	.4477E-04
CS2O	0.	0.	0.	0.	0.	0.	0.
BAO	.1101	.1023	.9573E-01	.9063E-01	.8709E-01	.8297E-01	.6776E-01
SRO	.2806E-02	.2579E-02	.2388E-02	.2237E-02	.2128E-02	.2007E-02	.1626E-02
LA2O3	.2302E-05	.2066E-05	.1836E-05	.1613E-05	.1398E-05	.1171E-05	.8450E-06
CEO2	.3972E-05	.3565E-05	.3168E-05	.2782E-05	.2412E-05	.2020E-05	.1458E-05
NB2O5	.3196E-08	.2868E-08	.2549E-08	.2239E-08	.1941E-08	.1625E-08	.1173E-08
CSI	.8895E-14	.7984E-14	.7096E-14	.6232E-14	.5403E-14	.4524E-14	.3265E-14
CD	0.	0.	0.	0.	0.	0.	0.
OXIDE MELT TEMP(K)	1609.	1605.	1600.	1596.	1592.	1588.	1585.
SOURCE RATE(GM/S)	1.904	2.057	2.243	2.481	2.788	3.236	4.357
AEROSOL DENSITY(GM/CM3)	7.416	7.387	7.354	7.317	7.272	7.226	7.282
AEROSOL SIZE(MICRON)	.1697	.1741	.1793	.1854	.1928	.2029	.2233

FIGURE 4.10. AEROSOL RELEASE DURING CONCRETE ATTACK FOR S_2DCF_2

SPECIES	TIME .0	1200.0	2400.0	3600.0	4800.0	6000.0	7200.0	8400.0
FEO	.1678E-11	.3482E-01	.4547E-01	.3889E-01	.3184E-01	.3699E-01	.9194E-01	.1437
CR2O3	.5144E-18	.4060E-18	.9964E-20	.2442E-01	.9009E-02	.1278E-02	.7341E-03	.6428E-03
NI	.7770	.2036	.4717E-02	.5078E-01	.4423E-01	.3889E-01	.3525E-01	.3223E-01
MO	.7469E-06	.1025E-06	.6779E-10	.3491E-05	.3755E-04	.3789E-02	.1043E-01	.1018E-01
RU	.5277E-05	.7336E-06	.5194E-09	.1889E-08	.1361E-08	.1017E-08	.7980E-09	.6417E-09
SN	1.474	.5767	.2735	9.789	10.99	14.03	15.61	16.05
SB	0.	0.	0.	0.	0.	0.	0.	0.
TE	1.344	.6371	.5529	19.02	20.25	20.35	20.89	21.89
AG	30.39	22.64	3.634	70.17	67.56	62.80	60.15	58.85
MN	0.	0.	0.	0.	0.	0.	0.	0.
CAO	0.	23.41	16.93	.4543	.5901	1.146	1.236	1.178
AL2O3	0.	.3639	.1322E-03	.1382E-05	.1683E-05	.1854E-05	.2059E-05	.2308E-05
NA2O	0.	0.	0.	0.	0.	0.	0.	0.
K2O	0.	0.	0.	0.	0.	0.	0.	0.
SIO2	0.	24.98	77.38	.2002	.6895E-01	.2215E-01	.1417E-01	.1232E-01
UO2	.6670	.1250	.1102E-02	.1043	.1659	.8838	1.191	1.087
ZRO2	.7558E-02	.1172E-02	.2014E-04	.9693E-03	.1055E-02	.1099E-02	.1159E-02	.1243E-02
CS2O	.1589	.1028	0.	0.	0.	0.	0.	0.
BAO	6.679	2.736	.4194	.1423	.2452	.6678	.7526	.7232
SRO	9.694	3.072	.7613	.4449E-02	.6794E-02	.1594E-01	.1747E-01	.1629E-01
LA2O3	.8603	.1536	.4176E-06	.1825E-04	.1986E-04	.2068E-04	.2182E-04	.2339E-04
CEO2	3.385	.6110	.3719E-02	.3138E-04	.3416E-04	.3556E-04	.3753E-04	.4022E-04
NB2O5	12.48	0.	0.	0.	0.	0.	0.	0.
CSI	.6292	.6645E-04	.1834E-14	.8007E-13	.8715E-13	.9074E-13	.9576E-13	.1026E-12
CD	31.46	20.36	0.	0.	0.	0.	0.	0.
OXIDE MELT TEMP(K)	2352.	2238.	1769.	1661.	1643.	1630.	1618.	1607.
SOURCE RATE(GM/S)	114.3	595.7	103.6	.4471	.2064	.1712	.1583	.1365
AEROSOL DENSITY(GM/CM3)	4.981	3.514	2.511	7.764	7.673	7.502	7.423	7.379
AEROSOL SIZE(MICRON)	.8202	1.016	.6221	.1097	.1047	.1027	.1000	.9688E-01

FIGURE 4.10. AEROSOL RELEASE DURING CONCRETE ATTACK FOR S_2DCF_2 (Continued)

SPECIES TIME	9600.0	10800.0	12000.0	13200.0	14400.0	15600.0	16800.0	18000.0
FEO	.2075	.2516	.2921	.3293	.3636	.3953	.4247	.4521
CR2O3	.5740E-03	.1321E-03	.1383E-03	.1439E-03	.1489E-03	.1535E-03	.1577E-03	.1614E-03
NI	.2991E-01	.2782E-01	.2604E-01	.2452E-01	.2320E-01	.2204E-01	.2102E-01	.2012E-01
MO	.1129E-01	.1155E-01	.1179E-01	.1200E-01	.1220E-01	.1238E-01	.1254E-01	.1269E-01
RU	.5312E-09	.4443E-09	.3779E-09	.3260E-09	.2847E-09	.2513E-09	.2240E-09	.2012E-09
SN	16.38	16.72	17.04	17.34	17.63	17.90	18.15	18.40
SB	0.	0.	0.	0.	0.	0.	0.	0.
TE	22.72	23.55	24.31	25.00	25.64	26.22	26.76	27.26
AG	57.47	56.28	55.19	54.18	53.25	52.39	51.59	50.84
MN	0.	0.	0.	0.	0.	0.	0.	0.
CAO	1.268	1.273	1.276	1.278	1.278	1.278	1.277	1.275
AL2O3	.2521E-05	.2751E-05	.2973E-05	.3187E-05	.3393E-05	.3591E-05	.3781E-05	.3964E-05
NA2O	0.	0.	0.	0.	0.	0.	0.	0.
K2O	0.	0.	0.	0.	0.	0.	0.	0.
SIO2	.1090E-01	.9775E-02	.8884E-02	.8166E-02	.7579E-02	.7094E-02	.6689E-02	.6348E-02
UO2	1.098	1.058	1.022	.9890	.9593	.9320	.9068	.8834
ZRO2	.1306E-02	.1376E-02	.1440E-02	.1498E-02	.1551E-02	.1599E-02	.1642E-02	.1681E-02
CS2O	0.	0.	0.	0.	0.	0.	0.	0.
BAO	.7887	.8002	.8091	.8157	.8205	.8238	.8258	.8267
SRO	.1738E-01	.1721E-01	.1702E-01	.1682E-01	.1662E-01	.1641E-01	.1620E-01	.1598E-01
LA2O3	.2457E-04	.2590E-04	.2711E-04	.2820E-04	.2918E-04	.3008E-04	.3091E-04	.3164E-04
CEO2	.4226E-04	.4455E-04	.4662E-04	.4850E-04	.5020E-04	.5175E-04	.5315E-04	.5442E-04
NB2O5	0.	0.	0.	0.	0.	0.	0.	0.
CSI	.1078E-12	.1137E-12	.1190E-12	.1238E-12	.1281E-12	.1320E-12	.1356E-12	.1389E-12
CD	0.	0.	0.	0.	0.	0.	0.	0.
OXIDE MELT TEMP(K)	1598.	1589.	1581.	1574.	1567.	1561.	1556.	1551.
SOURCE RATE(GM/S)	.1089	.9873E-01	.8672E-01	.7853E-01	.7170E-01	.6596E-01	.6107E-01	.5687E-01
AEROSOL DENSITY(GM/CM3)	7.322	7.278	7.239	7.204	7.172	7.143	7.116	7.091
AEROSOL SIZE(MICRON)	.9481E-01	.9233E-01	.9036E-01	.8864E-01	.8713E-01	.8579E-01	.8459E-01	.8351E-01

FIGURE 4.10. AEROSOL RELEASE DURING CONCRETE ATTACK FOR S_2DCF_2 (Continued)

SPECIES	TIME 19200.0	20400.0	21600.0	22800.0	24000.0	25200.0	26400.0	27600.0
FEO	.4775	.5012	.5234	.5442	.5637	.5820	.5991	.6153
CR2O3	.1648E-03	.1680E-03	.1708E-03	.1733E-03	.1757E-03	.1777E-03	.1796E-03	.1813E-03
NI	.1930E-01	.1857E-01	.1791E-01	.1731E-01	.1675E-01	.1625E-01	.1578E-01	.1536E-01
MO	.1283E-01	.1297E-01	.1309E-01	.1321E-01	.1332E-01	.1342E-01	.1352E-01	.1361E-01
RU	.1820E-09	.1657E-09	.1518E-09	.1397E-09	.1291E-09	.1199E-09	.1118E-09	.1046E-09
SN	18.63	18.86	19.07	19.28	19.48	19.68	19.87	20.05
SB	0.	0.	0.	0.	0.	0.	0.	0.
TE	27.73	28.16	28.57	28.95	29.31	29.65	29.96	30.26
AG	50.14	49.48	48.86	48.28	47.72	47.20	46.70	46.23
MN	0.	0.	0.	0.	0.	0.	0.	0.
CAO	1.273	1.271	1.268	1.264	1.261	1.257	1.253	1.249
AL2O3	.4140E-05	.4309E-05	.4471E-05	.4627E-05	.4778E-05	.4922E-05	.5060E-05	.5193E-05
NA2O	0.	0.	0.	0.	0.	0.	0.	0.
K2O	0.	0.	0.	0.	0.	0.	0.	0.
SIO2	.6058E-02	.5809E-02	.5595E-02	.5409E-02	.5247E-02	.5106E-02	.4982E-02	.4872E-02
UO2	.8616	.8412	.8221	.8040	.7869	.7707	.7553	.7407
ZRO2	.1717E-02	.1749E-02	.1778E-02	.1805E-02	.1829E-02	.1851E-02	.1871E-02	.1888E-02
CS2O	0.	0.	0.	0.	0.	0.	0.	0.
BAO	.8267	.8260	.8246	.8226	.8201	.8172	.8140	.8104
SRO	.1577E-01	.1556E-01	.1536E-01	.1515E-01	.1495E-01	.1475E-01	.1456E-01	.1437E-01
LA2O3	.3231E-04	.3292E-04	.3346E-04	.3398E-04	.3443E-04	.3484E-04	.3521E-04	.3554E-04
CEO2	.5557E-04	.5682E-04	.5757E-04	.5844E-04	.5922E-04	.5992E-04	.6055E-04	.6112E-04
NB2O5	0.	0.	0.	0.	0.	0.	0.	0.
CSI	.1418E-12	.1445E-12	.1469E-12	.1491E-12	.1511E-12	.1529E-12	.1545E-12	.1559E-12
CD	0.	0.	0.	0.	0.	0.	0.	0.
OXIDE MELT TEMP(K)	1547.	1542.	1538.	1535.	1531.	1528.	1525.	1522.
SOURCE RATE(GM/S)	.5326E-01	.5011E-01	.4734E-01	.4488E-01	.4268E-01	.4070E-01	.3890E-01	.3725E-01
AEROSOL DENSITY(GM/CM3)	7.068	7.048	7.028	7.008	6.990	6.974	6.959	6.944
AEROSOL SIZE(MICRON)	.8254E-01	.8165E-01	.8085E-01	.8011E-01	.7943E-01	.7881E-01	.7824E-01	.7771E-01

FIGURE 4.10. AEROSOL RELEASE DURING CONCRETE ATTACK FOR S_2DCF_2 (Continued)

SPECIES TIME	28800.0	30000.0	31200.0	32400.0	33600.0	34800.0	36000.0	37200.0
FEO	.8305	.8447	.8582	.8708	.8828	.8940	.7031	.7132
CR2O3	.1828E-03	.1841E-03	.1853E-03	.1863E-03	.1872E-03	.1880E-03	.1886E-03	.1892E-03
NI	.1498E-01	.1459E-01	.1425E-01	.1393E-01	.1364E-01	.1336E-01	.1310E-01	.1285E-01
MO	.1370E-01	.1378E-01	.1386E-01	.1394E-01	.1401E-01	.1408E-01	.1415E-01	.1422E-01
RU	.9822E-10	.9250E-10	.8737E-10	.8274E-10	.7856E-10	.7475E-10	.7129E-10	.6812E-10
SN	20.23	20.40	20.57	20.73	20.89	21.04	21.20	21.34
SB	0.	0.	0.	0.	0.	0.	0.	0.
TE	30.53	30.80	31.05	31.28	31.50	31.71	31.91	32.10
AG	45.78	45.35	44.95	44.56	44.19	43.83	43.50	43.17
MN	0.	0.	0.	0.	0.	0.	0.	0.
CAO	1.244	1.240	1.235	1.231	1.226	1.221	1.217	1.212
AL2O3	.5320E-05	.5441E-05	.5558E-05	.5670E-05	.5777E-05	.5880E-05	.5978E-05	.6073E-05
NA2O	0.	0.	0.	0.	0.	0.	0.	0.
K2O	0.	0.	0.	0.	0.	0.	0.	0.
SIO2	.4775E-02	.4689E-02	.4613E-02	.4544E-02	.4483E-02	.4427E-02	.4377E-02	.4332E-02
UO2	.7268	.7135	.7008	.6886	.6770	.6658	.6551	.6448
ZRO2	.1904E-02	.1917E-02	.1929E-02	.1940E-02	.1950E-02	.1958E-02	.1965E-02	.1970E-02
CS2O	0.	0.	0.	0.	0.	0.	0.	0.
BAO	.8065	.8024	.7981	.7936	.7890	.7843	.7795	.7706
SRO	.1418E-01	.1400E-01	.1382E-01	.1365E-01	.1348E-01	.1331E-01	.1315E-01	.1299E-01
LA2O3	.3583E-04	.3609E-04	.3632E-04	.3652E-04	.3670E-04	.3685E-04	.3698E-04	.3709E-04
CEO2	.6182E-04	.6207E-04	.6248E-04	.6281E-04	.6311E-04	.6337E-04	.6359E-04	.6379E-04
NB2O5	0.	0.	0.	0.	0.	0.	0.	0.
CSI	.1572E-12	.1584E-12	.1594E-12	.1603E-12	.1610E-12	.1617E-12	.1623E-12	.1628E-12
CD	0.	0.	0.	0.	0.	0.	0.	0.
OXIDE MELT TEMP(K)	1519.	1517.	1514.	1512.	1510.	1508.	1508.	1504.
SOURCE RATE(GM/S)	.3575E-01	.3437E-01	.3811E-01	.3194E-01	.3085E-01	.2985E-01	.2891E-01	.2804E-01
AEROSOL DENSITY(GM/CM3)	6.931	6.918	6.906	6.894	6.884	6.873	6.864	6.854
AEROSOL SIZE(MICRON)	.7722E-01	.7677E-01	.7635E-01	.7598E-01	.7560E-01	.7526E-01	.7494E-01	.7465E-01

FIGURE 4.10. AEROSOL RELEASE DURING CONCRETE ATTACK FOR S_2DCF_2 (Continued)

