AP1000 Design Certification

Meeting with NRC to Discuss Thermal-Hydraulic Issues

May 29, 2003

AP1000

AGENDA

8:30 AM	Introduction	Mike Corletti
8:40 AM	NOTRUMP Level Swell Validation	Andre Gagnon
9:00 AM	Presentation of Applicable Test Data	
	FLECHT-SEASET	Cesare Frepoli
	UPTF	Katsu Ohkawa
10:15 AM	NOTRUMP Presentation	Andre Gagnon
	Preliminary Results of NOTRUMP Bounding Calculation	
10:40 AM	Comparison of RELAP / NOTRUMP	Walt Jensen
11:00 AM	Presentation of APEX-1000 Test Results	Rick Wright
	Matrix	
	Test Results	
	Analytical Comparisons	
	Insights	
11:45 AM	Long-Term Cooling Issues	Terry Schulz
	Boron Precipitation	
12:15 PM	Long-Term Cooling Noding Studies	Bob Kemper
12:45 PM	Summary	Mike Corletti

AP1000

Purpose

- **Review Westinghouse plan / progress to resolve thermal-hydraulic issues related to AP1000**
  - Liquid entrainment issue
  - Post-LOCA boron precipitation
  - Long-term cooling analyses

Plan to Resolve Liquid Entrainment Issue

- **Demonstrate NOTRUMP Plant Calculations are Sufficiently Conservative**
  - Compare level swell predictions to test data
  - FLOAD4 modeling of momentum flux
- **Perform bounding NOTRUMP calculation of limiting SB LOCA**
- **Perform additional validation of NOTRUMP against APEX-1000**
  - Compare overall system performance

AP NOTRUMP Level Tracking

Andre F. Gagnon
LOCA Integrated Services
Westinghouse Electric Company, LLC
(412) 374-5574; gagnonaf@westinghouse.com

AP1000

AP NOTRUMP Level Tracking

Background

- **NOTRUMP Two-Phase Mixture Level Swell Model Validated In WCAP-14807, Revision 5**
- **ACRS Questioned Validity Of Assumed Mixture Level Coverage Given Calculated Core Collapsed Levels**

AP1000

AP NOTRUMP Level Swell Validation

Level Swell Background

- **Prediction Of Two-Phase Mixture Level Determines If Core Remains Covered Or Fuel Rod Heatup Occurs**
- **NOTRUMP Model Validated Against Several Tests**
  - Blowdown Tests With Varying Pressure
    - GE Small Vessel Blowdown
  - Constant Pressure Tests w/Heat Addition
    - Achilles (Low Pressure Level Swell Tests)
    - G2
  - SPES/OSU (APEX) Integral Facility Simulations

AP1000

AP NOTRUMP Level Swell Validation

GE Results Summary

- **Test Performed**
  - 8-21-1(1015 psia, 8.89 ft Collapsed Level, 3/8" Orifice, w/Restrictor Plate)
  - 8-25-1(1020 psia, 8.82 ft Collapsed Level, 1/2" Orifice, w/Restrictor Plate)
  - 1004-3 (1011 psia, 10.4 ft Collapsed Level, 3/8" Orifice, No Restrictor Plate)
  - 1004-2 (1011 psia, 10.5 ft Collapsed Level, 7/8" Orifice , No Restrictor Plate)

AP1000

AP NOTRUMP Level Swell Validation

GE Results Summary

- **NOTRUMP Closely Predicts Data Trends Observed In Tests**
  - Uncertainty In Results Due To Entrainment And Breakflow
  - With These Items Factored Out (Mass Matching), NOTRUMP Conservatively Estimates Two-Phase Mixture Level/Void Fraction

AP NOTRUMP Level Swell Validation

ACHILLES Test Summary

- **Two Test Simulated**
  - A1L066(17.64 psia, 96.5 kW)
  - A1L069(29 psia, 96.3 kW)
- **Consistent Trends In Results Observed**
- **For The Same Collapsed Level NOTRUMP Conservatively Predicts A Lower Two-Phase Mixture Level**

AP NOTRUMP Level Swell Validation

G2 Test Summary

- **Tests Performed**
  - 715 (779 psia, 0.603 MW, 114" Initial Level)
  - 716 (775 psia, 0.252 MW, 138" Initial Level)
  - 719 (394 psia, 0.267 MW, 138" Initial Level)
  - 720 (395 psia, 0.615 MW, 114" Initial Level)
  - 724 (96 psia, 0.252 MW, 126" Initial Level)
  - 725 (96 psia, 0.599 MW, 96" Initial Level)
  - 728 (50 psia, 0.596 MW, 84" Initial Level)

AP1000

AP NOTRUMP Level Swell Validation

G2 Test Summary

- **Tests Performed (Continued)**
  - 729 (50 psia, 0.250 MW, 114" Initial Level)
  - 732 (15.1 psia, 0.254 MW, 102" Initial Level)
  - 733 (15.8 psia, 0.6 MW, 72" Initial Level)

AP1000

AP NOTRUMP Level Swell Validation

G2 Test Summary

- **Facility Leakage Makes Modeling Difficult**
  - Analyses Performed Accounting For Uncertainties In Test Leakage
- **For A Majority Of Conditions NOTRUMP Predicts Two-Phase Mixture Level Below Test Even Considering Uncertainties**
  - NOTRUMP Conservatively Predicts Low Mixture Level

AP1000

AP NOTRUMP Level Swell Validation

Level Swell Validation Summary

- **Tests Performed Cover Range Of Expected Conditions**
  - Includes Heated Bundles and Depressurization Effects
- **NOTRUMP Calculations Of Average Level Swell Are Conservative For Nearly All Tests**

AP1000

AP NOTRUMP Level Swell Validation

a,b,c

[ ]

AP1000

AP NOTRUMP Level Swell Validation

DCD Transient Summary

- **Both AP600 and AP1000 Indicate Adequate Core Mixture Level To Preclude Core Uncovery**
  - Breaks Up To 8-Inch DVI Line Break
  - Core Heatup Predicted for Both AP600 and AP1000 For 10-Inch Cold Leg Break
    - AP1000 Heatup Not A Result Of Two-Phase Level Uncovery But Rather High Quality
      - Adiabatic Heatup Calculations Performed For Conservatism

AP1000 ACRS Meeting Synopsis

ACRS Core Collapsed Level Question

- **ACRS Questioned Whether Calculated Core Collapsed Levels Could Support Core Coverage**
  - Calculated Void Fractions Are Higher For AP1000 Plant Design
    - What Is The Relationship Between Collapsed Core Level And Core Cooling?
      - Stated That Full Scale Tests Were The Preferred Approach For Resolution

AP1000

Applicable Test Data Relative to Post- Quench Core Coverage and Heat Transfer in AP1000

Cesare Frepoli
LOCA Integrated Services
Westinghouse Electric Company, LLC
(412) 374-4156; frepolc@westinghouse.com

AP1000

Outline

- Considered Scenario
- AP1000 boundary conditions extracted from NOTRUMP calculation results.
- Applicability of Post-Quench FLECHT-SEASET Full Scale Tests data
- Expected Flow Regimes in AP1000 core
- Applicability of selected G2 Boil-off Tests data
- Collapsed Liquid and Core Coverage in AP1000
- System Effects

Considered Scenario

- After opening the ADS-4 stage and before the IRWST injection a time period of minimum vessel liquid inventory is expected to occur in AP1000

- At the time of minimum vessel inventory, core flow and core collapsed liquid level are at the minimum level

- The DEGDVI Transient was found to be one of the most limiting case

AP1000 Core Boundary Conditions at the time IRWST injection starts

AP1000

- Conditions were taken from the Base NOTRUMP calculation for the DEGDVI transient (25 psia containment back-pressure)
- Time = 1000 sec.
- Upper Plenum Pressure = 40 psia
- Core Peak Power = 0.22 kW/ft
- Top Skewed Power Shape
- Core Inlet Flow = 0.53 in/sec
- Inlet Liquid Subcooling = 27 F

AP1000 Core Power Shape

a,b,c

Applicability of FLECHT-SEASET Tests Data

- FLECHT-SEASET tests are forced reflood tests.
- Later in reflood, after test bundle is quenched fluid conditions are similar to the AP1000 core conditions during the considered time window.
- Five FLECHT-SEASET tests were considered in this analysis.

AP1000

Applicability of FLECHT-SEASET Tests Data

a,b,c

Flow Regime Map

- **Local equilibrium quality X_{eq} was simply estimated from a quasi-steady state mass and energy balance across the bundle (mass storage term is negligible).**

- **Equilibrium quality axial distribution is calculated as function of flow and inlet subcooling and by integrating the power assuming the cosine distribution.**

- **Local phasic superficial velocities are estimated as follows:**

$$j_g(z) = X_{eq}(z) u_{l.in} \frac{\rho_l}{\rho_g}$$

$$j_l(z) = (1 - X_{eq}(z)) u_{l.in}$$

AP1000

a,b,c

Flow Regime Map in FLECHT-SEASET Discussion

AP1000

- Mishima-Ishii is based on Tube data.
- Griffith et al. (1988) concluded that for rod bundles in which bubbles are formed by heat transfer, the maximum bubble size scaled with the rod pitch (which is similar to the hydraulic diameter)
- Mishima-Ishii is applicable to this bundle geometry.

FLECHT-SEASET
Measured Void Fraction Distribution

a,b,c

FLECHT-SEASET
Measured Void Fraction Distribution

a,b,c

FLECHT-SEASET

Measured Void Fraction Distribution

a,b,c

FLECHT-SEASET

AP1000

Summary on Void Fraction Distribution and Collapsed Liquid Level

- **FLECHT-SEASET Run 31544 was selected because it shows the bundle quenched with collapsed liquid level at about 30%**
- **Other tests show a higher collapsed liquid level as a result of a significant inlet subcooling.**
- **The measured void fraction was compared with commonly used void fraction correlation's (Yeh and Murao-Iguchi).**
- **Revised Yeh correlation is in good agreement with data.**
- **For given fluid conditions (Jg and Jl) Yeh correlation tends to underestimate the void fraction.**

FLECH-SEASET Run 35114: Flooding Limit?

a,b,c

FLECHT-SEASET: Onset of Entrainment?

