Westinghouse Electric Corporation
Energy Systems
Box 355
Pittsburgh Pennsylvania 15230-0355

AW-95-913

December 15, 1995

Document Control Desk
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

ATTENTION: MR. T. R. QUAY

APPLICATION FOR WITHHOLDING PROPRIETARY INFORMATION FROM PUBLIC DISCLOSURE

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

Dear Mr. Quay:

The application for withholding is submitted by Westinghouse Electric Corporation ("Westinghouse") pursuant to the provisions of paragraph (b)(1) of Section 2.790 of the Commission's regulations. It contains commercial strategic information proprietary to Westinghouse and customarily held in confidence.

The proprietary material for which withholding is being requested is identified in the proprietary version of the subject report. In conformance with 10CFR Section 2.790, Affidavit AW-95-913 accompanies this application for withholding setting forth the basis on which the identified proprietary information may be withheld from public disclosure.

Accordingly, it is respectfully requested that the subject information which is proprietary to Westinghouse be withheld from public disclosure in accordance with 10CFR Section 2.790 of the Commission's regulations.

Correspondence with respect to this application for withholding or the accompanying affidavit should reference AW-95-913 and should be addressed to the undersigned.

Very truly yours,

Brian A. McIntyre, Manager
Advanced Plant Safety and Licensing

/nja

cc: Kevin Bohrer NRC 12H5

2641A

AFFIDAVIT

COMMONWEALTH OF PENNSYLVANIA:

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COUNTY OF ALLEGHENY:

Before me, the undersigned authority, personally appeared Brian A. McIntyre, who, being by me duly sworn according to law, deposes and says that he is authorized to execute this Affidavit on behalf of Westinghouse Electric Corporation ("Westinghouse") and that the averments of fact set forth in this Affidavit are true and correct to the best of his knowledge, information, and belief:

Brian A. McIntyre

Brian A. McIntyre, Manager
Advanced Plant Safety and Licensing

Sworn to and subscribed
before me this 15th day
of December, 1995

Lorraine M. Piplica
Notary Public

2642A

Notarial Seal
Lorraine M. Piplica, Notary Public
Monroeville Boro, Allegheny County
My Commission Expires Dec. 14, 1999
Member, Pennsylvania Association of Notaries

(1) I am Manager, Advanced Plant Safety And Licensing, in the Advanced Technology Business Area, of the Westinghouse Electric Corporation and as such, I have been specifically delegated the function of reviewing the proprietary information sought to be withheld from public disclosure in connection with nuclear power plant licensing and rulemaking proceedings, and am authorized to apply for its withholding on behalf of the Westinghouse Energy Systems Business Unit.

(2) I am making this Affidavit in conformance with the provisions of 10CFR Section 2.790 of the Commission's regulations and in conjunction with the Westinghouse application for withholding accompanying this Affidavit.

(3) I have personal knowledge of the criteria and procedures utilized by the Westinghouse Energy Systems Business Unit in designating information as a trade secret, privileged or as confidential commercial or financial information.

(4) Pursuant to the provisions of paragraph (b)(4) of Section 2.790 of the Commission's regulations, the following is furnished for consideration by the Commission in determining whether the information sought to be withheld from public disclosure should be withheld.

(i) The information sought to be withheld from public disclosure is owned and has been held in confidence by Westinghouse.

(ii) The information is of a type customarily held in confidence by Westinghouse and not customarily disclosed to the public. Westinghouse has a rational basis for determining the types of information customarily held in confidence by it and, in that connection, utilizes a system to determine when and whether to hold certain types of information in confidence. The application of that system and the substance of that system constitutes Westinghouse policy and provides the rational basis required.

Under that system, information is held in confidence if it falls in one or more of several types, the release of which might result in the loss of an existing or potential competitive advantage, as follows:

(a) The information reveals the distinguishing aspects of a process (or component, structure, tool, method, etc.) where prevention of its use by any of Westinghouse's competitors without license from Westinghouse constitutes a competitive economic advantage over other companies.

(b) It consists of supporting data, including test data, relative to a process (or component, structure, tool, method, etc.), the application of which data secures a competitive economic advantage, e.g., by optimization or improved marketability.

(c) Its use by a competitor would reduce his expenditure of resources or improve his competitive position in the design, manufacture, shipment, installation, assurance of quality, or licensing a similar product.

(d) It reveals cost or price information, production capacities, budget levels, or commercial strategies of Westinghouse, its customers or suppliers.

(e) It reveals aspects of past, present, or future Westinghouse or customer funded development plans and programs of potential commercial value to Westinghouse.

(f) It contains patentable ideas, for which patent protection may be desirable.

There are sound policy reasons behind the Westinghouse system which include the following:

(a) The use of such information by Westinghouse gives Westinghouse a competitive advantage over its competitors. It is, therefore, withheld from disclosure to protect the Westinghouse competitive position.

(b) It is information which is marketable in many ways. The extent to which such information is available to competitors diminishes the Westinghouse ability to sell products and services involving the use of the information.

(c) Use by our competitor would put Westinghouse at a competitive disadvantage by reducing his expenditure of resources at our expense.

(d) Each component of proprietary information pertinent to a particular competitive advantage is potentially as valuable as the total competitive advantage. If competitors acquire components of proprietary information, any one component may be the key to the entire puzzle, thereby depriving Westinghouse of a competitive advantage.

(e) Unrestricted disclosure would jeopardize the position of prominence of Westinghouse in the world market, and thereby give a market advantage to the competition of those countries.

(f) The Westinghouse capacity to invest corporate assets in research and development depends upon the success in obtaining and maintaining a competitive advantage.

(iii) The information is being transmitted to the Commission in confidence and, under the provisions of 10CFR Section 2.790, it is to be received in confidence by the Commission.

(iv) The information sought to be protected is not available in public sources or available information has not been previously employed in the same original manner or method to the best of our knowledge and belief.

(v) Enclosed is Letter NTD-NRC-95-4610, December 15, 1995 being transmitted by Westinghouse Electric Corporation (W) letter and Application for Withholding Proprietary Information from Public Disclosure, Brian A. McIntyre (W), to Mr. T. R. Quay, Office of NRR. The proprietary information as submitted for use by Westinghouse Electric Corporation is in response to questions concerning the AP600 plant and the associated design certification application and is expected to be applicable in other licensee submittals in response to certain NRC requirements for justification of licensing advanced nuclear power plant designs.

This information is part of that which will enable Westinghouse to:

(a) Demonstrate the design and safety of the AP600 Passive Safety Systems.

(b) Establish applicable verification testing methods.

(c) Design Advanced Nuclear Power Plants that meet NRC requirements.

(d) Establish technical and licensing approaches for the AP600 that will ultimately result in a certified design.

(e) Assist customers in obtaining NRC approval for future plants.

Further this information has substantial commercial value as follows:

(a) Westinghouse plans to sell the use of similar information to its customers for purposes of meeting NRC requirements for advanced plant licenses.

(b) Westinghouse can sell support and defense of the technology to its customers in the licensing process.

Public disclosure of this proprietary information is likely to cause substantial harm to the competitive position of Westinghouse because it would enhance the ability of competitors to provide similar advanced nuclear power designs and licensing defense services for commercial power reactors without commensurate expenses. Also, public disclosure of the information would enable others to use the information to meet NRC requirements for licensing documentation without purchasing the right to use the information.

The development of the technology described in part by the information is the result of applying the results of many years of experience in an intensive Westinghouse effort and the expenditure of a considerable sum of money.

In order for competitors of Westinghouse to duplicate this information, similar technical programs would have to be performed and a significant manpower effort, having the requisite talent and experience, would have to be expended for developing analytical methods and receiving NRC approval for those methods.

Further the deponent sayeth not.

Attachment A to NTD-NRC-95-4610
Enclosed Responses to NRC Requests for Additional Information

Re: LOFTRAN
440.306

Re: NOTRUMP
440.327
440.329
440.334
440.432
440.433 *
440.439
440.483 *
440.488 *
440.499
440.515
440.516
440.517 *
440.518 *
440.519 *
440.520 *

Re: WCOBRA/TRAC
440.348 Revision 1 *

*** - Contains Westinghouse Proprietary Material**

Enclosure 2 to NTD-NRC-95-4610

(non-proprietary copy of Enclosure 1)

Question 440.306

Re: WCAP-14234 (LOFTRAN CAD)
Page 3-8. Is any smoothing done on the boiling curve for PRHR convective heat transfer? Are the convective heat transfer coefficients smoothed or lagged? Please show that conservation of energy is maintained for the PRHR if this is the case.

Response:

No smoothing is done on the boiling curve or heat transfer coefficients. The response to RAI 440.305 provides additional details on the numercial solution of the heat transfer in the PRHR, including the iterative method for calculating the heat transfer coefficients and secondary side heat transfer regime.

SSAR Revision: NONE

Question 440.327

Re: WCAP-14206 (NOTRUMP CAD)
On page 1-10, it is stated that the AP600 plant analysis will be validated against data to verify the PIRT, however no specific facilities were identified. Please provide a matrix of tests, both separate effects and integral that will be used for assessing each of the PIRT items. Also, identify the models that is to be validated or verified for each test.

Response:

RAI 440.327 is almost identical to RAI 440.334. Both RAIs ask about the NOTRUMP code validation and comparisons to specific data for specific model validation. More specifically RAI 440.334 asks for each of the PIRT items to be addressed. Using the final PIRT, provided in Table 4 of the response to RAI 440.325, the data used for each of the component and phenomena validation will be discussed and will provide the matrix of tests requested in the RAI.

ADS 1-3

Critical flow
The time period when this phenomena is ranked high is during the ADS blowdown as shown in Table 4. The data used to validate the NOTRUMP critical flow model, specifically for the ADS valves, are from the full scale ADS separate effects Phase B tests. These tests provide data to determine critical flow through the ADS valves (if it occurs) on a prototypical geometry at full scale for the AP600 ADS system. There is additional critical flow data from the SPES-2 and OSU test facilities which has been used to validate the critical flow models in the NOTRUMP code in the preliminary validation reports, as well as data in the open literature which was also used to validate the critical flow models as given in RAI 952.95. (Reference 440.327-1)

Two-Phase Pressure Drop
The ADS 1-3 two-phase pressure drop is also ranked high during the ADS blowdown period when the ADS 1-3 becomes the principle flow path out of the primary system. The pressure drop is also important when the fourth stage ADS valve opens since steam can still vent out of the primary system. The ADS tests provide data on the two-phase pressure drops at conditions typical of the ADS 1-3 operation and will be used to assess the NOTRUMP predictions for ADS 1-3 in the NOTRUMP Final Validation Report.

Valve Loss Coefficients
This phenomena is also ranked high during the ADS phase of the transient. There have been single phase tests performed to measure the valve loss coefficients and the results are reported in the ADS Test and Analysis Report. The single phase value loss coefficient is an input into the NOTRUMP code. This data will be used in the assessment of the NOTRUMP prediction of the two-phase ADS tests for the NOTRUMP Final Validation Report.

Single Phase Pressure Drop
The single phase pressure drop is ranked low for the IRWST phase of the transient. In the ADS Phase B experiments, single phase Pressure drops were measured over a range of steam flows in the ADS configuration.

The valve and piping losses were also calculated from the measurements such that this data can be compared to the NOTRUMP calculations. These comparisons will be presented in the NOTRUMP Final Validation Report.

ADS 4

Critical flow

This phenomena is ranked high in the Final Small Break LOCA PIRT during the ADS-4 phase of the transient, however there have been no specific experiments conducted on the ADS stage 4 valves and associated piping. The uncertainty in the critical flow model used in the NOTRUMP code was assessed relative to the venting capacity of the current (1995) ADS stage 4 system capacity and it was determined that the ADS stage 4 system capacity was sufficiently large such that if the uncertainties are considered in the calculation of the critical flow model, the ADS stage 4 would still have sufficient capacity to successfully depressurize the primary system. (See Reference 440.327-1) Therefore, there is no need for additional validation of this phenomena.

Subsonic Flow

This phenomena is ranked low during the ADS phase and medium during the IRWST phase. The validation that has been used for the ADS stage 4 critical flow and subsonic flow modeling is from the integral systems tests with SPES-2 and OSU and the data that exists in the literature which was referenced in the response to RAI 952.95 (Reference 440.327-1). The critical flow model is the Henry/Fauske correlation which is used up to a quality of 10% (including superheated steam) and the homogeneous equilibrium model which is used for qualities greater then 10%, as discussed in Section 4 of Reference 440.327-2. When validating this model, the measured break flow, the flow from ADS 1-3 stages, as well as the flow data from the ADS stage 4 piping and valves were used in the preliminary validation reports. The comparisons of the flow from the breaks and the ADS stages 1-3 and stage 4 piping were shown to be in reasonable agreement with the test data in the preliminary validation reports such that this particular component has been validated. These comparisons will be provided in the NOTRUMP Final Validation Report.

Two-Phase Pressure Drop

This phenomena is ranked medium for the ADS and IRWST phases of the transient. The two-phase pressure drop for the ADS stage 4 valve and piping was also measured in the OSU and the SPES-2 experiments such that the measured line pressure drops will be compared to the predicted values from the NOTRUMP code in the NOTRUMP Final Validation Report.

BREAK

Line Resistance

This is a low ranked phenomena. When the break flow is critical, the flow resistance in the cold leg piping is unimportant. The flow resistance does become slightly more important as the primary system depressurizes and the break flow becomes subsonic. At this time, however, the main vent path out of the primary system is no longer the break but rather the ADS 1-3 and ADS 4 stages. The line resistance can be calculated with sufficient accuracy from the geometry of the system. No additional validation is necessary.

Critical Flow (in complex geometries)
This is a high ranked phenomena for the first three phases of the transient. The SPES-2 and the OSU tests simulated breaks at several different locations with different geometries with different break areas and sizes including the cold leg, CMT balance line and the Direct Vessel Injection line. The break flows were measured and will be compared to the code predictions to validate the critical flow model used in the tests in the NOTRUMP Final Validation Report.

Subsonic Flow
This is a low ranked phenomena in the small break PIRT since as the AP600 transient proceeds, the primary leakage flow path shifts from the break (which is very important in the early stages of the transient when critical flow exists at the break) to the ADS 1-3 and ADS stage 4 valves later in the transient where the valve area is significantly larger then the break area for most cases. Therefore, when the break is in subsonic flow it is not the main vent path out of the reactor system. The subsonic flow can be calculated from the given geometry of the system, and no additional validation is necessary.

Discharge Coefficient
This is a medium ranked phenomena for the first two phases of the transient. The discharge coefficient for the Henry/Fauske critical flow model, when modeling the tests has been chosen to be unity. The reason for this is that a rounded nozzle is used for the break. The comparisons of the integrated break flow from the SPES-2 and from the OSU tests indicates that the choice is appropriate. Sufficient data from the SPES-2 and OSU tests exist to validate the appropriate break model and discharge coefficient. The nozzle was calibrated for the OSU tests and the discharge coefficient was found to be 1.06 such that the choice of unity is appropriate. Sufficient data is available from the OSU and SPES tests to validate the choice of coefficient.

When modeling the AP600 plant, the Moody break flow model is used with a discharge coefficient of unity. The effects of varying a discharge coefficient is achieved by performing a break spectrum which tests for the worst break.

Accumulators

Injection Flow Rate
This phenomena is ranked high during the ADS blowdown since this is when the accumulators inject. The accumulator injection flow rate is determined by the accumulator pressure, system pressure and the line resistance. The flow rate is measured for both the SPES-2 and the OSU tests such that direct comparisons can be made. The line resistances have been characterized for the experiments and in the plant, there is a specified range of resistances which will be verified when the plant begins operation. Therefore, there is sufficient data to validate the values used for the experiments such that the model validation becomes the comparisons of the measured and predicted accumulator flows. Comparisons of the injection flow were provided in the preliminary validation reports. These will also be provided in the NOTRUMP Final Validation Report.

Non-condensible Gas Entrainment
This is a low ranked phenomena for the ADS blowdown phase and the IRWST injection phase of the transient. The non-condensible gas which is used to pressurize the accumulators is simulated in both the SPES-2 and the

OSU experiments. There has been analysis performed on the data in the SPES-2 and OSU Test Analysis Reports to characterize the gas expansion coefficient. The effects of the non-condensibles on the system response has been assessed for both facilities as discussed in the response to RAI 440.325. While there are no specific measurements of the non-condensible gas in these experiments, the presence of the gas can be detected from the fluid thermocouples, which will indicate a temperature other then saturation, when if steam was present, the thermocouples would indicate the saturation temperature. As discussed in the response to RAI 440.325, the impact of the non-condensible gases is not detectible from the experiments, therefore, since the tests are scaled to the plant, no impact would be expected, thus this phenomena is ranked very low. There is no need for any computer code assessment for the phenomena.

Cold Legs

Flashing

This phenomena is ranked low during the ADS depressurization phase since it only has an effect as the system depressurizes when the ADS valves open. Since the mass in the cold legs is small, and the system response is determined by the ADS valves and their flow, the cold leg flashing effects have a negligible effect on the system response. The data which can indicate cold leg flashing are the thermocouples in the cold leg as well as the level measurements in the cold legs, and steam generator plenums. These data will indicate the liquid mass lost due to both flashing and due to the draining of the system out the break. However, specific data on the cold leg flashing alone is not available. Since this phenomena is ranked low, no computer code assessment is needed.

PBL-to-Cold Leg Tee

This phenomena is highly ranked since the flow regime change in the cold leg and the draining of the balance line indicate the end of the CMT recirculation and the beginning of the CMT draining. There are several indirect measurements on this phenomena in both the SPES-2 and OSU experiments which will indicate if a particular model for this junction and its flow behavior is functioning properly. The CMT flow, the balance line pressure drop, levels in the vessel downcomer (which can be used to infer a level in the cold legs), and the CMT level will indicate when the balance line has drained and the CMT recirculation has ended. Since there have been several tests over a wide range of breaks (or depressurizations) for both the SPES-2 and OSU facilities, there is ample data to validate a model. Comparisons of these parameters were provided in the Preliminary Validation Report and will also be provided in the NOTRUMP Final Validation Report.

Phase Separation

This phenomena is also highly ranked and is similar to the pressure balance line Tee behavior since the cold leg is expected to be in a separated flow regime as the pressure balance line drains. There is indirect data available from the SPES-2 and OSU experiments similar to that discussed for the PBL-to-Cold Leg Tee which indicate when the cold leg should be in a separated flow regime, but there is no specific measurements available from these experiments. NOTRUMP comparisons to the OSU and SPES data will indicate when the code is predicting a separated flow regime and the balance lines are draining as compared to the tests. As indicated for the PBL-to-cold leg Tee, data comparison of the indirect parameters which reflect the phase separation effects will be evaluated in the NOTRUMP Final Validation Report.

Stored Energy Release
This is a low ranked phenomena and is related to the energy release from the cold leg piping. Since the piping mass is small relative to the vessel wall and other components, this energy release will have a small effect on the system response. The metal nodes are modeled in the SPES-2 experiments where the heat loss is important and the heat loss is a scaling distortion. The metal nodes are not modeled in the AP600 plant calculation nor in the OSU model since the metal heat release per unit volume is small. No additional validation is needed.

Vessel/Core

Decay Heat
The decay heat is a highly ranked phenomena for the model and calculations. However, this is actually a boundary condition which is either supplied from the experiment or calculated from a given decay heat curve. The actual power was used in the experimental simulations while the Appendix K required ANS 1971 plus 20% decay heat is used in the AP600 plant calculations. No validation is required.

Forced Convection
This is a medium ranked phenomena which is important only at the beginning of the transient when the reactor pumps are operating. For heat transfer in the core, the correlation which is used, Dittus-Boelter, has been accepted for use in rod bundles for forced convection (Reference 440.327-3). Since the core remains covered for this time period, the details of the surface heat transfer are not important. No additional validation is needed.

Flashing
This phenomena is ranked as a medium importance when the primary system depressurizes during blowdown and ADS activation. The SPES-2 and OSU experiments captures the core flashing effects, which result in a liquid inventory decrease, as measured by the collapsed liquid level in the heated bundle. This data exists over a wide range of depressurization rates and pressures. The collapsed liquid levels in the vessel and core were compared in the preliminary validation report and will also be compared in the NOTRUMP Final Validation Report.

Wall Stored Energy
The wall stored energy from the heater rods is simulated in the experiments. However, since the experiments and the plant transients are nearly quasi-steady state, the initial stored energy is quickly dissipated and only the power generation, which is a boundary condition for the calculations, remains. The SPES-2 experiments, in particular, simulated the expected stored energy which a nuclear fuel rod would have at the beginning of a small break or SGTR transient. This effect is included when modeling the SPES-2 tests. No additional validation is needed.

The stored energy in the reactor vessel was modeled for both the SPES-2 and OSU experiments in the Preliminary Validation Reports as well as for the AP600 plant. The thick metal heat release, which will occur as the primary system depressurizes, is accounted for in the fluid energy calculations. Therefore, any additional steaming due to metal heat release is accounted for in the depressurization behavior of the AP600. The vessel metal heat release will be modeled in the runs in the NOTRUMP Final Validation Report. Since this modeling is only accounting for the geometry effects, which are input, no additional validation is needed.

Natural Circulation Flow and Heat Transfer
This phenomena is ranked as a medium for all the phases of the small-break LOCA transient. The SPES-2 and OSU tests cover this phenomena for the entire system including the natural circulation in the primary system, the PRHR and the CMT. The CMT separate effects tests also address the natural circulation and heat transfer phenomena, at a different scale, for the CMTs in the 500 series tests. Therefore, there is ample data to validate the NOTRUMP code from both the separate effects tests as well as the AP600 integral systems tests. Comparisons of the natural circulation flow and resulting heat transfer in the OSU, SPES, and CMT simulations will be provided in the NOTRUMP Final Validation Report.

Mixture Level Mass Inventory
This phenomena is ranked as high since the two-phase drift flux, and mixture level models determine the distribution of a two-phase mixture, within the reactor vessel or core, which determines if the core would become uncovered and experience a clad temperature heat-up. The AP600 integral systems tests provide data to assess the mass distribution in the reactor vessel and upper plenum. However, these tests do not provide a clear indication of the mixture height within the vessel or rod bundle, for a given mass inventory (collapsed level).

Therefore, Westinghouse will analyze a range of the G-2 level swell separate effects experiments with NOTRUMP to validate the mixture level, void fraction and drift flux models which have been used in the AP600 version of the NOTRUMP code. The addition of the G-2 level swell tests will supplement the data from the SPES-2 and OSU experiments and will give additional confidence in the AP600 plant calculations with NOTRUMP. The results of these analyses will be provided in the NOTRUMP Final Validation Report.

Mass Flow
The core and vessel mass flow is a medium ranked phenomena. The vessel inlet mass flow is a dependent parameter which is a function of the natural circulation flow in the system. There are no direct measurements of the mass flow in the OSU experiments such that other data such as the levels and mass inventories must be examined to assess if the flow into the bundle is appropriate. There are downcomer flow measurements in the SPES-2 experiments which can also be used to assess the mass flow rate into the vessel such that NOTRUMP can be validated. Comparisons of the level in the vessel and downcomer to assess the net effects of the vessel flow will be provided in the NOTRUMP Final Validation Report.

Flow Resistance
The flow vessel resistance is a low ranked item since the natural circulation flow is a weak function of the resistance and the vessel resistance as only on part of the total flow resistance. The flow vessel resistance is characterized by the full flow data at the beginning of the tests such that the core and vessel resistance can be characterized when modeling the test facility. Since the flows are small in the vessel during natural circulation, the resulting frictional pressure drop is also a small effect. The Preliminary NOTRUMP Validation Reports for OSU and SPES-2 did compare the CMT and PRHR flows which represent flow loops which include the vessel. These comparisons will be provided in the NOTRUMP Final Validation Report.

CMT - Draining Effects

Condensation on Cold Thick Steel Surfaces
This phenomena is ranked as medium importance for the small break LOCA since there is a recirculation period which will heat the CMT walls thereby reducing the condensation. The condensation effects on thick steel was measured in the CMT separate effects tests as well as in the SPES-2 and OSU integral systems tests. Therefore, there is ample data to validate the condensation heat transfer models in the NOTRUMP code.

Transient Conduction in the CMT Walls
The transient conduction effects in the CMT walls for the CMT draining has been simulated in the CMT separate effects tests as well as in the OSU and SPES-2 tests such that data exists for NOTRUMP validation of this phenomena. Since this is a one-dimensional conduction calculation in a fixed geometry, no additional validation is needed.

Interfacial Condensation on the CMT Water Surface
Although this phenomena is ranked high, it is break size dependent. For the small breaks, the CMT liquid will heat-up due to recirculation such that the interfacial condensation will be very small. As the break size increases, the recirculation time for the CMT decreases such that the CMT liquid stays cold and the interfacial condensation will occur. The amount of interfacial condensation has been estimated from the CMT test data for tests with direct steam injection into the CMT. For all tests the amount of steam condensation and mixing has also been characterized. The impact of the condensation is to reduce the pressure at the top of the CMT such that the CMT drain flow is reduced. This effect has been well characterized in the CMT separate effects experiments. The preliminary NOTRUMP/CMT Validation Report, (Reference 440.327-4) examined this phenomena and its effects on CMT draining. Therefore, sufficient data does exist to validate the NOTRUMP condensation models for the CMT. The SPES-2 and OSU experiments give confirmatory data on the systems effects of the CMT behavior. This will be included in the NOTRUMP Final Validation Report.

Dynamics of Steam Injection and Mixing with CMT Liquid and Condensate
This phenomena is also ranked highly and is same as the phenomena given above. The dynamics of the steam injection and the mixing with the CMT liquid has been reduced with the inclusion of a diffuser in the inlet nozzle of the CMT tank. Mixing and rapid condensation still occurs for the larger break when the CMT liquid is initially cold. The scaling logic for the CMT diffuser is given in WCAP-13963, Rev. 1 and this scaling was used consistently between the CMT, SPES-2 , OSU and the AP600 plant. The CMT test has sufficient fluid temperatures such that the mixing zone can be accurately determined. The NOTRUMP predictions have been made to the CMT data as given in Reference 440.327-4 which supports the choice of noding and modeling of the CMT. The same approach for modeling the CMT tests was also used for the integral tests and the AP600 plant. Sufficient data exists to validate the CMT modeling of this phenomena, and this will be presented in the NOTRUMP Final Validation Report.

Thermal Stratification and Mixing of Warmer Condensate with Colder CMT Water
This phenomena is also highly ranked for the recirculation phase of the small-break LOCA when CMT recirculation is occurring. The phenomena of interest is the development of a hot liquid layer at the top of the CMT which will reduce the steam condensation as the CMT drains later in the transient. The CMT diffuser is

specifically designed to create mixing at the top of the tank such that a hot liquid layer will be developed. The CMT separate effects test was designed with ample fluid thermocouples which can be used to detect and measure the mixing layer thickness. The fluid thermocouples can be used to assess the mixing which occurs in NOTRUMP and the thermal stratification which the code predicts. The CMT recirculation tests have been compared to the NOTRUMP Code in a Preliminary Validation Report (Reference 440.327-5). Similar data will be presented in the NOTRUMP Final Validation Report.

CMT Recirculation

Natural circulation of the CMT and the Balance Line
This phenomena is highly ranked for the blowdown and natural circulation phase of the small break LOCA. The CMT separate effects test program included natural circulation experiments with the flows recirculating from a reservoir to the simulated cold leg balance line into the CMT tank. Thermal mixing and stratification was observed in these experiments as the recirculating flows were measured. The NOTRUMP code has been compared to this data as given in Reference 440.327-5 for the Preliminary Validation Report. The SPES-2 and OSU tests also capture the CMT recirculation phase of the transient such that there are three facilities which can be used to validate the NOTRUMP CMT model. The NOTRUMP Final Validation Report will provide the SPES-2, OSU and CMT test comparisons.

Liquid Mixing of Cold Leg Balance Line, Condensate, and CMT liquid
This phenomena is ranked high for the CMT recirculation phase of the transient. This phenomena is directly related to the natural circulation behavior of the CMT as discussed in the previous item and comparisons were provided in Reference 440.327-6. The same data from the CMT test facility can be used to validate that NOTRUMP can model this phenomena. The measured liquid temperature distribution in the CMT has been compared to that predicted by NOTRUMP in the CMT Preliminary Validation Report. Numerical diffusion will occur in the NOTRUMP code relative to the data, however, this is not believed to be important for characterizing the response of the CMT and its recirculating and draining behavior. The SPES-2 and OSU tests also include this phenomena such that there are three experiments that will be used to validate the NOTRUMP code, in the NOTRUMP Final Validation Report.

Flashing Effects of Hot CMT Liquid Layer
This phenomena is of lower importance relative to the mixing and natural circulation behavior of the CMT. The degree of flashing is break scenario dependent since the larger breaks will not have any substantial flashing since there will not be a significant build-up of a hot liquid layer at the top of the CMT. For the smaller breaks, there will be a longer recirculation period during which a hot liquid layer can be developed. As the ADS valves open and the system depressurizes, some flashing of this hot liquid layer can occur which will aid in the injection of the cold CMT liquid into the reactor vessel. The 500 series of the CMT separate effects tests recirculated until the CMT was 20 %, 50 % and fully heated. After recirculation, the valving was positioned such that the CMT was depressurized at varying rates which were approximately similar to those calculated for the SSAR plant calculation and for the SPES-2 integral tests. These tests capture the flashing phenomena and will be used to validate the NOTRUMP code in the NOTRUMP Final Validation Report.

CMT Wall Heat transfer

This phenomena is of medium importance and represents the cooling of the hot liquid layer at the top of the CMT as the CMT drains. As the hot liquid layer cools, it will have the potential to condense additional steam as the tank drains. The CMT separate effects tests have wall thermocouple instrumentation which has been used to calculate the fluid to wall heat transfer. This has been done and has been compared to the liquid to wall heat transfer correlation which is used in the NOTRUMP code in the NOTRUMP CMT Preliminary Validation Report as given in Reference 440.327-5.

CMT Balance Lines

Pressure Drop

This phenomena is ranked highly during the natural circulation and ADS when the CMT recirculates and drains. The pressure drop models in the NOTRUMP code have been validated against the CMT recirculation separate effects tests, as given in Reference 440.327-5, since the CMT drain flow and injection flow were measured. The SPES-2 and OSU integral systems tests also measured the CMT drain flow as well as the pressure drop in the CMT balance line. These data have also been used to validate the NOTRUMP pressure drop calculations, as shown in the Preliminary Validation Reports. Additional comparisons of the CMT drain flow and balance line pressure drop will be provided in the NOTRUMP Final Validation Report.

Flow Composition

The flow composition is ranked highly during the natural circulation and ADS blowdown phases of the transient when the CMT change from a recirculation behavior, to the draining mode. There are no direct measurements of the void fraction in the CMT balance lines, however, the impact of the balance lines draining and changing from a water solid line to a two-phase mixture and vapor flow can be observed in the CMT flow response. As the balance line voids, the CMT driving head increases significantly and the resulting drain flow increases. This is particularly evident in the integral systems tests in OSU and SPES-2. Therefore, while direct data on the flow composition is not available, the effects of the flow regime transition from a liquid flow to a two-phase mixture can be observed in the test OSU and SPES-2 data and used to validate the NOTRUMP code. Comparisons of the CMT flow response have been provided in the preliminary validation reports and will be provided in the NOTRUMP Final Validation Report.

Downcomer/Lower Plenum

Flashing

This is a low ranked item since as the transient proceeds, subcooled water is injected into the downcomer from the CMTs, accumulators and the IRWST, which mixes with the original hotter downcomer water which subcools the downcomer and the lower plenum. If the injection flow would be degraded, then the downcomer liquid could reach saturation as ADS occurred and some weak flashing could occur. However, current calculations indicate that the downcomer and lower plenum remain slightly subcooled through the transient. The OSU and SPES-2 integral systems tests model the injection and depressurization effects such that if flashing does occur it would be present in the level and mass distribution data which will be compared to the NOTRUMP predictions for the NOTRUMP Final Validation Report.

Level
The downcomer level is a highly ranked parameter since it provides the gravity driving head for flow into the core during blowdown and natural circulation. During the ADS blowdown the downcomer level provides the inventory to maintain the core cooling during this period as well as during the IRWST injection period. The downcomer level is a dependent parameter which responds to the system behavior during the transient. Therefore, the best source for validation of NOTRUMP is the SPES-2 and OSU integral systems tests. The downcomer level will be compared for the OSU and SPES-2 tests in the NOTRUMP Final Validation Report.

Loop Asymmetry Effects
Loop asymmetry can occur during the early stages of the transient since the break is in one of the cold legs and the PRHR and the CMTs are in opposite cold legs. Loop asymmetry effects are ranked medium in the PIRT. The asymmetry has the potential to be the largest early in the transient when the cold leg break dominates. Later when the ADS 1-3 valves open, the primary break flow is on the hot leg side out the ADS valves such that the cold leg asymmetry is reduced. The PRHR and the CMTs balance lines also add to possible cold leg asymmetries. The loop asymmetries is the result of the system response for a given transient. The SPES-2 and OSU tests cover a range of break sizes and locations which can influence the loop asymmetry. The NOTRUMP code has been compared to these integral experiments to examine its predictability of any observed loop asymmetry in the Preliminary Validation Reports. These comparisons will all be included in the NOTRUMP Final Validation Report.

Stored Energy Release
The stored energy heat release is ranked as a low item in the PIRT. The downcomer is usually filled with subcooled liquid such that there is no excessive steam generation which can alter the transient. The metal heat release will help reduce the subcooling of the liquid as it enters the core such that the core steaming rate can increase. NOTRUMP models the metal nodes in the downcomer such that this effect is calculated by the code. Since this is a conduction calculation which requires the input geometry, no additional validation is needed.

Hot Legs

Countercurrent Flow
This phenomena, which is ranked low in the PIRT, is of importance for current PWRs during the reflux condensation phase of the transient after the loops have drained down and steam is condensed and returns to the reactor vessel via counterflow in the hot legs. With the AP600, the heat load is also shared with the PRHR in addition to the generators. As the reactor system drains, the PRHR will draw more of the steam that would have gone to the generators since it has a lower sink temperature (IRWST temperature). Also, as the system drains, the CMTs drain and the ADS 1-3 is activated and the primary pressure decreases below the secondary pressure of the generators such that the steam generators become a heat source, not a heat sink. Therefore, this particular phenomena, which was important for existing plants, does not have the same importance because of the AP600 design features.

The AP600 integral systems tests do simulate the steam generator heat removal capability, as well as the PRHR heat transfer. The tests have been used to determine when and how effective the generators are as heat sinks as compared to the PRHR, for the time period of interest, to determine if counterflow from the generators is a significant contributor to the core cooling for the large break LOCA. The experimental data from SPES-2 and OSU indicate that the steam generators are not as significant a heat removal path compared to current PWRs. Therefore, the hot leg counterflow phenomena is of less importance for the AP600. The Preliminary OSU and SPES NOTRUMP Validation Reports examined the steam generator behavior and the NOTRUMP Final Validation Report will examine the steam generator/hot leg draining and levels in additional detail.

Entrainment

Entrainment into the hot legs is ranked as a low phenomena for the initial blowdown and natural circulation periods since the reactor system is nearly full and the recirculation will carry either liquid or steam from the core into the hot legs in a predictable fashion. The steam entrainment is important for the PRHR since increased steam flow to the PRHR will increase its effectiveness. As the transient proceeds, the importance of the entrainment increases since when the ADS stage 4 opens, the entrainment out the fourth stage will influence the pressure drop and the rate of depressurization down to the IRWST pressure. The entrainment in the hot legs is a system effects parameter since it depends on the scenario investigated. Therefore, the SPES-2 and OSU tests provide the data needed to validate the NOTRUMP code since the mass flow is measured in the tests at ADS 1-3 and ADS-4; the preliminary validation reports compared these flows, and the NOTRUMP Final Validation Report will provide these comparisons to the ADS flows.

Flashing

This phenomena is ranked low since the amount of mass contained in the hot legs is small relative to the primary system such that the flashing effects are not important. The phase separation, as a result of flashing is addressed in a different phenomena classification. No additional validation is needed for this phenomena.

Horizontal Fluid Stratification

This phenomena is ranked high after the blowdown phase of the transient when the primary system is in natural circulation and for the remainder of the transient. During this phase, if the hot legs stratify, steam will more easily flow to the PRHR and will make the PRHR more effective in removing energy from the primary system. In a similar fashion, if the hot legs stratify, and the steam generators are still a heat sink, the steam will more easily flow to the generators to be condensed.

When ADS 1-3 occurs, the flow regime in the hot leg will determine the mixture that is entrained into the pressurizer as the ADS valves open and depressurizes the primary system. As the transient proceeds to IRWST injection, the flow regime in the hot legs will also determine the amount of entrained flow carried out the ADS stage four valves and the resulting line pressure drop.

The hot leg flow regime is not directly measured in the SPES-2 and OSU integral systems tests. However, based on other available data, such as level in the vessel upper plenum, and flow from the vessel to the steam generator plenum, as well as the flows and heat transfer rate through the PRHR, heat transfer in the generator, and the flows into the pressurizer and out the ADS valves; the hot legs behavior can be estimated. Additional assessment can be made by comparing the flow estimates to existing flow regime maps to determine if the hot leg is stratified or in another flow regime. The SPES-2 and OSU integral tests will be used to assess the NOTRUMP hot leg stratification predictions. These more detailed comparisons will be provided at the NOTRUMP Final Validation Report.

Phase Separation in Tees (Flow Regime)
This is very similar to the hot leg stratification phenomena since the hot leg flow regime will influence the resulting flow regime in the Tees such as the pressurizer surge line , the PRHR inlet line and the ADS stage 4 inlet line. There are pressure level transmitters on the pressurizer surge line as well as levels on the pressurizer and flow measurements for the ADS 1-3 stages in both the SPES-2 and OSU integral systems tests. These measurements will indicate the amount of flow and mass storage in these components during the test. In the OSU tests, early in the transient, both the vapor and the liquid phase mass flows out the ADS 1-3 are measured such that this data could be used to infer the flow regime in the different components and compare this to the NOTRUMP calculated values and flow regime. For the PRHR, the total mass flow out of the exchanger is measured as well as the overall exchanger heat transfer. The PRHR heat transfer rate can be used to infer the amount of steam flow entering the exchanger and thus the flow regime in the Tee line from the hot leg. A similar approach can be used for the ADS stage 4 flow path. While this approach is qualitative, it is sufficient to validate the NOTRUMP code for these analyses. These more detailed comparisons will be provided in the NOTRUMP Final Validation Report.

IRWST

Discharge Line Flashing
This phenomena is not ranked since the flow from the IRWST into the reactor vessel is subcooled.

Flow and Temperature Distribution in PRHR Bundle Region
This phenomena is ranked as a medium since it determines the effectiveness of the PRHR in removing heat from the primary system. The PRHR is cooled in the IRWST by natural circulation and boiling of the outside of the tubes. The natural circulation is aided by the boiling and a strong recirculation flow field is established within the IRWST. The NOTRUMP calculations did not predict the correct PRHR heat transfer in the SPES-2 and OSU preliminary validation reports. Additional detail in the modeling of the IRWST is expected to be needed to calculate the IRWST recirculation flow pattern. This will be presented in the NOTRUMP Final Validation Report.

The heat transfer on the secondary side of the PRHR is limited by critical heat flux (CHF) on the outside of the tubes. This is particularly true at the top horizontal portion of the exchanger where the margin to CHF is most likely the lowest since the boiling at the lower elevations will increase the void fraction in the horizontal section, and thereby reduce the CHF margin. Additional data is being examined to see what one could expect for the CHF limit on an exchanger like the PRHR which has very large tube-pitch -to diameter ratios. The larger pitch to diameter ratio will reduce the influence of one row of tubes on the following rows such that the PRHR multi-tube CHF limit is closer to the single horizontal tube limit, which is acceptable. This will be addressed in a response to DSER open item 21.3.3-1 on the PRHR.

Pool Level
The IRWST pool is the heat sink for the PRHR , and it is used to quench, as much as possible , the ADS steam flow. It is ranked as a medium during the natural circulation phase since this is when it is a heat sink for the PRHR. It is correspondingly ranked lower during the ADS blowdown phase since the ADS now becomes the principle heat removal path from the primary and the PRHR is less effective. The IRWST pool is highly ranked

during the IRWST cooling stage since it is the elevation head in the IRWST which will force the injection of flow into the reactor vessel. The IRWST pool level is a boundary condition for the NOTRUMP analysis and does not require any computer code validation. When analyzing the SPES-2 and OSU experiments, the IRWST pool level is used as given information for the analysis.

Gravity Draining
The IRWST gravity draining is highly important during the beginning IRWST injection phase of the transient since this is the source of cooling flow for the core. This is a system effects phenomena since the draining depends on the primary system pressure and the pressure drops in the vent paths out of the primary system such as the ADS stage 4 valves as well as the line resistances in the injection lines. The SPES-2 and OSU simulate the IRWST draining mode into the simulated core along with the corresponding line resistances, steam generation and the vent paths. Therefore, the data from these tests is adequate to validate the NOTRUMP calculations for this phenomena. The Preliminary Validation Reports on SPES and OSU compared the initial IRWST injection phase. This will also be compared in the NOTRUMP Final Validation Report.

Vapor Condensation
The vapor condensation phenomena for the IRWST is ranked low since if the vapor is not condensed in the IRWST, it will flow up to the steel shell of the containment and be condensed there. The condensate will then be channeled back to the IRWST. Therefore, the same effect will occur in terms of the steam mass. If there is vapor condensation in the IRWST, this will change the temperature for the PRHR heat transfer and for the IRWST injection temperature. NOTRUMP models the IRWST and correctly accounts for the energy deposition into the liquid. It, however, assumes perfect mixing in the two nodes used to represent the liquid volume in the tank. The OSU and the SPES-2 test data will be used to assess the NOTRUMP modeling of the heat transfer into the tank in the NOTRUMP Final Validation Report.

DVI Line Resistance (Flow Resistance)
The flow resistance for the direct vessel injection line is a input condition for the analysis from the design. The pressure drop which is calculated in the line is for single phase flow since the injection flows are subcooled. The DVI line resistance is ranked as a medium since its resistance directly effects the magnitude of the injection flow. The DVI line resistance has been characterized for the SPES-2 and OSU experiments and this information is used in the NOTRUMP code to calculate the pressure drop and hence the flow. Therefore, since the resistance is maintained in the SPES-2 and OSU tests to be the same (or scaled) to the plant, this phenomena is accounted for in the modeling of the tests.

Pressurizer

CCFL
This phenomena is ranked as medium importance during the ADS blowdown period since the ADS 1-3 valve opening will create a two-phase flow into the pressurizer from the hot leg of the primary system. The steam flow up the pressurizer surge line may be sufficient to prevent any liquid, which is separated out in the pressurizer, to flow back down the surge line. When the fourth stage ADS valves are opened on the hot legs, this now becomes the dominate vent path and the liquid contained in the pressurizer begins to drain in a counter flow situation to steam which is still flowing out the ADS 1-3 valves. The SPES-2 and OSU experiments were

specifically instrumented to measure the pressurizer level (mass), and the flow out the ADS 1-3 valves, such that the drawing call of the pressurizer can determined and compared to the NOTRUMP predictions. These comparisons were provided in the Preliminary Validation Report and will be included in the NOTRUMP Final Validation Report.

Entrainment/De-entrainment
The entrainment and de-entrainment phenomena in the pressurizer, which is ranked as medium in the PIRT, is of importance only during the ADS blowdown phase of the transient. The pressurizer response is measured in the SPES-2 and OSU experiments over a range of conditions. If significant liquid is entrained out of the pressurizer, this is measured in the ADS flow measurements for both experiments. There is no direct measurement of liquid de-entrainment (as droplets or films) in the experiments, however, there are detailed measurements of the liquid level in the pressurizer which indicate a net deentrainment and mass storage within the pressurizer component. The NOTRUMP code will be validated against the SPES-2 and OSU data to address this phenomena in the NOTRUMP Final Validation Report.

