March 9, 1993

ENCLOSURE 2

Mr. P. S. Walsh
B&W Owners Group
1700 Rockville Pike
Suite 525
Rockville, MD. 20852

Subject: Post-LOCA Reactor Vessel Recirculation to Avoid Boron Precipitation

References: A) BWNT Letter (JHT/92-186) to A. C. Thadani, dated November 7, 1991, re: Post-LOCA Boron Precipitation

B) BWOG Letter (OG-1136) to A. C. Thadani, dated February 4, 1993, re: Post-LOCA Boron Precipitation

Dear Mr. Walsh:

The purpose of this letter is to acknowledge your response to our concerns regarding the adequacy of post-LOCA recirculation for B&W nuclear plants. During a meeting on December 3, 1992, you provided us with the results of your analyses which demonstrate that gaps between the reactor outlet nozzles and the reactor internals provide an adequate backup to the primary recirculation flow path and, aside from procedure changes, you currently consider this issue to be resolved. We have reviewed the results of your analyses and we agree with your position on this matter.

Thank you for your prompt attention in addressing our concerns.

Sincerely,

/s/

Ashok C. Thadani, Director
Division of Systems Safety and Analysis
Office of Nuclear Reactor Regulation

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ENCLOSURE 3

# LONG TERM BORON DILUTION

# FOR B&W-DESIGNED PLANTS

PRESENTATION TO USNRC

ROCKVILLE, MD

12/3/92

JOHN KLINGENFUS & JIM DORMAN

B&W NUCLEAR SERVICE COMPANY

- PURPOSE OF MEETING
- BACKGROUND HISTORY
- MINIMUM TIME FOR DUMP-TO-SUMP FLOWS TO LIMIT BORON CONCENTRATION BUILD-UP
- PASSIVE HOT LEG NOZZLE GAP BORON DILUTION CALCULATIONS
- SBLOCA CONSIDERATIONS
- SUMMARY AND CONCLUSIONS

# PURPOSE OF MEETING

THE PURPOSE OF THIS MEETING IS TO PROVIDE THE NRC WITH DETAILS OF THE ANALYSES PERFORMED TO SHOW COMPLIANCE WITH 10 CFR 50.46 FOR LONG TERM COOLING BORON DILUTION FOLLOWING A POSTULATED LOCA SUCH THAT A TIMELY SER CAN BE COMPLETED.

- SUMMARIZE THE CHRONOLOGY OF THE BORON DILUTION CONCERNS FOR 177 LL FA PLANTS
- PROVIDE A SYNOPSIS OF THE CALCULATIONS PERFORMED
- IDENTIFY THE CONSERVATISMS CONTAINED IN ANALYSES
- PROVIDE AN OPEN FORUM FOR QUESTIONS

# BACKGROUND HISTORY

- AN INITIAL CONCERN WAS RAISED THAT 102% FULL POWER MAY NOT HAVE BEEN CONSERVATIVE FOR DETERMINING THE TIME PERIOD FOR RVVV LIQUID NATURAL CIRCULATION SPILL-OVER FLOWS FOLLOWING A LBLOCA EVENT.

- THE LIQUID SPILL-OVER DETERMINES THE TIME FOR OPERATOR ACTIONS TO INITIATE ONE OF THREE MODES OF ACTIVE DILUTION.

- THE ACTIVE DILUTION MODES LIMIT THE MAXIMUM BORON CONCENTRATION TO VALUES FAR BELOW THE SOLUBILITY LIMITS.

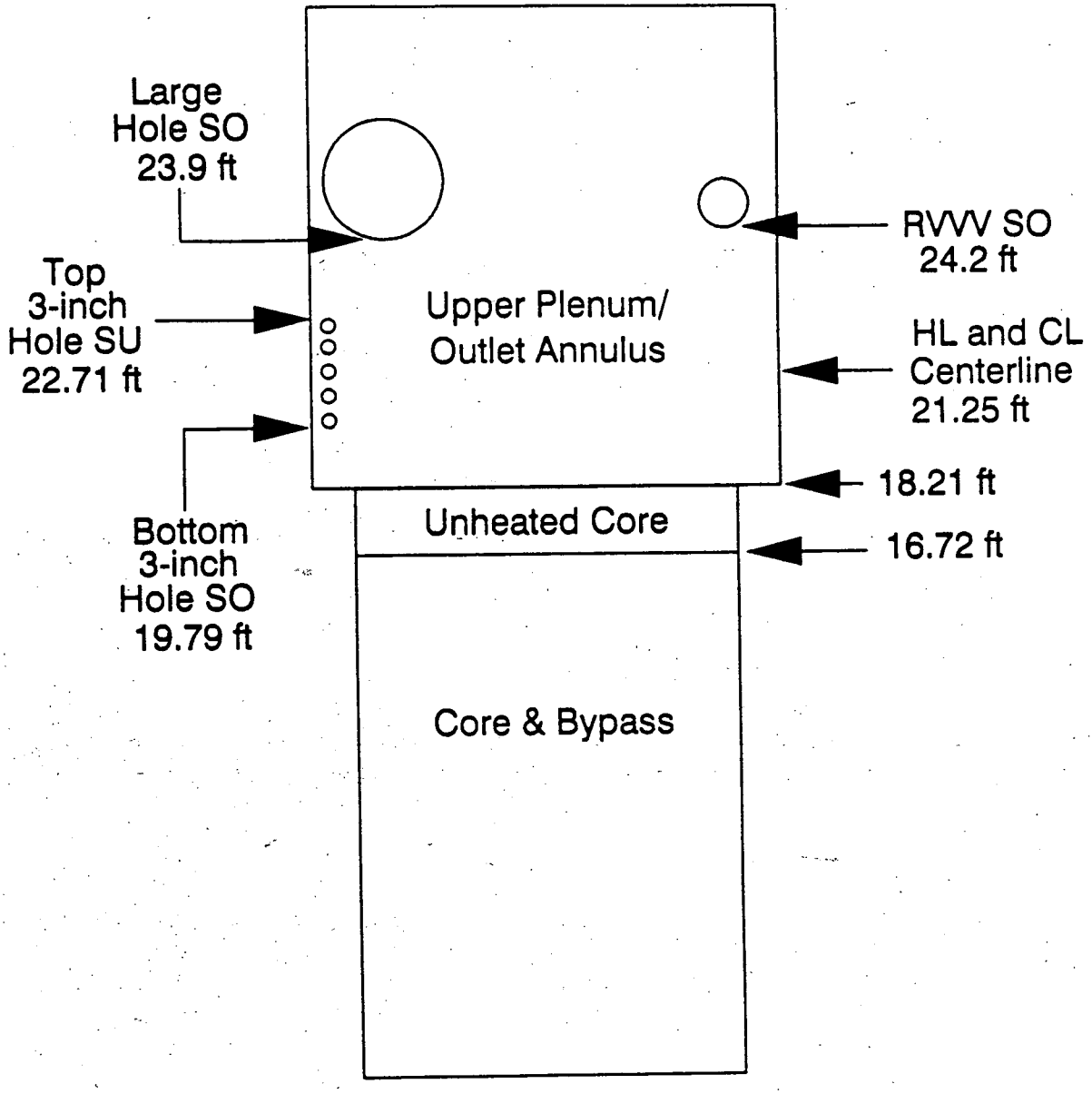
- PRELIMINARY RECALCULATION OF THE TIME AT WHICH THE OPERATOR ACTION TO INITIATE THE ACTIVE DILUTION MODES WAS PERFORMED USING A FULL RANGE OF CORE POWER LEVELS.

