AREVA

July 12, 2010
NRC:10:063

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U.S. Nuclear Regulatory Commission
Washington, D.C. 20555-0001

Draft Presentation Materials for July 15, 2010, Meeting with NRC to Discuss a Request for Additional Information Regarding Boron Dilution, Precipitation, and Long Term Cooling

A draft of AREVA NP Inc.'s (AREVA NP) presentation for the July 15, 2010 meeting with the NRC to discuss a request for additional information regarding boron dilution, precipitation, and long term cooling is attached.

AREVA NP considers some of the material contained in the enclosure to be proprietary. As required by 10 CFR 2.390(b), an affidavit is enclosed to support the withholding of the information from public disclosure. Proprietary and non-proprietary versions of the selected presentation pages are provided.

If you have any questions related to this submittal, please contact me by telephone at 434-832-2369 or by e-mail at sandra.sloan@areva.com.

Sincerely,

Sandra M. Sloan, Manager
New Plants Regulatory Affairs
AREVA NP Inc.

Enclosure

cc: G. Tesfaye
Docket No. 52-020

D077
NRO

AREVA NP INC.
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AFFIDAVIT

COMMONWEALTH OF VIRGINIA)
) ss.
COUNTY OF CAMPBELL)

1. My name is Gayle Elliott. I am Licensing Manager for AREVA NP Inc. and as such I am authorized to execute this Affidavit.

2. I am familiar with the criteria applied by AREVA NP to determine whether certain AREVA NP information is proprietary. I am familiar with the policies established by AREVA NP to ensure the proper application of these criteria.

3. I am familiar with the AREVA NP information contained in the presentation to the NRC on July 15, 2010 regarding the responses to U.S. EPR Design Certification Review RAI 403 and referred to herein as "Document." Information contained in this Document has been classified by AREVA NP as proprietary in accordance with the policies established by AREVA NP for the control and protection of proprietary and confidential information.

4. This Document contains information of a proprietary and confidential nature and is of the type customarily held in confidence by AREVA NP and not made available to the public. Based on my experience, I am aware that other companies regard information of the kind contained in this Document as proprietary and confidential.

5. This Document has been made available to the U.S. Nuclear Regulatory Commission in confidence with the request that the information contained in this Document be withheld from public disclosure. The request for withholding of proprietary information is made in accordance with 10 CFR 2.390. The information for which withholding from disclosure is

requested qualifies under 10 CFR 2.390(a)(4) "Trade secrets and commercial or financial information".

6. The following criteria are customarily applied by AREVA NP to determine whether information should be classified as proprietary:

(a) The information reveals details of AREVA NP's research and development plans and programs or their results.

(b) Use of the information by a competitor would permit the competitor to significantly reduce its expenditures, in time or resources, to design, produce, or market a similar product or service.

(c) The information includes test data or analytical techniques concerning a process, methodology, or component, the application of which results in a competitive advantage for AREVA NP.

(d) The information reveals certain distinguishing aspects of a process, methodology, or component, the exclusive use of which provides a competitive advantage for AREVA NP in product optimization or marketability.

(e) The information is vital to a competitive advantage held by AREVA NP, would be helpful to competitors to AREVA NP, and would likely cause substantial harm to the competitive position of AREVA NP.

The information in the Document is considered proprietary for the reasons set forth in paragraph 6(b) and 6(c) above.

7. In accordance with AREVA NP's policies governing the protection and control of information, proprietary information contained in this Document has been made available, on a limited basis, to others outside AREVA NP only as required and under suitable agreement providing for nondisclosure and limited use of the information.

8. AREVA NP policy requires that proprietary information be kept in a secured file or area and distributed on a need-to-know basis.

9. The foregoing statements are true and correct to the best of my knowledge, information, and belief.

SUBSCRIBED before me this 12th day of July, 2010.

Kathleen A. Bennett

Kathleen A. Bennett
NOTARY PUBLIC, COMMONWEALTH OF VIRGINIA
MY COMMISSION EXPIRES: 8/31/2011

KATHLEEN ANN BENNETT
Notary Public
Commonwealth of Virginia
[illegible]
My Commission Expires Aug 31, 2011

U.S. EPR
Design Certification Review
RAI 403 Proposed Response

AREVA NP Inc. and the NRC
July 15, 2010

EPR™ by AREVA

AREVA

Agenda
RAI 403 Proposed Response

▷ Boron Dilution - Questions 61 to 63	Lisa Gerken
▷ Boron Precipitation – Questions 64 to 68	Lisa Gerken & Don Rowe
▷ Long Term Cooling – Questions 69 to 77	Don Rowe

RAI 403, Question 15.06.05-61

CONDENSATE AMOUNT AND LOCATION:

- In response to Question 15.06.05-29, the applicant did not provide an assessment of the amount of condensate generated by reflux condensation as was requested. Instead, predictions for the liquid content in control areas defined as "steam generator (SG) outlet plenum," "loop crossover pipe," and "cold leg" were presented. Provide a calculation of the amount of condensate generated by reflux condensation accounting for conditions with emergency feed water (EFW) supply present for two or more SGs.
- The staff requests a mass balance accounting for the steam generated in the core by decay heat, steam lost out the break, steam condensed in the SGs, condensate in countercurrent flow returned to the reactor vessel hot leg, condensate collected on the SG, loop crossover pipe, and cold leg, condensate lost out the break, and condensate transported to the vessel downcomer.
- The staff requests a description of situations involving stratified conditions in the cold leg and downcomer regions.

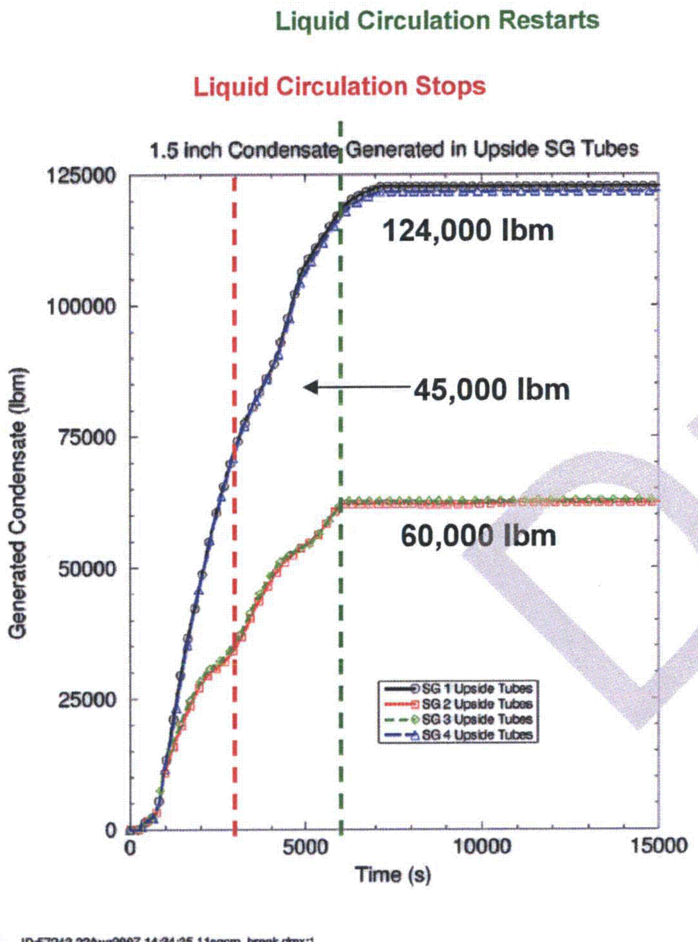
RAI 403, Question 15.06.05-61 Proposed Response

CONDENSATE AMOUNT AND LOCATION - SUMMARY OF PROPOSED RESPONSE:

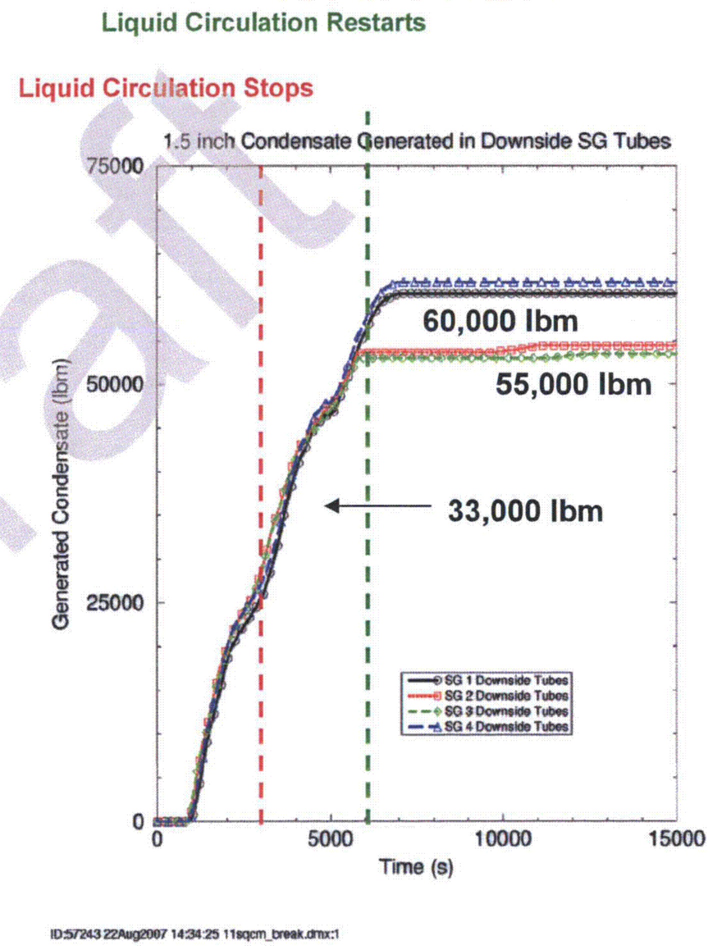
- Plots of condensation generated in various locations
- Mass balance accounting for this condensate
    - Break flow rates/ integrated flow rates
- Stratification Description