AP1000

a,b,c

AP1000

Flow Regime Map in AP1000

a,b,c

Calculated Void Fraction Profile (Yeh) & Collapsed Liquid Level in AP1000

AP1000

a,b,c

AP1000

AP1000: Below Flooding Limit?

a,b,c

AP1000

G2 Boil-off Tests

a,b,c

AP1000

Heat Transfer

- The comparison against Critical Heat Flux Data at low pressure and low flow conditions (Shoesse et al. (1997) and El-Genk et al. (1988) shows that the AP1000 power level is significant below the CHF limit for both annular film flow or intermittent churn flow.

- Rod temperature excursion can be expected if the mixture level drops below top of the core and determined by the flooding/flow reversal phenomenon.

System Effects

- **Assuming 0.53 in/sec inlet flow, the steady-state mass and energy balance leads to a 52% core collapsed liquid level with full core coverage and 70% exit quality.**
- **A minimum core inlet flow corresponding to 0.38 in/sec is required to match the steam generated in the core.**
- **NOTRUMP base calculation indicates a core inlet flow of at least 0.5 in/s which provides a 20% margin.**
- **System effects / sensitivities:**
  - A decrease in pressure promote more level swelling and higher injection.
  - A decrease in power reduces the level swelling but decreases the minimum flow requirements.

AP1000

UPTF Test Summary

Katsu Ohkawa
LOCA Integrated Services
1-412-374-5196 - ohkawak@westinghouse.com

Liquid Holdup in the Upper Plenum During ADS-4 Stage

AP1000

- **Issue:**
  Ability of NOTRUMP in predicting the amount of liquid present in the upper plenum during ADS-4 stage.

- **Concern:**
  A column of water in the upper plenum constitutes additional head for the steam vent from the core through hot legs and ADS-4 valves to the containment. A higher head would slow depressurization delaying core recovery during a postulated SBLOCA.

Liquid Holdup in the Upper Plenum During ADS-4 Stage

AP1000

- **NOTRUMP calculations show 40% to 60% liquid fraction from the upper core plate to the hot leg elevation.**

- **Comparisons made to a limited set of available data from the 2D/3D Program.**

- **2D/3D program summarized the upper plenum equilibrium liquid inventory as a** linear correlation **between UP liquid fraction and dimensionless velocity ratio (jl/jg) based on the total core exit water and steam flows. (Volume between UCP to HL mid elevation)**

Liquid Holdup in the Upper Plenum During ADS-4 Stage

a,b,c

Liquid Holdup in the Upper Plenum During ADS-4 Stage

AP1000

a,b,c

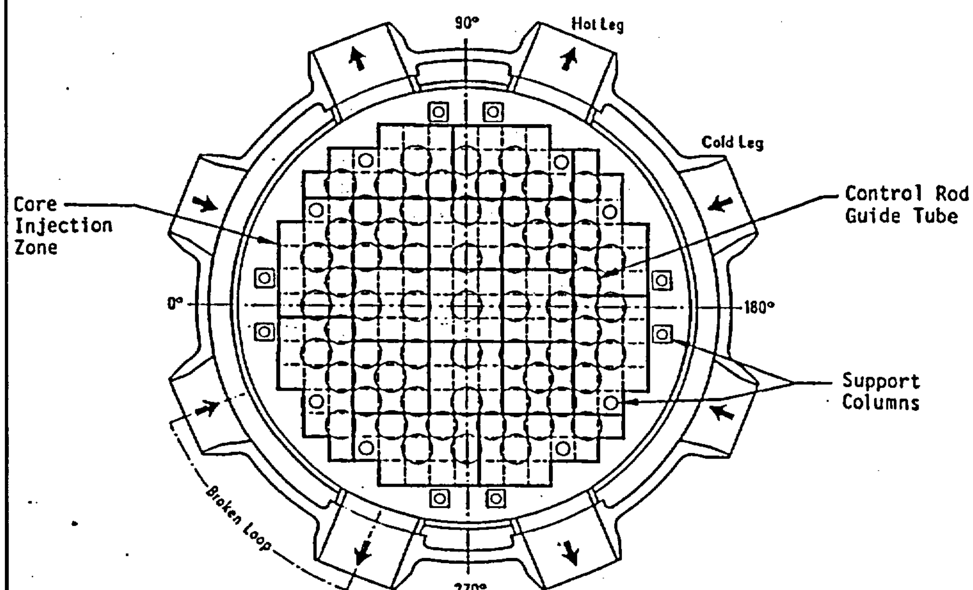
Liquid Holdup in the Upper Plenum During ADS-4 Stage

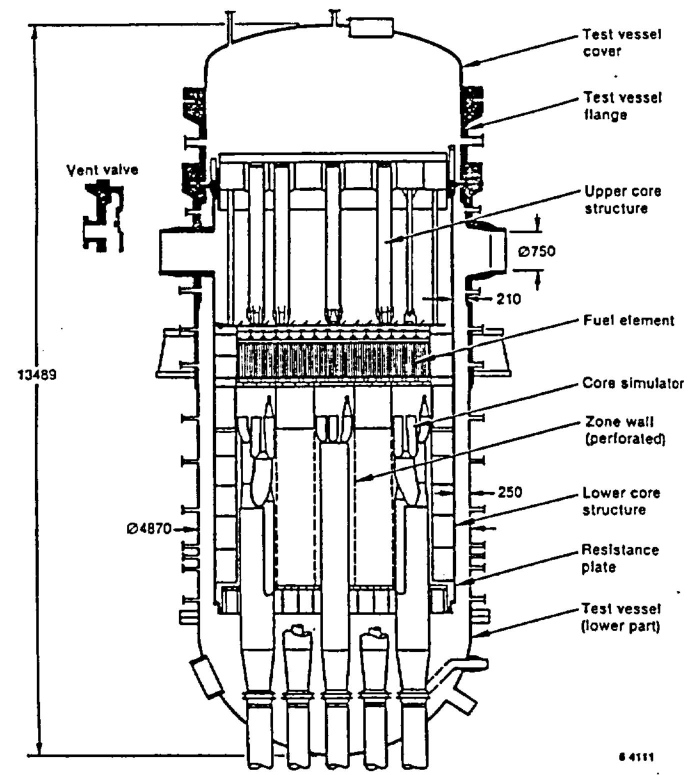
AP1000

a,b,c

Liquid Holdup in the Upper Plenum During ADS-4 Stage: UPTF Vessel

a,b,c





Liquid Holdup in the Upper Plenum During ADS-4 Stage: AP1000 UP

AP1000

a,b,c

Liquid Holdup in the Upper Plenum During ADS-4 Stage

AP1000

a,b,c

Liquid Holdup in the Upper Plenum During ADS-4 Stage

AP1000

a,b,c

AP1000

Liquid Holdup in the Upper Plenum During ADS-4 Stage

a,b,c

Liquid Holdup in the Upper Plenum During ADS-4 Stage

AP1000

a,b,c

Liquid Holdup in the Upper Plenum During ADS-4 Stage

AP1000

a,b,c

AP1000

Results of NOTRUMP Bounding Calculation

Andre F. Gagnon
LOCA Integrated Services
Westinghouse Electric Company, LLC
(412) 374-5574; gagnonaf@westinghouse.com

AP1000

AP1000 ACRS Meeting Synopsis

ACRS Entrainment Summary

- **Entrainment Effect Can Be Conservatively Bounded**
  - Perform Hand Calculations
  - Perform Bounding NOTRUMP Simulations
    - Conservatively Capture Effect Of Entrainment
      - Model Upper Plenum/Hot Legs/ADS-4 Paths As Homogenous

AP1000

AP1000 Bounding Calculation

NOTRUMP Bounding Calculation

- **AP1000 Modified As Follows:**
  - Normal Simulation Up To ADS-4 Opening Time
  - At ADS-4, Upper Plenum/Hot Legs and ADS-4 Paths Made Homogenous
    - Conservatively Captures Liquid Entrained Out Of Core Region Through ADS-4

AP1000

AP1000 Bounding Calculation

Preliminary Calculation Results

- **Significant Liquid Entrained Out Of ADS-4 Paths**
- **Currently Under Review**