Flashing
The flashing of the pressurizer, which is ranked high in the PIRT, is important at the very beginning of the transient when the break occurs and the primary system depressurizes to the steam generator secondary side pressure. The hot liquid in the pressurizer flashes and attempts to maintain the pressure in the primary system. This phenomena is captured in the pressurizer pressure measurements in the SPES-2 and the OSU experiments over a range of break sizes (depressurization rates). These data will be used to validate the NOTRUMP code for this phenomena in the NOTRUMP Final Validation Report. Also the separate effects ADS tests exercise the depressurization of a large vessel at different rates. The NOTRUMP Code will be compared to the level measurements in this separate effects test to assess the flashing effects. This will be contained in the NOTRUMP Final Validation Report.

Level (inventory)
The pressurizer level, which is ranked as medium in the PIRT, is of importance throughout the transient since is represents the primary system mass redistribution. The SPES-2 and OSU experiments are instrumented such that the transient mass can be determined and compared to the NOTRUMP code for the entire transient. This will be presented in the NOTRUMP Final Validation Report.

Level Swell
The level swell phenomena is ranked as a medium during those depressurization periods of the transient. Level swell occurs when the primary system depressurizes and the hotter fluid in the pressurizer flashes and the mass changes from a liquid level to a two-phase mixture. The level swell is determined by the initial liquid temperature and the depressurization rate. In the SPES-2 experiments, there are multiple pressure level cells on the pressurizer which can be used to infer the level swell in the pressurizer. Also, when the ADS 1-3 opens, the mass flow measurements out of the pressurizer will be used to help validate the NOTRUMP drift flux models which would be used to predict the pressurizer level swell. These comparisons will be provided in the NOTRUMP Final Validation Report.

Stored Energy Release
This is a low ranked phenomena for the pressurizer since for portions of the transient the pressurizer is empty and then refills, due to the ADS 1-3 activation during which mass and energy are leaving the system through the ADS valves. The pressurizer stored energy release is measured in the SPES-2 and OSU experiments using heat flux meters (OSU) and thermocouples for SPES-2. Metal nodes exist in the NOTRUMP models for these facilities such that the metal heat release can be calculated for the tests. Therefore, this phenomena is present in the SPES-2 and OSU tests. Since the stored energy is a low ranked phenomena, no specific validation for the stored energy release is needed.

Vapor Space Behavior
This phenomena is ranked low and is only important during the ADS 1-3 blowdown period when there is flow out of the pressurizer through the ADS valves. Since the ADS flow is measured in the SPES-2 and OSU experiments as well as the pressurizer level, the vapor space at the top of the pressurizer can be characterized and compared to the NOTRUMP calculations. No additional comparison or validation is needed for this phenomena.

Pressurizer Surge Line

Pressure drop
The phenomena is ranked a medium importance during the ADS blowdown phase of the transient. There are level transmitters on the pressurizer surge lines for both the SPES-2 and the OSU experiments. These transmitters are primarily present to measure the mass storage in the surge line during the transient to determine the mass distribution in the primary system. The frictional pressure drop is expected to be small for the surge line given the geometry and the ADS 1-3 flows and mass storage in the pressurizer. Therefore, there is sufficient data in the SPES-2 and OSU tests to assess this phenomena with the NOTRUMP code. Since the mass in the surge line will flow to the pressurizer, this phenomena will be accounted for in the comparisons to the pressurizer response which will be included in the NOTRUMP Final Validation Report.

Flooding
This phenomena is ranked low for the first two phases of the transient since the pressurizer will drain for small break LOCAs in lines other then the pressurizer. When the ADS 1-3 valves open, there will be significant flows up the surge line into the pressurizer. As the system depressurizes and the ADS stage 4 valves open, the liquid in the pressurizer and the surge line will flow back to the hot leg. This backward liquid flow may be limited by the steam flow up the surge line. The instrumentation that exists on the SPES-2 and OSU tests is such that an estimate can be made if there is flooding present or not in the surge line or pressurizer. The mass flow measurements out of the ADS 1-3 valves, along with the levels in the pressurizer and pressurizer surge line should indicate the liquid flow back to the hot leg and the steam flow out the ADS valves. Another more indirect indication is just the comparisons to the liquid levels in the pressurizer and the surge line. The NOTRUMP comparisons to the pressurizer behavior will address this particular phenomena and will be presented in the NOTRUMP Final Validation Report.

Steam Generator

Two-Phase Natural Circulation
This phenomena is ranked as a medium during those periods when the generators are heat sinks. The SPES-2 and OSU experiments have been specifically instrumented with levels in the steam generator tubes and thermocouples on the secondary side to determine the when the steam generators will transition from single phase recirculation to two-phase recirculation as the system drains. The secondary side thermocouples indicate the heat transfer from the primary side to the secondary side fluid. These data have been used to validate the NOTRUMP code for this phenomena and will be assessed in the NOTRUMP Final Validation Report.

Steam Generator Heat Transfer
This phenomena is ranked as a medium during the final period that the steam generators are a heat sink. The steam generator heat transfer was estimated from the SPES-2 and OSU data and is reported in the Test and Analysis reports for each of these tests. Once the ADS 1-3 activates, however, the primary system pressure drop below the secondary side pressure and the primary heat removal path is out the ADS valves and the heat removal or heat addition from the generators becomes negligible. These calculations, given in the test and analysis reports, will be used to assess the steam generator models for the NOTRUMP code in the NOTRUMP Final Validation Report.

Secondary Side Conditions
This phenomena is ranked as a medium. These are initial conditions for the transients which are modeled with NOTRUMP. The pressure variation and the heat sink capabilities of the secondary side are measured in the SPES-2 and OSU experiments such that the NOTRUMP code can be validated against this data. Comparisons of the secondary side parameters will be provided in the NOTRUMP Final Validation Report.

U-tube Condensation
This is a low ranked phenomena since the condensation of primary system steam in the steam generator tubes is only significant as the primary system drains before the ADS 1-3 activates. Also, the steam generators on the loop with the PRHR compete for the steam in that hot leg since the PRHR has a lower sink temperature then the steam generator. There is no specific data in the SPES-2 or OSU experiments which isolate the U-Tube condensation since only a total heat transfer can be calculated, however, the NOTRUMP calculations will be compared to the total heat transfer calculated from the data, when condensation is believed to be occurring to assess the performance of the condensation models in NOTRUMP. These comparisons will be provided in the NOTRUMP Final Validation Report.

Secondary Level
This phenomena is ranked as medium importance and is only significant when the steam generators are a heat sink early in the transient. The secondary level is an initial condition for the transient and the transient secondary level is measured in the SPES-2 and OSU experiments. Secondary level is an indirect indication of the heat transfer from the primary side of the generator. The NOTRUMP code will be compared to the SPES-2 and OSU tests to assess this phenomena, in the NOTRUMP Final Validation Report.

Secondary Pressure

This phenomena is ranked as a medium and is only significant for the first two periods of the small-break LOCA when the steam generators are a heat sink. The secondary pressure will determine the quasi-steady pressure level that the primary system will initially depressurize to when the break occurs. The initial secondary side pressure is a specified initial condition for the transient. The transient behavior of the secondary side pressure is measured in the SPES-2 and OSU experiments such that the NOTRUMP code will be compared to the test data to assess this phenomena in the NOTRUMP Final Validation Report.

Steam Generator Tube Draining

The steam generator tube draining, which is ranked as medium in the PIRT, represents a change in the mass distribution in the primary system during the blowdown and natural circulation periods of the transient and is of medium importance. The steam generator draining determines the end of the single phase and two-phase natural circulation in the primary system and is a precursor to developing a stratified level in the hot and cold legs. The SPES-2 and the OSU experiments have instrumented selected tubes such that the draining of the generators can be determined. This data will be used to assess the NOTRUMP predictions for this phenomena in the NOTRUMP Final Validation Report.

PRHR

Single Phase Heat transfer (in the tubes)

The single phase heat transfer in the PRHR tubes is ranked as a medium importance phenomena for the first two periods of the transient. There is nothing unique for the PRHR tubes such that conventional forced convection heat transfer should apply. The forced convection heat transfer correlation used in the NOTRUMP code is the Dittus-Boelter correlation which is appropriate for tube flow.

Two-Phase Heat Transfer Condensation

The two-phase condensation heat transfer in the PRHR is ranked as medium importance and occurs once natural circulation ends and the primary system drains. A fraction of the core generated steam will flow into the PRHR, as well as the steam generators, and be condensed. The SPES-2 and OSU tests modeled this phenomena in the small break LOCA transients over a wide range of conditions. While the local heat transfer coefficients can not be directly calculated form the data, there are calculations of the total heat removal rate of the PRHR. The condensation heat transfer correlations which are used for modeling the PRHR are applicable over a wide range of conditions which are typical of the AP600 PRHR. Therefore, while no direct local heat transfer data is available for the NOTRUMP PRHR validation, the total heat release will be used to assess the application of the heat transfer correlation in NOTRUMP for the PRHR, and will be reported in the NOTRUMP Final Validation Report.

Non-Condensible Gas Effects

The non-condensible gas effects in the PRHR are ranked low and are a result of the accumulator nitrogen accumulation in the PRHR tubes. As discussed in RAI 440.325, at the time when the accumulators would be releasing their nitrogen, the primary heat removal path is through the ADS 1-3 valves and the contribution of the heat removal rate from the PRHR is extremely small relative to the energy removal rate out the ADS 1-3. Therefore, when there is a potential for non-condensible gases to effect the PRHR heat removal capability, that heat removal path is not important. Also it was very difficult to determine from the SPES-2 and OSU data if the non-condensible gases significantly impacted the heat removal rate of the PRHR. This is confirmed in the SPES-2 and OSU Test and Analysis Reports. Since the PRHR is not a principle heat removal path when the non-condensibles are present, this additional modeling is not required.

Recirculation Flow

This phenomena is ranked as medium importance for the first two period of the transient when the PRHR is in single and two-phase recirculation before the primary system has drained down to the hot leg elevation. This phenomena is captured in the SPES-2 and OSU integral system tests over a range of break sizes and locations. Therefore, the NOTRUMP code will be compared to the measured PRHR flow rate for these tests, in the NOTRUMP Final Validation Report.

Upper Head/Upper Plenum

Draining Effects

This phenomena is ranked as medium and is most important during the natural circulation and ADS blowdown periods when larger breaks in the system are created by opening the ADS 1-3 valves. Also the minimum mass inventory usually occurs at the beginning of the IRWST injection. This phenomena is an integral effects behavior and is captured in the SPES-2 and OSU experiments. Therefore, the NOTRUMP code will be validated for this phenomena using these tests. The preliminary reports contain some comparisons of the upper head and upper plenum level and the NOTRUMP Final Validation Report will contain additional comparisons.

Flashing

The flashing phenomena for this component is ranked as medium and is most important during the ADS 1-3 blowdown period when the larger ADS valves open. The flashing will cause a mass redistribution within the primary system during this period of the transient. Both the SPES-2 and the OSU experiments simulate this phenomena over a wide range of break sizes and locations. The experiments have also been specifically designed to provide data on the transient mass distribution, which is measured as a collapsed level, for this period of the transient such that the NOTRUMP code can be validated. These collapsed level comparisons will be provided in the NOTRUMP Final Validation Report.

Mixture Level

This is a highly ranked phenomena since low mixture levels in the upper plenum can potentially lead to a core uncovery. The mass or collapsed level is measured in the upper plenum and upper head at several locations for the OSU and SPES-2 tests. These measurements can be compared to the corresponding predicted NOTRUMP mass or collapsed level to insure that the code predicts the correct mass distribution. The G-2 Core Uncovery Tests which were mentioned earlier will then be used to confirm that the NOTRUMP code will properly distribute the mixture such that a correct mixture level will be calculated. The combination of the SPES-2, OSU and G-2 experiments will confirm that NOTRUMP can correctly calculate the two-phase mixture level in a component. These comparisons will be provided in the NOTRUMP Final Validation Report.

Entrainment/Deentrainment

This phenomena is ranked medium and is most important during the ADS blowdown period and the IRWST injection period since it influences the pressure drop in the hot leg and the ADS stage 4 valves. The amount of liquid which is swept down the hot leg and out the ADS stage 4 valves is directly measured in the SPES-2 and OSU experiments. This data can be compared to the NOTRUMP predictions to validate the two-phase flow models in the hot leg and the amounts of entrainment which is swept from the upper plenum. The collapsed level measurements in the upper plenum and upper head determine the transient mass distribution in these components. The mass in the components is the net result of the net entrainment and deentrainment within the component. Therefore, NOTRUMP will be compared to the collapsed liquid level in the upper head and plenum to validate the two-phase models which predict the net effects of entrainment and deentrainment in the component in the NOTRUMP Final Validation Report.

RCP

Coast Down

This is low ranked phenomena since the AP600 pumps very quickly coast down. The pump inertia and windage losses are design input values into the NOTRUMP code which then solves for the pump speed. However, since the pump quickly coasts down any inaccuracies in modeling the pump behavior have a negligible effect on the transient results. No additional validation is needed.

Flow Resistance

The pump flow resistance is also ranked low and is a design parameter which is input into the code much like the piping geometry. This phenomena has a low ranking since the natural circulation flow is a weak function of the loop resistance and once the primary system drains there is no flow through the loops. The SPES-2 and OSU pump resistance is modeled in the test simulations to calculate the natural circulation flow in the loops. No additional validation is needed.

Reference

440.327-1 Letter, Liparulo to Borchardt, "Additional Information in Support of Westinghouse Response to RAI 952.95: AP600 Fourth Stage ADS Valve Sensitivity Study," NTD-NRC-94-4298, September 15, 1994

440.327-2 NOTRUMP OSU Preliminary Validation Report

440.327-3 Chelemer, H., Chu, P. T., Hochreiter, L. E., "THINC IV - An Improved Program for Thermal-Hydraulic Analysis of Rod Bundle Cores," WCAP-7956-A, February 1989

440.327-4 Cunningham, J. C., Haberstroh, R. C., and J. Jaroszewicz, Hochreiter, L. E., "AP600 NOTRUMP Core Makeup Tank Preliminary Validation Report," MT01-GSR-001, October 1994.

440.327-5 Jaroszewicz, J. and L. E. Hochreiter, "AP600 NOTRUMP Core Makeup Tank Preliminary Validation Report for 500 Series Natural Circulation Tests," MT01-GRS-011, April 1995.

SSAR Revision: NONE

Question 440.329

Re: WCAP-14206 (NOTRUMP CAD)
On page 3-1, the last paragraph, the statement is made recognizing additional verification may be needed to ensure that modeling of the temperature/density differences and low pressure conditions can be achieved with the same confidence as the modeling of conventional plants. While low pressure natural circulation is captured by NOTRUMP for conventional plants, the ability to accurately simulate these low pressure, low flow conditions have not been demonstrated since successful ECCS performance does not depend upon the very small gravitational or buoyancy driven natural circulation flows that characterize AP600 performance. With AP600, the driving forces are often extremely small and require much more accurate modeling than that for current designs. As a consequence, please describe the low flow correlations applicable to the prediction of the single and two-phase friction factors in NOTRUMP for AP600 over the full pressure range. Also, please identify the test data that will be used for the assessment.

Response:
The method used in NOTRUMP to calculate the pressure drop in the reactor system is to input values which correspond to the pressure drop expected at full flow and pressure conditions. This is done to balance the loop pressure drop against the pump head\flow curve such that the correct conditions exist at 100 percent power at the beginning of the transient. The input values represent the form losses due to area changes as well as the frictional losses. The majority of the loop pressure drop is due to the form losses, while the frictional losses are only significant in the core region and the steam generator tubes (For the inside of the steam generator tubes, L/D is input and f is internally calculated using a Reynolds number dependent friction expression). The expected pressure drops are taken from the design information on a given plant and system geometry. For the transient conditions, the same input value is used for a particular component, however, when the flow becomes two-phase, the Thom modified Martinelli-Nelson two-phase multiplier (Reference 440.329-1) is applied above 250 psia to calculate the pressure drop. The tables of two-phase multipliers have been extended down to atmospheric pressure by using the Martinelli-Nelson two-phase friction multipliers (see the response to RAI 440.481 for details).

The use of constant values for different flow conditions is not as precise as separating out the form and frictional terms and using a Reynolds number dependent friction expression. However, as mentioned above, the majority of the total pressure loss in the reactor system is due to form loss as a result of area changes. The friction contributions occur in the core and steam generator. As the small break transient progresses, the frictional terms are only of significance early in the transient during the initial blowdown and natural circulation phases when a closed loop recirculation is possible. One of the first components to drain is the steam generator tubes, which then breaks the loop natural circulation flow. After natural circulation is broken, the frictional effects become negligible since there is no net flow in the system. This is consistent with the PIRT (see response to RAI 440.325, Table 4) in which the loop resistance is not ranked and the vessel resistance is ranked low.

References

440.329-1 Convective Boiling and Condensation, Third Edition, J.G. Collier and J.R. Thom, Oxford University Press Inc. , New York, NY, 1994, pp. 54-59.

SSAR Revision: NONE

Question 440.334

Re: WCAP-14206 (NOTRUMP CAD)
Page 4-4 , Section 4.1 describes some of the separate effects and integral test simulations to be used for NOTRUMP validation. Please provide a test matrix showing the separate effects and integral tests to be used in the validation. The matrix should address each of the PIRT items.

Response:

Please see response provided to RAI 440.327.

SSAR Revision: NONE

Question 440.432

Re: NOTRUMP ADS PVR (RCS-GSR-003)
On page 3-1, it is stated that the entire ADS package is modeled as a single flow link and that the effective loss coefficient of the ADS system is also not needed since the flow is choked for all tests. This appears to be an over simplification since the three ADS valves in Fig. 3-1 do not appear to be arranged symmetrically. As such, choking is not expected to occur simultaneously in these lines. Please identify where choking occurs in the tests and show that the omission of form losses in the momentum equation do not influence the system depressurization rate. That is, please explain why asymmetric effects can be ignored in the modeling of the ADS lines. Please also show how the inertia and line loss terms were computed for the single flow link simulating the three ADS valves depicted in Fig. 3-1. Also, discuss the modeling of momentum flux effects in the momentum formulation in the ADS lines using NOTRUMP since there are many contractions and expansions in these lines.

Response:

In the NOTRUMP ADS preliminary validation report, the ADS valve package was considered to be choked. However, after the NOTRUMP ADS preliminary validation report was issued, an approach to verify ADS choking was developed (Appendix D of Reference 440.432-1) which indicates that the flow at the ADS package is not choked for most of the tests as discussed below.

As discussed in Reference 440.432-1, the most upstream choke location is the limiting choke location. If the flow area of a downstream location is more restricted, the upstream location will not be choked, and the downstream location becomes the choked location. Among the six tests simulated with NOTRUMP, the ADS valves are not choked for four tests, 221, 240 320, and 322, since the upstream central valve, VLI-2, is choked. The other two tests, 212 and 340, are choked at the ADS valves, since valve VLI-2 is not choked for these two tests. However, in these two tests, only one ADS line is open, stage 1 line in Test 212 and stage 2 line in Test 340.

When valve VLI-2 is choked, the flow rate will be the same whether the ADS valve package is choked or not, because the upstream central valve, VLI-2, is the limiting choke location, which determines the flow rate. Since the depressurization rate of the steam/water supply tank (pressurizer) depends only on the flow rate (see the response to the RAI question 440.437), the deprssurization rate will also be the same whether the ADS valve package is choked or not. To show this, Test 320 with all three ADS stages open was rerun with the NOTRUMP code by considering the ADS valve package not choked. As expected, the flow rate was the same as the case with the ADS valve package choked which is in the report. The pressure is also the same at all locations except at the upstream of the ADS package as shown in Figure 440.432-1. Therefore, it can be inferred that if all ADS lines are not choked simultaneously, the flow rate and depressurization will still be the same.

In the calculations for Figure 440.432-1, the loss coefficient of the ADS package as a single link is computed as follows:

$$K_{ADS} = \frac{A^2_{ADS}}{\left[\frac{A_1}{\sqrt{K_1}} + \frac{A_2}{\sqrt{K_2}} + \frac{A_3}{\sqrt{K_3}}\right]^2} = \frac{(0.474)^2}{\left[\frac{0.0645}{\sqrt{1.866}} + \frac{0.253}{\sqrt{1.297}} + \frac{0.253}{\sqrt{0.947}}\right]^2} = 1.855$$

(440.432-1)

where:

K_{ADS}	=	loss coefficient of the ADS package,
K_1	=	loss coefficient of the ADS stage 1 line,
	=	1.886 (from reference 440.432-1, Table 2-1, p.2-9),
K_2	=	loss coefficient of the ADS stage 2 line,
	=	1.297 (from reference 440.432-1, Table 2-1, p.2-9),
K_3	=	loss coefficient of the ADS stage 3 line,
	=	0.947 (from reference 440.432-1, Table 2-1, p.2-9),
A_{ADS}	=	effective area of the ADS package,
	=	length averaged area of the upstream and the downstream fluid nodes,
	=	$(0.5L_{up}A_{up} + 0.5L_{down}A_{down})/(0.5L_{up} + 0.5L_{down})$
A_1	=	flow area of stage 1 line = 0.0645 ft^2,
A_2	=	flow area of stage 2 line = 0.253 ft^2,
A_3	=	flow area of stage 3 line = 0.253 ft^2,

The inertia for the ADS flow link is also computed by the length average of the inertia of the upstream and downstream fluid nodes. In Reference 440.432-1 the inertia and the loss are not used in the code since the ADS valve package is assumed to be choked. In all cases, whether the ADS valve package is choked or not, the momentum flux is not used in the code.

Reference

440.432-1 Yeh, H.C., M.J. Loftus, R.W. Carlson, A.J. Brockie, and L.E. Hochreiter, ADS Phase B1 Test Analysis Report, WCAP-14305, 1995.

SSAR Revision: NONE

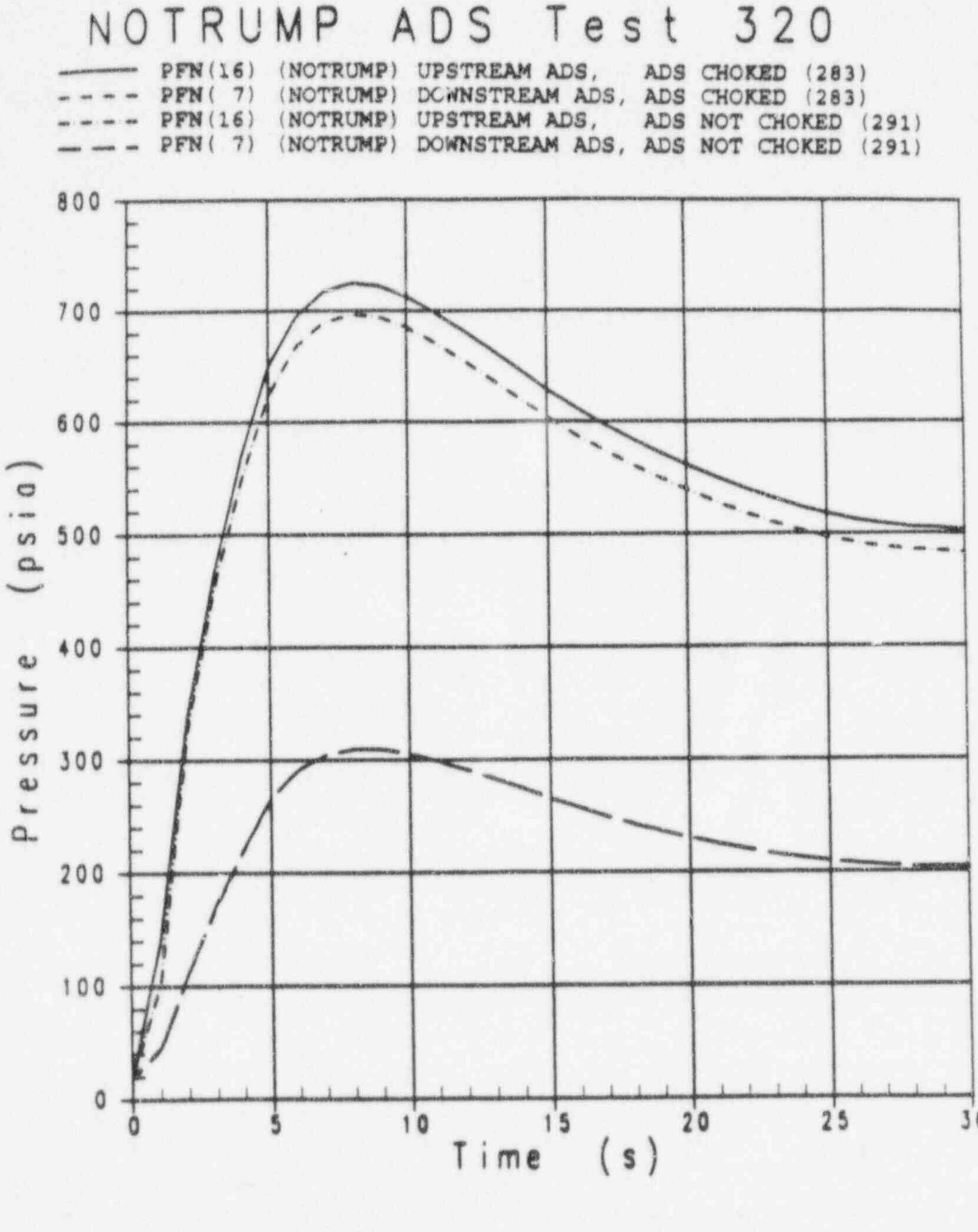

Figure 440.432-1 Comparison of the Pressure Upstream and Downstream of the ADS Package Between Choked and Unchoked Cases

Question 440.433

Re: NOTRUMP ADS PVR (RCS-GSR-003)
Page 3-1 states that NOTRUMP cannot model the air in the discharge lines, so the piping system was initially filled with steam. Air trapped in the lines could impact the dynamics of the system pressure response and could be a potential source of the errors in the ability of the NOTRUMP code to reproduce the flow quality transient behavior within the first 6 seconds of each test. Please explain the effect of not modeling air in the lines and the effect on the ADS system pressure, flow, and quality responses. Please also explain the effects of the initially steam filled pipes on system behavior.

Response:

The effect of not modeling air in the lines is negligible as can be seen below. The disagreement between the NOTRUMP calculated flow quality and the quality calculated from data in the first 6 seconds is, as discussed in the response to RAI 440.435, due to the fact that the actual valve opening time of valve VLI-2 is at 3.5 seconds. When the time is adjusted so that the valve opening time is at time zero, the comparison between the NOTRUMP quality and the data is in good agreement. Since there was no condensation occurring in the tests to cause the change of volume, it makes no appreciable difference whether the air or the steam is modelled.

The flow rate and pressure are not much different whether the lines are initially filled with air or steam as will be explained below. The flow rate depends on the pressure in the lines and the pressure in the lines is due to the flashing of the liquid which comes out of the steam/water supply tank. The energy for evaporation in flashing the liquid comes from the superheated liquid itself when it comes out of the supply tank and enters the lines which are at lower pressure. The liquid reaches a new thermodynamic equilibrium by giving up the heat by evaporating some of the liquid. Therefore, the flashing of the liquid does not depend on whether the lines are filled with air or steam. Consequently, the pressure and flow rate do not depend on whether the lines are initially filled with air or steam.

Furthermore, the initial gas, whether air or steam, in the lines will be swept out in 2.7 seconds as can be calculated as follows. Therefore, even if there is a small effect on the system pressure, flow rate, and flow quality, it lasts only 2.7 seconds. Initially valve VLI-1 is closed. That is, the upstream of valve VLI-1 is filled with high pressure liquid and the downstream of valve VLI-1 is filled with low pressure air. At time zero, valve VLI-1 starts to open and the high pressure liquid is discharged, flashes, pushes the air out, and eventually replaces the air with the steam/water mixture. In the response to RAI 440.435, it was shown that the average flow quality calculated from data downstream of valve VLI-1 in the first 3 seconds is about 0.4. The mixture mass required to replace the air can be computed as follows (neglect the liquid volume):

$$V = \int_0^t Q_v dt = \int_0^t \frac{1}{\rho_v} \dot{m}_v \, dt = \int_0^t \frac{1}{\rho_v} X \, \dot{m}_{mix} \, dt$$

$$\approx \left(\frac{X}{\rho_v}\right)_{avg} \int_0^t \dot{m}_{mix} \, dt = \left(\frac{X}{\rho_v}\right)_{avg} \Delta M_{mix} \qquad (440.433\text{-}1)$$

where:

V	=	volume in the lines downstream of valve VLI-1, ft^3 = 225 ft^3
Q_v	=	vapor volumetric rate of flow, ft^3/sec
t	=	time, seconds
$\dot{m}_v$, $\dot{m}_{mix}$	=	flow rates of vapor and steam/water mixture, respectively, lbm/sec
ρ_v	=	density of vapor = 1.337 lbm/ft^3 at 617 psia
X	=	flow quality = 0.4
ΔM_{mix}	=	$\int_0^t \dot{m}_{mix} \, dt$, lbm

For Test 240, $\left(\frac{X}{\rho_v}\right)_{avg} = \frac{0.4}{1.337}$. Therefore, from equation 440.433-1 one obtains:

$$\Delta M_{mix} = \frac{V}{\left(\frac{X}{\rho_v}\right)_{avg}} = \frac{225(1.337)}{0.4} = 752 \text{ lbm}$$

The mixture mass, ΔM_{mix}, is the mass that flows out of the supply tank. Figure 440.433-1 shows the mass in the supply tank as a function of time. (Note that valve VLI-1 opening time is not at time zero as per the discussion in the response to the RAI 440.435.) Figure 440.433-1 shows that the time for the mixture mass of 752 lb_m to flow out of the supply tank is 2.7 seconds.

For conservatism, in the above calculation the vapor density, ρ_v, is evaluated at 617 psia, which is the average between the initial supply tank pressure of 1200 psig and the initial pressure in the lines of 5 psig. In the actual case, the pressure is significantly reduced after the fluid passes through valve VLI-1. Therefore, the average pressure is lower, the vapor density and ΔM_{mix} are smaller, and the time for the mixture to replace the air is shorter.

Reference

440.433-1 WCAP-14324, "Final Data Repor. fo. ADS Phase B1 Tests," April, 1995.

SSAR Revision: NONE

(a,b)

Figure 440.433-1 Mass in Supply Tank (Reference 440.433-1)

Question 440.439

Re: NOTRUMP ADS PVR (RCS-GSR-003)
Accurate characterization of the ADS mass and energy loss rates is vital to the prediction of the RCS depressurization rate, subsequent ECC injection, and the vessel inventory. Modeling of elevation differences and line losses are therefore of most importance to modeling the effectiveness of the ADS. With this in mind, has the NOTRUMP code been assessed against single-phase and two-phase pressure drop data in piping systems with expansions and contractions present? If so, please provide the information. The Janssen (1) data provides an example of separate effects test data to validate the momentum flux and line loss modeling in a code such as NOTRUMP.

(1) Janssen, E., "Two-Phase Pressure Loss Across Abrupt Contractions and Expansions, Steam Water at 600 to 1400 psia," Proceedings of the Third International Heat Transfer Conference, Chicago, Illinois, August 7 through 12, 1966.

Response:

In the NOTRUMP code, the two-phase pressure drop in piping systems with expansions and contractions is computed by using the two-phase multiplier from the Thom correlation (Reference 440.439-1) for pressures equal to or greater than 250 psia and the Martinelli-Nelson correlation (Reference 440.439-2) for pressures lower than 250 psia.

The Janssen data consists of single contractions and expansions. NOTRUMP has been compared to LOFT, semiscale, OSU and SPES-2 tests, all of which have several different types of expansion and contraction losses. There have also been comparisons to the CMT tests (series 500, single phase flow) which also have expansions and contractions. Therefore, there is no need to compare to the Janssen data.

References

440.439-1 Thom, J. R. S., "Prediction of Pressure Drop During Forced Circulation Boiling of Water," *Int. J. of Heat and Mass Transfer*, 7, 709-724, 1964

440.439-2 Martinelli, R. C., Nelson, D. B., "Prediction of Pressure Drop During Forced Circulation Boiling of Water," *Transactions of ASME*, 695-702, 1948

SSAR Revision: NONE

Question 440.483

Re: NCTRUMP FVR FOR OSU TESTS, LTCT-GSR-001, JULY 1995
Please provide the results of a sample fill and drain calculation to demonstrate the model described in Section 4.18, entitled "Fluid Node Stacking Logic." The detailed verbal description regarding the fluid level tracking model in this section is very difficult to follow. As such, please provide a mathematical description of the logic used to track mixture level.

Response:

Due to the nature of the fluid node stacking logic, a completely "mathematical" description, if indeed feasible, would be just as difficult to follow. As such, a description will be provided which should be more easily followed and understood. It is "mathematical" where appropriate, but verbal where necessary.

Before the stacking logic is described in detail, a discussion of its relation to other model improvements is in order. The other model improvements that may interact with the Fluid Node Stacking Logic (described in Section 4.18) are Mixture Level Overshoot (Section 4.8), Region Birthing Logic (Section 4.13), and Bubble Rise (Section 4.9). (See the responses to RAI's 440.473, 440.478, and 440.474.)

The mixture level overshoot logic, when used, has a major impact on the stacking logic as follows. As discussed in Section 4.8, the optional, new mixture level overshoot logic passes the mixture level out of a node into the node above or below it in a natural manner. Without this logic, the mixture level simply reached the top or bottom of a node when the original depletion logic resolved any possible overdepletion of the disappearing region by adding its mass and energy (when either or both are non-positive) to the other region of the node and zeroing out the disappearing region's mass and energy. Thus, without the mixture level overshoot logic, the original depletion logic could only take the mixture level to the top or bottom of a node; it could not pass the level to the next node, above or below. The entire task of passing the mixture level to the next node then fell upon the stacking logic. When the mixture level overshoot logic is used, it passes the mixture level between nodes so this function does not need to be performed by the stacking logic. The stacking logic is still available for the now less likely event that the mixture level ends up being "stuck" at the exact top or bottom of a stacked node, i.e., at the boundary between two stacked nodes. Thus, it is seen that the mixture level overshoot logic, when activated, takes over the function of passing the mixture level between stacked nodes; the stacking logic merely provides a backup for those situations where the level ends up being "stuck" at the boundary between stacked nodes. Current modeling practice is generally to use the mixture level overshoot logic in all stacks. Thus, a large part of the stacking logic, i.e., that part involved with passing the mixture level between nodes, is rarely invoked.

The region birthing logic discussed in Section 4.13, when used, may impact the passing of the mixture level from one stacked node to another but only if stacking logic had just been invoked, i.e., when the mixture level is at the boundary between stacked nodes. Since the stacking logic is rarely invoked when the overshoot logic is used, the birthing logic is also rarely invoked in stacks. It is used, however, in non-stacked nodes, e.g., hot and cold leg nodes.

The impact on stacking logic of the bubble rise improvements, discussed in Section 4.9, is primarily to improve the behavior of small regions in a node. Thus, it improves the behavior of the mixture level in a stack as it approaches the boundary between two stacked nodes, i.e., when one region of the node with the level becomes small.

Following is the requested revised description of the fluid node stacking logic. It is in the form of a revision to Section 4.18 of LTCT-GSR-001 and PXS-GSR-002 which will be included in the NOTRUMP Final V&V Report. Work is currently underway to respond to the request for a sample calculation to demonstrate the model. The schedule and scope of this will be provided on or before December 31, 1995.

4.18 Fluid Node Stacking Logic

The NOTRUMP Node Stacking and Mixture Level Tracking Model as implemented for the Westinghouse SBLOCA Evaluation Model is described in Appendix N of Reference 1. Improvements to the model are described here.

The node stacking and mixture level tracking logic will now be described in detail. The logic in subroutine STACK is that described on pages N-2 and N-3, Appendix N with the following exception: instead of turning stacking flags on or off by setting them to +1 or -1, respectively, they are turned on or off by adding or subtracting 2, respectively. This allows for the potential generalization to multiple stacks in the logic in subroutines FLOW and FLOWLIM.

Another part of the node stacking and mixture level tracking model is performed in subroutine FLOW where the mixture fractions and flow fractions (also called "contact coefficients") are defined in special ways under certain special conditions. The purpose of this special logic is to provide for a smooth and natural movement of the stack mixture elevation from one node to another when the stack mixture elevation reaches the top or bottom of the node in which it currently resides.

The logic to redefine mixture fractions in special ways under certain special conditions within a stack is now described. The special conditions under which the logic is invoked are the following: either the stack mixture elevation is at the top of a stacked node (unless that node is the top node of the stack) or it is at the bottom of a stacked node (unless that node is the bottom node of the stack). It is under these conditions that the stack mixture elevation may be moving from one stacked node to another. The redefinition of the mixture fraction at each end of the point contact link connecting two stacked nodes is performed to assist a new region in forming in the node into which the stack mixture level may be moving. Two points are worth noting here. First, the "rules" for fluid nodes and flow links to be in a stack are given in the first paragraph of Appendix N of Reference 1. Basically, a stack of nodes must consist of a set of vertically non-overlapping fluid nodes connected by point contact flow links. These links must connect between exactly the top of the lower node and exactly the bottom of the upper node. A single stack mixture elevation will be tracked for a stack. (The initial position of the stack mixture elevation is determined by the input variables EMIXFN and ISTAKFN, described in Appendix B of Reference 1.) The second point worth noting is that when the mixture level overshoot logic (see Section 4.8) is active, the stacking logic to redefine mixture fractions and flow fractions under special conditions is rarely invoked. Since the overshoot logic itself passes the mixture level between stacked nodes, the stacking logic merely provides a backup for those situations where the level ends up being "stuck" at the boundary between stacking nodes. Current modeling practice is generally to use the mixture level overshoot logic in all stacks. Therefore, the logic to be described is rarely invoked.

To continue the description of the special stacking logic for redefining mixture fractions, consider a given flow link k (or K). First, it is checked to see if it is a non-critical, non-reflux flow link, if IREDOFL(k) = 0 (the IREDOFL(k) flag is always equal to 0 for operating plant and AP600 small break LOCA (including SPES-2 and OSU) analyses), if it is a point contact flow link, and if its upstream and downstream nodes are interior, stacked fluid nodes, i.e.,

[ ]a,c (4.18-1)

If these tests are met, tests are made to determine if the nodes are non-overlapping, i.e., to determine if the upstream node i (or I) is above the downstream node j (or J) or the upstream node is below the downstream node, i.e.,

[ ]a,c (4.18-2)

If these tests are met, then tests are made to determine which of these cases is true. Consider the case where the upstream node is below the downstream node, i.e., flow link k "points" upward. (The case of link k "pointing" downward is treated completely analogously and thus will not be described further here). For this case, tests are made to determine if the upstream elevation of flow link k is at the top of the lower upstream node i and the downstream elevation of flow link k is at the bottom of the upper downstream node j, i.e.,

[ ]a,c (4.18-3)

If these tests are met, then tests are made to determine if the upper downstream node j has no lower region and the lower upstream node i has no upper region, i.e.,

[ ]a,c (4.18-4)

If these tests are met, then it is possible that the stack mixture elevation is at the top of the lower node or at the bottom of the upper node. Further tests must be made. [

]a,c

[ ]a,c (4.18-5)

If these tests are met, then the stack mixture elevation is considered to have been draining. [

]a,c

The draining logic just described can be summarized "mathematically" as follows:

[ ]a,c (4.18-6)

This concludes the description of the draining logic. The filling logic will now be described.

(a,c)

[ ]

[ ]^a,c

(4.18-7)

If these tests are met, then the stack mixture elevation is considered to have been filling. [

]^a,c

The filling logic just described can be summarized "mathematically" as follows:

[ ]^a,c

(4.18-8)

This ends the description of the filling logic. The "stuck stack" logic will now be described.

[ ]^a,c

[ ]^a,c

(4.18-9)

If these tests are met, then the stack mixture elevation has been stuck at the node boundary for at least the last two time steps. It is not obvious if it should be draining or filling. An additional criterion is used to attempt to determine this.

[ ]^{a,c}

[ ]^{a,c} (4.18-10)

[ ]^{a,c}

[]]^{a,c}

[ ]^{a,c} (4.18-11)

[t']^{a,c}

This concludes the description of the "stuck stack" logic. One important point about this logic is that, unlike the draining and filling logic, it can be invoked even when the optional mixture level overshoot logic is active.

This concludes the description of the logic in subroutine FLOW to set the mixture fractions and stacking flags under certain conditions. Similar logic is used later in subroutine FLOW to set the flow fractions. The logic to determine whether the stack is draining or filling or is anticipated to drain or fill is identical to that described above.

[ ]^{a,c}

[ ]^{a,c} (4.18-12)

[ ]^{a,c}

[

]a,c

[ ]a,c (4.18-13)

This concludes the description of the improved NOTRUMP Node Stacking and Mixture Level Tracking Model.

The NOTRUMP Final V&V Report will contain a list of variable nomenclature. The following nomenclature will be included in the list.

EMIXFN = mixture elevation, E_{mix}, (ft)
(See pp. B-6 and D-3 of Reference 1.)

ISTAKFN = node stack and mixture level backing flag. (-)
(See page B-7 of Reference 1.)

ITYPEFL = flow link type flag. (-)
(See page B-13 of Reference 1.)

IREDOFL = flag for redoing certain flow link calculations. (-)
(The IREDOFL flag is always equal to 0 for operating plant and AP600 small break analyses.)

DCONTFL = continuous contact flow link diameter. (ft)
(See page B-18 of Reference 1.)

ITYPEFN = fluid node type flag.
(See page B-5 of Reference 1.)

EBOTFN = fluid node bottom elevation, E_{bot}, (ft)
(See page B-5 of Reference 1.)

ETOPFN = fluid node top elevation, E_{top}, (ft)
(See page B-5 of Reference 1.)

EUFL = flow link upstream elevation, E_u, (ft)
(See page B-17 of Reference 1.)

EDFL = flow link downstream elevation, E_d, (ft)
(See page B-17 of Reference 1.)

TMMFN = fluid node mixture region mass, M_M. (lbm)
(See page B-7 of Reference 1.)

TMVFN = fluid node vapor region mass, M_v (lbm)
(See page B-7 of Reference 1.)

TMMOFN = fluid node mixture region mass from previous time step, M_M^{old}. (lbm)
(See page B-7 of Reference 1.)

TMVOFN = fluid mode vapor region mass from previous time step, M_V^{old}. (lbm)
(See page B-7 of Reference 1.)

IDRNFN = fluid node mixture level overshoot drain flag. (-)
(See Section 4.8 of LTCT-GSR-001 and PXS-GSR-002.)

JREDOIT = local flag to cause drift flux to be done twice, first on a mass flow basis and second on a volumetric flow basis.

JFLUXON = local logical flag. If true, drift flux is done on a volumetric flow bases; otherwise on a mass flow basis.

ISMFN = fluid node mixture region state flag. (-)
(See page B-10a of Reference 1.)

BUFL = flow link upstream end mixture fraction, $b_{u(I),J}$. (-)
(See Section F-5 of Reference 1.)

BDFL = flow link downstream end mixture fraction, $b_{d(I),J}$. (-)
(See Section F-5 of Reference 1.)

IFILLFN = fluid node mixture level overshoot fill flag. (-)
(See Section 4.8 of LTCT-GSR-001 and PXS-GSR-002.)

WFFL = flow link liquid mass flow rate, W_f. (lbm/sec)
(See page B-18 of Reference 1.)

DWFFL = flow link partial derivative of liquid mass flow rate with respect to either W or Q state variable. (-) or (lbm/ft^3)

DELWFL = flow link change in either W or Q state variable. (lbm/sec) or (ft^3/sec)

CFUFL = flow link upstream liquid flow fraction, $C^{f}_{u(I),J}$, (-)
(See Section F-5 of Reference 1.)

CGUFL = flow link upstream gas flow fraction, $C^{g}_{u(I),J}$, (-)
(See Section F-5 of Reference 1.)

CFDFL = flow link downstream liquid flow fraction, $C^{f}_{d(I),J}$, (-)
(See Section F-5 of Reference 1.)

CGDFL = flow link downstream gas flow fraction, $C^{g}_{d(I),J}$, (-)

SSAR Revision: NONE

Question 440.488

Re: NOTRUMP PVR for OSU Tests, LTCT-GSR-001

Fig. 5.1-23 shows that the NOTRUMP code overpredicts the integrated break flow. Discuss the potential for the source of this error being an inadequate condensation and stratified flow model in the cold legs during accumulator injection. Demonstrate that this model, and result, is conservative with respect to AP600 small break LOCA ECC performance analyses. Also provide an expanded scale, after 400 seconds, for Fig 5.1-22 so the code comparison can be seen with the break flow data plot.