RAI 403, Question 15.06.05-61 Proposed Response

Upside Tubes

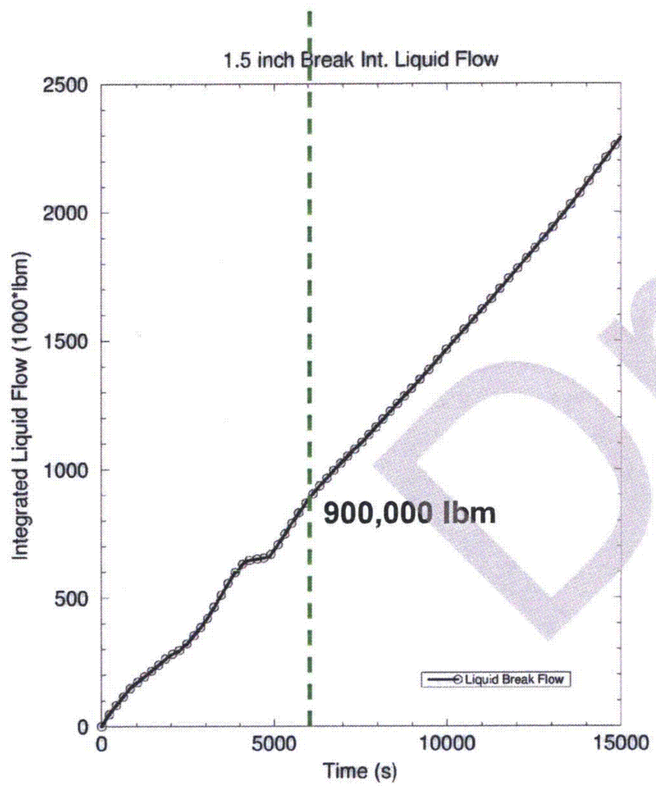


Downside Tubes



RAI 403, Question 15.06.05-61
Proposed Response

Break Flow



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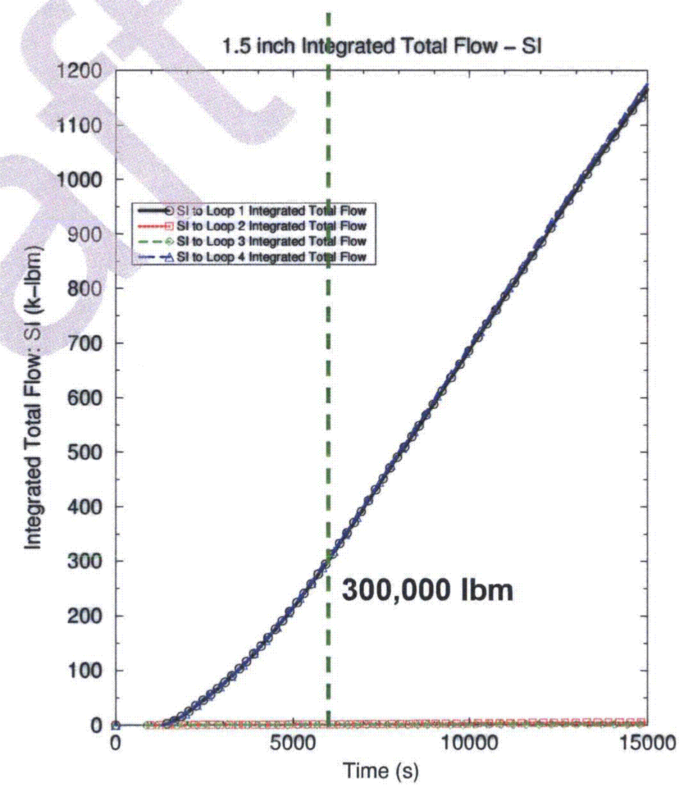
SI Flow



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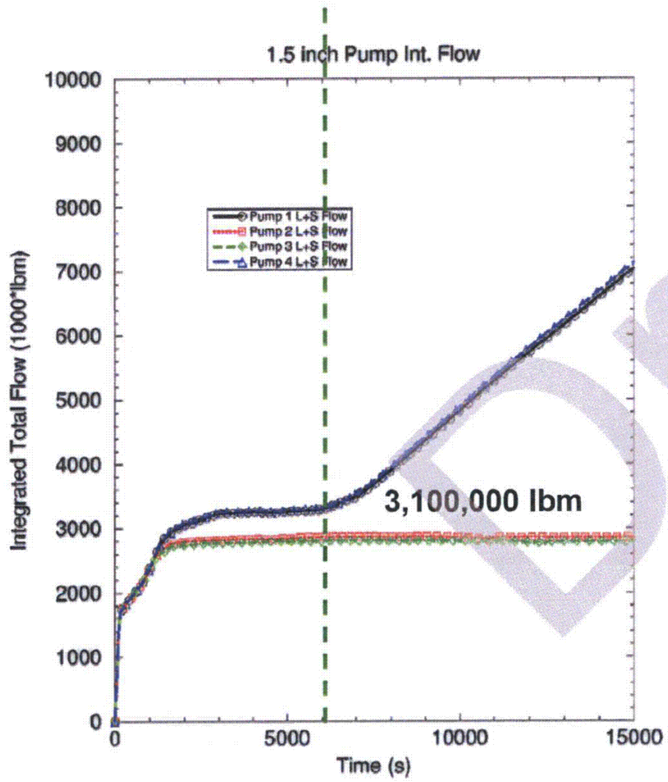
RAI 403, Question 15.06.05-61 Proposed Response

Flow through RCP



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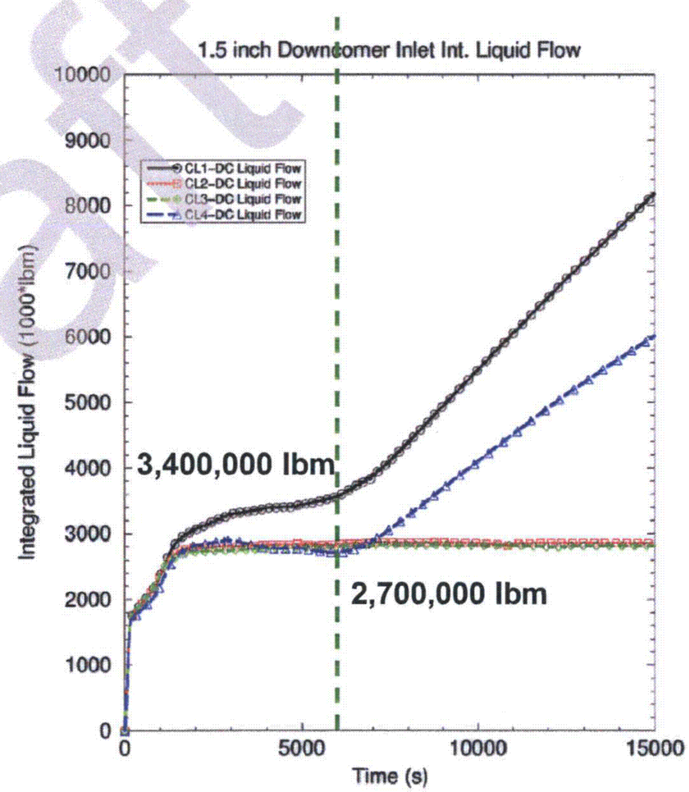
Cold Leg to Downcomer Flow



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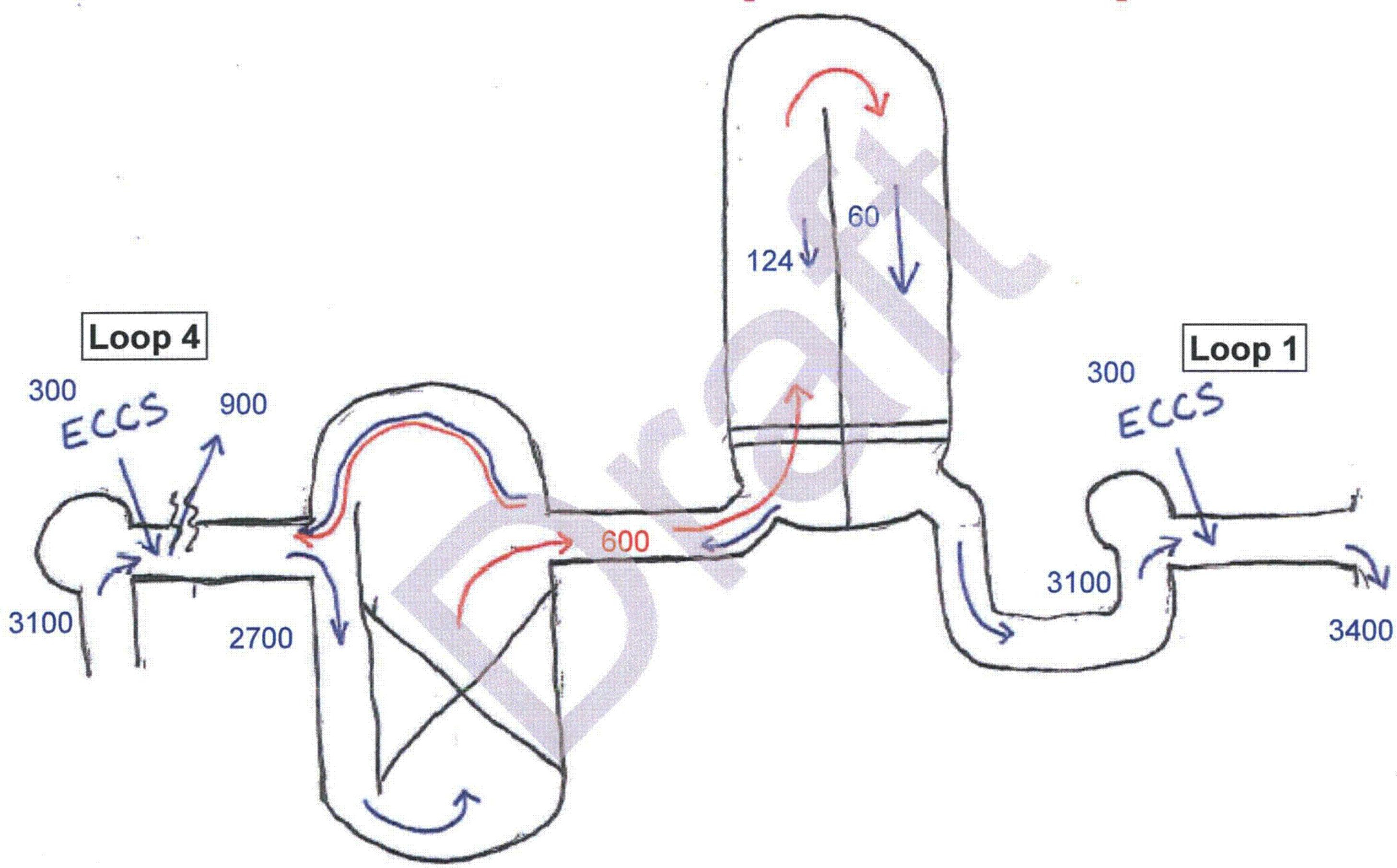
RAI 403, Question 15.06.05-61 Proposed Response



Numerical values are 'lbm x 10^{-3}'

RAI 403, Question 15.06.05-61 Proposed Response

CONDENSATE AMOUNT AND LOCATION - SUMMARY OF PROPOSED RESPONSE:

- Upside Condensate:
  - The steam produced in the core flows through the SG inlet plenum and upwards into the rising SG tubing. The rising steam voids cause rapid mixing of the condensate with borated water inside the rising SG tubing and in the SG inlet plenum. Consequently there is no accumulation of low-boron water in hot legs, SG inlet plena and rising SG tubing.
  - The mixing mechanism due to rising voids and has been empirically verified in PKL III Tests
- Downside Condensate:
  - The size of the cold side low-boron water slug volume per loop at restart of natural circulation is by system geometry. Surplus low-boron water is flowing back into the RPV and mixed with the ECC water plume in the downcomer.
  - A head balance calculation shows that a mixture level in the upside of the steam generator tubes must be present before we get water into the SG outlet plenum. Therefore before the erratic circulation will be present before filling the downside of the generator.

