Item A

BNL Informal Report
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CONTAINMENT LOADING FOR SEVERE ACCIDENTS IN BWRs WITH A MARK-I CONTAINMENT

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November 1984

Prepared for

U. S. Nuclear Regulatory Commission
Washington, D. C. 20555
Contract No. DE-AC-02-76CH0016
FIN A-3706

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ABSTRACT

This investigation analyzes the progression of a severe accident in a BWR Mark I containment in order to develop realistic containment temperature and pressure loading as part of the NRC's reexamination of the accident source term. The investigation considers a transient initiated event with loss of coolant make-up and focuses on the challenges to containment integrity. There is a large uncertainty as to the condition and location of the core debris after vessel failure so sensitivity studies are used to investigate the range of possible conditions. The results indicate that for a broad range of core debris conditions, the ultimate capacity of the containment will be reached within 2 to 5 hours after vessel failure.

ACKNOWLEDGEMENTS

This work has been performed for the Division of systems Integration (DSI) at the U.S. Nuclear Regulatory Commission (NRC) under the guidance of J. Rosenthal and J. Mitchell (Technical Monitor).

We would also like to express our appreciation to T. Rowland and S. Monteleone for their tireless dedication to the preparation of the manuscript.

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1. INTRODUCTION

The results described in this report are an outgrowth of our participation in the Containment Loads Working Group (CLWG) developed under the NRC's Accident Source Term Program Office (ASTPO). The initial specification of a standard problem for Mark I containments was described in the November 3, 1983 memorandum by M. Silberberg. The standard problem defined in Reference 1 addresses the issue of drywell temperature loadings during the ex-vessel interactions of the corium with concrete. The concern is that the integrity of the drywell would be compromised by high temperatures and/or high pressures shortly after vessel failure. Previous results by Yue and Cole (NUREG/CR-2825) indicate that for a transient initiated LOCA with failure of all make-up (TQUV) the containment would fail about 3 1/2 hours after accident initiation with drywell containment temperatures in excess of 1300°F. A loss of drywell integrity in Mark-I and Mark-II BWR containment designs is potentially important because radionuclide releases would occur directly into secondary buildings bypassing the suppression pool and potential pool scrubbing.

The approach taken has been to define a set of physically consistent initial conditions appropriate to the two base cases under consideration and for the Mark I containment type. This was done by reference to appropriate experimental evidence and by use of simple hand calculations. The sample problems defined[1] the initial masses, composition, and temperature of the corium. We therefore defined the dispersal and final deposition of the corium. These initial conditions were then used to calculate the subsequent corium/concrete interactions. The BCL developed[2] MARCH 1.1 computer code has been used extensively to model containment response during corium/concrete interactions. In addition, the MARCH 1.1B[3] computer code developed at ORNL has been used for application to severe accidents in BWR Mark-I plants. Both of these versions of MARCH utilize the INTER[4] code as a subroutine to model corium/concrete interactions. Murfin,[4] the developer of INTER, stressed that the model represented only a first prototypical containment building melt-through analysis. An improved core/concrete interaction model, CORCON[5], has been issued by Sandia National Laboratories. The CORCON model improves upon the preliminary INTER model because it is intended to provide quantitative estimates of full-scale reactor fuel-melt accidents. While it is outside the scope of this report to replace the INTER model in MARCH with CORCON, it is possible to run MARCH and CORCON concurrently. The initial conditions for core/concrete interactions obtained from the sample problem were input to CORCON. The output from CORCON involving water, hydrogen, carbon dioxide, and carbon monoxide was then input to a MARCH analysis which bypassed the INTER model.

1.1 Description of the Reference Mark I Containment

The Mark I containment system consists of the drywell, the pressure suppression pool, the vent system connecting the drywell and pressure suppression pool, a containment cooling system, isolation valves, and various service equipment. Figure 1.1 shows the arrangement of the drywell and pressure suppression pool.

The drywell is a steel pressure vessel with a spherical lower portion and a cylindrical upper portion. It is designed for an internal pressure of 0.531 MPa (62 psig) at a temperature of 138°C (281°F). Normal environment in the drywell during plant operation is an inert atmosphere of nitrogen at atmospheric pressure and a temperature of about 57°C (135°F).

The vent system consists of 8 circular vent pipes which connect the drywell to the pool. The pressure suppression pool is a toroidal shaped steel pressure vessel located below the drywell. The pool contains about 3823 m^3 (135,000 ft^3) of water and has an air space above the water pool of 3370 m^3 (119,000 ft^3). Inside the pool extending around the circumference of the torus, is a 1.45 m (4.75 ft) diameter vent header. The 8 drywell vents connect to this vent header. Projecting down from the vent header are 96 downcomer pipes which terminate 1.22 m (4 ft) below the surface of the water.

The torus which contains the pressure suppression pool is designed to essentially the same requirements as the drywell liner, i.e., a maximum internal pressure of 0.531 MPa (62 psig) at 138°C (281°F), but neither the drywell nor the torus is designed to withstand the stresses which would be created by a significant internal vacuum. To ensure that a significant vacuum cannot occur in the drywell, vacuum breaker valves are installed, which will open to permit flow from the pressure suppression pool airspace into the drywell whenever the suppression pool pressure exceeds the drywell pressure by more than 3447 Pa (0.5 psi). Additional vacuum breaker valves with the same setpoints are installed to permit flow from the Reactor Building into the pressure suppression pool airspace, to prevent a significant vacuum in the wetwell.

The specific design parameters for the standard problem are listed in Tables 1.1, 1.2, and 1.3.

1.2 Description of the Standard Problem

The "base case" accident sequence is a TQUV-type sequence in which the main steam system is isolated and all reactor vessel injection capability is lost at the time of a reactor trip from 100% power. Because of mass loss out of the SRV's and the lack of coolant injection, the core eventually becomes uncovered. In this sequence, automatic ADS actuation will not occur, and manual actuation is assumed not to occur, so that the RCS remains at high pressure. The uncovered core becomes molten and the debris falls into the reactor vessel lower plenum where, eventually, the corium attacks the reactor vessel bottom head.

When the reactor vessel bottom head fails, the corium falls onto the dry concrete floor of the drywell and the corium-concrete reaction begins. As steam is liberated from the concrete, previously unoxidized zirconium in the corium is oxidized, releasing large amounts of energy. If sufficient quantities of unreacted zirconium and steam are available, the drywell temperature may increase quickly to values significantly above the design temperature.

The comparison calculations are performed for a Mark I plant and the standard problem conditions are listed in Table 2.1. The output of interest

nere is the pressure and temperature (assuming both are spatially uniform) history of the drywell atmosphere as a function of time after vessel failure.

It is apparent that the details of this standard problem[1] provide information on the condition of the corium leaving the reactor vessel, but do not provide a specific description of how the corium disperses on the drywell floor. This was done to allow the analysts to use (and document) their best judgment on how this dispersal will occur.

1.3 Sequence Description

The TQUV sequence is concerned with failure to provide any ECCS make-up following an initiating event. A loss of all feedwater has been chosen to illustrate the event sequence. Upon a loss of feedwater, vessel water level starts to decrease because of a mismatch between the coolant inventory loss in the form of steam and the supply of feedwater. As the vessel water level decreases to Level 4, the reactor is scrammed and runback of the recirculation pump is initiated. At this point, the control rods are automatically inserted into the core, terminating full-power operation.

Because there is no ECCS make-up flow, the vessel water level continues to decrease due to boil-off from stored heat and fission product decay. At the Level 2 setpoint, the recirculation pumps are tripped and the MSIVs start to close. This isolates the reactor from the power conversion system. Soon afterwards, the vessel pressure reaches the SRV setpoints and excess vessel pressure is relieved by SRV steam discharges into the suppression pool.

Based on MARCH 1.1B calculations,[3] with no HPCI, RCIC, LPCI mode of RHR, or core spray, the core would uncover at about 33 minutes and core melt would start at about 70 minutes. The core melt/slump vessel failure sequence is highly uncertain and very sensitive to modeling assumptions. Without Control Rod Drive (CRD) flow, MARCH[3,6] predicts that the core will melt, slump, and fail the vessel head within about two hours with as much as 1700 pounds of hydrogen being generated. It should be noted that, with CRD flows, substantially more H_2 is predicted[7] to be generated but core damage is delayed for three or more hours and for most sequences core melt is prevented. While the TQUV sequence with CRD flow may be at least as likely as one without CRD flow, the net effect of delaying or preventing core melt makes it less interesting as a containment loading problem and it has not been examined as part of the standard problem.

After the core melts and slumps, MARCH predicts the vessel will be breached within about 30 minutes. There is a large uncertainty as to the condition and location of the core debris after vessel failure but for the purposes of the standard problem, it is assumed that a large fraction of the fuel (80%) along with all the zirconium and some of the lower head and support structure (140,000 lbs) is uniformly distributed on the drywell floor. Sensitivity studies are then used to investigate key parameters.

2. DISCUSSION OF MAJOR PHENOMENOLOGY AND ANALYTICAL METHODS

The standard problem addresses the issue of drywell temperature loadings during ex-vessel interactions of the corium with concrete. The concern is that the integrity of the drywell would be compromised by high temperatures and/or high pressures shortly after vessel failure. Previous results by Yue and Cole[6] indicate that for a TQUV sequence the containment would fail almost immediately after vessel failure due to drywell containment temperatures in excess of 704°C (1300°F). A loss of drywell integrity in Mark I BWR containment designs is potentially important because radionuclide releases would occur directly into secondary buildings bypassing the suppression pool and potential pool scrubbing.

Table 2.1 defines the initial masses, composition and temperature of the corium. The definition of the standard problem[1] permitted the individual analyst to define the dispersal and final disposition of the corium. The initial conditions were then used in combination with debris disposition and containment geometry to calculate the subsequent corium/concrete interactions. For the present calculations, the initial conditions for core/concrete interactions obtained from the sample problem were input to the CORCON-MOD 1 code. The output from CORCON-MOD 1 involving water, hydrogen, carbon dioxide, and carbon monoxide generation was then input to a MARCH 1.1B analysis, which bypassed the INTER subroutine.

Spreading of the corium melt specified within the Mark I pedestal area would produce a collapsed pool 85 cm deep. With gas fluidization (bubbling) from corium/concrete interactions (CCI), the pool depth will be even greater. It is clear that such a deep pool will remain molten and rapidly spread through the two pedestal access doors into the ex-pedestal (annular) space. An even spreading over the whole available area would produce a pool 22 cm deep (collapsed level). This is still a rather deep layer but based on the scoping estimates of heat losses for the Mark-I design, it appears that spreading over the entire drywell floor area is unlikely. Based on these heat loss estimates, maximum spreading case has been taken to be 5 meters in radius for standard problem purposes. This represents about 50% of the drywell floor. The calculations neglect the effect of the transient spreading of the corium.

There are two major variations of the TQUV base case: A high temperature case (at the fuel melting point) and a low temperature case (at the melting point of steel). It is assumed that for the low temperature case, the core debris could not flow and would remain confined within the pedestal wall. Conversely, the high temperature case is expected to spread rapidly into the annular space surrounding the pedestal. These two cases produce dramatically different results but most of this difference is due to the debris temperature difference and not to geometric differences.

In the Mark I containment, there are a number of sumps in the drywell floor (two-1 m deep sumps are immediately under the vessel inside the pedestal wall). The corium would therefore be rather deep above these sumps and the temperature of deep corium pool will respond differently than a shallow pool

during core/concrete interactions. The calculations for the shallow pool configuration are unlikely to be representative of the thermal response of the corium in the sumps. Additional calculations were therefore performed for a deep pool assuming all of the corium to be retained inside the pedestal wall. These are limiting calculations as the pool depth is overestimated. The corium stays hot much longer in the deep pool configuration but after 5 hours the total quantities of gases released are nearly the same as when the corium is spread across the entire floor area (shallow pool configuration).

2.1 Core/Concrete Interactions Modeling

The CLWG Standard Problem specification for the Mark I BWR is dominated by the calculation of the interaction of molten core debris and the concrete drywell floor. Several models currently exist and are in widespread use with which to make this calculation. Among these models are the INTER model,[4] CORCON-MOD 1,[5] and CORCON-MOD 2 computer codes.[8] For the present calculations, the BNL staff used the CORCON-MOD 1 code in a stand-alone configuration and input the results manually to the MACE subroutine in MARCH 1.1B.A description and comparison of these core-concrete interaction model follows.

CORCON-MOD 1 is a general model describing the thermal and chemical interactions between molten core debris and structural concrete. The major components of the system are the concrete cavity, the molten debris pool, and the gas atmosphere and surroundings above the pool. The geometry of the system is formulated as a two-dimensional, axisymmetrical system, although specific geometries not available as code-supplied options may be user-input.

The code offers three default concrete compositions or the user may input any specific concrete composition. The core debris is assumed to be molten and consist of metallic and oxidic phases, primarily UO_2, FeO, ZrO_2, steel, and Zr. The metallic and oxidic phases are assumed to separate into unmixed overlying layers. Mixture layers and an overlying water layer are not available in CORCON-MOD 1.

A gas atmosphere exists above the pool as well as structural surroundings, with which mass and energy exchange with the molten pool may occur.

Thermodynamic and transport properties as well as phase transition criteria for the molten debris pool are internally calculated at each time step. Mass and energy transfer between the various layers of core debris, as well as between the debris and the surroundings, occur instantaneously and are assumed to be in equilibrium. Models are included for heat transfer across the melt-concrete interface, between pool layers, and from the pool to the atmosphere and surroundings. The interaction between the pool and concrete is driven by the local temperature difference between the two and varies around the periphery of the pool. The pool-concrete interface is treated as an incompressible gas film composed of concrete decomposition gases. Heat transfer across this film is calculated by appropriate convective heat transfer models.

The erosion of concrete is modeled as one-dimensional, steady-state ablation. As the concrete is heated it decomposes, releasing H_2O and CO_2 into the pool or gas film and molten concrete slag into the pool. The molten oxide

slag is transported to the oxide layer, diluting the layer density and eventually resulting in an inversion of the oxide and metallic pool layers.

The concrete decomposition gases that bubble through the pool, H_2O and CO_2, oxidize the metallic layer, resulting in the release of chemical energy and production of H_2 and CO.

Convective heat transfer within the pool is enhanced by the bubbling of concrete decomposition gases. Internal heat transfer is modeled by either gas injection across liquid-liquid interfaces or gas agitation along liquid-liquid interfaces. Energy sources in the pool consist of chemical reactions or decay heat generation.

For the present calculations, it was intended to maximize the thermal attack on the concrete by eliminating convective and radiative energy transfer from the pool surface to the containment atmosphere and structural surroundings. This was accomplished by setting the pool surface-to-atmosphere convective heat transfer coefficient to zero and the emissivity of the drywell structures to a very small value. The results of the CORCON-MOD 1 calculations are in the form of core debris temperature and integrated gas release and are shown for the parametric sensitivity cases studied in Figures 2.1 to 2.6. The summary of the parametric variation for each case is listed in Table 2.1.

3. STANDARD PROBLEM RESULTS

The Mark-I Standard Problem was analyzed by BCL, SNL, and BNL using three different analytical methods. ORNL has performed similar calculations for the TQUV sequence which have been documented previously[6,7] and their results will not be repeated here.

The predicted drywell atmospheric temperatures, for the TQUV base case (high temperature, maximum debris spreading) are shown in Figure 3.1. BNL has assumed that the core debris is effectively "blanketed" by a combination of structure and aerosols. This assumption maximizes the attack on the concrete thus maximizing the production of steam and non-condensable gases. The drywell temperature is predicted to reach a peak of 343C (650°F) within one hour after vessel failure. Then the temperature drops to about 260C (500°F) over the next several hours.

The pressure loading calculations for the base case are shown in Figure 3.2. Two limiting calculations have been chosen from the sensitivity calculations to emphasize the extent of the uncertainty range. It should be emphasized that the specified base case is itself a somewhat limiting case (maximum Zr oxidation, maximum debris temperature and maximum debris spreading).

Thus, from Figures 3.1 and 3.2, it is clear that for this extreme case (high temperature debris, maximum H_2 generation and maximum debris dispersal), the thermal loading problem also becomes a pressure loading problem and it is a race between the two possible failure mechanisms.

4. SENSITIVITY STUDY RESULTS

As mentioned in the previous section, the base case should not be considered to be a best-estimate of the progression of a TQUV accident sequence. Rather it is a specified standard problem which provides the basis for comparisons between the various participants in the CLWG. Since there is considerable uncertainty in the accident conditions as well as design variations from plant to plant, the standard problem also addresses a series of sensitivity calculations as discussed in the following subsections. A complete set of results for the sensitivity study is included in Appendix A.

4.1 Debris Temperature

The rate of core/concrete interaction is very sensitive to the debris temperature at the time of vessel failure. The debris temperature calculated by MARCH is, in turn, sensitive to several input parameters including time-step size and clad oxidation, particularly during the core slump phase of the calculation. More detailed phenomenological modeling and experimental evidence would be needed to predict best-estimate debris temperatures for all possible accident sequences. The CLWG approach was to consider a range of possible debris temperatures, namely, the UO_2 melting temperature, 2277C (4130°F), and the stainless steel melting temperature, 1482C (2700°F). With present uncertainties related to in-vessel core meltdown progression, neither of these limits can be precluded at this time.

The temperature and pressure loadings for the two limiting cases are shown in Figure 4.1 and Figure 4.2 for the drywell compartment. For the high temperature limiting case the compartment pressure is calculated to exceed the threshold pressure (the point at which plastic yielding occurs and the containment will leak or rupture) 2-1/4 hours after vessel failure. However the compartment temperature is well above the seal design temperature (138C for Brown's Ferry) during this period rising to a peak of 365C (660°F) within 2 hours. The combination of high temperatures and pressures is expected to cause degradation of drywell seals and allow gases and fission products to leak from the primary containment. This leakage may have a net positive effect in that even a small amount of leakage may limit the pressure rise and prevent catastrophic overpressure failure.

4.2 Concrete Composition

The specific core/concrete reactions and the gases evolved from these reactions are very sensitive to the concrete composition. The sensitivity study (Table 2.1) specified two concrete compositions (representing limestone and basalt) plus two variations in the free water content. Figure 4.3 shows the predicted pressure response for the two nominal compositions with the high temperature limiting case. At these limiting temperatures the attack on basaltic concrete is predicted to generate considerably less non-condensable gas with the pressure estimated to be 35 psi less than the limestone case after 5 hours.

The containment response for basaltic concrete is very sensitive to the free water content while there is only a slight effect on the limestone concrete as shown in Figure 4.4. The high water-content concrete is taken to be twice the nominal content.

4.3 Debris Dispersal

The Mark I lower pedestal region would tend to confine the initial debris dispersal to a 6 m diameter area immediately beneath the reactor vessel. However, there are doorways in the pedestal which, for the high temperature case, would allow molten debris to flow outward into an angular region about 13 m in diameter. It is assumed that the high temperature debris will spread out and attack the entire drywell floor area but the low temperature debris will remain confined to the pedestal region as previously noted. However, in order to assess the importance of the debris spreading assumption, a high temperature case was also run in which the core debris was assumed to be retained within the pedestal region inspite of the access doors.

The pressure and temperature response for the high temperature spread and confined cases are shown in Figures 4.5 and 4.6. Note that the spread case initially has a much higher gas generation rate and results in a correspondingly more rapid pressure rise. However, for the confined case, the debris remains at a higher temperature and maintains a much more aggressive attack on the concrete. After about one hour the gas generation rate for the spread case is less than that for the confined case and the pressure rise rate has moderated until after 5 hours; the pressure for the confined case is nearly as high as the spread case.

4.4 Upward Heat Transfer

Preliminary calculations with CORCON indicated that with a transparent atmosphere, the dispersed debris would rapidly lose heat to the cooler structures above and would cool below the concrete ablation temperature within about one hour after vessel failure (see Figures 3.1 and 3.2). This case presents a problem for the CORCON-MOD 1 code in that there is no further core/concrete interactions and the code terminates the calculation. After the debris cools to the concrete ablation temperature, there will be very little non-condensable gas generation and the predominant energy exchange will be radiation to the structures and convection from the structures to the drywell atmosphere. This limiting case has not been analyzed past this point but it should be noted that this result is essentially in agreement with preliminary results from IDCOR for the TQUV sequence. As shown by IDCOR (Reference 9) under these conditions, the decay heat will be radiated to the drywell resulting in a gradual rise in the drywell temperature with little or no corresponding rise in pressure. Since the drywell wall is insulated, the temperatures will rise over a period of several hours until the containment fails by overtemperature.

However, there are several points that argue against the possibility of a frozen low temperature debris layer rapidly stopping core/concrete reactions.

1. There are a considerable number of structural barriers to preclude uniform spreading over the entire floor as well as to limit radiative view factors to upper structures. Thus, spreading over 50% of the drywell floor (5 m radius) has been taken as the limiting case with the highest non-condensable gas generation rate.

2. CORCON calculations indicate that the debris freezes rapidly and will have little opportunity to spread if it is released from the vessel in a confined configuration.

3. The large amount of aerosols generated from the core/concrete attack will limit radiation to structures and may provide a thermal blanketing effect.

With these several factors to consider, the BNL approach has been to make assumptions which tend to maximize the rate of non-condensable gas generation in an effort to investigate the limiting pressure loading on the containment. Thus, along with the limiting core debris temperature, 2277C (4130°F) specified in the standard problem, the BNL approach assumes a uniform spreading of the debris across the entire drywell floor and a thermal blanketing effect from the aerosols. "Direct heating" of the containment atmosphere may provide still higher pressure loading if a significant fraction of the sensible heat and chemical energy in the debris is transferred directly to the atmosphere during debris dispersal. Due to the structural confinement in the pedestal region, this is believed to be a low likelihood scenario for BWRs.

4.5 Heat Losses

There are three sources of energy in the containment after vessel failure: 1) chemical energy from the oxidation reactions, 2) sensible energy from the debris, and 3) decay heat from radionuclides. The first two are very sensitive to temperature and dominate the early containment response for the high temperature limiting case. As shown in Figure 4.7, the steel heat sinks (the steel shell and "miscellaneous steel") tend to ameliorate large spikes in temperatures, but they do very little to affect long-term behavior. However, for the maximum spread case, sufficient heat may be lost by concrete decomposition and thermal radiation to cool the debris down to the concrete ablation temperature. At this point upward radiation may be sufficient to remove the decay heat and prevent further concrete decomposition. As mentioned in the previous section, freezing of the core debris is prevented from occurring via the thermal blanketing (emissivity = 0) assumption. This assumption forces concrete decomposition to continue indefinitely, so the containment will continue to pressurize due to the addition of non-condensable gases and energy from the decay heat and oxidation reactions.

5. CONCLUSION

For a wide range of possible core debris conditions following vessel failure, the TQUV accident poses severe loads which threaten the structural integrity of the containment. For the limiting high temperature case, the analysis indicates that the drywell temperatures would rapidly exceed 600°F, while the pressure would build up to the ultimate capacity (132 psia) within 2 hours after vessel failure. For lower temperature debris the pressure/temperature buildup in the drywell is much slower than for the high temperature case but the containment would eventually be threatened by a combination of temperature and pressure loading.

6. REFERENCES

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7. R. M. Harrington and L. J. Ott, "The Effect of Small Capacity High Pressure Injection Systems on TQUV Sequences at Brown Ferry Unit One," NUREG/CR-3179, (Sept. 1983).

8. CORCON-MOD 2 Code Description, to be published.

9. IDCOR, "Peach Bottom Power Station Integrated Containment Analysis," IDCOR Task 23.1, to be published.

Table 1.1 BWR4 reactor vessel and core parameters

Number of assemblies	764
Fuel rods per assembly	62
Water rods per assembly	2
Fuel rod diameter (inch)	0.483
Fuel pellet diameter (inch)	0.410
Water rod diameter (inch)	0.591
Core equivalent diameter (inch)	187.1
Core hydraulic diameter (ft)	0.0459
Length of active fuel [including 6 inches of natural uranium at top and bottom of fuel column] (incn)	150
Core flow area (ft^2)	108.7
Reactor vessel internal diameter (inch)	251
Mass of UO_2 (lb)	351,440
Mass of Zr in cladding (lb)	95,536
Cladding thickness (inch)	0.032
Mass of Zr in channel boxes (lb)	48,846
Channel box wall thickness	0.080
Number of control rods	185
Mass of stainless steel and inconel in core (lb)	26,980
Mass of stainless steel structures beneath core (lb)	66,750
Mass of stainless steel in control rods (lb)	32,750
Mass of stainless steel in top guide assembly (lb)	15,200
Volume of liquid in reactor vessel (ft^3)	11,922
Volume of steam in reactor vessel (ft^3)	10,122
Volume of liquid in recirculation loops (ft^3)	1,320
Volume of steam in steam lines (ft^3)	1,218
Volume of liquid in feedwater line (ft^3)	1,233
Total reactor coolant volume (ft^3)	25,815
Weight of reactor vessel bottom head (lb)	207,500
Diameter of bottom head (ft)	20.915
Thickness of bottom head (ft)	0.713
Safety/relief valve rated capacity (lb/hr) at 1143 psia and fluid density of 2.608 lb/ft^3	838,900
Safety/relief valve setpoint (psia)	1,120
Safety/relief valve blowdown per actuation (psi)	50

Table 1.2 Containment design parameters

Drywell design pressure (psia)	70.7
Drywell design temperature (°F)	281
Drywell volume (ft^3)	70.7
Wetwell design pressure (psia)	281
Wetwell pool volume (ft^3)	138,700
Wetwell free volume (ft^3)	119,000
Predicted failure pressure (psia)*	132
Predicted failure location*	Intersection of spherical and cylindrical sections of drywell
Initial drywell temperature (°F)	135
Initial drywell pressure (psia)	15.3
Initial wetwell temperature (°F)	104
Initial wetwell pressure (psia)	14.7

*L.G. Greiman, et al., "Reliability Analysis of Steel Containment Strength," NUREG/CR-2442, June 1982.

Table 1.3 Containment heat sinks

Heat Sink	Material	Area (ft^2)	Thickness (ft)	Left Side	Right Side
Drywell Liner	Steel	18684	0.094	Drywell	Insulated*
Drywell Floor	Concrete	1640	4.73	Drywell	Insulated
Upper Reactor Pedestal	Concrete	4130	2.29	Drywell	Drywell
Lower Reactor Pedestal	Concrete	1814	3.5	Drywell	Drywell
Wetwell Liner (above pool)	Steel	17050	0.0625	Wetwell	Insulated
Drywell Misc. Steel	C Steel	41525	.0417	Drywell	Drywell
Wetwell Misc. Steel	C Steel	2520	.0417	Wetwell	Wetwell

*Drywell liner is separated from 3 ft of concrete by 2 1/4" polyester foam and 1/8" fiberglass laminate at 400°F; this will be compressed to 1"=.083 ft.

Table 1.4 Specifications for comparison calculations base case

Mass of corium exiting vessel (lb)	535,000
a. UO_2 (lb)	280,000
b. Steel (lb) (% oxidized)	140,000 15
c. Zirconium (lb) (% oxidized)	115,000 13
Temperature of corium exiting vessel (°F)	4130
Concrete type (details in Table 2)	Limestone
Vessel, containment specifications	
RCS pressure at vessel failure (psia)	1120
H_2 released up to time of vessel failure (lb)	1170*
Hole size in vessel lower head (inches)	6
Containment conditions at vessel failure:	
a. Drywell temperature (°F)	150
b. Pool temperature (°F)	133
c. Pressure (psia)	35

*The H_2 release directly correlated with the amount of zirconium and steel oxidized. They are displayed because of this correlation, and do not represent independent variations for these sensitivity studies.

Table 2.1 Summary of BWR Mark I sensitivity studies

Case Number	1	1a	2	3	3a	4
Corium Spread (m)	5		3	5		3
Debris Temperature (°F)	4130		2700	4130		2700
Concrete Type	L		L	B		B
Free H_2O (%)	3	6	3	4	8	4
Steel in Corium (lb)	140K		140K	140K		140K

ORNL-DWG 81-8602 ETD

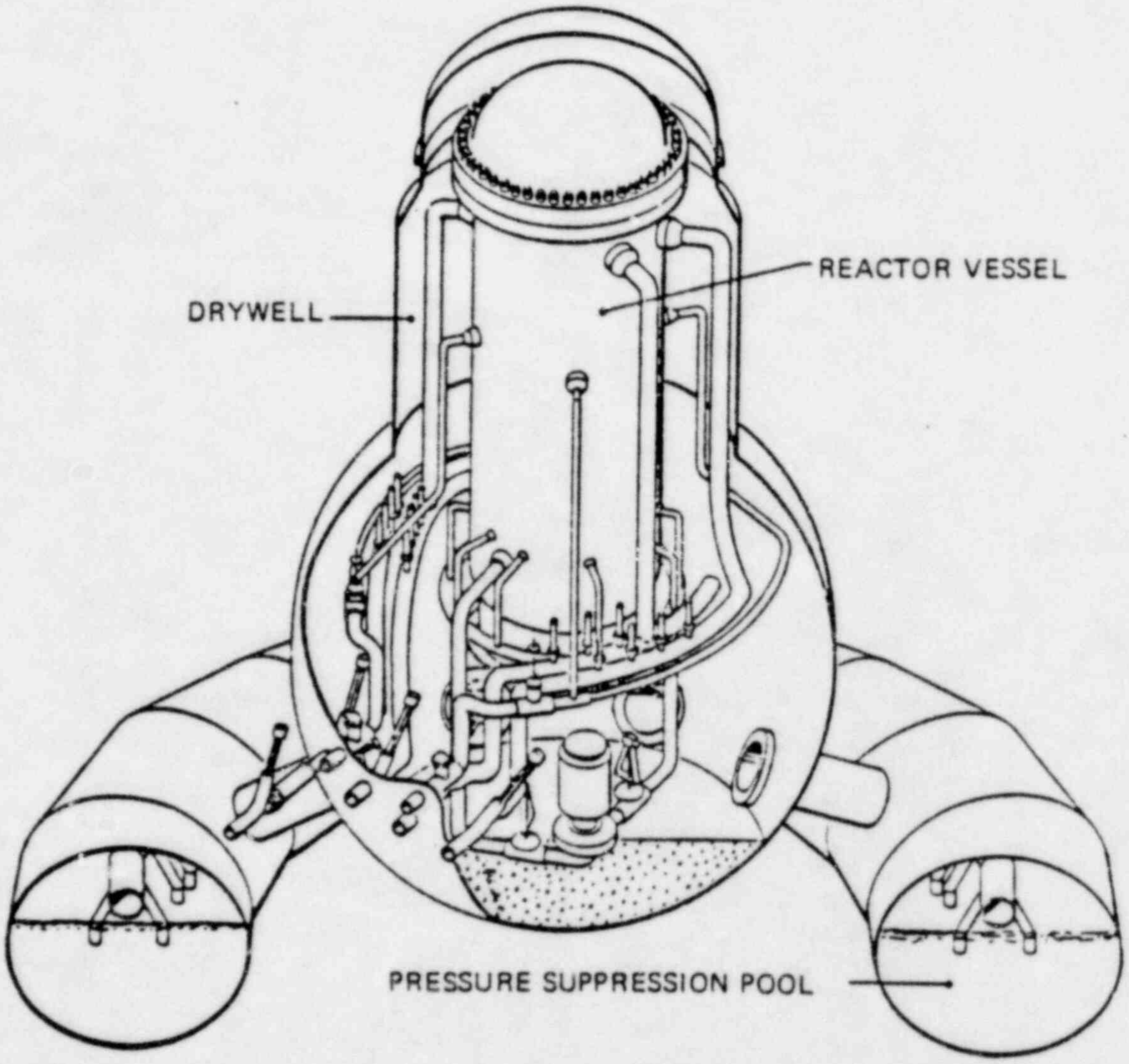
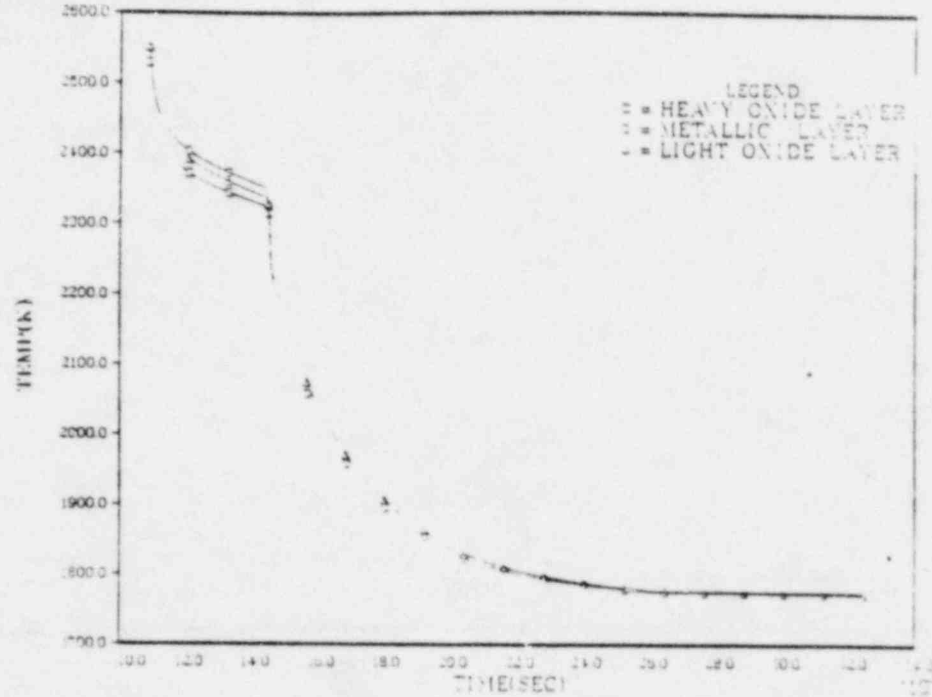


Figure 1.1

BWR STANDARD PROBLEM: TQUV-1
LAYER TEMPERATURES



BWR STANDARD PROBLEM: TQUV-1
GAS GENERATION

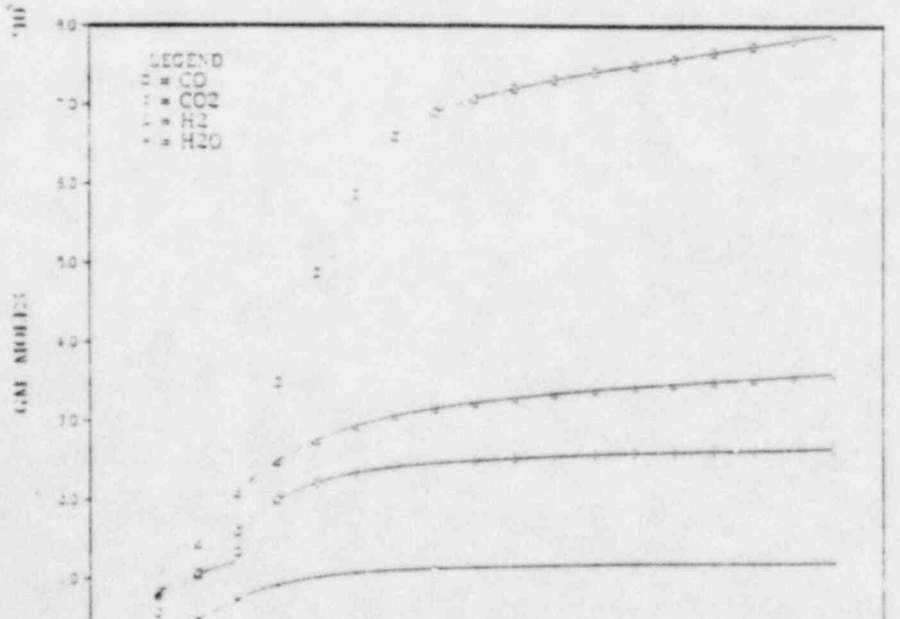
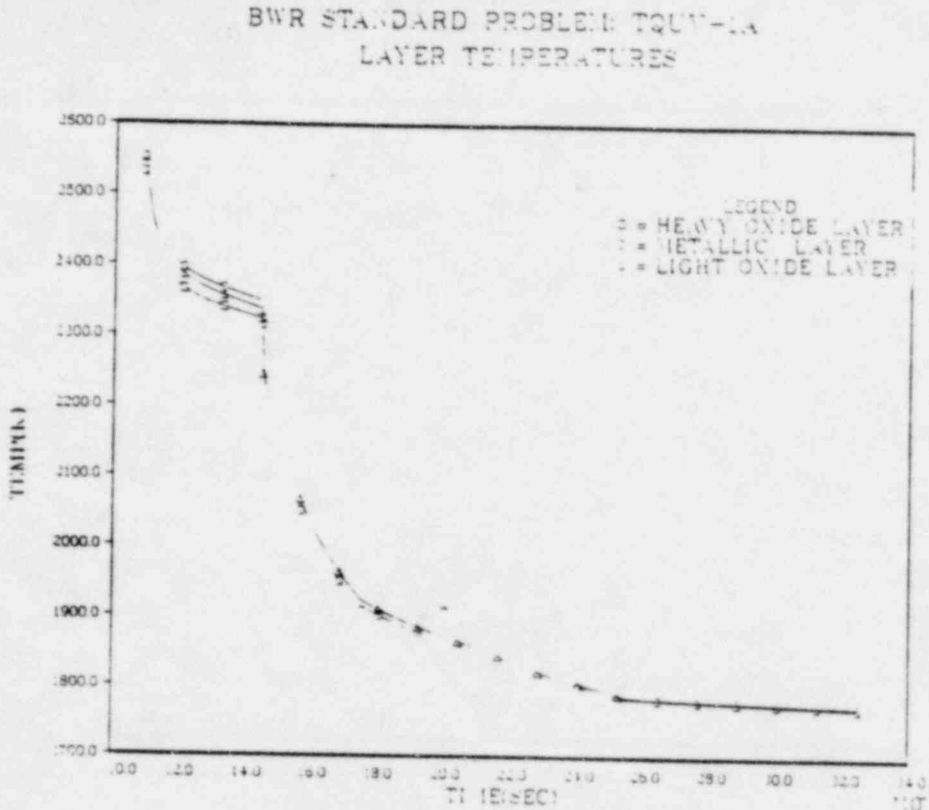
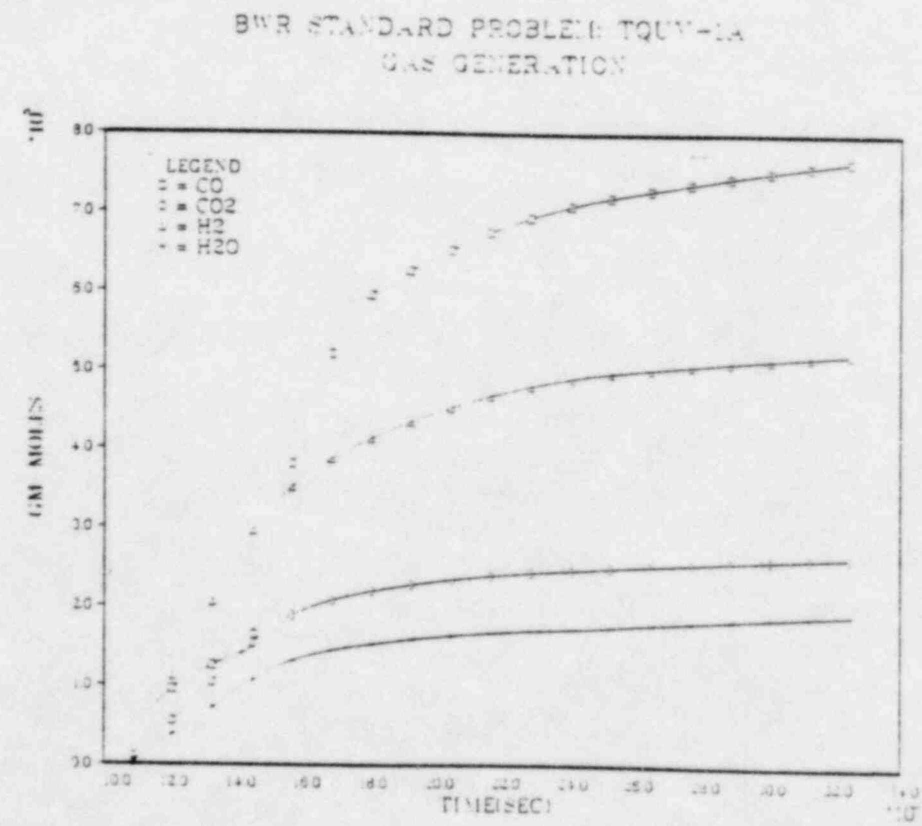


Figure 2.1



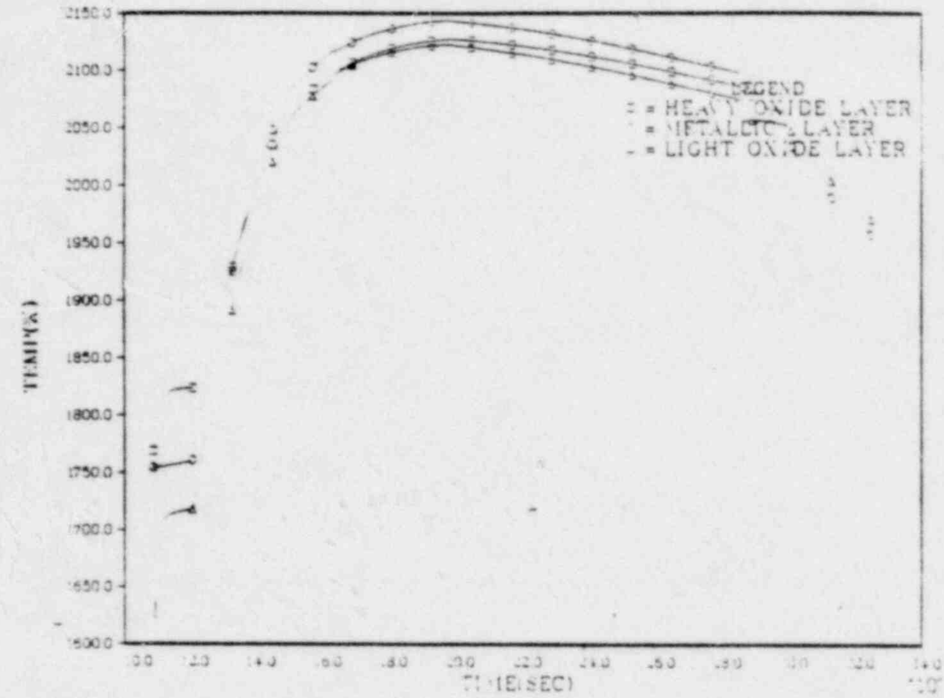
BWR STANDARD PROBLEM TQUV-1A
LAYER TEMPERATURES
LEGEND
HEAVY OXIDE LAYER
METALLIC LAYER
LIGHT OXIDE LAYER
TEMP(K)
TIME(SEC)



BWR STANDARD PROBLEM TQUV-1A
GAS GENERATION
LEGEND
CO
CO2
H2
H2O
GM MOLES
TIME(SEC)

Figure 2.2

BWR STANDARD PROBLEM: TQUV-2
LAYER TEMPERATURES



BWR STANDARD PROBLEM: TQUV-2
GAS GENERATION

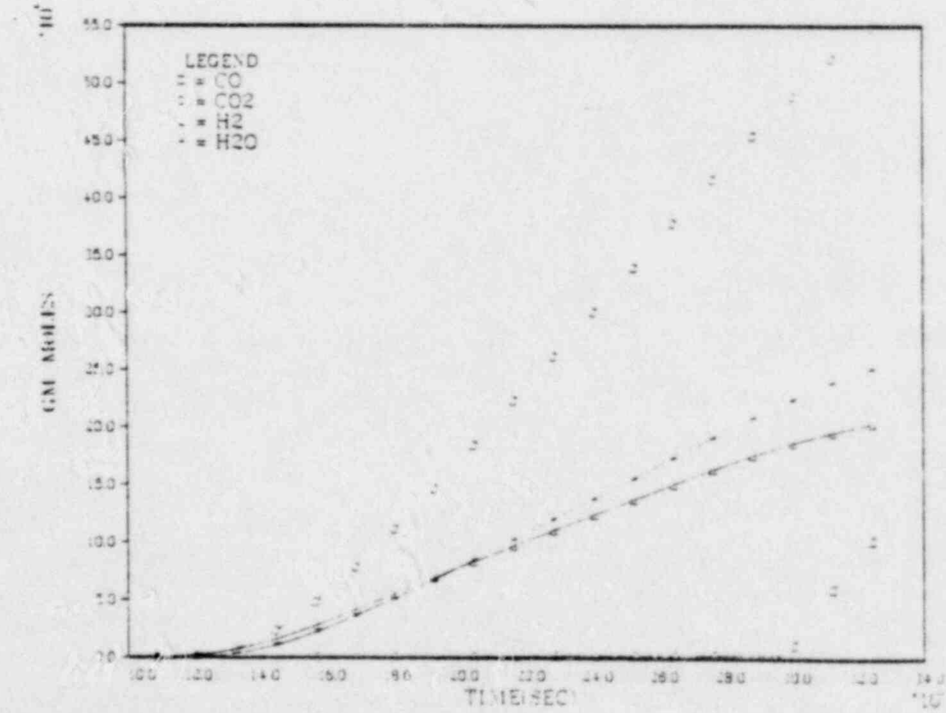
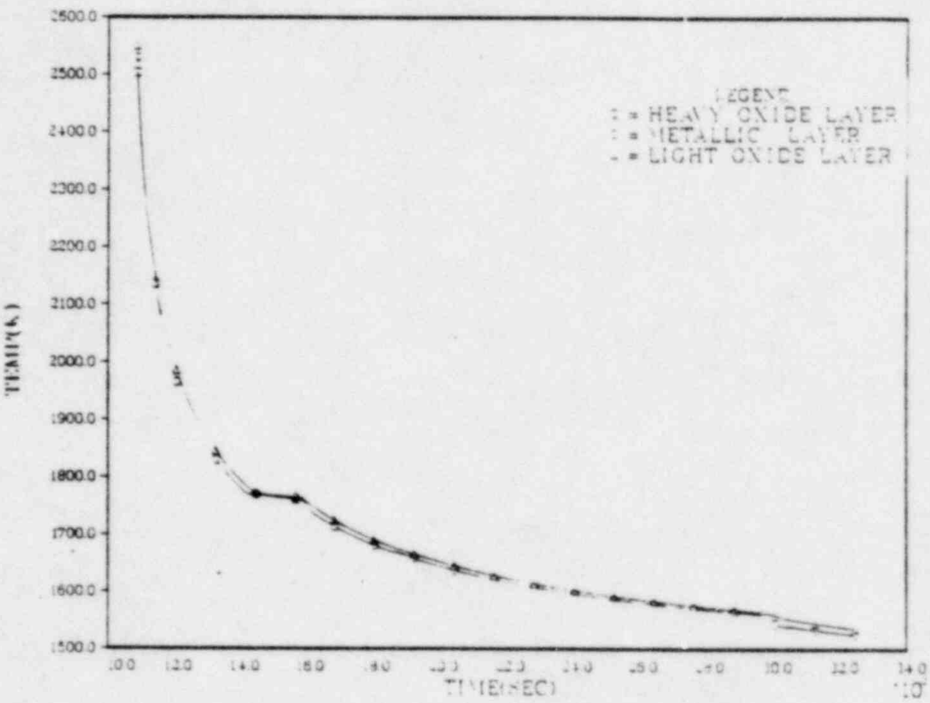


Figure 2.3

LAYER TEMPERATURES



BWR STANDARD PROBLEM
GAS GENERATION

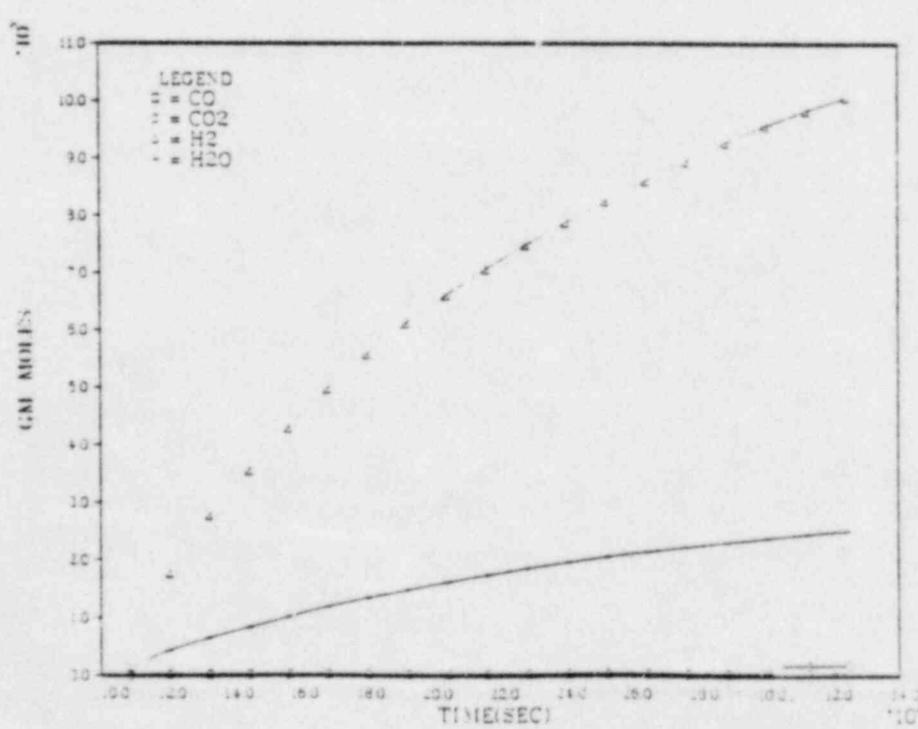
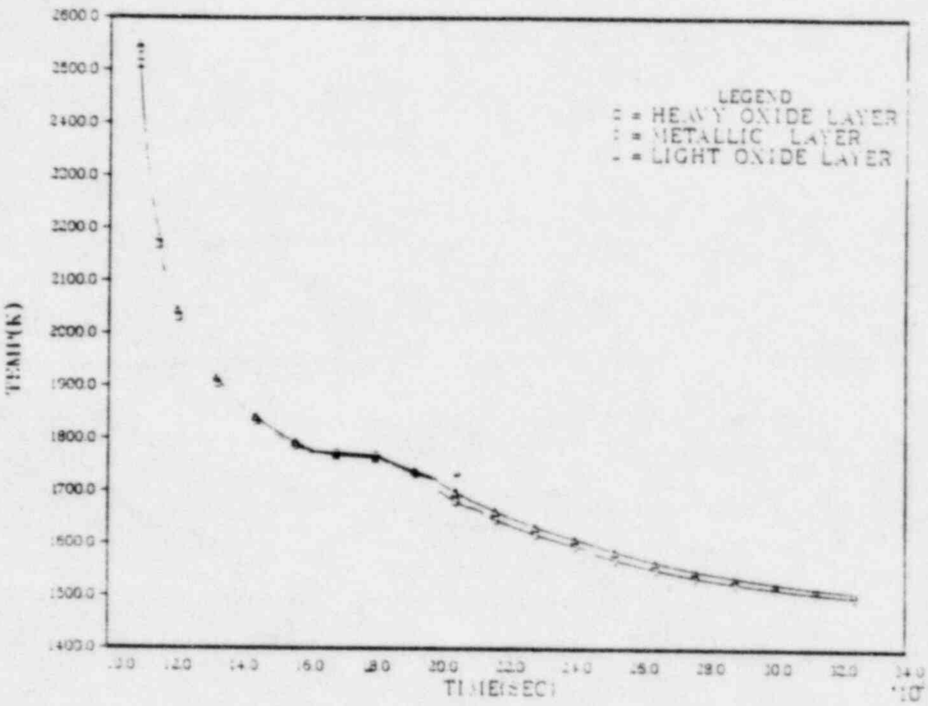


Figure 2.4

BWR STANDARD PROBLEM: TQUV-3A
LAYER TEMPERATURES



BWR STANDARD PROBLEM: TQUV-3A
GAS GENERATION

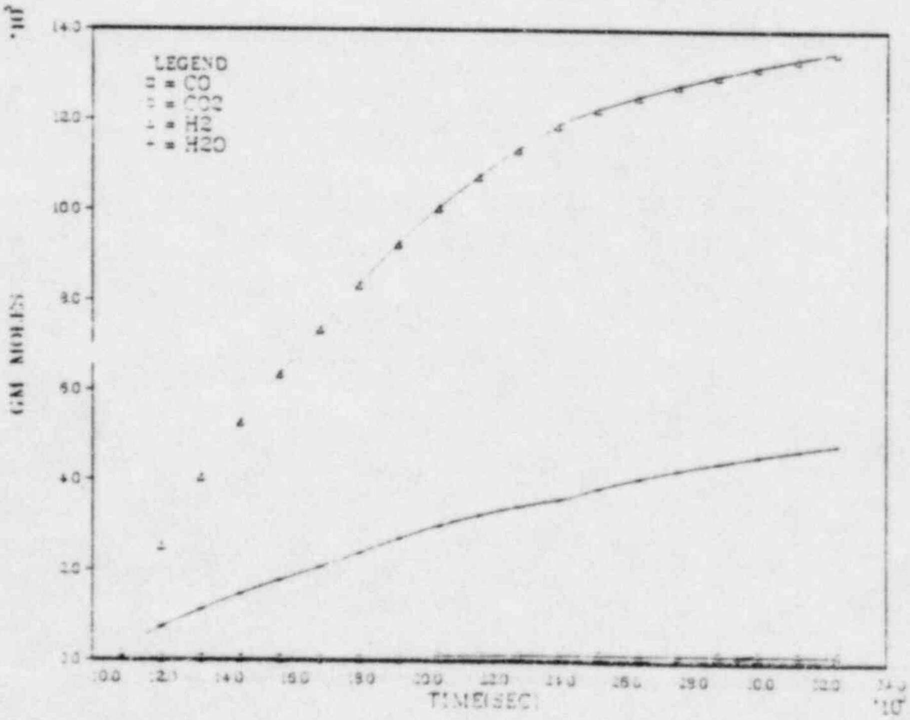
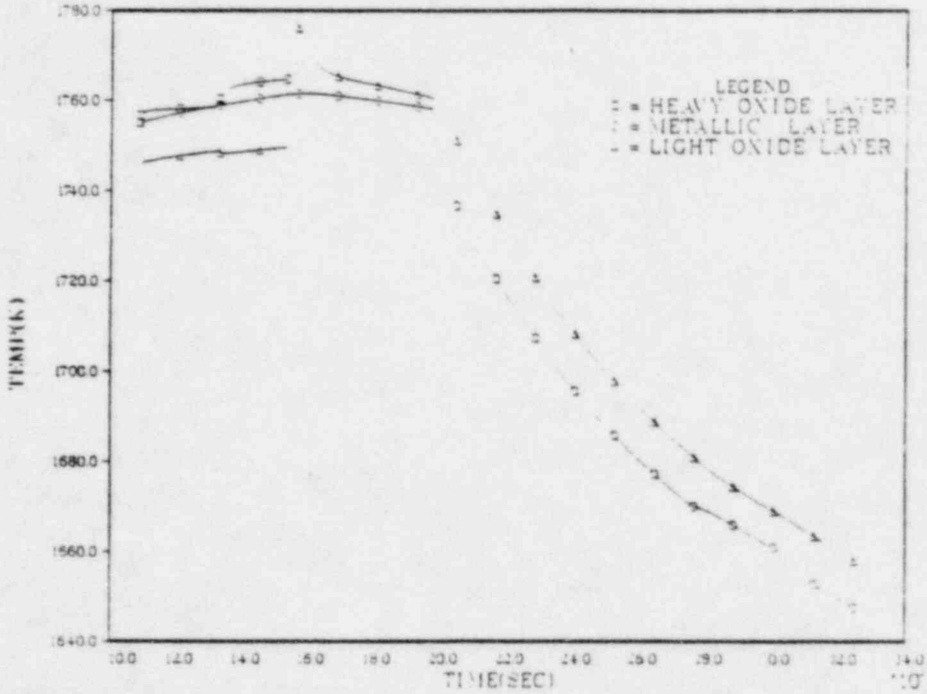