APEX-1000 Tests

AP1000

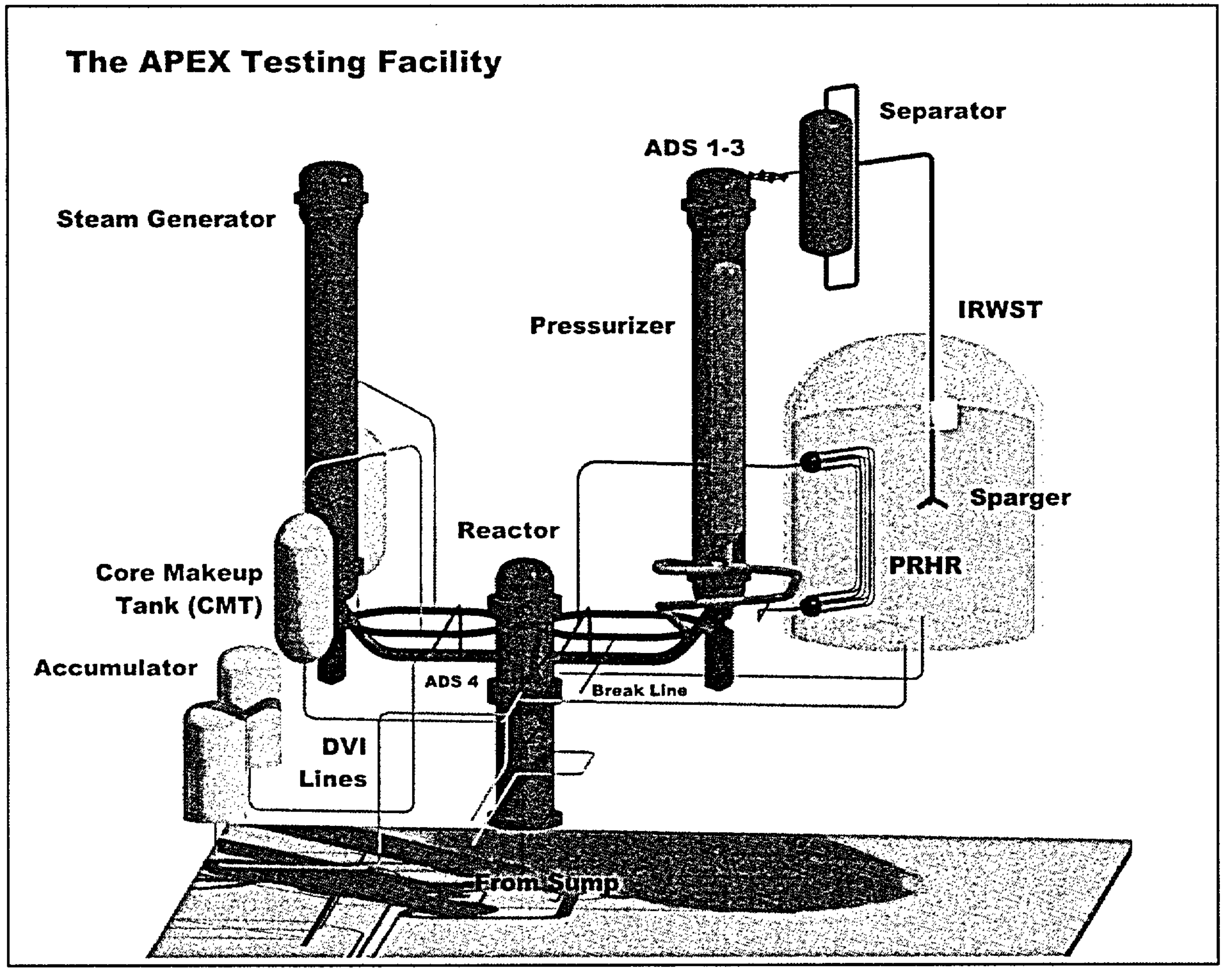
APEX-1000 Test Program

- **OSU is conducting APEX-1000 tests in cooperation with Westinghouse under a DOE NERI grant**
- **Westinghouse has provided AP1000 design details to OSU**
- **OSU Scaling Report prepared by Dr. Jose Reyes**
  - Reviewed by Westinghouse
- **APEX-1000 Facility Description Report prepared by OSU**
- **Test Matrix defined by Westinghouse**
  - Reviewed by Office of Research
- **Test Summary Reports prepared by OSU / W**

APEX-1000 Facility Description

a,b,c

APEX Facility Modifications



2 CMTs – Larger Volume	PRHR Lines - Larger Diameter
ADS 4 - Larger Flow Nozzle Area; Reduced line Resistance	IRWST Injection Lines - 1 Line Larger Diameter
Pressurizer - Larger Volume	IRWST Liquid Level - Increased Height
PZR Surge Line - Reduced Diameter	Sump Recirculation Lines - 1 Line Larger Diameter; Raise Flood-up Elevation
Reactor - 1 MW Power and Larger Core Flow Area	Data Acquisition System Replacement

APEX-1000 Test Program
Purpose for AP1000 Design Certification

AP1000

- **APEX-1000 Provides Integral System Performance Data for a Test Facility Properly Scaled for AP1000 for Important Phenomena**
  - Complements Earlier AP1000 PIRT and Scaling Work
    - Earlier scaling demonstrated that AP600 tests were sufficient with the exception of entrainment
    - APEX-1000 is properly scaled for AP1000
  - APEX-1000 DBA series tests will be used to further validate NOTRUMP
    - Resolves lack of applicable test data issue raised in NRC letter

Test Matrix

- **Design Basis Accident System Performance Tests**

DESIGN BASIS ACCIDENT TESTS		
Test ID	Description	Scheduled or *Completed
DOE-01 (DBA-01-D)	Double-Ended DVI Line Break with Failure of 1 ADS-4 valve on Loop 2 - Pressurizer Side. (Flow Nozzles)	*2/28/03
DOE-02 (DBA-02-D)	Double-Ended DVI Line Break with Failure of 1 ADS-4 valve on Loop 1 - Non-Pressurizer Side. (Reduced ADS-4 Line Resistance Venturi Nozzle) – Completed	*5/1/03
DOE-03 (DBA-03-D)	Double-Ended DVI Line Break with Failure of 1 ADS-4 valve on Loop 2 - Pressurizer Side. (Reduced ADS-4 Line Resistance Venturi Nozzle) Completed 5/15/03	*5/15/03
DOE-04 (DBA-04-D)	2-Inch (5 cm) Cold Leg Break with failure of 1 ADS-4 valve on Loop 2.	5/30/03

AP1000

Test Matrix

- **Additional Confirmatory Tests Planned**
  - Results Available to NRC

ADS-4 BLOWDOWN TRANSITION TESTS		
Test ID	Description	Scheduled or *Completed
DOE-05 (TR-01-D)	Full-Pressure ADS-4 Blowdown to Onset of IRWST Injection. Initial Pressure-100 psia; High Decay Power, Failure of 1 ADS-4 Valve.	6/14/03
DOE-06 (TR-02-D)	Full-Pressure ADS-4 Blowdown to Onset of IRWST Injection. Initial Pressure-140 psia; High Decay Power, Failure of 1 ADS-4 Valve.	6/30/03
DOE-07 (TR-03-D)	Full-Pressure ADS-4 Blowdown to Onset of IRWST Injection. Initial Pressure-100 psia; Low Decay Power, Failure of 1 ADS-4 Valve.	7/14/03
DOE-08 (TR-04-D)	Full-Pressure ADS-4 Blowdown to Onset of IRWST Injection. Initial Pressure-140 psia; High Decay Power, No ADS-4 Failures.	7/30/03

AP1000

Test Matrix

- **Additional Confirmatory Tests Planned**
  - Results Available to NRC

LOW PRESSURE STEADY-STATE ENTRAINMENT TESTS		
Test ID	Description	Scheduled or *Completed
DOE-09 (EN-01-D)	Steady-state upper plenum entrainment tests with upper internals scaled to preserve vapor volumetric flux, j_g. (~1 MW)	8/14/03
DOE-10 (EN-02-D)	Steady-state upper plenum entrainment tests with upper internals scaled to preserve vapor volumetric flux, j_g. (~700 kW)	8/30/03
PRA TEST		
DOE-11 (PRA-01-D)	Double-Ended DVI Line Break with Failure of the Intact Accumulator.	9/14/03

AP1000

APEX1000 Test Results

a,b,c

AP1000

APEX1000 Test Results

a,b,c

[ ]

APEX1000 Test Results

a,b,c

AP1000

APEX1000 Test Results

a,b,c

[ ]

AP1000

APEX1000 Test Results

a,b,c

[ ]

AP1000

APEX1000 Test Results

a,b,c

[ ]

AP1000

APEX1000 Test Results

a,b,c

[ ]

AP1000

APEX1000 Test Results

a,b,c

[ ]

AP1000

APEX1000 Test Results

a,b,c

[ ]

AP1000

APEX1000 Test Results

a,b,c

[ ]

AP1000

APEX1000 Test Results

a,b,c

[ ]

AP1000

APEX1000 Test Results

a,b,c

[ ]

AP1000

APEX1000 Test Results

a,b,c

AP1000

APEX1000 Test Results

a,b,c

[ ]

APEX1000 Test Results

a,b,c

[ ]

AP1000

APEX1000 Test Results

a,b,c

[ ]

AP1000

APEX1000 Test Results

a,b,c

[ ]

AP1000

APEX1000 Test Results

a,b,c

[ ]

APEX 1000 Test Simulations

Background

- **NOTRUMP Simulations To APEX-1000 Tests Currently Ongoing**
  - Modeling Being Refined To Better Match Initial Test Conditions

AP1000

APEX 1000 Test Simulations

Test Results

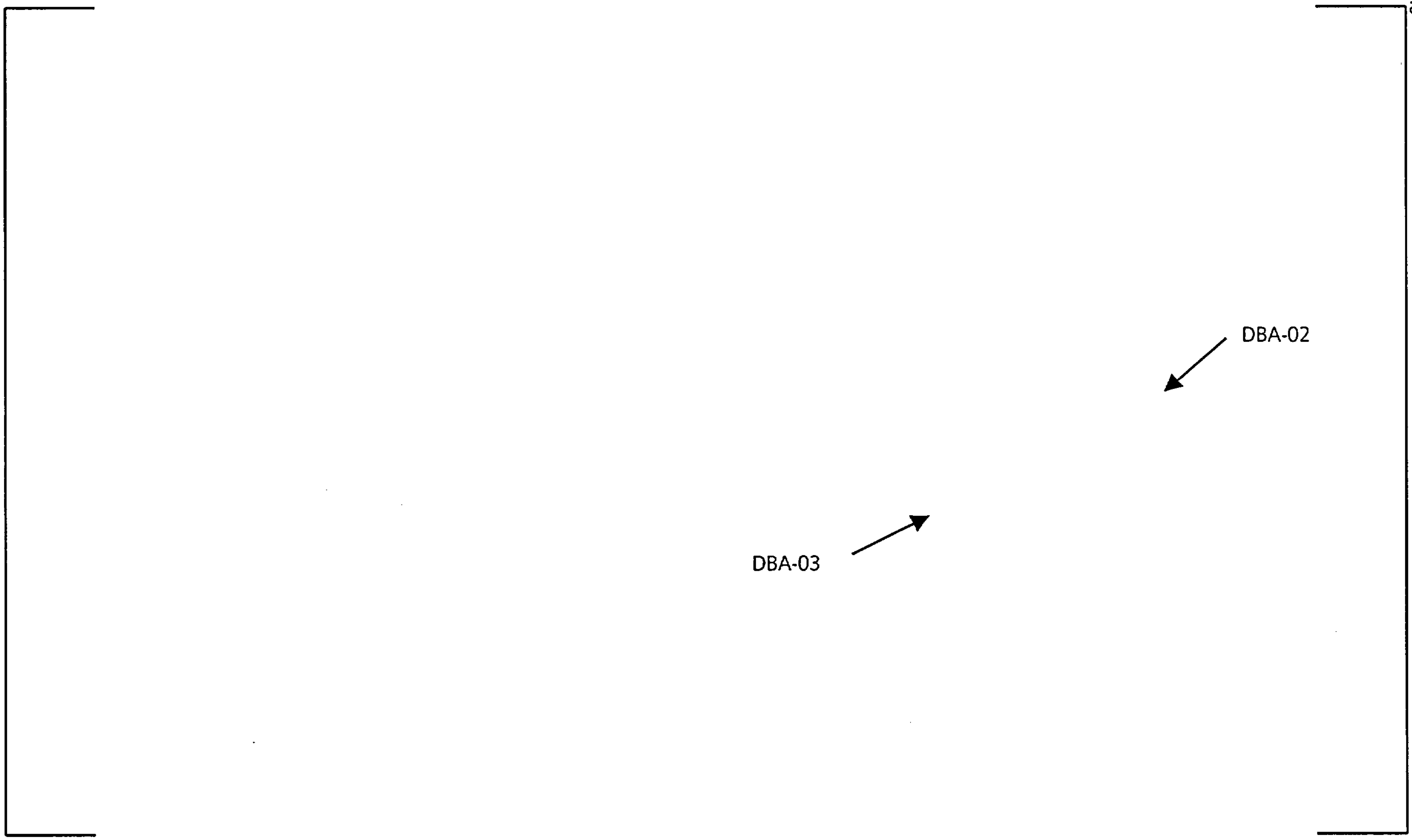
- **ADS-4 Failure Assumption Affects System Performance**
  - Location Of Assumed Failure Affects Pressurizer Drain/IRWST Injection
    - NOTRUMP Test Simulations Performed Exhibit Similar Trend
    - Plant Calculations Also Exhibit Similar Behavior