SPECIES TIME	38400.0	39600.0	40800.0	42000.0	43200.0	44400.0	45600.0	46800.0
FEO	.7226	.7315	.7399	.7479	.7554	.7625	.7692	.7800
CR2O3	.1897E-03	.1901E-03	.1904E-03	.1906E-03	.1907E-03	.1909E-03	.1908E-03	.1987E-03
NI	.1262E-01	.1240E-01	.1220E-01	.1200E-01	.1182E-01	.1164E-01	.1148E-01	.1083E-01
MO	.1428E-01	.1434E-01	.1440E-01	.1445E-01	.1451E-01	.1456E-01	.1461E-01	.1475E-01
RU	.6521E-10	.6254E-10	.6007E-10	.5779E-10	.5567E-10	.5367E-10	.5193E-10	.4507E-10
SN	21.49	21.63	21.77	21.91	22.04	22.17	22.30	22.61
SB	0.	0.	0.	0.	0.	0.	0.	0.
TE	32.27	32.44	32.60	32.75	32.90	33.04	33.16	33.82
AG	42.86	42.56	42.27	41.99	41.73	41.46	41.23	40.25
MN	0.	0.	0.	0.	0.	0.	0.	0.
CAO	1.207	1.202	1.197	1.193	1.188	1.183	1.178	1.171
AL2O3	.6163E-05	.6249E-05	.6332E-05	.6412E-05	.6488E-05	.6563E-05	.6628E-05	.6874E-05
NA2O	0.	0.	0.	0.	0.	0.	0.	0.
K2O	0.	0.	0.	0.	0.	0.	0.	0.
SIO2	.4291E-02	.4254E-02	.4219E-02	.4188E-02	.4159E-02	.2424E-02	.2447E-02	.2574E-02
UO2	.6349	.6253	.6161	.6073	.5987	.5904	.5824	.5738
ZRO2	.1975E-02	.1979E-02	.1982E-02	.1985E-02	.1986E-02	.1988E-02	.1987E-02	.2069E-02
CS2O	0.	0.	0.	0.	0.	0.	0.	0.
BAO	.7657	.7608	.7559	.7509	.7460	.7411	.7359	.7471
SRO	.1283E-01	.1268E-01	.1253E-01	.1239E-01	.1225E-01	.1211E-01	.1197E-01	.1193E-01
LA2O3	.3718E-04	.3726E-04	.3732E-04	.3736E-04	.3739E-04	.3742E-04	.3740E-04	.3895E-04
CEO2	.6394E-04	.6407E-04	.6417E-04	.6425E-04	.6430E-04	.6435E-04	.6432E-04	.6699E-04
NB2O5	0.	0.	0.	0.	0.	0.	0.	0.
CSI	.1632E-12	.1635E-12	.1637E-12	.1639E-12	.1641E-12	.1642E-12	.1641E-12	.1709E-12
CD	0.	0.	0.	0.	0.	0.	0.	0.
OXIDE MELT TEMP(K)	1502.	1500.	1499.	1497.	1496.	1494.	1493.	1487.
SOURCE RATE(GM/S)	.2723E-01	.2647E-01	.2576E-01	.2510E-01	.2449E-01	.2385E-01	.2334E-01	.2063E-01
AEROSOL DENSITY(GM/CM3)	6.846	6.837	6.829	6.822	6.814	6.807	6.801	6.772
AEROSOL SIZE(MICRON)	.7437E-01	.7412E-01	.7388E-01	.7365E-01	.7344E-01	.7323E-01	.7307E-01	.7192E-01

FIGURE 4.10. AEROSOL RELEASE DURING CONCRETE ATTACK FOR S_2DCF_2 (Continued)

SPECIES	TIME 48000.0	49200.0	50400.0	51600.0	52800.0	54000.0	55200.0	56400.0
FEO	.7876	.7927	.7974	.8019	.7792	.7454	.7258	.7180
CR2O3	.2023E-03	.2023E-03	.2023E-03	.2023E-03	.1559E-03	.1095E-03	.8443E-04	.6959E-04
NI	.1047E-01	.1035E-01	.1023E-01	.1011E-01	.1324E-01	.1863E-01	.2329E-01	.2697E-01
MO	.1483E-01	.1487E-01	.1491E-01	.1495E-01	.1446E-01	.1365E-01	.1305E-01	.1266E-01
RU	.4159E-10	.4039E-10	.3926E-10	.3820E-10	.7352E-10	.1884E-09	.2904E-09	.4162E-09
SN	22.82	22.93	23.04	23.15	22.05	20.59	19.67	19.13
SB	0.	0.	0.	0.	0.	0.	0.	0.
TE	34.17	34.28	34.38	34.48	31.25	27.12	24.40	22.60
AG	39.70	39.49	39.29	39.09	43.54	49.28	53.04	55.48
MN	0.	0.	0.	0.	0.	0.	0.	0.
CAO	1.168	1.162	1.157	1.153	1.159	1.152	1.135	1.115
AL2O3	.7169E-05	.7230E-05	.7289E-05	.7345E-05	.5711E-05	.4087E-05	.3201E-05	.2707E-05
NA2O	0.	0.	0.	0.	0.	0.	0.	0.
K2O	0.	0.	0.	0.	0.	0.	0.	0.
SIO2	.2645E-02	.2667E-02	.2688E-02	.2709E-02	.4194E-02	.5276E-02	.6707E-02	.8053E-02
UO2	.5663	.5598	.5537	.5477	.5461	.5420	.5319	.5177
ZRO2	.2107E-02	.2107E-02	.2107E-02	.2108E-02	.1623E-02	.1140E-02	.8792E-03	.7247E-03
CS2O	0.	0.	0.	0.	0.	0.	0.	0.
BAO	.7496	.7453	.7412	.7370	.6367	.5214	.4435	.3900
SRO	.1185E-01	.1174E-01	.1163E-01	.1152E-01	.1085E-01	.9856E-02	.9017E-02	.8324E-02
LA2O3	.3968E-04	.3966E-04	.3966E-04	.3965E-04	.3055E-04	.2146E-04	.1655E-04	.1364E-04
CEO2	.6821E-04	.6821E-04	.6820E-04	.6818E-04	.5255E-04	.3891E-04	.2846E-04	.2346E-04
NB2O5	0.	0.	0.	0.	0.	0.	0.	0.
CSI	.1741E-12	.1740E-12	.1740E-12	.1740E-12	.1341E-12	.9418E-13	.7262E-13	.5986E-13
CD	0.	0.	0.	0.	0.	0.	0.	0.
OXIDE MELT TEMP(K)	1484.	1483.	1481.	1480.	1507.	1543.	1569.	1588.
SOURCE RATE(GM/S)	.1843E-01	.1774E-01	.1734E-01	.1926E-01	.3981E-01	.8728E-01	.1438	.2001
AEROSOL DENSITY(GM/CM3)	6.758	6.750	6.745	6.740	6.879	7.087	7.197	7.285
AEROSOL SIZE(MICRON)	.7133E-01	.7118E-01	.7104E-01	.7091E-01	.7712E-01	.8637E-01	.9364E-01	.9920E-01

FIGURE 4.10. AEROSOL RELEASE DURING CONCRETE ATTACK FOR S_2DCF_2 (Continued)

SPECIES	TIME 57600.0	58800.0	60000.0	61200.0	62400.0	63600.0	64800.0	66000.0
FEO	.7119	.7109	.7115	.7125	.7130	.7127	.7114	.7089
CR2O3	.3087E-03	.3193E-03	.3209E-03	.3154E-03	.3052E-03	.2919E-03	.2769E-03	.2609E-03
NI	.2970E-01	.3160E-01	.3279E-01	.3344E-01	.3372E-01	.3371E-01	.3352E-01	.3319E-01
MO	.1243E-01	.1232E-01	.1230E-01	.1236E-01	.1247E-01	.1263E-01	.1282E-01	.1304E-01
RU	.5278E-09	.6150E-09	.6738E-09	.7076E-09	.7223E-09	.7224E-09	.7122E-09	.6953E-09
SN	18.83	18.71	18.71	18.82	18.99	19.21	19.48	19.78
SB	0.	0.	0.	0.	0.	0.	0.	0.
TE	21.39	20.58	20.04	19.68	19.45	19.29	19.18	19.12
AG	57.06	58.06	58.65	58.96	59.09	59.07	58.96	58.78
MN	0.	0.	0.	0.	0.	0.	0.	0.
CAO	1.095	1.075	1.056	1.036	1.017	.9976	.9778	.9575
AL2O3	.2407E-05	.2218E-05	.2098E-05	.2022E-05	.1971E-05	.1937E-05	.1913E-05	.1896E-05
NA2O	0.	0.	0.	0.	0.	0.	0.	0.
K2O	0.	0.	0.	0.	0.	0.	0.	0.
SIO2	.9114E-02	.9829E-02	.1020E-01	.1030E-01	.1020E-01	.9958E-02	.9620E-02	.9224E-02
UO2	.5008	.4821	.4624	.4423	.4222	.4025	.3834	.3650
ZRO2	.6260E-03	.5594E-03	.5128E-03	.4783E-03	.4514E-03	.4296E-03	.4111E-03	.3949E-03
CS2O	0.	0.	0.	0.	0.	0.	0.	0.
BAO	.3515	.3226	.3003	.2823	.2671	.2540	.2422	.2315
SRO	.7748E-02	.7261E-02	.6844E-02	.6477E-02	.6146E-02	.5843E-02	.5563E-02	.5300E-02
LA2O3	.1176E-04	.1053E-04	.9652E-05	.9003E-05	.8497E-05	.8086E-05	.7738E-05	.7433E-05
CEO2	.2026E-04	.1811E-04	.1660E-04	.1548E-04	.1461E-04	.1391E-04	.1331E-04	.1278E-04
NB2O5	0.	0.	0.	0.	0.	0.	0.	0.
CSI	.5171E-13	.4621E-13	.4235E-13	.3951E-13	.3728E-13	.3548E-13	.3396E-13	.3262E-13
CD	0.	0.	0.	0.	0.	0.	0.	0.
OXIDE MELT TEMP(K)	1597.	1605.	1610.	1612.	1613.	1613.	1613.	1611.
SOURCE RATE(GM/S)	.2508	.2947	.3307	.3586	.3804	.3976	.4114	.4227
AEROSOL DENSITY(GM/CM3)	7.345	7.384	7.410	7.425	7.433	7.437	7.437	7.436
AEROSOL SIZE(MICRON)	.1034	.1065	.1087	.1104	.1116	.1125	.1132	.1138

FIGURE 4.10. AEROSOL RELEASE DURING CONCRETE ATTACK FOR S_2DCF_2 (Continued)

SPECIES	TIME 67200.0	68400.0	69600.0	70800.0	72000.0	73200.0
FEO	.7052	.7002	.6940	.6868	.6781	.6682
CR2O3	.2448E-03	.2288E-03	.2131E-03	.3284E-04	.3178E-04	.3066E-04
NI	.3277E-01	.3228E-01	.3175E-01	.3113E-01	.3046E-01	.2985E-01
MO	.1329E-01	.1356E-01	.1388E-01	.1420E-01	.1458E-01	.1498E-01
RU	.6741E-09	.6502E-09	.6244E-09	.5955E-09	.5650E-09	.5383E-09
SN	20.11	20.48	20.87	21.30	21.76	22.25
SB	0.	0.	0.	0.	0.	0.
TE	19.07	19.03	19.01	19.00	19.00	18.97
AG	58.55	58.27	57.96	57.60	57.18	56.79
MN	0.	0.	0.	0.	0.	0.
CAO	.9368	.9157	.8941	.8720	.8493	.8260
AL2O3	.1882E-05	.1870E-05	.1859E-05	.1850E-05	.1843E-05	.1828E-05
NA2O	0.	0.	0.	0.	0.	0.
K2O	0.	0.	0.	0.	0.	0.
SIO2	.8794E-02	.8346E-02	.7887E-02	.7412E-02	.6931E-02	.6488E-02
UO2	.3473	.3303	.3140	.2984	.2834	.2691
ZRO2	.3802E-03	.3665E-03	.3537E-03	.3420E-03	.3310E-03	.3193E-03
CS2O	0.	0.	0.	0.	0.	0.
BAO	.2216	.2123	.2034	.1952	.1873	.1794
SRO	.5052E-02	.4816E-02	.4591E-02	.4377E-02	.4172E-02	.3970E-02
LA2O3	.7156E-05	.6899E-05	.6659E-05	.6438E-05	.6230E-05	.6010E-05
CEO2	.1231E-04	.1186E-04	.1145E-04	.1107E-04	.1071E-04	.1034E-04
NB2O5	0.	0.	0.	0.	0.	0.
CSI	.3140E-13	.3028E-13	.2922E-13	.2825E-13	.2734E-13	.2637E-13
CD	0.	0.	0.	0.	0.	0.
OXIDE MELT TEMP(K)	1610.	1608.	1606.	1604.	1601.	1599.
SOURCE RATE(GM/S)	.4325	.4417	.4519	.4627	.4691	.4740
AEROSOL DENSITY(GM/CM3)	7.432	7.428	7.422	7.414	7.406	7.398
AEROSOL SIZE(MICRON)	.1143	.1147	.1152	.1155	.1159	.1164

TABLE 4.11. AEROSOL RELEASE DURING CONCRETE ATTACK FOR TMLU

SPECIES TIME	.0	1200.0	2400.0	3600.0	4800.0	6000.0	7200.0	8400.0
FEO	.2159E-10	.1798E-03	.3749E-02	.1529E-01	.1124E-01	.4708E-02	.8587E-02	.1372E-01
CR2O3	.8218E-09	.1484E-01	.1525	.2809E-01	.9836E-02	.1416E-02	.1294E-03	.7943E-04
NI	.9204E-03	.9098E-01	.6783	.4042E-01	.2271E-01	.1213E-01	.7505E-02	.5844E-02
MO	.2092E-08	.2256E-05	.7493E-04	.7952E-06	.1313E-05	.1664E-04	.1389E-02	.1459E-02
RU	.3368E-10	.6308E-07	.2419E-05	.1398E-07	.3879E-08	.1127E-08	.4350E-09	.2314E-09
SN	.3430	1.776	3.797	1.331	1.484	1.587	2.046	2.090
SB	0.	0.	0.	0.	0.	0.	0.	0.
TE	.4251	1.559	1.833	1.237	1.416	1.439	1.414	1.519
AG	1.391	26.00	40.29	17.77	14.55	10.76	8.329	7.473
MN	0.	0.	0.	0.	0.	0.	0.	0.
CAO	0.	.2782E-02	20.77	.1688E-01	.2421E-01	.2874E-01	.4217E-01	.4277E-01
AL2O3	0.	.2357E-09	.9588E-05	.4912E-08	.1461E-07	.2402E-07	.3288E-07	.4406E-07
NA2O	0.	0.	0.	0.	0.	0.	0.	0.
K2O	0.	0.	0.	0.	0.	0.	0.	0.
SIO2	0.	.1372E-01	.3589	.7029E-01	.3663E-01	.8020E-02	.1261E-02	.8341E-03
UO2	.7430E-03	.1106	1.090	.4345E-01	.2985E-01	.3813E-01	.1172	.9760E-01
ZRO2	.1732E-04	.1862E-04	.3151E-04	.2074E-04	.2910E-04	.3603E-04	.4028E-04	.4685E-04
CS2O	.1131	.7902E-01	.3570E-01	.9186E-01	.9529E-01	.9956E-01	.1017	.1026
BAO	.2575E-02	.2717E-01	.4395E-01	.1119E-01	.1325E-01	.2273E-01	.5134E-01	.5273E-01
SRO	.1248E-03	.2749E-02	.6201E-02	.9853E-03	.8081E-03	.9715E-03	.1828E-02	.1722E-02
LA2O3	.3273E-06	.2716E-03	.5142E-02	.4526E-04	.5499E-06	.6808E-06	.7612E-06	.8852E-06
CEO2	.5650E-06	.6075E-06	.3559E-03	.6765E-06	.9494E-06	.1175E-05	.1314E-05	.1528E-05
NB2O5	.3088E-08	.1409E-04	.3805E-03	.3697E-08	.5189E-08	.6423E-08	.7182E-08	.8352E-08
CSI	.9894E-02	.6712E-01	.1043	.2576E-03	.7666E-04	.5122E-13	.5727E-13	.6680E-13
CD	97.71	68.25	30.84	79.34	82.30	86.00	87.88	88.60
OXIDE MELT TEMP(K)	1660.	1989.	2236.	1900.	1817.	1751.	1705.	1672.
SOURCE RATE(GM/S)	1.709	3.066	108.3	60.82	21.57	14.17	9.571	6.867
AEROSOL DENSITY(GM/CM3)	3.782	4.563	4.738	4.228	4.144	4.046	3.993	3.974
AEROSOL SIZE(MICRON)	.6474	.6291	.7591	.5870	.4969	.4493	.4216	.3921

