Westinghouse Electric Corporation
Energy Systems

Box 355
Pittsburgh Pennsylvania 15230-0355

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December 21, 1995

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U.S. Nuclear Regulatory Commission
Washington, D. C., 20555

ATTENTION: T. R. QUAY

SUBJECT: WESTINGHOUSE RESPONSES TO NRC REQUESTS FOR ADDITIONAL INFORMATION ON THE AP600

Dear Mr. Quay:

Enclosed are the Westinghouse responses to NRC requests for additional information on the AP600 Design Certification program. Enclosure 1 contains responses to questions pertaining to hydrogen generation and control during a severe accident. Enclosure 2 contains the response to additional information requested on two MAAP4 cases for the thermal/hydraulic uncertainty evaluation. A listing of the NRC requests for additional information responded to in this letter is contained in Attachment A.

These responses are also provided as electronic files in WordPerfect 5.1 format with Ms. Jackson's copy.

The enclosed request for additional information responses should be reviewed as discussed in our November 13, 1995 letter concerning AP600 design certification review priorities.

0258H

020015

E004
1/1

Please contact Cynthia L. Haag on (412) 374-4277 if you have any questions concerning this transmittal.

Brian A. McIntyre, Manager
Advanced Plant Safety and Licensing

Enclosures
Attachment

cc: W. Huffman, NRC (1E2)
D. Jackson, NRC (1E1, 1E2)
T. Collins, NRC (w/o Enclosure/Attachment)
J. Kudrick, NRC (w/o Enclosure/Attachment)

Attachment A to NTD-NRC-95-4616
Enclosed Responses to NRC Requests for Additional Information

Re: Hydrogen Generation and Control *
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Re: T/H Uncertainty - MAAP4 information **
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492.7

* - Responses provided in Enclosure 1
** - Responses provided in Enclosure 2

Enclosure 1 to Westinghouse
Letter NTD-NRC-95-4616

December 21, 1995

Response to Follow-on Questions Pertaining to Severe Accident Hydrogen Generation and Control

480.119

The staff is concerned about the effect of diffusion flames anchored to the IRWST vents on the containment shell.

Response:

Diffusion flame formation at the IRWST vents is being studied for the AP600. The study includes reviewing data and video tapes of the HCOG diffusion flame experiments, MAAP4 analyses to predict mixing in the IRWST, and modeling of the radiative and convective heat transfer from a flame at the vent to the containment wall to predict the wall temperature. The preliminary conclusion is that although the formation of diffusion flames cannot be ruled out, the expected duration of a diffusion flame is an order of magnitude less than the time required to creep the containment wall to failure.

480.120

Lumped-parameter codes have limitations when used to predict hydrogen distribution in containments. Lumped-parameter codes tend to over predict the rate of mixing which can result in under predicting local hydrogen concentrations. For example, in the HDR Test E11.2 the actual helium gas concentration in the upper dome region of the containment was 3 times larger than the CONTAIN (lumped parameter code) predicted value at the point of largest discrepancy (25% measured versus 8% calculated concentration). On what basis does one conclude that lumped parameter codes are adequate to predict hydrogen mixing? Also, how is the subnodal physics model capable of sufficiently predicting hydrogen stratification?

Response:

Section 46 of the PRA describes the containment mixing analysis that was conducted to demonstrate compliance with 10 CFR 50.34(f). One criterion from this regulation is that the combustible concentrations of hydrogen would not collect in areas where unintended combustion or detonation could cause loss of containment integrity or loss of appropriate mitigating features. The hydrogen mixing analyses were performed to confirm that this regulation was satisfied by the AP600 containment configuration. The hydrogen mixing analyses were performed with the WGOTHIC computer code, version 1.0 which is a lumped-parameter code. For the details of these analyses and a description of the code, Section 46 of the PRA should be consulted.

The performance of lumped-parameter codes in predicting mixing in containment depends upon several factors, such as plant specific parameters (containment geometry), sequence specific parameters (light gas injection point and flow rate (break size); availability of active mixing systems), and the nodalization scheme selected to represent them.

Good mixing is observed and well predicted in tests with large LOCAs or open containments (small number of compartments and large areas between compartments) or active internal mixing. For example a large scale test with a large LOCA, and active internal sprays, was run by NUPEC in Japan and compared to several lumped-parameter codes as part of International Standard Problem Number 35. Likewise, a large LOCA test (T31.5) with light gas injection near the containment's mid-height and no internal sprays was run in the HDR facility in Germany. These test conditions and configurations showed good mixing in containment. However, a small LOCA test (E11.2) in the HDR facility with no internal sprays and light gas injection near the containment's mid-height showed stratification until external sprays on the containment dome were turned on and successfully induced mixing in containment. Application of traditional lumped-parameter codes to the HDR E11.2 did not perform well in capturing the thermal stratification. It should be noted that the AP600 containment configuration is significantly different than the HDR E11.2 test. The AP600 containment is open with generally large areas between regions and a small number of subcompartments. Furthermore, the injection points for hydrogen are at or below the operating deck which means they are low in the containment.

To overcome mixing deficiencies in a lumped parameter code, the effects of thermal stratification must be considered. In the MAAP4 code, thermal plume and "subnodal physics"models are included to account for these effects. The thermal plume model considers light (less than ambient density) gaseous discharges from the reactor coolant system into the containment. The light gas plume is accelerated by buoyant forces and slowed because it entrains the ambient heavier gas. As the plume rises from one compartment to another, an equal volume of gas flows down to fill the void left by the rising plume. Thus, an exchange of gas between compartments due to plume behavior of gaseous effluents is modeled. The subnodal physics model determines the condition required for flow stagnation in the node in question (based on pressure equilibrium with its horizontally connected node). The required stagnation condition is that the penetration depth (within the node in question) of the lighter gas entering from the node above through a vertically oriented junction, or of the heavier gas entering from the node below exceeds the distance required to clear the nearest horizontally oriented junction, then the junction is shut off to any buoyancy-driven flow. The model, hence, does not always allow buoyancy-driven flow through the vertically-oriented junction. The rate of gas mixing among various nodes can then be properly predicted.

The results of MAAP4 calculations of the HDR Test E11.2 with and without the subnodal physics model are compared in Figures X-1, X-2, and X-3 [Ref. 1]. Figure X-1 shows an improvement in the calculated gas temperature at 0 m elevation from a maximum error of ~ 36 K to about 6 K. Figure X-2 and X-3 also shows a very good improvement in the calculated helium concentration in the upper dome and at the 10 m elevation. It can be noted that the trend of the test data, which is incorrectly predicted without the plume and subnodal physics models, is correctly predicted by the addition of these models.

Since the AP600 reactor containment is much more open and less compartmentalized than the HDR containment, the accuracy of the MAAP4 code for the reactor containment can be expected to be as good or better than that of the HDR benchmarking. This fact is demonstrated in the MAAP4 and W GOTHIC code benchmarking based on the NUPEC's large scale hydrogen mixing and distribution test # M-7-1 which is a 1/4 scale 4-loop PWR model containment with internal structures reflecting the real plant layout. This test included internal containment sprays which induced good mixing. Most lumped parameter codes, including W GOTHIC and MAAP4, performed well in predicting the helium concentrations [Ref. 2].

References:

1. MAAP4 User's Manual, Volume 2, Part 2, EPRI, 1994.

2. Final Comparison Report on ISP-35 NUPEC's Hydrogen Mixing and Distribution Test - Test M-7-1, ISP35-092 Rev. 5, September 10, 1994.

480.122

The first three stages of the ADS vent into the IRWST. The fourth stage vents into containment. It appears to exhaust into the lower containment either in the core makeup tank room or the steam generator room. The staff needs to have a better understanding of where the fourth stage vents into containment. What igniter locations have been provided for a release through this pathway. What effect do the elevated temperatures of this type of release have on the possible combustion loads?

Response:

The fourth stage ADS for each reactor coolant loop discharges into each respective loop compartment. The fourth stage ADS is attached to each hot leg by single line with a tee and two ADS valves in parallel. The elevation of the ADS valves is above the flooded-up water level in the containment (approximately 108 elevation). Six igniters have been located in each steam generator subcompartment. Igniters are placed on each of the subcompartment's four walls and vary in elevation between 115 feet and 130 feet. These igniter locations will be effective for hydrogen release pathways for the fourth stage ADS valves.

The effects of elevated temperatures on burns are accommodated in two principal ways in the MAAP4 calculations. The flammability limits for combustible gases (hydrogen and carbon monoxide) are adjusted as a function of the temperature of the gas mixture. As the temperature increases, the lean flammability limit decreases while the rich flammability limit increases. Thus, there is a general broadening of the flammability limits as the gas mixture temperature increases. Secondly, the laminar flame speed is calculated as a function of the gas mixture temperature. The flame speed affects the burning rate which affects the energy release rate during combustion calculations. The energy release rate influences the temperature and pressure in the various containment regions. Thus, the effects of elevated temperatures on the combustion process and sub-compartment pressures are included in the calculations performed with MAAP4.

480.123

The staff would like to discuss the Westinghouse response to NRC RAI 480.35, dated September 3, 1993. The response addressed the issue of impulsive loads from subsonic accelerated flames. The response referred to tests conducted by KfK in Germany were flame acceleration occurred as the burn front passed from region to region through restricted interconnecting areas. Westinghouse concluded that "a small number of interconnected regions exists in the AP600 containment configuration and they are connected by large flow areas which would not be expected to result in significant flame acceleration between the various regions". The staff would like to have a better understanding of the basis for this conclusion and why flame acceleration due to junction-induced turbulence in multi-compartment burns is not a concern for the AP-600. Also, the Westinghouse response has not addressed other mechanisms of flame acceleration and their associated pressure loads (e.g. flame acceleration could also occur in long subcompartments that have venting, or obstacles).

Response:

In the AP600 design, there are sufficient igniters strategically installed within the containment to not only control the level of hydrogen concentrations within the containment but also to minimize or eliminate the possibility of flame acceleration in the regions of partial confinement which include the IRWST gas space and the CMT/equipment bay. Igniters in these subcompartments are located close to one another such that the flame propagation distance would be limited. Flames simultaneously initiated by igniters in these subcompartments can only propagate through the unburned gases until colliding with neighboring flame fronts or walls or ceiling. The maximum flame propagation distance due to simultaneous ignitions from multiple igniters is found to be limited to about 10 m in the IRWST gas space (segment above the spargers). In other regions of the IRWST gas space and the CMT/equipment bay, the flame traveling distance is shorter than 33 ft (10 m).

With the provision that the flame traveling distance is limited to no more than 33 ft (10 m), the likelihood of flame acceleration due to long subcompartments is eliminated. The likelihood of flame acceleration due to gas expansion through restricted junction area connecting two regions is also greatly reduced or eliminated. Flame acceleration through a restricted junction could not be sustained since there would be no unburned gases to support further propagation. Therefore, flame acceleration is not of any concern if igniters operate during a severe accident.

The concentration of H_2 in the hydrogen source subcompartment (such as in the IRWST or in the subcompartment where the break occurs) is not expected to be high enough to cause any significant flame acceleration. At the same time, in most locations the hydrogen concentration required to promote flame acceleration must equal or exceed the downward flammability limits (~8.5%) as demonstrated by flame acceleration experiments at Sandia (FLAME facility), Bastelle-Frankfort and Pisa University.

Such a high concentration of hydrogen is possible only if the igniters fail to operate during a severe accident allowing hydrogen to accumulate. For the AP600 design, if hydrogen from

100% oxidation of zirconium cladding is allowed to accumulate uniformly in the containment with the passive containment cooling system (PCCS) operational, the H_2 concentration would be about 9 - 10% while the steam concentration would be in the range of 28 ~ 30%. (The numbers for steam concentration are observed from MAAP results.)

In case of igniter failure, there is a question of how combustion would be initiated. Since the existence of random ignition sources is difficult to be quantified the probability of such events having a successful random ignition is also extremely small. However, among the low probability events, the most likely one could be the recovery and accidental operation of the igniter system. In such scenarios, flame acceleration is not a concern due to the simultaneous ignitions of multiple fire balls in all locations and a limited flame propagation distance.

480.124

The staff is concerned about the possibility of detonable conditions when combustible gases are released through the IRWST. Near stoichiometric concentrations of hydrogen are predicted to exist at various times throughout the release of hydrogen based on separate work performed by Sandia [1] and the AP600 PRA. Steam concentrations are generally between 10-20% during times of high hydrogen concentrations. The transition of a deflagration to a detonation is the most likely mode of detonation initiation. Peraldi [2] has proposed a criterion for deflagration to detonation transition (DDT) which relates the detonation cell size of a mixture to a characteristic geometric length scale. Sandia used this criteria to give an estimate of the range of hydrogen concentrations that may detonate in the IRWST. Peraldi's criterion states that if a flame speed is near the sound speed in the combustion products, DDT will occur if the detonation cell size is on the order of, or less than, the minimum transverse dimension of the channel. The distance between the surface of the water and the top of the IRWST was estimated to be 0.5 m based on the input for MAAP calculations. Sandia estimated, according to Peraldi's criterion, what mixtures having detonation cell sizes on the order of 0.5 m or less may undergo a DDT. This corresponded to hydrogen-air-steam mixtures having hydrogen concentrations between approximately 18% and 56% for mixtures with 10% steam and 19% and 42% for mixtures with 20% steam. These conditions can occur for relatively long periods of time as was noted in the containment analysis report by Sandia [1].

Response:

The detonable conditions in the gas space of the IRWST as mentioned by the review staff can be postulated only in the event of igniter failures during certain classes of severe accident scenario. Whether DDT would occur or not depends on the availability of an ignition source. The only potential ignition source in the IRWST is the igniters.

The conditional probability of DDT occurrence within the containment is considered in the quantification of the AP600 CET by means of "early burn" and "late burn." In the quantification of these CET top nodes, the conditional probability of random ignition source(s) such as the unquenched core debris, or the hot gas at the pipe break, was conservatively estimated as a function of accident time. Furthermore, the maximum conditional probability of DDT given an ignition source and a detonable condition, was assigned 0.5 using the method described in NUREG/CR-4803. Hence, in the AP600 PRA a DDT is recognized with a certain probability.

480.125

WCAP-13388 addresses the likelihood of a deflagration to detonation transition (DDT) in the AP600 design. No structural analysis response is presented. However, the abstract states that "it is concluded that such detonations will not challenge the integrity of the AP600 containment." This statement gives the impression that if a DDT were to occur in the AP600 the containment (structurally) would not be challenged. The staff needs a better understanding of the containment's structural capability to withstand impulsive loadings due to hydrogen detonation.

Response:

Although it is believed that the AP600 containment could withstand the challenge presented by DDT, the AP600 PRA conservatively assumes that the containment fails in the event of DDT in either the IRWST or the lower compartments of the containment. The frequency of these DDT events then contribute to the containment failure frequency and conditional containment failure probability.

480.126

Besides DDT hot jet initiation is another mechanism that could initiate a detonation and should be addressed in the AP600 design.

Response:

Direct initiation of a detonation by a hot jet in the AP600 design is not considered to be possible. The initiation of a detonation by a hot jet would require a hot burning jet at sonic velocity to enter a non-inerted region with a high hydrogen concentration.

The AP600 design includes igniters which would burn hydrogen as it released such that its global concentration in containment would not exceed 10%. A hydrogen concentration of less than 10% in dry air is not detonable.

If the igniters were not operable the hydrogen concentration in containment could approach 14% if 100% of the zirconium in the core was oxidized by steam. For many sequences the primary system is depressurized by the first three stages of the ADS valves. The release of hydrogen from the primary system through the IRWST sparger and water pool would not produce a hot jet. For LOCA sequences a high temperature, hydrogen rich sonic jet could be produced. However, such a jet would not be burning as it exited the RCS as there would be no oxygen within the RCS to support burning. Such jets would lead to a diffusion flame (not detonation) if the jet encountered oxygen within the receiving containment region. Furthermore, such a blowdown to the containment would not encounter a high concentration of hydrogen in the containment. The potential source of hydrogen originates within the RPV due to zirconium oxidation in the core. The blowdown process could transfer the hydrogen from the RCS to the containment but the RCS would be depressurized in the process such that any subsequent hydrogen release from the RCS into a potentially flammable containment atmosphere would not be as a sonic jet.

Gas flows between the containment regions and sub-compartments in the open AP600 containment design during a blowdown are not expected to produce sonic jets. The large areas between containment regions are expected to minimize large sustained differential pressures and sonic velocities. However, if a burn occurred in a compartment below the operating deck a hot jet could be introduced to the upper containment of the AP600. If such a hot (burning) sonic and hydrogen rich jet were produced and if a burn occurred in the upper containment, a diffusion flame would result. Such a result was observed in an integral effects test (IET-11) conducted by Sandia National Laboratories in the Containment Technology Test Facility (Blanchard, T. K., et al., Quick-Look Report on the Eleventh Integral Effects Test (IET-11) in the Containment Technology Test Facility, September 1995). Thus, hot jet initiation of deflagrations but not detonations are considered for the AP600 design.

Sections 36 through 41 of the AP600 PRA provide decomposition event trees for key severe accident phenomena. Section 41 addresses hydrogen combustion. Section 43.6 (Other Ignition Sources) addresses hot jets as a potential mechanism for initiating deflagrations. The possibility of deflagrations and the transition from a deflagration to a detonation are addressed and quantified in the hydrogen decomposition event trees.

