Meeting with NRC Staff Applicability of AP600 Codes to AP1000

June 6, 2001

Purpose of Meeting

- Present W assessment of the applicability of AP600 safety analysis codes for AP1000

- Summarize W expectations for pre-application review on applicability of safety analysis codes

- Outline resolution path for Phase II review

Agenda

• 9:00	Introduction	Mike Corletti
• 9:10	AP1000 PIRT & Scaling Assessment	Bill Brown
• 10:10	Applicability of WGOTHIC	Rick Ofstun
• 11:30	Lunch	
• 1:00	Applicability of LOFTRAN	Ed Carlin
• 1:45	Applicability of WCOBRA-TRAC LBLOCA	Bob Kemper
• 2:30	Applicability of WCOBRA-TRAC LTC	Bob Kemper
• 3:00	Applicability of NOTRUMP	Andy Gagnon
• 3:45	Resolution of Phase II Review	Mike Corletti
• 4:30	Wrap-Up	All

AP600 Major Uprate

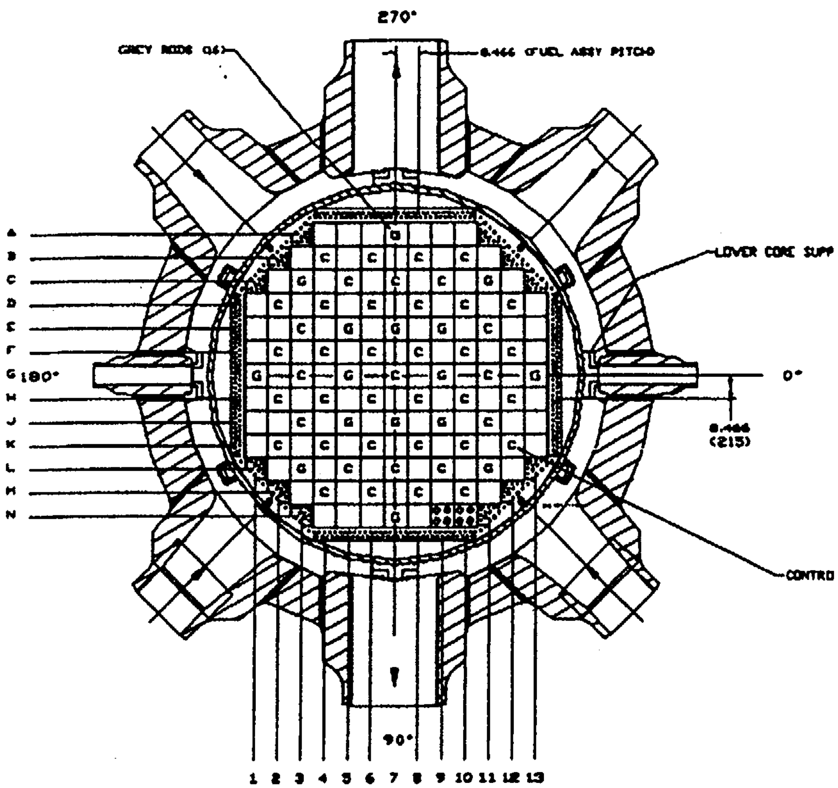
- **Maximize Core Power Output**
  - Use proven components and AP600 space constraints
  - Use same diameter reactor vessel with 12 more fuel assemblies
    - Same as operating 3-loop plants
  - Increase active fuel length 2 ft
    - Use Doel 4, Tihange 3, South Texas Units 1 & 2 fuel design
      - 14 ft active fuel length, 19.5" longer reactor vessel
      - Retains AP600 reactor vessel cavity
  - Core power density increased
    - Same as operating 3-loop plants
- **Size Key NSSS Components**
  - Steam Generator - Δ125 similar to ANO replacement
  - Reactor Coolant Pump - increase capacity, inertia
  - Pressurizer - increase volume

Comparison of Selected Parameters

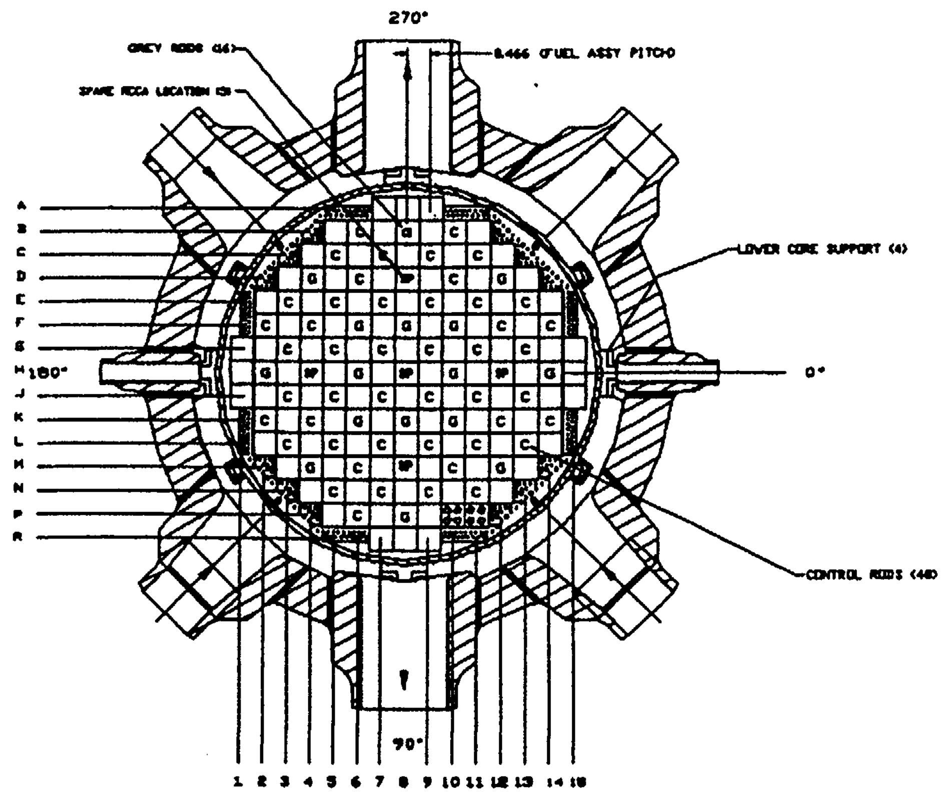
PARAMETER	AP600	AP1000
Net Electric Output, MWe	610	1090
Reactor Power, MWt	1933	3400
Hot Leg Temperature, ^{o}F	600	615
Number of Fuel Assemblies	145	157
Type of Fuel Assembly	17x17	17x17
Active Fuel Length, ft	12	14
Linear Heat Rating, kw/ft	4.10	5.71
Control Rods / Gray Rods	45 / 16	53 / 16
R/V I.D., inches	157	157
Steam Generator Surface Area, ft^2	75,000	125,000
Reactor Coolant Pump Flow, gpm	51,000	75,000
Pressurizer Volume, ft^3	1600	2100
Fuel Cycle, months	24	18

Core Design

AP600



AP1000



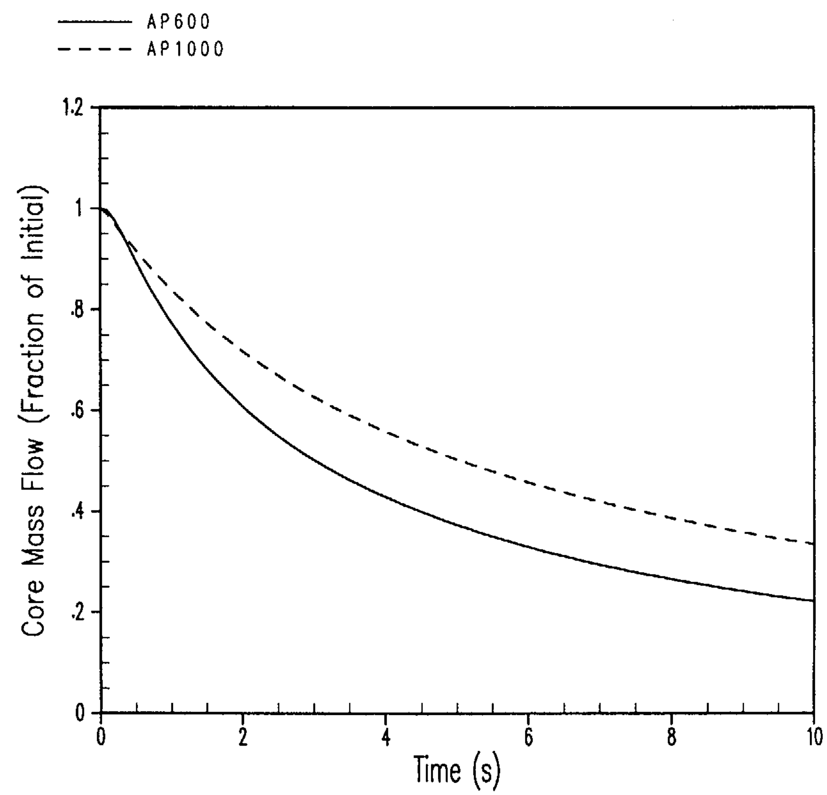
- **Number of Fuel Assemblies Increased from 145 to 157**
- **Active Fuel Length Increased from 12 ft to 14 ft**
- **Number of Control Rods Increased from 45 to 53**

AP1000 Safety Assessment

- **Analysis of Complete Loss of RCS Flow**
  - Conservative analysis to assess pump coastdown
  - Same assumptions and methods as AP600
    - ✦ Rod drop times increase for AP1000
      - Longer Fuel
      - Higher RCS Flow
    - ✦ Pump coastdown needs to be increased
      - Pump inertia increased
- **Acceptance Criteria**
  - RCS and SG pressures < 110% of Nominal
  - DNBR within acceptable limits