TABLE 4.11. AEROSOL RELEASE DURING CONCRETE ATTACK FOR TMLU (Continued)

SPECIES TIME	9600.0	10800.0	12000.0	13200.0	14400.0	15600.0	16800.0	18000.0
FEO	.1845E-01	.2404E-01	.3181E-01	.4431E-01	.6866E-01	.1411	.2984	.3110
CR2O3	.4790E-04	.4026E-04	.3813E-04	.4091E-04	.1670E-04	.3387E-04	.7003E-04	.7194E-04
NI	.4766E-02	.4429E-02	.4507E-02	.5081E-02	.6610E-02	.1172E-01	.2181E-01	.2035E-01
MO	.1608E-02	.1684E-02	.2288E-02	.3030E-02	.4540E-02	.9127E-02	.1904E-01	.1970E-01
RU	.1483E-09	.1099E-09	.9238E-10	.8856E-10	.1001E-09	.1566E-09	.2609E-09	.2203E-09
SN	2.265	2.595	3.159	4.157	6.195	12.40	25.74	26.52
SB	0.	0.	0.	0.	0.	0.	0.	0.
TE	1.700	1.986	2.446	3.237	4.832	9.660	19.99	20.60
AG	7.245	7.530	8.408	10.25	14.24	26.75	52.39	51.12
MN	0.	0.	0.	0.	0.	0.	0.	0.
CAO	.4551E-01	.5095E-01	.6041E-01	.7732E-01	.1120	.2176	.4389	.4392
AL2O3	.5822E-07	.7765E-07	.1065E-06	.1539E-06	.2474E-06	.5267E-06	.1151E-05	.1236E-05
NA2O	0.	0.	0.	0.	0.	0.	0.	0.
K2O	0.	0.	0.	0.	0.	0.	0.	0.
SIO2	.6348E-03	.5419E-03	.5149E-03	.5498E-03	.6850E-03	.1174E-02	.2130E-02	.1950E-02
UO2	.8971E-01	.8946E-01	.9656E-01	.1141	.1547	.2840	.5447	.5214
ZRO2	.5538E-04	.6731E-04	.8522E-04	.1150E-03	.1739E-03	.3507E-03	.7294E-03	.7493E-03
CS2O	.1024	.1014	.9912E-01	.9484E-01	.8585E-01	.5811E-01	0.	0.
BAO	.5655E-01	.6349E-01	.7526E-01	.9608E-01	.1386	.2677	.5371	.5343
SRO	.1726E-02	.1832E-02	.2008E-02	.2471E-02	.3454E-02	.6498E-02	.1271E-01	.1237E-01
LA2O3	.1046E-05	.1272E-05	.1610E-05	.2172E-05	.3286E-05	.6626E-05	.1376E-04	.1416E-04
CEO2	.1607E-05	.2196E-05	.2780E-05	.3751E-05	.5673E-05	.1144E-04	.2379E-04	.2444E-04
NB2O5	.9873E-08	.1200E-07	.1519E-07	.2050E-07	.3101E-07	.6251E-07	.1300E-06	.1336E-06
CSI	.7873E-13	.9569E-13	.1212E-12	.1635E-12	.2473E-12	.4985E-12	.1037E-11	.1065E-11
CD	88.47	87.55	85.62	81.92	74.15	50.20	0.	0.
OXIDE MELT TEMP(K)	1647.	1627.	1610.	1597.	1585.	1575.	1566.	1558.
SOURCE RATE(GM/S)	5.046	3.678	2.598	1.738	1.049	.4796	.2139	.1943
AEROSOL DENSITY(GM/CM3)	3.973	3.990	4.029	4.108	4.286	4.950	7.308	7.268
AEROSOL SIZE(MICRON)	.3636	.3345	.3035	.2693	.2285	.1705	.1161	.1142

TABLE 4.11. AEROSOL RELEASE DURING CONCRETE ATTACK FOR TMLU (Continued)

SPECIES	TIME 19200.0	20400.0	21600.0	22800.0	24000.0	25200.0	26400.0	27600.0
FEO	.3218	.3310	.3388	.3455	.3510	.3557	.3595	.3626
CR2O3	.7347E-04	.7466E-04	.7557E-04	.7624E-04	.7667E-04	.7692E-04	.7701E-04	.7695E-04
NI	.1911E-01	.1803E-01	.1710E-01	.1628E-01	.1555E-01	.1490E-01	.1432E-01	.1379E-01
MO	.2034E-01	.2097E-01	.2159E-01	.2220E-01	.2281E-01	.2342E-01	.2403E-01	.2465E-01
RU	.1889E-09	.1641E-09	.1442E-09	.1279E-09	.1145E-09	.1033E-09	.9380E-10	.8570E-10
SN	27.26	27.97	28.65	29.30	29.93	30.54	31.14	31.71
SB	0.	0.	0.	0.	0.	0.	0.	0.
TE	20.94	21.33	21.67	21.97	22.23	22.46	22.67	22.84
AG	49.96	48.88	47.88	46.94	46.06	45.24	44.46	43.73
MN	0.	0.	0.	0.	0.	0.	0.	0.
CAO	.4385	.4371	.4351	.4326	.4297	.4264	.4229	.4192
AL2O3	.1316E-05	.1389E-05	.1457E-05	.1519E-05	.1576E-05	.1628E-05	.1675E-05	.1718E-05
NA2O	0.	0.	0.	0.	0.	0.	0.	0.
K2O	0.	0.	0.	0.	0.	0.	0.	0.
SIO2	.1806E-02	.1689E-02	.1594E-02	.1514E-02	.1447E-02	.1390E-02	.1340E-02	.1298E-02
UO2	.5004	.4814	.4639	.4479	.4331	.4195	.4067	.3949
ZRO2	.7652E-03	.7776E-03	.7871E-03	.7940E-03	.7986E-03	.8012E-03	.8021E-03	.8014E-03
CS2O	0.	0.	0.	0.	0.	0.	0.	0.
BAO	.5303	.5253	.5195	.5132	.5064	.4993	.4920	.4846
SRO	.1203E-01	.1170E-01	.1138E-01	.1107E-01	.1077E-01	.1048E-01	.1020E-01	.9928E-02
LA2O3	.1446E-04	.1469E-04	.1487E-04	.1500E-04	.1509E-04	.1514E-04	.1516E-04	.1514E-04
CEO2	.2496E-04	.2537E-04	.2568E-04	.2590E-04	.2605E-04	.2613E-04	.2616E-04	.2614E-04
NB2O5	.1364E-06	.1386E-06	.1403E-06	.1416E-06	.1424E-06	.1428E-06	.1430E-06	.1429E-06
CSI	.1086E-11	.1105E-11	.1119E-11	.1129E-11	.1135E-11	.1139E-11	.1140E-11	.1139E-11
CD	0.	0.	0.	0.	0.	0.	0.	0.
OXIDE MELT TEMP(K)	1551.	1545.	1539.	1534.	1529.	1525.	1521.	1517.
SOURCE RATE(GM/S)	.1783	.1651	.1539	.1445	.1363	.1293	.1231	.1176
AEROSOL DENSITY(GM/CM3)	7.233	7.200	7.171	7.144	7.120	7.097	7.076	7.057
AEROSOL SIZE(MICRON)	.1126	.1113	.1101	.1091	.1083	.1076	.1070	.1065

TABLE 4.11. AEROSOL RELEASE DURING CONCRETE ATTACK FOR TMLU (Continued)

SPECIES	TIME 28800.0	30000.0	31200.0	32400.0	33600.0	34800.0	36000.0
FEO	.3651	.3670	.3684	.3693	.3699	.3700	.3699
CR2O3	.7675E-04	.7645E-04	.7606E-04	.7557E-04	.7502E-04	.7440E-04	.7374E-04
NI	.1332E-01	.1289E-01	.1249E-01	.1213E-01	.1180E-01	.1149E-01	.1121E-01
MO	.2526E-01	.2591E-01	.2656E-01	.2723E-01	.2790E-01	.2860E-01	.2932E-01
RU	.7874E-10	.7268E-10	.6740E-10	.6276E-10	.5866E-10	.5501E-10	.5175E-10
SN	32.27	32.82	33.36	33.88	34.39	34.89	35.38
SB	0.	0.	0.	0.	0.	0.	0.
TE	23.00	23.13	23.24	23.34	23.42	23.48	23.54
AG	43.04	42.38	41.75	41.15	40.58	40.04	39.51
MN	0.	0.	0.	0.	0.	0.	0.
CAO	.4153	.4113	.4072	.4031	.3988	.3946	.3903
AL2O3	.1756E-05	.1791E-05	.1822E-05	.1849E-05	.1873E-05	.1894E-05	.1912E-05
NA2O	0.	0.	0.	0.	0.	0.	0.
K2O	0.	0.	0.	0.	0.	0.	0.
SIO2	.1260E-02	.1227E-02	.6540E-03	.6638E-03	.6723E-03	.6798E-03	.6864E-03
UO2	.3838	.3735	.3638	.3547	.3462	.3381	.3305
ZRO2	.7994E-03	.7963E-03	.7922E-03	.7872E-03	.7814E-03	.7750E-03	.7680E-03
CS2O	0.	0.	0.	0.	0.	0.	0.
BAO	.4770	.4695	.4619	.4543	.4468	.4395	.4322
SRO	.9669E-02	.9421E-02	.9182E-02	.8952E-02	.8731E-02	.8519E-02	.8316E-02
LA2O3	.1510E-04	.1505E-04	.1497E-04	.1487E-04	.1476E-04	.1464E-04	.1451E-04
CEO2	.2608E-04	.2597E-04	.2584E-04	.2568E-04	.2549E-04	.2528E-04	.2505E-04
NB2O5	.1425E-06	.1420E-06	.1412E-06	.1403E-06	.1393E-06	.1382E-06	.1369E-06
CSI	.1136E-11	.1132E-11	.1126E-11	.1119E-11	.1111E-11	.1102E-11	.1092E-11
CD	0.	0.	0.	0.	0.	0.	0.
OXIDE MELT TEMP(K)	1514.	1510.	1507.	1505.	1502.	1499.	1497.
SOURCE RATE(GM/S)	.1128	.1084	.1045	.1010	.9774E-01	.9480E-01	.9323E-01
AEROSOL DENSITY(GM/CM3)	7.039	7.022	7.006	6.991	6.977	6.964	6.952
AEROSOL SIZE(MICRON)	.1061	.1058	.1055	.1053	.1051	.1050	.1049

5. RADIONUCLIDE RELEASE AND TRANSPORT

5.1 S_2DC_r Sequence

5.1.1 Transport in the Reactor Coolant System

In the S_2DC_r sequence, primary system pressures and temperatures are intermediate in value, ranging roughly between 700 and 1350 psia (48 to 92 atmospheres) and 640 F and 1340 F (610 K to 1000 K), respectively. Flows are intermediate, also. Under these conditions, the predicted progression with time of release from fuel and of deposition within the RCS of the three volatile fission product species CsI, CsOH, and Te, and of the structural and fuel material aerosol, is as shown in Table 5.1. 72.4 percent of CsI, 72.3 percent of CsOH, 52.6 percent of Te, and 69.2 percent of aerosol released from the fuel during this period are retained in the RCS. Table 5.1 also shows that little additional deposition of any of these species occurs after the beginning of core slump (6505 sec) despite continued, if reduced, release from fuel. This can be traced to the following circumstances: with core slumping, the RCS surface temperatures exceed those of the cooled gas and the volatile fission products condense largely on aerosol particles. Sorption is not competitive with this process. Vapor pressures at the cooled gas temperatures are so low that little transport occurs in the vapor phase. Aerosol release from the melt is reduced by the lower melt temperature to the point where less agglomeration takes place in the core region and smaller particles transport through the system with lower residence time. Aerosol retention is therefore significantly reduced. Since the volatile fission products are condensed on the aerosols, the extent of their retention is similarly reduced.

Table 5.2 gives the total quantities of material released from the fuel and retained on RCS surfaces at the end of the in-vessel release period for each of the elemental release groups.

Figures 5.1 through 5.4 provide a more detailed view of the transport behavior of the volatile fission products and of structural material aerosols in the RCS as a function of time. Each curve shows the mass of the given species that has been transported beyond the specified control volume

TABLE 5.1. MASSES OF DOMINANT SPECIES RELEASED FROM FUEL (TOTAL) AND RETAINED ON RCS STRUCTURE SURFACES (RET) AS A FUNCTION OF TIME - S_2DC_r SEQUENCE

	CSI		CSOH		TE		AEROSOL	
TIME (S)	RET (KG)	TOTAL (KG)	RET (KG)	TOTAL (KG)	RET (KG)	TOTAL (KG)	RET (KG)	TOTAL (KG)
5783.	.4	3.9	3.1	26.1	.1	.3	8.3	44.5
5899.	2.5	7.9	16.3	49.1	.3	.6	26.7	67.8
6013.	5.6	12.0	34.7	72.7	.6	1.1	49.2	95.8
6129.	9.3	16.1	56.5	96.5	1.0	1.6	75.1	124.2
6246.	13.1	19.7	78.9	117.7	1.6	2.3	102.0	151.3
6361.	16.5	22.5	98.8	134.9	2.2	3.1	127.8	176.7
6479.	19.2	24.8	115.6	148.8	2.9	4.5	153.9	209.3
6593.	21.0	26.4	127.9	159.3	5.3	7.5	190.8	260.7
6708.	21.5	27.6	130.4	166.4	6.2	9.3	201.9	266.0
6824.	21.6	28.2	131.0	170.8	6.6	10.3	203.3	270.2
6940.	21.7	28.8	131.3	174.4	6.7	11.0	203.8	273.5
7057.	21.7	29.2	131.5	177.2	6.8	11.5	204.1	276.3
7174.	21.7	29.5	131.7	179.1	6.8	11.8	204.3	278.9
7289.	21.8	29.7	131.8	180.3	6.9	12.1	204.5	281.4
7405.	21.8	29.8	131.8	180.9	6.9	12.3	204.6	283.9
7520.	21.8	29.9	131.9	181.5	6.9	12.5	204.8	286.3
7642.	21.8	29.9	131.9	182.0	6.9	12.7	205.0	288.7
7755.	21.8	30.0	132.0	182.4	6.9	12.9	205.3	291.3
7869.	21.8	30.0	132.1	182.7	7.0	13.1	205.6	294.7
7989.	21.8	30.1	132.3	183.0	7.0	13.3	206.8	298.8

TABLE 5.2. MASSES OF RADIONUCLIDES RELEASED FROM FUEL AND RETAINED ON RCS SURFACES (BY ELEMENTAL GROUP) - S_2DC_r SEQUENCE

GROUP	RELEASED (KG)	RETAINED (KG)
I	14.7	10.7
CS	177.7	128.5
TE	13.3	7.0
SR	.0	.0
RU	.0	.0
LA	.0	.0
NG	334.0	.0
CE	.0	.0
BA	.8	.4