Response:

NOTRUMP predicts that sub-cooled liquid appears in the bottom of the broken cold leg at about 600 seconds and that this liquid is released through the break. Since liquid was not present at this time in the test, NOTRUMP overpredicts the break flow rate beyond 600 seconds. Refer to Figure 440.488-1 which shows a revised comparison of break flow rate from the test and the NOTRUMP prediction. The new break flow rate from the test is the result of smoothing the break separator liquid level LDP which removed much of the noise in the measurement. The source of the sub-cooled liquid in the cold leg in NOTRUMP at about 600 seconds is attributed to the more rapid discharge of accumulator water, see Figure 5.1-13 (from LTCT-GSR-001) and Figure 440.488-2 (replaces Figure 5.1-14 in LTCT-GSR-001), and a general overprediction in the downcomer water level, Figure 5.1-12 (from LTCT-GSR-001).

SSAR Revision: NONE

AP600

Total Break Flow

——— MTH00007 1 0 0 Test Data (SB01)
- - - - MTH00011 80 0 .0 NOTRUMP Simulation

(a,b

Figure 440.488-1

ACC-2 Total Flow

———	MT-00014	1	0	0 Test Data (SB01)
- - - -	WF_	61	0	0 NOTRUMP Simulation

(a,c)

Figure 440.488-2

Question 440.499

Re: NOTRUMP PVR FOR OSU TESTS, LTCT-GSR-001, JULY 1995

What is the effect of the nitrogen from the accumulators on system response. Can the NOTRUMP code model nitrogen entering the RCS? If not, please justify the omission of nitrogen effects on AP600 response following small break LOCAs.

Response:

This is a similar question to RAI 440.325 on the NOTRUMP Code Applicability Document, regarding modeling the non-condensible gases from the accumulators. As discussed in the response to RAI 440.325, the time period when the non-condensible gas could enter the primary system is after the larger ADS stages 1-3 valves have opened and the system is depressurizing. At this time, the PRHR and the steam generators cease to be significant heat removal paths and the ADS becomes the dominate heat removal path out of the primary system. Therefore, any possible non-condensible blockage or reduction of the heat transfer in the PRHR will not effect the depressurization transient once ADS is activated.

The SPES and OSU test data did model the non-condensible gas pressurization of the accumulators in the experiments. There was a significant effort to examine the possible effects of the non-condensible gas on the experimental results, however, the tests indicated that if there was any effect it was extremely small and had no impact on the transient results and the performance of the passive safety systems.

Therefore, there is no need to explicitly model the effects of the accumulator non-condensible gas release for the AP600 small-break LOCA.

SSAR Revision: NONE

Question 440.515

Re: NOTRUMP PVR FOR OSU TESTS, LTCT-GSR-001, JULY 1995

The conclusions state that the NOTRUMP code "captures and accurately represents the key thermal hydraulic phenomena of importance for the AP600 small break LOCA." An important small break LOCA thermal hydraulic phenomenon is two-phase level swell; in particular the two-phase level in the inner vessel region containing the lower plenum, core, upper plenum, and upper head. Because there were no comparisons of the liquid level nor the two-phase level in the inner vessel, there is no assurance that the NOTRUMP code captures this important phenomenon. Based on the over predicted downcomer liquid level transient data and the fact that the upper head also prematurely drained in the NOTRUMP calculations, there is no assurance that the NOTRUMP code can adequately assess the potential for core uncovery for AP600 during small break LOCAs. Major changes have been made to the code bubble rise, drift flux, and level tracking models with no separate effects nor integral test comparisons (the OSU and SPES-2 test comparisons do not provide verification of the code ability to model level swell) provided to verify and validate the capabilities of the code to predict two-phase level swell. Until appropriate benchmark to level swell data can be provided, the NOTRUMP code's ability to accommodate two-phase level swell phenomena is an open issue. Candidate level swell test data for benchmarking NOTRUMP:

(1) THTF bundle uncovery tests(1,2,3,4) includes steady-state and transient bundle uncovery data where the code mixture, liquid level, and void distributions can be used to verify the code level swell and heatup models.

(2) The Containment System Experiments(5,6) provide level swell data from the simple blowdown of a vessel from side and bottom exit nozzles. Test B-10(5) provides pressure and level data for a bottom blowdown while tests B-50 through B-53(6) provide top blowdown level swell data.

(3) The G-2 test facility consists of a test vessel with a simulated core and includes bundle uncovery data(7) for a range of power levels and pressures down to and including atmospheric conditions. Please show the NOTRUMP code mixture levels, void distributions, steam and fuel r .d temperatures for several of these tests covering a range of pressures and power levels. Please also provide the downcomer liquid level response for the tests chosen.

(4) The GE level swell data(8) provide level swell data for the top blowdown of a vessel with and without heat addition, presented in Section B.4.

(5) Additional GE level swell tests(9) were performed which also contains axial void distribution data.

REFERENCES

1. Anklam, T. M., Mills, R. J., White, M. D., "Experimental Investigations of Steady State Bundle Heat Transfer and Two-Phase Mixture Level Swell Under High Pressure Low Heat-Flux Conditions," Oak Ridge National Laboratory, NUREG/CR-2456, March, 1982.

2. "Experimental Investigation of Bundle Boiloff and Reflood Under High-Pressure Low Heat-Flux Conditions," NUREG/CR-2455 ORNL-5846, April, 1982.

3. "Heat Transfer Above the Two-Phase Mixture Level Under Core Uncovery Conditions in a 336-Rod Bundle," Westinghouse Electric Corp., EPRI NP-1692, Vol. 1, January, 1981.

4. Anklam, T. M., "ORNL Small Break LOCA Heat Transfer Test Series I: Rod Bundle Heat Transfer Analysis," Oak Ridge National Laboratory," NUREG/CR-2052, August, 1981.

5. "Experimental High Enthalpy Water Blowdown From a Simple Vessel Through a Bottom Outlet," Battelle Northwest, BNWL-1411, June, 1970.

6. "Coolant Blowdown Studies of a Reactor Simulator Vessel Containing a Perforated Sieve Plate Separator," Battelle Northwest, BNWL-1463, February, 1971.

7. "Heat Transfer Above the Two-phase Mixture Level Under Uncovery Conditions in a 336-rod Bundle," Westinghouse Electric Corporation, EPRI-1692, January 1981.

8. Slifer, B. C., "Loss of Coolant Accident and Emergency Core Cooling Models for General Electric Boiling Water Reactors," NEDO-10329, April 1971.

9. "BWR Refill-Reflood Program - Model Qualification Task Plan," EPRI Report No. EPRI NP-1527, October, 1991.

Response:

For the OSU and SPES-2 tests, comparison plots of core and upper plenum levels are being provided in response to RAIs 440.492, 440.518, and 440.520. These plots show reasonable agreement between NOTRUMP and the tests. However, since the two-phase level in the vessel and core is ranked as a high in the final PIRT table for the AP600 small-break LOCA as given in the response to RAI 440.325, Westinghouse will perform analysis of the G-2 level swell experiments given in EPRI report EPRI-NP-1692. Tests will be simulated over the full pressure range given in the test data at different bundle powers. Comparisons of the mixture height as a function of time, void distributions, vapor temperatures, and heater rod temperatures will be provided. These separate effects experiments, along with the existing comparisons to the SPES and OSU tests will provide sufficient validation of the NOTRUMP level swell and drift flux models.

The results of the analysis of these G-2 experiments are scheduled to be provided to the NRC in early March, 1996. Westinghouse will meet with the NRC staff before this date to discuss progress on modeling these tests.

SSAR Revision: NONE

Question 440.516

Re: NOTRUMP PVR FOR SPES-2 TESTS, PXS-GSR-002
Was the secondary steam generator relief valve set point reduced for the SPES-2 test comparisons as was done for the OSU modeling? Please explain.

Response:

The secondary steam generator relief valve setpoint was not reduced for the SPES-2 test comparisons as was done for the OSU modeling (see the response to RAI 440.511 for discussion of OSU modeling). It was set at 1044 psia based on data available at the time the input deck was generated. It is not planned to reduce the setpoint per the OSU modeling for the SPES-2 analyses for the NOTRUMP Final V&V report, although the setpoint might change slightly to reflect more recent information on the actual setpoint for the test facility. The intent for the SPES-2 analyses has been and will continue to be to model with the actual setpoint.

SSAR Revision: NONE

Question 440.517

Re: NOTRUMP PVR FOR SPES-2 TESTS, PXS-GSR-002
Please provide the downcomer liquid level plots for each of these tests with a comparison to the NOTRUMP code predictions.

Response:

The requested comparison between the SPES-2 and NOTRUMP downcomer liquid levels are provided in Figures 440.517-1 through 440.517-4 for tests s00303, s00605, s00706 and s00908. Both the test and NOTRUMP data represent collapsed liquid levels. The SPES-2 data are as presented in Reference 440.517-1 and the overall downcomer level is tracked by the separate collapsed liquid levels for the annular and tubular downcomer regions. The single NOTRUMP curve tracks the collapsed liquid level over the model representation of these two regions. All data is presented relative to the top of the heated rod length.

For the tests, the annular downcomer is plotted as curve A and the tubular downcomer as curve B. In general, the annular downcomer drains before there is any indication of a significant reduction in tubular downcomer level. In cases where there is an observed reduction in tubular downcomer level while the annular downcomer is nearly full, this is an indication of the presence of two-phase fluid at the bottom of the tubular downcomer. This has not been allowed for in the NOTRUMP data, which should therefore be compared with the annular downcomer level (curve A) when that region is not fully drained and the tubular downcomer level (curve B) at other times. In general there is reasonable agreement between the code and test data.

Reference

440.517-1 WCAP-14254, Revision 1, "AP600 SPES-2 Test Analysis Report," Proprietary [PXS-TZR-110], November 1995

SSAR Revision: NONE

Question 440.518

Re: NOTRUMP PVR FOR SPES-2 TESTS, PXS-GSR-002
Please provide the liquid level plots and the void distribution plots in the core and upper plenum regions for these tests. Please show a comparison of the core liquid level plots with the NOTRUMP code prediction.

Response:

The requested liquid level and void fraction plots, together with a comparison to NOTRUMP for the core liquid levels, are presented in Figures 440.518-1 to 440.518-16 for tests s00303, s00605, s00706 and s00908. All liquid levels are collapsed liquid levels and are presented relative to the top of the heated rod length. The test data is calculated as reported in Reference 440.518-1. The NOTRUMP core collapsed liquid level has been determined using the arithmetic mean of the void fractions for the four core nodes, since the two phase level is always above the heated rod length.

Reference

440.518-1 WCAP-14254, Revision 1, "AP600 SPES-2 Test Analysis Report," Proprietary [PXS-TZR-110], November 1995.

SSAR Revision: NONE

Question 440.519

Re: NOTRUMP PVR FOR SPES-2 TESTS, PXS-GSR-002
Please provide the secondary steam generator pressure, level, and temperature comparisons with the NOTRUMP predictions for each of the tests and explain the reasons for differences, should they exist.

Response:

The requested comparisons between the SPES-2 and NOTRUMP secondary side pressures, fluid temperatures and liquid levels are presented in Figures 440.519-1 to 440.519-12 for tests s00303, s00605, s00706 and s00908. The test data represents the pressure as measured at the top of the steam dome, the fluid temperature is the average reading of all the fluid on the secondary side and the level is the collapsed liquid level on the secondary side. In all four tests the collapsed liquid level remains above the elevation of the highest thermocouple. The NOTRUMP data represents the pressure at the top of the simulated steam generator, the average fluid temperature in the mixture region and the two-phase fluid level on the secondary side. The fluid void fraction was not output for the preliminary NOTRUMP analyses and thus a NOTRUMP calculated collapsed liquid level is not available. All levels are presented relative to the top of the active fuel.

In three of the four tests, the secondary side pressure in the NOTRUMP simulation initially agrees very well with the test data and subsequently, falls further and earlier than that in the test. Examination of the associated temperature data shows that, in general, corresponding differences exist within that data. Two possible explanations for this are NOTRUMP excessive predictions of the secondary-to-primary side heat transfer, or heat loses to the environment. In the other test (s00605) there is good agreement between the NOTRUMP and test data throughout.

Excess secondary-to-primary side heat transfer is likely for s00303 where the delay in the actuation of ADS-1 means there is liquid within the steam generator U-tubes for longer than is the case in the test. For test s00908 the simulation also maintains a two-phase mixture in the U-tubes for longer than is the case in the tests. However, it is important to note that where differences between the test results and NOTRUMP simulations occur, they are at times in the transient during which the steam generators are inactive (see Reference 440.519-1). Agreement between the tests and NOTRUMP is very good during the initial transient where the steam generators are the route for primary-to-secondary heat transfer.

For all four tests, the NOTRUMP mixture elevation is lower than the test collapsed liquid level throughout the transient. This indicates that the initial steam generator secondary side inventory in the simulations was not consistent with the test conditions. This will be investigated further for the NOTRUMP Final Validation Report.

Reference

440.519-1 WCAP-14254, Revision 1, "AP600 SPES-2 Test Analysis Report," Proprietary [PXS-TZR-110], November 1995.

SSAR Revision: NONE

Question 440.520

Re: NOTRUMP PVR FOR SPES-2 TESTS, PXS-GSR-002
For the two inch cold leg break and the double-ended guillotine DVI line break, the NOTRUMP code overpredicted the liquid level above the top of the core. As shown in Fig. 5.1-23, the NOTRUMP code overpredicted the level above the core by as much as six feet and did not capture the trend in the level data throughout the 3000 second two inch cold leg break transient. Although the core remains covered during this test, this very poor comparison to the data demonstrates that the NOTRUMP code is incapable of simulating the trends and the magnitude of the liquid level in the core/upper plenum region following a small break LOCA in the AP600 plant. At 1500 seconds in Fig. 5.1-23, the test data shows the level receding below the two foot elevation while the NOTRUMP code is predicting a rapid increase in level to the eight foot elevation. The ability to predict two-phase level response is essential for assessing small break LOCA ECCS performance. The NOTRUMP prediction of the two inch cold leg break suggests that the code is inadequate for assessing small break LOCA ECCS performance. In view of the poor performance of the NOTRUMP codes ability to predict the level response in the system, please describe what future work is planned to correct this major code deficiency. Please explain the rationale for utilizing the NOTRUMP code for assessing the potential for core uncovery in the AP600 plant in view of the inability of the code to properly trend and simulate system component liquid level responses for both the OSU and SPES-2 tests.

Response:

The comparisons presented in Reference 440.520-1 were based on preliminary test analysis results when the two phase level in the tests was not yet available. Figures 440.520-1 to 440.520-8 present comparisons of both power channel two-phase level and the collapsed liquid level above the simulated core for tests s00303, s00605, s00706 and s00908. Both levels are presented relative to the top of the heated rod length.

The SPES-2 two-phase level has been determined as described in Reference 440.520-2. The SPES-2 collapsed liquid level above the core has been calculated using the total pressure change indicated by the three differential pressure cells which span the region from the top of the heated rods to the bottom of the upper head, as defined in Reference 440.520-2. A mean fluid temperature over the region encompassed by these differential pressure cells has been used in the calculation.

It can be seen from Figures 440.520-1 to 440.520-8 that the agreement between the NOTRUMP and test data is generally good. In particular, for test s00303, after allowing for the event timing differences between the test and NOTRUMP simulation, there is both qualitative and quantitative agreement with the two-phase level being generally at the hot leg elevation except after accumulator and IRWST injection which cause the level to rise above the hot legs.

The agreement between the code and test data is much better than indicated by the preliminary results presented in Reference 440.520-1 and these give confidence that the NOTRUMP code is adequate to model the power channel level response. As outlined in the response to RAI 440.515, new comparison work using the G2 level swell separate effects test results will be undertaken to further demonstrate the adequacy of the NOTRUMP code.

References

440.520-1 Preliminary, "NOTRUMP Preliminary Validation Report for SPES-2 Tests," Proprietary [PXS-GSR-002], July 1995.

440.520-2 WCAP-14254, Revision 1, "AP600 SPES-2 Test Analysis Report," Proprietary [PXS-TZR-110], November 1995.

SSAR Revision: NONE

Question 440.348

Re: WCAP-14171 (WCOBRA/TRAC CAD)
To clarify WCOBRA/TRAC's ability to calculate downcomer injection:

a) Compare the WCOBRA/TRAC flooding curves for the CCTF and UPTF calculations to the those based on the test data. Include comparisons to the Wallis and Kutateladze flooding curves as appropriate. Clarify the reasons for any differences between the WCOBRA/TRAC curves and the test data or the WCOBRA/TRAC curves and the Wallis and Kutateladze curves.

b) Compare the WCOBRA/TRAC calculated and the experimentally measured vessel refill rates for the CCTF and UPTF tests.

c) Analyze the baseline tests for CCTF Run 58 and UPTF Test 21 with WCOBRA/TRAC. Compare the calculated and measured results for all the tests and clarify if the trends observed in the experiments from the baseline case to the test case were properly calculated by WCOBRA/TRAC. If not, clarify why and discuss any implications for AP600 BE LBLOCA analyses.

d) Because only one PCT comparison was available from the downcomer injection tests presented in WCAP- 1 41 71, provide the results of other CCTF tests with downcomer injection if possible. Alternately, downcomer injection tests from other test facilities could be used to provide additional, quantitative PCT data on WCOBRA/TRAC's ability to accurately calculate downcomer injection. If additional downcomer injection tests with PCT are not available, provide additional comparisons to downcomer injection tests without PCT data if available.

e) Compare the conditions in CCTF Run 58 and UPTF Test 21 to those expected in AP600. For those conditions in AP600 not covered by the CCTF or UPTF tests, justify the use of WCOBRA/TRAC to calculate the AP600 response under those conditions, or provide additional assessments to cover the required range of conditions.

Response: (Revision 1)

a) The CCTF test 58 does not simulate the ECC water bypass period of a LBLOCA transient, so it is not considered in this response.

The direct comparison between the calculation and the experiment of the lower plenum liquid penetration rates is consistent with WCOBRA/TRAC providing a good prediction of "flooding", with a tendency to underpredict the liquid penetration rate. This conclusion is further substantiated by UPTF test 21 sensitivity calculations which investigated the effects of increasing the broken loop pressure loss coefficients (Refer to RAI response part (c)).

The Wallis and Kutateladze correlations are not appropriate to the UPTF facility because it is full scale, and the correlations are based on data from reduced scale facilities. It was found in Reference 440.348-1 that it is not possible to fit this type of correlation to UPTF total downcomer penetration because of the effect of location of ECC injection. Also it was noted in Reference 440.348-1 that during a test, penetration far away from the broken loop can be injection limited, while there is no penetration from injection points close to the broken leg.

The UPTF test 21 data for downcomer liquid penetration has been compared with the correlation presented in Reference 440.348-2. This correlation is based on the approaches of Wallis and Kutateladze, but it has been extended to account for the scale dependent effects that are observed in the full scale UPTF facility. The main difference between Kutateladze scaling and the correlation of Reference 440.348-2 is that the correlation accounts for the azimuthal distribution of the sources of injected water to the downcomer, whereas the Kutateladze approach assumes homogenous flow. It is observed in the tests that penetration occurs around the injection sources far from the broken cold leg, but much less penetration occurs near the broken cold leg.

The correlation predicts for phases A and B1 that there is no penetration from the downcomer nozzle close to the broken cold leg and complete penetration from the downcomer nozzle far from the broken cold leg, (i.e., the rate of lower plenum water build-up for phases A and B1 are 2006 lb/sec and 1884 lb/sec respectively). The measured rate of lower plenum liquid buildup in phase A (Figure 3.2-16) is of the order of 1000 lb/sec during 50-80 seconds and no penetration at other times. The measured rate of liquid build-up in the lower plenum in phase B1 (Figure 3.2-24) is approximately 250 lb/sec over the full duration of the phase. The correlation predicts that for phase B2 there is no penetration from either downcomer nozzle. The measured rate of liquid build-up in the lower plenum during phase B2 (Figure 3.2-32) is approximately 75 lb/sec. The correlation predicts that for phase B3 there is ~~complete penetration of the liquid from both downcomer nozzles, i.e., a combined flow rate of 3791~~ from both downcomer nozzles, a combined flow rate of 2250 lb/sec. The measured rate of liquid buildup in the lower plenum during phase B3 (Figure 3.2-32) is approximately 1300 lb/sec for 20 seconds and then no further liquid penetration.

Thus, it can be seen that the correlation overpredicts the rate of liquid penetration in phases A, B1, and B3. This overprediction is attributed to the downcomer water injection velocity. In UPTF test 6, water is injected from the intact cold legs with a typical average velocity of 3 feet/second, whereas in UPTF test 21, the water is injected from the downcomer nozzles with a typical average velocity of 80 feet/second. The higher injection velocity in UPTF test 21 causes more effective break-up of the water jet, which decreases the amount of penetration to the lower plenum and increases the amount of carryover to the broken cold leg.

Thus, the correlation of Reference 440.348-1 is not applicable to UPTF test 21. However, as has been stated in the report, WCOBRA/TRAC has provided good modelling of the phenomena occurring during the test and the WCOBRA/TRAC calculations are in reasonable agreement with the test results.

(b) CCTF Run 58 simulates the reflood phase of a LBLOCA. It was initiated with the lower plenum filled to a level of 2.82 ft. The downcomer quickly fills with water after initiation of accumulator injection and the downcomer remains full up to the cold leg elevation (Figure 3.1-35, WCAP-14171). As shown, the WCOBRA/TRAC calculation accurately predicts this refill sequence, as well as the filling of the vessel during the subsequent core reflood.

UPTF Test 21 simulates the end of the blowdown phase of a large break LOCA. The integrated mixture discharge rates can be seen in Figures 3.2-19, 3.2-27 and 3.2-34 and the lower plenum refill rates can be inferred from Figures 3.2-16, 3.2-24 and 3.2-32. The mixture discharge rate is over-predicted in test phases A, B1 and B3. The discharge is well predicted in test phase B2. In phase A the lower plenum penetration is not predicted. In phase B1 the rate of penetration is over-predicted initially, then penetration is predicted to cease until the end of the test phase. In phase B2 the penetration is not predicted. In phase B3 the measured penetration is at a uniform rate, then the penetration ceases. In the calculation of phase B3, the initial rate is correct and the penetration is then predicted to cease. Only the duration of the penetration is underpredicted. Hence the general tendency for the predictions is to overpredict discharge at the break and underpredict penetration to the lower plenum.

(c) In response to this question, the direct vessel injection calculations which are discussed below were performed in a manner consistent with WCOBRA/TRAC CQD RAI responses using the latest modeling criteria. Changes to the CCTF model include the losses in the broken cold leg leading to the containment simulator tanks, heater rod material properties, and minor adjustments to flow areas and wetted perimeters in the vessel. Results obtained for Run 62 are provided in Reference 440.348-3. The UPTF model was similarly changed to improve the broken cold leg pressure loss calculation. The cold leg break modeling was [ ] (a,c)

[ ] (a,c)

The baseline test for CCTF is C2-4 (Run 62). This test simulated cold leg injection and can be compared directly to the downcomer injection test C2-AA2 (Run 58), which is similar in all respects except for the ECC injection location. The major differences in the experimental data of the two tests are as follows. Run 58 experienced significant downcomer/core flow oscillations throughout the test which were not evident in Run 62. The explanation for these oscillations put forward by the experimentalists states that they are perpetuated by the following sequence of events. When the downcomer collapsed liquid level rises, the downcomer injection nozzles became submerged and the condensation of steam is reduced, resulting in an increase in the downcomer pressure. At the same time, the core level falls, causing a reduction in the steam production rate in the core. The increased ΔP between the downcomer and the core forces the liquid back into the core, which uncovers the downcomer injection nozzles. The consequences of the core recovering and the associated decrease in downcomer level are increased steam production in the core, uncovery of the downcomer nozzles that results in an increased condensation rate at the ECC injection point, resulting in a reduced downcomer pressure which causes the cycle to repeat.

Another difference between the two tests is that the downcomer liquid in Run 58 is more subcooled because the ECC liquid is injected directly into the downcomer without mixing with the intact loop steam. The injected ECC liquid in the base case test, however, is significantly heated by its nearly complete mixing with intact loop steam in the cold legs before it enters the downcomer.

The final difference is the effect of the oscillatory downcomer/core flow on the quench front progression in Run 58. The quench front progression is retarded in Run 58 compared to the base case because the transfer of heat from the rods is reduced during the period of decreased liquid level in the core, which corresponds to the flow reversal period of the oscillation cycle.

A brief summary description of the WCOBRA/TRAC calculated results is now provided. The times discussed refer to the start of the transient in the experiment, i.e. time zero is the start of accumulator injection to the lower plenum.

CCTF Calculation Run 62 (Reference 440.348-3)

The calculated system pressure shows good agreement with the data throughout the transient. A good prediction of the steam flow in the two hot legs is achieved except for a slight overprediction in the broken loop (~ 0.5 lb/sec) after 200 seconds. Again, a good prediction of the liquid flows in the hot legs is achieved except for an overprediction (~ 0.5 lb/sec) in both the intact and broken loops between 60 and 200 seconds. The total core differential pressure is underpredicted after 300 seconds, and a stable oscillatory flow behavior is indicated during the period from 200 to 500 seconds. The pressure oscillations are fairly significant (~ 0.5 psi) and are not observed in the experiment. The pressure fluctuation is, as expected, reflected in the calculated total downcomer differential pressure. The downcomer differential pressure falls below the data after 200 seconds. The calculated overall core thermal response is good. There is a tendency to overpredict the clad temperatures above mid-elevation due to an underprediction of the quench front progression, which is approximately 50 seconds delayed compared to experiment. The calculated peak clad temperatures in the lower half of the core are well predicted.

CCTF Calculation Run 58

Figures 440.348-1 through 440.348-35 are attached to compare the newly calculated system parameters for CCTF Test 58 with the experimental data. The system pressure is slightly overpredicted for the majority of the transient. This corresponds to the overprediction of steam production in the core due to predicting an early advancement of the quench front. The hot leg steam flow is slightly overpredicted in the intact loops (~ 0.3 lb/s) and is a bit more overpredicted in the broken loop (0.6 to 1.0 lb/s). Liquid flow in the intact loop hot legs is generally well predicted by WCOBRA/TRAC until more than 500 seconds have elapsed and is overpredicted from 150-300 seconds. After this time hot leg liquid flows are significantly overpredicted, probably due to the advanced quench front. The calculated total core differential pressure agrees well with the test data, while the downcomer differential pressure is slightly lower than the data, indicating that the collapsed liquid level is lower in the calculation. In terms of the calculated core thermal response, the peak clad temperatures at all elevations are well predicted with a tendency for overprediction at very high elevations (10 ft). The greatest discrepancy is the quench front progression, which is calculated to be in advance of the data by approximately 80 seconds.

Comparison between WCOBRA/TRAC test predictions of the data

The calculations are very similar in most respects except for the effects of the different rates of quench front progression. The rates of quench front progression seen in the calculations are retarded and advanced relative to those observed in the experiments for CCTF Test 62 and Test 58, respectively. The cause of each difference appears to be the same: the core oscillatory flow behavior corresponds to a lower quench front progression rate than does a more stable core flow. In Run 58 the calculated collapsed downcomer liquid level stabilizes below the downcomer injection point, so the rapid oscillating flow cycle observed in the test is not calculated in either magnitude or time interval. In Run 62 an oscillatory flow between the downcomer and the core is predicted by

WCOBRA/TRAC, contrary to what is seen in the test, and quench front advancement is underpredicted. The code prediction may be explained by the following argument. Liquid slugs falling into the downcomer from the cold legs force an increased amount of liquid into the core. The resulting increase in core steam production in turn forces the downcomer liquid level to rise, and the liquid is ejected into the broken cold leg. This causes a local pressurization as the steam from the intact loops flows out the broken cold leg with an increased liquid content and therefore at an increased pressure drop. The downcomer liquid level then decreases, and the flow cycle continues. This flow behavior cause the calculated collapsed liquid level to fall below the data. This is indicated by the downcomer differential pressure comparison. By 400 seconds, the WCOBRA/TRAC downcomer differential pressure is more than one psi below the data of Run 62 (Reference 440.348-3). The downcomer fluid subcooling difference observed between the experimental tests is also seen in the calculations.

The WCOBRA/TRAC simulation of Run 58 overpredicts the upper plenum pressure (Figure 440.348-19) because the code is removing energy at a faster rate than the test, as shown in quench front plots 440.348-16, 17 and 18. The code predicts a faster reflood than occurred in the test, but the high powered rod PCT prediction are conservatively high.

UPTF WCOBRA/TRAC Predictions

The baseline test for the UPTF series of tests is test 6. These are five different phases (131, 132, 133, 135, and 136) associated with this test. All simulate cold leg injection with no direct downcomer injection and model the bypass flow period of an LBLOCA. The total ECC injection flow was ~ 3,200 lb/sec for each phase, and the combined steam generator and core simulator- injected steam flow varied from 230 lb/sec to 960 lb/sec over the range of phases. The ECC liquid subcooling varied from 50° F to 110° F. In comparison, the equivalent downcomer ECC injection test, Test 21 phases A, BI, BII and BIII, simulated an ECC injection rate of ~ 4160 lb/sec (885 lb/sec for BII) with a corresponding range of steam flows, from 500 to 1515 lb/sec. The liquid subcooling varied from 85°F to 380°F. Unlike the CCTF test 62 and 58, the UPTF tests are not directly comparable, so only general trends will be described.

The experimental test results for each phase of test 6 show that water penetration to the lower plenum was mainly controlled by the cold leg arrangement with respect to the break and steam injection rate. There is complete bypass from the cold leg adjacent to the break with partial delivery to the lower plenum from the two opposite cold legs for steam flows greater than 600 lb/sec. There is complete bypass from the adjacent cold leg and nearly complete delivery from the opposite cold legs for steam flows between 220 to 600 lb/sec. There is partial delivery from the adjacent cold leg and complete delivery from the opposite cold legs for steam flows less than 220 lb/sec. The delivery of flow to the lower plenum was in the form of plugs of liquid which first accumulated in the cold legs. The measurement of subcooling in the downcomer indicated that the water present in the downcomer was localized around the cold leg nozzles, leading to a heterogeneous flow.

The downcomer flow regime for the UPTF test 21 was different and relates to the method of ECC liquid injection. The flow from the injection nozzles deflected off the core barrel and dispersed around the downcomer. The upward flow of steam from the core carried a significant proportion of the liquid out of the break. Some penetration occurred and the rest was deposited in the intact loops where it accumulated. The process of dispersing liquid around the downcomer causes the ECC liquid delivery rate to the lower plenum to be significantly less for the downcomer injection test, UPTF 21, compared to cold leg injection UPTF test 6.

The calculated results for the different phases of UPTF test 6 are similar in terms of their comparison with the data (Reference 440.348-3). The system pressure for each of the phases is in general slightly underpredicted. The delivery into the downcomer and lower plenum is by slugs of liquid from the intact legs, as observed in the experiment. The rate of delivery was accurately calculated; however, the timing in all cases was delayed. As a consequence of the delay the degree of bypass was overpredicted.

Inspection of the predictions for UPTF test 21 shows that there is a tendency to underpredict the discharge of steam from the break and to over-predict the pressure in the system. This is attributed to the modelling of the break separator. In the calculations reported in WCAP-14171, the break separator has been modelled[ ] (a,c)

[ ] (a,c)

results of these calculations are attached as Figures 440.348-36 through 440.348-59, and they correspond to Figures 3.2-16 to 3.2-39 in WCAP-14171. The downcomer injection UPTF test 21 simulations exhibited a tendency to underpredict the downcomer pressure. The different flow behavior as a result of the ECC water break up on the core barrel was predicted by the calculations. For the low steam flow test phases, B2 and B3, the calculation predicted a high rate of penetration into the lower plenum at the start of phase B3, but the duration of the penetration was less, resulting in a smaller quantity of water reaching the lower plenum. The lower rate of penetration observed in the test during phase B2 was not predicted. For the higher steam flow phases, A and B1, no significant liquid penetration into the lower plenum was predicted.

The UPTF test comparisons presented in Reference 440.348-3, in WCAP-14171 and herein show that the WCOBRA/TRAC computer code is capable of predicting the different ECC flow behaviors associated with either cold leg or downcomer injection. The rate of liquid delivery into the lower plenum is for the majority of cases well predicted, while the timing and duration of this delivery is not. This results in the overprediction of the ECC bypass flow for all tests considered, which is conservative.

Regarding the AP600 ECCS performance analysis, the oscillations which were observed in the CCTF Test 58 are judged to be less likely to occur during the reflooding of the AP600 core. At CCTF the downcomer injection nozzle was located at almost the same elevation as the cold legs, so the covering and uncovering of the ECC injection stream and the subsequent condensation effects are pronounced. The AP600 reactor vessel design, on the other hand, locates the DVI nozzle at an elevation two feet below the bottom of the cold leg. Once the nozzles recover, ECC injection flow is likely to remain submerged throughout the core reflood phase of a postulated large break LOCA event in AP600. Downcomer condensation and the associated oscillations will therefore be minimized.

(d) Test C2 - AA2 (Run 58) is the only CCTF test which simulated long term downcomer injection with the vent valves (which allow a flow path between the upper plenum and the downcomer) in the closed position. Tests which simulated downcomer injection with the vent valves open exhibit different flow behavior which is not prototypic of the AP600 plant design, so these tests are not appropriate as validation data for WCOBRA/TRAC.

Overall, the test comparisons provide the necessary assurance that WCOBRA/TRAC can properly predict the large break LOCA thermal-hydraulic performance of the AP600. Within the core itself, the reflood heat transfer behavior of the fuel rods is independent of whether the ECC injection locations are in the downcomer or the cold legs. Also, the PCT behavior of CCTF Test C2-AA2 is not significantly different from the CCTF tests with which WCOBRA/TRAC was compared in the CQD.

(e) The design of the UPTF test facility was based on a 3900 MWt German PWR. Runs 272 and 274, selected for analysis from the series of five quasi-steady state runs which form UPTF Test 21, simulate the end of blowdown and beginning of refill phases of a LBLOCA. The two runs were performed to investigate the possible bypass of the ECC water to the broken loop. The test conditions were as tabulated below:

UPTF Cases

Run/Phase	Total ECC Injection To Downcomer (lb/sec)	Steam Flowrate From Core To Downcomer (lb/sec)	Subcooling Of ECC Water (°F)
272/A	4017	692	211
274/BI	3750	657	101
274/BII	1951	227	56
274/BIII	3791	225	47

An assessment of the WCOBRA/TRAC calculation for a typical AP600 DECLGB (C_D = 0.8) transient shows that during the period of bypass of ECC water to the broken loop, the corresponding calculated conditions vary as shown below:

WCOBRA/TRAC C_D = 0.8, DECLG Break

Total ECC Injection To Downcomer (lb/sec)	Steam Flowrate From Core To Downcomer (lb/sec)	Subcooling Of ECC Water (°F)
1860 to 1940	550 to 250	280 to 167

The major parameters affecting bypass are the steam velocity up the downcomer to the break, the ECC injection locations and rate of injection and the subcooling of the ECC water. Both UPTF and AP600 have four cold legs and two downcomer injection nozzles. The height and cross-sectional flow areas of the downcomers are similar and therefore the steam flowrates up the downcomer should be approximately the same, in order for the steam velocities and bypass phenomena to be similar. The above tables show that the AP600 steam flowrates are within the range covered by the UPTF tests. The ECC injection rates in AP600 correspond to the lowest of those used in the UPTF tests. The higher pressures associated with the early phase of the bypass period in the AP600 transient produce ECC subcoolings which are greater than those simulated in the UPTF test phases, however during the later phase of bypass when complete bypass is no longer calculated the ECC subcooling is comparable with the UPTF test conditions.

Given the conservative calculations of the amount of ECC liquid bypassed to the break by WCOBRA/TRAC, we believe that the overall good correspondence between the UPTF and AP600 conditions gives confidence that this phase of a LBLOCA is well validated by the UPTF calculations. Furthermore, the AP600 reactor vessel is equipped with flow diverters opposite the direct vessel injection line penetrations to direct flow downward.

CCTF Run 58 simulates the end of refill and reflood phases of a LBLOCA typical of Appendix K conditions for a "standard" 4-loop plant. One of the main objectives of the experiment was the assessment of the PCT during the transient. This is dictated, to a large extent, by the stored energy in the fuel rods at the beginning of reflood. In CCTF Run 58, the PCT at the beginning of reflood was 1466°F, which is representative of an unquenched core following blowdown.

The WCOBRA/TRAC calculations for a typical AP600 DECLGB (C_D = 0.8) transient shows that the PCT at the beginning of reflood is only 670°F. This relatively low value is the result of the core-wide quench produced by the flow from the upper head during blowdown.

We believe that the good WCOBRA/TRAC calculation of the reflood behavior and clad temperatures of CCTF Run 58 gives added confidence to the existing reflood validation evidence. We therefore are confident that WCOBRA/TRAC adequately calculates reflood behavior for the less onerous conditions associated with AP600.

Also, the WCOBRA/TRAC simulations of other CCTF tests, tests which responded similarly to Run 58, comprise a large data base assessing WCOBRA/TRAC for large break LOCA reflood.

References:

440.348-1 "Summary of Results from the UPTF Downcomer Separate Effects Tests - Comparison to Previous Scaled Tests and Application to U. S. PWRs", MPR-1163, July 1990

440.348-2 H. Glaeser, "Downcomer and Tie Plate Counter-current Flow in the Upper Plenum Test Facility (UPTF)," Nuclear Eng. and Des., 133, (1992), pp 259-283.

440.348-3 Letter, N. J. Liparulo to USNRC, "Prelimary Responses to Requests for Additional Information Regarding WCAP-12945-P," NTD-NRC-95-4399, Attachment U, February 9, 1995

SSAR Revision: NONE

List of Figures

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LOW POWERED ROD - CLAD TEMPERATURE AT 1 25 ft (DEG F)

