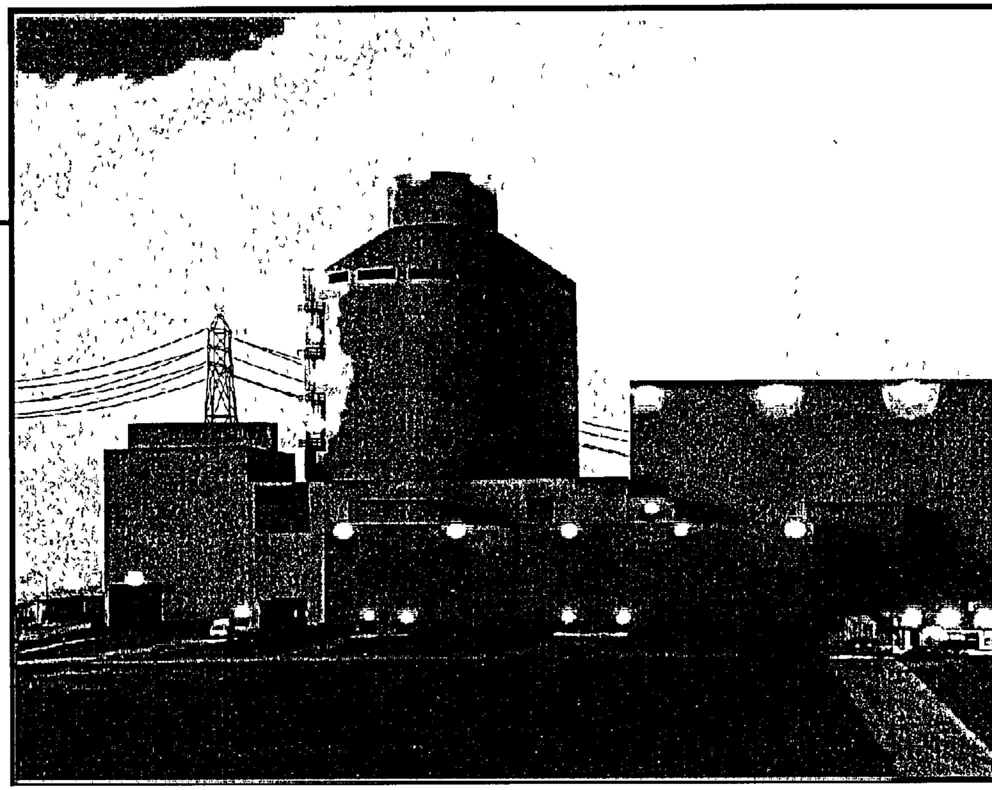


AP1000 Design Certification Review

Westinghouse Electric Company

Presentation to

Advisory Committee on Reactor Safeguards

Thermal-Hydraulics Sub-Committee

March 19 - 20, 2003

BNFL

Westinghouse

AP1000

Agenda

Wednesday March 19, 2003

- **Introduction** — **Graham Wallis, ACRS** — **8:30 am**
  - Review goals and meeting objectives
- **Summary of Pre-Application Review** — **John Segala, NRR** — **8:35 am**
  - Issues Identified during Pre-Application Review
  - Follow-on Issues
- **Resolution of Issues** — **Mike Corletti, Westinghouse** — **9:15 am**
  - Pre-Application Review Issues
  - Response to NRC RAI
  - ACRS Issues
- **BREAK** — **10:15 am**
- **Safety Analysis Results** — **Westinghouse** — **10:30 am**
  - Large-Break LOCA / Long-Term Cooling — Robert Kemper
  - Small Break LOCA — Andy Gagnon
  - Containment Analysis — Rick Wright
- **LUNCH** — **12:15 - 1:15 pm**

Agenda

Wednesday March 19, 2003

- **Status of NRC Staff Review** **NRR** **1:30 pm**
  - Pre-Application Review Issues
  - Follow-on issues
- **BREAK** **2:45 pm**
- **Importance of Liquid Entrainment in SB LOCA** **Westinghouse** **3:00 pm**
  - Summary of Liquid Entrainment Bill Brown
  - Discussion of WCAP-15833 Katsu Ohkawa, Robert Kemper, Rick Wright
- **Adjourn** **5:00 pm**

AP1000

Agenda

Thursday March 20, 2003

• **Introduction**	**Graham Wallis, ACRS**	**8:30 am**
– Review goals and meeting objectives		
• **Status of NRC Assessment of Liquid Entrainment**	**Steve Bajorek, RES**	**8:35 am**
– Issues Identified during Pre-Application Review		
– Follow-on Issues		
• **BREAK**		**10:15 am**
• **APEX-1000 Test Program**		**10:30 am**
– APEX-1000 Facility and Scaling	Jose Reyes, Oregon St. University	
– AP1000 Test Matrix	Bill Brown, Westinghouse	
– Results from Test Matrix #1	Rick Wright	
• **LUNCH**		**12:00 - 1:00 pm**
• **Summary of Future Actions**		**1:00 pm**
– Westinghouse Presentation	Mike Corletti, Westinghouse	
– NRC Presentation	NRR / RES	
• **General Discussion and Adjournment**	**ACRS Members**	**2:30 - 3:00 pm**

W Objectives of the Meeting

- **Provide a Presentation of AP1000 Safety Analysis Issues of Interest to the Committee**
  - LOCA / Containment
  - Treatment of Liquid Entrainment
  - Other RAI

Design Certification Schedule

Major Milestones

1. W Submits DCD Application (DCD / PRA)	3/28/02
2. Staff Issues RAI	9/30/02
3. W Provide Responses to All RAI	12/2/02
2. NRC Identify Potential DSER Open Items	2/28/03
4. W Addresses Potential DSER Open Items	4/15/03
5. NRC Issues DSER	6/16/03

W Goal is to Address All Open Items Prior to Issuance of DSER

6. ACRS Full Committee & Letter	7 / 2003

W OBJECTIVE IS TO PROVIDE THE NRC / ACRS WITH THE NECESSARY INFORMATION SO THAT A FINAL SAFETY DETERMINATION ON AP1000 CAN BE MADE IN 2003

ACRS Meetings

• **Pre-Certification Review**	**Three Meetings '01-'02**
• **Overview to Full Committee**	**November 7, 2002**
• **PRA Subcommittee**	**January 23-24, 2003**
• **Thermal-Hydraulic Subcommittee**	**March 19-20, 2003**
• **AP1000 Subcommittee**	**May & June 2003**
– Reliability of ADS-4 Squib valves	
– Containment structural design	
– Materials	
– Shutdown Maintenance	
– Man-Machine Interface Design	
• **ACRS Full Committee Meeting**	**July 2003**

AP1000

AP1000 Design Certification Status

Mike Corletti
AP600 & AP1000 Projects
412-374-5355 - corletmm@westinghouse.com

BNFL

Westinghouse

Phased Approach to AP1000 Licensing

- **Phase 1 (complete)**
  - Establish goals and estimate for Prelicensing Review
  - Westinghouse prepare submittals to support goals
- **Phase 2 (complete)**
  - NRC perform Pre-Certification Review
  - NRC estimate Cost and Schedule for AP1000 Design Certification
  - Westinghouse develop Safety Analysis Report
- **Phase 3 (in progress)**
  - NRC perform Design Certification Review

AP1000 Design Certification Application

Submitted March 28, 2002

- **AP1000 Design Control Document (DCD)**
  - Tier 1 Information
    - Inspections, Tests, Analysis and Acceptance Criteria (ITAAC)
  - Tier 2 - Information
    - Standard Safety Analysis Report
    - Technical Specifications
    - PRA Insights
- **AP1000 PRA Report submitted with application**
- **20 AP1000 Topical Reports have been submitted in support of Design Certification**

Results of Pre-Certification Review (Phase 2)

AP1000

- **SECY-02-0059**
  - Design Acceptance Criteria can be used for AP1000
    - Piping DAC approach is acceptable
      - DAC specifics will be performed as part of Design Certification
    - Structural Design will not use DAC
      - Structural design of nuclear island critical sections is performed
        - » Same approach as AP600
- **March 25th Letter to Westinghouse on Remaining Issues**
  - AP600 tests are applicable to AP1000
  - AP600 analysis codes validated to these tests can also be used for AP1000
    - Treatment of entrainment phenomenon in the upper plenum / hot leg in SBLOCA analysis will be addressed in Design Certification review
- **ACRS Letter Endorsing AP1000 Conclusions**

AP1000 Precertification Review
Westinghouse Position on Codes and Testing

AP1000

- **AP1000 introduces no new phenomena compared to AP600**
- **AP600 separate effects tests and integral effects tests are acceptably scaled to AP1000**
  - Upper plenum entrainment is a local effect that is self-limiting
- **Additional testing should not be required for code validation**
- **Westinghouse can apply safety analysis codes validated to AP600 tests for AP1000 Design Certification**

NRC Conclusions: Pre-Certification Review

- **Applicability of AP600 Test Program and Analysis Codes to the AP1000 Standard Design**
  - AP600 separate-effects and integral-system test programs are appropriate for use in support of the AP1000 analysis
  - Analysis codes validated for the AP600 design could be extended to the analysis of the AP1000 design
  - Plant response during ADS-4 operation
    - "AP600 integral tests do not provide data over the range of conditions necessary to validate entrainment models in the NOTRUMP and WCOBRA/TRAC codes used for SBLOCA analysis"

AP1000

Proposed Resolution Path

- **Treatment of upper plenum and hot leg entrainment for SB LOCA**
  - WCAP-15833 Rev 1 "WCOBRA/TRAC AP1000 ADS4/IRWST Phase Modeling"
    - Sophisticated analysis tool developed to assess importance of phenomenon not explicitly modeled in NOTRUMP
      - Momentum flux
      - Upper plenum and hot leg entrainment
      - Code validated against test data
    - Sensitivity studies performed to demonstrate importance of entrainment
      - » Variations in upper plenum noding
      - » Variations in upper plenum entrainment rate
      - » Variations in interfacial drag in upper plenum
      - » Variations of coefficients governing inception of hot leg entrainment
      - » Comparisons of WCOBRA-TRAC entrainment calculations to Kataoka-Ishii pool entrainment model
    - Results indicate AP1000 SBLOCA performance not sensitive to variations in upper plenum and hot leg entrainment
      - No core uncovery for spectrum of sensitivity studies
      - Small changes in predicted minimum system inventory
- **Issue still not resolved**

Additional NRC Open Items

Pre-Certification Review of Safety Analysis Codes

- **LOFTRAN**
  - Transient Analysis Code
  - AP1000 uses LOFTRAN code developed and approved for AP600
- **Pre-certification Open Item:**
  - Demonstrate ability of LOFTRAN code to evaluate potential steam voids within the reactor system following a main steamline break
    - Would larger steam generator result in a loss of RCS subcooling for main steam line break event
- **Open Item Resolved**
  - Main steam line break analysis performed for AP1000 with approved methodology
    - RCS subcooling maintained for DBA analysis

Additional NRC Open Items

AP1000

Pre-Certification Review of Safety Analysis Codes

- **NOTRUMP**
  - PRHR heat transfer model
- **Pre-Certification Open Item**
  - Demonstrate NOTRUMP PRHR heat transfer model is conservative over range of AP1000 conditions
- **Open Item Resolved**
  - Response to RAI provides comparison of NOTRUMP PRHR heat transfer predictions to test data
    - Additional details will be provided in SB LOCA analysis presentation

Additional NRC Open Items

AP1000

Pre-Certification Review of Safety Analysis Codes

- **NOTRUMP**
  - Staff did not review the methodology used to calculate peak clad temperature (PCT) in the event that the core becomes uncovered during a small break LOCA for AP600
- **Pre-Certification Open Item**
  - If core uncovery is predicted for SBLOCA - staff would review Westinghouse methodology for calculating PCT
- **Open Item Resolved**
  - SBLOCA analysis of 10-inch break case shows very high void
    - Analysis conservatively assumed core uncovery
    - Bounding analysis of PCT performed - Additional details will be provided in SB LOCA analysis presentation

Additional NRC Open Items

AP1000

Pre-Certification Review of Safety Analysis Codes

- **NOTRUMP**
  - Momentum flux model
- **Pre-Certification Open Item**
  - W proposed to implement ADS-4 subcritical flow resistance adjustment to account for lack of detailed momentum flux model
    - Similar methodology as approved for AP600
  - W also committed to perform a supplemental calculation of IRWST/ADS4 Phase of SBLOCA with WCOBRA/TRAC
- **Open Item Resolved**
  - WCAP-15833 provides results of supplemental calculation - Additional details will be provided in SB LOCA analysis presentation

Additional NRC Open Items

AP1000

Pre-Certification Review of Safety Analysis Codes

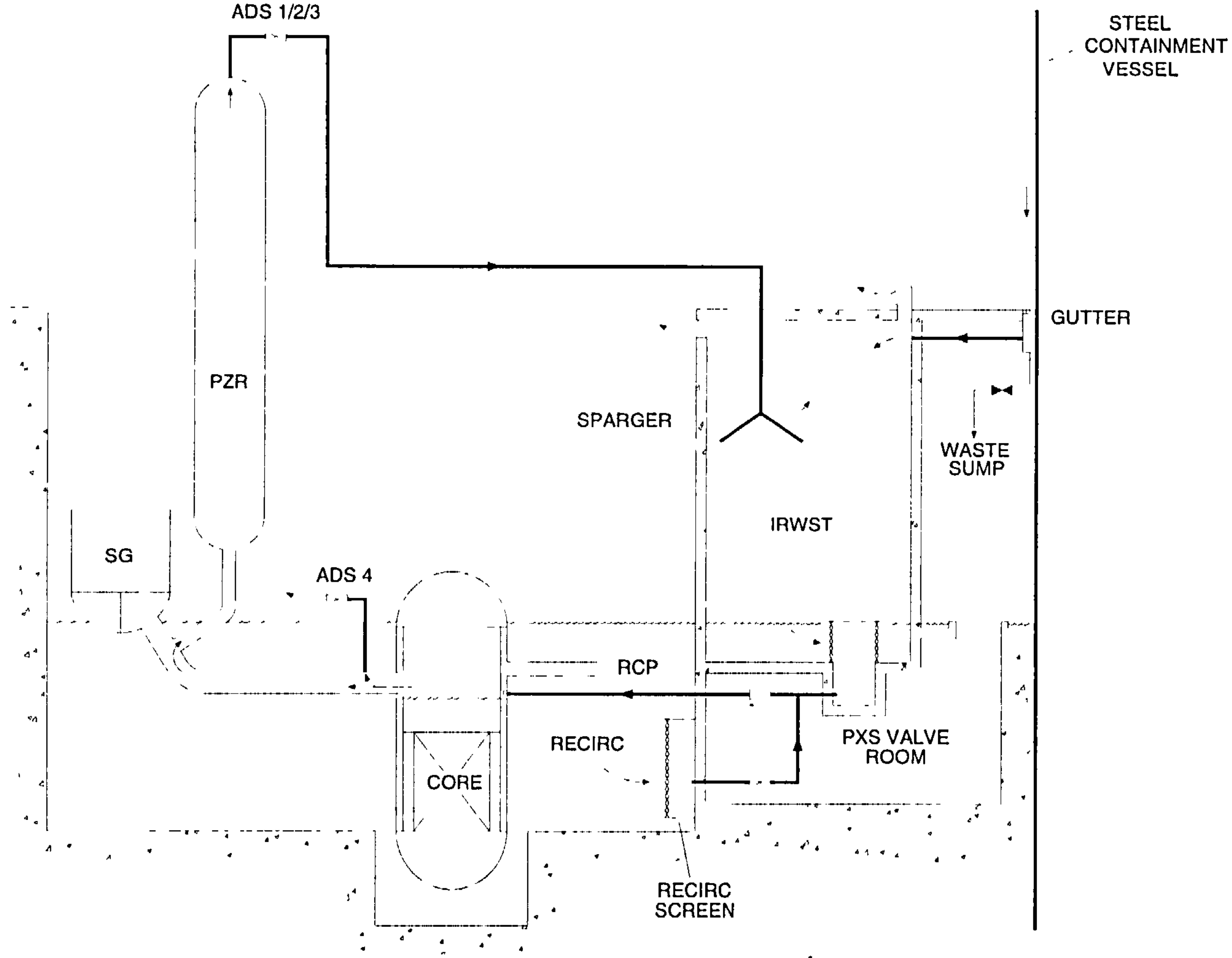
- **WGOTHIC**
  - Containment Analysis Code
  - AP1000 uses WGOTHIC code developed and approved for AP600
- **Pre-Certification Open Item**
  - Westinghouse needs to perform the WGOTHIC containment analyses with an evaluation model and appropriate boundary conditions to ensure that the mass and heat transfer correlations remain valid for the AP1000 design
- **Open Item Resolved**
  - Analysis performed in accordance with approved methodology

Additional NRC Open Items

Pre-Certification Review of Safety Analysis

- **Post-LOCA Boron Precipitation**
  - Westinghouse did not justify that the increased flow area of the ADS-4 would support the liquid expulsion to avoid boron precipitation in the vessel during long-term cooling
- **Open Item Resolved**
  - W performed a series of calculations and analysis to calculate post-LOCA boron concentration in the core and sump
    - Inputs from WCT Long-term cooling analysis
    - Conservative assumptions selected to maximize boron concentration in the core
      - Calculated peak boron concentration < 5500 ppm
      - Boron solubility limit ~ 35,000 ppm
  - RAI requested additional WCT Long-term cooling analysis
    - Additional calculation demonstrated large margin maintained

AP1000
LOCA Long-Term Cooling



Summary of W Responses to NRC Requests for Additional Information

AP1000

- 709 NRC Requests for Additional Information
- 188 Items Open (2/28/03)
- W / NRC are holding technical meetings to resolve issues
  - W has provided revised responses to > 100 RAI
- W will provide revised RAI responses for remaining items this month

Auxilliary Systems	21
Chemical technology	3
Component Integrity	29
Containment Systems	9
Effluent Treatment	11
Electrical Power Systems	15
Fire Protection	11
General	3
Geotechnical Engineering	3
Human Systems Interfaces	43
Hydrology	4
Inservice Inspection	3
ITAAC	1
Instrument and Controls	46
Materials Application	9
Mechanical Engineering	70
Meteorology	7
Quality Assurance	3
Radiation Protection	10
Radiological Impact	13
Reactor Systems	184
Reliability and Risk Assessment	98
Seismology	19
Structural Engineering	19
Tech Specs / Reliability Assuranc	53
USIs/GSIs	6
Pre-operational testing	16

Summary of T&H-Related RAI

- **Additional Accident Analysis**
  - Complete spectrum of SB LOCA
  - Shutdown accident analysis
    - LOCA
    - Loss of RNS cooling
    - Long-term operation of PRHR
- **ATWS Analysis**
  - Reduce unfavorable exposure time to zero
- **PRA Success Criteria Analysis**
- **Multiple Steam-Generator Tube Rupture Analysis**
- **Low-Temperature Overpressure Analysis**
  - Demonstrate Appendix G limits are met

AP1000 Large Break LOCA Analysis Summary

Robert M. Kemper
Advanced Technical Engineer
Westinghouse Electric Company
(412) 374-4579 - kemperrm@westinghouse.com

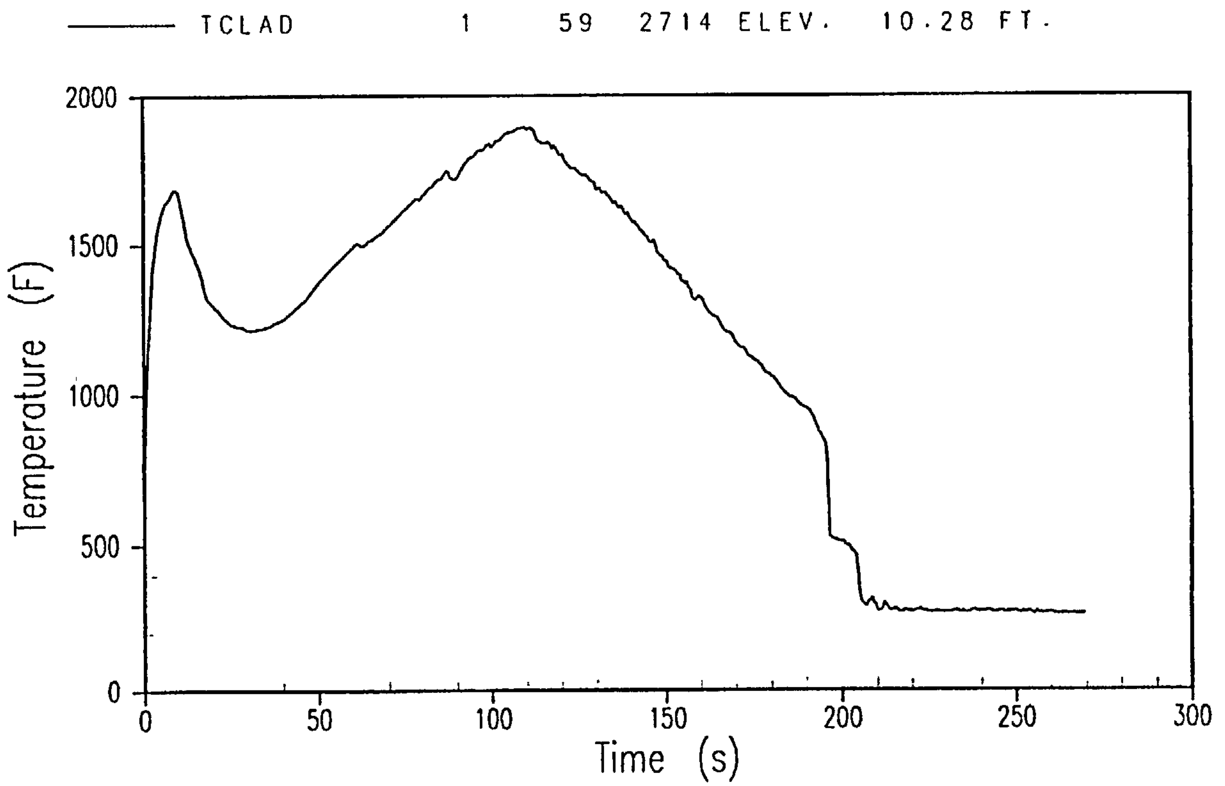
BNFL

Westinghouse

AP1000 Large Break LOCA Analysis Summary

- **AP600 Methodology Reviewed & Approved in AP600 Design Certification (NUREG 1512)**
- **AP1000 LBLOCA Analysis Follows the AP600-Approved Methodology**
  - Approved in the AP1000 Pre-Certification Review provided that the NUREG-1512 limitations were addressed
  - Limitations from NUREG-1512 have been observed