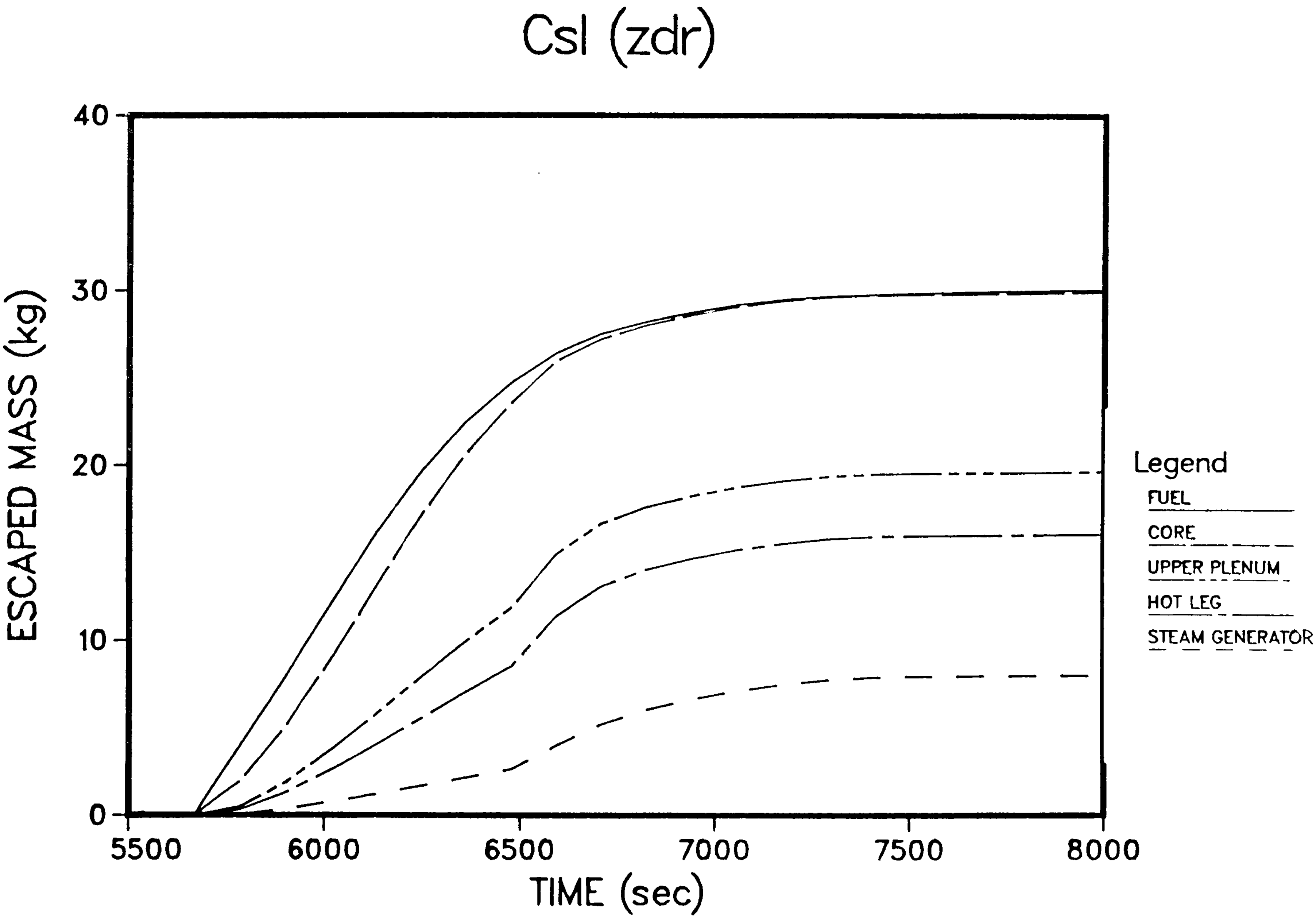

FIGURE 5.1. MASS OF CsI RELEASED FOR INDICATED RCS COMPONENT AS A FUNCTION OF TIME - S_2DC_R SEQUENCE

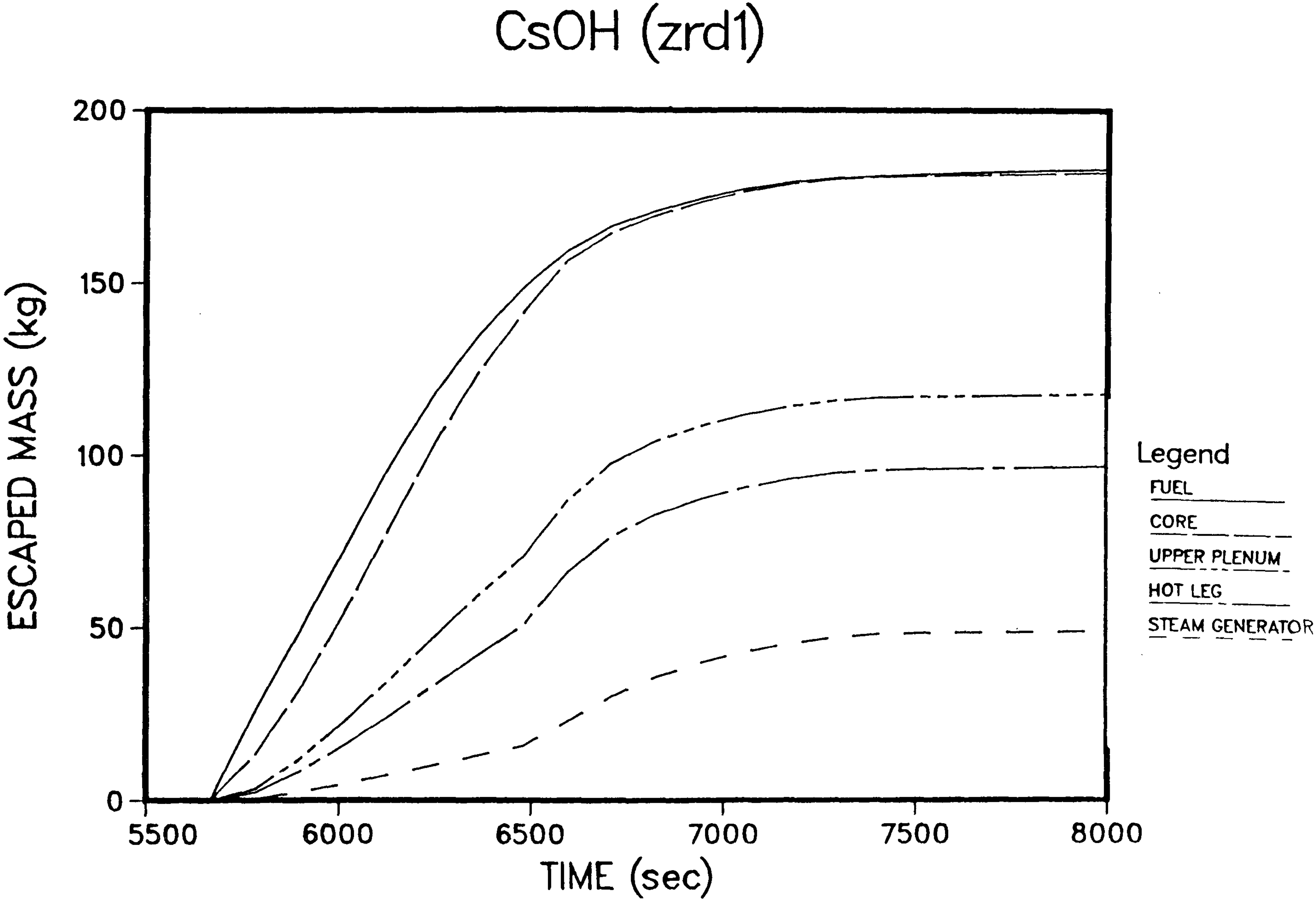

FIGURE 5.2. MASS OF CsoH RELEASED FOR INDICATED RCS COMPONENT AS A FUNCTION OF TIME - S_2DC_R SEQUENCE

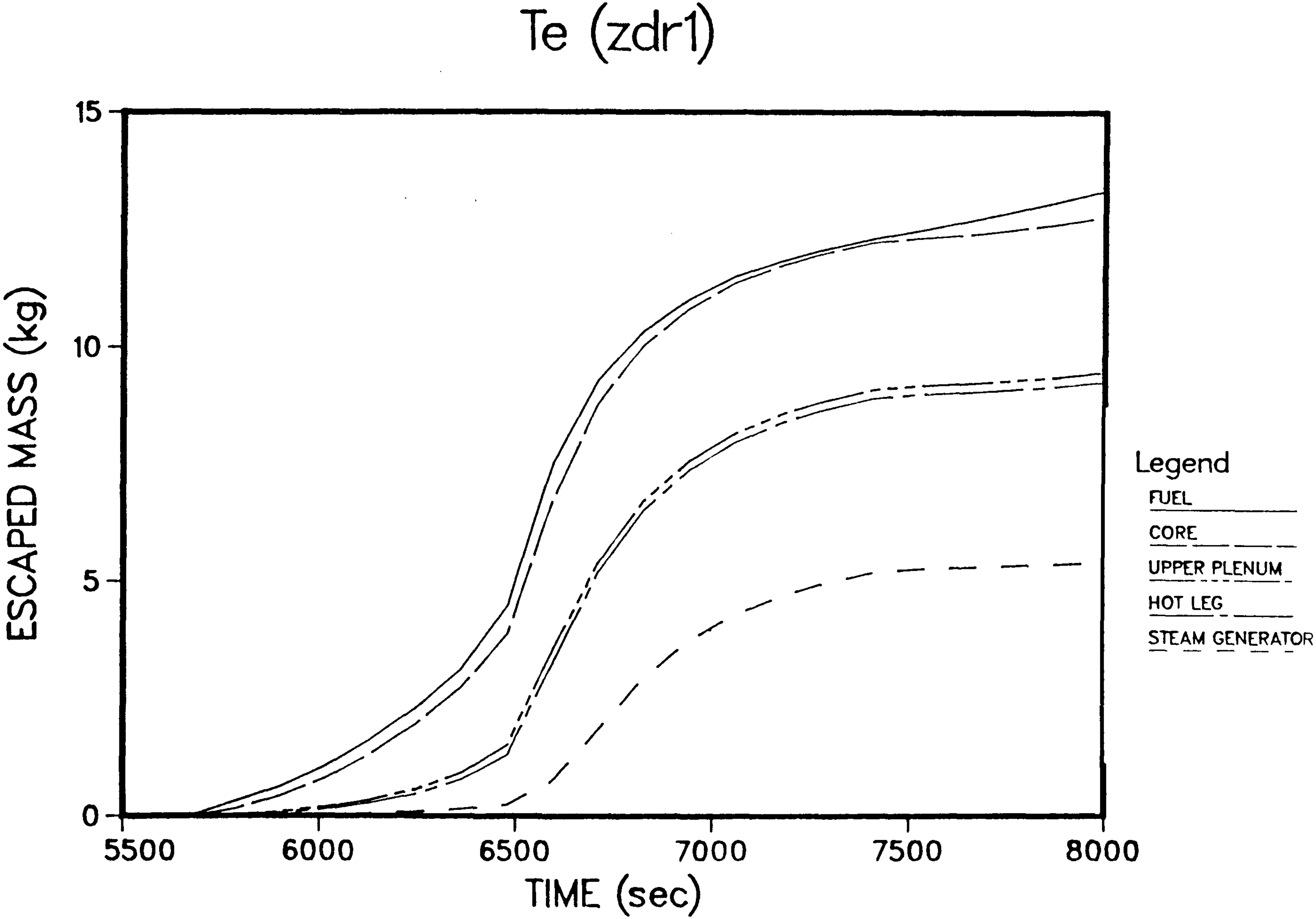

FIGURE 5.3. MASS OF TE RELEASED FOR INDICATED RCS COMPONENT AS A FUNCTION OF TIME - S_2DC_R SEQUENCE

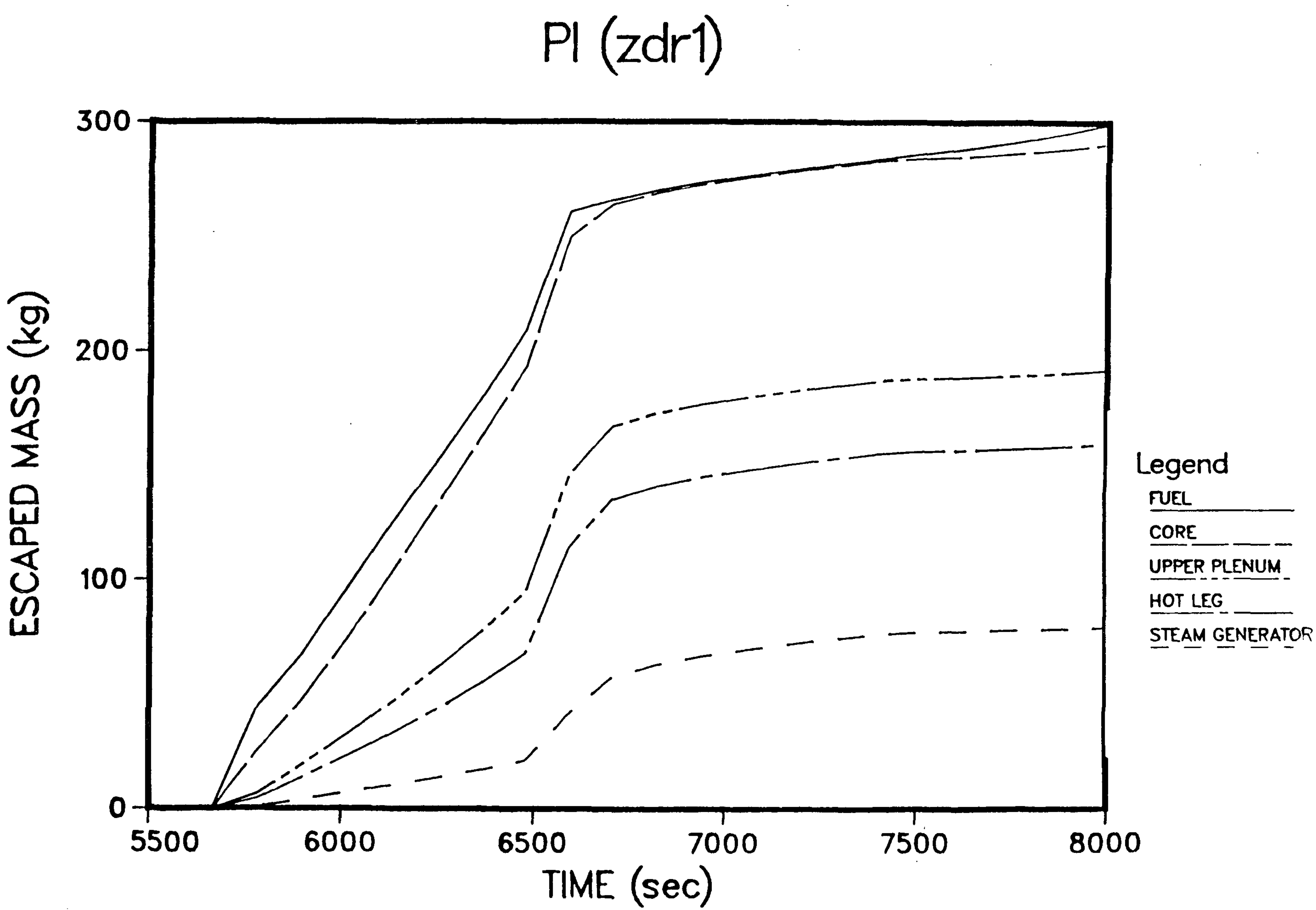

FIGURE 5.4. MASS OF STRUCTURAL MATERIAL AEROSOL RELEASED FOR INDICATED RCS COMPONENT AS A FUNCTION OF TIME - S_2DC_R SEQUENCE

and is therefore no longer subject to capture by that control volume or control volumes upstream of it. It is clear from the curves that little flow holdup occurs--the releases from each of the indicated volumes closely track the release from fuel (solid line). With melt quenching after core collapse, release rates are much reduced and this is reflected by the sharp decrease of slope for the aerosol release from fuel curve (Figure 5.4). The corresponding curves for these volatile fission products show a gentler transition because their release rates continually diminish with fuel inventory depletion. Note that most retention occurs in the upper plenum and the steam generator.

5.1.2 Transport in Containment for the S_2DC_r Sequence

In this sequence, the containment fails almost 22 hours after vessel failure, thus allowing the radionuclides considerable time to deposit in the containment. Table 5.3 summarizes the various sources of radionuclides to the containment atmosphere. The time-dependent size distribution of airborne particles in the containment is shown in Table 5.4, and the fraction of core inventory released from the containment as a function of time is listed in Table 5.5. Table 5.6 presents the locational distribution of the radionuclides at the end of the accident. The core inventory fractions listed as captured in cavity water are those predicted by the VANESA code.