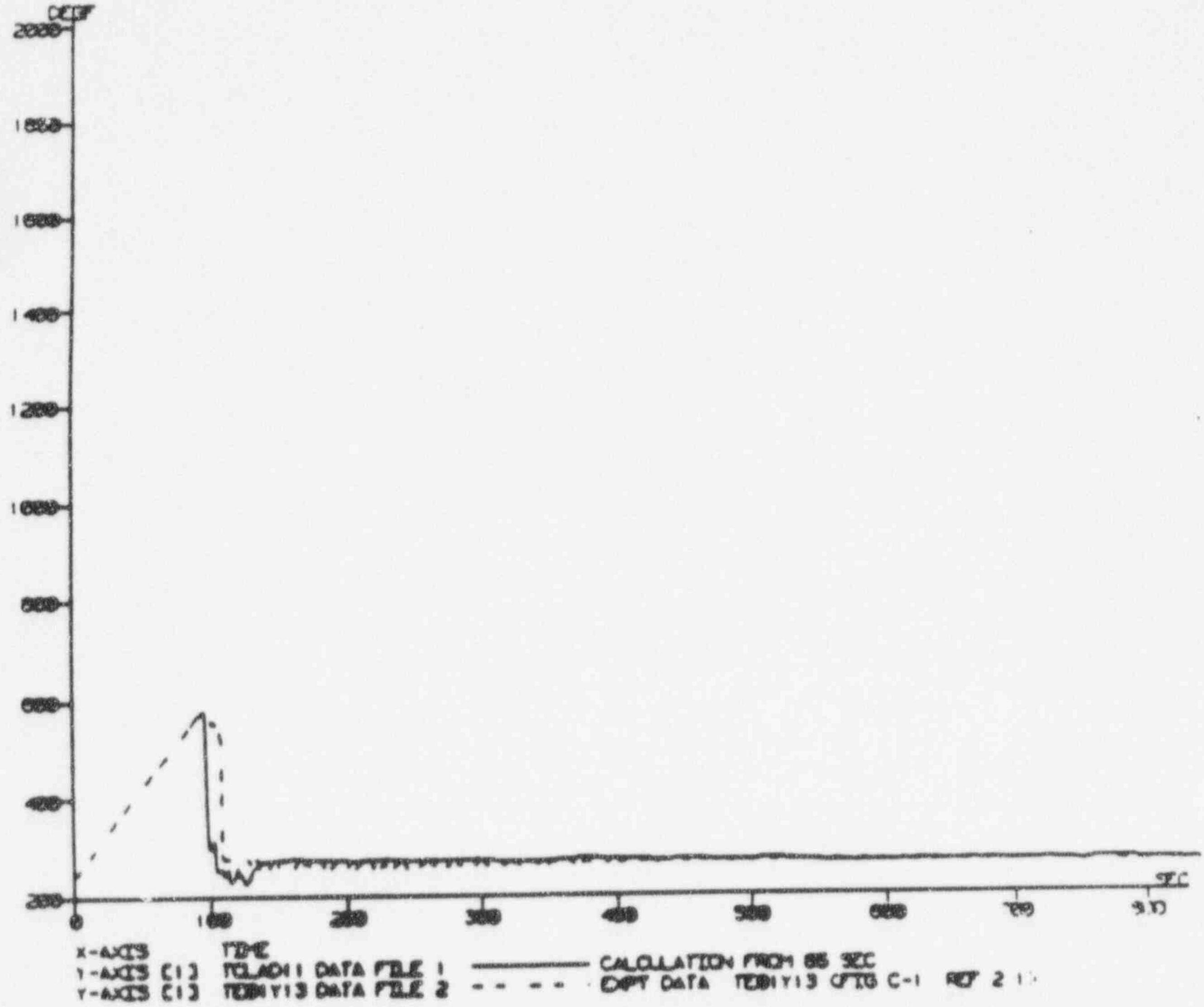


Figure 440.348-1 CCTF Run 58, Low Powered Rod, Clad Temperature at 1.25 ft

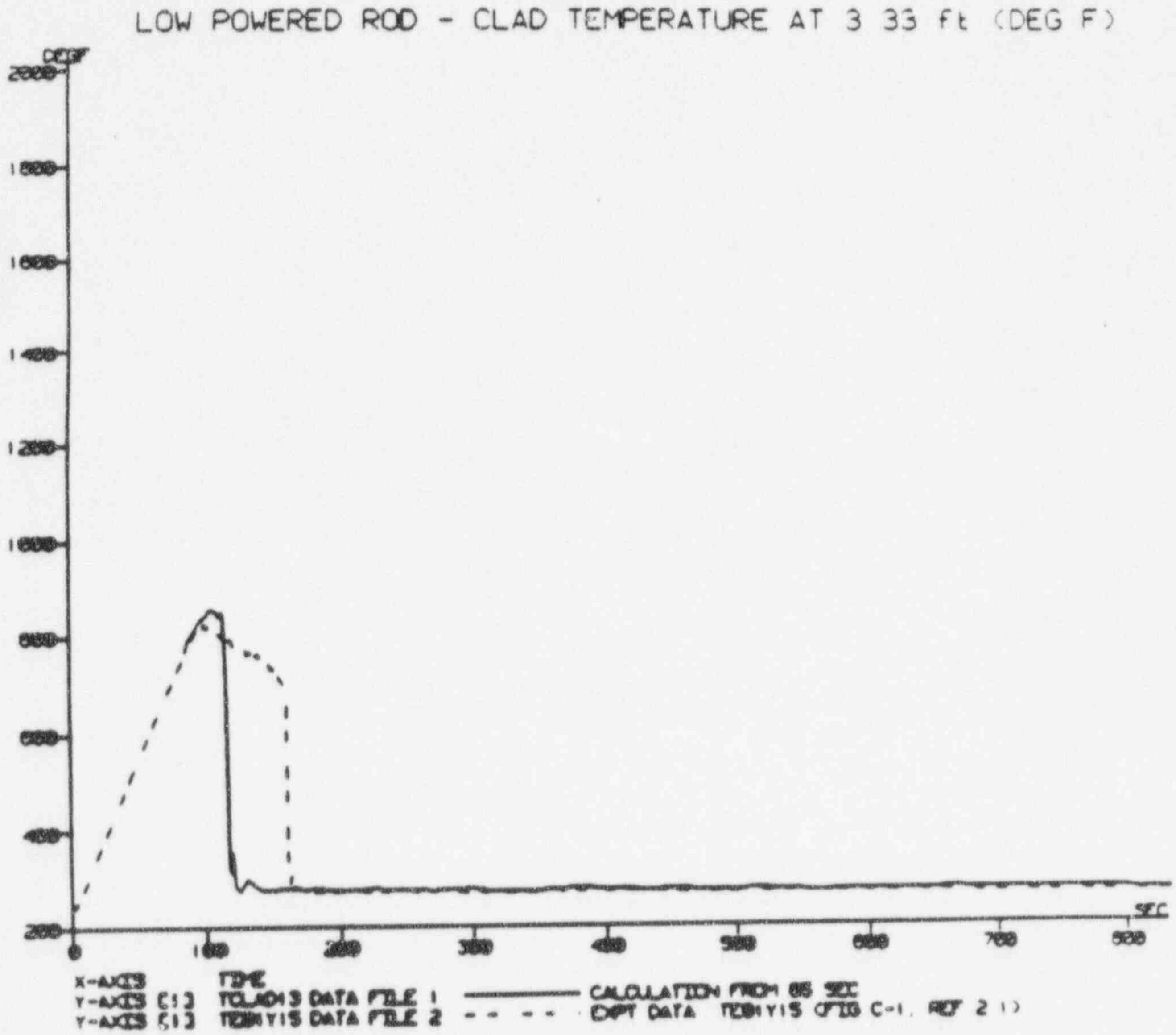


Figure 440.348-2 CCTF Run 58, Low Powered Rod, Clad Temperature at 3.33 ft

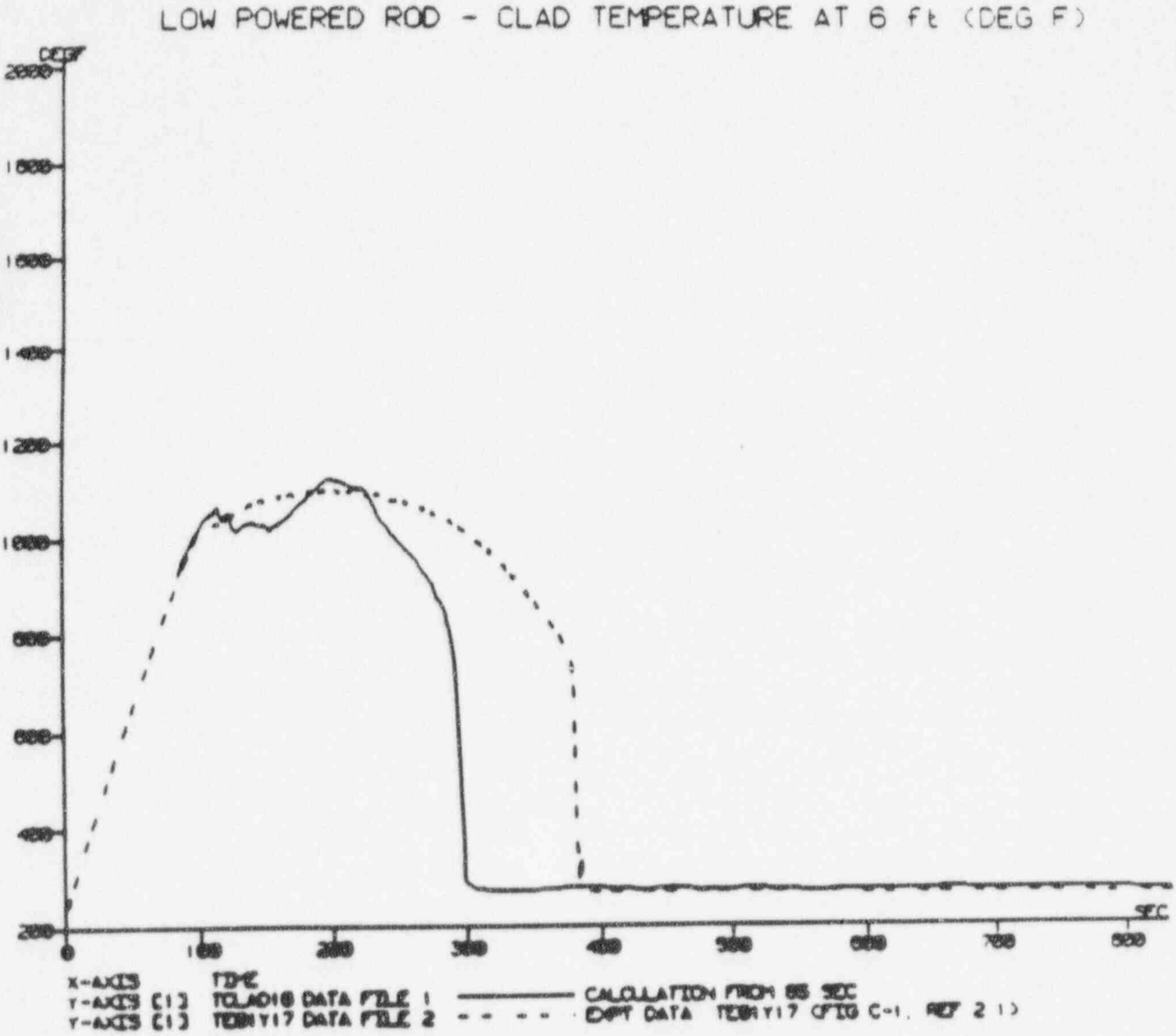


Figure 440.348-3 CCTF Run 58, Low Powered Rod, Clad Temperature at 6 ft

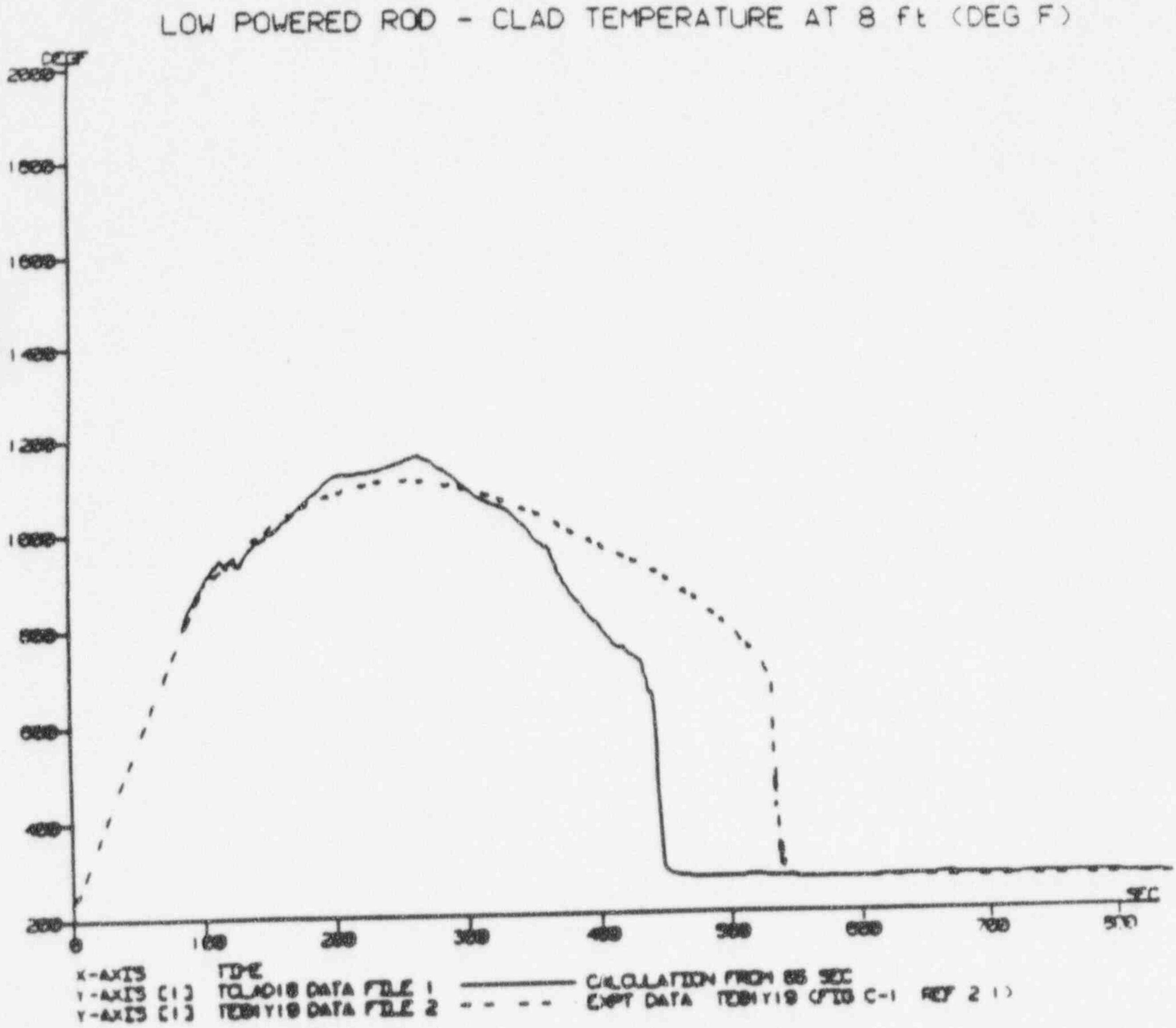


Figure 440.348-4 CCTF Run 58, Low Powered Rod, Clad Temperature at 8 ft

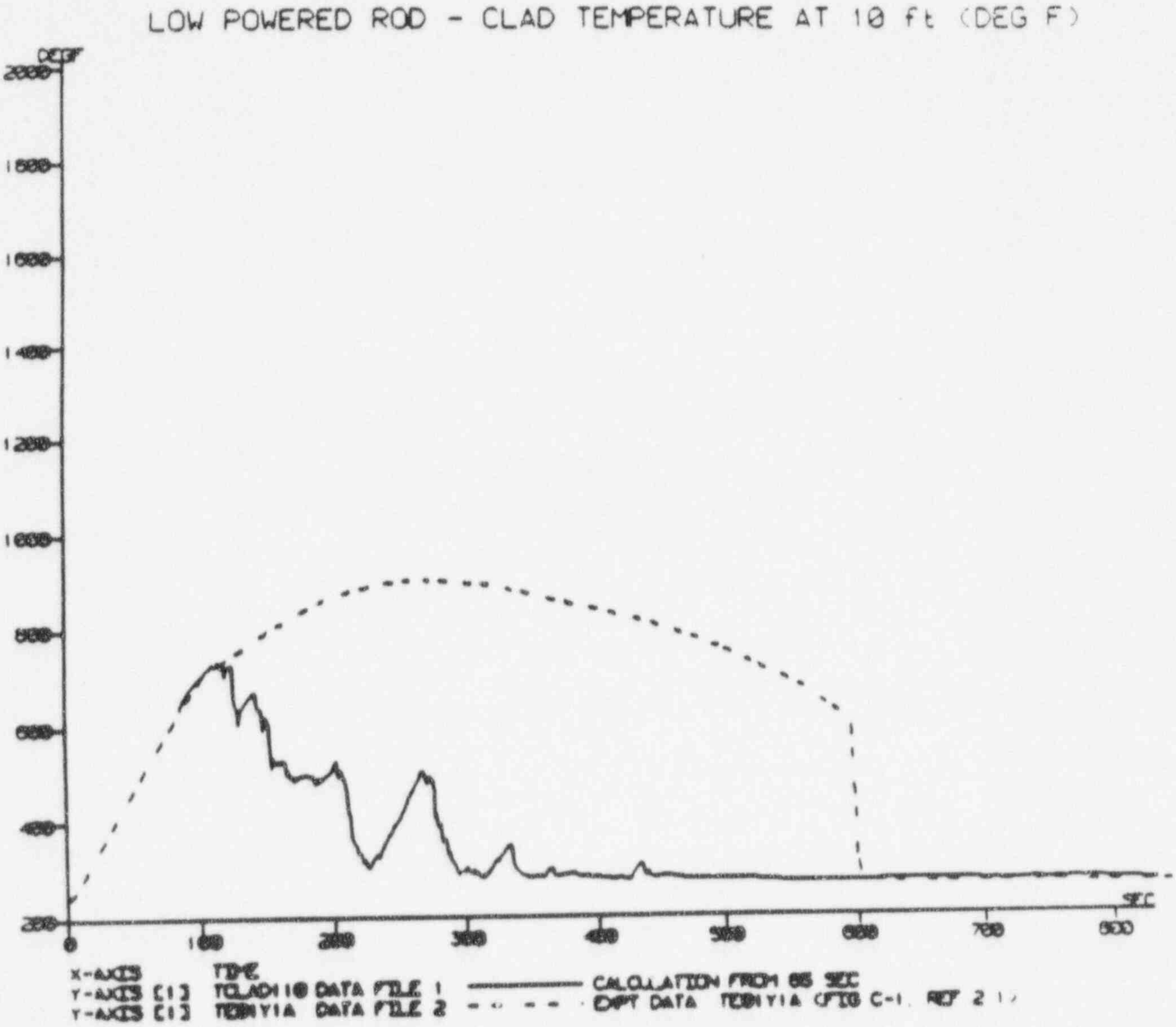


Figure 440.348-5 CCTF Run 58, Low Powered Rod, Clad Temperature at 10 ft

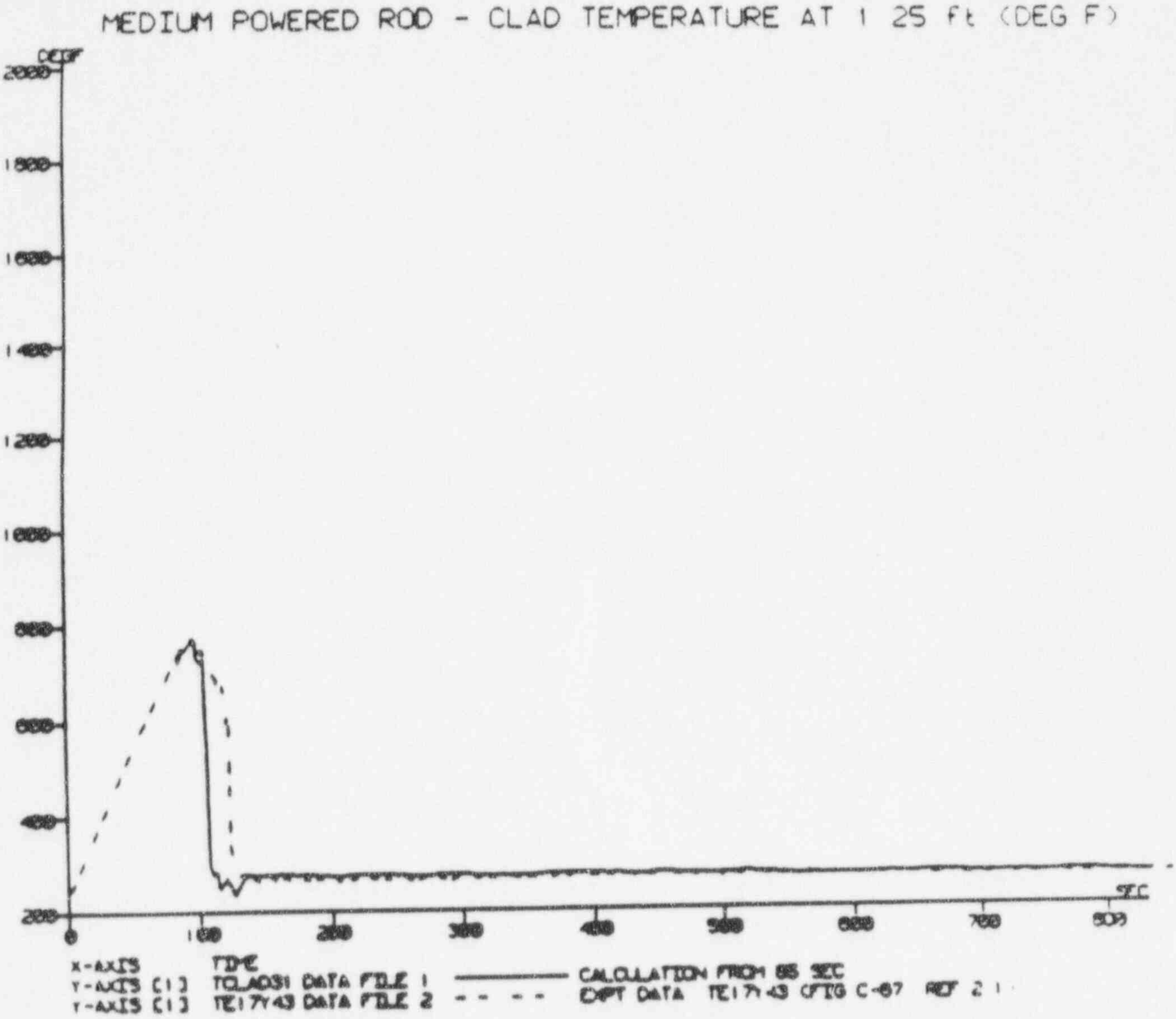


Figure 440.348-6 CCTF Run 58, Medium Powered Rod, Clad Temperature at 1.25 ft

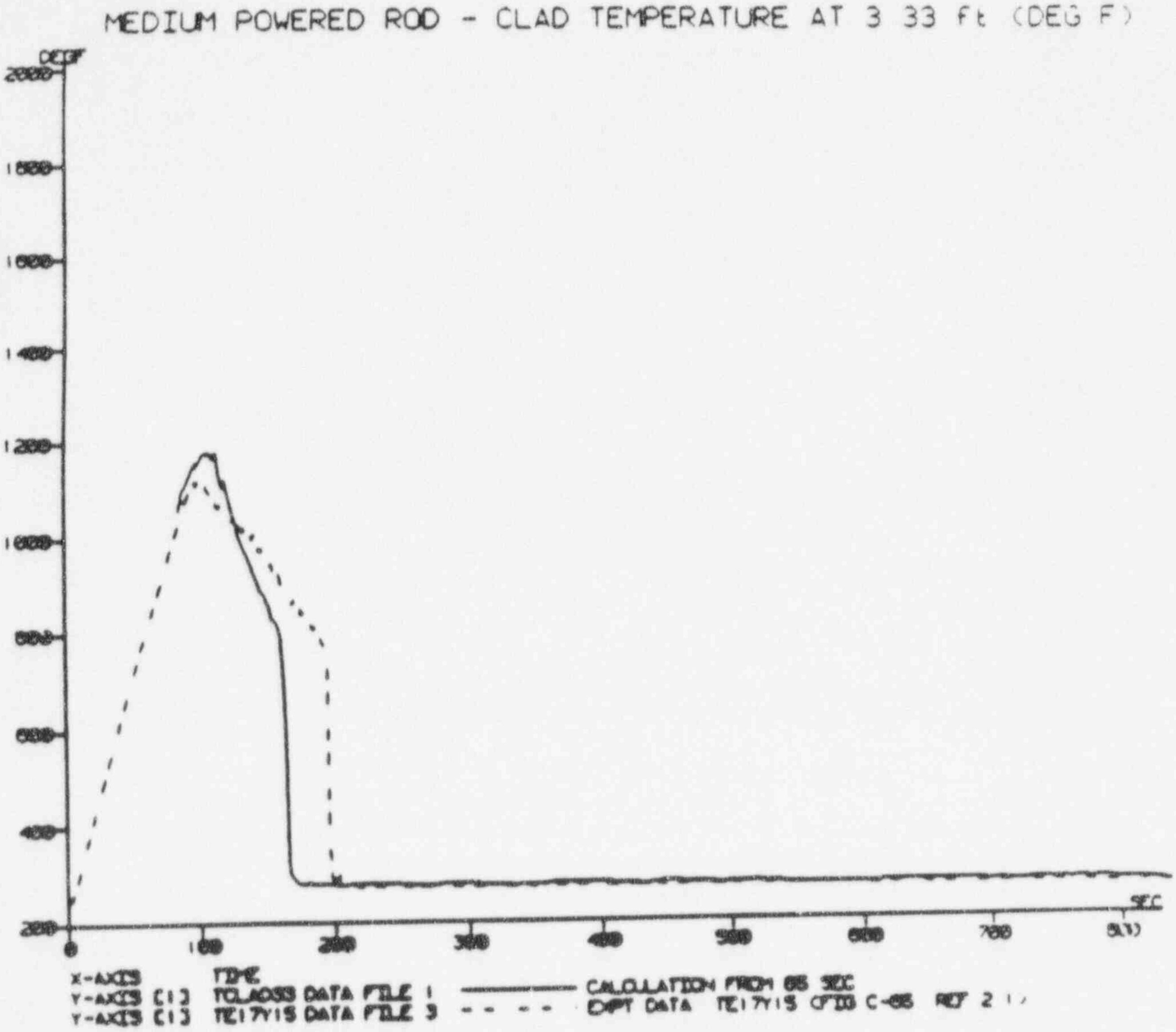


Figure 440.348-7 CCTF Run 58, Medium Powered Rod, Clad Temperature at 3.33 ft

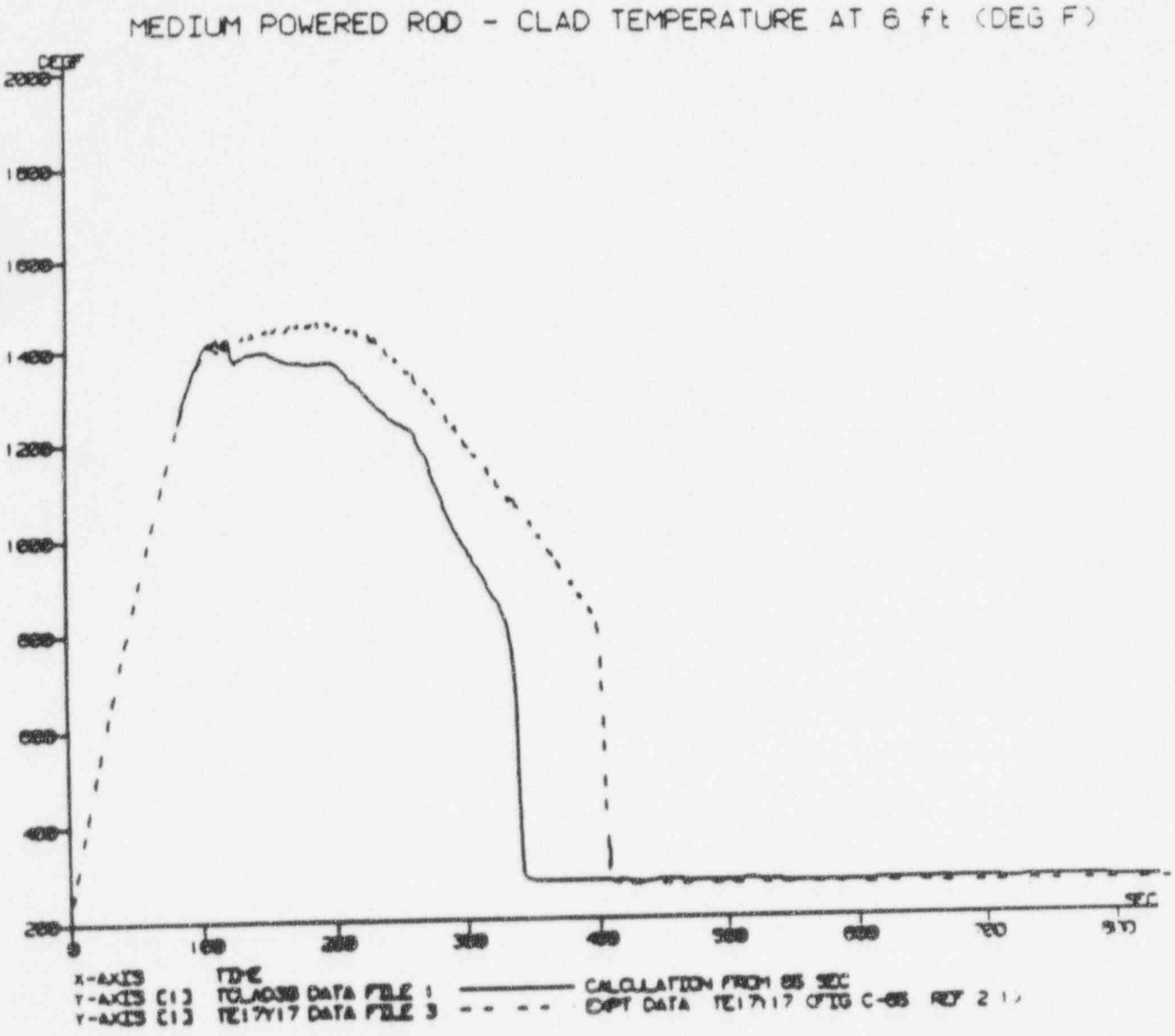


Figure 440.348-8 CCTF Run 58, Medium Powered Rod, Clad Temperature at 6 ft

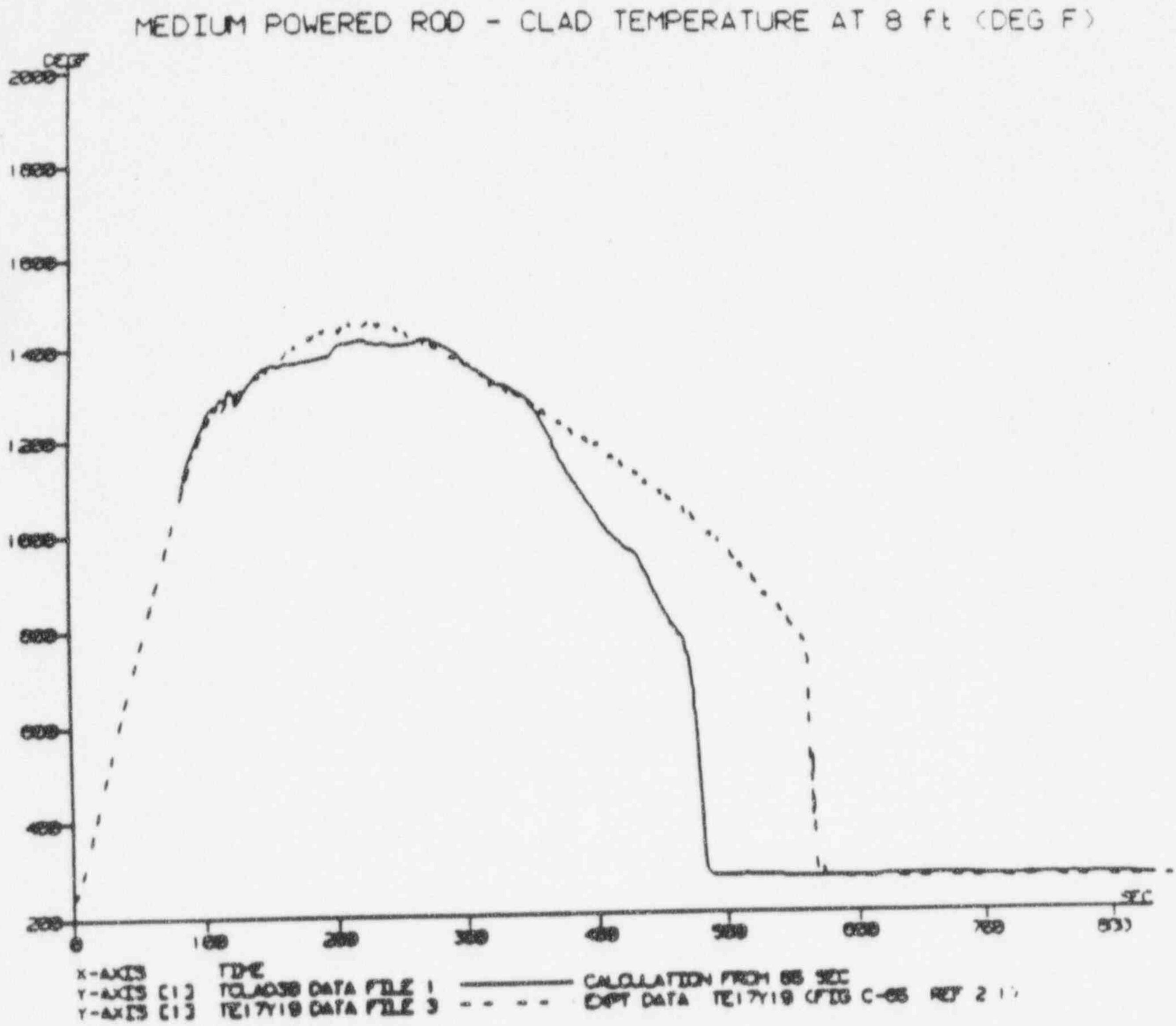


Figure 440.348-9 CCTF Run 58, Medium Powered Rod, Clad Temperature at 8 ft

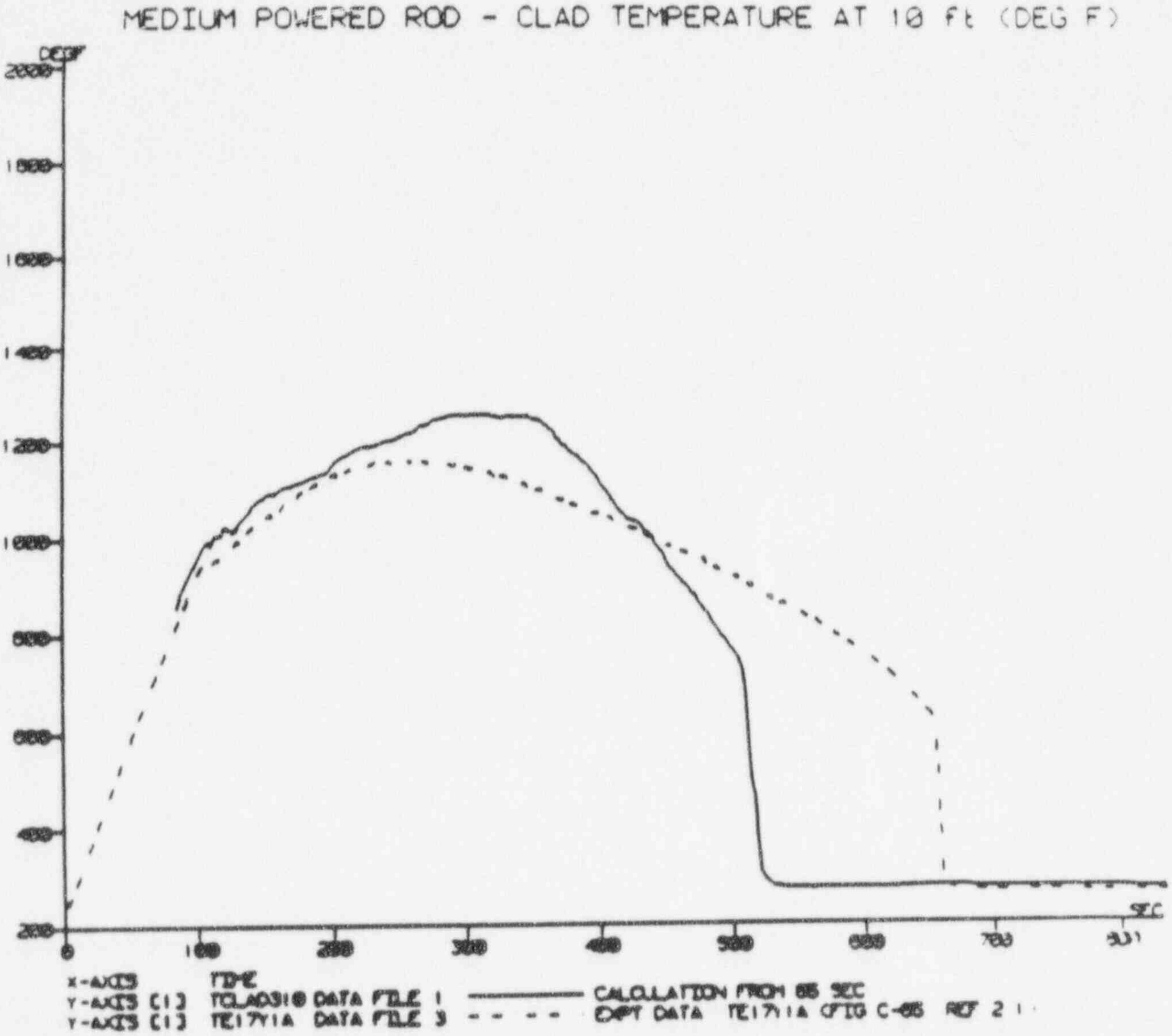


Figure 440.348-10 CCTF Run 58, Medium Powered Rod, Clad Temperature at 10 ft

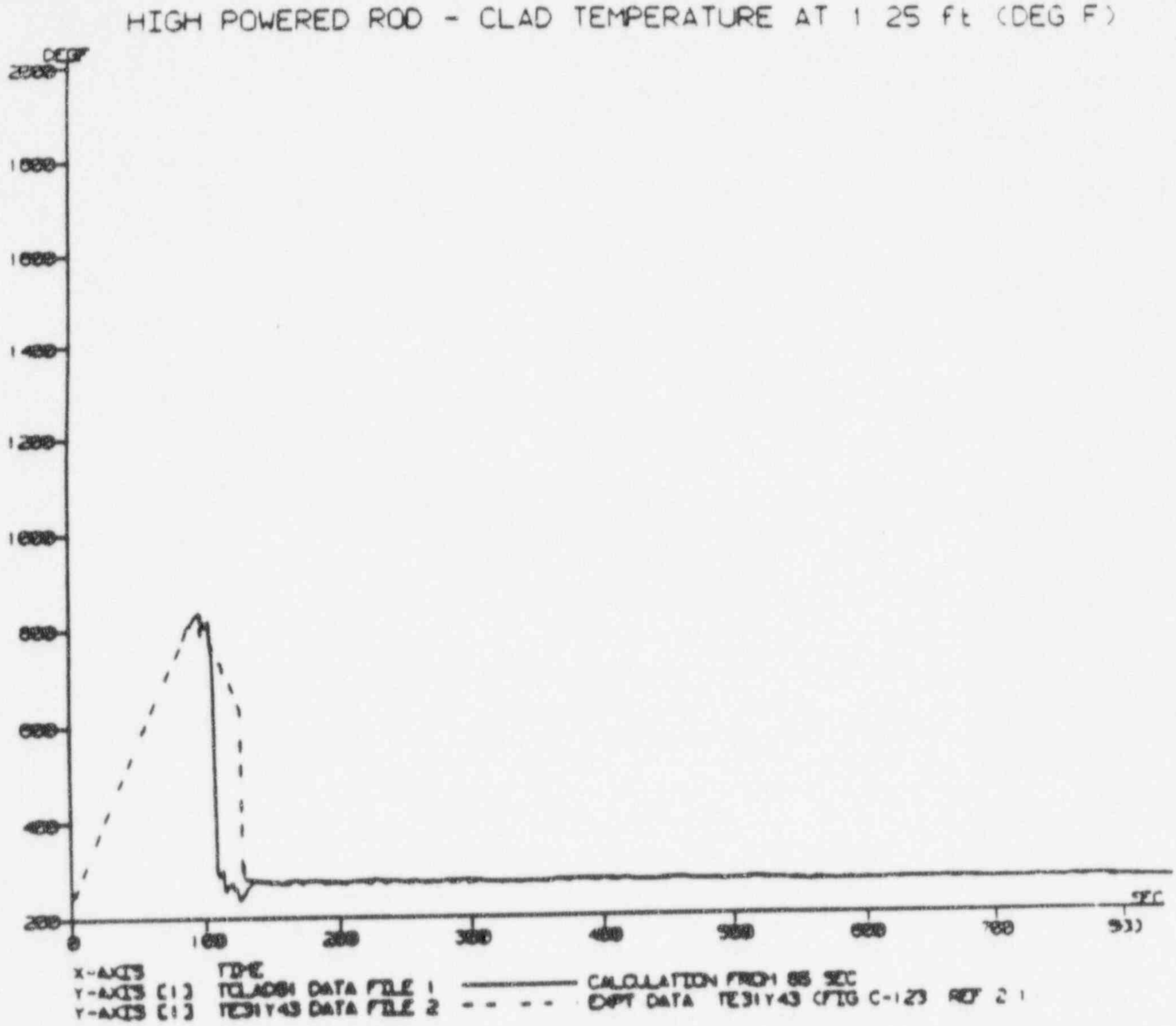


Figure 440.348-11 CCTF Run 58, High Powered Rod, Clad Temperature at 1.25 ft

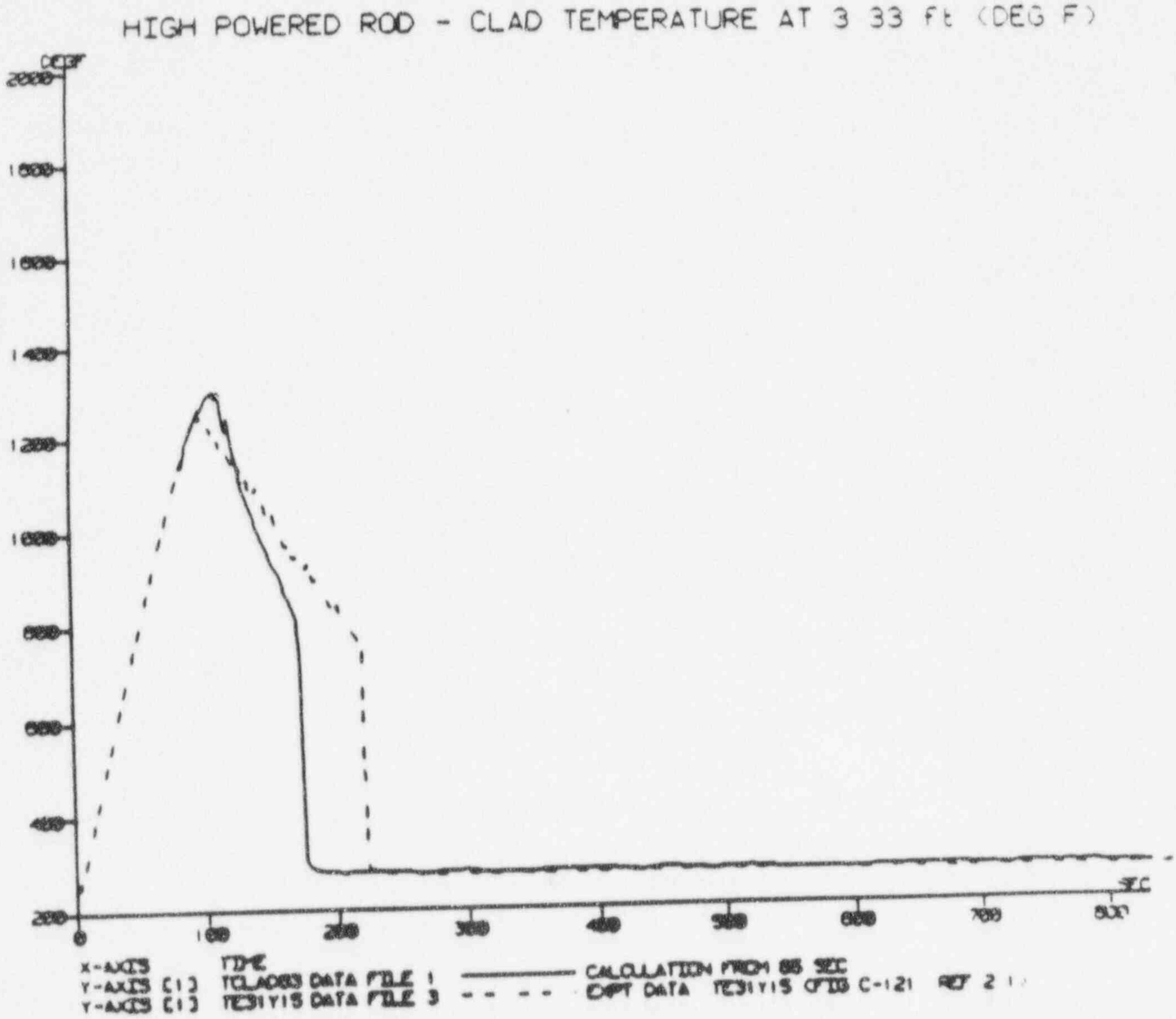