480.127

Figure 2-11 of WCAP-13388 was used to calculate the likelihood of DDT by defining cell width dependency based on steam and hydrogen concentrations. The data from Figure 2-11 are at a different temperature than the one used to define the DDT likelihood in AP600. What is the impact of the temperature differences between the data taken from the plots and the AP600 data?

Response:

The data presented in Figure 2-11 was taken at 373K (212°F). Per Table 6-2 of Section 41 of the PRA for the AP600 the pre-burn containment temperature ranges from 360 to 400K (188°F to 260°F) for a spectrum of accident sequences. This representative spectrum of sequences was used in the PRA analyses including the hydrogen combustion analysis. The temperature range observed for the AP600 assessment is close ($\pm$ 25K) to the temperature used to derive Figure 2-11, therefore, there is little temperature dependency due to the general consistency between the AP600 temperature values and the 373K value. The small temperature differences have limited impact on the detonation cell width and their impact is within the factor of 2 safety margin employed to accommodate such uncertainties.

480.128

Figure 2-11 from WCAP-13388 presents some experimental data and plots of hydrogen in steam concentration versus cell width. The plots are based on theoretical models and can be misleading and non-conservative when used to determine cell size. Caution should be exercised when using Figure 2-11 because the cell width is on a log scale and at the hydrogen concentration used to determine cell size the plot has a very steep slope. The value chosen for cell width is lower than the value provided by the plots and higher than the value the experimental data provides. Why wasn't experimental data value used to define cell size?

Response:

The estimation of the detonation cell width is described in the second paragraph on page 4-14 of the Hydrogen Deflagration and Detonation section of WCAP-13388. An extreme condition of a dry containment atmosphere was assumed and used to estimate an equivalence ratio of 0.4. Figure 2-11 was used to estimate the approximate detonation cell size as being 0.3 meters (1.0 ft). As suggested in this question, if the fitted model (Shepherd curve) is used, an estimated value of 0.35 meters (1.15 ft) is obtained for detonation cell width. If the data points are interpolated the detonation cell width could be estimated to be approximately 0.24 meters (0.79 ft). The value reported in WCAP-13388 was an estimate which was approximately the mean of these two values. Nevertheless, if the detonation cell width of 0.24 meters (0.79 ft) was used in the calculations of scale factors as presented in Tables 4-3 and 4-4, the same conclusion would be reached regarding the potential for DDT. It should also be noted that if the conditions reported in Table 4-2 which include the steam mole fraction of approximately 0.28 were used to estimate the equivalence ratio a value of 0.35 would be obtained. Figure 2-11 would then imply by the Shepherd model curve a detonation cell width of 0.8 meters (2.6 ft) and interpolation of the data points would yield an estimate for the detonation cell width of 0.35 meters (1.15 ft). Again, detonation cell widths in this range would yield scaling factors in the calculations documented in Tables 4-3 and 4-4 that would lead to the conclusion that the potential for DDT did not exist in the AP600 containment. Thus, the reported result used an estimated detonation cell width 0.3 meters (1.0 ft) which is judged to be representative for the AP600 containment conditions. The stated conclusion is robust in that it is not altered by the range of mixture classes which could result from the range of estimated values for the detonation cell width presented above.

480.129

To calculate the likelihood DDT in the AP600 design WCAP-13388 uses a set of initial conditions derived from severe accident analyses. The staff needs a better understanding of why these initial conditions are appropriate for these calculations.

Response:

The assessment presented in WCAP-13388 for the likelihood of DDT in the AP600 containment is summarized in Tables 4-3 and 4-4 of the section on Deflagration and Detonation of Hydrogen. The initial conditions used in the DDT scaling assessment are stated in these tables and include a maximum hydrogen concentration (14.1% on a dry basis) and a minimum steam inerting condition (10% steam mole fraction).

The hydrogen mole fraction was determined by assuming complete oxidation of 100% of the zirconium in the reactor core region. No credit was taken for the distributed igniter system in performing these calculations. The igniter system is designed to burn hydrogen at low concentrations such that a 10% global hydrogen concentration is not exceeded for the containment. The assessment of the ignite; configuration deployed in the AP600 containment (see Section 47 of the AP600 PRA) shows it is effective in maintaining the hydrogen concentration close to the lower flammability limit throughout the containment. The lower flammability limit is approximately 4% hydrogen. The assumed value of 14.1% hydrogen in containment provided a bounding estimate on the well mixed hydrogen concentration for the AP600 general containment. This bounding estimate for the amount of hydrogen in a dry environment was used to calculate the equivalence ratio and imply the detonation cell width for this condition.

The amount of steam inerting considered was minimized by assuming a 10% steam mole fraction. Assessments provided for a variety of cases including LOCAs and transients as presented in the AP600 PRA showed that the steam mole fraction in containment varied between 15 and 50% for extended periods of time during severe accident sequences. Thus the scaling assessment did not fully credit the steam inerting which would be possible as initial conditions in the AP600 for these calculations.

The initial conditions selected for the DDT scaling assessments in WCAP-13388 were chosen to provide margin in these calculations based on global hydrogen distribution. Localized effects or gradients in the hydrogen concentration are addressed in the DETs provided in Chapter 41 of the PRA.

480.130

In WCAP-1338 the equation that defines the scale factor uses a safety factor parameter. This parameter is not mentioned in the methodology introduced by Sherman and Berman. What is the purpose of the safety factor (e.g., to count for cell measurement uncertainties, conservatism, etc.)?

Response:

The safety factor was used to account for detonation cell width measurement uncertainties and to provide conservatism in the assessment. The estimated detonation cell widths were divided by two for the safety analysis which is consistent with the recommendation provided in NUREG/CR-5525. [Stamps, D.W. and Berman, M., "Hydrogen-Air-Dilutant Detonation Study for Nuclear Reactor Safety Analyses," Sandia National Laboratories Report, SAND89-2398, NUREG/CR-5525, January 1991 (pp. 15 and 59).]

480.131

Tables 4-3 and 4-4 of WCAP-13388 list the steam generator compartment, steam generator annulus, CMT, and equipment bay as geometric class 3. Immediately after the geometric class determination in Tables 4-3 and 4-4 the report concludes that there is "no potential for DDT". It is not clear how this conclusion was reached. Proper use of this methodology has the analyst define a mixture class. Then the geometric class is combined with the mixture class to define a result class. These steps are missing from the report. In addition, the conclusion reached in the report does not appear to represent any of the result classes mentioned in the methodology used.

Response:

The methodology is applied in the proper manner. The methodology is not clear from the table, but is described in the text in WCAP-13388. The assignment of the mixture class, conditional probability of DDT and the discussion of why it is concluded that there is little probability of containment threat from DDT is on page 4-18 of the Hydrogen Phenomenological Evaluation in WCAP-13388.

Additionally, DDT is treated in the containment event tree and decomposition event tree analyses. The probability values for the DDT result classes are assigned directly to the containment failure nodes in the CET.

480.132

The geometric class assigned to the IRWST and steam generator subcompartments appears to be non-conservative. It appears that a qualitative method was used to assign these geometric classes. The staff would like to have a better understanding of the process used to assign the geometric classifications for the subcompartments stated above.

Response:

The process used to assign the geometric classifications for the IRWST and the steam generator subcompartments is described starting on page 4-15 on the section of WCAP-13388 that discusses the probability and consequences of deflagration and detonation of hydrogen. The process involved gaining an understanding of the geometry of these subcompartments in the AP600 containment. The next step in the process was to review the descriptions of the geometric classes for flame acceleration and make a qualitative comparison between the plant geometry and the class descriptions.

For example, the IRWST gas space is approximately 6700 cubic feet, has no obstructions, and is vented along the circumference of the containment. The vents represent transverse venting if a flame front were to accelerate within the IRWST across its water surface and beneath the ceiling of the subcompartment. Examples provided for geometric class 4 are large volumes with hardly any obstacles and large amounts of venting transverse to the flame path or small volumes without obstacles. Examples for geometric class 3 are large tubes without obstacles or small tubes (several inch diameter) with obstacles. The IRWST gas space geometry was judged to be most similar to the examples provided for geometric class 4. This is a qualitative assignment based on the available information.

A similar qualitative comparison and assessment was employed to determine that the geometric class that best described the steam generator compartments was class 3.

The reported geometric classes for the IRWST (class 4) and for the steam generator subcompartment (class 3) are combined with the mixture class (class 4) to determine the potential for a DDT. The sensitivity of the potential for DDT on the geometric class assignments can be determined by referring to Table C-3 of the section on Hydrogen Deflagration and Detonation in WCAP-13388. If the IRWST geometric class is considered to be 3 instead of 4 the result class changes from 5 to 4. In the case of the steam generator subcompartment a change in the geometric class from 3 to 2 would not cause the result class to change, i.e., it would remain at 4. A result class of 4 (see Table C-4) is classified as DDT is possible but unlikely. Thus, given the conservative assumptions (no steam inerting, total failure of the igniter system and 100% oxidation of the zirconium in the reactor core) made to establish the requisite initial conditions for a deflagration and the assessment of the result class for the IRWST and steam generator subcompartments it is concluded that essentially no potential for DDT exists for the AP600 configuration.

480.133

DDT has been observed in hydrogen-air mixtures at hydrogen concentrations as low as 12.5% which is less than the value of 15% reported in WCAP-13388. A mixture of 11.7% hydrogen in air at STP was also observed to be intrinsically detonable in the HDT [3] as compared to the 13% value quoted on page 2-8 of WCAP-13388. Also, the detonation limit observed in a stoichiometric hydrogen--air-steam mixture at 100°C and 1 atm initial pressure is between 38.8% and 40.5% steam and will increase with increasing scale. This is greater than the conjecture reported on page 2-1 of WCAP-13388 that mixtures with 30% steam may be immune to detonations.

Response:

As stated in the HDT reference (Stamps, D. W. and Berman, M., "Hydrogen-Air-Dilutant Detonation Study for Nuclear Reactor Safety Analysis, " NUREG/CR-5525, January 1991) and repeated in the above question, the detonation limit observed in a stoichiometric hydrogen-air-steam mixture at 100°C and 1 atmosphere initial pressure is between 38.8% and 40.5% steam. On page 2-1 of WCAP-13388 it is stated that mixtures of 30% steam may be immune to detonations. This conjecture refers to the AP600 configuration. The complete reaction of zirconium in the reactor core for the AP600 would produce a dry hydrogen concentration in the AP600 containment of 14.1%. This is less than one-half of the hydrogen fraction in dry air (0.296) for a stoichiometric mixture. The situation for the AP600 described in WCAP-13388 is significantly less than the stoichiometric condition and, hence less steam would be required to produce a mixture immune to detonations.

480.134

WCAP-13388 states that in the case of combustible gas generation ex-vessel (i.e. a dry cavity), the gas temperature in the reactor cavity would be sufficiently high to promote combination of the combustible gas. Even if some of the combustible gas leaves the reactor cavity it could be safely burned in the steam generator compartment or in the tunnel connecting the steam generator compartments. Therefore, no igniters are located in the reactor cavity. The staff would like to have a better understanding of the basis for this conclusion. Also, are there any other restricted volumes within the containment that do not have igniter coverage?

Response:

Chapter 16 of the AP600 PRA provides a description of the location and placement of the 58 igniters distributed throughout the AP600 containment. The unlikely case of the dry reactor cavity with core debris on the reactor cavity floor is discussed in WCAP-13388 (section on Deflagration and Detonation of Hydrogen). The reactor cavity communicates directly to the tunnel connecting the two steam generator compartments by a grating in the ceiling which is approximately 10 ft by 10 ft square. Combustible gases produced during core concrete interactions in the reactor cavity could exit the reactor cavity by this flowpath. Igniters are located in the tunnel connecting the steam generator compartments and are therefore in the flowpath for hydrogen egress from the reactor cavity. If the igniters were unavailable to ignite hydrogen or carbon monoxide released from the reactor cavity, autoignition of high temperature gas mixtures could still occur in regions that contained sufficient oxygen to support combustion. Thus, if combustible gases were formed in an oxygen depleted reactor cavity, they would escape through this flowpath into the tunnel connecting the steam generator loop compartments and then into the loop compartments themselves. Sufficiently hot gases rich in combustible material would undergo autoignition upon entering oxygen rich areas of the containment. The first areas that would be encountered by gases exiting the reactor cavity would be the tunnel connecting the steam generator compartments and then the steam generator compartments themselves.

As described in Section 48 of the AP600 PRA, all the restricted volumes within the containment have igniters located in them. This includes the valve rooms and accumulator rooms.

Enclosure 2 to Westinghouse
Letter NTD-NRC-95-4616

December 21, 1995

0258H

Response to RAIs 492.6 and 492.7

The following information is in response to the NRC's request for additional information on MAAP4 case x4j and a revised case m5f3. Specifically, the cases are:

Case x4j
4.75 inch hot leg break
Failure of both CMTs
Failure of containment isolation (254 in^2 opening)
No PRHR
2 Accumulators
1 line IRWST gravity injection
2 stage 4 ADS (Manually actuated 30 minutes after the failed CMT actuation signal)

Revised Case m5f3 (Designated as Case m5f4)
4 inch DVI line break
Failure of both CMTs
Failure of containment isolation (254 in^2 opening)
No PRHR
1 Intact Accumulator (Faulted accumulator is not modelled -- it is assumed to be lost out the break)
1 intact line IRWST gravity injection
2 stage 4 ADS (Manually actuated 30 minutes after the failed CMT actuation signal)

A list of the requested plotted output parameters is contained in Table 1. In addition to the plot data, summaries of actuation times are provided in Table 2 and Table 3. The two requested scenarios are similar, but core uncovery and heatup results are different due to the effect of the accumulators. In the 4.75" hot leg break, the RCS depressurizes such that the 2 accumulators inject as soon as the core starts to uncover. The accumulator injection recovers the core, and there is no noticeable impact on core temperatures.

In the DVI line break (4" equivalent diameter), the RCS is slower to depressurize and only 1 accumulator is able to provide make-up inventory. The accumulator flowrate, driven by the pressure difference between the accumulator and RCS, is adequate to make up the inventory being lost out the break, but is not enough to recover the core. The top of the core remains uncovered until after the operator manually actuates 2 stage 4 ADS lines. The maximum core temperature reaches almost 1200°F.

The MAAP4 parameter file and other assumptions used to generate the provided data are the same as those used in the computer runs discussed at the September 12 - 14, 1995 meeting. This is also the same as the "base" assumptions presented at the October 24 - 25, 1995 meeting. Please note that design change updates to the MAAP4 parameter file will be implemented before the final set of success criteria analyses are completed.

Table 1 **Provided Output Parameters**
Decay heat
RCS pressure [1]
Containment pressure
Break liquid flow rate
Break vapor flow rate
ADS liquid flow rate
ADS vapor flow rate
Accumulator(s) flow rate
IRWST flow rate
RCS mass inventory
Core mixture level [2]
Collapsed water level
Peak core temperature [3]

Notes:

(1) Pressurizer pressure is the same.

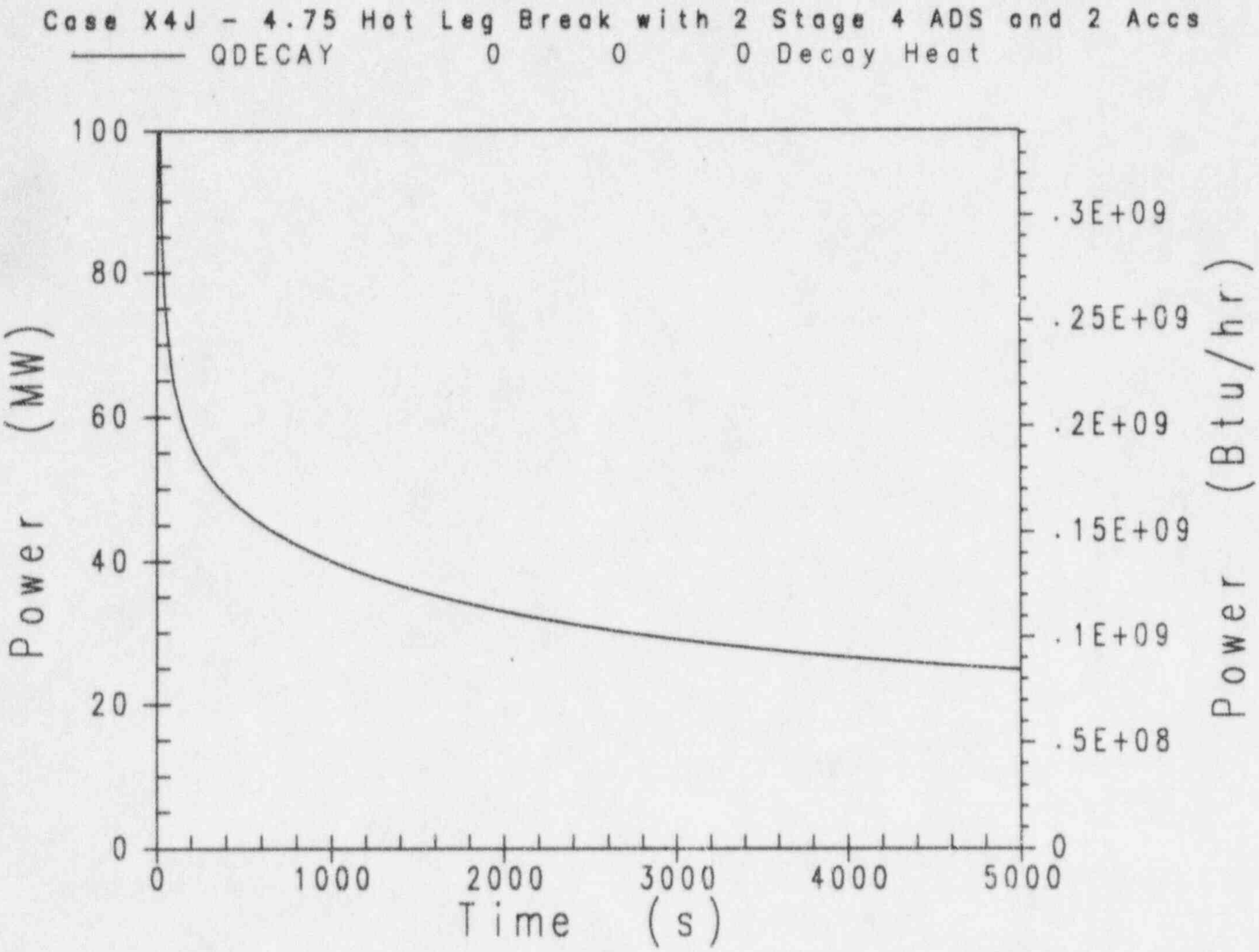
(2) Not tracked above the bottom of the loops. Therefore, levels greater than or equal to 24 feet are represented as 24 feet.