AP1000 Large Break LOCA Analysis Summary



AP1000 Hot Rod Cladding Temperature, Reference Transient, PCT Elevation

AP1000 Large Break LOCA Analysis Summary

AP1000 Best-Estimate Large-Break LOCA Results

Parameter	Value	Criteria
Calculated 50th percentile PCT (°F)	1840	N/A
Calculated 95th percentile PCT (°F)	2124	2200
Maximum cladding oxidation (%)	12.7	17
Maximum hydrogen generation (%)	0.73	1
Coolable geometry	Core remains coolable	Core remains coolable
Long-term cooling	Core remains cool in long term	Core remains cool in long term

AP1000 Large Break LOCA Analysis Summary

AP1000

- **Limitations from NUREG-1512 Have Been Observed in the AP1000 LBLOCA Analysis**
  - Approval restrictions carried over from the 3/4 loop plant methodology
  - AP600-related restrictions
    - Global model matrix and 95th percentile PCT calculations performed
    - PCT sensitivity to PRHR/CMT elimination established
    - 10CFR50.46 oxidation criteria calculated using approved methods

AP1000 Large Break LOCA Analysis Summary

AP1000

- **RAI Responses**
  - An expanded DCD Section 15.6.5.4A presentation of the LBLOCA analysis
  - Continuation of the LBLOCA transient out to IRWST actuation time

AP1000

AP1000 LOCA Long-Term Cooling Analysis Summary

Robert M. Kemper
Advanced Technical Engineer
Westinghouse Electric Company
(412) 374-4579 - kemperrm@westinghouse.com

BNFL

Westinghouse

AP1000 LOCA Long-Term Cooling Analysis Summary

AP1000

- **The WCOBRA/TRAC Methodology Developed and Approved for AP600 Is Used**
- **Limitations of NUREG-1512 Are Observed in the AP1000 Long-Term Cooling Analysis**
  - Nodalization continues to be that used in the validation calculations of several OSU APEX facility tests
  - Window–Mode Approach long-term cooling transient case exhibits a steady-state solution
  - No core dryout or heatup is predicted to occur for AP1000

AP1000 LOCA Long-Term Cooling Analysis Summary

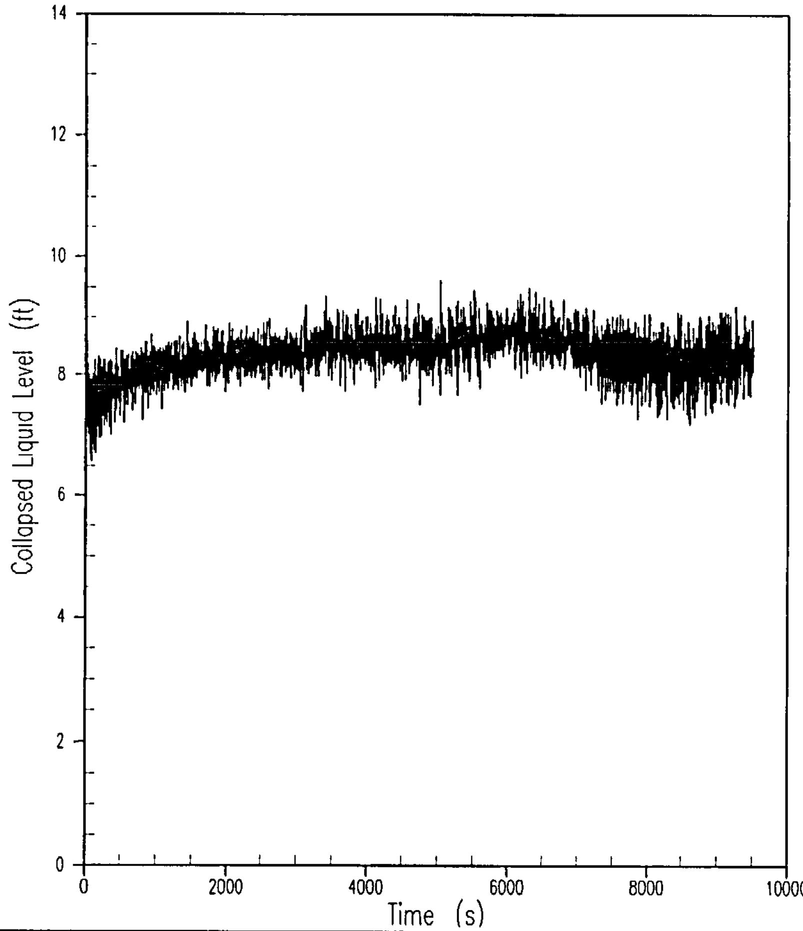
- **The Limiting Cases from the AP600 DCD Are Analyzed**
  - DEDVI line break
  - Wall-to-wall floodup case (window-mode approach)

  For AP1000, the DEDVI line break case is executed continuously from end of NOTRUMP onward through the start of containment recirculation

AP1000 LOCA Long-Term Cooling Analysis Summary

AP1000

- **LTC Analysis DEDVI Break Core Liquid Level**



AP1000

AP1000 Small Break LOCA Analysis

Andre F. Gagnon
LOCA Integrated Services
(412) 374-5574; gagnonaf@westinghouse.com

BNFL

Westinghouse

AP1000 NOTRUMP

- **NOTRUMP Open Items From Pre-Certification Review**
  - ADS-4 Momentum Flux Issue
  - Upper Plenum/Hot Leg Entrainment
  - PRHR Heat Transfer
  - Non-Condensable Gas Treatment
  - Core Uncovery Treatment

AP1000

AP1000 NOTRUMP (Momentum Flux)

- **ADS-4 Momentum Flux**
  - Address ADS-4 pressure drop in a more direct manner
    - Utilize ADS-4 resistance adjustment in lieu of IRWST Level Penalty
      - Standalone model of AP1000 ADS-4 path generated to determine resistance adjustment
        - » Based on RAI 440.796f, Part-a methodology
        - » 70% adjustment to post-critical flow loss coefficient
    - ADS-4 resistance implementation demonstrated to significantly improve fidelity with test data

AP1000 NOTRUMP (WCT Supplemental Calculation)

- **Perform supplementary calculation with WCOBRA/TRAC (WCT) for ADS-4 - IRWST initiation phase**
  - Code contains momentum flux in momentum equation
    - Addresses ADS-4 modeling
  - Code contains upper plenum and hot leg entrainment models
  - Code contains horizontal flow models

AP1000 NOTRUMP (WCT Supplemental Calculation)

- **Supplementary WCT calculation (Continued)**
  - Demonstrate that adjusted NOTRUMP model provides conservative prediction of AP1000 behavior during ADS-4/IRWST initiation phase
    - NOTRUMP provides a conservative representation of IRWST injection

WCOBRA/TRAC Predictions vs. NOTRUMP

- **WCOBRA/TRAC Comparison to NOTRUMP**
  - Breaks simulated
    - DEDVI Line break
    - Inadvertent ADS actuation scenario
  - WCOBRA/TRAC predicts much greater entrainment through the ADS-4 flow paths
  - WCOBRA/TRAC depressurization occurs more rapidly due to the restrictive NOTRUMP flow modeling

AP1000

WCOBRA/TRAC Predictions vs. NOTRUMP

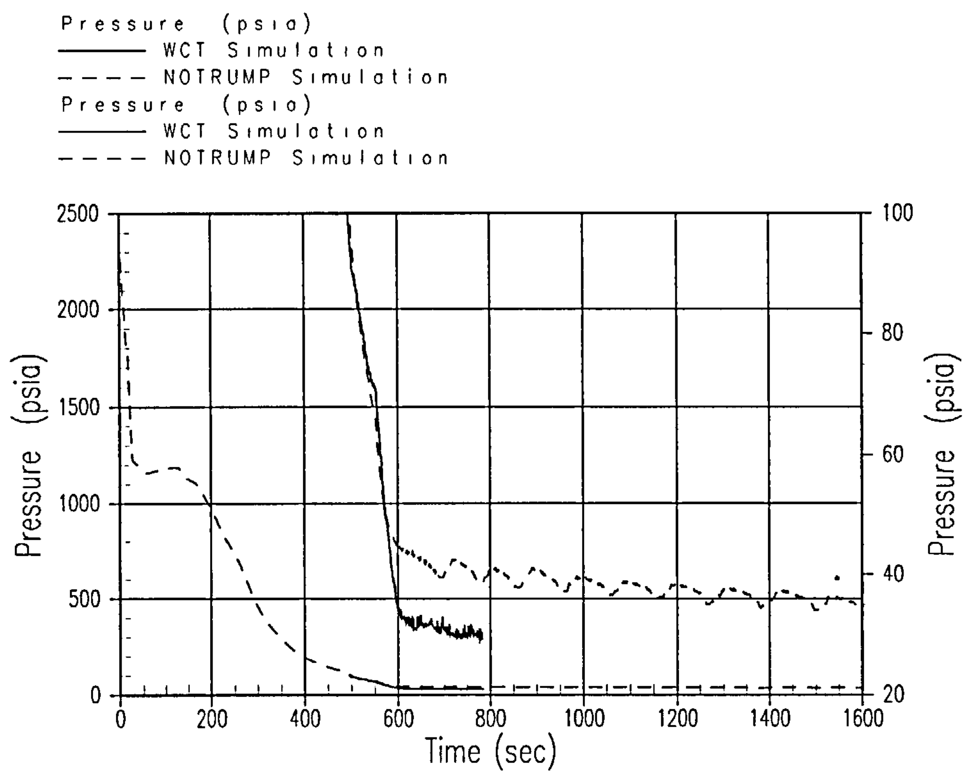


Figure 3-9 AP1000 DEDVI Break Downcomer Pressure

WCOBRA/TRAC Predictions vs. NOTRUMP

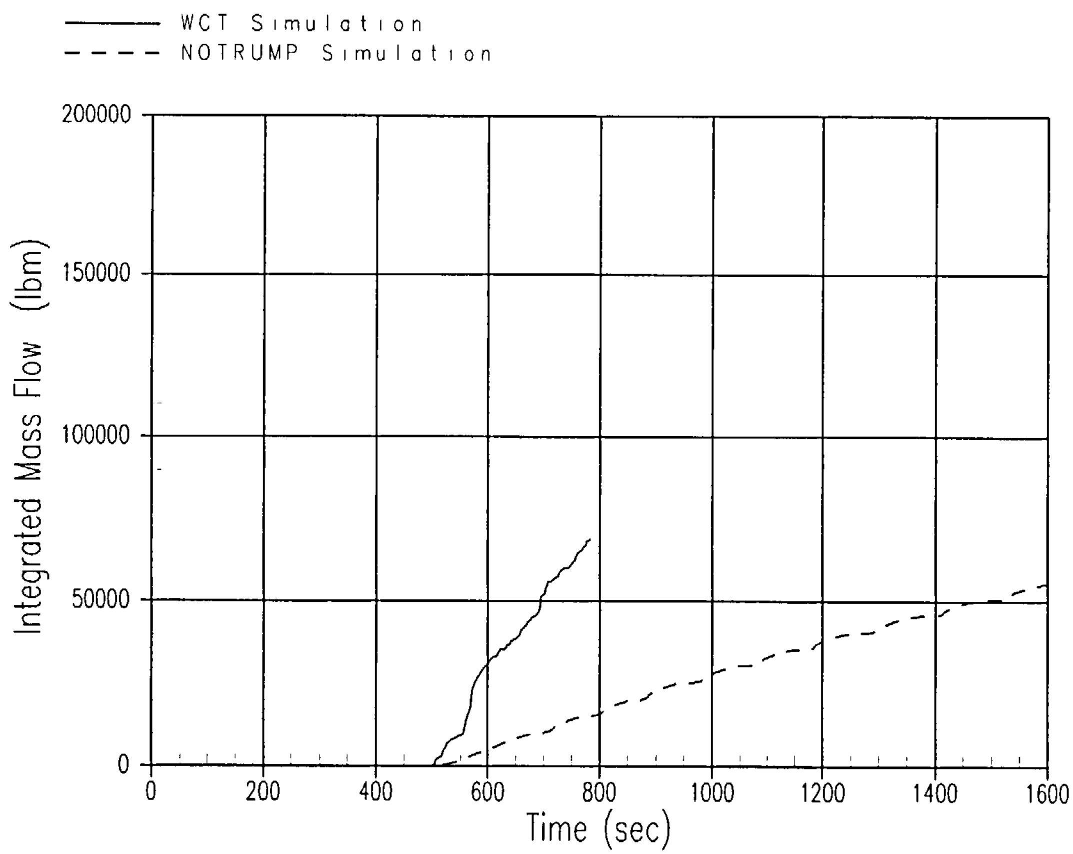


Figure 3-12 AP1000 DEDVI Break Intact Loop ADS-4 – Integrated Liquid Flow

WCOBRA/TRAC Predictions vs. NOTRUMP

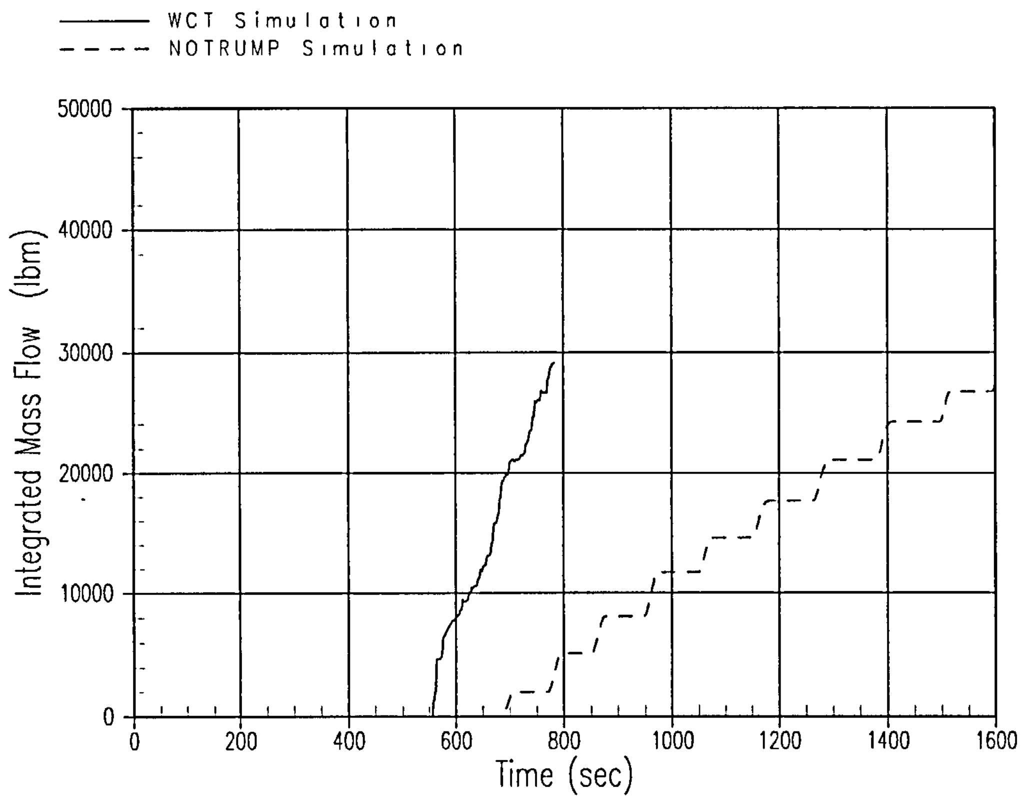


Figure 3-14 AP1000 DEDVI Break Single Failure Loop ADS-4 – Integrated Liquid Flow

WCOBRA/TRAC Predictions vs. NOTRUMP

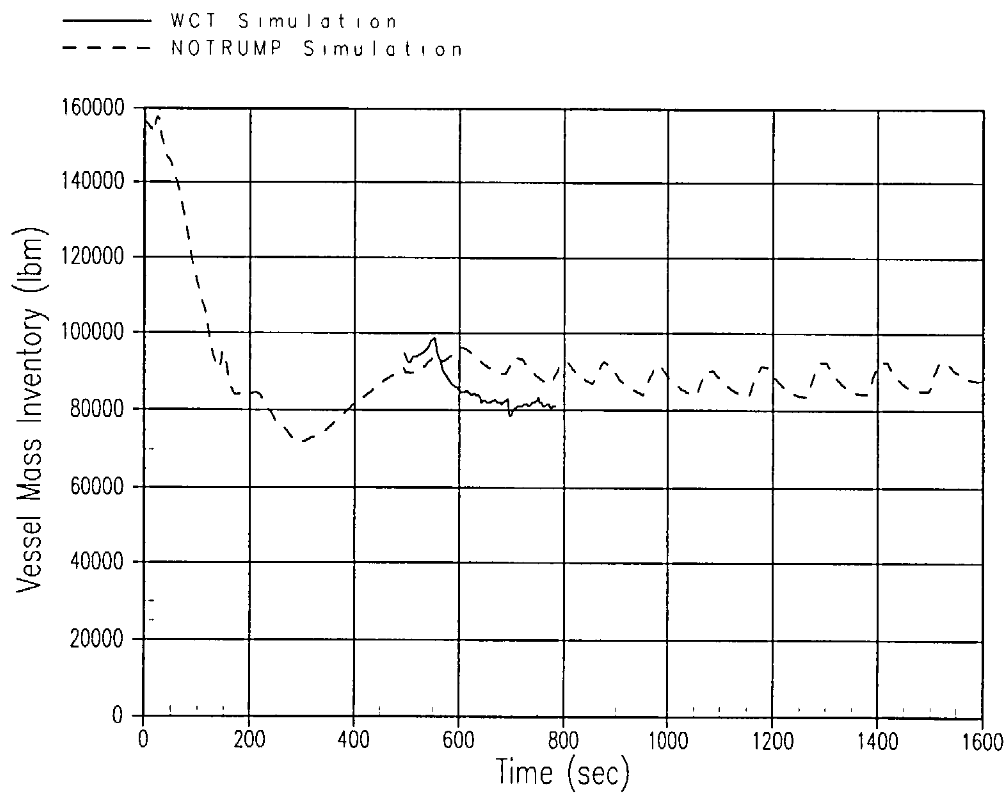


Figure 3-16 AP1000 DEDVI Break Vessel Mass Inventory

WCOBRA/TRAC Predictions vs. NOTRUMP

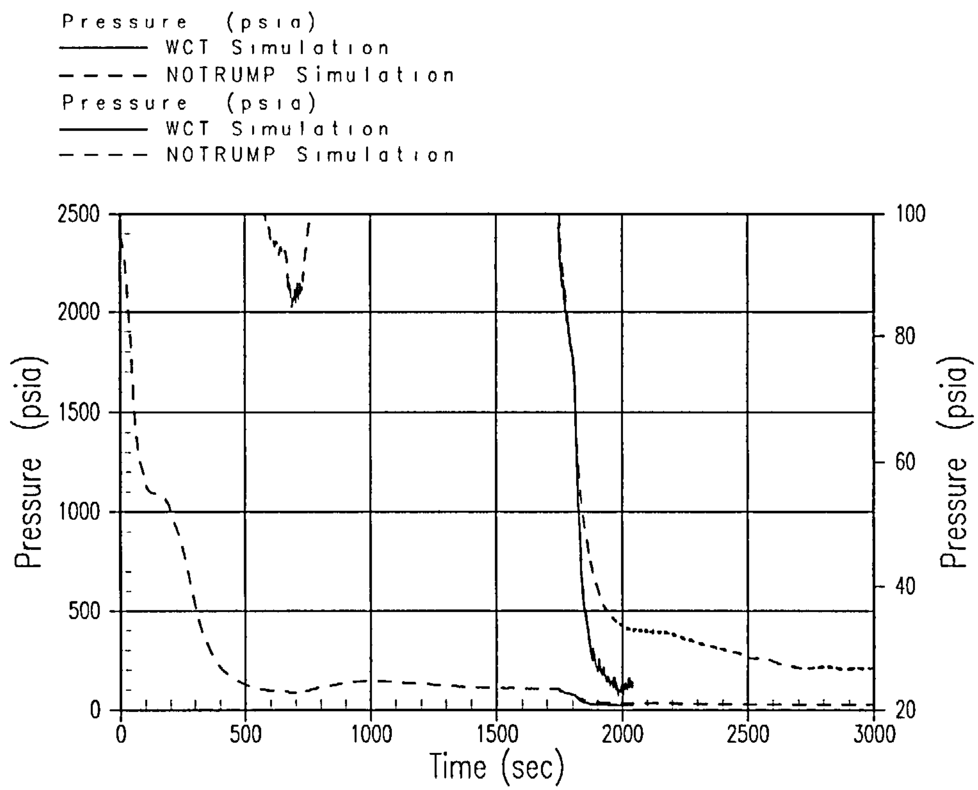


Figure 3-18 AP1000 Inadvertent ADS Actuation Scenario – Downcomer Pressure

WCOBRA/TRAC Predictions vs. NOTRUMP

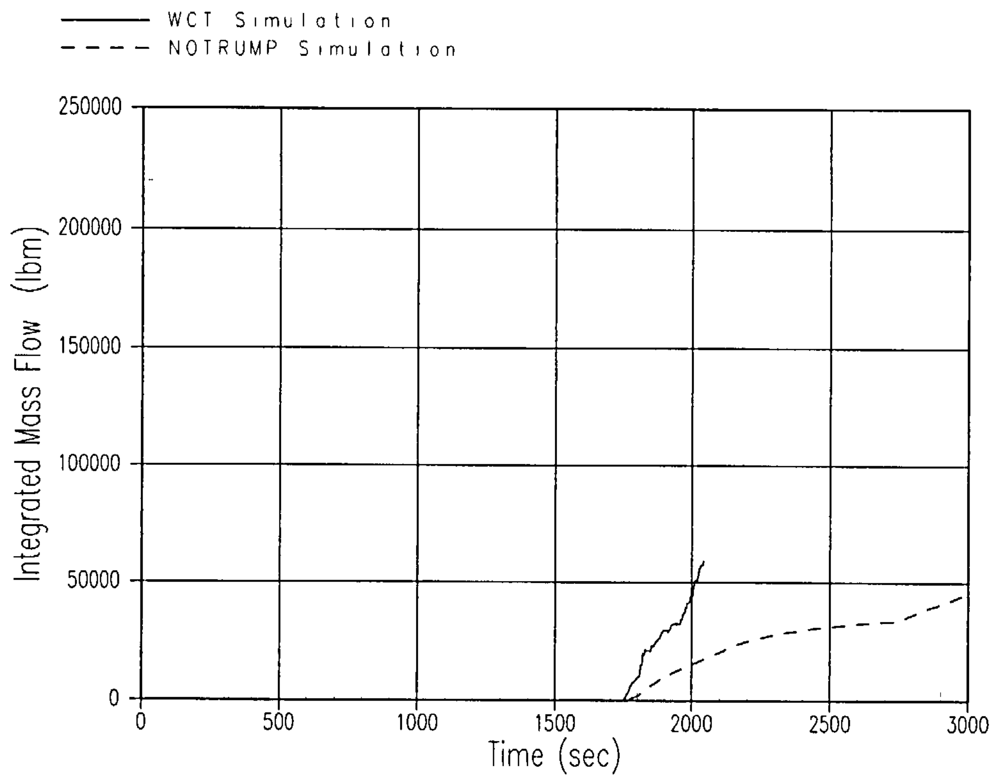


Figure 3-21 AP1000 Inadvertent ADS Actuation Scenario Intact Loop ADS-4 – Integrated Liquid Flow