In addition to the long residence time for deposition before the containment fails, the deposition by diffusiophoresis is enhanced by condensation early in the accident. As a result, releases to the environment are low with the maximum being about 0.2 percent of core inventory for Te.

5.2 $S_2DC_{ir}F_{ir}$ Sequence

5.2.1 Transport in the Reactor Coolant System

The $S_2DC_{ir}F_{ir}$ sequence is identical to the S_2DC_r sequence for phenomena pertaining to the RCS. The latter was described already in 5.1.1.

TABLE 5.3. SUMMARY OF RELEASES TO CONTAINMENT FOR S_2DC_r SEQUENCE

GROUP	DURING IN-VESSEL RELEASE	DURING PUFF RELEASE	DURING CORE-CONCRETE ATTACK
I	.2637	8.4180E-03	2.9031E-04
CS	.2654	9.0790E-03	2.8058E-04
PI	6.1718E-04	9.9528E-05	-
TE	.1755	2.8838E-02	1.6679E-02
SR	1.1058E-04	2.7217E-05	2.2759E-02
RU	1.4568E-07	2.4812E-08	4.7841E-08
LA	1.3206E-08	1.4210E-09	5.4715E-04
NG	.9830	9.6393E-03	-
CE	0.	0.	4.7112E-04
BA	2.3067E-03	6.5334E-04	1.6193E-02

TABLE 5.4. SIZE DISTRIBUTION OF AEROSOLS IN CONTAINMENT - S_2DC_r SCENARIO

TIME	24.003	24.251	24.503	24.754	25.002	25.500	26.001	27.004	28.006	30.016
DENSITY	2.72E+00	2.72E+00	2.72E+00	2.73E+00	2.73E+00	2.75E+00	2.77E+00	2.88E+00	2.91E+00	2.91E+00
PARTICLE DIAMETER (MICRONS)										
5.00E-03	5.07E-09	2.91E-09	3.37E-09	5.15E-09	7.70E-09	1.21E-08	2.26E-08	5.60E-08	7.33E-14	8.01E-21
8.20E-03	1.37E-07	1.16E-07	1.66E-07	2.42E-07	3.57E-07	6.33E-07	1.18E-06	2.71E-06	1.26E-08	2.44E-11
1.35E-02	2.07E-06	2.27E-06	3.60E-06	5.29E-06	7.67E-06	1.46E-05	2.76E-05	6.15E-05	6.15E-06	4.40E-07
2.21E-02	1.75E-05	2.16E-05	3.50E-05	5.31E-05	7.73E-05	1.54E-04	2.97E-04	6.91E-04	2.48E-04	7.30E-05
3.62E-02	9.01E-05	1.11E-04	1.71E-04	2.59E-04	3.79E-04	7.80E-04	1.54E-03	3.97E-03	2.78E-03	1.57E-03
5.95E-02	3.09E-04	3.56E-04	4.89E-04	6.92E-04	9.75E-04	1.96E-03	3.87E-03	1.11E-02	1.17E-02	9.77E-03
9.76E-02	7.00E-04	7.58E-04	9.12E-04	1.15E-03	1.47E-03	2.61E-03	4.84E-03	1.41E-02	1.88E-02	2.00E-02
1.60E-01	8.63E-04	9.29E-04	1.03E-03	1.17E-03	1.37E-03	2.03E-03	3.27E-03	8.65E-03	1.21E-02	1.44E-02
2.63E-01	5.23E-04	5.44E-04	5.80E-04	6.28E-04	6.92E-04	8.92E-04	1.25E-03	2.80E-03	3.69E-03	4.37E-03
4.31E-01	4.34E-03	4.31E-03	4.31E-03	4.32E-03	4.33E-03	4.37E-03	4.42E-03	4.62E-03	4.77E-03	4.98E-03
7.07E-01	7.36E-02	7.34E-02	7.34E-02	7.34E-02	7.35E-02	7.36E-02	7.37E-02	7.28E-02	7.34E-02	7.57E-02
1.16E+00	3.73E-01	3.73E-01	3.73E-01	3.73E-01	3.74E-01	3.74E-01	3.73E-01	3.67E-01	3.66E-01	3.76E-01
1.90E+00	4.42E-01	4.43E-01	4.43E-01	4.42E-01	4.42E-01	4.40E-01	4.37E-01	4.24E-01	4.19E-01	4.15E-01
3.12E+00	1.00E-01	1.00E-01	9.95E-02	9.87E-02	9.79E-02	9.59E-02	9.35E-02	8.73E-02	8.30E-02	7.59E-02
5.12E+00	4.12E-03	4.08E-03	3.99E-03	3.88E-03	3.77E-03	3.53E-03	3.28E-03	2.77E-03	2.37E-03	1.75E-03
8.41E+00	3.26E-05	3.16E-05	2.95E-05	2.73E-05	2.52E-05	2.10E-05	1.72E-05	1.11E-05	7.21E-06	3.02E-06
1.38E+01	5.15E-08	4.74E-08	3.97E-08	3.26E-08	2.63E-08	1.65E-08	9.92E-09	3.38E-09	1.16E-09	1.54E-10
2.26E+01	1.69E-11	1.37E-11	8.95E-12	5.71E-12	3.58E-12	1.32E-12	4.59E-13	6.17E-14	8.45E-10	2.13E-09
3.71E+01	3.21E-11	7.29E-11	1.00E-10	1.36E-10	1.88E-10	3.51E-10	6.52E-10	1.16E-09	1.62E-09	4.59E-09
6.09E+01	2.30E-09	5.22E-09	7.18E-09	9.65E-09	1.35E-08	2.51E-08	4.67E-08	8.33E-08	1.30E-07	3.29E-07
1.00E+02	5.50E-09	1.25E-08	1.72E-08	2.35E-08	3.22E-08	6.01E-08	1.12E-07	1.99E-07	3.11E-07	7.86E-07

TABLE 5.5. FRACTION OF CORE INVENTORY RELEASED FROM CONTAINMENT - S_2DC_r SCENARIO

TIME (HR)	FISSION PRODUCT GROUP										
	I	CS	PI	TE	SR	RU	LA	CE	BA	PE	TR
24.003	2.88E-06	2.91E-06	6.77E-09	4.20E-06	1.72E-06	1.40E-11	9.93E-09	2.52E-08	1.40E-06	4.32E-02	9.65E-07
24.251	2.89E-06	1.03E-05	6.77E-09	1.01E-03	5.12E-04	1.18E-08	2.81E-06	7.44E-06	4.15E-04	1.30E+01	9.65E-07
24.503	2.90E-06	1.18E-05	6.77E-09	1.22E-03	6.21E-04	1.44E-08	3.41E-06	9.02E-06	5.04E-04	1.57E+01	9.65E-07
24.754	2.90E-06	1.30E-05	6.77E-09	1.39E-03	7.00E-04	1.64E-08	3.84E-06	1.02E-05	5.68E-04	1.77E+01	9.65E-07
25.002	2.90E-06	1.38E-05	6.77E-09	1.51E-03	7.57E-04	1.80E-08	4.16E-06	1.10E-05	6.14E-04	1.92E+01	9.65E-07
25.500	2.90E-06	1.48E-05	6.77E-09	1.67E-03	8.29E-04	2.04E-08	4.55E-06	1.20E-05	6.72E-04	2.10E+01	9.65E-07
26.001	2.90E-06	1.54E-05	6.77E-09	1.77E-03	8.67E-04	2.21E-08	4.76E-06	1.26E-05	7.04E-04	2.20E+01	9.65E-07
27.004	2.90E-06	1.57E-05	6.77E-09	1.85E-03	8.88E-04	2.37E-08	4.87E-06	1.29E-05	7.20E-04	2.25E+01	9.65E-07
28.006	2.90E-06	1.58E-05	6.77E-09	1.90E-03	8.96E-04	2.48E-08	4.92E-06	1.30E-05	7.27E-04	2.28E+01	9.65E-07
30.016	2.90E-06	1.59E-05	6.77E-09	1.94E-03	9.04E-04	2.60E-08	4.97E-06	1.31E-05	7.34E-04	2.30E+01	9.65E-07

TABLE 5.6. DISTRIBUTION OF FISSION PRODUCTS BY GROUP - S_2DC_r SEQUENCE

Species	RCS	Cavity Water	Melt	Containment	Environment
I	0.72	3.5×10^{-3}	0	0.27	2.9×10^{-6}
Cs	0.72	3.6×10^{-3}	0	0.27	1.6×10^{-5}
Te	0.23	0.20	0.35	0.22	1.9×10^{-3}
Sr	2.6×10^{-4}	0.30	0.68	2.2×10^{-2}	9.0×10^{-4}
Ru	3.8×10^{-7}	8.1×10^{-7}	1.0	1.9×10^{-7}	2.6×10^{-8}
La	4.1×10^{-8}	6.8×10^{-3}	0.99	5.4×10^{-4}	5.0×10^{-6}
Ce	0	6.4×10^{-3}	0.99	4.6×10^{-4}	1.3×10^{-5}
Ba	5.6×10^{-3}	0.21	0.76	1.8×10^{-2}	7.3×10^{-4}
Tr	0	0	0	0.99	9.6×10^{-7}

5.2.2 Transport in Containment for the S_2DCF1 Scenario

Table 5.7 provides a summary of the sources of radionuclides to the containment atmosphere for the S_2DCF1 scenario. Although the releases from the reactor coolant system are the same as for S_2DC_r, the ex-vessel release is higher.

In this scenario, the containment fails subsequent to reactor vessel failure due to hydrogen combustion and direct heating. The time-dependent size distribution of airborne particles in the containment is shown in Table 5.8, and the fraction of core inventory released from the containment as a function of time is listed in Table 5.9. Table 5.10 presents the locational distribution of the radionuclides at the end of the accident.

The radionuclide release to the environment is high for this sequence due to the complete abseance of containment engineered safety features as well as a very short residence time of fission products in the containment. The fractional releases for Cs, I, and Te are 0.22, 0.22, and 0.32, respectively. The major removal mechanism in this sequence is sedimentation. Condensation onto particles occurs only near the end of the accident, so it contributes very little to the removal of radionuclides.

5.2.3 Transport in Containment for the S_2DCF2 Scenario

Table 5.11 provides a summary of the source terms to the containment for the S_2DCF2 scenario. In this scenario the containment fails 14 hours after the reactor vessel fails. The time-dependent size distribution of airborne particles in the containment is shown in Table 5.12, and the fraction of core inventory released to the environment as a function of time is listed in Table 5.13. Table 5.14 presents the locational distribution of the radionuclides at the end of the accident.

The relatively long time between the time the core starts to melt to the time the containment fails allows sedimentation and diffusion processes to remove the majority of the radionuclides from the containment air space. As a

TABLE 5.7. SUMMARY OF RELEASE TO CONTAINMENT FOR THE S_2DCF_1 SEQUENCE

GROUP	DURING IN-VESSEL RELEASE	DURING PUFF RELEASE	DURING CORE-CONCRETE ATTACK
I	.2637	8.4180E-03	1.7702E-03
CS	.2654	9.0790E-03	2.7226E-03
PI	6.1718E-04	9.9528E-05	-
TE	.1755	2.8838E-02	.3351
SR	1.1058E-04	2.7217E-05	5.2069E-02
RU	1.4568E-07	2.4812E-08	5.7576E-04
LA	1.3206E-08	1.4210E-09	2.5329E-03
NG	.9830	9.6393E-03	-
CE	0.	0.	8.9470E-04
BA	2.3067E-03	6.5334E-04	3.6000E-02

TABLE 5.8. SIZE DISTRIBUTION OF AEROSOLS IN CONTAINMENT - S_2DCF_1 SCENARIO WITH EARLY CONTAINMENT FAILURE

TIME	2.200	2.701	3.500	4.500	5.500	7.000	9.000	11.000	15.003	20.001
DENSITY	3.00E+00	3.00E+00	3.08E+00	3.82E+00	3.87E+00	4.00E+00	4.21E+00	4.50E+00	5.09E+00	5.09E+00
PARTICLE DIAMETER (MICRONS)										
5.00E-03	2.58E-20	0.	6.39E-28	0.	6.59E-14	8.01E-12	1.28E-11	1.17E-11	0.	0.
8.20E-03	1.14E-17	0.	4.18E-21	1.34E-12	5.53E-11	1.04E-09	1.56E-09	1.58E-09	0.	0.
1.35E-02	2.81E-15	2.36E-18	8.16E-17	2.53E-10	5.13E-09	4.99E-08	7.34E-08	8.03E-08	0.	0.
2.21E-02	4.25E-13	9.31E-12	8.87E-13	2.14E-08	2.27E-07	1.24E-06	1.80E-06	2.11E-06	0.	0.
3.62E-02	6.36E-11	1.86E-08	2.84E-09	9.40E-07	5.36E-06	1.69E-05	2.42E-05	3.03E-05	4.59E-22	0.
5.95E-02	3.03E-08	1.86E-06	1.00E-06	2.15E-05	6.94E-05	1.32E-04	1.87E-04	2.48E-04	1.93E-11	1.04E-17
9.76E-02	2.34E-06	4.18E-05	7.35E-05	2.53E-04	5.04E-04	6.34E-04	9.07E-04	1.26E-03	7.90E-07	1.11E-09
1.60E-01	6.14E-05	4.34E-04	1.71E-03	1.66E-03	2.31E-03	2.02E-03	3.04E-03	4.45E-03	1.59E-04	5.53E-06
2.63E-01	8.02E-04	2.79E-03	1.50E-02	7.97E-03	7.56E-03	4.50E-03	7.57E-03	1.19E-02	3.64E-03	5.24E-04
4.31E-01	6.23E-03	1.28E-02	5.08E-02	3.33E-02	1.85E-02	9.64E-03	1.38E-02	2.50E-02	2.82E-02	8.90E-03
7.07E-01	3.08E-02	4.48E-02	8.31E-02	1.35E-01	5.07E-02	2.76E-02	2.34E-02	3.78E-02	1.49E-01	8.58E-02
1.16E+00	9.82E-02	1.18E-01	1.27E-01	3.67E-01	2.16E-01	1.37E-01	9.76E-02	8.83E-02	3.49E-01	3.48E-01
1.90E+00	2.01E-01	2.18E-01	2.12E-01	3.34E-01	4.18E-01	3.84E-01	3.51E-01	3.19E-01	2.06E-01	3.46E-01
3.12E+00	2.64E-01	2.67E-01	2.51E-01	9.59E-02	2.30E-01	3.22E-01	3.66E-01	3.72E-01	1.58E-01	1.72E-01
5.12E+00	2.27E-01	2.11E-01	1.81E-01	2.04E-02	4.92E-02	8.93E-02	1.18E-01	1.22E-01	7.63E-02	3.44E-02
8.41E+00	1.25E-01	1.00E-01	6.93E-02	4.47E-03	6.41E-03	1.23E-02	1.76E-02	1.70E-02	7.62E-03	1.13E-03
1.38E+01	4.03E-02	2.33E-02	9.20E-03	3.32E-04	3.70E-04	6.88E-04	9.95E-04	8.35E-04	8.69E-03	5.70E-06
2.26E+01	6.09E-03	1.54E-03	1.86E-04	4.95E-06	6.37E-06	1.16E-05	1.61E-05	1.10E-05	9.08E-03	5.85E-05
3.71E+01	3.57E-04	1.44E-05	5.10E-07	1.66E-08	2.74E-08	4.91E-08	6.36E-08	3.43E-08	1.45E-03	2.55E-08
6.09E+01	1.91E-05	1.92E-08	2.57E-10	1.29E-11	2.77E-11	4.93E-11	5.82E-11	2.44E-11	1.29E-04	1.34E-09
1.00E+02	9.18E-07	4.92E-12	2.69E-14	2.29E-15	6.42E-15	1.13E-14	1.21E-14	3.92E-15	1.93E-06	1.34E-11