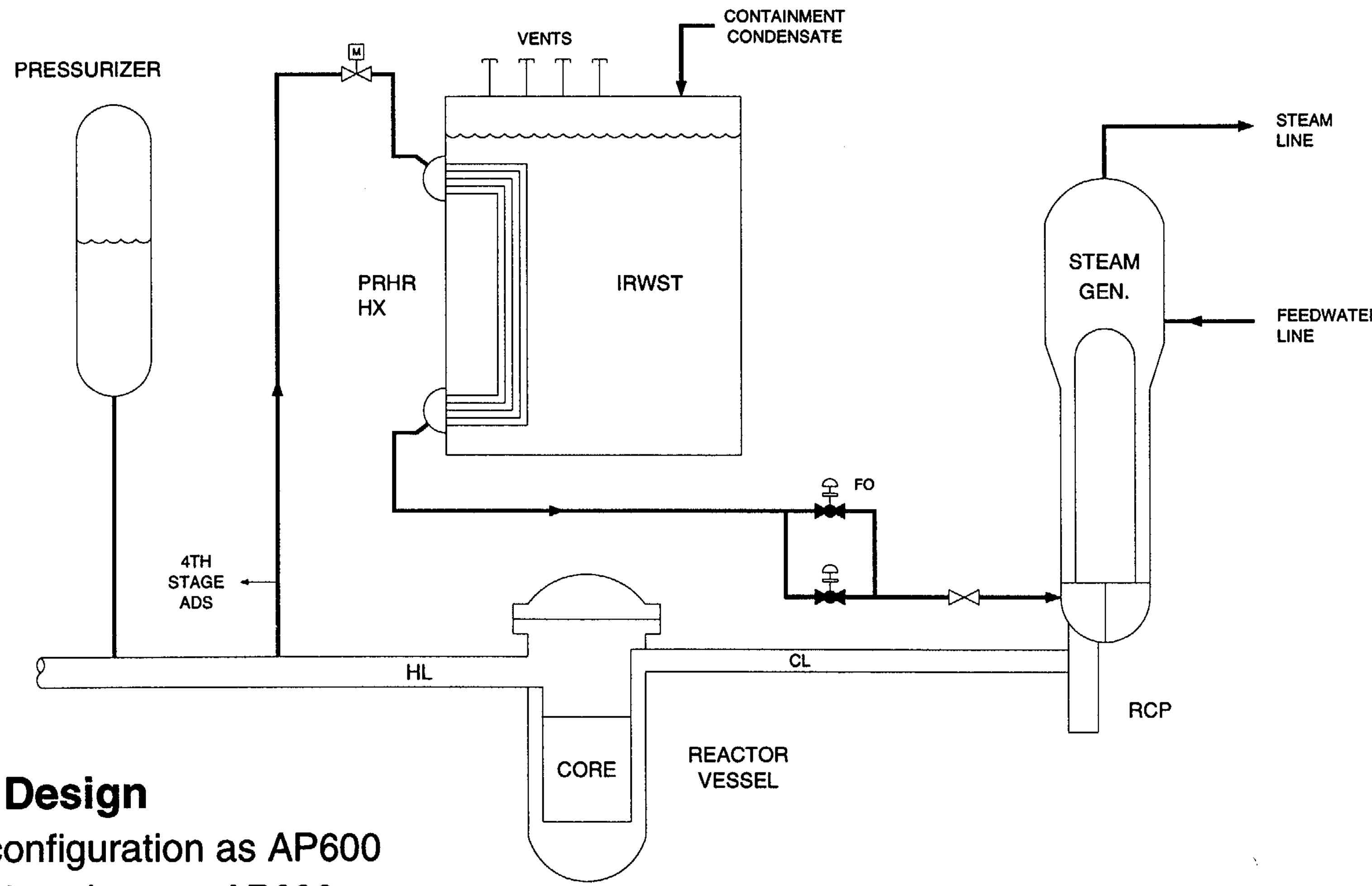
Complete Loss of RCS Flow Assessment

- **Preliminary Analysis Shows**
  - DNBR margin is similar for both plants
  - AP1000 flow at time of minimum DNBR is within limits of standard plant DNB correlation



	AP1000	AP600
DNBR Limit (typical cell)	1.24	1.24
Minimum DNBR	1.447	1.484
DNBR Margin	13.6%	15.8%
Mass Flow (lbm/hr-ft^2)	1.11×10^6	0.78×10^6

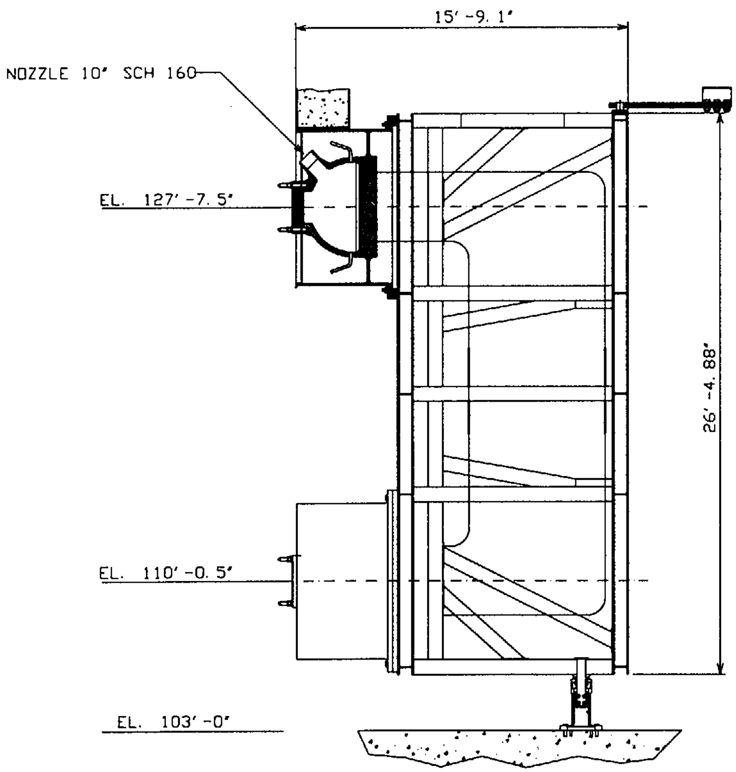
Passive Decay Heat Removal



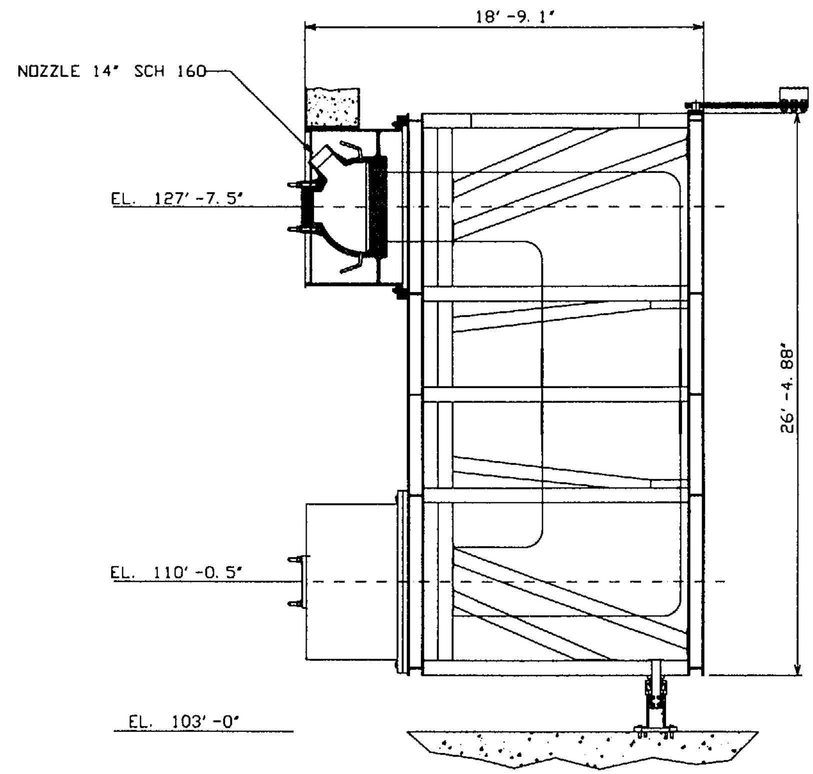
- **PRHR HX Design**
  - Same configuration as AP600
  - Same elevations as AP600
  - Larger pipe sizes (14 vs 10")
  - Heat transfer area increased 22%

Passive RHR Heat Exchanger

AP600



AP1000



- **PRHR HX Surface Area Increased 22%**
  - Added 18 tubes
  - Increased horizontal tube length 3'

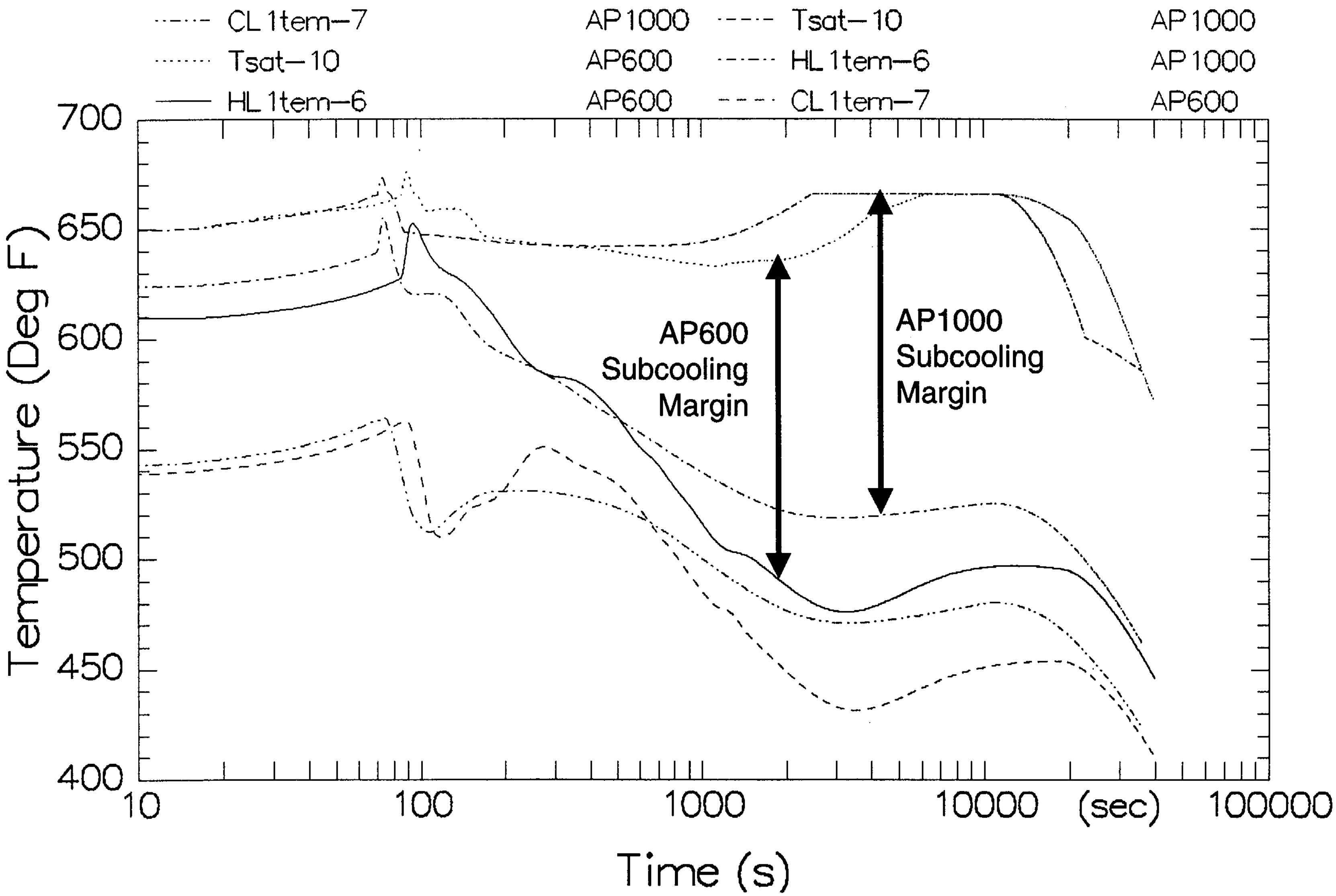
PRHR Margin Assessment

	AP600 [1]	AP1000 [1]
PRHR HX Surface Area	100%	122%
PRHR Flow Path Resistance	100%	33%
Calculated PRHR Heat Transfer (Nat Circ)		
, Heat transfer	[redacted]	[redacted]
, Time to match decay heat (min.)	38	44
SG Secondary Side Water		
, Initial water mass per MW	100%	136%
, Final water mass per MW	[redacted]	[redacted]

