Submittal of "Summary of Small Break Loss of Coolant Accident Analysis Changes and Results for AP1000 Plant" (Non-Proprietary)

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Westinghouse Electric Company
1000 Westinghouse Drive
Cranberry Township, PA 16066

Summary of Small Break Loss of Coolant Accident Analysis Changes and Results for AP1000 Plant

Andre F. Gagnon

Principal Engineer

LOCA Integrated Services

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Executive Summary

- Core Reference Report (CRR) analysis revised to address Automatic Depressurization System (ADS) stage 4 (ADS-4) single failure assumption
- Minor core uncovery and cladding heat-up observed
- Significant margin to 10 CFR 50.46 limits exist

Overview

- ADS-4 failure location discussion/background
- Summarize Small Break LOCA (SBLOCA) changes from the Core Reference Report (CRR), Rev. 0
- Present summary of revised SBLOCA results contained in CRR Rev. 1
- Thermal Conductivity Degradation (TCD) assessment

Background

- Analyzed SBLOCA single failure for **AP1000®** plant was a failure of an ADS-4 valve on the PRHR side.
  - Testing at the Oregon State University (OSU) APEX1000 test facility indicated that a single failure of an ADS-4 valve on the non-Passive Residual Heat Removal (PRHR) heat exchanger side could be more limiting.
- Analysis work has been completed to incorporate ADS-4 valve failure on non-PRHR side in SBLOCA analysis in CRR Rev. 1.
  - Consistent with the staff recommendation in Chapter 21 of **AP1000** plant Final Safety Evaluation Report (FSER) (NUREG-1793)

Background

- Major changes to SBLOCA analysis described in Revision 0 of the Core Reference Report (CRR; WCAP-17524-P)
  - Single failure assumption
    - ADS-4 on non-PRHR side
  - Enhanced containment backpressure for select breaks
    - Containment backpressure used currently for Double-ended Direct Vessel Injection (DEDVI) line break
    - Transient pressure history now being utilized for 2 inch Cold Leg Break and Inadvertent Automatic Depressurization System (INADS) simulations
  - Use of SBLOCTA (To be discussed later)
    - Minor core uncovery predicted by NOTRUMP code

ADS-4 Failure Location Effect

- Failure of ADS-4 valve on non-PRHR side results in liquid hold-up in hot leg
  - Liquid draindown from Pressurizer is entrained out the PRHR (i.e., Pressurizer) side ADS-4 discharge path
    - Does not return to vessel as easily
    - Results in loss of vessel inventory during the injection gap period
- Failure of ADS-4 valve on PRHR side
  - Liquid draindown from Pressurizer is drawn through the upper plenum before it can be discharged out ADS-4 path
    - Provides vessel makeup during injection gap period

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NOTRUMP **AP1000** Plant Noding Diagram

[a,c]

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Containment Pressure Response Generation

- Mass and energy (MNE) releases from atmospheric containment pressure SBLOCA analysis generated with NOTRUMP
  - 2 inch Cold Leg Break
  - Inadvertent ADS
- MNE releases utilized in WGOTHIC minimum containment pressure model to generate containment pressure response for associated SBLOCA cases
- Additional iteration performed with 2 inch Cold Leg Break utilizing variable containment MNE releases to demonstrate effect

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AP1000 Plant WGOTHIC Minimum Pressure EM Background

- Used to calculate the minimum containment pressure for the DEDVI, SBLOCA break analysis discussed in Section 15.6.5.4B.3.1 of Revision 19 of the DCD
- Assumptions defined in Section 13.8 of WCAP-15846, Revision 1, "WGOTHIC Containment Minimum Pressure Calculation for Small-Break LOCA and Long-Term Cooling"
- Section 13.8 of WCAP-15846, Revision 1 states:

*"A conservative calculation of the containment pressure is needed to provide the containment boundary conditions for the **AP1000** small-break LOCA analysis and the long-term cooling analysis….For this reason, the WGOTHIC containment pressure calculation is biased to obtain the minimum containment pressure for a given event."*

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AP1000 Plant WGOTHIC Minimum Pressure EM Modeling and Analysis for 2 inch and INADS

- Started with WGOTHIC **AP1000** plant DCD Revision 19 Double Ended Cold Leg Break LOCA peak containment pressure model
- Modeling/analysis performed in accordance with approved methodology and assumptions
  - Table 13-136 (Section 13.8) of WCAP-15846, Revision 1
- The following are some of the parameters conservatively biased in the WGOTHIC EM to calculate a minimum containment pressure according to Table 13-136:

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–	

a,c]

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AP1000 Plant WGOTHIC Minimum Pressure EM Modeling Assumption for 2 inch and INADS

- Containment Purge Valve for Minimum Pressure Calculation
  - [ ]^{a,c}
  - FSER Page 15-47: Isolated on a high containment pressure signal
- 2 inch and INADS SBLOCA will not pressurize the containment atmosphere high enough to isolate the purge system on a high containment pressure signal
- Sections 7.3.1.1 and 7.3.1.2.1 of the DCD states automatic containment isolation occurs on a safeguard actuation (S) signal which include: low pressurizer pressure, high-2 containment pressure, low cold leg temperature, and low lead-lag compensated steam line pressure
- Therefore, purge system is isolated on [ ]^{a,c} (S) signal consistent with:
  - [ ]^{a,c}
  - **AP1000** plant safeguard actuation signals/logic