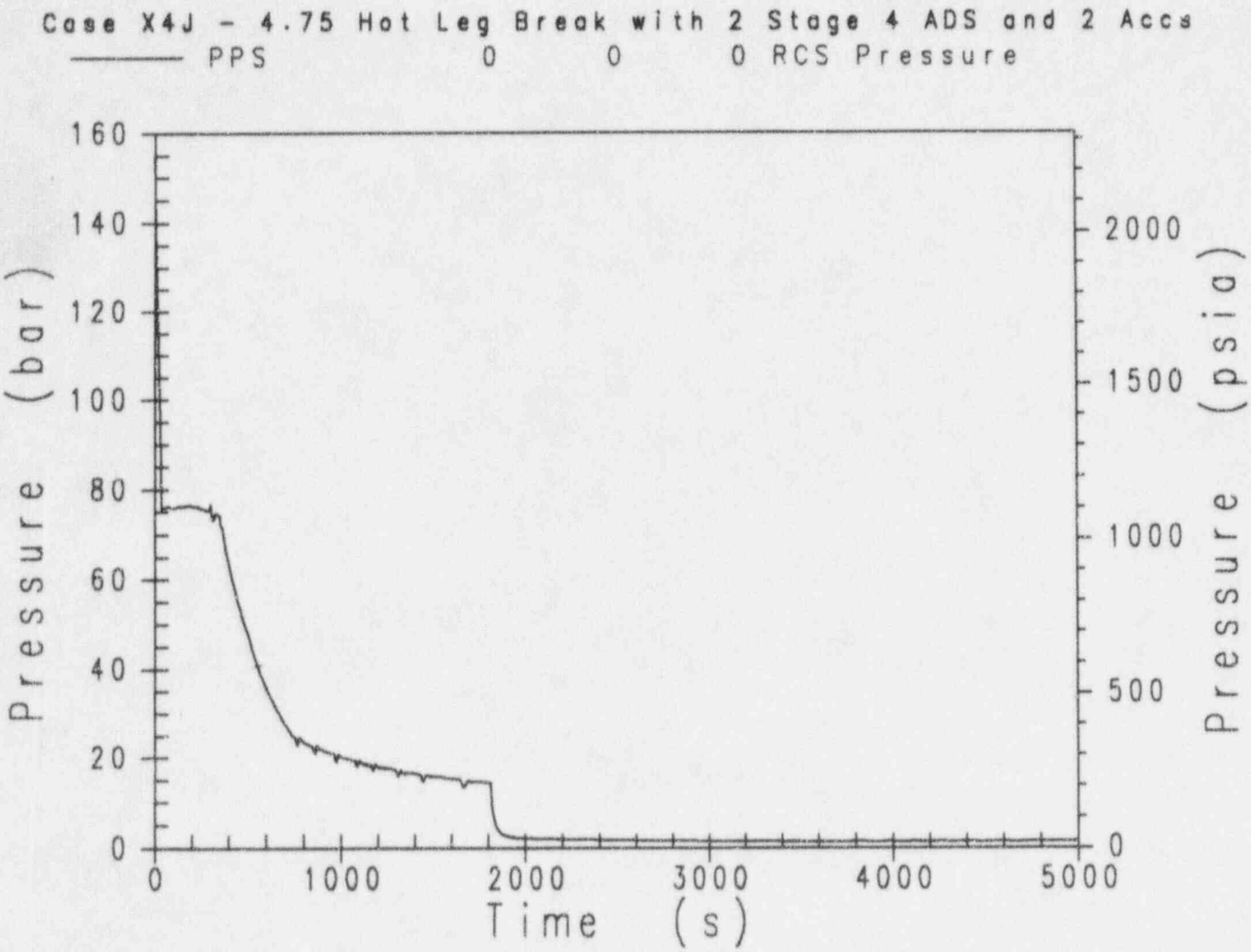
(3) Cannot provide summaries of peak fuel centerline and peak cladding temperatures.

Table 2 **Sequence of Events for Case x4j - 4.75" Hot Leg Break**	
Reactor Trip on Low Pressurizer Pressure	10 sec
CMT Actuation Signal (Failed)	12 sec
RCS Void Fraction Reaches VFSEP of 0.6	292 sec
Break Location Uncovers	367 sec
Top of Core Uncovers	493 sec
Accumulator Injection Begins	499 sec
Core Recovers	573 sec
Manual ADS Actuation	1812 sec
Break Location Recovers	1818 sec
Accumulators Empty	1944 sec
IRWST Injection Begins	2059 sec

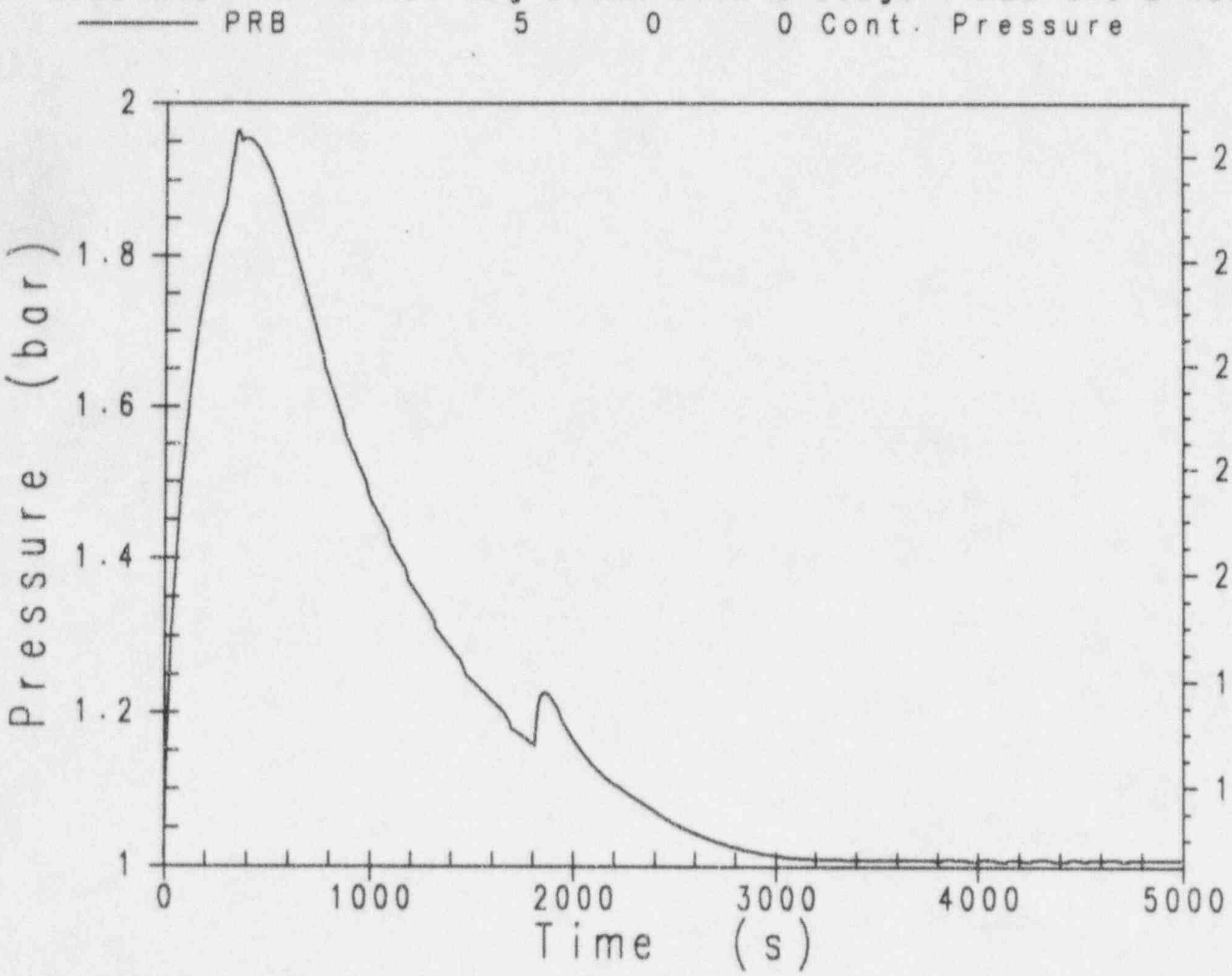
Table 3
Sequence of Events for Case m5f4 - DVI Line Break

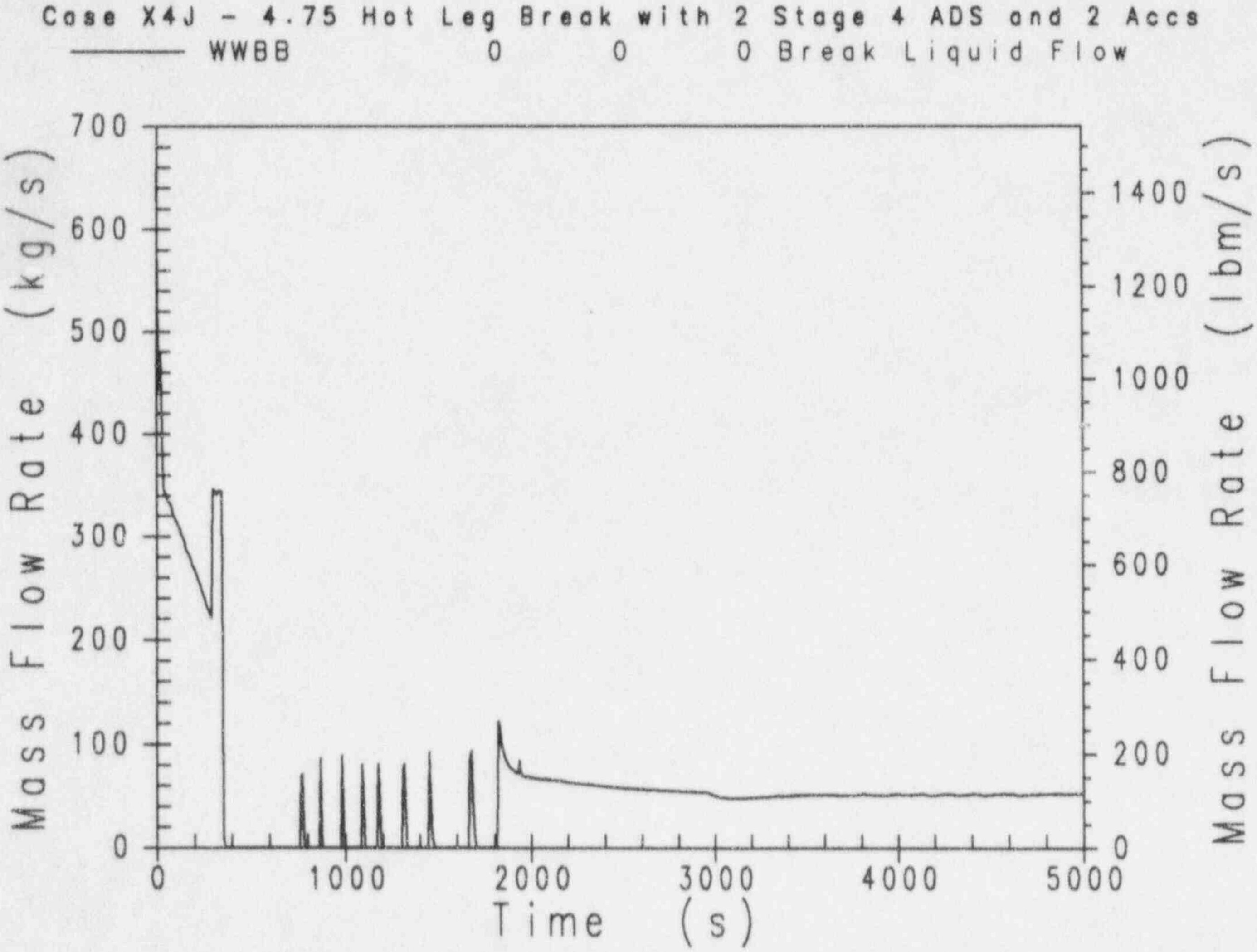
Reactor Trip on Low Pressurizer Pressure	9 sec
CMT Actuation Signal (Failed)	10 sec
RCS Void Fraction Reaches VFSEP of 0.6	393 sec
Break Location Uncovers	469 sec
Accumulator Injection Begins	771 sec
Top of Core Uncovers	878 sec
Manual ADS Actuation	1810 sec
Core Recovers	1861 sec
Accumulator Empties	1979 sec
IRWST Injection Begins	2214 sec
Break Location Recovers	2649 sec

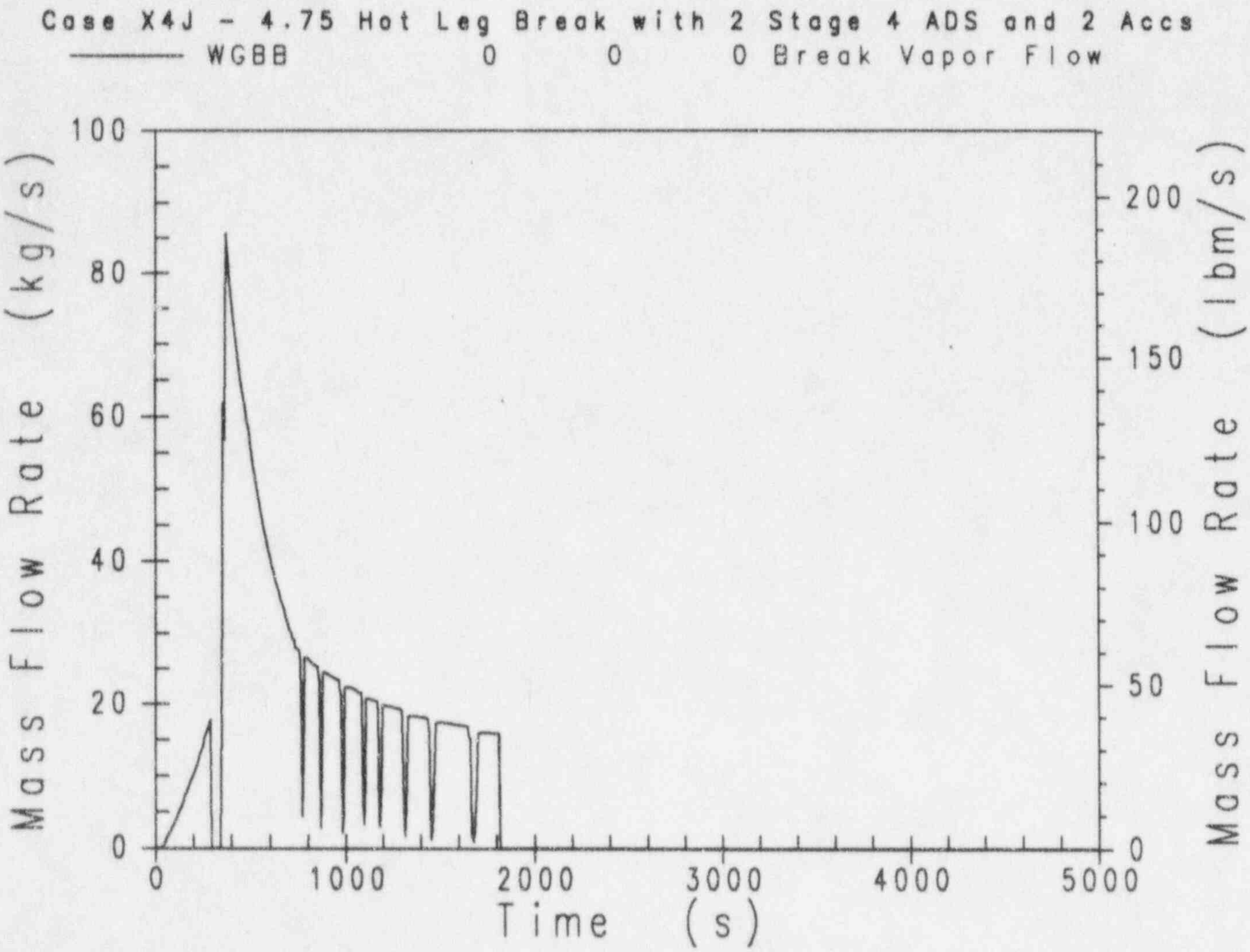

Case X4J - 4.75 Hot Leg Break with 2 Stage 4 ADS and 2 Accs
QDECAY 0 0 0 Decay Heat
Power (MW)
Power (Btu/hr)
Time (s)
0
20
40
60
80
100
1000
2000
3000
4000
5000
.5E+08
.1E+09
.15E+09
.2E+09
.25E+09
.3E+09