TABLE 5.9. FRACTION OF CORE INVENTORY RELEASED FROM CONTAINMENT - S_2DCF_1 SCENARIO WITH EARLY CONTAINMENT FAILURE

TIME (HR)	FISSION PRODUCT GROUP I	CS	PI	TE	SR	RU	LA	CE	BA	PE	TR
2.200	3.82E-06	3.81E-06	8.84E-09	2.08E-06	1.48E-09	2.05E-12	1.94E-13	0.	3.03E-08	0.	0.
2.701	1.82E-01	1.84E-01	4.82E-04	1.41E-01	9.39E-05	1.15E-07	9.78E-09	0.	2.03E-03	0.	7.09E-01
3.500	2.01E-01	2.03E-01	5.33E-04	1.56E-01	1.27E-04	1.27E-07	1.74E-08	3.24E-08	2.25E-03	1.20E+00	7.95E-01
4.500	2.11E-01	2.14E-01	5.61E-04	1.84E-01	1.40E-02	1.43E-07	7.19E-04	2.35E-04	1.16E-02	5.86E+02	8.42E-01
5.500	2.16E-01	2.18E-01	5.72E-04	2.13E-01	2.42E-02	2.04E-07	1.20E-03	4.11E-04	1.85E-02	1.04E+03	8.61E-01
7.000	2.19E-01	2.21E-01	5.79E-04	2.38E-01	3.04E-02	5.08E-07	1.50E-03	5.19E-04	2.28E-02	1.35E+03	8.73E-01
9.000	2.20E-01	2.23E-01	5.82E-04	2.54E-01	3.29E-02	1.04E-06	1.62E-03	5.62E-04	2.46E-02	1.49E+03	8.78E-01
11.000	2.21E-01	2.23E-01	5.84E-04	2.73E-01	3.47E-02	2.09E-06	1.70E-03	5.93E-04	2.59E-02	1.60E+03	8.81E-01
15.003	2.21E-01	2.24E-01	5.86E-04	3.05E-01	3.65E-02	7.48E-05	1.78E-03	6.23E-04	2.71E-02	1.74E+03	8.84E-01
20.001	2.22E-01	2.25E-01	5.86E-04	3.23E-01	3.72E-02	1.66E-04	1.82E-03	6.36E-04	2.77E-02	1.81E+03	8.88E-01

TABLE 5.10. DISTRIBUTION OF FISSION PRODUCTS BY GROUP - S_2DCF_1 SCENARIO WITH EARLY CONTAINMENT FAILURE

Species	RCS	Cavity Water	Melt	Containment	Environment
I	0.72	2.1×10^{-3}	0	5.2×10^{-2}	0.22
Cs	0.72	1.3×10^{-3}	0	5.3×10^{-2}	0.22
Te	0.23	6.7×10^{-2}	0.20	0.18	0.32
Sr	2.6×10^{-4}	4.8×10^{-2}	0.90	1.4×10^{-2}	3.7×10^{-2}
Ru	3.8×10^{-7}	2.4×10^{-4}	1.0	2.0×10^{-3}	1.6×10^{-4}
La	4.1×10^{-8}	2.6×10^{-3}	0.99	6.5×10^{-4}	1.8×10^{-3}
Ce	0	8.2×10^{-4}	1.0	2.4×10^{-4}	6.4×10^{-4}
Ba	5.6×10^{-3}	3.2×10^{-2}	0.92	1.0×10^{-2}	2.8×10^{-2}
Tr	0	0	0	7.9×10^{-2}	0.92

TABLE 5.11. SUMMARY OF RELEASE TO CONTAINMENT FOR THE S_2DCF_2 SEQUENCE

GROUP	DURING IN-VESSEL RELEASE	DURING PUFF RELEASE	DURING CORE-CONCRETE ATTACK
I	.2837	8.4180E-03	1.768E-05
CS	.2654	9.0790E-03	2.2905E-04
PI	6.1718E-04	9.9528E-05	-
TE	.1755	2.8838E-02	.05815
SR	1.1058E-04	2.7217E-05	.01954
RU	1.4568E-07	2.4812E-08	2.0608E-06
LA	1.3206E-08	1.4210E-09	6.8644E-04
NG	.9830	9.6393E-03	-
CE	0.	0.	4.6762E-04
BA	2.3067E-03	6.5334E-04	.01321

TABLE 5.12. SIZE DISTRIBUTION OF AEROSOLS IN CONTAINMENT - S_2DCF_2 SCENARIO WITH LATE CONTAINMENT FAILURE

TIME	15.000	15.502	16.002	16.501	17.000	18.000	19.000	20.000	22.000	24.005
DENSITY	3.06E+00	3.06E+00	3.07E+00	3.11E+00	3.19E+00	3.94E+00	5.03E+00	5.80E+00	6.56E+00	6.68E+00
PARTICLE DIAMETER (MICRONS)										
5.00E-03	2.02E-12	1.77E-09	9.72E-09	3.92E-08	3.90E-08	1.79E-08	6.98E-09	5.70E-09	3.16E-09	0.
8.20E-03	3.18E-10	9.10E-08	3.83E-07	1.25E-06	1.34E-06	8.52E-07	4.93E-07	3.31E-07	1.93E-07	0.
1.35E-02	2.40E-08	1.69E-06	7.43E-06	2.07E-05	2.43E-05	2.10E-05	1.37E-05	9.68E-06	5.89E-06	0.
2.21E-02	8.10E-07	1.70E-05	7.37E-05	1.92E-04	2.50E-04	2.81E-04	2.07E-04	1.52E-04	9.65E-05	4.03E-17
3.62E-02	1.11E-05	9.12E-05	3.93E-04	1.07E-03	1.59E-03	2.18E-03	1.76E-03	1.35E-03	8.84E-04	2.51E-09
5.95E-02	6.58E-05	2.71E-04	1.11E-03	3.37E-03	6.39E-03	1.11E-02	9.37E-03	7.33E-03	4.92E-03	7.95E-06
9.76E-02	1.82E-04	4.60E-04	1.58E-03	5.07E-03	1.32E-02	4.09E-02	3.53E-02	2.73E-02	1.85E-02	5.50E-04
1.60E-01	2.38E-04	4.38E-04	1.16E-03	3.45E-03	1.09E-02	8.52E-02	1.08E-01	8.14E-02	5.22E-02	7.83E-03
2.63E-01	1.53E-04	2.29E-04	4.67E-04	1.17E-03	3.65E-03	6.39E-02	1.94E-01	2.08E-01	1.34E-01	5.36E-02
4.31E-01	4.20E-04	4.35E-04	4.87E-04	6.18E-04	1.03E-03	1.55E-02	1.14E-01	2.49E-01	2.97E-01	2.31E-01
7.07E-01	7.70E-03	7.80E-03	8.00E-03	8.19E-03	8.31E-03	8.62E-03	2.31E-02	8.67E-02	2.71E-01	3.96E-01
1.16E+00	6.78E-02	6.89E-02	7.07E-02	7.21E-02	7.27E-02	6.27E-02	4.58E-02	3.84E-02	8.07E-02	1.91E-01
1.90E+00	2.85E-01	2.93E-01	2.95E-01	2.99E-01	2.99E-01	2.54E-01	1.78E-01	1.22E-01	6.68E-02	7.00E-02
3.12E+00	4.45E-01	4.47E-01	4.47E-01	4.44E-01	4.35E-01	3.52E-01	2.33E-01	1.48E-01	6.54E-02	4.60E-02
5.12E+00	1.74E-01	1.69E-01	1.59E-01	1.50E-01	1.38E-01	9.88E-02	5.57E-02	2.94E-02	8.66E-03	4.08E-03
8.41E+00	1.92E-02	1.69E-02	1.39E-02	1.13E-02	9.03E-03	4.66E-03	1.76E-03	5.94E-04	8.22E-05	2.43E-05
1.38E+01	6.24E-04	4.40E-04	2.64E-04	1.49E-04	8.26E-05	2.07E-05	3.93E-06	8.55E-07	8.42E-08	1.88E-08
2.26E+01	4.92E-06	2.21E-06	6.62E-07	1.75E-07	5.67E-08	8.01E-09	1.10E-09	1.86E-10	1.42E-11	2.52E-12
3.71E+01	8.65E-09	1.80E-09	1.96E-10	2.24E-11	5.47E-12	5.29E-13	5.54E-14	7.65E-15	7.04E-11	7.28E-11
6.09E+01	3.31E-12	2.56E-13	2.00E-10	3.38E-10	3.66E-10	3.11E-10	1.95E-10	1.30E-10	7.60E-11	7.86E-11
1.00E+02	7.87E-11	2.39E-10	7.21E-10	1.22E-09	1.32E-09	1.12E-09	7.05E-10	4.70E-10	2.74E-10	2.84E-10

TABLE 5.13. FRACTION OF CORE INVENTORY RELEASED FROM CONTAINMENT - S_2DCF_2 SCENARIO WITH LATE CONTAINMENT FAILURE

TIME (HR)	I	CS	PI	TE	SR	RU	LA	CE	BA	PE	TR
			FISSION PRODUCT GROUP								
5.000	3.89E-03	3.93E-03	1.04E-05	3.39E-03	3.68E-04	5.88E-09	1.21E-05	8.64E-06	2.91E-04	6.60E+00	1.66E-02
5.502	1.95E-02	1.97E-02	5.21E-05	1.71E-02	1.85E-03	3.23E-08	6.07E-05	4.32E-05	1.46E-03	3.31E+01	8.32E-02
6.002	2.46E-02	2.48E-02	6.58E-05	2.18E-02	2.33E-03	4.63E-08	7.66E-05	5.46E-05	1.84E-03	4.19E+01	1.05E-01
6.501	2.56E-02	2.59E-02	6.85E-05	2.28E-02	2.43E-03	5.15E-08	7.98E-05	5.69E-05	1.92E-03	4.38E+01	1.09E-01
7.000	2.57E-02	2.60E-02	6.88E-05	2.29E-02	2.44E-03	5.33E-08	8.02E-05	5.72E-05	1.93E-03	4.40E+01	1.10E-01
8.000	2.59E-02	2.62E-02	6.94E-05	2.35E-02	2.46E-03	6.56E-08	8.09E-05	5.77E-05	1.95E-03	4.47E+01	1.11E-01
9.000	2.60E-02	2.63E-02	6.97E-05	2.41E-02	2.47E-03	8.69E-08	8.12E-05	5.79E-05	1.96E-03	4.56E+01	1.11E-01
0.000	2.61E-02	2.64E-02	6.98E-05	2.52E-02	2.47E-03	1.26E-07	8.14E-05	5.80E-05	1.97E-03	4.69E+01	1.12E-01
2.000	2.62E-02	2.65E-02	7.01E-05	2.90E-02	2.49E-03	2.85E-07	8.17E-05	5.83E-05	2.00E-03	5.17E+01	1.12E-01
4.005	2.63E-02	2.66E-02	7.04E-05	3.41E-02	2.49E-03	5.16E-07	8.20E-05	5.84E-05	2.03E-03	5.83E+01	1.12E-01

TABLE 5.14. DISTRIBUTION OF FISSION PRODUCTS BY GROUP - S_2DCF_2 SCENARIO WITH LATE CONTAINMENT FAILURE

Species	RCS	Cavity Water	Melt	Containment	Environment
I	0.72	3.5×10^{-3}	0	0.25	2.6×10^{-2}
Cs	0.72	3.8×10^{-3}	0	0.25	2.7×10^{-2}
Te	0.23	0.22	0.33	0.19	3.4×10^{-2}
Sr	2.6×10^{-4}	0.32	0.66	1.7×10^{-2}	2.5×10^{-3}
Ru	3.8×10^{-7}	6.0×10^{-7}	1.0	3.4×10^{-7}	5.2×10^{-7}
La	4.1×10^{-8}	7.0×10^{-3}	0.99	3.8×10^{-4}	8.2×10^{-5}
Ce	0	7.2×10^{-3}	0.99	4.1×10^{-4}	5.8×10^{-5}
Ba	5.6×10^{-3}	0.22	0.76	1.4×10^{-2}	2.0×10^{-3}
Tr	0	0	0	0.88	0.11

result, only a few percent of the volatile and lesser amount of the nonvolatile radionuclides are predicted to be released to the environment.

5.3 TMLU Sequence

5.3.1 Transport in the Reactor Coolant System

The TMLU sequence is characterized by high, 2,370 psia (161 atmospheres), primary system pressure and temperatures, 800 F to 1825 F (700 K to 1270 K), and relatively low flow rates. For these conditions, the predicted progress with time of the release from fuel and of deposition within the RCS of the three volatile fission product species CsI, CsOH, and Te, and of the structural and fuel material aerosol is as shown in Table 5.15. These data are characterized by monotonically increasing depositions which, however, experience a jump increase during the period of core slumping (between 10,639 and 10,762 seconds). This jump can be traced to the surge in steam flow accompanying slumping and the resultant transfer of material out of the core region and into regions (such as the upper plenum and pressure relief line) of the RCS with high deposition efficiency. Beyond the core collapse period deposition is diminished for the same reasons as those given for the S_2DC_r sequence. Table 5.15 shows that 77.6 percent of CsI, 81.1 percent of CsOH, 52.7 percent of Te and 78.3 percent of aerosol released from the fuel during this period are retained in the RCS.

Table 5.16 gives the total quantities of material released from the fuel and retained on RCS surfaces at the end of the in-vessel release period for each of the elemental release groups.

Figures 5.5 through 5.8 give a more detailed view of transport behavior of the volatile fission products and of structural material aerosols in the RCS as a function of time. As for the S_2DC_r sequence, each curve gives the mass of the given species that has been transported beyond the specified control volume and is thus no longer subject to capture by that control volume or control volumes upstream of it. Unlike the case for the S_2DCr sequence, significant holdup occurs before the beginning of core slumping. Indeed, the large amount of retention indicated before about 10,400 seconds for CsI in Figure 5.5 in the core region (difference between the solid curve and the

TABLE 5.15. MASSES OF DOMINANT SPECIES RELEASED FROM FUEL (TOTAL) AND RETAINED ON RCS STRUCTURE SURFACES (RET) AS A FUNCTION OF TIME - TMLU SEQUENCE

TIME (S)	CSI RET (KG)	CSI TOTAL (KG)	CSOH RET (KG)	CSOH TOTAL (KG)	TE RET (KG)	TE TOTAL (KG)	AEROSOL RET (KG)	AEROSOL TOTAL (KG)
9047.	.1	4.6	.4	29.5	.0	.3	.5	44.4
9167.	.3	7.2	2.1	43.7	.0	.6	3.0	56.7
9289.	.8	9.8	5.1	58.3	.1	.9	7.0	72.4
9414.	1.4	12.0	8.5	70.5	.1	1.3	11.2	85.9
9534.	1.9	13.4	11.6	77.1	.2	1.7	15.0	91.3
9662.	2.4	15.1	14.5	85.1	.3	2.2	18.4	101.4
9782.	2.8	16.3	16.5	91.1	.3	2.7	20.8	109.8
9908.	3.0	17.3	18.0	96.5	.4	3.2	22.5	118.4
10029.	3.2	18.0	18.7	99.8	.4	3.7	23.4	124.7
10149.	3.2	18.6	19.2	103.1	.4	4.2	24.0	131.9
10274.	3.3	19.6	19.6	110.0	.4	4.8	24.6	151.0
10395.	3.4	22.9	20.2	129.2	.5	5.3	25.4	192.5
10518.	7.9	24.6	46.0	147.8	1.6	6.2	64.2	223.5
10639.	12.4	26.1	73.1	156.4	3.0	8.2	107.6	263.1
10762.	20.3	27.8	132.0	167.4	4.6	11.1	272.4	357.5
10885.	21.6	29.2	138.5	177.3	6.0	13.7	307.5	382.5
11008.	22.6	28.9	144.2	182.1	7.1	14.9	322.8	403.3
11130.	23.2	30.2	147.4	183.6	7.9	15.6	336.0	422.2
11254.	23.4	30.3	148.9	184.3	8.4	16.1	347.6	439.5
11376.	23.5	30.3	149.5	184.3	8.7	16.5	356.3	454.9

TABLE 5.16. MASSES OF RADIONUCLIDES RELEASED FROM FUEL AND RETAINED ON RCS SURFACES (BY ELEMENTAL GROUP) - TMLU SEQUENCE

GROUP	RELEASED (KG)	RETAINED (KG)
I	14.8	11.5
CS	179.0	144.6
TE	16.5	8.7
SR	.1	.0
RU	.0	.0
LA	.0	.0
NG	338.2	.0
CE	.0	.0
BA	1.5	1.1