- THE WORST POWER LEVEL WAS DEFINED BY THE INTERSECTION OF TWO LIMITS, THE RVVV LIQUID SPILL-OVER CESSATION AND THE INTEGRATED CORE BOIL-OFF REQUIRED TO CONCENTRATE THE BORON TO THE SOLUBILITY LIMIT.

- DURING THE CALCULATIONAL REVIEW AN ADDITIONAL CONCERN WAS RAISED ABOUT THE VALIDITY OF THE FOAM2 CODE TO MODEL THE UPPER PLENUM AND OUTLET ANNULUS REGION MIXTURE LEVELS AND PREDICT THE RVVV LIQUID OVER-FLOW.

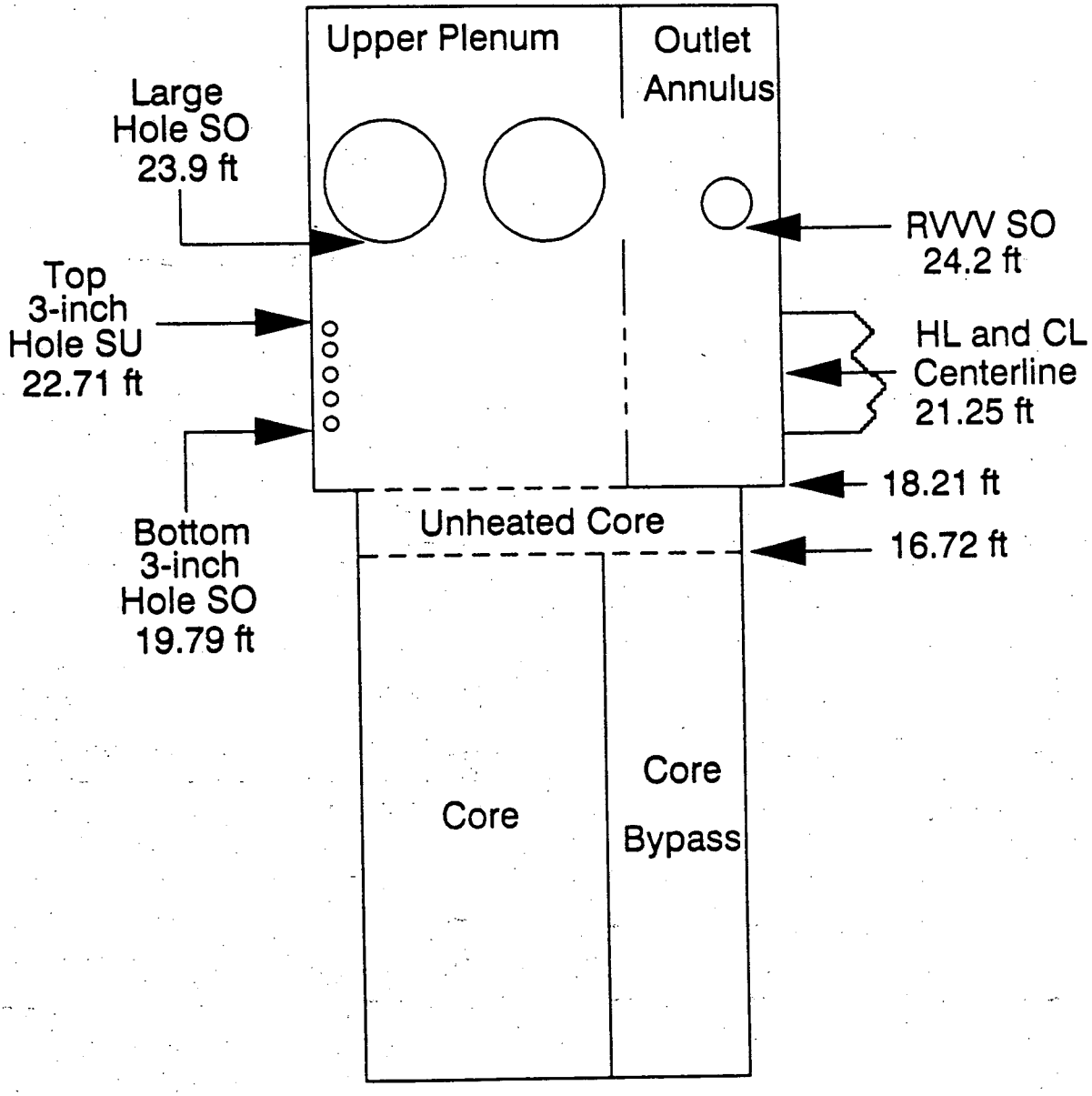
- CONTINUOUS RVVV LIQUID SPILL-OVER WAS POSTULATED TO END WITHIN SEVERAL HOURS AFTER THE TRANSIENT INITIATION, NOT DAYS AS THE PREVIOUS ANALYSES SHOWED. NOTICE OF THE REVISED TIME FOR OPERATOR ACTION WAS GIVEN TO THE OPERATING UTILITIES TO ACCOUNT FOR THIS PERCEIVED DEFICIENCY.