WCOBRA/TRAC Predictions vs. NOTRUMP

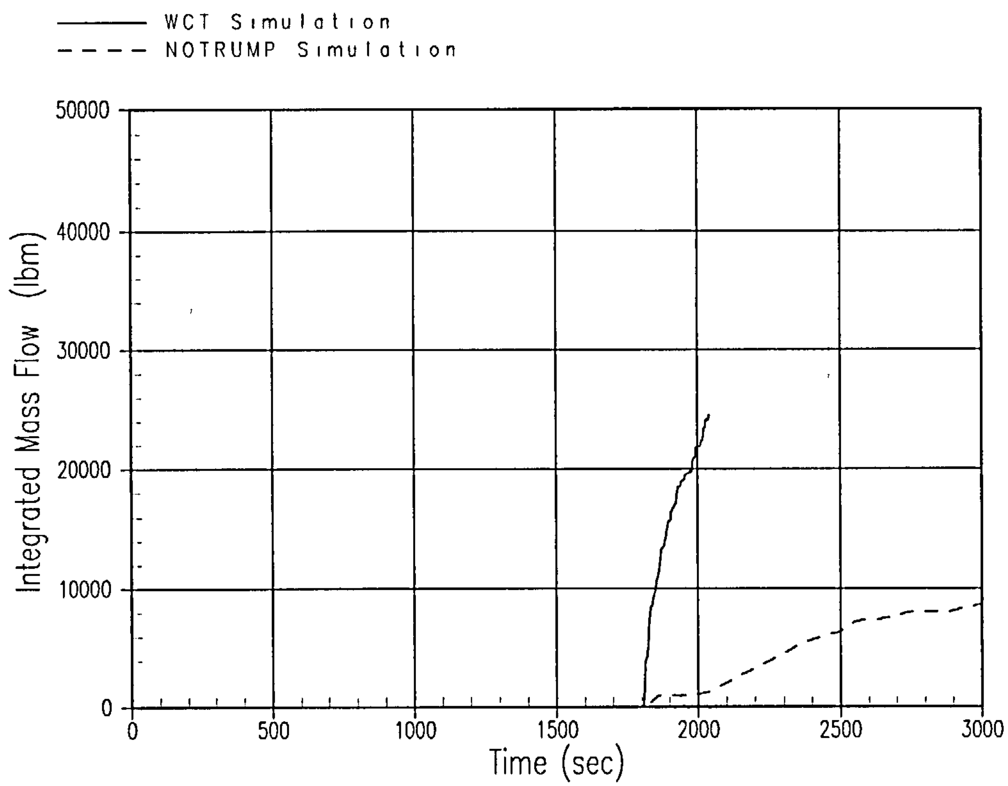


Figure 3-23 AP1000 Inadvertent ADS Actuation Scenario Single Failure Loop ADS-4 – Integrated Liquid Flow

WCOBRA/TRAC Predictions vs. NOTRUMP

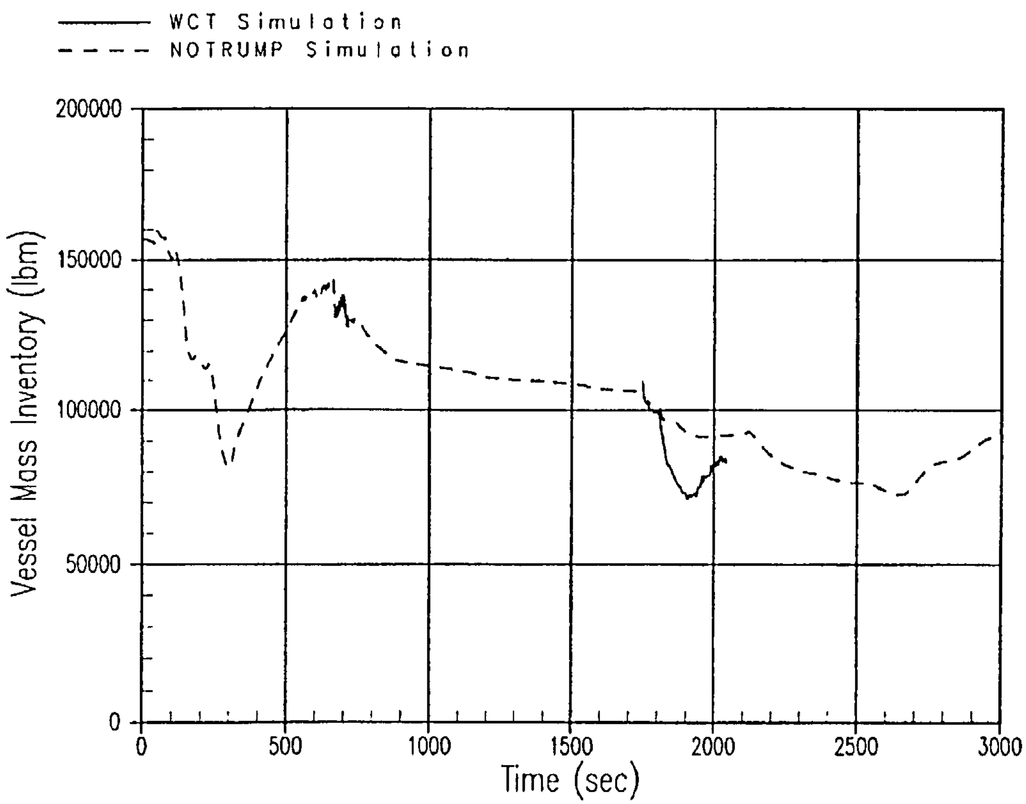


Figure 3-25 AP1000 Inadvertent ADS Actuation Scenario Break Vessel Mass Inventory

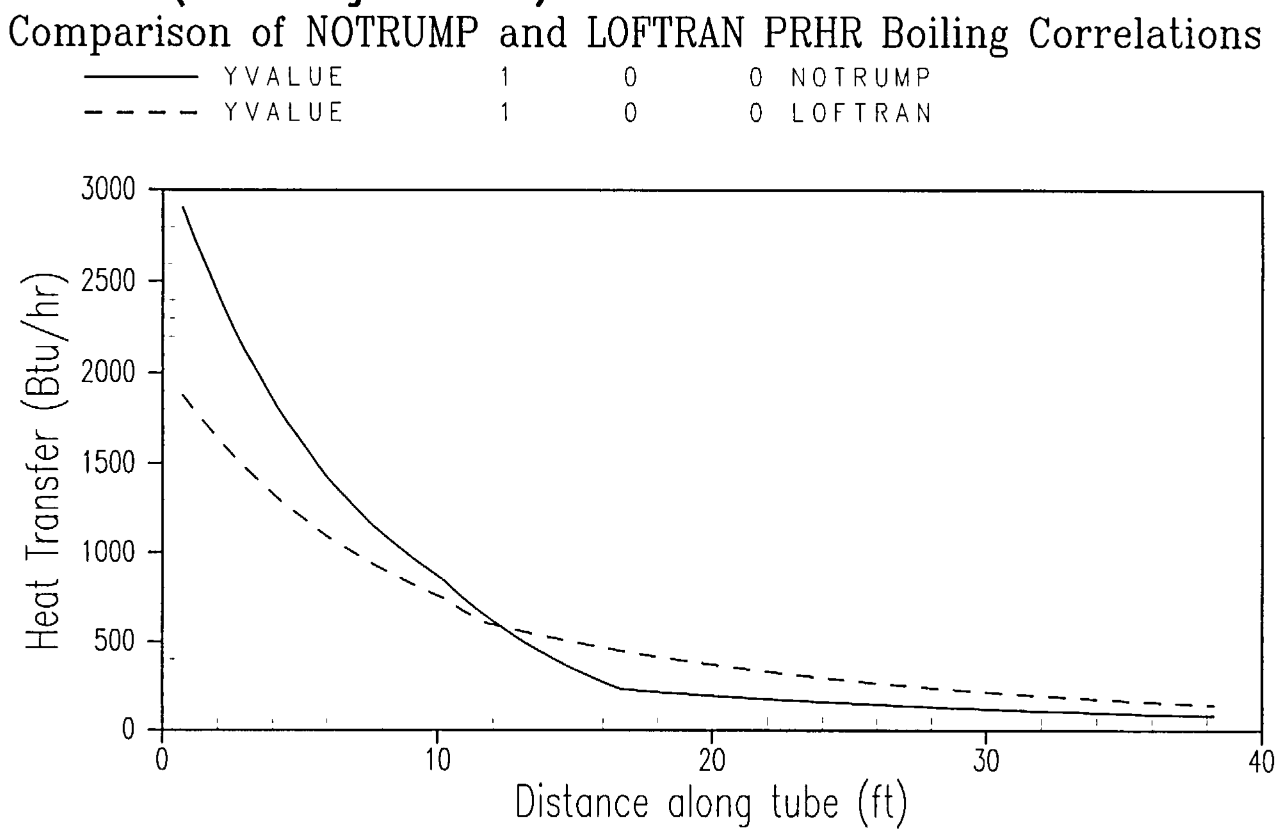
AP1000

AP1000 NOTRUMP (PRHR HTA)

- **PRHR Heat Transfer**
  - Demonstrate NOTRUMP PRHR heat transfer model conservative compared to test data
    - NOTRUMP model did not incorporate revised Rosenhow correlation
    - NOTRUMP model conservative when adjusted
      - RAI 440.054 presents details that support this conclusion

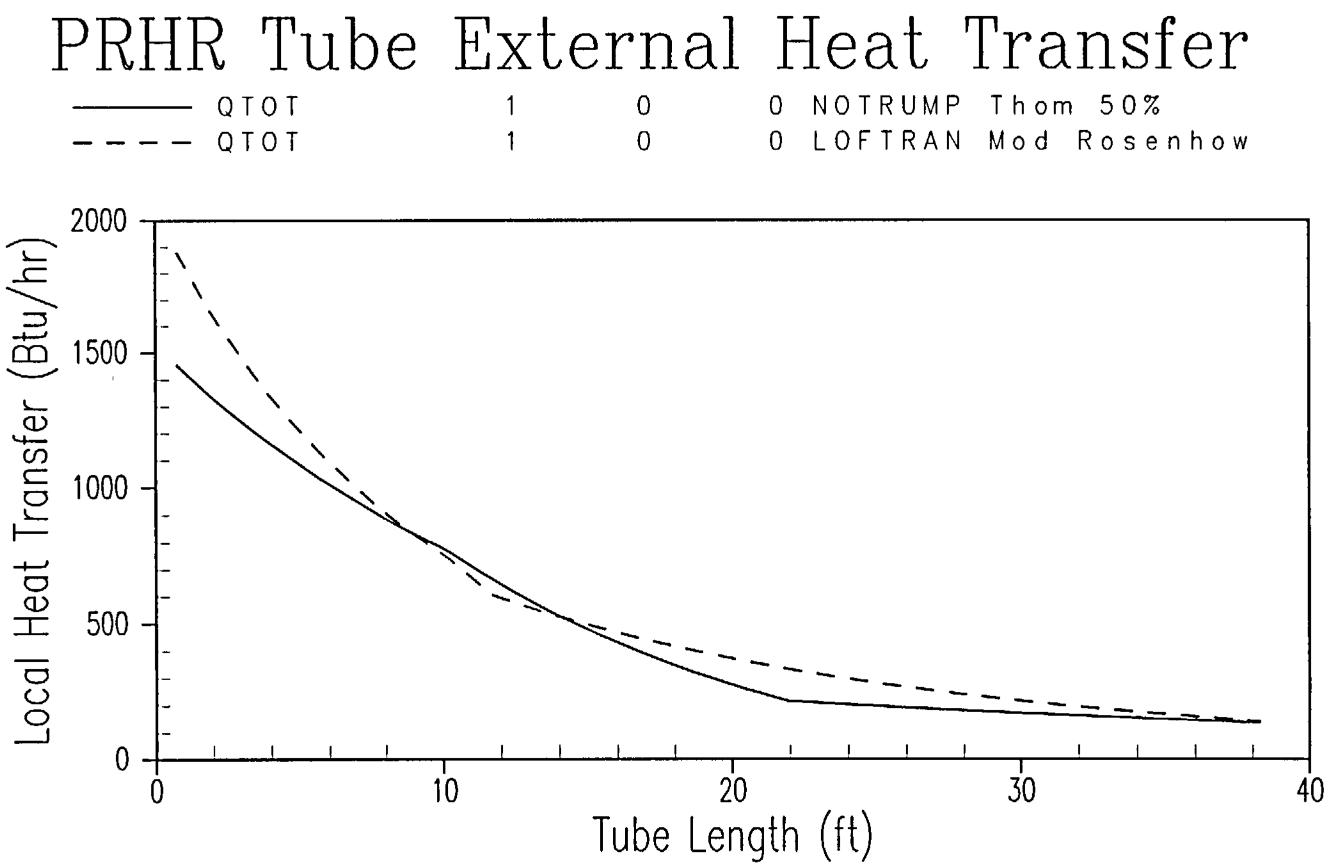
AP1000 NOTRUMP (PRHR HTA)

Single Phase (Unadjusted)



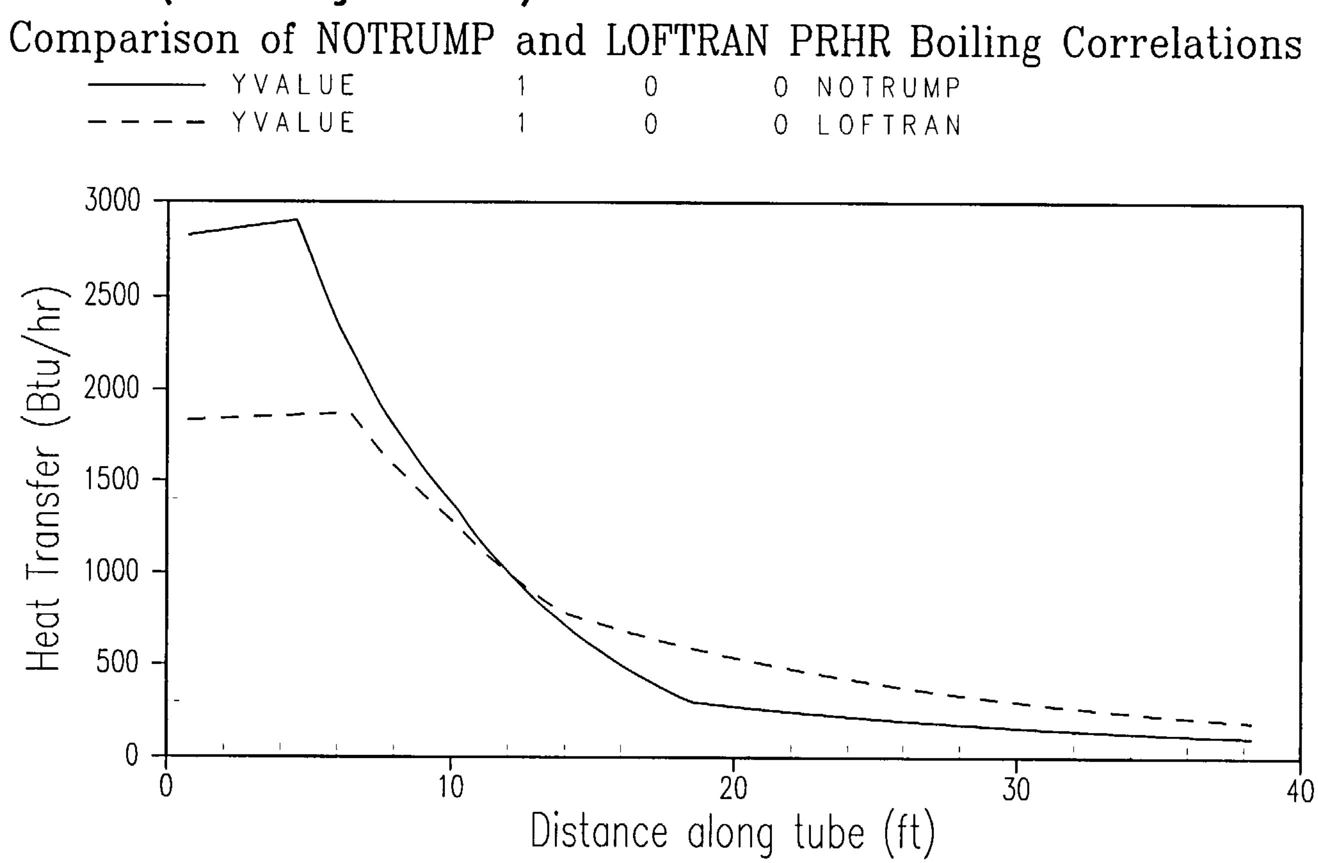
AP1000 NOTRUMP (PRHR HTA)

Single Phase (Adjusted)



AP1000 NOTRUMP (PRHR HTA)

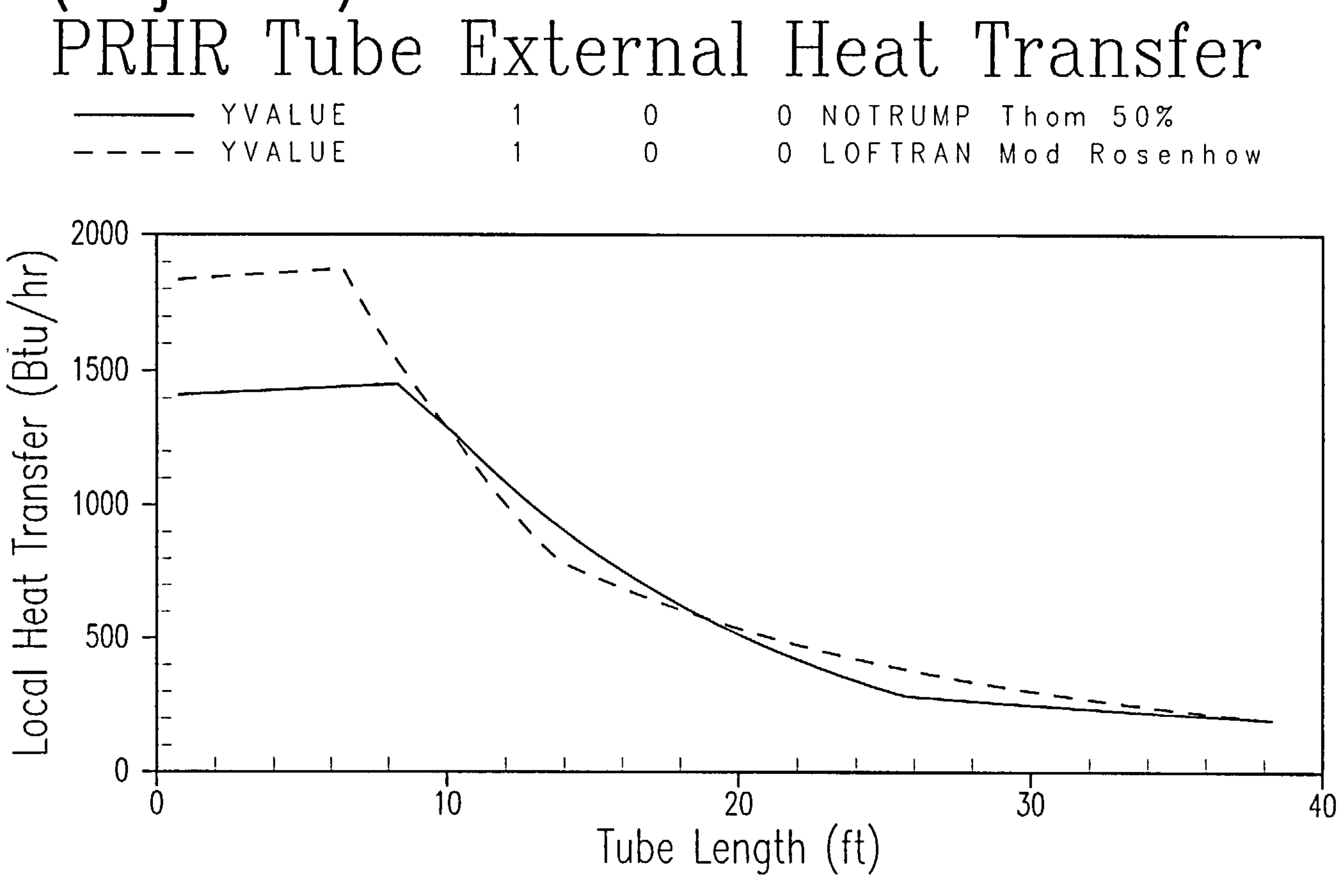
Two Phase (Unadjusted)



AP1000 NOTRUMP (PRHR HTA)

AP1000

Two Phase (Adjusted)



AP1000 NOTRUMP (NC Gases)

- **Non-Condensable Gas Issue**
  - PRHR model removed when possibility of non-condensable gas injection encountered
    - Typically intact accumulator empty time
  - Same methodology utilized as for AP600

AP1000 NOTRUMP (Core HT Models)

- **Core Uncovery Treatment**
  - Staff had not reviewed NOTRUMP core heat transfer package under core uncovery conditions
    - AP600 did not uncover except for 10-Inch Cold Leg Break
  - Heat transfer package unchanged from standard evaluation model

