NRC Review of AP1000 Analytical Codes and Test Programs

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NRC Review of AP1000

- **Presentation Outline**
  - Show review process.
  - Discuss some of the important thermal-hydraulic issues and how they were resolved.

NRC considers AP1000 a safe plant.

NRC Review of AP1000
(Starting Point)

- Both Westinghouse and NRC relied on review of AP600 for guidance in review of AP1000. (AP600 review was extensive, lasting from 1992 to 1998.)

- Westinghouse View: Safety codes and methods used for AP600 are applicable to AP1000. Experimental data supporting AP600 are sufficient for supporting AP1000.

- NRC View: Major design changes (in addition to 75% increase in core power) made AP1000 a "new" design. Many AP600 issues should be re-considered.

AP600 to AP1000 Design Changes

- **Increase Core Height & Number of Assemblies**
- **Increase Size of Key NSSS Components**
  - Increased height of Reactor Vessel
  - Larger Steam Generators (similar to W/CE SGs)
  - Larger canned RCPs (variable speed controller)
  - Larger Pressurizer
- **Increase Containment Volume & Design Pressure**
- **Capacity Increases in Passive Safety System Components**

Comparison of AP1000 / AP600 / Conventional PWR

Parameter	Doel 4/Tihange 3	AP600	AP1000
Net Electric Output, MWe	985	610	1117
Reactor Power, MWt	2988	1933	3400
Hot Leg Temperature, ^{o}F	626	600	610
Number of Fuel Assemblies	157	145	157
Type of Fuel Assembly	17x17	17x17	17x17
Active Fuel Length, ft	14	12	14
Linear Hear Rating, kw/ft	5.02	4.1	5.71
Control Rods / Gray Rods	52 / 0	45 / 16	53 / 16
R/V I.D., inches	157	157	157
Vessel Flow, Thermal Design, gpm	295,500	194,200	300,000
Steam Generator Surface Area, ft2	68,000	75,000	125,000
Pressurizer Volume, ft3	1400	1600	2100

NRC Review of AP1000 Codes / Tests

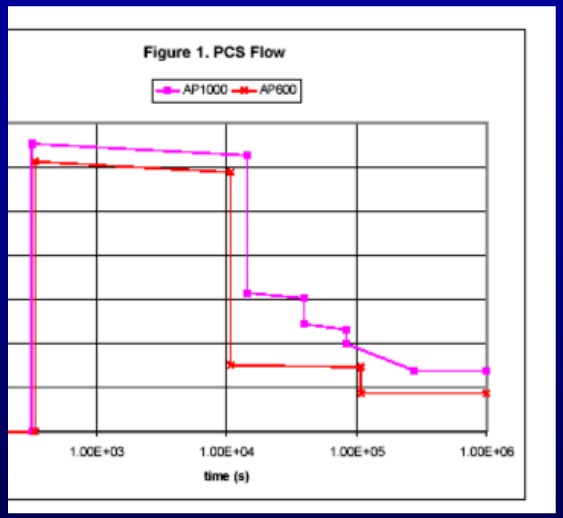
- **Review of AP1000 performed in two stages:**
- **"Pre-Design Certification" began in 2001**
  - Identification of important review topics
- **Design Certification submittal in March 2002.**
  - Request for Additional Information (RAIs) by NRC
  - Resolution of Open Issues
- **FSER (Final Safety Evaluation Report) was issued in September 2004.**

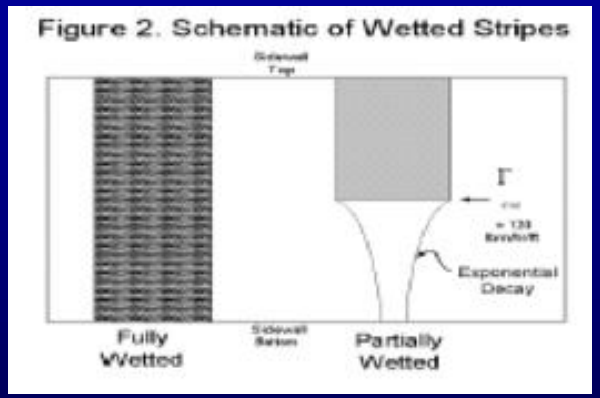
NRC Review of Test Programs

- **VAPORE**
  - Flow through ADS-1/2/3 valves
  - No design change therefore remained applicable
- **CMT**
  - Core makeup tank transients similar
  - Test data remained applicable
- **PRHR**
  - Examine heat transfer from PRHR tubes to IRWST
  - Basis derived from simulations of ROSA PRHR, and considered acceptable for AP1000 conditions.