Figure 2.5

BWR STANDARD PROBLEM: TQUV-4
LAYER TEMPERATURES



BWR STANDARD PROBLEM: TQUV-4
GAS GENERATION

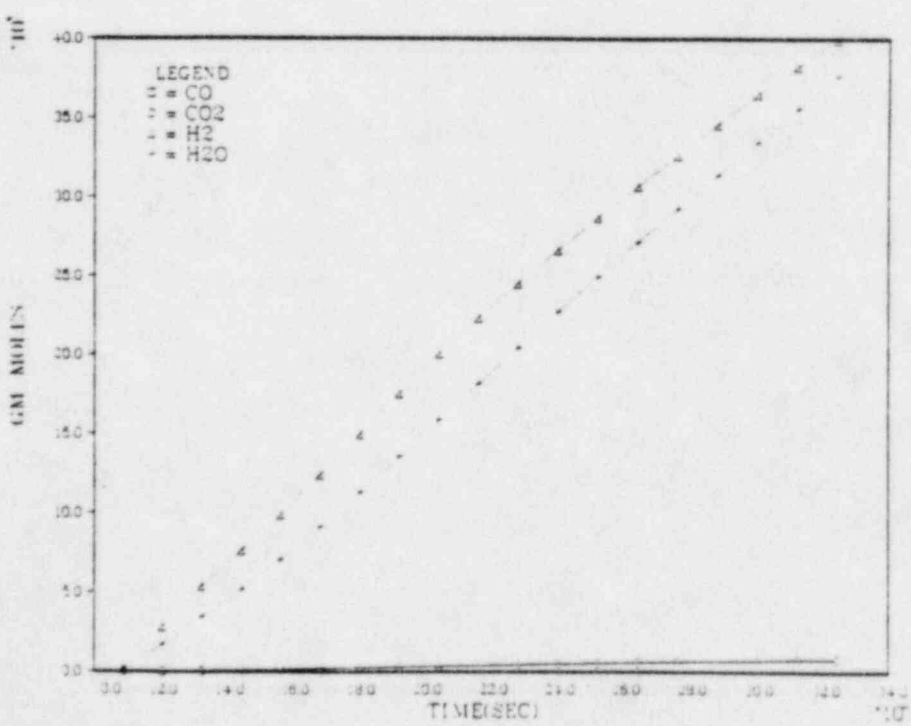
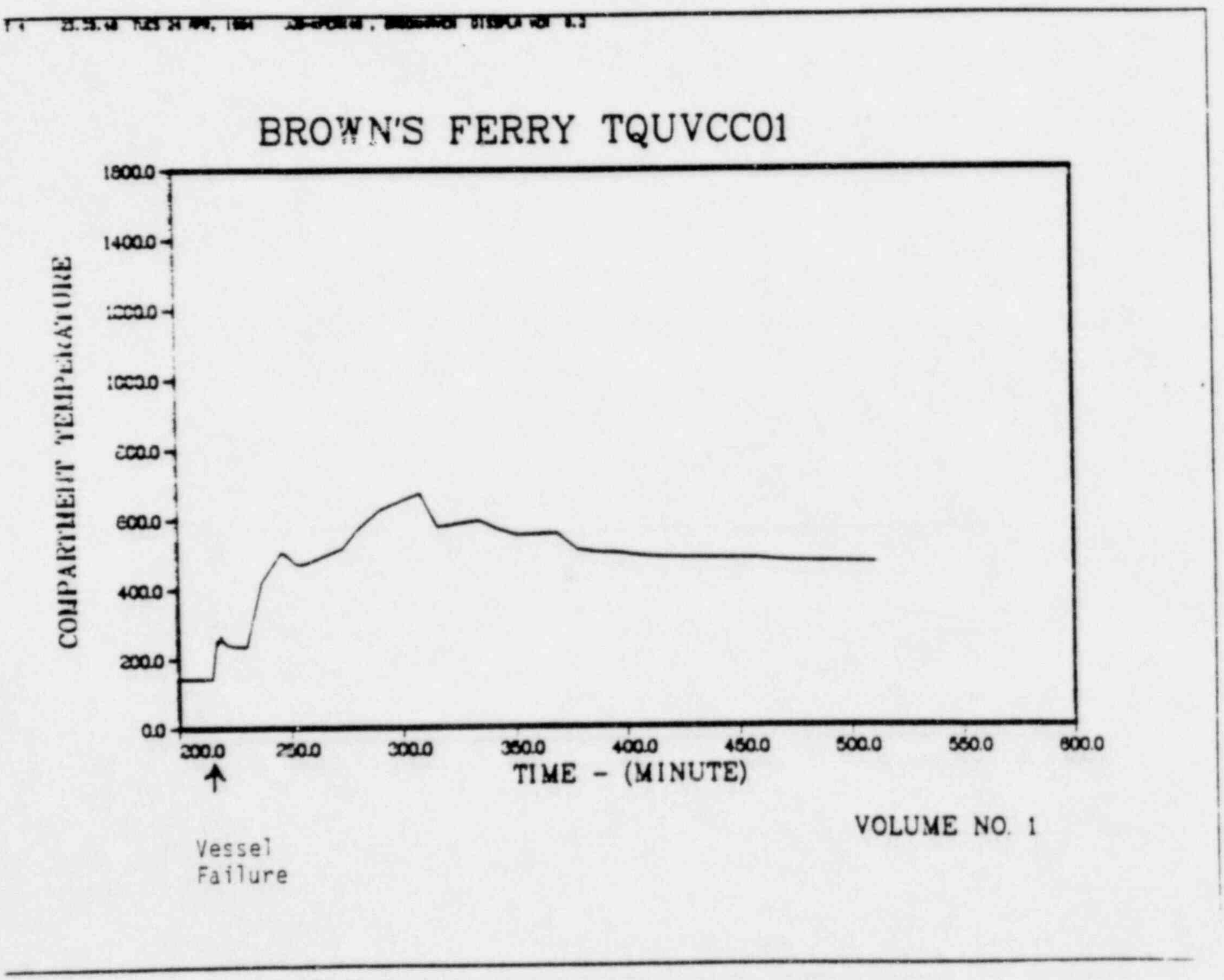


Figure 2.6



BROWN'S FERRY TQUVCC01
COMPARTMENT TEMPERATURE
TIME - (MINUTE)
VOLUME NO. 1
Vessel
Failure

Figure 3.1

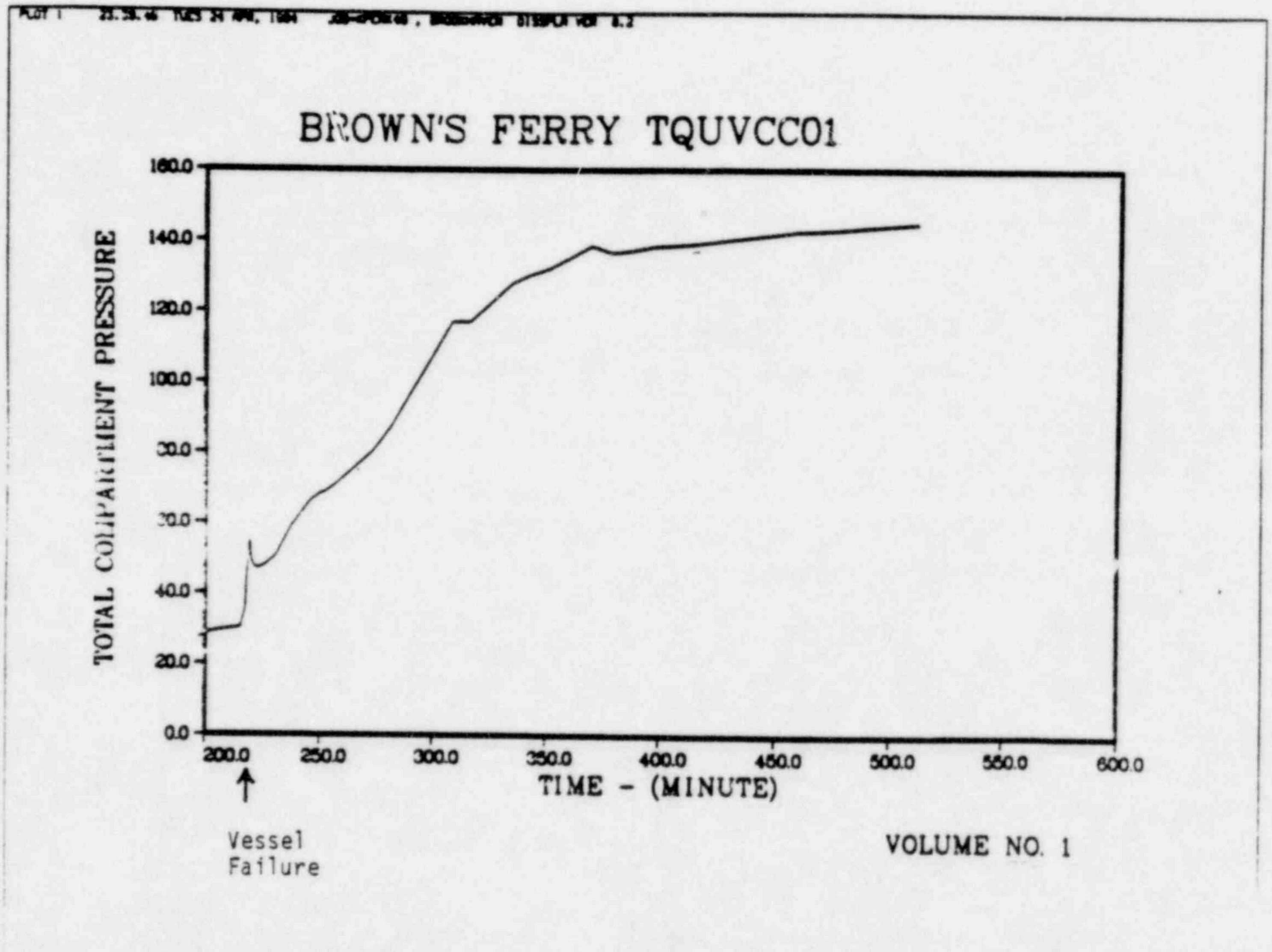

BROWN'S FERRY TQUVCC01
TOTAL COMPARTMENT PRESSURE
160.0
140.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
200.0
250.0
300.0
350.0
400.0
450.0
500.0
550.0
600.0
TIME - (MINUTE)
Vessel
Failure
VOLUME NO. 1

Figure 3.2

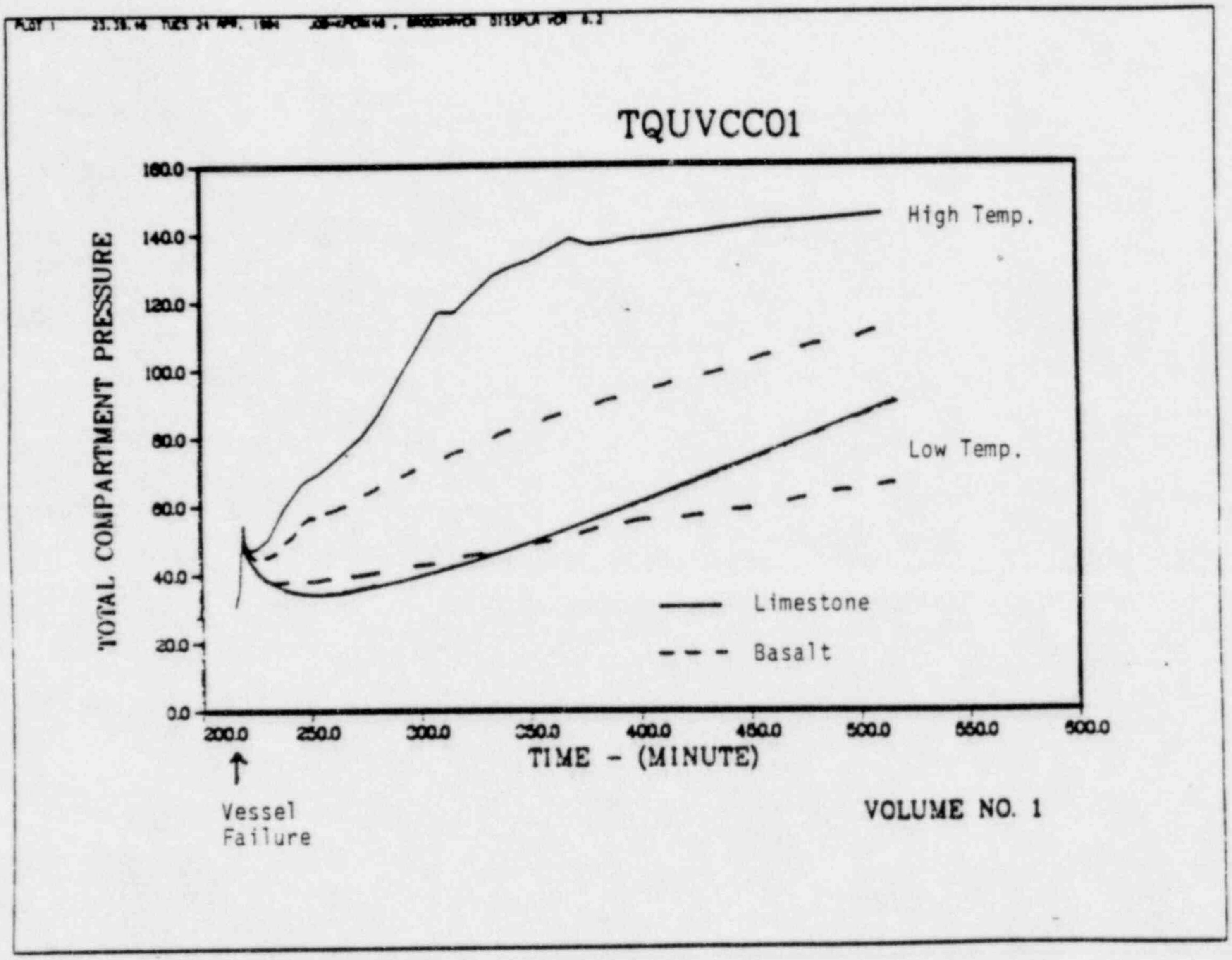

TQUVCC01
TOTAL COMPARTMENT PRESSURE
0.0
20.0
40.0
60.0
80.0
100.0
120.0
140.0
160.0
200.0
250.0
300.0
350.0
400.0
450.0
500.0
550.0
600.0
TIME - (MINUTE)
High Temp.
Low Temp.
Limestone
Basalt
Vessel
Failure
VOLUME NO. 1

Figure 4.1

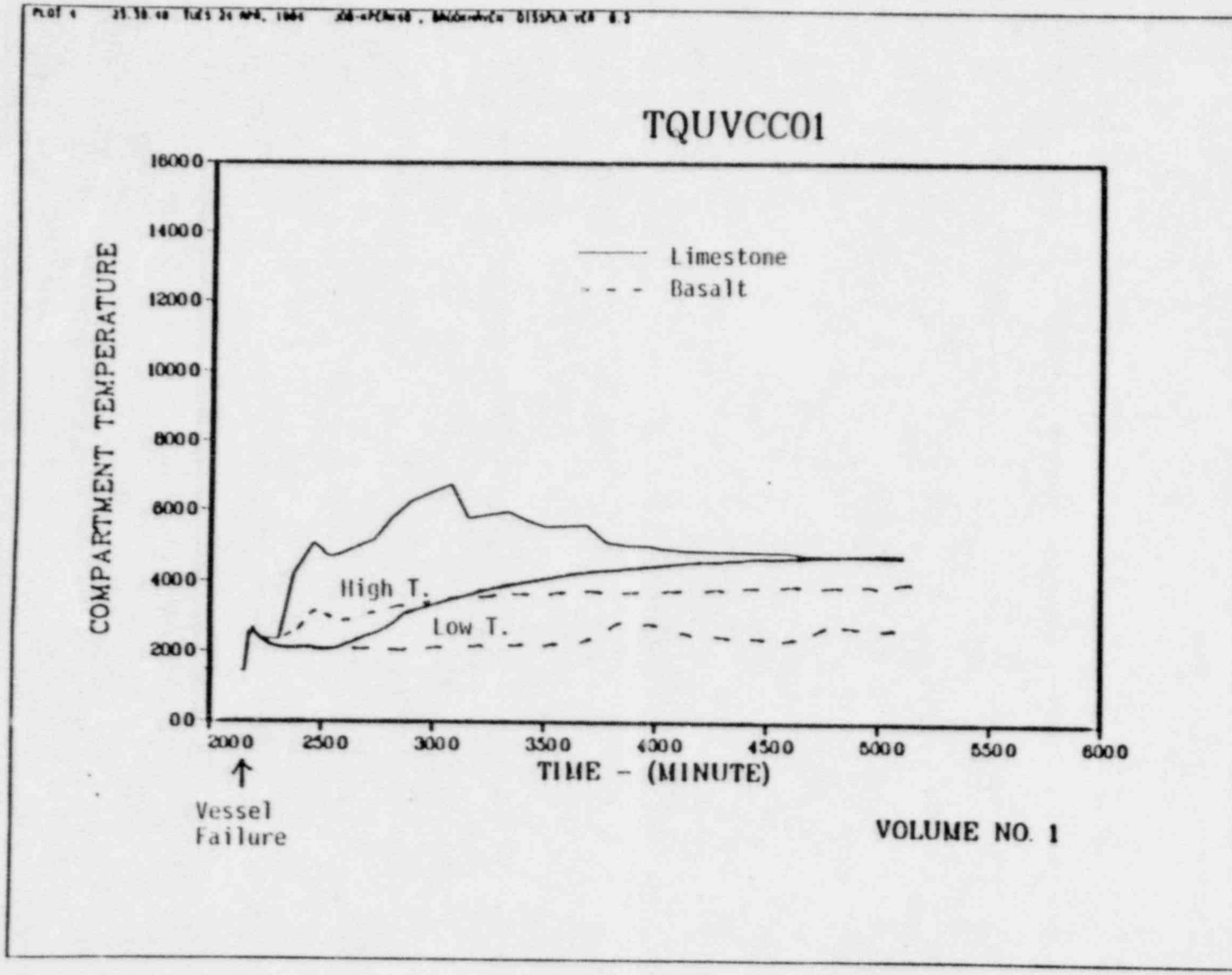

TQUVCC01
Limestone
Basalt
High T.
Low T.
COMPARTMENT TEMPERATURE
TIME - (MINUTE)
Vessel
Failure
VOLUME NO. 1
0.0
2000.0
4000.0
6000.0
8000.0
10000.0
12000.0
14000.0
16000.0
2000.0
2500.0
3000.0
3500.0
4000.0
4500.0
5000.0
5500.0
6000.0

Figure 4.2

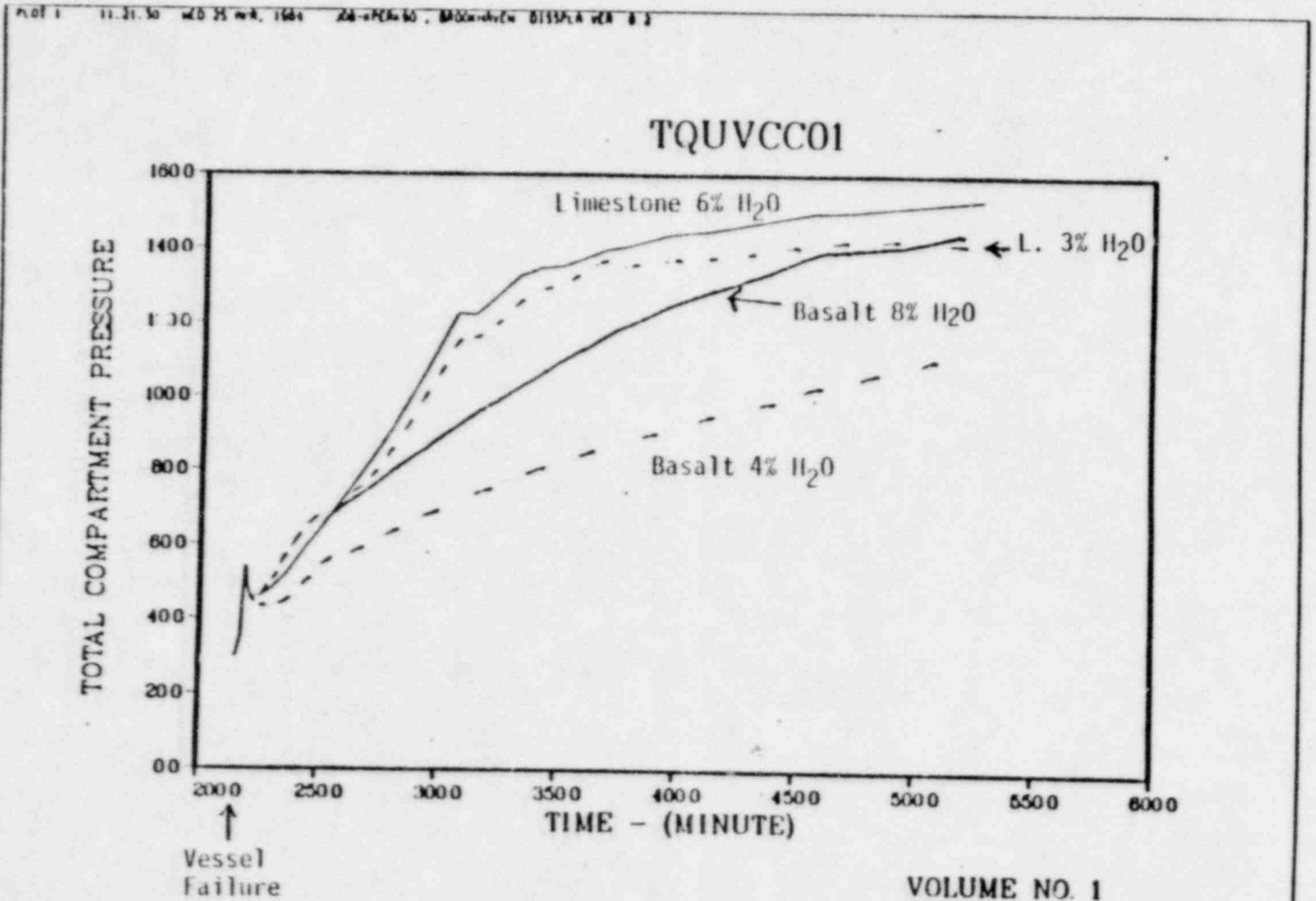

TQUVCC01
Limestone 6% H_2O
L. 3% H_2O
Basalt 8% H_2O
Basalt 4% H_2O
TOTAL COMPARTMENT PRESSURE
TIME - (MINUTE)
Vessel
Failure
VOLUME NO. 1

Figure 4.3

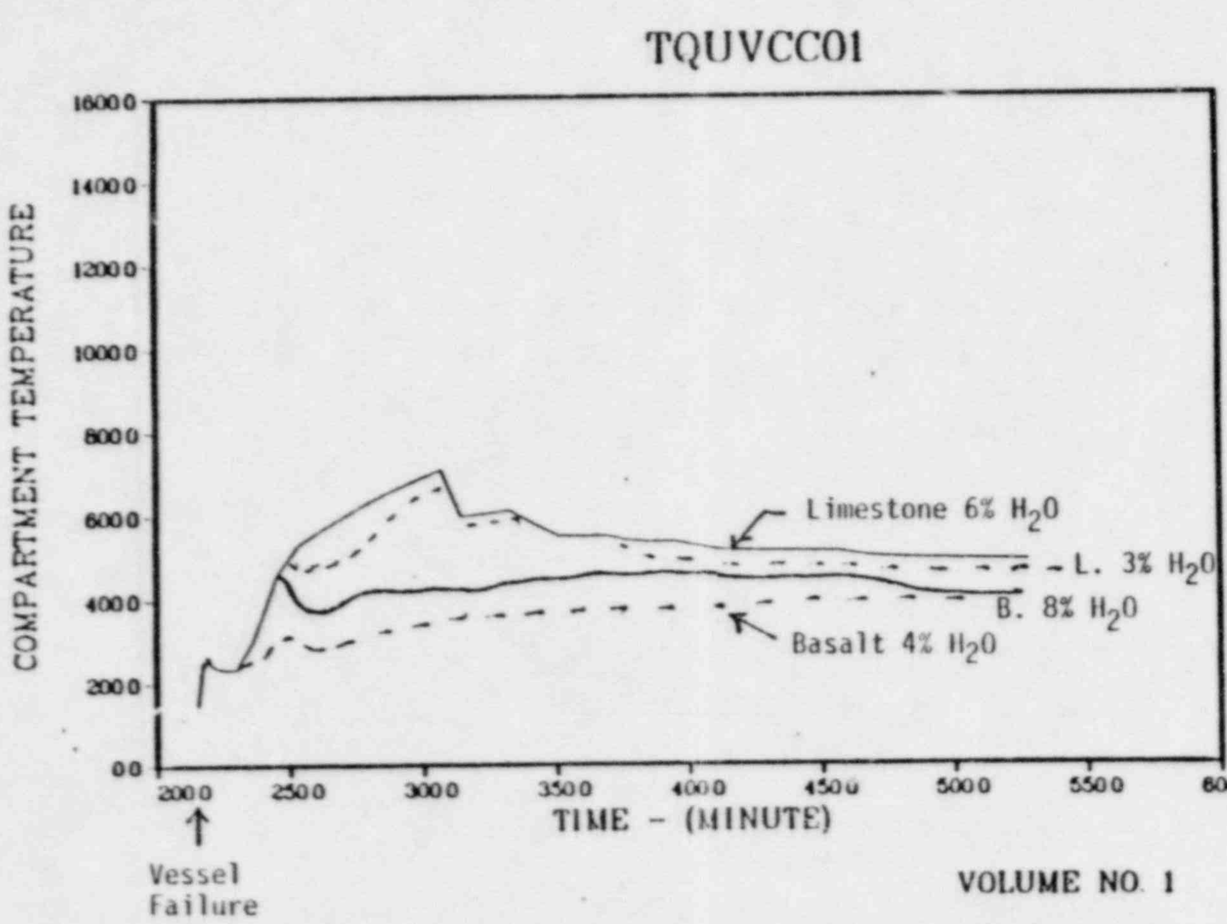
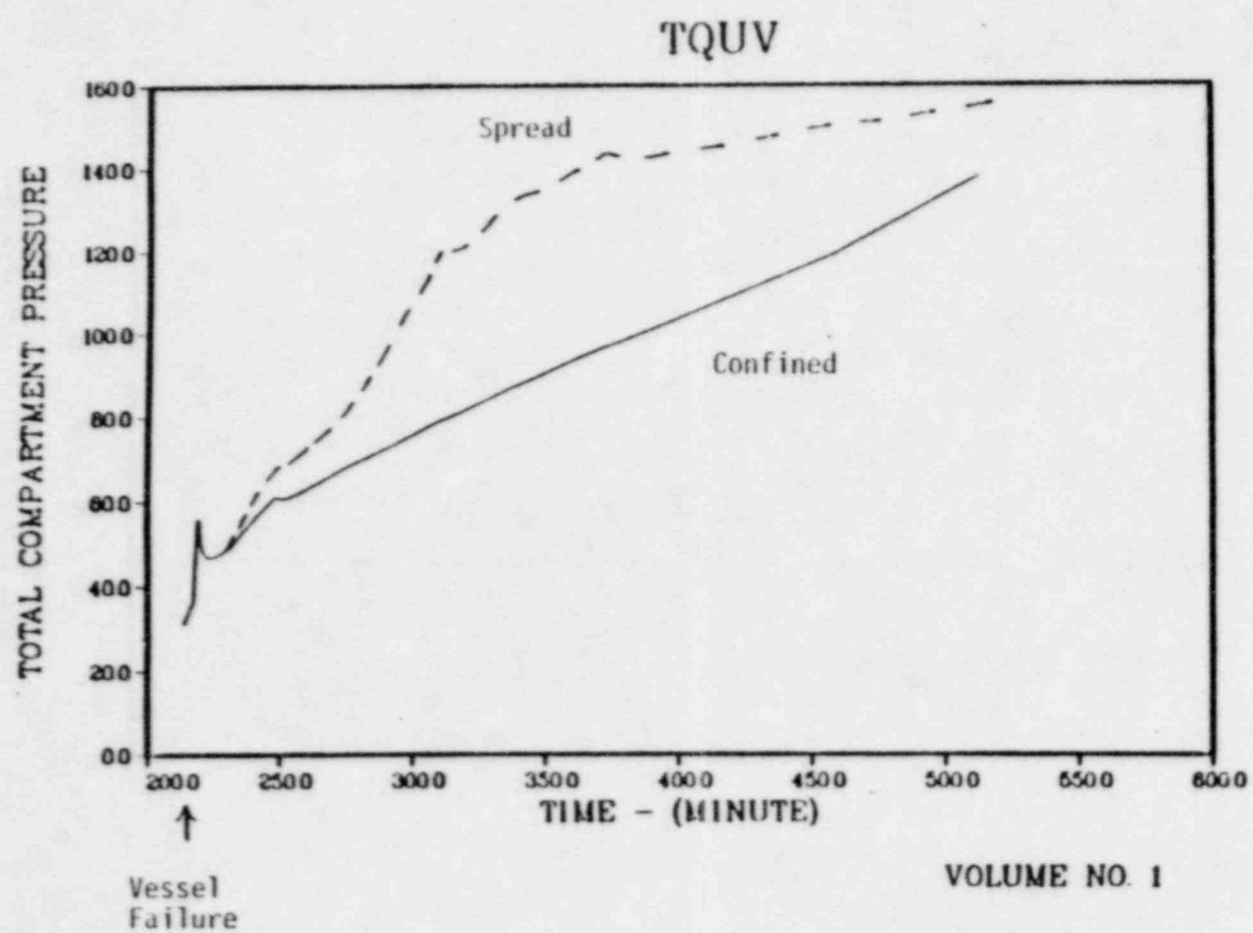
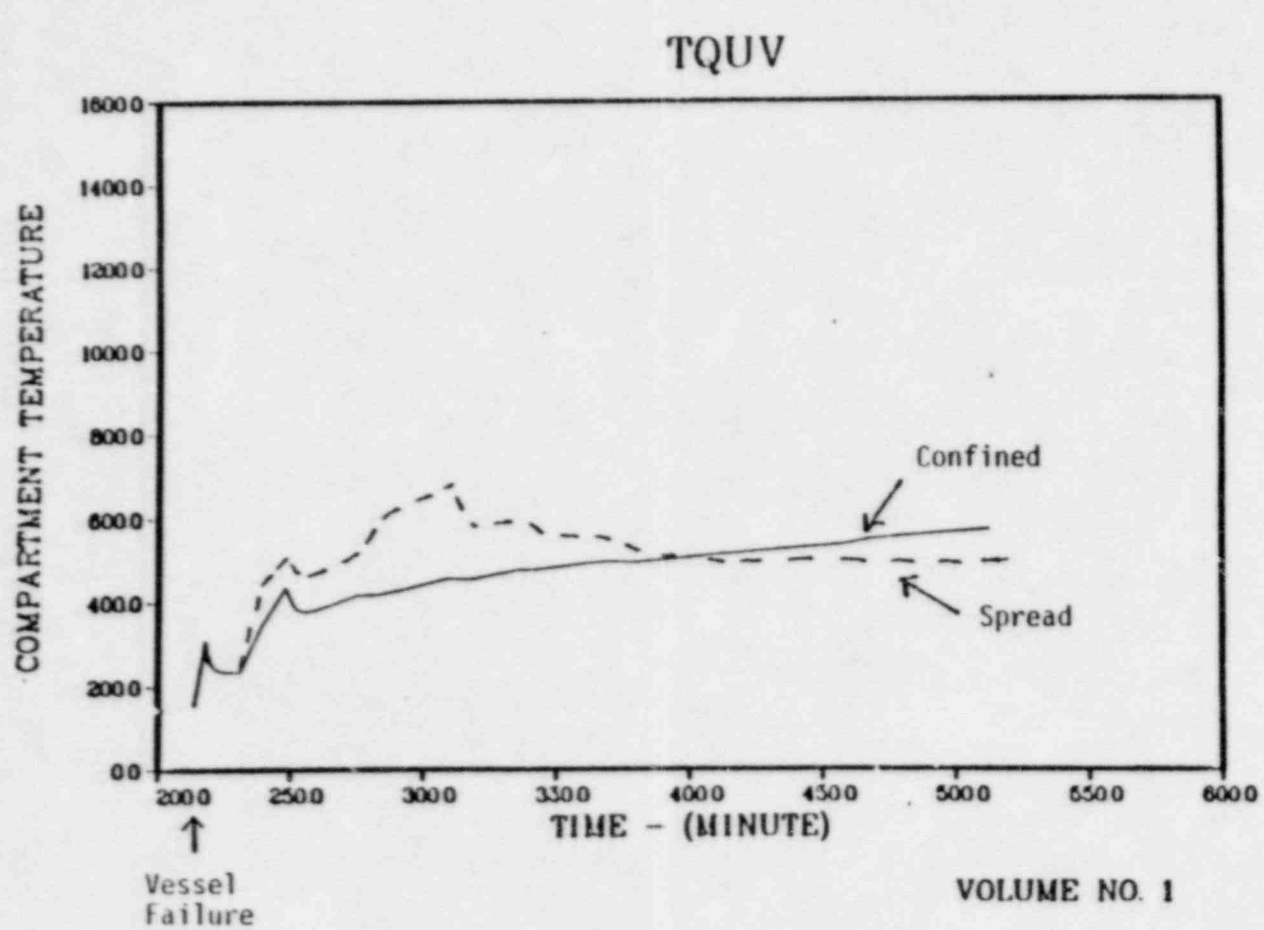

TQUVCC01
COMPARTMENT TEMPERATURE
0.0
200.0
400.0
600.0
800.0
1000.0
1200.0
1400.0
1600.0
2000
2500
3000
3500
4000
4500
5000
5500
6000
TIME - (MINUTE)
Vessel Failure
Limestone 6% H_2O
L. 3% H_2O
B. 8% H_2O
Basalt 4% H_2O
VOLUME NO. 1

Figure 4.4



TQUV
TOTAL COMPARTMENT PRESSURE
TIME - (MINUTE)
Spread
Confined
Vessel
Failure
VOLUME NO. 1
0.0
200.0
400.0
600.0
800.0
1000.0
1200.0
1400.0
1600.0
2000.0
2500.0
3000.0
3500.0
4000.0
4500.0
5000.0
6000.0

Figure 4.5



TQUV
COMPARTMENT TEMPERATURE
1600.0
1400.0
1200.0
1000.0
800.0
600.0
400.0
200.0
0.0
2000.0
2500.0
3000.0
3500.0
4000.0
4500.0
5000.0
5500.0
6000.0
TIME - (MINUTE)
Confined
Spread
Vessel
Failure
VOLUME NO. 1

Figure 4.6

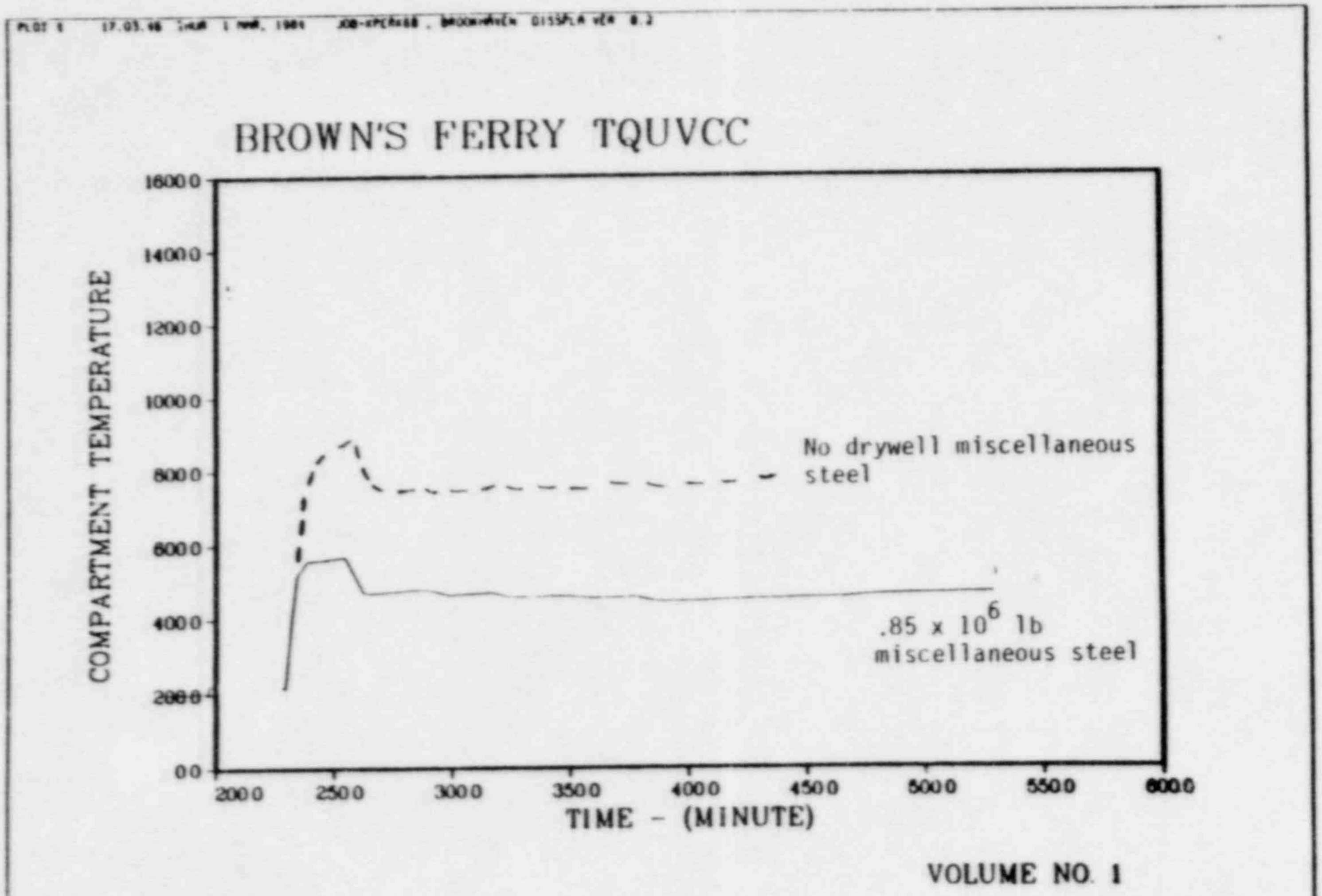

BROWN'S FERRY TQUVCC
COMPARTMENT TEMPERATURE
16000
14000
12000
10000
8000
6000
4000
2000
0.0
2000
2500
3000
3500
4000
4500
5000
5500
6000
TIME - (MINUTE)
No drywell miscellaneous steel
.85 x 10^6 lb miscellaneous steel
VOLUME NO. 1

Figure 4.7

APPENDIX A

RESULTS FOR THE CONTAINMENT LOADING SENSITIVITY STUDY

The BWR Mark I containment loads were calculated using the MARCH 1.1B code with concrete decomposition calculated separately with CORCON MOD 1 and input as gas generation "events." A summary of the Mark I sensitivity study is given in Table A.1. Note that the standard problem conditions and modeling evolved throughout the investigation. The results in Table A.1 are for the MARCH/CORCON modeling described in the main report. The historical evolution of the standard problem presents a more extensive sensitivity study. Based on these results the following conclusions can be made:

Concrete Composition:

1. Much higher containment temperatures and pressures are generated with limestone than with basalt.

2. Calculations with basalt concrete are very sensitive to free water in the concrete.

Corium Disposition:

1. Spreading of the debris over 50% of the drywell floor leads to much more rapid gas generation and correspondingly higher containment pressures, but the debris is also cooled more rapidly.

2. If the debris is confined within the pedestal wall, it stays hot (or heats up if it is cool) and maintains an aggressive attack on the concrete.

Corium Temperature:

1. The containment pressure and temperature is very sensitive to the initial temperature of the debris.

An estimate of the uncertainty range for Case 1 is included in Table 4.2. Note that Case 1 is, itself, an extreme case (maximum temperature, maximum H_2 generation, and maximum spreading) and should not be confused with a best estimate. Thus, the "high estimate" corresponds to a limiting case of a limiting case and has an extremely low probability of occurrence.

The results of the complete sensitivity study are summarized in Table A.3. The nomenclature in the case description is given in Table A.4, and the calculated results for each case are included in the succeeding figures. Note that the figures are intended to be self explanatory with the legend (e.g., Volume No. 1 = Drywell) included in Table A.3.

Table A.1 Summary of BWR Mark I standard problem results

Case Number	1	1a	1e	2	3	3a	4
Corium Spread (m)	5			3	5		3
Debris Temperature (°F)	4130			2700	4130		2700
Concrete Type	L			L	B		B
Free H_2O (%)	3	6		3	4	8	4
Steel in Corium (lb)	140K			140K	140K		140K
Upward Radiation to Structures	No	No	Yes	No	No	No	No
RESULTS							
Peak Pressure (psia)	145*	154*	87	88*	108*	142*	65*
Peak Temperatures (°F)							
Drywell Atmosphere	660	700	460	500*	400	450	280*
Drywell Liner	360	380	210	300*	270*	310*	240*
Wetwell Atmosphere	286*	270*	460	200*	220*	227*	220*
Wetwell Liner	175*	159*	139	138	142*	143*	143*

*Temperature or pressure is still rising after five hours

Table A.2 Uncertainty in the high temperature limiting case with limestone

	High Estimate*	Low Estimate*
Pressure Loading	164**	87
Temperature Loading (°F) (Drywell Atmosphere)	700+	460+

*Within five hours of vessel failure.

**Note that this pressure exceeds the predicted ultimate capacity and is included.

+Thermal radiation will raise local temperatures considerably above this value (to 1000°F or more).

Table A.3 Legend for Brown's Ferry containment load calculations for TQUV sequences with MARCH 1.1B and CORCON-1

Case	Corium Spread (m)	Debris Temp. (F)	Concrete Type	Free H_2O (1)	Debris Emissivity	Drywell Misc. Steel (10^6 lb)	Failure Time* (min)	Peak Pressure (psia)	Drywell Peak T. (F)	D. Liner Peak T. (F)	Wetwell Peak T. (F)	W. Liner Peak T. (F)
Old INTER	3.0	4130	L (old)**	3	0.5	0.0	30	>130	1250	~600	410	-
Old CORCON	3.0	4130	L (old)	3	0.5	0.0	>300	115	850	~600	400+	-
New Base	3.0	4130	L	3	0.0	0.0	220	>130	880	~600	~400+	-
NBase HS	3.0	4130	L	3	0.0	.85	260	140+	580+	360+	280+	175+
01HSNORAD	5.0	4130	L	3	0.0	.85	120	155+	670	410+	370+	275+
01HSWWRADH2	5.0	4130	L	3	0.0	.85	85	164+	676	365	286+	175+
01HSWWRAD	5.0	4130	L	3	0.0	.85	133	145+	660	360	266+	175+
01AHSWWRAD	5.0	4130	L	6	0.0	.85	125	154+	700	380	270+	159+
01EHSWWRAD	5.0	4130	L	3	0.5	.85	N/A	87	460	210	460	139
02HSWWRAD	3.0	2700	L	3	0.0	.85	>>300	88+	500+	300+	200+	138
02AHSWWRAD	3.0	2700	B	4	0.0	.85	>>300	65+	280	240+	175	138
03HSWWRAD	5.0	4130	B	4	0.0	.85	>300	108+	400	270+	220+	142+
03AHSWWRAD	5.0	4130	B	8	0.0	.85	210	142+	450	310	227+	143+

Volume No. 1 = Drywell
Volume No. 2 = Wetwell
NOD(1) = Drywell Liner
NOD(4) = Drywell Miscellaneous Steel
NOD(5) = Wetwell Miscellaneous Steel

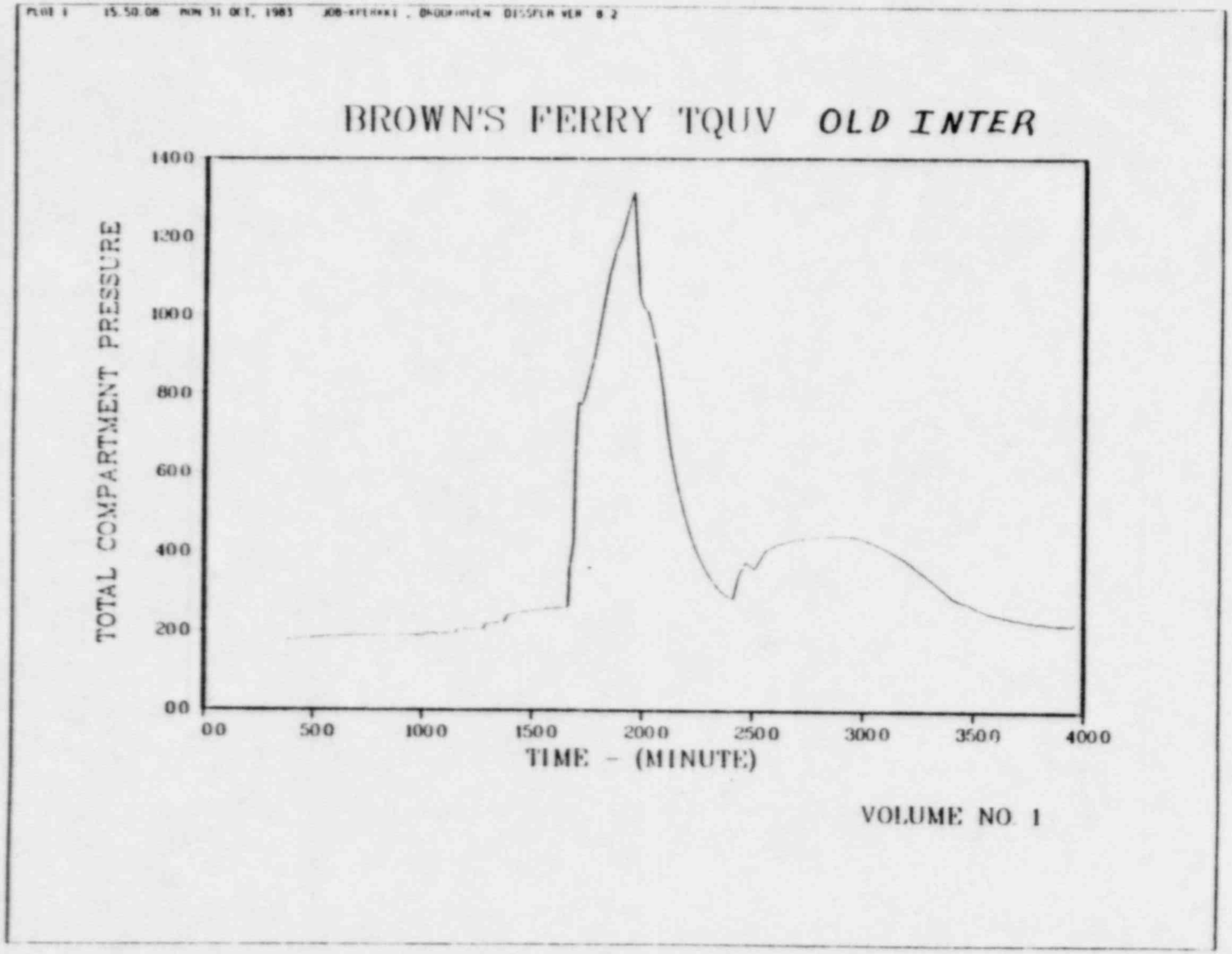
*Failure time after vessel failure is based on a containment failure pressure of 132 psia but other Mark I's may be somewhat higher or lower.
**Note that L(old) has a slightly different limestone composition as described in the initial standard problem dated November 3, 1984.
+Temperature or pressure is still rising after 5 hours.

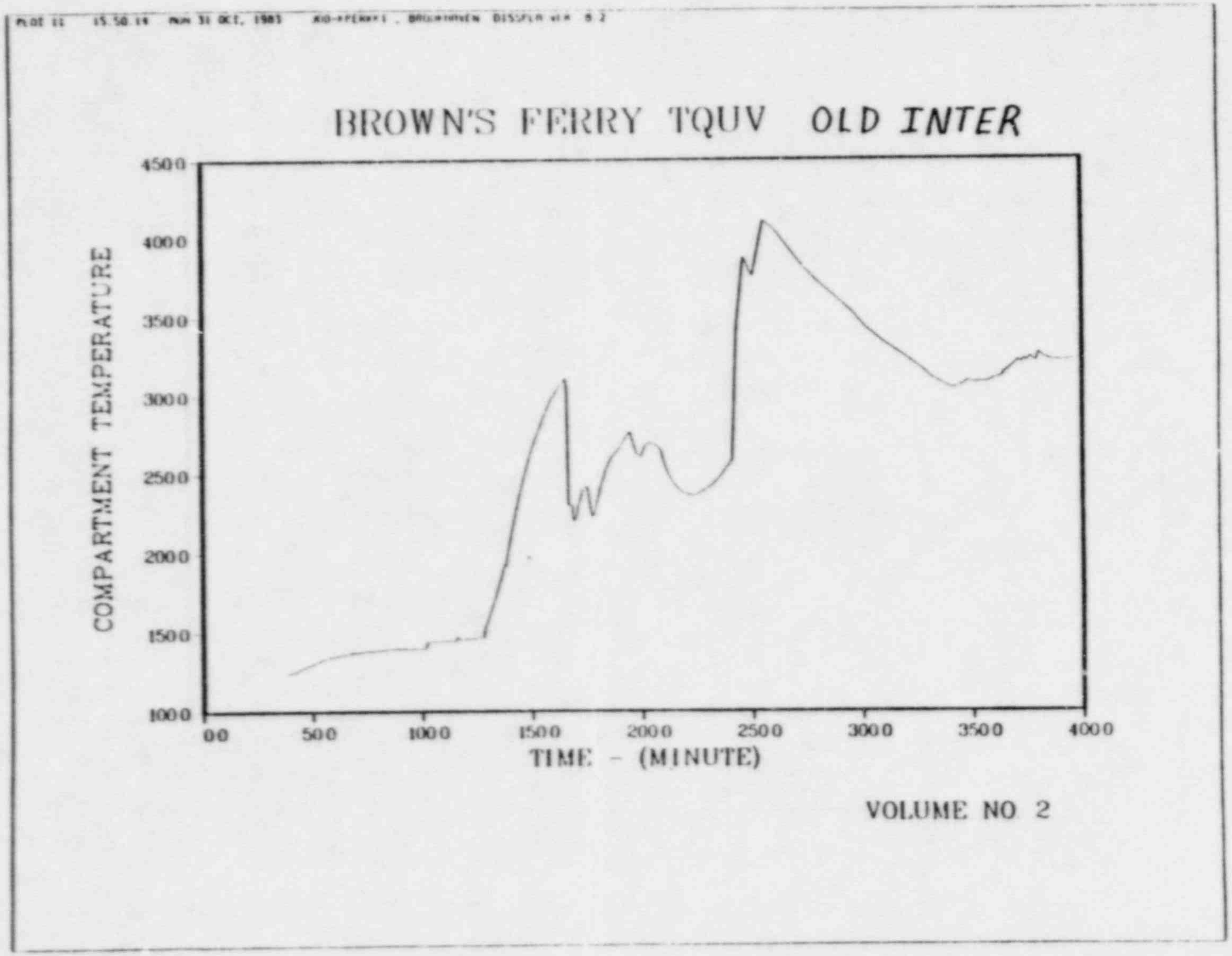
Table A.4 Case descriptions for the various sensitivity runs

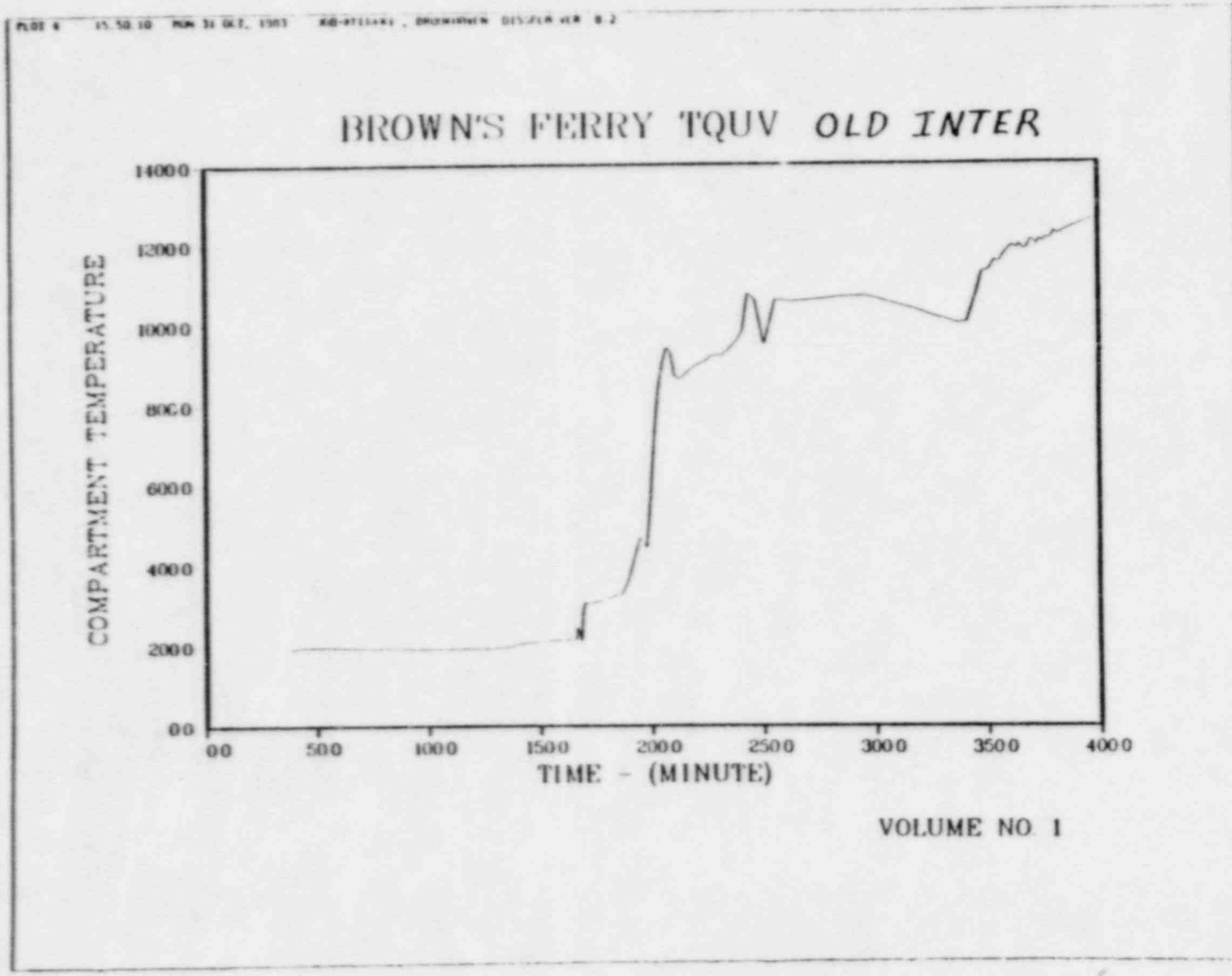
Case	Description	Comments
Old INTER	High temperature confined case using MARCH 1.1B and INTER.	The short failure time (30 min) and high drywell temperature are consistent with Oak Ridge results (NUREG/CR-2825).
Old CORCON	High temperature confined case using MARCH 1.1B with CORCON MOD-1.	Note that the use of CORCON delays over pressure failure by 5 hours and decreases drywell temperatures.
N Base	High temperature confined case with CORCON MOD-1 and new limestone composition.	The change in limestone composition hastens the overpressure failure and increases drywell temperatures.
Base HS	New Base case (above) with .85 x 10^6 lb steel heat sink in drywell.	The addition of the heat sink considerably moderates the peak temperature and slightly delays overpressure failure.
01HSNORAD	Same as N Base HS with spreading to 5 m. NORAD refers to the absence of the wetwell radiation model (below). The wetwell outside wall is assumed to be perfectly insulated as in all the above cases.	Note that spreading the corium out to 5m results in much more core/concrete interaction and much earlier overpressure failure.
01HSWWRAD	Same as 01HSNORAD except a heat transfer coefficient of 2.0 Btu/hr-ft°F is added to account for thermal radiation from the wetwell wall to surrounding concrete.	The WWRAD model substantially reduces the wetwell atmospheric temperature which was unrealistically high (300°F above the pool temperature).
01HSWWRADH2	Same as WWRAD except 1000 lbs of hydrogen is added to the containment as an event to bring the total to 1700 lbs. (Note that this increases the pressure before vessel failure beyond the standard problem specification of 35 psia.)	The additional H_2 has a direct effect on the pressure loading of about 20 psi.