AP1000 NOTRUMP (Core HT Models)

- **Core Uncovery Treatment (Continued)**
  - AP1000 10-Inch break does not uncover
    - High void period encountered during initial blowdown
      - >90 percent void fraction
        - » Composite core level created
      - Adiabatic heat-up calculation performed to conservatively estimate cladding temperature
        - » PCT < 1370 F

2-Inch Cold Leg Break (CLB) Results Comparisons

AP1000

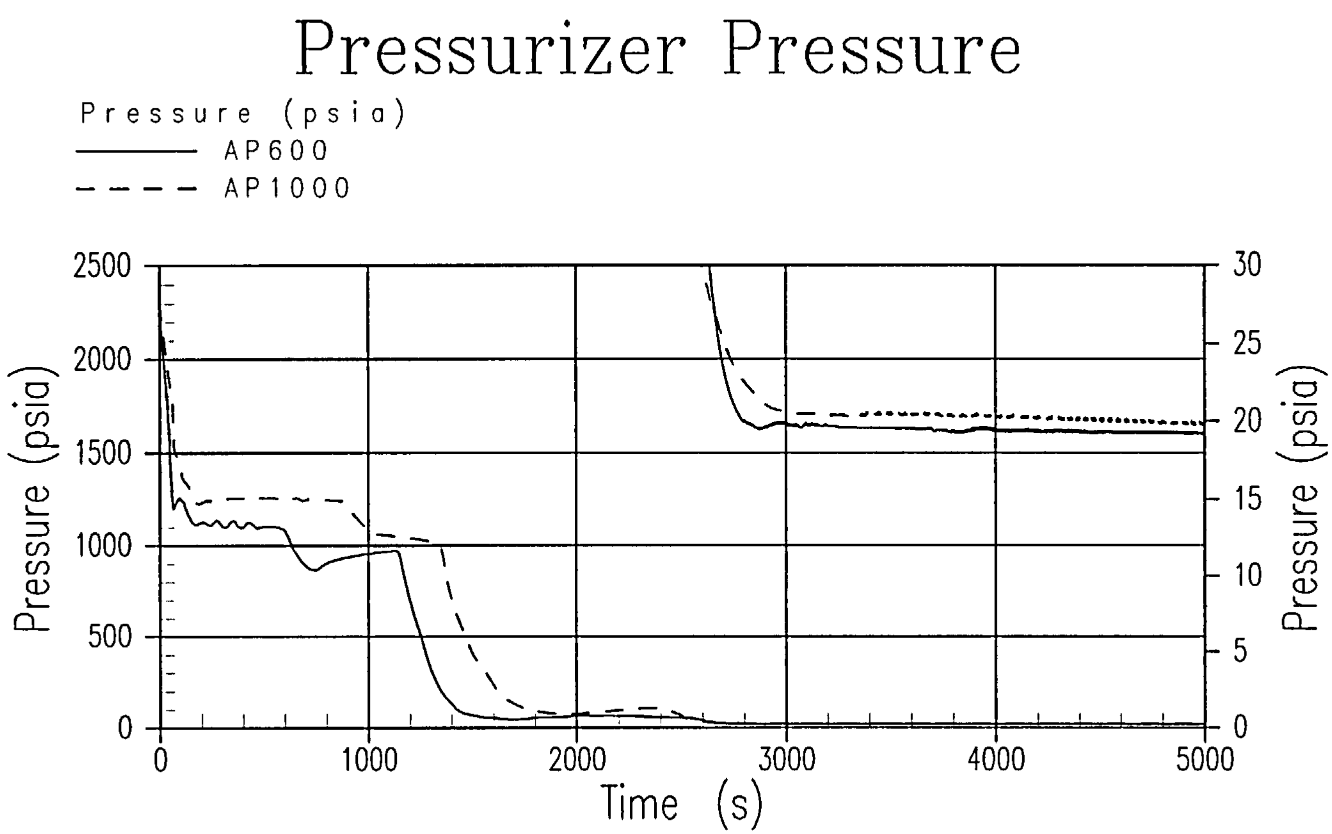
Event	AP600 (DCD)	AP1000 (DCD)
Break opens	0.0	0.0
Reactor trip	33.3	54.7
"S" signal	39.5	61.9
MFW Isolation	44.5	63.9
RCP Trip	55.7	67.9
ADS 1	1138	1334
ACC Injection	1200	1405

2-Inch CLB Results Comparisons

Event	AP600 (DCD)	AP1000 (DCD)
ADS 2	1208	1404
ADS 3	1328	1524
ACC Empty	1575	1940
ADS 4	2522	2419
CMT empty	2920	2895
IRWST Injection	3560	3280

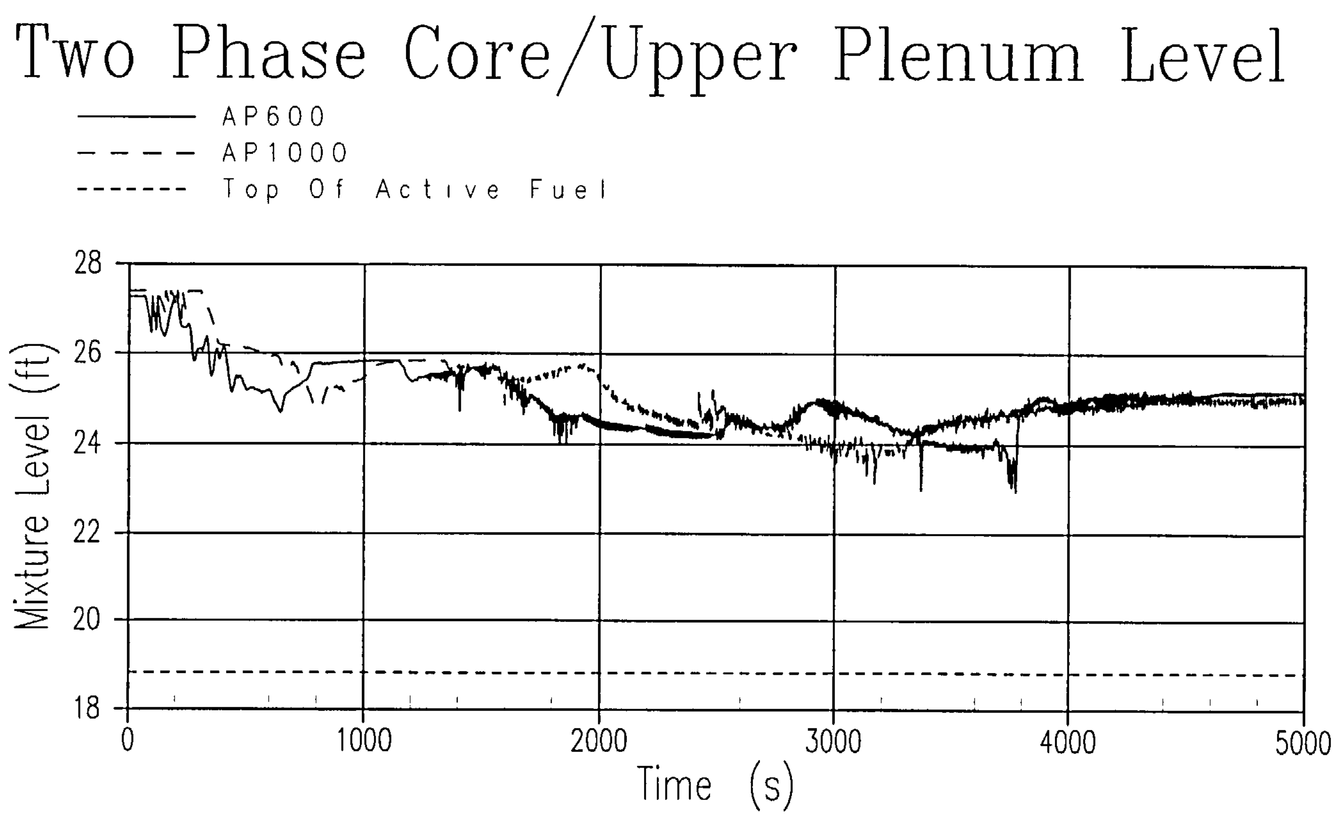
2-Inch CLB Results (AP600 vs. AP1000)

AP1000

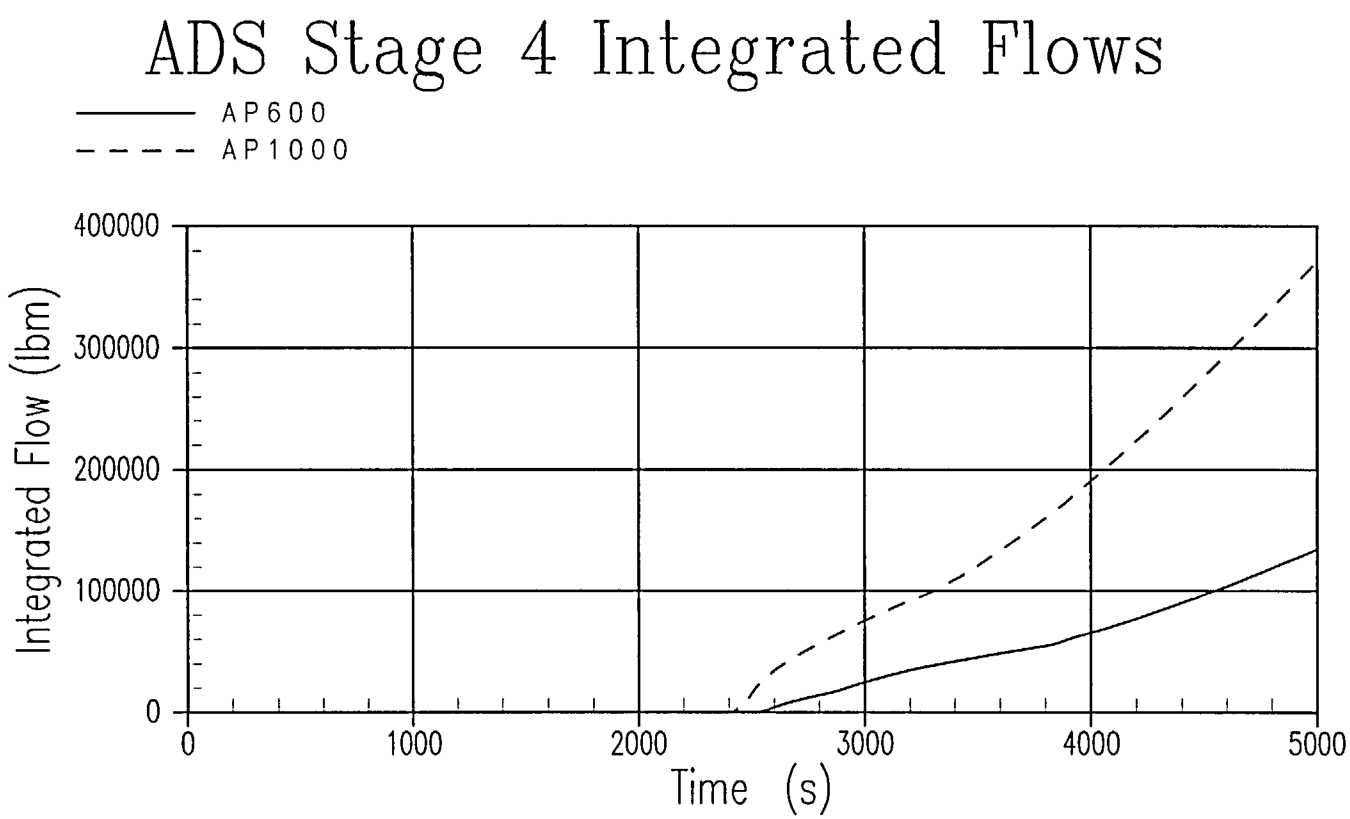


2-Inch CLB Results (AP600 vs. AP1000)

AP1000

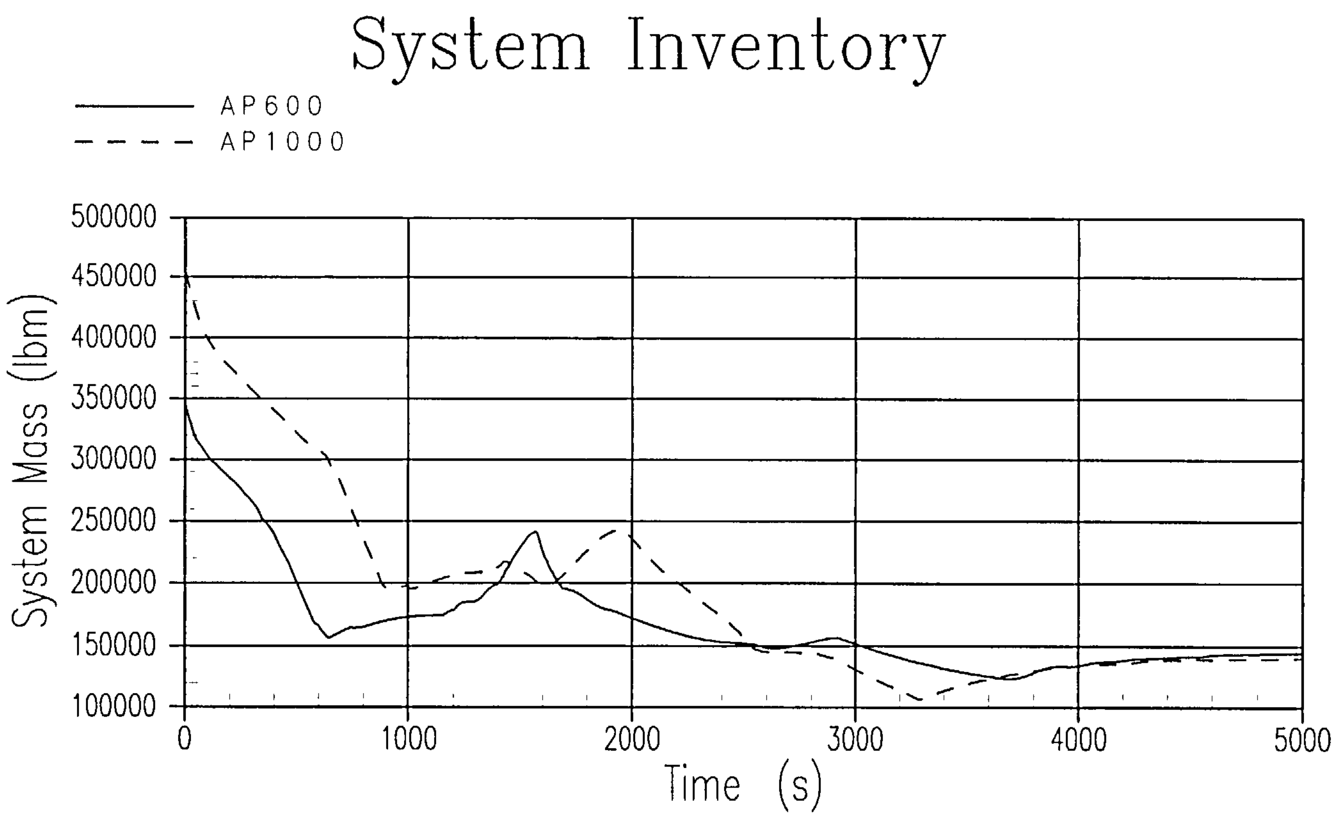


2-Inch CLB Results (AP600 vs. AP1000)



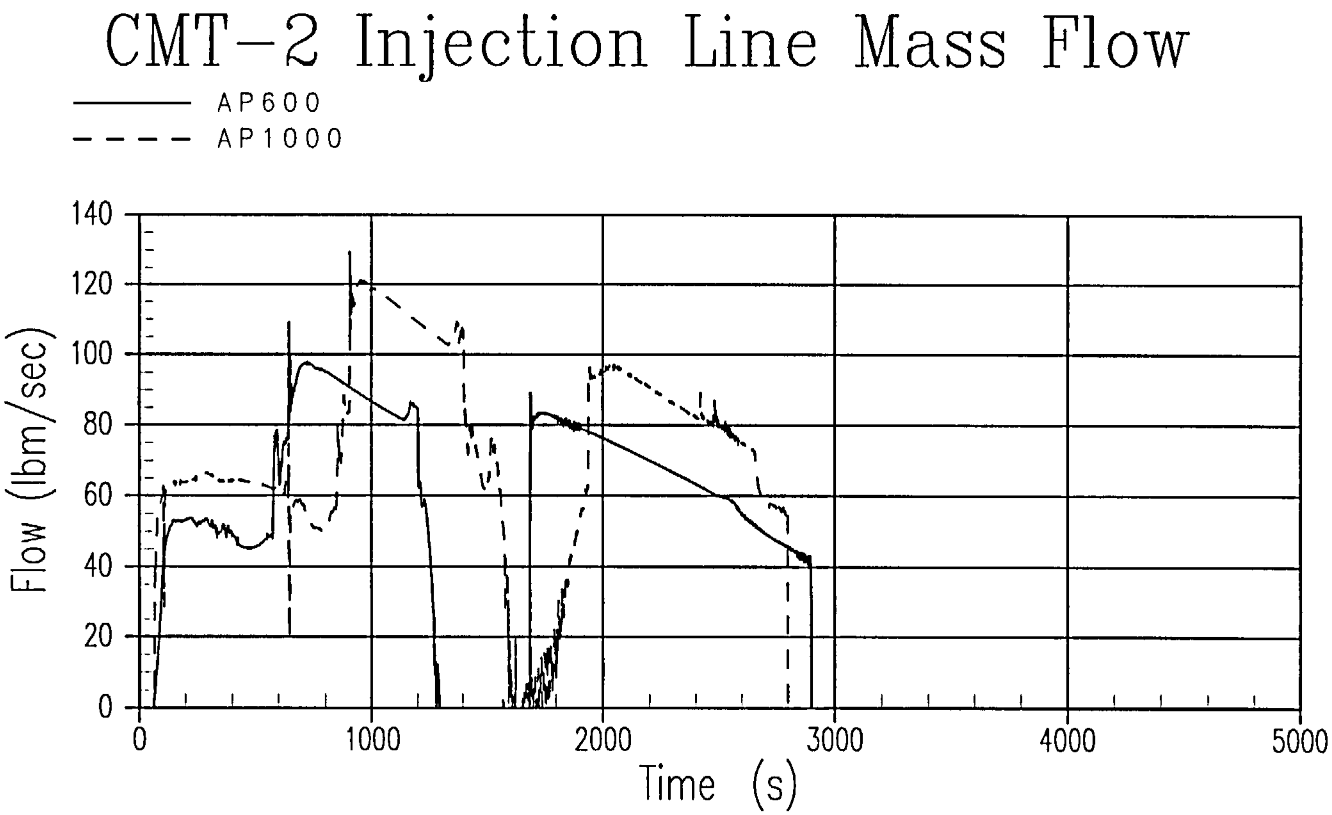
2-Inch CLB Results (AP600 vs. AP1000)

AP1000



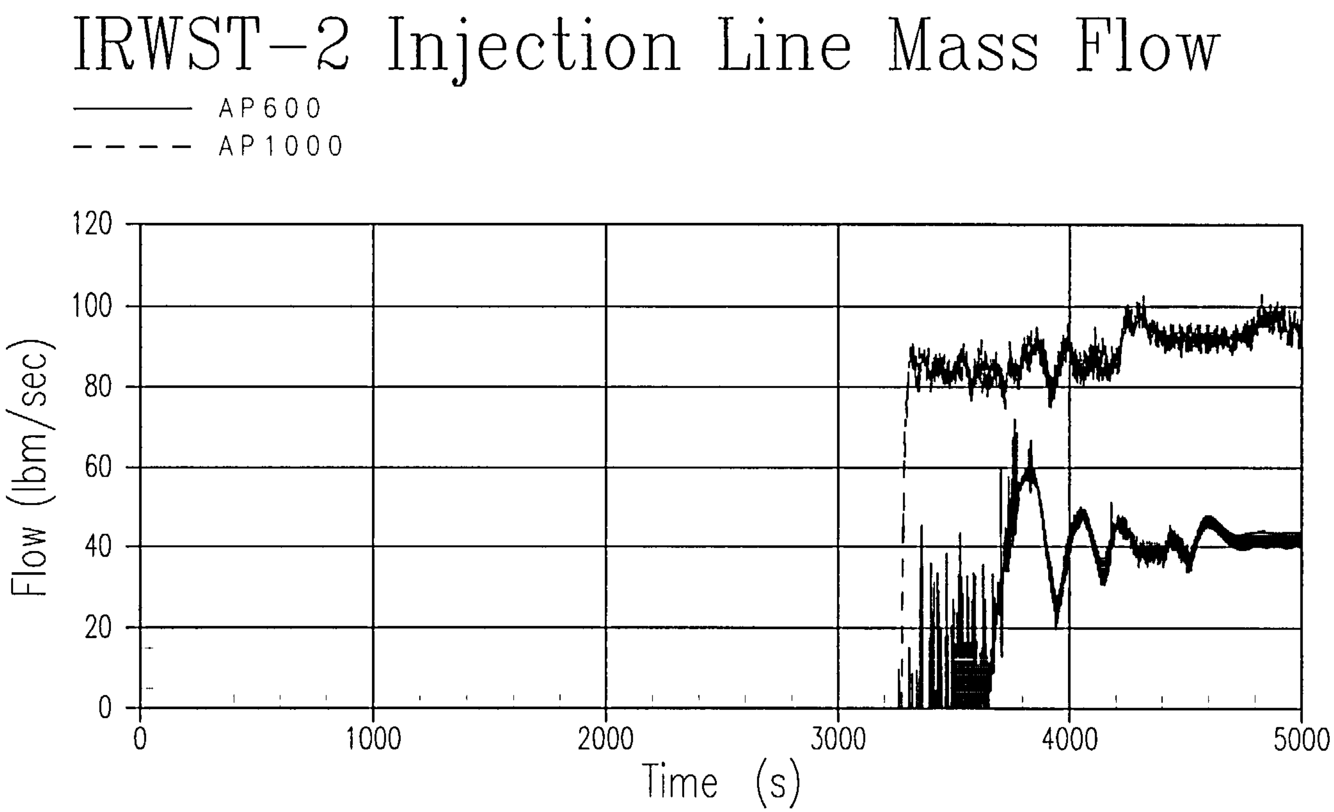
2-Inch CLB Results (AP600 vs. AP1000)