RAI 403, Question 15.06.05-61 Proposed Response

- The RAI response will discuss the locations of condensates and potential stratification. The stratification and mixing which occurs in the cold leg and downcomer regions will be supported by the following technical resources:
  - *"Potential for Boron Dilution During Small-Break LOCAs in PWRs" Brookhaven National Laboratory, BNL-NUREG-62261*: Examines the mixing processes associated with a slow moving stream of diluted water through the loop seal to the core
  - *Jacobsen, Sven Some Local Dilution Transients in a Pressurized Water Reactor Institute of Technology, Dept. of Mech Eng, S-581 83 Linkoping, Sweden*
  - *Kiger, K.T. and F. Gavelli "Boron Mixing in Complex Geometries: Flow Structure Details" Nuclear Engineering and Design 208 (2001) 67-85*
  - *UPTF TRAM Series tests*
  - *ROCOM tests*

RAI 403, Question 15.06.05-62

CONDENSATE AMOUNT AND LOCATION:

- As follow-up to response to question 15.06.05-30, demonstrate that deborated condensate accumulated in one or more loops (SG plena, loop seals, cold legs, downcomer) experiencing a complete or partial depravation of SI will not pose a recriticality threat to the U.S. EPR if transported towards the core due to natural circulation restart to identify and consider limiting conditions, assumptions, and scenarios in terms of condensate accumulation in individual loops and associated regions as well as transportation mechanisms involving possible restart in multiple primary loops.
- The dynamics of reboration of the crossover pipe in any idle loop prior to restart should be explained and justified.
- If the cold leg pipe break is below the elevation of the impeller discharge there does not appear to be a mechanism for backfill of the crossover pipe.
- Explain which of the postulated scenarios identified in the response to question 15.6.06.05-30 provides the greatest challenge to core recriticality and explain why.

RAI 403, Question 15.06.05-62 Proposed Response

SUMMARY OF PROPOSED RESPONSE:

- Discussion of various SI and EFW scenarios
  - Discuss the industry test setups which correlate to the various scenarios
  - Discuss the phenomena which are independent of SI/EFW availability and how they successfully prevent recriticality
- Discussion of intermittent circulation
  - Discuss the process of reboration
  - Discuss the confirmatory tests and analyses
  - Discuss probabilities for limited reboration from intermittent circulation

RAI 403, Question 15.06.05-62 Proposed Response

- SI Scenarios
  - Configurations leading to limiting scenarios:
    - **When 1 train is out for maintenance the LHSI cross-connects are open**
      - Loop 1 and loop 2 are connected
      - Loop 3 and loop 4 are connected
    - **One EBS pump supplies two loops.**
      - EBS train 1 supplies loop 1 and loop 2
      - EBS train 2 supplies loop 3 and loop 4
  - The most limiting SI scenario, which would deprive two loops of SI and EBS: SF/PM on EDG 1 and EDG 2

- EFW Scenarios
  - One EFW train per EDG
  - Most limiting EFW scenario per loop : No SF or PM
    - **An unfed SG could reduce the amount of condensate generated <u>in that loop</u>**
  - Total condensate = System Energy – Energy out the break
    - **Prescribed cooldown rate is independent of the number of generators**
    - **Total condensate remains unchanged**

- Most limiting combined scenario: PM on EDG 1, SF on loop 2 SI pump
  - Note: RELAP analyses were not used to define slug size

RAI 403, Question 15.06.05-62 Proposed Response

- Phenomena Independent of ECCS configuration and EFW availability:
  - One loop starts natural circulation first
  - Restart of NC is significantly delayed in other loops
  - The boron concentration of the slug increases due to water entrainment from the hot to cold side of the SG
  - The intermittent circulation prior to stable natural circulation significantly raises the concentration of the slug
  - No accumulation of low-boron water in the SG inlet plena
  - System inventory refill – Same amount of ECCS delivered
  - Backflow to the crossover pipe
  - Downcomer mixing

RAI 403, Question 15.06.05-63

CONDENSATE AMOUNT AND LOCATION:

- As follow-up to response to question 15.6.06.05-36, present the available experimental database pertaining to boron dilution relevant to the U.S. EPR boron dilution analysis. The staff considers limiting the database to Primärkreislauf-Versuchsanlage (PKL) Test F1.1 only, to be insufficient.
- Explain why experimental observations and in particular PKL findings can be applied to justify the assumptions and conditions used in the analysis of the U.S. EPR under critical LOCA conditions of interest.
- Explain how the entire matrix of relevant tests conducted at PKL or other facilities validates the assumptions in the boron dilution analysis including: (1) restart of natural circulation in only one loop at a time, (2) initial restart in a loop without SI, (3) justification of the boundary conditions assumed in the CFD mixing analysis of core inlet boron concentration and in particular substantiation of the slug injection rate deduced from the PKL experiments.

RAI 403, Question 15.06.05-63 Proposed Response

SUMMARY OF PROPOSED RESPONSE:

- **Description of tests, analyses, and their results**
  - **PKL:** Refill processes and restart of natural circulation phenomena
  - **UPTF-TRAM:** Mixing processes of the dilute water slug in the cold-leg piping, the RPV downcomer, and the lower plenum after restoration of natural circulation
  - **Etc.**
- **PKL justification**
  - **ANP-10288, Boron technical report and Q 36 describe conclusions from the E series and F1.1 PKL tests**
  - **Applicability – Answer to Q 36 was for the E series and F1.1 PKL tests**
    - Geometry
    - Systems
  - **F1.1 test was only specified to show that similar conditions in the F1.1 test and our S-RELAP5 analysis showed the same phenomena**
- **Star-CD CFD Justification and NC Restart Rate Comparison**
  - **Applicability: Analysis specific to a representative EPR**
  - **S-RELAP5 dilution parameter comparison**

RAI 403, Question 15.06.05-63
Proposed Response

- Star-CD CFD analyses were performed for a representative EPR to assess the mixing between the deborated water of the moving slug, the highly borated water of the SI and EBS, and the borated water in the cold leg, downcomer, and lower plenum.

	Slug Size (ft^3)	Concentrations		Restart Rate (lbm/s)	Pressure (psia)	Temperature (ºF)
		SI (ppm)	EBS (ppm)			
Star-CD Case 3 and 4	388 Two slugs: 639, 480	2700	11750	480	290	392
U.S.EPR	-	3235	13335	200-450	200-500	400

- U.S. EPR Volumes:
  - Crossover Pipe: 157 ft^3
  - Pump: 138 ft^3
  - Cold Leg: 156 ft^3
  - Crossover Pipe/Pump Constrained Volume: 171 ft^3
  - Xover + RCP + CL Total: 493 ft^3

RAI 403, Question 15.06.05-64

LIMITING MIXTURE VOLUME WITH TIME

> The analysis of boric acid build-up and precipitation was also requested by the staff with the break located on the top of the discharge leg piping, since the analysis assumed a less limiting location which was the double-ended guillotine break. With respect to two-phase mixture level, which was also assumed to be based on a fixed volume, this assumption was not justified and may not be conservative since the volume occupied by the two-phase mixture is increasing with time following the start of reflood. Provide an analysis of the boric acid build-up with a break on the top of the pipe and the loop seal vertical section completely filled with two-phase fluid. Justify and identify the limiting conditions and assumptions for this analysis. Include the locked rotor k-factor in computing loop resistance and its' influence on level depression in the core. Show the mixture volume with time.

RAI 403, Question 15.06.05-64 Proposed Response

LIMITING MIXTURE VOLUME WITH TIME – SUMMARY OF PROPOSED RESPONSE:

- **Discuss the use of a fixed volume equal to the volume of liquid in the concentrating region following reflood volume**
- **Provide S-RELAP5 volume versus time results justifying the conservatism of the fixed volume approach**
- **Provide quasi-steady, static-balance model volume versus time results justifying the conservatism of the fixed volume approach**
- **Provide calculation showing minimum time to loop seal reformation**

RAI 403, Question 15.06.05-64 Proposed Response

- **Fixed Value Concentrating Volume**
  - Liquid volume within the mixing region is extracted at the end of reflood
  - Reflood is defined as the period of time from the end of refill until the fuel cladding temperature transient is terminated
  - Core mixing volume extracted from highest PCT case (based on ANP-10278P, Rev. 0)
- **S-RELAP5 Volume Versus Time**
  - Sensitivity studies showing the effects of decay heat, *locked rotor,* axial power shape on the core mixing volume confirm that the constant concentrating volume used is consistent with a conservative boron precipitation calculation
  - The fixed volume value is shown to be conservative for all perturbations of post-reflood volumes

RAI 403, Question 15.06.05-64 Proposed Response

End of Reflood Concentrating Regions Liquid Volumes*

Includes Lower Plenum, Core Regions, Bypass Regions, and Upper Plenum Up To Hot Legs

[ ]

EPR™ by AREVA

RAI 403, Question 15.06.05-64 Proposed Response

5-Region Concentrating Volume vs. Time: Locked Rotor Comparision
Equilibrium Cycle, Case 24

[ ]

RAI 403, Question 15.06.05-64 Proposed Response

▷ Quasi-Steady Static Balance Volume Versus Time

- ◇ **Estimate the core collapsed level as a function of time using quasi-steady, static-balance model.**
  - Model can be applied only during a quasi-steady time period
  - System analysis can be used to evaluate the system liquid volumes prior to that period
- ◇ **Apply locked rotor resistance to the calculation.**
- ◇ **Apply logic to define the number of loops venting steam.**
- ◇ **Select model parameters that produce results consistent with S-RELAP5 during this early post-reflood period – out to 2 hours.**
- ◇ **Compute the boron concentration versus time**
- ◇ **Estimate the time to reach the precipitation limit.**

RAI 403, Question 15.06.05-64
Proposed Response

▷ **COLLAPSED CORE LEVEL USING LTCC MODEL**

[ ]

RAI 403, Question 15.06.05-65

AXIAL POWER SHAPE SENSITIVITY:

- Show the sensitivity of the timing for boric acid precipitation to axial power shape. A bottom peak will generate more vapors in the core and cause an earlier precipitation time.

AXIAL POWER SHAPE SENSITIVITY – SUMMARY OF PROPOSED RESPONSE:

- Provide scatter plot of concentrating times versus axial shape index (ASI)
- Provide ASI sensitivity results

RAI 403, Question 15.06.05-65 Proposed Response

End of PCT Transient Concentrating Volume vs. Axial Shape Index

[ ]

RAI 403, Question 15.06.05-65
Proposed Response

5-Region Concentrating Volume vs. Time: Axial Shape Comparision
Cycle 1 Case 36

[ ]

RAI 403, Question 15.06.05-66

HOT LEG INJECTION ENTRAINMENT:

- Since the hot side injection at 60 minutes will be entrained into the hot legs and inlet plenum, there is no assurance that sufficient water will enter the core in a timely manner to prevent boron precipitation. As water enters the steam generators slug flow can increase the loop resistance and upper plenum pressure which can limit the growth of the mixing volume and lower the reflood rate. Stating the water will eventually drain back into the core is inappropriate. Provide the model and results to demonstrate that hot side injection is not entrained into the loops causing a potential inadequate core cooling conditions. Describe the entrainment model and show the results demonstrating that hot leg injection is effective in preventing boron precipitation.

