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The B&W Owners Group

Revision to BAW-2374 – SG Tube Loads following a LBLOCA

BWOG Discussions with NRC (Warren Lyon) –
April 27 & 28, 2004
Lynchburg, VA

Meeting Agenda - Tuesday

- Background and Understanding of Key Parts of Demonstrating Long-Term Core Cooling
  - Brief Statement of BWOG and NRC Expectations
  - Background History – Common Understanding of Where We Are
  - Thermal-Hydraulic Analyses and Key Boundary Conditions
  - SG Tube Loads versus Break Size, Break Location, and Tube Location within SG
  - SG Tube Flaws and Potential for Failure Based on Methods Used
  - Number of SG Tubes Broken or Leaking (Equivalent Primary-to-Secondary Break Area)
  - Plant Specific Steam Line Geometry and Leakage Calculations
  - Secondary Side Boundary Conditions (Single Failure Considerations)
  - LPI pump NPSH Considerations
  - Dose Considerations

Meeting Agenda - Wednesday

- Consensus on Key Boundary Conditions Input to Case(s) that Demonstrate Long-Term Cooling
  - Review history of where we are
  - Review key inputs whose value is conservative for certain aspects and non-conservative for others and select value for use in the analysis
  - Operator actions credited or prescribed
  - Method of analysis and objectives to be met
  - Define changes to or additions to next revision of BAW-2374
  - Review any open items or issues
  - Summary and Conclusions

Background

- The ECCS refill following a LOCA in the upper portions of hot leg piping will rapidly cool the SG tubes and result in a large temperature differential between the SG shell and SG tubes.
- This temperature differential results in a large tension load on the tubes that could lead to failure of SG tubes from circumferential cracks and/or volumetric flaws.
- While the early PCT, peak local oxidation, and hydrogen generation predictions do not seriously challenge the acceptance criteria, long-term cooling is not easily demonstrated.
- RCS liquid can be lost to the secondary, which could potentially compromise ECCS pump NPSH during the sump recirculation phase of the event leading to a loss of long-term cooling and subsequently high PCTs, peak local oxidation, and hydrogen generation later in the event.
- The dose from the RCS leakage outside of containment must also be evaluated and shown to be in compliance with 10 CFR 100 limits, etc.

Background (cont)

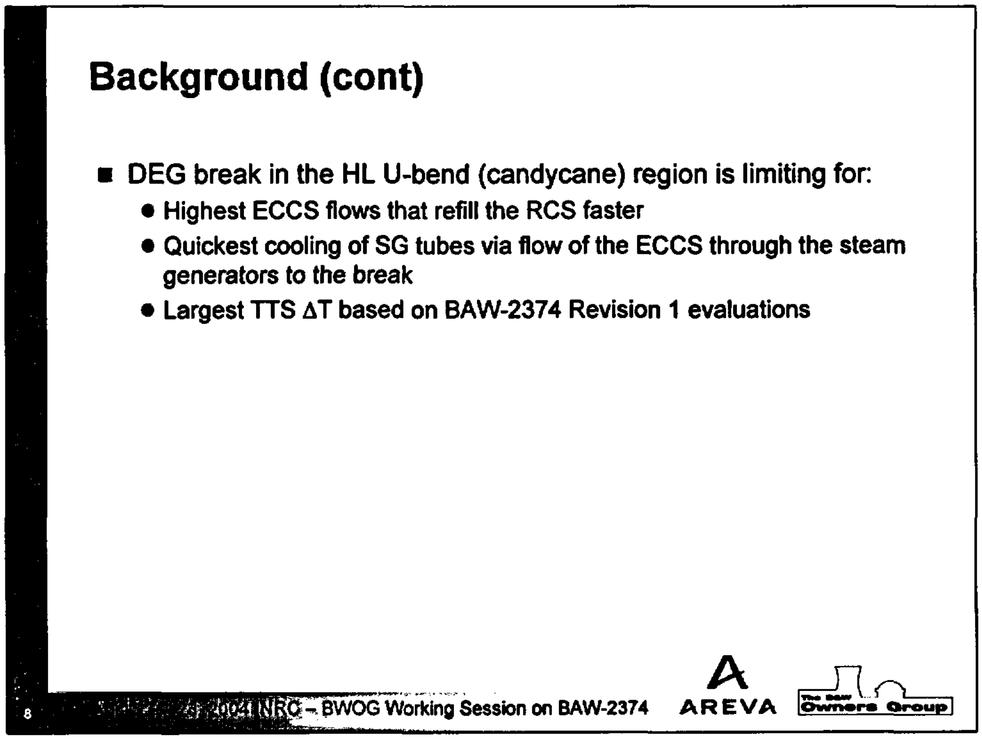
- Maximum SG tube loads are calculated for the largest temperature differential between the SG shell and tubes (TTS ΔT)
- SG tube loads are dependent on the radial location of the tubes. Tubes on the periphery have the highest loads. The loads on the interior tubes are lower due to the deflection of the tube sheets.
- Many parameters have some bearing on the SG tube and SG shell temperatures.
- Keys to establishing the maximum TTS ΔT include
  - SG tube temperatures during the transient
  - Initial SG shell temperature plus the transient cooling

Background (cont)

- SG tube temperatures
  - Dependent on break size and location
    - *Lower and middle hot leg breaks limit SG tube refill level*
      - Tubes approaches RCS saturation temperature based primarily on ECCS flow, break area, and containment pressure
    - Upper hot leg break
      - Ultimately approaches ECCS liquid temperature plus temperature rise from core decay heat contribution
      - Break size determines the ECCS flow rates, which determines the time for the RCS refill and time required for the tube to asymptotically approach its quasi-steady long-term temperature
      - Number of ECCS trains in operations defines the refill time and time of maximum TTS ΔT

Background (cont)

- SG shell average temperature
  - A function of initial operating conditions
    - SG pressure – DC saturation temperature
    - T_{hot}-core power level, RCS flow, T_{ave}
    - SG superheat
      - MFW flow, T_{hot}, RCS flow, Fouling, SG tube plugging, etc.
  - Transient cooling
    - Conduction-limited slower cooling (no ambient losses)
    - Secondary side level
      - Initial OTSG water inventory
      - MFW termination
      - MFW line flashing (not credited in BWOG evaluations to date)
      - EFW flow



Background (cont)

- DEG break in the HL U-bend (candycane) region is limiting for:
  - Highest ECCS flows that refill the RCS faster
  - Quickest cooling of SG tubes via flow of the ECCS through the steam generators to the break
  - Largest TTS ΔT based on BAW-2374 Revision 1 evaluations

Background (cont)

- However, if tubes break, the DEG break may limit primary-to-secondary leak rate.
  - ΔP across SG tubes after rupture is controlled by containment pressure, SG pressure, and RCS elevation head
  - After the SG secondary fills, the steam line (SL) geometry will determine the secondary side elevation head
  - Liquid lost may only be to SG secondary and SL and not continuous

Background (cont)

- A reduced RCS break area will raise the primary side pressure and increase ΔP across SG tubes and push liquid over SL spill over (SO) elevation.
- But, a reduction in the RCS break size would
  - Eliminate or reduce the number of fuel pins that could rupture
  - Reduce the TTS ΔT and SG tube load
  - Reduce the number of SG tubes that fail
  - Reduce the primary-to-secondary flow rate
  - Increase the time before NPSH is lost

Background (cont)

- A failure of secondary side isolation has the potential for continual loss of RCS liquid which depletes the sump inventory.
- The dose will be a function of:
  - Leakage rate based on number of failed tubes and EOP actions
  - Fuel failure percentage
    - Break size, core power shape, CFT initial conditions
  - Sump pH

Objectives

- Determine limiting RCS break area that will result in continued loss of RCS liquid.
  - Dependent upon SL SO elevations for each BWOG plant.
- Determine the number of tubes ruptured for the limiting RCS break area and resultant SG tube loads.
- Determine the time to reach the NPSH limit for the configuration considered.
- Determine the smallest break size for which no fuel pin rupture is expected and use that to determine the source term in the calculation of the dose rates.