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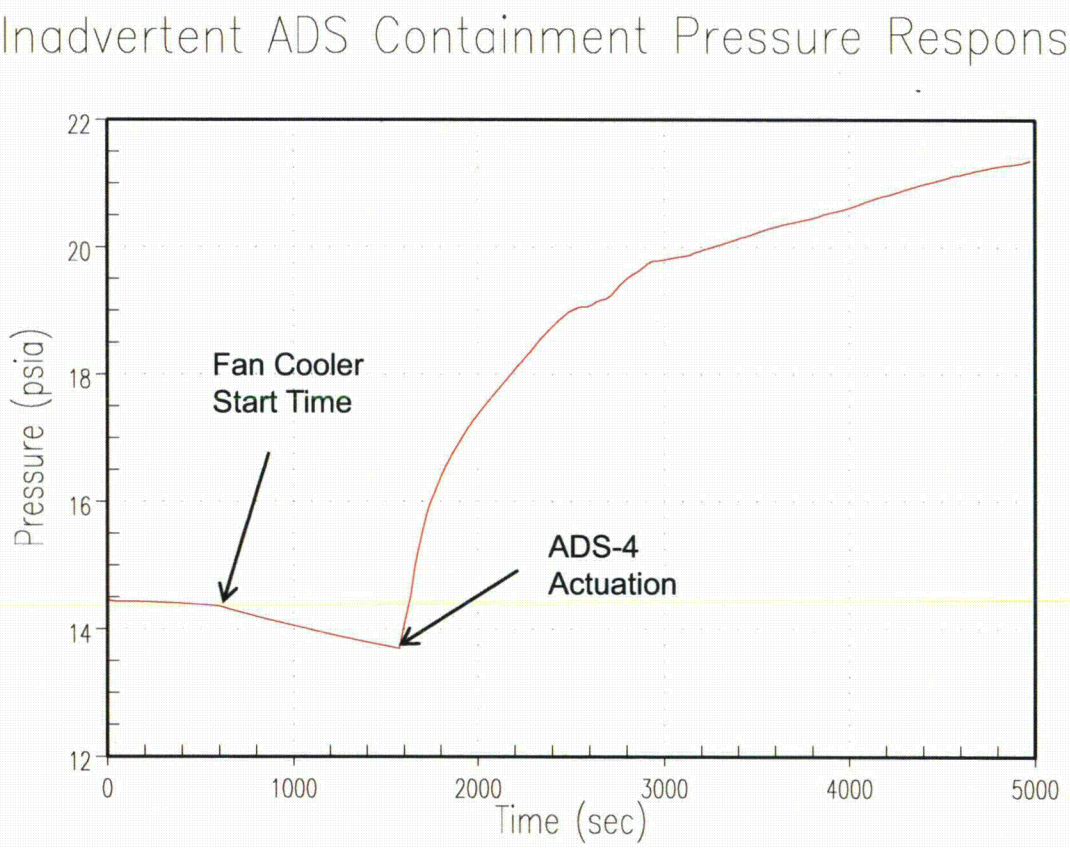
Containment Pressure Response (Inadvertent ADS)



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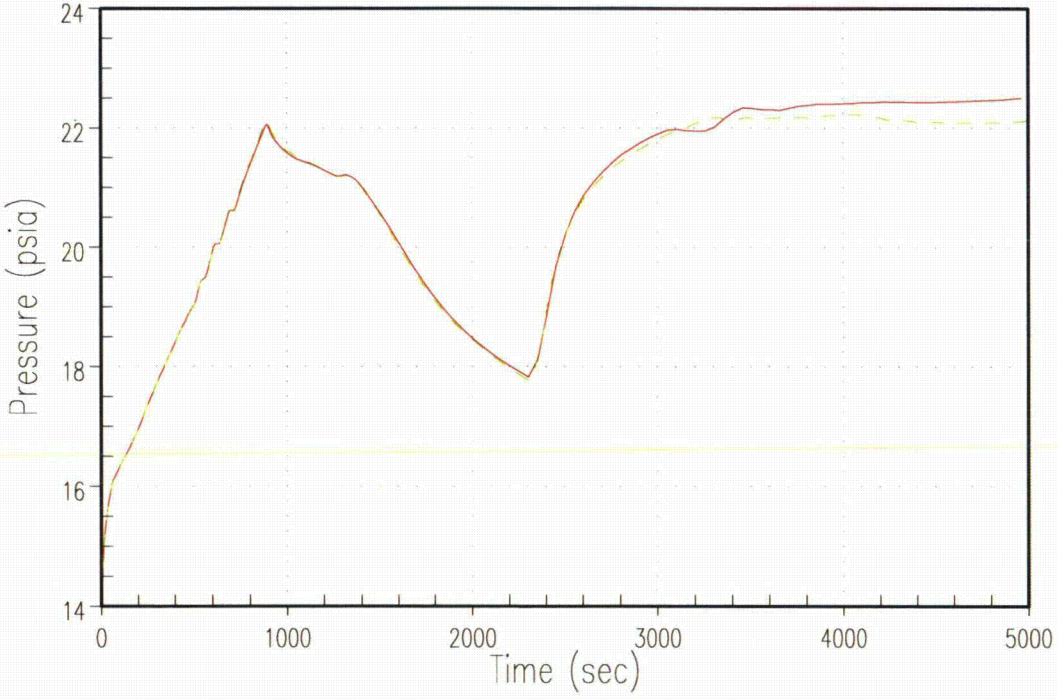
Containment Pressure Response (2 inch Cold Leg Break)

2-Inch Cold Leg Break Containment Pressure Response

[ ]a,c



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SBLOCTA Background

- SBLOCTA is the fuel rod heat-up code used for small break LOCA analyses completed with the NOTRUMP-EM

- Modified version of the LOCTA-IV Code
  - LOCTA-IV: WCAP-8301
  - Modified for use in the NOTRUMP-EM: WCAP-10054-P-A

- Currently utilized to support **AP1000** plant Probabilistic Risk Assessment (PRA) SBLOCA efforts

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SBLOCTA Description

- Calculates the fuel rod cladding temperature and oxidation transients for the hot rod and hot assembly average rod
  - 1-D radial heat conduction of a fuel rod
    - [ ]a,c
  - Zirc-water oxidation reaction based on the Baker-Just model
  - Accounts for fuel rod swelling, burst and blockage
- Requires boundary conditions from the NOTRUMP code
  - [ ]a,c

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SBLOCA Analysis Results Summary

- Minor core uncovery observed for INADS and 2 inch Cold Leg Breaks
  - INADS PCT = 654.7°F
  - 2 inch PCT = 663.5°F
- Larger break simulations not adversely impacted
  - DEDVI
  - 10 inch Cold Leg Break
  - DEDVI entrainment studies not re-performed
- Significant Margin Exists to 10 CFR 50.46 Limits