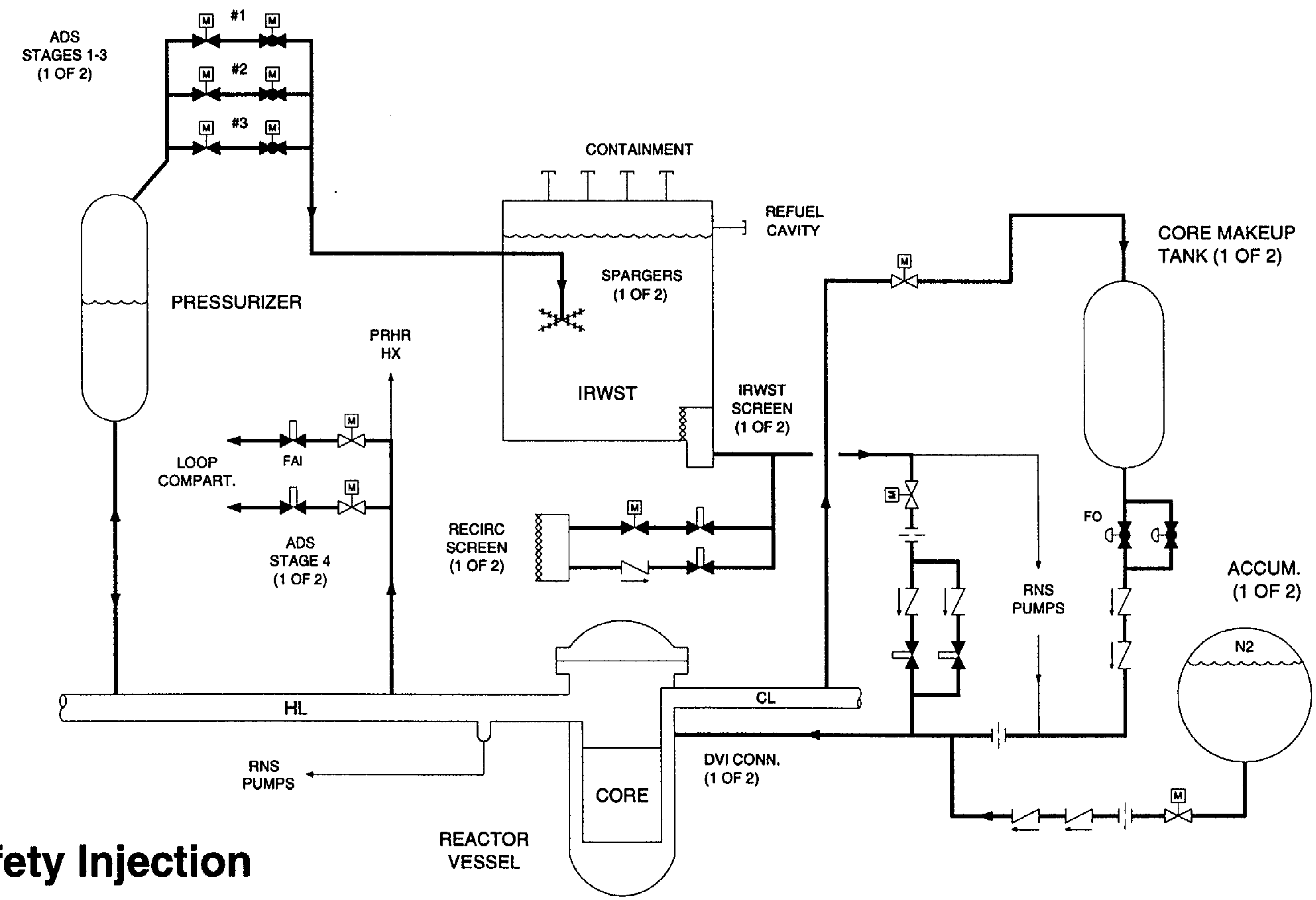
(1) Based on hand calculations.

- AP1000 PRHR HX Expected to Provide Increased Margin
  - PRHR HX heat transfer capacity increased almost by core power ratio (176%)
  - SG secondary mass increased greater than core power ratio

Feedline Rupture - Comparison



AP1000 Passive Safety Injection



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

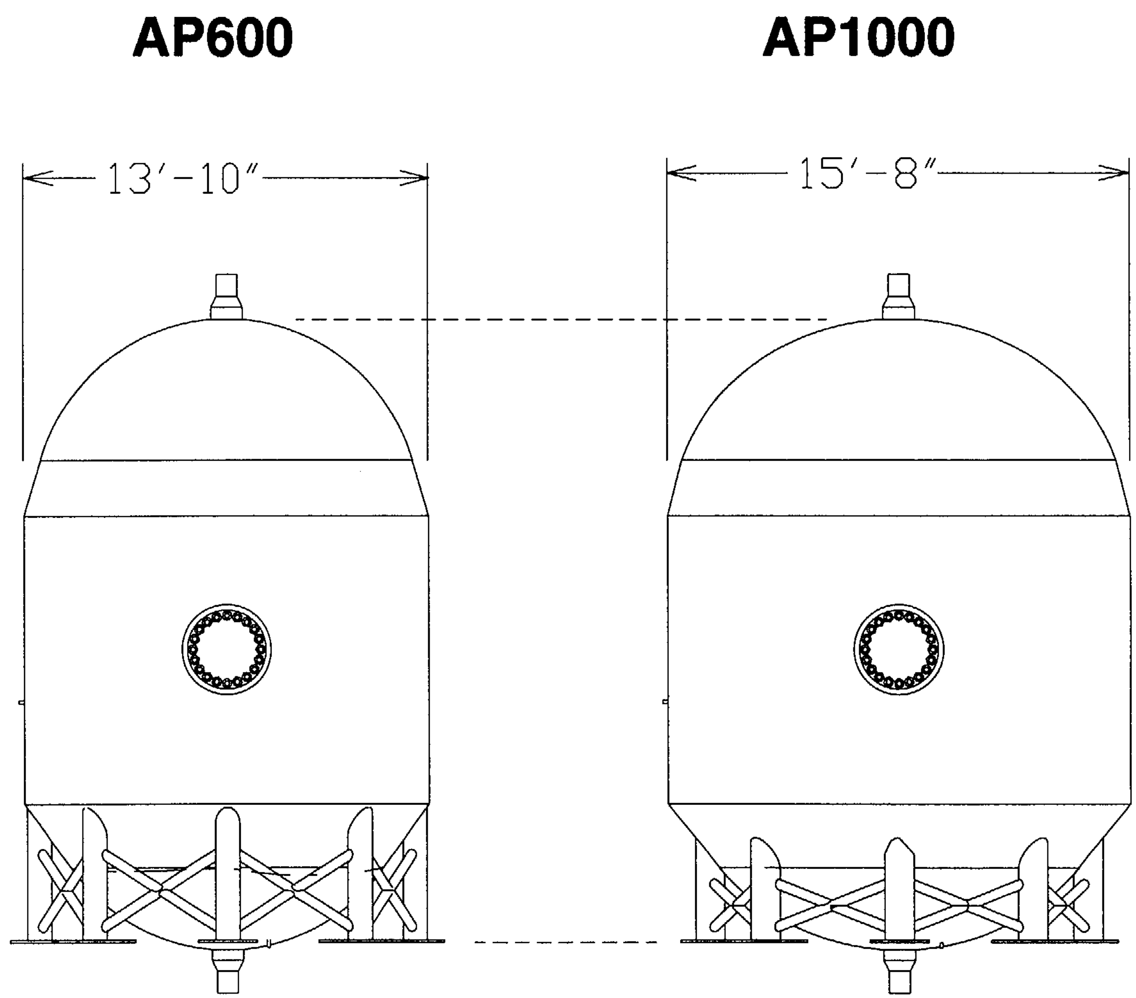
Accumulator Margin Assessment

	AP600	AP1000 (1)
Accumulator injection capability	100%	100%
Reflood PCT with uncertainty (F)	[redacted]	[redacted]

(1) Based on hand calculations.

- AP1000 Accumulator Expected to Provide Adequate Margin
  - AP1000 uses same accumulator capacity as AP600
    - Same water volume, gas pressure, line resistance
    - Same mitigating feature as operating plants, little uncertainty
    - Tank size constrained by containment concrete ceiling, floors, walls
  - Large LOCA PCT should have comfortable margin
    - Same reactor vessel lower plenum volume
    - Similar margin to operating plants, less than AP600
  - Sufficient flow rate / duration to mitigate small LOCA's

Core Makeup Tanks



- **Core Makeup Tank Volume and Flow Rate Increased 25%**
  - 2000 to 2500 ft^3

CMT Margin Assessment

	AP600 (1)	AP1000 (1)
CMT line resistance (outlet CMT to DVI)	100%	64%
CMT flow capability	100%	125%
CMT flow capability vs. required flow (flow required to remove decay and sensible heat at time of accumulator empty in DVI LOCA)	[redacted]	[redacted]

(1) Based on hand calculations.

- Core Makeup Tank Expected to Provide Adequate Margins
  - Both tank volume and flow capacity increased by ~ 25%
    - Flow tuning orifice changed - CMT line sizes not changed
    - Tank size constrained by floor and ceiling
    - Maintains injection duration of CMT same as AP600
    - Maintains time available for ADS to depressurize RCS to IRWST cut-in
  - AP1000 CMT has sufficient capability to mitigate small LOCA's
    - Increase in CMT would not be required for DBA small LOCA's
    - Increase in CMT capacity provides margin for DBA small LOCA's and multiple failure accidents

IRWST Margin Assessment

	AP600 (1)	AP1000 (1)
IRWST injection line resistance	100%	32%
IRWST initial water level (ft)	130.00'	131.58'
Available driving pressure (%)	100%	108%
IRWST injection flow	[redacted]	[redacted]

(1) Based on hand calculations.

- AP1000 IRWST Injection Expected to Provide Increased Margin
  - Initial driving head increased
    - Minimum normal water level increased, max normal remains same
  - Line resistance reduced by increasing pipe sizes (6" to 8"/10")

ADS Margin Assessment

	AP600 (1)	AP1000 (1)
ADS 4 valve vent flow area	100%	176%
ADS 4 flow resistance	100%	28%
ADS 4 differential pressure	100%	100%
ADS 4 vent flow capability	>>> 100% <<<	>>> 189% <<<

(1) Based on hand calculations.