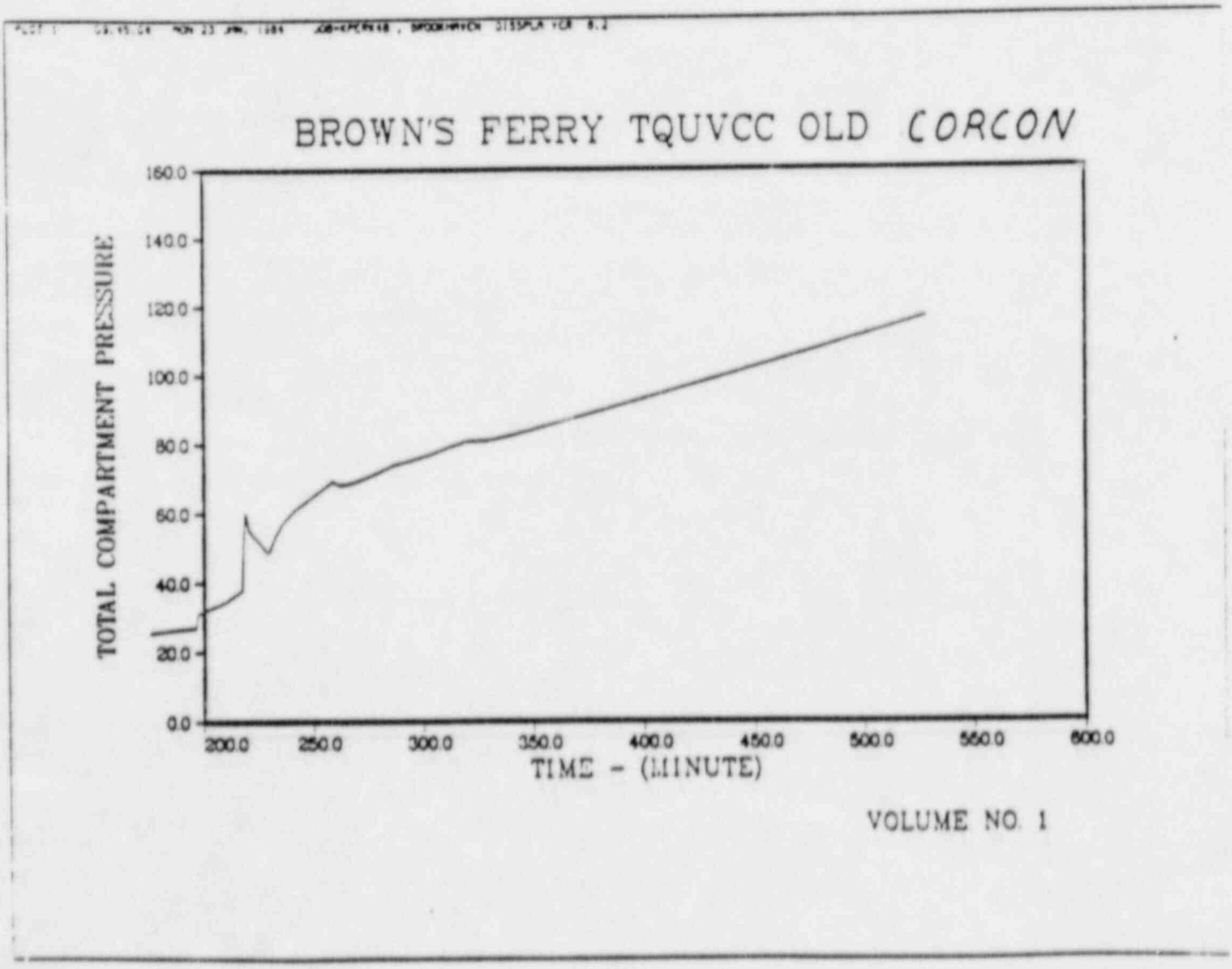
Table A.4 (Cont'd)

Case	Description	Comments
01AHSWWRAD	The remaining calculations summarized in Table A.3 have consistent modeling features and are used in the standard problem results listed in Table A.1.	Equivalent to case 1a in Table A.1.
01EHSWWRAD	Equivalent to case 1e.	
02HSWWRAD	Equivalent to case 2.	
03HSWWRAD	Equivalent to case 3.	
03AHSWWRAD	Equivalent to case 3a.	
02AHSWWRAD	Equivalent to case 4.	

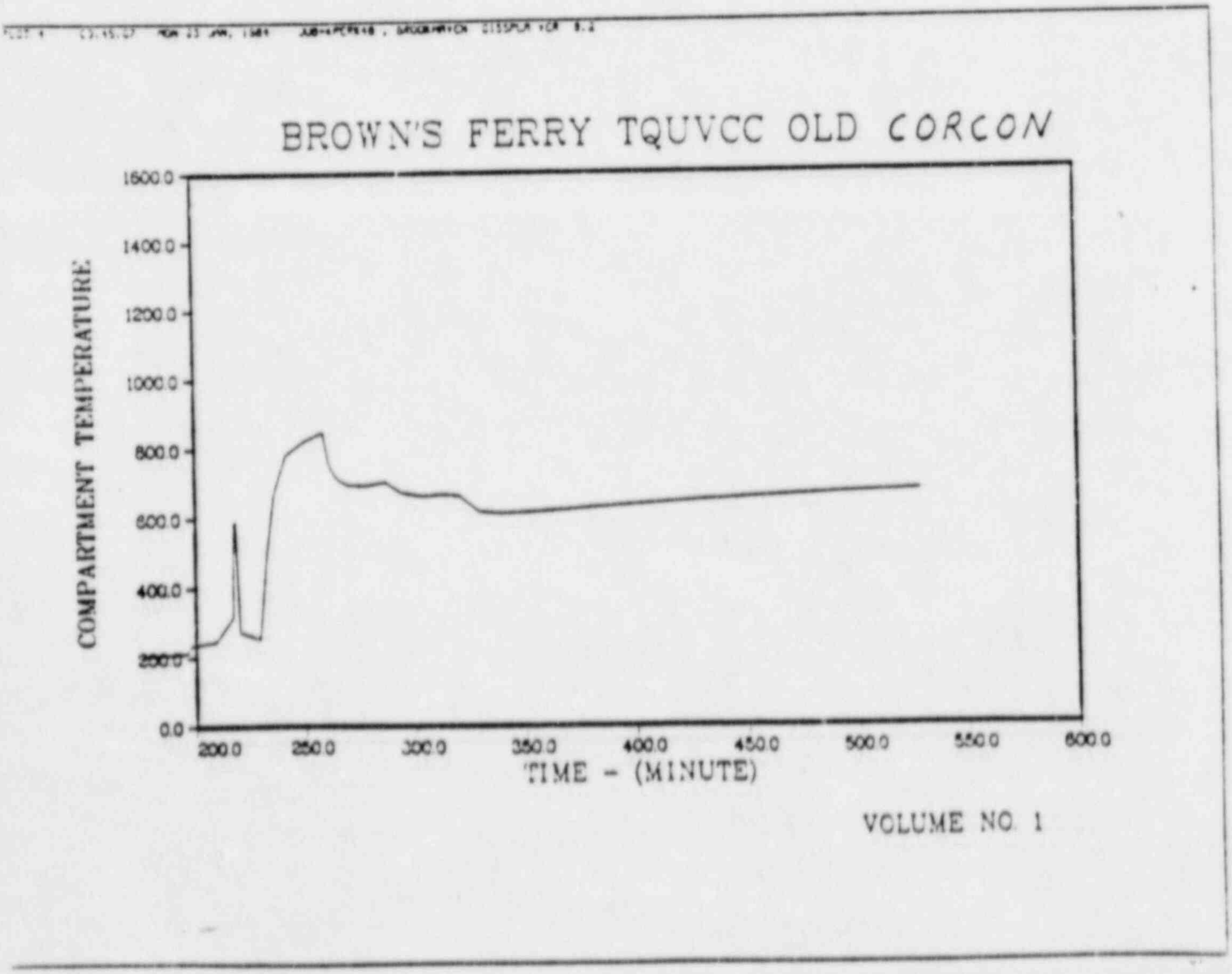

BROWN'S FERRY TQUV OLD INTER
TOTAL COMPARTMENT PRESSURE
00
200
400
600
800
1000
1200
1400
00
500
1000
1500
2000
2500
3000
3500
4000
TIME - (MINUTE)
VOLUME NO. 1


BROWN'S FERRY TQUV OLD INTER
COMPARTMENT TEMPERATURE
4500
4000
3500
3000
2500
2000
1500
1000
0.0
500
1000
1500
2000
2500
3000
3500
4000
TIME - (MINUTE)
VOLUME NO 2

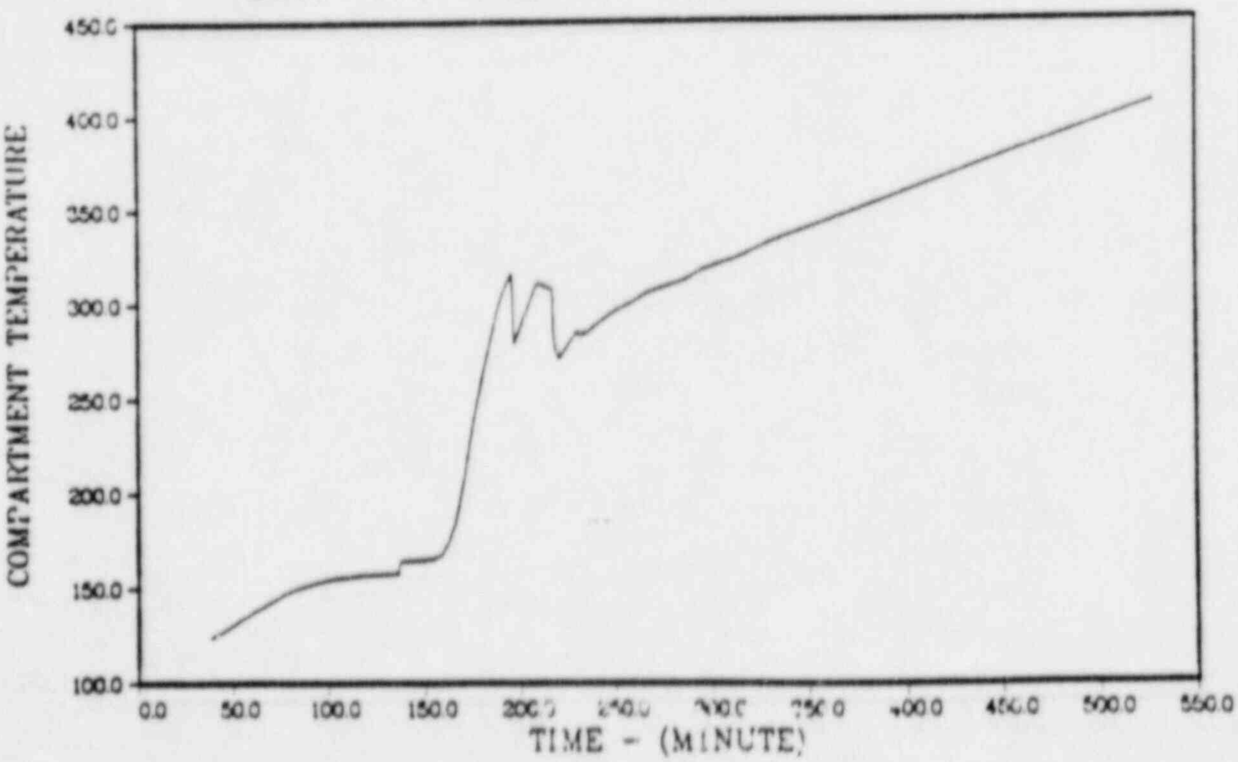

BROWN'S FERRY TQUV OLD INTER
COMPARTMENT TEMPERATURE
TIME - (MINUTE)
VOLUME NO. 1



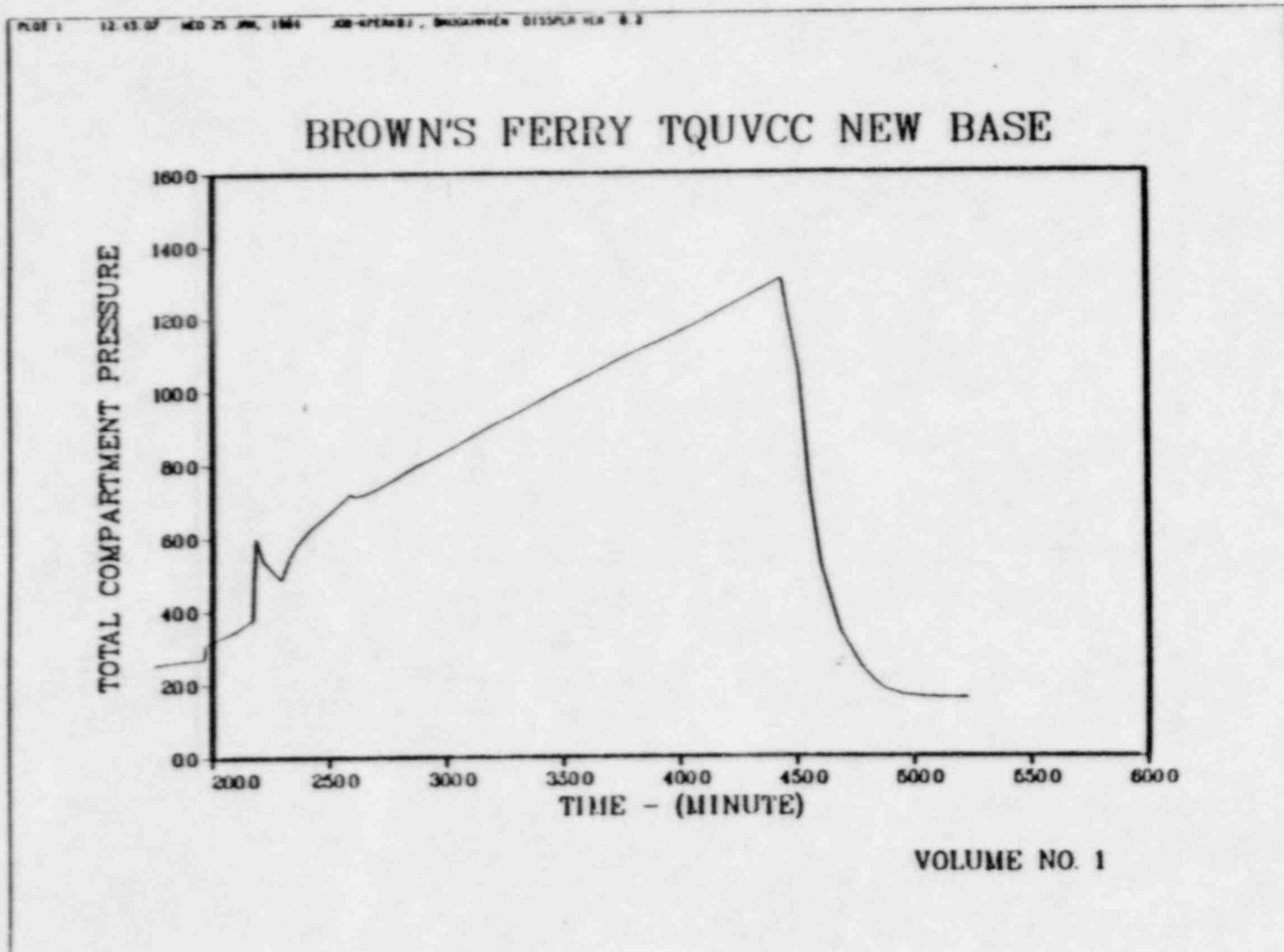
BROWN'S FERRY TQUVCC OLD CORCON
TOTAL COMPARTMENT PRESSURE
TIME - (MINUTE)
VOLUME NO. 1


BROWN'S FERRY TQUVCC OLD CORCON
COMPARTMENT TEMPERATURE
1600.0
1400.0
1200.0
1000.0
800.0
600.0
400.0
200.0
0.0
200.0
250.0
300.0
350.0
400.0
450.0
500.0
550.0
600.0
TIME - (MINUTE)
VOLUME NO. 1

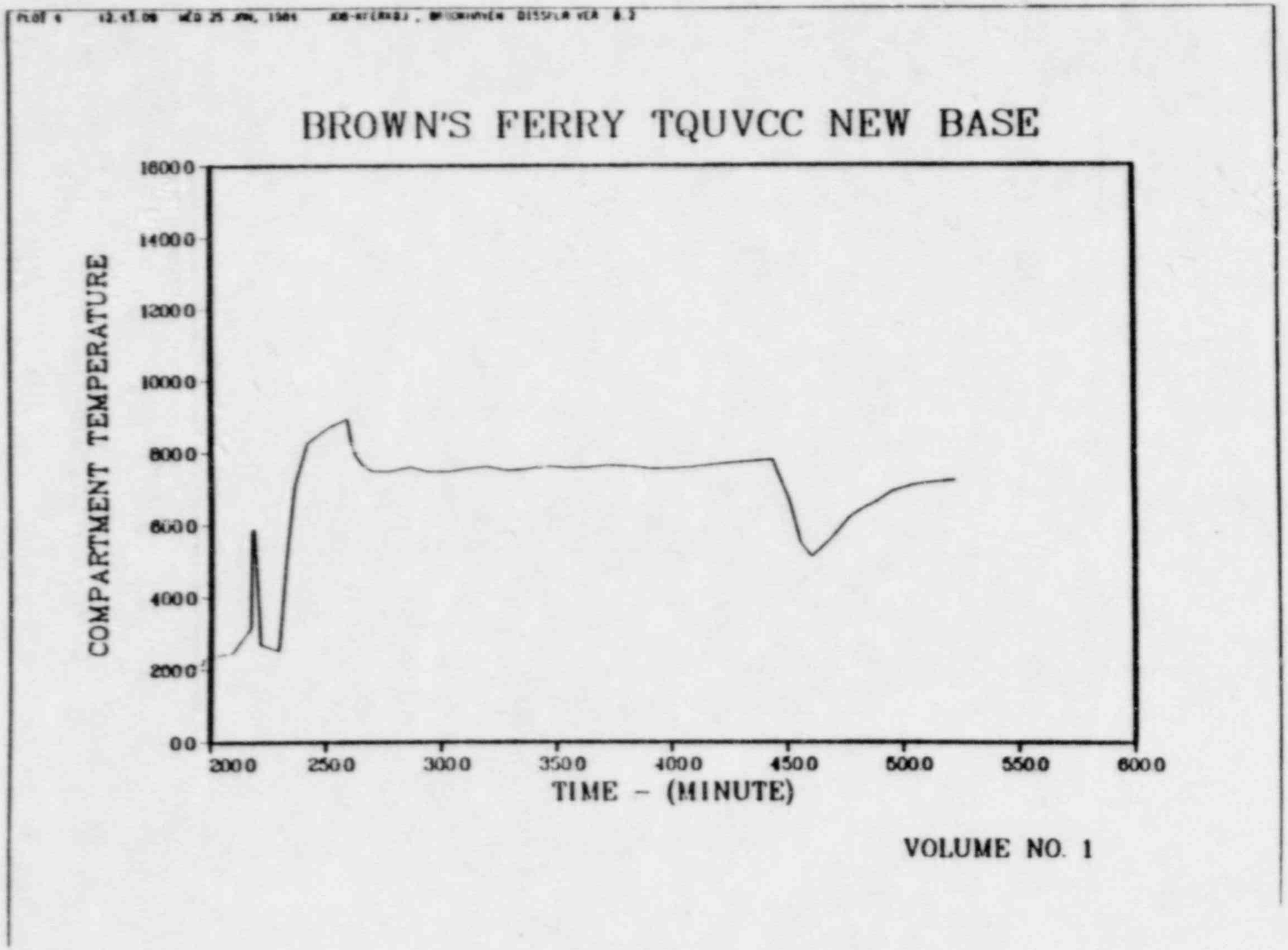
BROWN'S FERRY TQUVCC OLD CORCON

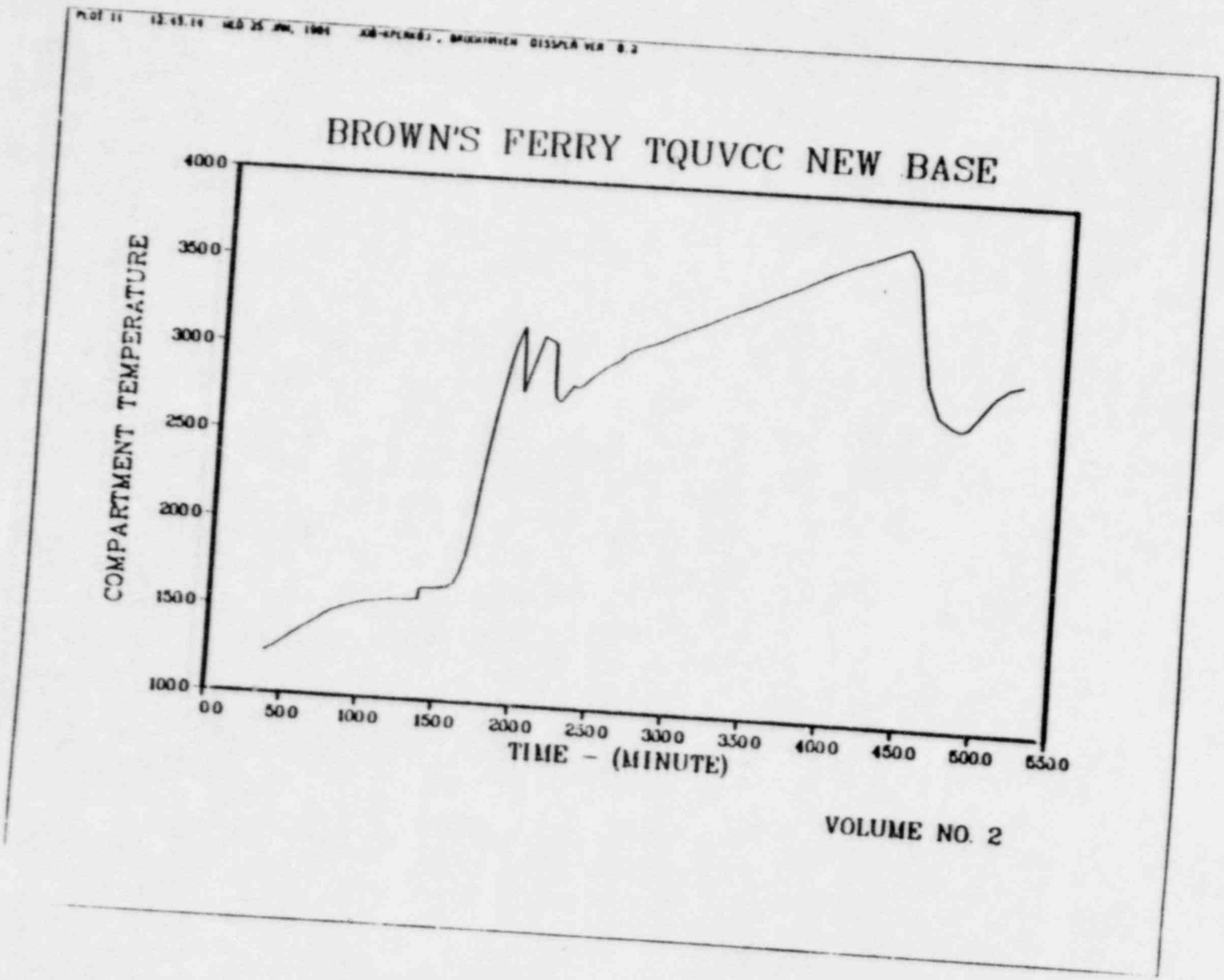


VOLUME NO. 2

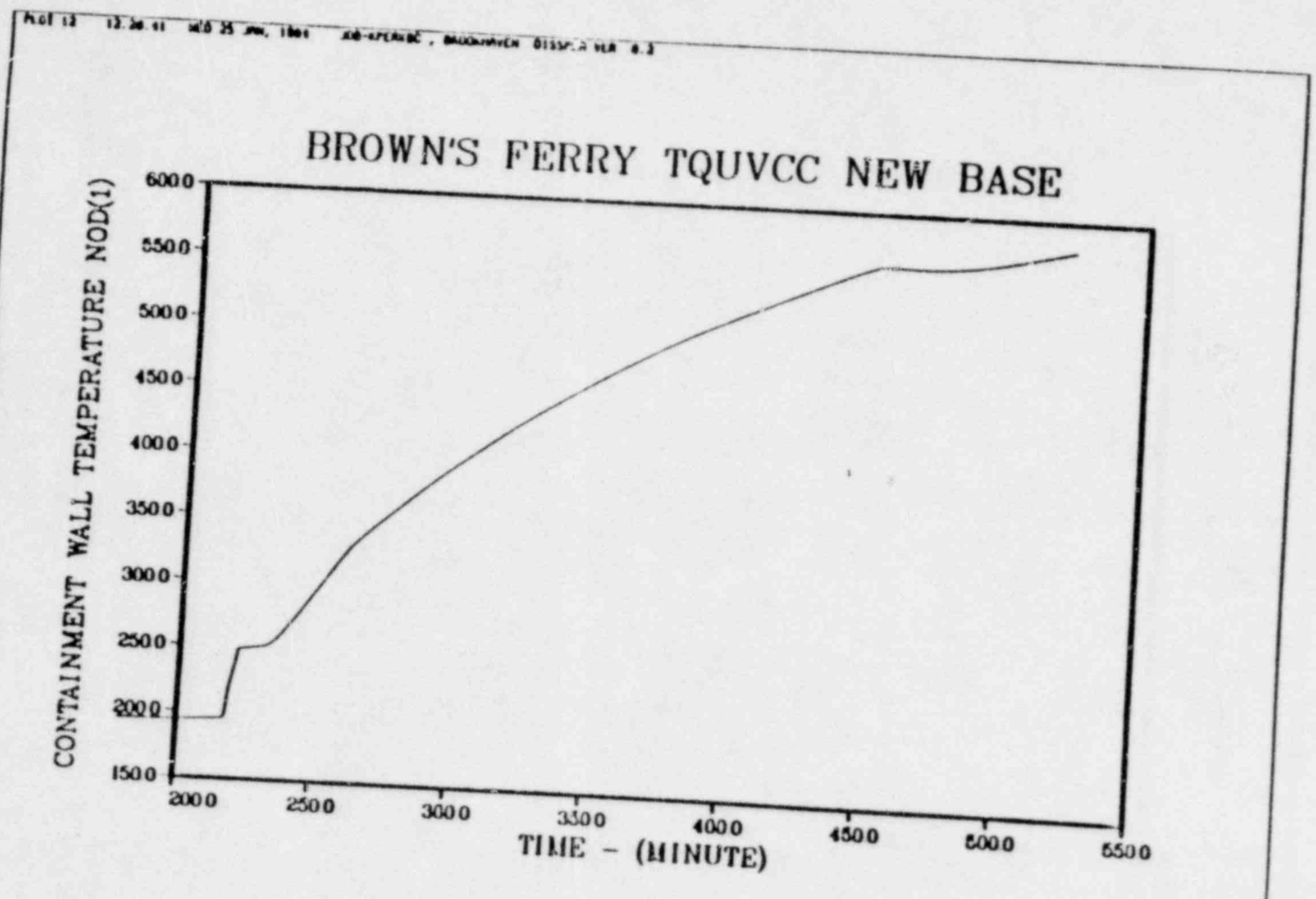


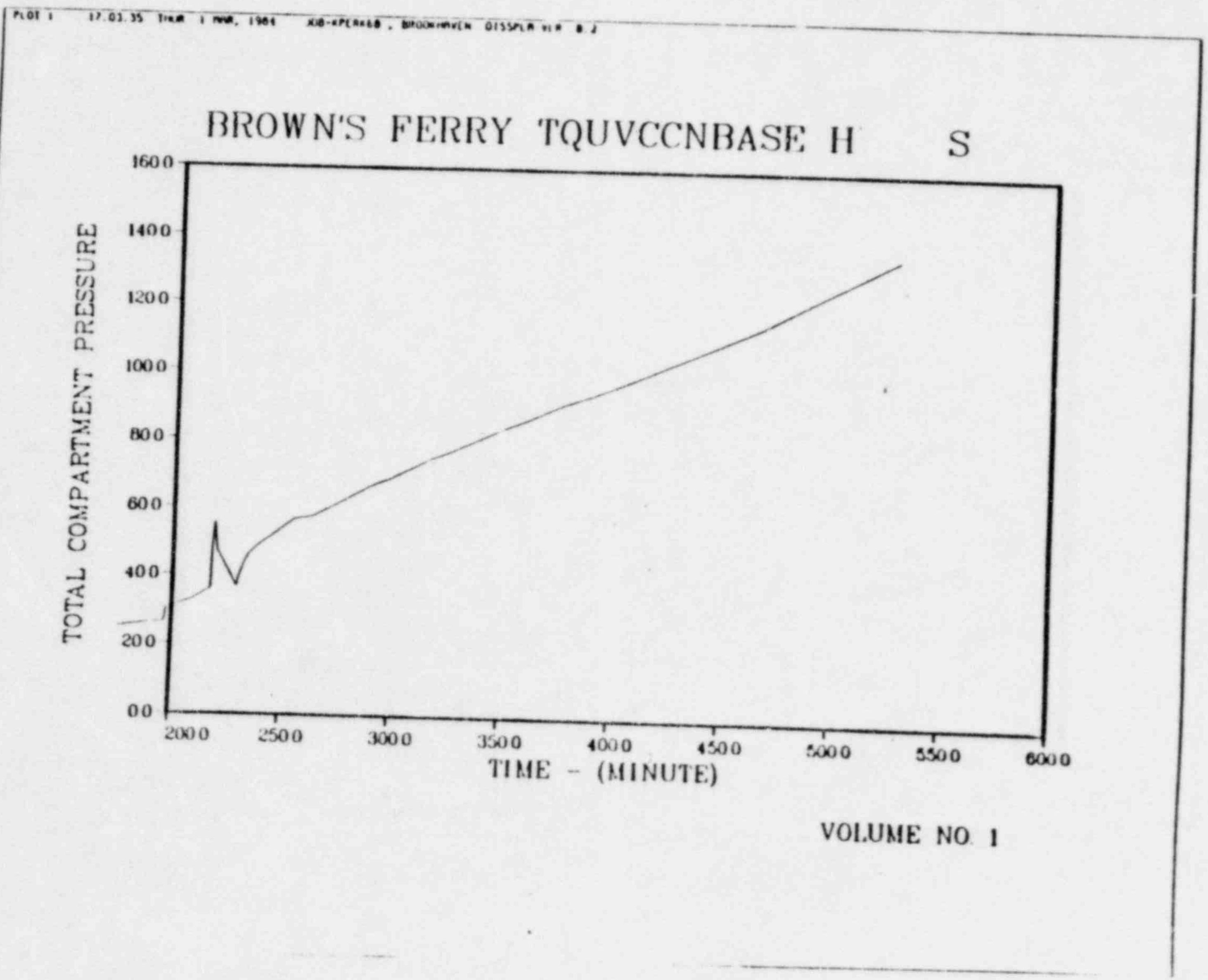
BROWN'S FERRY TQUVCC NEW BASE
TOTAL COMPARTMENT PRESSURE
TIME - (MINUTE)
0.0
200.0
400.0
600.0
800.0
1000.0
1200.0
1400.0
1600.0
2000
2500
3000
3500
4000
4500
5000
5500
6000
VOLUME NO. 1

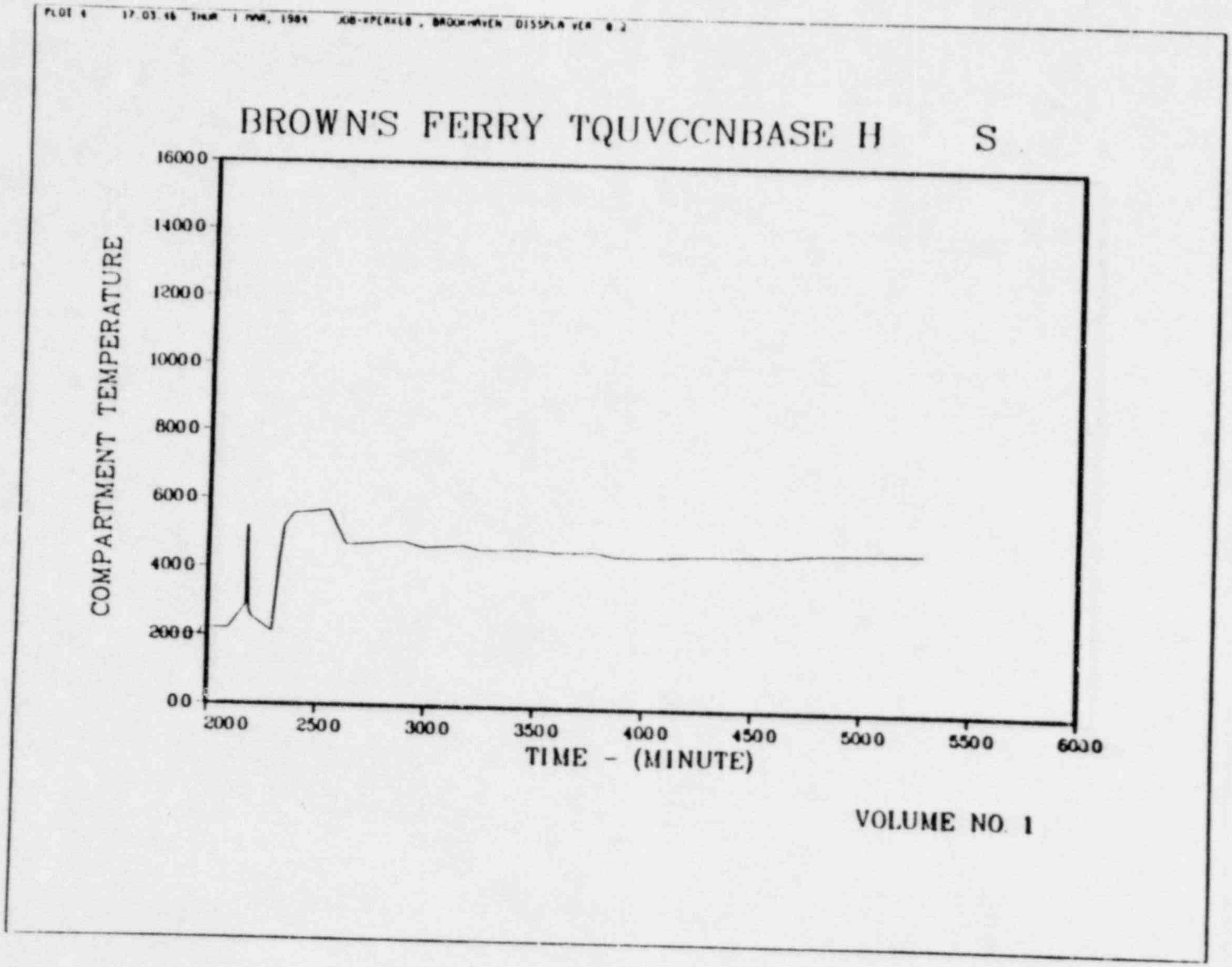

BROWN'S FERRY TQUVCC NEW BASE
COMPARTMENT TEMPERATURE
TIME - (MINUTE)
VOLUME NO. 1
0.0
200.0
400.0
600.0
800.0
1000.0
1200.0
1400.0
1600.0
200.0
250.0
300.0
350.0
400.0
450.0
500.0
550.0
600.0

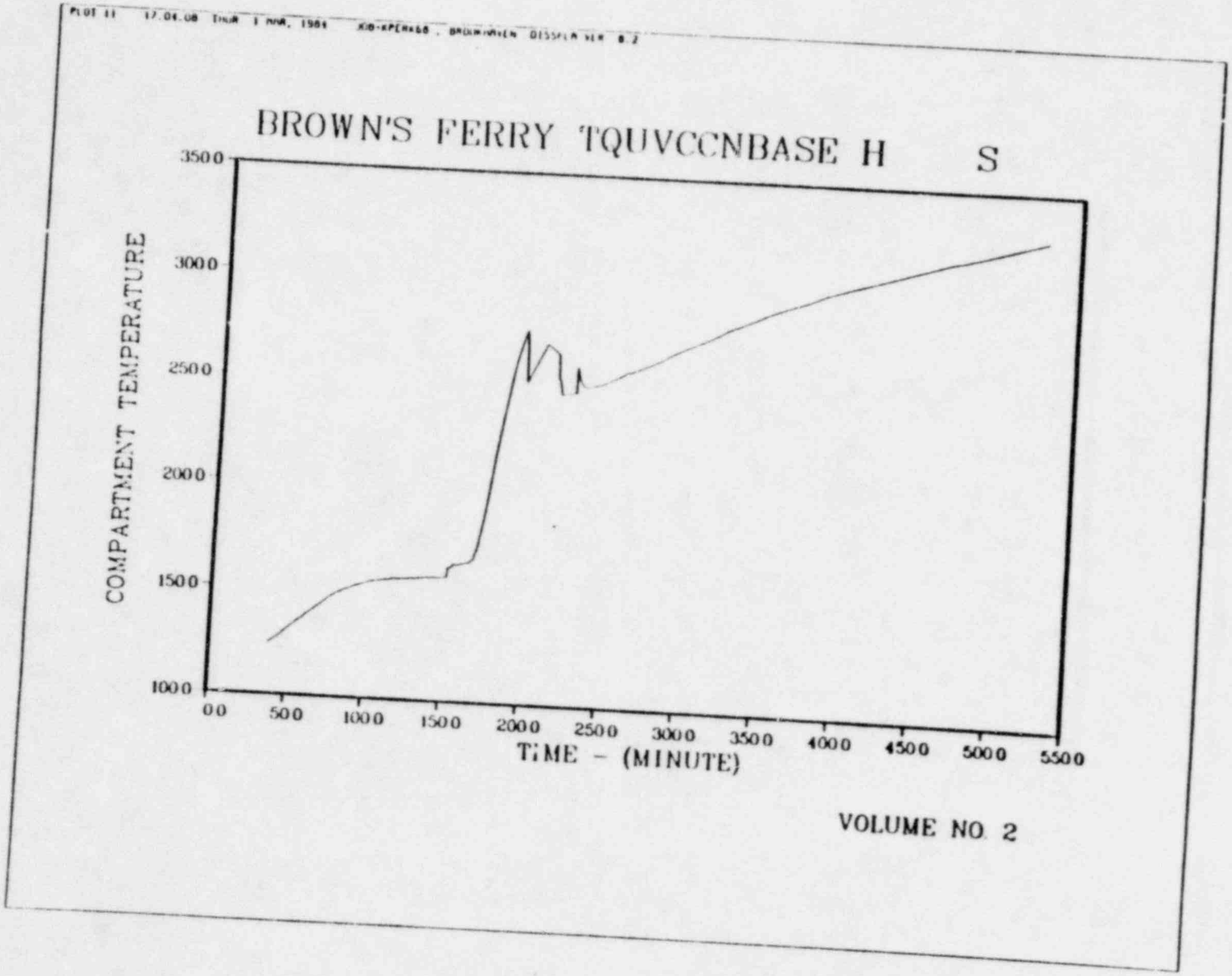


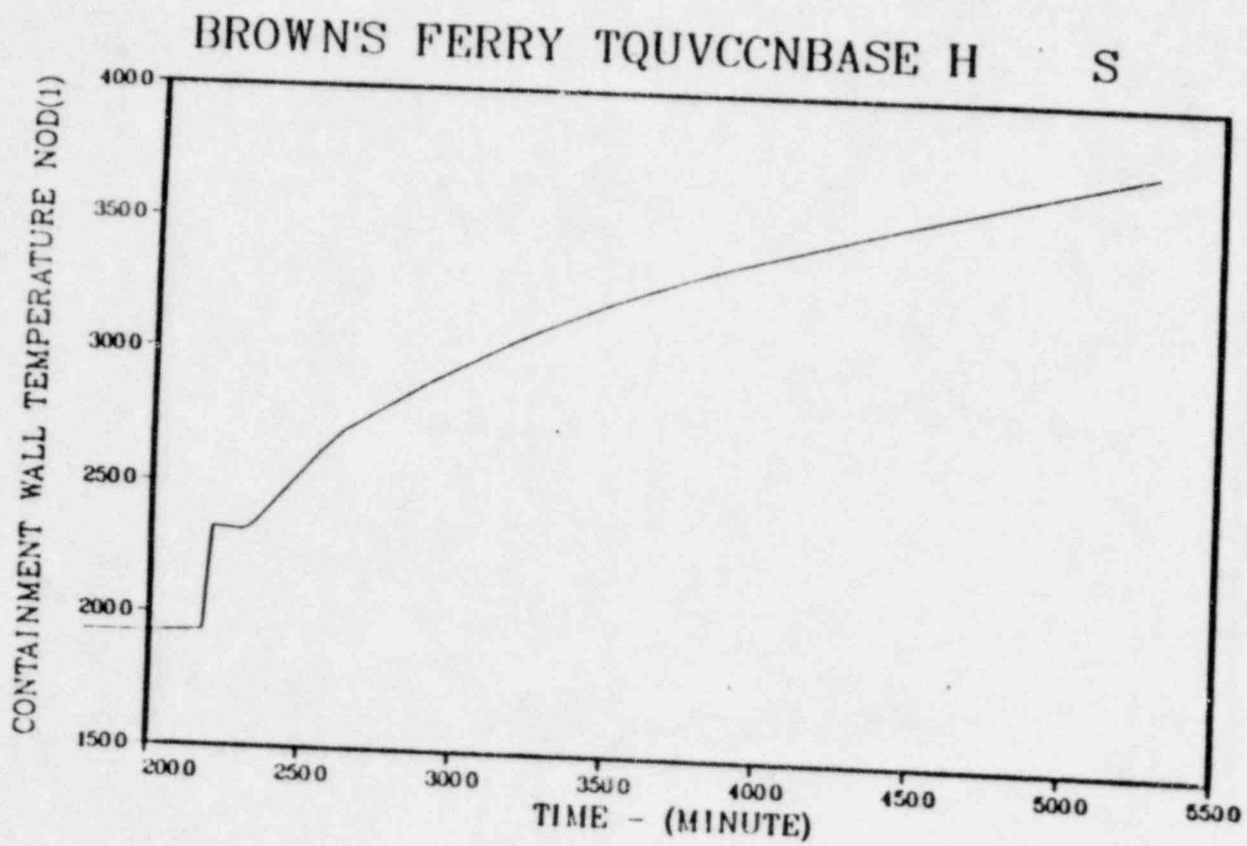
BROWN'S FERRY TQUVCC NEW BASE
COMPARTMENT TEMPERATURE
TIME - (MINUTE)
100.0
150.0
200.0
250.0
300.0
350.0
400.0
0.0
50.0
100.0
150.0
200.0
250.0
300.0
350.0
400.0
450.0
500.0
550.0
VOLUME NO. 2


BROWN'S FERRY TQUVCC NEW BASE
CONTAINMENT WALL TEMPERATURE NOD(1)
600.0
550.0
500.0
450.0
400.0
350.0
300.0
250.0
200.0
150.0
200.0
250.0
300.0
350.0
400.0
450.0
500.0
550.0
TIME - (MINUTE)

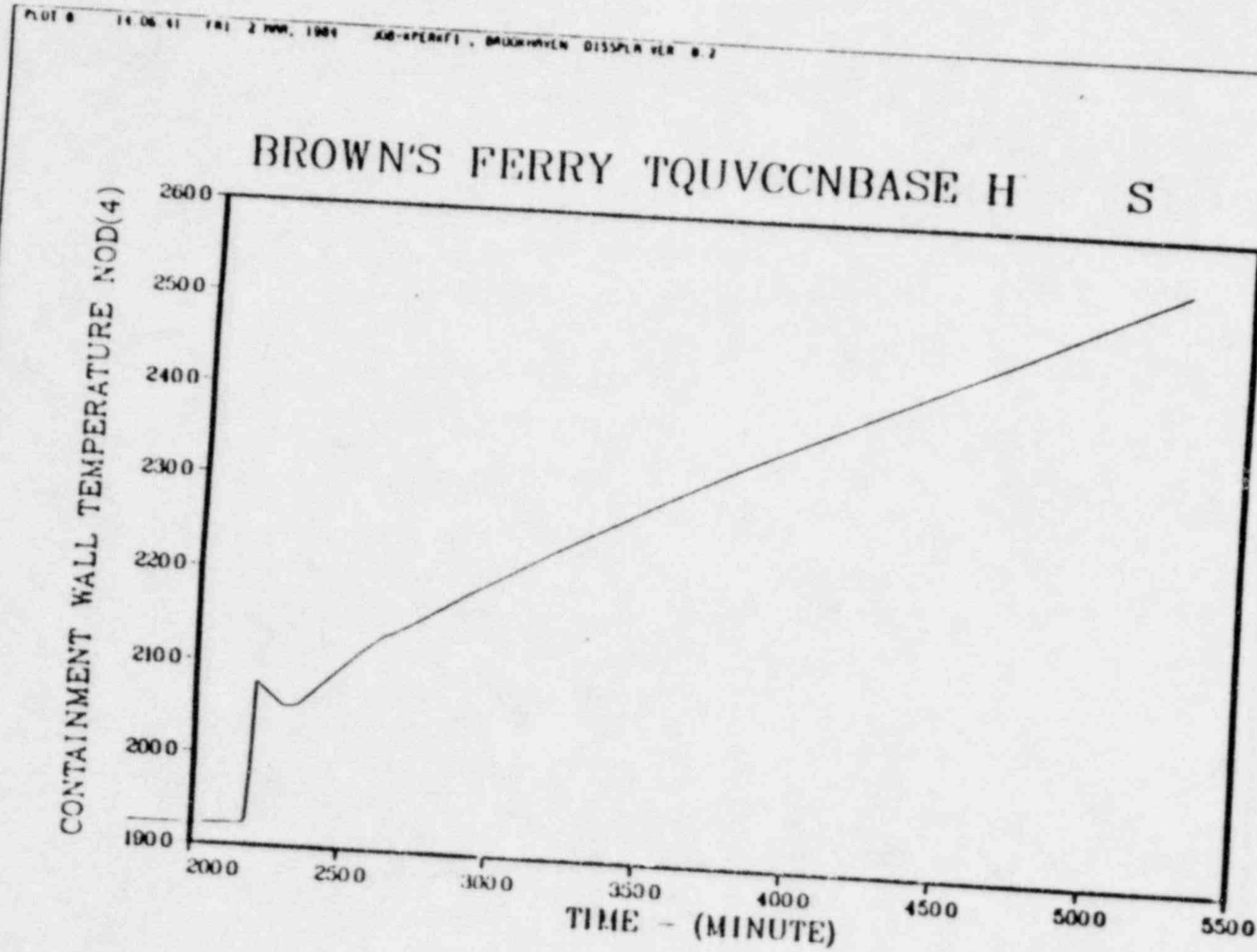

BROWN'S FERRY TQUVCCNBASE H S
TOTAL COMPARTMENT PRESSURE
160.0
140.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
200.0
250.0
300.0
350.0
400.0
450.0
500.0
550.0
600.0
TIME - (MINUTE)
VOLUME NO. 1

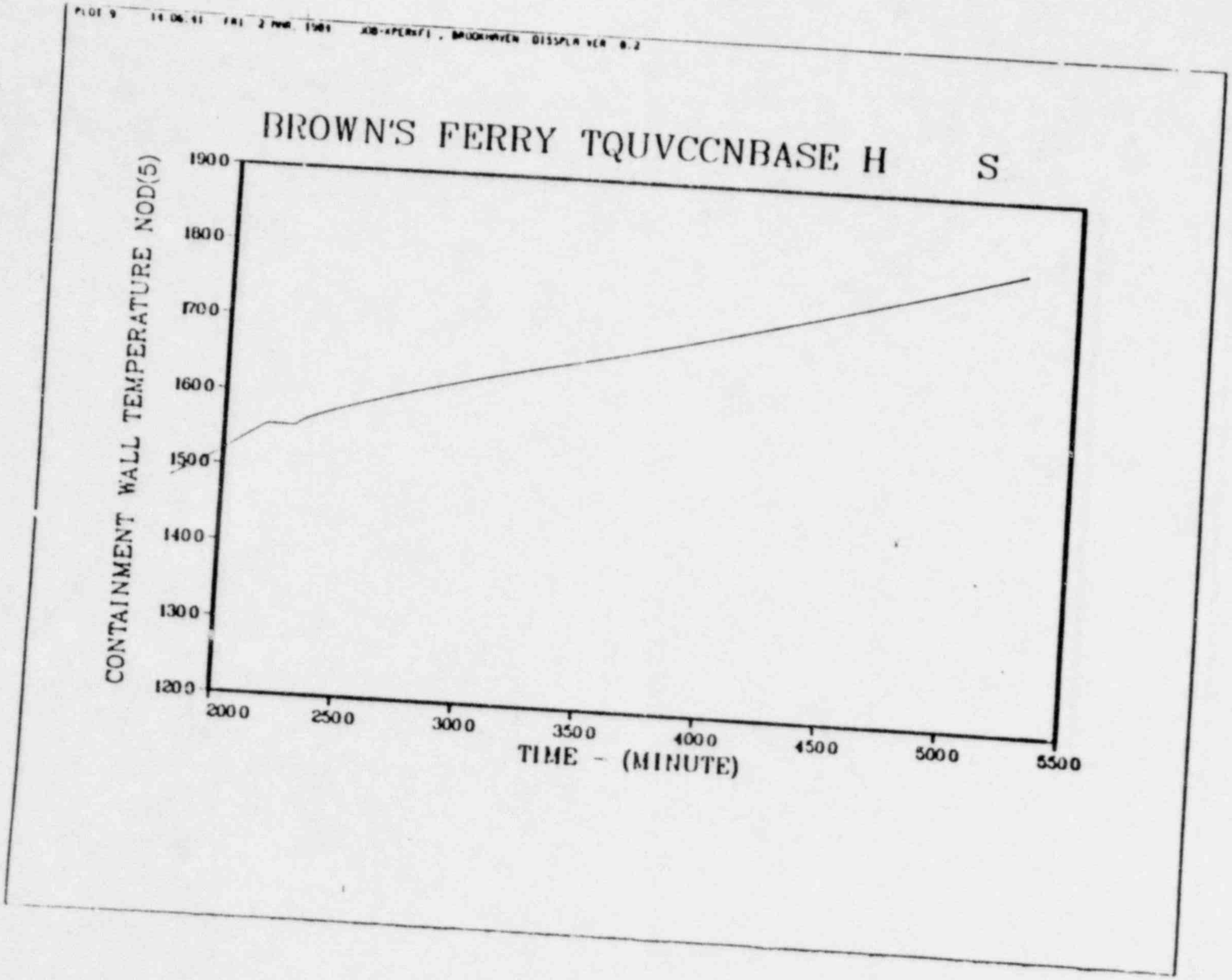

PLOT 4 17.03.16 THUR 1 MAR, 1984 JOB-XPERKLB , BROOKHAVEN DISSPLA VER 9.2
BROWN'S FERRY TQUVCCNBASE H S
COMPARTMENT TEMPERATURE
1600.0
1400.0
1200.0
1000.0
800.0
600.0
400.0
200.0
0.0
200.0
250.0
300.0
350.0
400.0
450.0
500.0
550.0
600.0
TIME - (MINUTE)
VOLUME NO. 1


BROWN'S FERRY TQUVCCNBASE H S
COMPARTMENT TEMPERATURE
TIME - (MINUTE)
VOLUME NO. 2
100.0
150.0
200.0
250.0
300.0
350.0
0.0
50.0
100.0
150.0
200.0
250.0
300.0
350.0
400.0
450.0
500.0
550.0



BROWN'S FERRY TQUVCCNBASE H S
CONTAINMENT WALL TEMPERATURE NOD(1)
TIME - (MINUTE)
1500
2000
2500
3000
3500
4000
4500
5000
5500


BROWN'S FERRY TQUVCCNBASE H S
CONTAINMENT WALL TEMPERATURE NOD(4)
2600
2500
2400
2300
2200
2100
2000
1900
2000
2500
3000
3500
4000
4500
5000
5500
TIME - (MINUTE)