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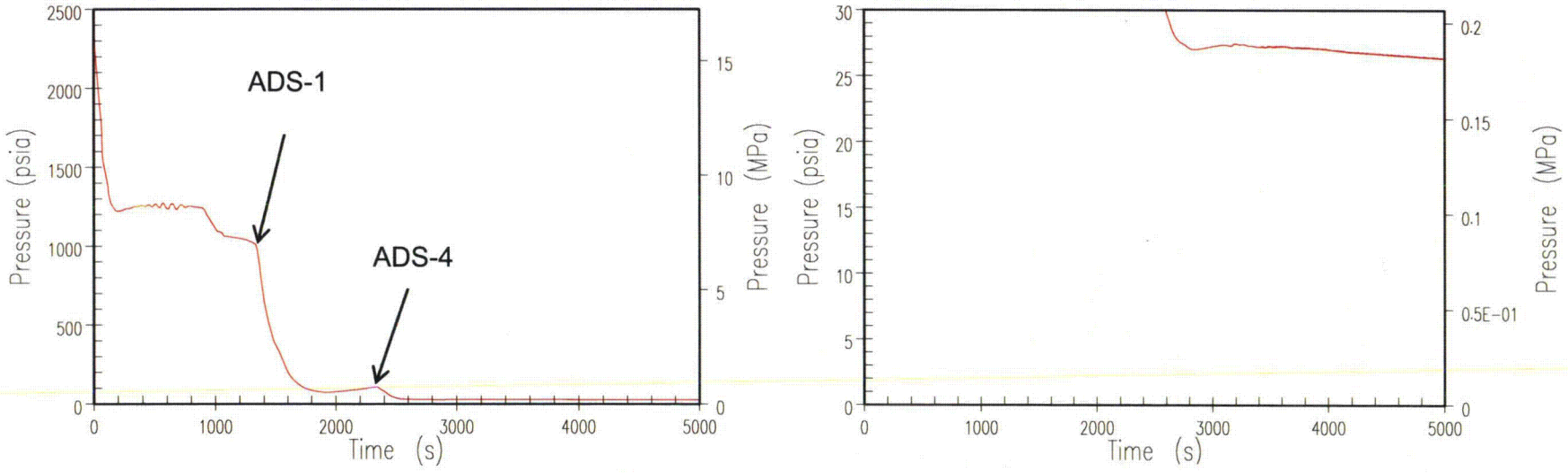
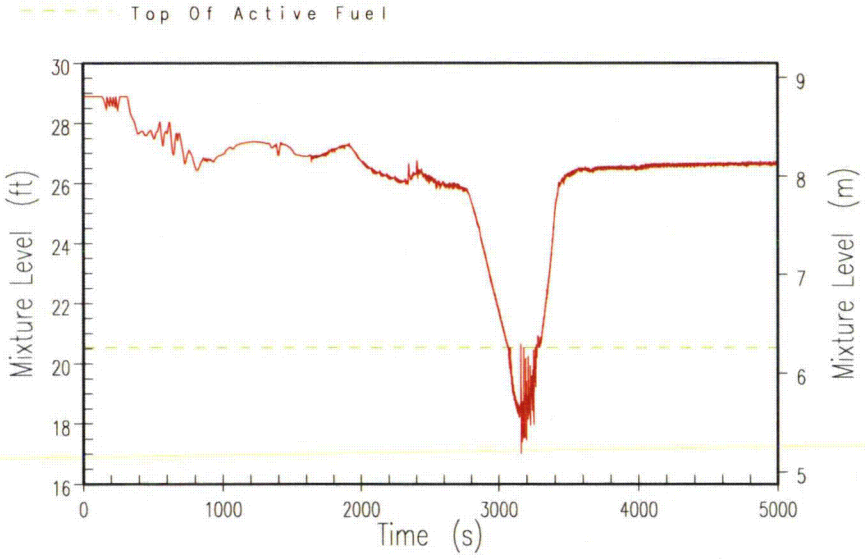
2 inch Cold Leg Break

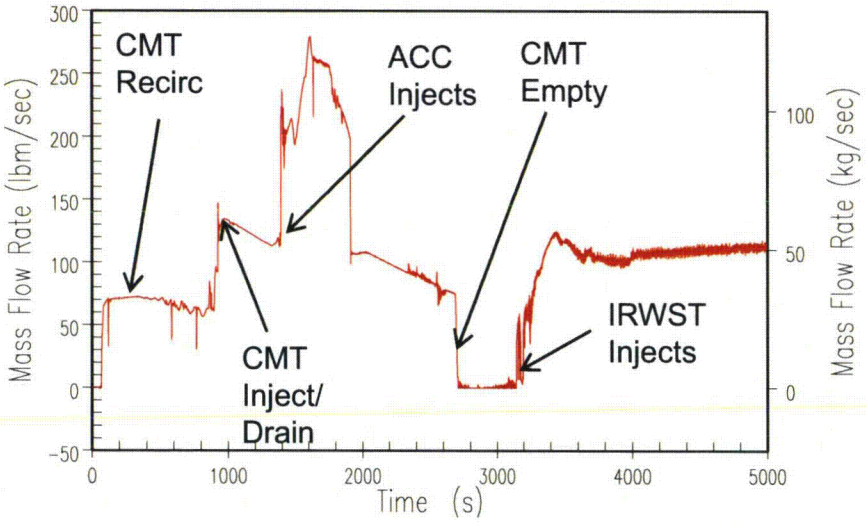


RCS Pressure

2 inch Cold Leg Break



Core/Upper Plenum Mixture Level



DVI-2 Injection Characteristics

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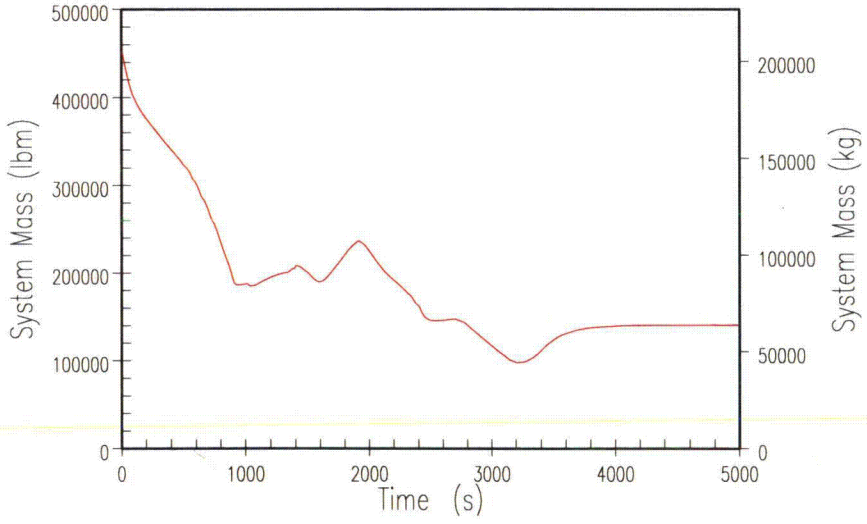
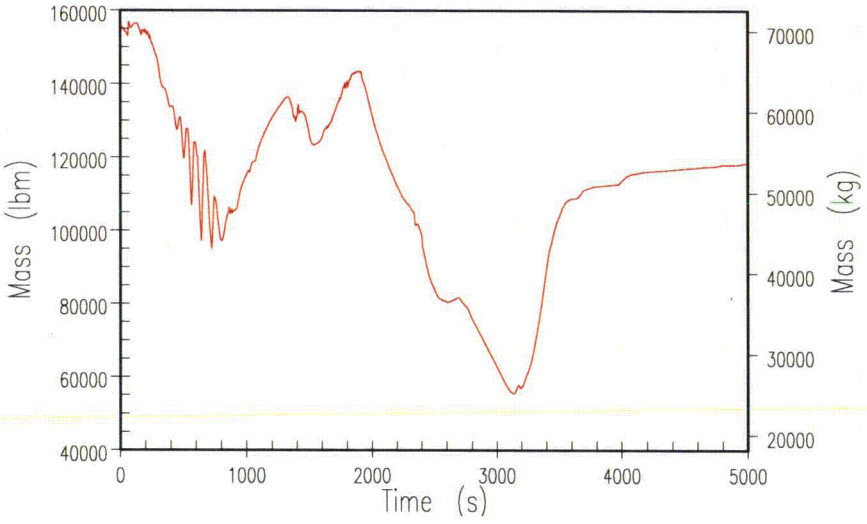
2 inch Cold Leg Break