RAI 403, Question 15.06.05-66 Proposed Response

HOT LEG INJECTION ENTRAINMENT - SUMMARY OF PROPOSED RESPONSE:

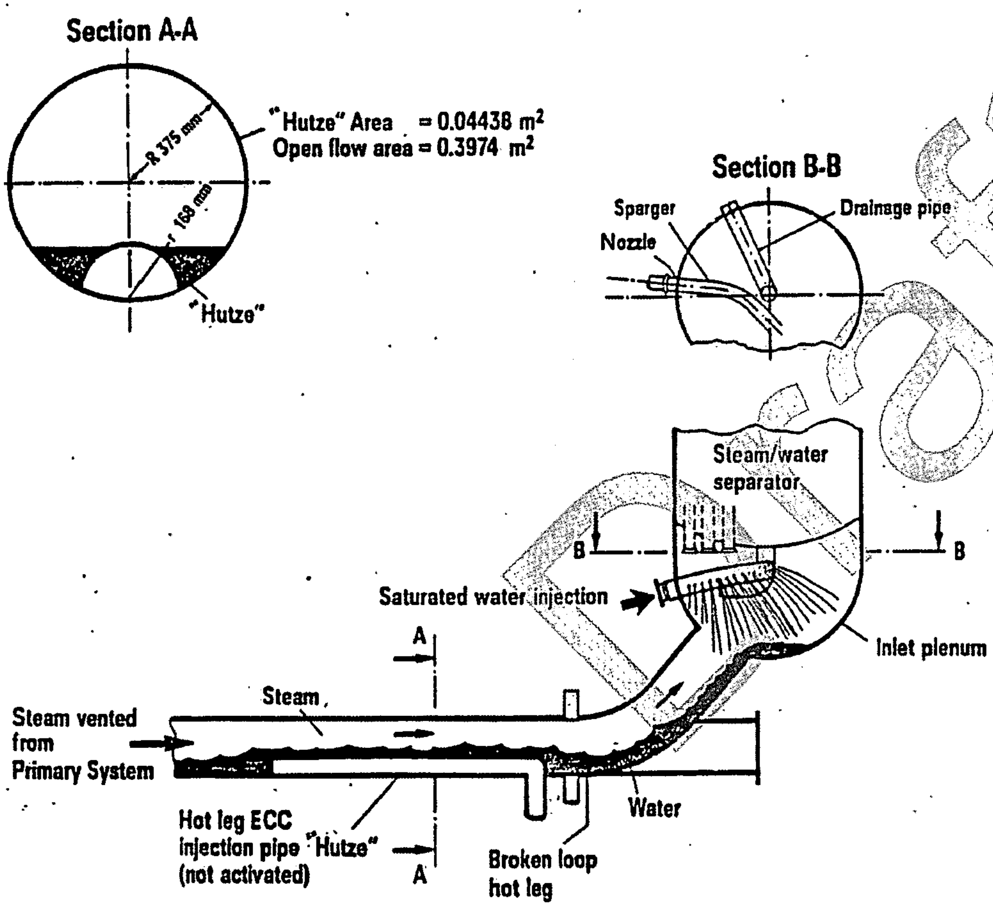
- **Describe standard entrainment models used in S-RELAP5 analyses**
- **Describe MPR correlation**
  - **Test applicability**
  - **Comparison to other correlations**
- **Perform S-RELAP5 RLBLOCA analyses with an increase in the decay heat to simulate ANS 1973 x 1.2**
- **Perform S-RELAP5 analyses using the MPR correlation**
  - **Compare results**
- **Summarize hot leg injection presentation from March audit**
  - **Induced mixing flows**
  - **Test data showing penetration**
  - **CFD showing penetration**

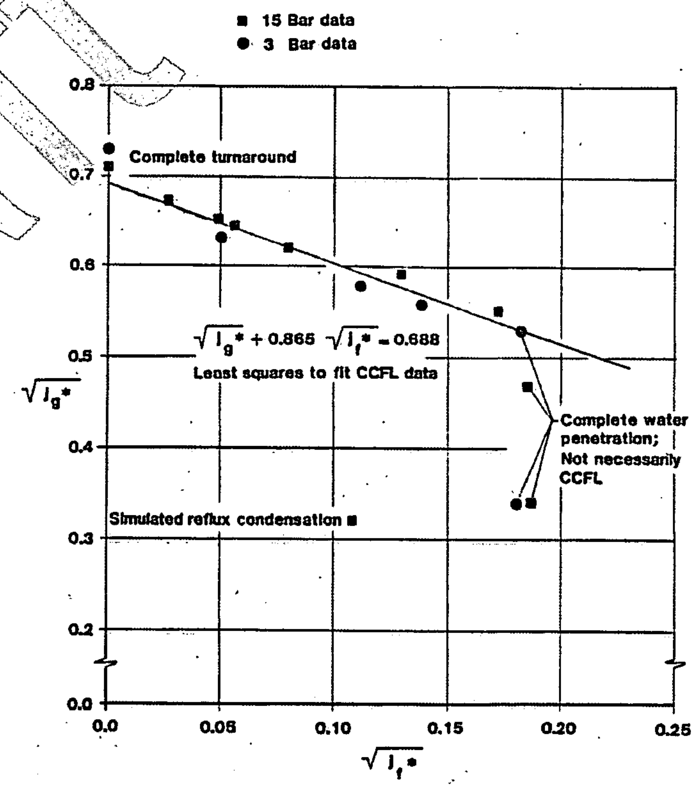
RAI 403, Question 15.06.05-66 Proposed Response

- S-RELAP5 Entrainment Model

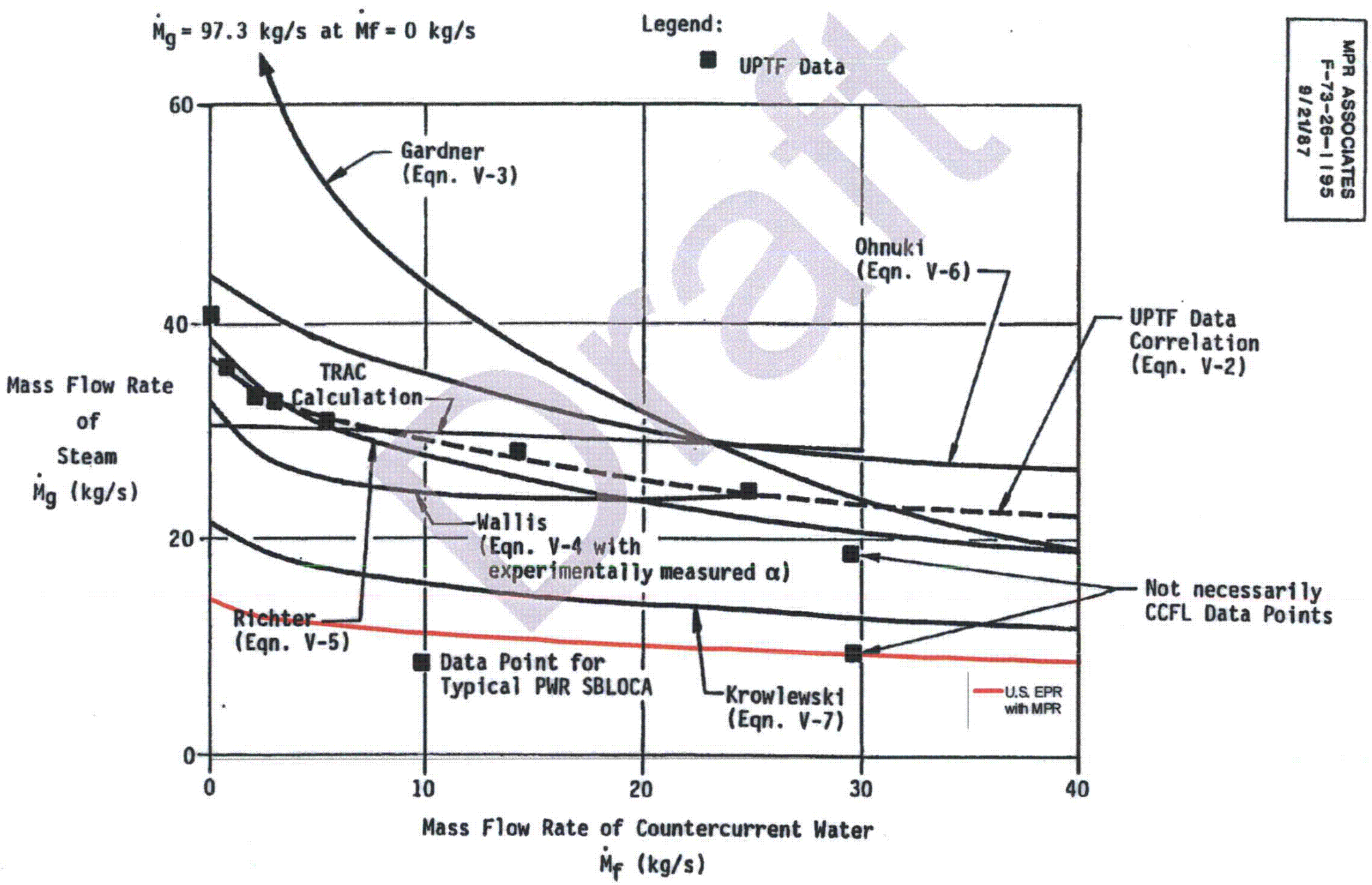
[ ]