NRC Review of Test Programs

- **Containment PCCS Issues Considered:**
  - Film coverage
  - Thermal striping
- **Westinghouse film coverage tests reviewed & compared to conditions expected in AP1000.**





Data/correlations adequate.

Conservative value of mass flux used in W calculations.

NRC Review of Test Programs

- **SPES and APEX-AP600 integral tests provided:**
  - Data for thermal-hydraulic code assessment
  - Verification of safety margin
  - Scaling evaluations by both W and NRC showed facilities to be a reasonable representation of AP600 plant for specific periods
- **Comprehensive scaling evaluation performed to determine if APEX-AP600 tests reasonably represented AP1000.**

Integral Facility Scaling Evaluation

- **NRC performed independent scaling evaluations of SPES, ROSA, and APEX for applicability to AP1000.**

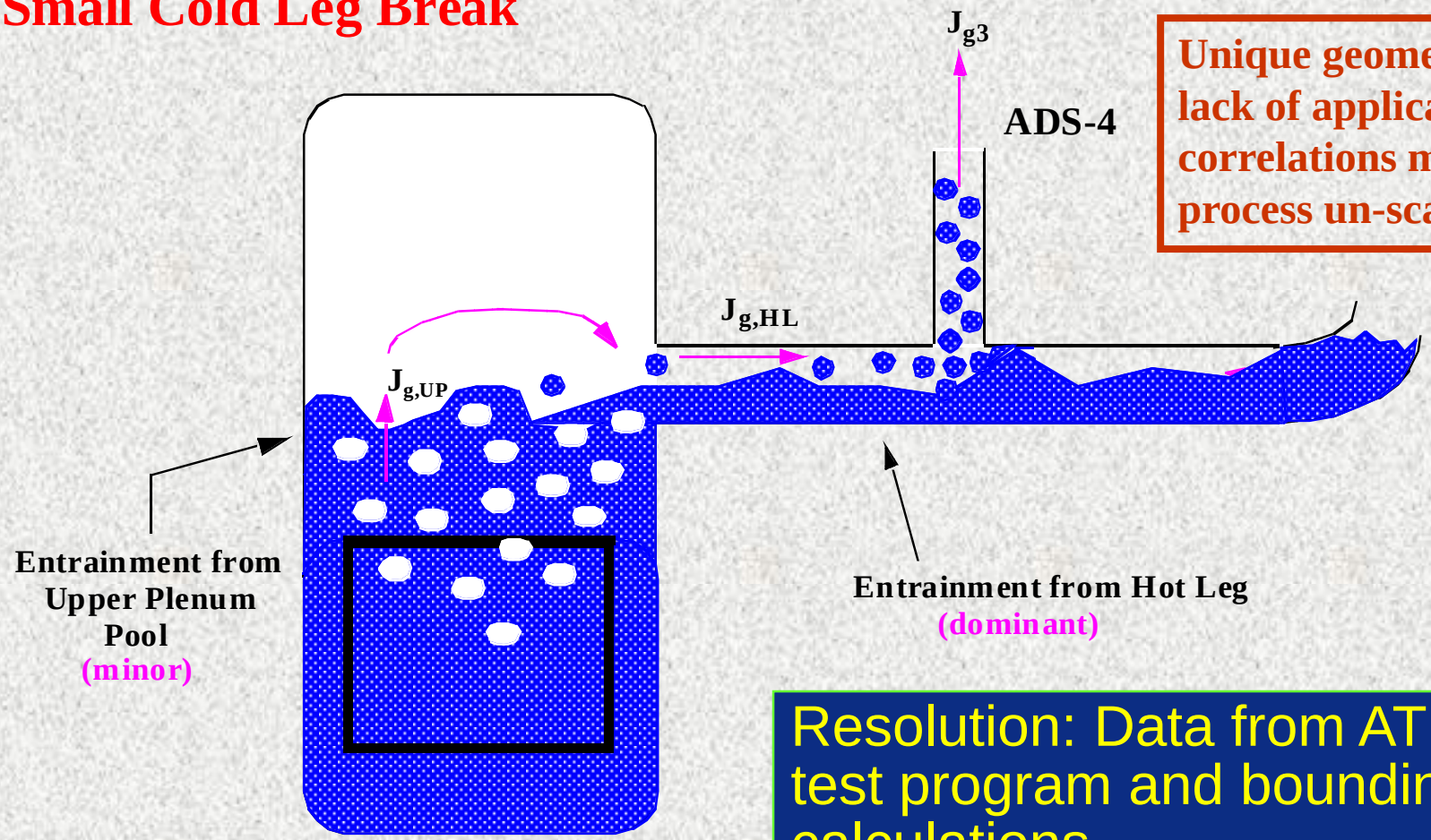
- **"Hierarchical Two-Tiered Scaling (H2TS) Methodology:**
  - "Top-Down" Scaling – for global system response
  - "Bottom-up" Scaling – for individual processes