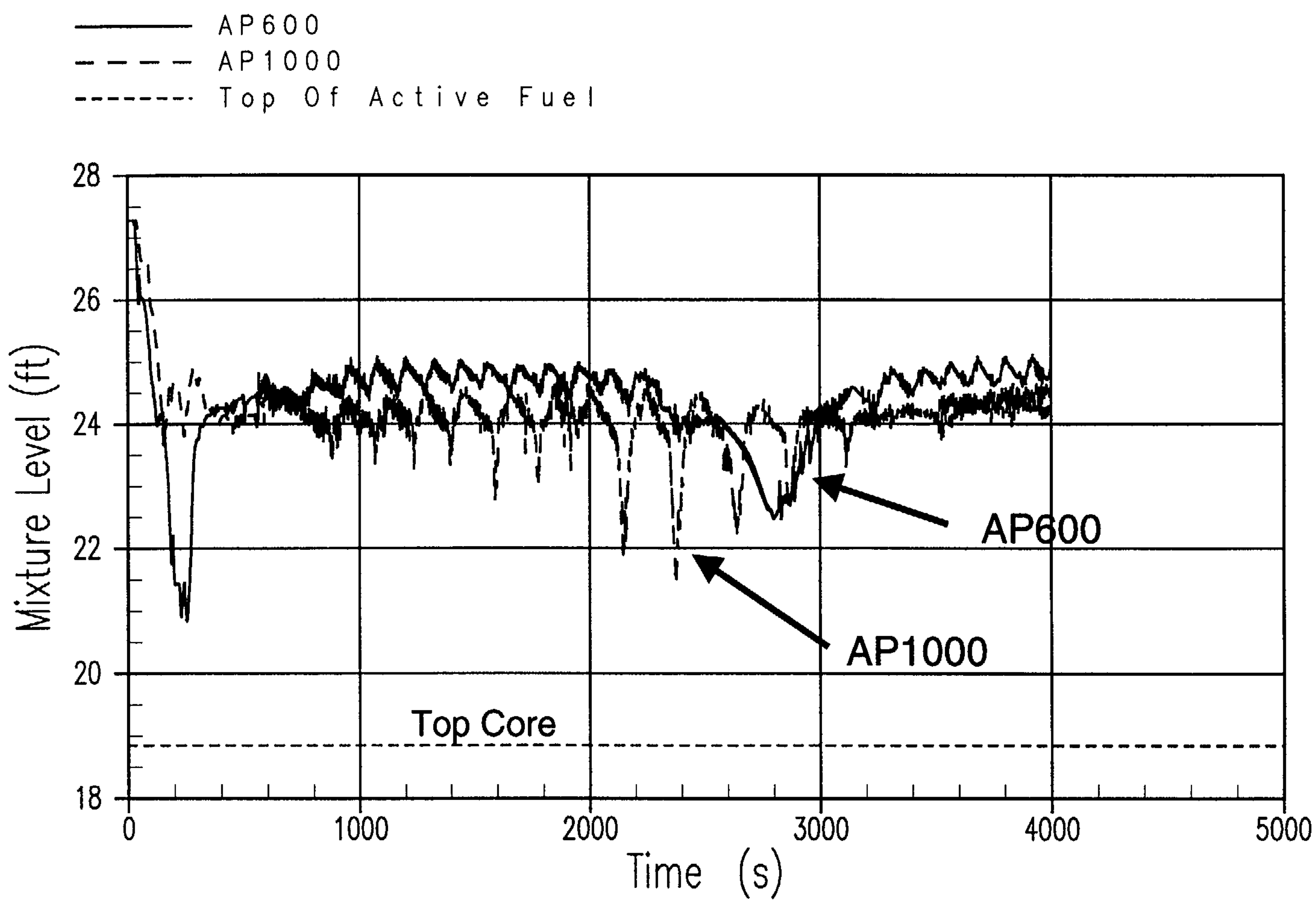
- AP1000 ADS Expected to Provide Increased Margin
  - ADS 1, 2, 3 not changed
    - AP600 size adequate for pressure reduction at higher pressures
    - Not important in providing IRWST injection / containment recirc
      - Water in Pzr severely limits vent flow at low pressure
  - ADS 4 capacity increased
    - Very important in providing IRWST injection / containment recirc
    - Line sizes increased
      - HL common line increased from 12" to 18"
      - ADS 4 valve line increased from 10" to 14"

AP1000 SBLOCA T&H Assessment

- **DBA Analysis Performed to Assess PXS Design Modifications**
  - Same assumptions / methods utilized for AP600
    - 10 CFR Appendix K based analyses
  - Acceptance criteria
    - Peak Clad Temperature < 2200 ºF
  - Performance goal
    - No core uncovery for small LOCAs
      - DVI LOCA or smaller
  - Several small break LOCA's were analyzed
    - 2" CL, DVI, inadvertent ADS

DVI LOCA Comparison

Core/Upper Plenum Mixture Level



Cont. Recirc Margin Assessment

	AP600 (1)	AP1000 (1)
Containment Recirc Line Resistance	100%	39%
- Time recirc occurs (hr)	2.10	2.67
- RNS pump operation	Yes	No (2)
- Containment water level (ft)	106.2'	107.7'
- Available driving pressure (psi)	100%	177%
- Required flow (core power, recirc time)	100%	159%
- Calc passive recirc flow (%)	[redacted]	[redacted]

(1) Based on hand calculations.
(2) RNS operation not limiting in AP1000; RNS connected to outside containment water supply.

- **AP1000 Containment Recirc Expected to Provide Increased Margin**
  - Containment water flood level increased
    - Increased initial IRWST level
    - Eliminated holdup volume in refueling cavity
  - RNS operation case made non-limiting by using outside water supply
    - Prevents adverse interaction, faster draining of IRWST by RNS
  - Line resistance reduced by increasing pipe sizes (6" to 8")

AP1000 Long-Term Cooling

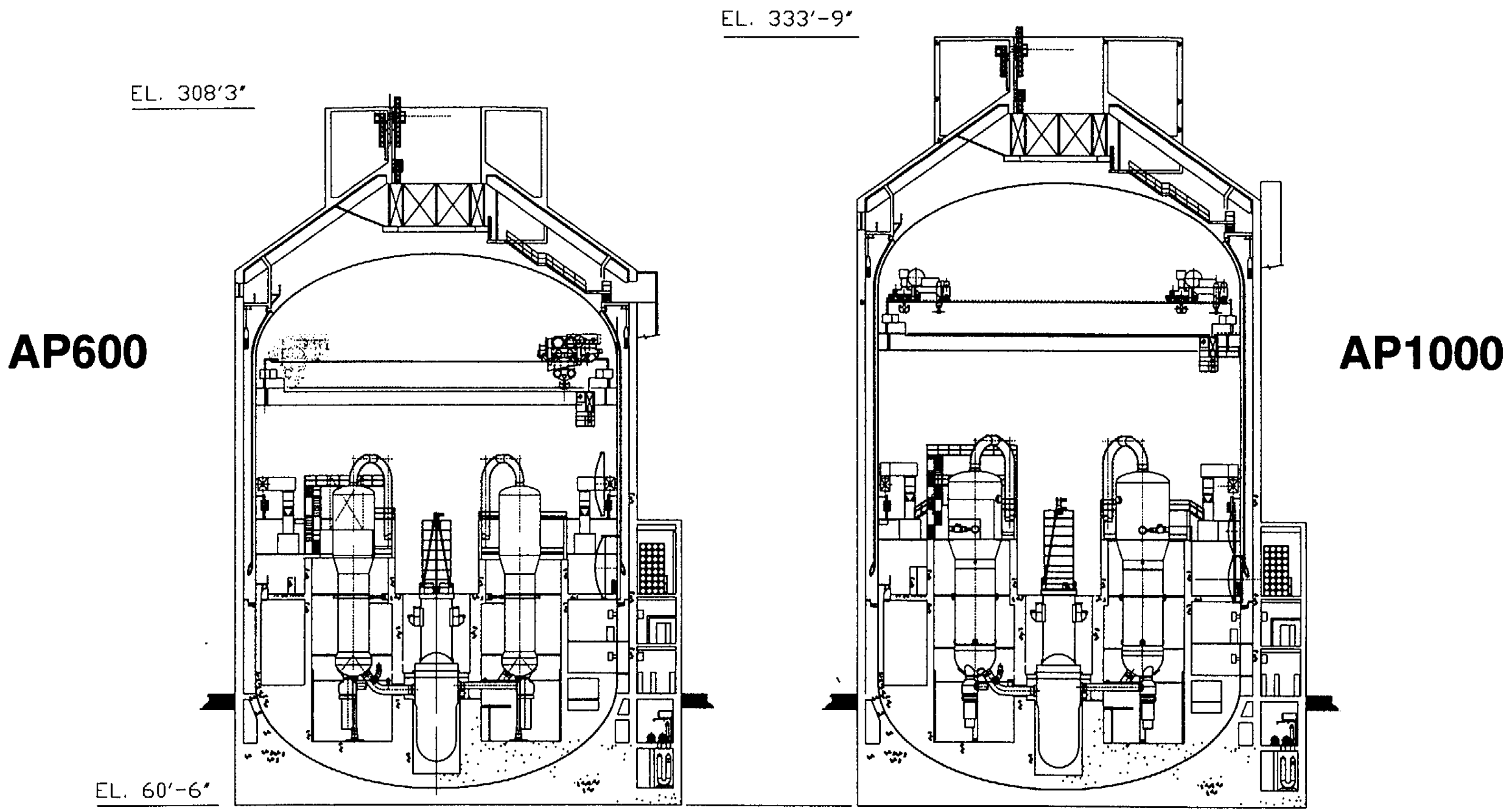
- **Analysis Performed to Assess PXS Design Modifications During Post LOCA Long-Term Cooling**
  - Same assumptions / methods utilized for AP600
  - Acceptance criteria
    - Stable IRWST injection and containment recirculation flow
    - Core cooling maintained indefinitely
  - Performance goal
    - No core uncovery
  - Limiting AP600 SSAR case analyzed (DVI LOCA)
    - AP600 limiting case is DVI with RNS injection
    - AP1000 limiting case is DVI without RNS injection
  - Assessment Results
    - Similar behavior / performance to AP600
    - No core uncovery

Expected AP1000 Safety Margins

	Typical Plant	AP600	AP1000
Loss Flow Margin to DNBR Limit	~ 1 – 5%	15.8%	13.6% (1)
Feedline Break Subcooling Margin	>0°F	~170°F	~140°F (1)
SG Tube Rupture	Operator actions required in 10 min	Operator actions ***NOT*** required	Same as AP600 (1)
Small LOCA	3" LOCA core uncovers PCT ~1500 °F	$\leq$ 8" LOCA ***NO*** core uncovery	Same as AP600 (1)
Large LOCA PCT (with uncertainty)	2000 – 2200°F	1644°F	~1940°F

(1) Based on preliminary AP1000 T&H analysis using AP600 SSAR computer codes.