Limiting RCS Break Area

- For breaks that are not choked (most large breaks)
  - $P_{RCS} = f(A_{break}, w_{break}, P_{containment})$
  - As A_{break} ↓, P_{RCS} ↑ , $P_{Containment}$ ↓
  - RCS flow will be maintained by ECCS at an appropriate balance between P_{RCS} & w_{break}
- Time for Max TTS ΔT
  - RCS completely refilled and tubes cooled
  - $w_{ECCS} = w_{break}$
  - For SG tube rupture at this point, w_{tubes} would be small enough to not affect P_{RCS} or w_{ECCS}
  - So, $w_{ECCS} = w_{break} + w_{tubes}$
  - RCS pressure will augment the manometric imbalance

Limiting RCS Break Area (cont)

- A simplified model of the HL, SG primary, and SG secondary can be used to model phenomenon.
- Model will determine:
  - Max height on secondary side as a function of RCS break size
    - Determine if a reduced RCS break area can be considered
  - The rate and amount of liquid lost to secondary side as a function of RCS break size and number of SG tubes failed
    - If SL SO elevations do not support a smaller RCS break area
- Two methods:
  - RELAP5
  - Excel spreadsheet and macro

Limiting RCS Break Area (cont)

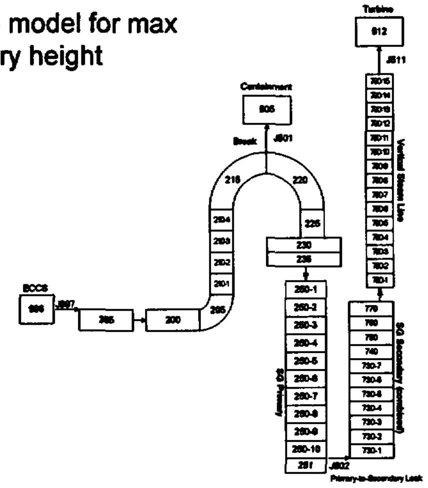
- RELAP5 Model
  - HL, SG primary, and SG secondary only
    - Including RCS loop and associated flow losses has a negligible effect on the results (<5%)
  - Initialized to conditions at the time near the maximum tube load (~600 seconds after 2A DEG LBLOCA)
    - RCS has refilled to break
    - ECCS injecting against RCS pressure
    - Core decay heat included
    - Containment pressure based on the same minimum value used for TTS ΔT calculation
    - Run to 3500 seconds

Limiting RCS Break Area (cont)

- RELAP5 Model (cont)
  - After 20 seconds, the primary-to-secondary path is opened to simulate the failure of 6 SG tubes
    - Delay allows for system to come to an equilibrium
  - Two models are used
    - The first determines maximum height on secondary side
    - The second determines the spillover flow based on the SL SO elevation.
  - Various input changes can be made, but requires a bit of time to run and tabulate for many variables and plant designs

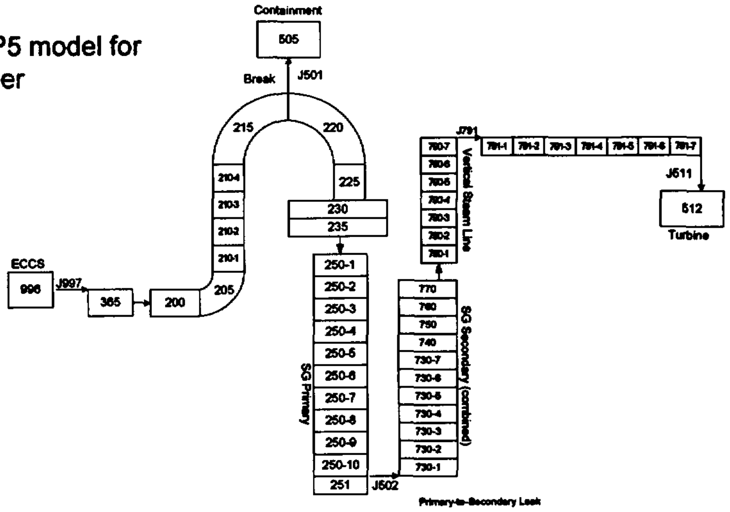
Limiting RCS Break Area (cont)

- RELAP5 model for max secondary height



Limiting RCS Break Area (cont)

- RELAP5 model for spill over



Limiting RCS Break Area (cont)

- Excel Model
  - Essentially the same representation as the RELAP5 model
  - Same initial conditions at time of refill (~600 seconds after 2A DEG LBLOCA)
  - Certain boundary conditions are specified
    - Containment pressure as a function of time
    - ECCS flow rate as a function of RCS pressure
    - Secondary side pressure (outside containment pressure for unisolated system)
    - RCS break area
    - Number of SG tube failures
    - Initial level of liquid on SG secondary
    - Plant – defines SG design (volume) and SL SO elevation

Limiting RCS Break Area (cont)

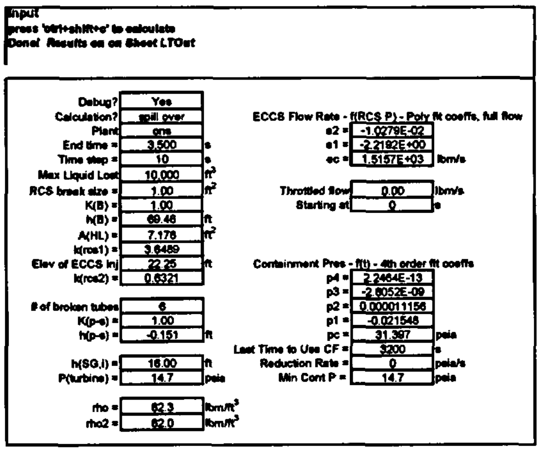
- Excel Model (cont)
  - Macro using Visual Basic with input from Excel worksheet
  - Uses elevation head and flow rate to determine pressure at certain points in the system
  - Uses Bernoulli equation to determine primary-to-secondary (P-to-S) break flow rate
  - Uses the premise that $w_{ECCS} = w_{break} + w_{tubes}$
  - Iterates to convergence – variation in P-to-S leak rate < 0.01 lbm/s.
  - Advances time and performs calculation again