APEX-1000 Test Data Comparison

AP1000

Pressurizer Water Level

a,b,c



AP1000

APEX 1000 Test Data

a,b,c

APEX Test Results
Insights

AP1000

- **APEX-1000 DBA Tests Demonstrate Good Passive Safety System Performance**
  - Integral system response for AP1000 is similar to equivalent AP600 response
  - Test shows good core cooling for the most demanding SBLOCA

APEX Test Results Conclusions

AP1000

- **APEX-1000 Provides Integral System Performance Data for a Test Facility Properly Scaled for AP1000 for Important Phenomena**
  - Complements Earlier AP1000 PIRT and Scaling Work
    - Earlier scaling demonstrated that AP600 tests were sufficient with the exception of entrainment
    - APEX-1000 is properly scaled for AP1000
    - Therefore validation of NOTRUMP to APEX-1000 DBA series tests is sufficient to resolve lack of applicable test data
  - Future NRC Confirmatory Tests Not Required for Design Certification

AP1000

AP1000 Long-Term Core Cooling Boron Precipitation

Terry Schulz
Advisory Engineer
412-374-5120 - schulztl@westinghouse.com

AP1000

AP1000 LTC Boron Precipitation

- **AP1000 Long-Term Core Cooling (Post LOCA)**
  - System design features
  - Boron precipitation evaluation
    - Minimum water flow through core (and out ADS 4) calculated
      - Insights from OSU testing and plant analysis (WCOBRA-TRAC)
      - Simplified, bounding hand calculation
        - » Model
        - » Results (preliminary)
    - Maximum core boron concentration calculated
      - Core equilibrium boron concentration reached when
        - » Boron injected in PXS water = boron removed in ADS 4 water
    - Show that minimum water flow through core is sufficient to prevent boron precipitation with margin

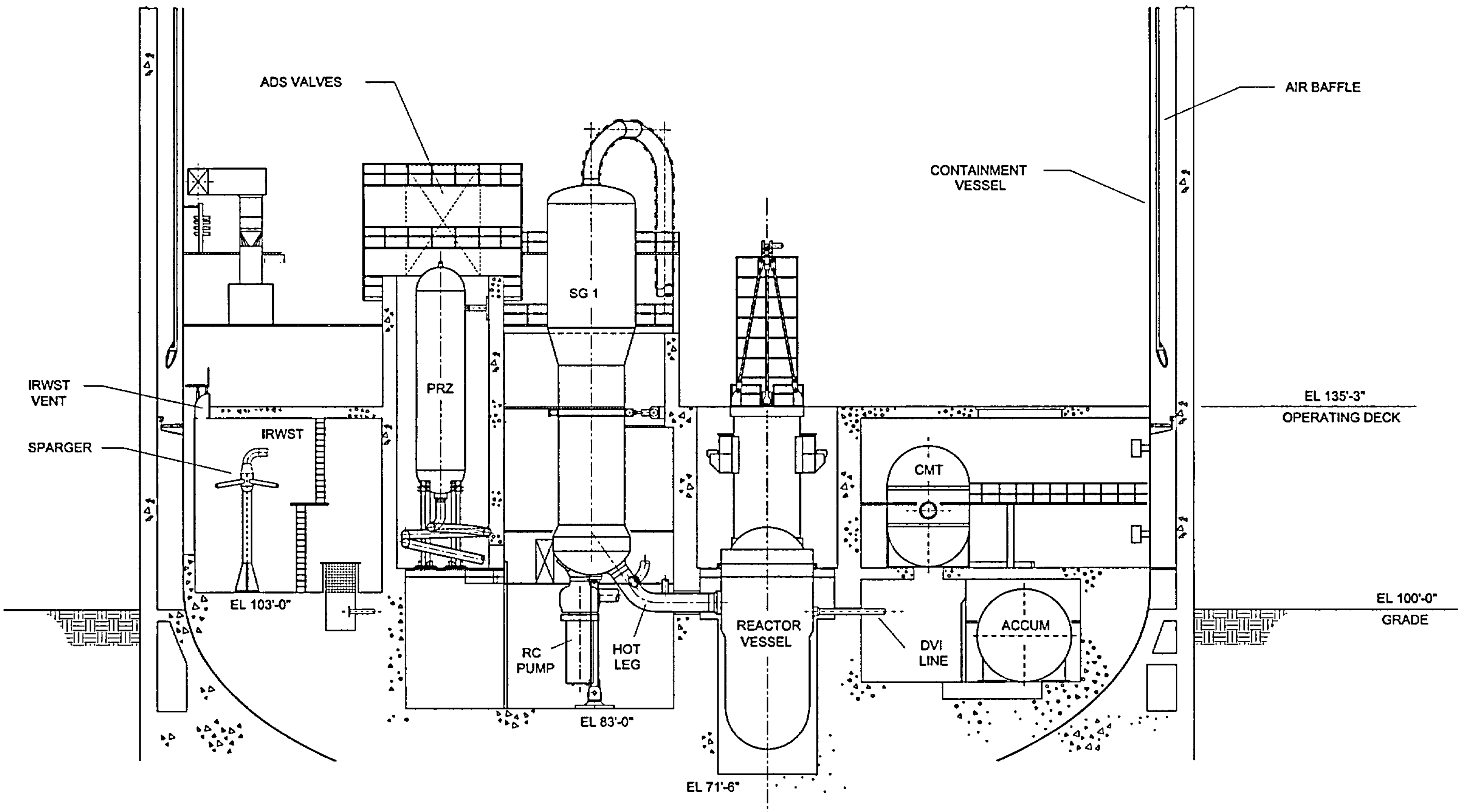
AP1000

AP1000 LTC

- **PXS Design Features**
  - Following a LOCA
    - PXS injection provided by
      - Accum and CMTs
        - » for 30 min or more
      - IRWST gravity injection after Accum / CMTs drain
        - » for 2.5 hours or more
      - Containment recirc after IRWST drains
        - » After 2.5 hours
    - Injection path into RCS is always through the DVI (CL) connection

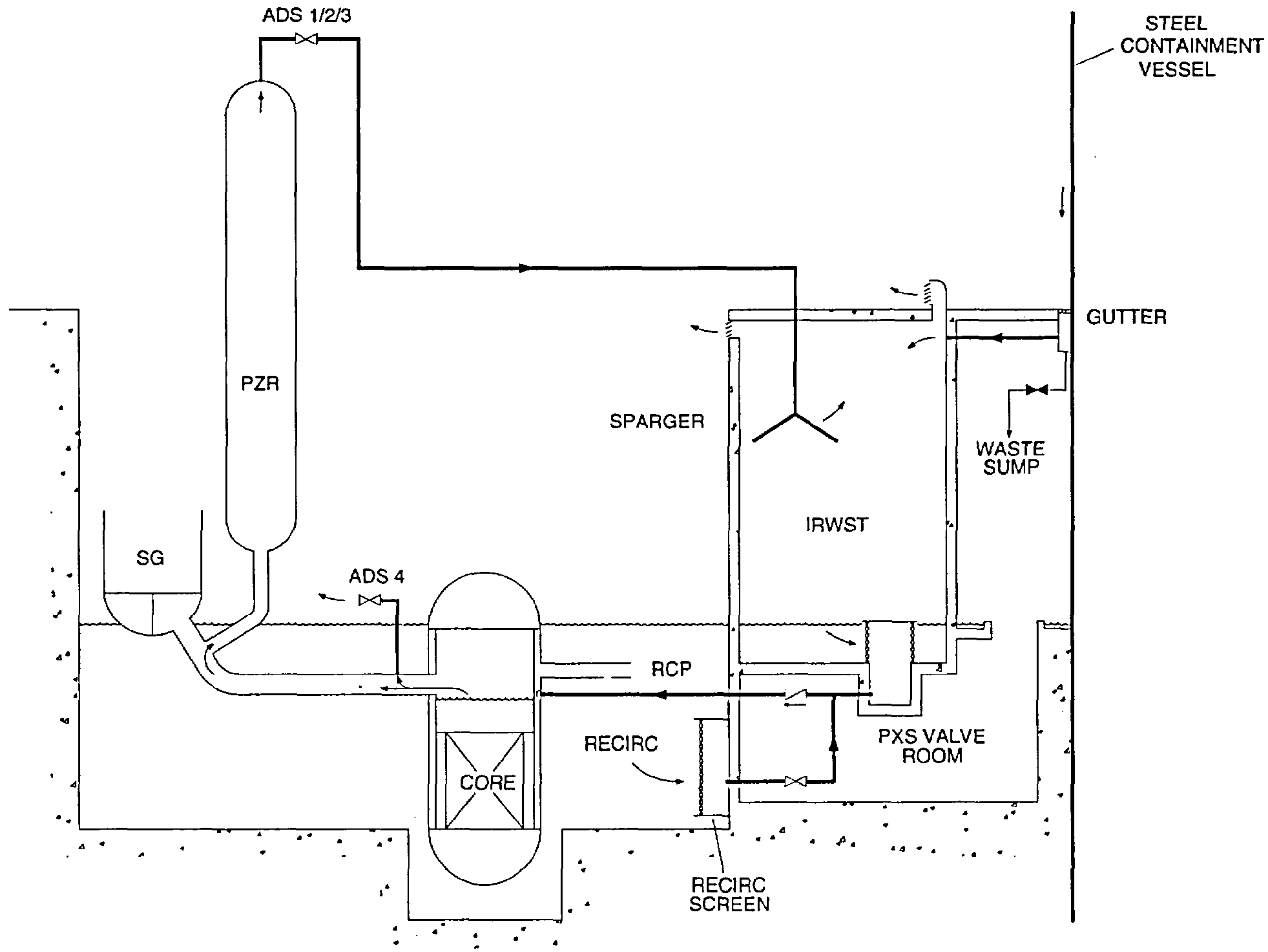
AP1000

PSI Equipment Layout



AP1000

LOCA LTC Operation



AP1000 LTC Water Carryover

- **Insights from OSU Testing and Plant Analysis**
  - Shows that during recirc PXS injection / ADS venting process is cyclical
    - With a reduced HL level, ADS 4 venting is mostly steam
    - ADS 4 venting with mostly steam has low DP
    - With these conditions PXS provides excess injection, HL fills
    - When HL fills, ADS 4 venting becomes mostly water
    - DP increases greatly (both friction and head)
    - ADS 4 flow is reduced to less than required to remove decay heat
    - Steam accumulates in RCS (RV upper head)
    - Increased RCS pressure reduces PXS injection
    - RCS pressure becomes sufficient to push water out ADS 4
    - RCS pressure and HL level decrease
    - Cycle starts all over again (cycle period is < 500 sec)