Case X4J - 4.75 Hot Leg Break with 2 Stage 4 ADS and 2 Accs
PPS
0 0 0 RCS Pressure
Pressure (bar)
Pressure (psia)
Time (s)
0
20
40
60
80
100
120
140
160
0
500
1000
1500
2000
1000
2000
3000
4000
5000

Case X4J - 4.75 Hot Leg Break with 2 Stage 4 ADS and 2 Accs

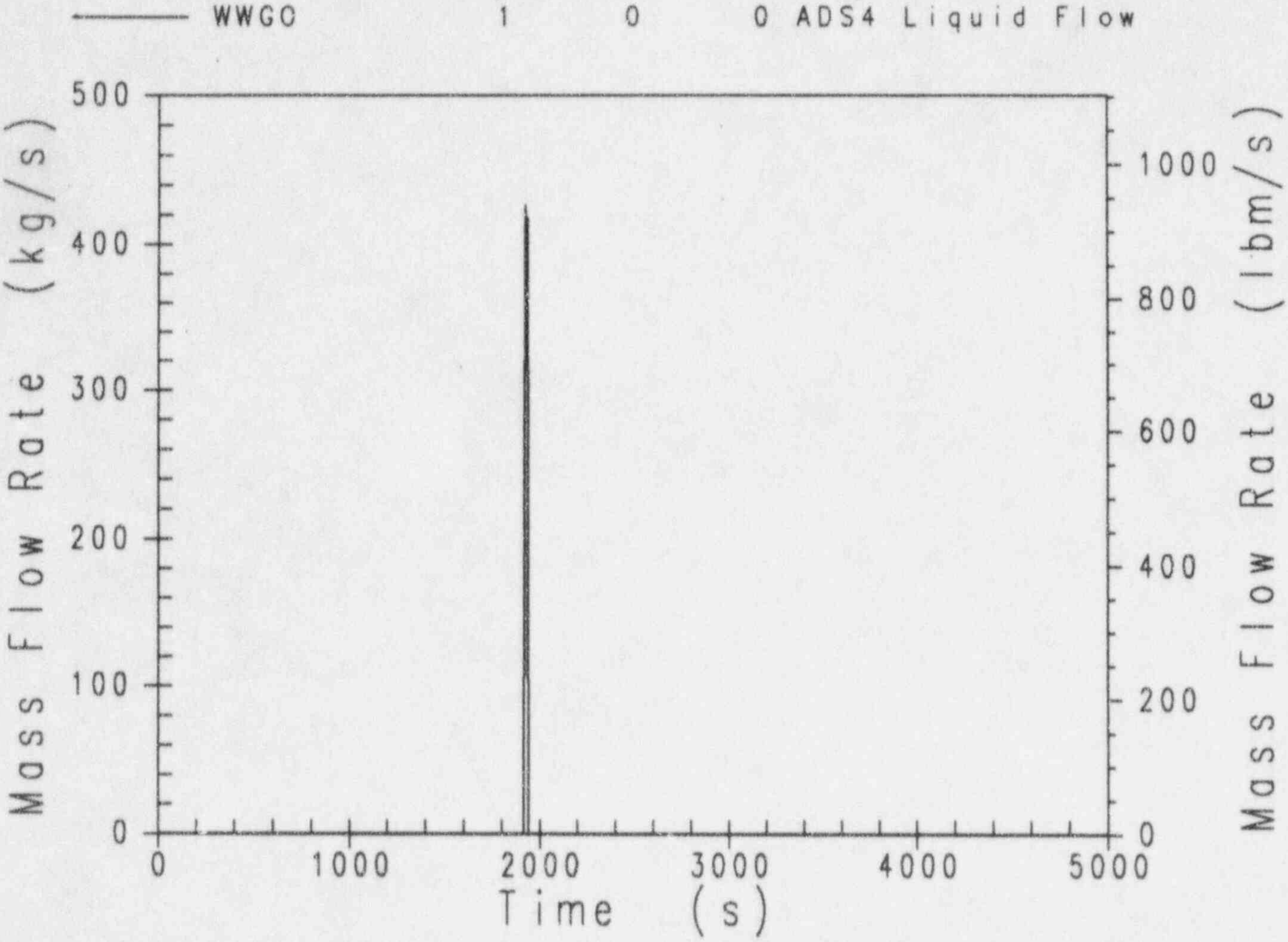


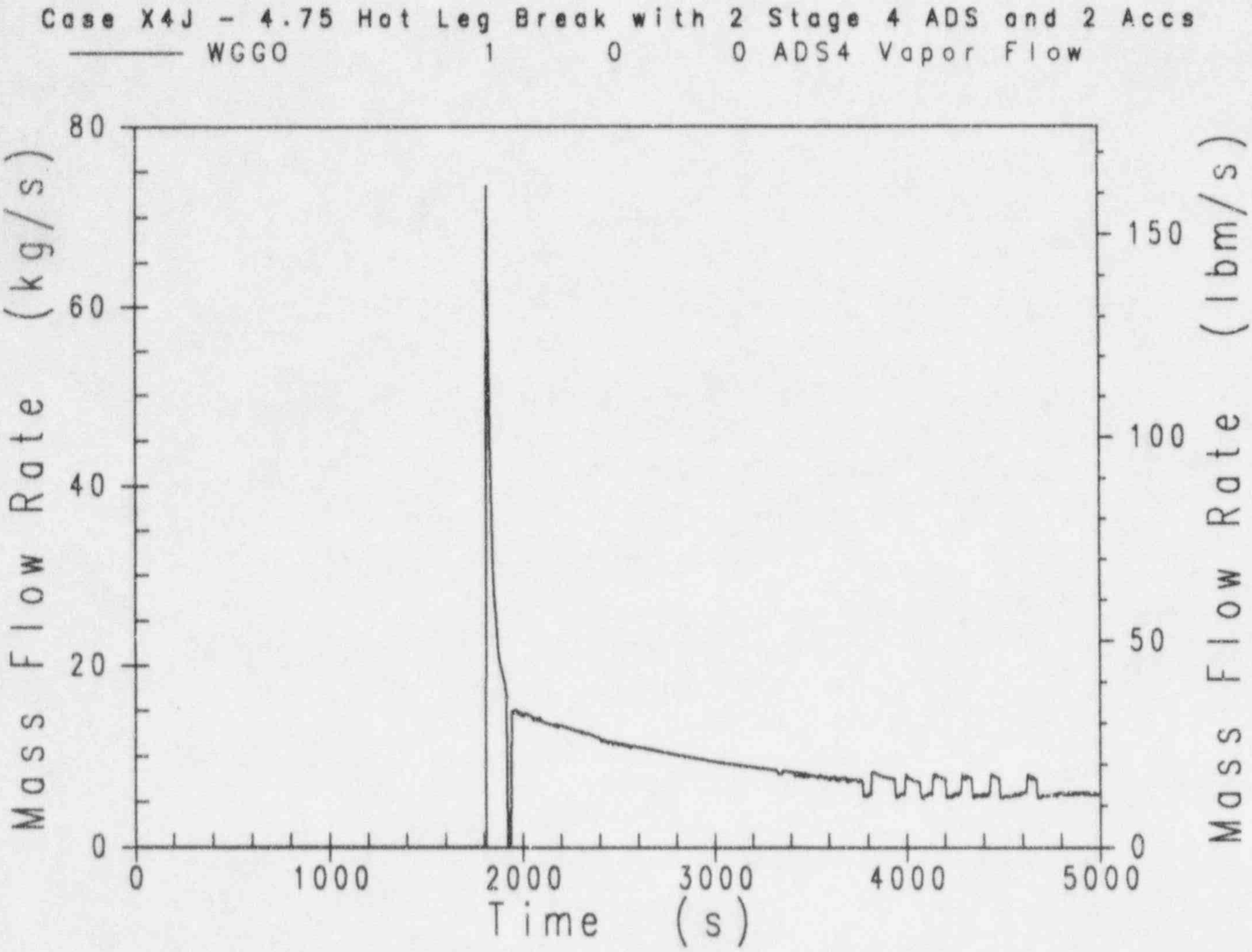

Case X4J - 4.75 Hot Leg Break with 2 Stage 4 ADS and 2 Accs
WWBB 0 0 0 Break Liquid Flow
Mass Flow Rate (kg/s)
Mass Flow Rate (lbm/s)
Time (s)
0
100
200
300
400
500
600
700
0
1000
2000
3000
4000
5000
0
200
400
600
800
1000
1200
1400

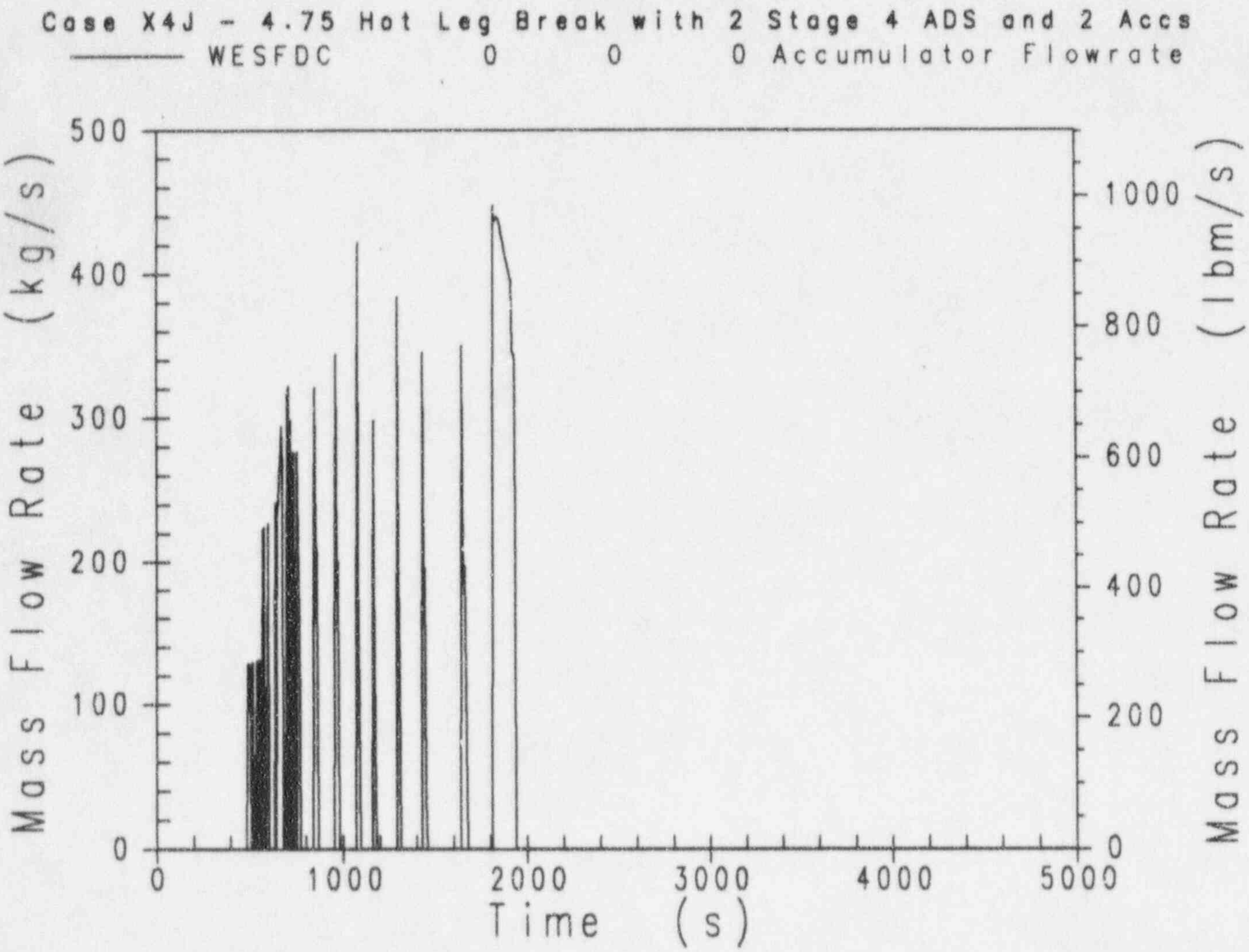


Case X4J - 4.75 Hot Leg Break with 2 Stage 4 ADS and 2 Accs
WGBB 0 0 0 Break Vapor Flow
Mass Flow Rate (kg/s)
Mass Flow Rate (lbm/s)
Time (s)
0
20
40
60
80
100
50
150
200
1000
2000
3000
4000
5000

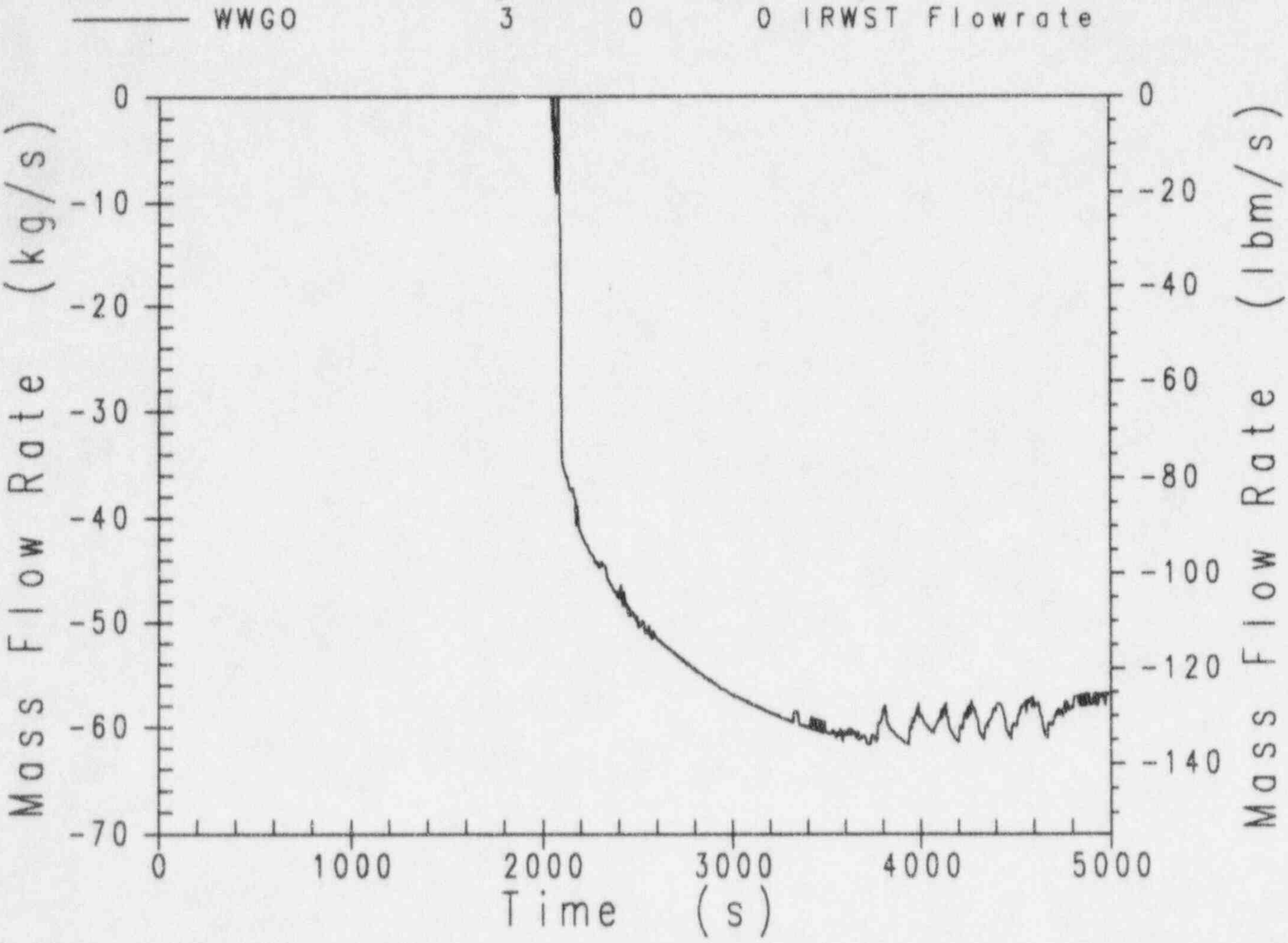
Case X4J - 4.75 Hot Leg Break with 2 Stage 4 ADS and 2 Accs