Figure 440.348-12 CCTF Run 58, High Powered Rod, Clad Temperature at 3.33 ft

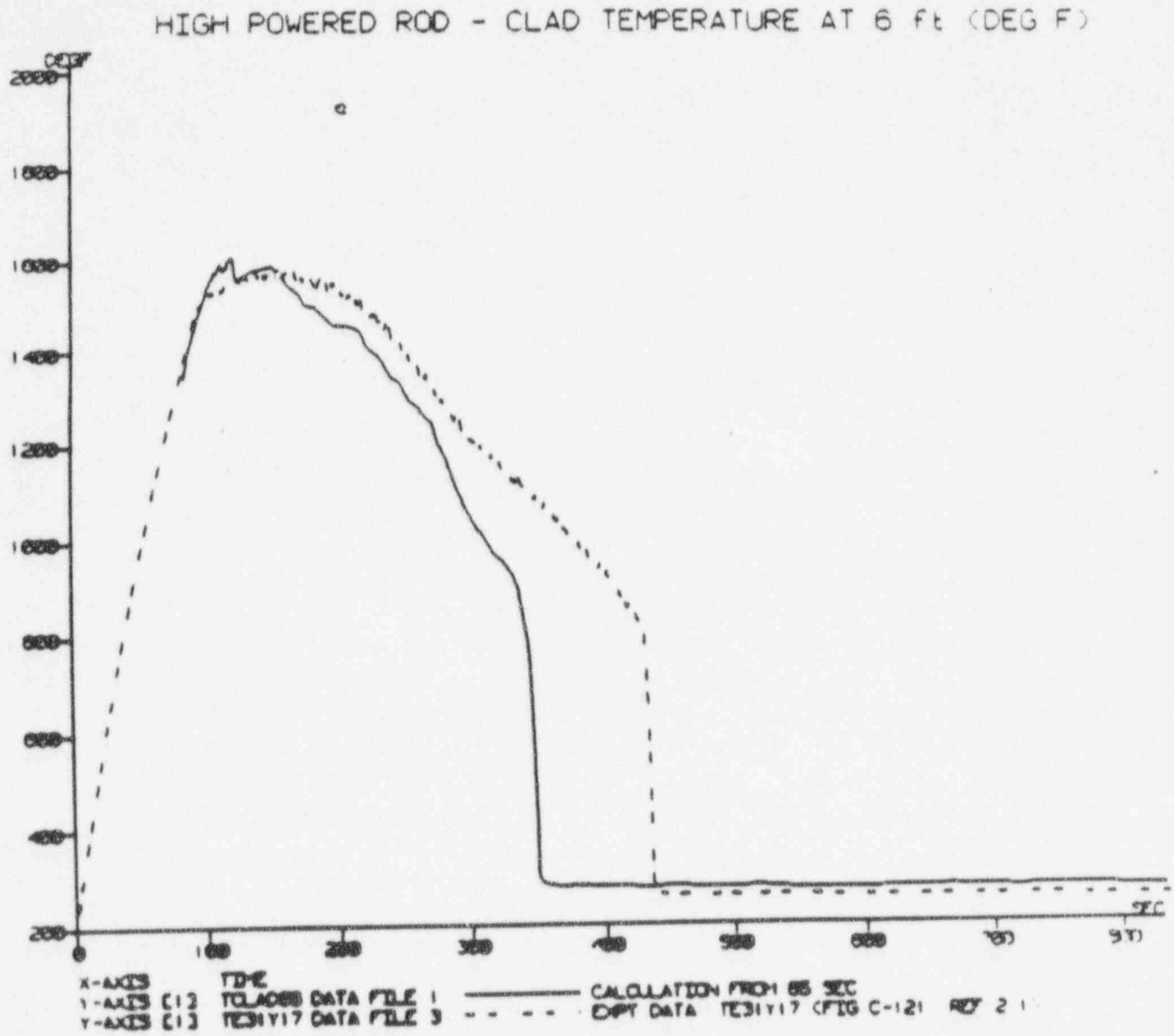


Figure 440.348-13 CCTF Run 58, High Powered Rod, Clad Temperature at 6 ft

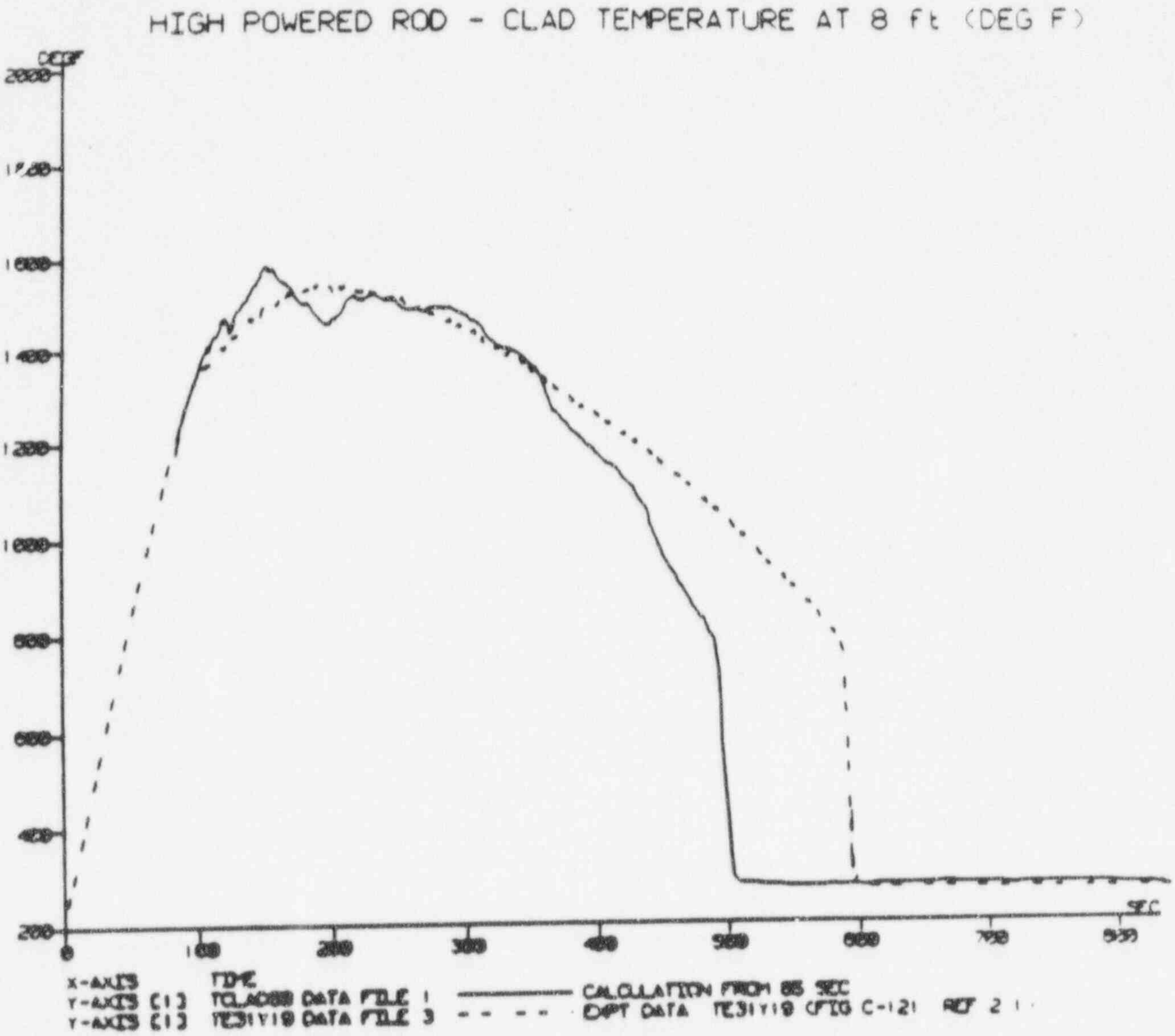


Figure 440.348-14 CCTF Run 58, High Powered Rod, Clad Temperature at 8 ft

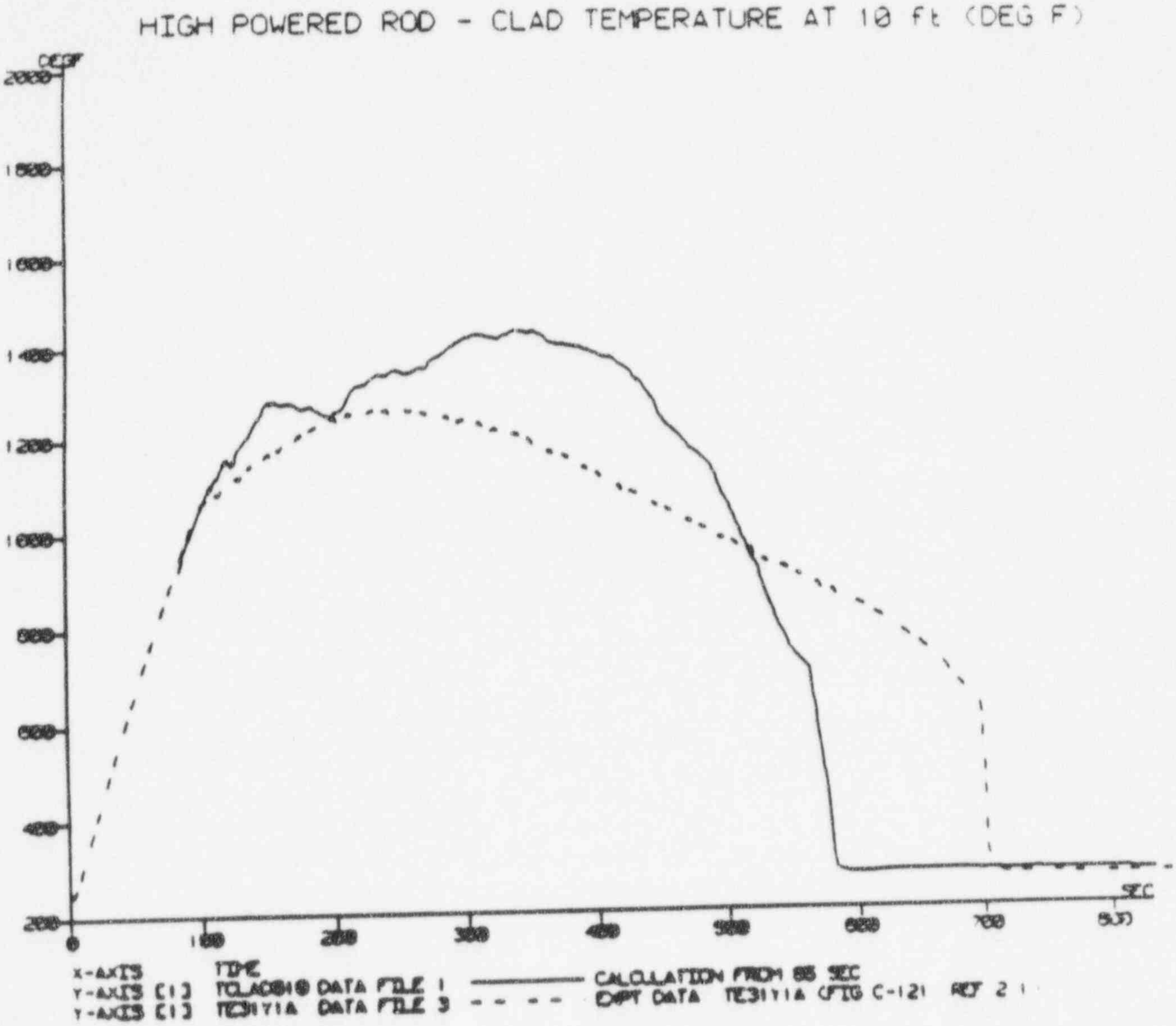


Figure 440.348-15 CCTF Run 58, High Powered Rod, Clad Temperature at 10 ft

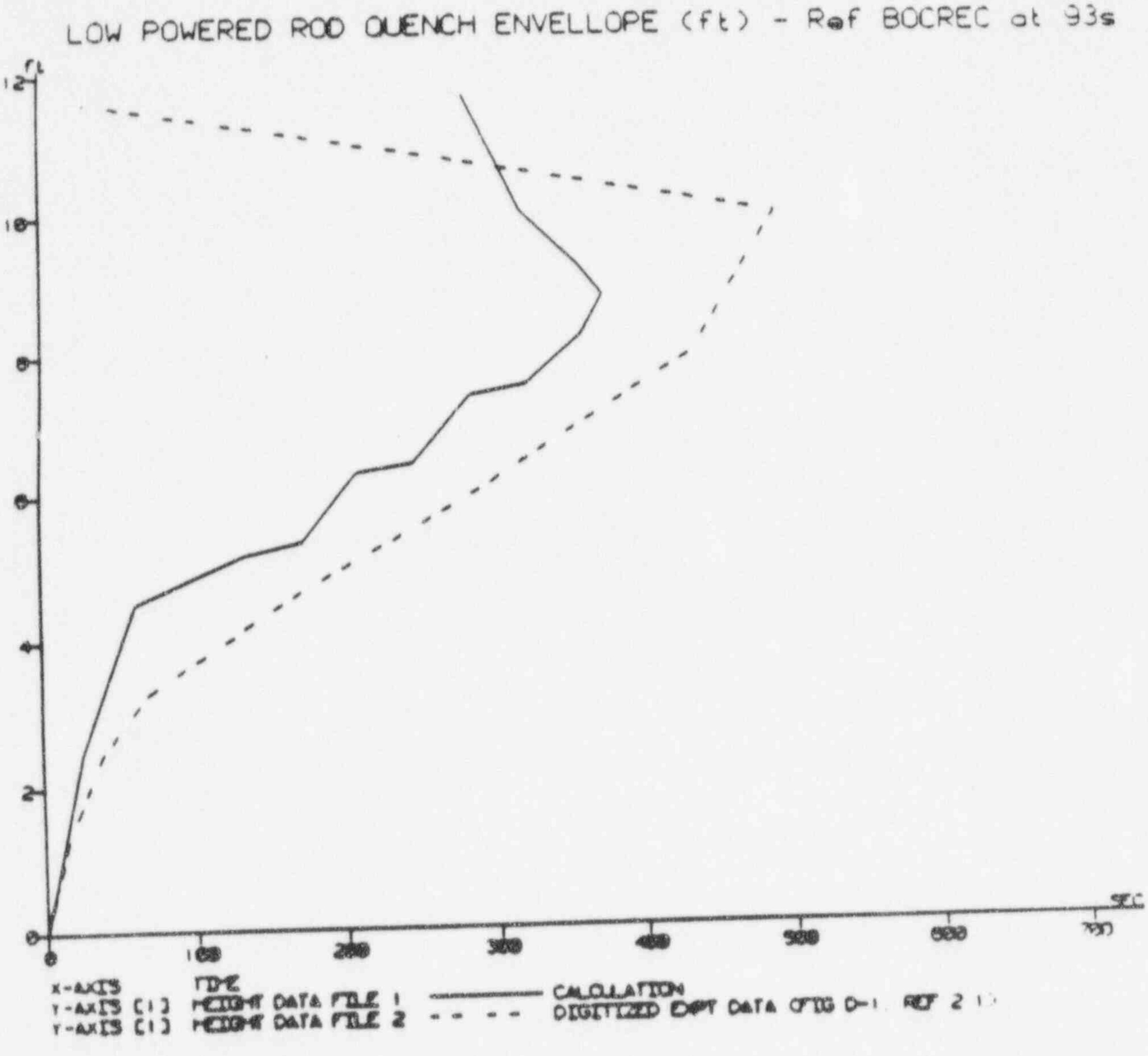


Figure 440.348-16 CCTF Run 58, Quench Envelope - Low Powered Rod

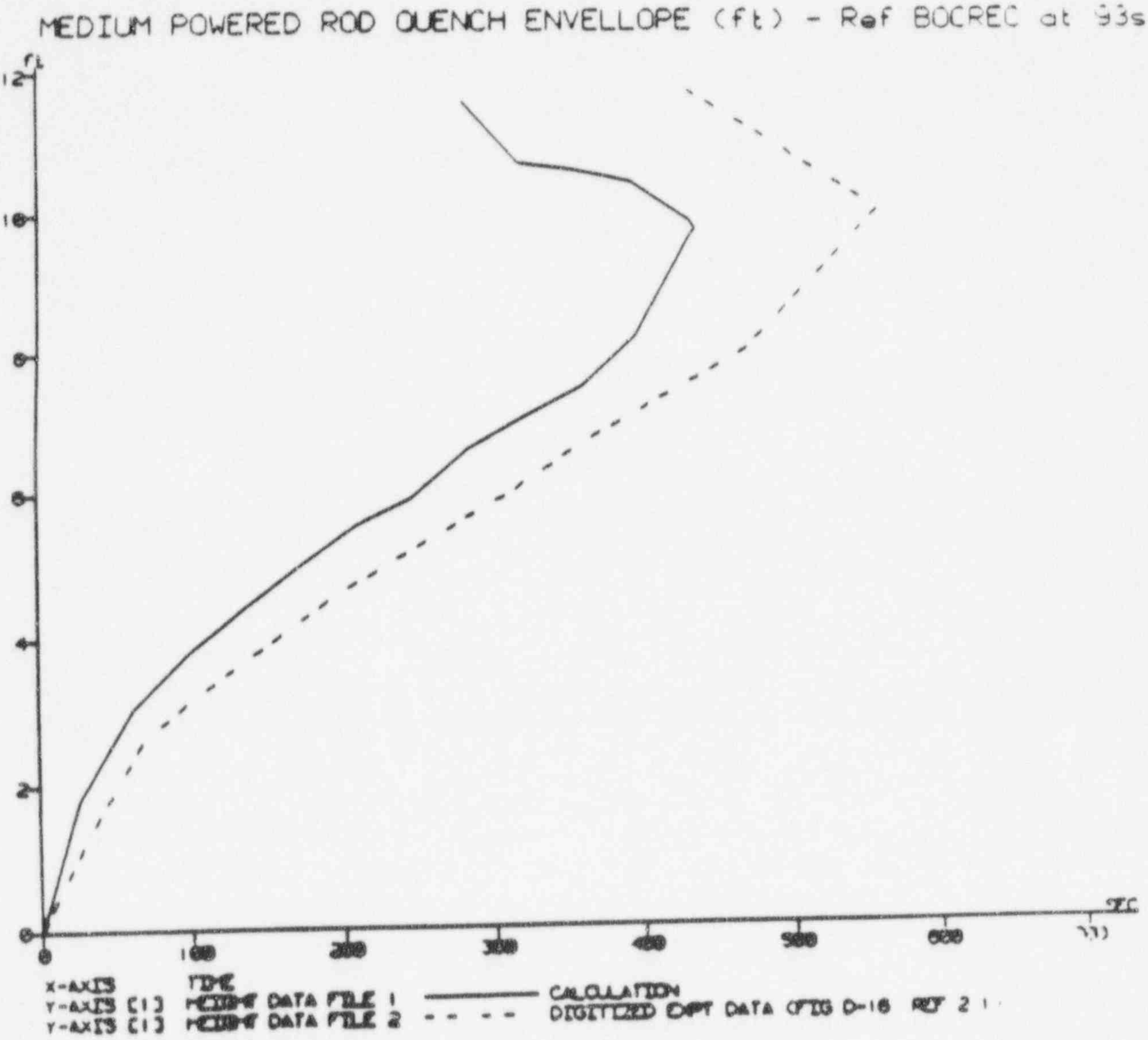


Figure 440.348-17 CCTF Run 58, Quench Envelope - Medium Powered Rod

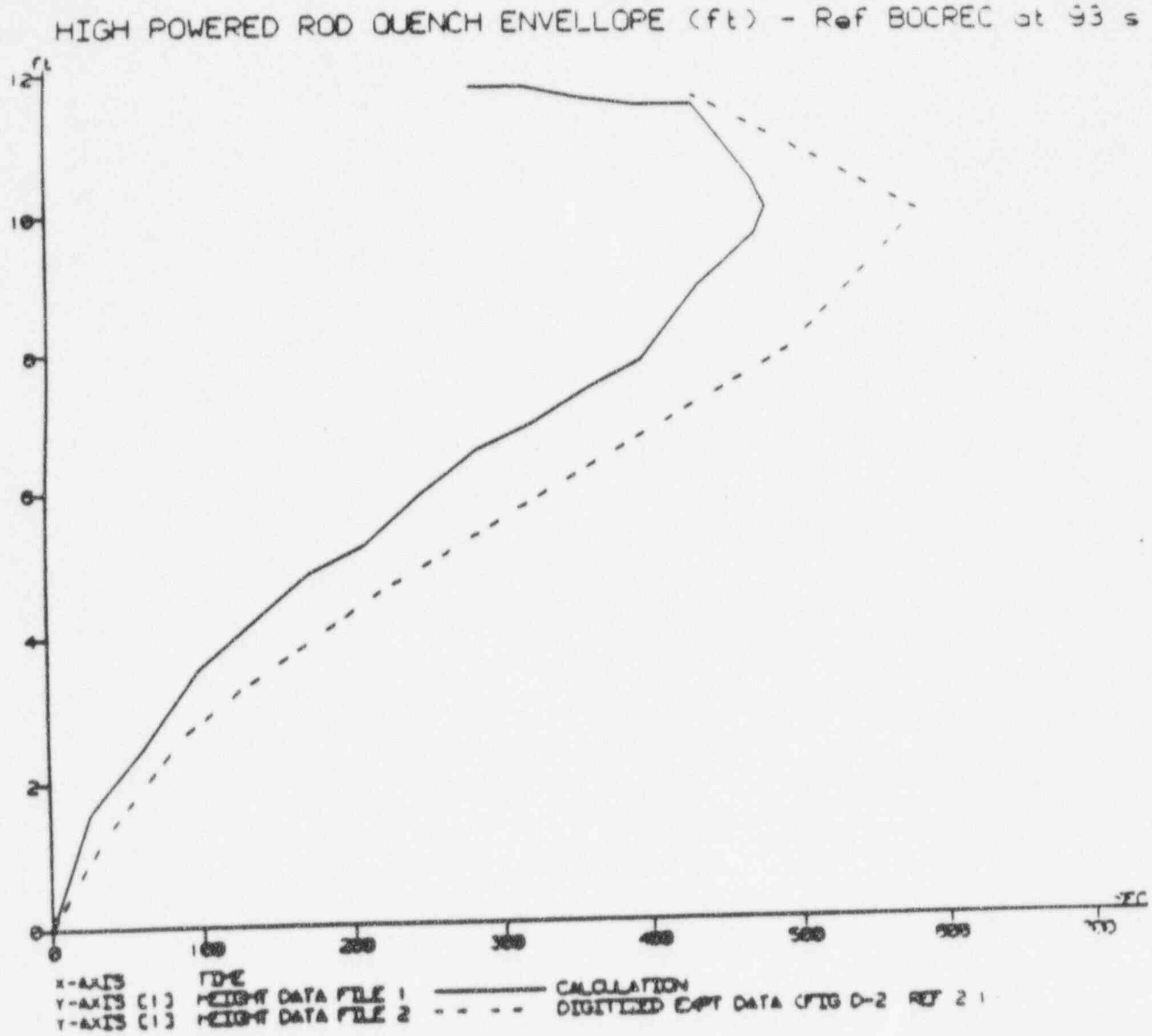


Figure 440.348-18 CCTF Run 58, Quench Envelope - High Powered Rod

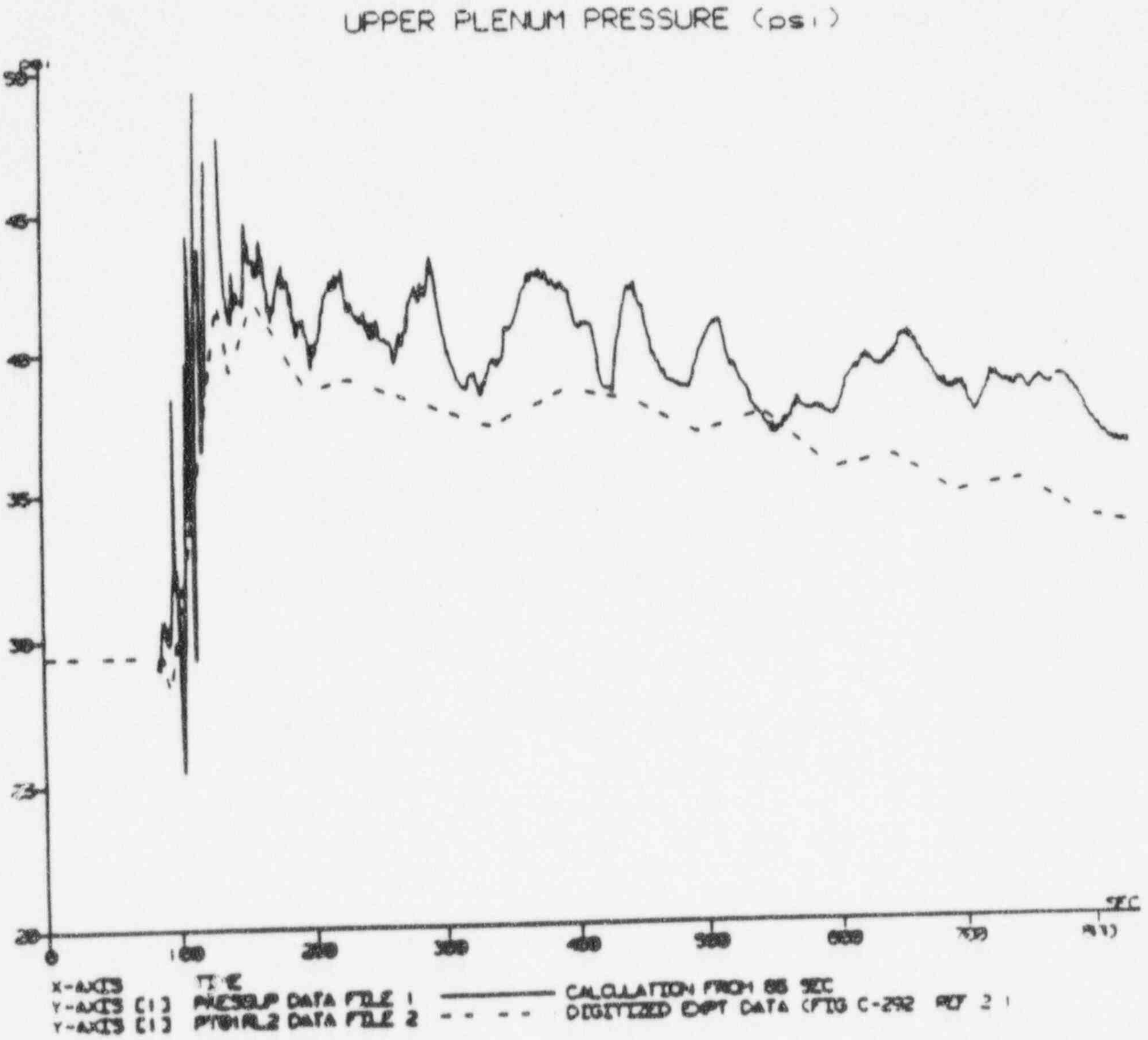


Figure 440.348-19 CCTF Run 58, Upper Plenum Pressure

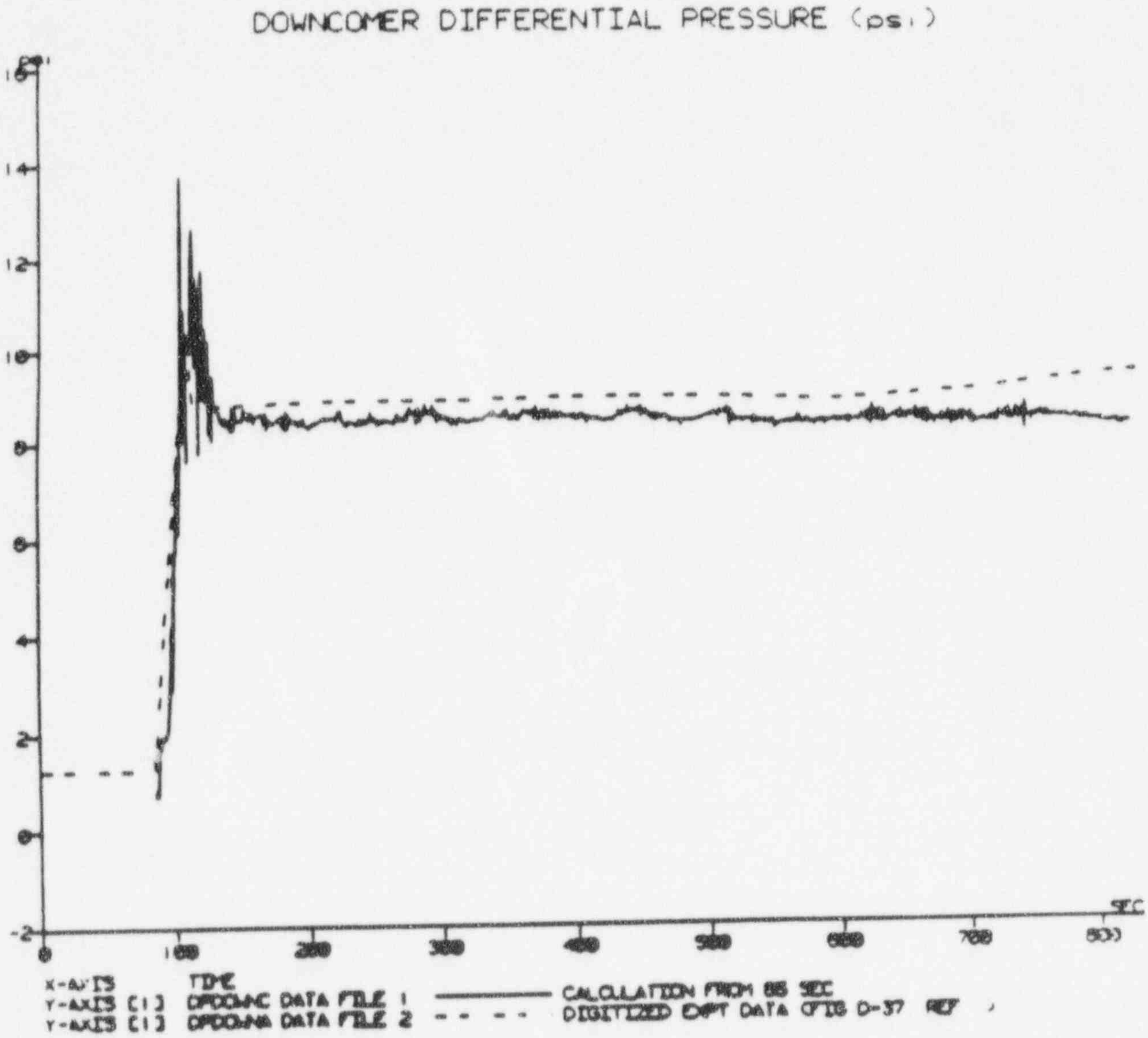


Figure 440.348-20 CCTF Run 58, Downcomer Differential Pressure

AP600

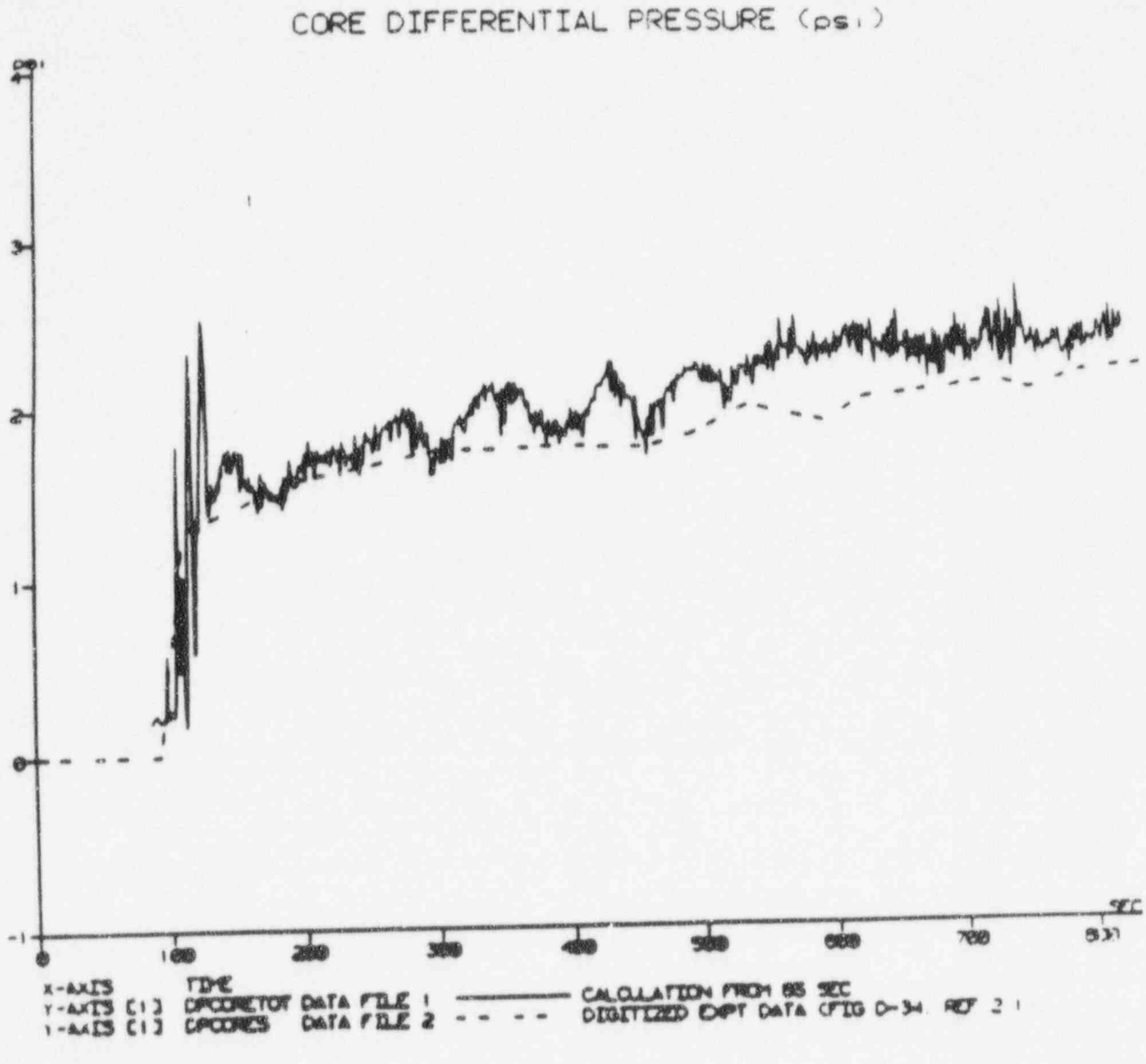


Figure 440.348-21 CCTF Run 58, Core Differential Pressure

Westinghouse

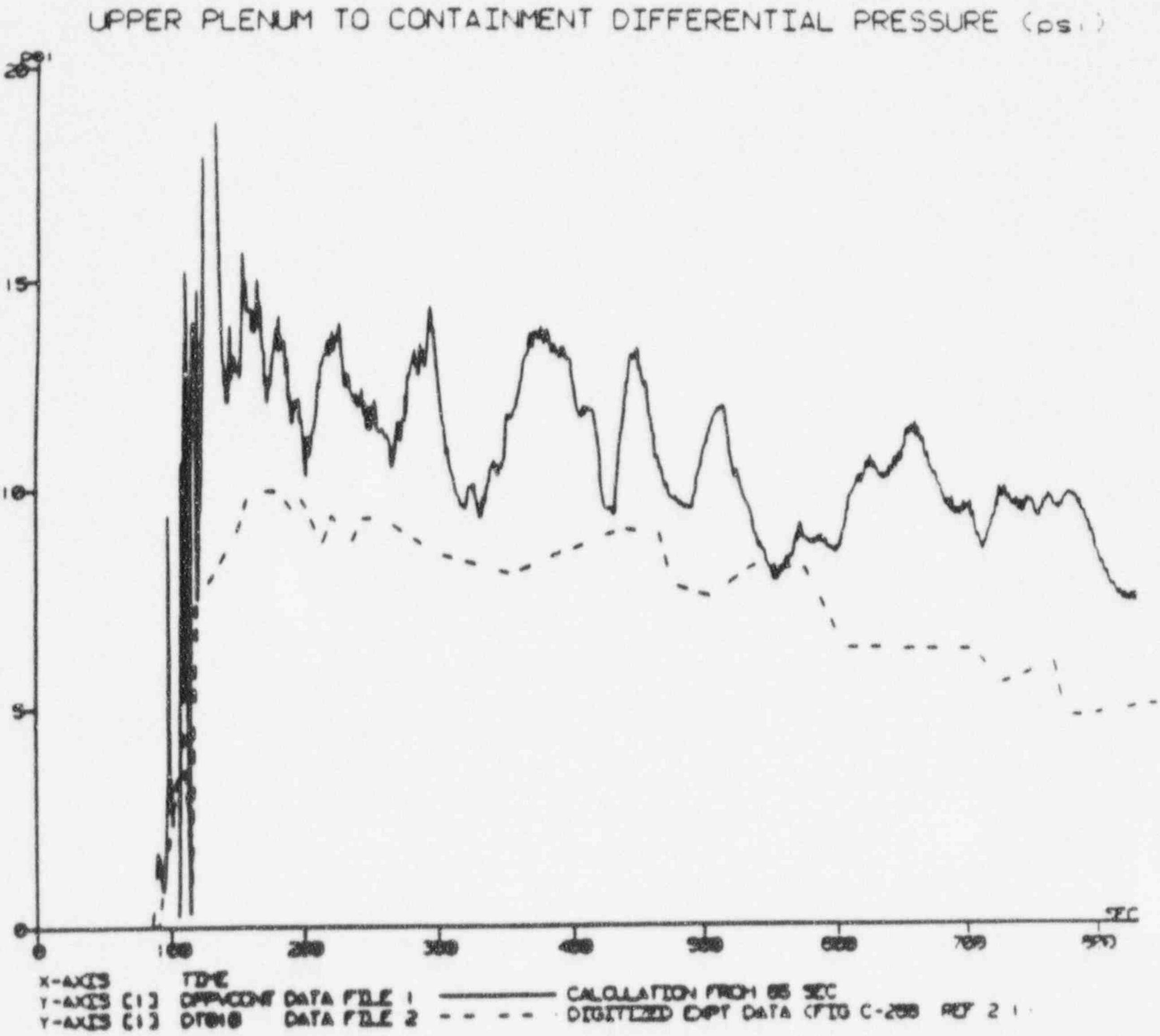


Figure 440.348-22 CCTF Run 58, Upper Plenum to Containment Differential Pressure

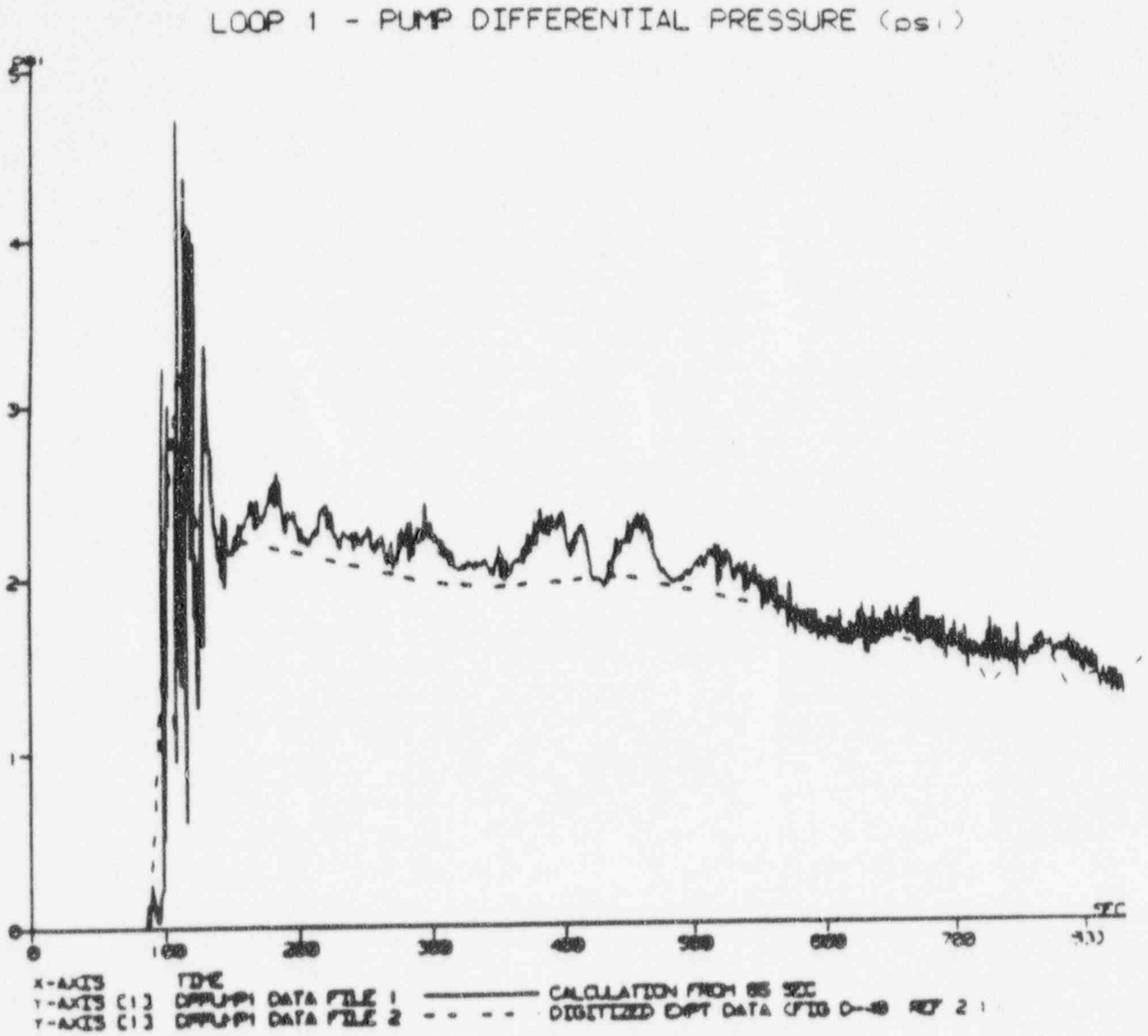


Figure 440.348-23 CCTF Run 58, Loop 1 Pump Simulator Differential Pressure