RAI 403, Question 15.06.05-66 Proposed Response

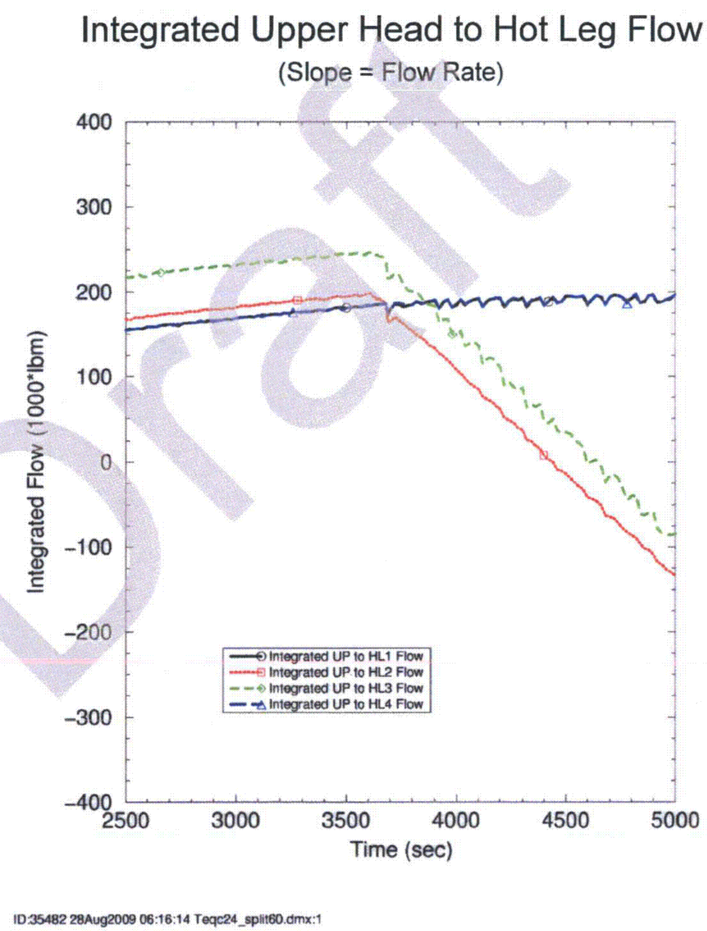




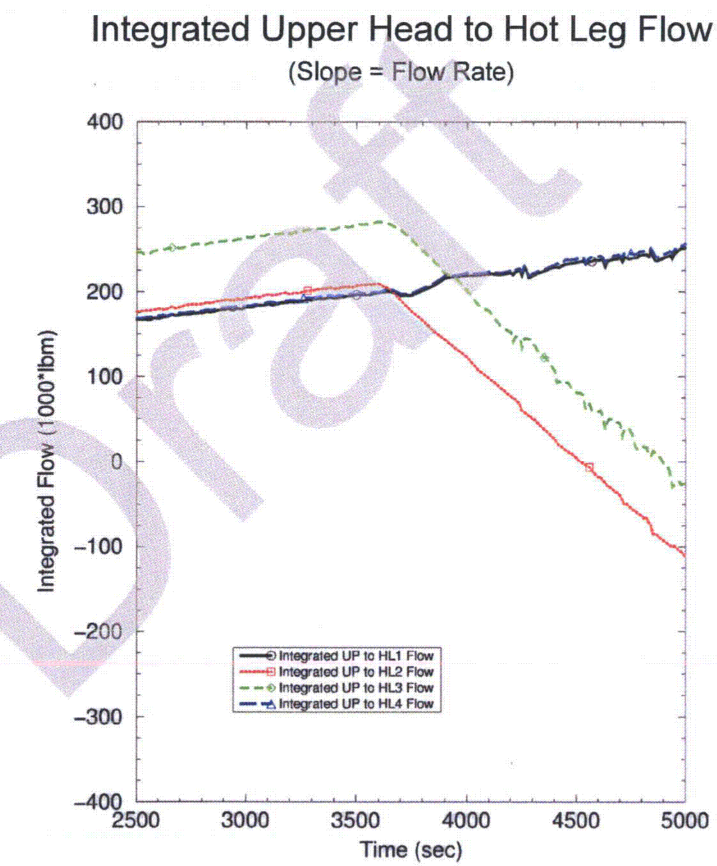
RAI 403, Question 15.06.05-66 Proposed Response



RAI 403, Question 15.06.05-66 Proposed Response



RAI 403, Question 15.06.05-66 Proposed Response



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RAI 403, Question 15.06.05-66
Proposed Response

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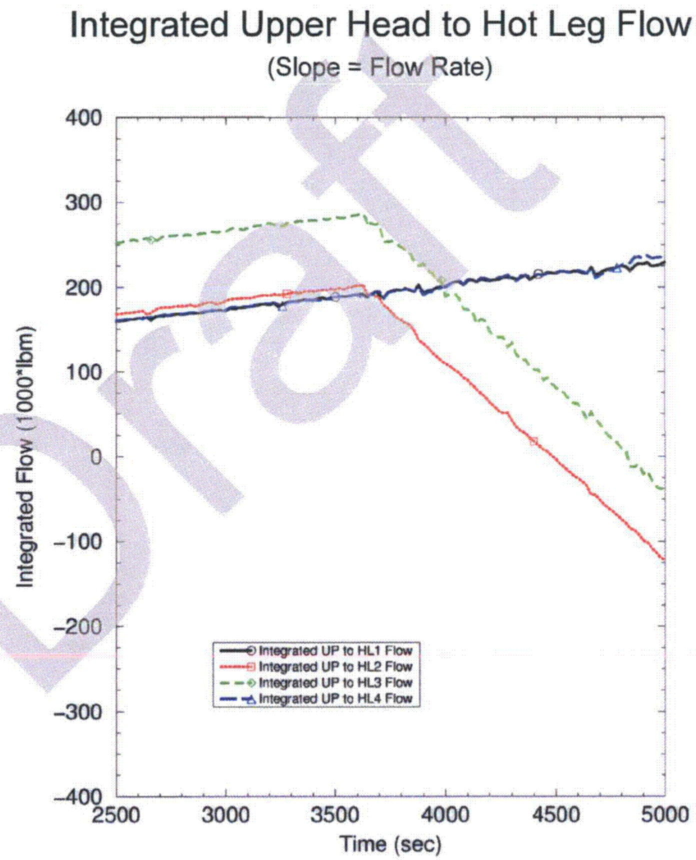

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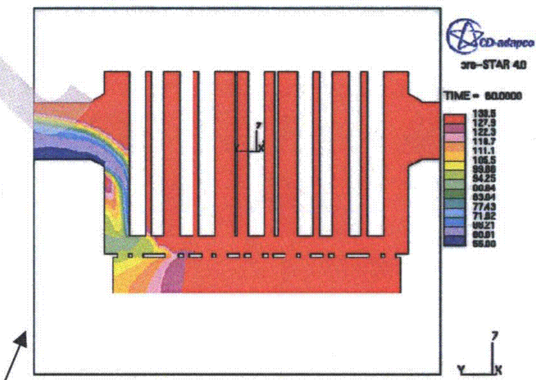
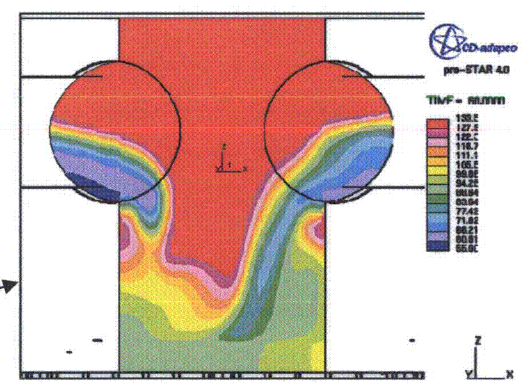
RAI 403, Question 15.06.05-66
Proposed Response

- **Hot Leg Injection:**
  - **Efficient mixing occurs in the reactor vessel**
  - **Recirculation takes place along entire length of core**
  - **Because of efficient mixing in core, steam production is suppressed**
- **Tests and CFD confirm core mixing and steam suppression**
  - **SCTF CORE-III Combined Injection Reflood Tests**
  - **CCTF Core-II Test**
  - **UPTF-TRAM**
  - **STAR-CD CFD Upper Plenum Mixing**
    - Simulation of UPTF Test 6a
    - U.S. EPR case
      - U.S. EPR upper plenum fluid temperature distribution
      - U.S. EPR core fluid temperature distribution





RAI 403, Question 15.06.05-67

S-RELAP5 LEVEL SWELL VALIDATON:

- The level swell validations described for S-RELAP5 were pertinent to large break loss of coolant accident (LBLOCA) short term conditions during the periods of significant entrainment. No comparisons of the models to long term level swell when entrainment subsides were provided. Show validation of the level swell model against low pressure level swell data such as those, for example but not limited to, the Achilles and Thetis low pressure level swell tests. For clarification, it is understood that an under predicted void fraction value in the upper plenum compensated will significantly increase the liquid mass within the mixing volume.

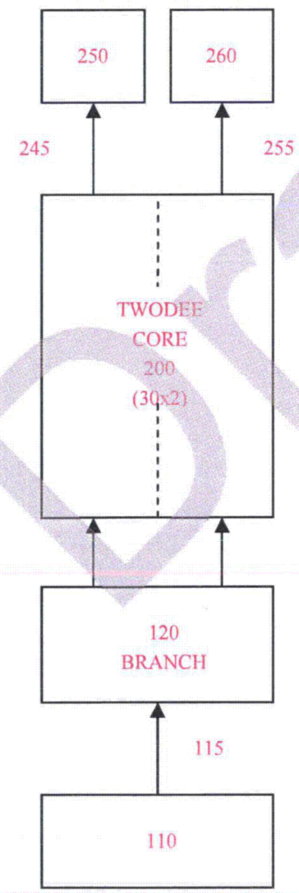
RAI 403, Question 15.06.05-67 Proposed Response

S-RELAP5 LEVEL SWELL VALIDATON – SUMMARY PROPOSED RESPONSE

- **Develop S-RELAP5 model of the ACHILLES Test A1L066**
- **Compute collapsed liquid and mixture levels for comparison to reported results.**
- **Test features:**
  - 69-rod electrically heated rod bundle with stepped sine axial power
  - Low pressure (1.2 bar),
  - Constant power (80 kW)
  - Water levels are measured during boil-off
- **Used standard LOCA analysis S-RELAP5 code options.**

RAI 403, Question 15.06.05-67 Proposed Response

▶ **ACHILLES PRELIMINARY NODAL MODEL FOR S-RELAP5**



RAI 403, Question 15.06.05-67 Proposed Response

▷ **ACHILLES LEVEL SWELL COMPUTED BY S-RELAP5 (Preliminary)**

[ ]

RAI 403, Question 15.06.05-67 Proposed Response

▶ PRELIMINARY VALIDATION CONCLUSION

- ◇ Further optimization of the S-RELAP5 computation is expected to produce collapsed and two-phase mixture levels consistent with the ACHILLES A1L066 test data at low pressure.

RAI 403, Question 15.06.05-67 Proposed Response

▷ PRELIMINARY VALIDATION CONCLUSION

- Collapsed and two-phase mixture levels computed by S-RELAP5 are consistent with test data at low pressure.

RAI 403, Question 15.06.05-68

MAXIMUM INJECTION CONCENTRATION:

- The average concentration of all of the boric acid sources was calculated to be 1,929 ppm based on their volumetric contents and boric acid concentrations. Since liquid from the various sources is injected into the reactor coolant system (RCS) at individual flow rates and concentrations over different periods of time, setting the concentration of the fluid entering the core equal to the volume-averaged value is not justified.
- If the EBS is injecting at its maximum rate, this concentration at this flow rate can be conservatively postulated to enter the core region along with the remainder needed to supply the core boil-off rate at the in-containment refueling water storage tank (IRWST) concentration. The excess spills to containment. Show the timing to boric acid precipitation under these specific flow conditions using all other limiting conditions suggested/questioned above.