BROWN'S FERRY TQUVCCNBASE H S
CONTAINMENT WALL TEMPERATURE NOD(5)
1900
1800
1700
1600
1500
1400
1300
1200
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2500
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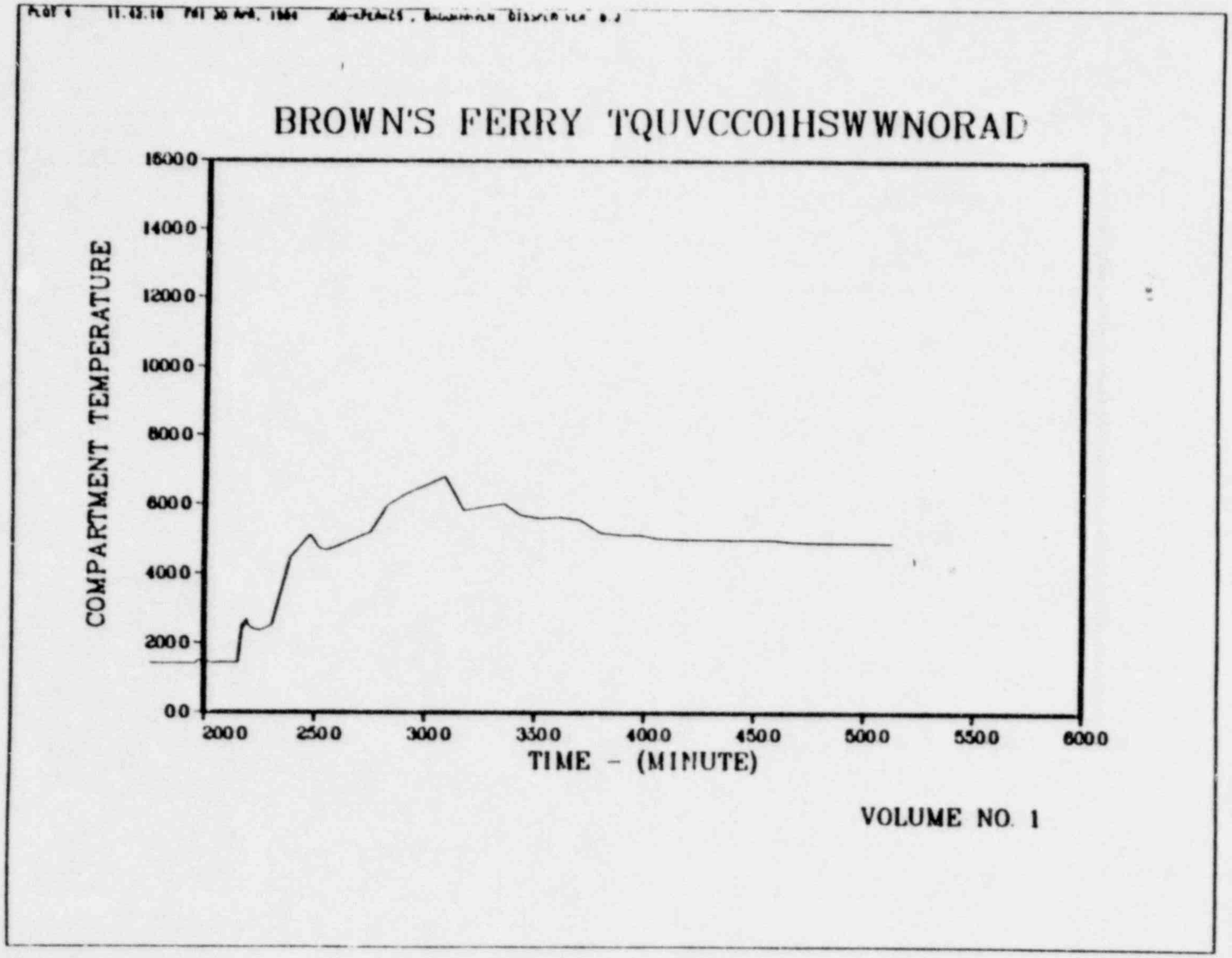
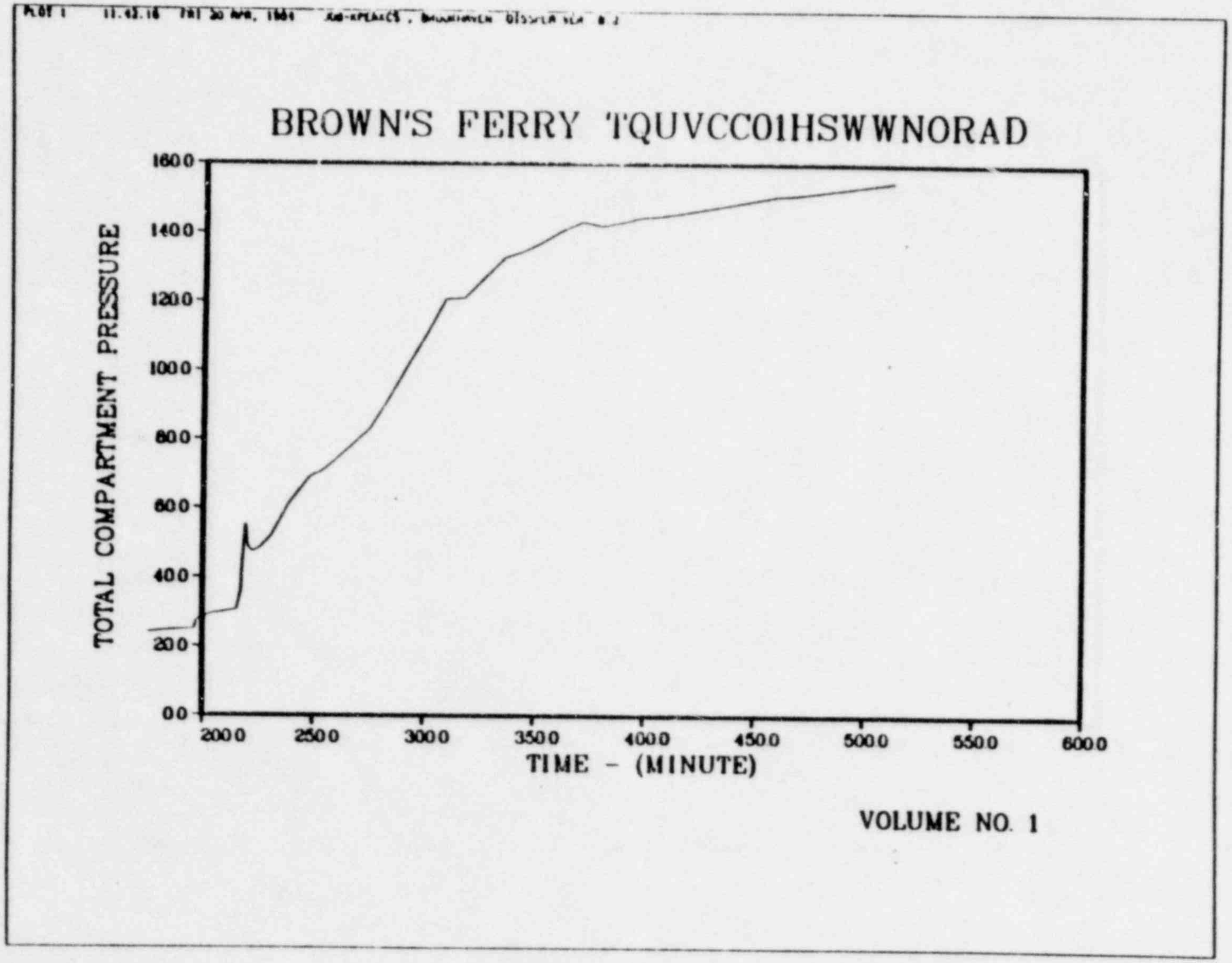
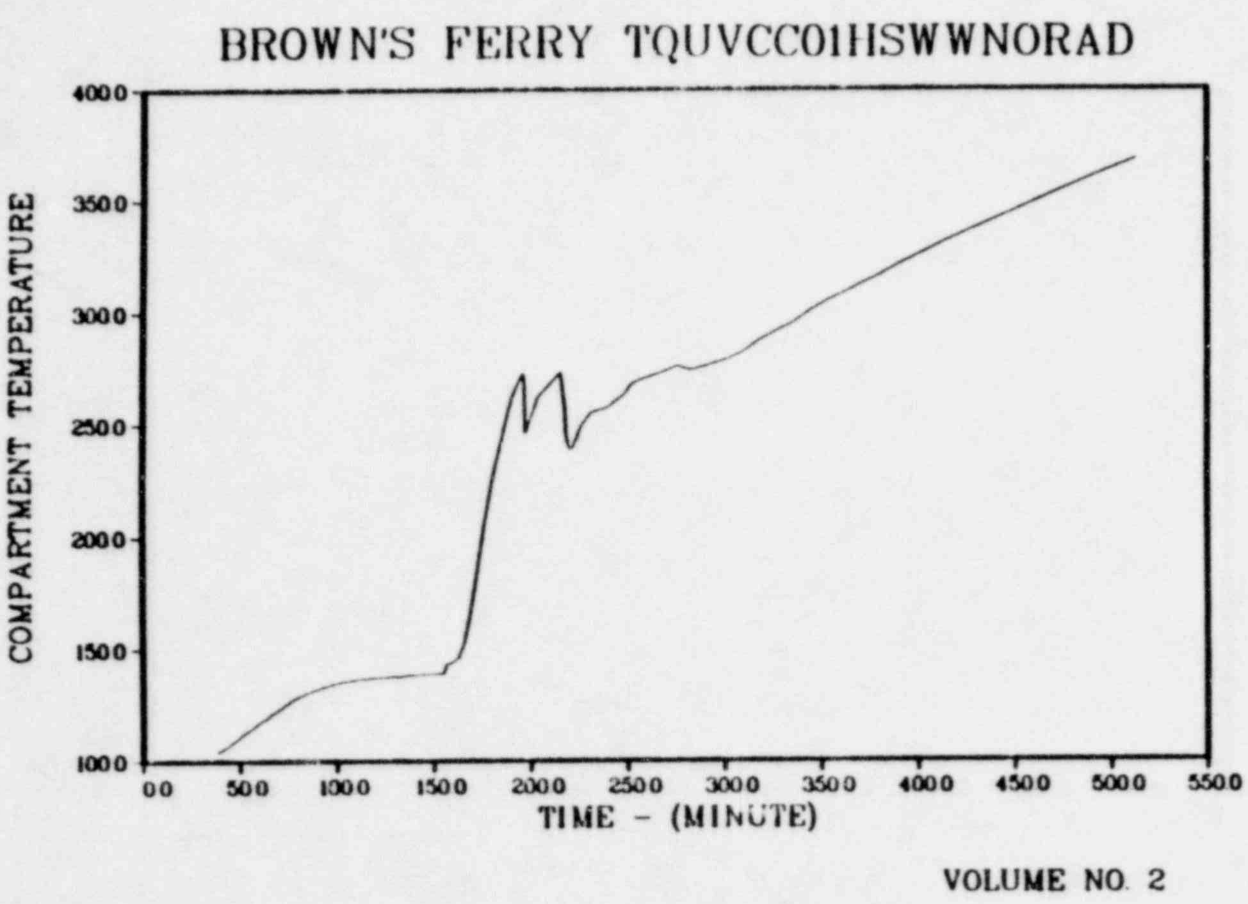
4000
4500
5000
5500
TIME - (MINUTE)

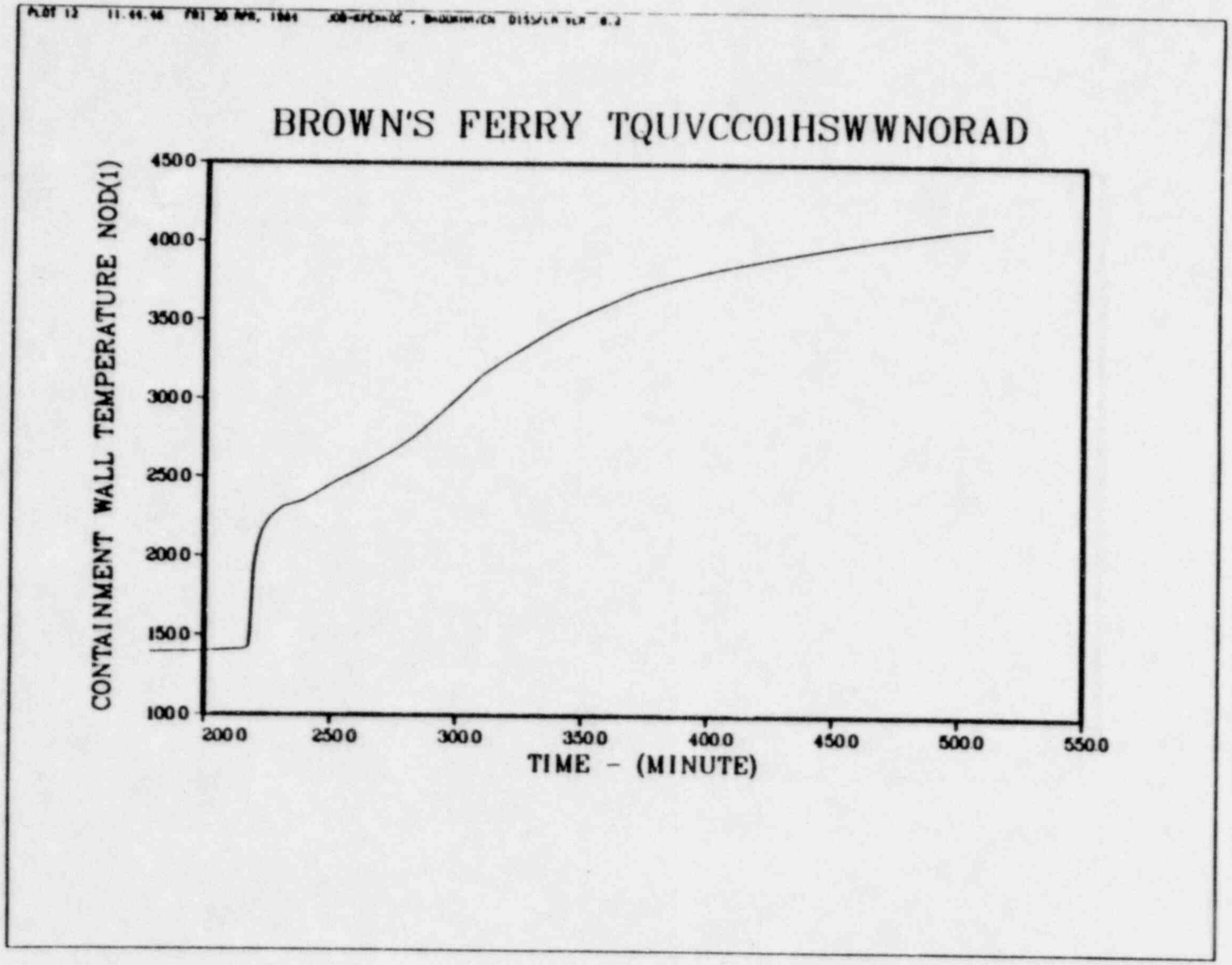


BROWN'S FERRY TQUVCC01HSWWNORAD
COMPARTMENT TEMPERATURE
1600.0
1400.0
1200.0
1000.0
800.0
600.0
400.0
200.0
0.0
200.0
250.0
300.0
350.0
400.0
450.0
500.0
550.0
600.0
TIME - (MINUTE)
VOLUME NO. 1

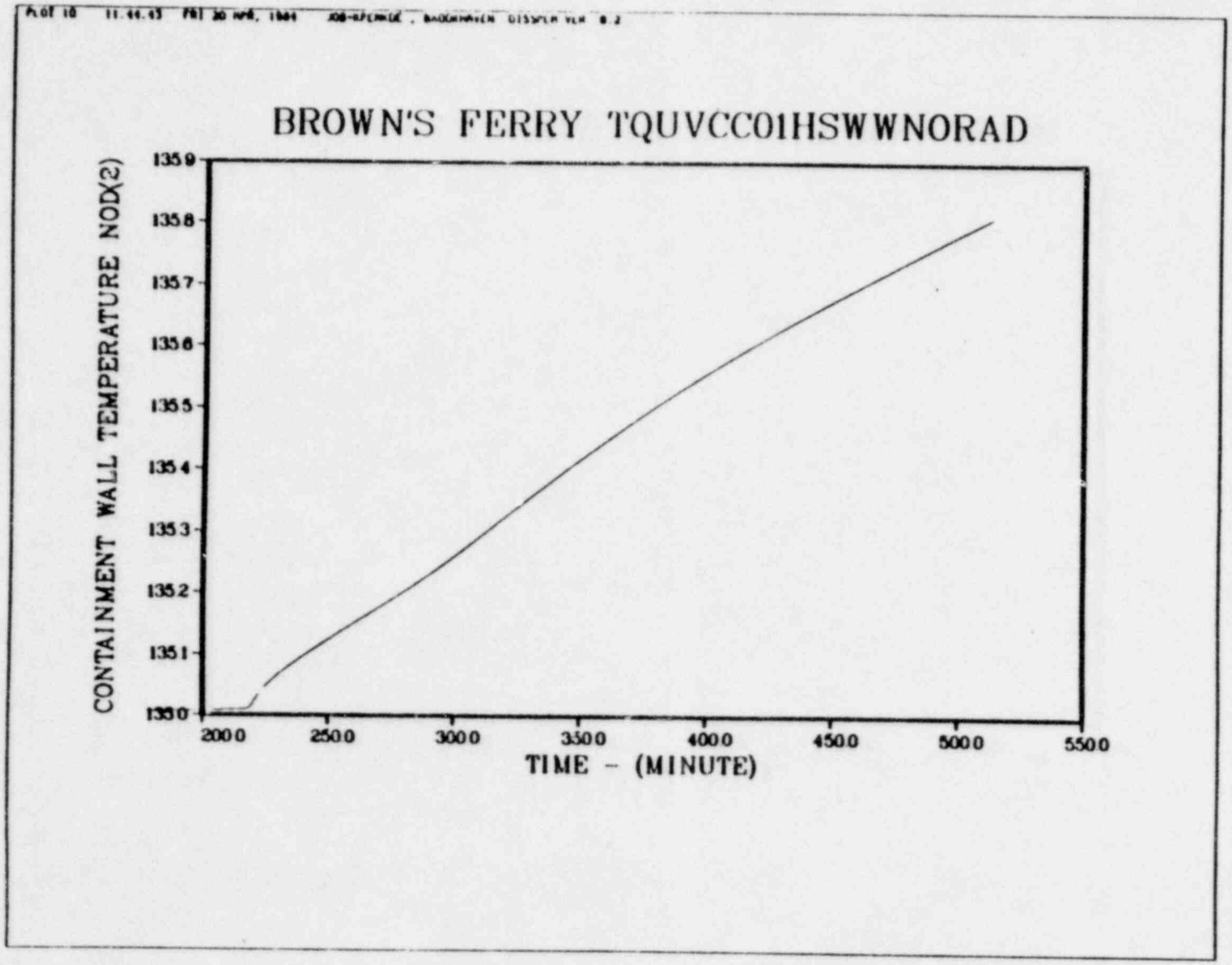


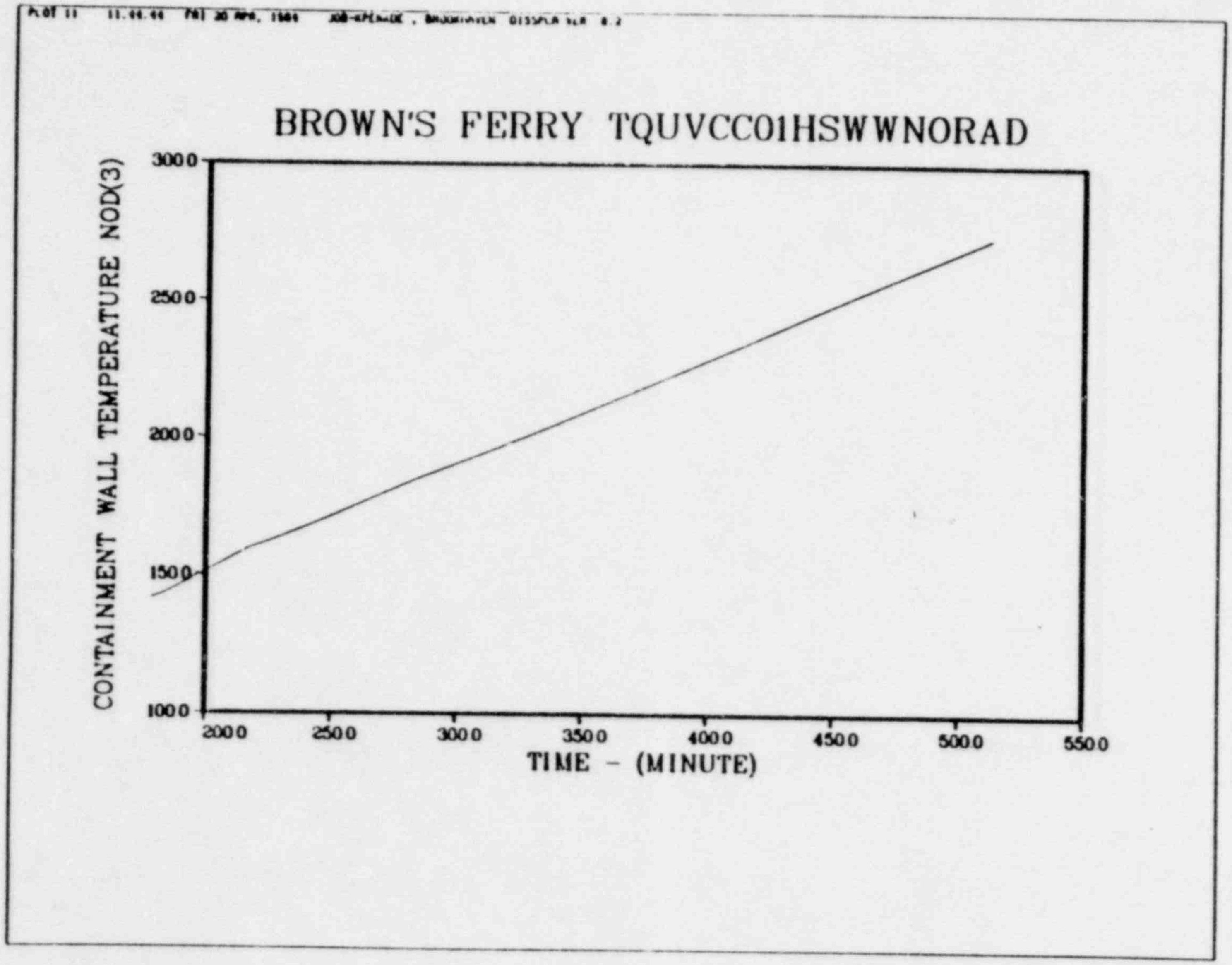
BROWN'S FERRY TQUVCC01HSWWNORAD
TOTAL COMPARTMENT PRESSURE
0.0
20.0
40.0
60.0
80.0
100.0
120.0
140.0
160.0
200.0
250.0
300.0
350.0
400.0
450.0
500.0
550.0
600.0
TIME - (MINUTE)
VOLUME NO. 1

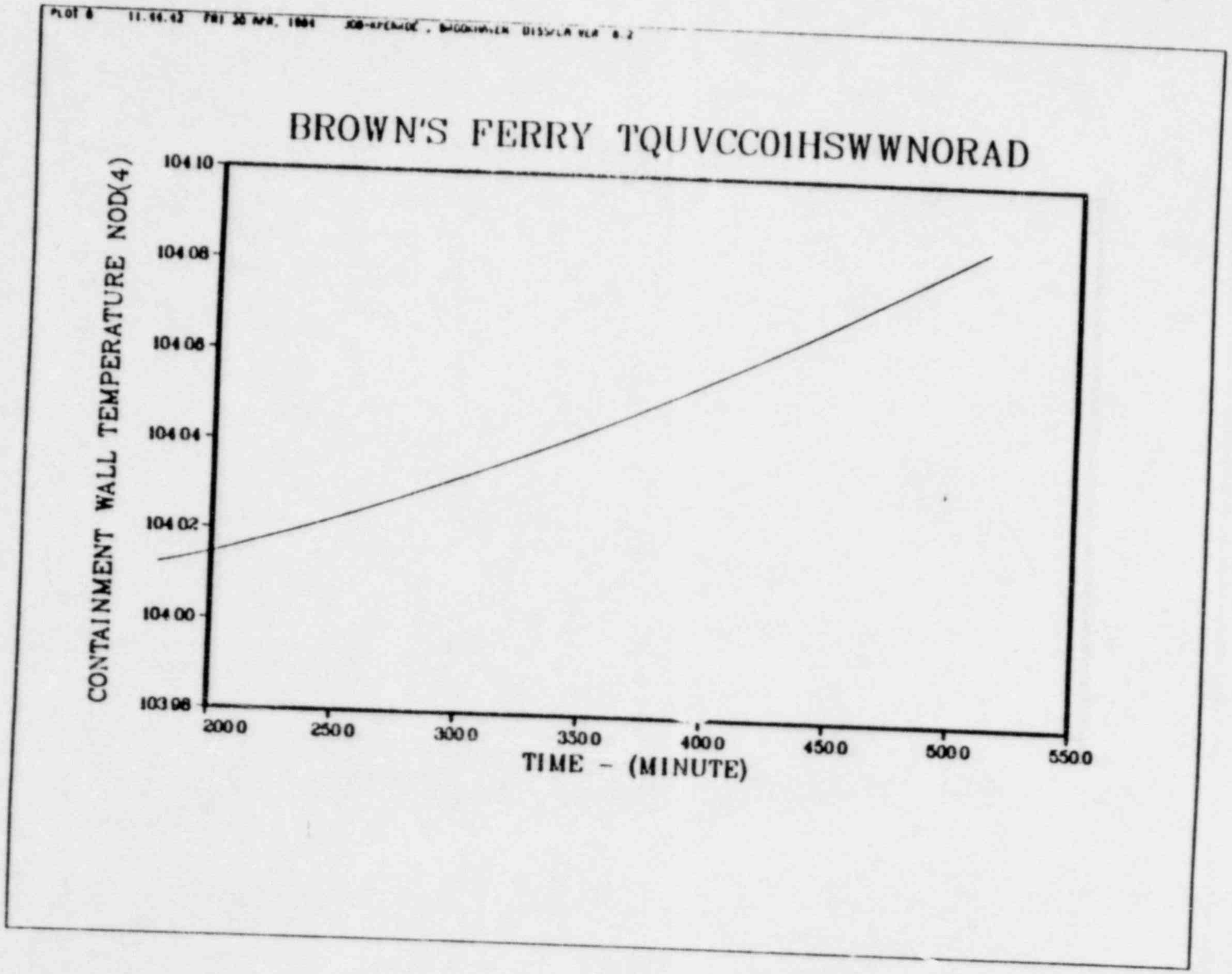

BROWN'S FERRY TQUVCC01HSWWNORAD
COMPARTMENT TEMPERATURE
100.0
150.0
200.0
250.0
300.0
350.0
400.0
0.0
50.0
100.0
150.0
200.0
250.0
300.0
350.0
400.0
450.0
500.0
550.0
TIME - (MINUTE)
VOLUME NO. 2



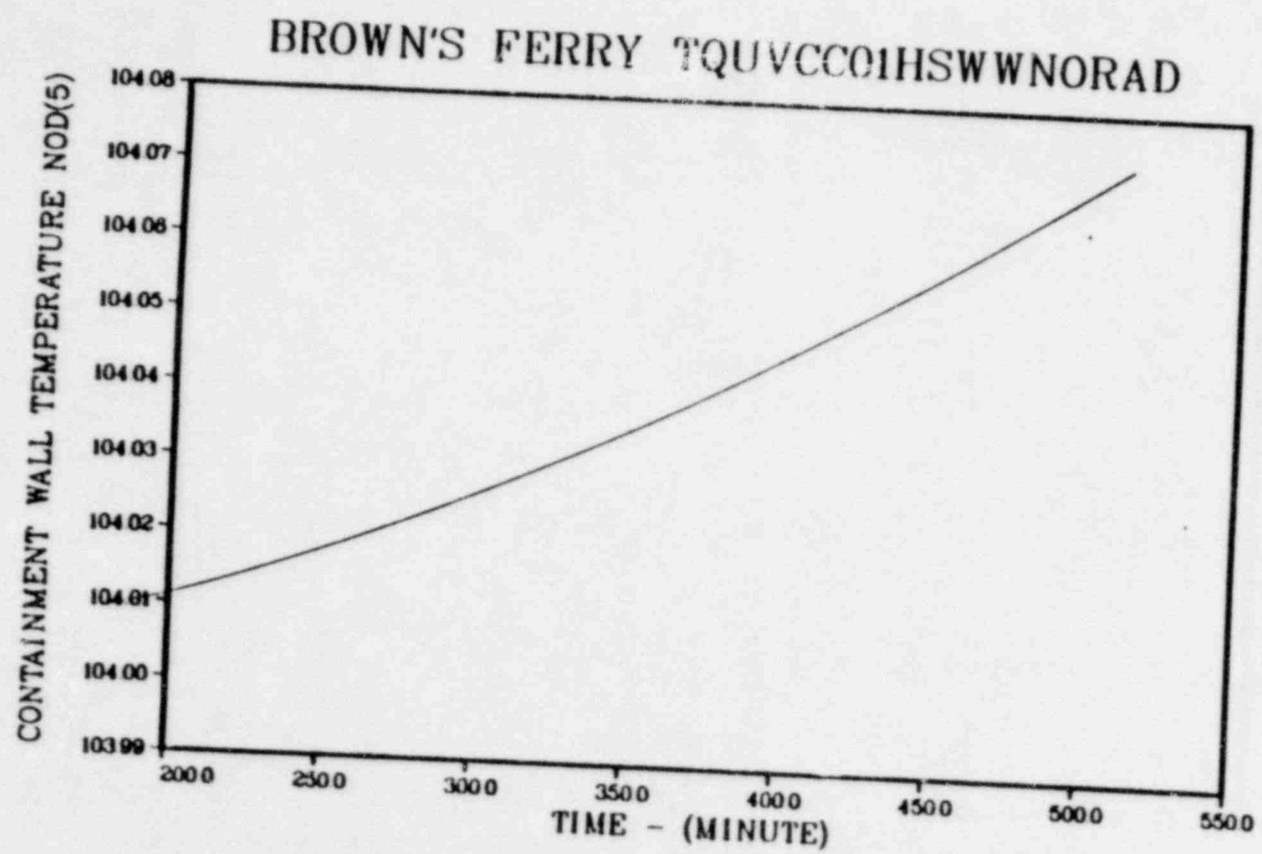
BROWN'S FERRY TQUVCC01HSWWNORAD
CONTAINMENT WALL TEMPERATURE NOD(1)
TIME - (MINUTE)
1000
1500
2000
2500
3000
3500
4000
4500
2000
2500
3000
3500
4000
4500
5000
5500


BROWN'S FERRY TQUVCC01HSWWNORAD
CONTAINMENT WALL TEMPERATURE NOD(2)
135.9
135.8
135.7
135.6
135.5
135.4
135.3
135.2
135.1
135.0
2000
2500
3000
3500
4000
4500
5000
5500
TIME – (MINUTE)

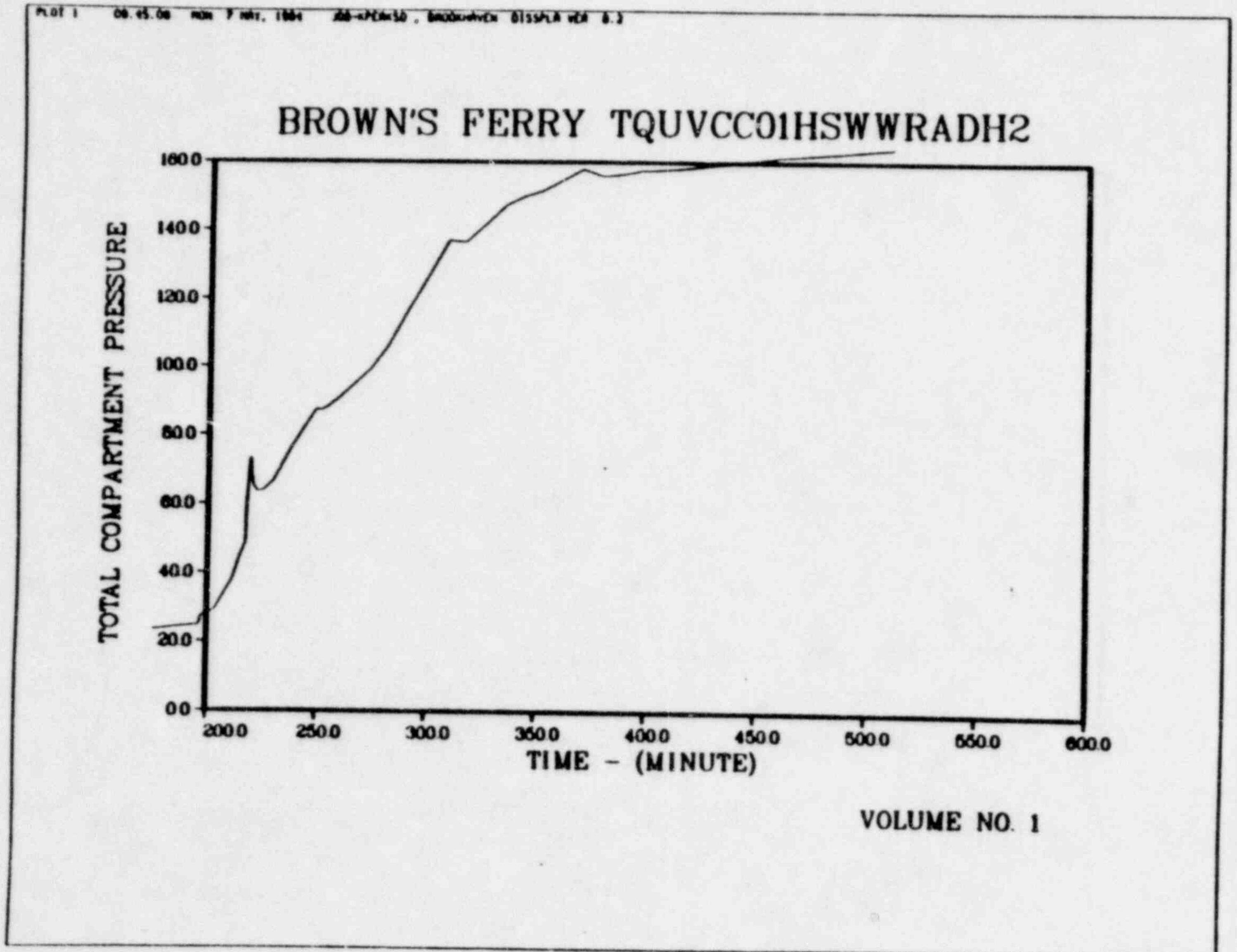

BROWN'S FERRY TQUVCC01HSWWNORAD
CONTAINMENT WALL TEMPERATURE NOD(3)
300.0
250.0
200.0
150.0
100.0
200.0
250.0
300.0
350.0
400.0
450.0
500.0
550.0
TIME - (MINUTE)

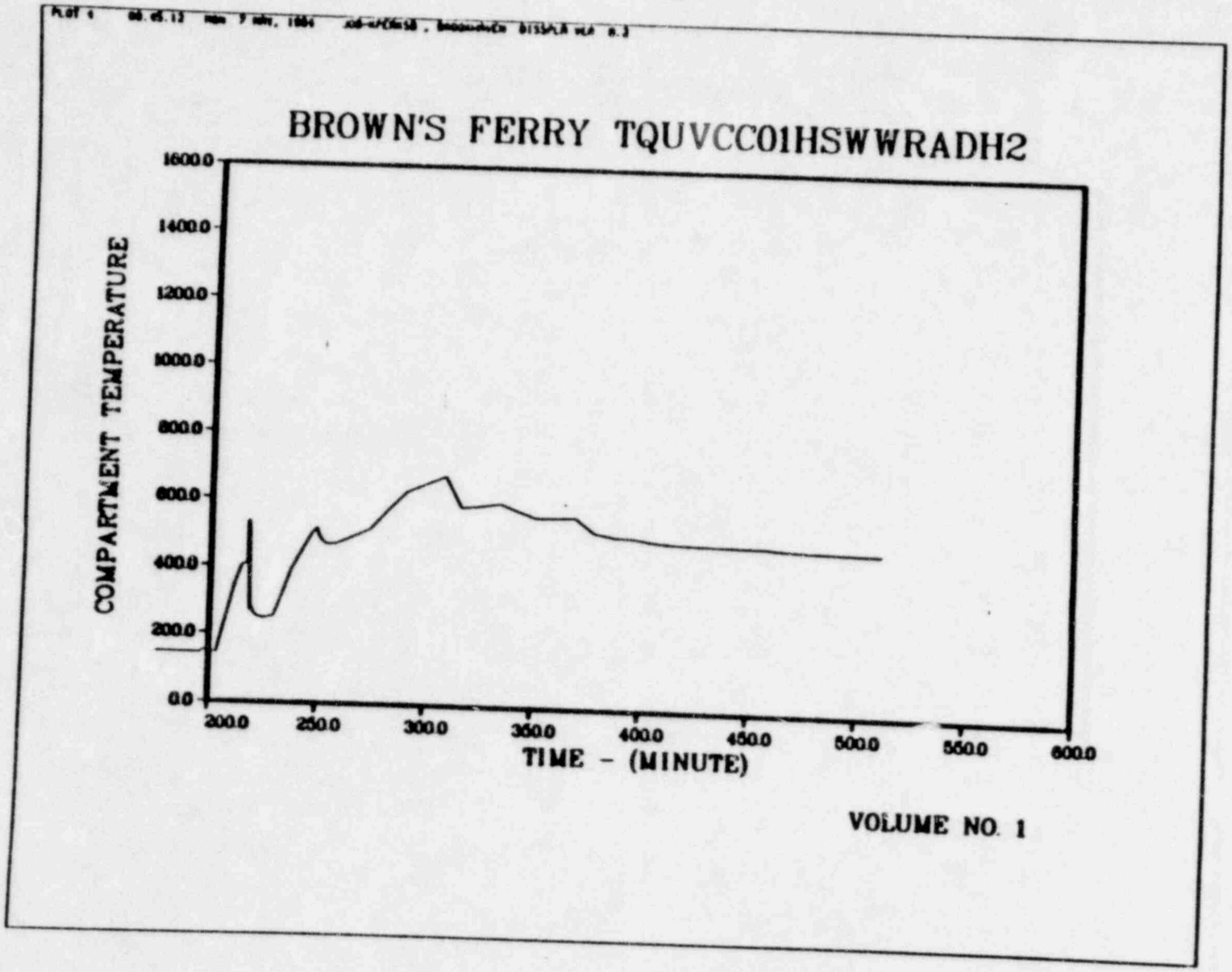


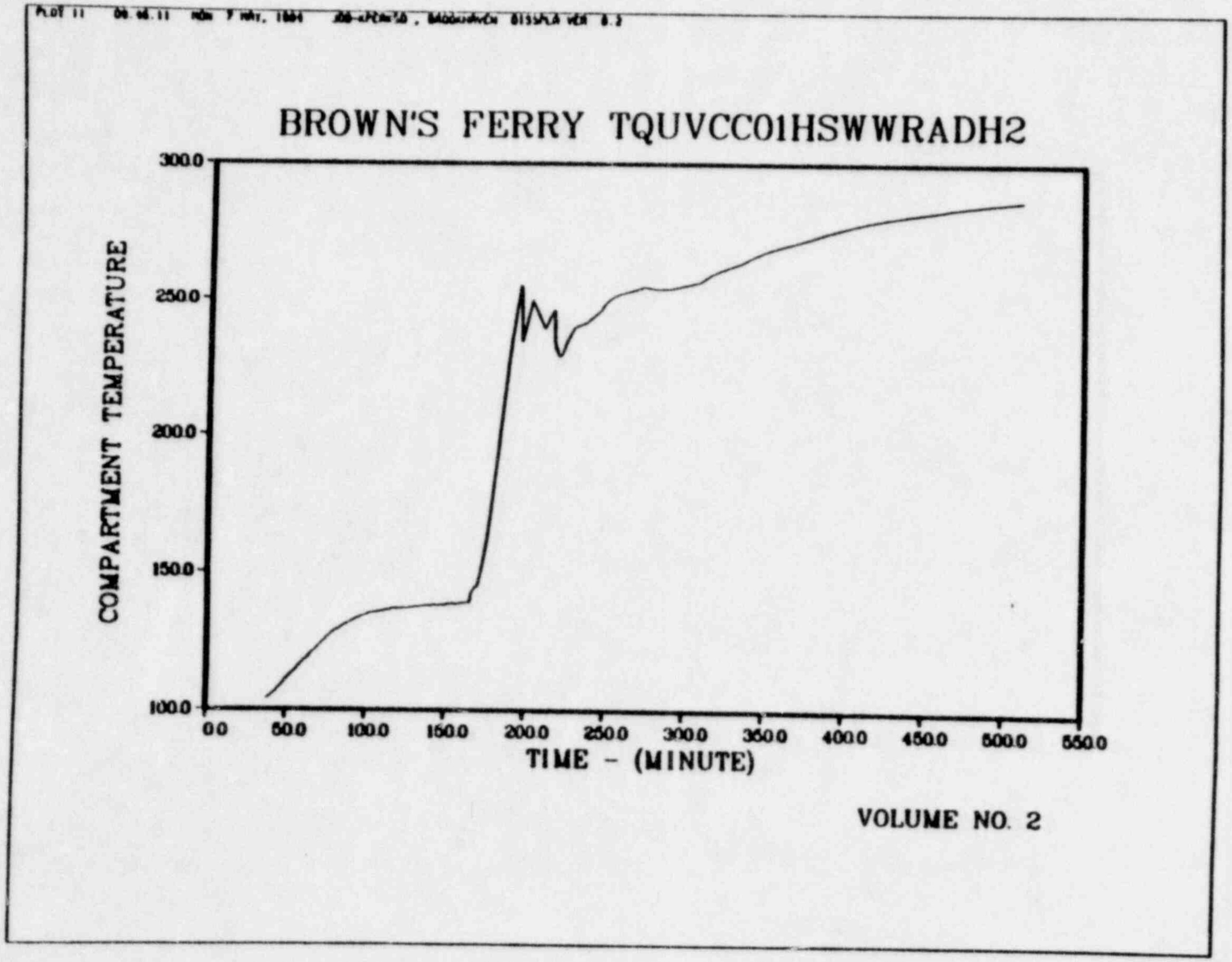
BROWN'S FERRY TQUVCC01HSWWNORAD
CONTAINMENT WALL TEMPERATURE NOD(4)
104.10
104.08
104.06
104.04
104.02
104.00
103.98
200.0
250.0
300.0
350.0
400.0
450.0
500.0
550.0
TIME - (MINUTE)

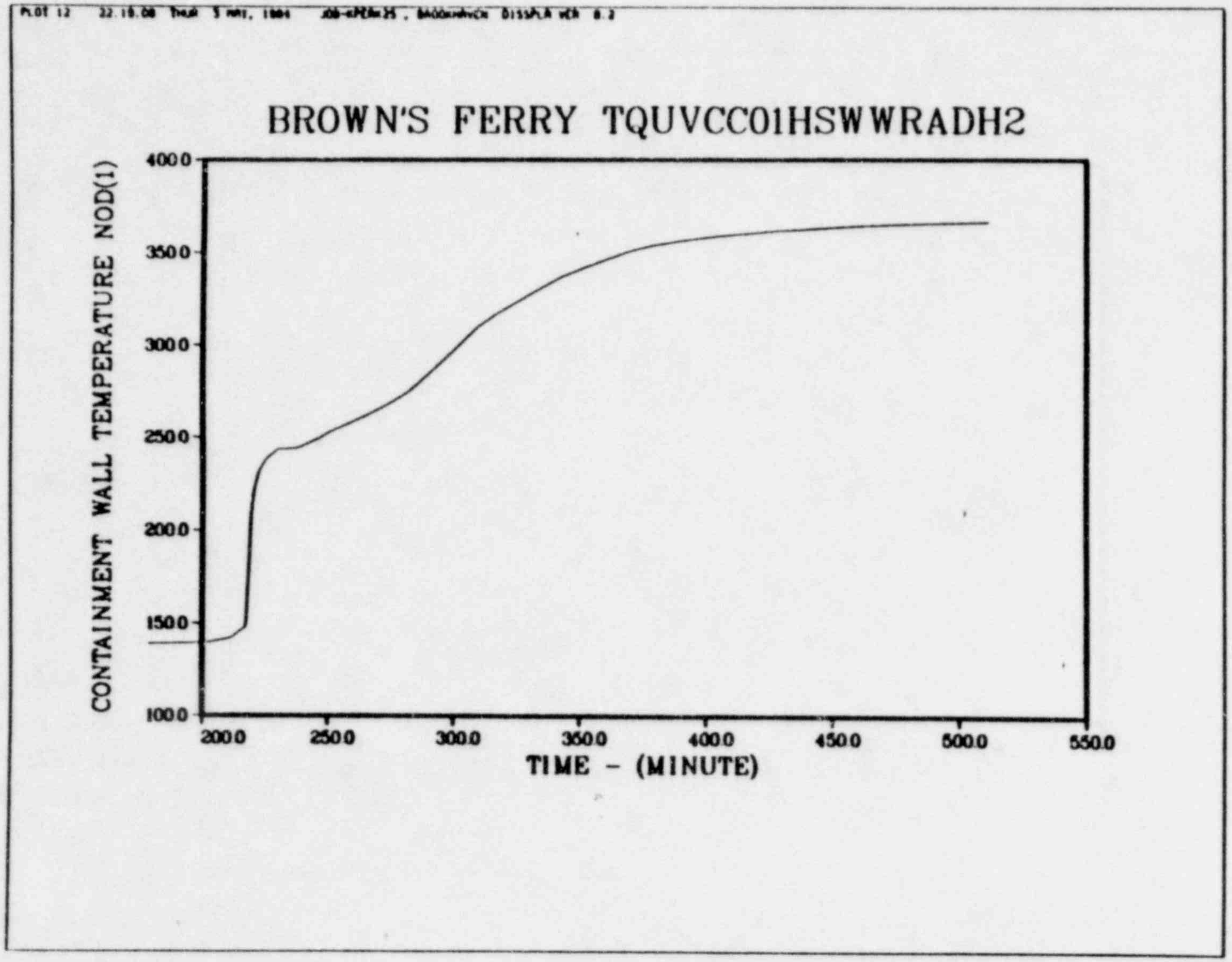


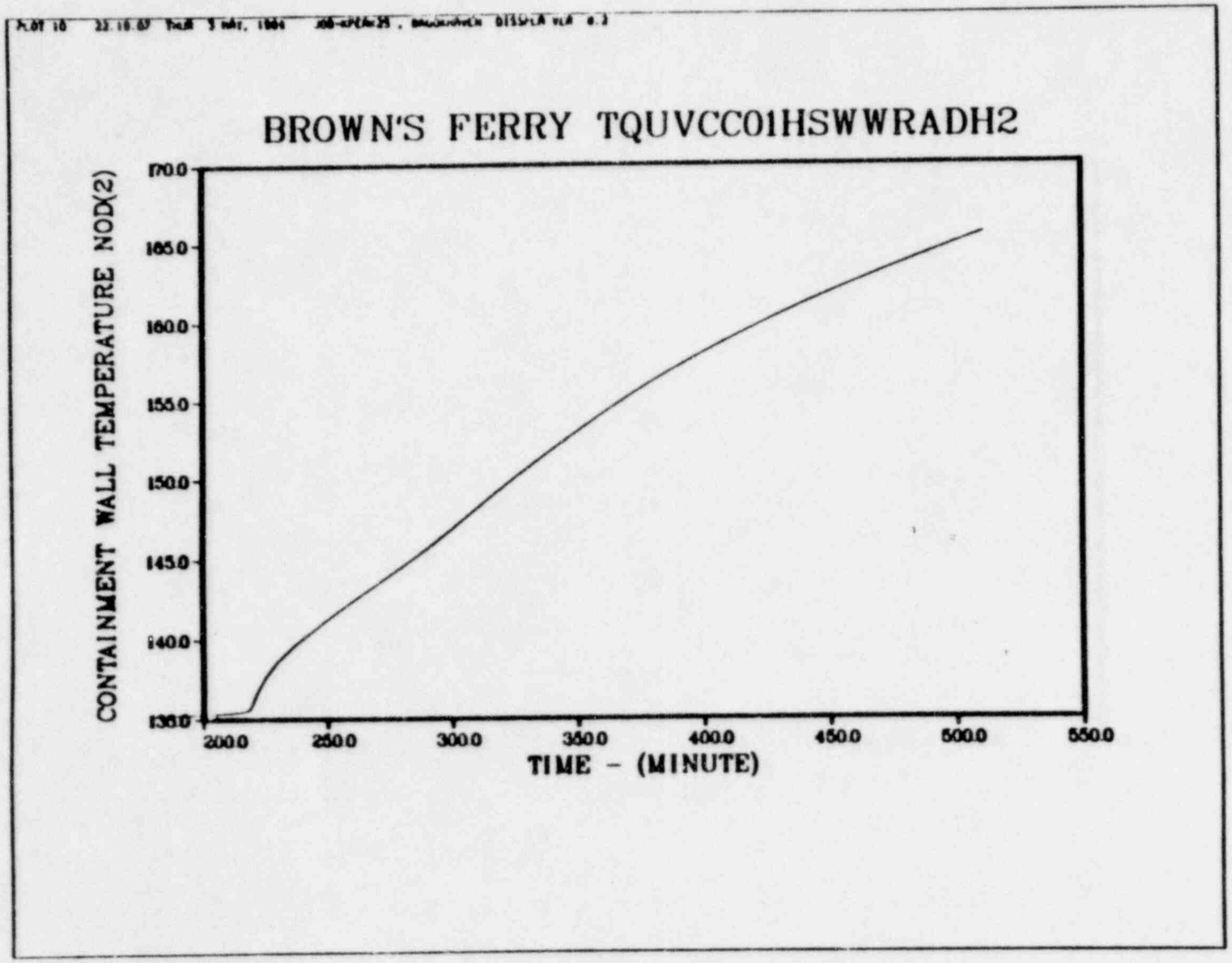
BROWN'S FERRY TQUVCC01HSWWNORAD
CONTAINMENT WALL TEMPERATURE NOD(5)
104.08
104.07
104.06
104.05
104.04
104.03
104.02
104.01
104.00
103.99
200.0
250.0
300.0
350.0
400.0
450.0
500.0
550.0
TIME - (MINUTE)


BROWN'S FERRY TQUVCC01HSWWRADH2
TOTAL COMPARTMENT PRESSURE
0.0
20.0
40.0
60.0
80.0
100.0
120.0
140.0
160.0
200.0
250.0
300.0
350.0
400.0
450.0
500.0
550.0
600.0
TIME - (MINUTE)
VOLUME NO. 1

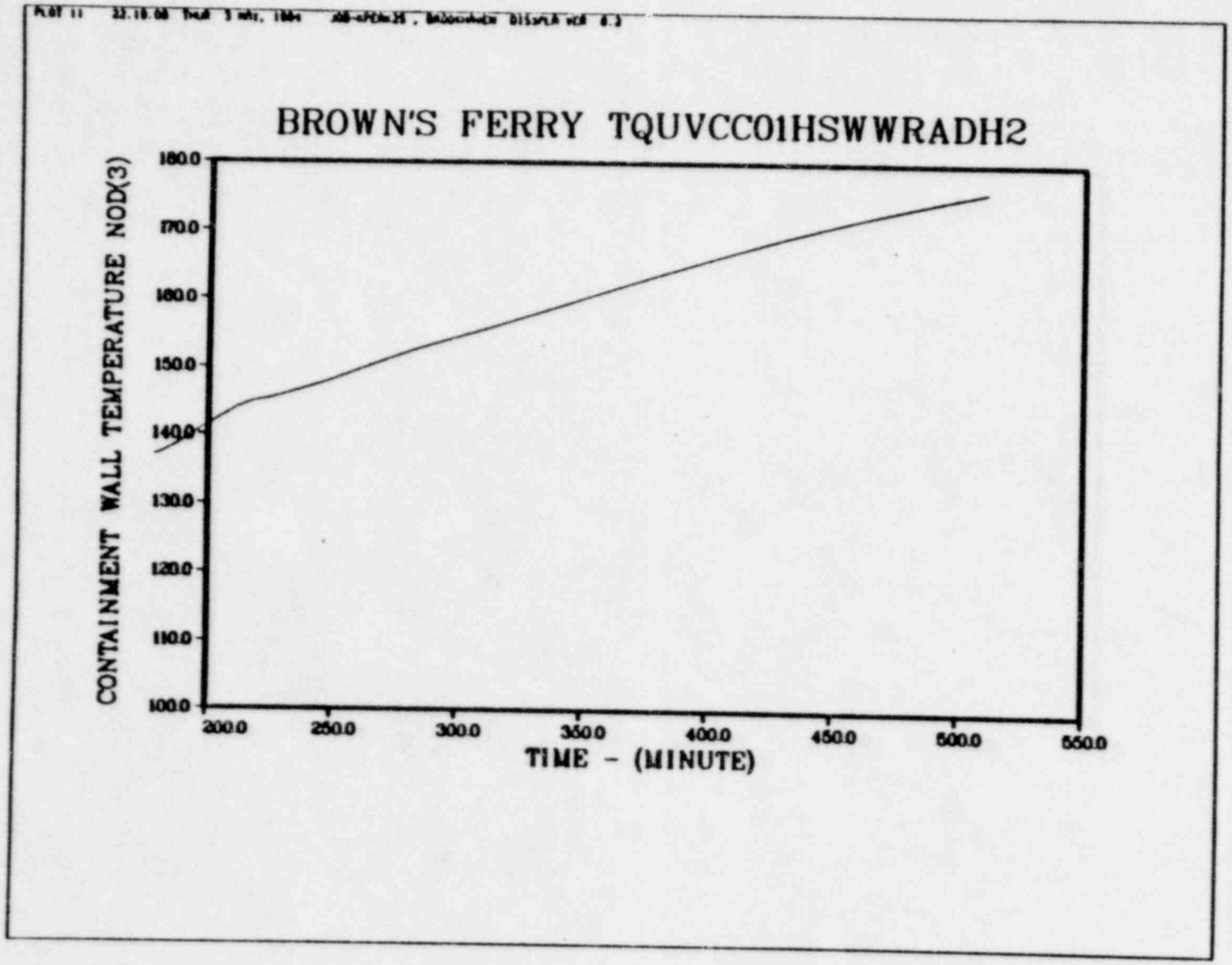

BROWN'S FERRY TQUVCC01HSWWRADH2
COMPARTMENT TEMPERATURE
0.0
200.0
400.0
600.0
800.0
1000.0
1200.0
1400.0
1600.0
200.0
250.0
300.0
350.0
400.0
450.0
500.0
550.0
600.0
TIME - (MINUTE)
VOLUME NO. 1

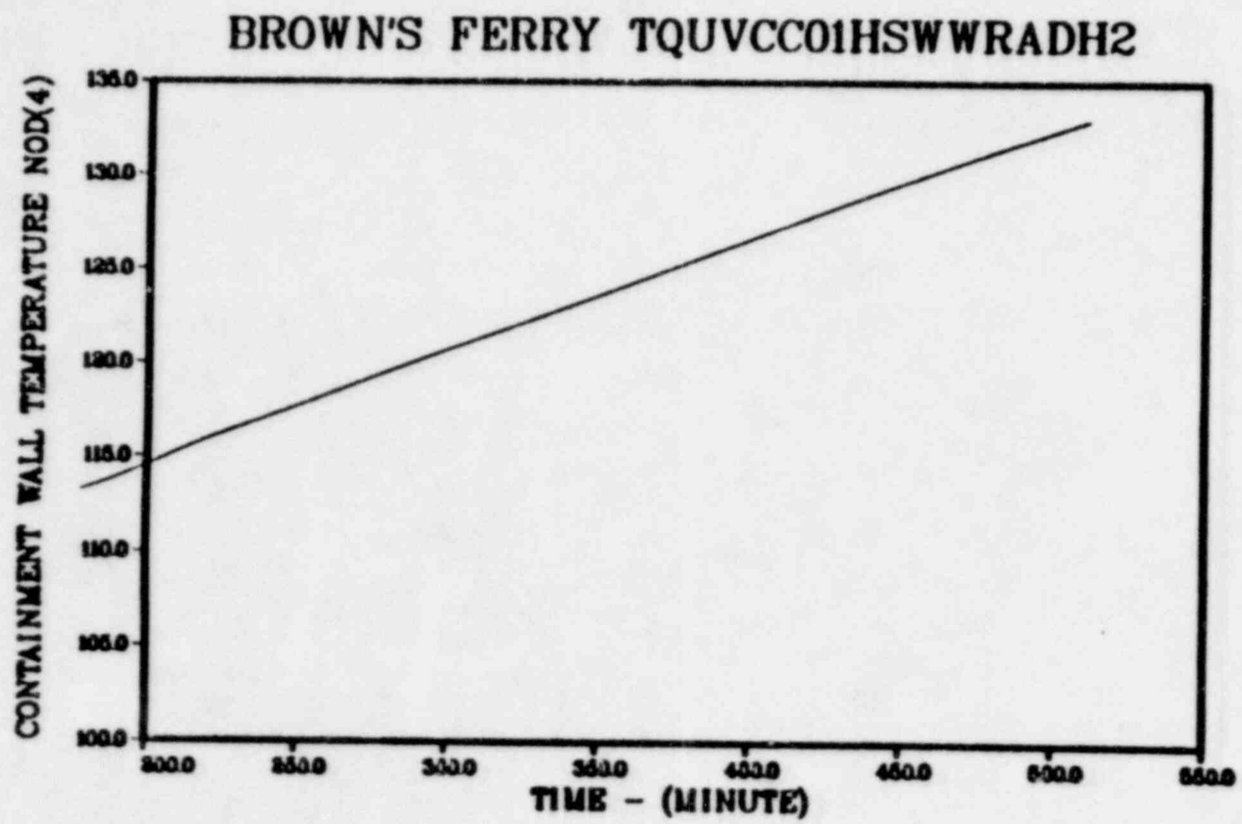

BROWN'S FERRY TQUVCC01HSWWRADH2
COMPARTMENT TEMPERATURE
TIME - (MINUTE)
300.0
250.0
200.0
150.0
100.0
0.0
50.0
100.0
150.0
200.0
250.0
300.0
350.0
400.0
450.0
500.0
550.0
VOLUME NO. 2