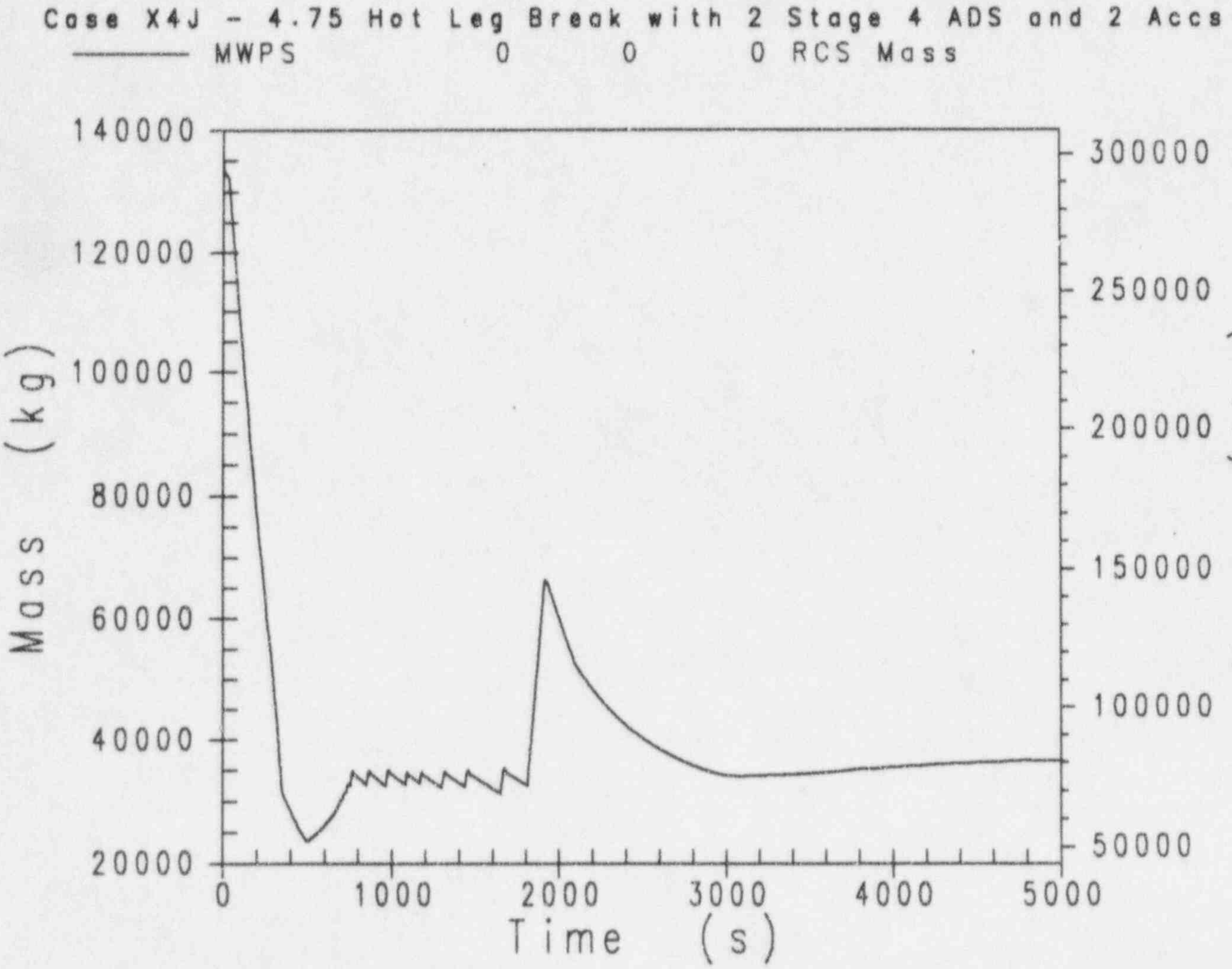



Case X4J - 4.75 Hot Leg Break with 2 Stage 4 ADS and 2 Accs
WGGO 1 0 0 ADS4 Vapor Flow
Mass Flow Rate (kg/s)
Mass Flow Rate (lbm/s)
Time (s)
0
20
40
60
80
50
100
150
1000
2000
3000
4000
5000

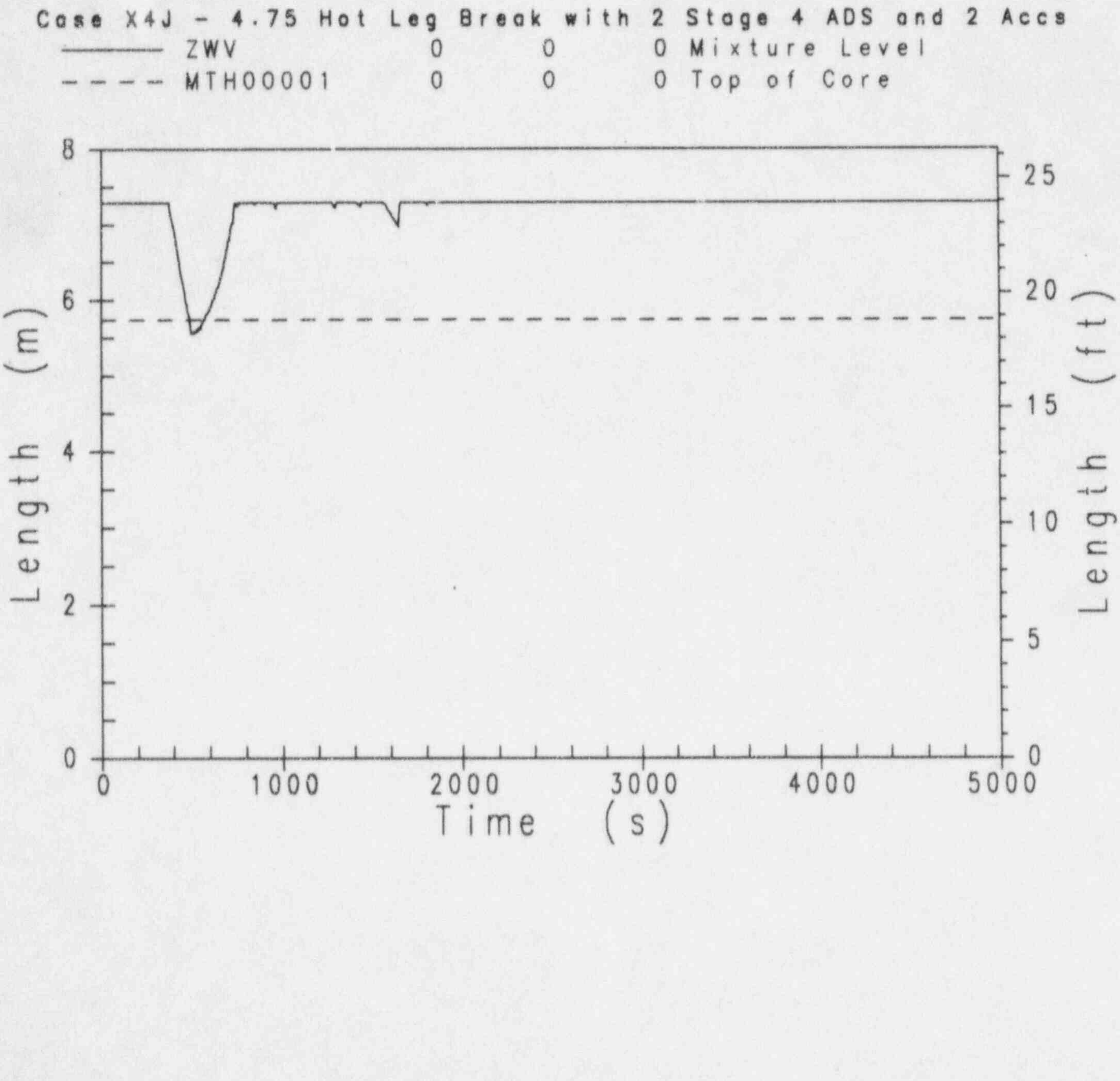

Case X4J - 4.75 Hot Leg Break with 2 Stage 4 ADS and 2 Accs
WESFDC 0 0 0 Accumulator Flowrate
Mass Flow Rate (kg/s)
Mass Flow Rate (lbm/s)
Time (s)
0
100
200
300
400
500
1000
2000
3000
4000
5000
600
800

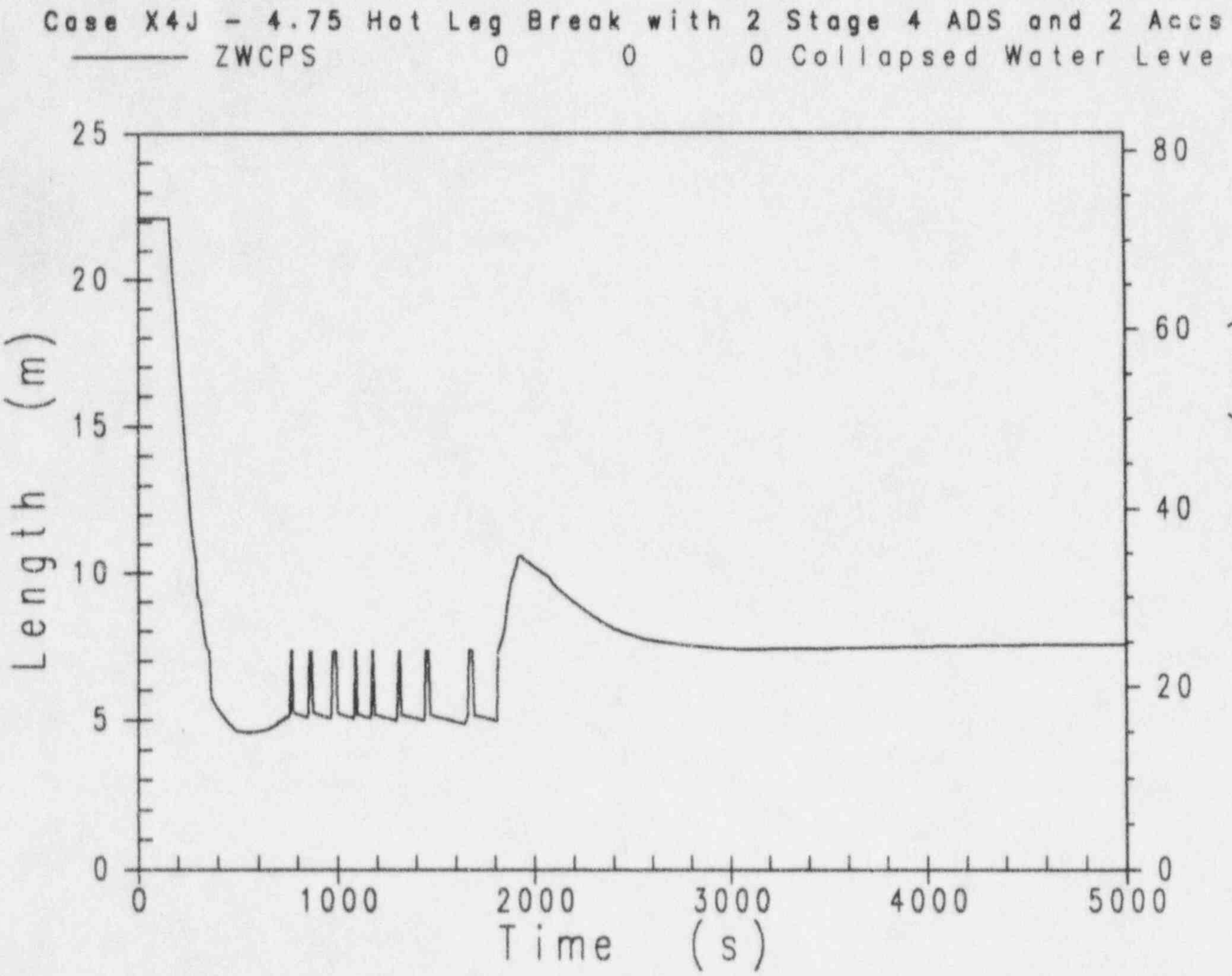
Case X4J - 4.75 Hot Leg Break with 2 Stage 4 ADS and 2 Accs



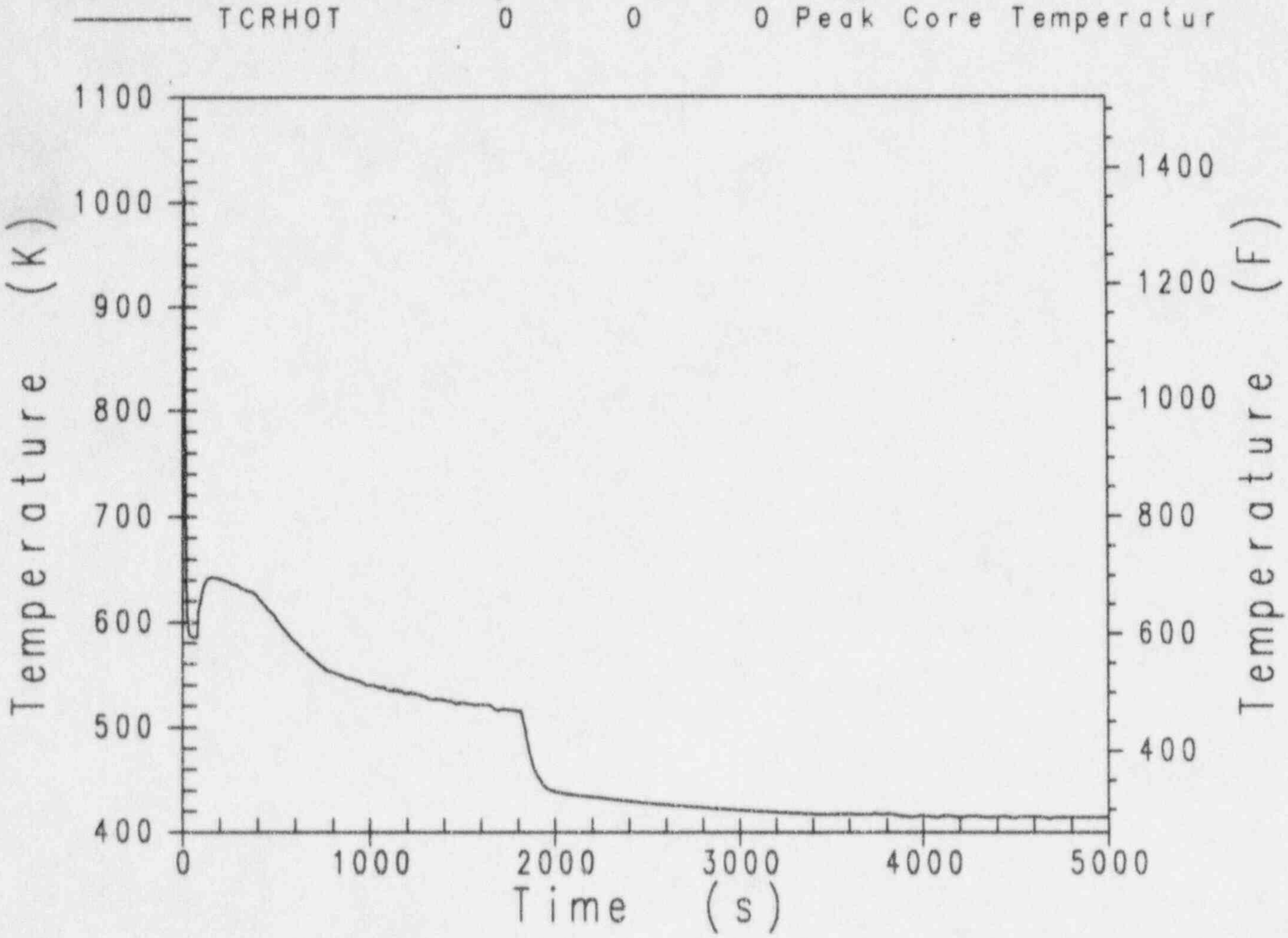


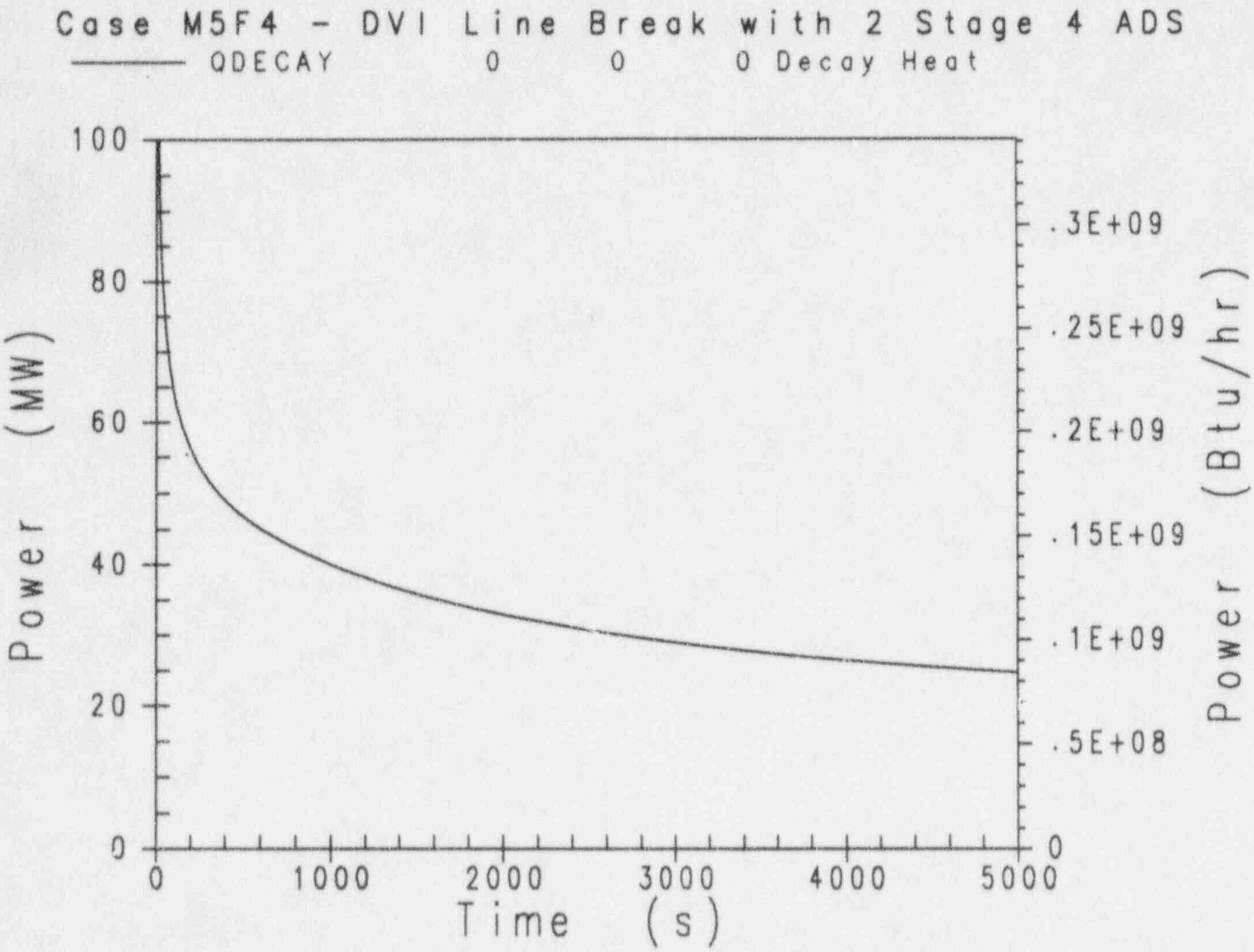
Case X4J - 4.75 Hot Leg Break with 2 Stage 4 ADS and 2 Accs
MWPS 0 0 0 RCS Mass
Mass (kg)
Mass (lbm)
Time (s)
140000
120000
100000
80000
60000
40000
20000
300000
250000
200000
150000
100000
50000
0
1000
2000
3000
4000
5000