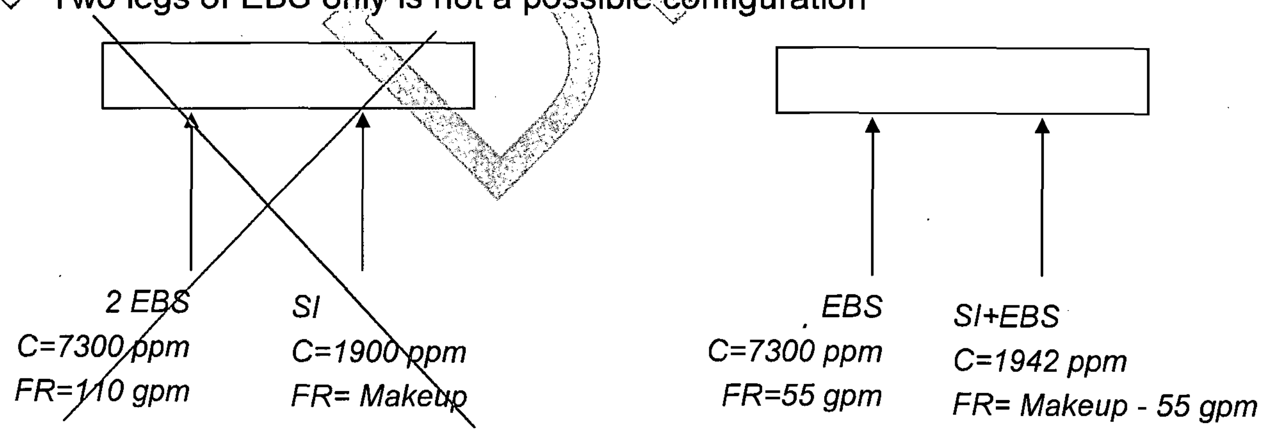
RAI 403, Question 15.06.05-68 Proposed Response

MAXIMUM INJECTION CONCENTRATION-SUMMARY OF PROPOSED RESPONSE:

- Calculation of Flow Rate Weighted Concentrations
  - Boron precipitation results with these concentrations
- Evaluation of EBS/SI system configuration to determine maximum EBS, minimum SI concentration
  - Boron precipitation results with this concentration and assuming:
    - No mixing in downcomer
    - One train of EBS, in non-SI loops, goes directly to core and boils at 212°F
    - SI loops provide just enough flow to maintain core volume

RAI 403, Question 15.06.05-68 Proposed Response

- Mixed Volume Concentration Used: 1929 ppm
- Flow Rate Weighted Concentrations
  - 0 EBS + 2 (MHSI+LHSI): 1900 ppm
  - 1 EBS + 2 (MHSI+LHSI): 1949 ppm
  - 2 (EBS + MHSI + LHSI): 1998 ppm
- Maximum EBS, Minimum SI
  - Diagrams provided for configurations with possible SF/PM scenarios
  - Two legs of EBS only is not a possible configuration



RAI 403
LONG TERM CORE T-H BEHAVIOR

▷ PURPOSE

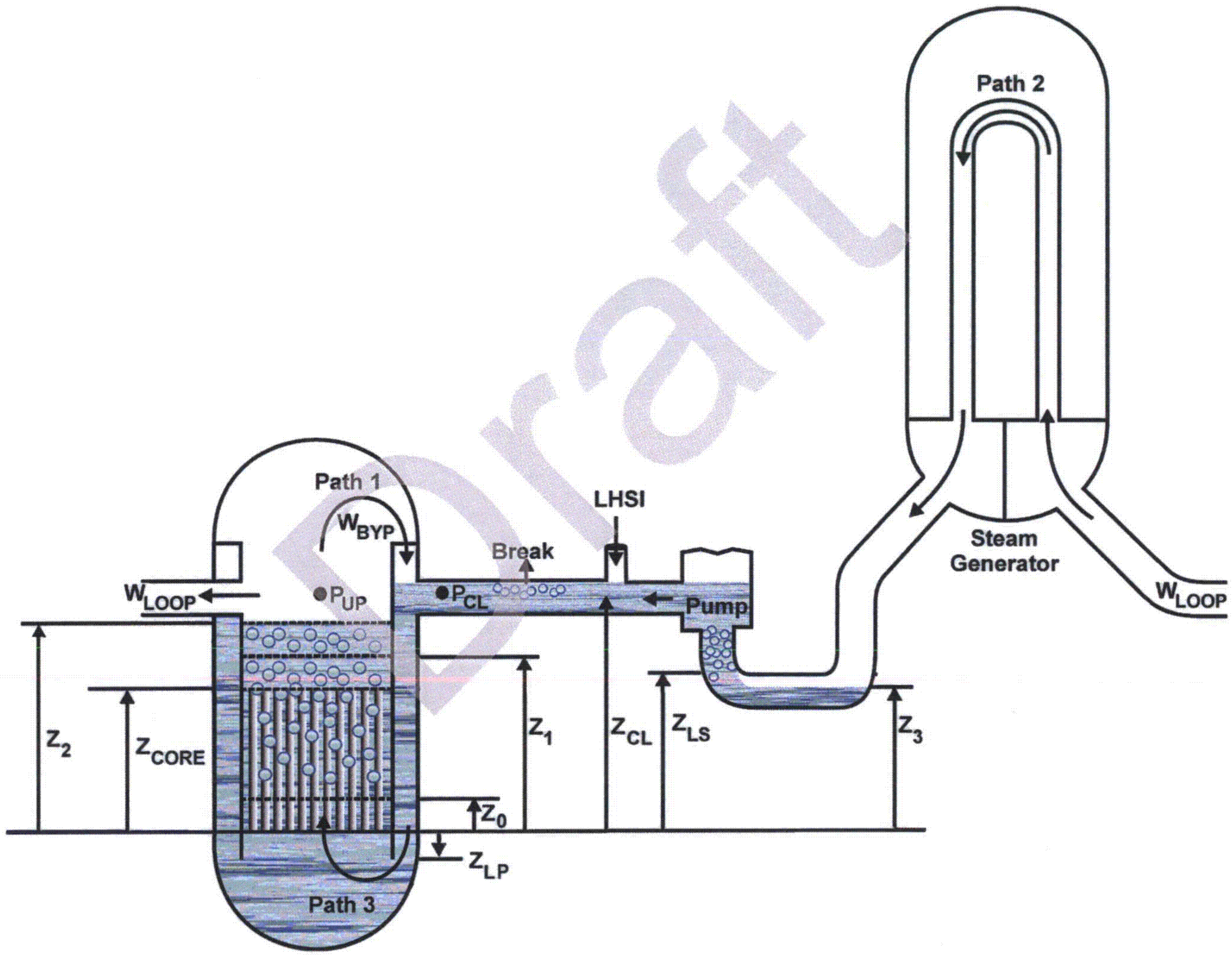
- ◇ **Review LTCC Modeling Changes Needed for RAI Responses**
  - Modeling Enhancements
  - Nodal solution for two-phase flow
  - Define number of vented loops
- ◇ **Review Proposed Approach and/or Preliminary Responses for Questions (69-77)**

LONG TERM CORE T-H BEHAVIOR
RAI 403

▶ **MODELING ENHANCMENTS FOR RAI RESPONSE**

[ ]

LONG TERM CORE T-H BEHAVIOR
RAI 403



LONG TERM CORE T-H BEHAVIOR
RAI 403

▷ TWO-PHASE MIXTURE LEVEL NODAL SOLUTION

RAI 403, Question 15.06.05-77 Proposed Response

TYPICAL RESULT -- FINAL CASE

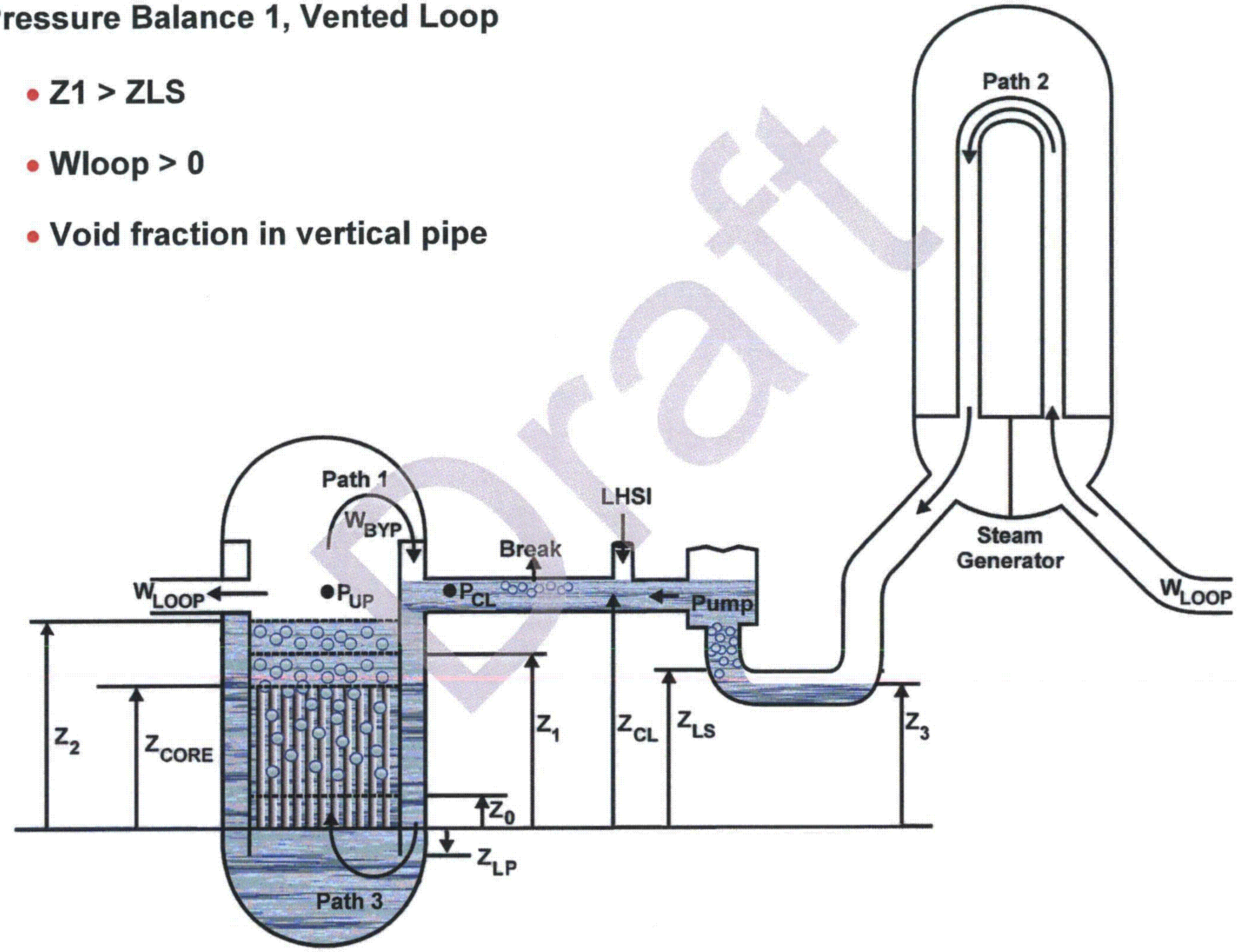
LONG TERM CORE T-H BEHAVIOR
RAI 403

▷ **SELECT NUMBER OF VENTED LOOPS AT EACH DECAY POWER**

[ ]