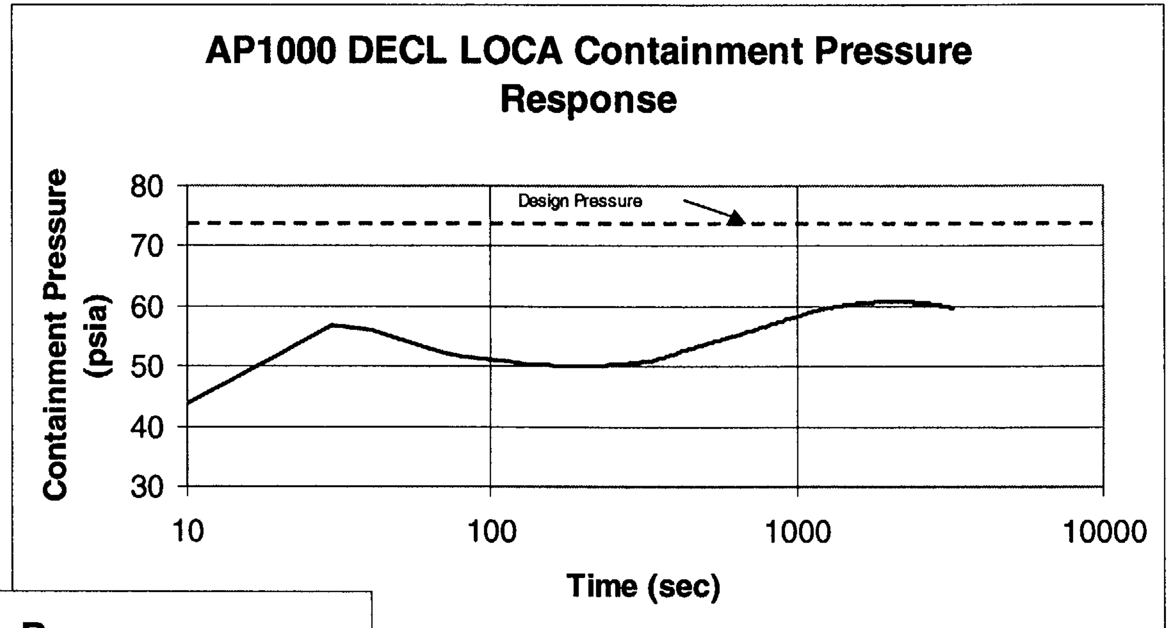
AP1000 Containment Comparison

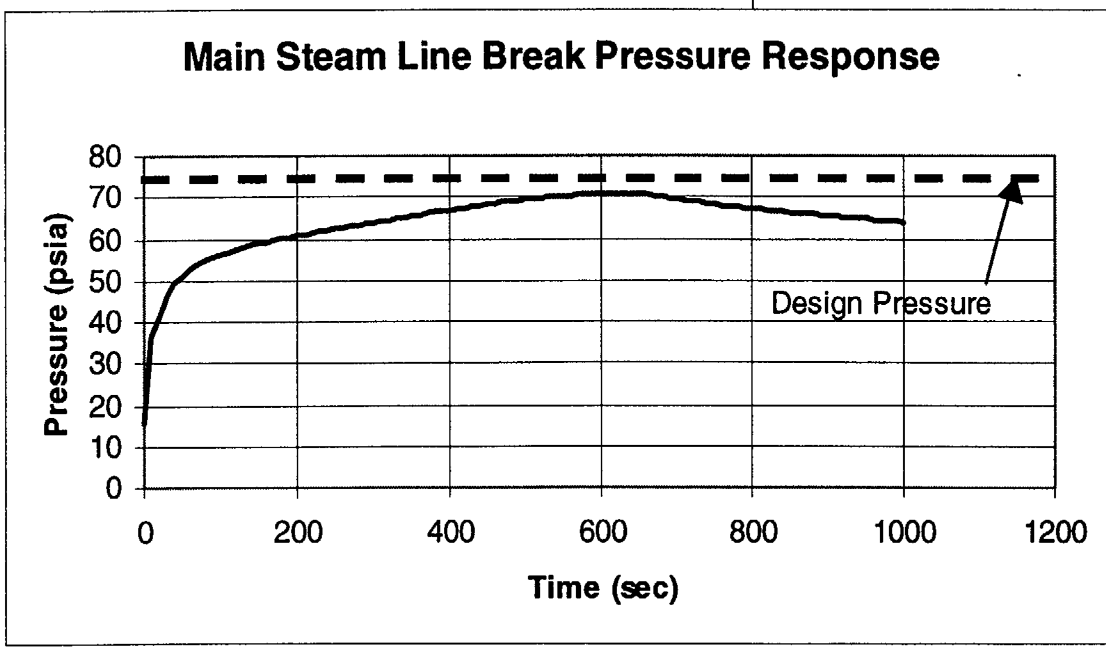


	AP600	AP1000
Total Free Volume	100%	122%
Design Pressure, psig	45	59
Shell Thickness	1 5/8"	1 3/4"
Material	A537 Class 2	SA738 Grade B
PCS Water Drain Vol (72 hr)	100%	162%

Containment Analysis Results

- **AP1000 Containment Expected to Provide Increased Margins**
  - Similar response to AP600
  - Large LOCA has large margins
    - ✦ With more realistic SG energy input





- Main Steam Line Break is Limiting
  - Not sensitive to passive containment cooling performance

AP1000 PIRT and Scaling Assessment

Bill Brown

LOCA Integrated Services

(412) 374-5224; Brownwl@westinghouse.com

Main Goal and Steps of PIRT/Scaling Assessment

- Main goal of PIRT/Scaling assessment:
  - Determine extent to which AP600 experimental test database is applicable to AP1000 to support safety analysis code validation in accordance with 10 CFR part 52.

- Main steps in PIRT/Scaling assessment:
  - First, AP600 PIRTs reviewed by several experts for application to AP1000.
  - Then, scaling of most important phenomena (high-ranked) obtained from PIRT review assessed relative to AP1000.

PIRT Reviewers/Summary of important changes for AP1000

- PIRT reviewers included following experts:
  - Dr. S. M. Bajorek, Kansas State University
  - Dr. S. G. Bankoff, Northwestern University
  - Dr. L. E. Hochreiter, Penn State University
  - Dr. T. K. Larson, INEEL
  - Dr. P. F. Peterson, University of California
  - Mr. G. E. Wilson, INEEL
- Summary of important PIRT changes for AP1000:
  - LBLOCA
    - Core entrainment/de-entrainment increased from Medium to High
  - SBLOCA including long term cooling
    - Entrainment increased to High for IRWST/sump injection
    - ADS-4 two-phase pressure drop increased to High for IRWST/sump injection
  - Containment SLB/DE CL LOCA and Non-LOCA
    - No important changes

Summary of Important Phenomena Addressed in Scaling Analysis

- Top-Down Scaling
  - Reactor vessel inventory
  - Core exit quality
  - RCS pressure
  - Core decay heat
  - ADS flow
  - ADS-4 two-phase pressure drop
  - CMT/IRWST injection
  - Sump injection
  - Natural circulation-PRHR
  - Pressurizer level
  - Containment pressure
  - Break mass/energy into containment
  - Containment volume/gas compliance
  - Heat/mass transfer to internal heat sinks

- Bottom-Up Scaling
  - Entrainment in HL/ADS paths
  - Hot leg/cold leg flow pattern
  - Surge line pressure drop
  - Phase separation at CL-CMT balance line tee
  - Core exit void fraction
  - Condensation on inside containment surfaces
  - Evaporation on outside surface containment shell
  - Water film stability/coverage on outside shell surface
  - Circulation/stratification inside containment

Scope of Scaling assessment

- Scaling assessment focuses on high-ranked phenomena for passive plants:
  - Small Break LOCA - core cooling/vessel inventory.
  - Steam Line Break - containment pressure
- Phenomena found in conventional PWR plants for which test databases already exist need not be scaled for AP1000 such as:
  - LBLOCA phenomena
  - Blowdown & S.G. circulation phenomena of SBLOCA.
  - Non-LOCA (except for CMT/PRHR phenomena)
- Scaling assessment of low-ranked/medium-ranked phenomena in AP600 scaling effort sufficient for AP1000

Basis and Approach for AP1000 Scaling Assessment

- AP600 scaling analyses serve as basis for AP1000
- AP1000 scaling assessment leverages results, insights, lessons learned from AP600
  - Processes not important or minor are not scaled
  - Simplified models/equations used to highlight important features
- Emphasize features different or scaled up from AP600 (core power, volume, ADS4 vent area etc)
- Scaling assessment accomplished via examination and comparison of range of operating conditions and geometric similarity between AP1000 and test facility; AP600 scaling analysis usually sufficient
  - This is typically sufficient for separate effects tests
- Where comparison between AP1000 and test facility not easily accomplished from examination described above, then assessment supplemented with scaling analysis
  - This is typically needed for integral effects tests

AP600 Test Data Sources Included in Scaling Assessment

	Assessment	Scaling analysis
• Integral Effects Tests		
– SPES-2	√	√
– OSU	√	√
– ROSA-AP600	√	
– LST	√	√
• Separate Effects Tests		
– ADS (1-3)	√	
– CMT	√	
– PRHR	√	
– DNB	√	
– U.of Wisconsin Condensation	√	√
– Heated flat plate	√	√
– Water distribution	√	√
– Wind tunnel/bench experiment	√	
– Air-flow path Δp	√	
– Water film formation	√	√

Major Results of PXS Scaling Analysis

- Overall results similar to AP600
- At least one IET facility can be identified for each phase of SBLOCA transient where important phenomena is acceptably scaled to AP1000 to provide database suitable for code validation:
  - SPES acceptable for high pressure phases of SBLOCA transient; distorted after ADS-4 flow transitions to subsonic
  - OSU acceptable for low pressure phases of SBLOCA transient;distorted until ADS-4 is actuated
  - AP600 SETs acceptable for AP1000
  - ADS test acceptable as ADS 1-3 valves/sparger same as AP600. Tested range of conditions covers AP1000
  - CMT test covers range of conditions in AP1000
  - PRHR test covers tested range of conditions in AP1000. Heat transfer correlation developed from test provides acceptable agreement with ROSA-AP600 results

Major Results of PCS Scaling Analysis

- As with AP600, LST is distorted for code validation of AP1000 pressure transient
  - AP600 used bounding analysis for pressure transient
  - AP1000 uses same approach
- LST acceptable as separate effect test data base for validation of steady state heat/mass transfer correlations for AP1000
- Key dimensionless scaling groups for heat/mass transfer and liquid film stability/coverage are acceptably scaled in SETs
- CFD analysis demonstrates AP1000 and AP600 similarly mixed inside containment

Overall Conclusion of AP1000 PIRT and Scaling Assessment

- PIRT/scaling assessment documented in WCAP-15613 demonstrates that the AP600 integral effects test/separate effects test facilities capture the important phenomena for AP1000 and provide acceptable test database for code validation in accordance with requirements of 10 CFR part 52

WGOTHIC Code Applicability for AP1000 Containment DBA Analyses

Rick Ofstun, PE

Senior Engineer

Containment and Radiological Analysis

(412) 374-4430; ofstunrp@westinghouse.com

Background

- GOTHIC was developed by NAI/EPRI for performing containment DBA analyses
- GOTHIC is capable of performing transient T/H calculations in 1, 2 or 3-dimensions
- GOTHIC has an extensive validation program
  - Compared to integral test data
  - Compared to separate effects test data
  - Compared to analytical solutions

Background

- Westinghouse selected the GOTHIC code for development and modeling of the AP600 passive containment design
- WGOTHIC was created from GOTHIC
  - Special subroutines were added to model the PCCS film flow and the condensation and evaporation heat and mass transfer (Climes)
  - The GOTHIC validation test set was re-run with WGOTHIC to demonstrate no unintended side effects were introduced due to the addition of the clime models