NRC Scaling Evaluation

- **NRC scaling evaluation showed SPES well scaled for AP1000 initial periods (blowdown and ADS-1/2/3 blowdown).**
- **"Bottom-up" scaling of APEX-AP600 facility identified distortions in entrainment rates:**
  - Hot leg at ADS-4 branch line
  - Upper plenum
- **APEX-AP600 data reasonably well scaled for AP1000 based on "top-down" approach.**

Hot Leg Flow Pattern & Offtake to ADS-4

Small Cold Leg Break

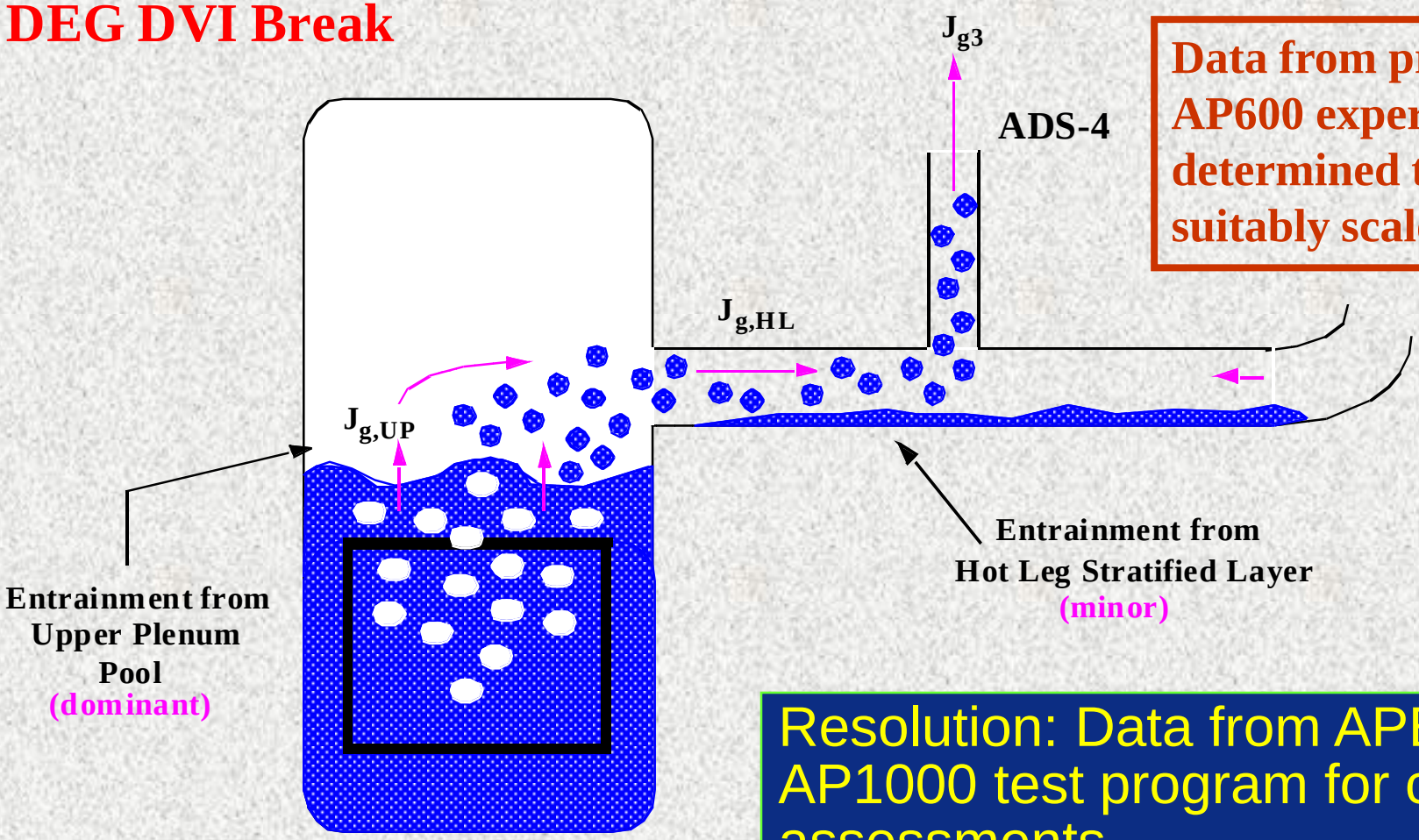


Unique geometry and lack of applicable data & correlations made process un-scalable.

Resolution: Data from ATLATS test program and bounding calculations.