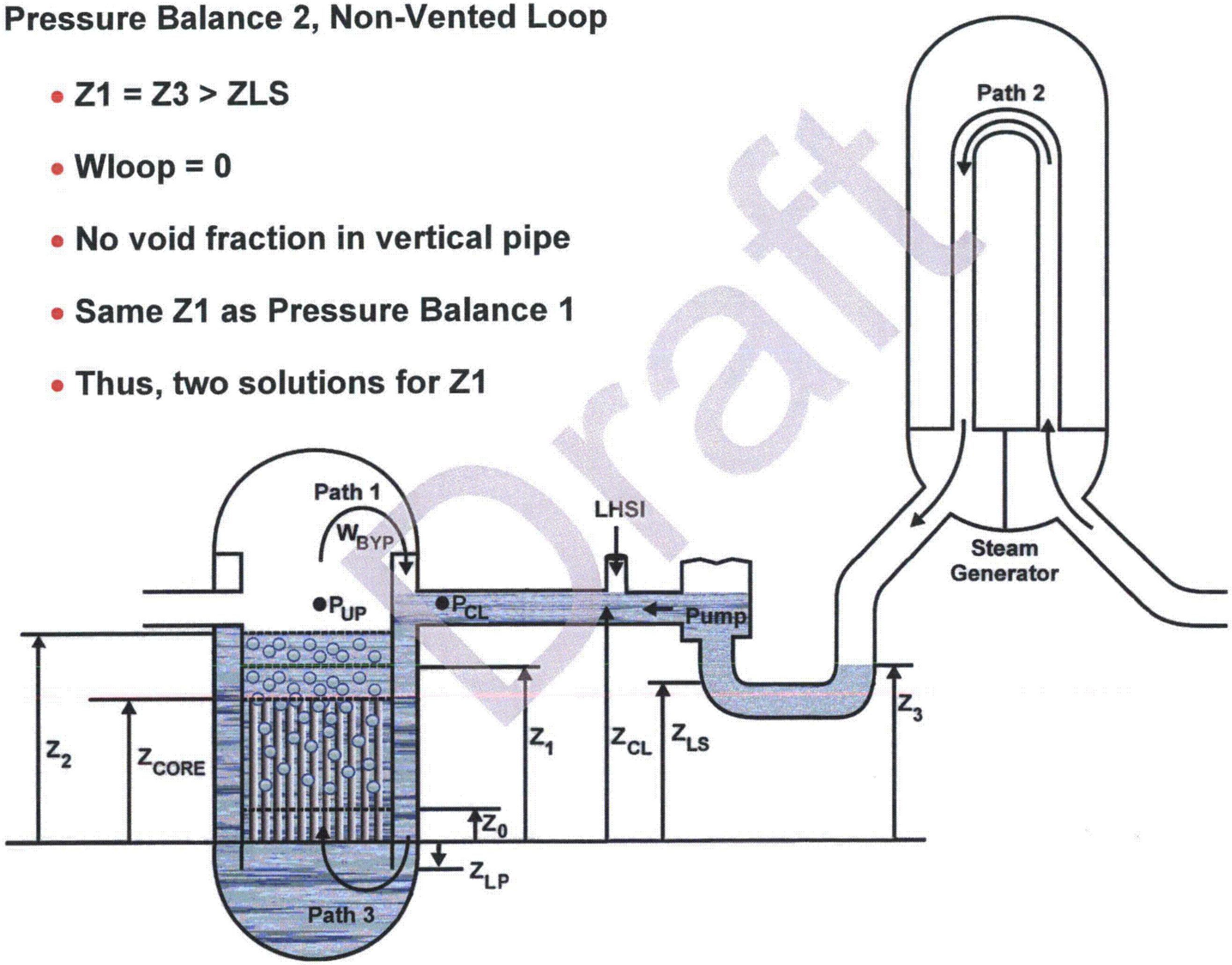
LONG TERM CORE T-H BEHAVIOR RAI 403

- Pressure Balance 1, Vented Loop
  - Z1 > ZLS
  - Wloop > 0
  - Void fraction in vertical pipe



LONG TERM CORE T-H BEHAVIOR RAI 403

- Pressure Balance 2, Non-Vented Loop
  - Z1 = Z3 > ZLS
  - Wloop = 0
  - No void fraction in vertical pipe
  - Same Z1 as Pressure Balance 1
  - Thus, two solutions for Z1



LONG TERM CORE T-H BEHAVIOR
RAI 403

▷ VENTED LOOP SELECTION EXAMPLE

LONG TERM CORE T-H BEHAVIOR
RAI 403

▷ OVERALL SUMMARY RESPONSE (Questions 69-77)

- ◇ The loop seal elevation in the US EPR™ is only 30 mm below the top of active fuel.
- ◇ The minimum core collapsed level remains near the elevation of the loop seal with loop seal venting criteria.
- ◇ Severe depression of core level not possible with ample safety injection
- ◇ Boiling in the core assures coverage of the fuel by a two-phase mixture.
- ◇ The fuel rods are well cooled in the post-reflood period.

RAI 403, Question 15.06.05-69

SELECT AND VALIDATE TWO-PHASE CORRELATION

- Follow-up to 241, Question 15.06.05-51
- The response to Question 15.06.05-51 includes reference to three two-phase correlations: Zuber-Findlay, Cunningham-Yeh, and Wilson. Explain their applicability and accuracy under post LOCA low pressure conditions. If these correlations are not based on low pressure test data consider validation of these correlations under low pressure atmospheric conditions, or use of alternate methods for level swell.
- The chosen model for the evaluation of level swell should be selected based on comparisons of the proposed model to low pressure test data. As such, show the predictions of the model used in the analysis to low pressure level swell data; for example, the Achilles and Thetis low pressure data. The model in FLASH-6 (see eqs. C.2-8 through C.2-11)for level swell, for example, provides an alternate method for predicting two-phase level well that can be compared to Wilson (see Beyer, J. et al, "FLASH-6; A Fortran IV Computer Program for Reactor Plant Loss-of Coolant Accident Analysis," WAPD-TM-1249, July 1976) . The drift velocity correlation, eq. 5.189, pg 248, from Lahey and Moody, "The Thermal Hydraulics of a Boiling Water Nuclear Reactor," American Nuclear Society, Second edition, 1993, provides an additional model for level swell. These models can be compared to low pressure level swell data to choose the appropriate method and validate the approach and its particular use in the application. Sensitivity studies on the key model parameters should also be provided.

RAI 403, Question 15.06.05-69 Proposed Response

TWO-PHASE CORRELATION – SUMMARY PROPOSED RESPONSE

- Cunningham-Yeh Correlation Selected for Analysis
- Validate with Hitachi level swell data.
  - Full length (12 ft) 7x7 electrically-heated test assembly
  - Sine axial power shape
  - Atmospheric pressure
- Following plot shows good agreement between data and computation using Cunningham-Yeh.

RAI 403, Question 15.06.05-69
Proposed Response

Hitachi Level Swell Experiment, Preliminary Validation Comparison

[ ]

RAI 403, Question 15.06.05-70

BYPASS FLOW RESISTANCE

- Follow-up to 241, Question 15.06.05-51

- The calculations in the response to Question 15.06.05-51 take credit for bypass identified as Path 1 in Figure 15.06-51-1. Since it is difficult to predict the gap sizes and the dimensional changes as the vessel and core barrel cool down, explain why credit for bypass is appropriate and conservative. Justify the minimum gap resistance value used in the analysis.

RAI 403, Question 15.06.05-70 Proposed Response

BYPASS FLOW RESISTANCE – SUMMARY PROPOSED RESPONSE

- Upper plenum to cold leg bypass is an EPR™ design feature.
- The resistance is appropriate to include.
- Not a question of conservative or non-conservative.
- Resistance is a model input parameter within an expected design range.
- Two-phase mixture always covers fuel regardless of choice in resistance.

▷ BYPASS RESISTANCE

- **Resistance range defined from vessel hydraulic analysis.**
  - Nominal dimensions produce a higher K/A2 = 303 1/ft4
  - Maximum dimensions produce a lower K/A2 = 50 1/ft4
- **Steaming (power) transition occurs when loop steam flow rate goes to zero.**

$$w_{g\,Z_{1,MIN}} = \sqrt{\frac{2\rho_g \rho_{l_{CL}} \left(Z_{CL} - Z_{LS}\right) g}{\left(K/A^2\right)_{BYP}}}$$

- **High resistance puts minimum collapsed level (Z1) at low power, smaller level swell**
- **Low resistance puts minimum collapsed level (Z1) at higher power, more level swell.**
- **Infinite resistance does not produce a transition.**
- **Following plot shows change in timing of minimum but core remains covered.**

RAI 403, Question 15.06.05-70 Proposed Response

- ▷ **BYPASS RESISTANCE**

[ ]

RAI 403 Question 15.06.05-71

AXIAL POWER DISTRIBUTION

- ◇ The axial power distribution is taken as uniform. The staff believes that a top skewed power distribution will result in a lower two-phase mixture level due to less void swell. Quantitatively show the sensitivity of the two-phase mixture level to a top skewed axial power distribution under most limiting physically realizable top peak profile.

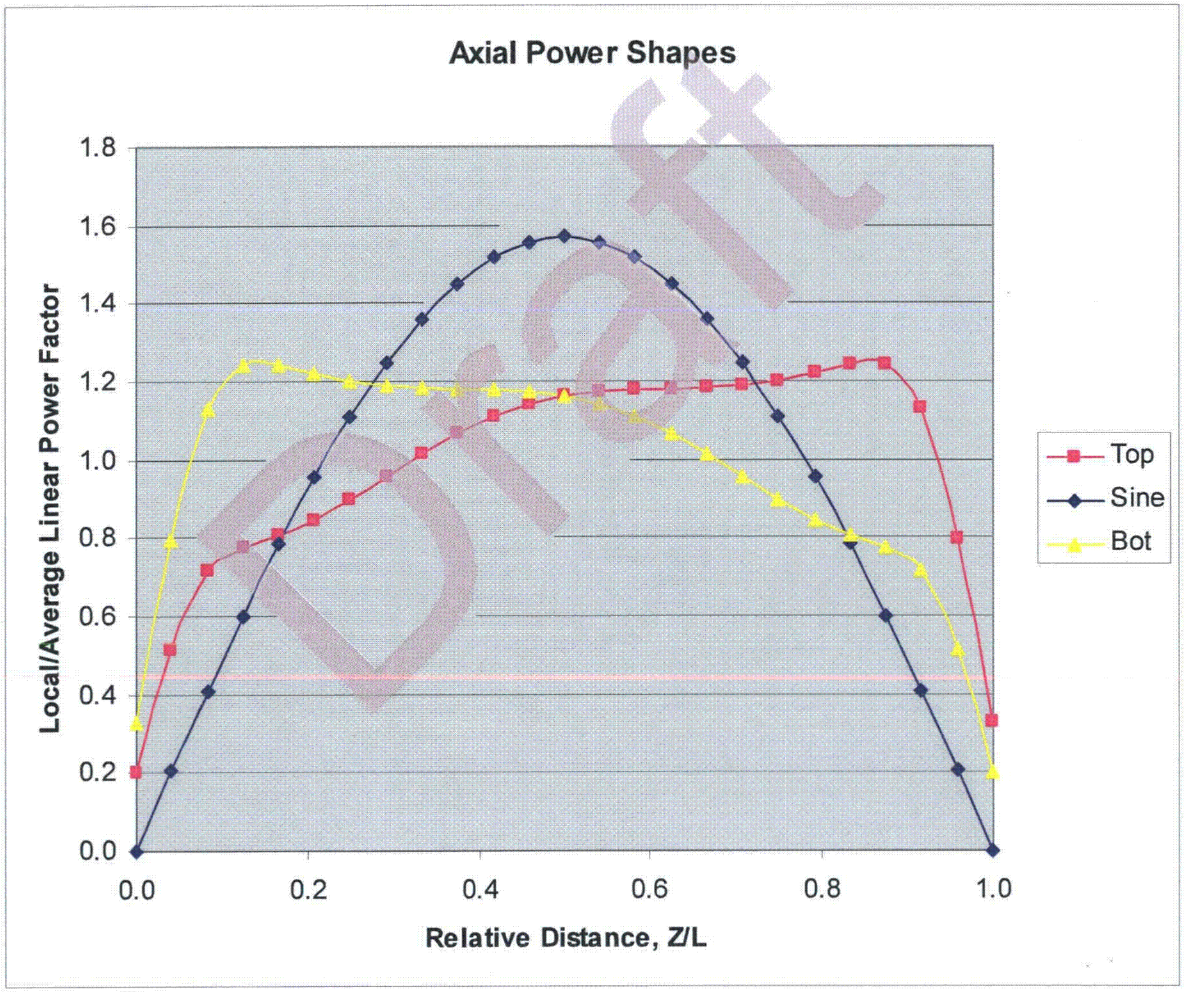
RAI 403 Question 15.06.05-71 Proposed Response