AP1000

Simplified LTC Analysis

- **Purpose**
  - Evaluate LTC (containment recirc) for boron concentration
    - Slant analysis toward minimum water carryover
      - Models
      - Assumptions
      - Inputs
    - Consider variations in assumptions and inputs
  - Provide independent analysis from tests / computer analysis
    - Use simplified, bounding hand calculation

AP1000

Simplified LTC Analysis

- **Model**
  - Inputs
    - Containment pressure (total and partial steam), water level
    - Margins applied to decay heat and PXS line resistances
    - Time after shutdown
  - Assumptions
    - Downcomer assumed to be full
      - Confirmed by analysis
    - No metal heat assumed
      - Reasonable given long time after shutdown
    - Core exit quality same as ADS 4 vent quality
      - With adjustment for water flashing between core exit and ADS 4 discharge

AP1000

Simplified LTC Analysis

- **Model**
  - Assumptions (cont)
    - Water level is at top of HL
      - Steam bubbles up through water
      - Quality based on calculated steam bubble rise velocity (small bubbles)
    - ADS 4 DP calc using 2 phase multiplier
      - Uses max of Homogeneous and Martinelli-Nelson
    - ADS 4 DP includes momentum effects
  - Calc method
    - ADS 4 vent quality is guessed
    - PXS recirc flow calculated >>> DP through RCS calculated
    - ADS 4 quality changed until calc ADS 4 exit pres. equals cont. pres.

Simplified LTC Analysis Results

		Case 1a	Case 1b	Case 1c
Basis for decay heat		Max	Max	Max
Basis for flow resistance		Max	Max	Max
Time after accident (days)		14.00	14.00	14.00
Total containment pres (psia)		19.0	19.0	19.0
Recirc water temp (F)		138.8	138.8	138.8
Recirc water elev. (ft)		103.3	103.3	103.3
ADS 4 vent quality		90.00%	30.00%	56.67%
Core exit quality		89.00%	28.08%	55.14%
Collapsed core liquid level (ft)		8.49	12.61	10.81
PXS Flows				
Recirc flow	(lb/sec)	10.20	25.87	15.37
ADS 4 water vent	(lb/sec)	1.02	18.11	6.66
ADS 4 steam vent	(lb/sec)	9.18	7.76	8.71
Pressures:				
Containment	(psia)	19.00	19.00	19.00
ADS 4 discharge	(psia)	21.38	16.95	19.00
ERROR (Cont pres - ADS 4 pres)		2.4E+00	-2.1E+00	-2.4E-08
Pressure losses				
Cont Recirc line	(psi)	0.06	0.25	0.11
ADS 4 line	(psi)	0.12	0.31	0.19

- **ADS 4 Vent Quality is Varied**
  - Until ADS 4 discharge pres equals containment pres
  - With ADS 4 quality too high
    - Case 1a shows example
    - DP through system is too low
    - ADS 4 discharge pres is too high
  - With ADS 4 quality too low
    - Case 1b shows example
    - DP through system is too high
    - ADS 4 discharge pres is too low
  - With correct ADS 4 quality
    - Shown in Case 1c
    - ADS 4 discharge pres = cont pres

AP1000

Simplified LTC Analysis Results

		Case 1	Case 2	Case 3
Basis for decay heat		Max	BE	Min
Basis for flow resistance		Max	BE	Min
Time after accident (days)		14.00	14.00	14.00
Total containment pres (psia)		19.0	19.0	19.0
Recirc water temp (F)		138.8	138.8	138.8
Recirc water elev. (ft)		103.3	103.3	103.3
ADS 4 vent quality		56.67%	53.45%	52.32%
Core exit quality		55.14%	51.86%	50.71%
Collapsed core liquid level (ft)		10.81	11.03	11.11
PXS Flows				
Recirc flow	(lb/sec)	15.37	12.91	5.80
ADS 4 water vent	(lb/sec)	6.66	6.01	2.76
ADS 4 steam vent	(lb/sec)	8.71	6.90	3.03
Pressures:				
Containment	(psia)	19.00	19.00	19.00
ADS 4 discharge	(psia)	19.00	19.00	19.00
ERROR (Cont pres - ADS 4 pres)		-2.4E-08	-8.9E-09	-3.6E-10
Pressure losses				
Cont Recirc line	(psi)	0.11	0.03	0.00
ADS 4 line	(psi)	0.19	0.06	0.01

- **Impact of Decay Heat and Flow Resistance Margins**
  - Max / Max case is limiting
    - Highest ADS vent quality
    - Limiting with respect to boron
    - Max quality < 57%
  - Other cases have lower qualities
    - Lower decay heat
      - Reduces steam flow, ADS 4 DP
      - More water can be carried out
    - Lower flow resistances
      - Reduces flow DPs
      - More water can be carried out

AP1000

Simplified LTC Analysis Results

		Case 10	Case 11	Case 12	Case 13
Basis for decay heat		Max	Max	Max	Max
Basis for flow resistance		Max	Max	Max	Max
Time after accident (days)		0.10	1.00	14.00	30.00
Total containment pres (psia)		24.0	23.0	19.0	18.0
Recirc water temp (F)		175.9	170.3	138.8	127.7
Recirc water elev. (ft)		107.8	107.4	103.3	103.3
ADS 4 vent quality		77.82%	52.59%	56.67%	54.76%
Core exit quality		76.72%	51.05%	55.14%	53.14%
Collapsed core liquid level (ft)		9.19	10.98	10.81	10.99
PXS Flows					
Recirc flow	(lb/sec)	52.49	40.85	15.37	11.41
ADS 4 water vent	(lb/sec)	11.64	19.37	6.66	5.16
ADS 4 steam vent	(lb/sec)	40.85	21.49	8.71	6.25
Pressures:					
Containment	(psia)	24.00	23.00	19.00	18.00
ADS 4 discharge	(psia)	24.00	23.00	19.00	18.00
ERROR (Cont pres - ADS 4 pres)		-4.7E-07	-3.3E-07	2.0E-08	-8.8E-08
Pressure losses					
Cont Recirc line	(psi)	0.88	0.56	0.11	0.07
ADS 4 line	(psi)	2.74	1.20	0.19	0.10

- **Impact of Time After Shutdown**
  - All use Max / Max assumptions
    - Shown limiting in previous slide
  - Cont pres / level varies with time
    - Min cont level reached in 14 days
      - All lower compartments flooded
  - Highest quality at 0.1 day (2.5 hr)
    - 78% at 0.1 day (2.5 hr)
    - Later times have lower qualities
      - 57% or less after 0.1 day

AP1000

AP1000 LTC Summary

- **Simplified Analysis**
  - Results seem to be reasonable
    - Higher qualities than tests and plant analysis
    - One issue is steady-state vs cyclical results
      - OSU tests and plant analysis (COBRA-TRAC) show cyclical results
      - Simplified results indicate that they will not be steady-state
        - » HL filled with very low quality mix < 1%
        - » ADS 4 has a much higher quality (78% to 52%)
        - » ADS 4 connected directly to top HL
      - Cycle period (~100 sec) is much shorter than time to reach equil (~10 hr)
  - Highest quality at earlier time
    - Calculated ADS 4 vent quality is
      - 78% at 2.5 hours
      - < 57% afterwards