AP1000



AP1000

2-Inch CLB Results (AP600 vs. AP1000)



Double-Ended DVI Line (DEDVI) Break Results Comparisons

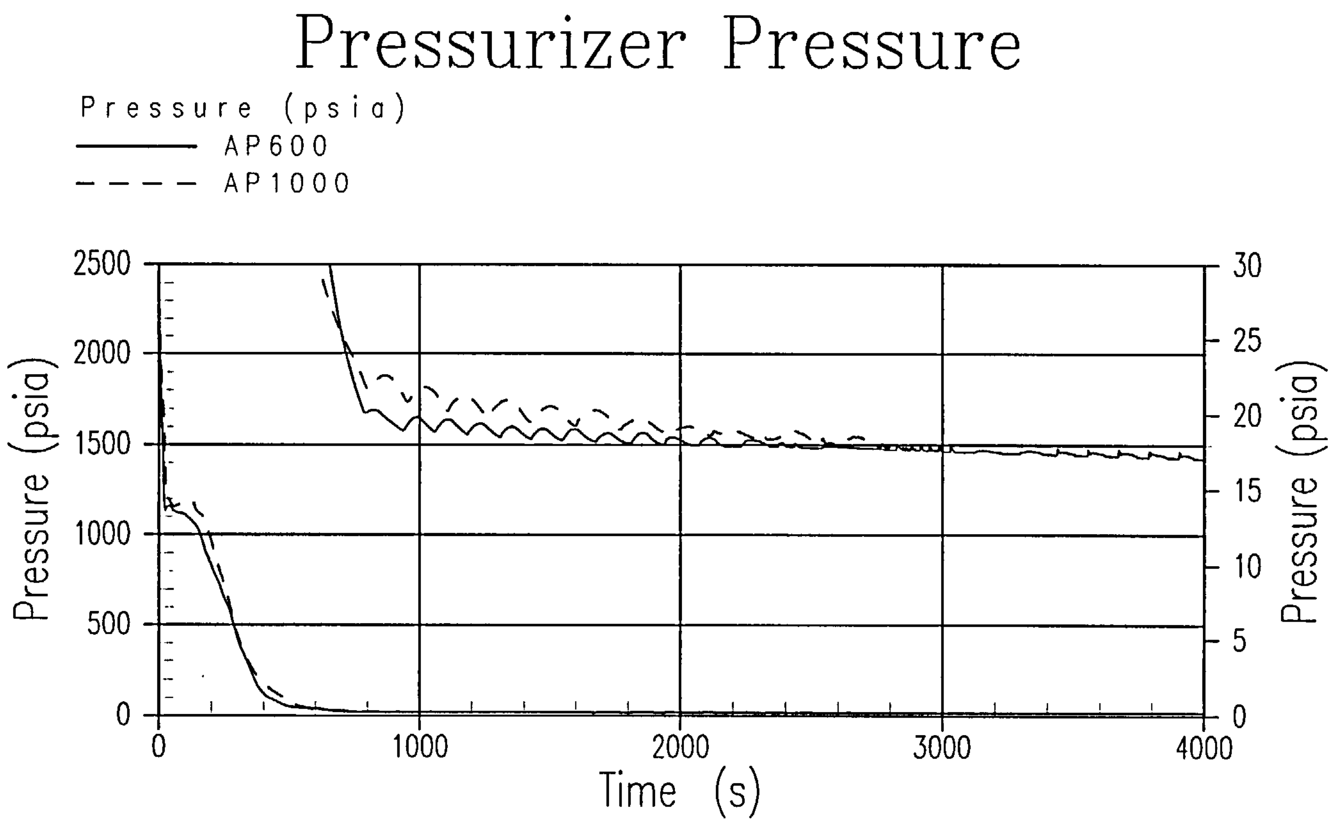
AP1000

Event	AP600	AP1000 (DCD)
Break opens	0.0	0.0
Reactor trip	8.5	13.1
"S" signal	10.3	18.5
MFW Isolation	15.3	20.5
RCP Trip	26.5	24.5
ADS 1	253	183
Int. ACC Inject.	230	251

DEDVI Results Comparisons

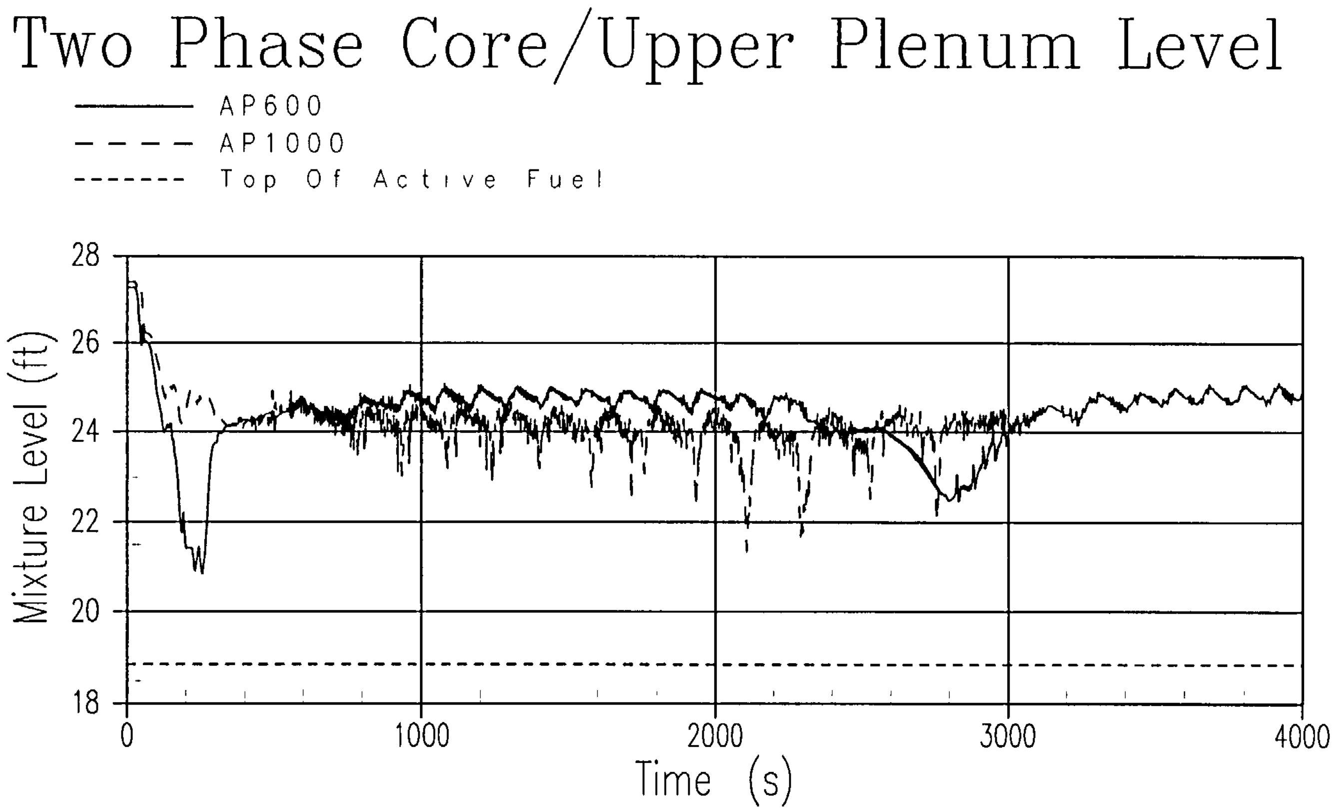
Event	AP600	AP1000 (DCD)
ADS 2	323	253
ADS 3	443	373
ADS 4	563	493
Int. ACC Empty	597	598
CMT empty	2005	2006
IRWST Injection	2540	2076

DEDVI Results (AP600 vs. AP1000)



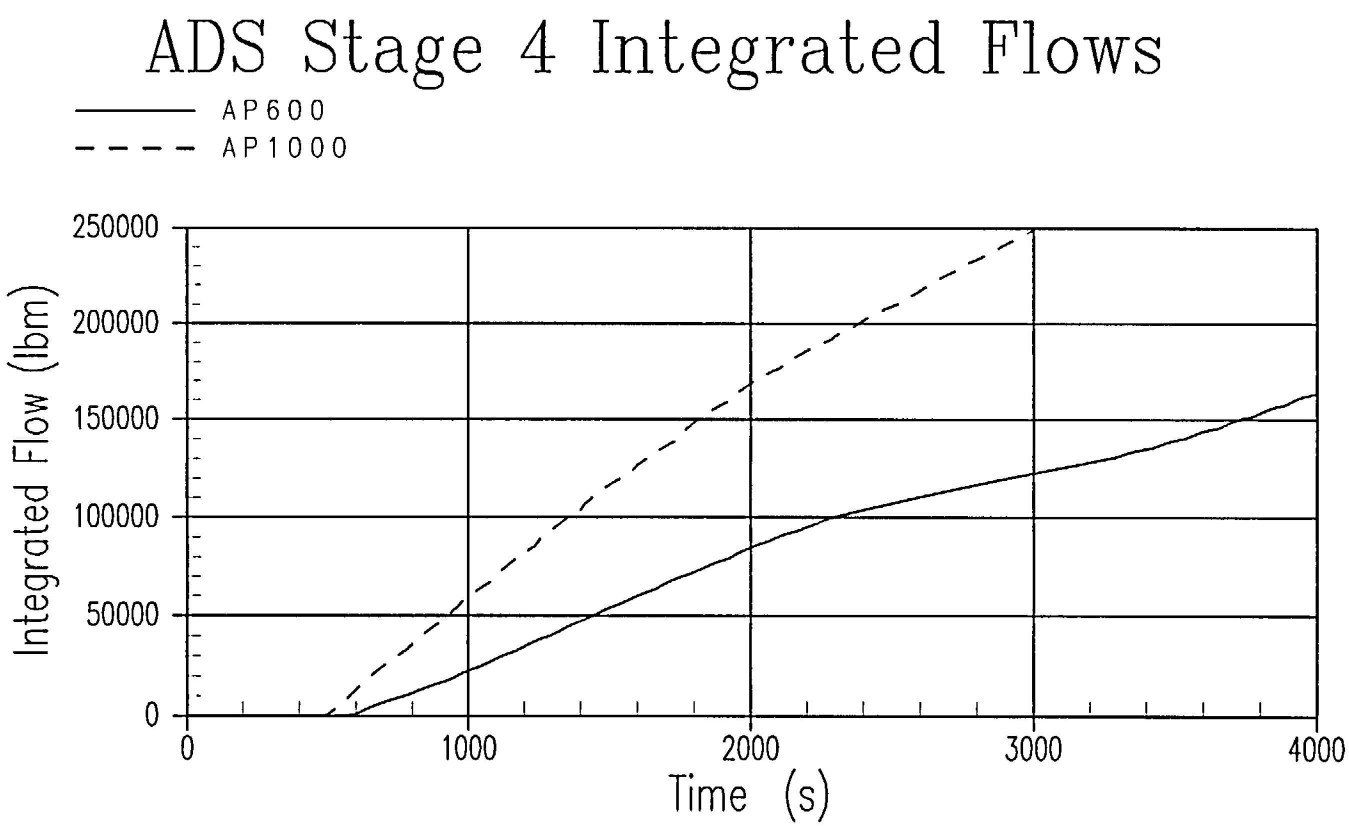
AP1000

DEDVI Results (AP600 vs. AP1000)



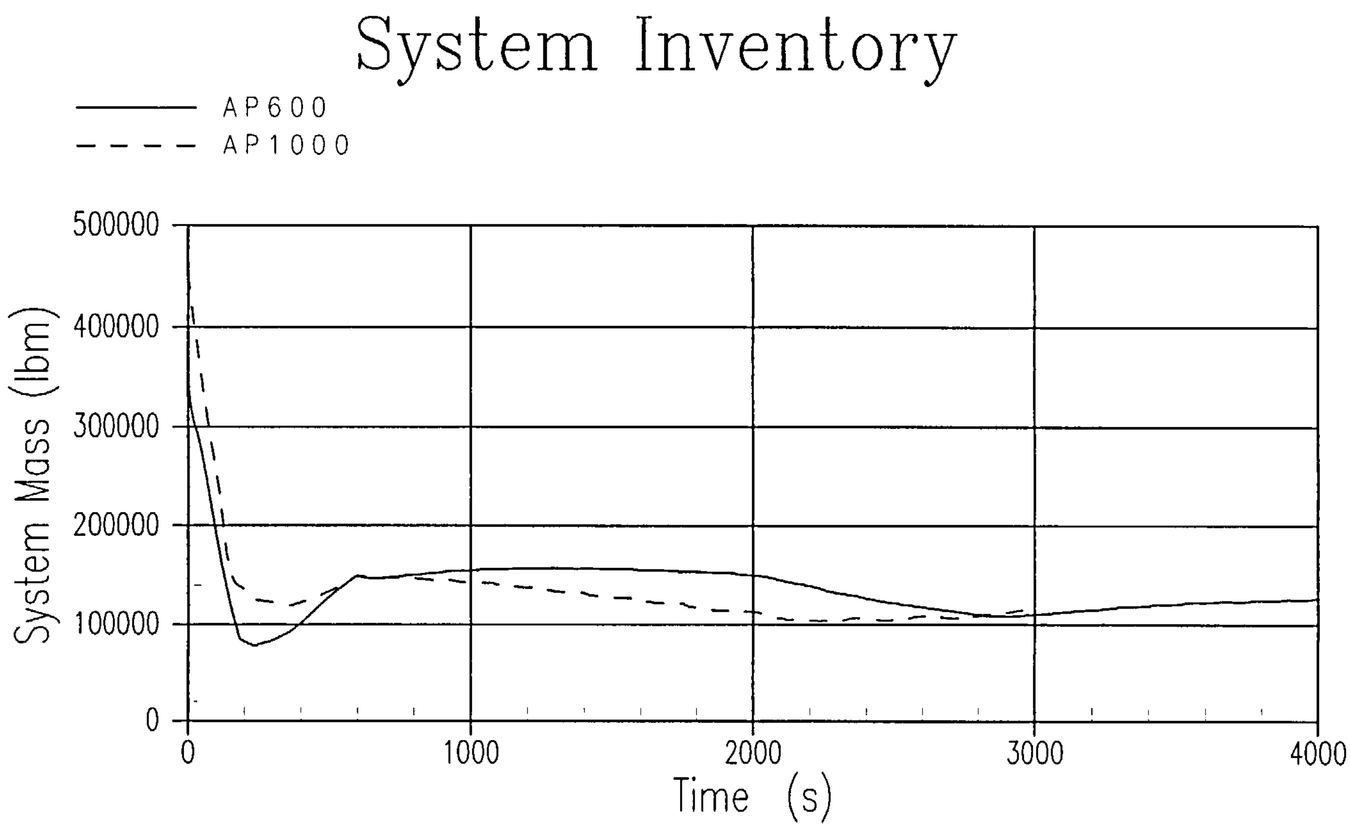
DEDVI Results (AP600 vs. AP1000)

AP1000



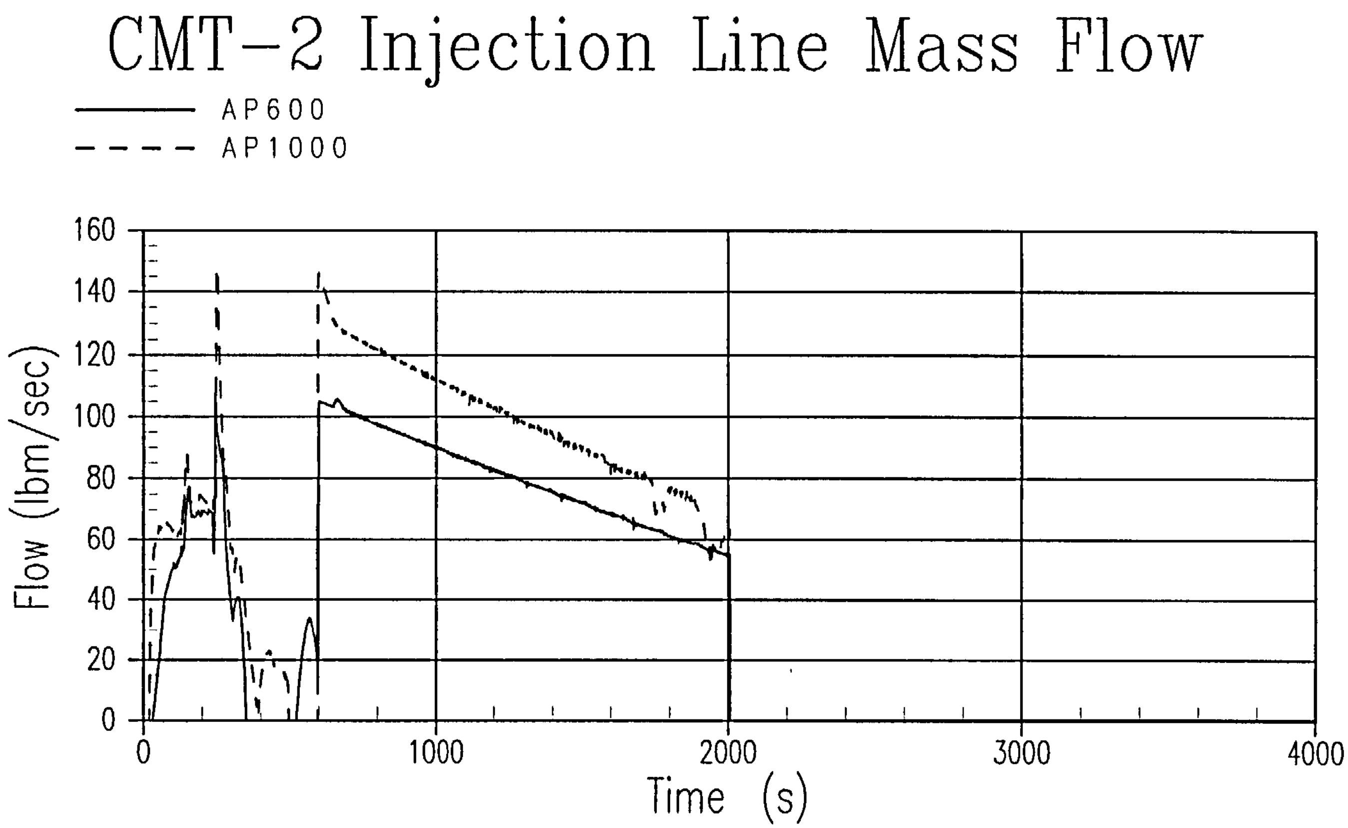
AP1000

DEDVI Results (AP600 vs. AP1000)



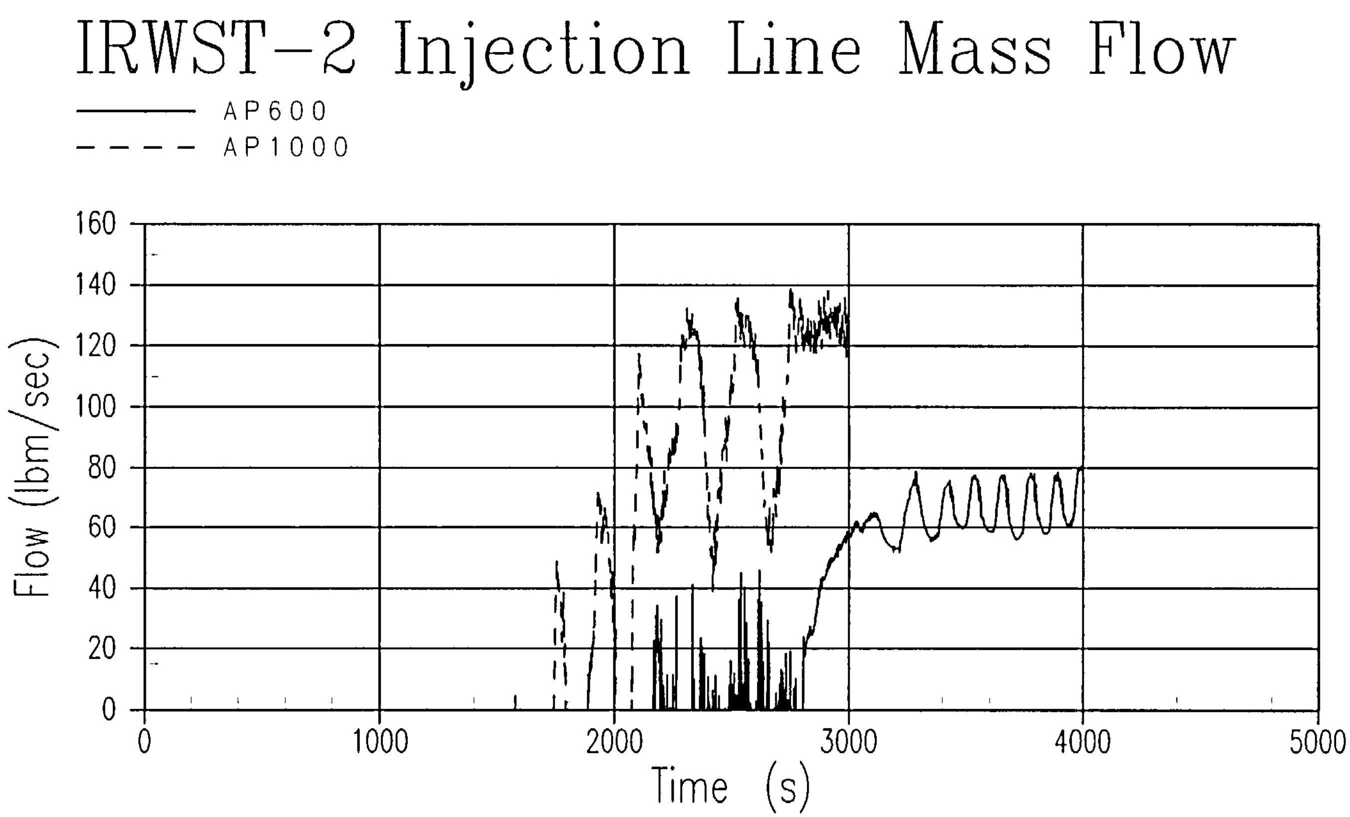
DEDVI Results (AP600 vs. AP1000)

AP1000



AP1000

DEDVI Results (AP600 vs. AP1000)