Limiting RCS Break Area (cont)

- Excel Model (cont)
  - Variations of input can be examined quickly
    - ECCS flow rate
    - RCS break area
    - Containment pressure
    - Plant – determines SL SO elevation and SG type
    - End time
    - Number of SG tube failures
  - Runs more quickly than the RELAP5 model

Limiting RCS Break Area (cont)

- Excel worksheet input



Input
press 'ctrl+shift+c' to calculate
Done! Results are on Sheet LTOut

Debug?	Yes	
Calculation?	spill over	
Plant	one	
End time =	3,500	s
Time step =	10	s
Max Liquid Lost	10,000	ft³
RCS break size =	1.00	ft²
K(B) =	1.00	
h(B) =	69.46	ft
A(HL) =	7.178	ft²
k(rcs1) =	3.6489	
Elev of ECCS Inj	22.25	ft
k(rcs2) =	0.6321	
# of broken tubes	6	
K(p-s) =	1.00	
h(p-s) =	-0.151	ft
h(SG,I) =	16.00	ft
P(turbine) =	14.7	psia
rho =	62.3	lbm/ft³
rho2 =	62.0	lbm/ft³

ECCS Flow Rate - f(RCS P) - Poly fit coeffs, full flow

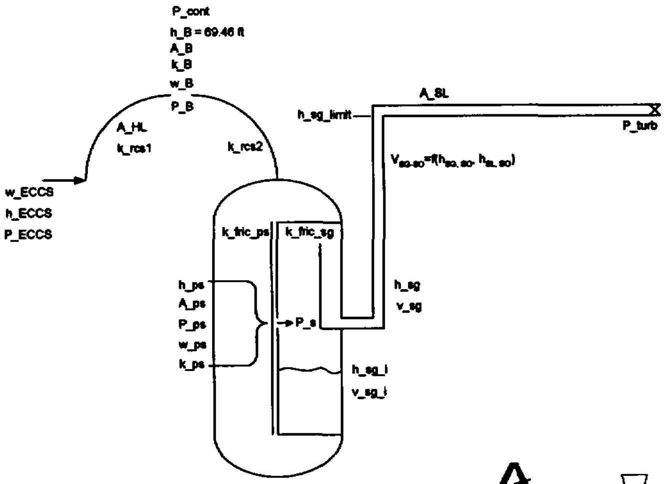
e2 =	-1.0279E-02	
e1 =	-2.2192E+00	
ec =	1.5157E+03	lbm/s
Throttled flow	0.00	lbm/s
Starting at	0	s

Containment Pres - f(t) - 4th order fit coeffs

p4 =	2.2464E-13	
p3 =	-2.6052E-09	
p2 =	0.000011156	
p1 =	-0.021546	
pc =	31.397	psia
Last Time to Use CF =	3200	s
Reduction Rate =	0	psia/s
Min Cont P =	14.7	psia

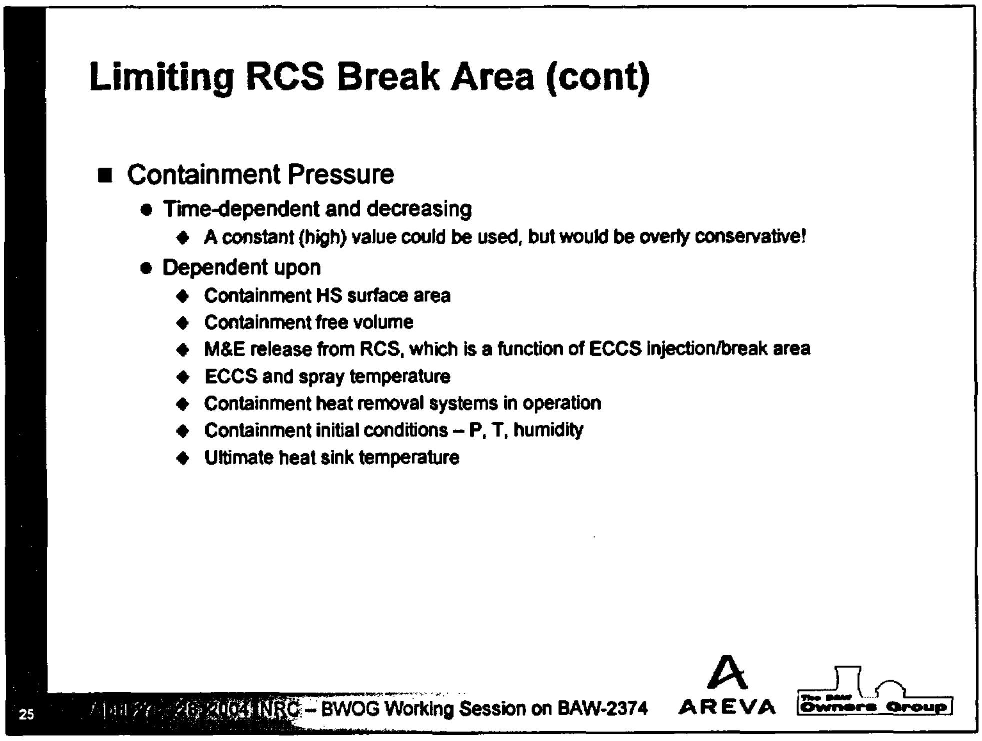
Limiting RCS Break Area (cont)

- Excel model



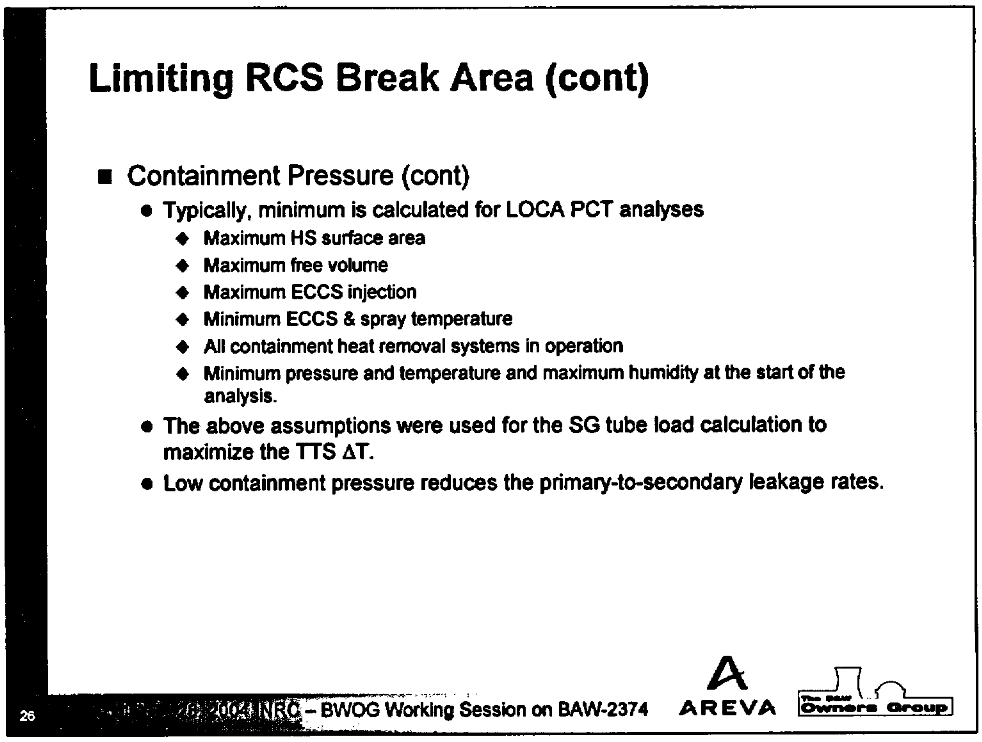
Limiting RCS Break Area (cont)