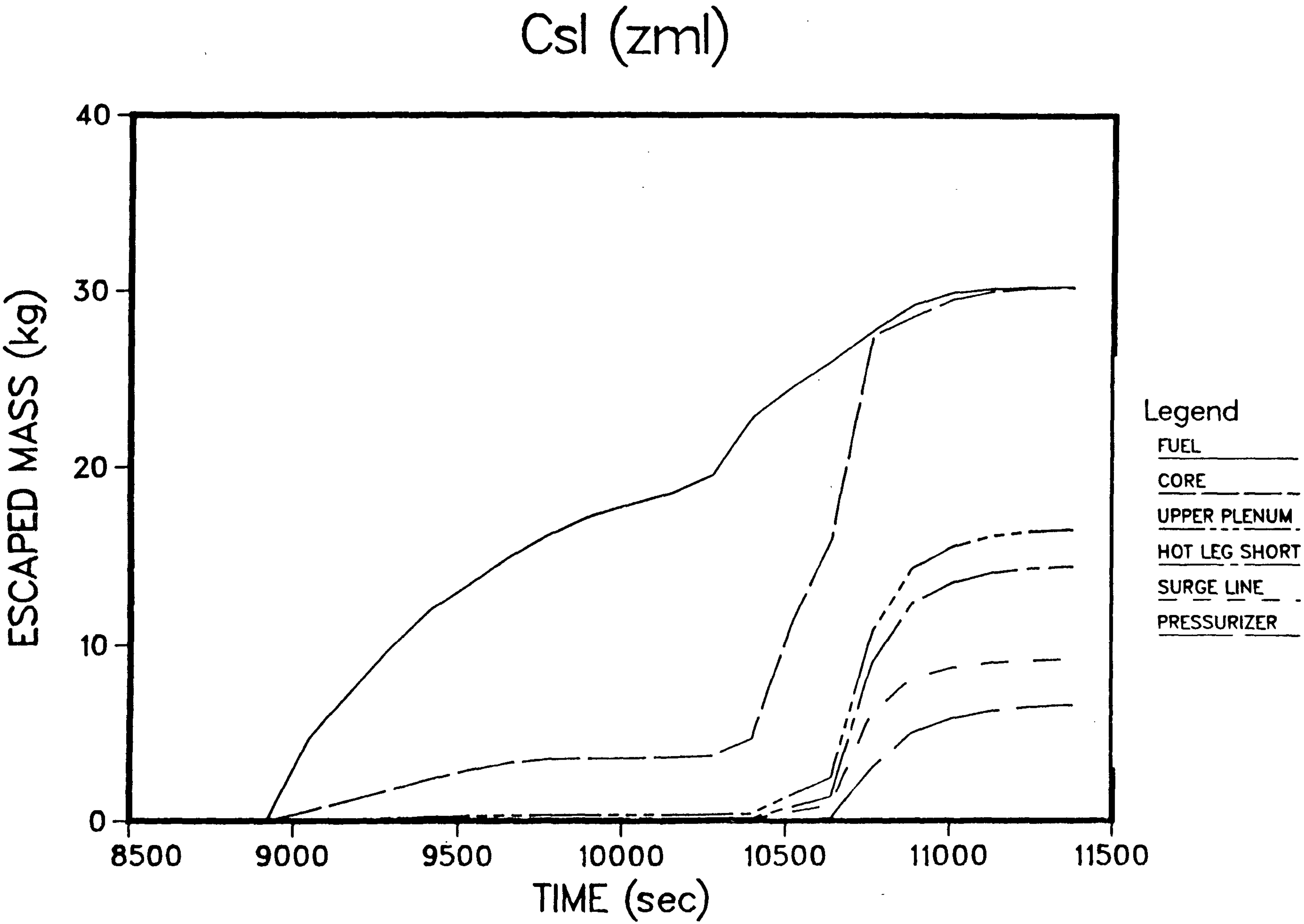

FIGURE 5.5. MASS OF CsI RELEASED FROM INDICATED RCS COMPONENT AS A FUNCTION OF TIME - TMLU SEQUENCE

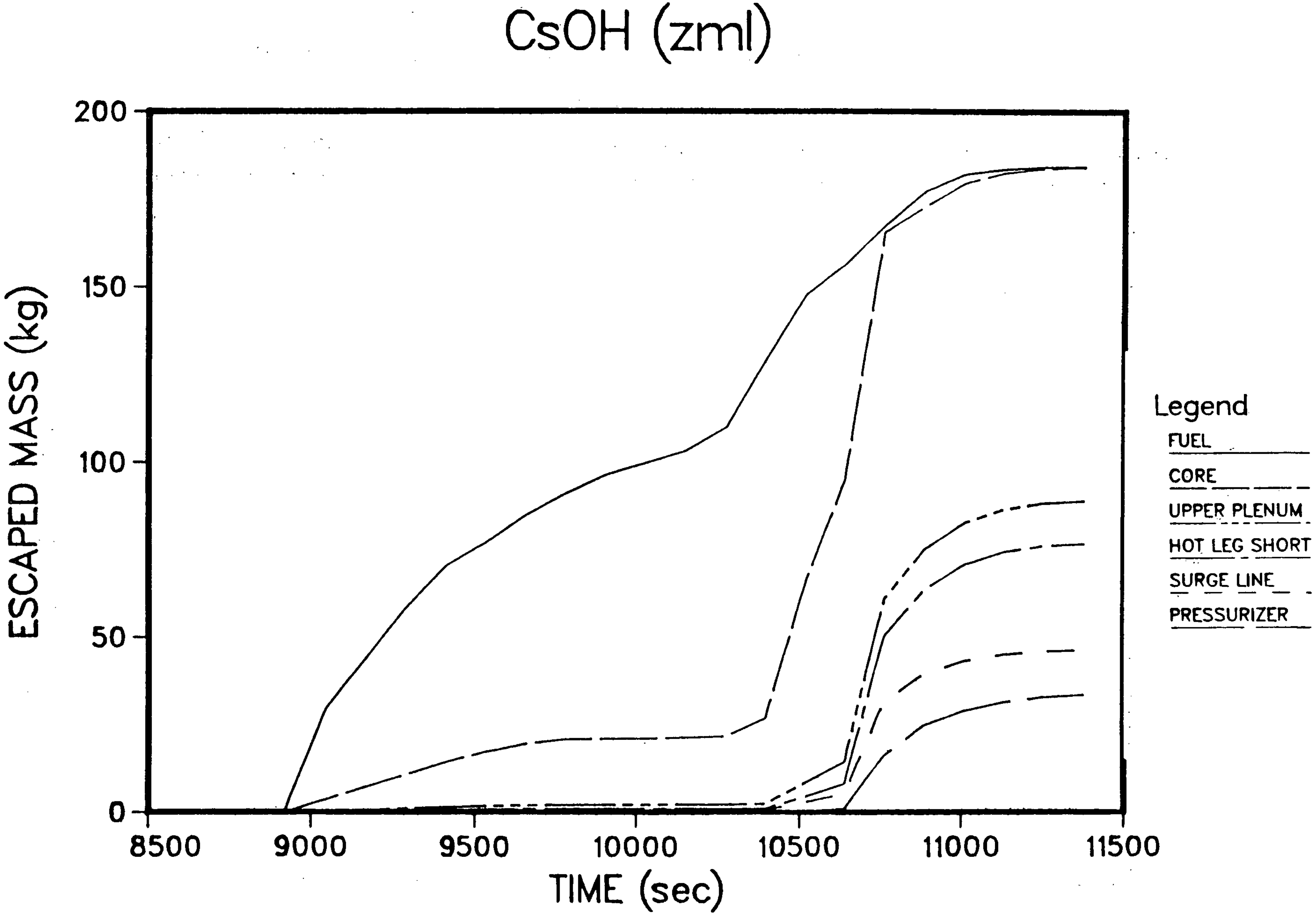

FIGURE 5.6. MASS OF CsOH RELEASED FROM INDICATED RCS COMPONENT AS A FUNCTION OF TIME - TMLU SEQUENCE

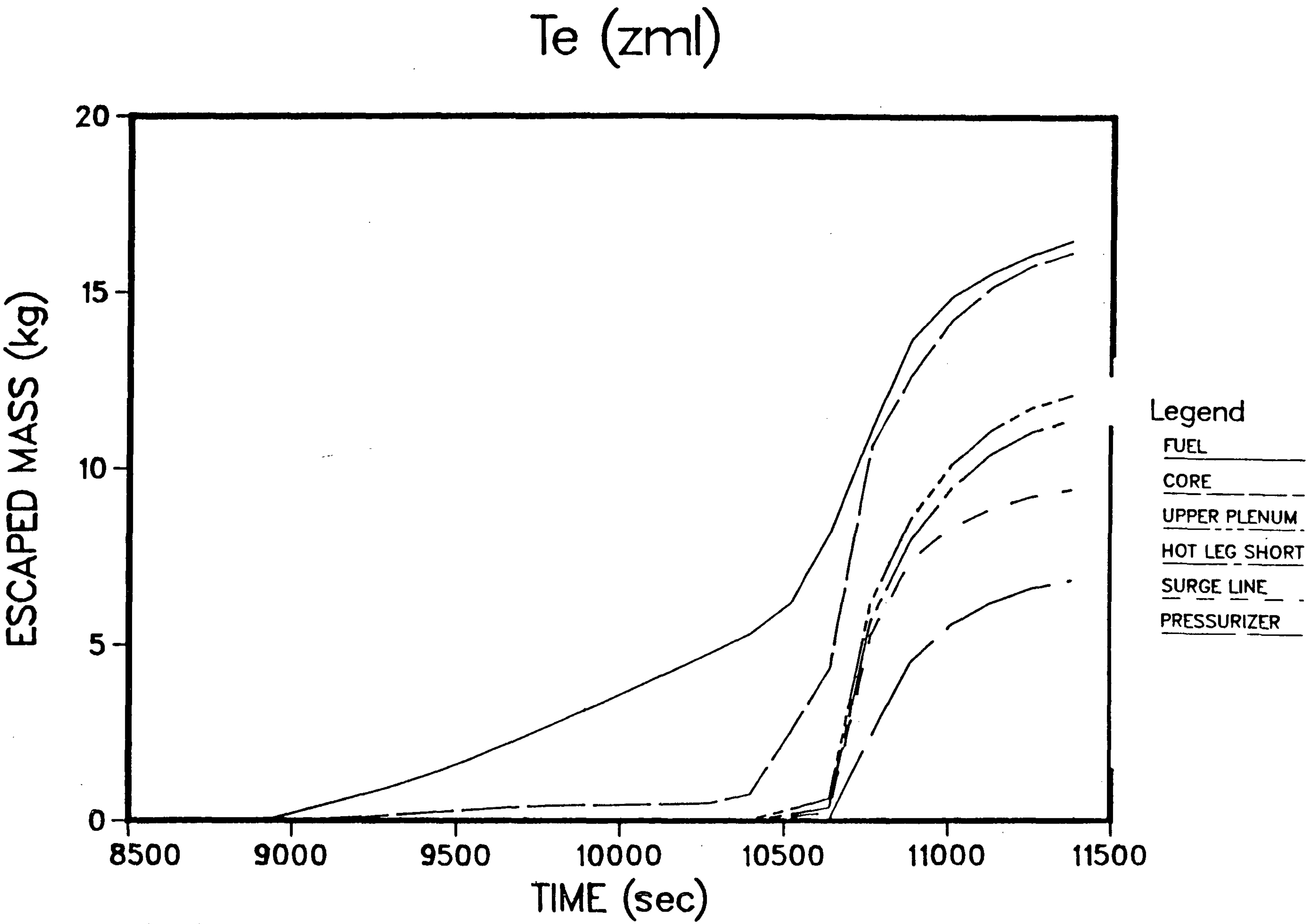

FIGURE 5.7 MASS OF TE RELEASED FROM INDICATED RCS COMPONENT AS A FUNCTION OF TIME - TMLU SEQUENCE

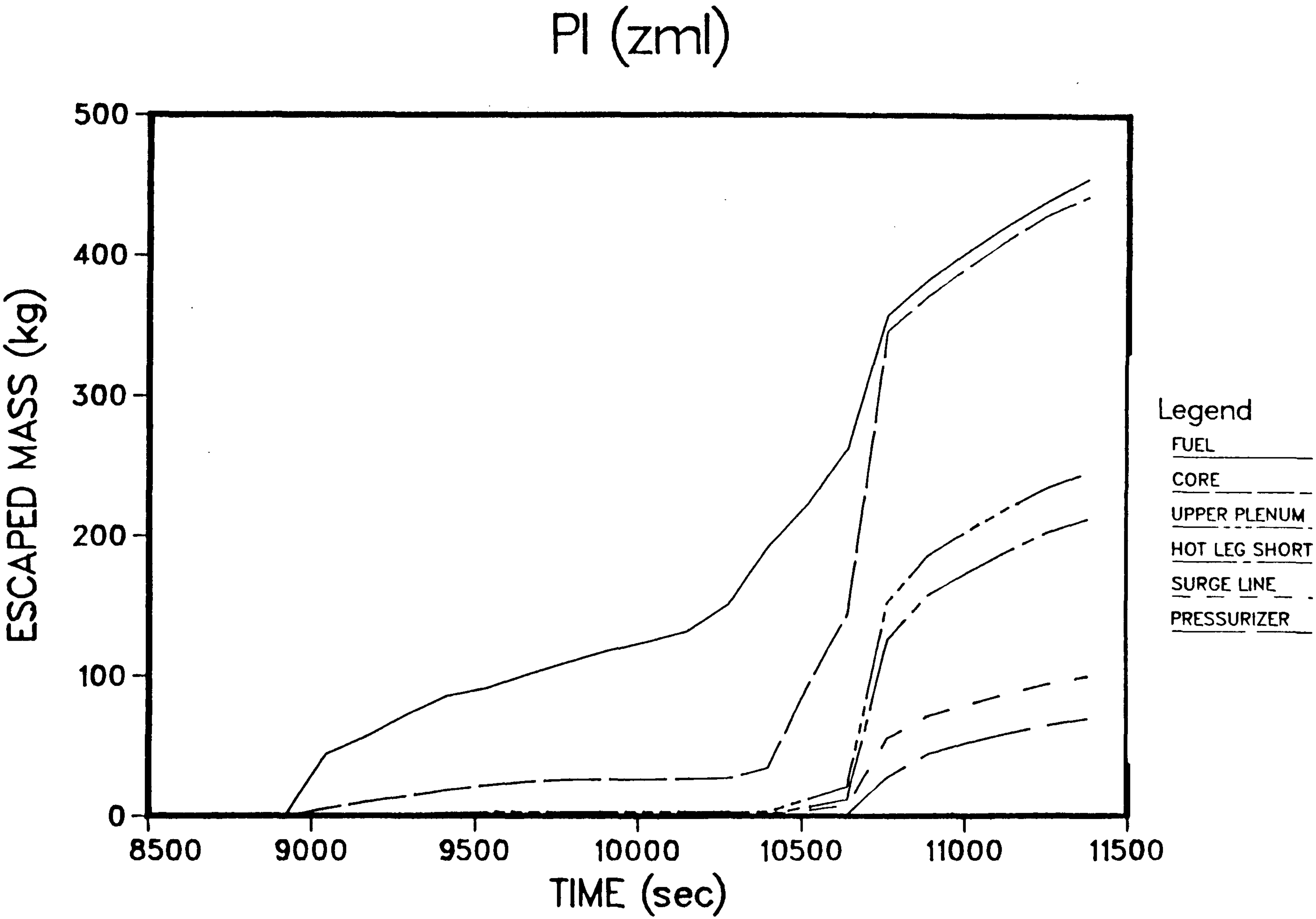

FIGURE 5.8. MASS OF STRUCTURAL MATERIAL AEROSOL RELEASED FROM INDICATED RCS COMPONENT AS A FUNCTION OF TIME - TMLU SEQUENCE

dashed curve of the core), is seen to be entirely due to holdup since the fuel and core curves merge later in time. If natural convection between the core region and the upper plenum were taken into account, it is likely that fission products would move out of the core region and be subject to deposition in the upper plenum earlier in the scenario than indicated. In the TMLU sequence it is again the upper plenum that plays a major role in retention of all species.