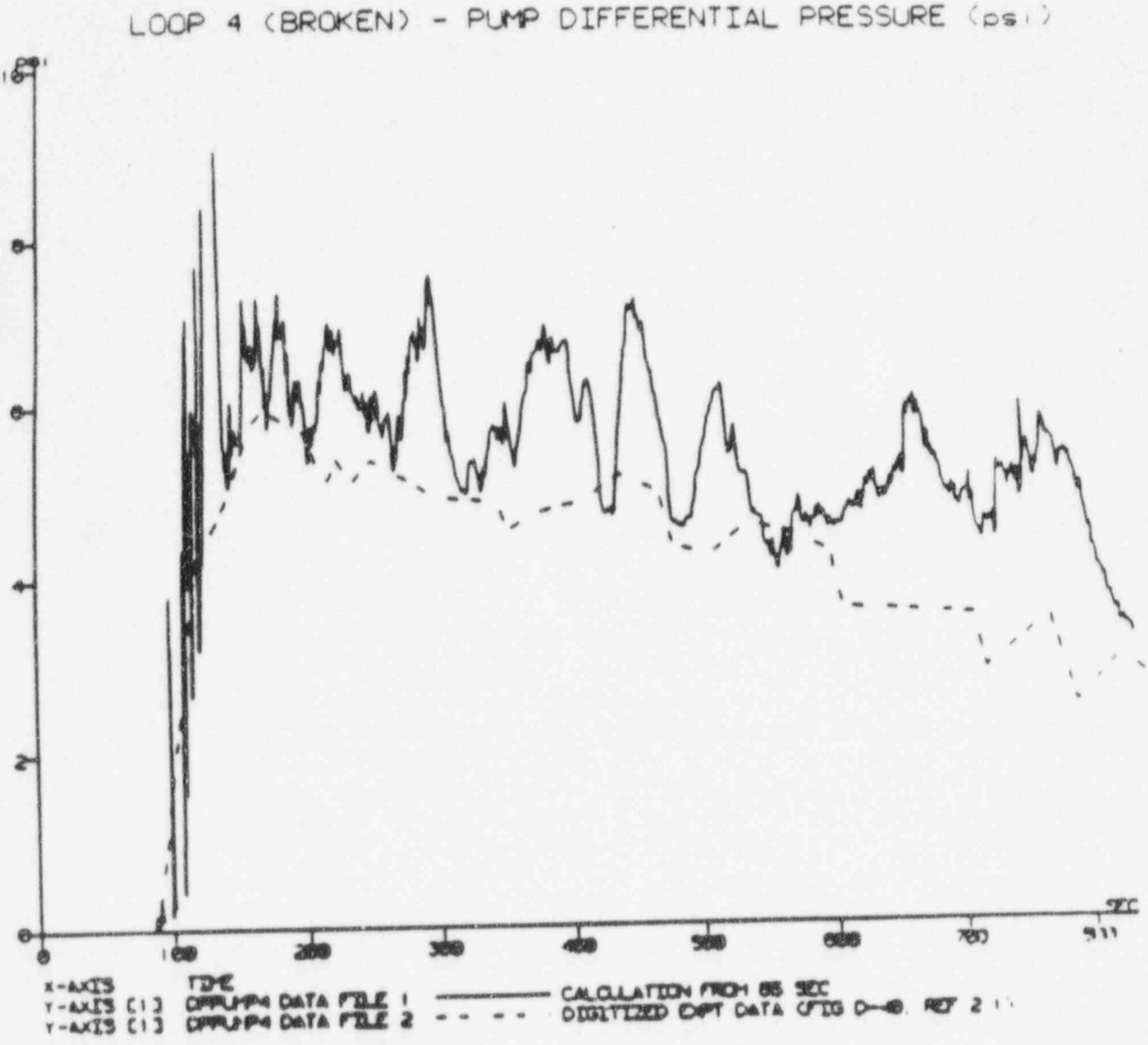


Figure 440.348-24 CCTF Run 58, Loop 4 Pump Simulator Differential Pressure

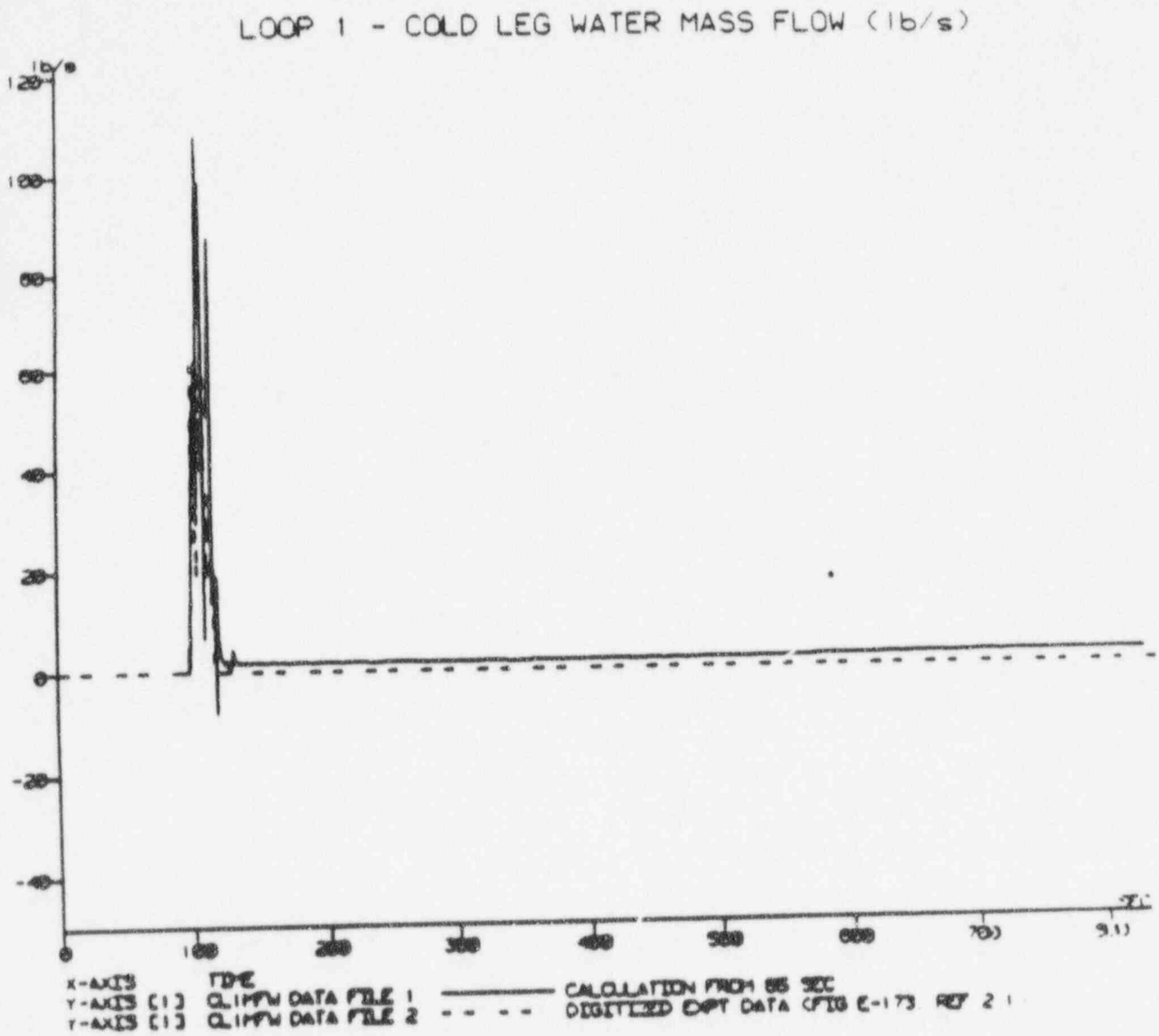


Figure 440.348-25 CCTF Run 58, Loop 1 Cold Leg Water Mass Flow

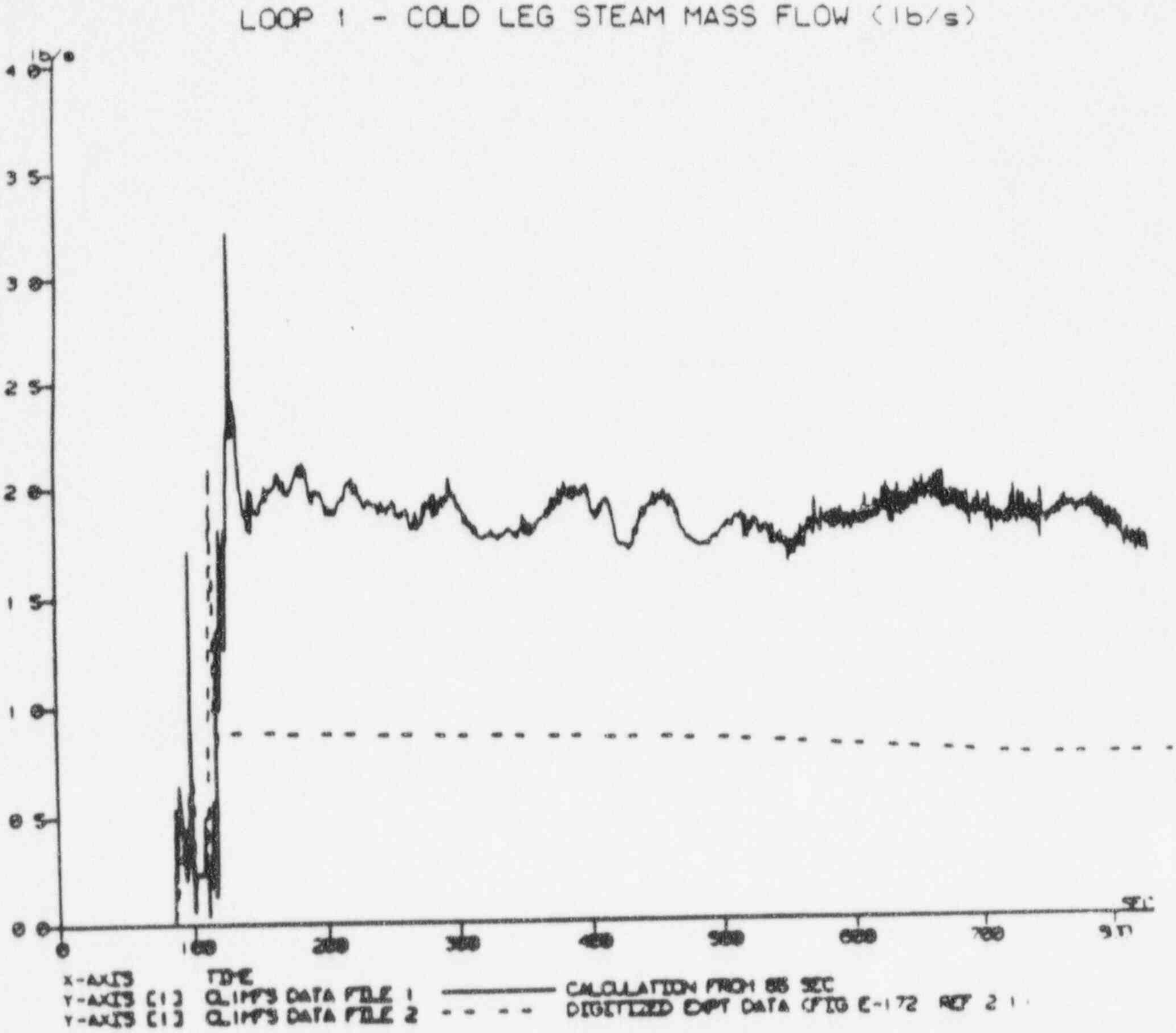


Figure 440.348-26 CCTF Run 58, Loop 1 Cold Leg Steam Mass Flow

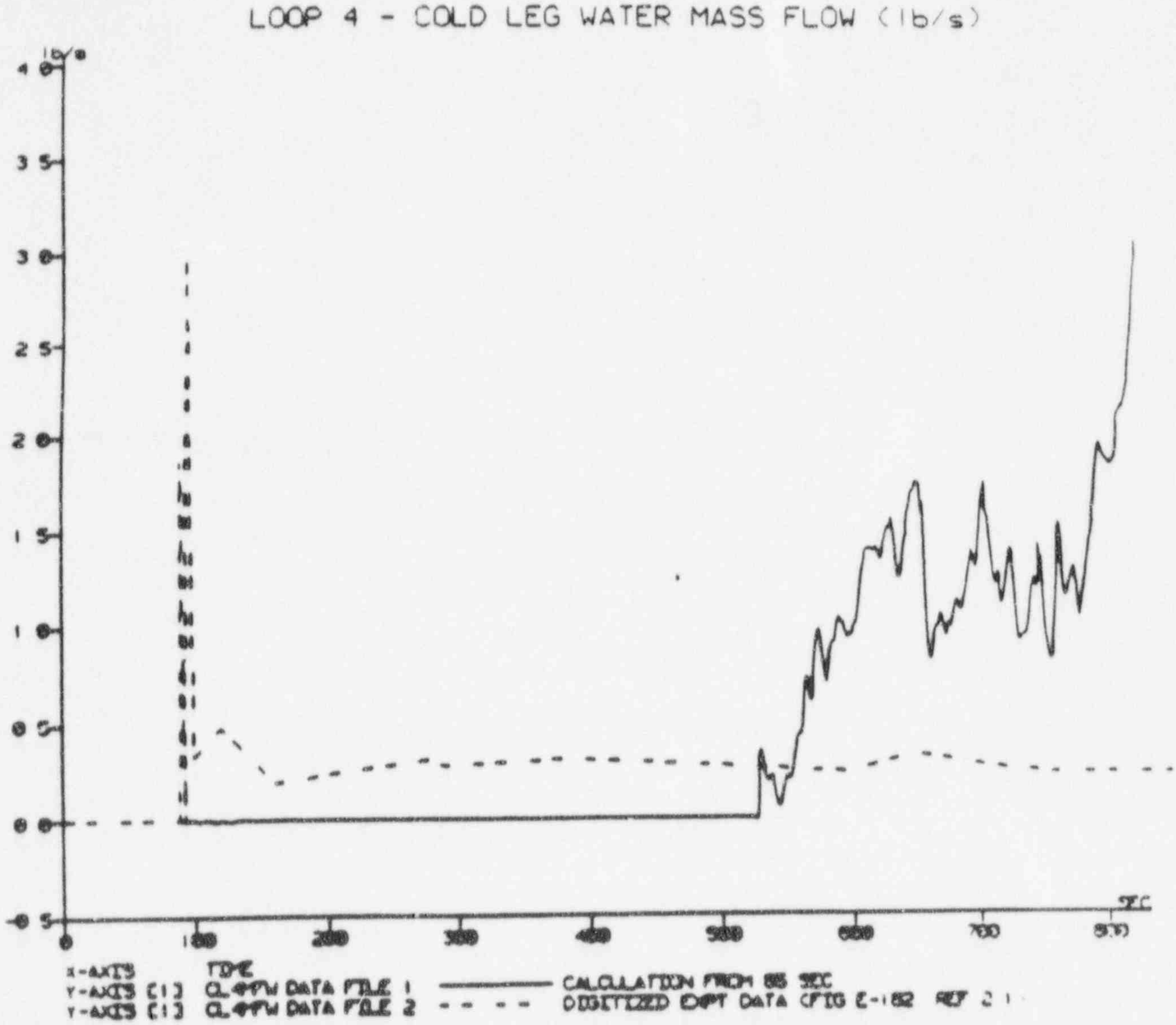


Figure 440.348-27 CCTF Run 58, Loop 4 Cold Leg Water Mass Flow

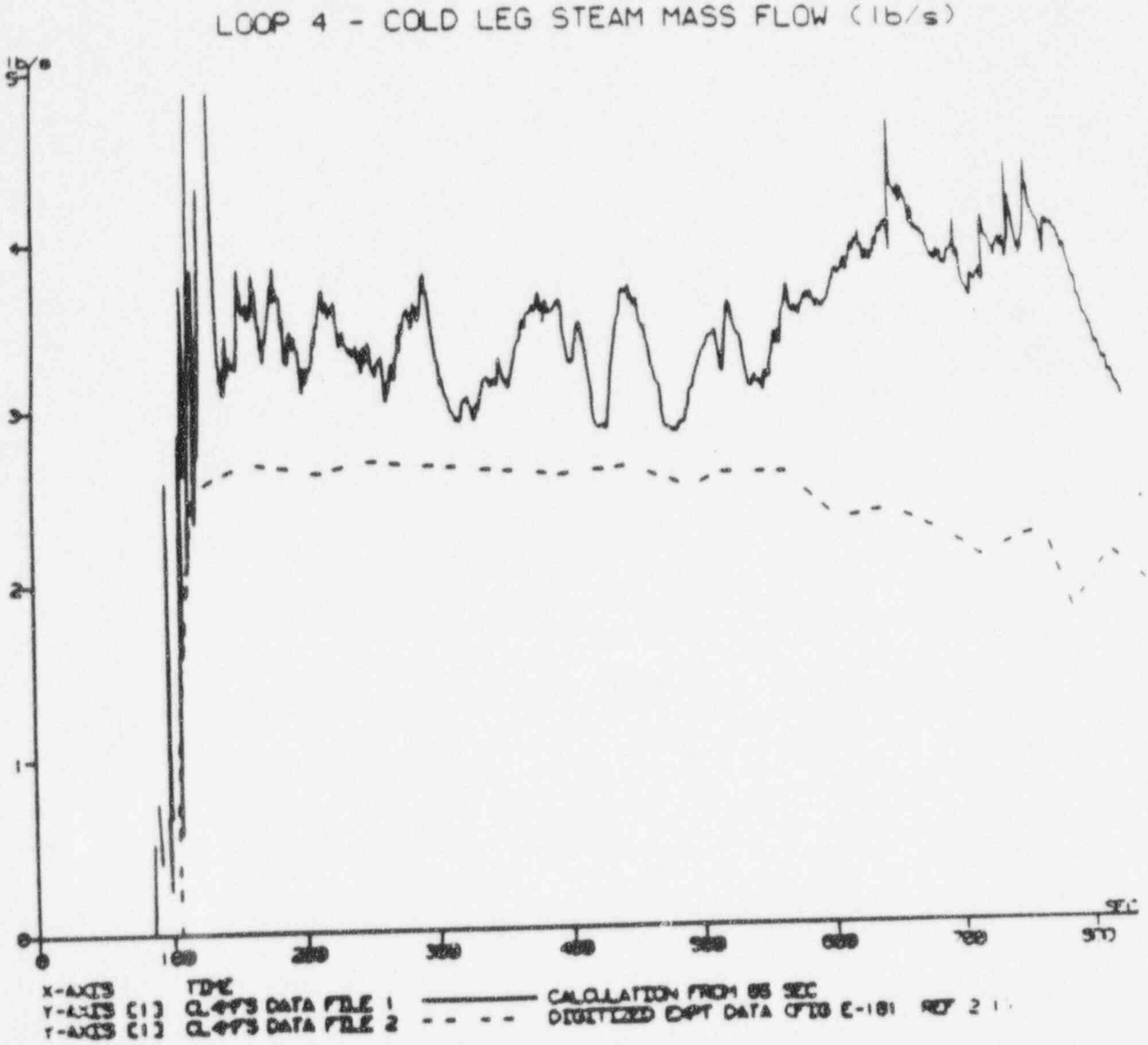


Figure 440.348-28 CCTF Run 58, Loop 4 Cold Leg Steam Mass Flow

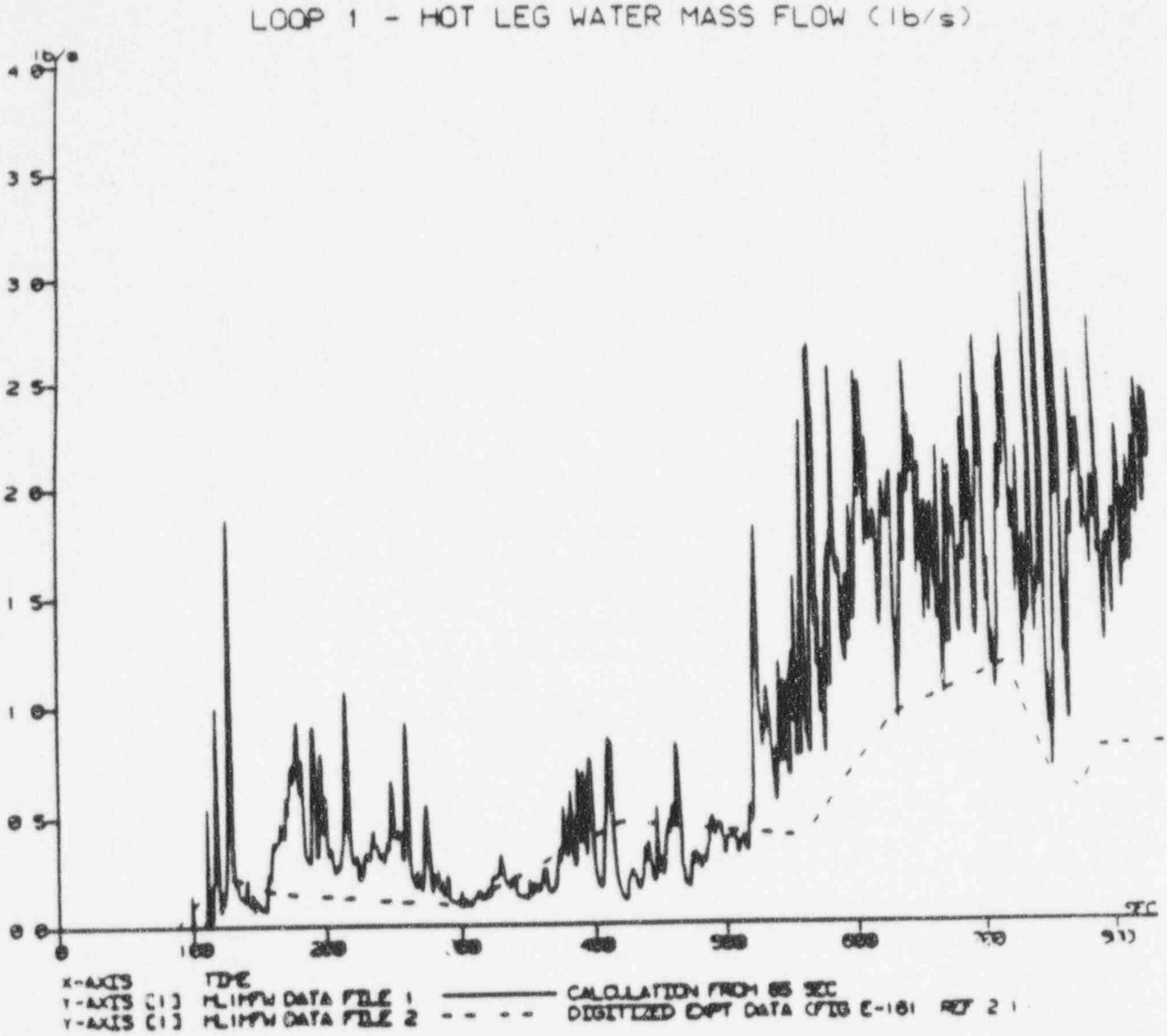


Figure 440.348-29 CCTF Run 58, Loop 1 Hot Leg Water Mass Flow

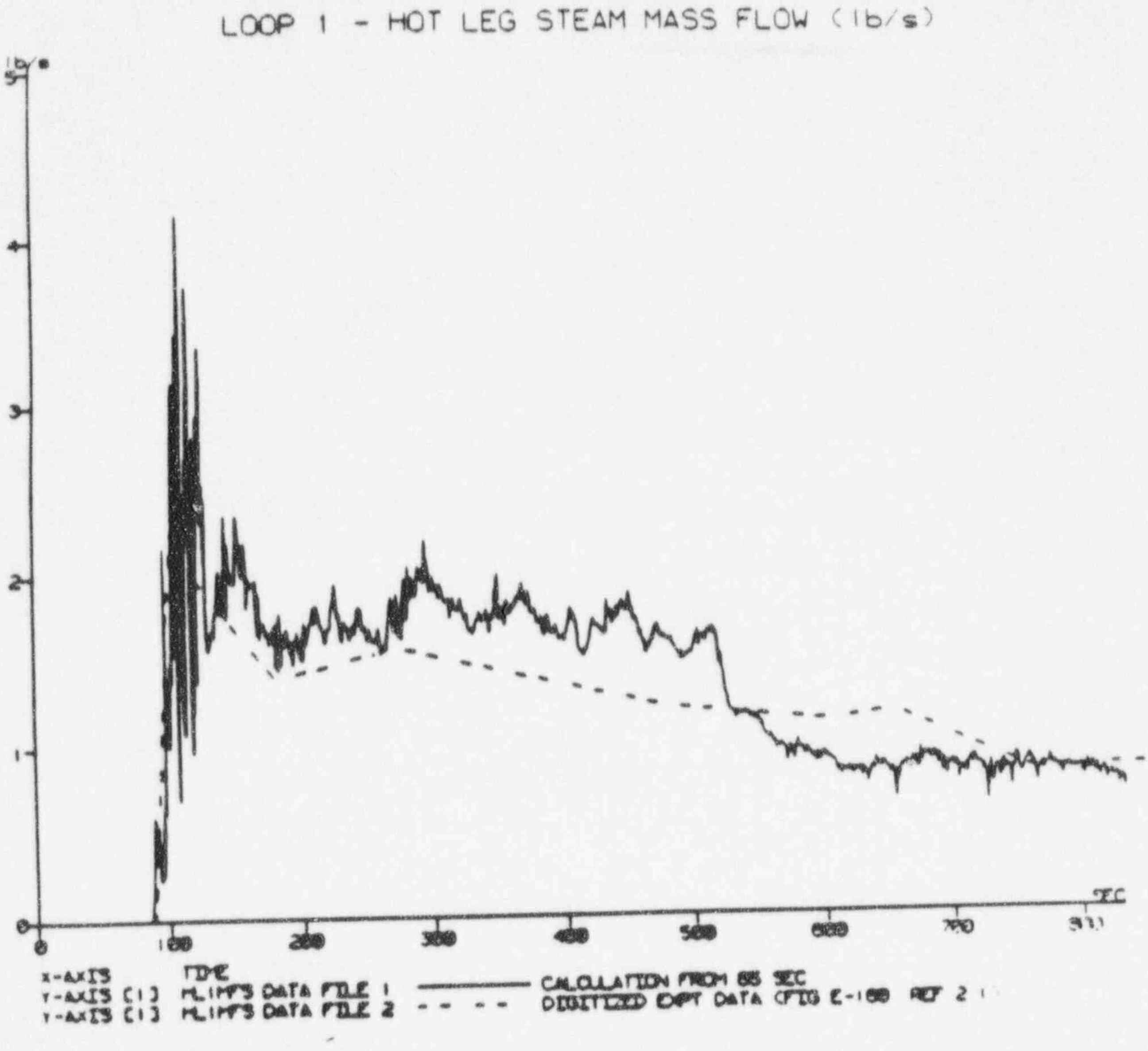


Figure 440.348-30 CCTF Run 58, Loop 1 Hot Leg Steam Mass Flow

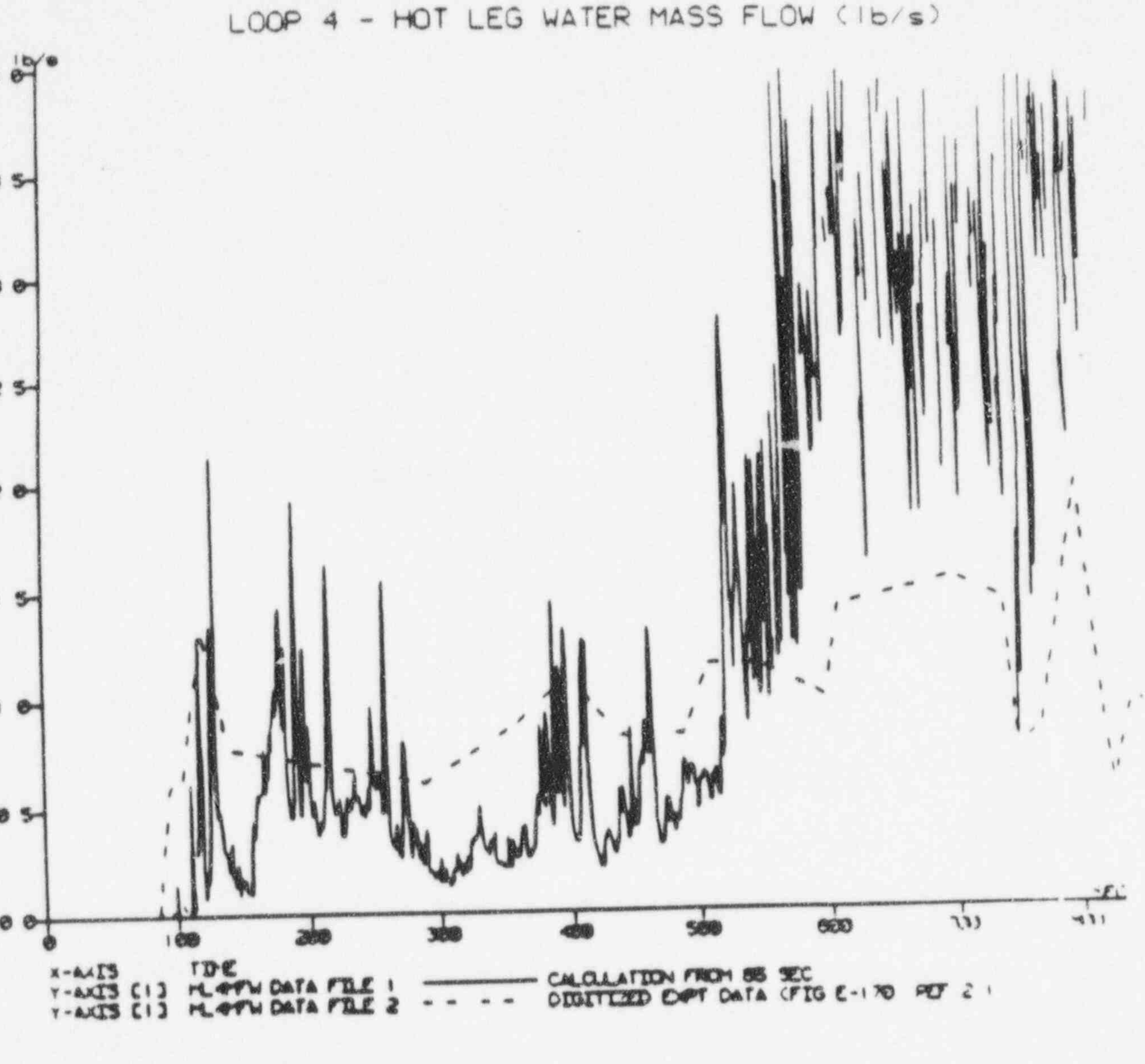


Figure 440.348-31 CCTF Run 58, Loop 4 Hot Leg Water Mass Flow

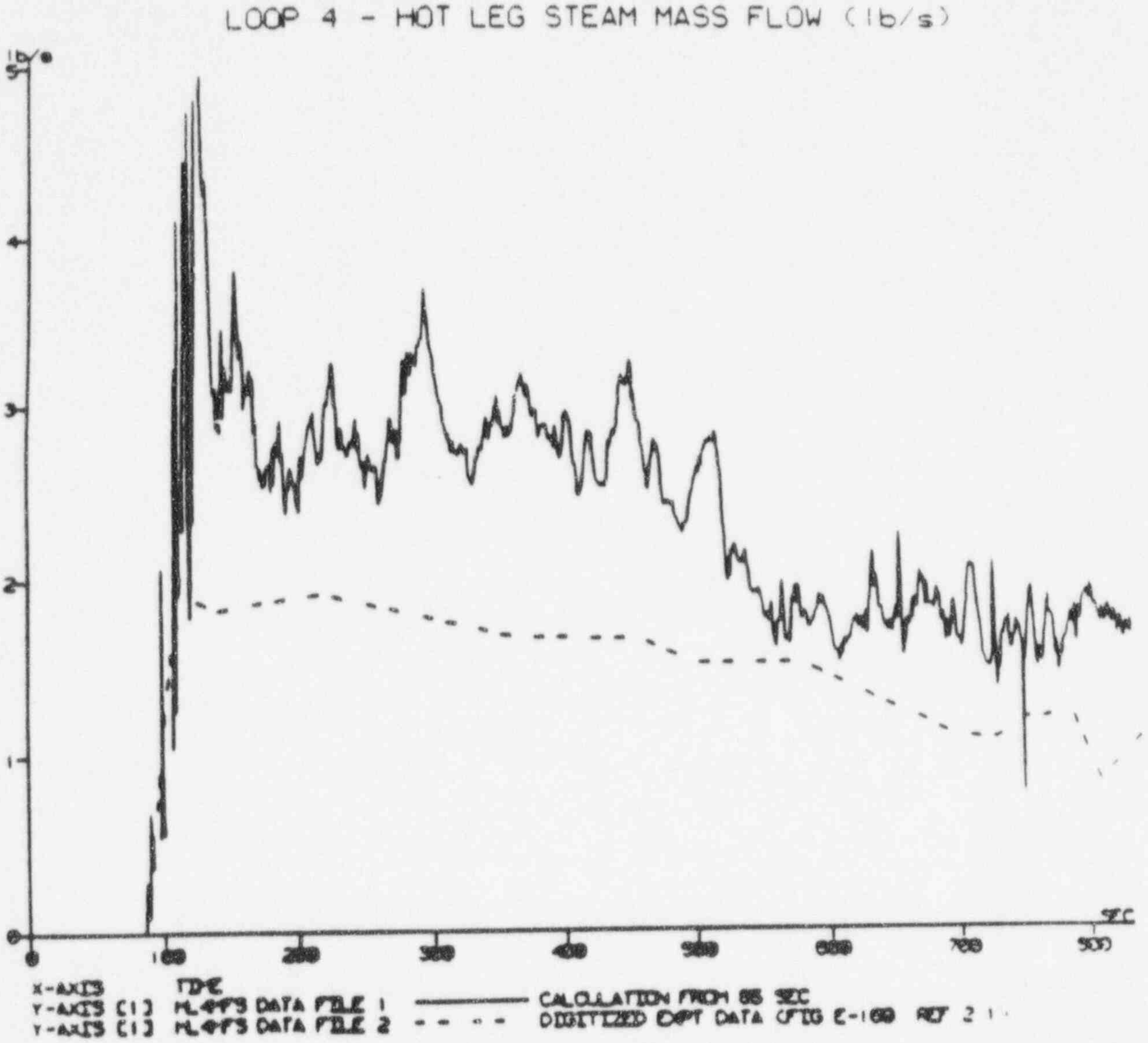


Figure 440.348-32 CCTF Run 58, Loop 4 Hot Leg Steam Mass Flow

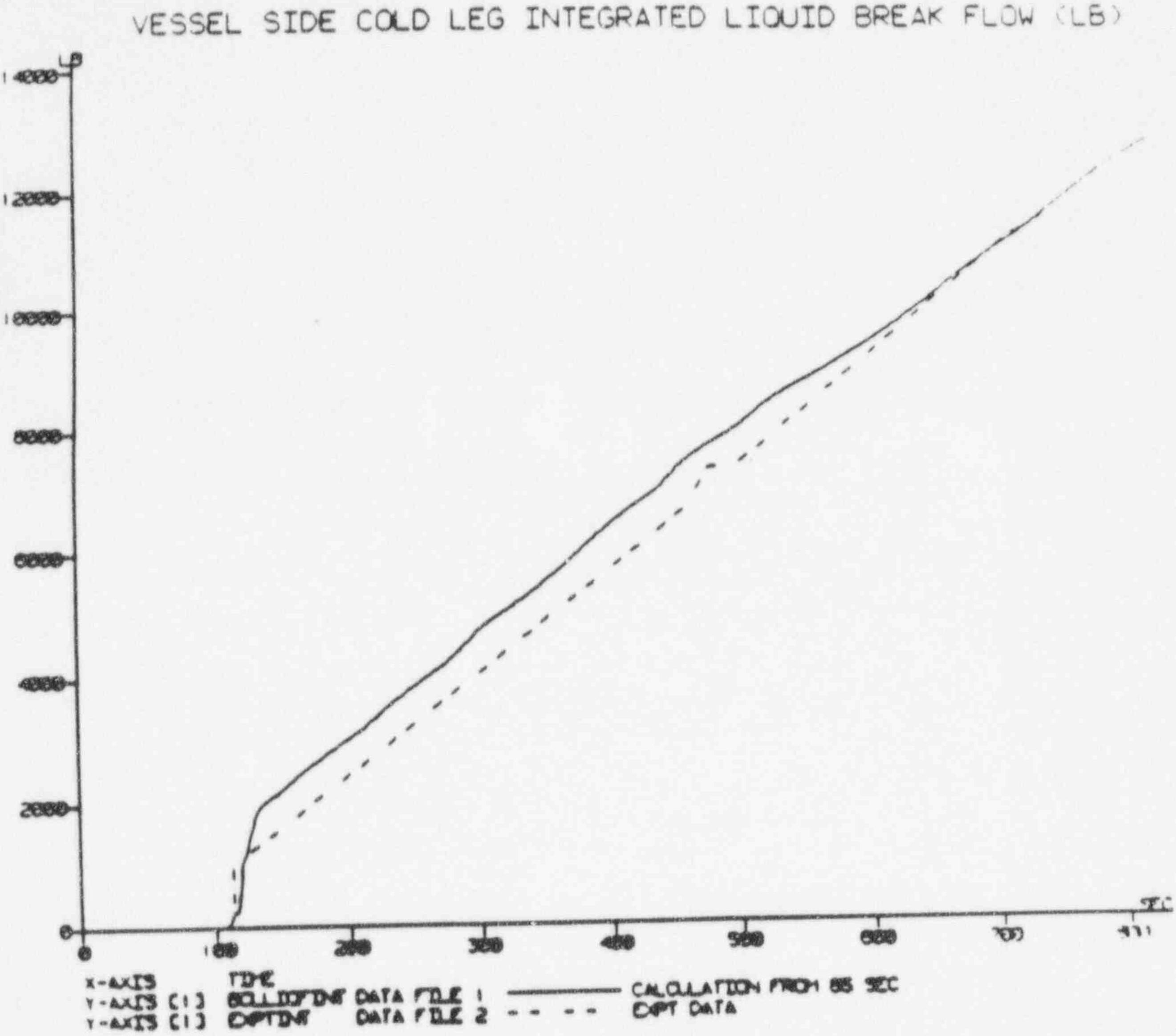


Figure 440.348-33 CCTF Run 58, Vessel Side Cold Leg Integrated Liquid Break Flow

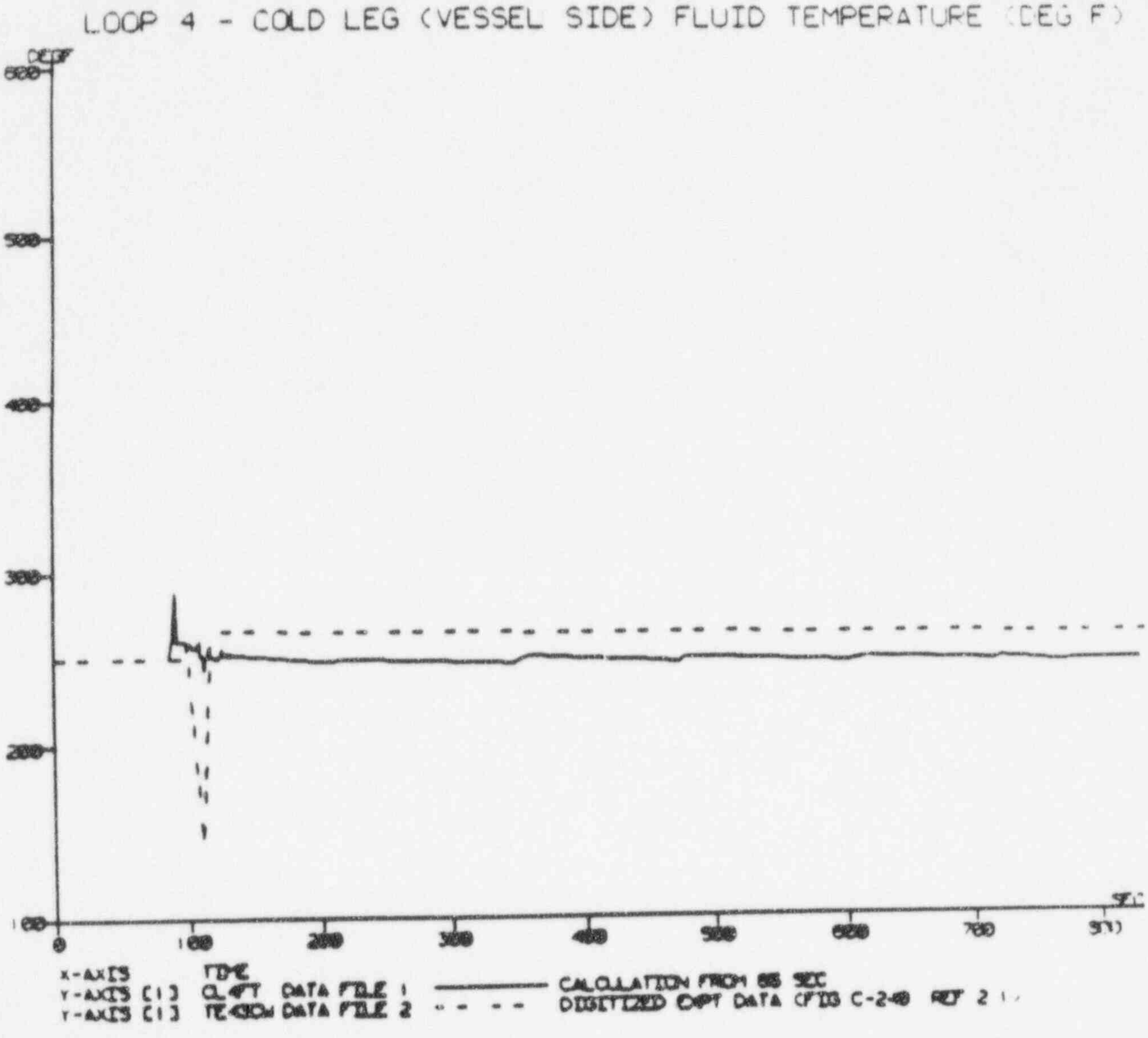


Figure 440.348-34 CCTF Run 58, Vessel Side, Loop 4, Cold Leg Fluid Temperature

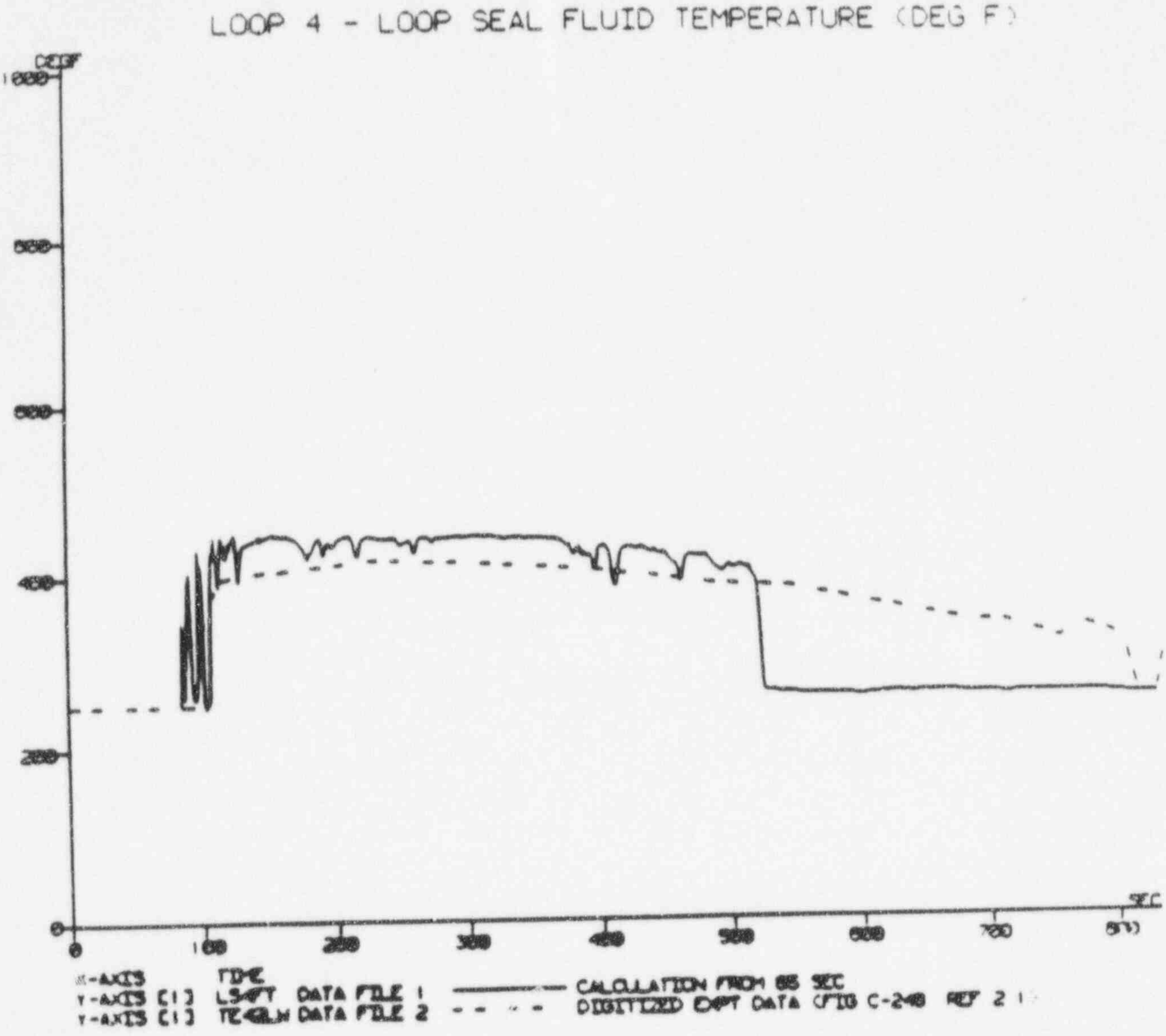


Figure 440.348-35 CCTF Run 58, Loop 4, Loop Seal Fluid Temperature

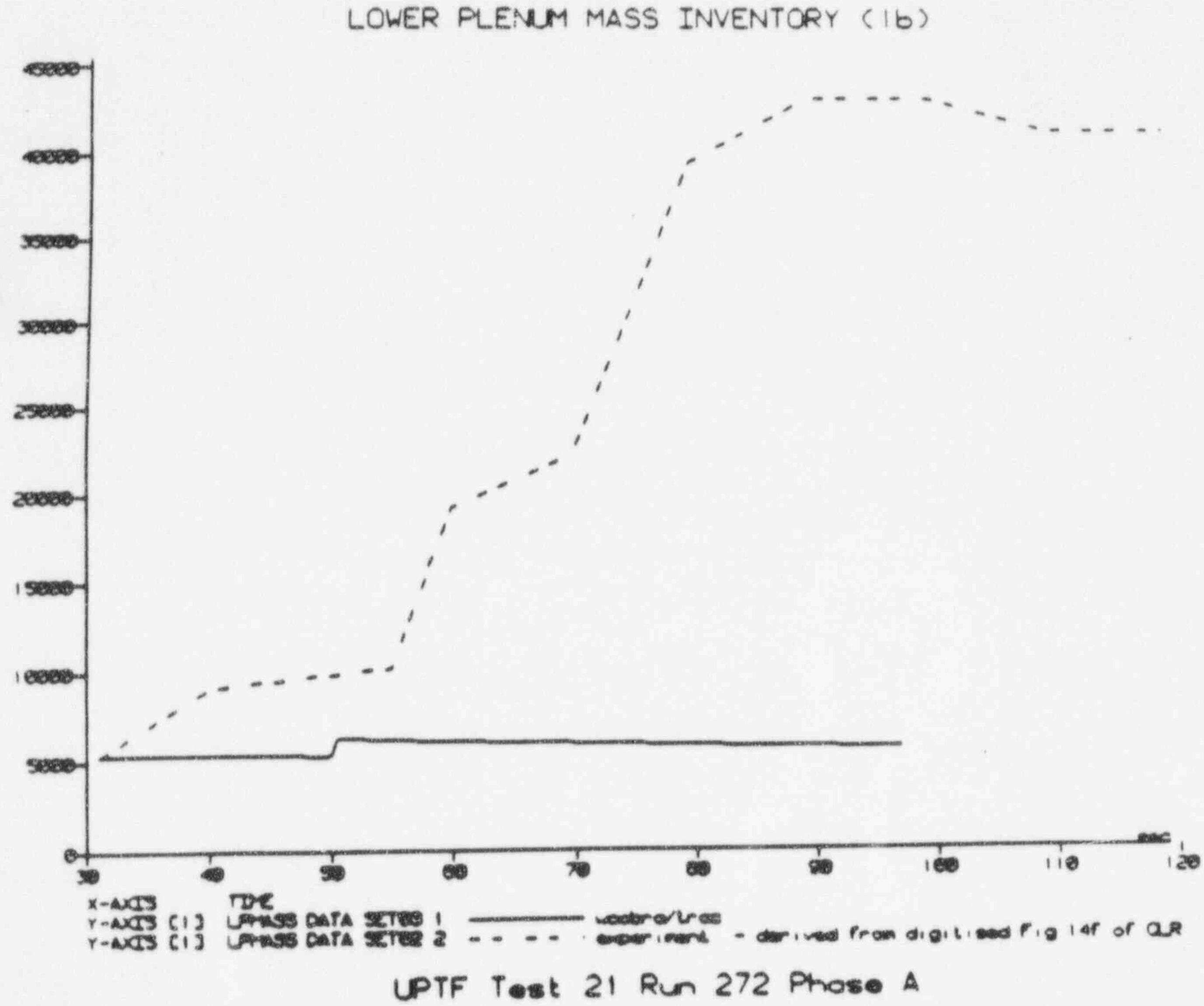