RCS Inventory



Vessel Mixture Mass

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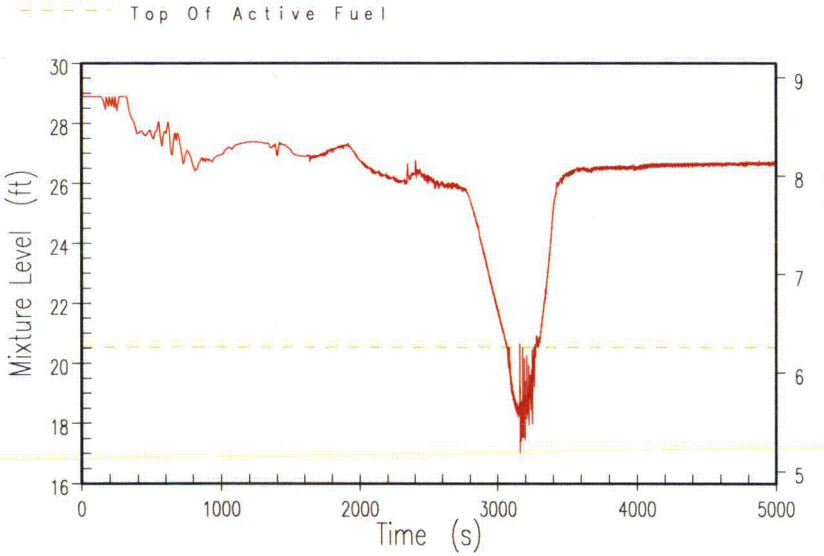
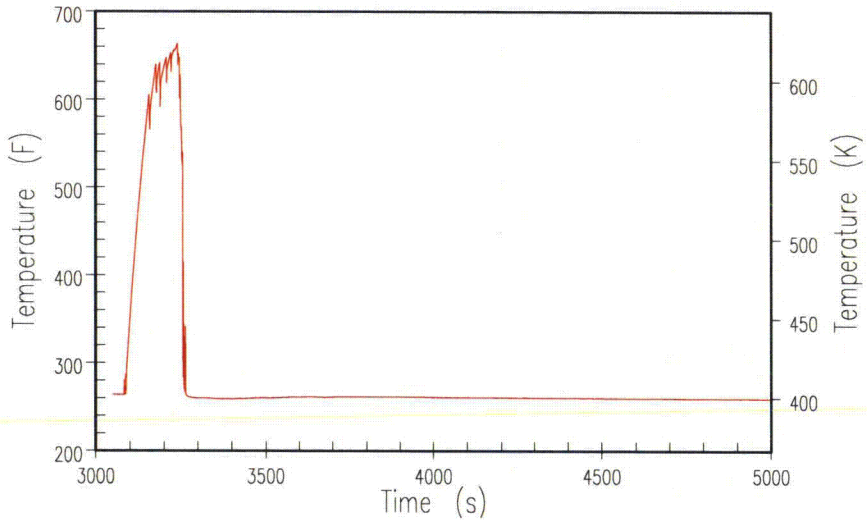
2 inch Cold Leg Break



Core/Upper Plenum Mixture Level



Peak Cladding Temperature

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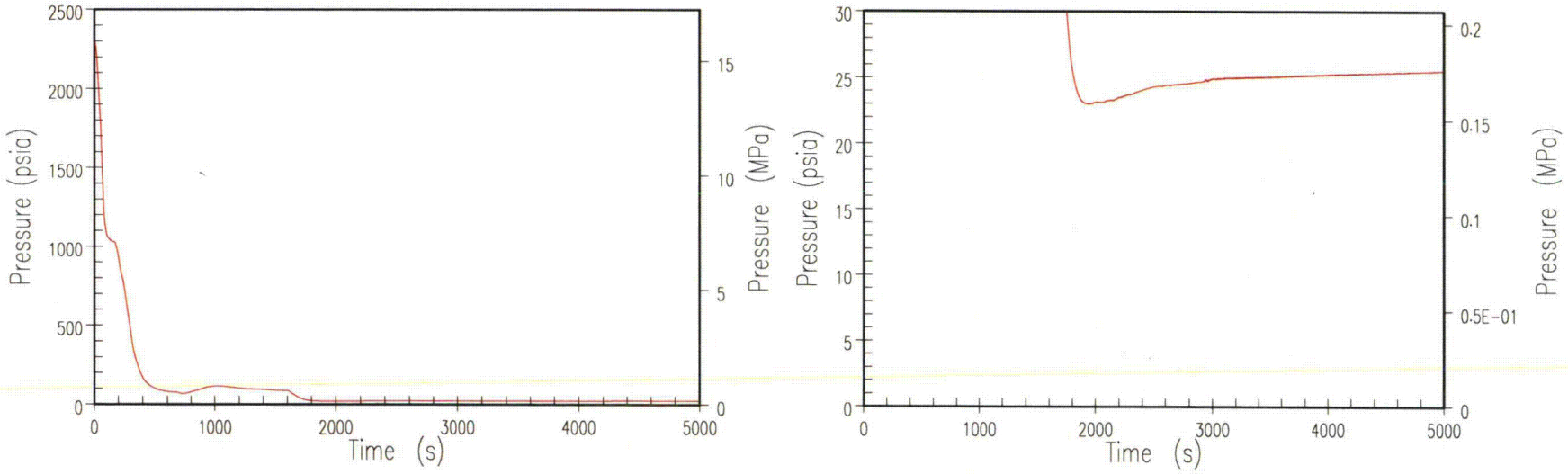
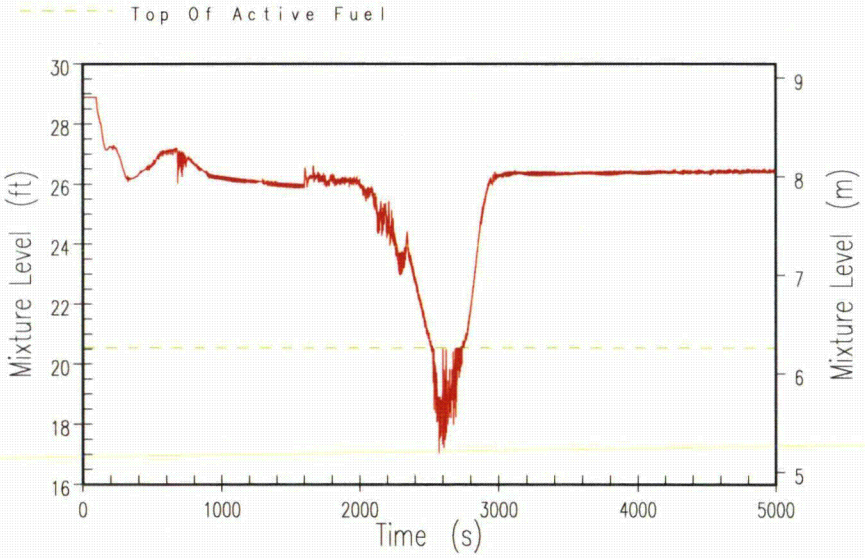
INADS Results