Double-Ended DVI Line (DEDVI) Break Results Comparisons

AP1000

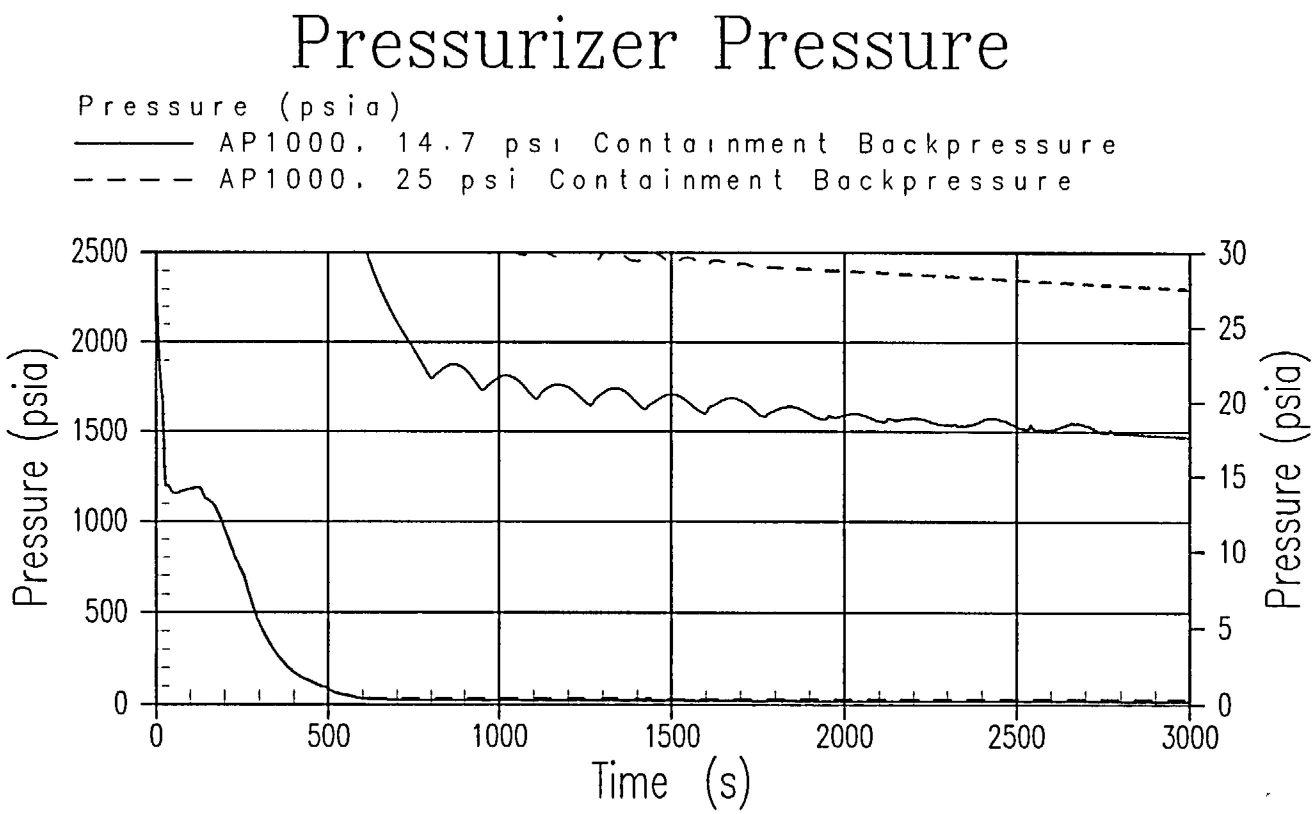
Event	AP1000 (14.7 psi)	AP1000 (25 psi)
Break opens	0.0	0.0
Reactor trip	13.1	13.1
"S" signal	18.5	18.5
MFW Isolation	20.5	20.5
RCP Trip	24.5	24.6
ADS 1	183	182
Int. ACC Inject.	251	255

DEDVI Results Comparisons

Event	AP1000 (14.7 psi)	AP1000 (25 psi)
ADS 2	253	252
ADS 3	373	372
ADS 4	493	492
Int. ACC Empty	598	601
CMT empty	2006	2350
IRWST Injection	2076	1440

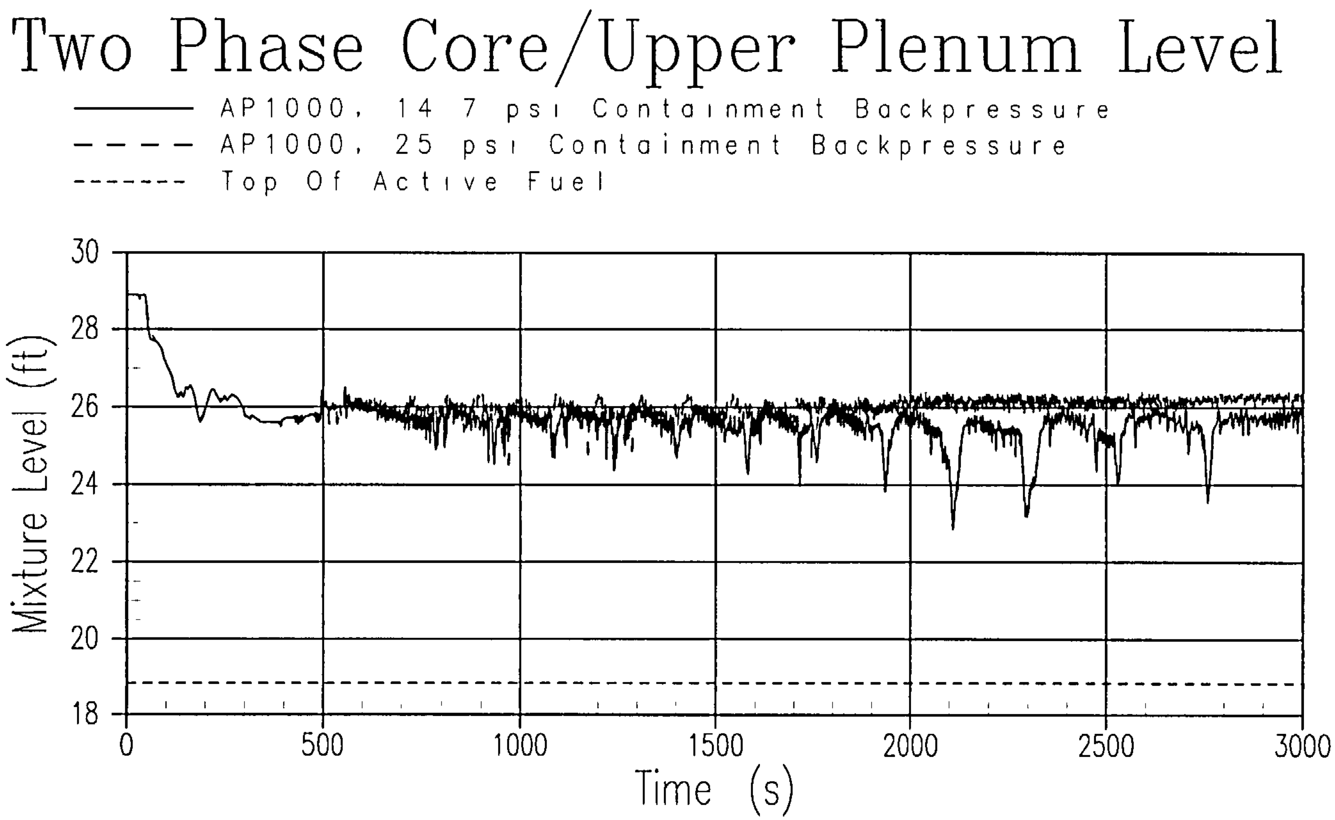
DEDVI Results (AP1000)

AP1000



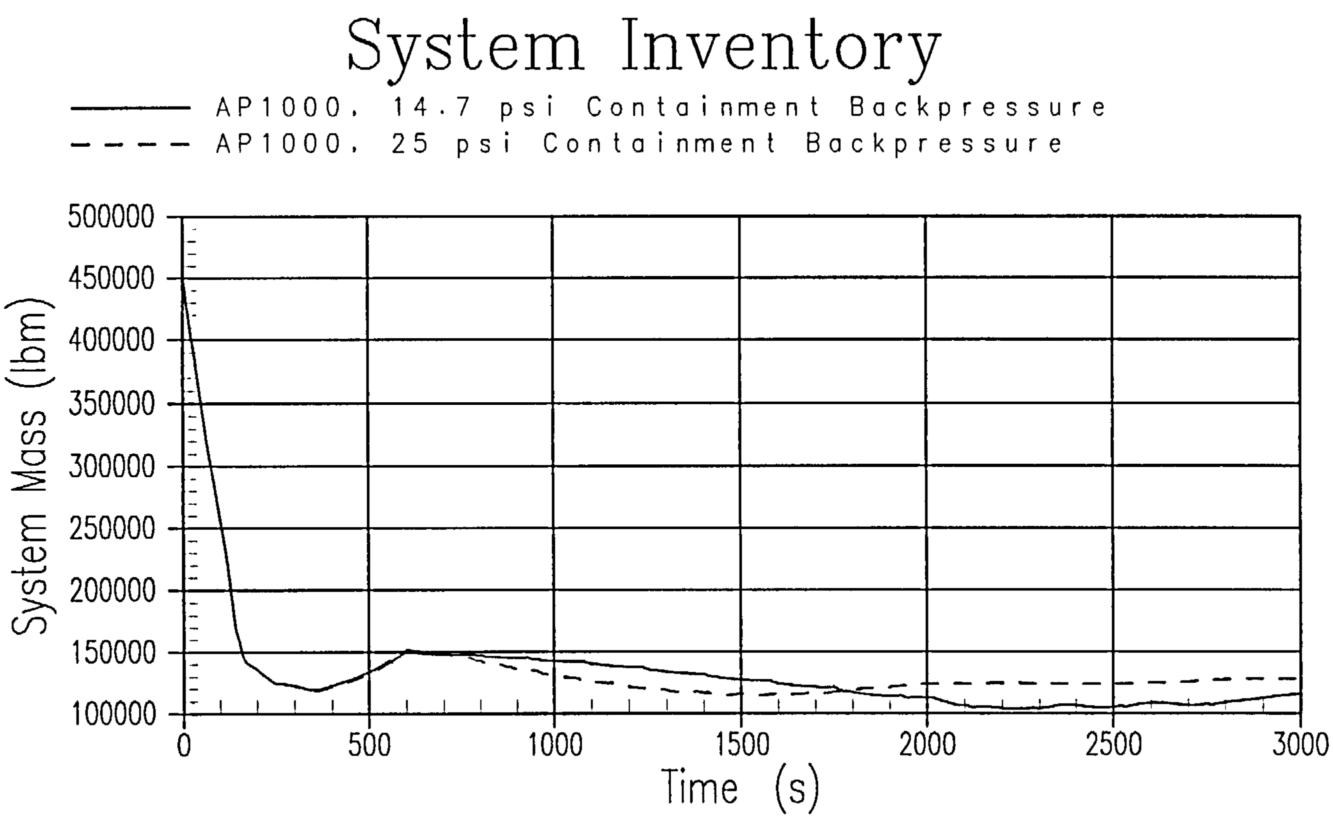
AP1000

DEDVI Results (AP1000)



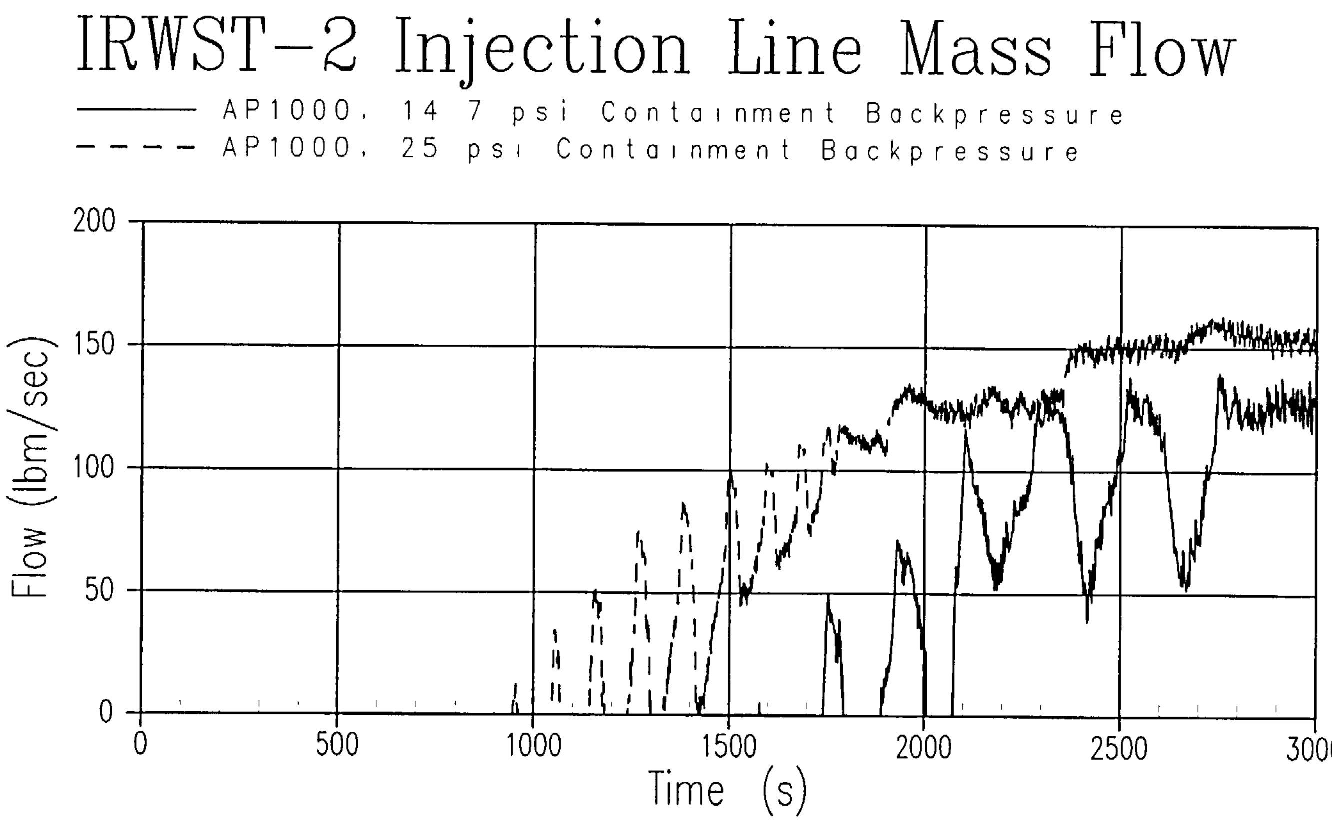
AP1000

DEDVI Results (AP1000)



DEDVI Results (AP1000)

AP1000



10-Inch Cold Leg Break (CLB) Results Comparisons

AP1000

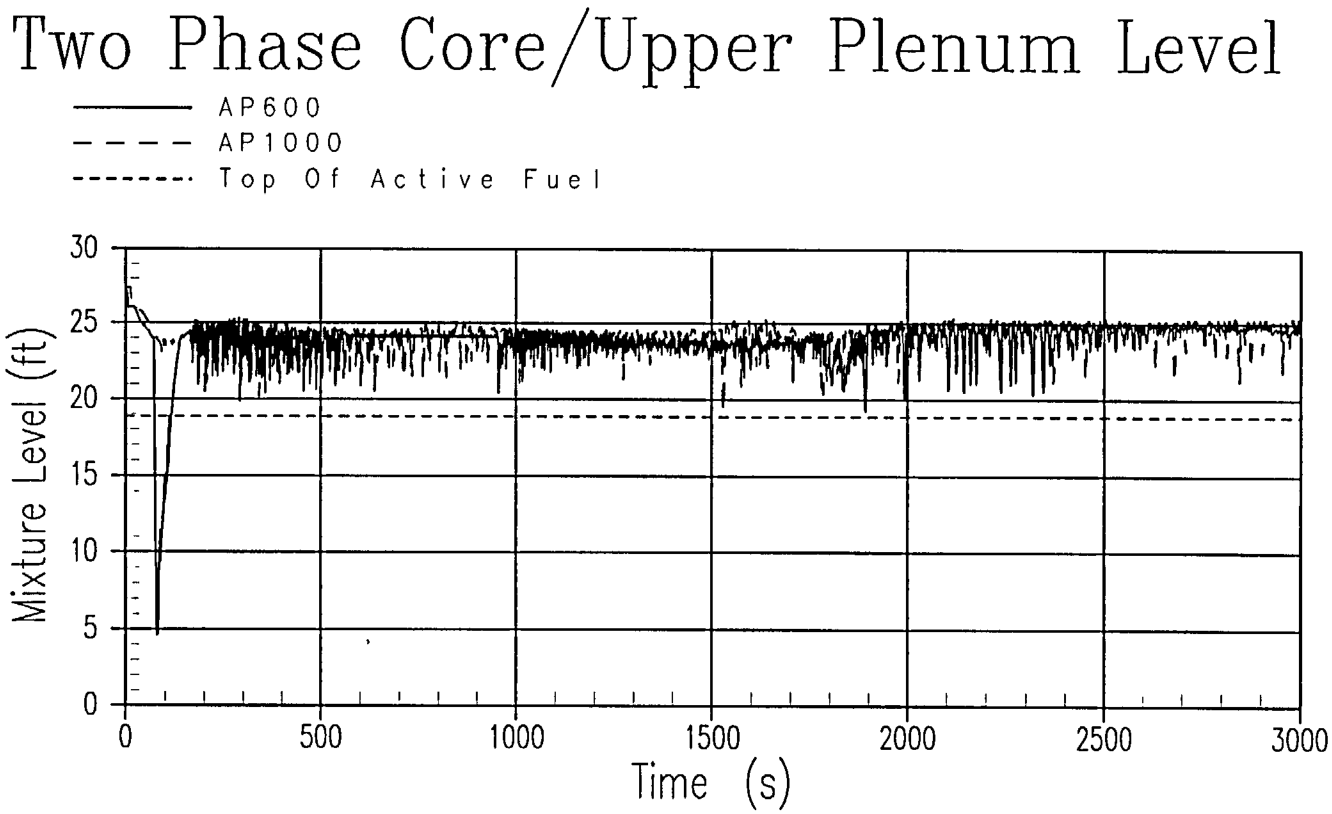
Event	AP600	AP1000 (DCD)
Break opens	0.0	0.0
Reactor trip	3.5	5.2
"S" signal	3.5	6.4
MFW Isolation	8.5	8.4
RCP Trip	19.7	12.4
ACC Injection	70	85
ACC Empty	317	~420

10-Inch CLB Results Comparisons

Event	AP600	AP1000 (DCD)
ADS 1	945	750
ADS 2	1015	820
ADS 3	1135	940
ADS 4	1731	1491
IRWST Injection	1843	1800

10-Inch CLB Results (AP600 vs. AP1000)

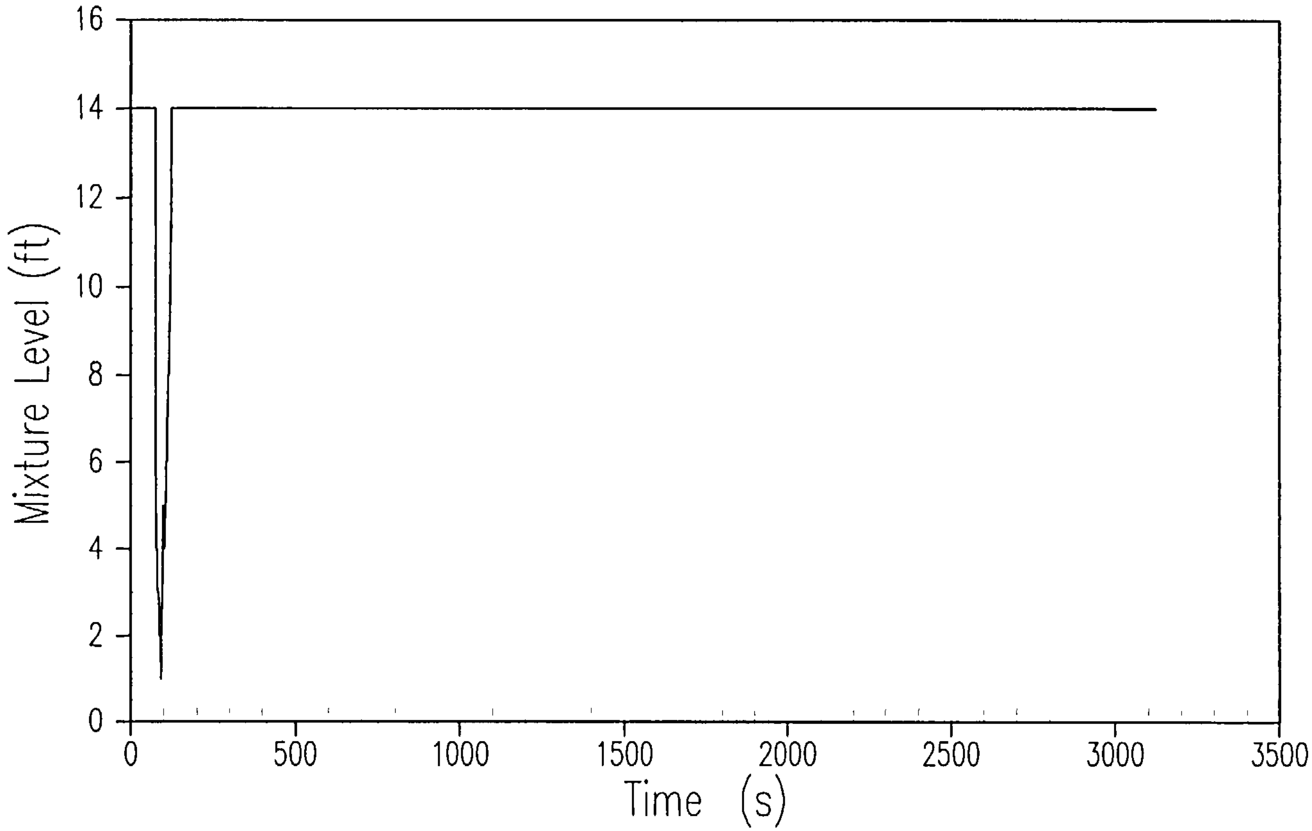
AP1000



10-Inch CLB Results (AP600 vs. AP1000)

AP1000

Composite Core Mixture Level



Overall Results (AP600 vs. AP1000)