Figure 440.348-36 UPTF Test 21, Phase A, Lower Plenum Mass Inventory

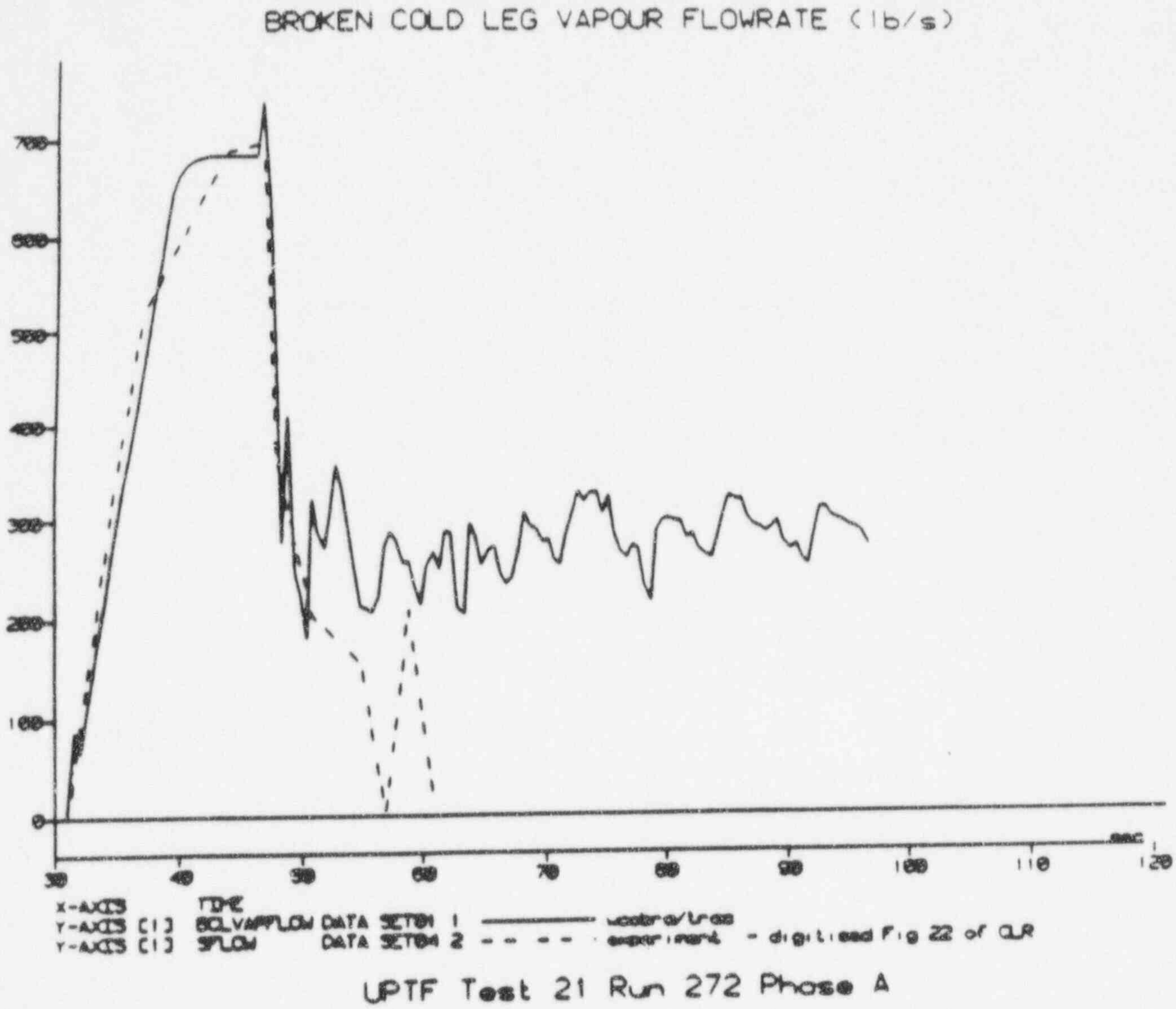


Figure 440.348-37 UPTF Test 21, Phase A, Broken Cold Leg Steam Mass Flow

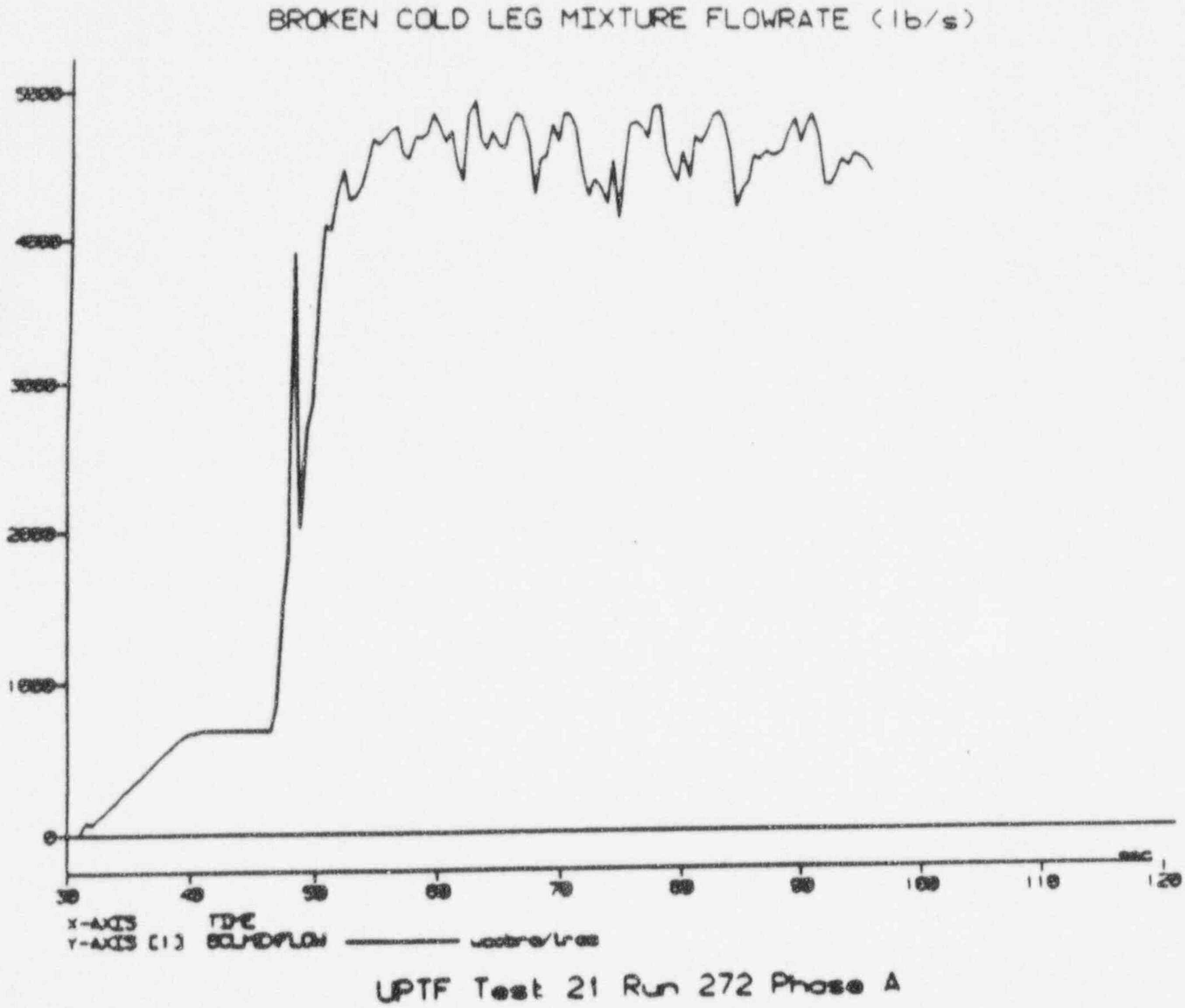


Figure 440.348-38 UPTF Test 21, Phase A, Broken Cold Leg Mixture Mass Flow

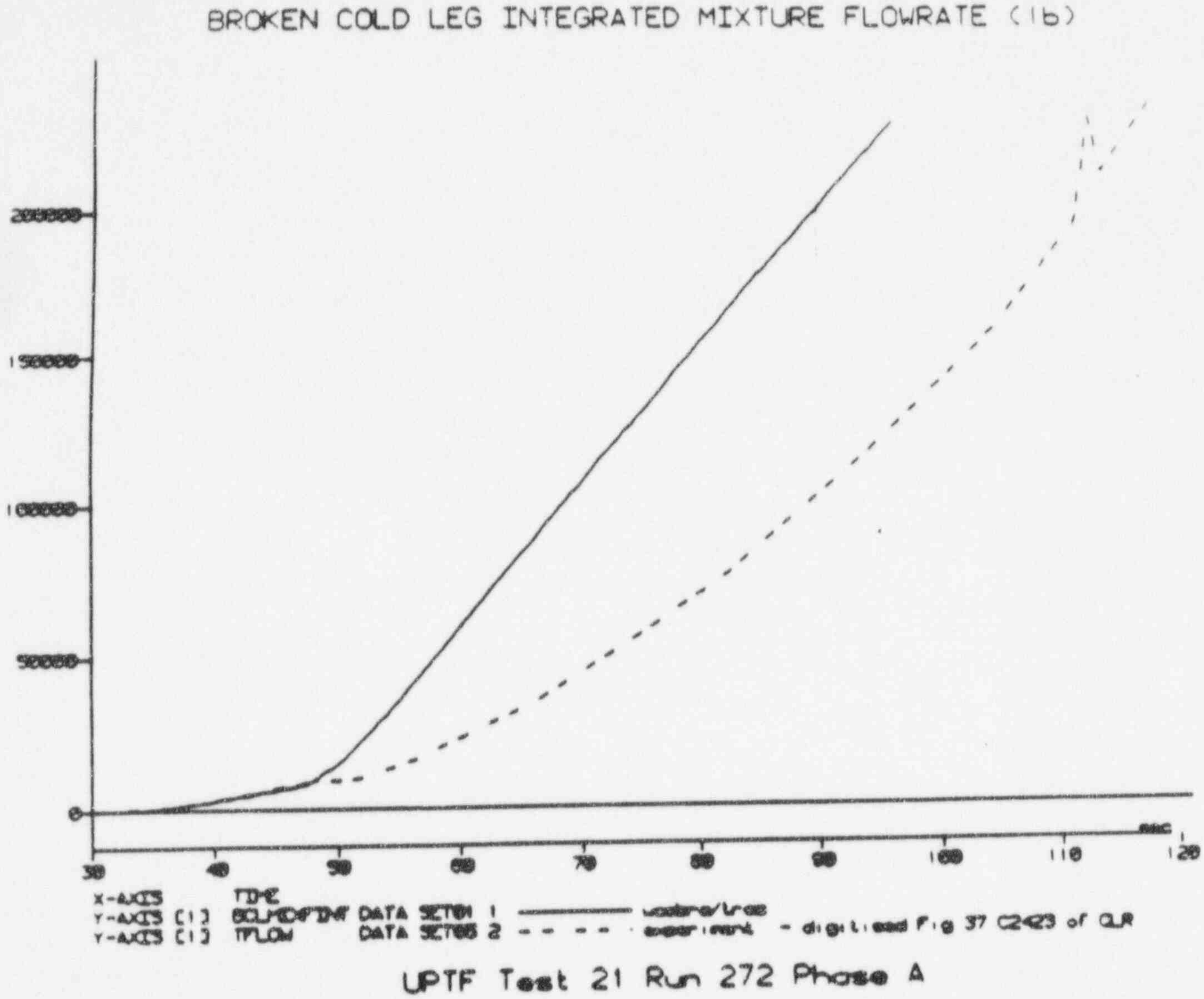


Figure 440.348-39 UPTF Test 21, Phase A, Broken Cold Leg Integrated Mixture Mass Flow

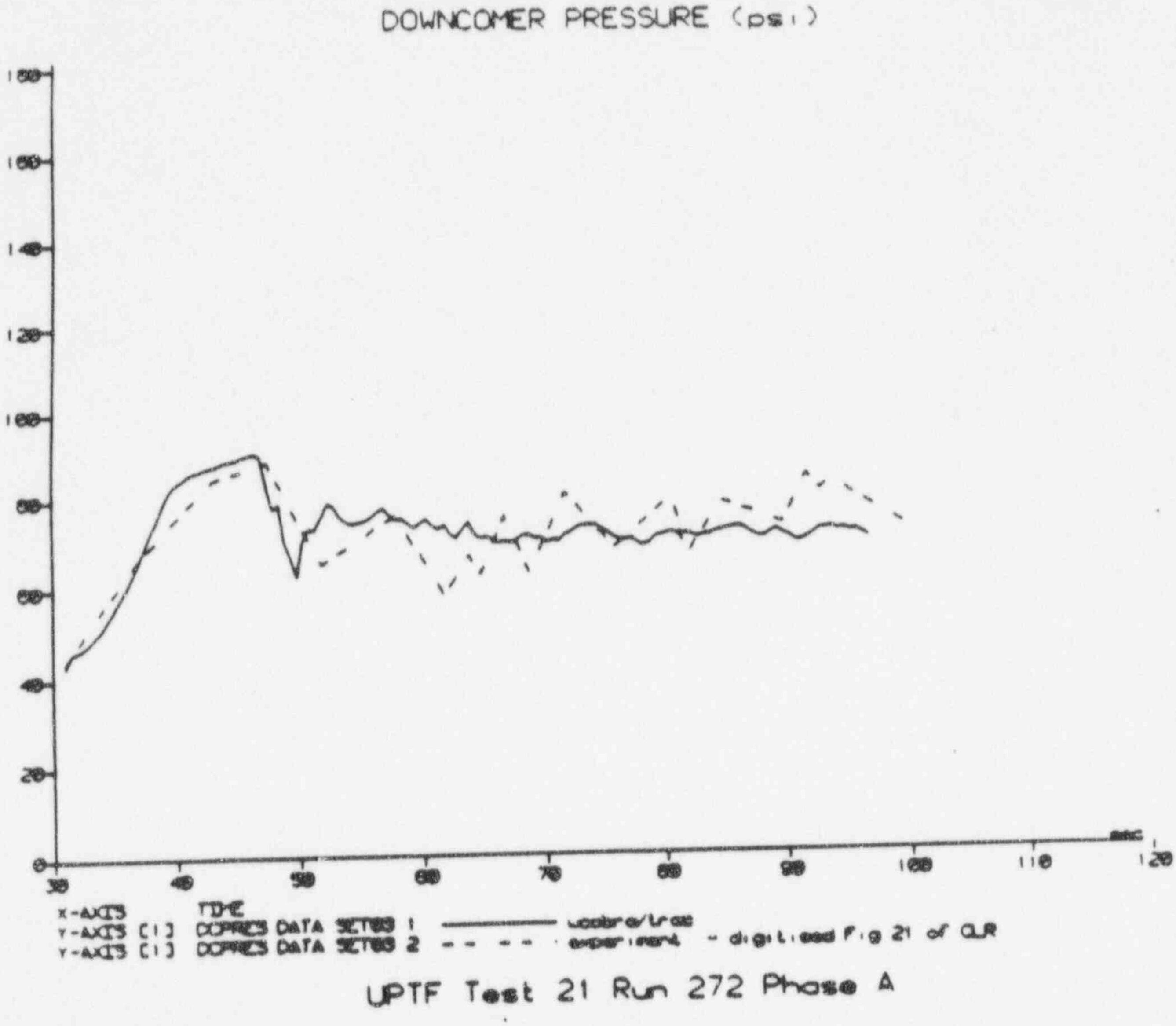


Figure 440.348-40 UPTF Test 21, Phase A, Downcomer Pressure

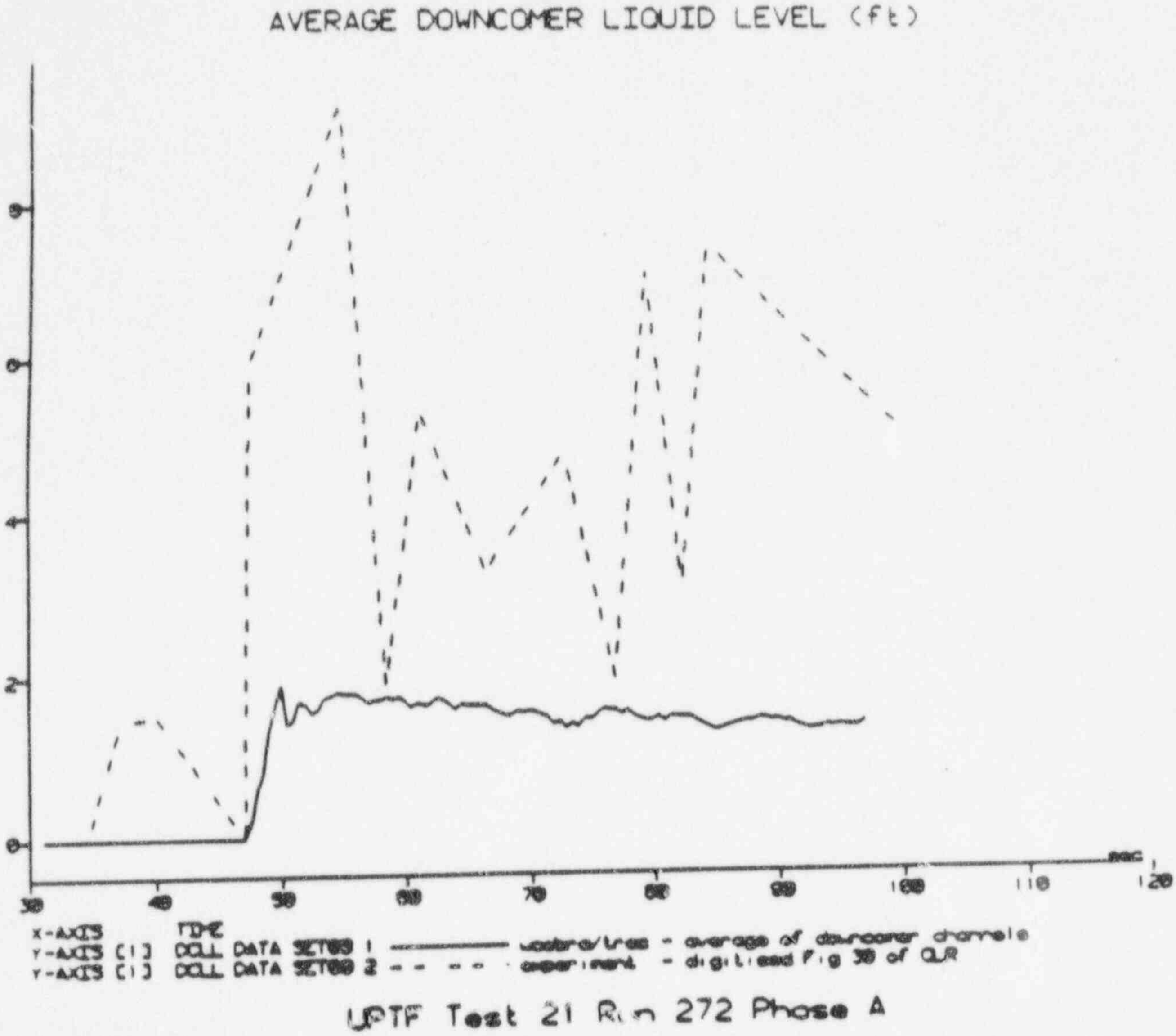


Figure 440.348-41 UPTF Test 21, Phase A, Downcomer Collapsed Liquid Level

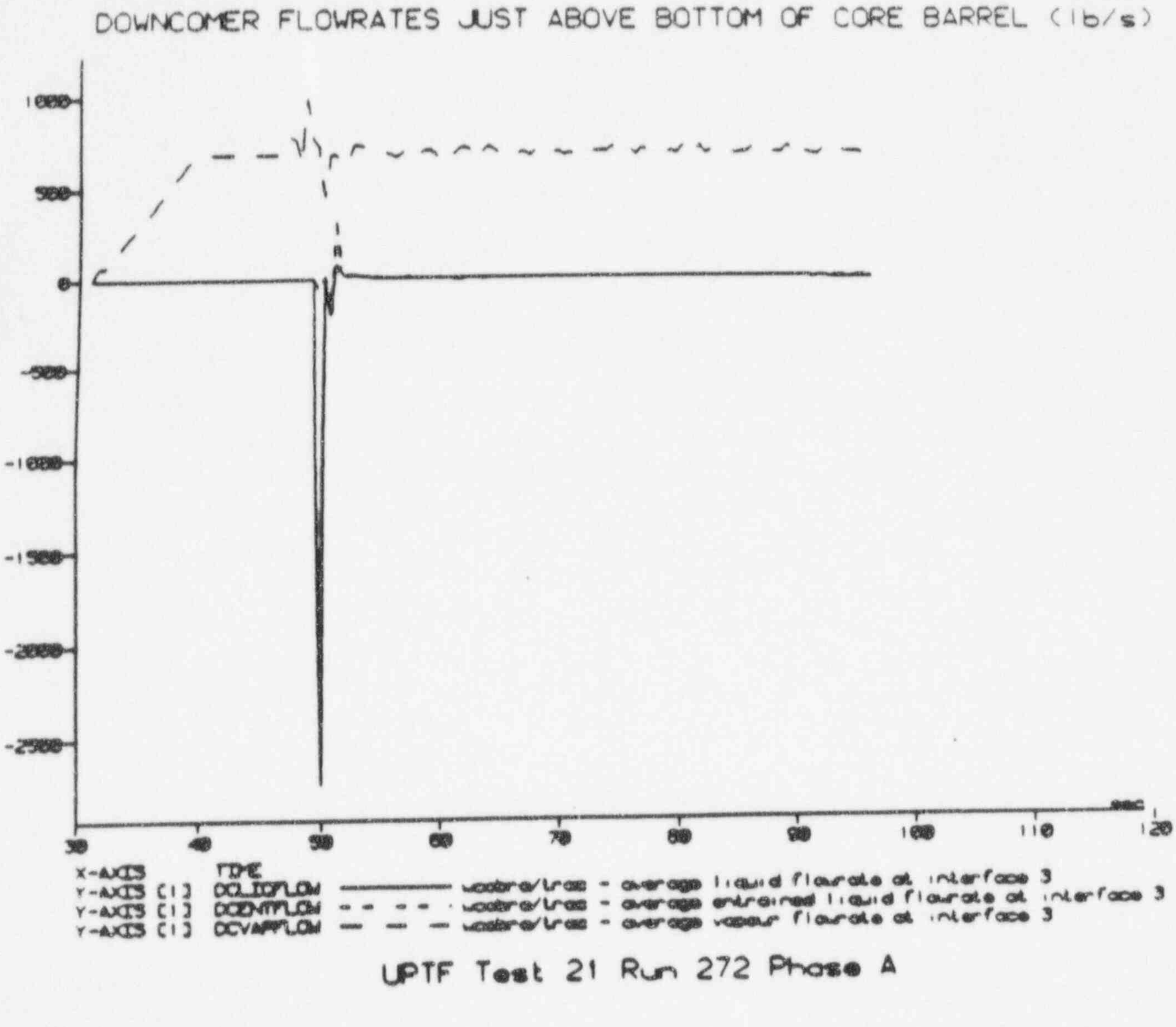


Figure 440.348-42 UPTF Test 21, Phase A, Downcomer Mass Flow Above Bottom of Core Bar

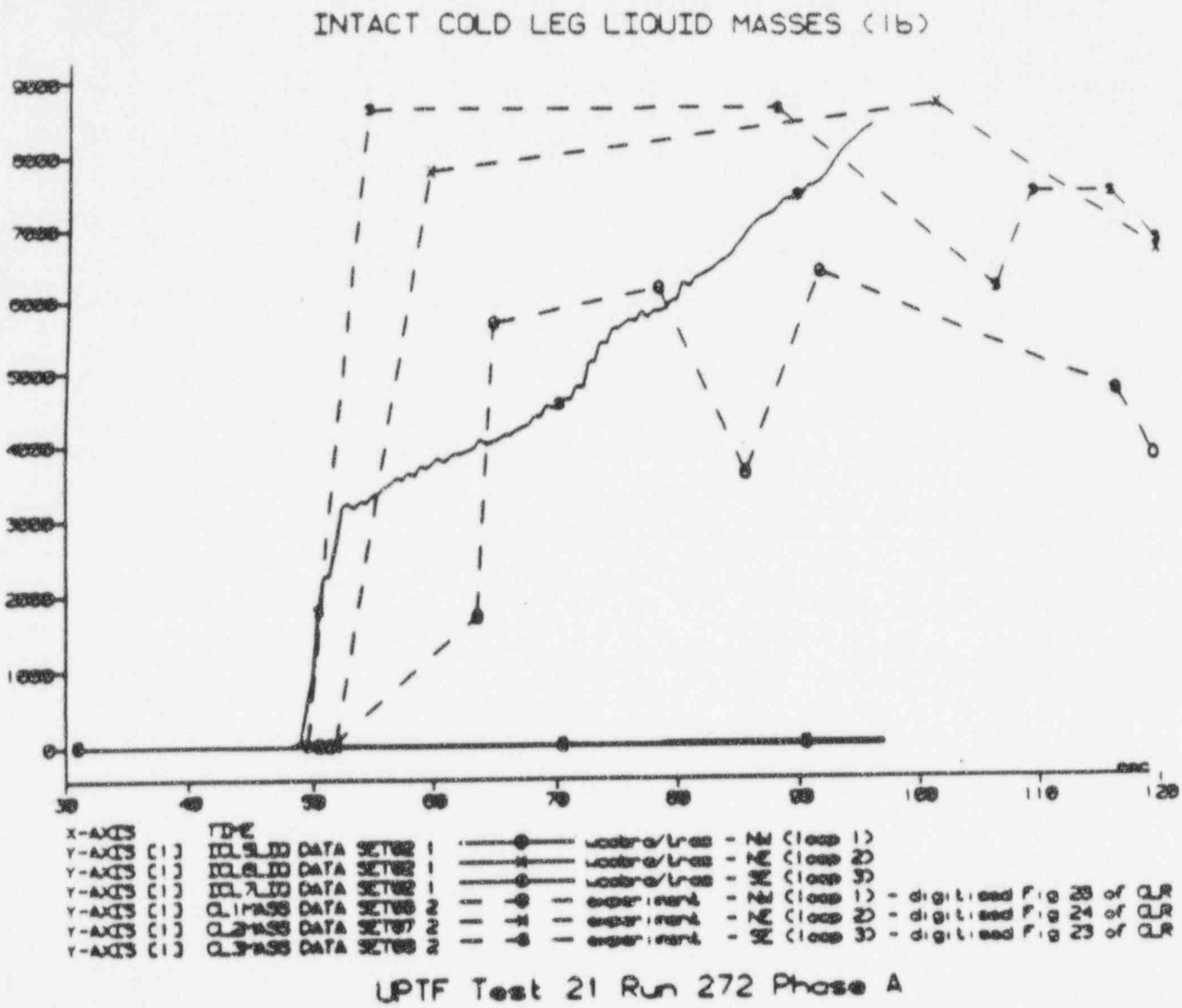


Figure 440.348-43 UPTF Test 21, Phase A, Intact Cold Leg Mass Inventories

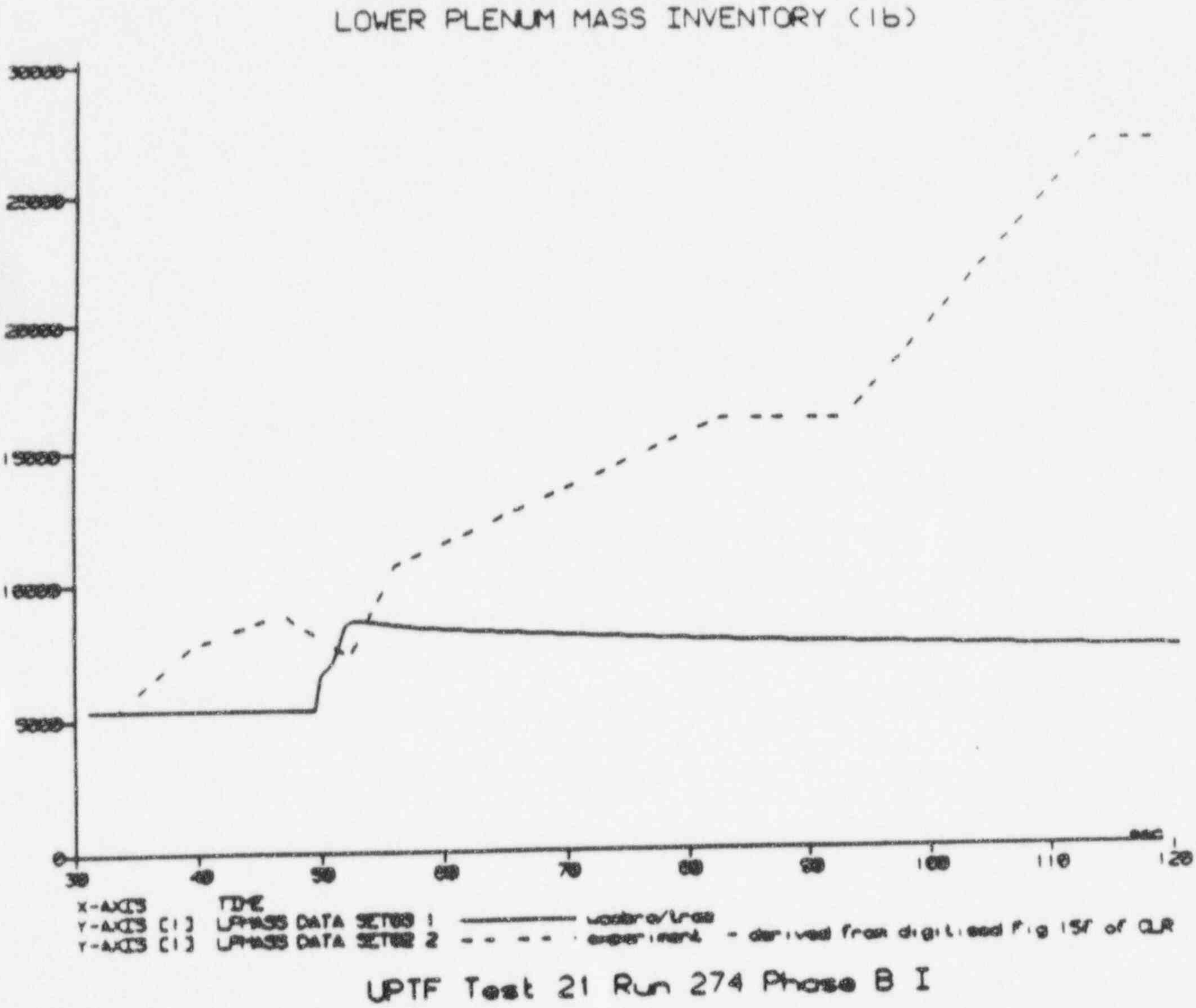


Figure 440.348-44 UPTF Test 21, Phase B I, Lower Plenum Mass Inventory

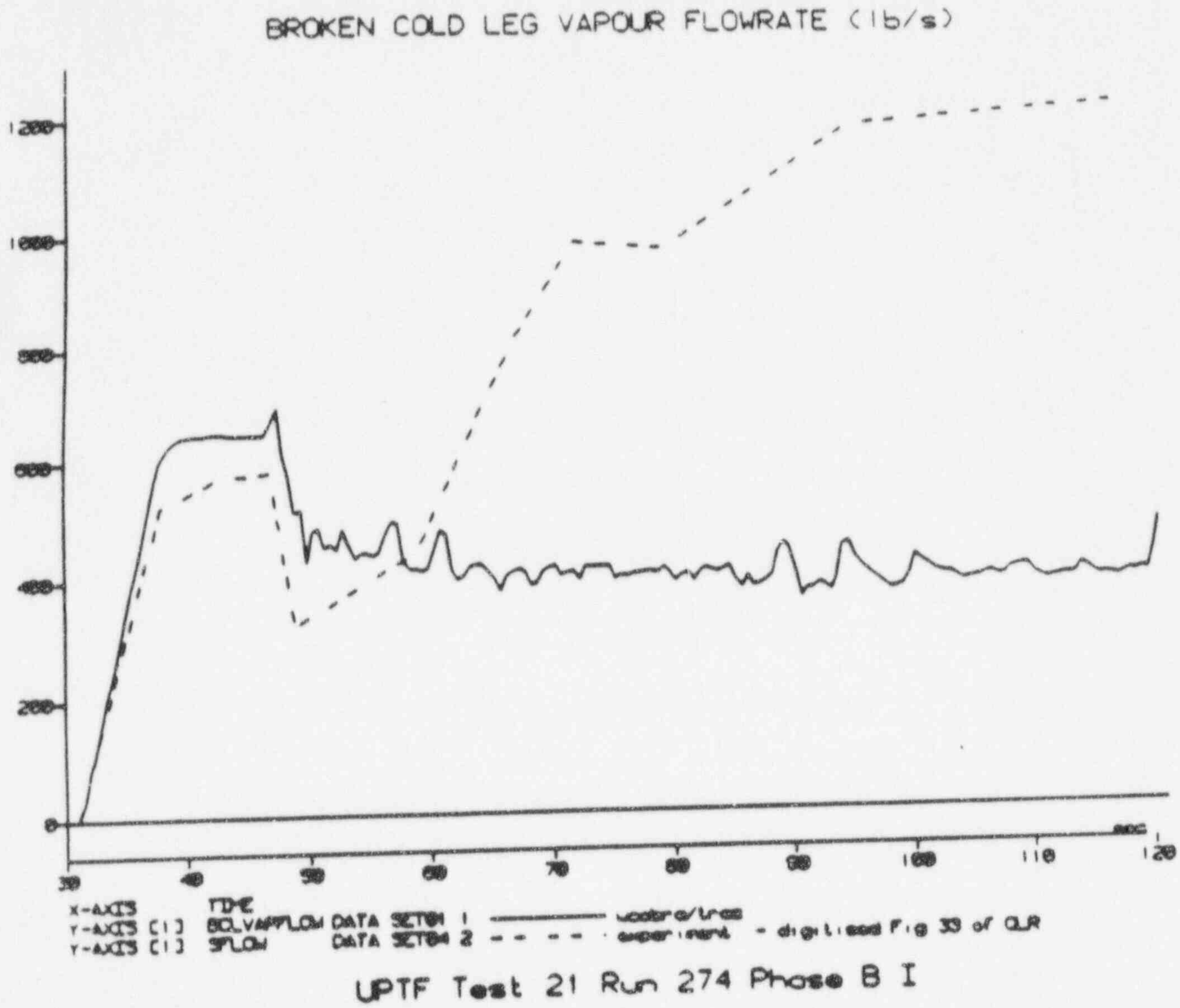


Figure 440.348-45 UPTF Test 21, Phase B I, Broken Cold Leg Steam Mass Flow

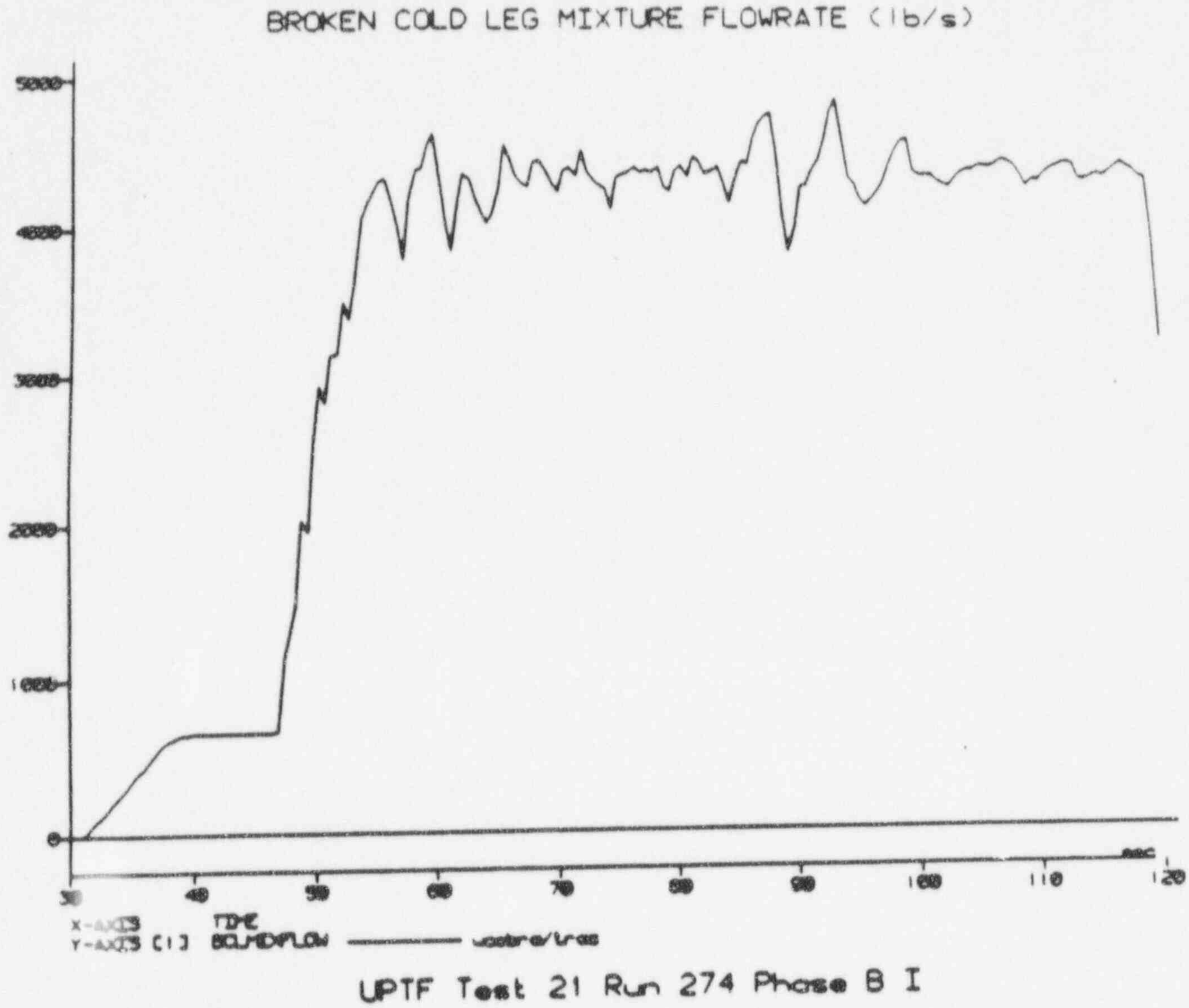


Figure 440.348-46 UPTF Test 21, Phase B I, Broken Cold Leg Mixture Mass Flow

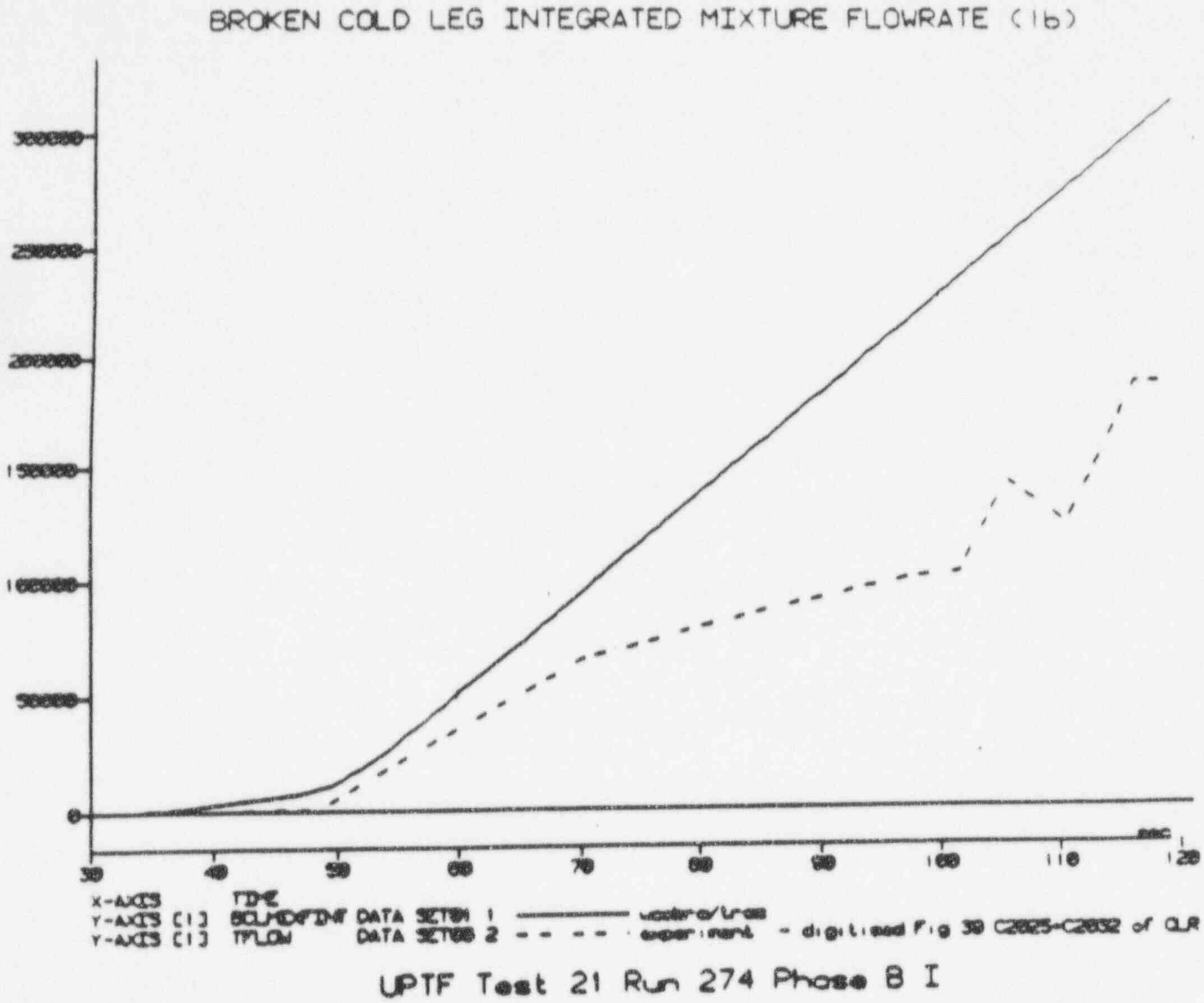
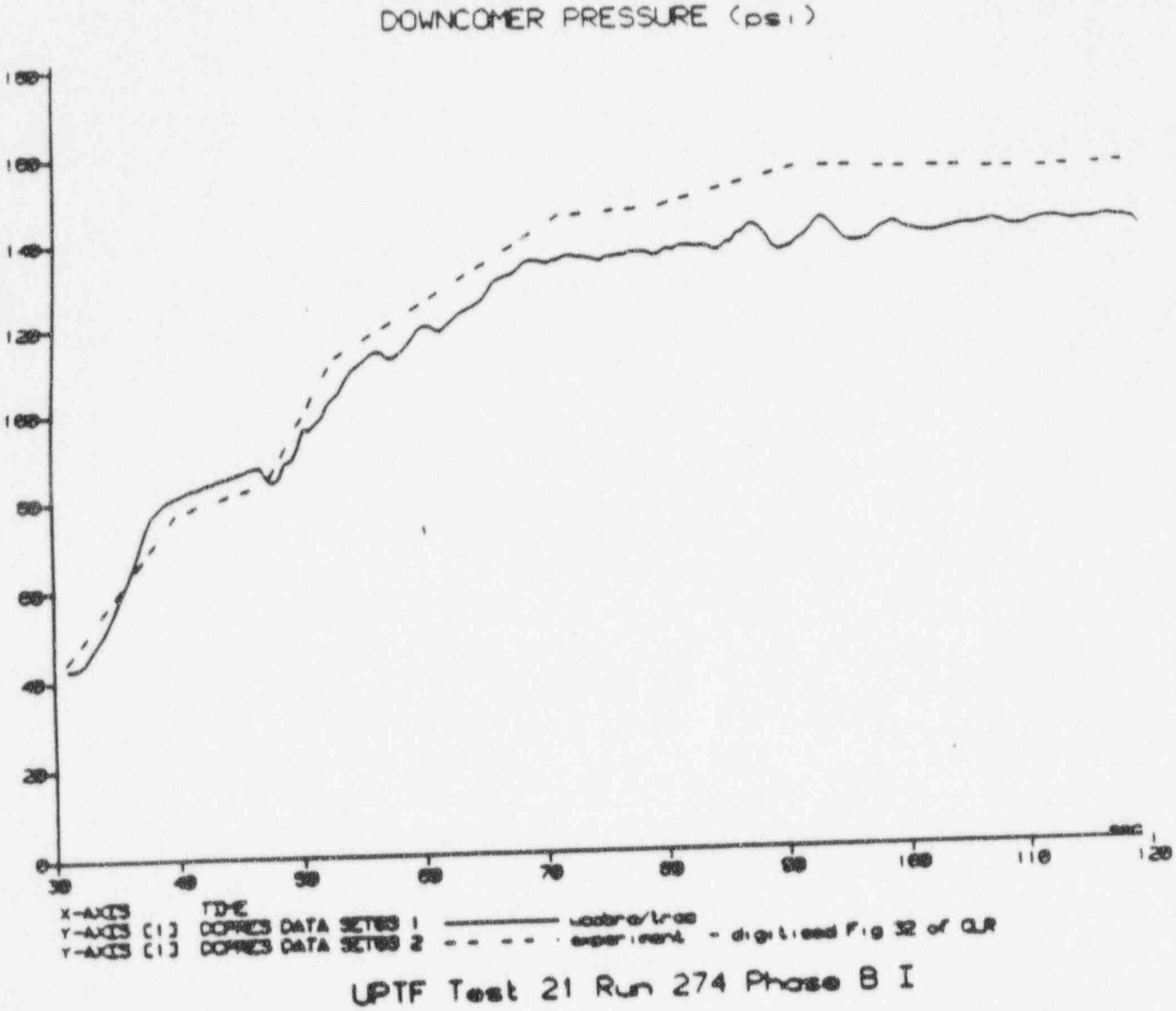