- Results achieved with either RELAP5 or Excel are strongly a function of
  - Containment Pressure
  - Primary to secondary break area (i.e. number of SG tubes ruptured)
  - Elevation of SL SO elevation w.r.t. RCS break elevation
  - ECCS injection rate
  - Secondary side pressure



Limiting RCS Break Area (cont)

- Containment Pressure
  - Time-dependent and decreasing
    - A constant (high) value could be used, but would be overly conservative!
  - Dependent upon
    - Containment HS surface area
    - Containment free volume
    - M&E release from RCS, which is a function of ECCS injection/break area
    - ECCS and spray temperature
    - Containment heat removal systems in operation
    - Containment initial conditions – P, T, humidity
    - Ultimate heat sink temperature



Limiting RCS Break Area (cont)

- Containment Pressure (cont)
  - Typically, minimum is calculated for LOCA PCT analyses
    - Maximum HS surface area
    - Maximum free volume
    - Maximum ECCS injection
    - Minimum ECCS & spray temperature
    - All containment heat removal systems in operation
    - Minimum pressure and temperature and maximum humidity at the start of the analysis.
  - The above assumptions were used for the SG tube load calculation to maximize the TTS ΔT.
  - Low containment pressure reduces the primary-to-secondary leakage rates.

Limiting RCS Break Area (cont)

- Containment Pressure (cont)
  - A higher containment pressure will have a more detrimental affect on the primary-to-secondary liquid loss calculation.
  - The ECCS conditions will be maintained consistent with TTS ΔT calculation.
    - Maximum ECCS injection
    - Consistent minimum ECCS & spray temperature
    - All containment heat removal systems in operation
  - Other parameters may be changed to get maximum pressure
    - Minimum HS surface area
    - Minimum free volume
    - Maximum pressure and temperature at the start of the analysis.
    - Reduced efficiency of the fan coolers

Limiting RCS Break Area (cont)

- Number of SG tubes failed
  - Based on TTS ΔT , which is a function of RCS break area.
  - Therefore, determining number of failures is an iterative process that has not been characterized at this time.

Limiting RCS Break Area (cont)

- Elevation of SL spillover
  - Elevation of HL spillover w.r.t. UFLTS (Upper face lower TS)
    - Bottom of pipe = 66.5 ft
    - Top of pipe = 69.5 ft
  - Elevation of SL spillover w.r.t. UFLTS
    - CR-3: 52.1 ft
    - TMI-1 53.1 ft
    - DB-1: 68.9 ft
    - ANO-1: 71.2 ft
    - ONS: 76.6 ft
  - Most BWOG plants have potential for SL SO just as a result of the elevation difference between RCS break location and SL SO elevation

Limiting RCS Break Area (cont)

- ECCS flow rate
  - Maximum ECCS injection was used in the TTS ΔT calculation to maximize the RCS refill rate. For this calculation, it will
    - Elevate the RCS pressure and
    - Maximize the liquid lost to the secondary side
  - At the time of the SG tube failure (~10 minutes for LBLOCA),
    - Core exit subcooling should have been regained
    - Operators may isolate HPI and throttle LPI to an assured delivery of 1,000 gpm/line
  - Both scenarios will be considered.

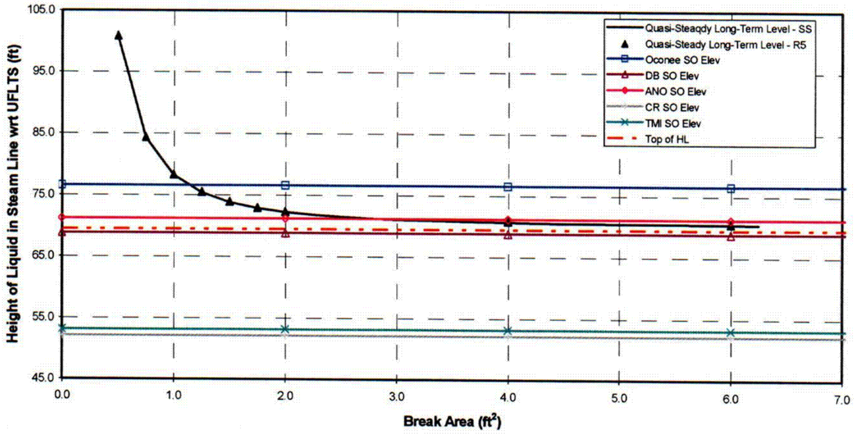
Limiting RCS Break Area (cont)

- Example Problem
  - Boundary Conditions
    - Containment pressure
      - Consistent with TTS ΔT calculation (minimum)
    - ECCS Flow Rate
      - Maximum & throttled
    - Number of failed SG tubes = 6
      - Not important to outcome since the quasi-steady level is determined – timing and max height are not of interest
  - Calculation
    - RELAP5 & Excel
      - Provides a verification of Excel calculation
    - Varied RCS break size

Limiting RCS Break Area (cont)

- Results
  - RELAP5 and Excel calculations match
  - Maximum break area that needs to be considered for each plant for max ECCS
    - TMI-1, CR-3, DB-1 need to consider full HL area breaks
    - ANO-1 needs to consider breaks up to ~4 ft^2
    - ONS-1,2-3 needs to consider breaks up to ~1 to 2 ft^2
  - Maximum break area that needs to be considered for each plant for throttled ECCS
    - TMI-1, CR-3, DB-1 need to consider full HL area breaks
    - ANO-1 needs to consider breaks up to ~0.7 ft^2
    - ONS-1,2-3 needs to consider breaks up to ~0.3 ft^2