Background

- Clime heat and mass transfer correlations were validated via separate effects tests
  - See WCAP-14326 for details
- Lumped and distributed parameter models were developed for transient comparison with LST data
  - See WCAP-14382 for details
  - Lumped parameter model significantly over-predicted the transient pressure response

Background

- Developed a lumped parameter containment DBA evaluation model for AP600
  - A detailed model description is provided in WCAP-14407
  - Limitations and biases were applied to the models for important phenomena to develop a bounding methodology for calculating the passive containment pressure and temperature response

Major Issues for the AP600 Containment Evaluation Model

- Modeling of circulation and mixing within the AP600
- Validation of the AP600 PCCS heat and mass transfer correlations
- Modeling of the external water coverage
- Validation of the AP600 evaluation model against scaled transient data

Circulation and Mixing

- Westinghouse addressed this concern in Section 9 of WCAP-14407
  - Experimental results from various international tests show global circulation occurs when the break source is located in a lower compartment
  - LST and HDR show circulation/mixing is enhanced when external cooling water is applied to the top of test facility

Circulation and Mixing

- The model input is biased to account for potential stratification within the lower compartments
  - Heat transfer to floors was eliminated
  - Heat transfer to heat sinks within dead-ended compartments was eliminated after blowdown

PCCS Heat and Mass Transfer

- Westinghouse addressed this concern in WCAP-14326
  - Range of the separate effects test data dimensionless heat and mass transfer parameters covers the operating range of AP600
- Bounding multipliers are applied to the heat and mass transfer correlations in the evaluation model

PCS Water Coverage Modeling

- Westinghouse addressed this concern in Section 7 of WCAP-14407
  - Initial coverage input is based on full-scale water distribution test data
  - The time dependent PCS flow rate input is "evaporation limited"
- Bounding model for PCS flow rate input limits energy removal via sensible heating

Evaluation Model Validation with Scaled Transient Data

- Scaling analysis (WCAP-14845)
  - Demonstrates that the LST is not well scaled for modeling the AP600 containment DBA blowdown transient, however, steady state LST test data is acceptable for separate effects comparison

NRC Review/Acceptance

- NRC reviewed the Westinghouse submittal using a process that was similar to the Draft Standard Review Plan (Section 15.0.2 of NUREG-0800) and the Draft Regulatory Guide, DG-1096
- The NRC concluded that WGOTHIC, combined with the conservatively biased AP600 containment evaluation model could be used to demonstrate that the AP600 containment design meets the requirements of General Design Criteria 16, 38 and 50. The approval was subject to the limitations and restrictions described in Section 21.6.5.8.3 of NUREG-1512

WGOTHIC Application to AP1000

- Same type of plant
  - Both AP600 and AP1000 employ the same Passive Containment Cooling System
- Same modeling requirements for the DBA application
  - Condensation/Evaporation heat and mass transfer to/from the shell
  - Natural draft cooling in the annulus
- Same code version and evaluation model methodology, including AP600 FSER limitations and restrictions
  - Include an additional active clime layer to account for the additional cylindrical height/volume of AP1000
  - Incorporate volume/heat sink design changes for AP1000

WGOTHIC Code Applicability Evaluation Process

- Experts reviewed the AP600 containment PIRT for application to the AP1000
  - No new phenomena were identified
  - No changes in the importance ranking were recommended
  - The review is documented in WCAP-15613

WGOTHIC Code Applicability Evaluation Process

- Westinghouse reviewed the AP600 containment scaling analysis for application to the AP1000
  - The LST is acceptable as a source of data for separate effects comparison
  - This review is documented in WCAP-15613

WGOTHIC Code Applicability Evaluation Process

- Westinghouse reviewed the AP600 separate effects test data for application to the AP1000
  - The separate effects test data range for the dimensionless heat and mass transfer parameters covers the range of the AP1000 in the important downcomer and riser regions of the annulus. Therefore, the correlations are also valid for the AP1000.
  - The PCS test data covered the operating range of the important film coverage parameters for both the AP600 and AP1000. Therefore, the constant coverage area input values and evaporation limited PCS water flow rate input model are also applicable for the AP1000.
  - This review is documented in WCAP-15613

WGOTHIC Code Applicability Evaluation Process

- Westinghouse evaluated the impact of the increased containment height on mixing above the operating deck
  - Correlations and test data indicate Ra number should increase as the elevation between the hot floor and cold ceiling increases
  - A detailed 2-D CFD analysis shows similar temperature response as the height is increased
  - Concluded the well-mixed assumption for the volume above the operating deck is also valid for AP1000
  - This evaluation is documented in WCAP-15613

Conclusion

- The previously accepted, bounding AP600 containment evaluation model, which is based on WGOTHIC version 4.2, is acceptable to perform the AP1000 containment DBA analyses with appropriate input changes to reflect the AP1000 containment design changes.

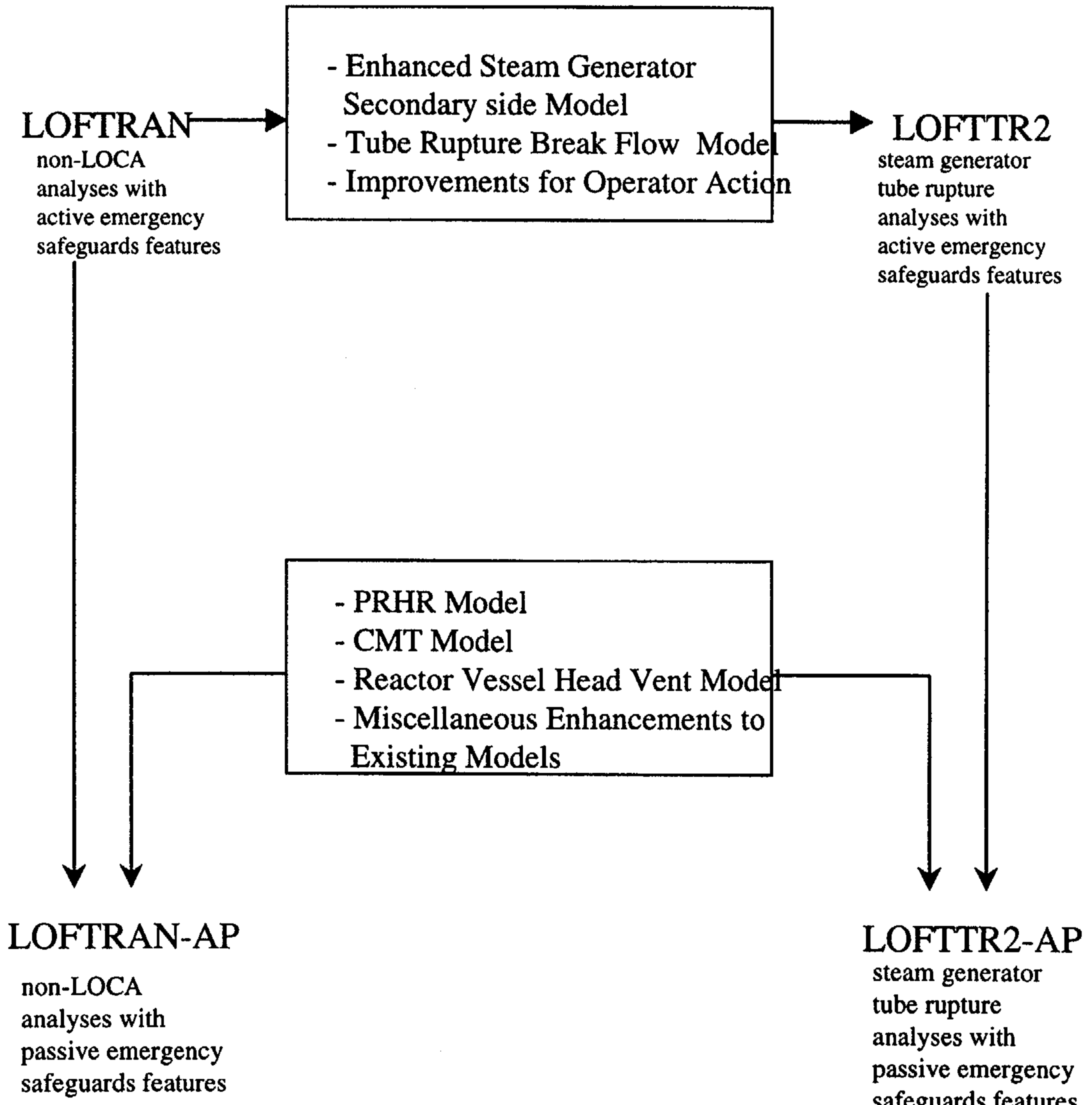
LOFTRAN-AP Code Validation

Ed Carlin
Transient Analysis
(412) 374-4167; carlinel@westinghouse.com

BNFL

LOFTRAN Code Family

Version	Used For	Documentation
LOFTRAN	operating plant non-LOCA analyses	WCAP-7907-P-A
LOFTTR2	operating plant steam generator tube rupture analyses	WCAP-10698-P-A Supplement 1 to WCAP-10698 WCAP-11002
LOFTRAN-AP	passive plant non-LOCA analyses	WCAP-14234 WCAP-14307 NRC review documented in NUREG-1512
LOFTTR2-AP	passive plant steam generator tube rupture analyses	


LOFTRAN
non-LOCA
analyses with
active emergency
safeguards features
- Enhanced Steam Generator
Secondary side Model
- Tube Rupture Break Flow Model
- Improvements for Operator Action
LOFTTR2
steam generator
tube rupture
analyses with
active emergency
safeguards features
- PRHR Model
- CMT Model
- Reactor Vessel Head Vent Model
- Miscellaneous Enhancements to
Existing Models
LOFTRAN-AP
non-LOCA
analyses with
passive emergency
safeguards features
LOFTTR2-AP
steam generator
tube rupture
analyses with
passive emergency
safeguards features

NRC AP600 Review

- NRC approved the use of LOFTRAN codes for AP600 (Section 21.6.1 of NUREG-1512)
- Section 21.6.1 identifies the following issue areas:
  - Use of auxiliary codes with LOFTRAN
  - Partial loss of forced RCS flow methodology
  - Phenomena Identification and Ranking Table (PIRT)
  - Primary and secondary system analytical models in previously approved LOFTRAN versions
  - Passive Plant Components and Systems
    - Automatic Depressurization System (ADS)
    - Core Makeup Tanks (CMTs)
    - Passive Residual Heat Removal (PRHR) heat exchanger and In-containment Refueling Water Storage Tank (IRWST)

Use of Auxiliary Codes with LOFTRAN

- AP600 Analyses
  - FACTRAN - Detailed fuel & heat flux modeling
  - THINC - sub-channel T/H code for DNBR calculation

    or

  - WESTAR - sub-channel T/H code for DNBR calculation

- AP1000 Analyses
  - FACTRAN - Detailed fuel & heat flux modeling
  - VIPRE - sub-channel T/H code for DNBR calculation

VIPRE Code

- VIPRE developed by Battelle Pacific Northwest Laboratories under EPRI sponsorship
- VIPRE is a transient three-dimensional sub-channel thermal hydraulic code for describing reactor core. Boundary conditions supplied by LOFTRAN and FACTRAN
- NRC has reviewed and approved use of VIPRE (generic and several utility submittals for core reload evaluations
- Application of VIPRE for core T/H analyses by Westinghouse has previously reviewed and approved by the NRC (WCAP-14565-P-A & WCAP-15306-NP-A). Code options selected give comparable results to those of THINC-IV and FACTRAN.
- VIPRE is to be the standard Westinghouse core T/H code
  - (new plant submittals & operating plant reloads)