# Figure 6: FOAM2 Model and Key Elevations




NOTE: Elevations referenced to the upper face of the SG lower tubesheet

# Figure 6: RV Model and Key Elevations




NOTE: Elevations referenced to the upper face of the SG lower tubesheet

## BACKGROUND HISTORY, CONT'D

- THE 3 ACTIVE DILUTION MODES ARE DEFINED AS:

MODE 1- WITH 2 OPERATIONAL LPI PUMPS, SUCTION OF ONE PUMP IS ALIGNED WITH THE HOT LEG DECAY HEAT DROP LINE TO OBTAIN APPROXIMATELY 3000 GPM POSITIVE CORE DILUTION FLOWS. (THE NRC SER RECOMMENDED THAT THIS MODE NOT BE USED.)

MODE 2- WITH 1 OPERATIONAL LPI PUMP, THE DECAY HEAT DROP LINE IS OPENED TO INITIATE A GRAVITY DRIVEN DUMP-TO-SUMP THROUGH THE INOPERABLE LPI STRING. POSITIVE CORE FLOWS GREATER THAN 500 GPM ARE EXPECTED.

MODE 3- IF MODE 1 OR MODE 2 CANNOT BE ESTABLISHED, HOT LEG INJECTION REVERSE CORE FLOW DILUTION SHOULD BE ACTIVATED EITHER BY INITIATING PRESSURIZER SPRAY FLOW OF APPROXIMATELY 40 GPM OR LPI INJECTION FLOW INTO THE DECAY HEAT DROP LINE OF APPROXIMATELY 140 GPM.

- THE COMBINATION OF THESE MODES PROVIDE REDUNDANT SAFETY GRADE BORON DILUTION FOLLOWING LOCA BASED ON THE ORIGINAL CALCULATIONS.

- THE SUCCESSFUL DILUTION WITH MODE 3 REQUIRES THE CORE BOIL-OFF RATE DUE TO DECAY HEAT TO BE LESS THAN THE HOT LEG INJECTION FLOW RATE.

- THE DECAY HEAT AT 40 DAYS AFTER AN EVENT FROM 102% OF 2568 MW IS EQUAL TO THE PRESSURIZER SPRAY ABSORPTION CAPACITY.

- THEREFORE, IF RV LIQUID CIRCULATION DOES NOT CONTINUE FOR 40 DAYS, THE PRESSURIZER SPRAY FLOW IS NOT AN ACCEPTABLE MEANS OF ACTIVE BORON DILUTION.

## BACKGROUND HISTORY, CONT'D

- THE UTILITIES WERE INFORMED OF THE PRESSURIZER SPRAY LIMITATIONS FOR BORON DILUTION AND INSTRUCTED TO PREFERENTIALLY USE MODE 2.
- THIS DILUTION MODE REQUIRES USE OF THE DECAY HEAT DROP LINE, AS DOES THE HOT LEG INJECTION OR SUCTION OPTIONS.
- NOT ALL THE 177 LL PLANTS HAVE REDUNDANT SAFETY-GRADE DUMP-TO-SUMP CAPABILITY.
- A SINGLE FAILURE OF EITHER THE VALVE ACTUATOR POWER SUPPLY OR ONE OF THE ISOLATION VALVES ARRANGED IN SERIES IN THE DECAY HEAT DROP LINE APPEARS TO VIOLATE THE SINGLE WORST FAILURE CRITERIA.
- THE SINGLE FAILURE CRITERIA CAN DEFEAT THE ACTIVE MODES OF BORON DILUTION, HOWEVER, A NON-CREDITED PASSIVE MODE IS AVAILABLE.
- THE PASSIVE DILUTION MODE IS PROVIDED VIA LIQUID RECIRCULATION THROUGH THE GAPS BETWEEN THE RV HOT LEG NOZZLE FLANGE AND THE PLENUM CYLINDER.
- THIS GAP DILUTION MODE WAS PRESENTED PREVIOUSLY IN BAW-10091 SUPPLEMENT 1. NO FORMAL NRC-ACCEPTANCE OR REJECTION WAS RECEIVED FOR THE HOT LEG NOZZLE GAP DILUTION MODE.
- AT THE TIME OF SUBMITTAL, THE GAP FLOW WAS NOT REQUIRED SINCE THE COMBINATION OF THE ACTIVE DILUTION MODES PROVIDED A REDUNDANT, SAFETY-GRADE METHOD FOR PRECLUDING EXCESSIVE CORE BORON CONCENTRATION BUILD-UP. B&W AND THE UTILITIES CHOSE NOT TO PURSUE LICENSING VIA THE GAP DILUTION METHOD AT THAT TIME.