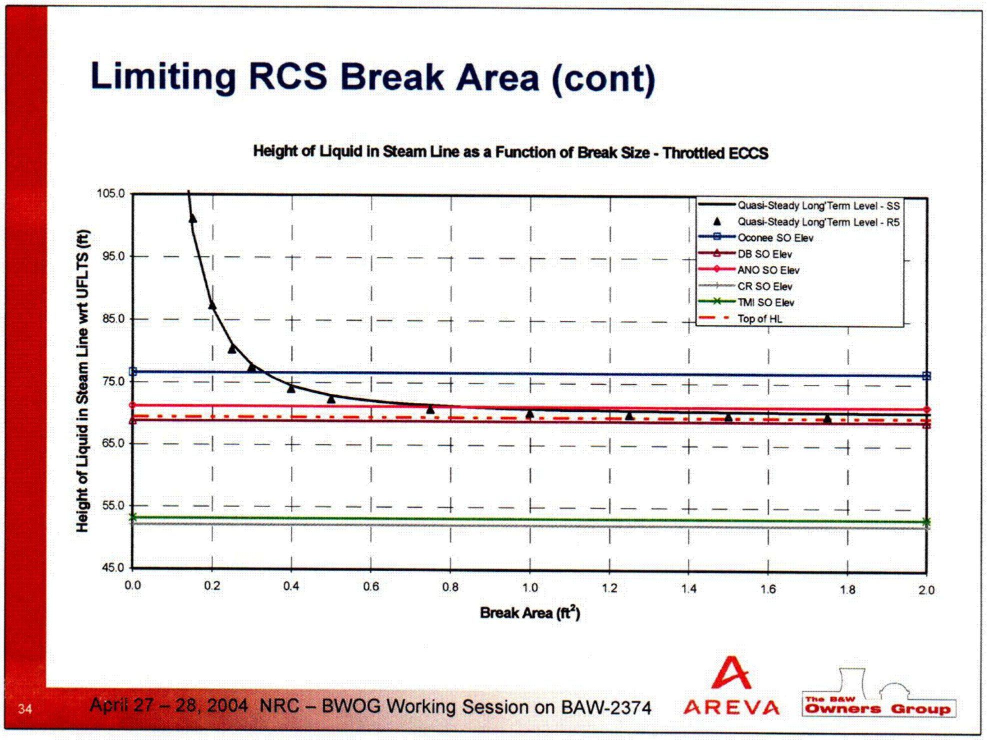
Limiting RCS Break Area (cont)



Height of Liquid in Steam Line as a Function of Break Size - Unthrottled ECCS

C01

Limiting RCS Break Area (cont)

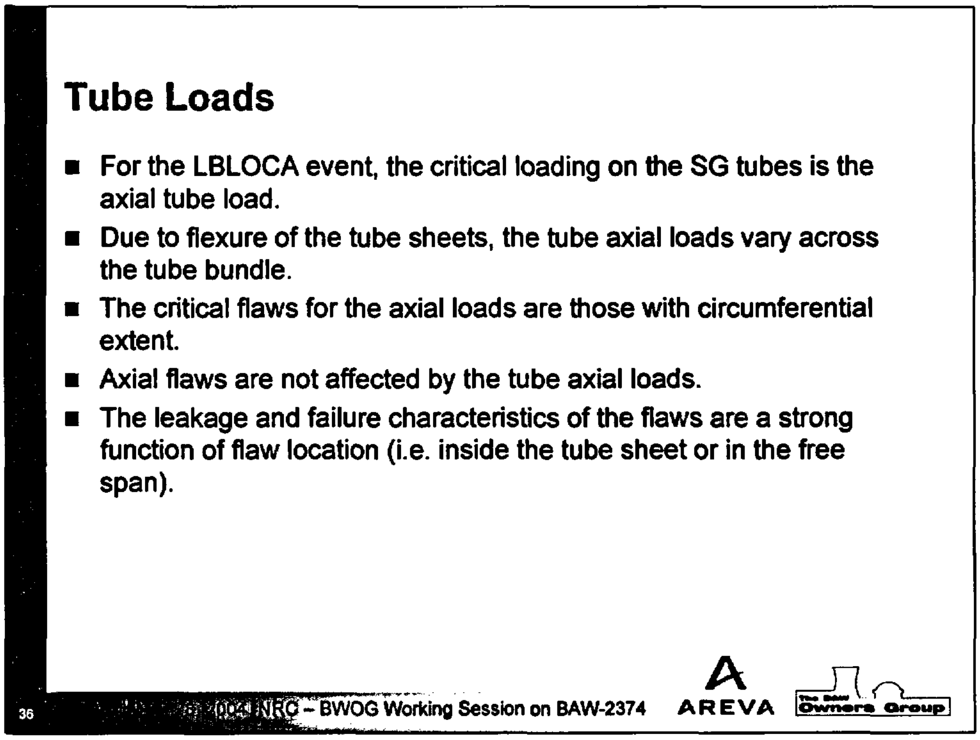


Height of Liquid in Steam Line as a Function of Break Size - Throttled ECCS

C02

Limiting RCS Break Area (cont)

- Conclusions
  - **Only valid for selected containment pressure!**
    - As $P_{containment}$ increases, RCS break area increases
    - Since a low value was used, it is expected that the break area that needs to be considered will increase
  - Essentially, all BWOG plants need to consider that liquid will be lost over the SL SO.
  - In some cases, the containment pressure may decrease to a point that spill over will not be predicted. But, the timing must be compared to operator action times credited to minimize the liquid lost.



Tube Loads

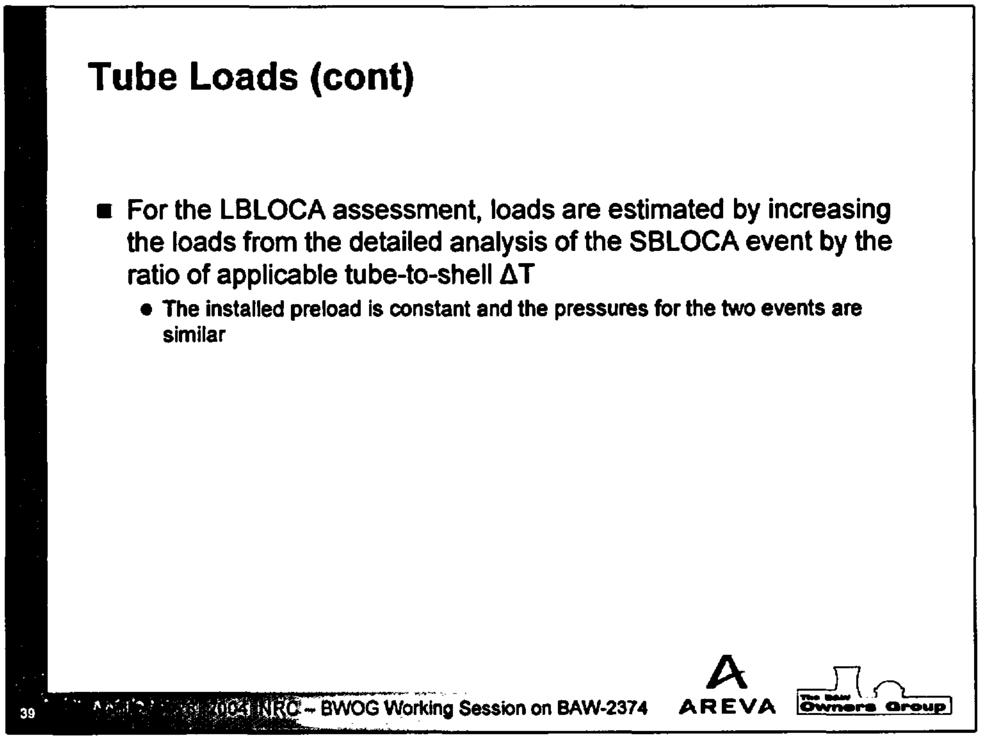
- For the LBLOCA event, the critical loading on the SG tubes is the axial tube load.
- Due to flexure of the tube sheets, the tube axial loads vary across the tube bundle.
- The critical flaws for the axial loads are those with circumferential extent.
- Axial flaws are not affected by the tube axial loads.
- The leakage and failure characteristics of the flaws are a strong function of flaw location (i.e. inside the tube sheet or in the free span).