- **Conclusions reached from AP600 analysis effort are unchanged for AP1000**
  - No core uncovery observed
  - No new phenomena observed

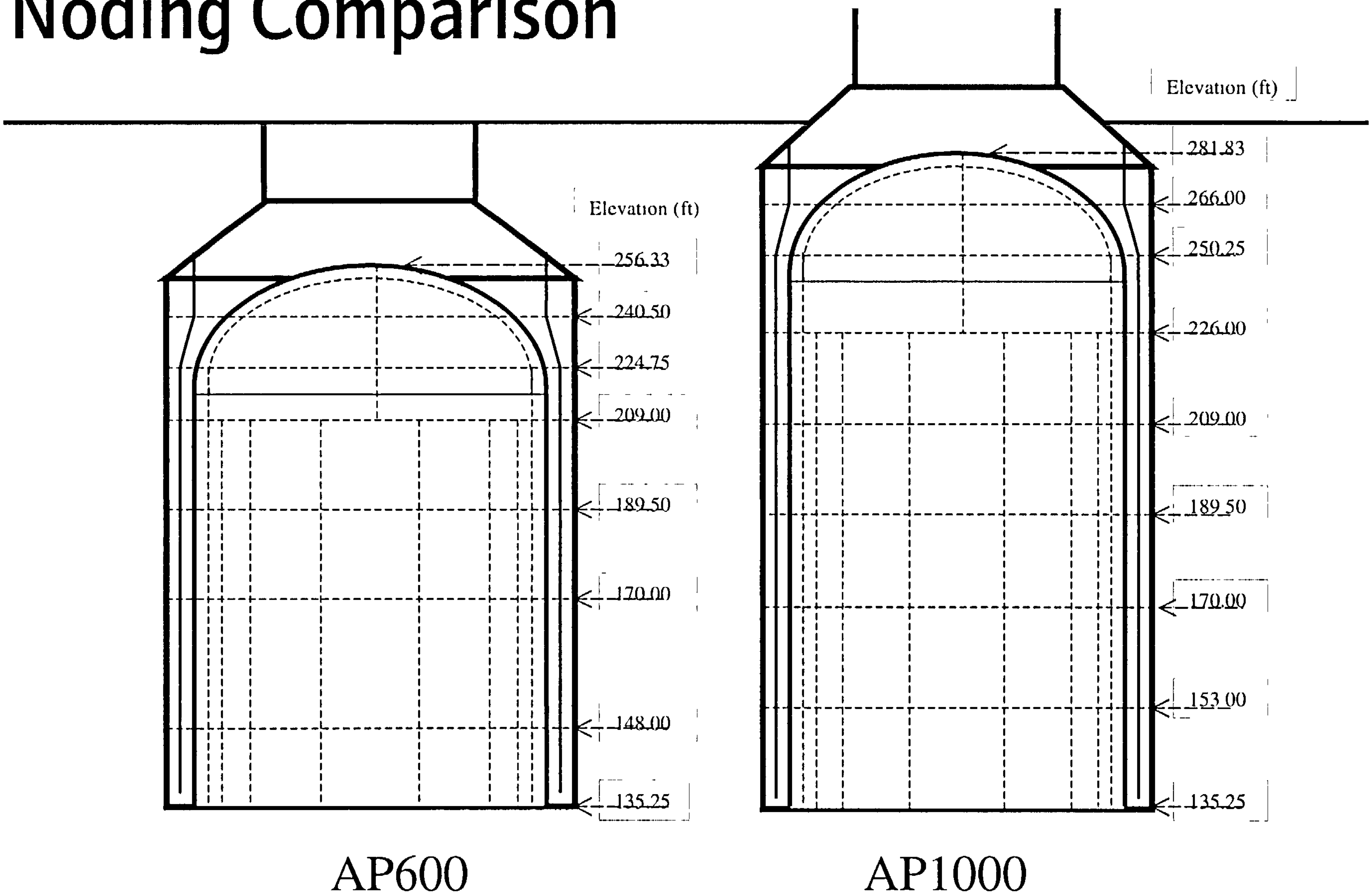
AP1000 Containment Analyses

Rick Wright
Passive Plant Engineering
(412) 374-4719 - wrightrf@westinghouse.com

Pre-Certification Review

- **Open Item - "Westinghouse needs to perform the WGOTHIC containment analyses with an evaluation model and appropriate boundary conditions to ensure that the mass and heat transfer correlations remain valid for the AP1000 design."**
  - AP1000 containment evaluation model transient response with mass and heat transfer comparison was provided in DCP/NRC-1484, Attachment 3, 9/12/2001
  - DCD analysis uses the evaluation model as documented in WCAP-15846

Noding Comparison



Boundary Conditions

AP1000

- **Calculated the MSLB and LOCA M&E releases using the latest design information**
  - MSLB releases for FDER at 0%, 30%, 70% and 101% power were calculated using LOFTRAN
  - LOCA releases were calculated for DEHLG and DECLG at 101% power
    - Methodology is described in WCAP-15846
    - Due to larger RCS and SG volumes, energy removal takes longer than in AP600
    - Method is conservative compared to WCOBRA-TRAC LBLOCA analysis

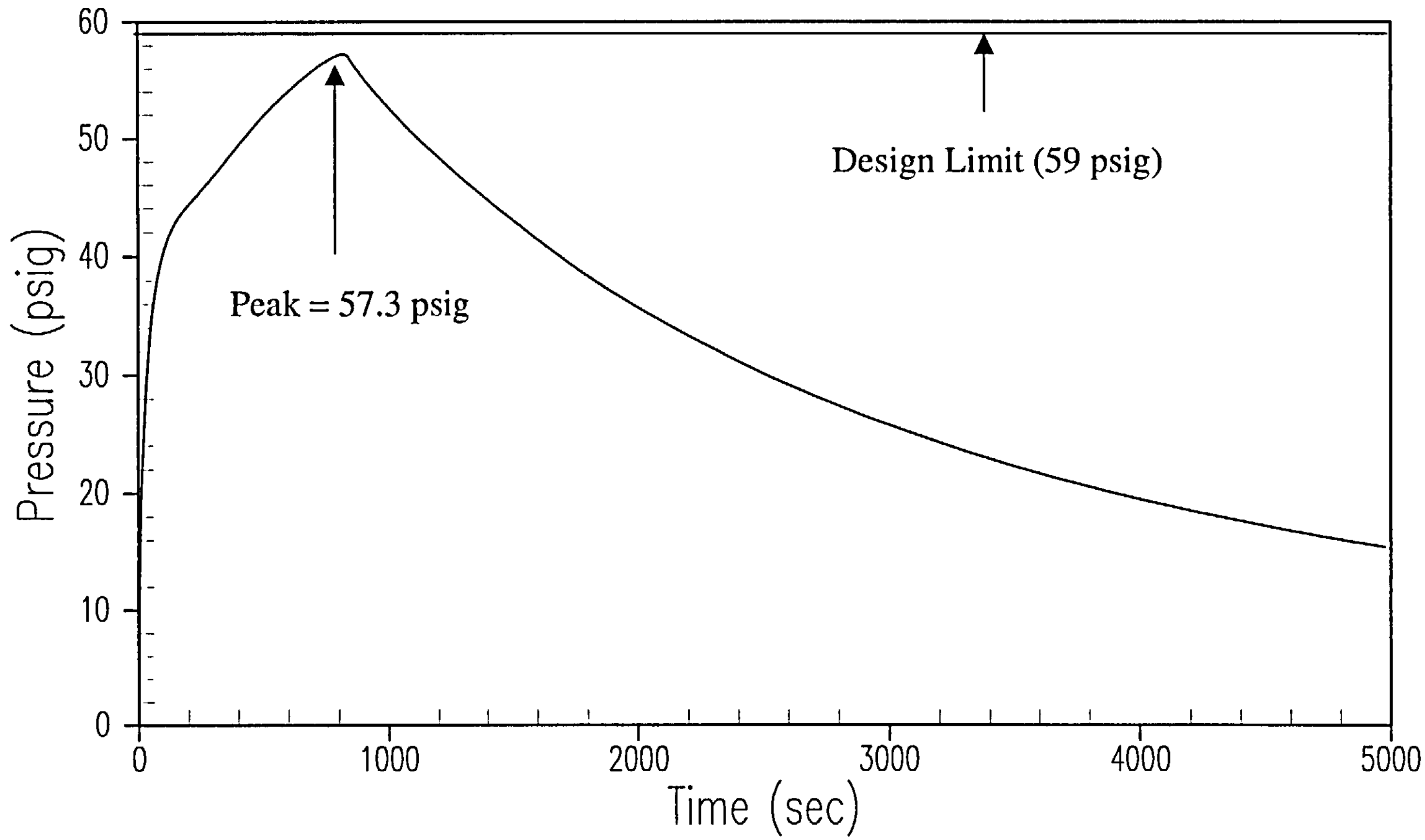
Boundary Conditions

- **Used iterative approach to determine the evaporation-limited PCS flow rate**
  - Start with the applied PCS flow rate
  - Spreadsheet conservatively calculates wetted area and evaporation rate from the shell
  - Reduce PCS flow rate input to use only the predicted evaporation rate for next iteration

AP1000 Containment Analysis

AP1000

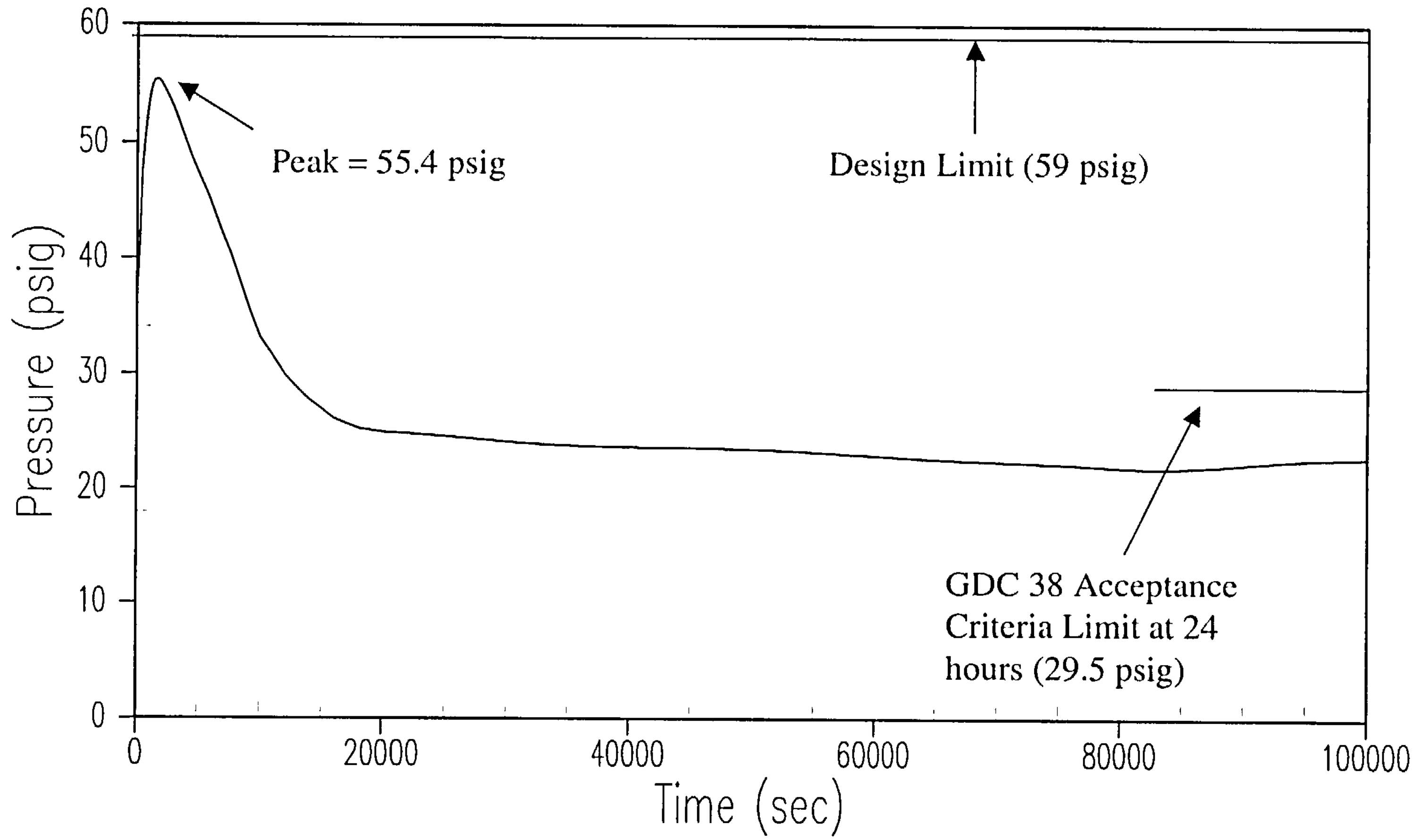
AP1000 Containment Response for Full DER MSLB @ 30% Power



AP1000 Containment Analysis

AP1000

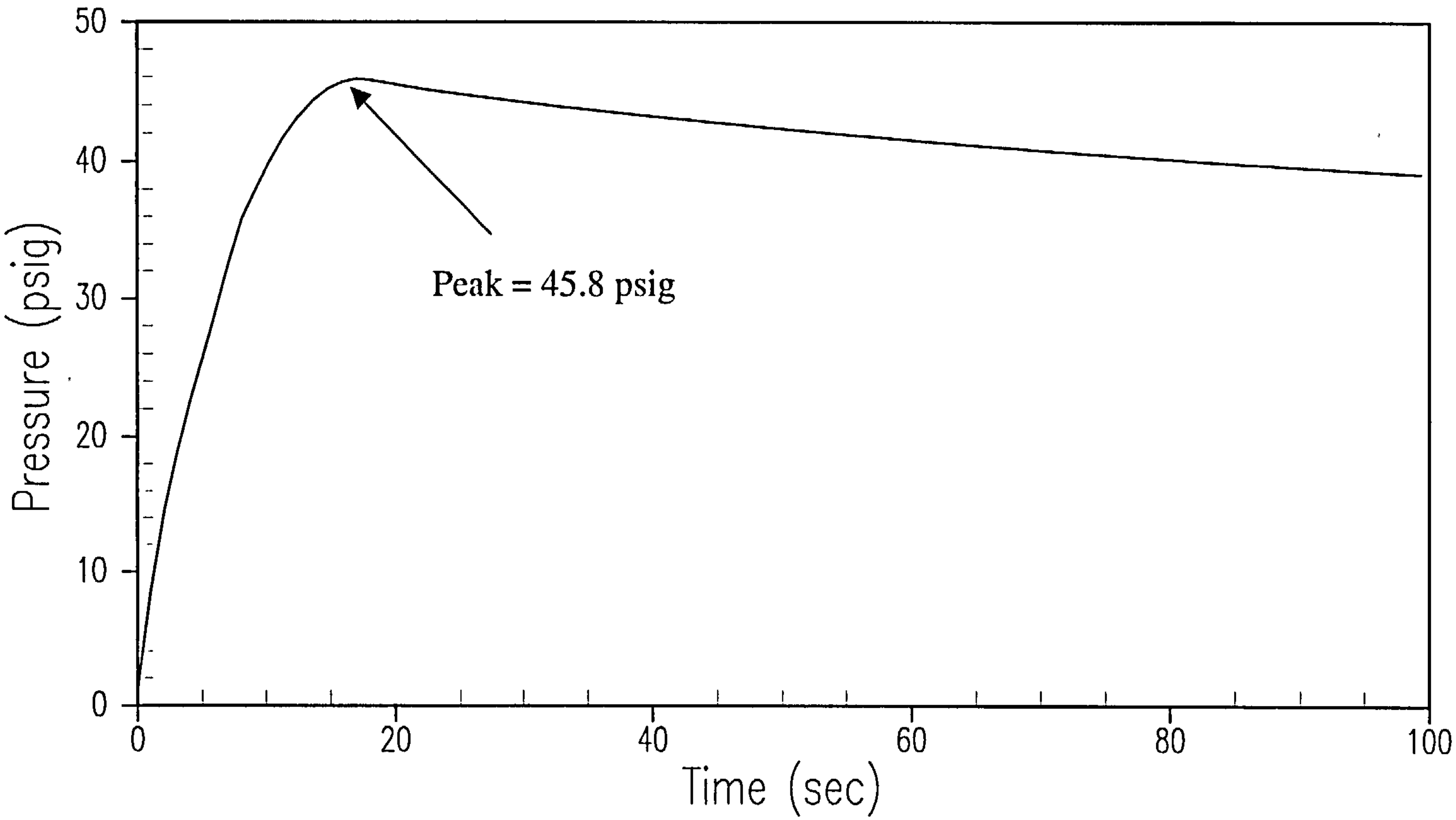
AP1000 Containment Response for DECLG LOCA



AP1000 Containment Analysis

AP1000

AP1000 Containment Response for DEHLG LOCA



Comparison of Key Dimensionless Parameters for AP1000 and Test Data			
Parameter	Composite of Test Data	AP1000 Range (est)	AP1000 WGOTHIC Calc (limiting location)
Riser			
Re	<500,000	<210,000	150,000
Gr	$<1.0\times10^{11}$	$<1.5\times10^{9}$	1.1×10^{9}
Pr	0.72 – 0.9	0.72 – 0.9	0.8
Downcomer			
Re	<500,000	<190,000	103,000
Gr	$<1.0\times10^{11}$	$<2.1\times10^{10}$	5.2×10^{9}
Pr	~0.72	~0.72	0.72

AP1000

AP1000 WGOTHIC Containment Model

- **WGOTHIC models air cooling annulus as two stacks of lumped parameter nodes; wet & dry**
  - Volumes connected by flow paths with friction and form losses
- **Flow characteristics of the flow path were determined from test data**
  - 1/6 scale, 14-degree sector model (Ref.1)
  - Losses conservatively increased 30% for AP600
  - Same losses assumed for AP1000 with increased friction loss from increased flow path

Ref 1: Tests of Air Flow Path for Cooling the AP600 Reactor Containment, WR&D Report 88-8E9-ADLWR-R2, 1988.

AP1000 WGOTHIC Containment Model

- **Air flow path heat transfer correlations**
  - Free convection - McAdams

    $h_{forced} = 0.13\ k\ \{ g\beta\Delta TPr / \nu^2 \}^{1/3}$

  - Forced convection - Colburn

    $h_{free} = 0.023\ k/d_h\ Re^{0.8}\ Pr^{1/3}$

  - Mixed

    $h = \{h_{forced}{}^3 + h_{free}{}^3\}^{1/3}$

NRC Staff Review of Pre-Application Issues for AP1000 Except Entrainment Meeting of

ACRS Thermal/Hydraulic Phenomena Subcommittee
March 19, 2003

Walton L. Jensen
NRR/Reactor Systems Branch

LOFTRAN and NOTRUMP

- LOFTRAN: Used to evaluate non-LOCA transients and accidents including SGTR in conjunction with other codes. (RCS pressure, fuel temperature, DNBR)

- NOTRUMP: Used to evaluate small break LOCA to the time when IRWST flow to the reactor vessel is established.

- Detailed NRC staff reviews for operating plants mid 1980s and for AP600 1998.

Scope of NRC Staff Review for AP1000

- **Reviewed code capabilities and limitations from AP600 review to evaluated code capabilities for modeling AP1000 components. (PRHRHX, SGs, ADS4)**

- **Reviewed scaling of separate effect and integral system tests used to qualify the codes for AP600 for applicability to AP1000.**

- **Reviewed Westinghouse User Standards for developing code input.**

- **Performed independent audit calculations using RELAP5. (MSLB and SBLOCA)**

NRC Staff Pre-Application LOFTRAN Conclusions:

LOFTRAN is acceptable for analysis of non-LOCA transients and accidents for AP1000 including SGTR with the exception of one outstanding open issue.

Open Issue from pre-application review:

Westinghouse had not performed the analysis of a main steam line break to evaluate reactor system voiding. NRC staff concerned that steam might form in the intact loop steam generator tubes and CMT pressure balance lines which might cause natural circulation to be lost.

RESOLVED by additional analyses using LOFTRAN and a RELAP5 audit calculation showing no coolant loop voiding or CMT draining.

NRC Staff NOTRUMP Conclusions

NOTRUMP is acceptable for analysis of small break LOCA for AP1000 with exception of the following outstanding issues.

1. Liquid entrainment from upper plenum, through hot legs and ADS4. Westinghouse benchmarked NOTRUMP against a modified WCOBRA/TRAC and performed sensitivity studies (WCAP-15833). NRC staff requires additional experimental verification.

UNRESOLVED

2. The staff concluded that the conservatism of the PRHRHX model needed to be justified for high heat flows. Westinghouse proposed to reduce the heat transfer area in NOTRUMP by 50%. This penalty needed to be justified in a data comparison.

RESOLVED by Westinghouse's comparison of the NOTRUMP model with the 50% penalty to the modified Rosenhow correlation approved for LOFTRAN which was developed using test PRHRHX test data as discussed in WCAP-12980.