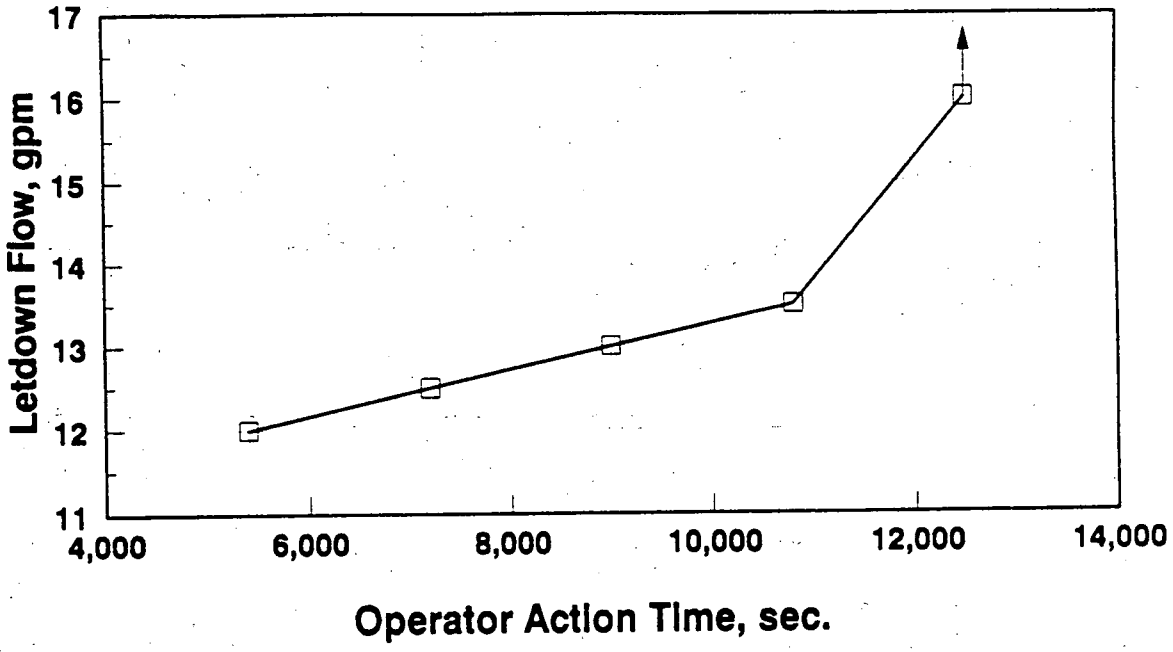
## BACKGROUND HISTORY, CONT'D

- REVISED ANALYSES HAVE BEEN PERFORMED TO DEMONSTRATE EFFECTIVE CORE BORON DILUTION FOLLOWING LOCA.
- THE FIRST ANALYSIS DEFINED THE MINIMUM TIME FOR OPERATOR ACTIONS TO INITIATE A PUMPED OR GRAVITY DRIVEN DUMP-TO-SUMP MODE VIA THE DECAY HEAT DROP LINE NOT CREDITING ANY RV LIQUID CIRCULATION (RVVV OR HL NOZZLE GAP).
- THE UTILITIES WERE NOTIFIED OF THE PREFERRED DILUTION MODE 2 AND THE REVISED TIME FOR OPERATOR ACTION.
- A SECOND DETAILED ANALYSIS OF THE HOT LEG NOZZLE GAP FLOWS AND THEIR IMPACT ON THE VESSEL BORON CONCENTRATIONS WAS PERFORMED.
- THE DETAILS AND RESULTS OF THESE CALCULATIONS WERE DESCRIBED IN THE BWNT SUMMARY REPORT 51-1206351-00, "LONG TERM BORON DILUTION FOLLOWING LARGE LOCA ACCIDENTS", JAN. 1992.
- A TELECON WAS ALSO HELD TO DISCUSS SOME OF THE NRC QUESTIONS IN OCTOBER. A FORMAL PRESENTATION WAS REQUESTED DURING THE CONVERSATION.

## Timing for Operator Action to Initiate Dump-to-Sump Dilution Mode

- Following identification of the PSC, several attempts were made to determine when RVVV liquid spill-over flows ceased.
- Code and hand calculations were performed to assess the fluid composition flowing through the RVVV following the end of core reflooding phase.
- Continuous RVVV liquid overflow was not confirmed in the time given for resolution, therefore, a conservative analysis crediting no RV liquid NC was performed to determine the time for dump-to-sump actions following a LOCA.
- Time for initiation of active dilution mode 2 was conservatively defined and advised that it be activated at the same time that the ECCS suction is switched from the BWST to the sump.
- The conservative assumptions used are given on page 19 of the summary report.
- No HL nozzle gap liquid flow or RVVV liquid flow was credited in the simple bounding analysis.
- These calculations were used as emergency guidance until a final conservative HL gap flow analysis could be completed.

## Figure 8: Constant Decay Heat Line Dump-to-Sump Flows Initiated as a Function of Time Required To Preclude Reaching Solubility Limit



## RV Boron Concentration Calculations with HL Gap Flow

- The original calculations performed for BAW-10091 Supplement 1 were not available since the method was not defended in 1975.

- A new, but similar method for calculation of the RV boron concentrations was created because the original code was not available on the current computer systems. This method was verified by hand calculations and comparisons to closed form solutions or limits.

- The analyses used conservative initial boundary conditions, limiting boron concentrations in the ECCS injection fluid, and no RVVV liquid overflow to maximize the boron concentrations.

- New HL nozzle gap flows were calculated for use in the dilution calculations. The gap flows were minimized by identifying conservative boundary conditions for the gap flow calculations.

  1. Transient differential pressure across the HL nozzle gap
  2. Transient gap width calculations
  3. Minimum gap area available for liquid flow
  4. Transient gap flows

## HL Nozzle Gap Differential Pressure

- The worst break location and boundary conditions that would minimize RV liquid natural circulation flows, produce the smallest gap size due to the ECCS temperature assumptions, and limit the gap liquid flow area from power level considerations were identified.

  1. A CLPD break at the inlet nozzle elevation would minimize the RVVV liquid overflow and the outlet annulus levels.

  2. The minimum liquid level in the RV nozzle gap was determined as a function of decay heat power from FOAM2 void distributions and static manometric balances in the RV upper plenum and outlet annulus region.

  3. The minimum differential pressure across the gap was defined as the RVVV minimum opening DP.

## Gap Size Calculations

- The initial cold gap based on "as-built" measurements from Q/A data packages.
- The average "as-built" nozzle gap is calculated for each nozzle based on the eight locations measured.
- "As-built" RVI nozzle radius calculated based on nominal RV radius (81.5") minus measured gap.
- The RVI temperature is assumed to be 212°F consistent with the fluid temperature. The free thermal expansion of the RVI nozzle is calculated as $R\alpha\Delta T$.
- The RV nozzle displacement is calculated using the same expression but the values of $\alpha$ and $\Delta T$ are varied over the temperature range of 210°F to 550°F.
- The RV/RVI nozzle gap as a function of the average RV temperature is then calculated as the difference $\delta_{RV} - \delta_{RVI}$.
- The RV/RVI nozzle gap as a function of time is determined from the thermal transient analysis and the gap as a function of RV temperature data.