5.3.2 Transport in Containment for the TMLU Sequence

In this sequence the containment fails at the time of vessel failure. The containment sprays operate until the containment fails. Table 5.17 summarizes the sources of radionuclides to the containment atmosphere from the reactor coolant system and from the interaction of molten fuel debris with concrete. The time-dependent size distribution of airborne particles in the containment is given in Table 5.18, and the fraction of core inventory released from the containment as a function of time is listed in Table 5.19. Table 5.20 presents the locational distribution of the radionuclides at the end of the accident.

The sprays during the in-vessel release period are quite effective at removing the airborne particles. Therefore, the majority of the I, Cs, and Te released to the containment is retained in the containment. In general, the radionuclide release to the environment is low for this sequence with the highest percentage being 4 percent of the Te.

5.4 Noble Gas and Energy Release to the Environment

The release of noble gases to the environment is calculated by the MARCH 3 code rather than the fission product transport codes TRAP and NAUA since the noble gases are assumed to be transported with the bulk flow of gases without attenuation. The energy associated with gases escaping the containment is also calculated in the MARCH 3 code. The environmental releases of noble gases and energy are tabulated in Table 5.21. The heat of vaporization of the steam in the escaping gases is not included in the tabulated energies.

TABLE 5.17. SUMMARY OF RELEASES TO CONTAINMENT FOR TMLU SEQUENCE

GROUP	DURING IN-VESSEL RELEASE	DURING PUFF RELEASE	DURING CORE-CONCRETE ATTACK
I	.2177	6.6661E-03	6.1 E-05
CS	.1846	7.3361E-03	1.03 E-04
PI	5.4046E-04	2.2779E-04	-
TE	.2217	3.1414E-02	1.6751E-02
SR	1.6625E-04	1.0242E-04	1.2 E-05
RU	2.7192E-07	1.7125E-07	4. E-07
LA	2.8121E-08	1.3557E-08	6. E-07
NG	.9819	1.7115E-02	-
CE	0.	0.	3.2 E-08
BA	3.0169E-03	1.9876E-03	1.38 E-04

TABLE 5.18. SIZE DISTRIBUTION OF AEROSOLS IN CONTAINMENT - TMLU SCENARIO

TIME	3.200	3.701	4.500	5.500	6.500	8.000	10.001	12.001	14.002	16.007
DENSITY	3.00E+00	3.00E+00	3.01E+00	3.24E+00	3.33E+00	3.42E+00	3.49E+00	3.60E+00	3.65E+00	3.69E+00
PARTICLE DIAMETER (MICRONS)										
5.00E-03	0.	0.	5.39E-28	0.	2.46E-26	3.68E-21	3.07E-15	6.03E-14	4.52E-13	0.
8.20E-03	1.54E-19	0.	1.42E-22	3.19E-24	6.57E-21	8.27E-17	4.07E-12	5.49E-11	3.23E-10	0.
1.35E-02	2.67E-12	0.	6.91E-18	8.08E-19	3.00E-16	4.63E-13	1.83E-09	1.79E-08	8.53E-08	1.28E-13
2.21E-02	4.47E-09	0.	9.62E-14	3.20E-14	2.88E-12	7.08E-10	2.81E-07	2.07E-06	8.28E-06	3.39E-08
3.62E-02	5.75E-07	1.64E-19	6.90E-10	2.21E-10	5.87E-09	2.95E-07	1.41E-05	8.28E-05	2.85E-04	2.47E-05
5.95E-02	1.95E-05	4.33E-11	3.27E-07	2.61E-07	2.44E-06	3.17E-05	2.42E-04	1.17E-03	3.62E-03	1.17E-03
9.76E-02	2.89E-04	3.64E-07	2.02E-05	5.36E-05	2.16E-04	9.15E-04	1.55E-03	6.31E-03	1.87E-02	1.25E-02
1.60E-01	2.47E-03	5.16E-05	3.08E-04	2.23E-03	4.38E-03	8.45E-03	5.46E-03	1.42E-02	4.05E-02	4.31E-02
2.63E-01	1.39E-02	1.29E-03	1.79E-03	2.13E-02	2.46E-02	3.21E-02	2.02E-02	2.42E-02	4.38E-02	5.69E 02
4.31E-01	5.25E-02	1.36E-02	8.86E-03	5.79E-02	5.99E-02	7.10E-02	6.47E-02	6.47E-02	6.90E-02	7.72E-02
7.07E-01	1.31E-01	7.60E-02	5.18E-02	7.26E-02	9.65E-02	1.18E-01	1.34E-01	1.41E-01	1.40E-01	1.48E-01
1.16E+00	2.15E-01	2.15E-01	1.91E-01	1.57E-01	1.64E-01	1.78E-01	2.03E-01	2.13E-01	2.10E-01	2.17E-01
1.90E+00	2.38E-01	3.00E-01	3.25E-01	3.00E-01	2.91E-01	2.81E-01	2.94E-01	2.95E-01	2.78E-01	2.75E-01
3.12E+00	1.86E-01	2.29E-01	2.61E-01	2.54E-01	2.46E-01	2.26E-01	2.16E-01	1.98E-01	1.69E-01	1.51E-01
5.12E+00	1.04E-01	1.15E-01	1.21E-01	1.08E-01	9.53E-02	7.46E-02	5.69E-02	4.09E-02	2.69E-02	1.83E-02
8.41E+00	4.20E-02	4.04E-02	3.50E-02	2.53E-02	1.75E-02	9.24E-03	3.97E-03	1.54E-03	5.20E-04	1.75E-04
1.38E+01	1.20E-02	8.34E-03	4.63E-03	2.15E-03	9.26E-04	2.20E-04	3.11E-05	3.58E-06	3.52E-07	4.24E-08
2.26E+01	2.39E-03	6.73E-04	1.45E-04	4.01E-05	8.87E-06	7.49E-07	2.81E-08	8.06E-10	2.26E-11	1.23E-12
3.71E+01	3.13E-04	9.35E-06	8.28E-07	1.54E-07	1.55E-08	4.43E-10	4.16E-12	2.91E-14	5.01E-10	7.99E-10
6.09E+01	2.39E-05	1.72E-08	9.70E-10	1.24E-10	5.43E-12	5.20E-14	1.53E-10	5.28E-10	1.47E-09	2.34E-09
1.00E+02	8.07E-07	6.09E-12	2.46E-13	2.16E-14	5.01E-11	1.18E-10	4.09E-10	1.41E-09	3.92E-09	6.25E-09

TABLE 5.19. FRACTION OF CORE INVENTORY RELEASED FROM CONTAINMENT - TMLU SCENARIO

TIME (HR)	FISSION PRODUCT GROUP										
	I	CS	PI	TE	SR	RU	LA	CE	BA	PE	TR
3.200	7.60E-04	6.34E-04	2.63E-04	3.82E-03	1.11E-05	1.92E-08	1.54E-09	0.	2.25E-04	0.	1.16E-01
3.701	4.94E-03	5.42E-03	1.68E-03	2.49E-02	7.55E-05	1.26E-07	9.98E-09	0.	1.43E-03	0.	7.36E-01
4.500	4.94E-03	5.52E-03	1.68E-03	2.49E-02	7.65E-05	1.26E-07	1.01E-08	4.09E-17	1.43E-03	6.22E-05	7.36E-01
5.500	5.08E-03	5.31E-03	1.74E-03	2.66E-02	7.85E-05	1.35E-07	9.10E-08	4.18E-09	1.57E-03	1.98E+01	7.62E-01
6.500	5.46E-03	6.01E-03	1.84E-03	3.15E-02	8.62E-05	1.63E-07	2.84E-07	1.31E-08	1.63E-03	7.78E+01	8.09E-01
8.000	5.54E-03	6.15E-03	1.89E-03	3.53E-02	9.09E-05	2.29E-07	3.46E-07	1.73E-08	1.73E-03	1.22E+02	8.31E-01
10.001	5.60E-03	6.26E-03	1.91E-03	3.68E-02	9.26E-05	3.15E-07	3.79E-07	1.91E-08	1.77E-03	1.46E+02	8.40E-01
12.001	5.68E-03	6.33E-03	1.92E-03	3.82E-02	9.37E-05	3.72E-07	3.90E-07	1.96E-08	1.77E-03	1.54E+02	8.42E-01
14.002	5.72E-03	6.36E-03	1.92E-03	4.00E-02	9.38E-05	4.10E-07	3.93E-07	1.98E-08	1.77E-03	1.57E+02	8.43E-01
16.007	5.72E-03	6.36E-03	1.92E-03	4.00E-02	9.38E-05	4.30E-07	3.93E-07	1.98E-08	1.82E-03	1.57E+02	8.43E-01

TABLE 5.20. DISTRIBUTION OF FISSION PRODUCTS BY GROUP - TMLU SEQUENCE

Species	RCS	Cavity Water	Melt	Containment	Environment
I	0.77	9.6×10^{-4}	0	0.22	5.7×10^{-3}
Cs	0.81	8.4×10^{-4}	0	0.19	6.4×10^{-3}
Te	0.28	0.15	0.30	0.23	4.0×10^{-2}
Sr	7.8×10^{-4}	1.3×10^{-4}	0.90	1.9×10^{-4}	9.4×10^{-5}
Ru	1.2×10^{-6}	3.2×10^{-6}	1.0	4.6×10^{-7}	4.3×10^{-7}
La	1.3×10^{-7}	8.0×10^{-6}	1.0	2.7×10^{-7}	3.9×10^{-7}
Ce	0	4.5×10^{-7}	1.0	1.2×10^{-8}	2.0×10^{-8}
Ba	1.4×10^{-2}	1.2×10^{-3}	0.98	3.5×10^{-3}	1.8×10^{-3}
Tr	0	0	0	0.16	0.84

TABLE 5.21. ENVIRONMENTAL RELEASE OF NOBLE GASES AND ENERGY

Scenario S2DCF1			Scenario S2DCF2		
Time (Hr)	Group 1 (Fraction)	Energy (Btu)	Time (Hr)	Group 1 (Fraction)	Energy (Btu)
2.2	0.0	0.0	15.0	0.362	2.62(7)
2.7	0.817	5.11(7)	15.5	0.899	5.78(7)
3.5	0.870	5.34(7)	16.0	0.932	6.02(7)
4.5	0.934	5.68(7)	16.5	0.947	6.18(7)
5.5	0.950	5.82(7)	17.0	0.953	6.26(7)
7.0	0.956	5.88(7)	18.0	0.955	6.29(7)
9.0	0.962	5.96(7)	19.0	0.958	6.34(7)
11.0	0.968	6.04(7)	20.0	0.962	6.39(7)
15.0	--	--	22.0	0.967	6.49(7)
20.0	--	--	24.0	--	--

Scenario S2DCr			Scenario TMLU		
Time (Hr)	Group 1 (Fraction)	Energy (Btu)	Time (Hr)	Group 1 (Fraction)	Energy (Btu)
24.0	0.0	0.0	3.2	0.198	1.56(7)
24.25	0.778	5.26(7)	3.7	0.768	3.27(7)
24.5	0.842	5.65(7)	4.5	0.768	3.27(7)
24.75	0.928	6.17(7)	5.5	0.798	3.33(7)
25.0	0.939	6.28(7)	6.5	0.897	3.56(7)
25.5	0.952	6.43(7)	8.0	0.937	3.82(7)
26.0	0.962	6.59(7)	10.0	0.969	4.14(7)
27.0	0.976	6.88(7)	12.0	0.985	4.47(7)
28.0	--	--	14.0	0.992	4.79(7)
30.0	--	--	16.0	--	--

6. SUMMARY AND CONCLUSIONS

This report presents results of source term analyses for several accident sequences for the Zion large dry containment PWR supplementing those given in Volume VI of BMI-2104. The current analyses have focused on the more likely core melt accident sequences as identified by the Accident Sequence Evaluation Program (ASEP). The containment failure modes considered include some occurring late in time as well as some assumed to take place relatively early in the course of the accident sequences. The latter failure modes are believed to be of very low probability for the large volume, high strength containment being considered.

Among the insights arising from the results of present analyses are the following:

1. All the accident scenarios considered indicate significant retention of the volatile fission product species on reactor coolant system surfaces. The possible long-term revaporization of these species has not been included in the present analyses.
2. The predicted environmental fission product releases for delayed containment failure, even in the absence of active engineered safety features, are quite low.
3. For early containment failure in the absence of any engineered safety feature operation, the predicted environmental releases of the volatile fission products are considerable; the releases of some of the less volatile species may also be of concern.
4. For the assumed early containment failure mode with initial availability of the containment sprays, the predicted environmental source terms are generally low, with the tellurium release from corium-concrete interactions at about 4 percent being the highest.

The source term analyses presented in this report were performed as input to a broader study aimed at developing updated risk profiles for a number of reference plant designs. The results presented should not be viewed in isolation but consideration should be given to the relative probabilities of the accident sequences as well as the containment failure modes.

7. REFERENCES

1. Gieseke, J. A., et al., "Source Term Code Package: A User's Guide", NUREG/CR-4587, Draft, April, 1986.

2. Gieseke, J. A., et al., "Radionuclide Release Under Specific LWR Accident Conditions", BMI-2104, Volume VI, Draft, July, 1984.

3. Silberberg, M., et al., "Reassessment of the Technical Bases for Estimating Source Terms", NUREG-0956, Draft, July, 1985.

4. Wooton, R. O., Cybulskis, P., and Quayle, S. F., "MARCH2 (Meltdown Accident Response Characteristics) Code Description and User's Manual", Battelle's Columbus Laboratories, NUREG/CR-3988, BMI-2115, September, 1984.

5. Kuhlman, M. R., Lehmicke, D. J., and Meyer, R. O., "CORSOR User's Manual", Battelle's Columbus Laboratories, NUREG/CR-4173, BMI-2122, March, 1985.

6. Cole, R. K., Kelly, D. P., and Ellis, M. A., "CORCON MOD2: A Computer Program for Analysis of Molten Core Concrete Interactions", NUREG/CR-3920, August, 1984.

7. Powers, D. A., Brockmann, J. E., and Shiver, A. W., "VANESA, A Mechanistic Model of Radionuclide Release and Aerosol Generation During Core Debris Interactions with Concrete", Sandia National Laboratories, NUREG/CR-4308, SAND85-1370, Draft.

8. Muir, J. F., et al., "CORCON-Mod 1: An Improved Model for Molten-Core/Concrete Interactions", Sandia National Laboratories, NUREG/CR-2141, SAND80-2415, July, 1981.

9. Freeman-Kelly, R., and Jung, R. G., "A User's Guide for MERGE", Battelle's Columbus Laboratories, NUREG/CR-4172, BMI-2121, March, 1985.

10. Jordan, H., and Kuhlman, M. R., "TRAP-MELT2 User's Manual", Battelle's Columbus Laboratories, NUREG/CR-4105, BMI-2124, May, 1985.

11. U.S. Nuclear Regulatory Commission, "Reactor Safety Study - An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants", WASH-1400 (NUREG 75-104), October, 1975.

12. Bunz, H., Kayro, M., and Shock, W., "NAUA--Mod 4: A code for Calculating Aerosol Behavior in LWR Core Melt Accidents", KfK-3554 (August, 1983).

13. Commonwealth Edison, "Zion Probabilistic Safety Study", (1981).

14. Murfin, W. B., "Report of the Zion/Indian Point Study", NUREG/CR-1410 (August, 1980).

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13. ABSTRACT (200 words or less)

This report presents results of analyses of the environmental releases of fission products (source terms) for severe accident scenarios in a pressurized water reactor with a large dry containment. The analyses were performed to support the Severe Accident Risk Reduction/Risk Rebaselining Program (SARRP) which is being undertaken for the U.S. Nuclear Regulatory Commission by Sandia National Laboratories. In the SARRP program, risk estimates are being generated for a number of reference plant designs. The Zion Plant has been used in this study as an example of a large dry containment PWR design.

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