Tube Loads (cont)

- The total tube axial load is made up of three basis parts
  - Fabrication installed preload
  - Load due to primary-to-secondary ΔP
  - Load due to tube-to-shell ΔT
- The largest contributor to accident condition tube axial loads is the tube-to-shell ΔT
- Break size and location are the main controlling parameters that determine the overall TTS ΔT, with ECCS flow, core power, BWST temperature also having some influence on the temperature difference.

Tube Loads (cont)

- Typically, tube loads are determined using inputs taken directly from the detailed thermal hydraulic analysis of the event.
  - Inputs include time dependent bulk fluid temperatures, pressures, heat transfer coefficients, and tube temperatures
- The loads at critical times in the event are determined using a detailed ANSYS finite element model of the OTSG.
  - The axisymmetric model includes the SG shell, tubes, upper and lower heads, and support skirt



Tube Loads (cont)

- For the LBLOCA assessment, loads are estimated by increasing the loads from the detailed analysis of the SBLOCA event by the ratio of applicable tube-to-shell ΔT
  - The installed preload is constant and the pressures for the two events are similar

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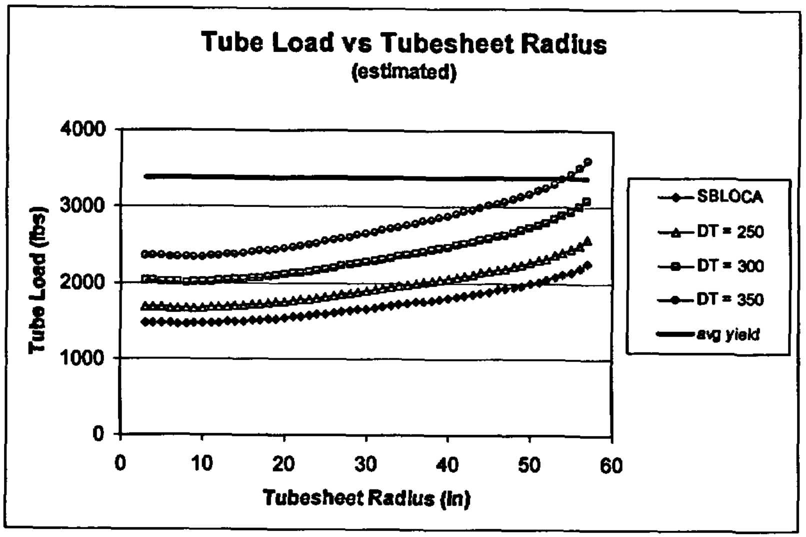
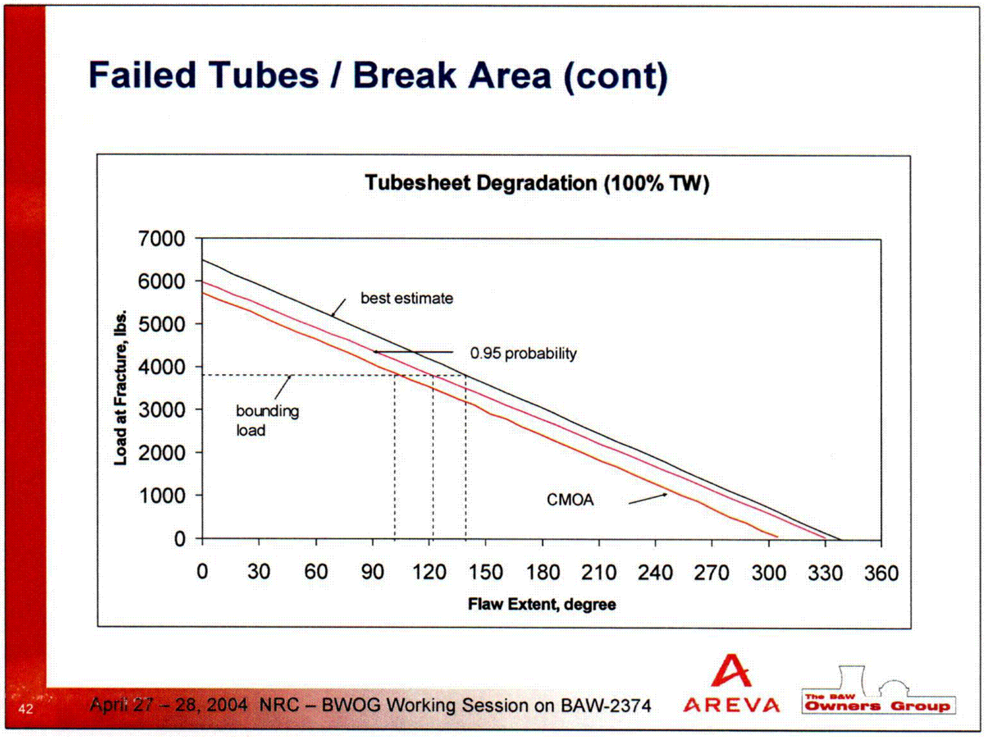
Tube Loads (cont)



Failed Tubes / Break Area

- The tube axial loads as a function of tube sheet radius are used to determine the allowable (critical) circumferential flaw sizes.
- The critical flaw size is also dependant on whether the flaw is located within the tube sheet or in the free span.
- There are multiple options for determining the critical flaw size:
  - best-estimate
  - 95-95 estimate
  - CMOA evaluation accounting for NDE sizing, tube properties, probability of detection, etc.



Failed Tubes / Break Area (cont)

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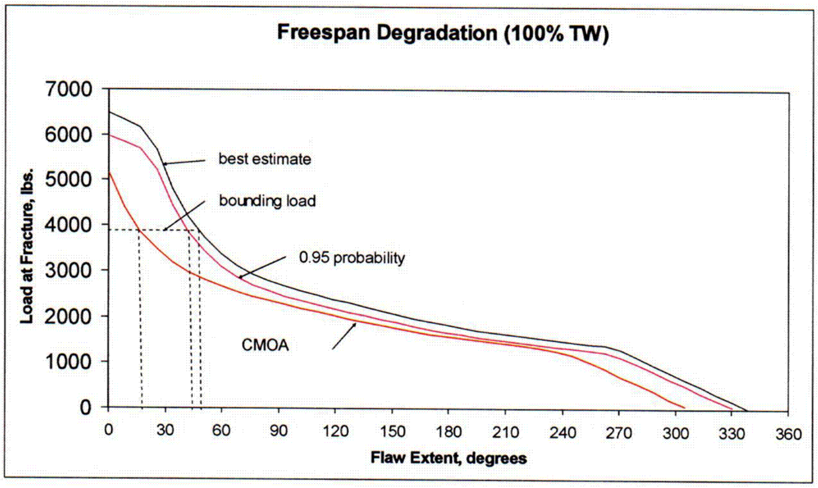
Failed Tubes / Break Area (cont)



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Failed Tubes / Break Area (cont)

- Details of existing inspection techniques (probability of detection, growth rates, etc.) and their results are used to predict future flaw sizes, locations, and number of flaws.
    - This is done by Monte Carlo analysis performed by an AREVA computer program
- The predicted flaws are then compared to the critical flaw size to determine if the tube(s) will sever or not.
- Those flaws that are not predicted to sever are evaluated to determine if they may propagate through-wall.