# RV Thermal Transient Analysis

- Two cross-sections of the RV shell were modeled using FEM techniques.
- Two rapid cooldown cases were considered.
  1. $T_{RV}=557^{o}F$, $T_{RVI}=212^{o}F$, $T_{FLUID}=140^{o}F$
  2. $T_{RV}=557^{o}F$, $T_{RVI}=212^{o}F$, $T_{FLUID}=212^{o}F$
- Two sets of HTCs were used.
  1. To represent the wetted region below the RV nozzle a time dependent function was used for the HTC.
  2. To represent the steam region above the nozzle a constant HTC was used.
- Assumptions for thermal analysis
  1. No fluid mixing in the downcomer was assumed. This is conservative since the injection location is 90 degrees from the RV nozzle.
  2. The RVI are assumed to be at the fluid temperature throughout the transient.
  3. The downcomer fluid is ramped from $557^{o}F$ to either $140^{o}F$ or $212^{o}F$ over 0.01 seconds.

## Gap Flow Calculation

- A Bernoulli-type of analysis of the HL nozzle gap liquid flow was performed using the fully certified flow network analysis FSPLIT code.

  1. The nozzle gap geometry was used to determine the flow resistance across the gap (inlet loss, gap friction as function of Reynolds number and L/D, and exit loss) for a range of gap sizes.

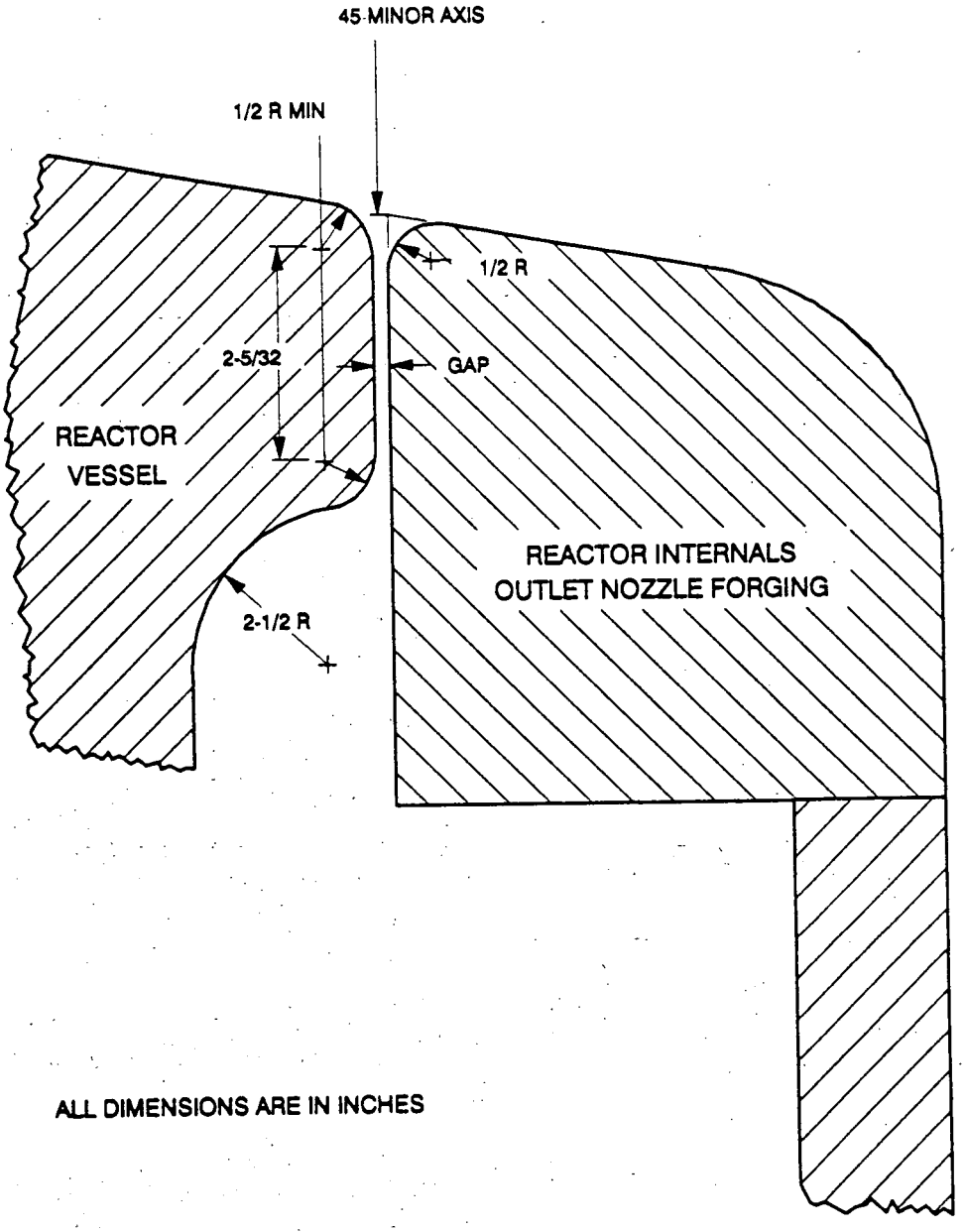
  2. A minimum differential pressure across the gap was used. (RVVV minimum opening pressure 0.125 psia)

  3. The minimum RV outlet annulus liquid level from the FOAM2 analysis was used to define the height of the HL nozzle gap to use for liquid flow.