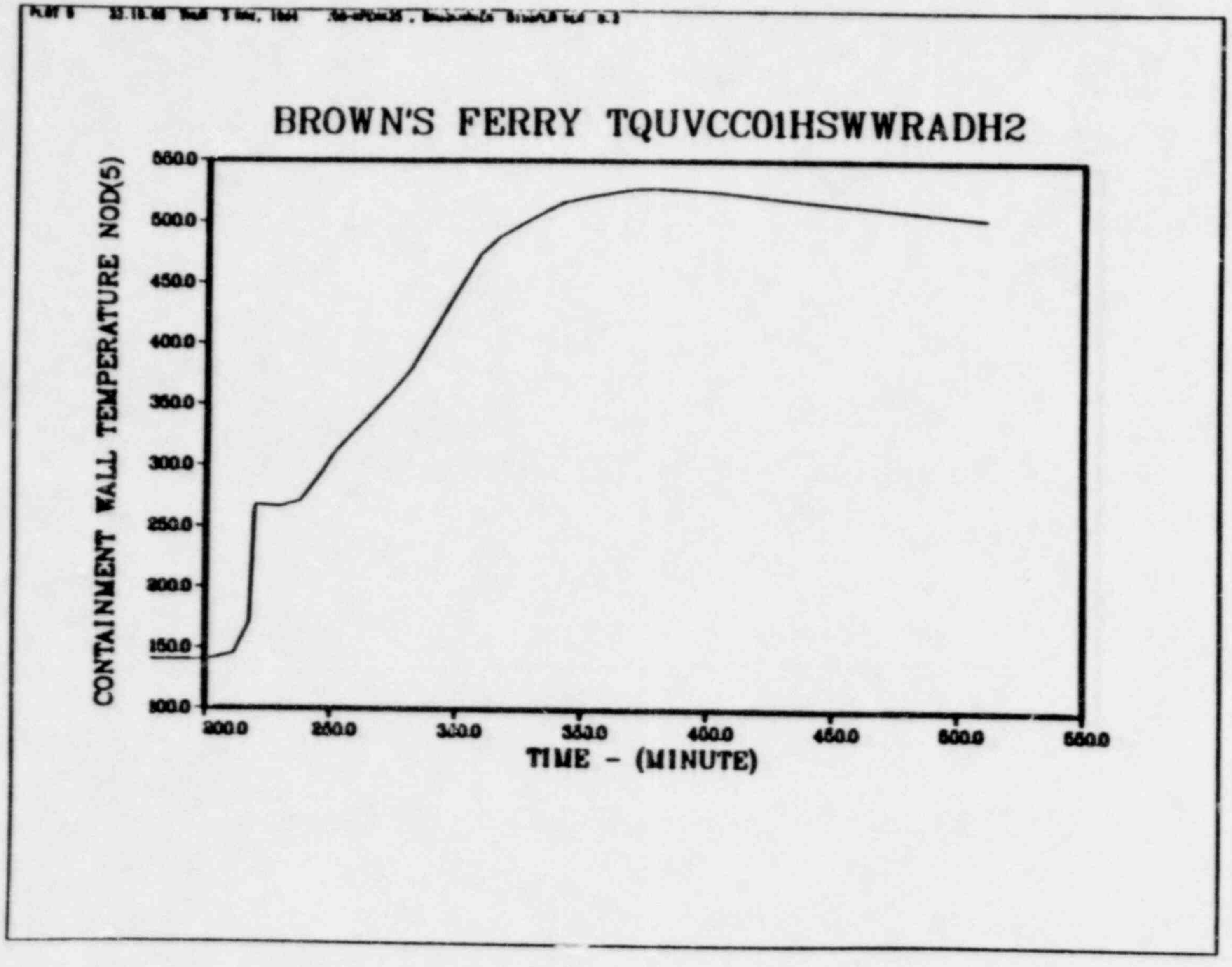

BROWN'S FERRY TQUVCC01HSWWRADH2
CONTAINMENT WALL TEMPERATURE NOD(1)
100.0
150.0
200.0
250.0
300.0
350.0
400.0
200.0
250.0
300.0
350.0
400.0
450.0
500.0
550.0
TIME - (MINUTE)

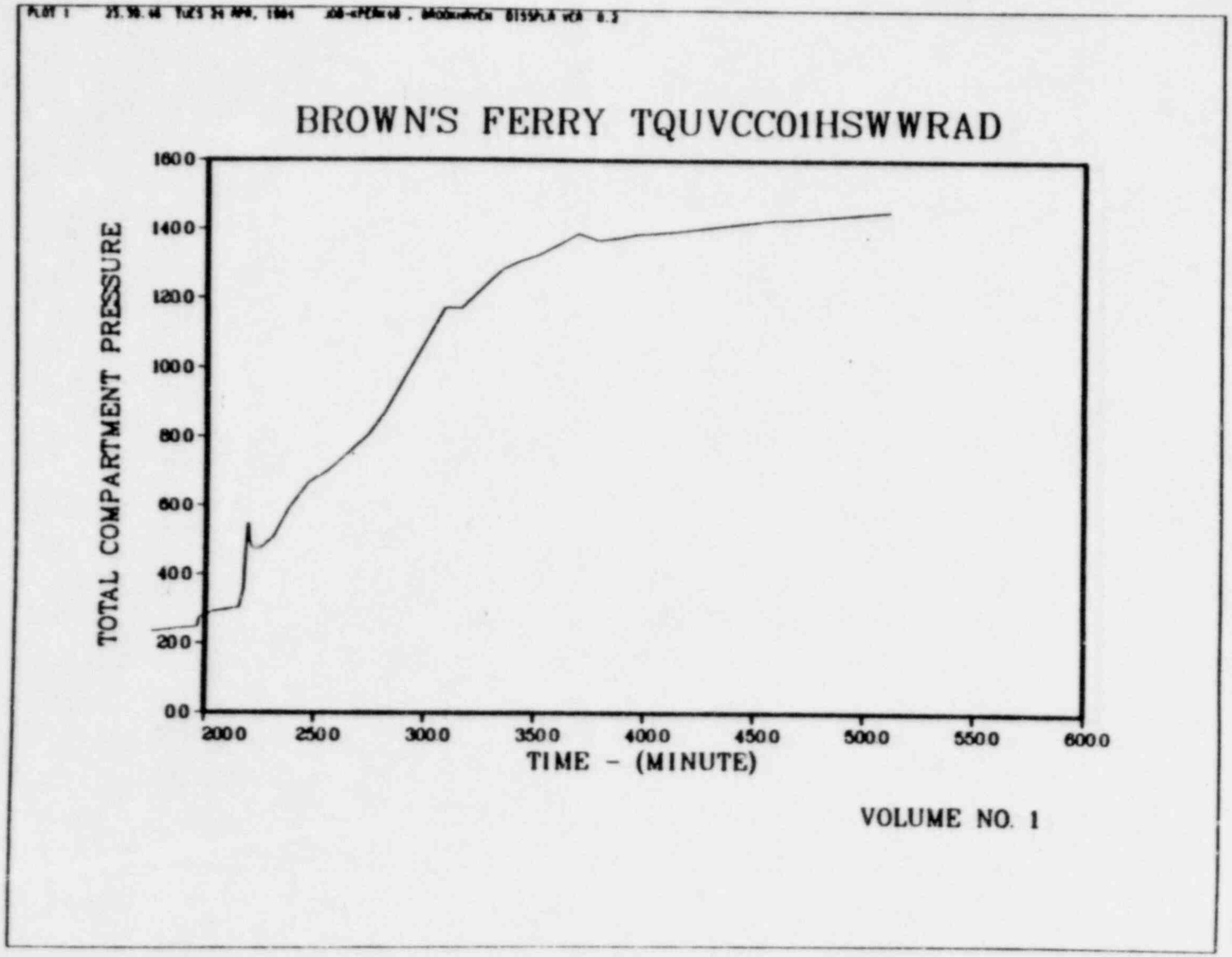


BROWN'S FERRY TQUVCC01HSWWRADH2
CONTAINMENT WALL TEMPERATURE NOD(2)
170.0
165.0
160.0
155.0
150.0
145.0
140.0
136.0
200.0
250.0
300.0
350.0
400.0
450.0
500.0
550.0
TIME - (MINUTE)

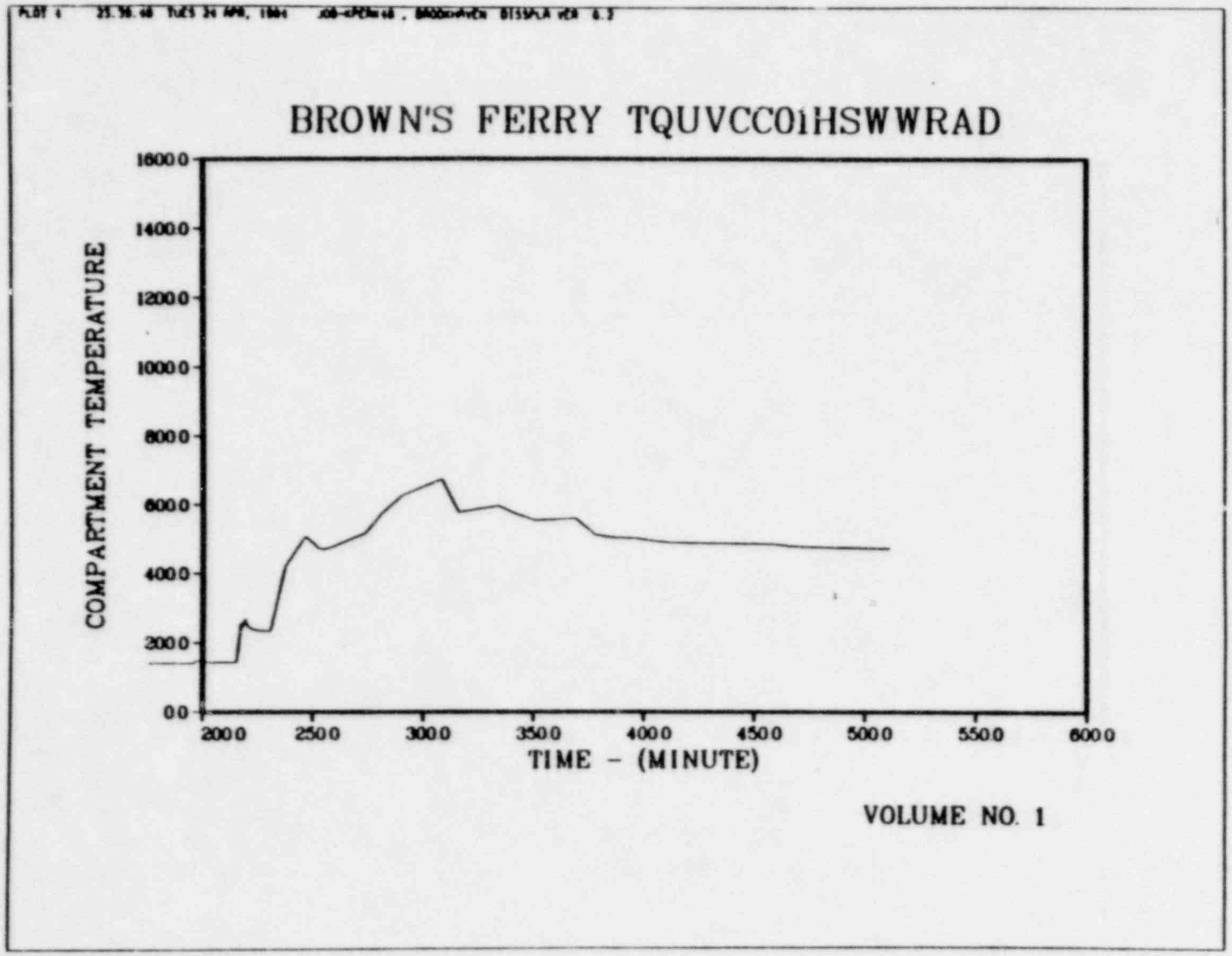

BROWN'S FERRY TQUVCC01HSWWRADH2
CONTAINMENT WALL TEMPERATURE NOD(3)
180.0
170.0
160.0
150.0
140.0
130.0
120.0
110.0
100.0
200.0
250.0
300.0
350.0
400.0
450.0
500.0
550.0
TIME - (MINUTE)

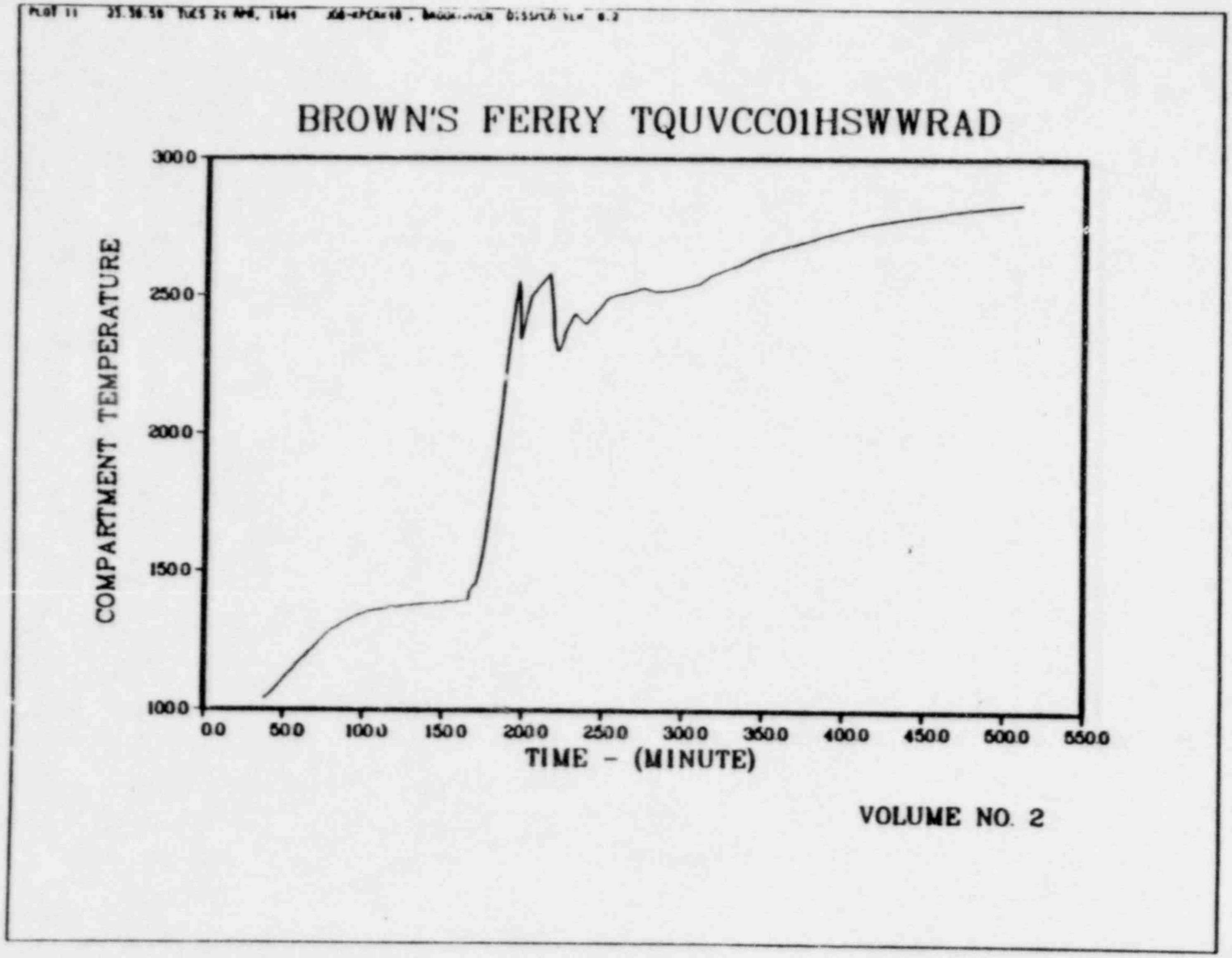

BROWN'S FERRY TQUVCC01HSWWRADH2
CONTAINMENT WALL TEMPERATURE NOD(4)
135.0
130.0
125.0
120.0
115.0
110.0
105.0
100.0
200.0
250.0
300.0
350.0
400.0
450.0
500.0
550.0
TIME - (MINUTE)


BROWN'S FERRY TQUVCC01HSWWRADH2
CONTAINMENT WALL TEMPERATURE NOD(5)
550.0
500.0
450.0
400.0
350.0
300.0
250.0
200.0
150.0
100.0
200.0
250.0
300.0
350.0
400.0
450.0
500.0
550.0
TIME - (MINUTE)

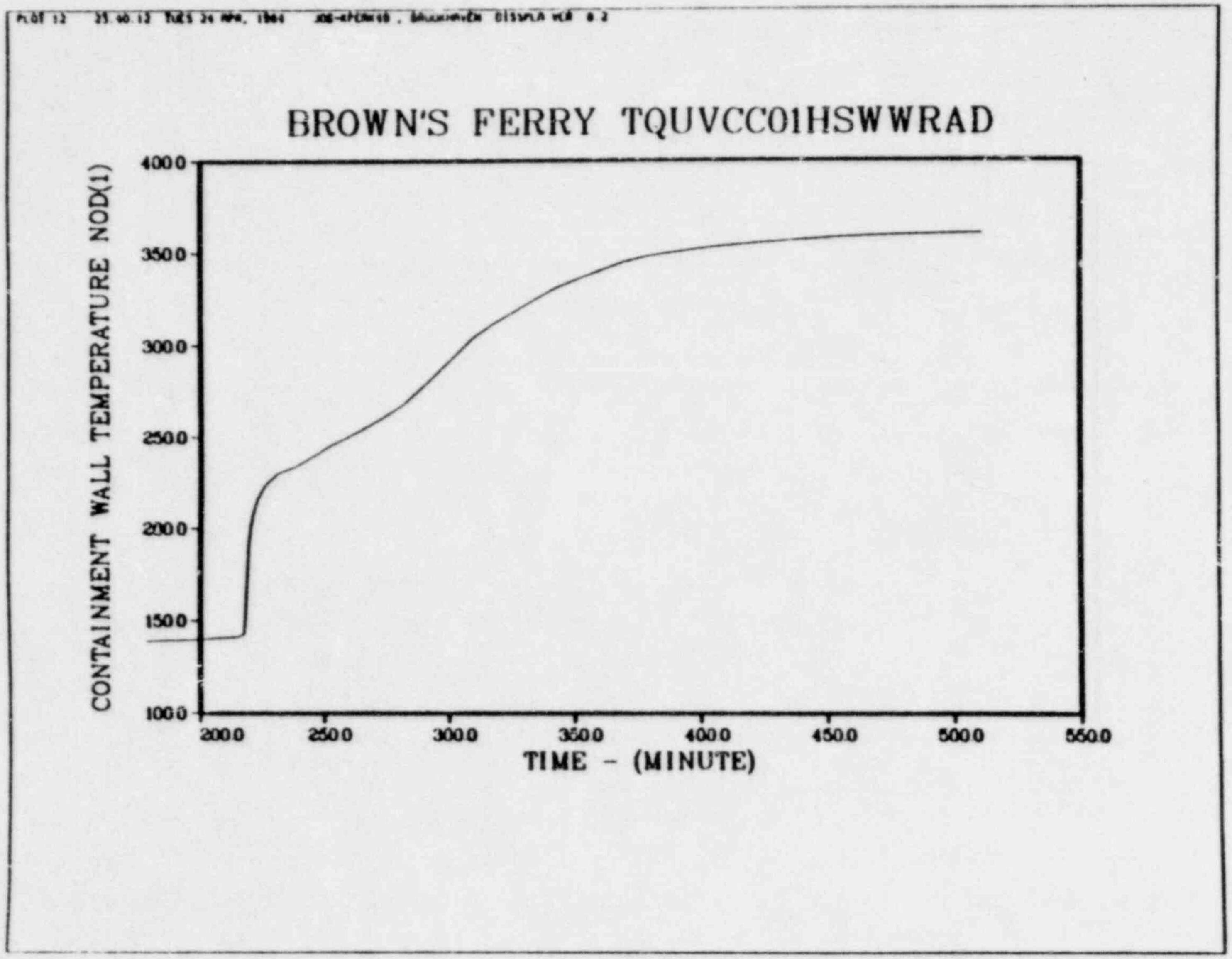


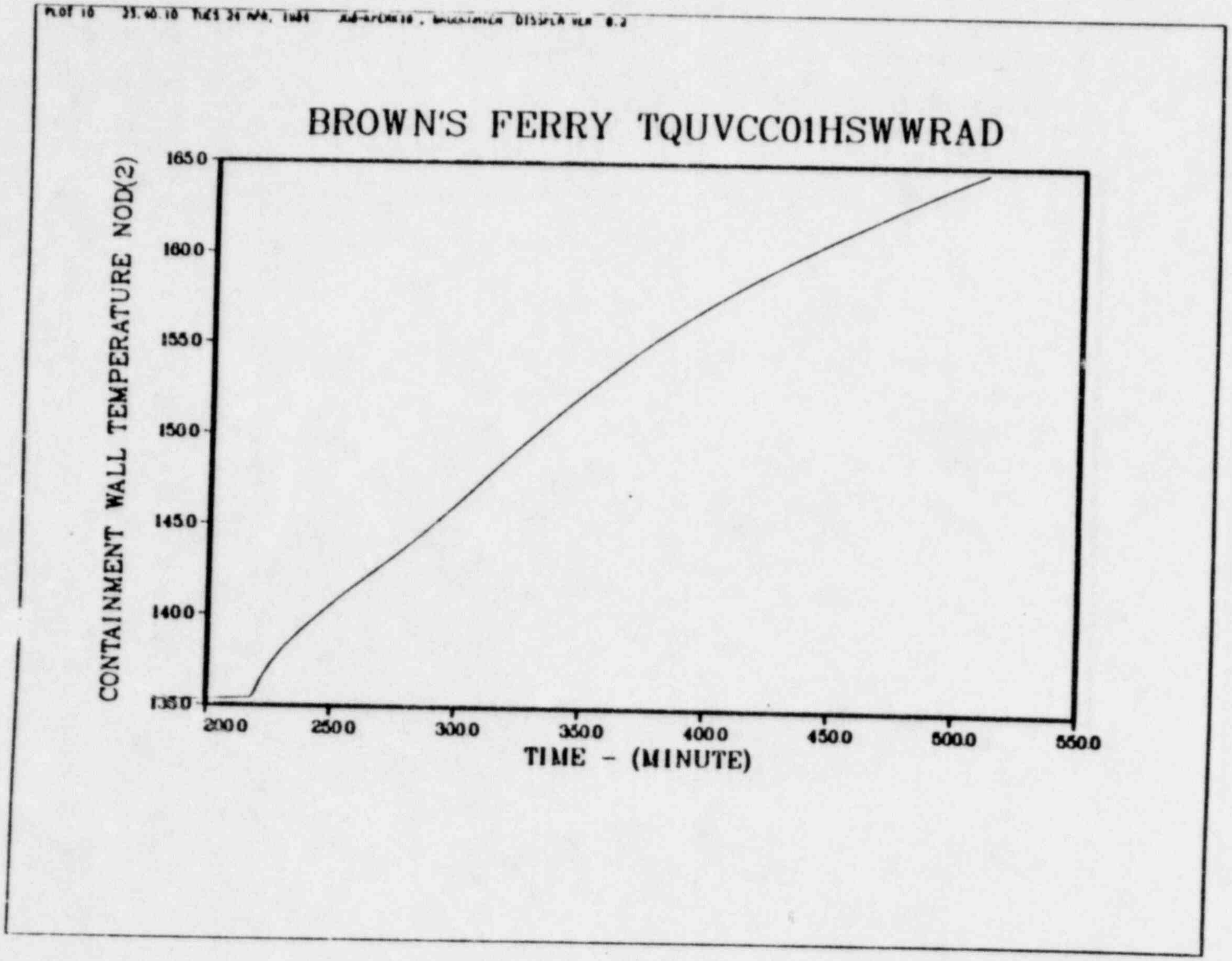
BROWN'S FERRY TQUVCC01HSWWRAD
TOTAL COMPARTMENT PRESSURE
0.0
200.0
400.0
600.0
800.0
1000.0
1200.0
1400.0
1600.0
2000.0
2500.0
3000.0
3500.0
4000.0
4500.0
5000.0
5500.0
6000.0
TIME - (MINUTE)
VOLUME NO. 1


BROWN'S FERRY TQUVCC01HSWWRAD
COMPARTMENT TEMPERATURE
0.0
200.0
400.0
600.0
800.0
1000.0
1200.0
1400.0
1600.0
2000
2500
3000
3500
4000
4500
5000
5500
6000
TIME - (MINUTE)
VOLUME NO. 1

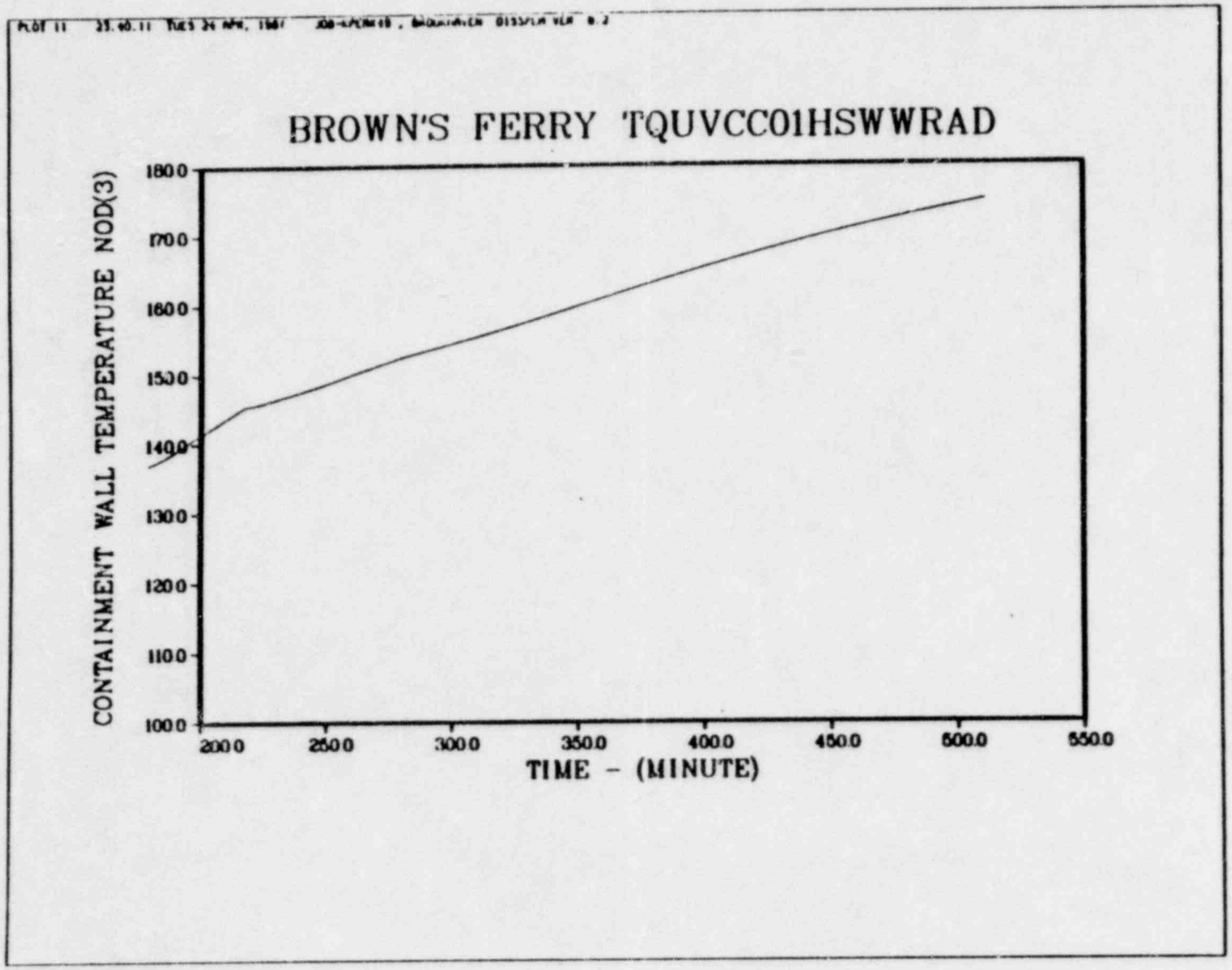


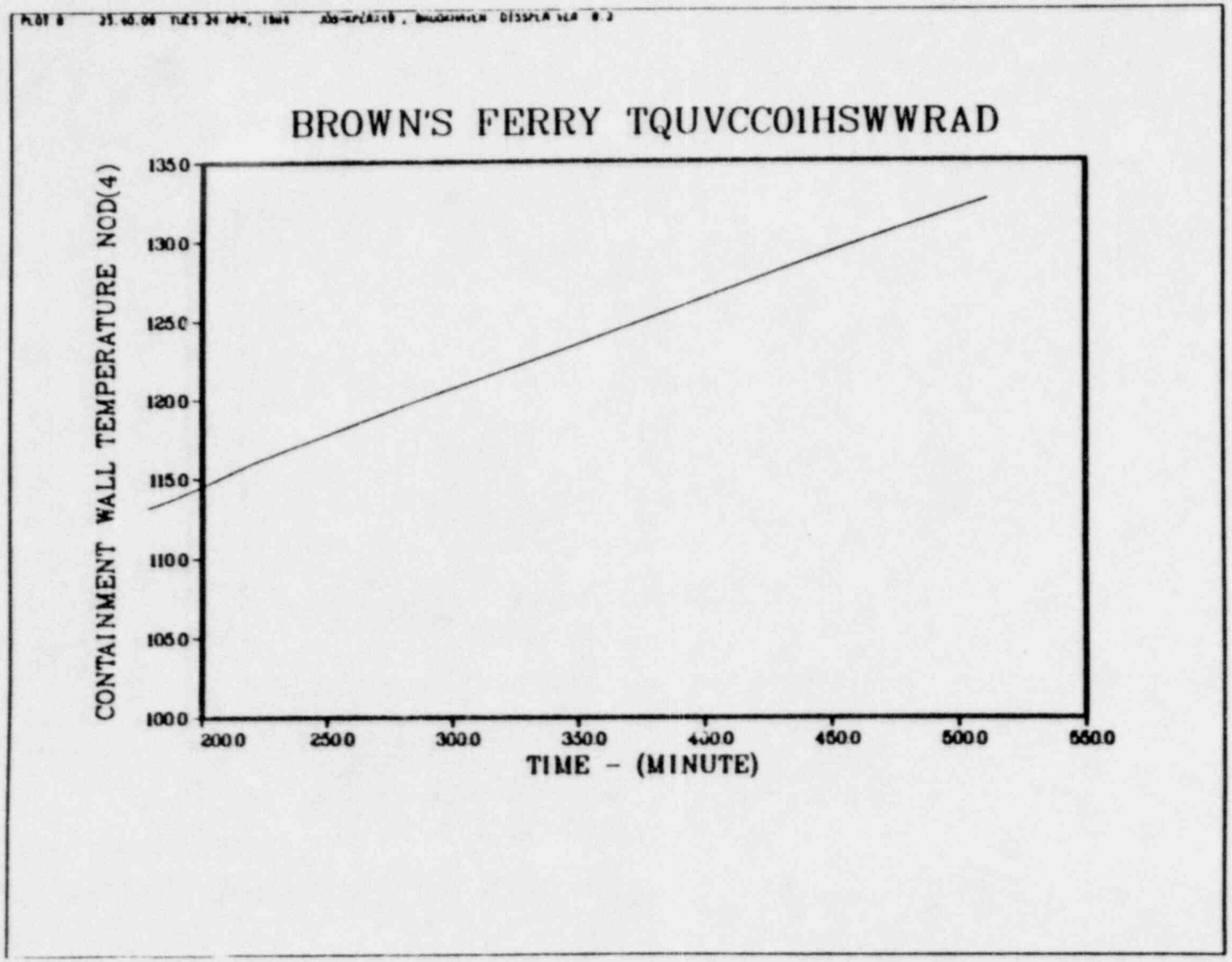
BROWN'S FERRY TQUVCC01HSWWRAD
COMPARTMENT TEMPERATURE
300.0
250.0
200.0
150.0
100.0
0.0
50.0
100.0
150.0
200.0
250.0
300.0
350.0
400.0
450.0
500.0
550.0
TIME - (MINUTE)
VOLUME NO. 2


BROWN'S FERRY TQUVCC01HSWWRAD
CONTAINMENT WALL TEMPERATURE NOD(1)
400.0
350.0
300.0
250.0
200.0
150.0
100.0
200.0
250.0
300.0
350.0
400.0
450.0
500.0
550.0
TIME - (MINUTE)



PLOT 10 DISSPLA VER 8.2
BROWN'S FERRY TQUVCC01HSWWRAD
CONTAINMENT WALL TEMPERATURE NOD(2)
165.0
160.0
155.0
150.0
145.0
140.0
135.0
200.0
250.0
300.0
350.0
400.0
450.0
500.0
550.0
TIME - (MINUTE)


BROWN'S FERRY TQUVCC01HSWWRAD
CONTAINMENT WALL TEMPERATURE NOD(3)
180.0
170.0
160.0
150.0
140.0
130.0
120.0
110.0
100.0
200.0
250.0
300.0
350.0
400.0
450.0
500.0
550.0
TIME - (MINUTE)


BROWN'S FERRY TQUVCC01HSWWRAD
CONTAINMENT WALL TEMPERATURE NOD(4)
TIME - (MINUTE)
100.0
105.0
110.0
115.0
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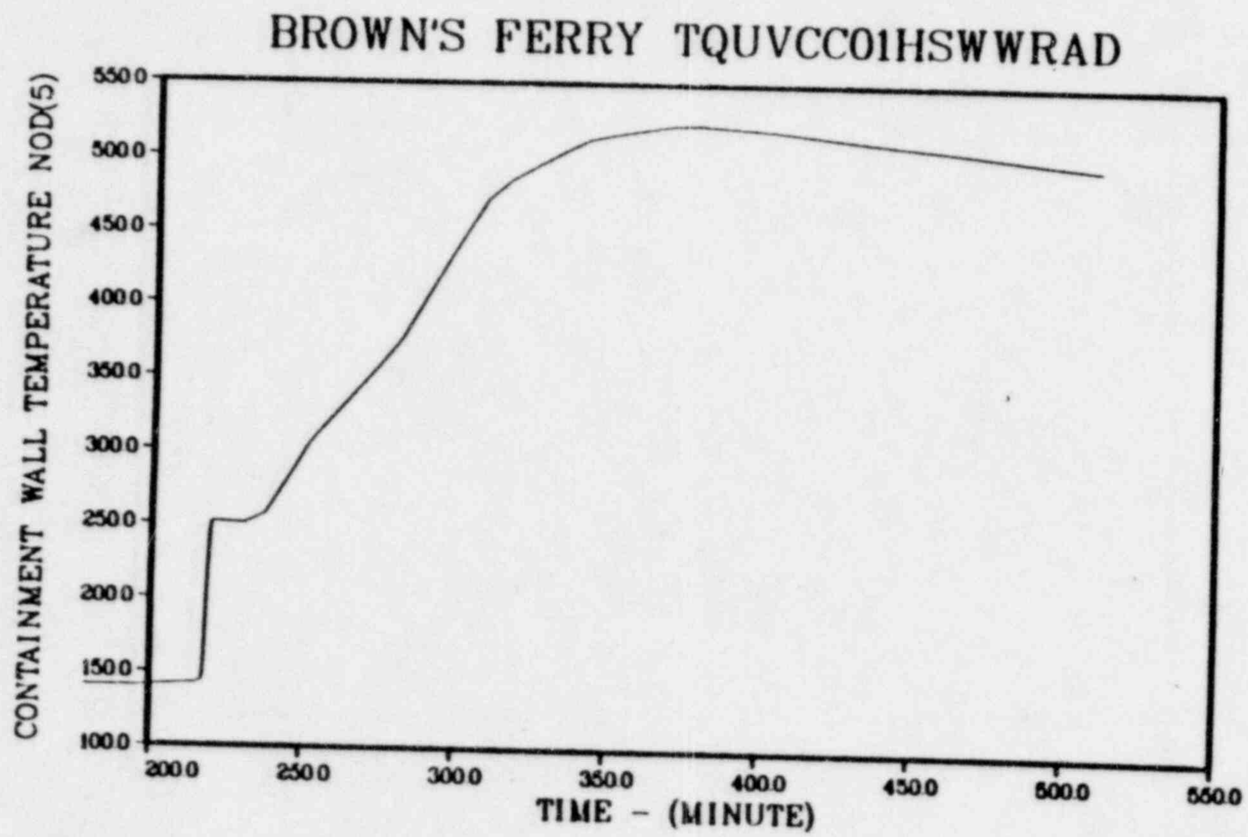
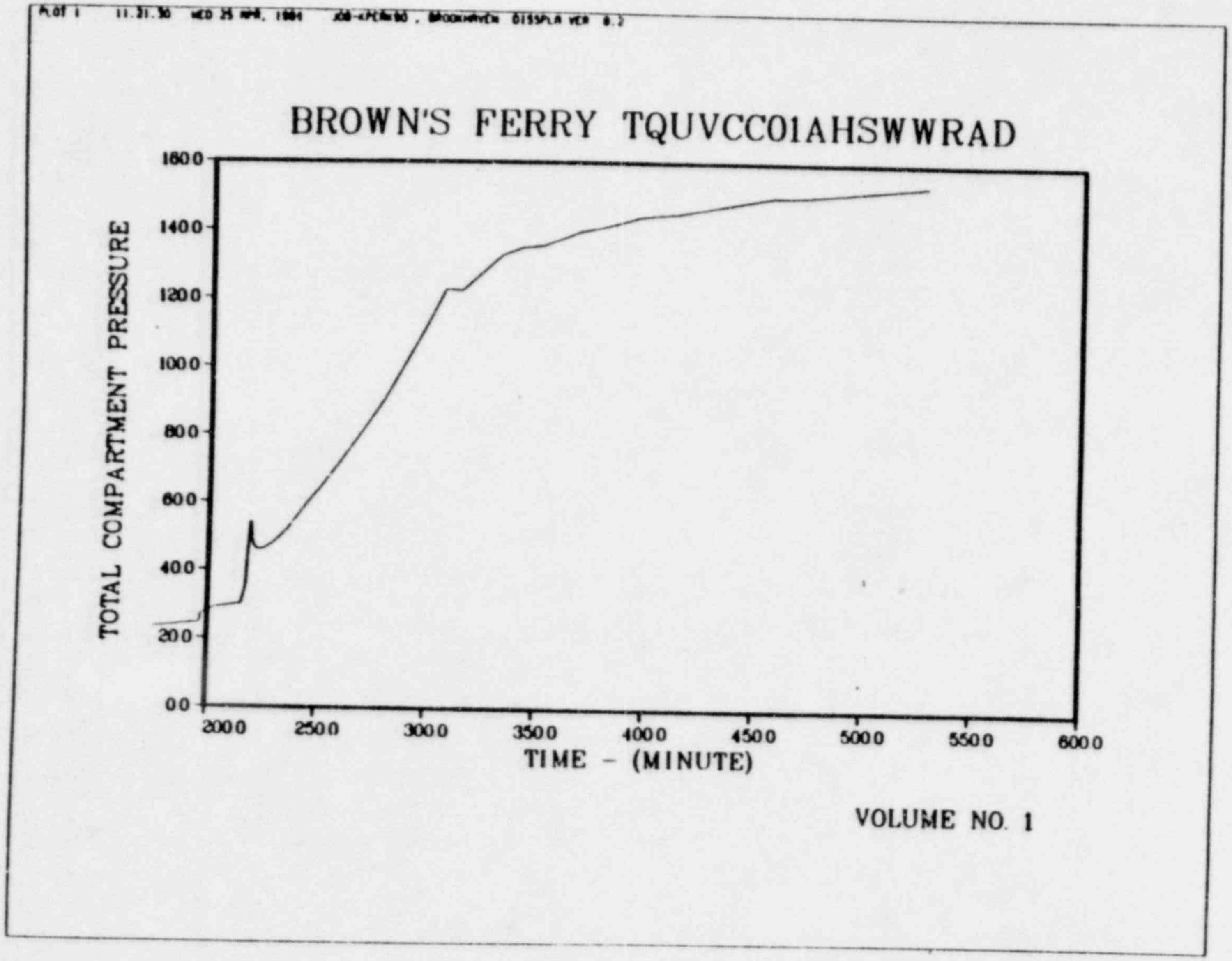
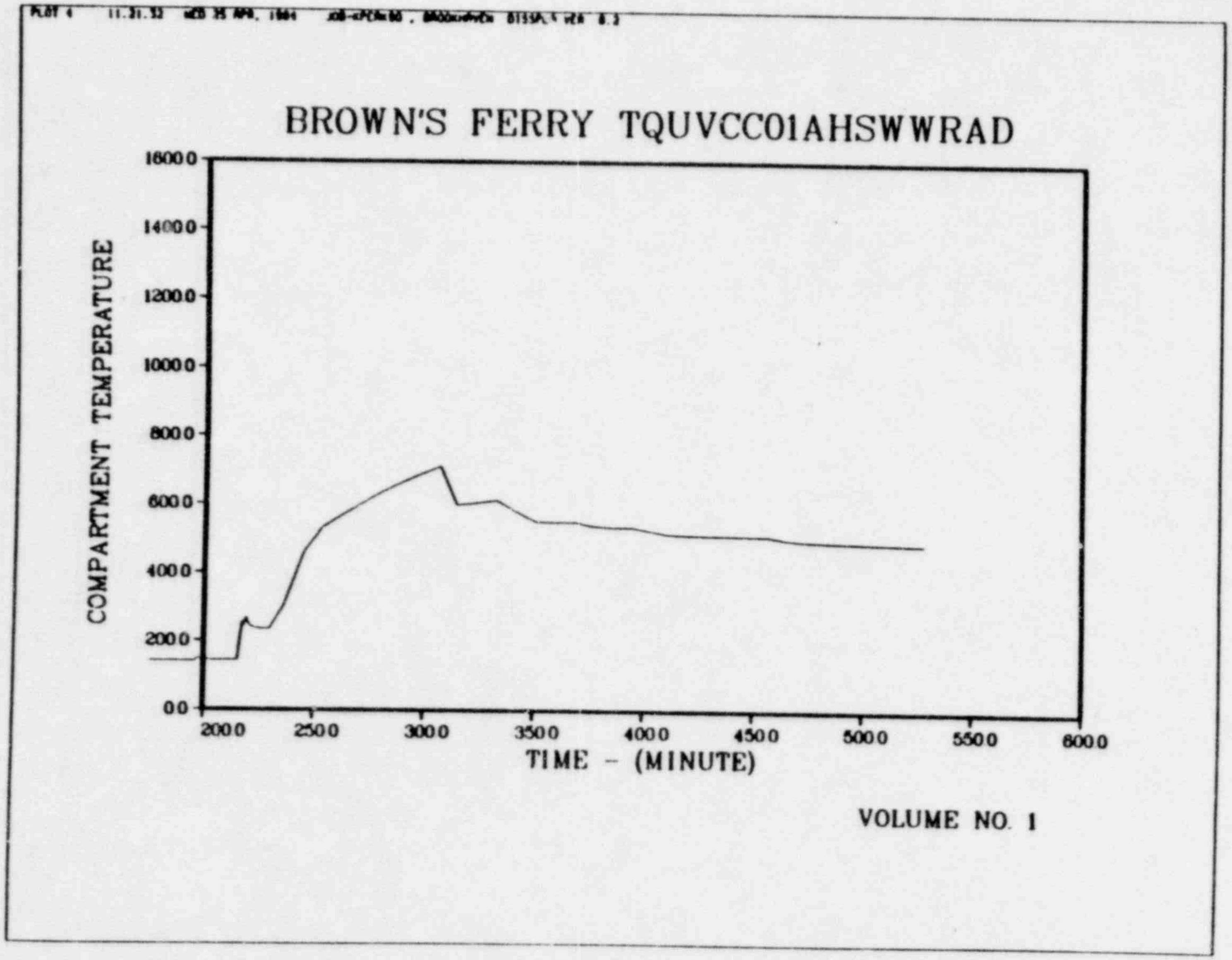
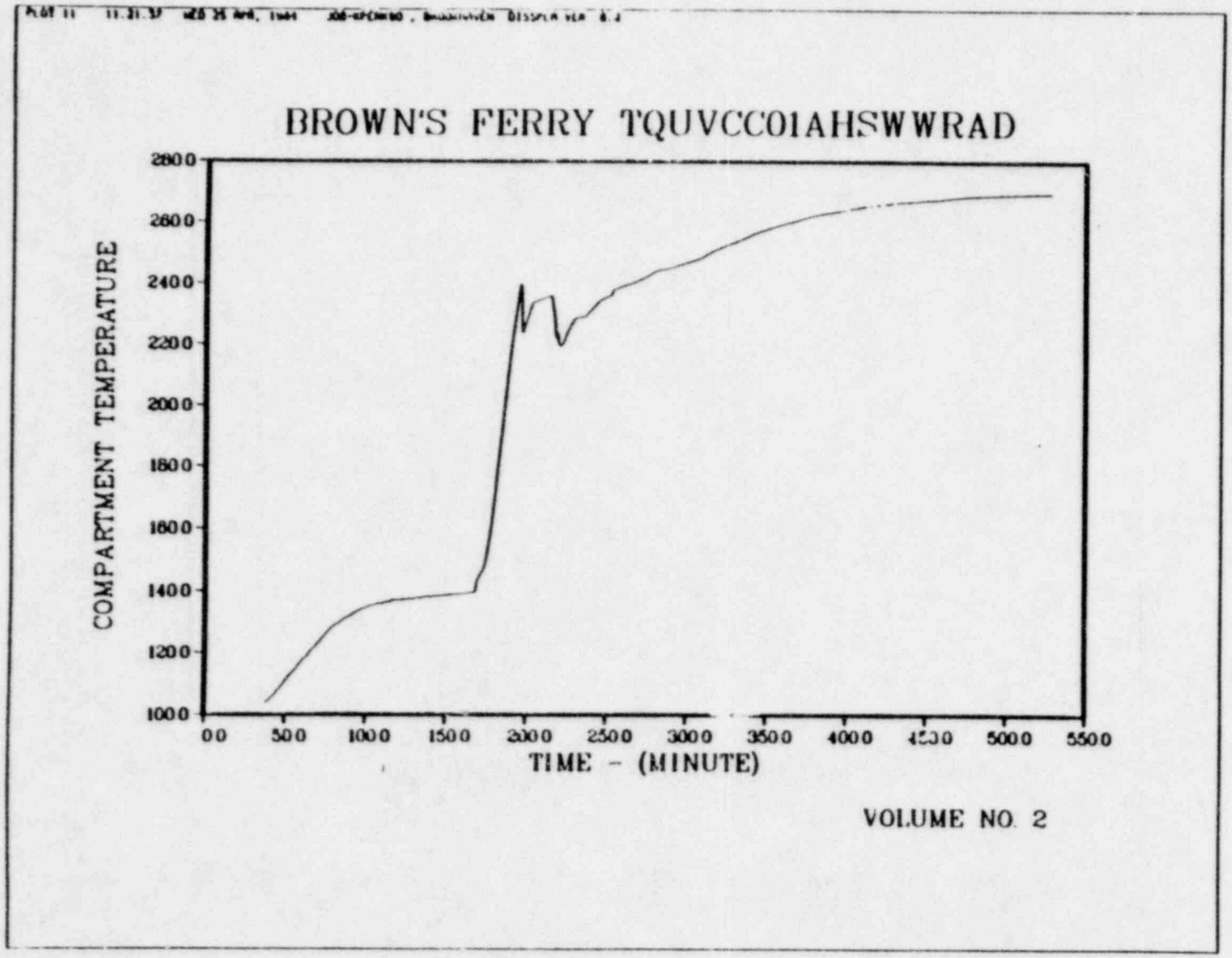
450.0
500.0
550.0

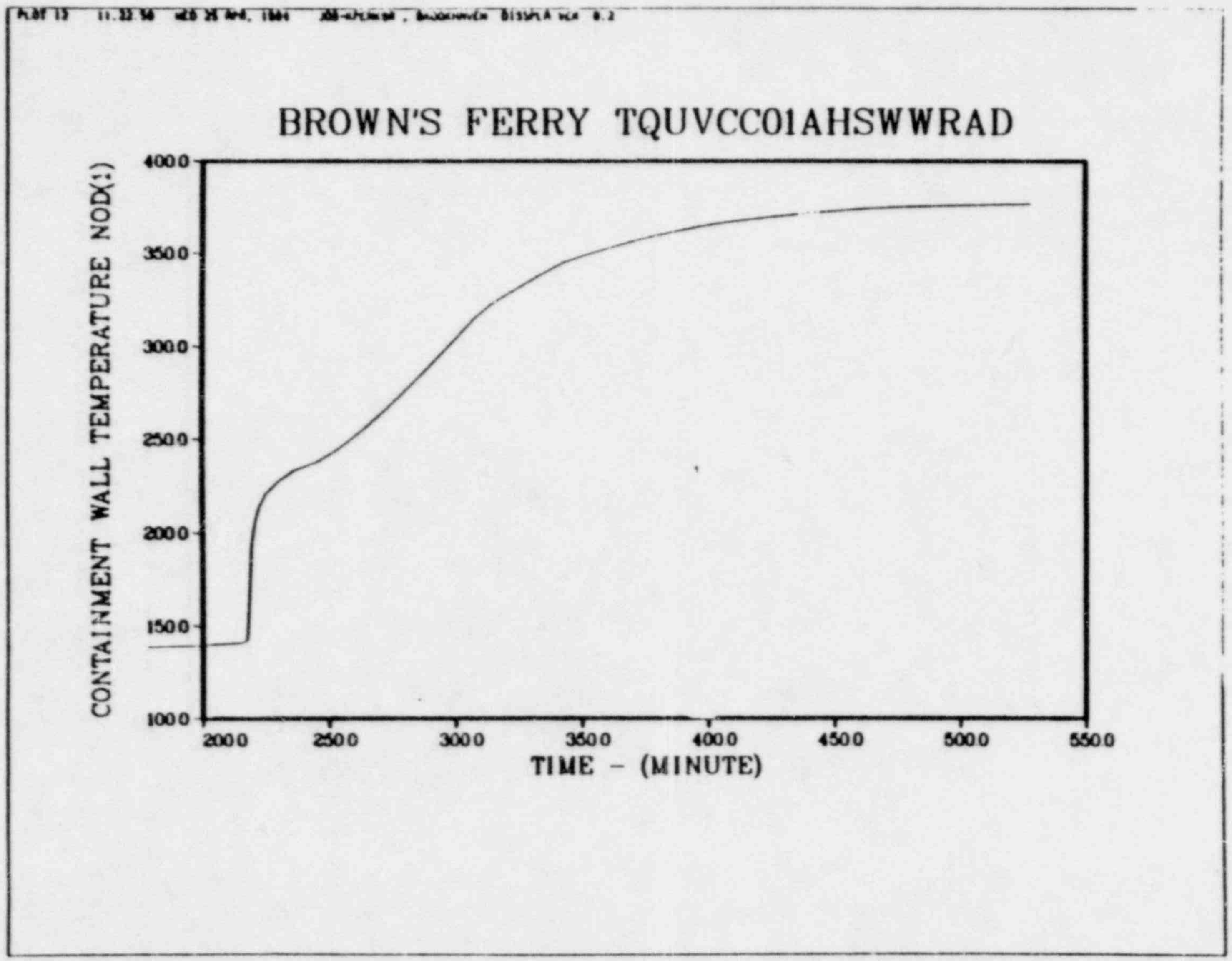

BROWN'S FERRY TQUVCC01HSWWRAD
CONTAINMENT WALL TEMPERATURE NOD(5)
550.0
500.0
450.0
400.0
350.0
300.0
250.0
200.0
150.0
100.0
200.0
250.0
300.0
350.0
400.0
450.0
500.0
550.0
TIME - (MINUTE)


BROWN'S FERRY TQUVCC01AHSWWRAD
TOTAL COMPARTMENT PRESSURE
0.0
200.0
400.0
600.0
800.0
1000.0
1200.0
1400.0
1600.0
2000
2500
3000
3500
4000
4500
5000
5500
6000
TIME - (MINUTE)
VOLUME NO. 1

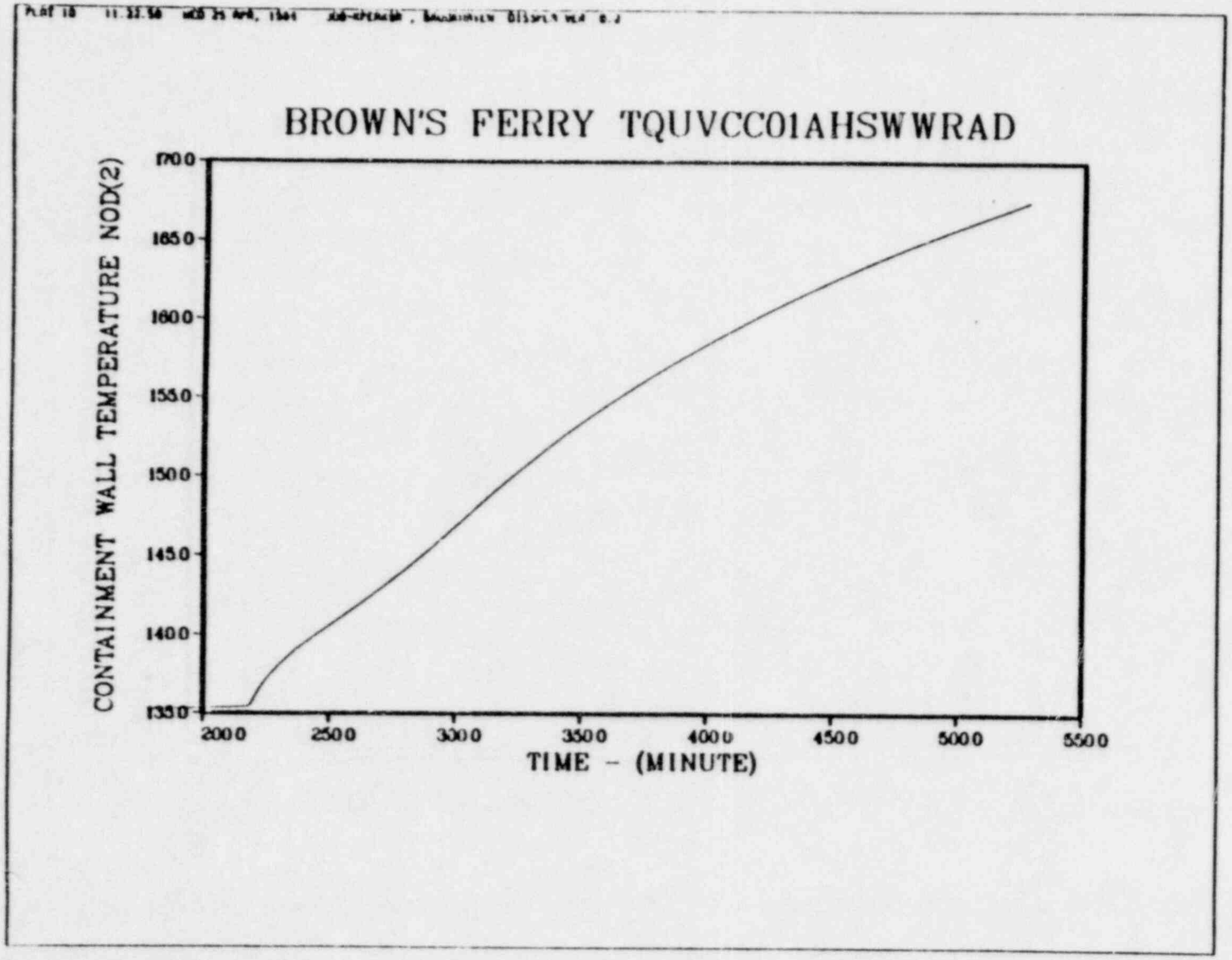

BROWN'S FERRY TQUVCC01AHSWWRAD
COMPARTMENT TEMPERATURE
0.0
200.0
400.0
600.0
800.0
1000.0
1200.0
1400.0
1600.0
200.0
250.0
300.0
350.0
400.0
450.0
500.0
550.0
600.0
TIME - (MINUTE)
VOLUME NO. 1