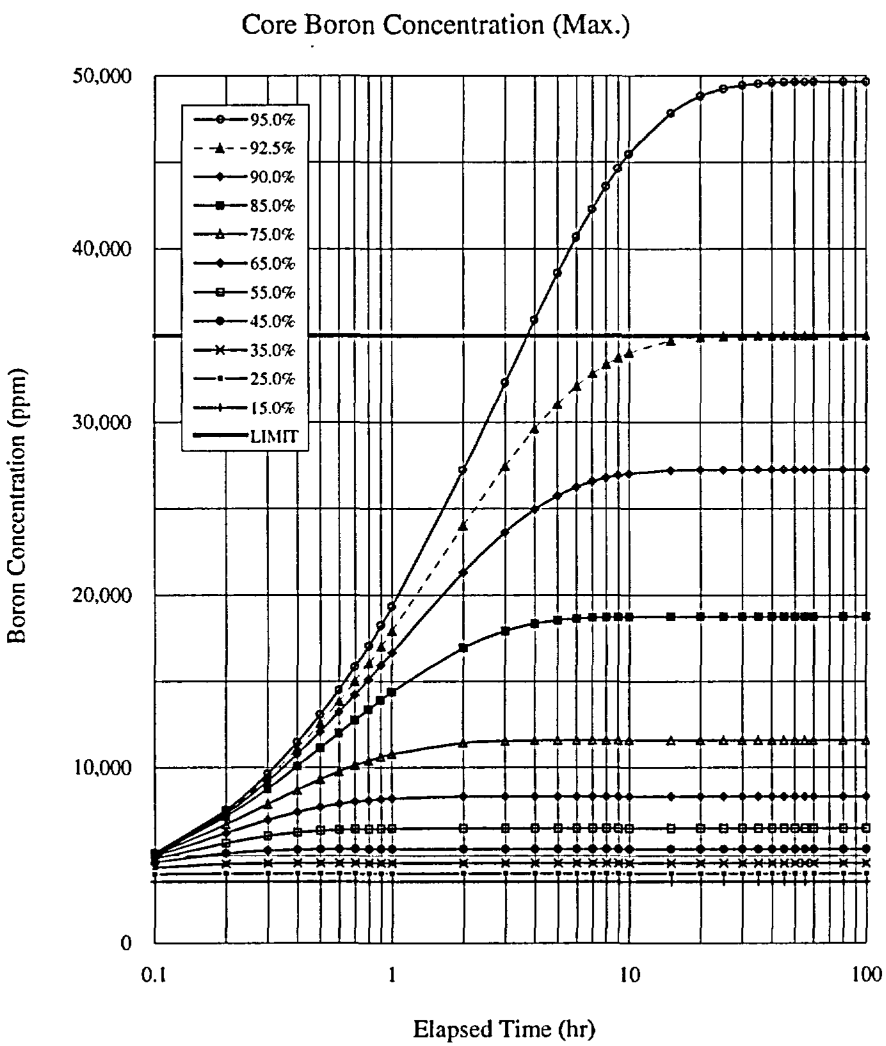
AP1000

AP1000 Core Boron Analysis

- **Calculated Possible Buildup of Boron in Core**
  - Approach is to calculate core equilibrium boron concentration
    - Boron added in PXS recirc flow equals boron removed in ADS 4 water flow
  - Conservative assumptions are used
    - Core water does not mix with other parts of reactor
    - Boron only leaves RCS in water carried out ADS 4
    - Conservatively high decay heat values
    - Maximum initial boron concentrations / volumes
      - Includes addition of CVS boric acid tank
  - 35,000 ppm is set as the maximum core boron concentration
    - Solubility limit at 180°F
    - This concentration limit could be higher
      - 50,700 ppm at 212°F
      - 81,800 ppm at 240°F

AP1000

AP1000 Core Boron Buildup



- **Calculated Core Boron Conc**
  - ADS vent quality limit
    - Needs to be less than 92.5%
    - Limits core conc to < 35,000 ppm
  - Build up occurs in ~ 10 hours
  - Max core conc for calc ADS qualities
    - 13,340 ppm with 78% ADS vent quality
    - 6,590 ppm with 55% ADS vent quality
  - Containment boron concentration only decreases slightly
    - 2984 ppm (initial) to 2978 ppm (final)
  - Provides significant margin to limits

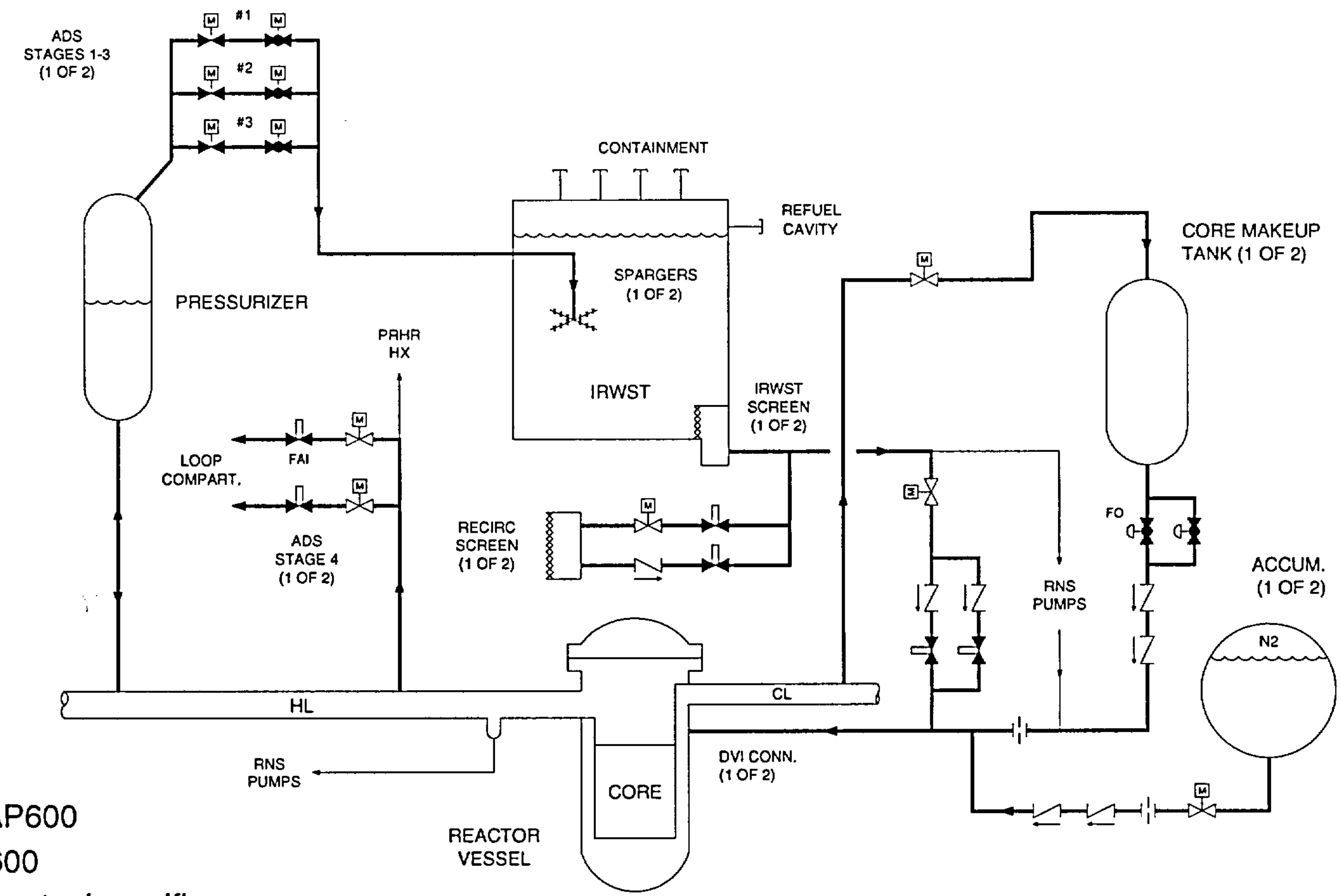
AP1000

AP1000 Boron Buildup Summary

- **AP1000 Design Effectively Limits Buildup in Core**
  - PXS tends to overfill HL during recirc operation
    - Causes significant water to be pushed out ADS 4
    - Overfill capability increases with time
  - Min calculated water flow through cores result in core boron concentrations well below limits
    - 78% ADS 4 vent quality at 2.5 hr >> 13,340 ppm
    - 55% ADS 4 vent quality after 1 day >> 6,590 ppm
    - Conservative core boron limit set at 35,000 ppm
      - Solubility limit at 180 F
      - Would require 92% ADS 4 vent quality to reach this limit

AP1000

AP1000 Passive Safety Injection



- **Passive Safety Injection**
  - Same configuration as AP600
  - Same elevations as AP600
  - Larger CMT and CMT flow tuning orifice
  - Larger IRWST, Recirc, ADS 4 pipe sizes

AP1000

AP1000 LOCA Long-Term Cooling Analysis Core Noding Study

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

AP1000 LOCA Long-Term Cooling Analysis Core Noding Study

AP1000

- **The WCOBRA/TRAC Methodology Developed and Approved for AP600 Is the Basis**
  - Validated against a series of OSU APEX facility tests
  - OSU model used two nodes for the heater rod region in the long-term cooling transient simulations of WCAP-14776
  - 10CFR50.46 Appendix K approach, with limiting single failure (one ADS stage 4 valve) assumed for AP1000

AP1000 LOCA Long-Term Cooling Analysis Core Noding Study

AP1000

- **The Limiting Case from the AP600 DCD Is Analyzed**
  - DEDVI line break

For AP1000, the DEDVI line break case is executed continuously from the start of the long-term cooling phase through the start of containment recirculation

AP1000 LOCA Long-Term Cooling Analysis Core Noding Study

AP1000

- **Nodalization Used in the AP1000 Long-Term Cooling Study**
  - Two core nodes used in the OSU APEX validation calculations for the 36-inch heated rod length
  - For AP1000, this translates to ten cells axially in the core (a 16.8 inch uniform cell height)

AP1000 LOCA Long-Term Cooling Analysis Core Noding Study

AP1000

- **Core Radial Variation Is also Addressed**
  - The four channel representation from the AP1000 LBLOCA analysis core model is applied
  - The hot rod and hot assembly rod are specified at their maximum design peaking factor values
  - The impact of power on predicted hot assembly conditions is therefore considered