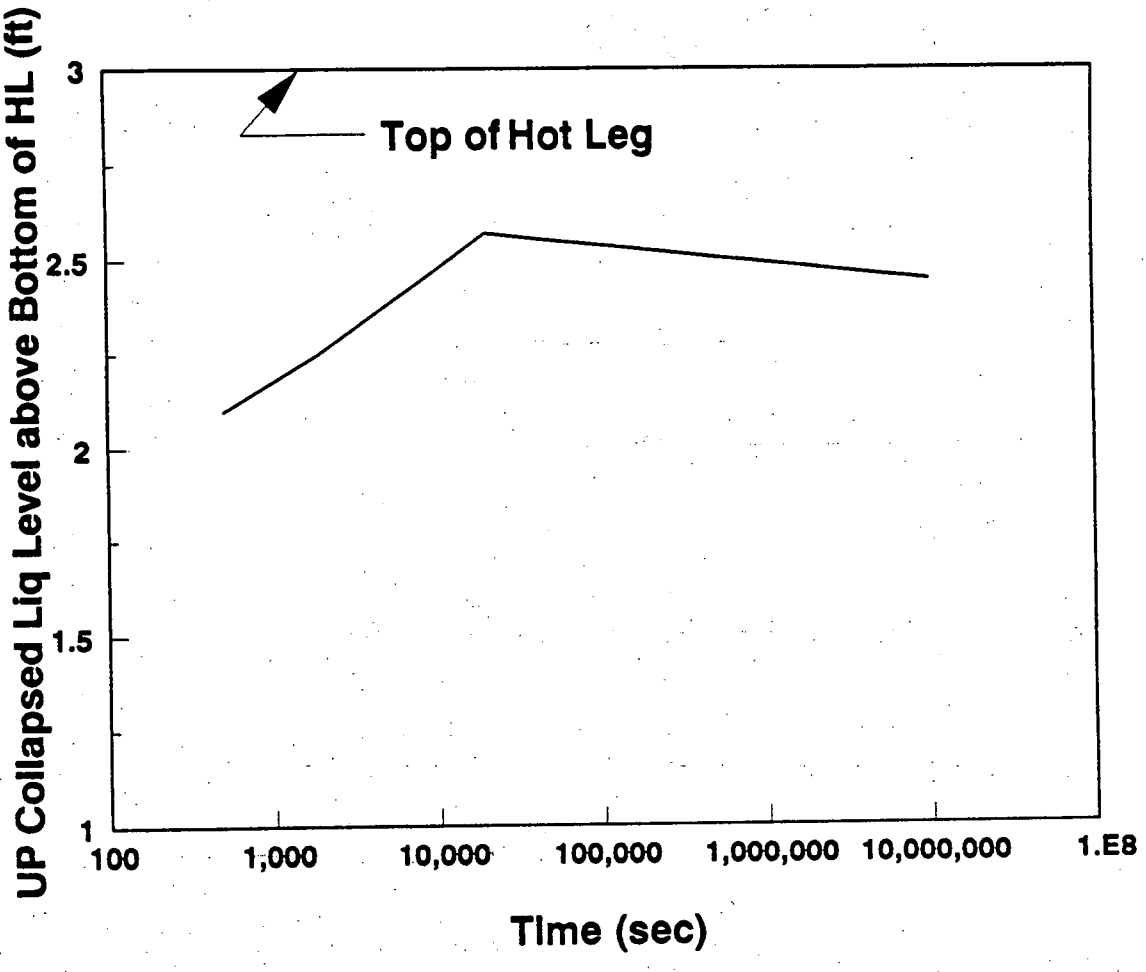
- For the range of gap widths, these conditions were provided to the FSPLIT code to determine a family of gap liquid flow curves.

- The transient gap width from the thermal analysis used this family of flow rates to determine the transient liquid flow specified in RV boron dilution calculations.

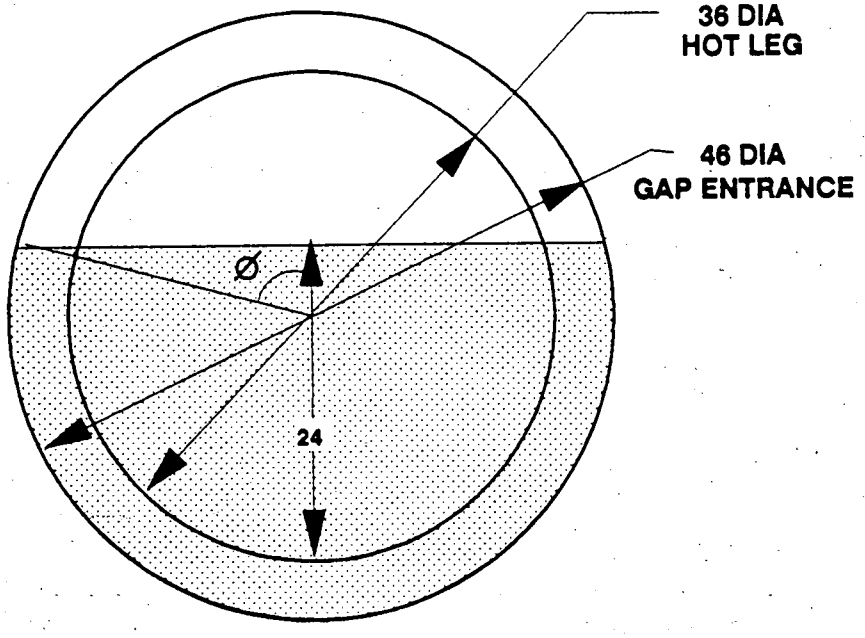
Figure 12: RV Outlet Nozzle Interface Configuration
(from Reference 12)