Partial Loss of Forced RCS Flow Methodology

- AP600 & AP1000 use two cold legs per RCS loop
- LOFTRAN simulates a single cold leg per RCS loop
- For AP600 and AP1000 analyses
  - Twin cold legs are lumped together
    - uniform flow is predicted in the twin cold legs
    - LOFTRAN can not simulate asymmetric cold leg flow in a RCS loop.
- Events with asymmetric cold leg flow in a RCS loop
  - Partial loss of forced reactor coolant flow events
  - Locked or broken reactor coolant pump (RCP) shaft events
  - Startup of an inactive RCP
- For asymmetric cold leg flow events, conservative time dependent loop flows are input to LOFTRAN as boundary conditions

Partial Loss of Forced RCS Flow Methodology

- Bounding net flows derived using conservative assumptions, hand calculations, and auxiliary codes
- Methodology for deriving asymmetric cold leg flow
  - Outlined in AP600 RAI 440.279 Response
  - Sample calculations given in SDSER Open Item 21.6.1.7-3 Response
  - NRC concluded methodology was conservative & closed SDSER Open Item 21.6.1.7-3
- AP600 conservative methodology is applicable and acceptable for AP1000

Phenomena Identification and Ranking Table (PIRT)

- General agreement with slight differences between the Westinghouse and NRC PIRT for AP600 non-LOCA and SGTR PIRT
- Differences between W & NRC AP600 PIRT
  - Upper head flashing during SGTR
    - W ranked as low, NRC ranked as medium
    - Difference in ranking acceptable because calculations showed no flashing with up to 10 ruptured tubes which is beyond design basis
  - CMT balance line initial temperature distribution
    - W ranked as low, NRC ranked as medium
    - Differences found acceptable because initial temperature distribution explicitly input to LOFTRAN
- Staff concluded that PIRT developed for AP600 transients analyzed with LOFTRAN was applicable and acceptable

Phenomena Identification and Ranking Table (PIRT)

- AP1000 non-LOCA and SGTR PIRT
  - PIRT included in WCAP-15613, "AP1000 PIRT and Scaling Assessment"
  - WCAP-15613 included review by industry experts
  - AP1000 PIRT same as AP600 except for the ranking of CMT "gravity draining injection phenomena"
    - AP600 ranked as Not Applicable
    - AP1000 ranked as "medium" until analyses confirm whether phenomena occurs
    - (preliminary AP1000 steam line breaks for mass and energy releases do not exhibit gravity draining)

Primary and Secondary System Analytical Models in Previously Approved LOFTRAN Versions

- Staff AP600 RAIs included question related to thermal-hydraulic models in the previously approved versions of LOFTRAN and LOFTTR2 used for operating plants
  - Pressurizer location
  - wall friction
  - use of global pressure formulation
  - compressibility effects
  - reverse flow
  - heat transfer options
- All AP600 RAIs on these subjects were completed and responses were found to be acceptable. SDSER Open Item 21.6.1.4-1 was closed
- Resolution of NRC concerns in these areas also apply to AP1000

Passive Plant Components and Systems Important to Non-LOCA & SGTR Analyses

- Automatic Depressurization System (ADS)

- Core Makeup Tanks (CMTs)

- Passive Residual Heat Removal (PRHR) heat exchanger and In-containment Refueling Water Storage Tank (IRWST)

Automatic Depressurization System (ADS)

- NRC Issues (SDSER Open Item 21.6.1.7-5) LOFTRAN should not be used for any analysis involving actuation of the ADS (involves global two phase flow & code is not benchmarked against ADS tests)

- Resolution Response to SDSER Open Item 21.6.1.7-5
  - W confirmed ADS is not used for mitigation of non-LOCA & SGTR events
  - Only LOFTRAN case with ADS is short term (up to reactor trip) RCS depressurization event due to spurious opening of an ADS train
    - Analysis is similar to that performed with LOFTRAN for inadvertent opening of a pressurizer relief valve
    - Maximum depressurization rate is conservative and it is conservative to ignore ADS piping interactions

- Same approach for AP1000 will provide acceptable & conservative results

Core Makeup Tanks (CMTs)

- NRC AP600 Issues (SDSER Open Item 21.6.1.7-4) LOFTRAN CMT model is not written for simulation of two phase flow
  - Steam formation in the CMT balance line may invalidate the calculated CMT performance

- Resolution Response to SDSER Open Item 21.6.1.7-4 W modified coding to check for saturation in the balance line
  - If saturation occurs a warning is output and a buoyancy head penalty is applied such that CMT flow is terminated

PRHR HX & IRWST

- AP600 review issues with the PRHR & IRWST model
  - Validity of modeling IRWST as a single, homogeneous fluid region
    - Resolved by LOFTRAN sensitivity studies using IRWST temperature profiles from SPES & PRHR test program and demonstrating that homogenous IRWST temperature profile produces conservative results
  - Validity of straight tube PRHR test to develop final PRHR C-tube design heat transfer correlations
    - Resolved based on LOFTRAN PRHR simulations from SPES tests & blind test comparisons of the ROSA full height C-tube heat exchanger performance

LOFTRAN Code Versions for AP1000

- AP600 Final Analyses used:
  - Version 1.8 of LOFTRAN-AP for non-LOCA
  - Version 1.6 of LOFTTR2-AP for SGTR
- Enhancements & Upgrades to LOFTRAN Version used for operating plants have continued independent of AP600 and AP1000
  - Data transfer interfaces to auxiliary codes (*)
  - Enhanced pressurizer safety & relief valve model (*)
  - Enhanced steam generator safety & relief valve model (*)
  - Input and output formatting
  - VVER system models
  - Enhanced RCS thick metal heat transfer model
- LOFTRAN-AP to be upgraded to be consistent with latest LOFTRAN version used for operating plants

(*) New features of interest and use for AP1000. The enhanced pressurizer relief valve model simulates each valve independently (instead of lumping). This more realistic relief valve model was used in a special LOFTRAN-AP version for AP600 NRC questions related to pressurizer safety valve operability.

Nodalization Changes

- AP1000 PRHR model same as AP600 PRHR model except that 4 additional nodes are added to PRHR heat exchanger horizontal regions
  - (AP1000 has longer horizontal C-tube sections)

- For other regions, AP1000 nodalization remains the same as AP600

Conclusions

- NRC review of LOFTRAN code for the AP600 is documented in NUREG-1512 Review concluded that LOFTRAN was modified to include necessary models for the AP600 plant features and the behavior expected during AP600 non-LOCA transients. All issues & open items during the review were resolved

- After code upgrades for AP1000, LOFTRAN will continue to give comparable results to those previously obtained for the AP600

- Preliminary AP1000 analyses of WCAP-15612 show safety margins comparable to that of AP600 and resulted in no new phenomena

- Conclusions from AP1000 PIRT and scaling analysis (WCAP-15613) indicate that non-LOCA code which acceptably predicted the AP600 performance will acceptably predict AP1000 performance

- Configuration of AP1000 systems & components important to non-LOCA analyses remain the same as AP600. No changes to LOFTRAN are required for the AP1000

WCOBRA/TRAC Applicability to AP1000 Large Break LOCA Analysis

Robert M. Kemper

Senior Engineer

LOCA Integrated Services

(412) 374-4579; kemperrm@westinghouse.com

AP1000 Large Break LOCA Phenomena

- The unique passive systems do not contribute to core cooling during accident mitigation through the time of PCT for DECLG and large split break LOCA events
- AP1000 phenomena are the same as AP600
- Therefore, important AP1000 phenomena are well understood from the generic large break LOCA test database
- A qualified, established large break LOCA analysis code and methodology may be applied to AP1000

The WCOBRA/TRAC Computer Code

- Has been reviewed & approved by NRC as a best-estimate code per the CSAU methodology for the W 3-loop and 4-loop plant applications
- A comprehensive code qualification document (WCAP-12945) exists for the 3-loop / 4-loop plant BELOCA application
- The extension of the approved BE methodology to AP600 in WCAP-14171 was approved by the staff
- The applicability of WCOBRA/TRAC to AP1000 large break LOCA analysis is presented in WCAP-15644

Acceptance of WCOBRA/TRAC for AP600 Large Break LOCA Analysis

- WCAP-14171 assessed the code for direct vessel injection (DV I) related phenomena
  - CCTF Test 58 reflood test
  - UPTF Run 21 ECC bypass test
- Range of applicability of blowdown / reflood core heat transfer models shown for AP600 in WCAP-14171
  - ORNL blowdown tests
  - FLECHT-SEASET tests
- A simplified uncertainty methodology for the 95th percentile PCT is established in WCAP-14171
- Approval granted as a 10CFR50.46 best-estimate analysis code compatible with RG 1.157

WCOBRA/TRAC Acceptability for AP1000 Large Break LOCA Analysis

- As for AP600, ample validation exists for the AP1000 DVI injection configuration and the range of core heat transfer parameters
- As for AP600, a simplified variation of the approved Westinghouse plant BELOCA methodology is used
- Therefore, as long as the restrictions of the AP600 FSER are met, WCOBRA/TRAC is an acceptable analysis tool for the AP1000 DCD analysis

WCOBRA/TRAC Code Version for AP1000 Large Break LOCA Analysis

- The version of WCOBRA/TRAC to be created for use in the AP1000 LBLOCA analysis will include
  - the passive plant updates from the AP600 code version
  - discretionary and non-discretionary code changes made since the AP600 DCD analysis was performed
- An error correction reported in the 1998 10CFR50.46 Model Assessments increased AP600 PCT to 1687F
- The 1999 and 2000 WCOBRA/TRAC code changes have a 0F impact on the AP600 95% PCT result

Restrictions in NUREG-1512 on the use of WCOBRA/TRAC for AP600 LBLOCA

- The same list as in 3/4-loop plant approval document
- Others that apply if the 95% PCT exceeds 1725F:
  - The global model matrix of cases & the final uncertainty calculations shall be repeated
  - The sensitivity to CMT & PRHR modeling parameters, if any, shall be added as a bias to increase the 95% PCT result
  - Westinghouse shall perform both local and core-wide oxidation calculations using the techniques approved for the 3-loop and 4-loop plant BELOCA analyses
- The AP1000 95% PCT will exceed 1725F, so the DCD large break LOCA analysis will conform to the identified restrictions

AP1000 Large Break LOCA Analysis Conclusions

- The AP1000 LBLOCA phenomena are the same as those identified for AP600
- WCOBRA/TRAC and the 95% PCT methodology were validated for AP600 in WCAP-14171
- WCOBRA/TRAC and the BELOCA methodology approved for AP600 in NUREG-1512 can be applied to AP1000 DCD LBLOCA analysis
- The AP600 FSER restrictions, including those that apply when the 95% PCT exceeds 1725F, apply to AP1000 and will be incorporated in the DCD analysis

WCOBRA/TRAC Applicability to AP1000 Long-Term Cooling Analysis

Robert M. Kemper
Senior Engineer
LOCA Integrated Services
(412) 374-4579; kemperrm@westinghouse.com