Case X4J - 4.75 Hot Leg Break with 2 Stage 4 ADS and 2 Accs
ZWV 0 0 0 Mixture Level
MTH00001 0 0 0 Top of Core
Length (m)
Length (ft)
Time (s)
0
2
4
6
8
0
5
10
15
20
25
0
1000
2000
3000
4000
5000

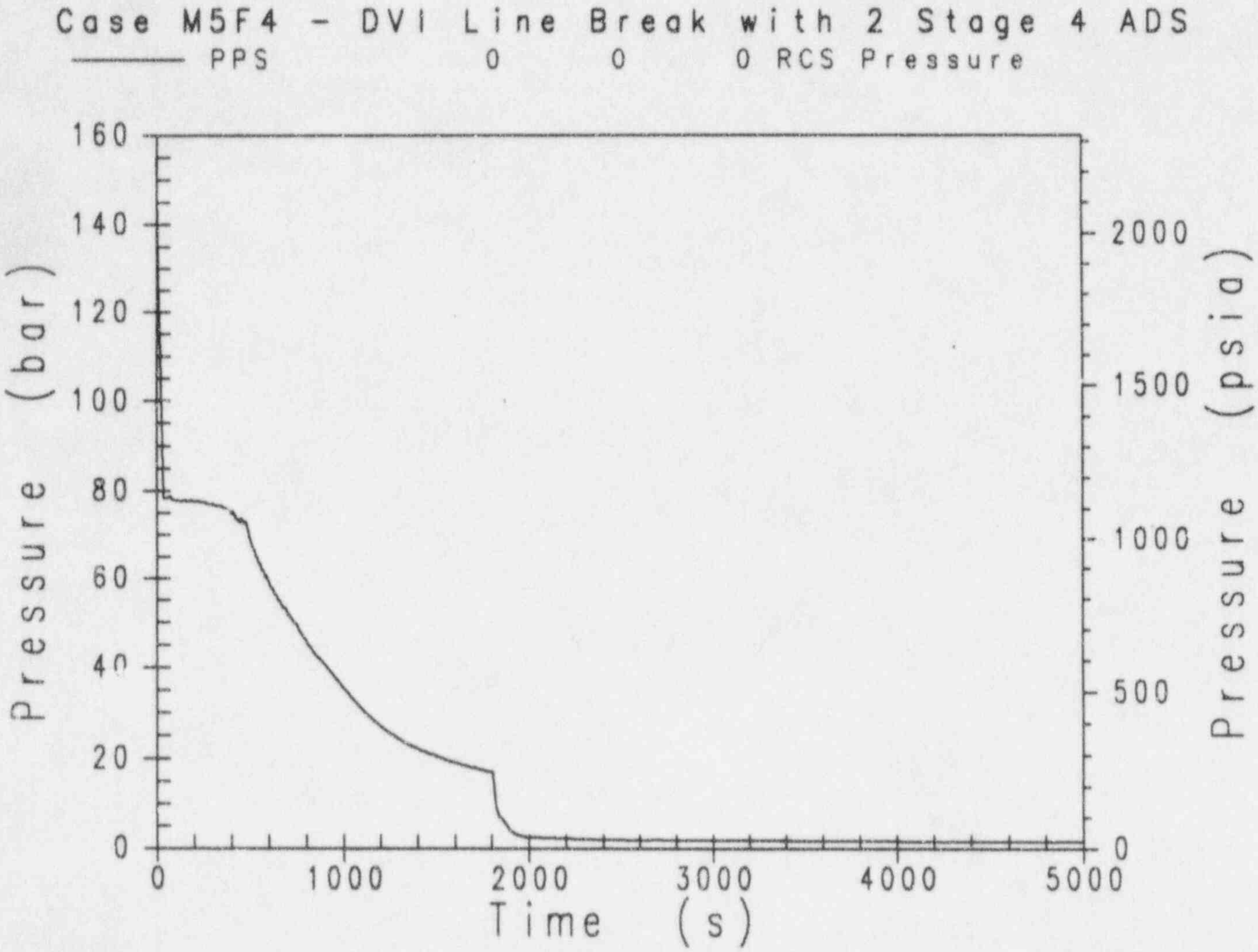

Case X4J - 4.75 Hot Leg Break with 2 Stage 4 ADS and 2 Accs
ZWCPS 0 0 0 Collapsed Water Leve
Length (m)
Length (ft)
Time (s)
0
5
10
15
20
25
20
40
60
80
1000
2000
3000
4000
5000

Case X4J - 4.75 Hot Leg Break with 2 Stage 4 ADS and 2 Accs

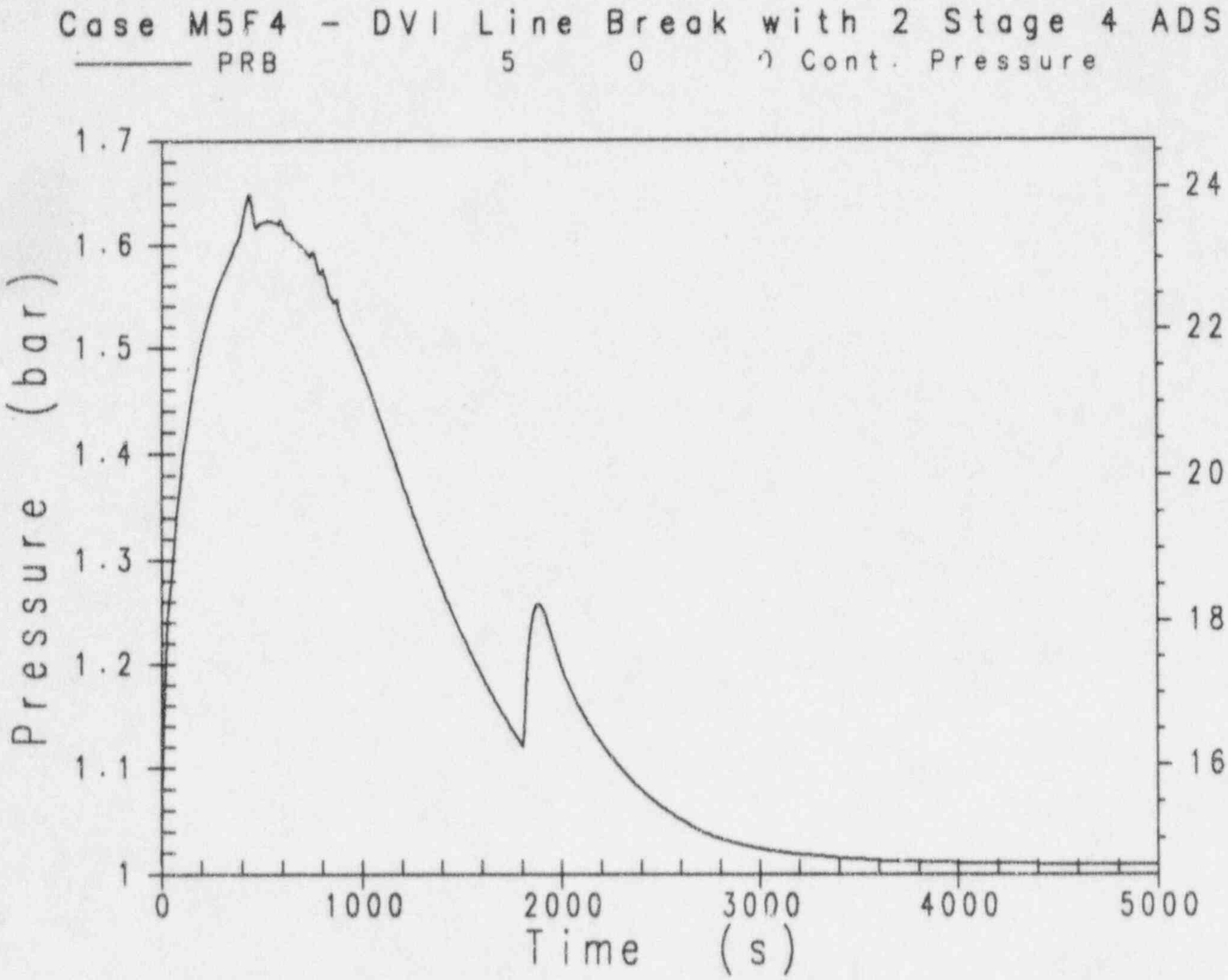




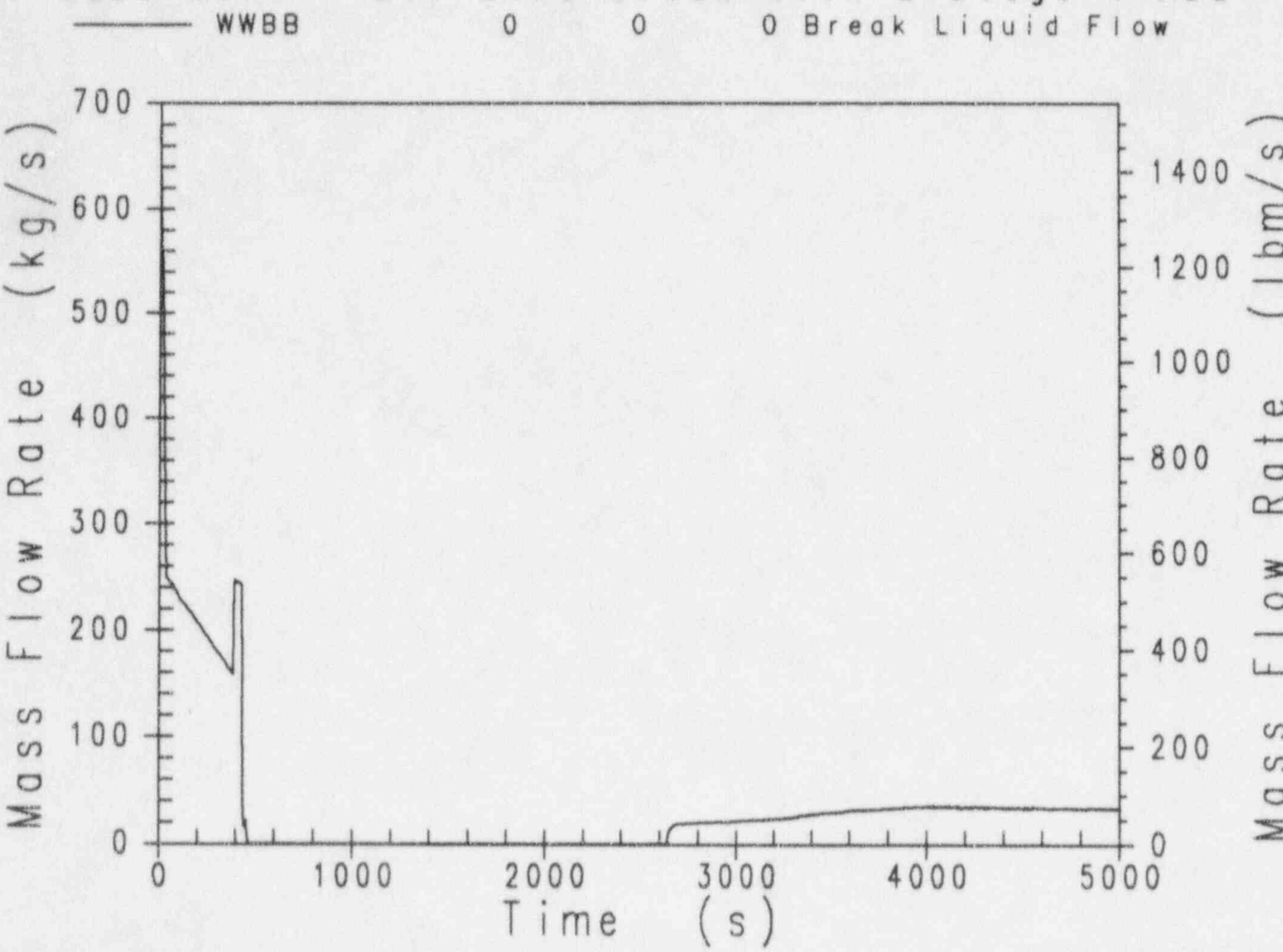
Case M5F4 - DVI Line Break with 2 Stage 4 ADS
QDECAY 0 0 0 Decay Heat
Power (MW)
Power (Btu/hr)
Time (s)
0
20
40
60
80
100
.5E+08
.1E+09
.15E+09
.2E+09
.25E+09
.3E+09
1000
2000
3000
4000
5000