## Figure 11: FOAM2 Calculated Upper Plenum Collapsed Liquid Level vs. Time

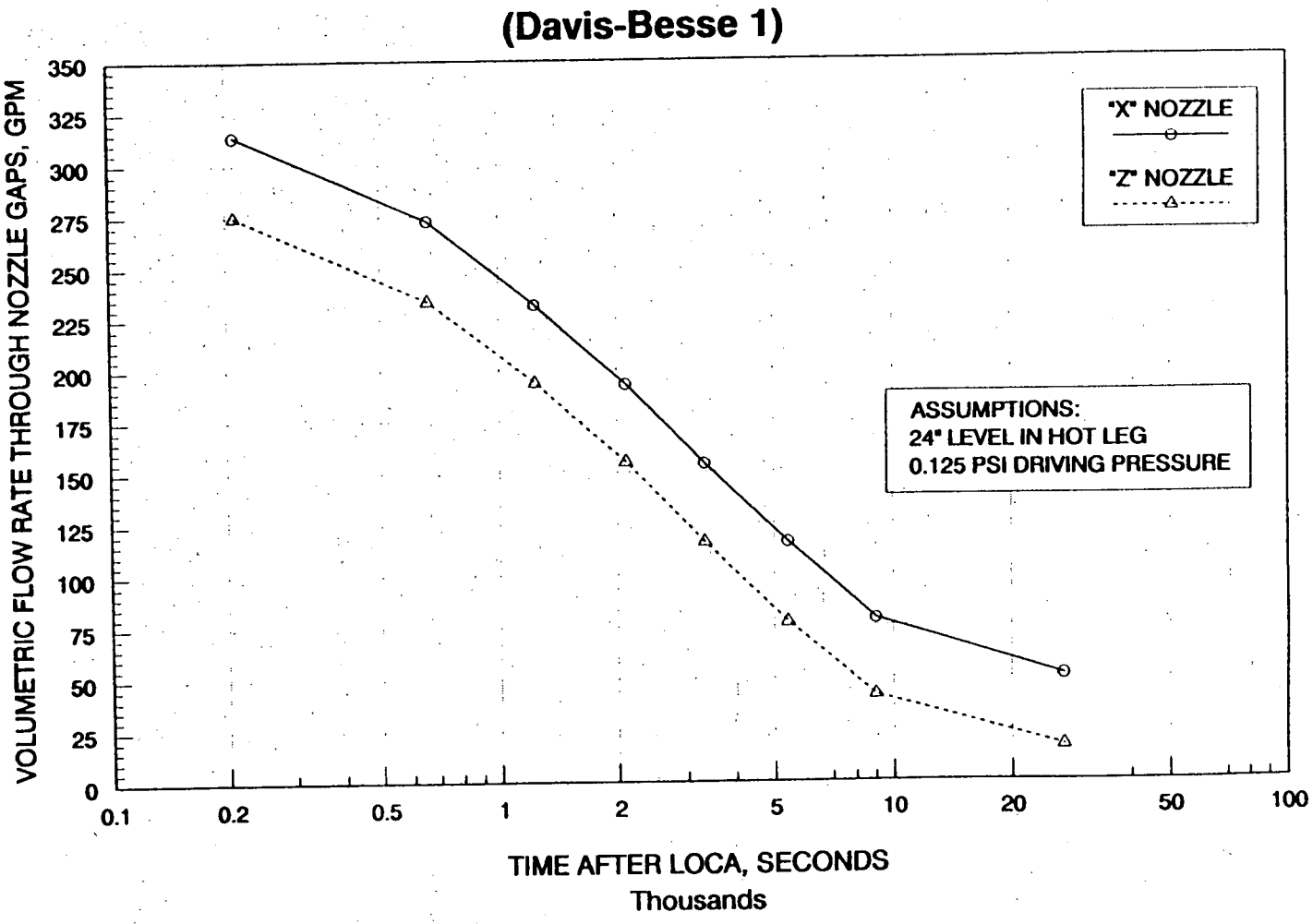


## Figure 13: Gap Flow Area for 24-Inch HL Liquid Level




Ø = ARCCOS [(6)/(46/2)] = 74.88 DEGREES
GAP FLOW AREA = (180 - 74.88/180)(PI)(46)(GAP WIDTH)

# Figure 14: Outlet Nozzle Gap Flow Rate vs. Time



## RV Boron Dilution Calculations

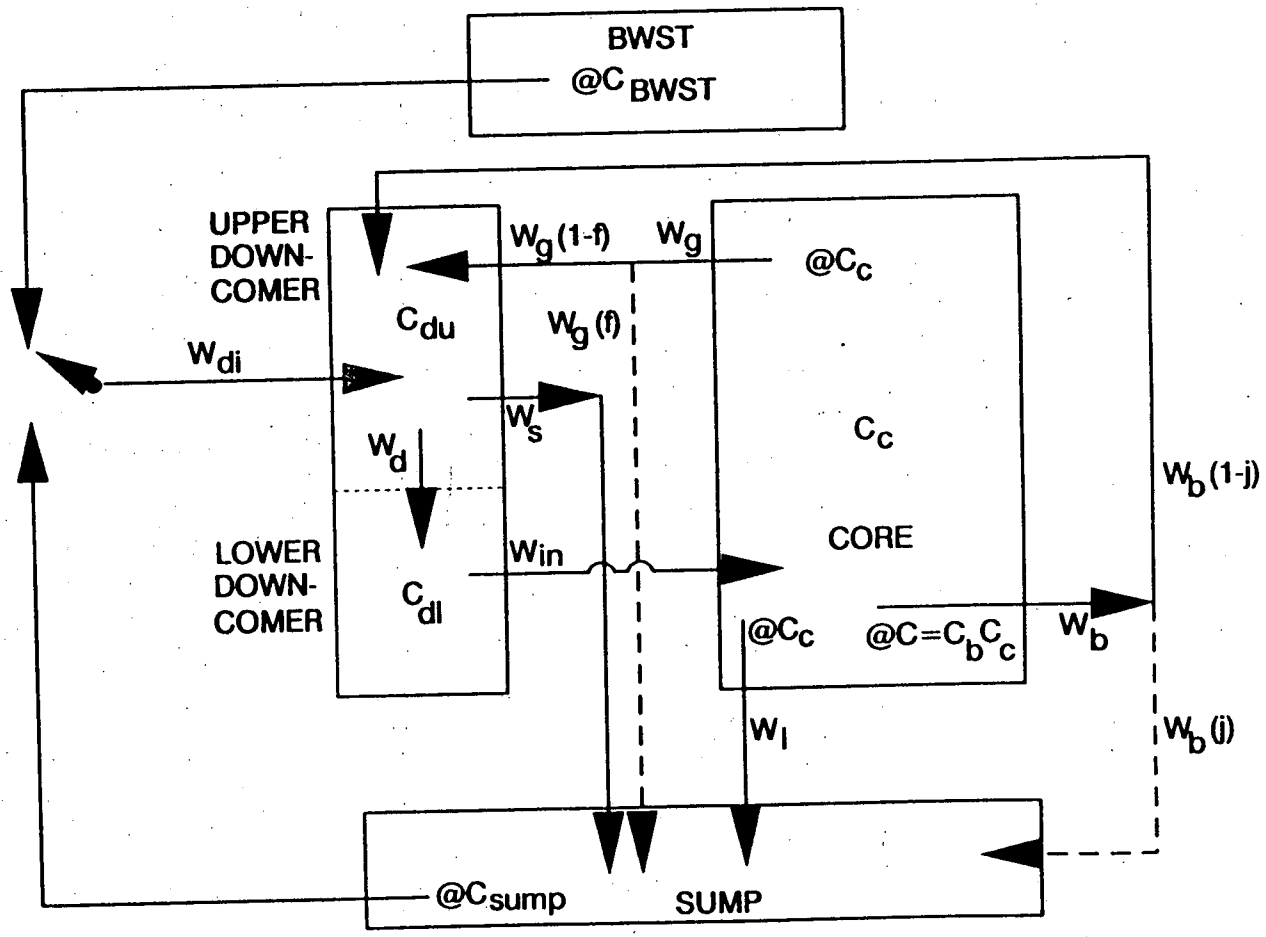
- A four control volume Advanced Continuous Simulation Language (ACSL) model was constructed and configured to provide specification of key boundary conditions and internal circulation paths required to perform the time-dependent dilution calculations.