Failed Tubes / Break Area (cont)

- The same program used to evaluate structural integrity of flaws is also used to determine leak rates.
  - Leak rates are determined for severed tubes and also those flaws that are predicted to propagate through-wall
- Location of the flaw, whether within tube sheet or free span, is taken into account when determining leak rates
  - Leakage for flaws within the tube sheet maybe limited by the flow through the annular region defined by the tube sheet bore and the tube outside diameter.
  - It takes a number of failed tubes inside the tube sheet to equal the leakage flow from one free span break.

Failed Tubes / Break Area (cont)

- The total calculated leakage is then used with applicable inputs from the calculations (pressure, temperature, etc.) to determine an equivalent break area.
- The equivalent break area is used in a detailed time history analysis to determine leak rate as a function of transient time.

Time to Reach NPSH Limit

- Lots of scenarios that are dependent on
  - Containment pressure
  - SL SO elevation
  - SG design
  - ECCS injection rate
  - Number of failed SG tubes
  - Etc.
- Use Excel to narrow down variables
  - Excel calculation has been benchmarked for max level on secondary side.
  - Need to benchmark to spillover calculation

Time to Reach NPSH Limit (cont)

- Excel SO calculation compared to RELAP5 calculation
  - Same containment pressure as maximum level analysis
  - Vary RCS break size
  - Vary number of failed SG tubes
- Compare results:
  - Time of spillover
  - Mass of liquid spilled
  - Primary-to-secondary side mass flow rate at end of run (EOR)

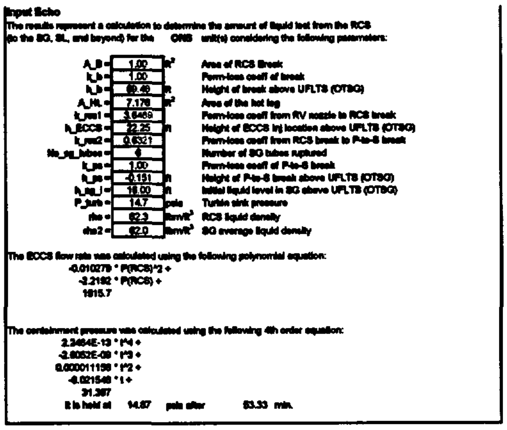
Time to Reach NPSH Limit (cont)

- Results of benchmark

			RELAP5				Spreadsheet			
Break Size	Number of SG Tubes Broken	Case Name	Time of Spillover	Liquid Spilled		P-to-S break flow at EOR	Time of Spillover	Liquid Spilled		P-to-S break flow at EOR
ft^2			s	lbm	ft^3	lbm/s	s	lbm	ft^3	lbm/s
0.5	10	bm0p5c10	1200	181589	2928.85	76.12	1210	184438	2960.49	77.20
6.0	20	bm6p0c20	730	26814	432.48	0.00	710	29557	474.43	0.00
0.5	6	b0p5u	2040	68901	1111.31	46.6	2050	70767	1135.90	47.60
0.75	6	b0p75u	2350	31280	504.52	26.3	2360	32161	516.24	27.01
1.00	6	b1p0u	2540	12851	207.27	12.3	2550	13199	211.87	12.37

Time to Reach NPSH Limit (cont)

- Results of benchmark – 1.0-ft^2 case



Input Echo

The results represent a calculation to determine the amount of liquid lost from the RCS (to the SG, SL, and beyond) for the ONS unit(s) considering the following parameters:

A_B =	1.00	ft^2	Area of RCS Break
k_b =	1.00		Form-loss coeff of break
h_b =	69.46	ft	Height of break above UFLTS (OTSG)
A_HL =	7.178	ft^2	Area of the hot leg
k_rcs1 =	3.6469		Form-loss coeff from RV nozzle to RCS break
h_ECCS =	22.25	ft	Height of ECCS inj location above UFLTS (OTSG)
k_rcs2 =	0.6321		Form-loss coeff from RCS break to P-to-S break
No_sg_tubes =	6		Number of SG tubes ruptured
k_ps =	1.00		Form-loss coeff of P-to-S break
h_ps =	-0.151	ft	Height of P-to-S break above UFLTS (OTSG)
h_sg_l =	16.00	ft	Initial liquid level in SG above UFLTS (OTSG)
P_turb =	14.7	psia	Turbin sink pressure
rho =	62.3	lbm/ft^3	RCS liquid density
rho2 =	62.0	lbm/ft^3	SG average liquid density

The ECCS flow rate was calculated using the following polynomial equation:

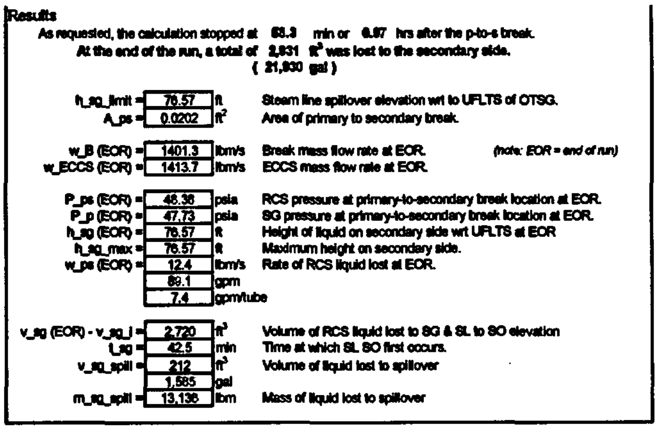
-0.010279 * P(RCS)^2 +
-2.2192 * P(RCS) +
1815.7

The containment pressure was calculated using the following 4th order equation:

2.2464E-13 * t^4 +
-2.8052E-09 * t^3 +
0.000011156 * t^2 +
-0.021548 * t +
31.387
It is held at 14.87 psia after 83.33 min.