Upper Plenum "Pool" Entrainment

DEG DVI Break

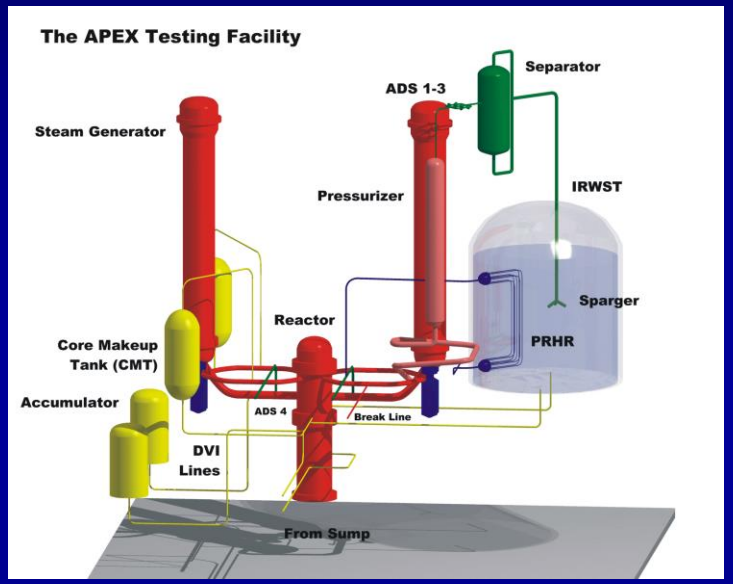


Data from previous AP600 experiments determined to be not suitably scaled.

Resolution: Data from APEX-AP1000 test program for code assessments.

APEX-AP1000 Experiments

- To help resolve entrainment issues, Westinghouse obtained new data at the "APEX-AP1000" facility.
- Tests began in the newly modified "APEX-AP1000" facility in March 2003. Modifications were made through DOE-NERI grant funding.
- A total of 11 tests were completed in 2003-2004, jointly funded by U.S. DOE and NRC. (Data was shared, but evaluated independently.)