AP1000 LOCA Long-Term Cooling Core Noding Diagrams

AP1000

a,b,c

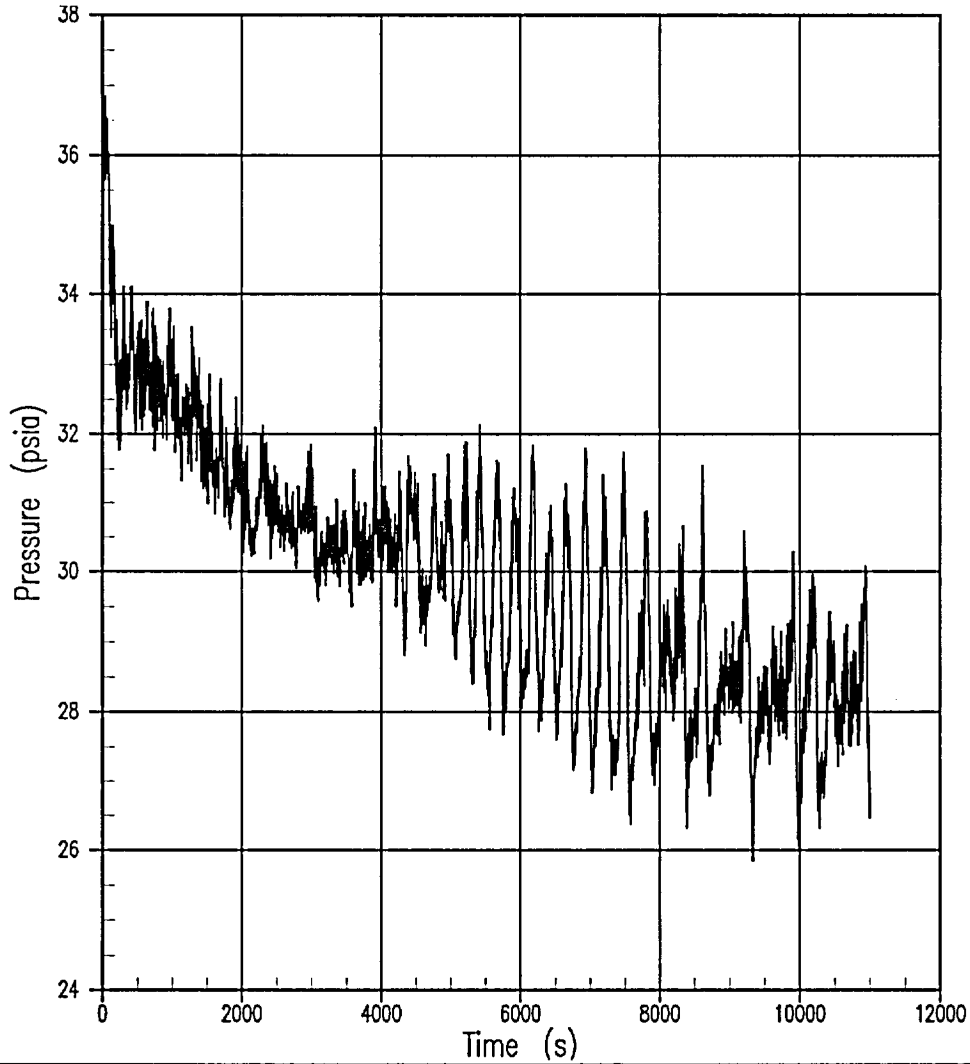
AP1000 LOCA LTC Model System Diagram

a,b,c

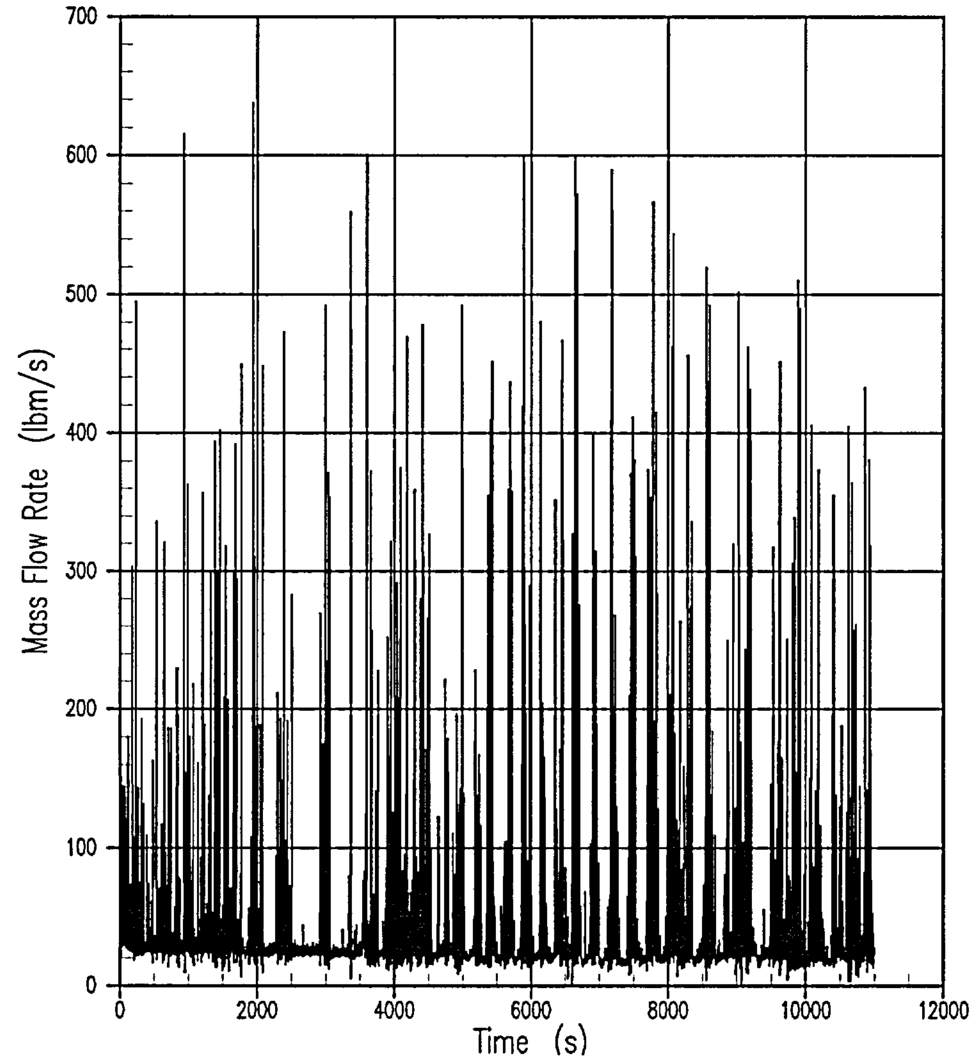
AP1000 LOCA Long-Term Cooling Analysis Core Noding Study

- **Selected plots of WCOBRA/TRAC Predicted Results Using this Nodalization**

AP1000 LOCA LTC Analysis Upper Plenum Pressure

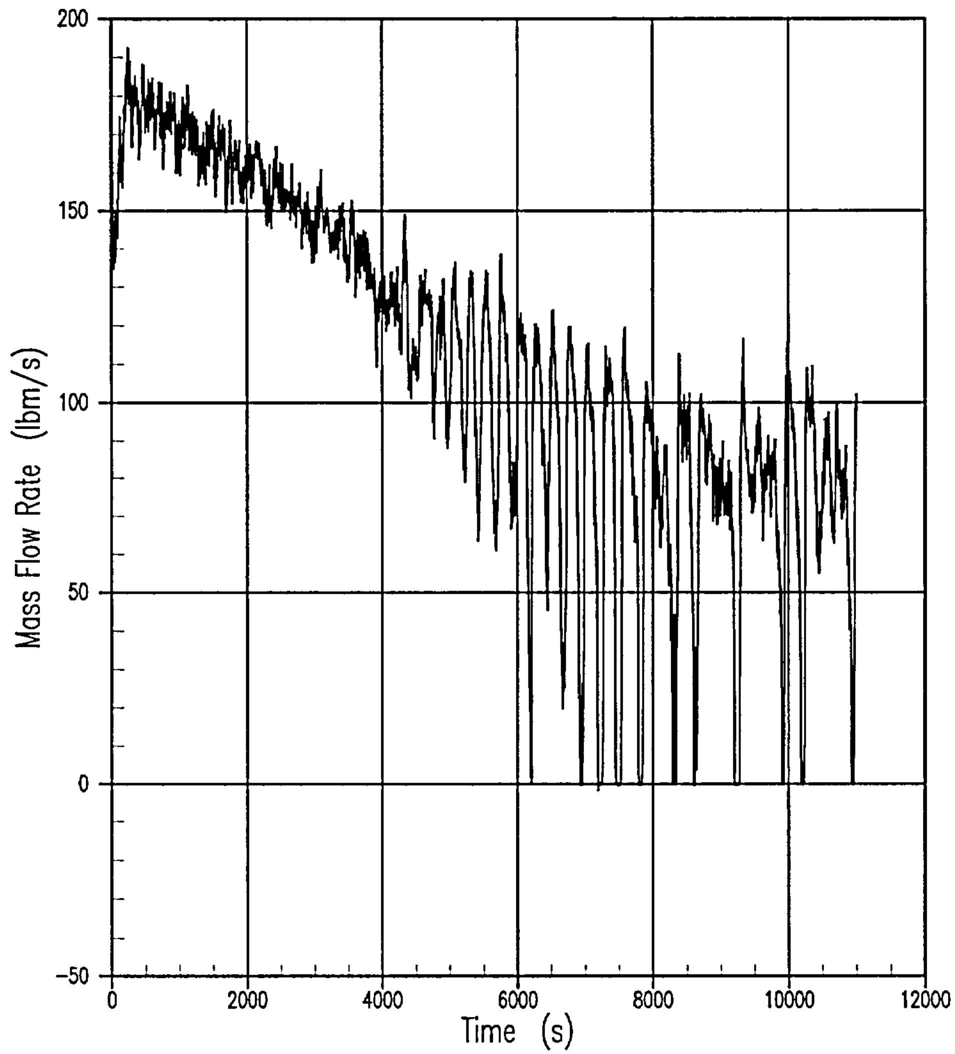


AP1000 LOCA LTC Analysis ADS-4 Mass Flow (Single Flow Path)