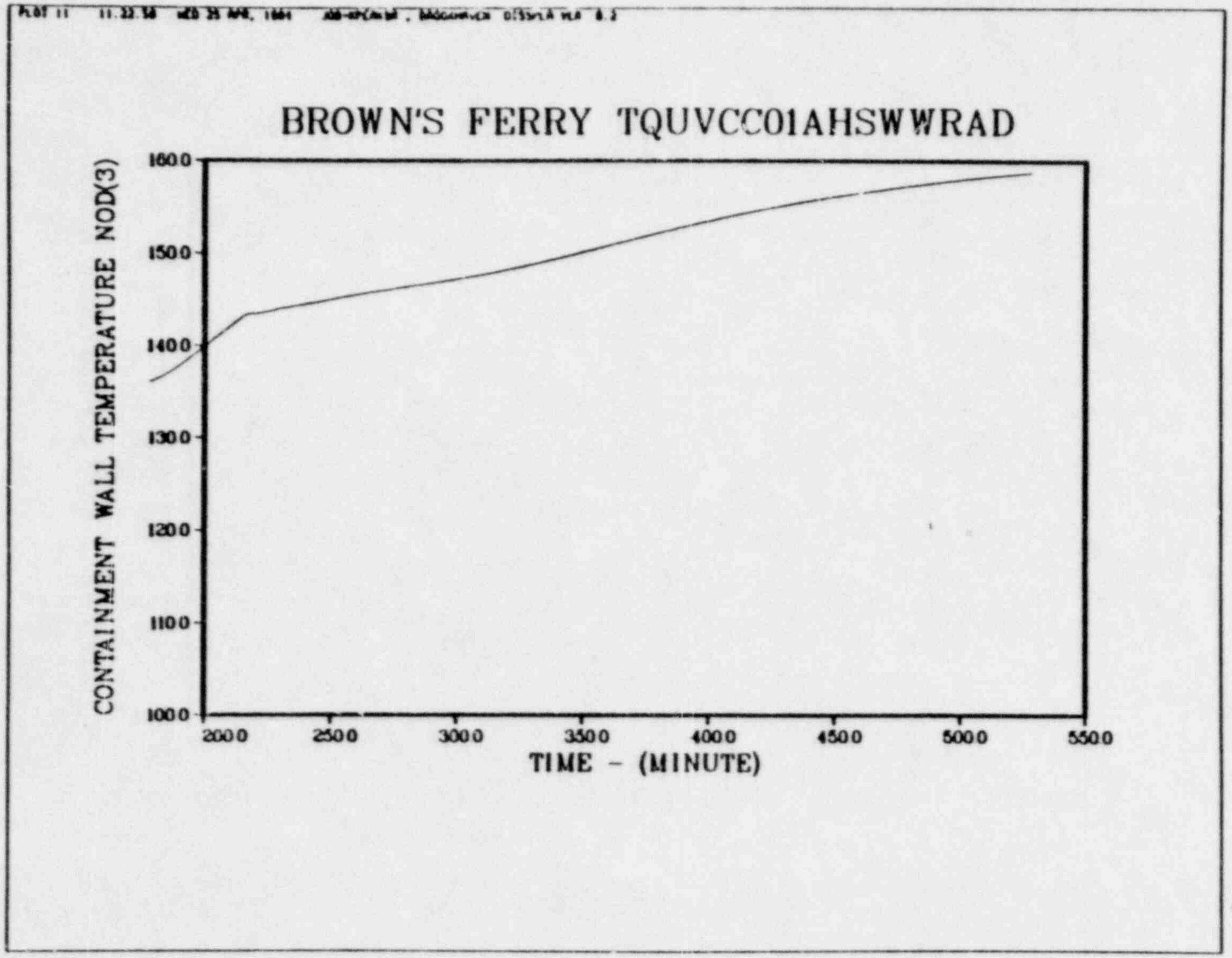
BROWN'S FERRY TQUVCC01AHSWWRAD
COMPARTMENT TEMPERATURE
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
00
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
TIME - (MINUTE)
VOLUME NO. 2



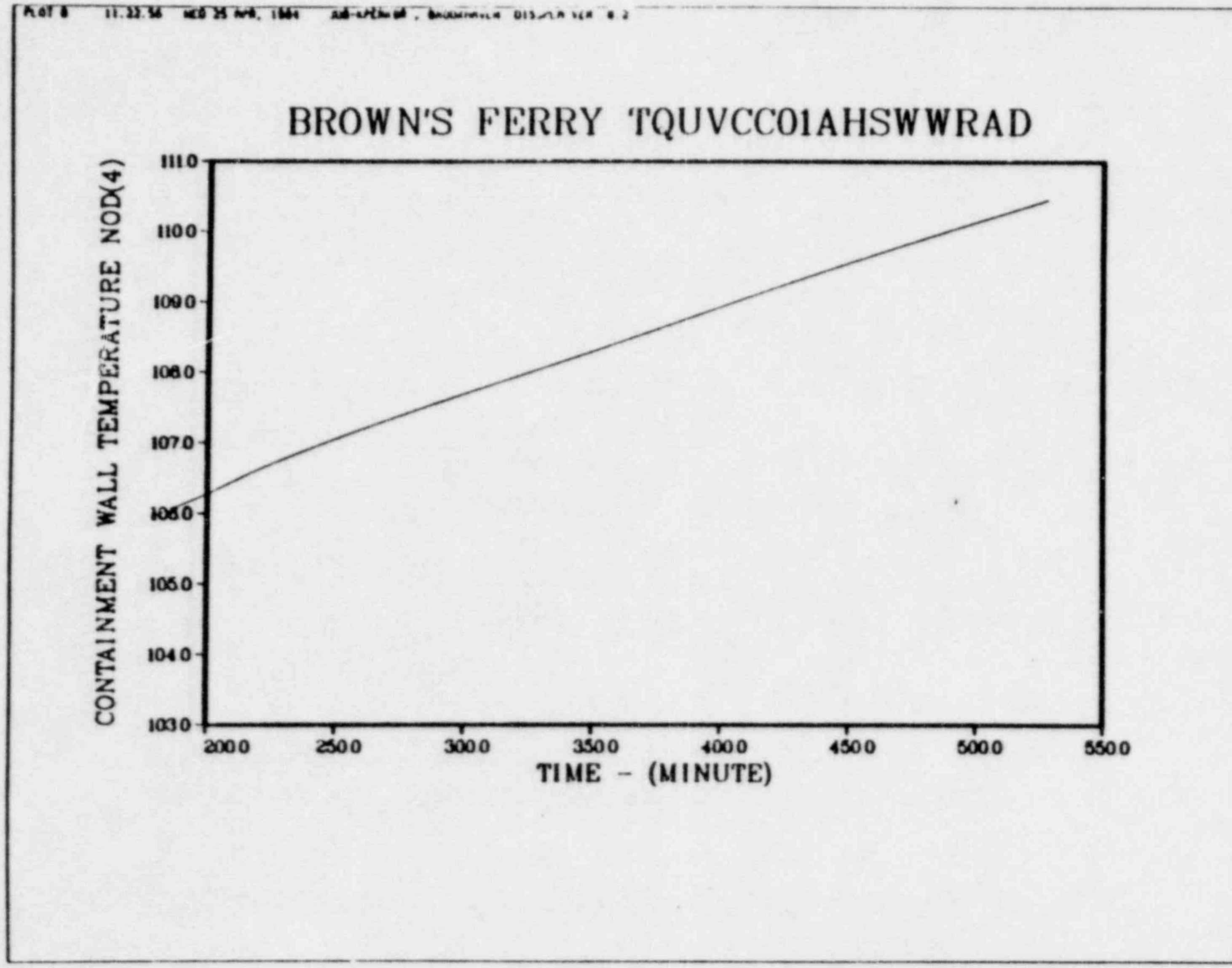
BROWN'S FERRY TQUVCC01AHSWWRAD
CONTAINMENT WALL TEMPERATURE NOD(1)
400.0
350.0
300.0
250.0
200.0
150.0
100.0
200.0
250.0
300.0
350.0
400.0
450.0
500.0
550.0
TIME - (MINUTE)

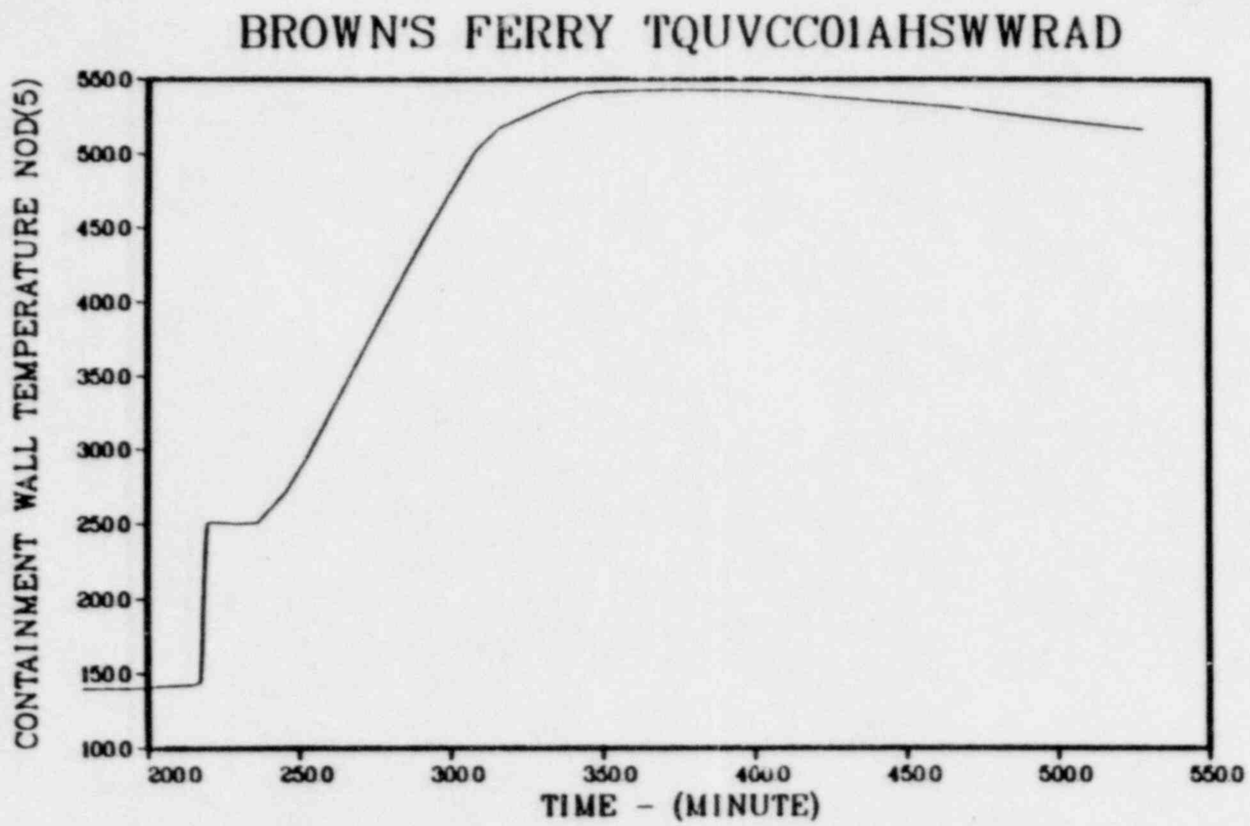


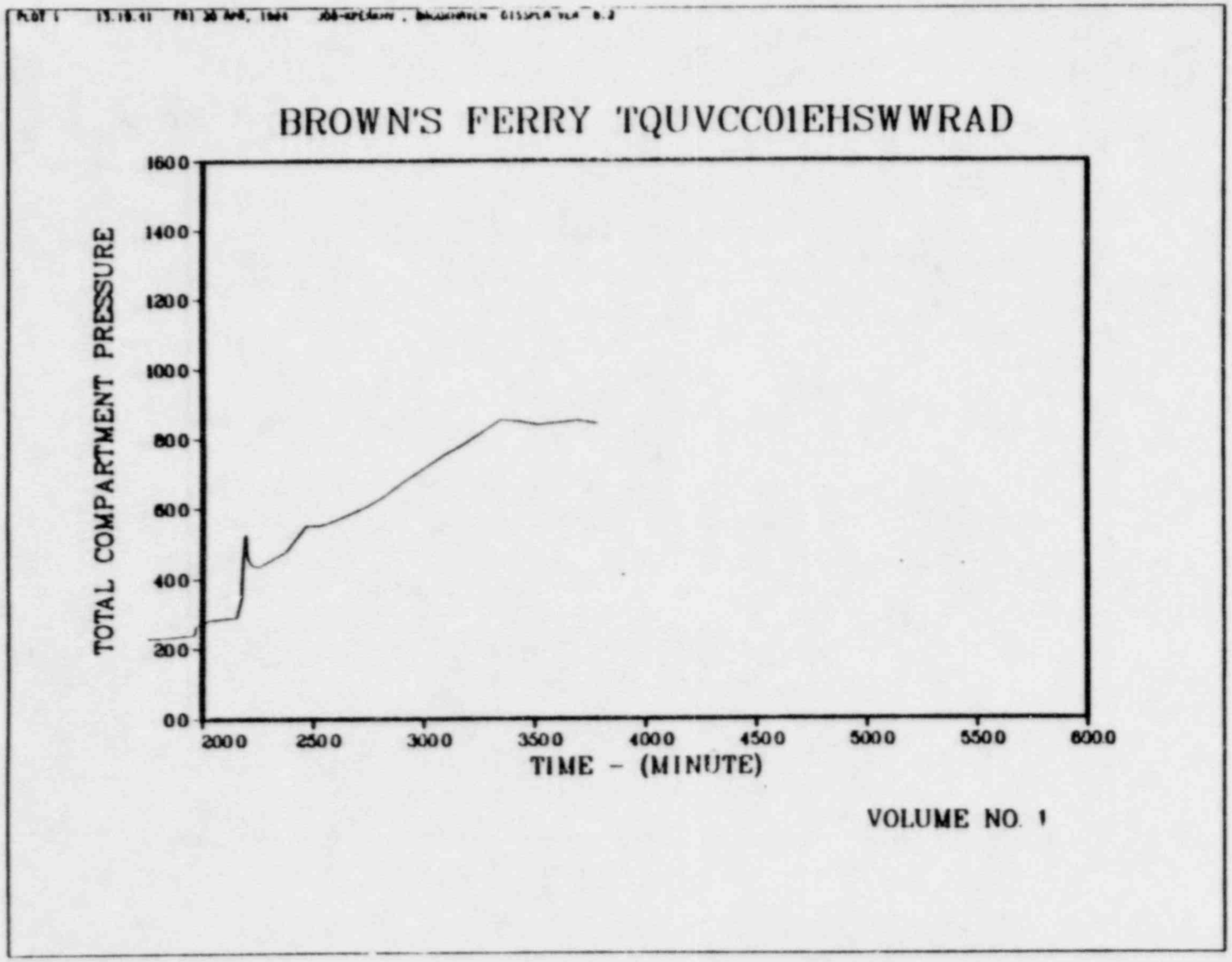
BROWN'S FERRY TQUVCC01AHSWWRAD
CONTAINMENT WALL TEMPERATURE NOD(2)
170.0
165.0
160.0
155.0
150.0
145.0
140.0
135.0
2000
2500
3000
3500
4000
4500
5000
5500
TIME - (MINUTE)



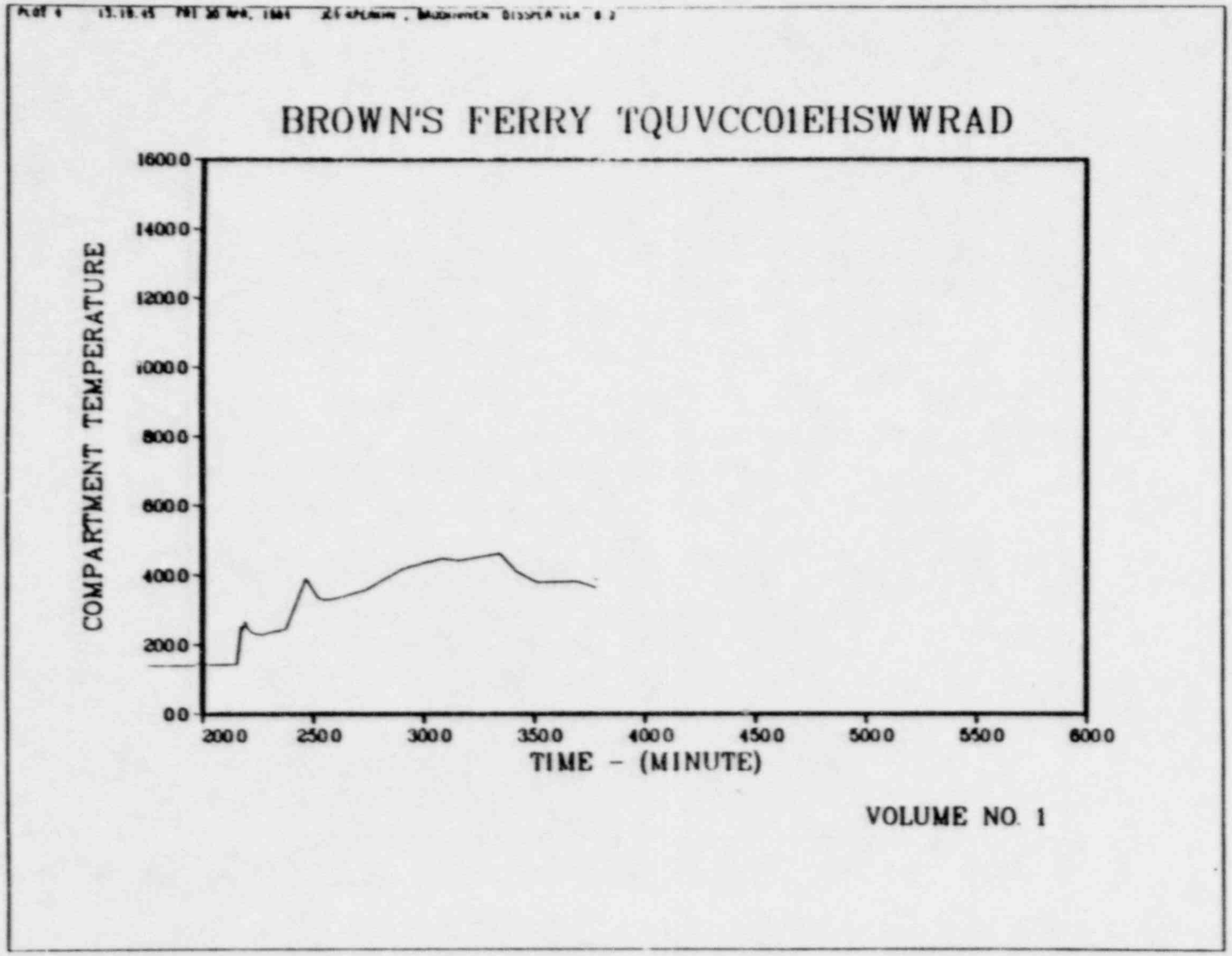
BROWN'S FERRY TQUVCC01AHSWWRAD
CONTAINMENT WALL TEMPERATURE NOD(3)
100.0
110.0
120.0
130.0
140.0
150.0
160.0
2000
2500
3000
3500
4000
4500
5000
5500
TIME - (MINUTE)


BROWN'S FERRY TQUVCC01AHSWWRAD
CONTAINMENT WALL TEMPERATURE NOD(4)
111.0
110.0
109.0
108.0
107.0
106.0
105.0
104.0
103.0
200.0
250.0
300.0
350.0
400.0
450.0
500.0
550.0
TIME - (MINUTE)

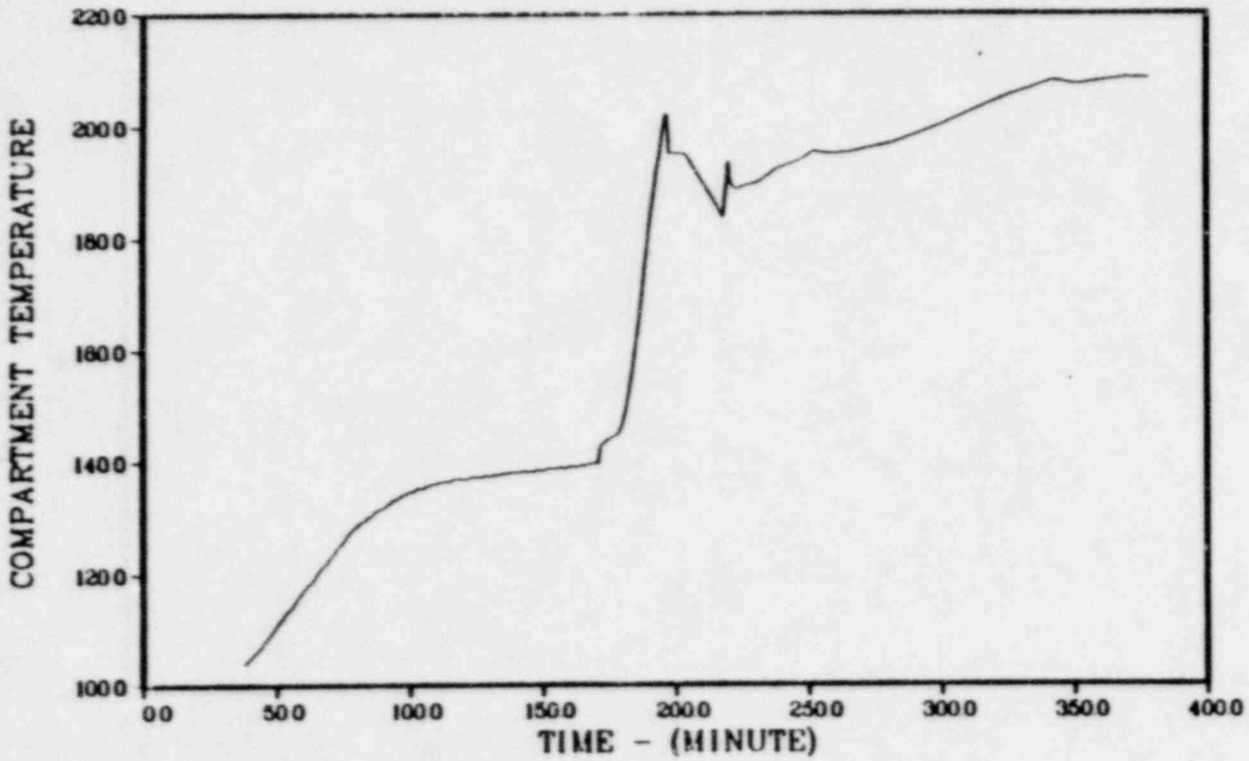

BROWN'S FERRY TQUVCC01AHSWWRAD
CONTAINMENT WALL TEMPERATURE NOD(5)
550.0
500.0
450.0
400.0
350.0
300.0
250.0
200.0
150.0
100.0
200.0
250.0
300.0
350.0
400.0
450.0
500.0
550.0
TIME - (MINUTE)



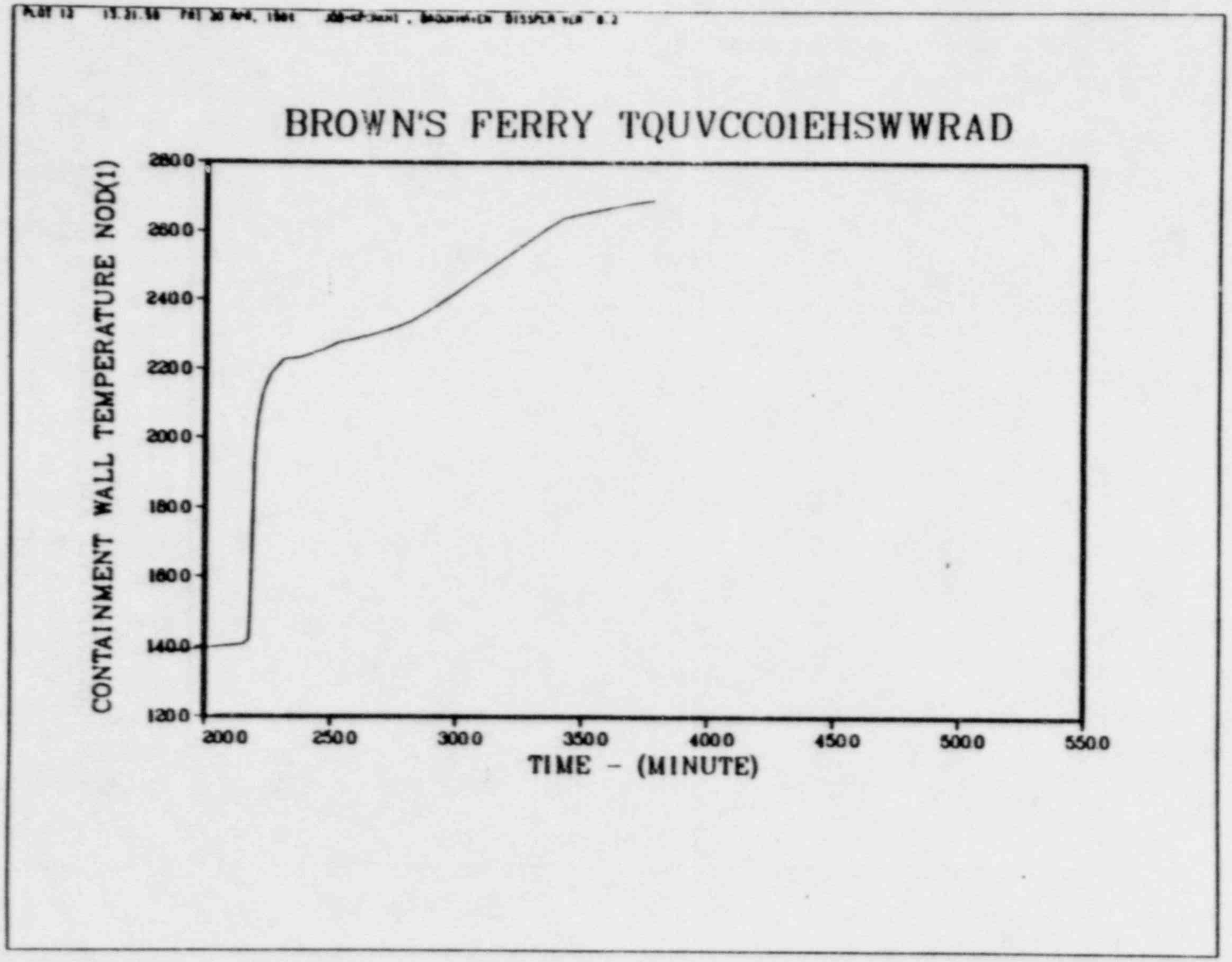
BROWN'S FERRY TQUVCC01EHSWWRAD
TOTAL COMPARTMENT PRESSURE
1600
1400
1200
1000
800
600
400
200
0.0
2000
2500
3000
3500
4000
4500
5000
5500
6000
TIME - (MINUTE)
VOLUME NO. 1

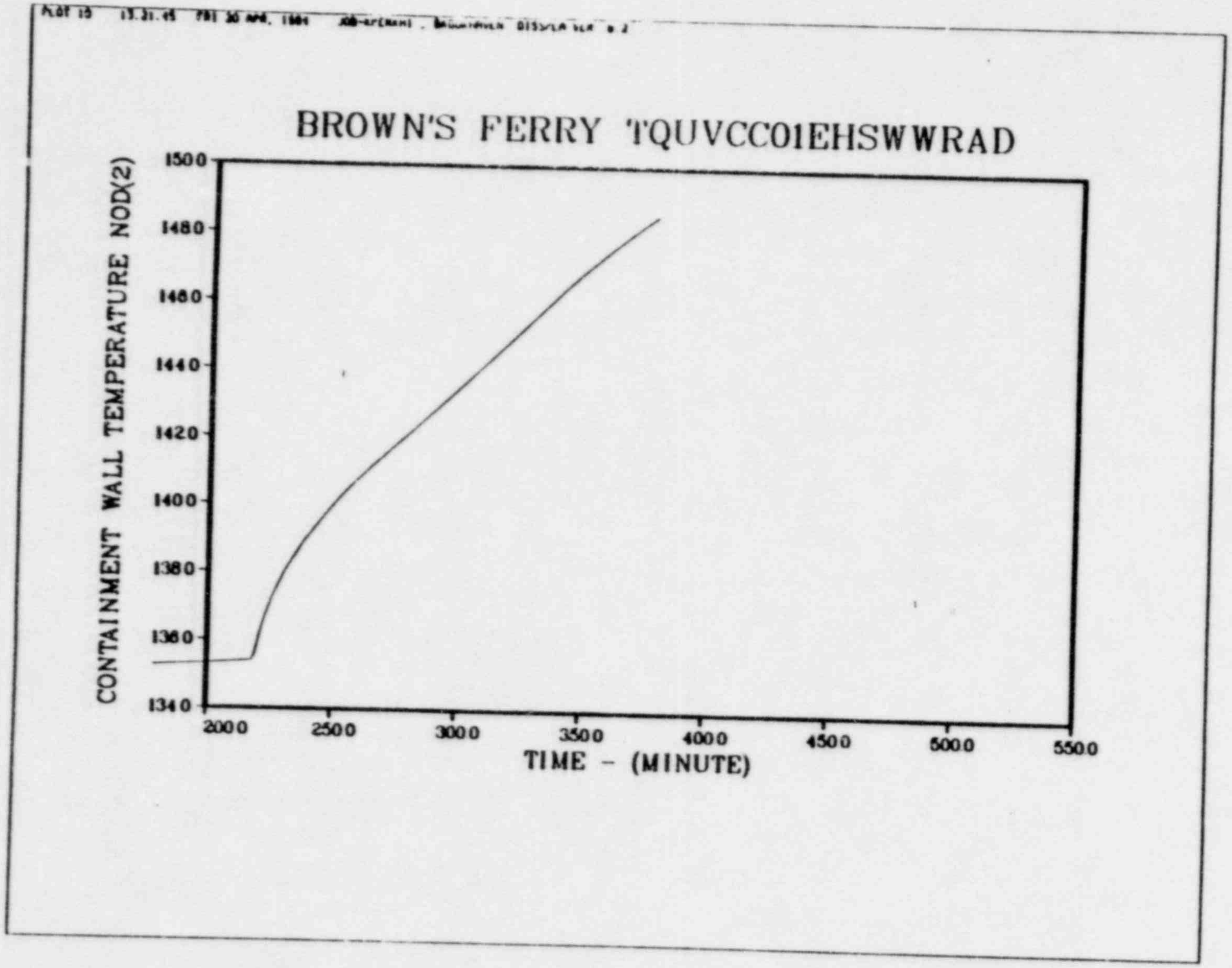

BROWN'S FERRY TQUVCC01EHSWWRAD
COMPARTMENT TEMPERATURE
1600.0
1400.0
1200.0
1000.0
800.0
600.0
400.0
200.0
0.0
2000
2500
3000
3500
4000
4500
5000
5500
6000
TIME - (MINUTE)
VOLUME NO. 1

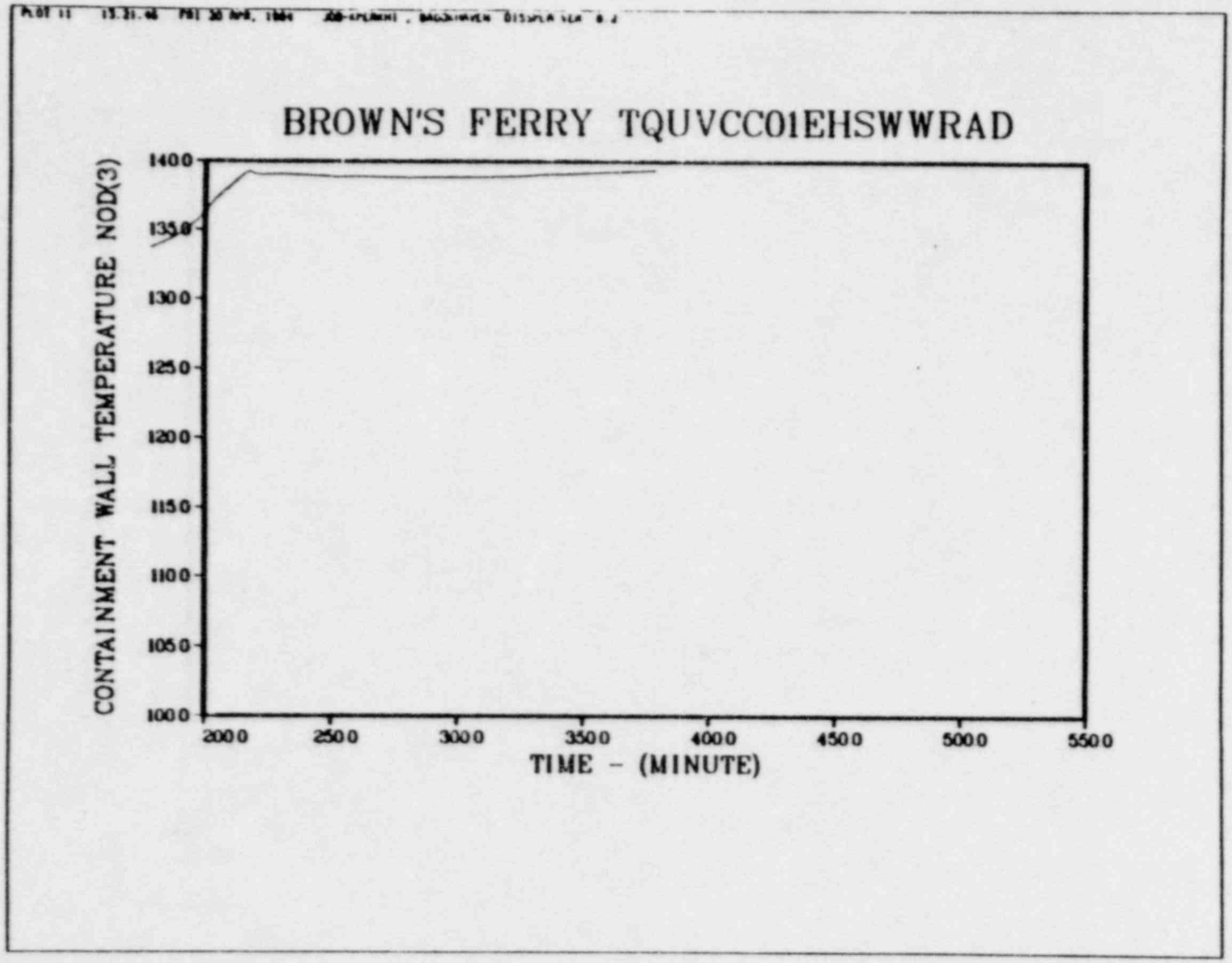
BROWN'S FERRY TQUVCC01EHSWWRAD

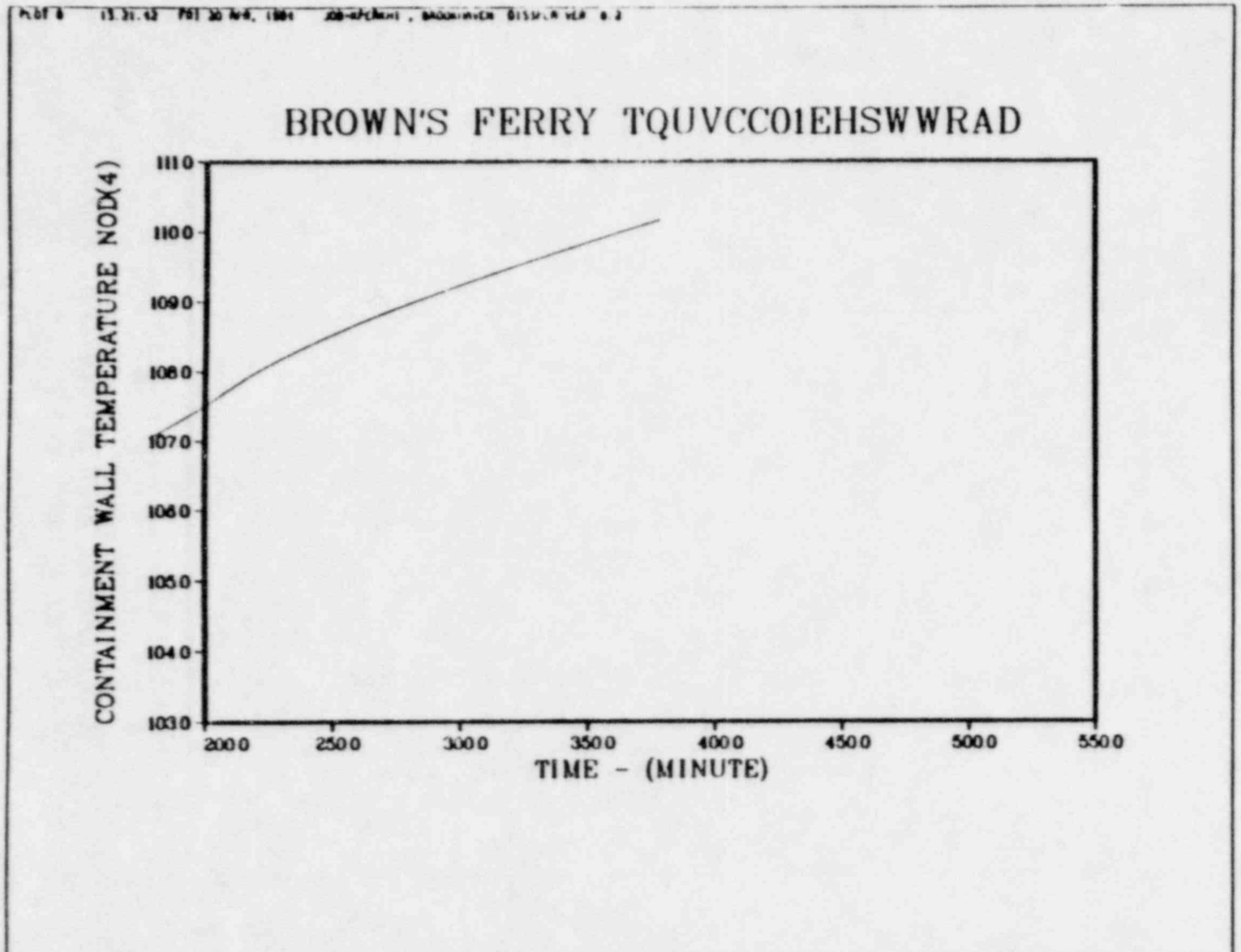


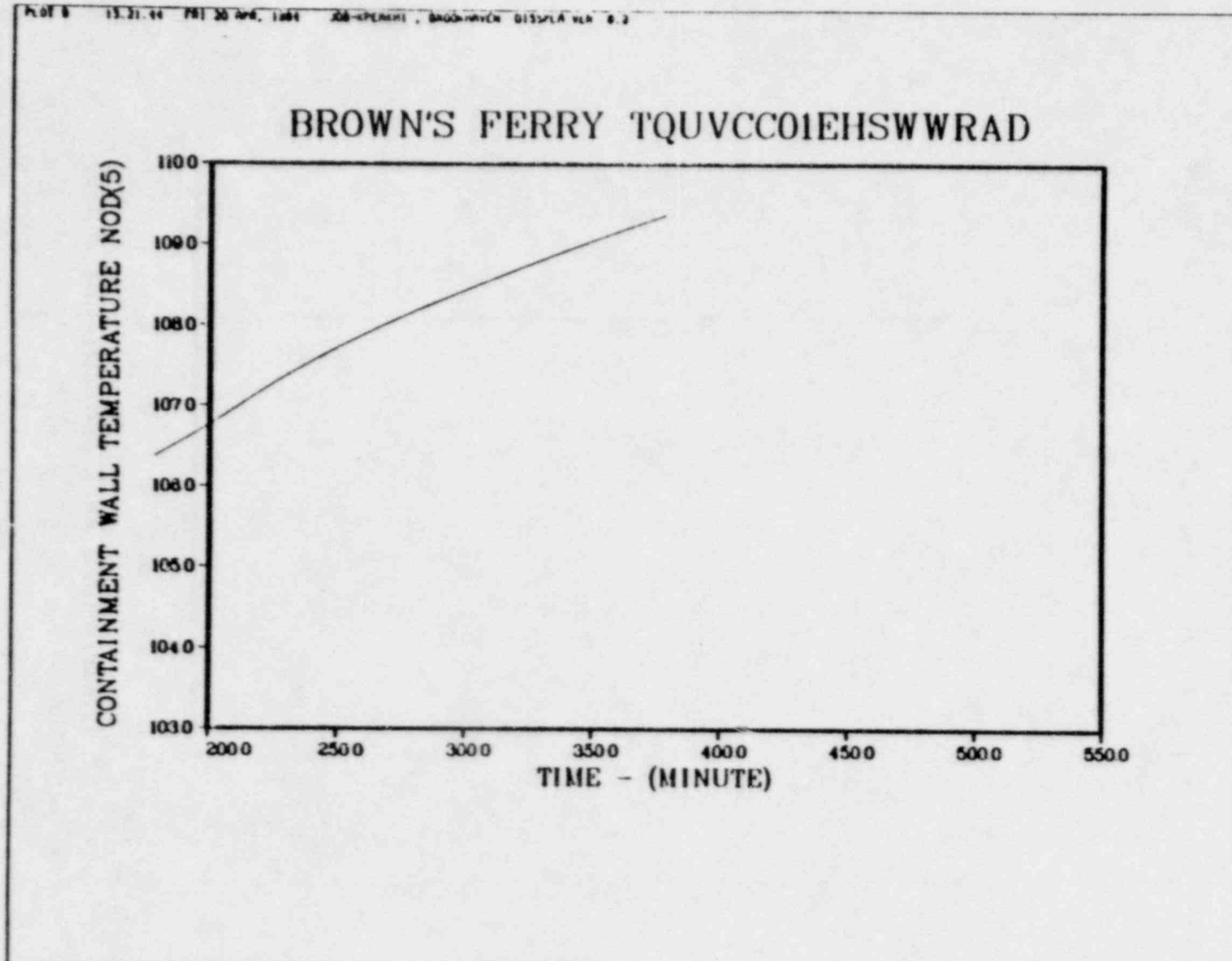
VOLUME NO. 2

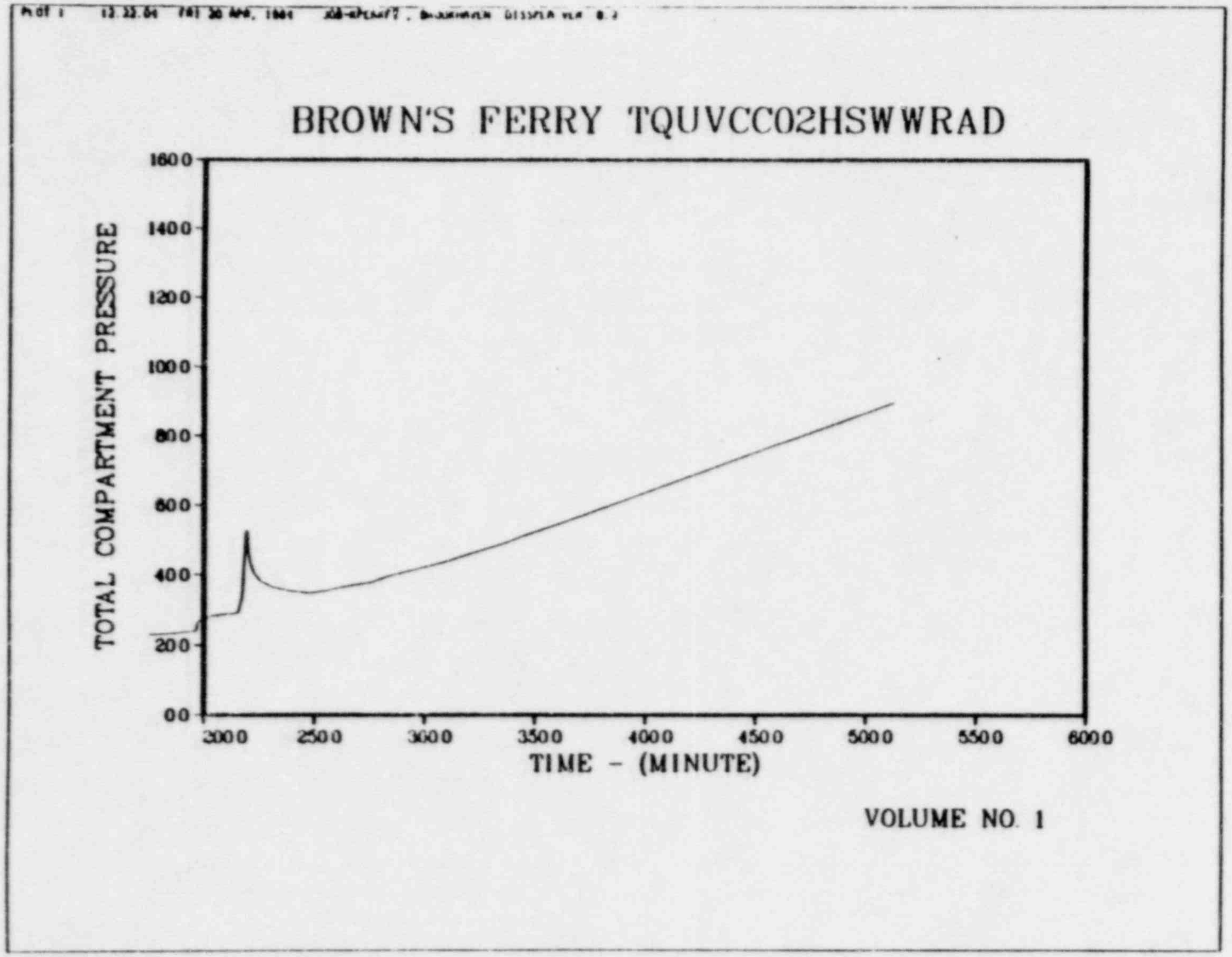

BROWN'S FERRY TQUVCC01EHSWWRAD
CONTAINMENT WALL TEMPERATURE NOD(1)
280.0
260.0
240.0
220.0
200.0
180.0
160.0
140.0
120.0
200.0
250.0
300.0
350.0
400.0
450.0
500.0
550.0
TIME - (MINUTE)

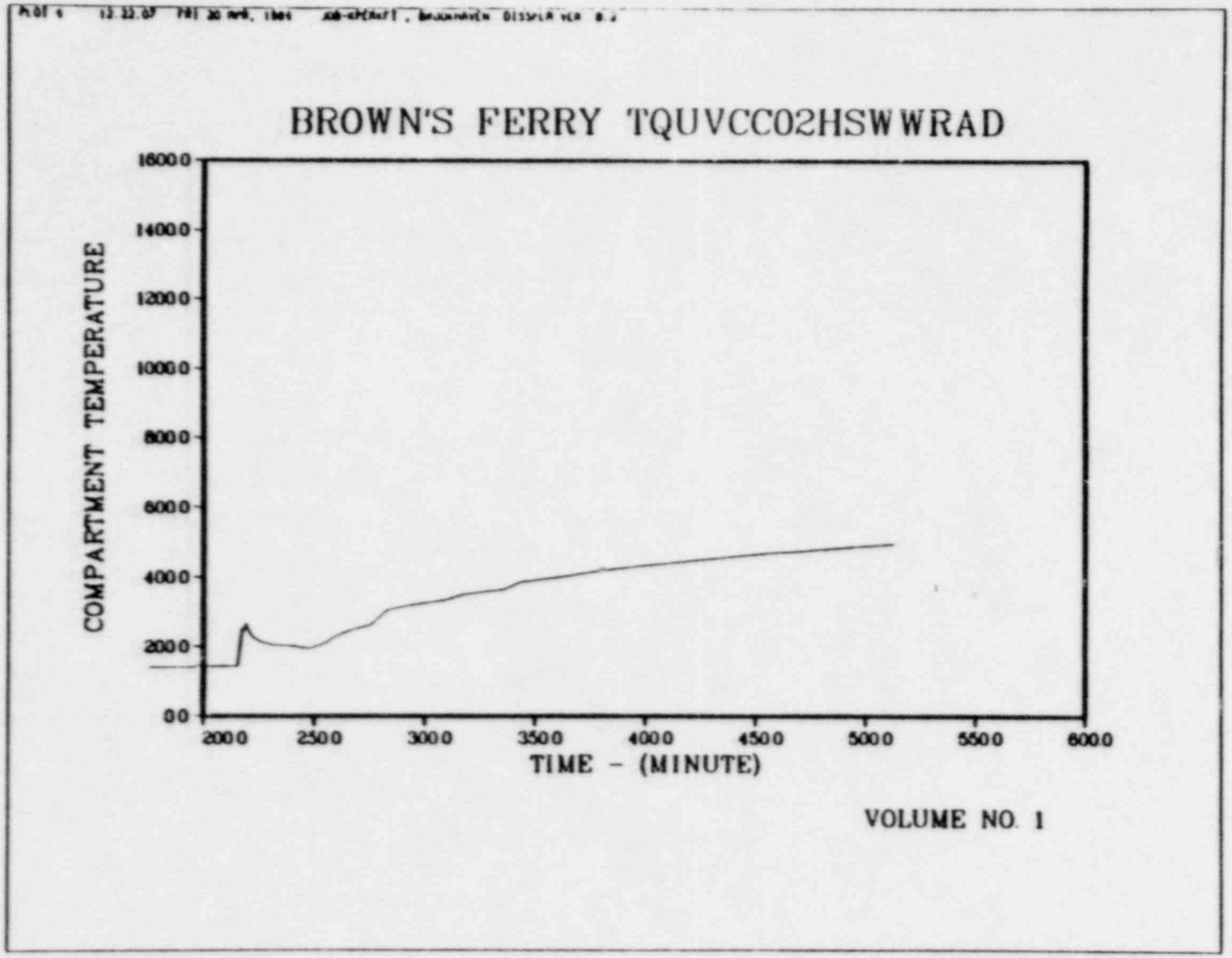

BROWN'S FERRY TQUVCC01EHSWWRAD
CONTAINMENT WALL TEMPERATURE NOD(2)
1340
1360
1380
1400
1420
1440
1460
1480
1500
2000
2500
3000
3500
4000
4500
5000
5500
TIME - (MINUTE)

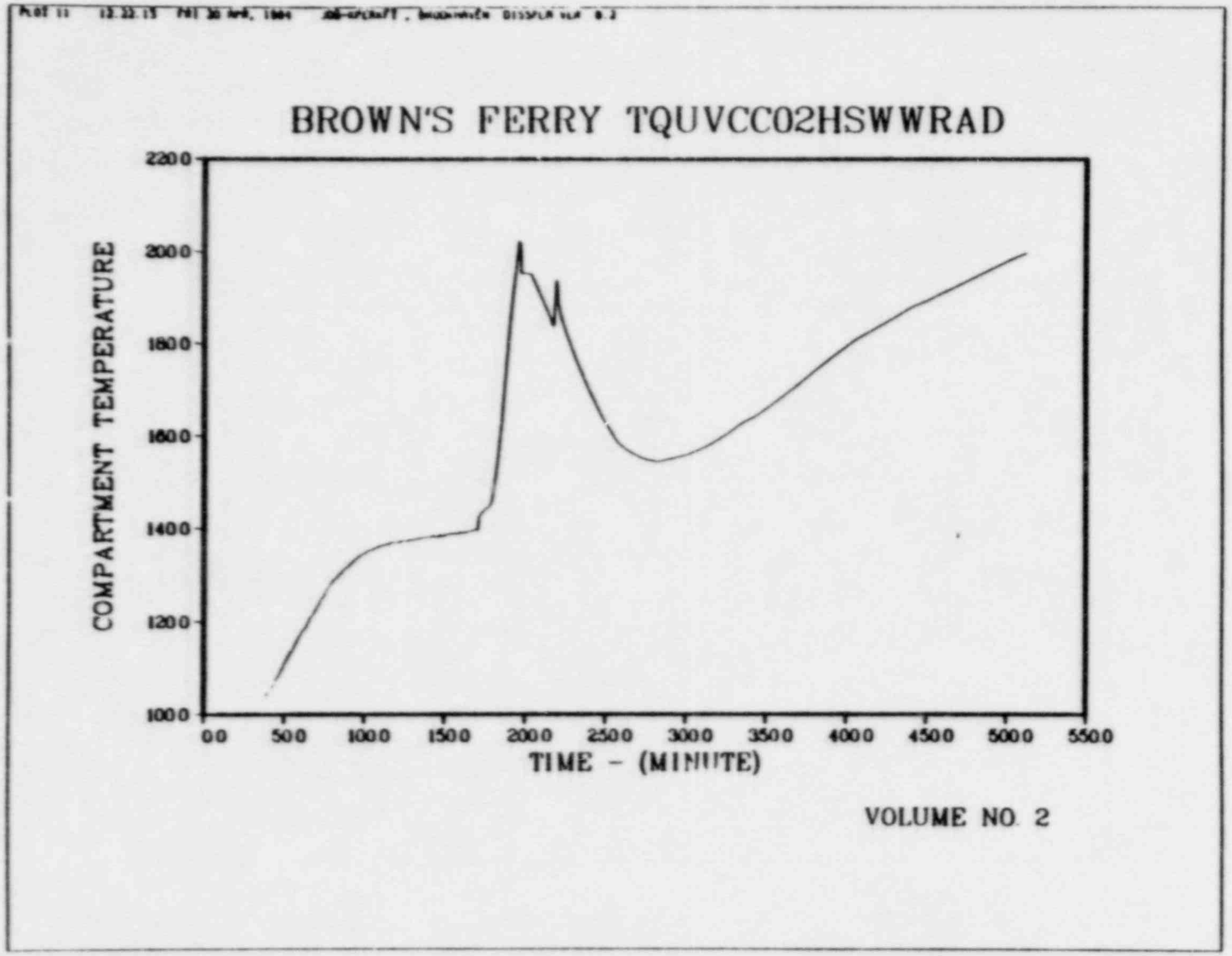

BROWN'S FERRY TQUVCC01EHSWWRAD
CONTAINMENT WALL TEMPERATURE NOD(3)
140.0
135.0
130.0
125.0
120.0
115.0
110.0
105.0
100.0
200.0
250.0
300.0
350.0
400.0
450.0
500.0
550.0
TIME - (MINUTE)

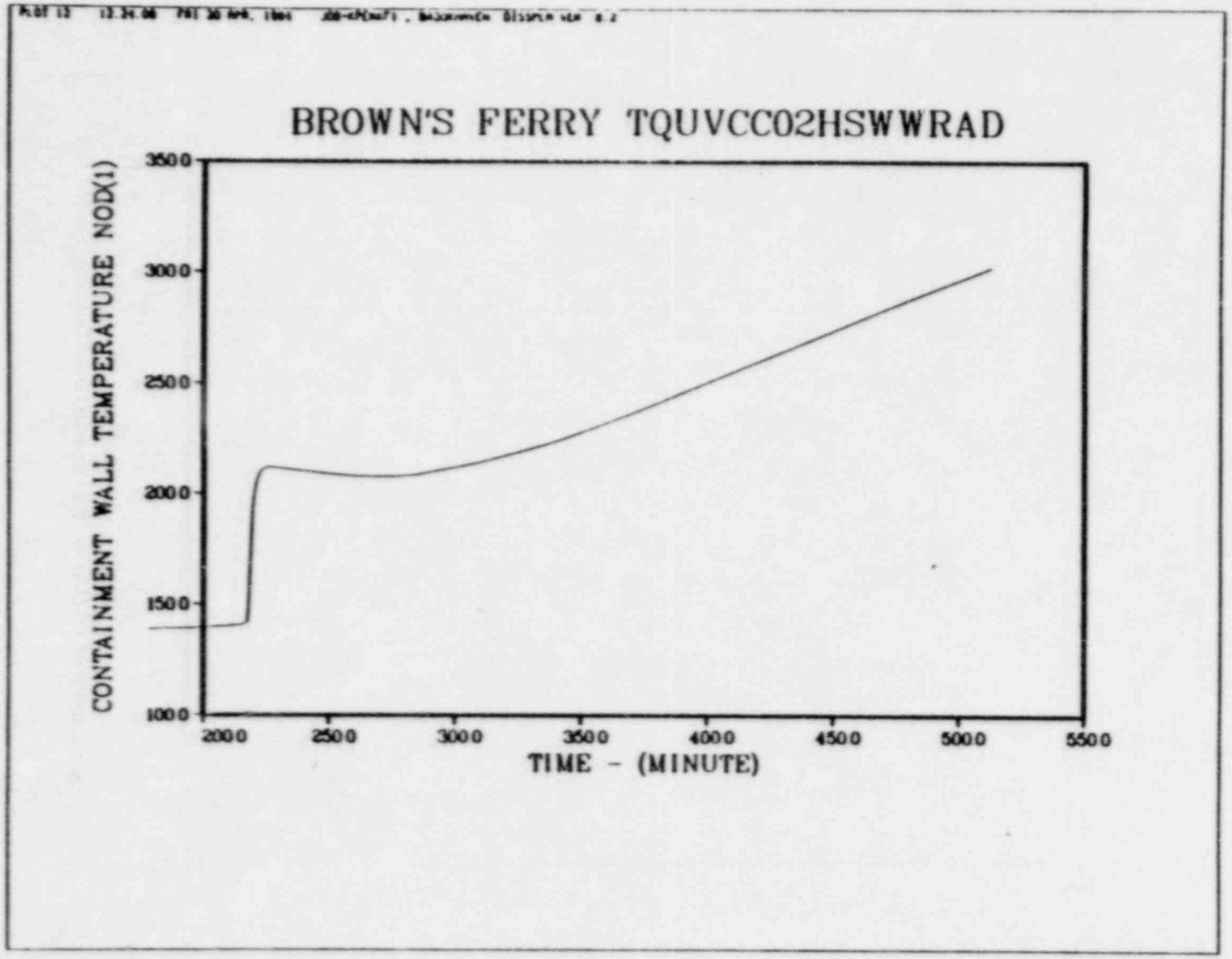

BROWN'S FERRY TQUVCC01EHSWWRAD
CONTAINMENT WALL TEMPERATURE NOD(4)
1110
1100
1090
1080
1070
1060
1050
1040
1030
2000
2500
3000
3500
4000
4500
5000
5500
TIME - (MINUTE)