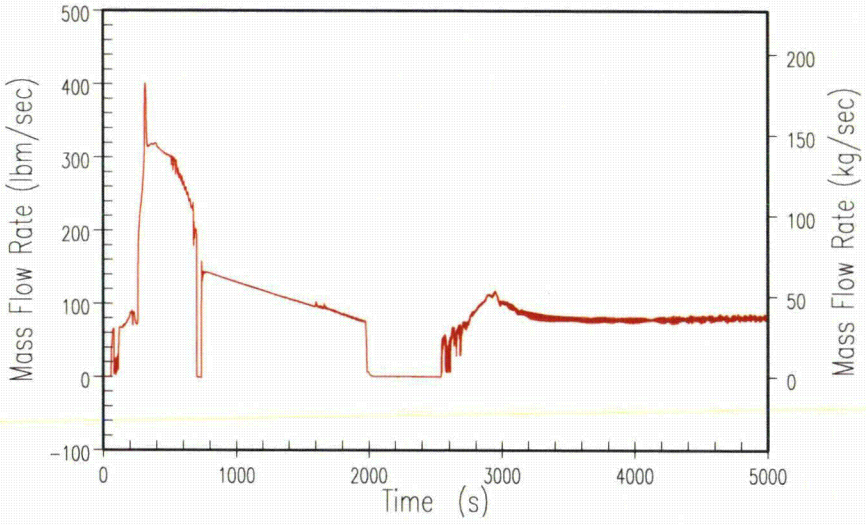


RCS Pressure

INADS Results



Core/Upper Plenum Mixture Level



DVI-2 Injection Characteristics

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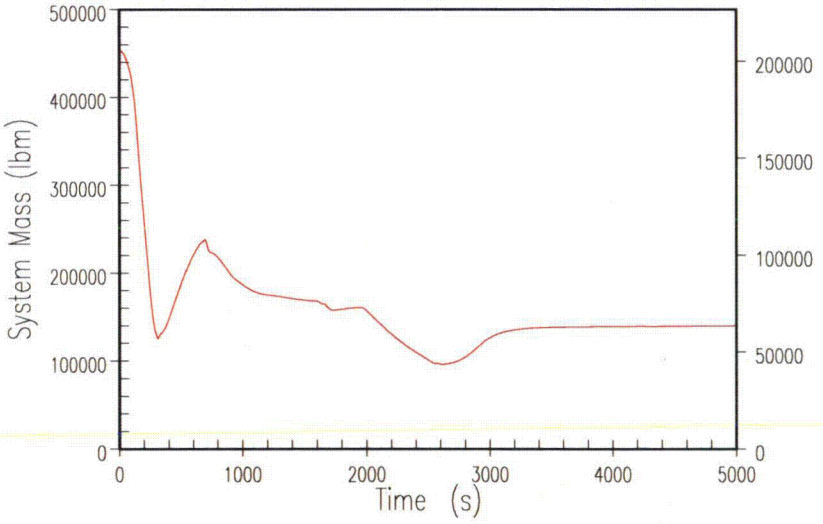
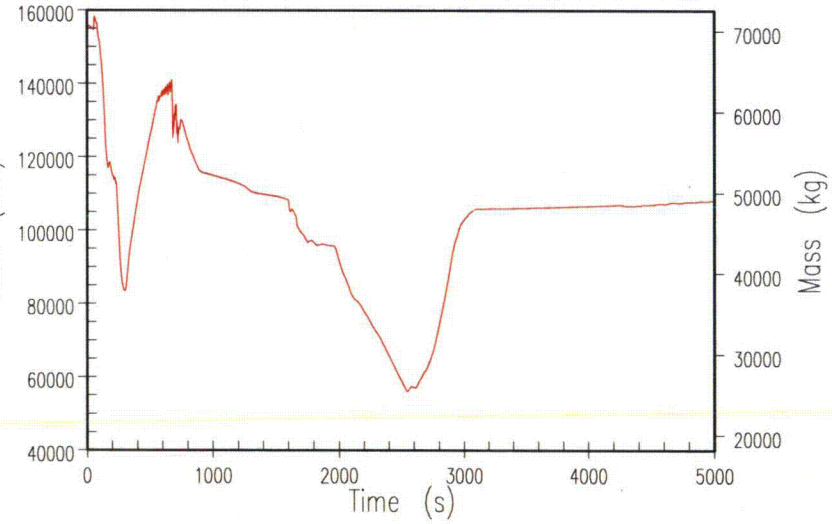
INADS Results



RCS Inventory



Vessel Mixture Mass

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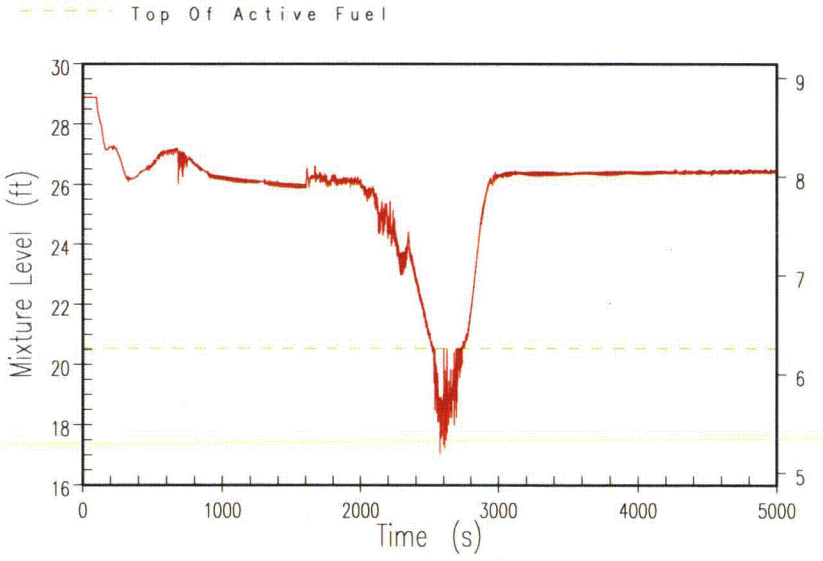
INADS Results