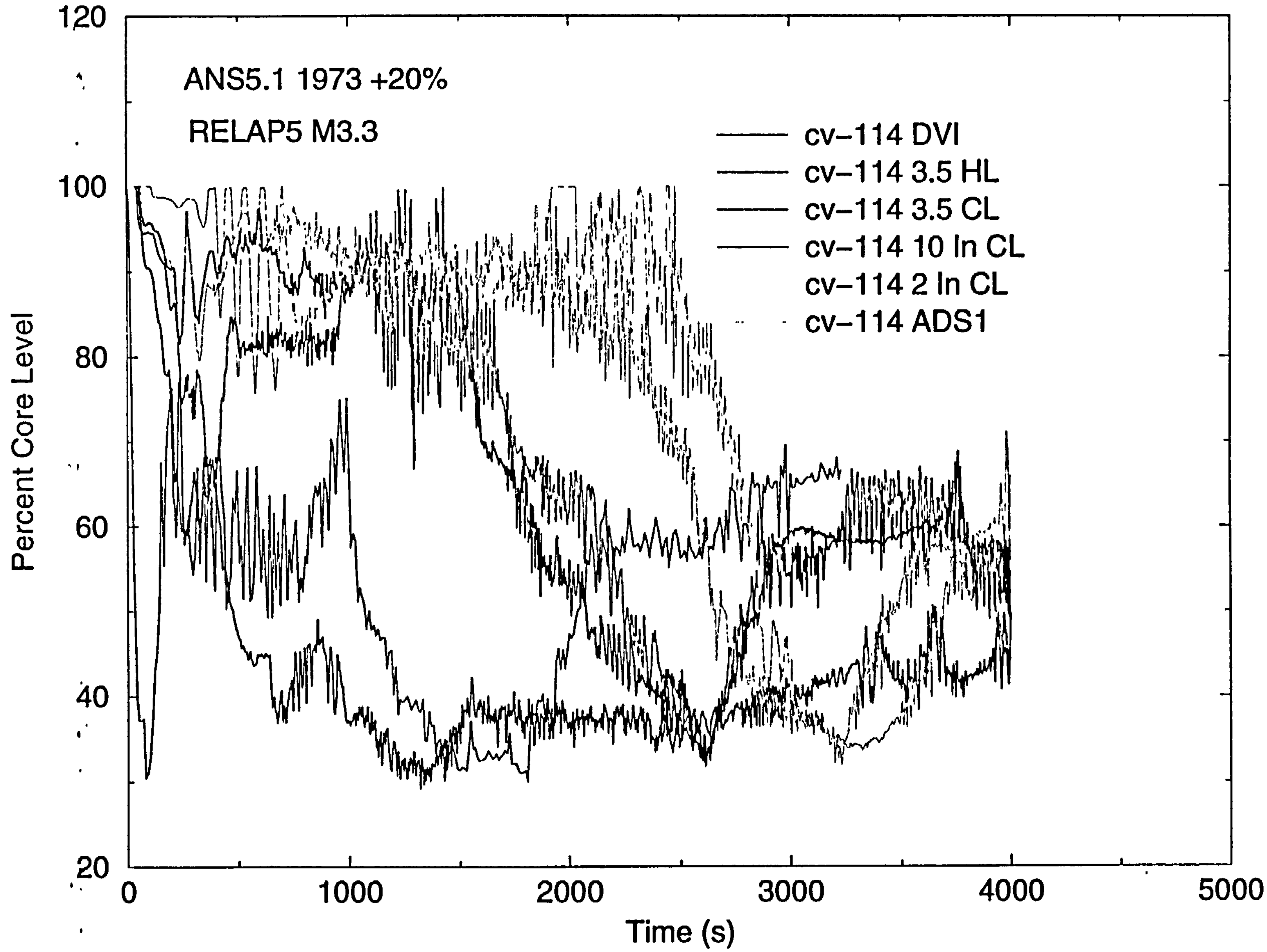
NRC Staff NOTRUMP Conclusions (Continued)

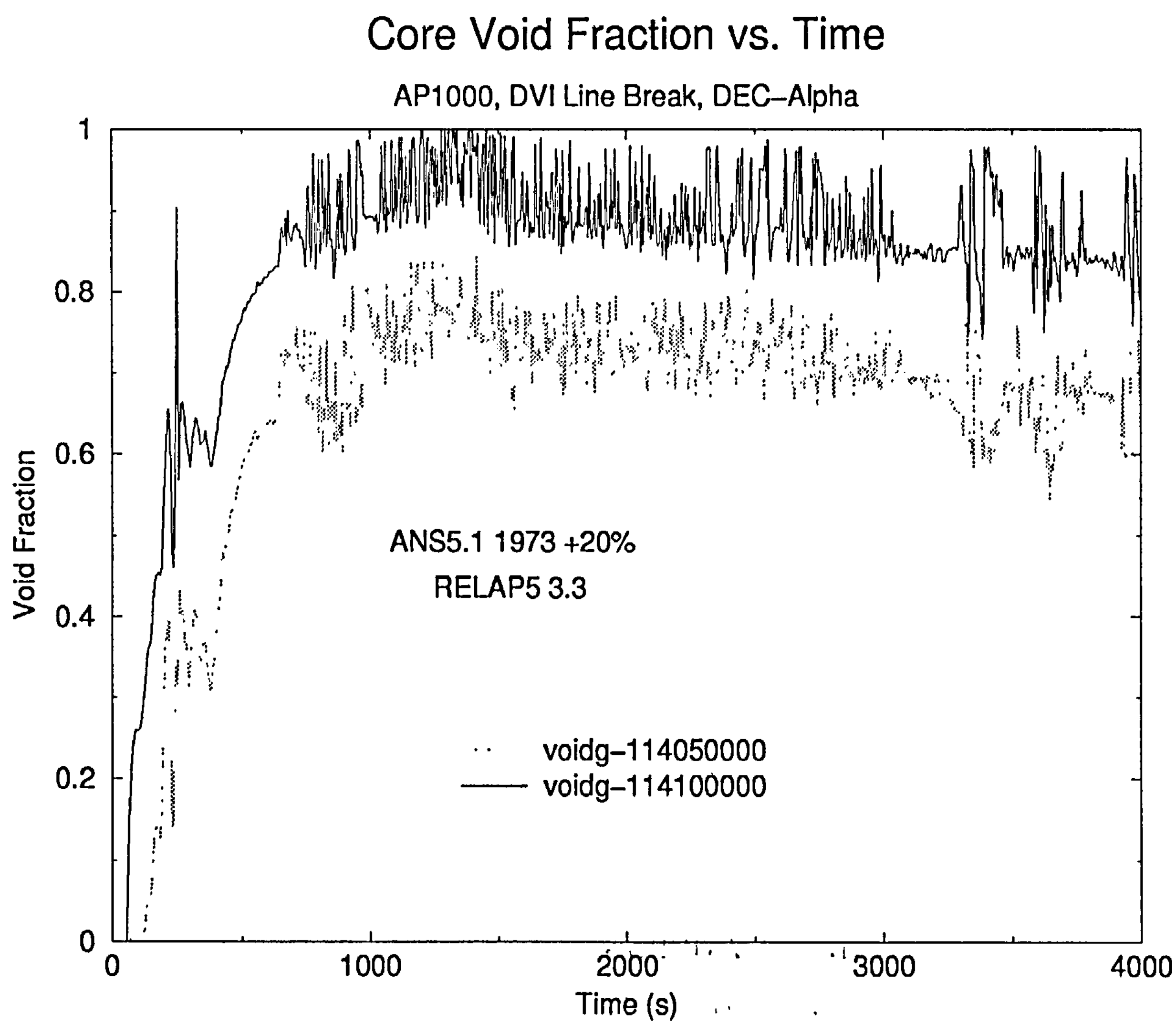
3. Only a limited number of breaks had been analyzed. The staff was concerned that additional breaks might cause the core to be uncovered and then Westinghouse's core heatup methodology would have to be qualified for AP1000 application.

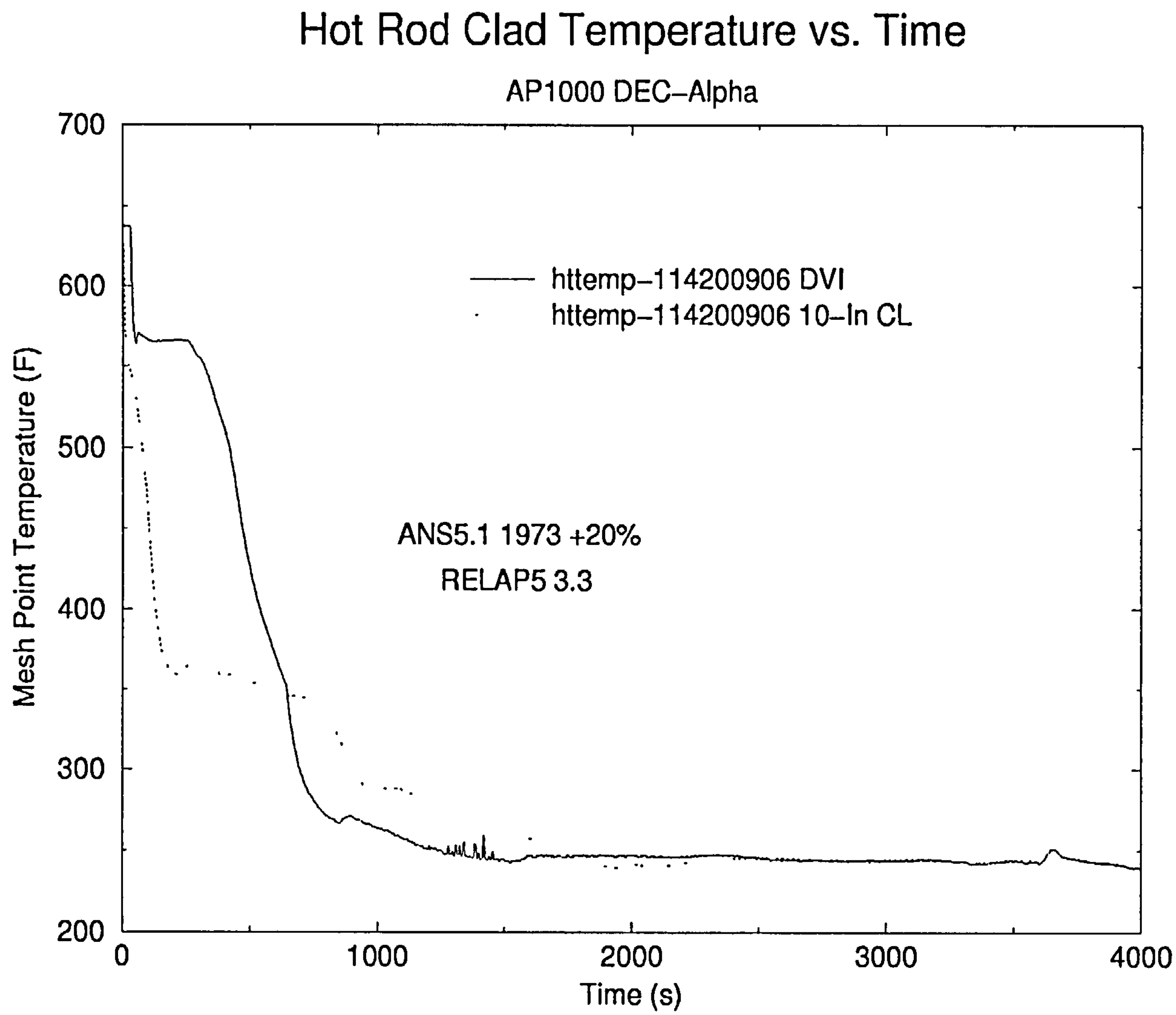
RESOLVED Westinghouse performed additional small break LOCA analyses showing the core to remain covered. The staff made additional audit calculations using RELAP5. No core uncovery was predicted. Minimum core inventory was found to not be a strong function of small break size or location.

Core Collapsed Level vs. Time

AP1000, DEC–Alpha




Core Void Fraction vs. Time
AP1000, DVI Line Break, DEC–Alpha
Void Fraction
Time (s)
ANS5.1 1973 +20%
RELAP5 3.3
voidg–114050000
voidg–114100000
0
0.2
0.4
0.6
0.8
1
0
1000
2000
3000
4000


Hot Rod Clad Temperature vs. Time
AP1000 DEC–Alpha
httemp–114200906 DVI
httemp–114200906 10–In CL
ANS5.1 1973 +20%
RELAP5 3.3
Mesh Point Temperature (F)
Time (s)
700
600
500
400
300
200
0
1000
2000
3000
4000

BORON PRECIPITATION / LONG TERM COOLING

- Long Term Cooling (LTC) is analyzed using WCOBRA/TRAC
- The LTC function has been validated for AP600 using OSU experiments
- W claims that the AP600 validation suffices for the AP1000 LTC analysis
- WCOBRA/TRAC validation includes steam-water mixture flow out of the ADS-4 during the LTC phase. Liquid expulsion from the vessel is necessary to avoid boron concentration and/or precipitation in the core.
- Open item: the staff finds that the geometry and the flow conditions are different in AP1000. The staff requested that the liquid droplet entrainment model in the steam flow through the ADS-4 be validated for AP1000.

WGOTHIC Computer Program

Presentation to the Advisory Committee on Reactor Safeguards

Subcommittee on Thermal-Hydraulic Phenomena

March 19, 2003

Edward D. Throm
Senior Reactor Engineer
Plant Systems Branch
Division of Systems Safety and Analysis
Office of Nuclear Reactor Regulation
U.S. Nuclear Regulatory Commission
Telephone: (301) 415-3153

WGOTHIC Computer Program

WGOTHIC is used to evaluate the containment pressure and temperature response to design-basis accidents (LOCA/MSLB).

WGOTHIC is described in WCAP-15846, "WGOTHIC Application to AP600 and AP1000," April 2002.

Staff evaluation in NUREG-1512, "Final Safety Evaluation Report Related to Certification of the AP600 Standard Design," 09/98.

Conservative models are used in the WGOTHIC Evaluation Model (EM) to address the following areas:

- Lumped-parameter network representation
- Circulation and stratification
- PCS flow and the mass and heat transfer models

WGOTHIC Computer Program

Results From Phase II Review

- No new phenomena identified, PIRT rankings unchanged
- Mass and heat transfer correlations are being used within their applicable ranges, based on W studies
- Using the approved evaluation modeling approach, WGOTHIC is applicable to the AP1000
- Certification results need to be reviewed to confirm findings

  Use of the "evaporated flow" model

  Standard Review Plan mass and energy releases

  ADS4, IRWST and sump flows for AP1000

WGOTHIC Computer Program

Results From Design Certification Review

- The AP1000 WGOTHIC model is consistent with the approved evaluation model

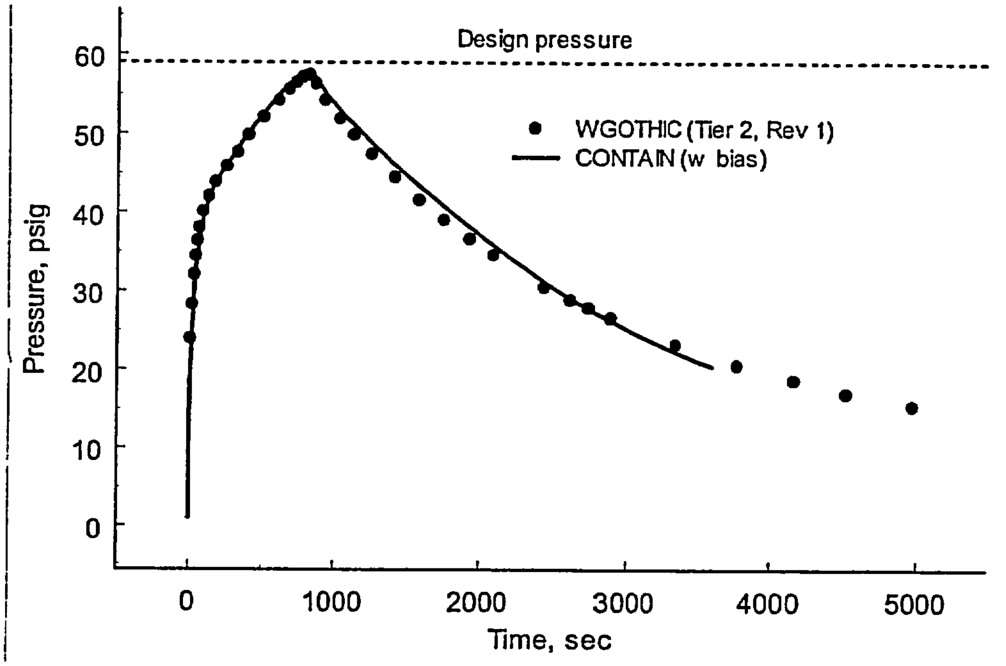
- Calculations are based on approved methodologies and consistent with guidance in the Standard Review Plan

- Margin to design pressure

  - LOCA 3.6 psi
  - MSLB 1.7 psi

- CONTAIN 2.0 calculations

WGOTHIC Computer Program



Preliminary CONTAIN 2.0 - MSLB from 30% Power

Preliminary CONTAIN 2.0 - LOCA DEG-CL Break

Nusselt number (Nu) is convective heat transfer divided by conductive heat transfer. It is a function of the Gr and Pr numbers. Nu=(h*L)/k=(heat transfer coefficient*body length)/thermal conductivity. It is ALSO a function of Re number and is the dominant parameter in forced convection.

Prandtl number (Pr) is viscous diffusivity divided by thermal diffusivity. It may be loosely interpreted as the ratio of viscous effects to conduction effects. $Pr=(\mu^*c_p)/k$=(viscosity*specific heat at constant pressure)/thermal conductivity.

Grashof number (Gr) gives the effect of bouyancy. It is the dominant parameter in free convection (absence of forced convection). Gr=g*▲density*L^3/(kinematic viscosity^2*initial density)=gravity*▲density*body length^3/(kinematic viscosity^2*initial density). Check for missing thermal expansion term (beta) in the numerator.

Rayleigh number (Ra) is the product of Grashof and Prandtl. Ra number governs heat transfer under natural convection conditions (the so called critical Ra no. is a definition of the onset of natural convection). It is the parameter that governs the overturning of an unstable (density increasing upward) ocean or atmosphere. Rayleigh numbers of between 10^{15}-10^{17} are typical for a molten reactor core (per conversation with Ali). For laminar vertical plate convection, Ra=(density^2*C_p*g*ß(T_w-T_∞)*x^3)/(k*μ)=(density^2*specific heat at constant pressure*gravity*thermal expansion coefficient(wall temperature - ambient temperature)*length^3/(thermal conductivity*viscosity). Not to be confused with Taylor instability which considers the overturning of an unstable (density increasing upward)ocean or atmosphere which is above the less dense body.

Reynolds Number (Re) allows one to distinguish between laminar and turbulent flow. Also can be thought of as the ratio of the inertial forces to the viscous forces. Re=[density(Kg/m^3)*velocity(m/s)*length(m)]/viscosity(kg/m.s).

Froude Number (Fr) is the ratio of the inertial forces to the gravitational forces. For flow in an open channel: Fr<1 flow is subcritical, tranquil, or streaming, Fr=1 flow is critical, Fr>1 flow is supercritical, rapid or shooting. Fr=(velocity(m/s))^2/depth(m)*gravity(m/s^2).

AP1000 DESIGN CERTIFICATION REVIEW

Status of NRC Staff Thermal-Hydraulic Review

ACRS Meeting of the Subcommitte on Thermal-Hydraulic Phenomena

John Segala, AP1000 Project Manager

New Reactor Licensing Project Office
Office of Nuclear Reactor Regulation

March 19, 2003

AGENDA

- Background
- Summary of Pre-Application Review
- Summary of Design Certification Review
- Status of Pre-Application Issues
- Status of Follow-On Issues

BACKGROUND

- AP600 certified on 12/16/1999 (FSER in 9/1998)
- Interest in applying for AP1000 design certification using much of the AP600 design
- 3-Phase Approach
  - Pre-Application Review
    - Phase 1 - Scoping Review (Completed 7/2000)
    - Phase 2 - 4 Issues (Completed 3/2002)
  - Phase 3 - Design Certification Review (Ongoing)

SUMMARY OF PRE-APPLICATION REVIEW

Thermal-Hydraulic Review

- ACRS Briefings re: Phase 2 Pre-Application Review
  - Future Plant Designs Subcommittee, 2/14 - 2/15/2002
  - Thermal-Hydraulic Phenomena Subcommittee, 2/14 -2/15/02
  - Full Committee, 3/7 - 3/9/2002
- ACRS letter to NRC, 3/14/2002
  - Agreed with the staff's conclusions regarding the pre-application review.
- NRC letter to Westinghouse, 3/25/2002
  - Identified 6 issues regarding the applicability of the AP600 analysis codes and test programs to the AP1000 design.

SUMMARY OF DESIGN CERTIFICATION REVIEW

- Westinghouse (W) submitted Design Certification application on 3/28/2002.
- NRC Staff reviewed and issued 714 RAIs.
- W responded to RAIs by 12/2/2002.
- NRC Staff reviewed RAI responses and provided additional comments to W.
- Numerous Conference Calls and Meetings
- W issued revised RAI responses
- 188 unresolved RAIs as of 2/28/2002 letter to W.

RAIs

- We issued 714 RAIs (starting on 6/27/02 and most by 9/30/02)
  - General - 3
  - Mech. Eng. - 70
  - Structural Eng. - 19
  - Seismology - 19
  - Hydrol. and Meteor - 4
  - Geotech. Eng. - 3
  - ISI - 3
  - Component Integrity - 29
  - Materials Application - 9
  - QA and RAP - 3
  - EP - 3
  - Containment Systems - 9
  - TSs - 53
  - ITAAC - 1
  - Initial Test Program -13
  - Fire Protection - 11
  - Chemical Technology - 3
  - Auxiliary Systems - 21
  - I&C - 46
  - Electric Power - 15
  - Reactor Systems - 187
  - Meteorology - 8
  - Effluent Treatment - 11
  - Radiological Impact - 13
  - Radiation Protection - 10
  - Human System Int. - 43
  - PRA - 99
  - USI/GSI - 6

PRE-APPLICATION ISSUES

Thermal-Hydraulic Review

- Liquid entrainment in upper plenum or hot leg during ADS-4 actuation
  - Staff issued 48 RAIs
  - 6 RAIs unresolved
  - Staff issued 3/18/2003 letter to W. requesting new test data
- Potential Steam Voids in RCS following MSLB
  - Resolved
- Non-conservative boiling heat transfer correlation in NOTRUMP at high heat fluxes in PRHR HX
  - Resolved

PRE-APPLICATION ISSUES (Cont.)

Thermal-Hydraulic Review

- Potential boron precipitation in the vessel during long term cooling
  - Unresolved
- Concern for core uncovery during SBLOCA in performing complete break spectrum
  - Resolved
- Use of the approved WGOTHIC containment evaluation model to address large scale test short comings
  - Resolved

FOLLOW-ON ISSUES

- Issued about 48 RAIs related to Chapter 15 Analysis
- Westinghouse responded satisfactorily to all except the following:
  - Feedwater line break analysis to identify the limiting case
  - TS required flow to support the adequate flow mixing in the RCS
  - ATWS Analysis to identify the limiting case

SUMMARY OF FUTURE ACTIONS

- NRLPO PMs are currently tracking the unresolved issues to ensure Westinghouse has been engaged on each item prior to the issuance of the DSER
- DSER input due 4/21/2003 from reviewers
- DSER scheduled to be issued on 6/16/2003
- ACRS Interactions:
  - Future Plant Design Subcommittee, April/May 2003
    - Scope and agenda to be determined
  - Full Committee, June/July 2003
    - DSER and Open Items