AXIAL POWER DISTRIBUTION – SUMMARY PROPOSED RESPONSE

- Perform the analysis with bottom, sine, top and uniform axial power shapes
- Show that top peaked produces lowest swell but impact is small.
- Core is always covered by a two-phase mixture regardless of axial power shape

RAI 403 Question 15.06.05-71
Proposed Response

AXIAL POWER SHAPES



EFFECT OF AXIAL POWER DISTRIBUTION

RAI 403, Question 15.06.05-72

LOOP SEAL WATER TEMPERATURE

- Explain the sensitivity of the two-phase mixture level in the core to loop seal water temperature. What would happen to the two-phase mixture level in the core if the water temperature in the loop seal reaches safety injection (SI) temperature with saturated conditions remaining in the downcomer?

RAI 403, Question 15.06.05-72 Proposed Response

LOOP SEAL WATER TEMPERATURE – SUMMARY PROPOSED RESPONSE

- ◇ **The loop seal (cold leg) water temperature affects gravity head and the resulting core collapsed level (Z1).**
- ◇ **The impact of the cold leg (loop seal) water temperature is small for the US EPR™ design.**
- ◇ **The level swell produces a two-phase mixture level (Z2) above the top of the active fuel.**

RAI 403, Question 15.06.05-72 Proposed Response

LOOP SEAL WATER TEMPERATURE

[ ]

RAI 403, Question 15.06.05-73

DEPRESSION OF WATER IN LOOP SEAL

- Follow-up to 241, Question 15.06.05-51
- What degree of depression of liquid level below the top of the loop seal horizontal piping (elevation ZLS in Figure 15.06.05-51-1 in response to Question 15.06.05-51) is needed to vent steam through the loop seal to prevent further pressure buildup and corresponding level suppression in the core? Provide a conservative estimate of the degree of depression of the liquid level in the horizontal section of the loop seal pipe to provide a steam relief path. What is the two-phase mixture level in the core if the water level in the loop seal (Z3 in Figure 15.06.05-51-1 in response to Question 15.06.05-51) is assumed at the middle or bottom of the horizontal portion of the loop seal?

RAI 403, Question 15.06.05-73 Proposed Response

DEPRESSION OF WATER IN LOOP SEAL – SUMMARY PROPOSED RESPONSE

- **There are three modeled water levels (Z3) related to the loop seal.**
  - Pre-Transition: Z3 is an input parameter ranging from top to bottom of loop seal
  - At Transition: Z3 is at the top of the loop seal by definition, no loop flow
  - Post-Transition: Z3 is above the loop seal on the steam generator side
- **There is not a one-to-one relationship between the collapsed level (Z1) and Z3 (Pre-Transition) because of void fraction in vertical leg.**
- **Bottom of loop seal is selected as the most conservative.**
- **Following plot shows small impact of ranging Z3 from top to bottom of loop seal (Pre-Transition).**

RAI 403, Question 15.06.05-73
Proposed Response

WATER LEVEL IN LOOP SEAL

[ ]

RAI 403, Question 15.06.05-74

[Question intentionally deleted]

RAI 403, Question 15.06.05-75

WATER ELEVATION IN COLD LEG PIPE

- The analysis assumed the liquid at the center line of the cold leg at the discharge. As this is not limiting, provide the results with the break and liquid level located at the top elevation of the discharge piping. Provide the highest elevation of the SI lines downstream of the check valve connected to the discharge legs. If this elevation is above the top of the discharge leg, provide an evaluation of the two-phase mixture level in the core with the break at this highest elevation.

RAI 403, Question 15.06.05-75 Proposed Response

WATER ELEVATION IN COLD LEG PIPE – SUMMARY PROPOSED RESPONSE

- Review how the liquid elevation in the cold leg enters the static balance model.
- The cold leg water elevation (ZCL) is a model parameter.

RAI 403, Question 15.06.05-75 Proposed Response

WATER ELEVATION IN COLD LEG PIPE

- Cold Leg water elevation (ZCL) is used in the static balance and in equation that defines the transition steaming rate (power).

$$w_{g\,Z_{1,MIN}} = \sqrt{\frac{2\rho_g \rho_{l_{CL}} \left(Z_{CL} - Z_{LS}\right) g}{\left(K/A^2\right)_{BYP}}}$$

- ZCL affects timing of the transition and affects gravity head in downcomer.
  - ZCL at top moves the transition earlier in time
  - ZCL range over pipe diameter has no significant impact on water levels
  - ZCL at bottom of pipe is most conservative because of reduced head in downcomer.
- ZCL at top of pipe is used for final case per NRC request (Question 75).

WATER ELEVATION IN COLD LEG PIPE

[ ]

RAI 403, Question 15.06.05-76

VOID FRACTION IN LOOP SEAL VERTICAL SECTION

◇ Describe how the void fraction in the loop seal vertical section was calculated and justify the model.

RAI 403, Question 15.06.05-76 Proposed Response

VOID FRACTION IN LOOP SEAL VERTICAL SECTION – SUMMARY PROPOSED RESPONSE

- Void fraction is computed with drift flux model.
- Computations now use C_o = 1.05 and V_{gj} constant = 2.9 from Lahey and Moody book.
- Produces lower void fraction (more conservative) than the Zuber-Findlay parameters.
- Well known and widely used method to compute void fraction.
- While the void fraction is an important part of the static balance model, variation of typical drift flux parameters has minimal impact on the computation of collapsed level (Z1).

RAI 403, Question 15.06.05-77

REQUESTED INFORMATION AND PLOTS

- For the worst case, show the following plots: (1) axial void distribution in the vessel at the minimum two-phase mixture level; (2) core steaming rate as a function of time; (3) vapor mass flow rates in the loops as a function of time; ([4]) liquid/boric acid density in the inner vessel region when the level is at a minimum in the core; ([5]) liquid density and void fraction in the vertical section of the loop seal as a function of time; ([6]) mass flow rate through the bypass as a function of time. Provide an analytical description/write-up of the model used to compute the system response for these evaluations. Provide a copy of the computer program used to produce these results.

RAI 403, Question 15.06.05-77 Proposed Response

REQUESTED INFORMATION AND PLOTS – SUMMARY PROPOSED RESPONSE

- **Present the parameters for the worst case**
- **Present requested plots or comment on:**
  - (1) axial void distribution in the vessel at the minimum two-phase mixture level
  - (2) core steaming rate as a function of time
  - (3) vapor mass flow rates in the loops as a function of time
  - (4) liquid/boric acid density in the inner vessel region when the level is at a minimum in the core
  - (5) liquid density and void fraction in the vertical section of the loop seal as a function of time
  - (6) mass flow rate through the bypass as a function of time.
- **Provide an analytical description/write-up of the model used to compute the system response for these evaluations. Provide a copy of the computer program used to produce these results.**

RAI 403, Question 15.06.05-77 Proposed Response

▷ SELECTED FINAL (WORST) CASE

- ZCL at top of cold leg pipe (as requested by NRC per Question 75)
- Z3 prior to transition is at bottom of loop seal pipe (small decrease in Z1)
- Bypass flow resistance is the minimum (creates early minimum Z1)
- Top peaked axial power shape (least level swell, Z2)
- Subcooled water in cold leg/loop seal (small decrease in Z1)
- Saturated downcomer (least gravity head, reduces Z1)
- Saturated enthalpy at core inlet (consistent with saturated downcomer)

RAI 403, Question 15.06.05-77 Proposed Response

FINAL CASE

[ ]

RAI 403, Question 15.06.05-77 Proposed Response

Item 1 -- Core Void Fraction

RAI 403, Question 15.06.05-77 Proposed Response

Items 2, 3, and 6 -- Steam Flow Rates

[ ]

Draft

RAI 403, Question 15.06.05-77 Proposed Response

Item 4)

- Liquid/boric acid density will peak within the first couple of hours.
- Hot leg injection and other boron control measures will not allow high boron concentration late in the post-reflood period when a minimum collapsed level could occur.
- Deep suppression of the core water levels from the concentration of boron is not credible in the later post-reflood period.
- The collapsed and two-phase mixture levels are high in the early post-reflood period and the core is well covered by a two phase mixture.

RAI 403, Question 15.06.05-77 Proposed Response

Item 5 – Void Fraction in Vertical Leg, rhol=62.11 lbm/ft3

[ ]

RAI Set 403, 15.06.05-78

[Question intentionally deleted]

RAI 403, Question 15.06.05-77 Proposed Response

ADDED INFORMATION AND PLOTS

- ▷ Documentation and computer source code for this analysis will be provided to the NRC as requested.

LONG TERM CORE T-H BEHAVIOR
RAI 403

▷ **OVERALL SUMMARY RESPONSE (Questions 69-77)**

- **The loop seal elevation in the US EPR™ is only 30 mm below the top of active fuel.**
- **The minimum core collapsed level remains near the elevation of the loop seal with loop seal venting criteria.**
- **Severe depression of core level not possible with ample safety injection**
- **Boiling in the core assures coverage of the fuel by a two-phase mixture.**
- **The fuel rods are well cooled in the post-reflood period.**

Summary
RAI 403 Proposed Response

- Responses have been proposed to all questions
- Future Actions