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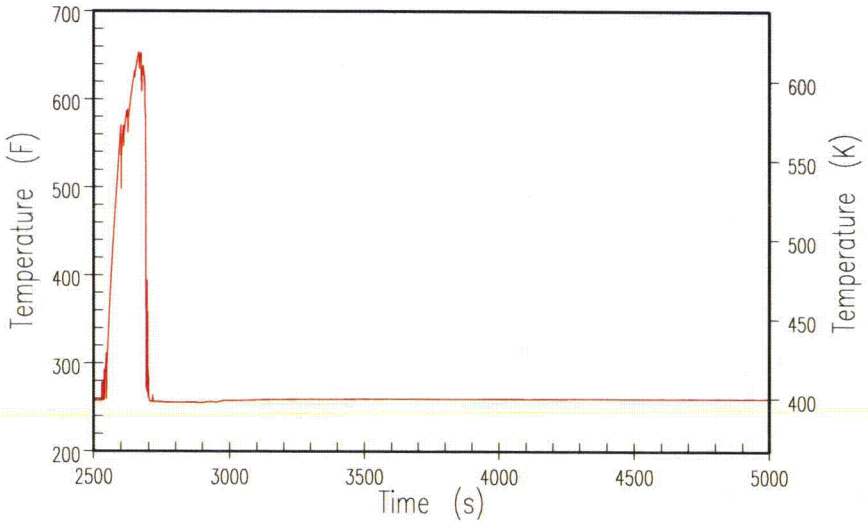

Peak Cladding Temperature

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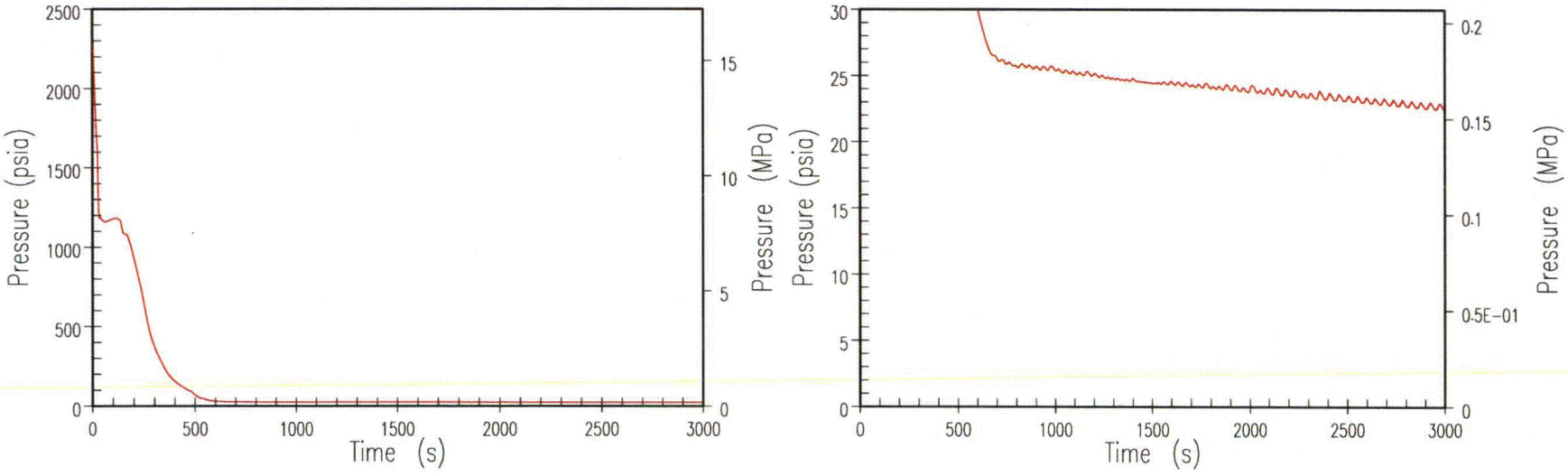
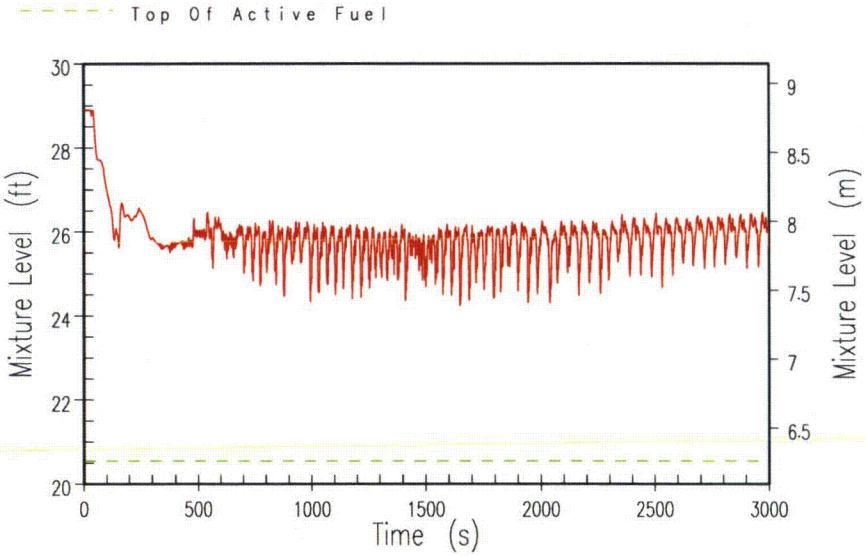
DEDVI Line Break (20 psi containment pressure)

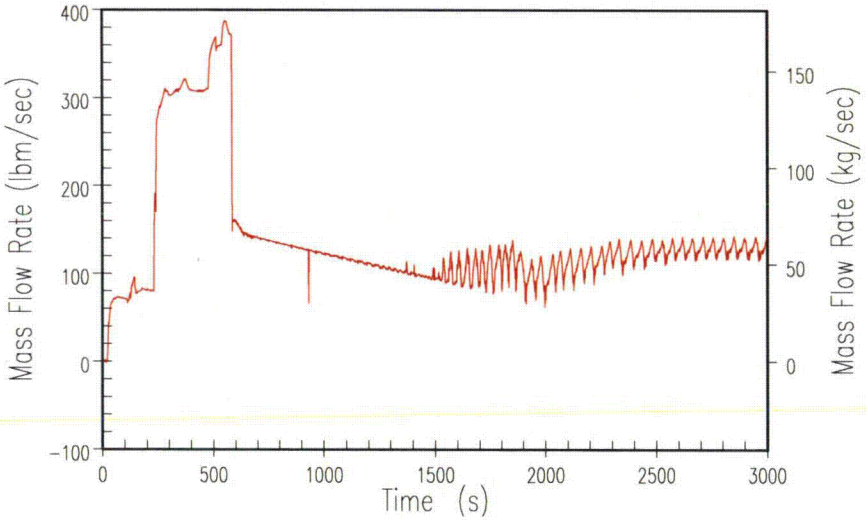


RCS Pressure

DEDVI Line Break (20 psi containment pressure)