NRC Review of Safety Codes

- **NRC performed a design review of the AP1000**
  - Relied on work performed for the AP600
    - RELAP5 code adequacy assessment
    - Focused review on phenomena that were more important in the AP1000
      - **Level swell**
      - **Entrainment**
        - » **Upper plenum**
        - » **Hot leg**
- **NRC did not perform a code acceptance review of NOTRUMP and WCOBRA-TRAC**
  - Identified code deficiencies were handled by performance of bounding calculations to demonstrate margins in the design
    - 10 CFR 50.46 for LOCAs
      - **2200 F, oxidation limits and maintenance of coolable geometry**

NRC Review of Safety Codes

- **Main thermal-hydraulic review topics:**
  - Scaling of APEX
  - Identification of limiting transient
  - Backpressure assumption
  - Early phase collapsed liquid level (CLL)
    - Level swell
    - Entrainment (UP and HL)
    - ADS-4 pressure drop
  - NOTRUMP/RELAP5 comparisons
  - Long-term cooling CLL
  - Boron precipitation
- **Independent analyses**

DEDVI Break Review "Roadmap"

Event Phase	Phenomena	Primary Analysis Tool	Validation Method	Alternate Assessment	Conclusion
Break Opens to ADS	Core voiding	NOTRUMP	WCAP 14807 + Comparison to APEX data	None	Acceptable comparison to test data
ADS Depressurization	Core voiding and Downcomer mixing	NOTRUMP	WCAP 14807 + Comparison to APEX data	NOTRUMP simulation of downcomer thermal mixing observed in test	Increased core voiding does not propagate to later phases
ADS Depressurization	Core voiding	NOTRUMP	WCAP 14807 + Comparison to CHF data	CHF assessment relative to data	Core heat flux less than CHF at increased void condition

Validation to CHF correlation using RELAP5 results

DEDVI Break Review "Roadmap"

Event Phase	Phenomena	Primary Analysis Tool	Validation Method	Alternate Assessment	Conclusion
Transition to IRWST injection	ADS 4 pressure drop	NOTRUMP	WCAP 14807 + Comparison to APEX data + Detailed analysis of ADS4 piping (FLOAD4)	Comparison to DP data NOTRUMP Sensitivity Analysis	ADS4 Flow resistance acceptably represented in NOTRUMP Ample margin for ADS4 Resistance uncertainty
Transition to IRWST injection	Level swell	NOTRUMP	WCAP 14807 +Comparison to full scale data	Comparison to APEX data	Acceptable comparison to full scale and APEX data
Transition to IRWST injection	Entrainment	NOTRUMP	WCAP 14807 +Comparison to APEX data	NOTRUMP simulation with homogeneous flow in UP/HL/ADS4	Acceptable core cooling even with bounding analysis