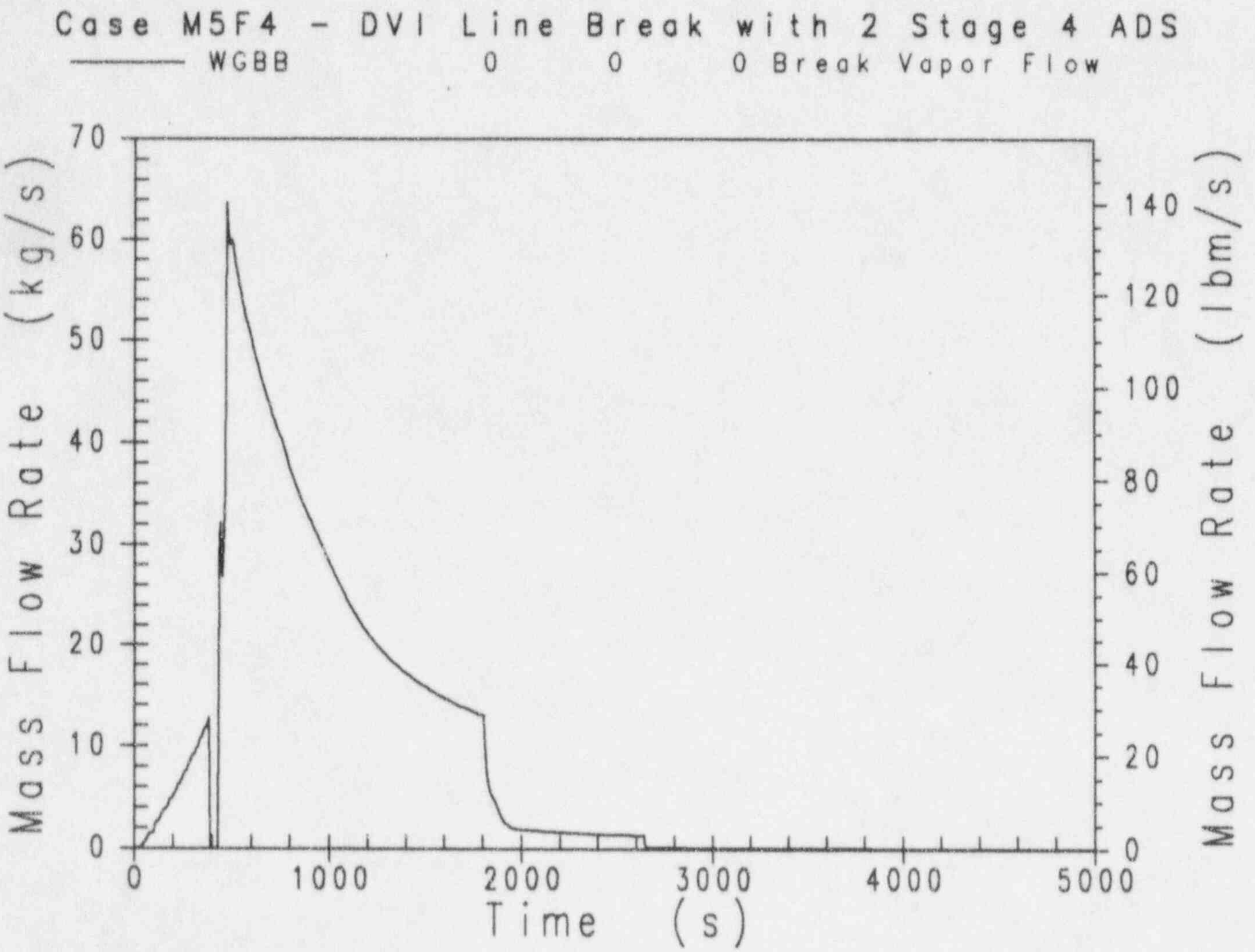


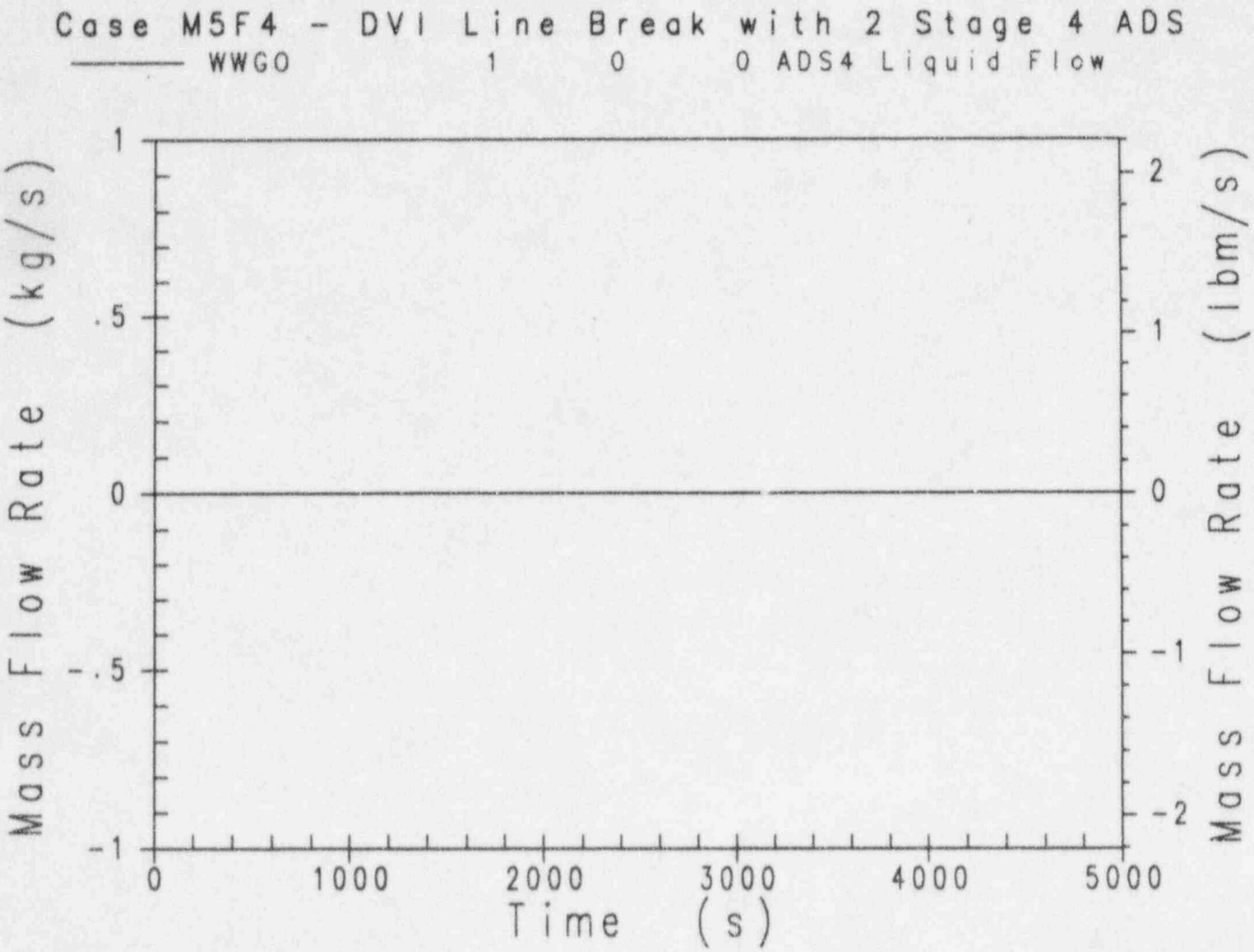
Case M5F4 - DVI Line Break with 2 Stage 4 ADS
PPS
0 0 0 RCS Pressure
Pressure (bar)
160
140
120
100
80
60
40
20
0
Pressure (psia)
2000
1500
1000
500
0
0
1000
2000
3000
4000
5000
Time (s)


Case M5F4 - DVI Line Break with 2 Stage 4 ADS
PRB 5 0 0 Cont. Pressure
Pressure (bar)
Pressure (psia)
Time (s)
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
24
22
20
18
16
0
1000
2000
3000
4000
5000

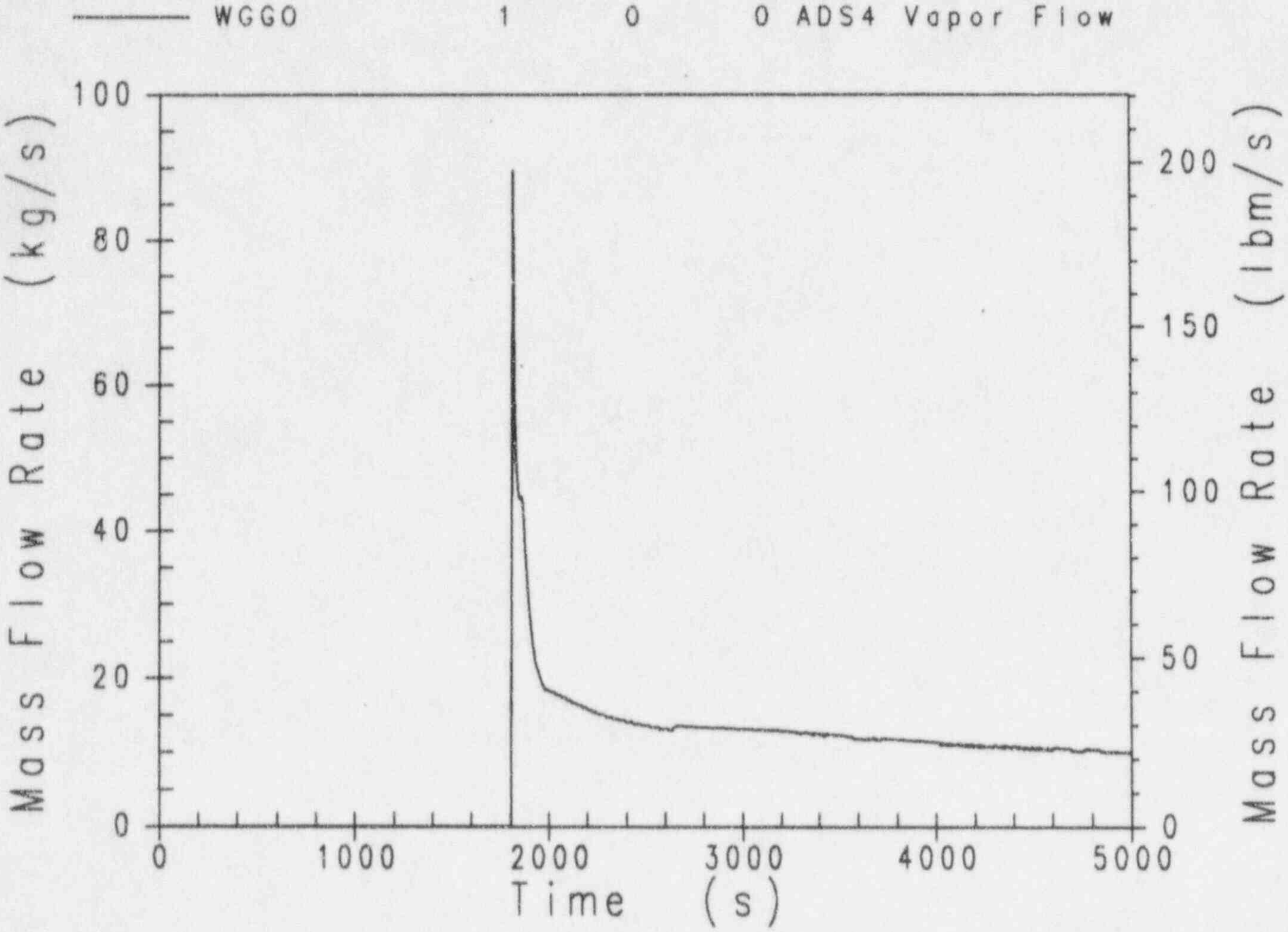
Case M5F4 - DVI Line Break with 2 Stage 4 ADS

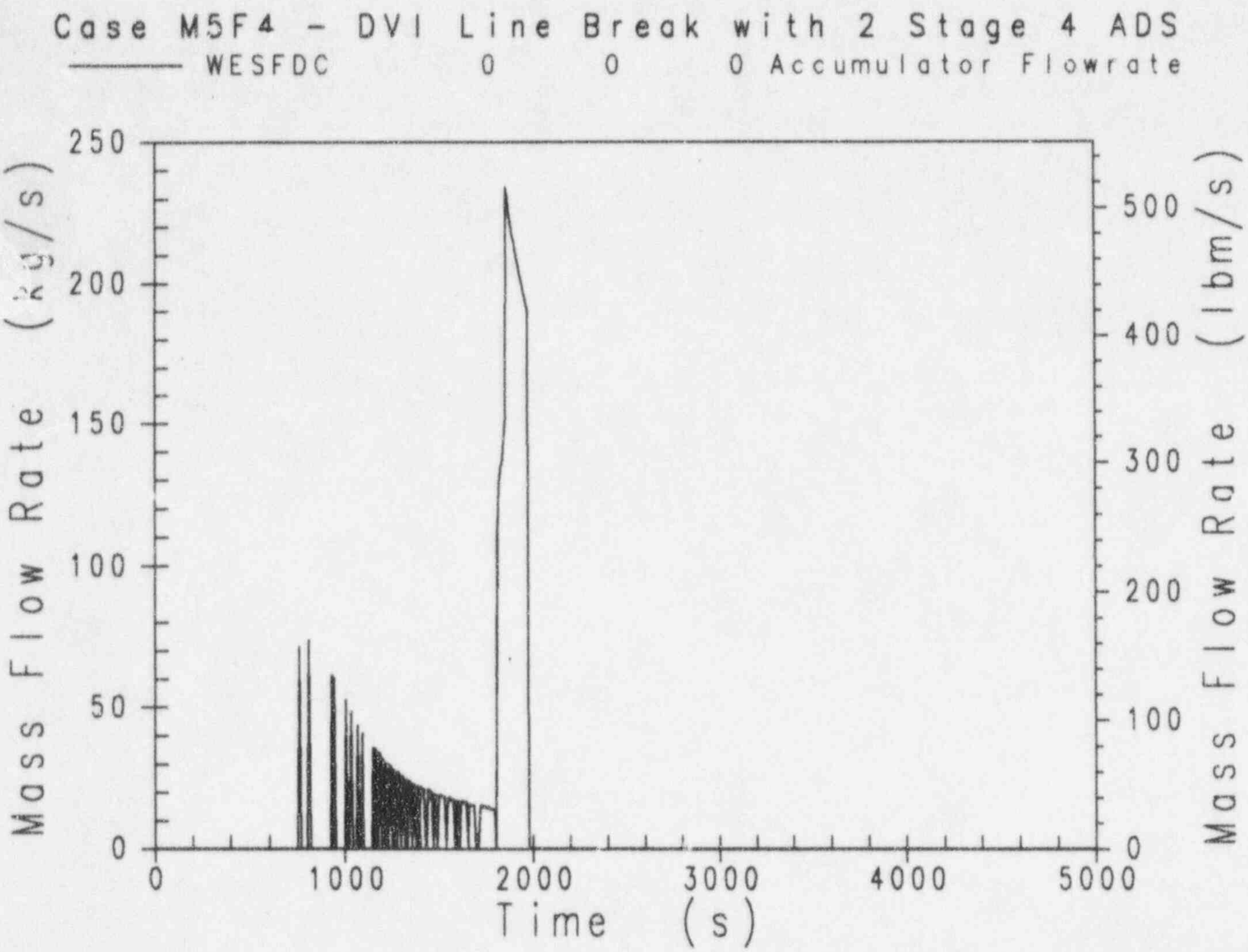



Case M5F4 - DVI Line Break with 2 Stage 4 ADS
WGBB 0 0 0 Break Vapor Flow
Mass Flow Rate (kg/s)
Mass Flow Rate (lbm/s)
Time (s)
0
10
20
30
40
50
60
70
0
20
40
60
80
100
120
140
0
1000
2000
3000
4000
5000

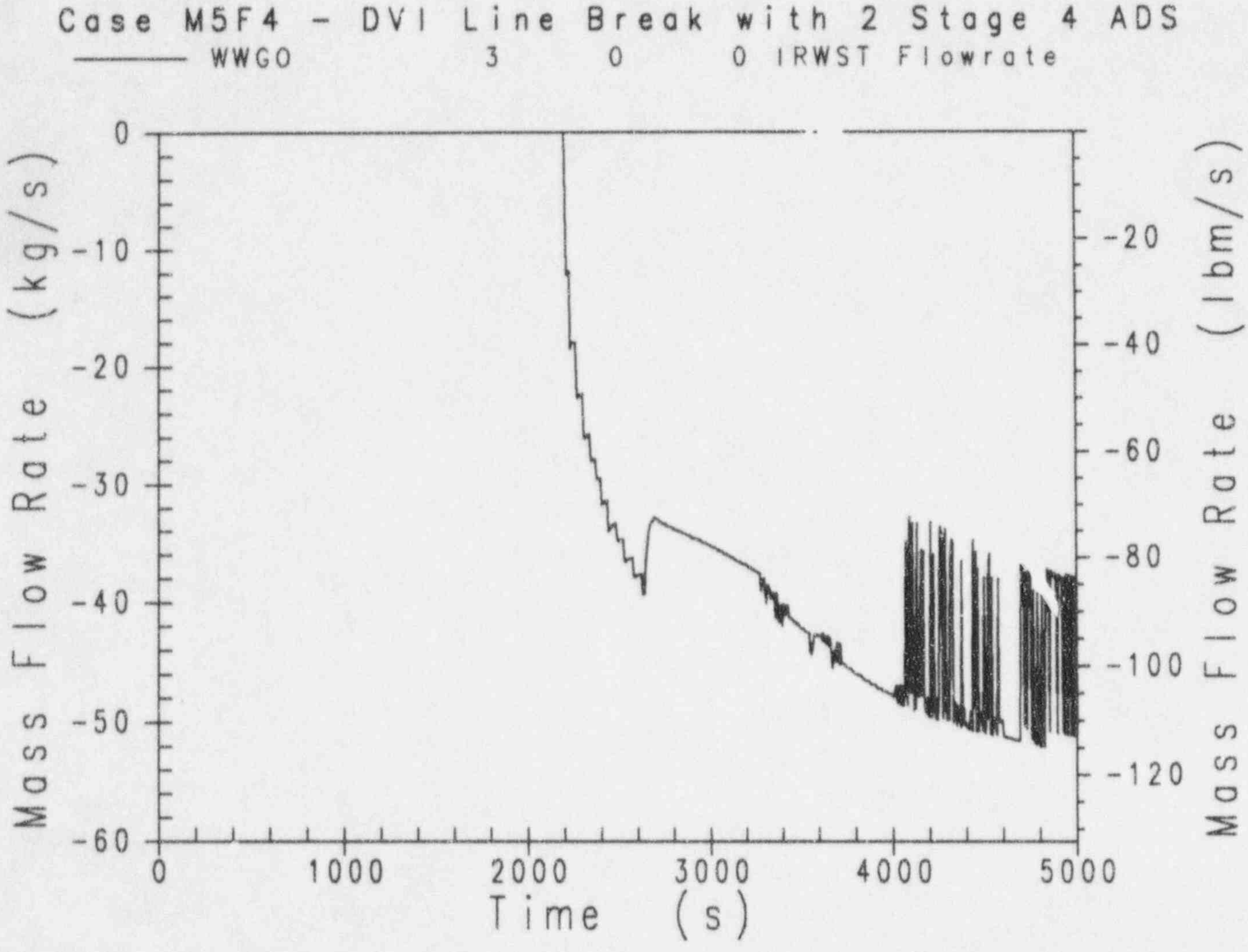

Case M5F4 - DVI Line Break with 2 Stage 4 ADS
WWGO 1 0 0 ADS4 Liquid Flow
Mass Flow Rate (kg/s)
Mass Flow Rate (lbm/s)
Time (s)
1
.5
0
-.5
-1
2
1
0
-1
-2
0
1000
2000
3000
4000
5000