Core/Upper Plenum Mixture Level



DVI-2 Injection Characteristics

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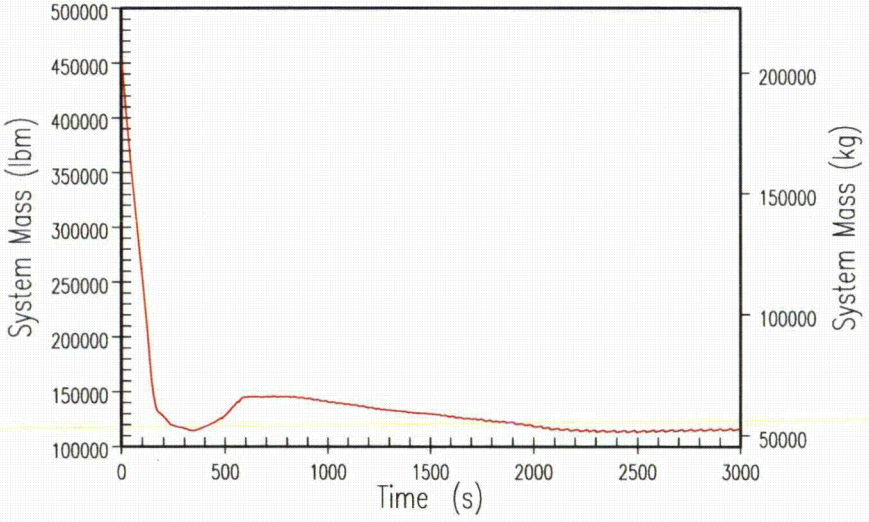
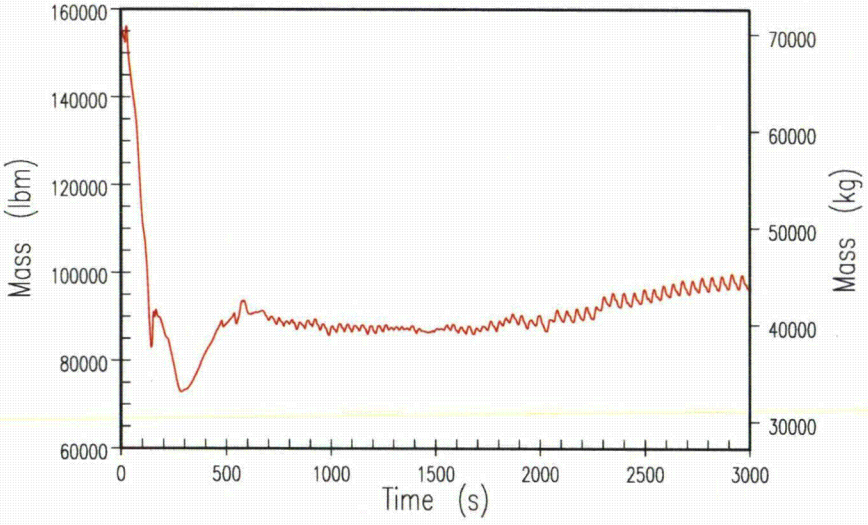
DEDVI Line Break (20 psi containment pressure)



RCS Inventory



Vessel Mixture Mass

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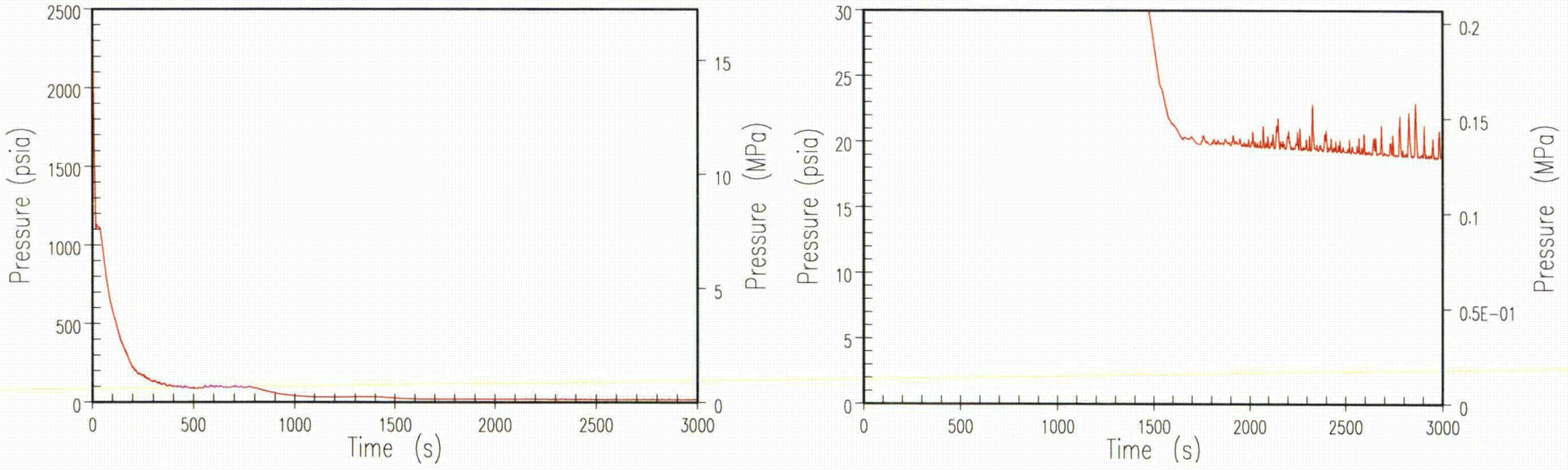
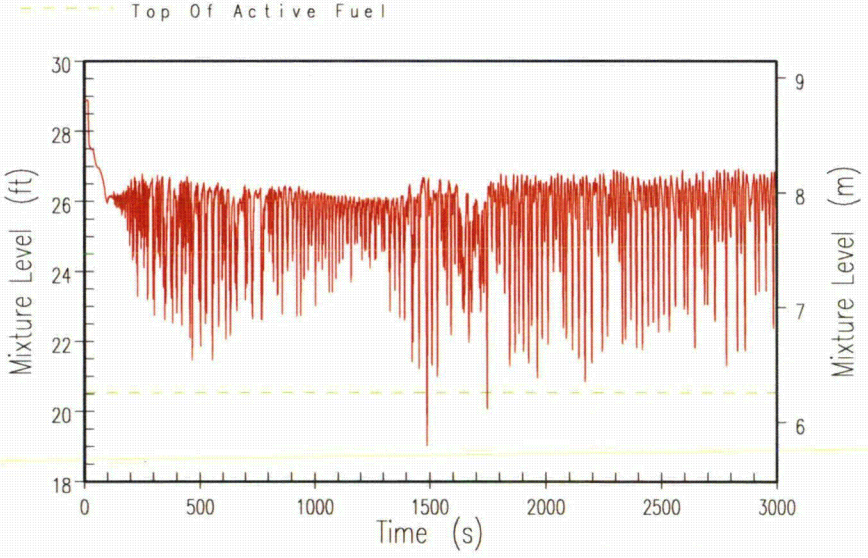
10 inch Cold Leg Break