RELAP5 CLL swelled using DF model and conservative heat up assumptions

Independent verification using RELAP5 and data

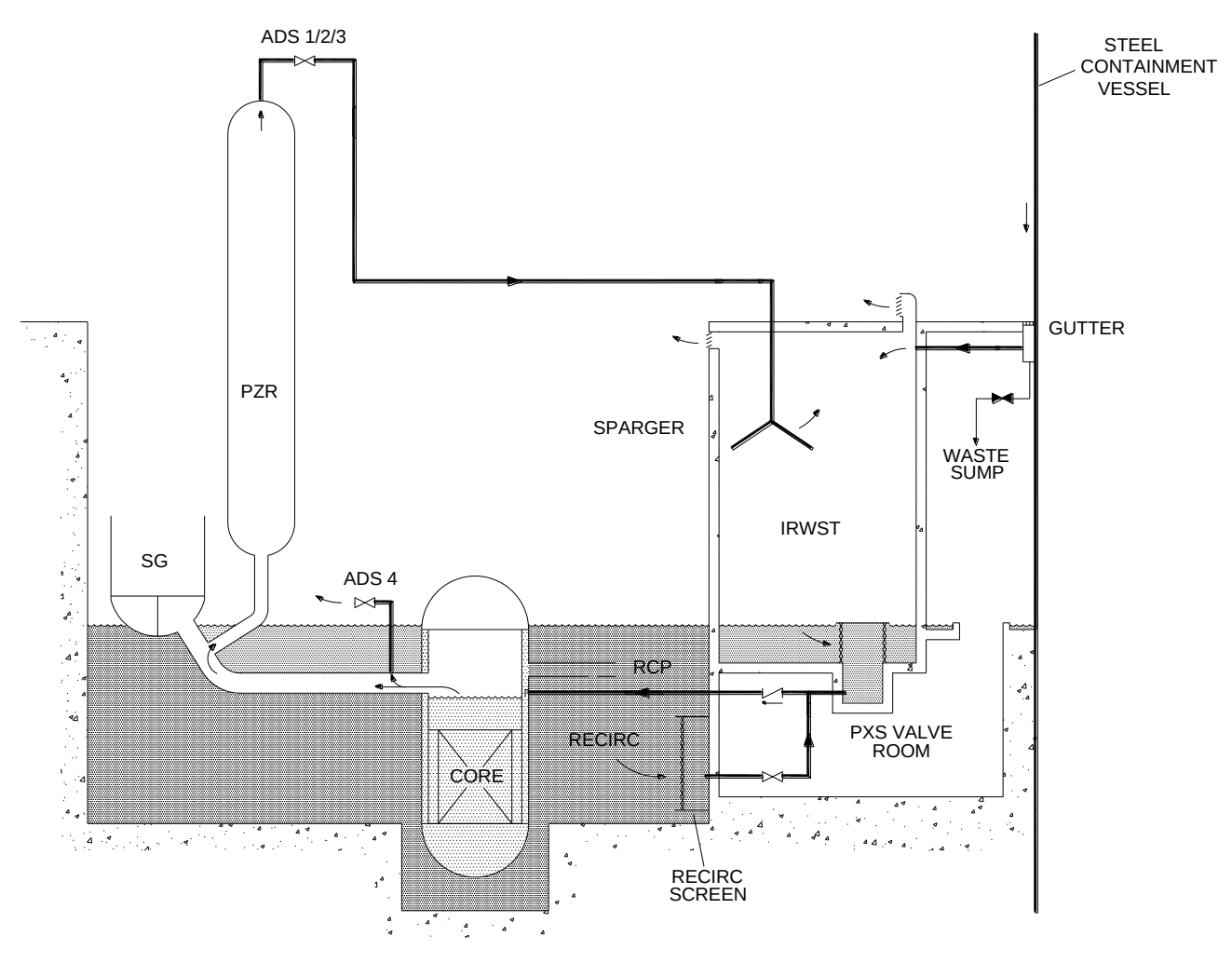
DEDVI Break Review "Roadmap"

Event Phase	Phenomena	Primary Analysis Tool	Validation Method	Alternate Assessment	Conclusion
Long Term Cooling	Level swell	WCOBRA /TRAC	WCAP 14776	Additional comparison to full scale level swell data	Acceptable comparison to level swell data.
Long Term Cooling	ADS4 Pressure Drop, level swell, entrainment	WCOBRA /TRAC	WCAP 14776	First principles steady state model	First Principles model confirms equilibrium condition provides adequate core cooling. .
Long Term Cooling	Boron concentration	First principles steady state model	WCOBRA/ TRAC for liquid discharge	None	First Principles model confirms equilibrium condition provides adequate liquid discharge.

Bounding assumptions, simplified model

RELAP5 calculations, simplified model and pressure drop data

LOCA Long Term Cooling



Westinghouse Safety Basis

- **Deficiencies in modeling were resolved with bounding calculations.**
- **Evaluation Model**
  - **NOTRUMP**
    - ADS-4 blowdown
      - CLL is over-predicted => heat flux for hot rod compared to CHF
    - IRWST transition phase
      - Entrainment is deficient => NOTRUMP run with homogeneous assumption in UP, HL and ADS-4
        - » Maximizes liquid entrainment and ADS-4 pressure drop
  - **WCOBRA/TRAC for LTC**
    - Boron precipitation assumes no boron in steam phase

Summary

- **Review of AP1000 design adequacy**
  - Reliance on AP600
  - Focus on differences between designs
- **Independent analyses on issues related to 10CFR 50.46 acceptance criteria.**
- **NRC confirmed that the AP1000 thermal-hydraulic design meets the regulatory requirements.**