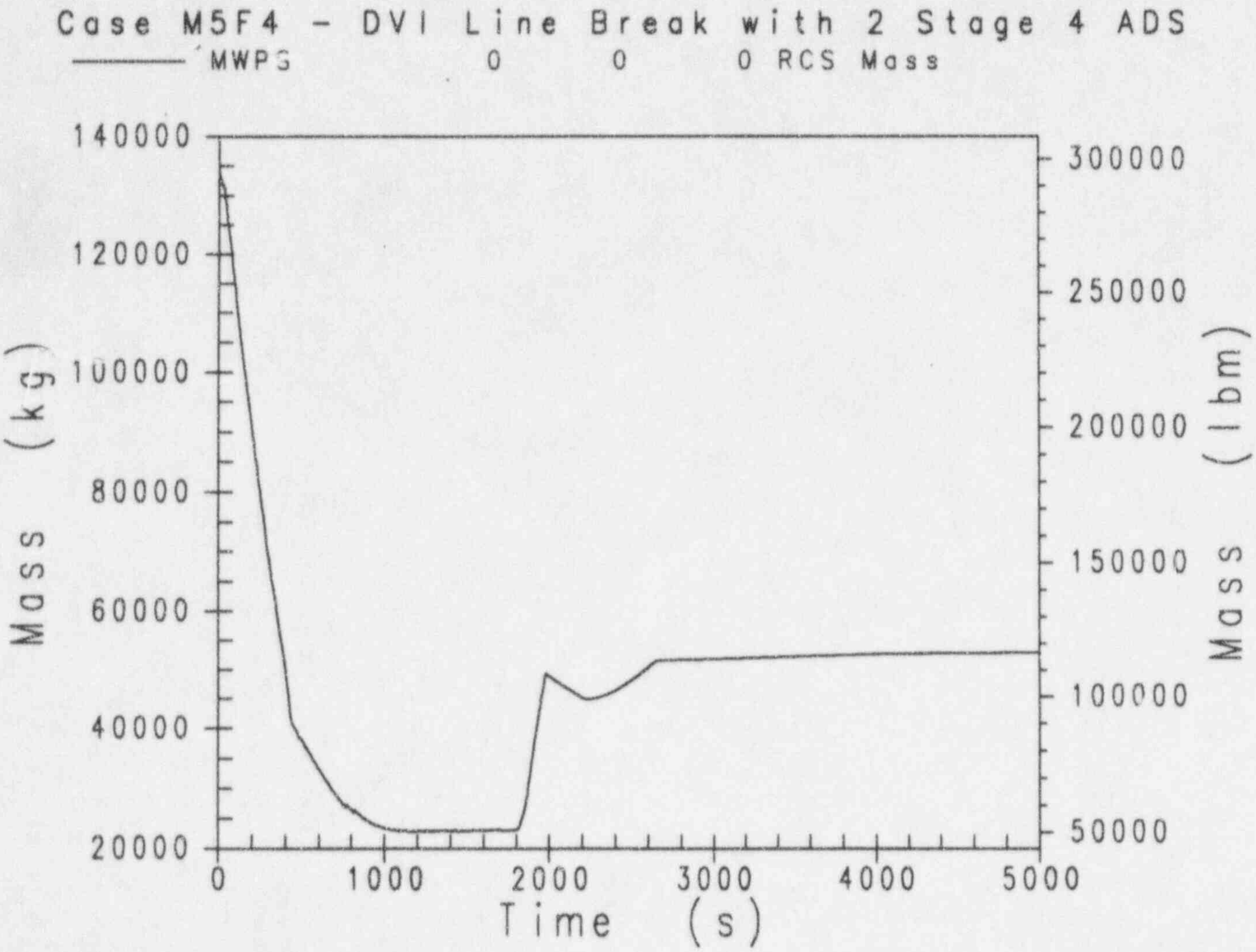
Case M5F4 - DVI Line Break with 2 Stage 4 ADS



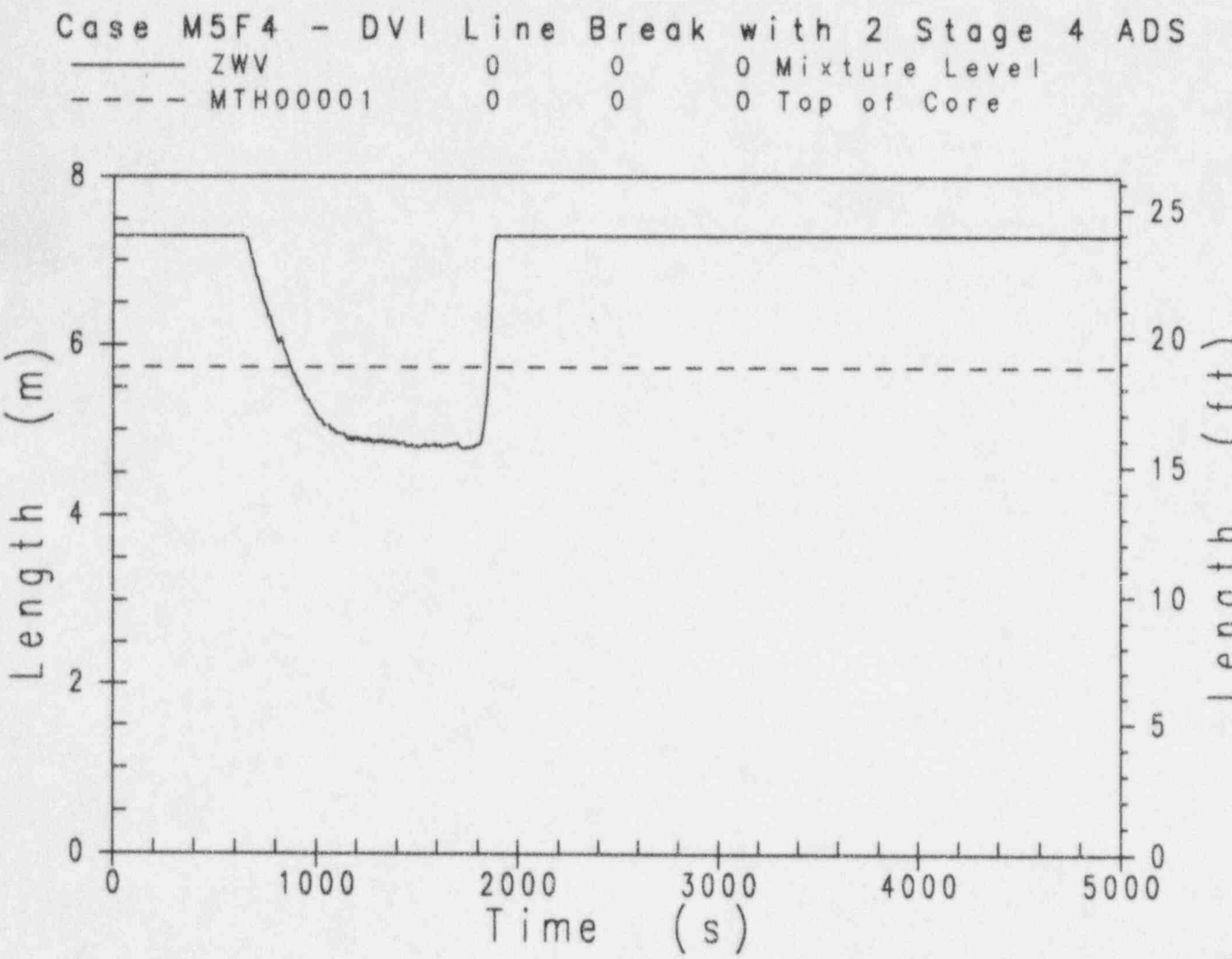


Case M5F4 - DVI Line Break with 2 Stage 4 ADS
WESFDC 0 0 0 Accumulator Flowrate
Mass Flow Rate (kg/s)
Mass Flow Rate (lbm/s)
Time (s)
0
50
100
150
200
250
100
200
300
400
500
1000
2000
3000
4000
5000

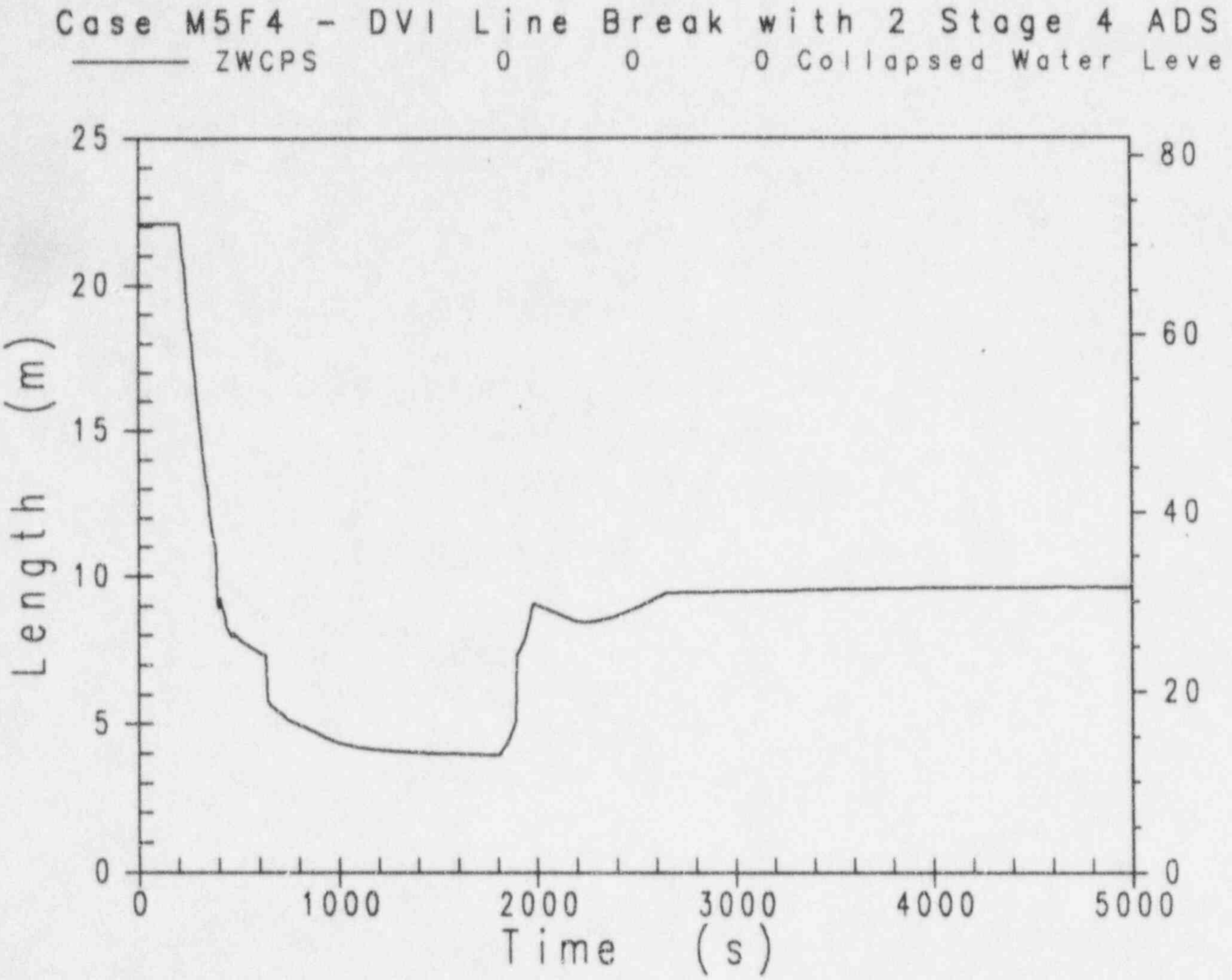

Case M5F4 - DVI Line Break with 2 Stage 4 ADS
WWGO 3 0 0 IRWST Flowrate
Mass Flow Rate (kg/s)
Mass Flow Rate (lbm/s)
Time (s)
0
-10
-20
-30
-40
-50
-60
-20
-40
-60
-80
-100
-120
0
1000
2000
3000
4000
5000

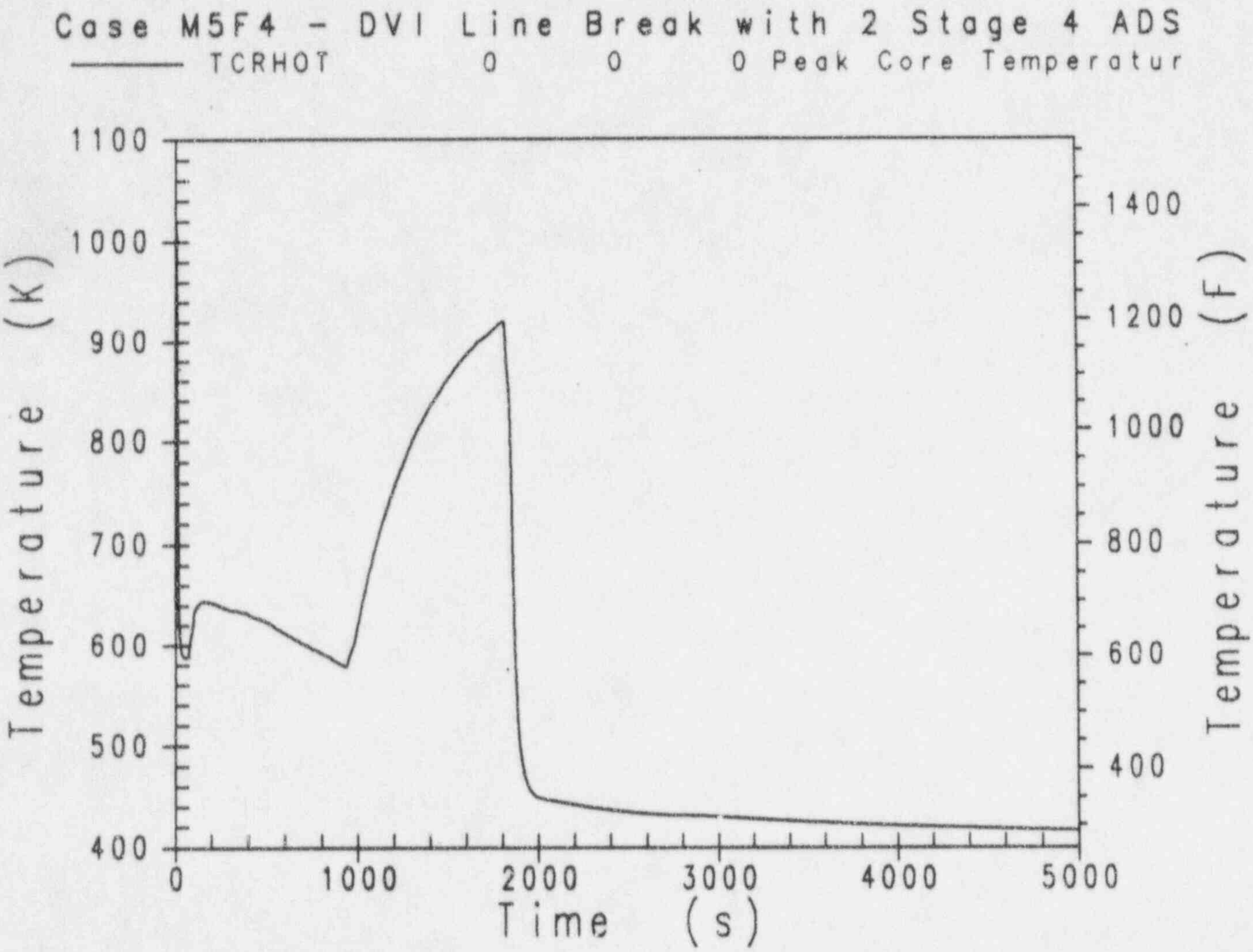


Case M5F4 - DVI Line Break with 2 Stage 4 ADS
MWPS 0 0 0 RCS Mass
140000
120000
100000
80000
60000
40000
20000
Mass (kg)
300000
250000
200000
150000
100000
50000
Mass (lbm)
0
1000
2000
3000
4000
5000
Time (s)



Case M5F4 - DVI Line Break with 2 Stage 4 ADS
ZWV 0 0 0 Mixture Level
MTH00001 0 0 0 Top of Core
Length (m)
Length (ft)
Time (s)
0
2
4
6
8
0
5
10
15
20
25
0
1000
2000
3000
4000
5000


Case M5F4 - DVI Line Break with 2 Stage 4 ADS
ZWCPS 0 0 0 Collapsed Water Leve
Length (m)
Length (ft)
Time (s)
0
5
10
15
20
25
20
40
60
80
1000
2000
3000
4000
5000


Case M5F4 - DVI Line Break with 2 Stage 4 ADS
TCRHOT 0 0 0 Peak Core Temperatur
Temperature (K)
Temperature (F)
Time (s)
1100
1000
900
800
700
600
500
400
1400
1200
1000
800
600
400
0
1000
2000
3000
4000
5000