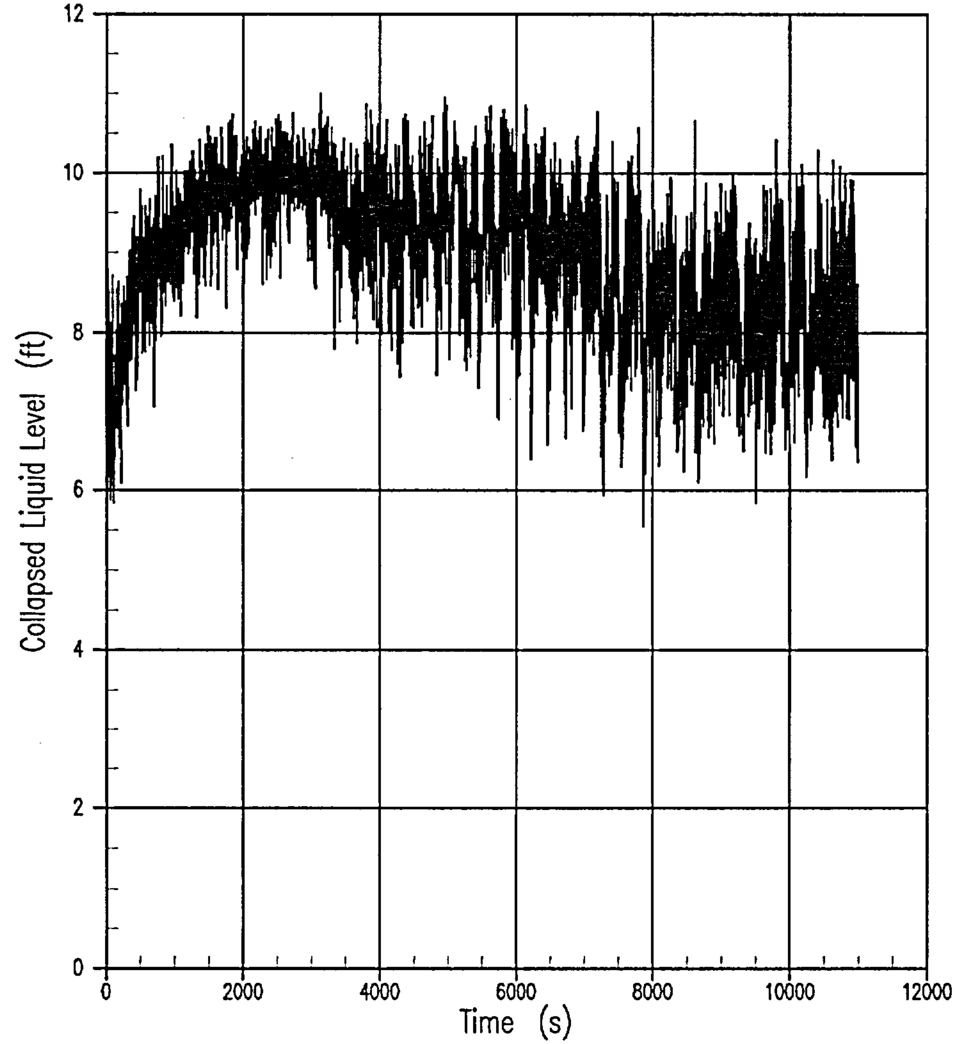


AP1000 LOCA LTC Analysis Intact DVI Line Injection Rate

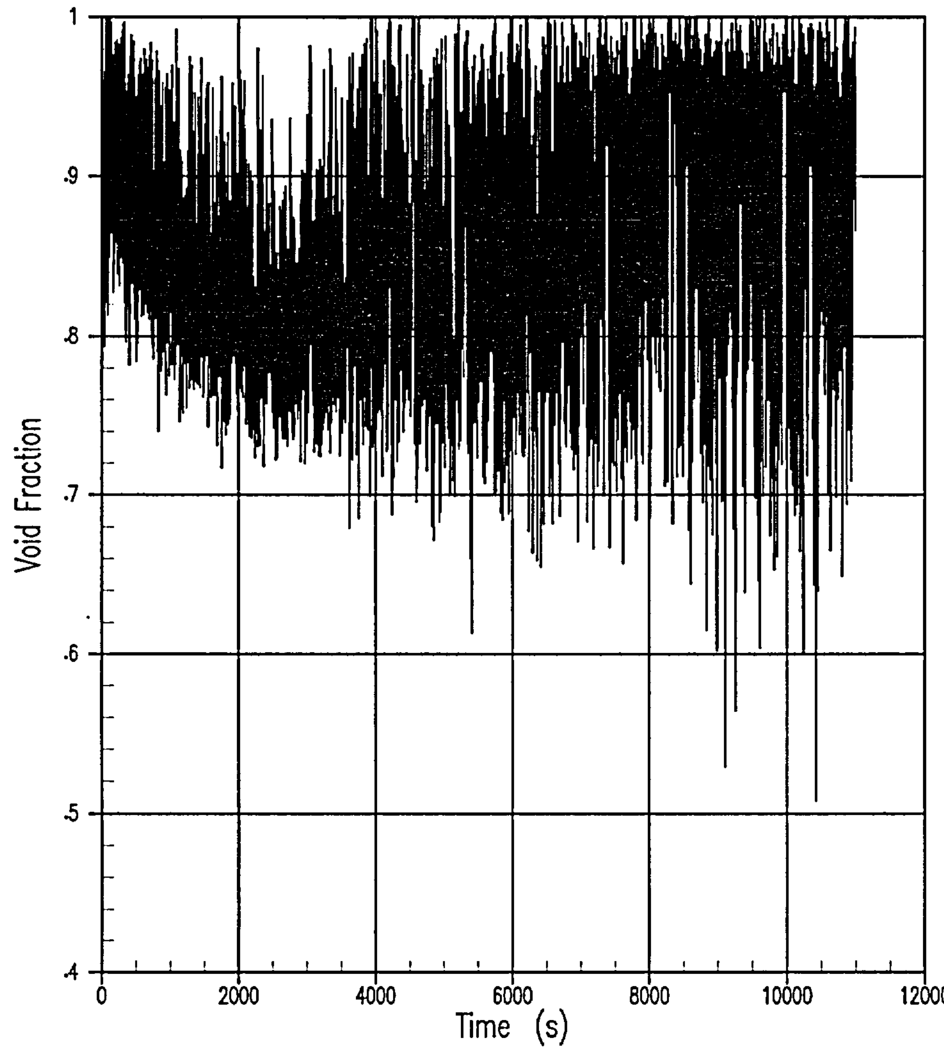
AP1000



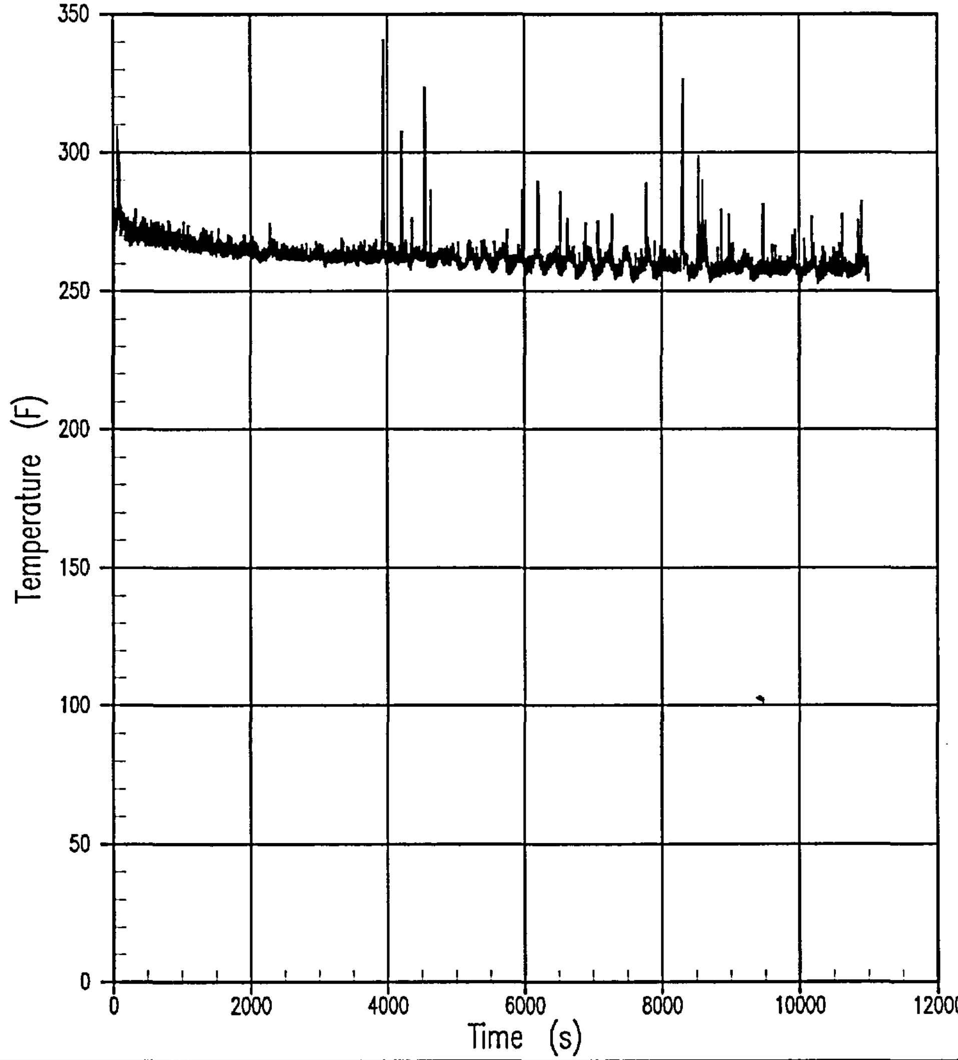
AP1000 LOCA LTC Analysis
Core Average Collapsed Level



AP1000 LOCA LTC Analysis Hot Assembly Void (134.4-151.2 in.)



AP1000 LOCA LTC Analysis Hot Rod Calculated PCT



AP1000 LOCA Long-Term Cooling Analysis Core Noding Study

AP1000

- **Results and Conclusions**
  - Using a detailed model of the active fuel region, the AP1000 DEDVI break WCOBRA/TRAC long-term cooling analysis predicts adequately high liquid levels and injection flow rates to comply with 10CFR50.46
  - Minimal fuel cladding heatup is predicted during the long-term cooling transient

AP1000

Meeting Summary

AP1000

Plan to Resolve Liquid Entrainment Issue

- **Future APEX-1000 (OSU) Submittals**
  - APEX-1000 Reports are Prepared by OSU
    - Reviewed by Westinghouse
    - Contain W Proprietary Data
  - Schedule for Submittal to NRC
    - APEX-1000 Scaling Report 5/30/2003
    - APEX-1000 Facility Description Report 5/30/2003
    - Test Summary Reports 6/6/2003
      - DBA-01
      - DBA-02
      - DBA-03
      - Other reports as testing is completed

Future Submittals

- **AP1000 PIRT & Scaling Assessment**
  - Updated to include summary of additional test data to be used for AP1000
  - Reference APEX-1000 Scaling

- **AP1000 Code Applicability Report**
  - NOTRUMP Update
    - Momentum Flux / FLOADS4
    - Additional Benchmarking to APEX-1000
  - WCT Long-Term Cooling Model
    - Update core noding

AP1000

Future Submittals

- **Analysis Updates**
  - Update Long-Term Cooling Analyses with 10-node core model
    - DCD Chapter 15 LOCA LTC Analyses
    - PRA Thermal-Hydraulic Uncertainty Cases

- **WCAP-15833**
  - Update to include final RAI responses