AP1000 Long-Term Cooling Phenomena

- Passive systems provide gravity injection through the DVI lines from the IRWST and the containment sump with steam venting through ADS flow paths; OSU test facility was built to obtain data on this unique design
- Decay heat removal is accomplished by heat transfer through the containment shell
- AP1000 PIRT shows that there are no new long-term cooling (LTC) phenomena relative to AP600
- WCAP-15613 concludes the OSU AP600 test facility is adequately scaled for the AP1000 application

WCOBRA/TRAC Computer Code for Long-Term Core Cooling Analysis

- The code was validated against integral systems test data from OSU for LTC phenomena in WCAP-14776
- A much simpler nodalization than that used in large LOCA analyses was adopted for LTC analysis
- The OSU simulations were "window" mode analyses of quasi-steady-state time intervals during LTC
- The WCOBRA/TRAC code used in the AP1000 DCD LTC analysis will contain the changes identified for large break LOCA, relative to the AP600 DCD code version; the changes do not impact predicted LTC performance

WCOBRA/TRAC Acceptance for the AP600 LTC Analyses

- The range of validation cases is sufficiently broad to support use of the code for AP600 LTC analysis
- The code was judged to adequately represent LTC phenomena and to accurately predict key parameters of pressure, DVI/ADS flow rates, vessel liquid levels in the WCAP-14776 simulations
- Window mode is judged to be adequate for prediction of the quasi-steady state phenomena during LTC

WCOBRA/TRAC Acceptability for AP1000 LTC Analysis

- The AP600 PIRT applies to the AP1000 LTC phase with no major changes, and there are no additional phenomena for AP1000 that would require the addition of new features to the code
- Scaling of the OSU test facility is adequate for AP1000, so the validation of WCOBRA/TRAC that is documented and approved in WCAP-14776 applies
- WCAP-15644 concludes that if the restrictions of the AP600 FSER are met, WCOBRA/TRAC may be used for AP1000 LTC analysis

Restrictions on WCOBRA/TRAC in NUREG-1512 for AP600 LTC Analysis

- Nodalization shall correspond to that used in OSU calculations: the same nodalization used for AP600 and in WCAP-14776 calculations is used on AP1000
- Window time span shall result in a quasi-steady state condition: AP1000 DCD window mode cases will be executed long enough to achieve this
- Code shall not be applied outside the test parameter range, particularly for core dryout/heatup situations: based on the WCAP-15612 analysis, the AP1000 plant design precludes LTC core uncovery for DBAs

AP1000 LTC Analysis Conclusions

- The data obtained at the AP600 OSU facility applies to AP1000 also
- The validation performed against OSU data justifies use of WCOBRA/TRAC for AP1000 LTC analysis
- The limiting case DEDVI break will be analyzed continuously from the start of LTC into containment recirculation
- The WCOBRA/TRAC code may be used to perform the AP1000 DCD LTC analysis

Applicability of NOTRUMP-AP600 Code To The AP1000 Plant Design

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

BNFL

Objectives

- Provide an overview of the Code Applicability Document (CAD) related to SBLOCA
  - Provide a summary of the concerns raised regarding the application of NOTRUMP for AP600 application
  - Provide a summary of the methods utilized to address concerns for the AP1000 application
- Conclusions regarding applicability of NOTRUMP to AP1000

AP1000 SBLOCA CAD Overview

- NRC conclusions regarding NOTRUMP for AP600 Application
  - NOTRUMP code has identified limitations
    - Westinghouse must observe conditions regarding application of NOTRUMP to AP600
  - NOTRUMP acceptable for AP600
    - Phenomena expected during SBLOCA events predicted reasonably well by NOTRUMP

AP1000 SBLOCA CAD Overview

- Deficiencies in NOTRUMP identified from AP600 review
  - ADS-4 two-phase pressure drop
    - Assessed as minimal due to lack of momentum flux terms
      - Two-phase pressure drop during non-critical flow
    - Addressed in DSER via level penalty implementation
    - RAI response (440.796F, Part a) demonstrates required ADS-4 resistance adjustment for OSU
      - Determine based on detailed momentum flux model for OSU test facility
        - » ~35% increase In ADS-4 resistance required
      - Equivalent effort performed for AP600
        - » ~60% increase in ADS-4 resistance required
    - Methods shown to provide similar response in delaying IRWST injection

AP1000 SBLOCA CAD Overview

- Deficiencies in NOTRUMP identified from AP600 review (continued)
  - Downcomer mixture level for DEDVI line break
    - Assessed as minimal for DEDVI line break case only
      - Two-dimensional nature not simulated with one-dimensional code
      - Self-corrects prior to ADS 1-3 blowdown completion
      - Core level unaffected by this behavior
    - IRWST level penalty and break discharge coefficient ranging assure long term conservatism
      - Prevent early IRWST injection and range break response

AP1000 SBLOCA CAD Overview

- Deficiencies in NOTRUMP identified from AP600 review (continued)
  - Phase separation at tee junctions
    - Cold leg tee junctions deemed conservative due to artificial balance line refilling
      - Results In delayed CMT drain and ADS actuation
    - No model changes required in this phase
    - Hot leg tee junctions deemed minimal due to ad-hoc model usage
      - Impact deemed small as ADS-4 liquid discharge controlled by near-constant primary inventory
        - » AP1000 behavior expected to be similar

AP1000 SBLOCA CAD Overview

- Deficiencies in NOTRUMP identified from AP600 review (continued)
  - Pressurizer and surge line level swell
    - Model assessed as minimal and non-conservative during Pressurizer drain period (i.e. Post ADS-4 actuation)
      - Caused by poor ADS-4 pressure drop prediction
    - Addressed via IRWST level penalty implementation
      - Conservatively delays IRWST injection flow

AP1000 SBLOCA CAD Overview

- Deficiencies in NOTRUMP identified from AP600 review (continued)
  - PRHR heat transfer/Recirculation flow
    - Model assessed as minimal and conservative provided primary flow low
      - Low flow through primary results in conservatively low PRHR heat rejection
        - » Requires Steam Generators/Break and ADS paths remove additional energy
    - Assessed via confirmation that flow <= 1.5 ft/sec In all simulations
      - If > 1.5 ft/sec, reduce surface HTA by 50% and re-perform limiting case

AP1000 SBLOCA CAD Overview

- Deficiencies in NOTRUMP identified from AP600 review (continued)
  - Non-condensable gas injection
    - Non-condensable model does not exists
    - Assessed via the removal of the PRHR prior to introduction of non-condensable gases (post ADS stage 3 actuation)
      - Major heat removal source for AP600 removed
        - » Requires ADS flow paths/break to remove core heat generation

AP1000 SBLOCA CAD Overview

- AP1000 PIRT Issues
  - No new phenomena identified
  - Re-ranked phenomena for AP1000
    - Re-ranked phenomena not new but rather a result of AP600 lessons learned
      - ADS-4 subsonic, two-phase flow (raised to high importance)
      - Upper plenum/hot leg entrainment post ADS (raised to high importance)
      - Pressurizer surge line CCFL (raised to high importance)

AP1000 SBLOCA CAD Overview

- AP1000 scoping analysis results
  - Limited break spectrum performed to date
    - 2-Inch cold leg break
    - Double-Ended Direct Vessel Injection line (DEDVI)
    - Inadvertent ADS actuation
  - Scoping AP1000 transient results indicate comparable margin to AP600
    - AP1000 plant physical size results in breaks acting like smaller breaks when compared to AP600
    - No core uncovery observed
  - No new phenomena observed

AP1000 SBLOCA CAD Overview

- How NOTRUMP deficiencies addressed For AP1000
  - Address ADS-4 deficiency in a more direct manner
    - Utilize ADS-4 resistance adjustment in lieu of IRWST Level Penalty
    - ADS-4 resistance implementation demonstrated to significantly improve fidelity with test data
  - "Other" issues addressed in a similar manner as AP600
  - Perform supplementary calculation with WCOBRA/TRAC model to support continued NOTRUMP usage
    - Provide additional benchmark tool to which NOTRUMP model can be compared/adjusted

AP1000 SBLOCA CAD Overview

- Perform supplementary calculation with WCOBRA/TRAC (WCT) for ADS-4 - IRWST initiation phase
  - Code contains complete momentum flux equation
    - Addresses ADS-4 modeling
  - Code contains state-of-the-art entrainment models
    - Addresses hot leg to ADS-4 tee junction modeling
  - Code contains horizontal flow models
  - WCT model will be validated against applicable OSU test data
    - Commence transient at ADS-4, to start of IRWST injection
  - Will be used as Appendix-K type code to conservatively predict AP600 integral effects test for ADS-4 - IRWST initiation phase of SBLOCA transient

AP1000 SBLOCA CAD Overview

- Supplementary WCT calculation (Continued)
  - Begin at ADS-4 actuation time in AP1000 DCD Calculation
    - Provide overlap period where NOTRUMP results considered valid
      - Prior to ADS-4 non-critical flow point
  - Demonstrate that adjusted NOTRUMP model provides appropriate prediction of AP1000 behavior during ADS-4/IRWST initiation phase
    - NOTRUMP provides a conservative representation of IRWST injection

AP1000 NOTRUMP CAD Conclusions

- NOTRUMP AP1000 SBLOCA application
  - Deficiencies need to be appropriately addressed
    - Methods discussed in CAD provide confidence that NOTRUMP conservatively calculates AP1000 response
      - Supplemental WCT calculation provides additional benchmark tool
  - AP1000 margins expected to be comparable to AP600
    - As indicated by preliminary analysis results
  - NOTRUMP acceptable for AP1000 application

Meeting Summary

Resolution of Phase II Review

- AP1000 configuration is essentially the same as the AP600
  - No new phenomena
    - Core power increased
    - Capacities of passive systems increased accordingly
- AP600 test results are sufficiently scaled
  - Well-scaled for important phenomena

Safety-analysis codes validated against AP600 test data can also be used for AP1000

Expectations for AP600 Test Applicability

- AP600 tests are sufficient to meet the requirements of 10CFR52.47(b)(2)(I)A for AP1000

Expectations for Applicability of AP600 Safety Analysis Codes

- AP600 approved analysis codes and methods can be used for AP1000
  - Proposed incremental update to codes are acceptable because they have been previously evaluated / approved
    - Corrections of errors to the codes reported in accordance with 10CFR50.46
    - Updates that were incorporated / evaluated as part of AP600 RAI responses
    - Updates that were incorporated / evaluated for operating plants subsequent to AP600 Design Certification
  - Additional WCOBRA-TRAC analysis to supplement NOTRUMP SBLOCA analysis of ADS-4 / IRWST transition can be used to support NOTRUMP applicability

NRC Supplemental Analyses

- NRC is performing independent analysis to confirm AP1000 analysis results
  - Can be used to independently assess safety of AP1000
  - Can be used to test range of applicability of AP600 / AP1000 analysis codes
- Acceptable approach for licensing new plant designs
  - Used extensively on AP600

Approach for Applicability Review

- Approved codes need only be reviewed for applicability

- Issues with code applicability should be raised during Phase 2

- Issues regarding analysis results not related to code applicability will be deferred to Phase 3