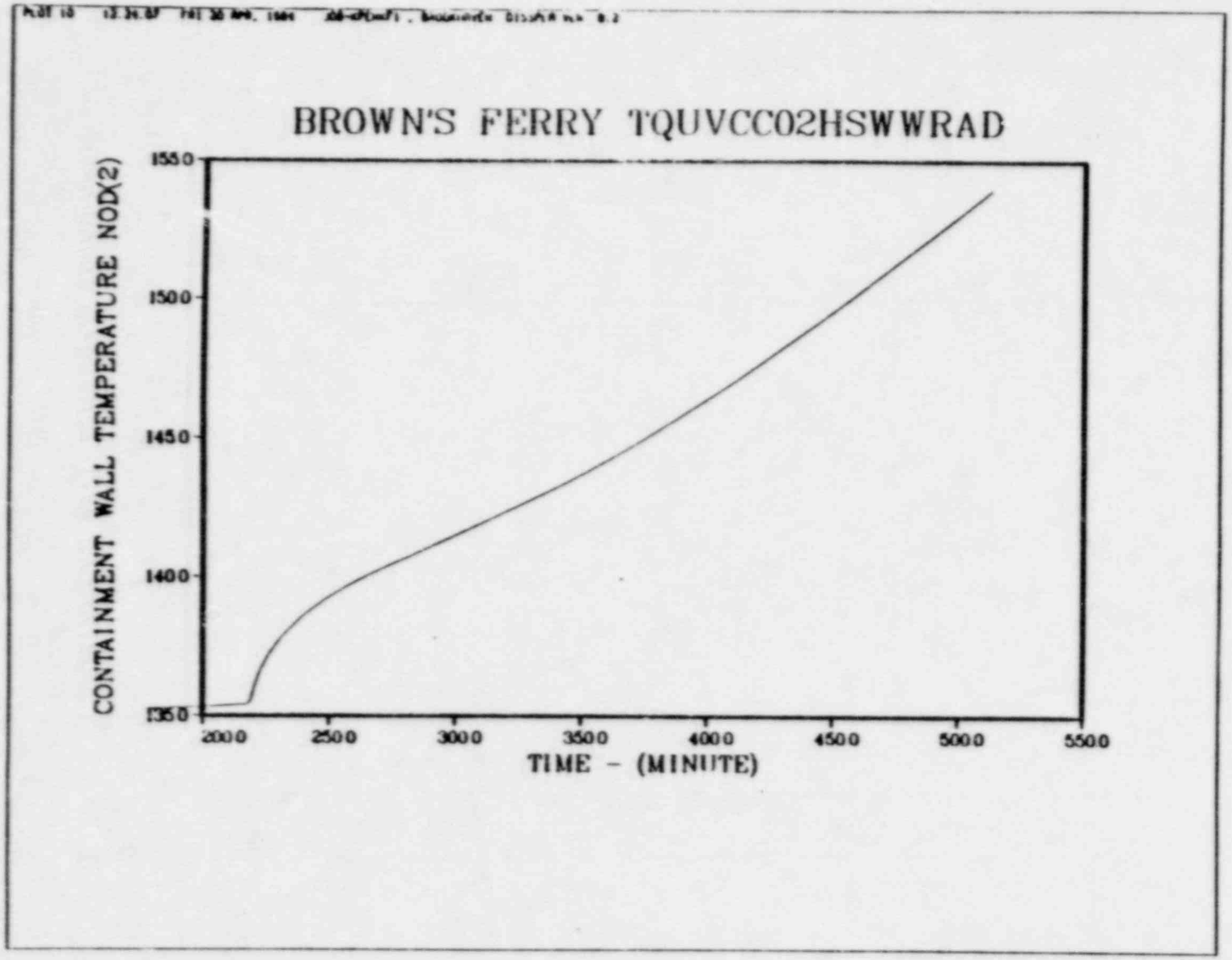

BROWN'S FERRY TQUVCC01EHSWWRAD
CONTAINMENT WALL TEMPERATURE NOD(5)
110.0
109.0
108.0
107.0
106.0
105.0
104.0
103.0
200.0
250.0
300.0
350.0
400.0
450.0
500.0
550.0
TIME - (MINUTE)

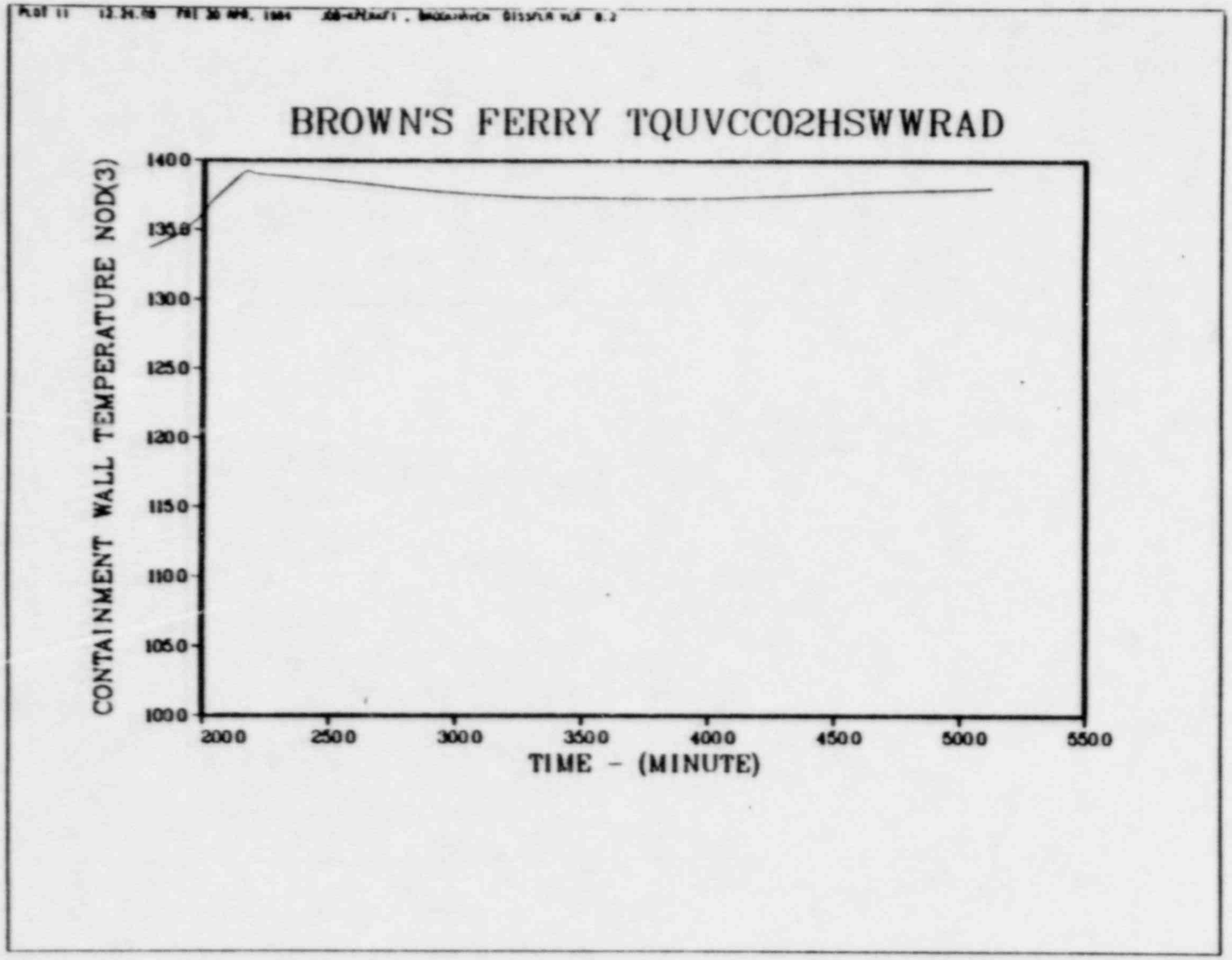

BROWN'S FERRY TQUVCC02HSWWRAD
TOTAL COMPARTMENT PRESSURE
0.0
200.0
400.0
600.0
800.0
1000.0
1200.0
1400.0
1600.0
2000
2500
3000
3500
4000
4500
5000
5500
6000
TIME - (MINUTE)
VOLUME NO. 1

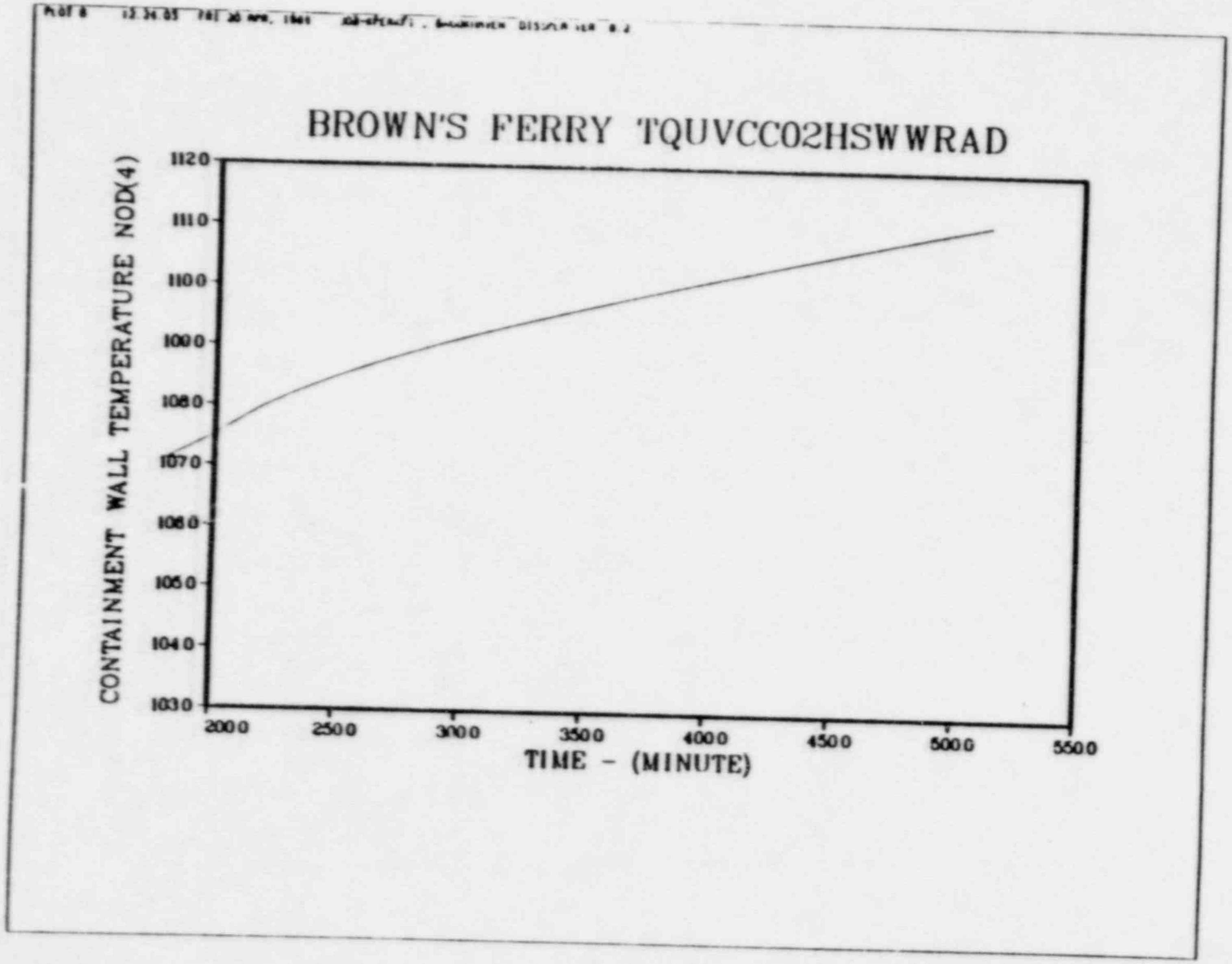

BROWN'S FERRY TQUVCC02HSWWRAD
COMPARTMENT TEMPERATURE
1600.0
1400.0
1200.0
1000.0
800.0
600.0
400.0
200.0
0.0
200.0
250.0
300.0
350.0
400.0
450.0
500.0
550.0
600.0
TIME - (MINUTE)
VOLUME NO. 1

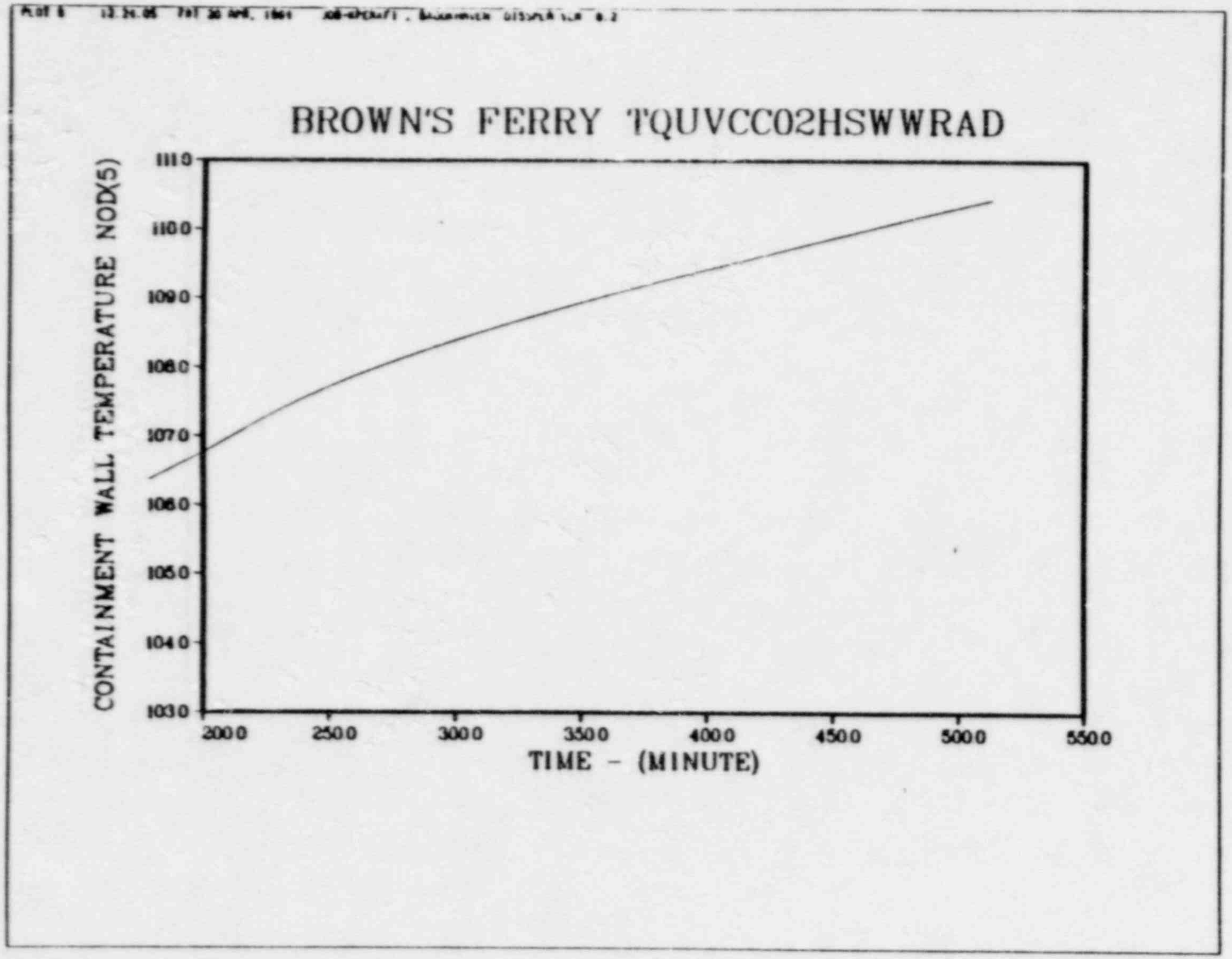

BROWN'S FERRY TQUVCC02HSWWRAD
COMPARTMENT TEMPERATURE
2200.0
2000.0
1800.0
1600.0
1400.0
1200.0
1000.0
0.0
500.0
1000.0
1500.0
2000.0
2500.0
3000.0
3500.0
4000.0
4500.0
5000.0
5500.0
TIME - (MINUTE)
VOLUME NO. 2


BROWN'S FERRY TQUVCC02HSWWRAD
CONTAINMENT WALL TEMPERATURE NODX(1)
3500
3000
2500
2000
1500
1000
2000
2500
3000
3500
4000
4500
5000
5500
TIME - (MINUTE)


BROWN'S FERRY TQUVCC02HSWWRAD
CONTAINMENT WALL TEMPERATURE NOD(2)
1550.0
1500.0
1450.0
1400.0
1350.0
2000
2500
3000
3500
4000
4500
5000
5500
TIME - (MINUTE)


BROWN'S FERRY TQUVCC02HSWWRAD
CONTAINMENT WALL TEMPERATURE NOD(3)
140.0
135.0
130.0
125.0
120.0
115.0
110.0
105.0
100.0
200.0
250.0
300.0
350.0
400.0
450.0
500.0
550.0
TIME - (MINUTE)


BROWN'S FERRY TQUVCC02HSWWRAD
CONTAINMENT WALL TEMPERATURE NOD(4)
1120
1110
1100
1090
1080
1070
1060
1050
1040
1030
2000
2500
3000
3500
4000
4500
5000
5500
TIME - (MINUTE)


BROWN'S FERRY TQUVCC02HSWWRAD
CONTAINMENT WALL TEMPERATURE NOD(5)
TIME - (MINUTE)
1030
1040
1050
1060
1070
1080
1090
1100
1110
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2500
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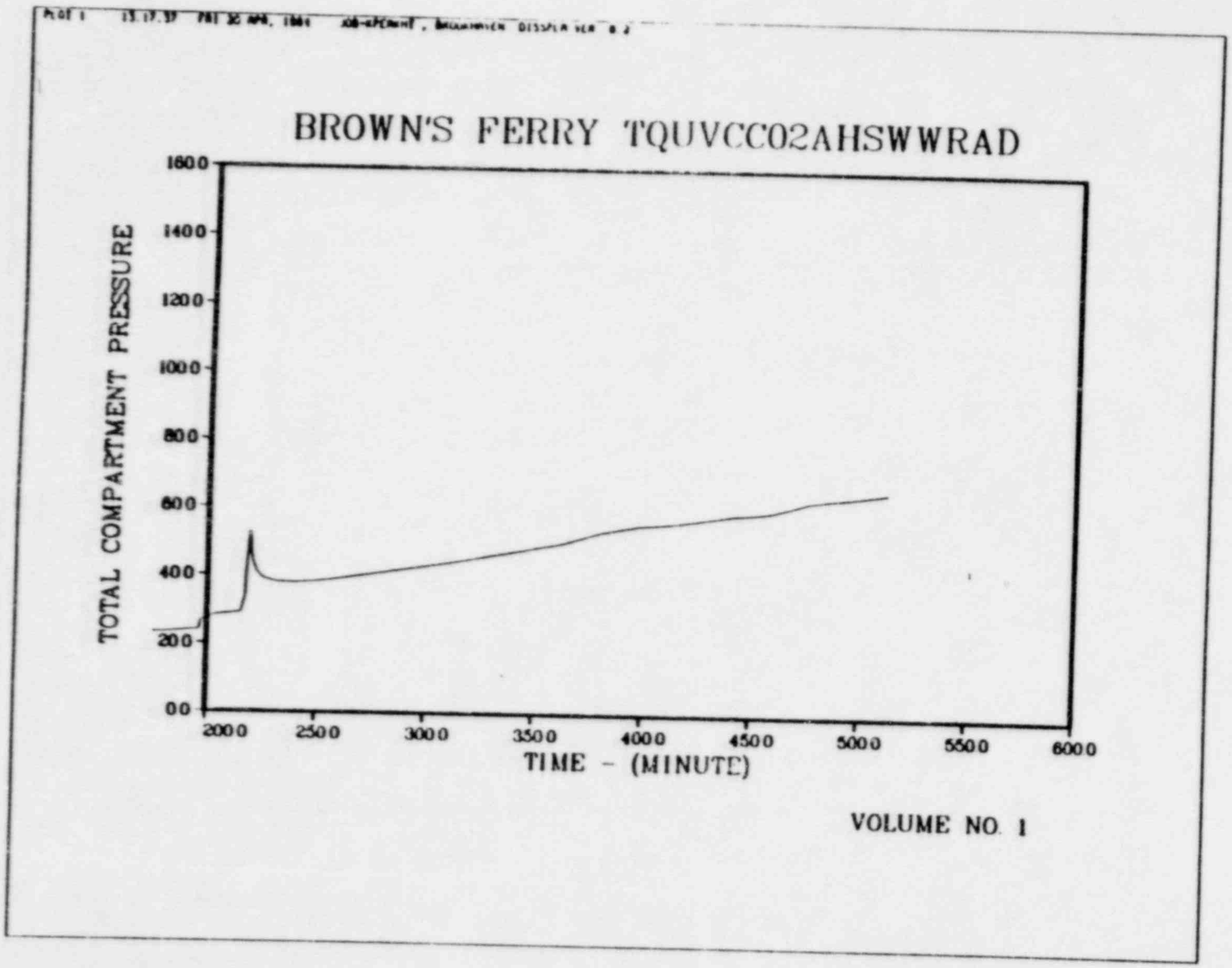
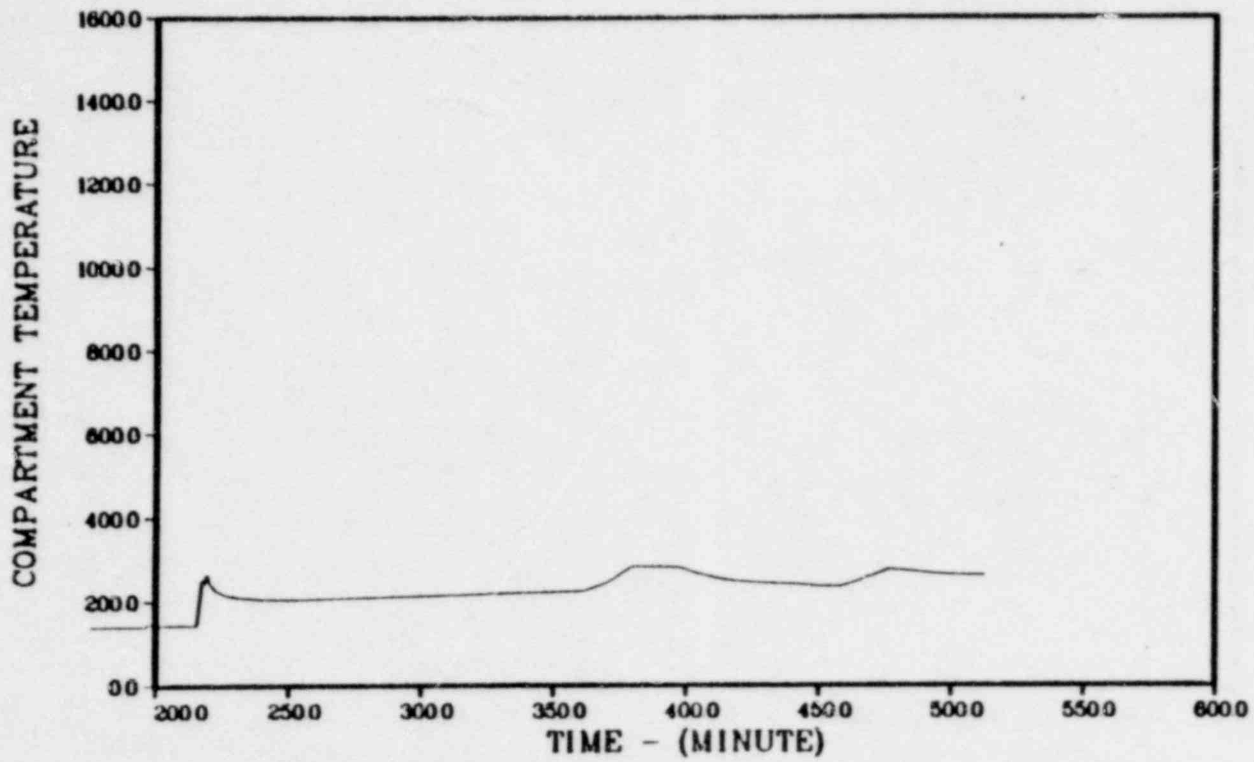
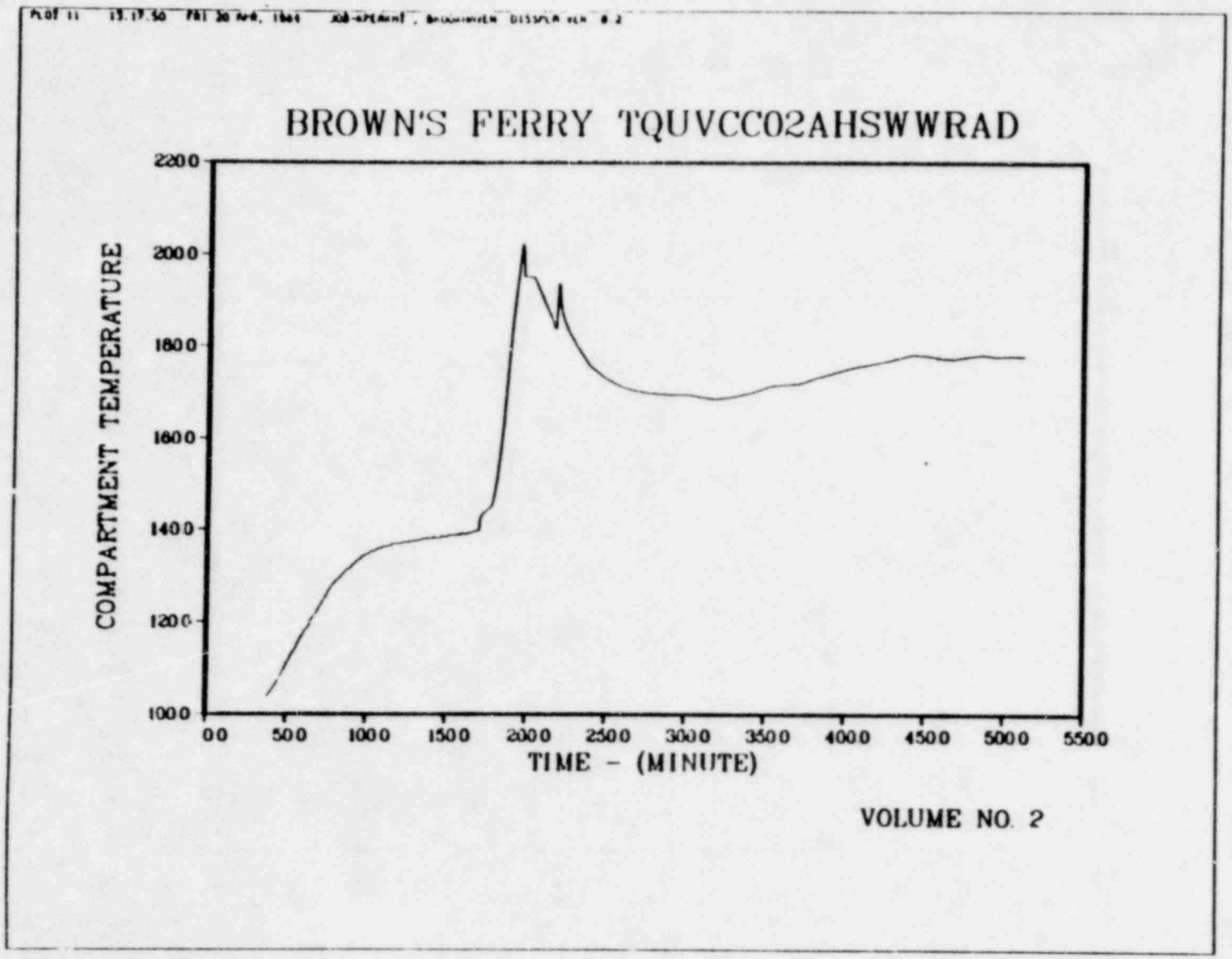
3500
4000
4500
5000
5500

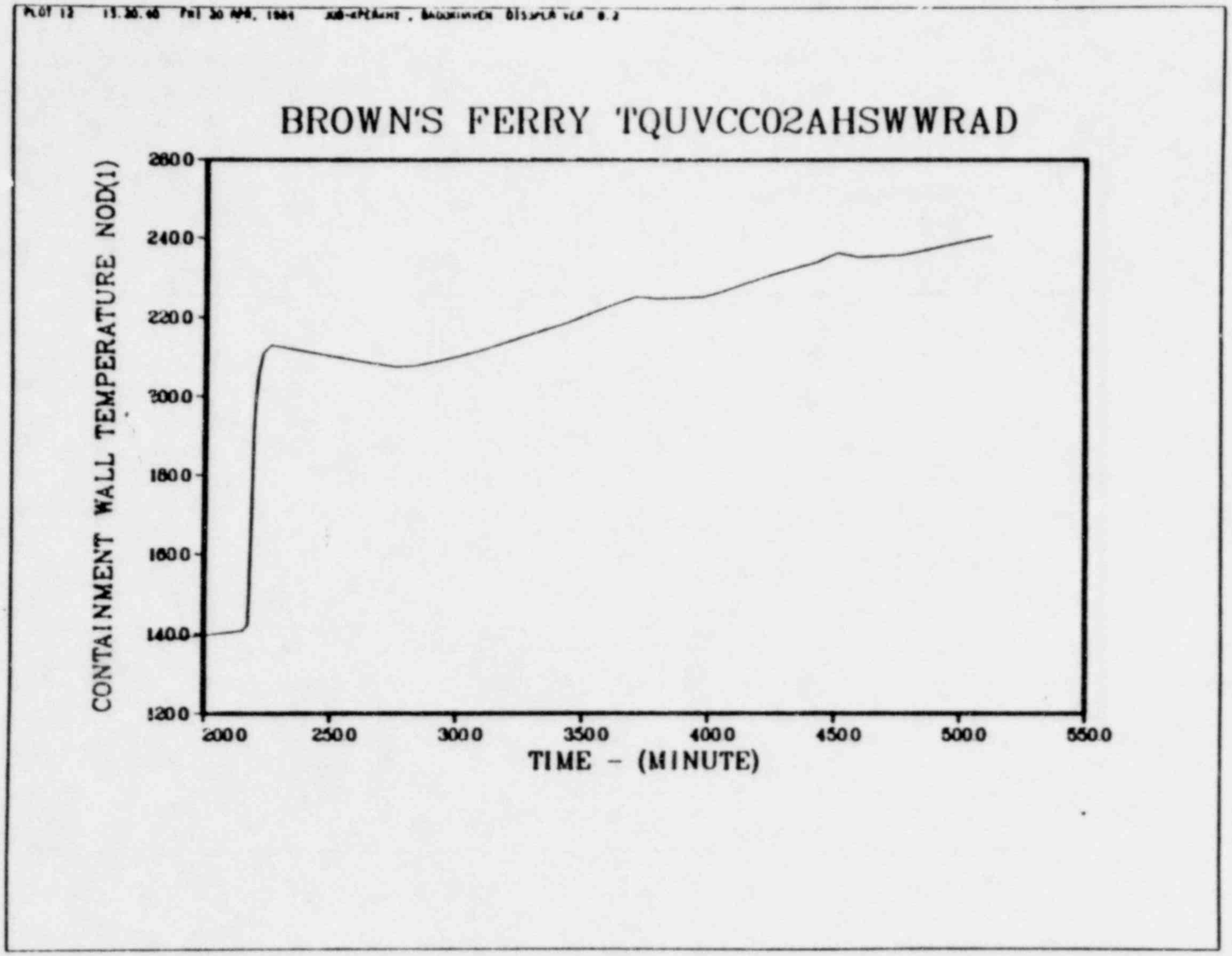

BROWN'S FERRY TQUVCC02AHSWWRAD
TOTAL COMPARTMENT PRESSURE
0.0
200.0
400.0
600.0
800.0
1000.0
1200.0
1400.0
1600.0
2000.0
2500.0
3000.0
3500.0
4000.0
4500.0
5000.0
5500.0
6000.0
TIME - (MINUTE)
VOLUME NO. 1

BROWN'S FERRY TQUVCC02AHSWWRAD

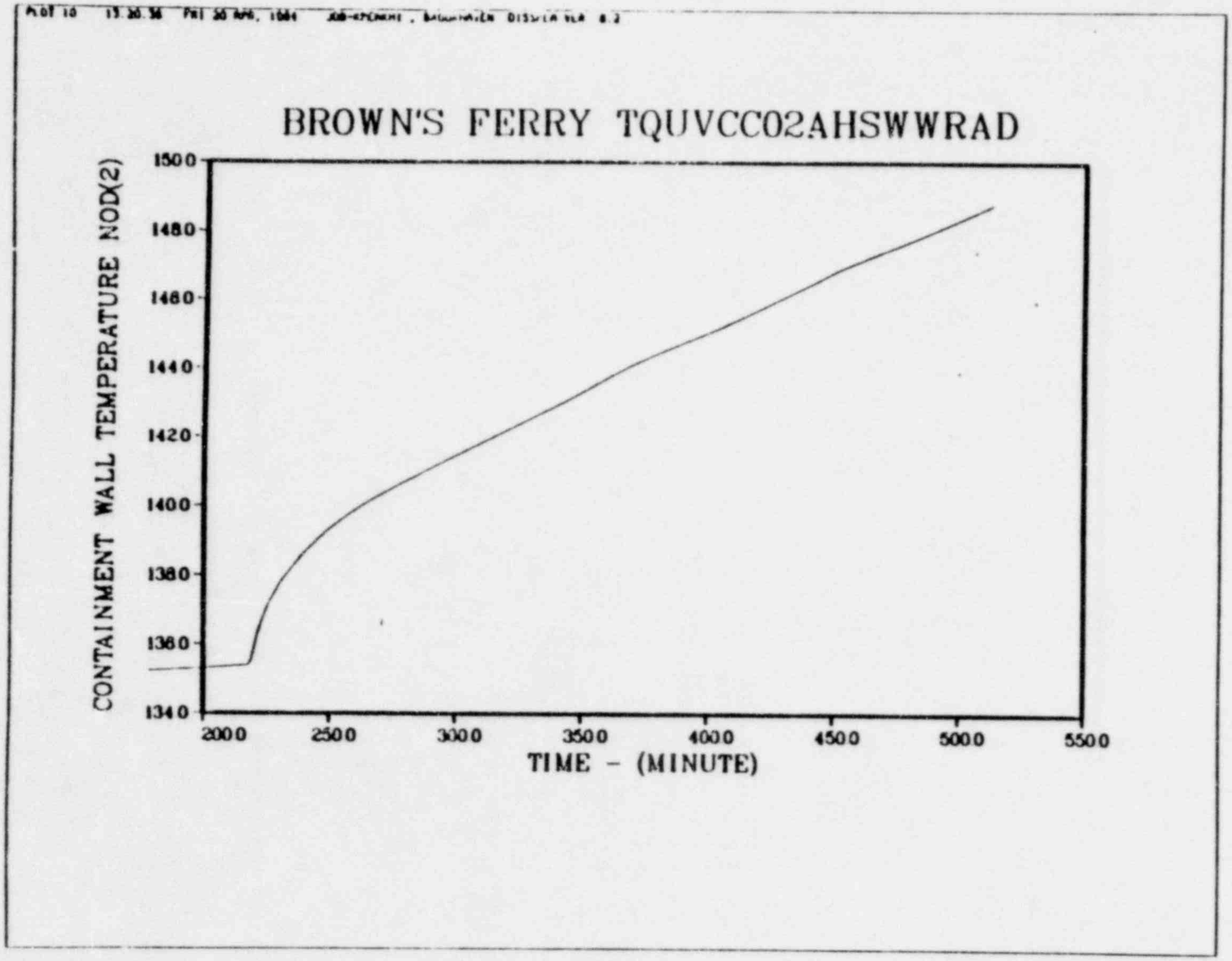


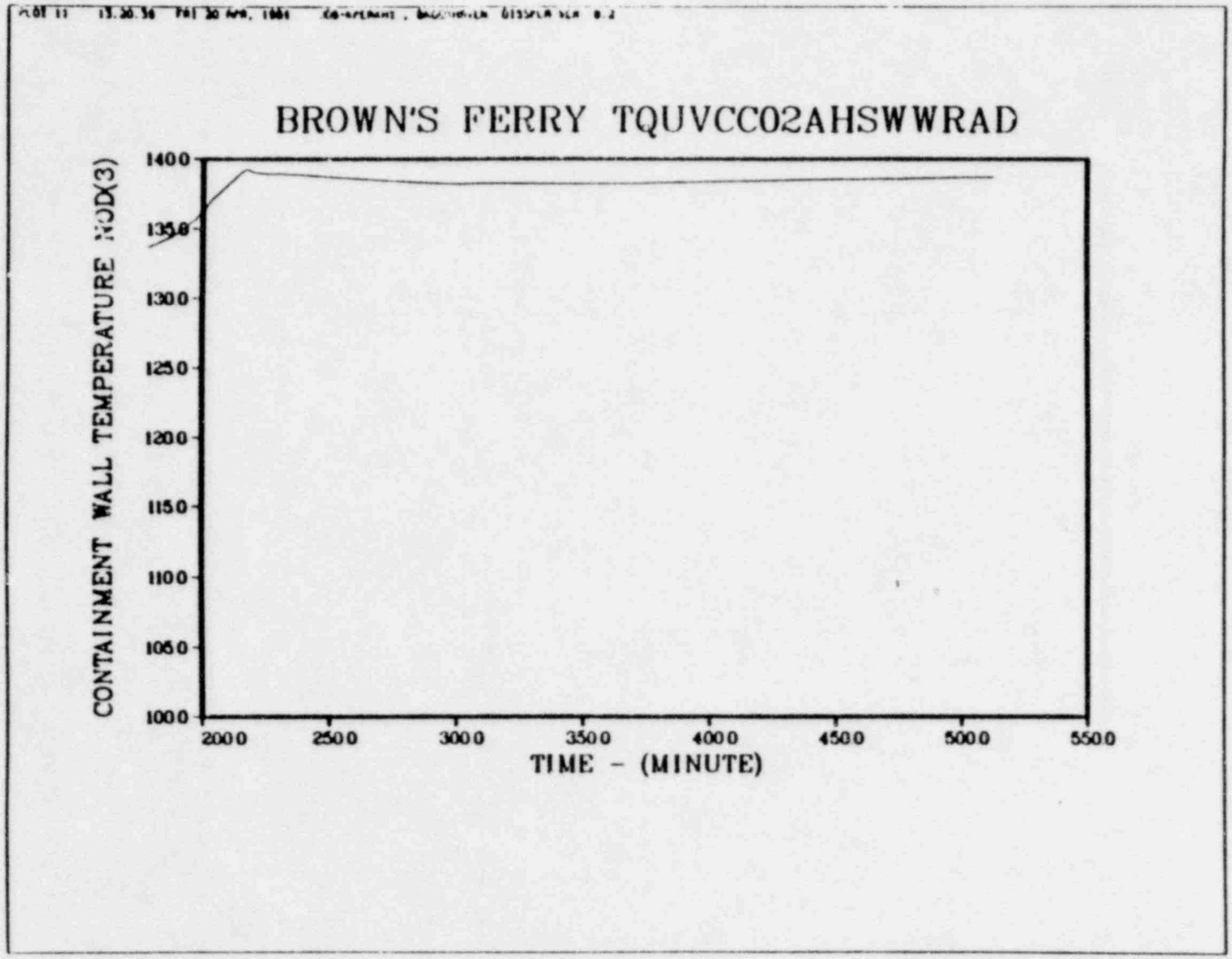
VOLUME NO. 1

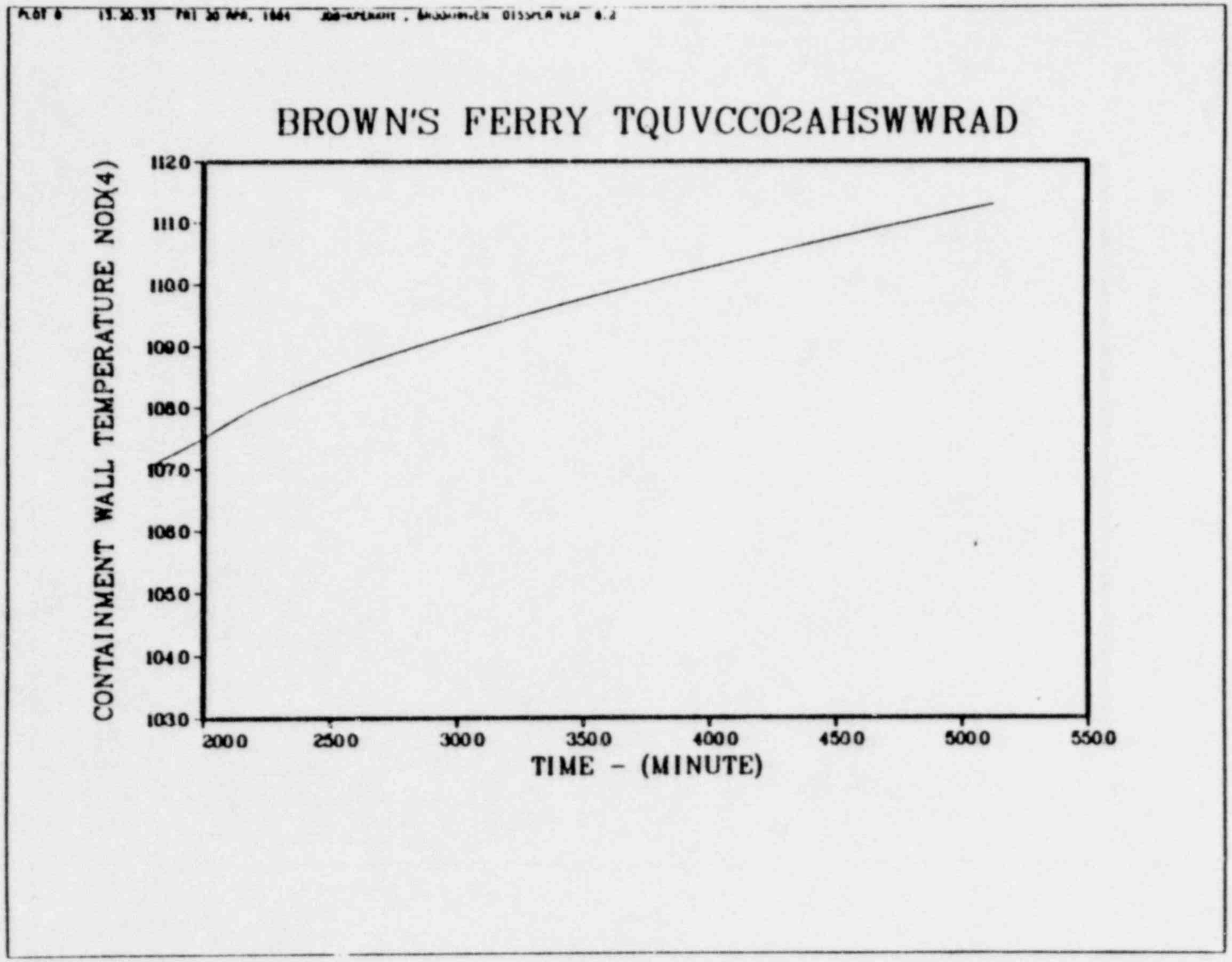

BROWN'S FERRY TQUVCC02AHSWWRAD
COMPARTMENT TEMPERATURE
2200
2000
1800
1600
1400
1200
1000
00
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
TIME - (MINUTE)
VOLUME NO. 2

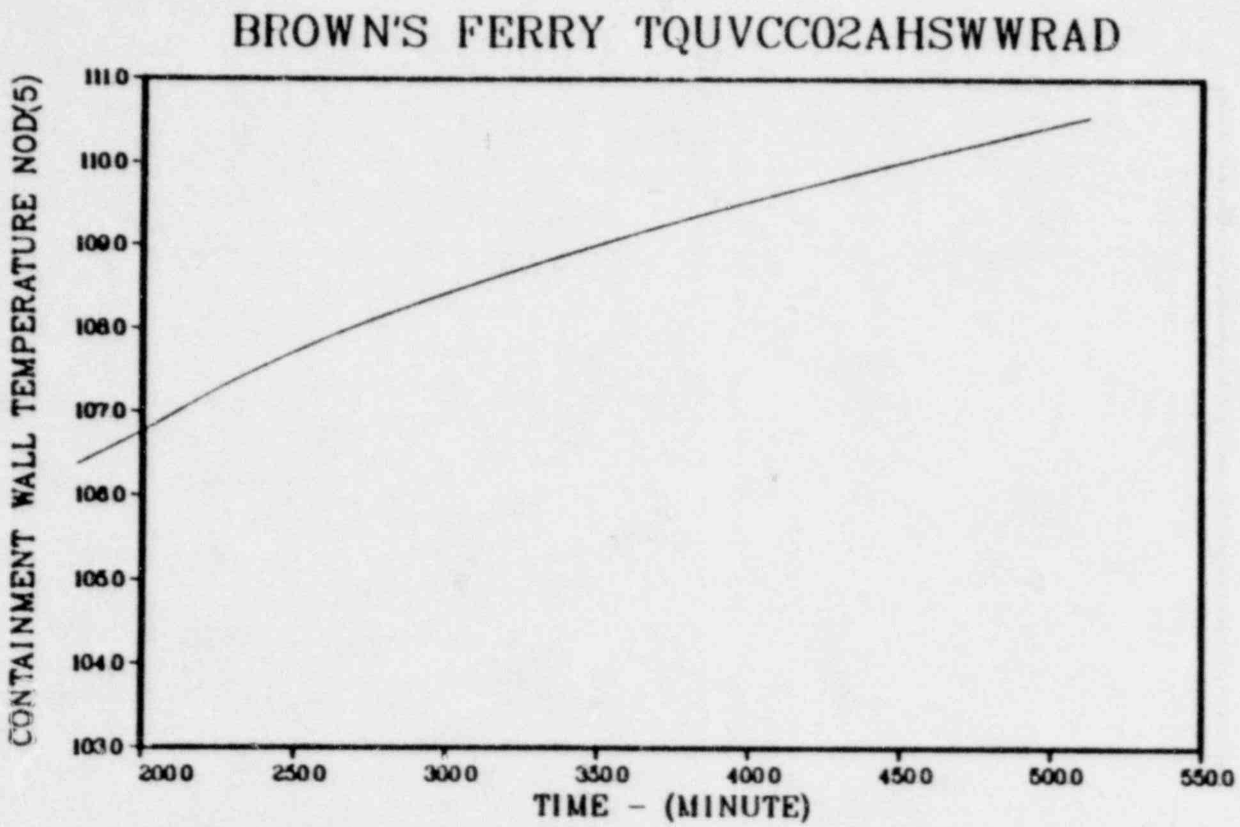


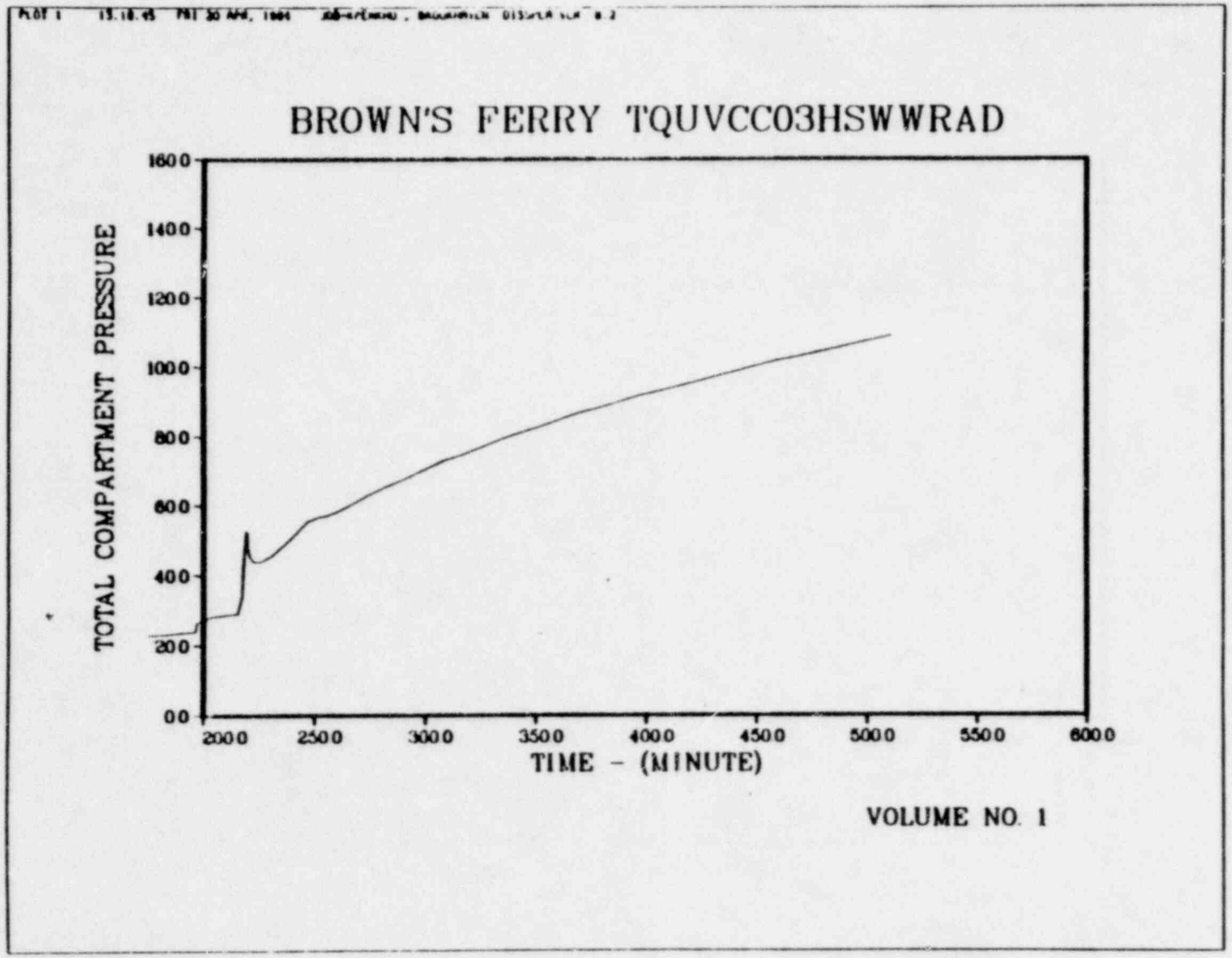
BROWN'S FERRY TQUVCC02AHSWWRAD
CONTAINMENT WALL TEMPERATURE NOD(1)
2600.0
2400.0
2200.0
2000.0
1800.0
1600.0
1400.0
1200.0
2000.0
2500.0
3000.0
3500.0
4000.0
4500.0
5000.0
5500.0
TIME - (MINUTE)


BROWN'S FERRY TQUVCC02AHSWWRAD
CONTAINMENT WALL TEMPERATURE NOD(2)
1500
1480
1460
1440
1420
1400
1380
1360
1340
2000
2500
3000
3500
4000
4500
5000
5500
TIME - (MINUTE)

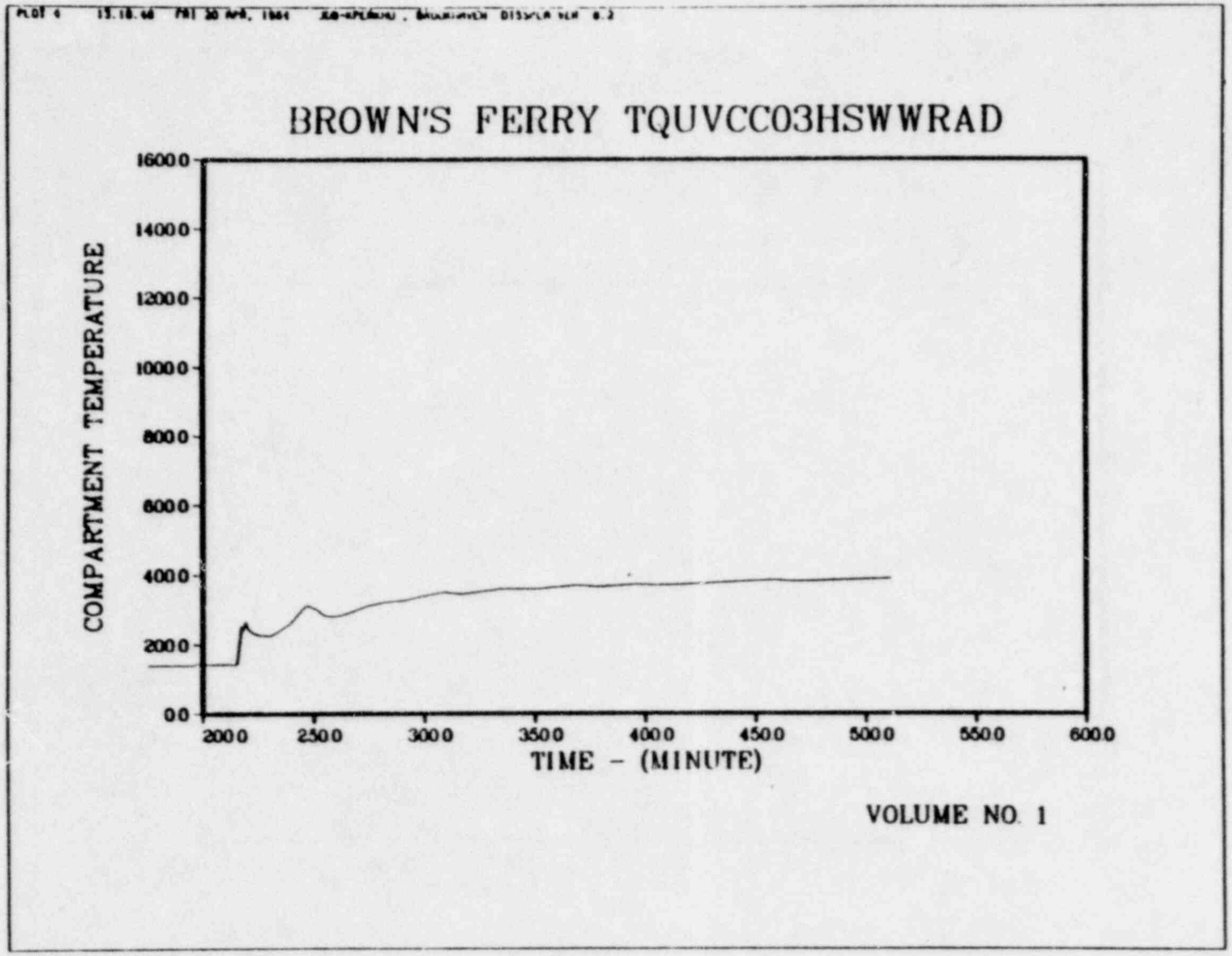

BROWN'S FERRY TQUVCC02AHSWWRAD
CONTAINMENT WALL TEMPERATURE NOD(3)
1400.0
1350.0
1300.0
1250.0
1200.0
1150.0
1100.0
1050.0
1000.0
2000.0
2500.0
3000.0
3500.0
4000.0
4500.0
5000.0
5500.0
TIME - (MINUTE)