Figure 440.348-47 UPTF Test 21, Phase B I, Broken Cold Leg Integrated Mixture Mass Flow



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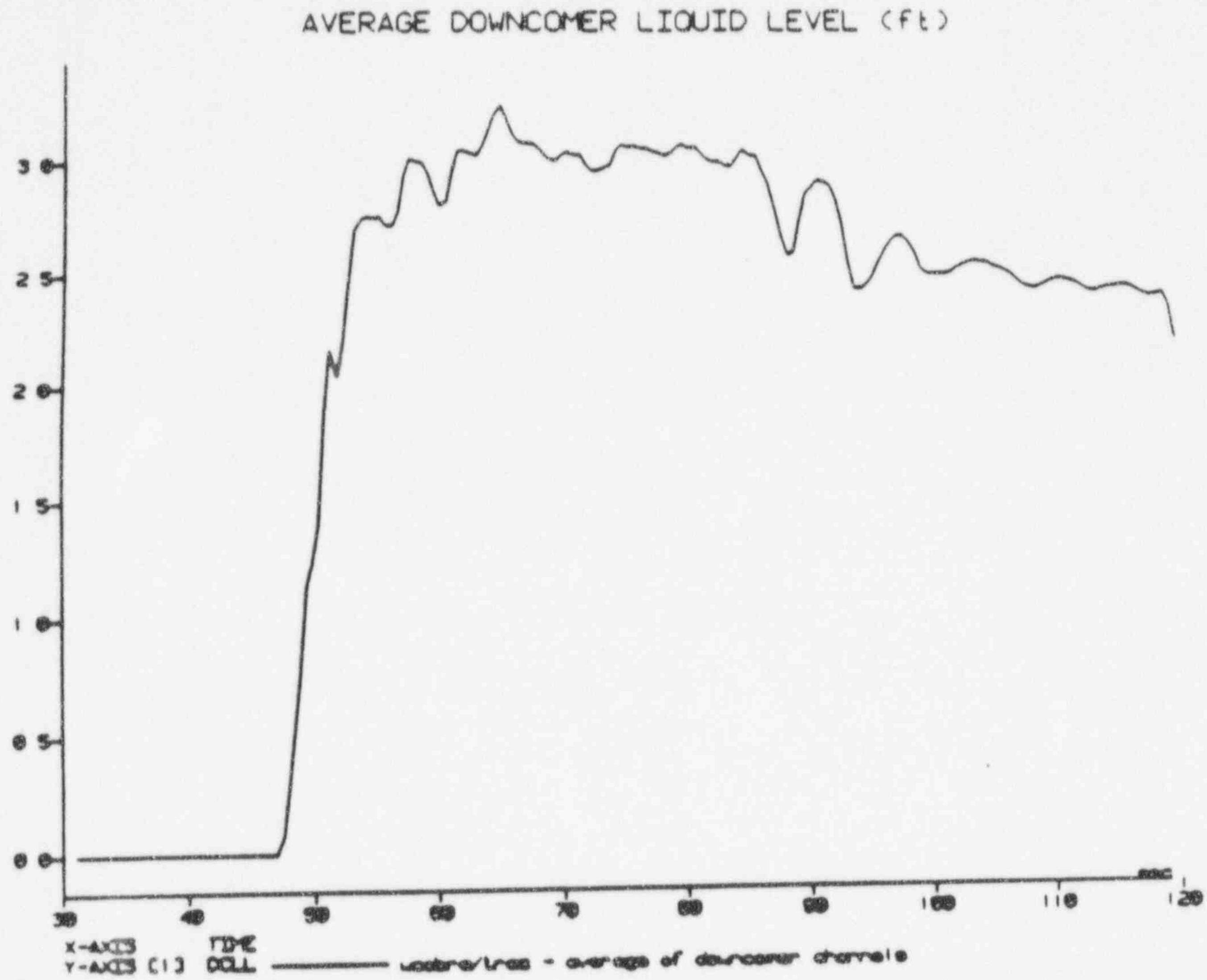

Figure 440.348-49 UPTF Test 21, Phase B I, Downcomer Collapsed Liquid Level

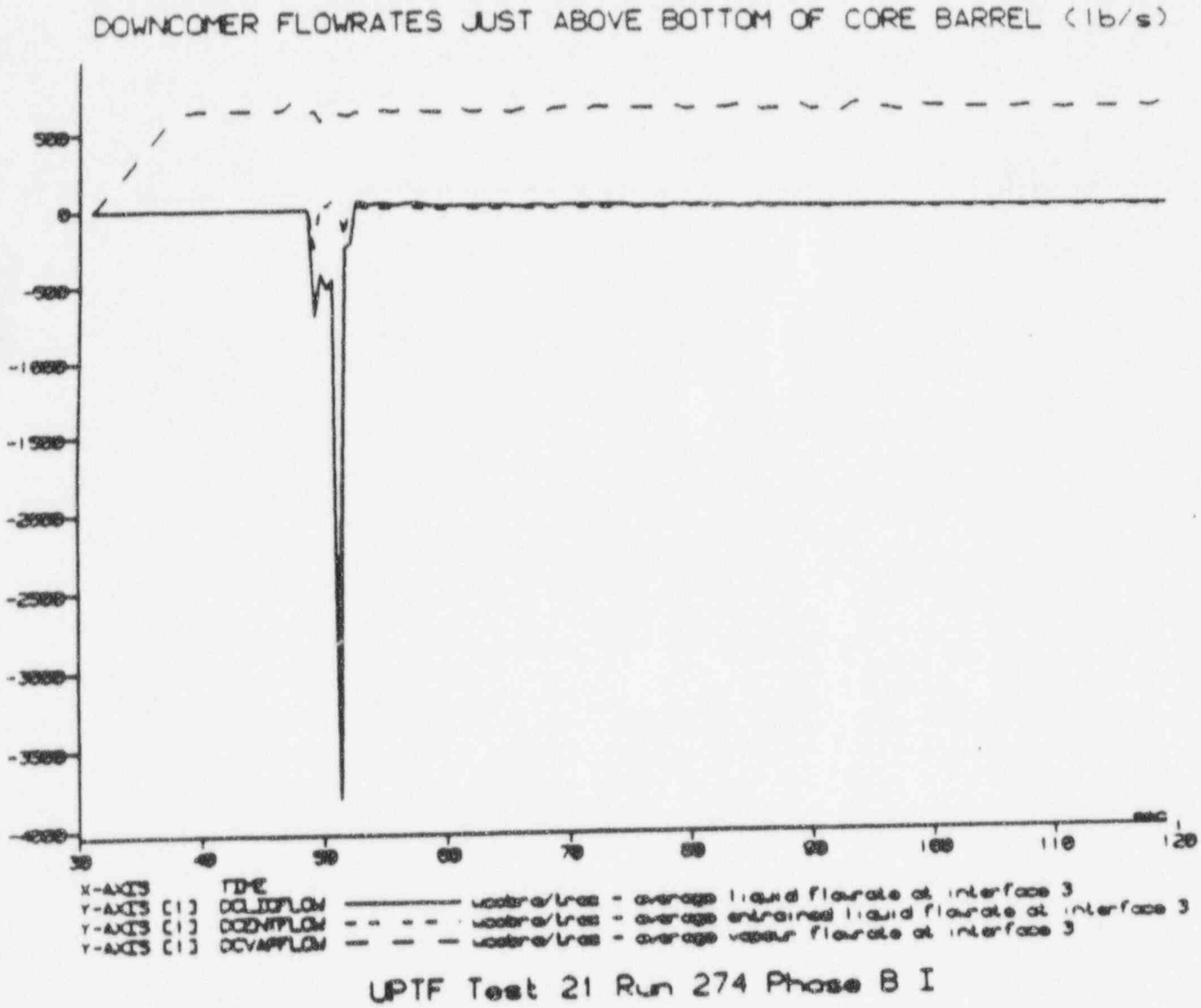

Figure 440.348-50 UPTF Test 21, Phase B I, Downcomer Mass Flow Above Bottom of Core Ba

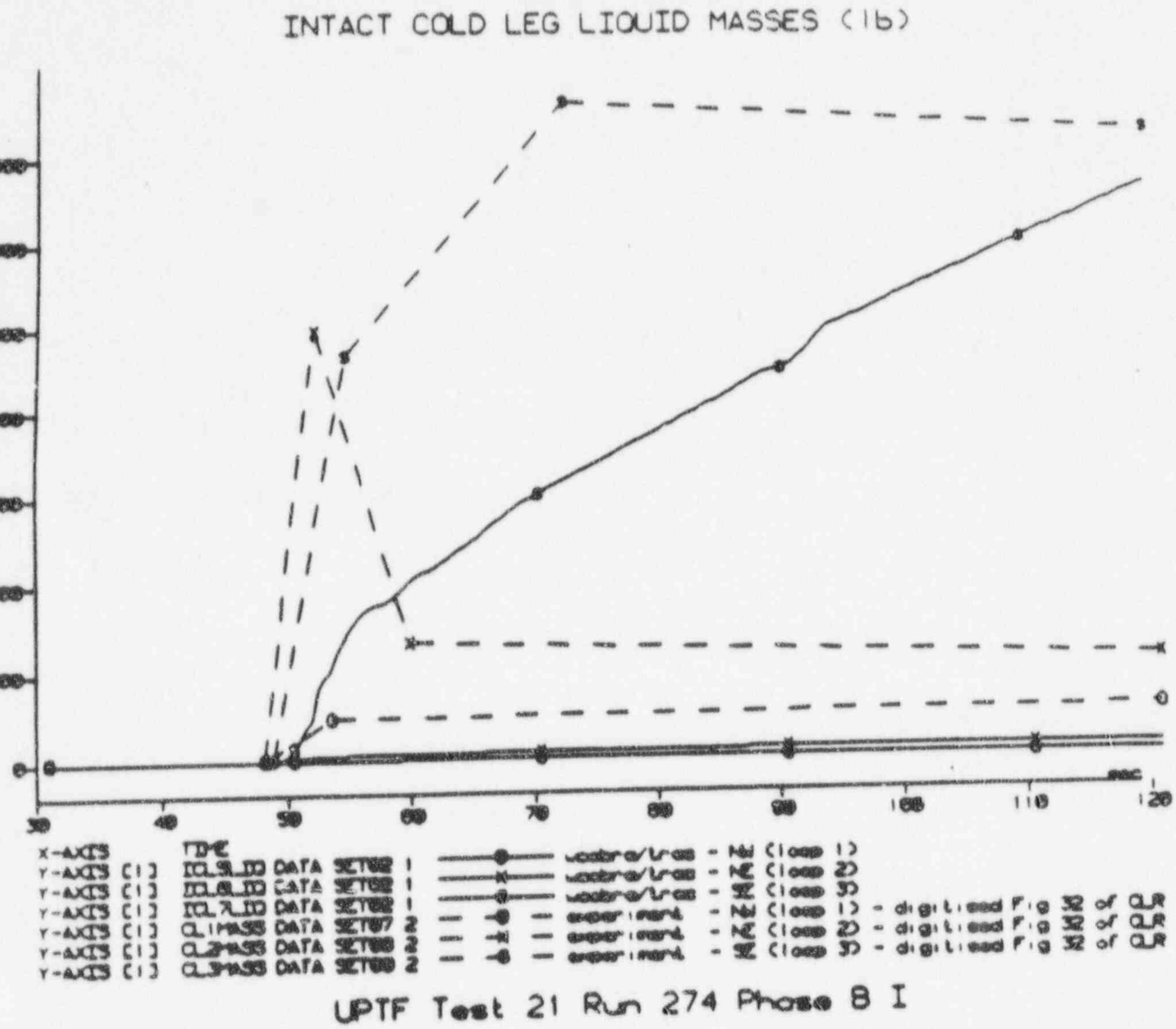

Figure 440.348-51 UPTF Test 21, Phase B I, Intact Cold Leg Mass Inventories

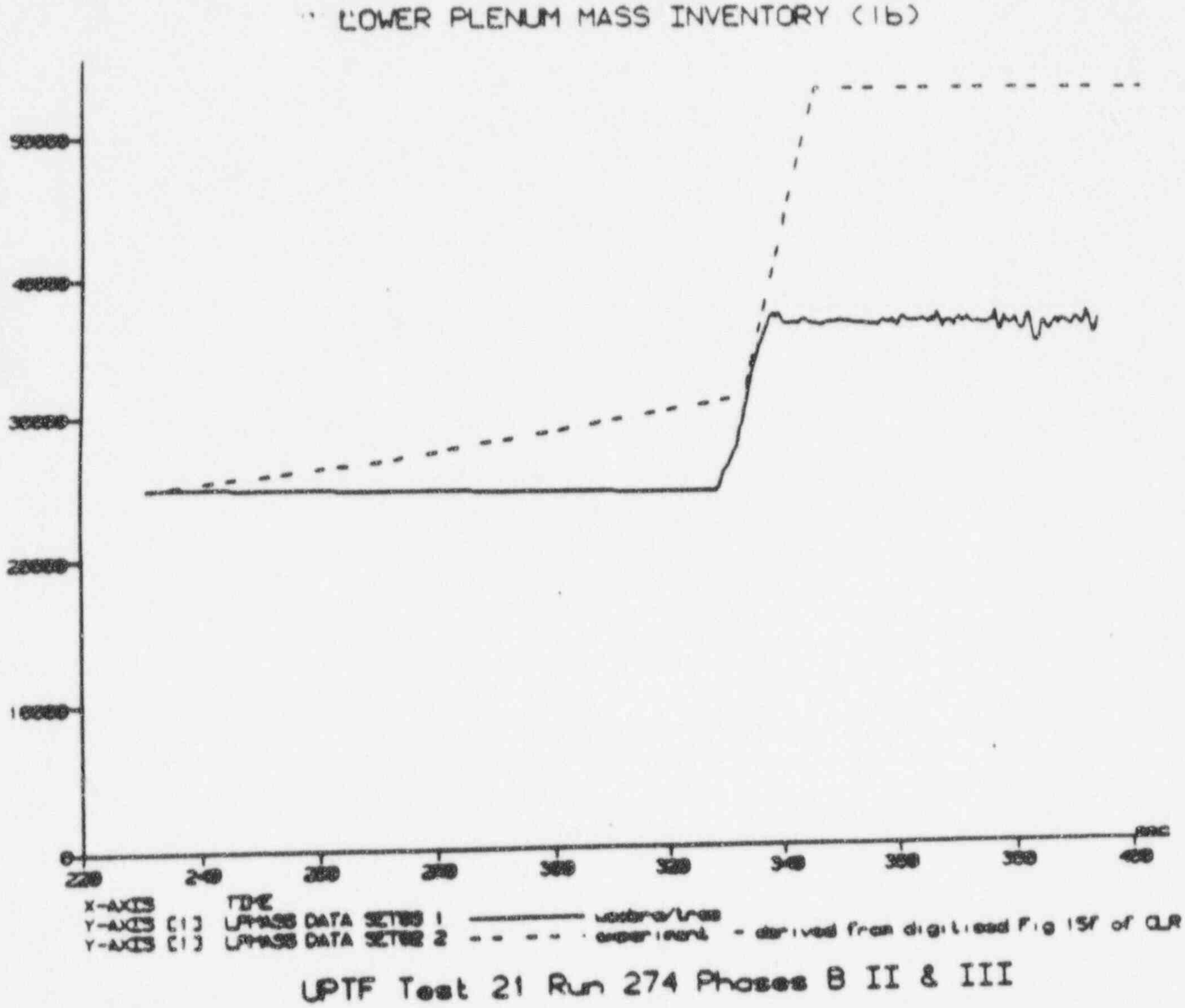

Figure 440.348-52 UPTF Test 21, Phase B II&III, Lower Plenum Mass Inventory

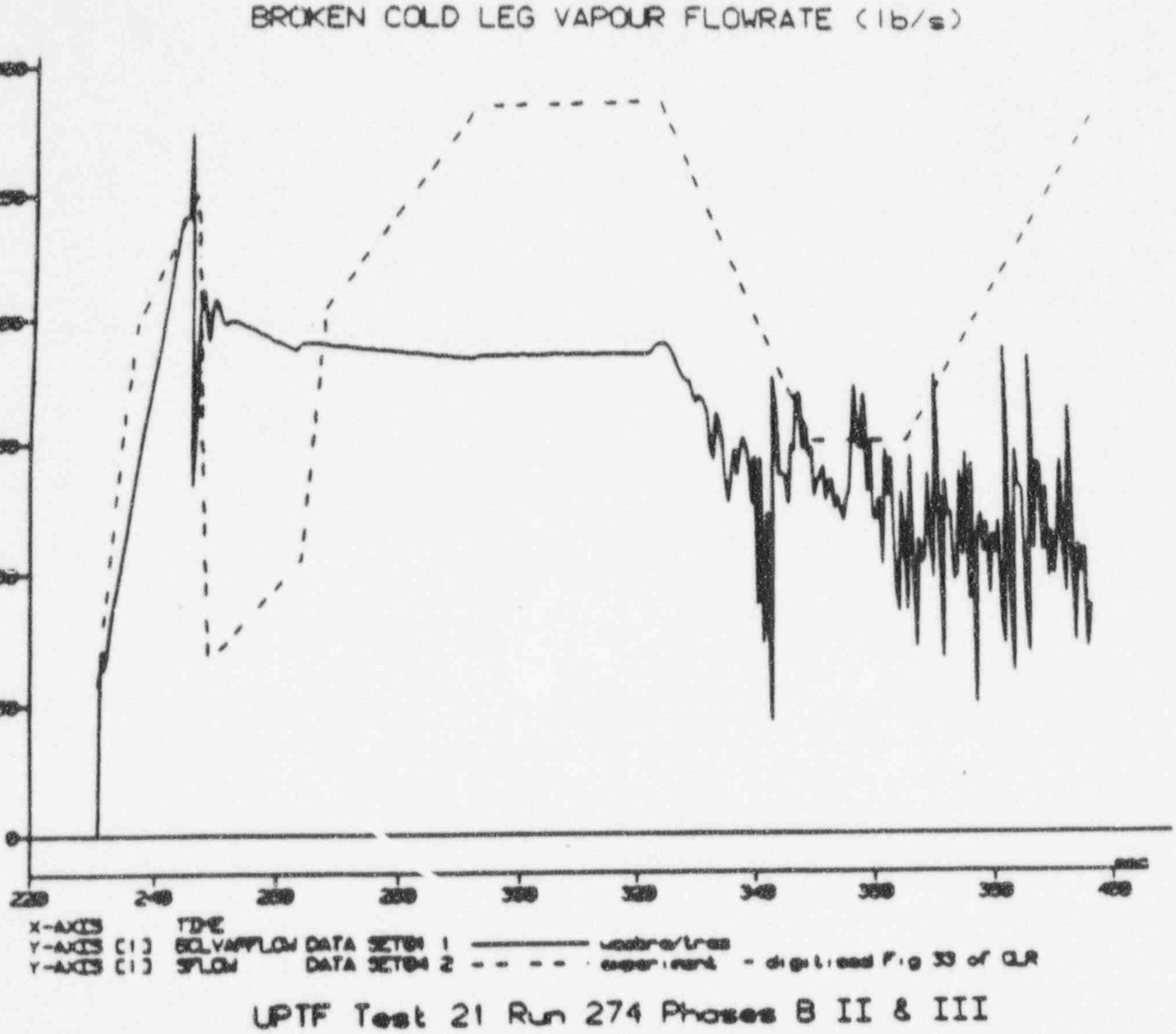

Figure 440.348-53 UPTF Test 21, Phase B II&III, Broken Cold Leg Steam Mass Flow

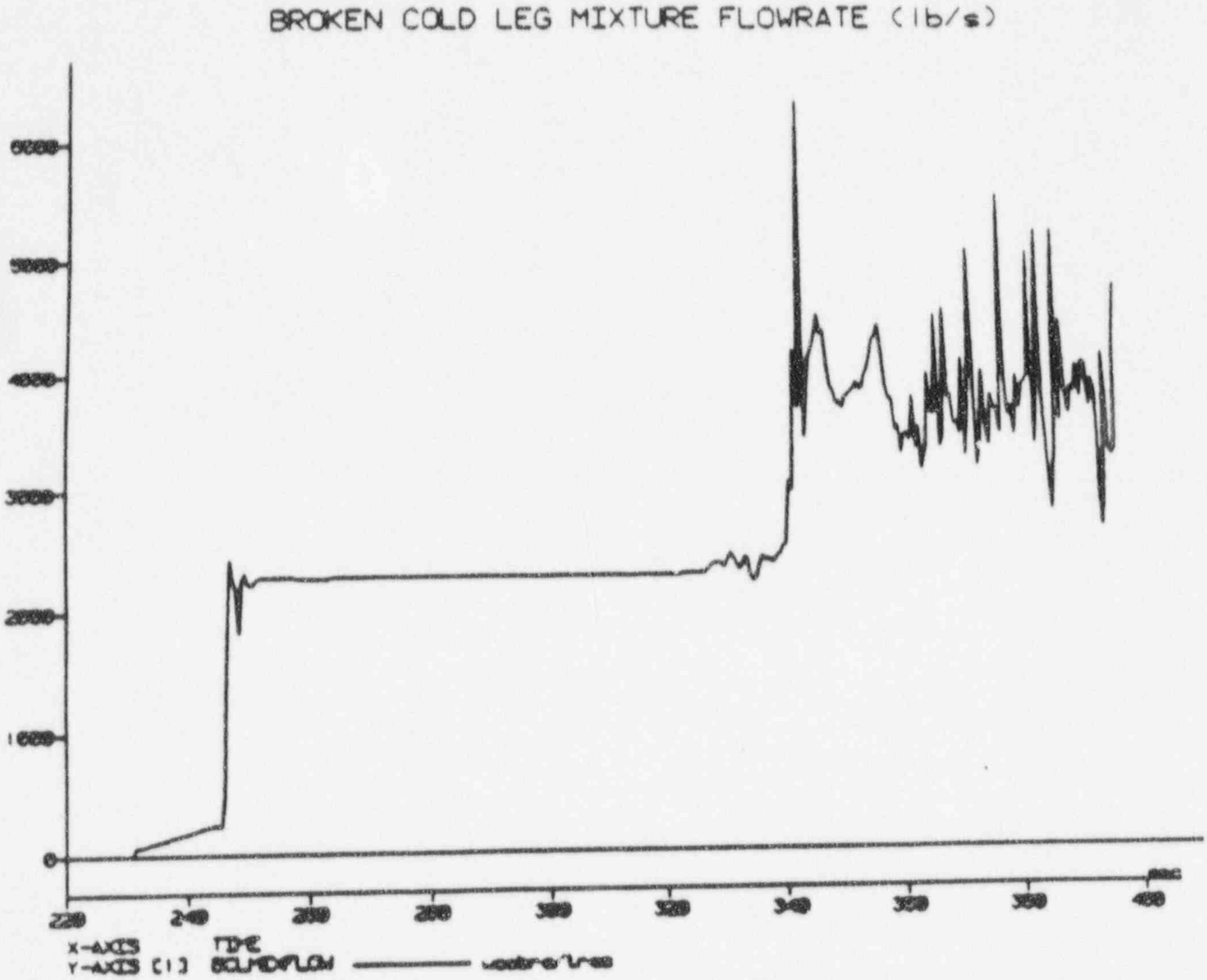

Figure 440.348-54 UPTF Test 21, Phase B II&III, Broken Cold Leg Mixture Mass Flow

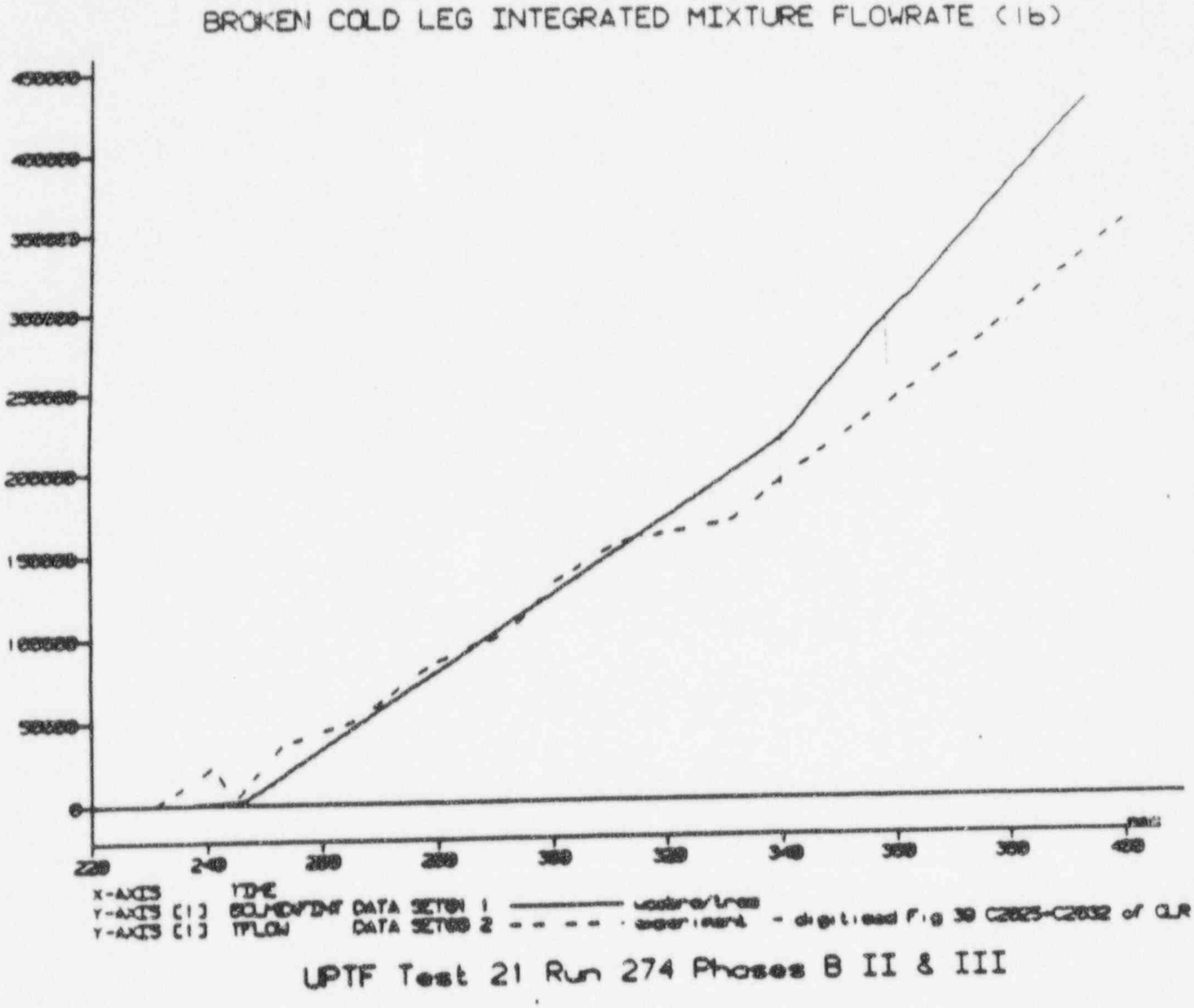

Figure 440.348-55 UPTF Test 21, Phase B II&III, Broken Cold Leg Integrated Mixture Mass F

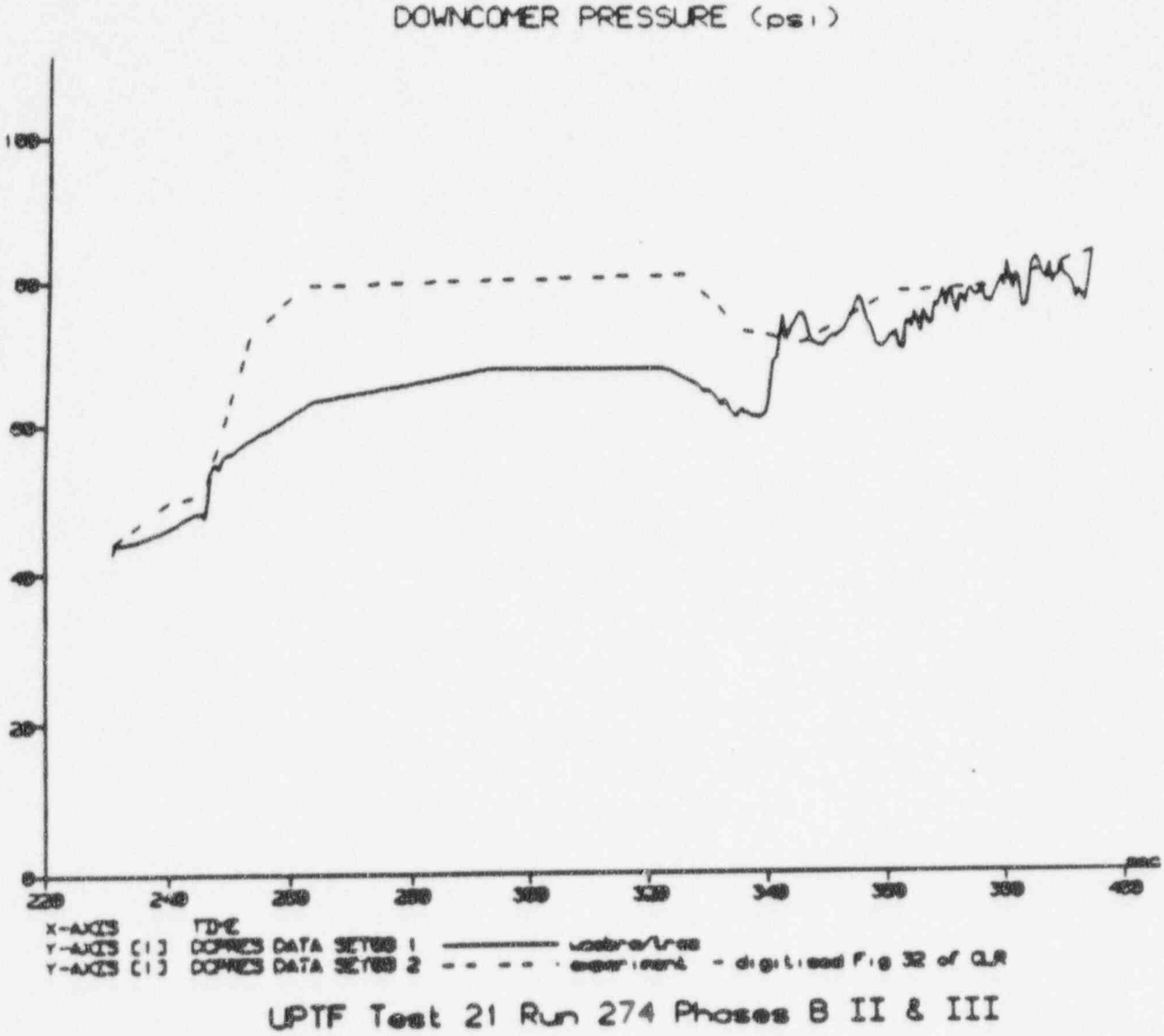

Figure 440.348-56 UPTF Test 21, Phase B II&III, Downcomer Pressure

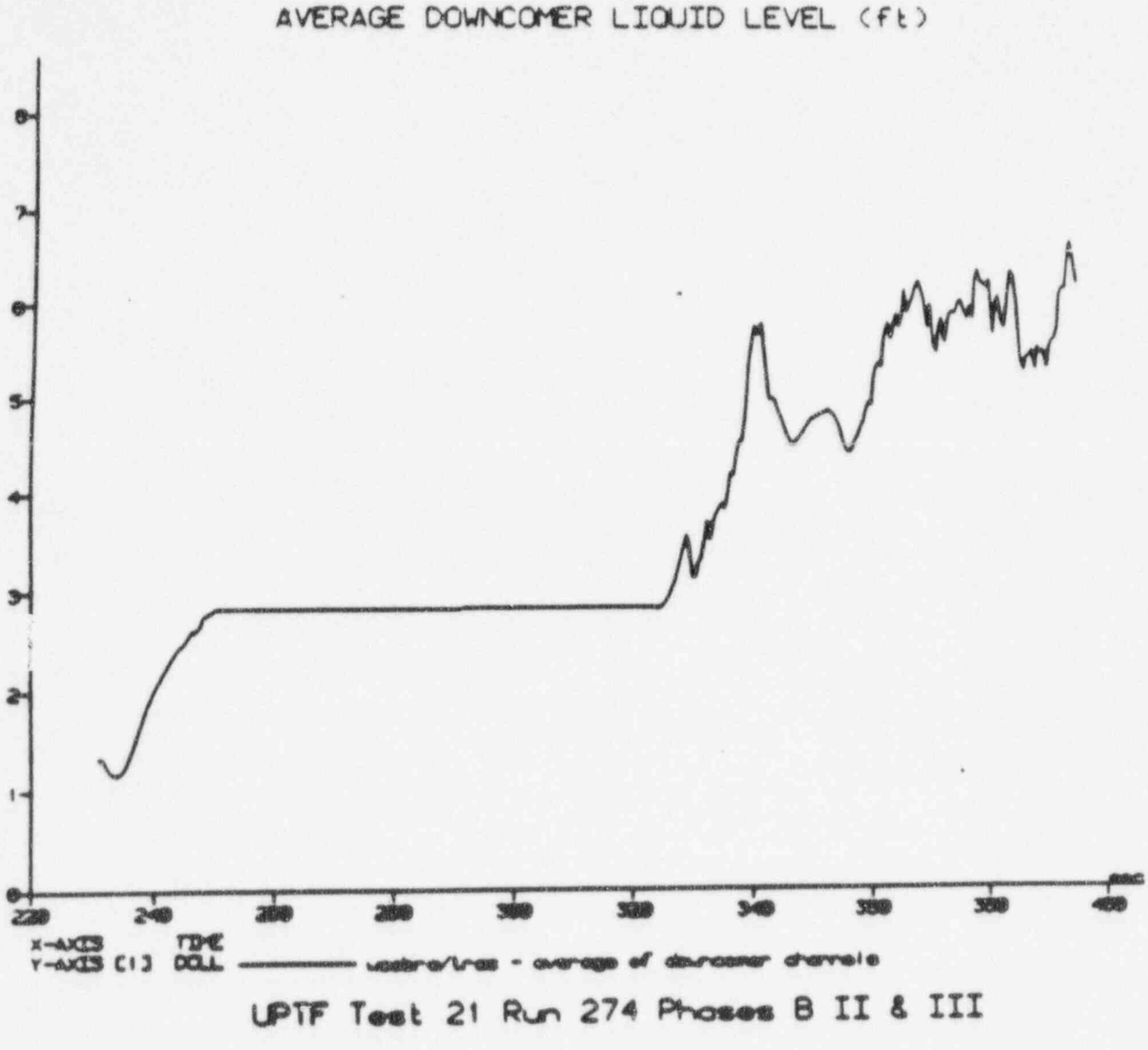

Figure 440.348-57 UPTF Test 21, Phase B II&III, Downcomer Collapsed Liquid Level

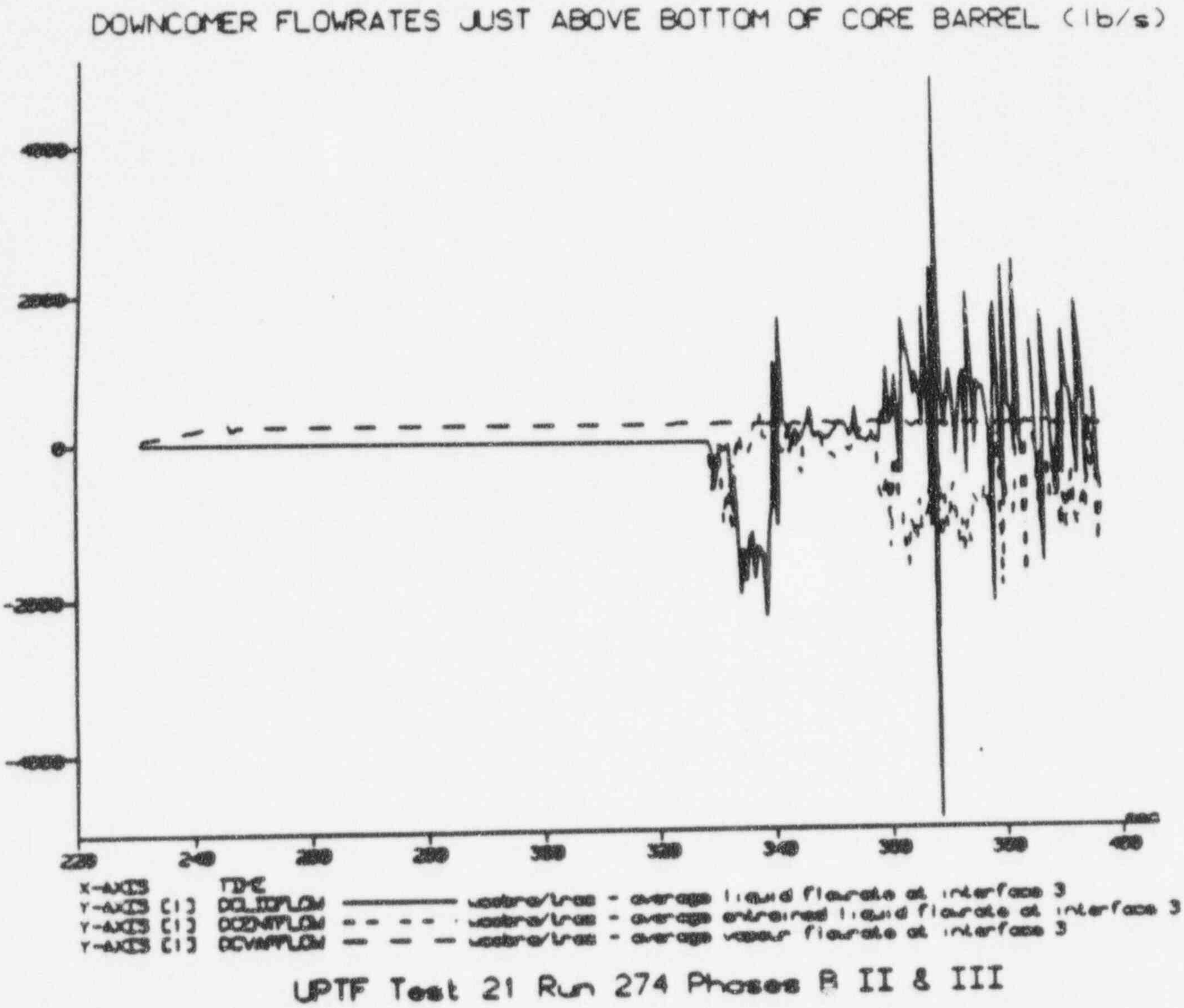

Figure 440.348-58 UPTF Test 21, Phase BII&III, DC Mass Flow Above Bottom of Core Barrel

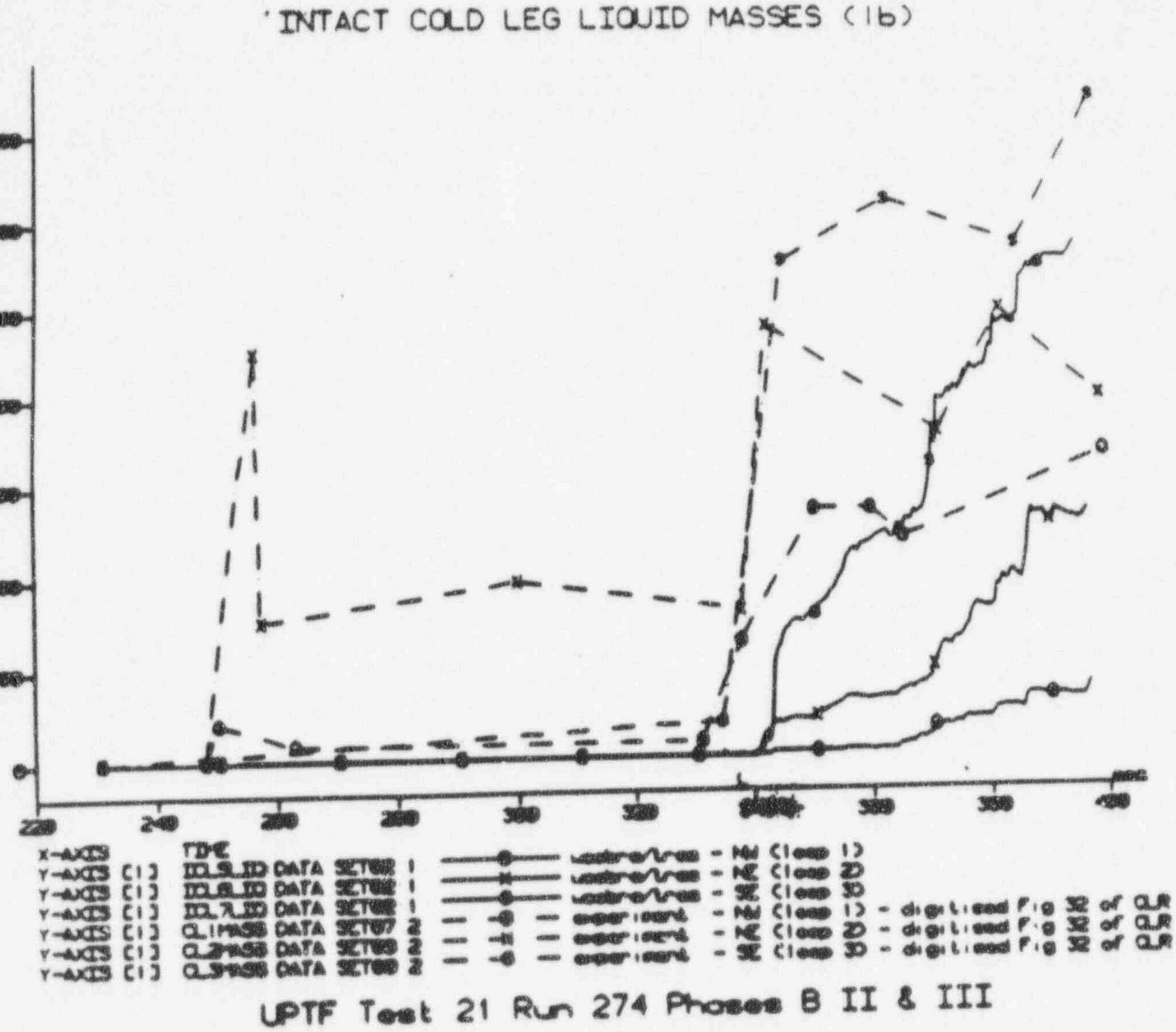

Figure 440.348-59 UPTF Test 21, Phase B II&III, Intact Cold Leg Mass Inventories