- Hand calculations and comparisons against simple transients were performed to demonstrate the adequacy of the ACSL model and its results. Several sensitivity studies were performed to demonstrate convergence of results.

- A maximum boron concentration of 10,000 ppm was calculated with the passive internal RV liquid recirculation through the HL nozzle gaps.

- This maximum concentration is approximately one-fourth the solubility limit, therefore, adequate long term cooling boron dilution following a postulated LOCA is demonstrated.

Figure 15: ACSL Boron Dilution Model



# BORON DILUTION FOLLOWING SBLOCAS

- BORON DILUTION FOLLOWING A POSTULATED SBLOCA WAS INVESTIGATED TO DETERMINE IF THE LBLOCA ANALYSES ARE BOUNDING.

- LBLOCA ANALYSES SHOULD BOUND SBLOCA EVENTS.

  THE CORE STORED ENERGY AND SOME DECAY HEAT IS TYPICALLY REJECTED VIA THE STEAM GENERATORS BEFORE THE LOSS OF RCS FLOW, THUS REDUCING THE CORE BOILING CONTRIBUTION CONSIDERED IN THE LBLOCA.

  FOLLOWING LBLOCAS ALL CORE STEAM IS ASSUMED TO GO OUT THE BREAK. DURING SBLOCAS ONLY SOME OF CORE STEAM EXITS THROUGH BREAK. THE REST CONDENSES ON HPI OR IN STEAM GENERATORS AND IS RETURNED TO THE CORE THUS REDUCING THE CORE BORON CONCENTRATION IN THE INLET FLUID.

- THE EVALUATION CONTINUED BY DIVIDING THE WORST CLPD SBLOCAS INTO THREE APPROXIMATE BREAK RANGES BASED ON THE EVOLUTION OF THE TRANSIENT.

  1. BREAKS LARGER THAN APPROXIMATELY 0.05 $FT^2$ DEPRESSURIZE TO LPI AUTOMATICALLY AND CANNOT BE REFILLED. THEREFORE, LBLOCA ANALYSES ARE DIRECTLY APPLICABLE TO THESE BREAKS. THE HL GAP FLOWS SHOULD BE SIMILAR AS WELL SINCE THE SAME RV CONDITIONS EXIST.

  2. BREAKS LESS THAN 0.01 $FT^2$ WILL RESULT IN SYSTEM REFILL AND RE-ESTABLISHMENT OF LOOP NC. THEREFORE THE ENTIRE RCS VOLUME IS THE MIXING VOLUME AND BORON CONCENTRATION WILL NOT APPROACH SOLUBILITY LIMIT WHEN THE DHRS IS ACTUATED.

## BORON DILUTION FOLLOWING SBLOCAS, CONT'D

3. BREAKS IN THE 0.01 $FT^2$ TO 0.05 $FT^2$ RANGE WILL NOT DEPRESSURIZE WITHOUT OPERATOR ACTION. AS LONG AS THE SYSTEM IS HOT, THERE IS NO SOLUBILITY PROBLEM. HOWEVER, ONCE THE OPERATOR COOLS THE PLANT AND INITIATES DHRS THE TEMPERATURE DROPS RAPIDLY AND THE SOLUBILITY LIMIT DECREASES.

   CALCULATIONS SHOW THAT THE SYSTEM CAN BE DEPRESSURIZED TO DHRS CUT-IN IN THREE HOURS (AT 100°F/HR COOLDOWN). THIS IS ABOUT THE SAME TIME THE LBLOCA SHOW THAT DUMP-TO-SUMP SHOULD BE INITIATED. LBLOCA CONCENTRATIONS LIMITS WITHOUT RV LIQUID NC BOUND THE SBLOCA VALUES, THEREFORE, THE OPERATOR ACTION AT THIS TIME WILL PRECLUDE EXCESSIVE BORON CONCENTRATIONS.

   ALSO, ONCE THE RCS IS DEPRESSURIZED AND LPI FLOW IS INITIATED, THE CORE BOILING IS SUPPRESSED SUCH THAT THE RV IS PARTIALLY REFILLED AND LIQUID CIRCULATION THROUGH THE RVVVS IS RESTORED.

- IN SUMMARY, SBLOCA BORON CONCENTRATIONS ARE BOUNDED BY THE LBLOCA VALUES. THE TRANSIENT EVOLUTION FOR THE INTERMEDIATE OR SMALL BREAKS SHOULD LIMIT THE CONCENTRATIONS. THE LARGEST SBLOCAS EVOLVE TO A STATE SIMILAR TO THE LBLOCA, SUCH THAT THE LBLOCA CALCULATIONS WITH THE HL NOZZLE GAP FLOWS APPLY DIRECTLY.

## Summary and Conclusions

- The previous NRC-approved boron dilution analyses for 177LL plants non-conservatively estimated the length of time for RVVV liquid overflow.

- The shorter time for RVVV liquid NC invalidates the auxiliary pressurizer spray as a redundant safety-grade active means for boron dilution without credit for HL nozzle gap flows.

- New boron dilution analyses following a postulated LOCA have been performed using passive HL nozzle gap liquid flows that were conservatively calculated.

- The revised analyses show that HL nozzle gaps provide sufficient liquid NC in the RV to maintain the boron concentration well below any solubility limits.

- The active dilution modes are not required for long term boron dilution. They augment the passive dilution that is provided by the RVVV liquid and HL nozzle gap liquid circulation flows.