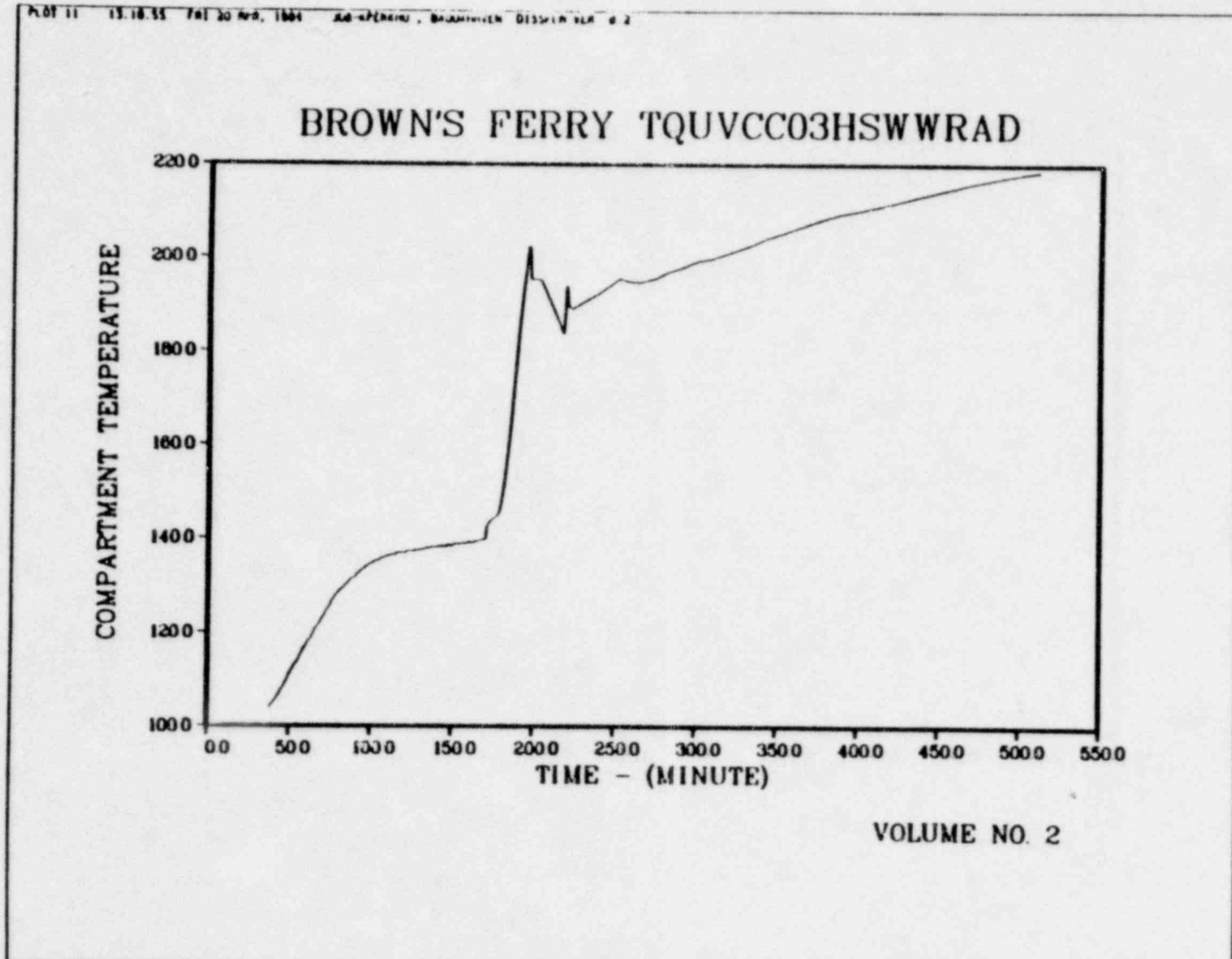

BROWN'S FERRY TQUVCC02AHSWWRAD
CONTAINMENT WALL TEMPERATURE NOD(4)
1120
1110
1100
1090
1080
1070
1060
1050
1040
1030
2000
2500
3000
3500
4000
4500
5000
5500
TIME - (MINUTE)

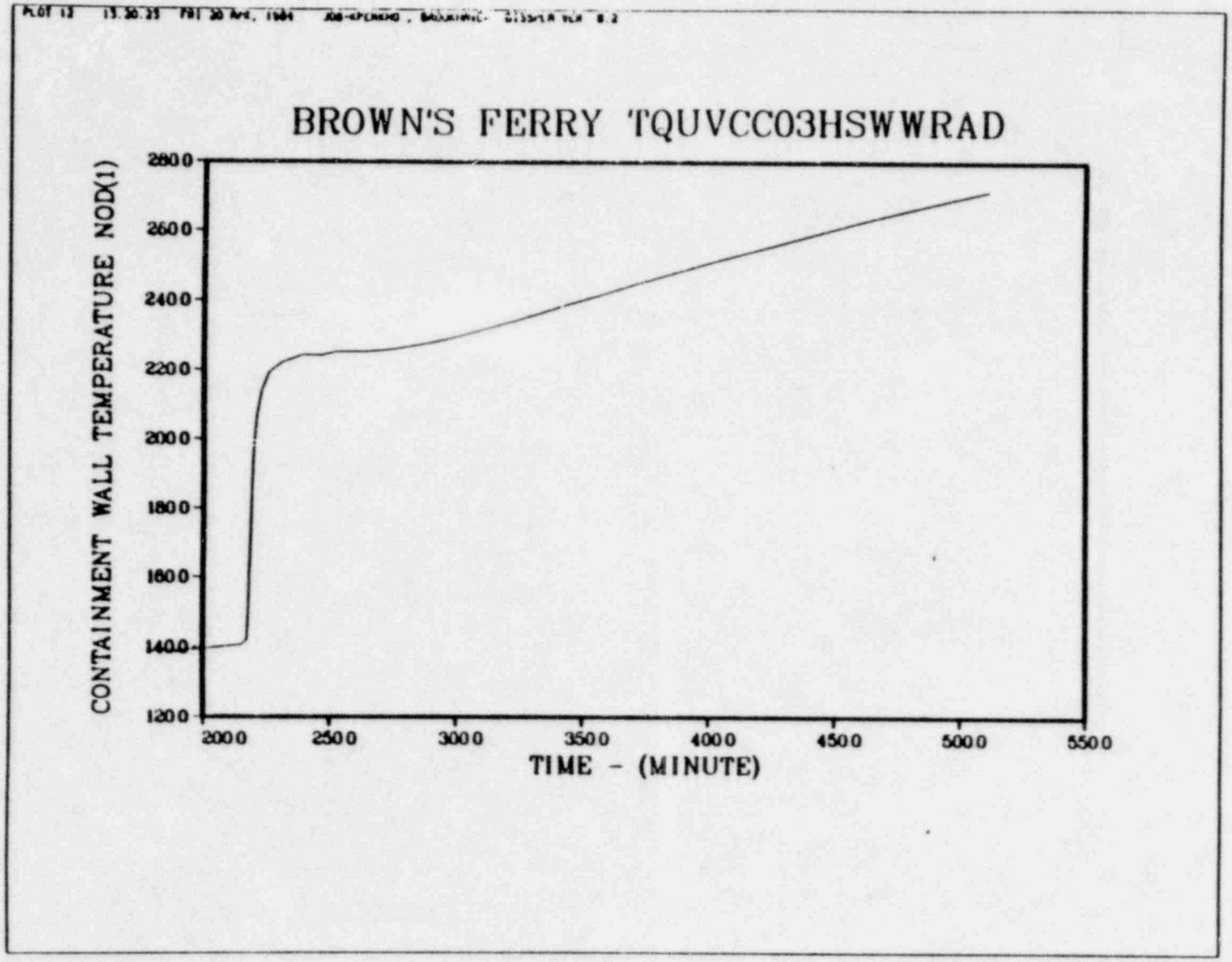

BROWN'S FERRY TQUVCC02AHSWWRAD
CONTAINMENT WALL TEMPERATURE NOD(5)
111.0
110.0
109.0
108.0
107.0
106.0
105.0
104.0
103.0
200.0
250.0
300.0
350.0
400.0
450.0
500.0
550.0
TIME - (MINUTE)



BROWN'S FERRY TQUVCC03HSWWRAD
TOTAL COMPARTMENT PRESSURE
1600
1400
1200
1000
800
600
400
200
00
2000
2500
3000
3500
4000
4500
5000
5500
6000
TIME - (MINUTE)
VOLUME NO. 1


BROWN'S FERRY TQUVCC03HSWWRAD
COMPARTMENT TEMPERATURE
1600.0
1400.0
1200.0
1000.0
800.0
600.0
400.0
200.0
0.0
200.0
250.0
300.0
350.0
400.0
450.0
500.0
550.0
600.0
TIME - (MINUTE)
VOLUME NO. 1


BROWN'S FERRY TQUVCC03HSWWRAD
COMPARTMENT TEMPERATURE
2200.0
2000.0
1800.0
1600.0
1400.0
1200.0
1000.0
0.0
500.0
1000.0
1500.0
2000.0
2500.0
3000.0
3500.0
4000.0
4500.0
5000.0
5500.0
TIME - (MINUTE)
VOLUME NO. 2


BROWN'S FERRY TQUVCC03HSWWRAD
CONTAINMENT WALL TEMPERATURE NOD(1)
TIME - (MINUTE)
2800
2600
2400
2200
2000
1800
1600
1400
1200
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2500
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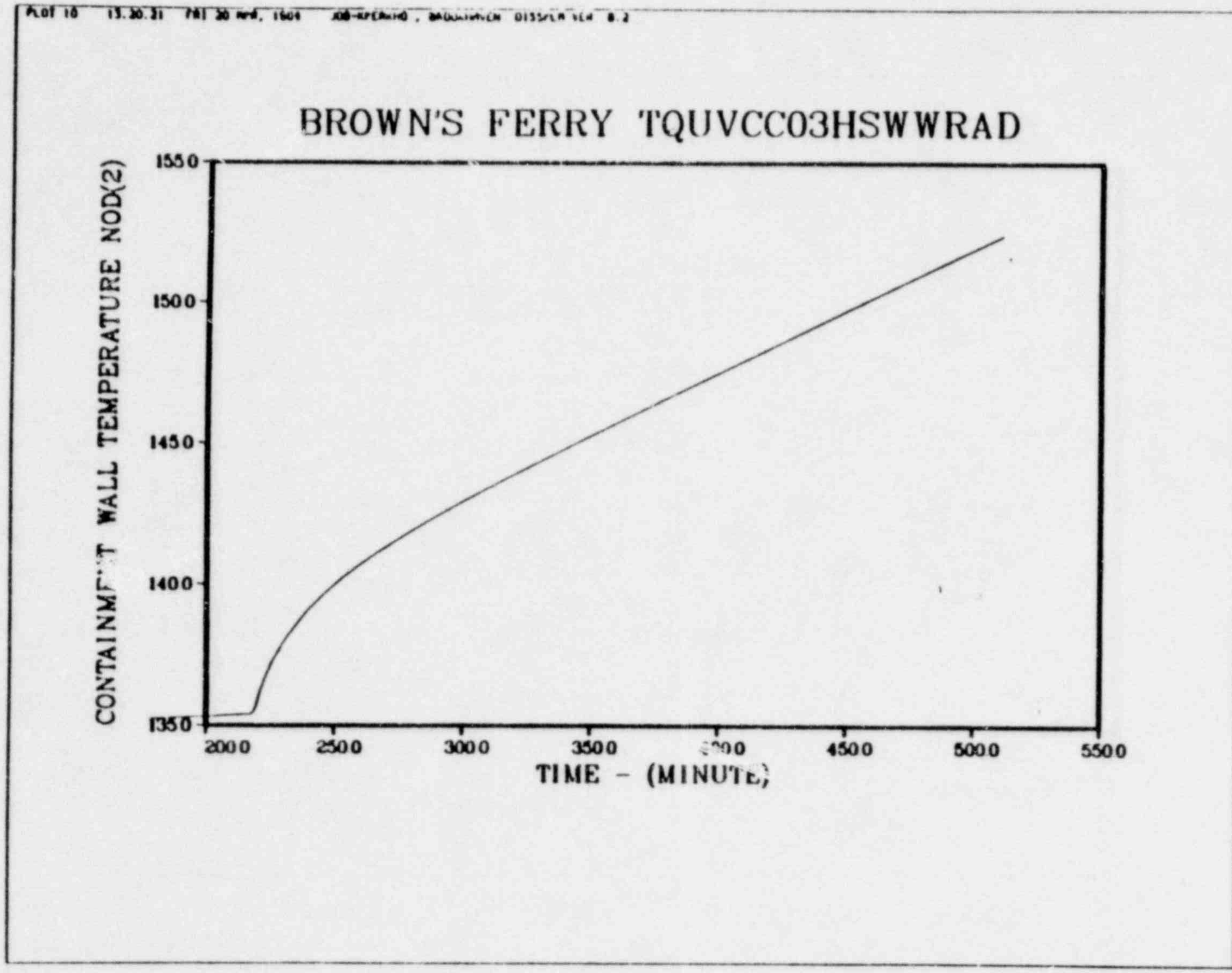
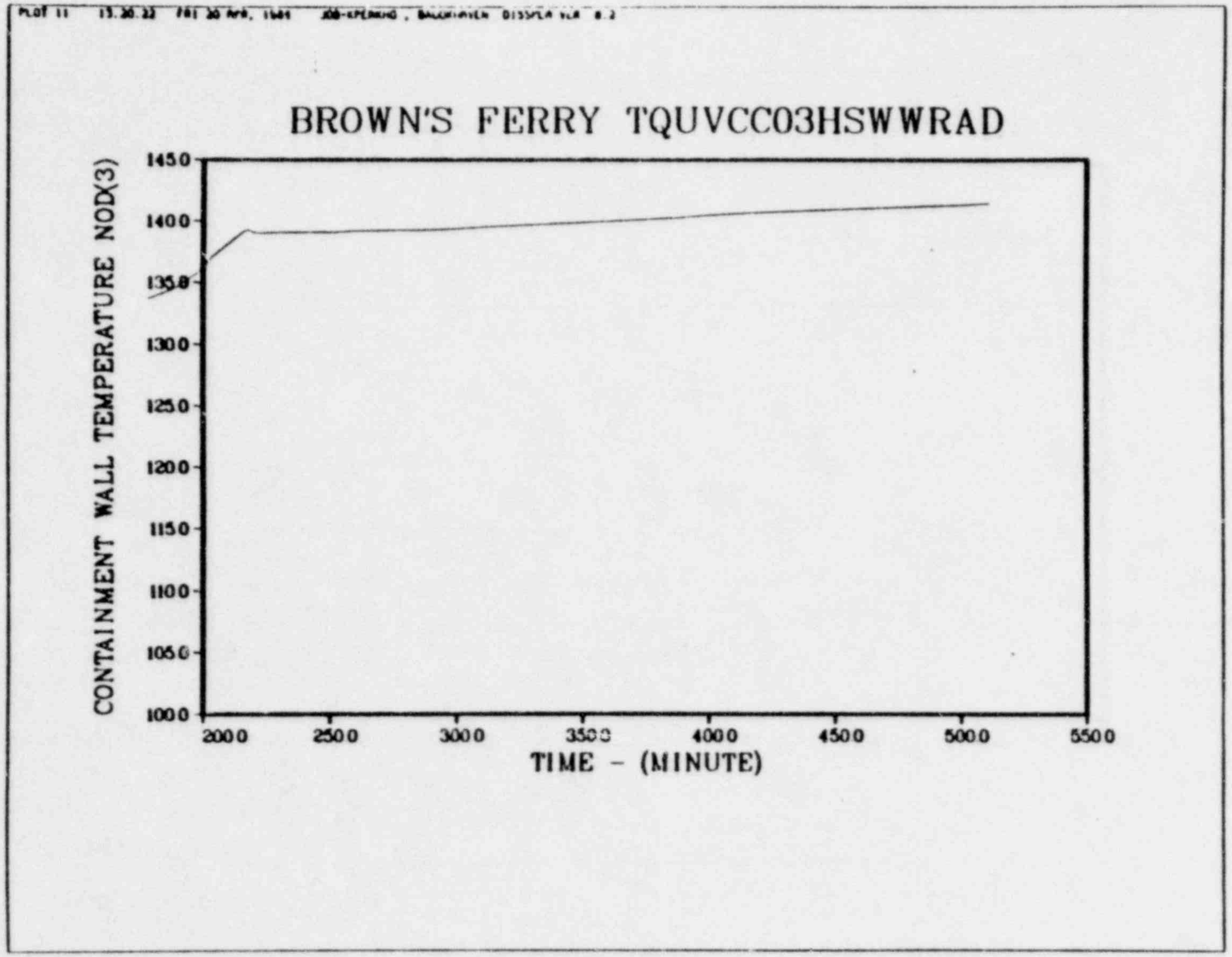
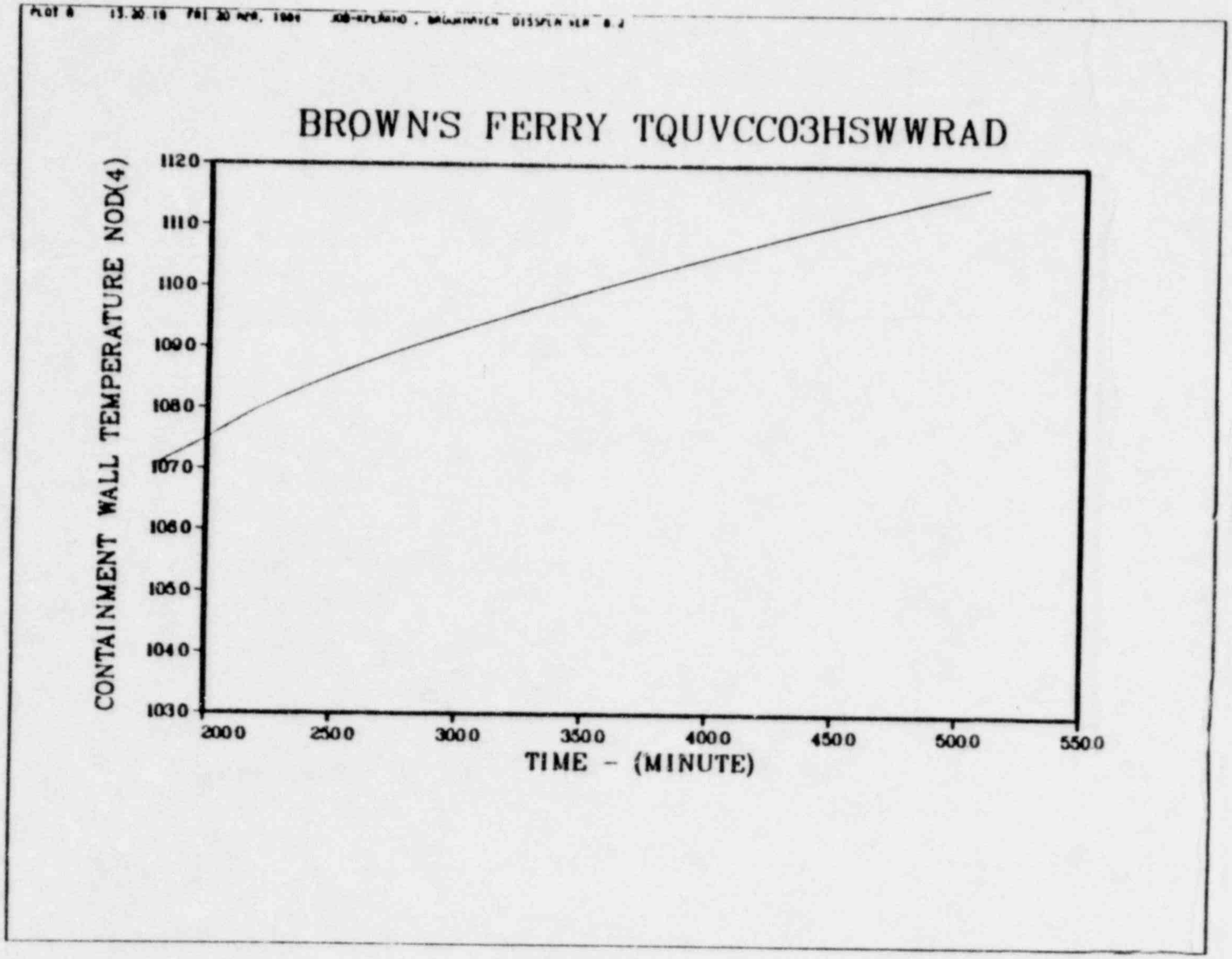
3500
4000
4500
5000
5500

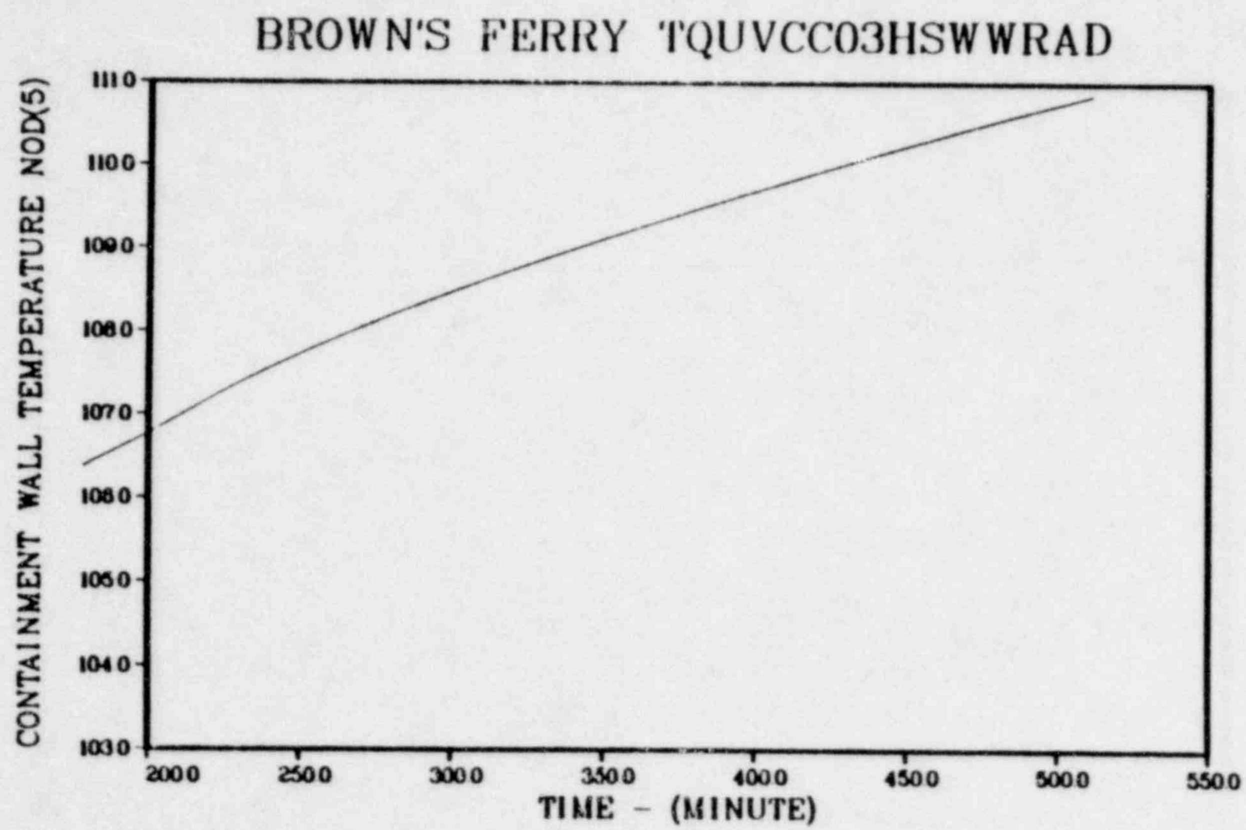


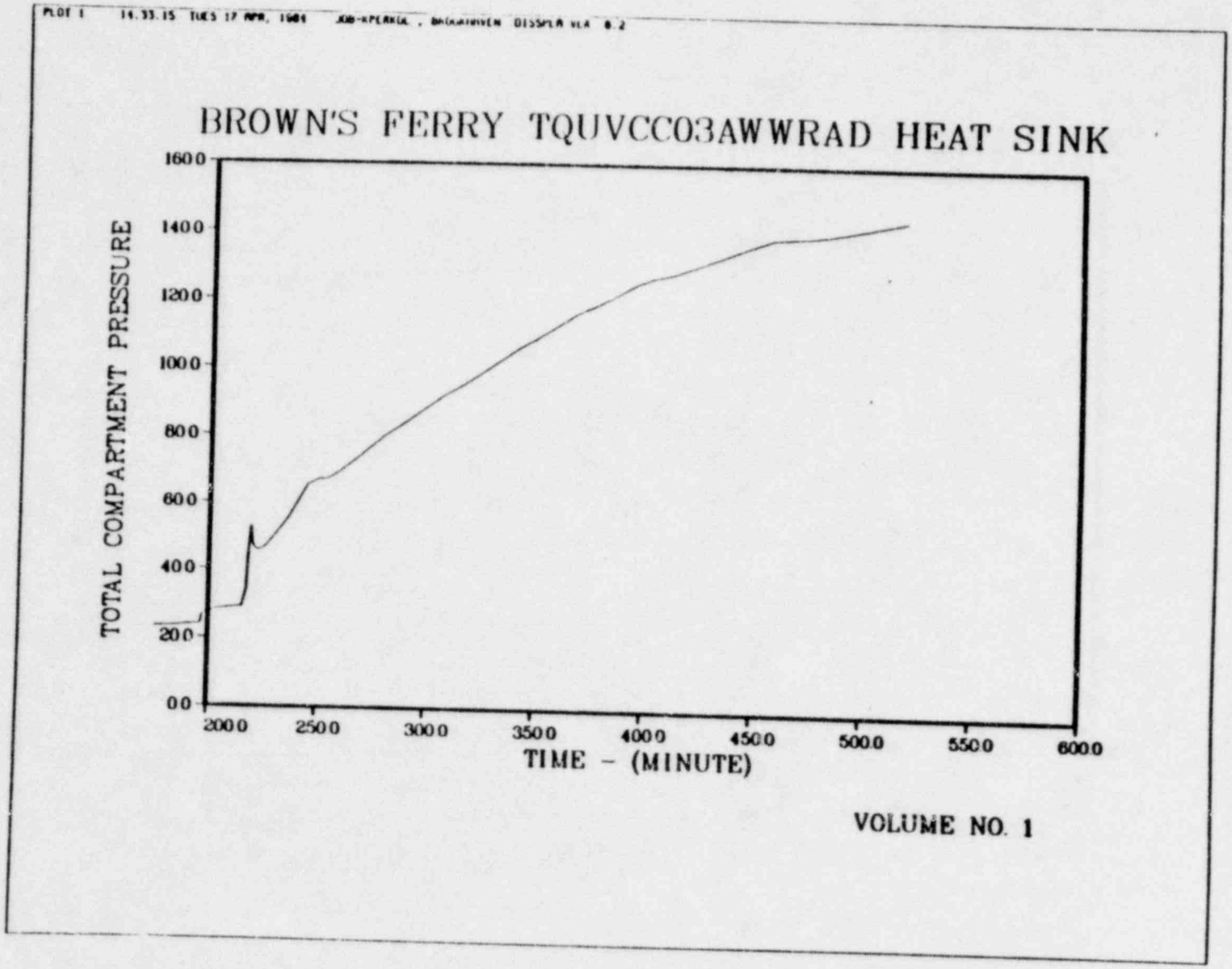
BROWN'S FERRY TQUVCC03HSWWRAD
1550.0
1500.0
1450.0
1400.0
1350.0
CONTAINMENT WALL TEMPERATURE NOD(2)
2000
2500
3000
3500
4500
5000
5500
TIME - (MINUTE)

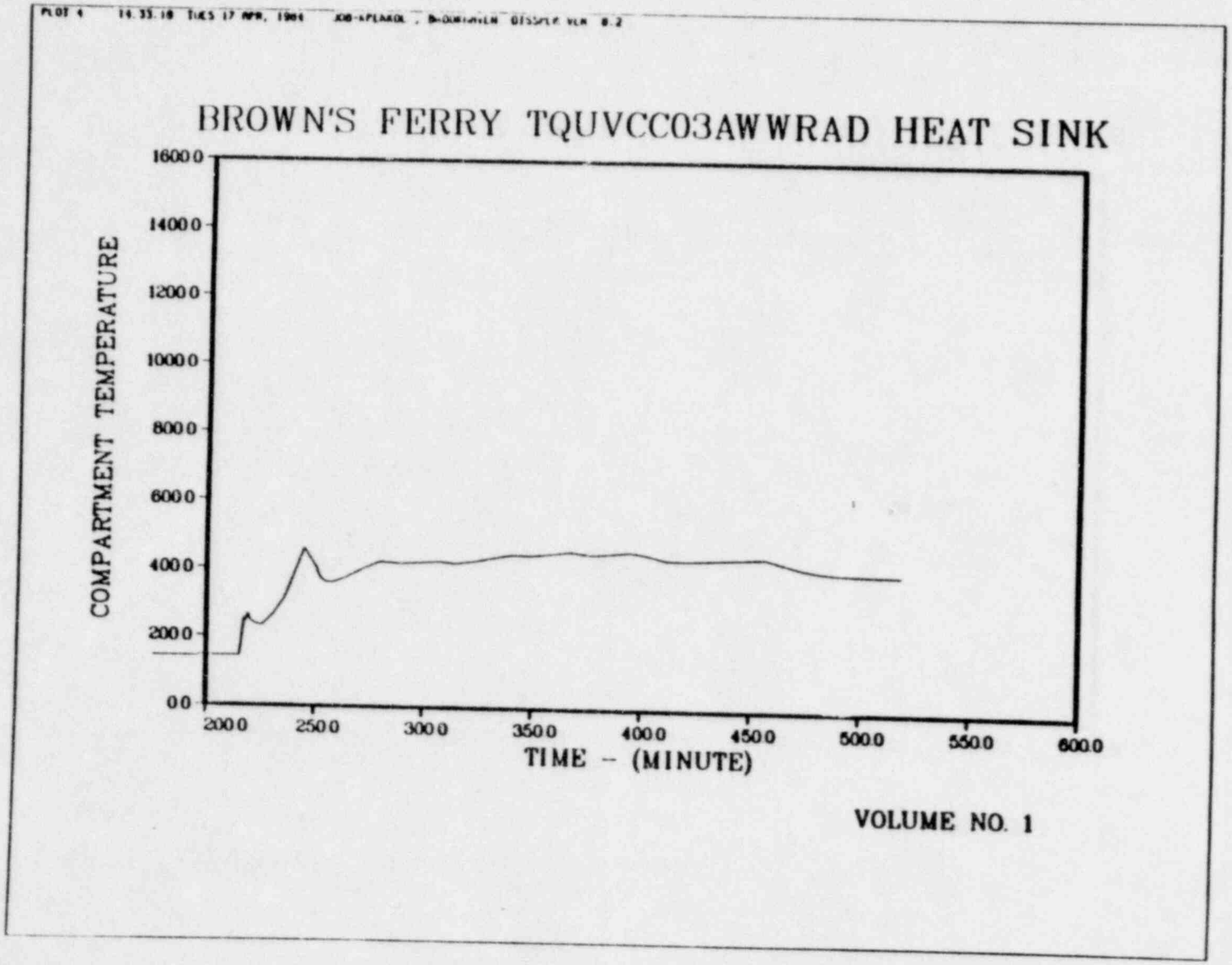


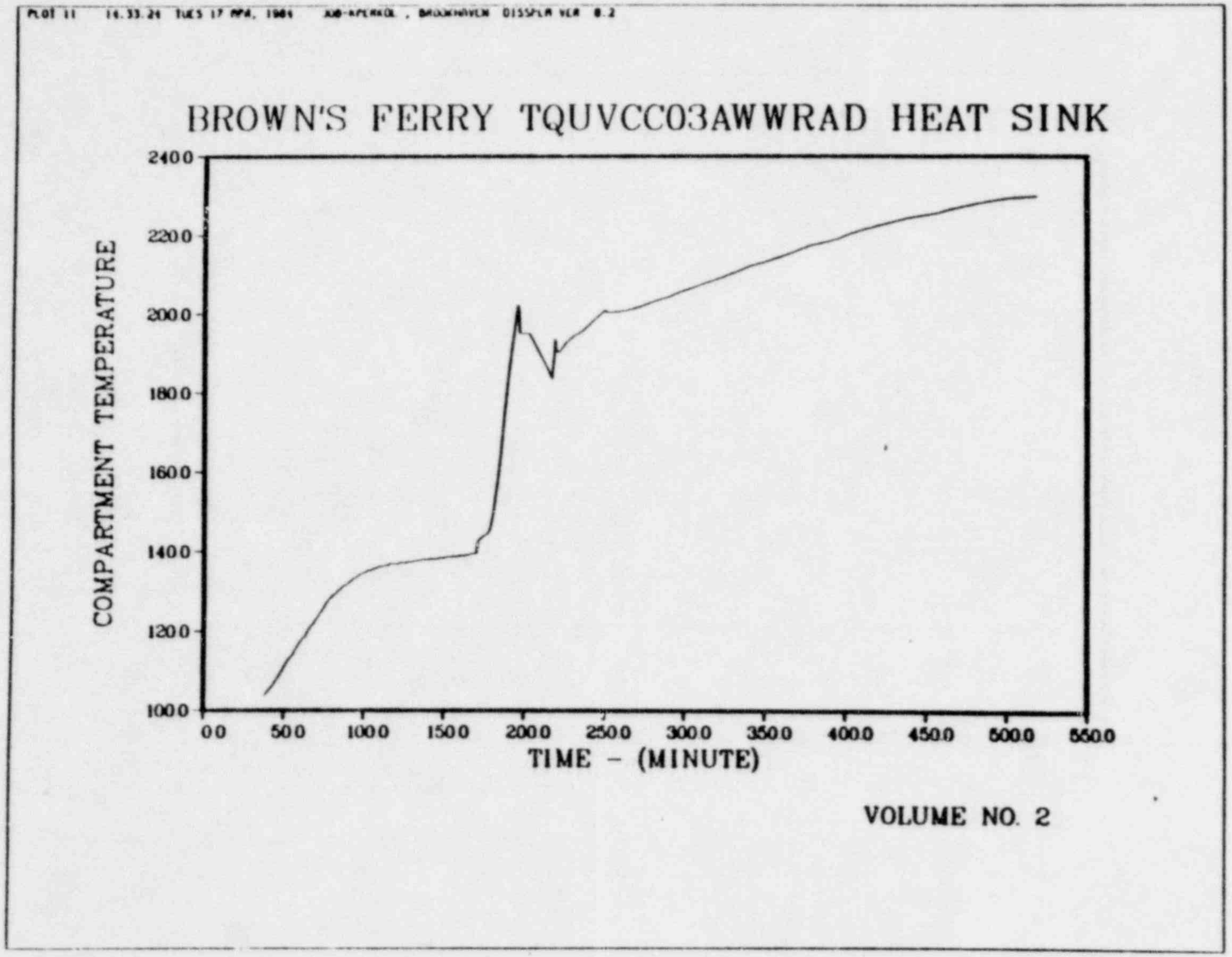
BROWN'S FERRY TQUVCC03HSWWRAD
CONTAINMENT WALL TEMPERATURE NOD(3)
145.0
140.0
135.0
130.0
125.0
120.0
115.0
110.0
105.0
100.0
200.0
250.0
300.0
350.0
400.0
450.0
500.0
550.0
TIME - (MINUTE)


BROWN'S FERRY TQUVCC03HSWWRAD
CONTAINMENT WALL TEMPERATURE NOD(4)
1030.0
1040.0
1050.0
1060.0
1070.0
1080.0
1090.0
1100.0
1110.0
1120.0
200.0
250.0
300.0
350.0
400.0
450.0
500.0
550.0
TIME - (MINUTE)


BROWN'S FERRY TQUVCC03HSWWRAD
CONTAINMENT WALL TEMPERATURE NOD(5)
1110
1100
1090
1080
1070
1060
1050
1040
1030
2000
2500
3000
3500
4000
4500
5000
5500
TIME - (MINUTE)

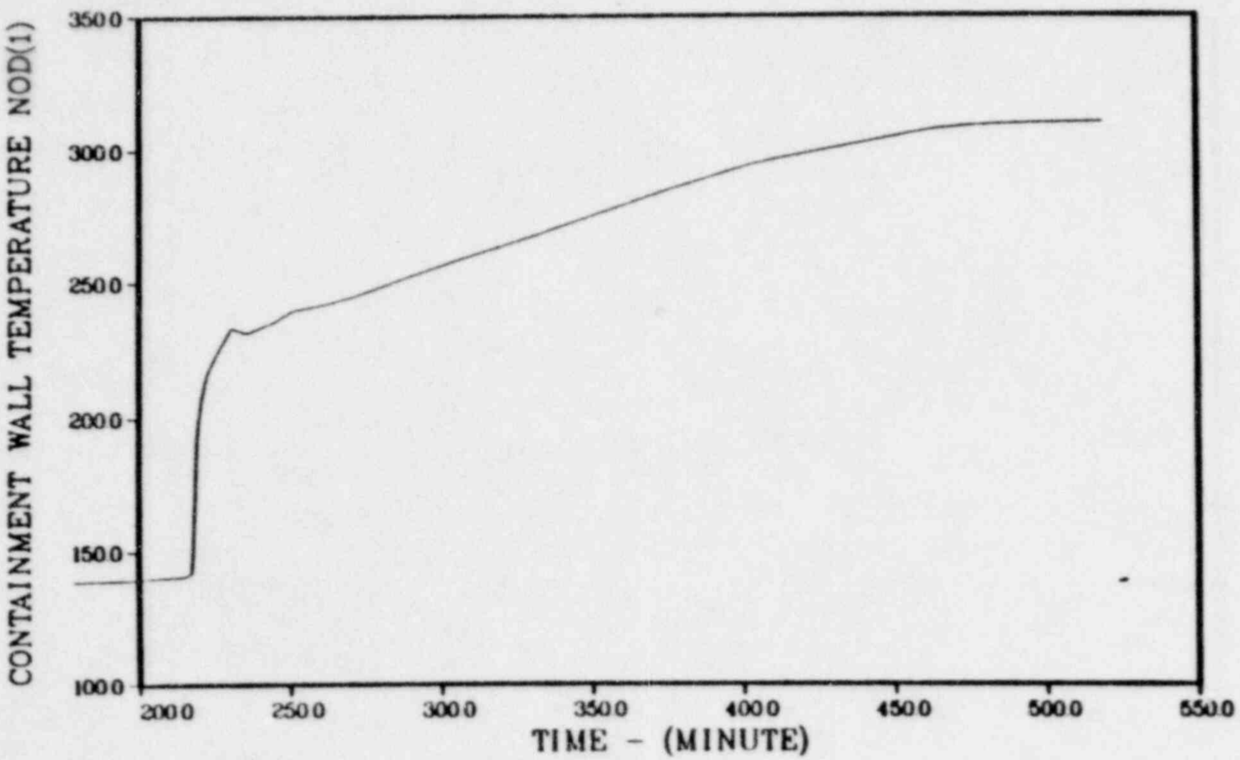

PLOT 1 14.33.15 TUES 17 APR, 1984 JOB-KPERKIA , BROOKHAVEN DISSPLA VER 8.2
BROWN'S FERRY TQUVCC03AWWRAD HEAT SINK
TOTAL COMPARTMENT PRESSURE
0.0
20.0
40.0
60.0
80.0
100.0
120.0
140.0
160.0
200.0
250.0
300.0
350.0
400.0
450.0
500.0
550.0
600.0
TIME - (MINUTE)
VOLUME NO. 1

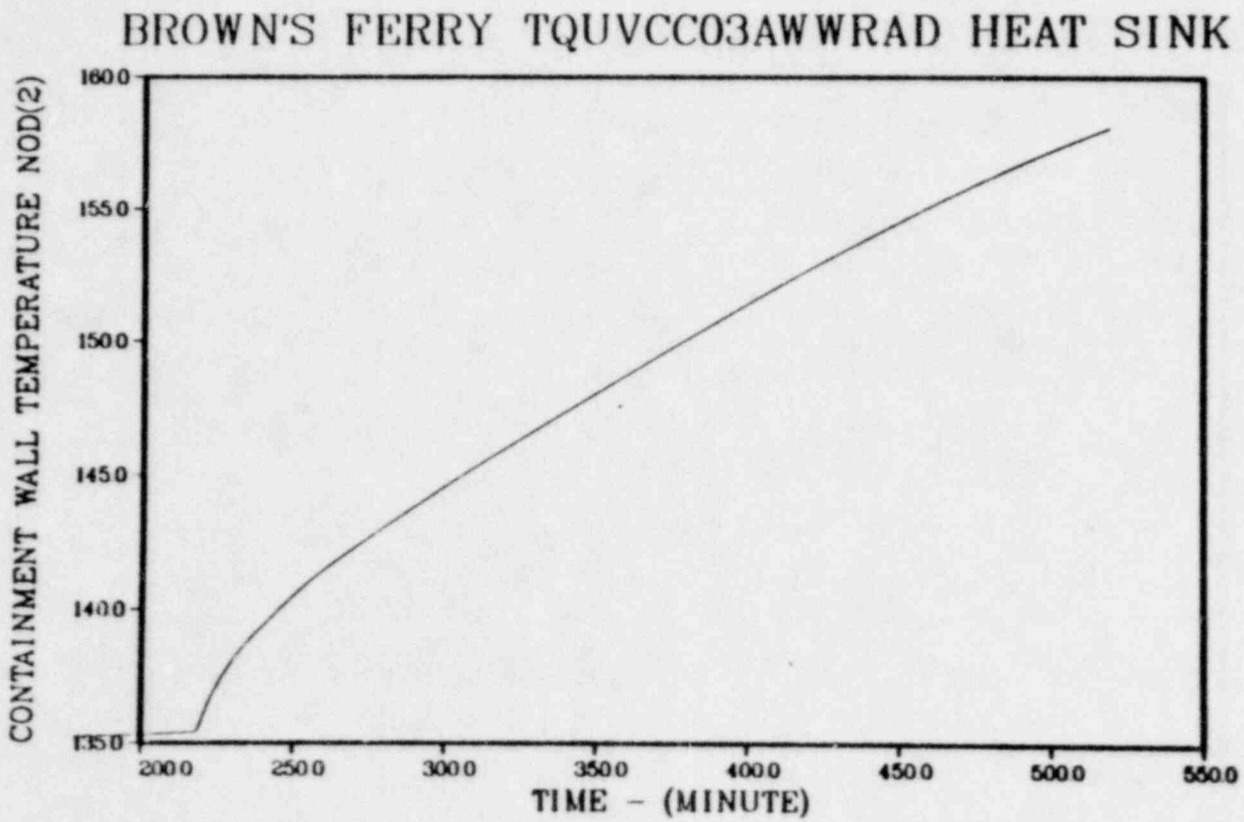

BROWN'S FERRY TQUVCC03AWWRAD HEAT SINK
COMPARTMENT TEMPERATURE
1600.0
1400.0
1200.0
1000.0
800.0
600.0
400.0
200.0
0.0
200.0
250.0
300.0
350.0
400.0
450.0
500.0
550.0
600.0
TIME – (MINUTE)
VOLUME NO. 1


BROWN'S FERRY TQUVCC03AWWRAD HEAT SINK
COMPARTMENT TEMPERATURE
240.0
220.0
200.0
180.0
160.0
140.0
120.0
100.0
0.0
50.0
100.0
150.0
200.0
250.0
300.0
350.0
400.0
450.0
500.0
550.0
TIME - (MINUTE)
VOLUME NO. 2

PLOT 12 14.33.33 TUES 17 APR, BROOKHAVEN DISSPLA VER 8.2

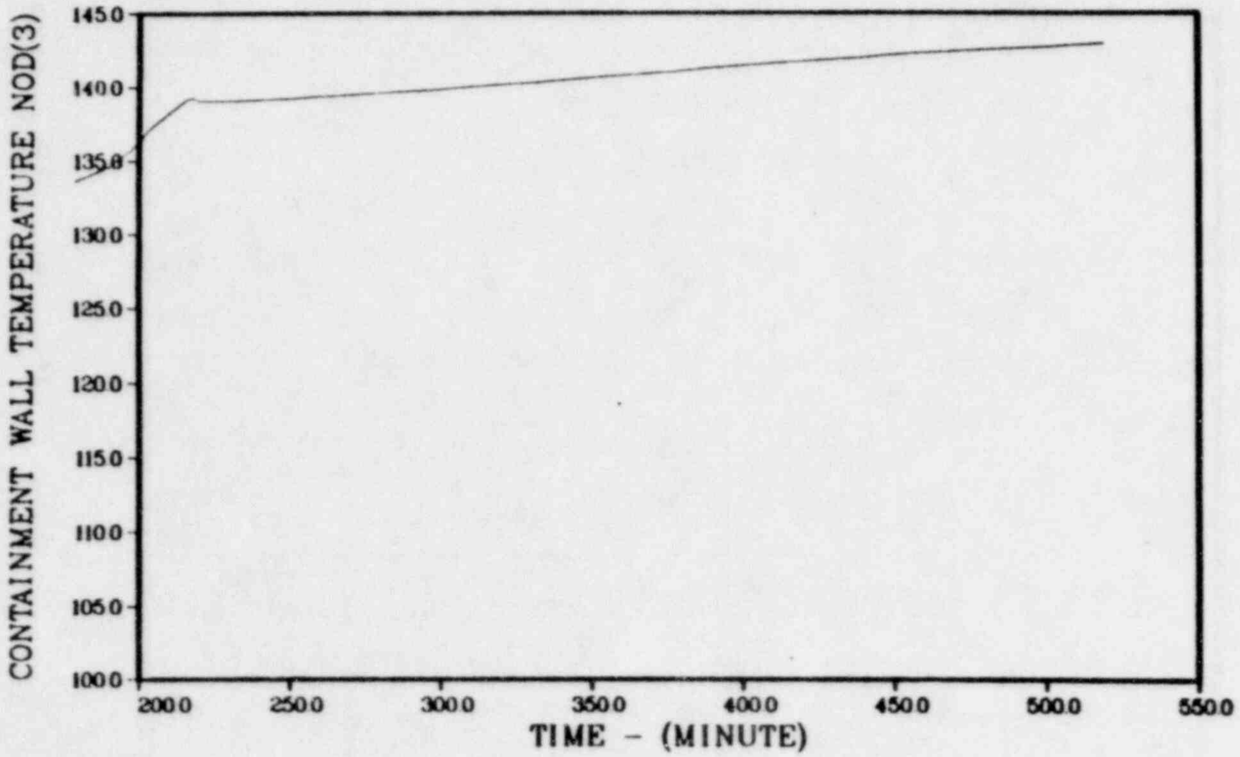
BROWN'S FERRY TQUVCC03AWWRAD HEAT SINK

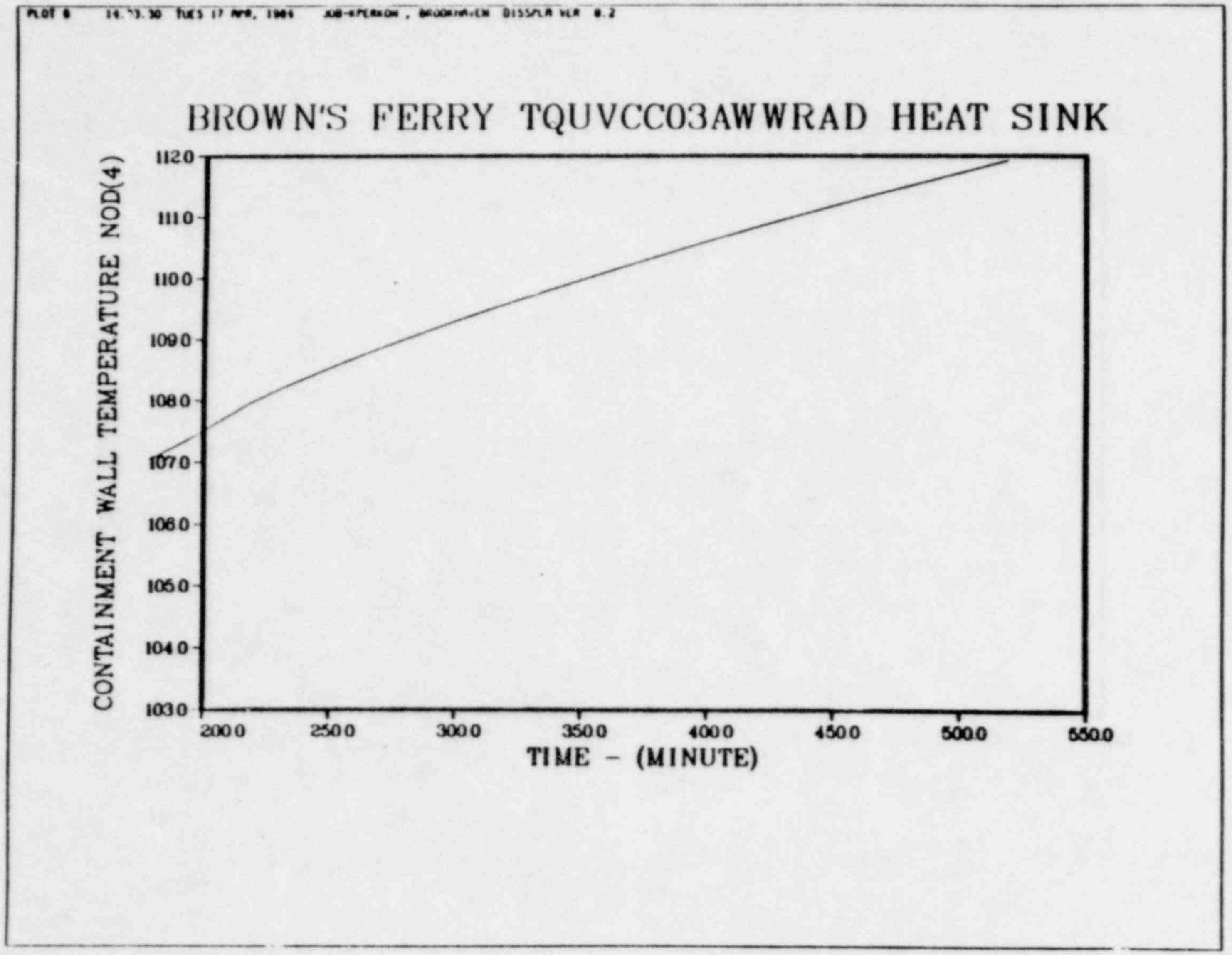


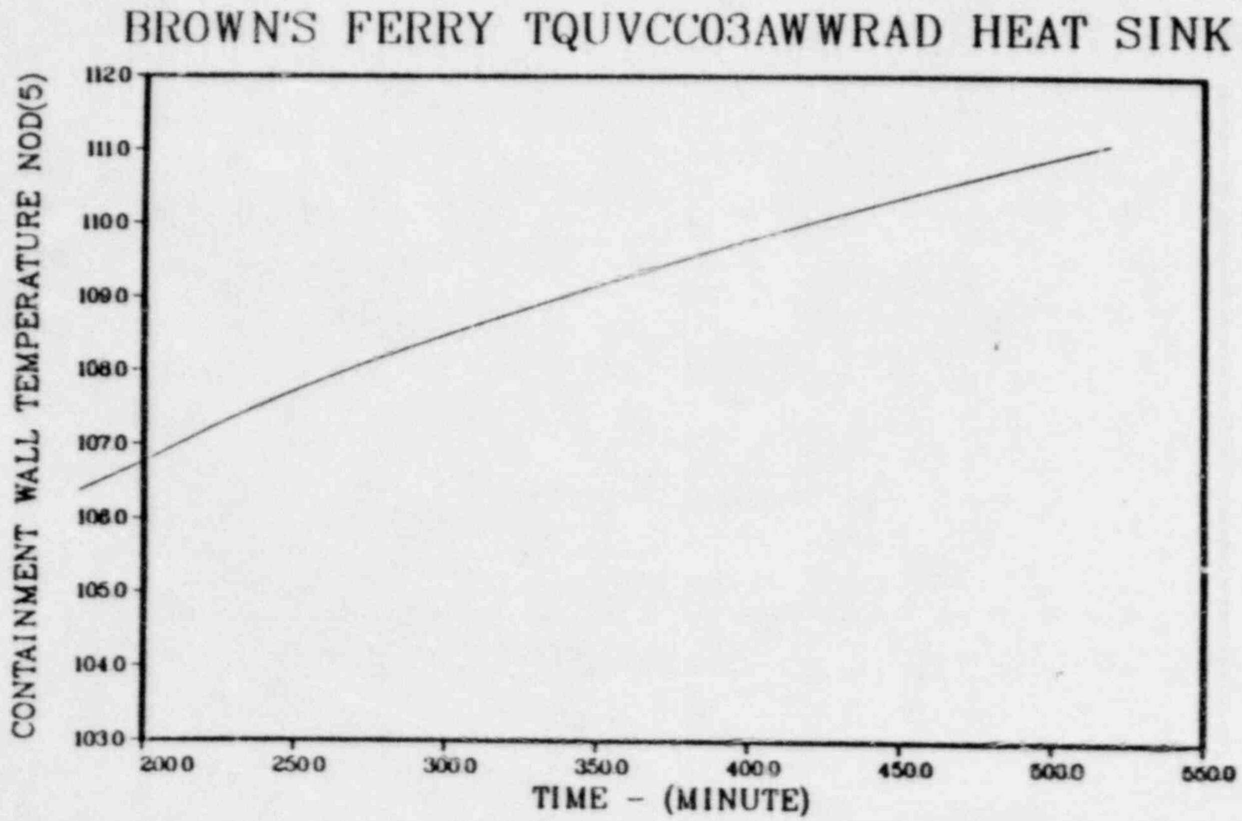

BROWN'S FERRY TQUVCC03AWWRAD HEAT SINK
CONTAINMENT WALL TEMPERATURE NOD(2)
1600
1550
1500
1450
1400
1350
2000
2500
3000
3500
4000
4500
5000
5500
TIME - (MINUTE)

PLOT 11 14.33.32 TUES 17 APR, 1984 JOB-KPERKON , BROOKHAVEN DISSPLA VER 8.2

BROWN'S FERRY TQUVCC03AWWRAD HEAT SINK




BROWN'S FERRY TQUVCC03AWWRAD HEAT SINK
CONTAINMENT WALL TEMPERATURE NOD(4)
112.0
111.0
110.0
109.0
108.0
107.0
106.0
105.0
104.0
103.0
200.0
250.0
300.0
350.0
400.0
450.0
500.0
550.0
TIME - (MINUTE)



BROWN'S FERRY TQUVCC03AWWRAD HEAT SINK
CONTAINMENT WALL TEMPERATURE NOD(5)
TIME - (MINUTE)
1030
1040
1050
1060
1070
1080
1090
1100
1110
1120
200.0
250.0
300.0
350.0
400.0
450.0
500.0
550.0