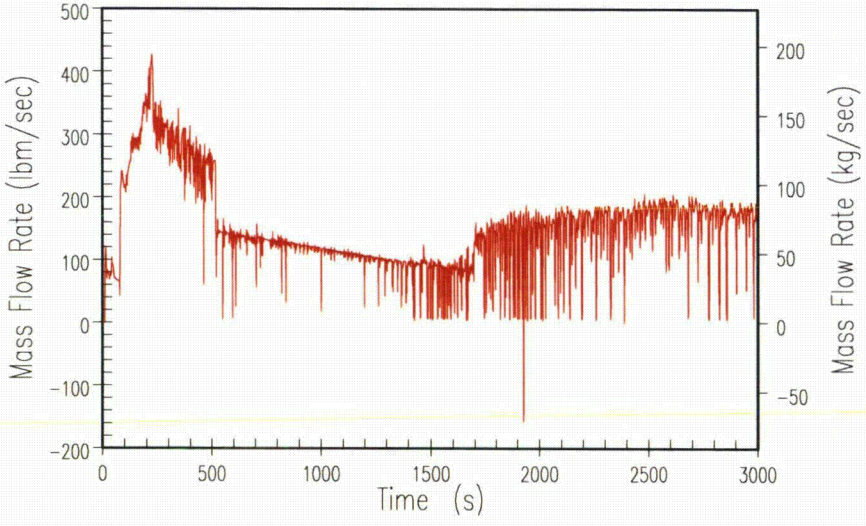


RCS Pressure

10 inch Cold Leg Break



Core/Upper Plenum Mixture Level



DVI-2 Injection Characteristics

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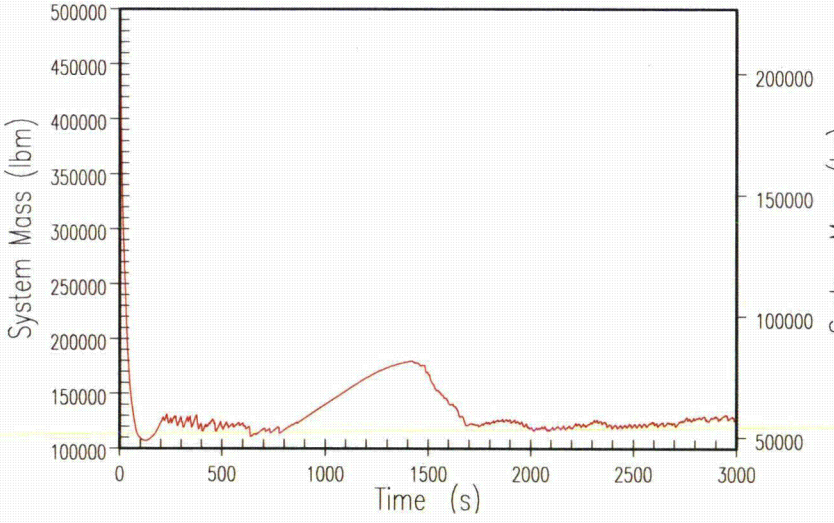
10 inch Cold Leg Break



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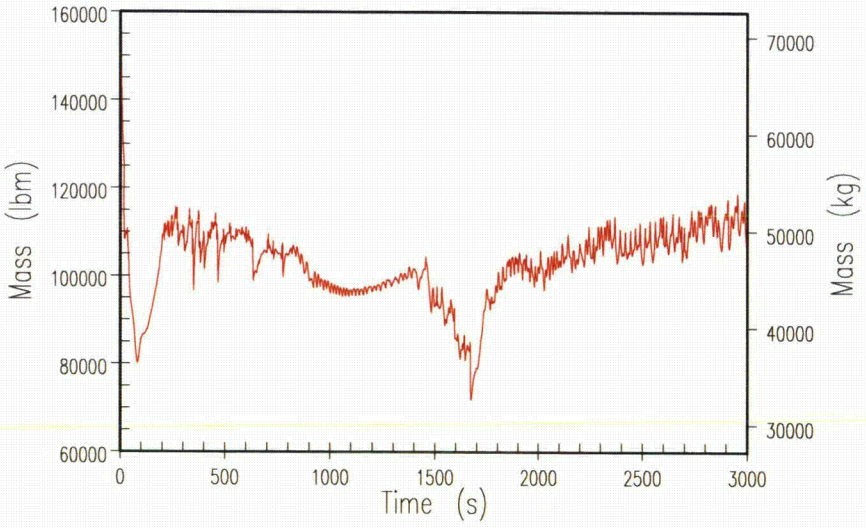

Vessel Mixture Mass

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Thermal Conductivity Degradation (TCD) Assessment

- The effects of TCD on SBLOCA for **AP1000** plant were previously assessed in LTR-NRC-12-56, LTR-NRC-12-86 and LTR-NRC-13-18
  - Core stored energy increases due to TCD do not affect SBLOCA due to the nature of the transients
  - Rod internal pressure effects on burst and blockage, if significant core uncovery and cladding heat-up predicted, accounted for as part of burn-up studies
  - CRR Rev. 0 transients did not result in core uncovery and therefore not affected by TCD
- Due to revision of the SBLOCA CRR results, the impact of TCD has been re-assessed
  - SBLOCA results are negligibly impacted when considering the effects of TCD
    - Initial core stored energy increase removed prior to uncovery
    - PCTs are low therefore fuel rod burst and blockage not a concern for **AP1000** SBLOCA

Conclusion

- Single-Failure on non-PRHR side ADS-4 discharge path more limiting
  - Affected Core Reference Report sections updated to reflect the limiting failure location
- Limited duration uncovery observed for small breaks
- Significant Margin to 10 CFR 50.46 PCT Limits

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