Time to Reach NPSH Limit (cont)

- Results of benchmark – 1.0-ft² case



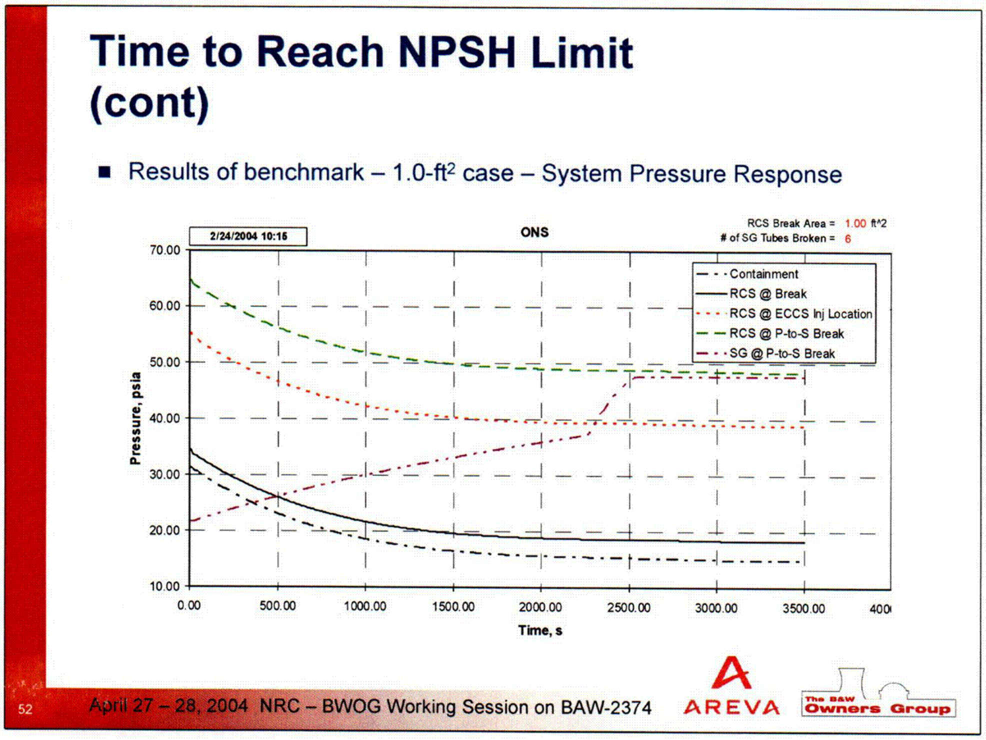
Results

As requested, the calculation stopped at 58.3 min or 0.97 hrs after the p-to-s break.

At the end of the run, a total of 2,931 ft³ was lost to the secondary side.

(21,930 gal)

h_sg_limit =	76.57	ft	Steam line spillover elevation wrt to UFLTS of OTSG.
A_ps =	0.0202	ft²	Area of primary to secondary break.
w_B (EOR) =	1401.3	lbm/s	Break mass flow rate at EOR. *(note: EOR = end of run)*
w_ECCS (EOR) =	1413.7	lbm/s	ECCS mass flow rate at EOR.
P_ps (EOR) =	48.36	psia	RCS pressure at primary-to-secondary break location at EOR.
P_p (EOR) =	47.73	psia	SG pressure at primary-to-secondary break location at EOR.
h_sg (EOR) =	76.57	ft	Height of liquid on secondary side wrt UFLTS at EOR
h_sg_max =	76.57	ft	Maximum height on secondary side.
w_ps (EOR) =	12.4	lbm/s	Rate of RCS liquid lost at EOR.
	89.1	gpm	
	7.4	gpm/tube	
v_sg (EOR) - v_sg_i =	2,720	ft³	Volume of RCS liquid lost to SG & SL to SO elevation
t_sg =	42.5	min	Time at which SL SO first occurs.
v_sg_spill =	212	ft³	Volume of liquid lost to spillover
	1,585	gal	
m_sg_spill =	13,136	lbm	Mass of liquid lost to spillover



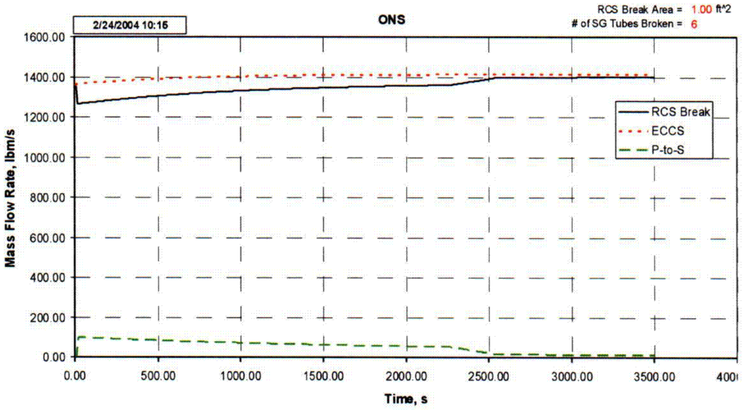
Time to Reach NPSH Limit (cont)

- Results of benchmark – 1.0-ft^2 case – System Pressure Response

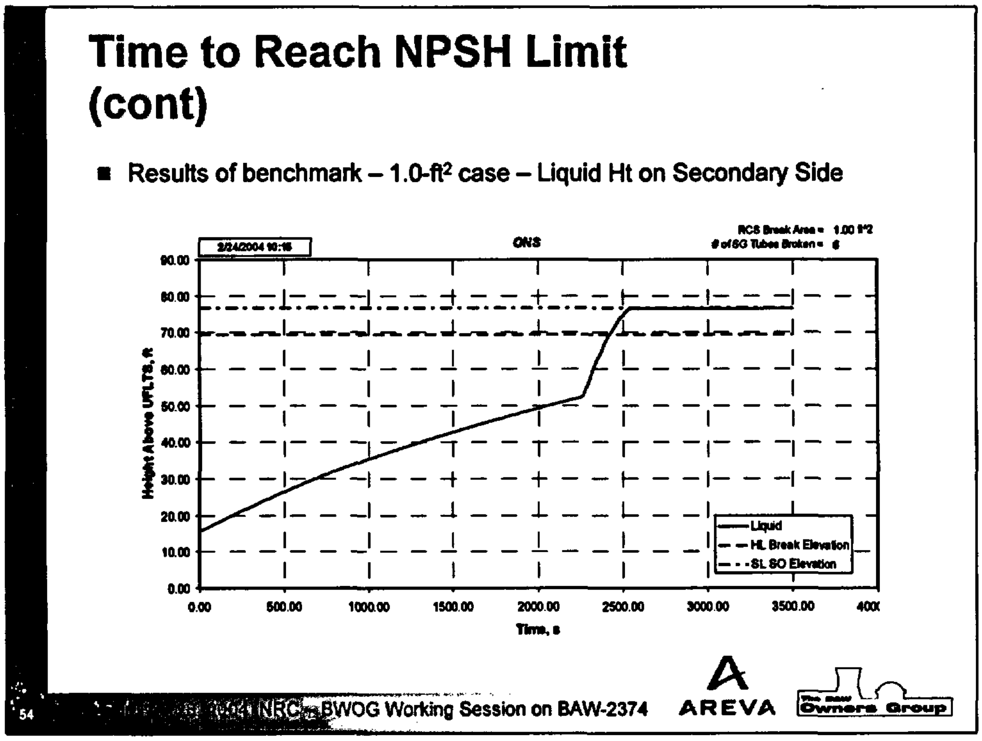
C05

Time to Reach NPSH Limit (cont)

- Results of benchmark – 1.0-ft² case – System Mass Flow Rates



C06

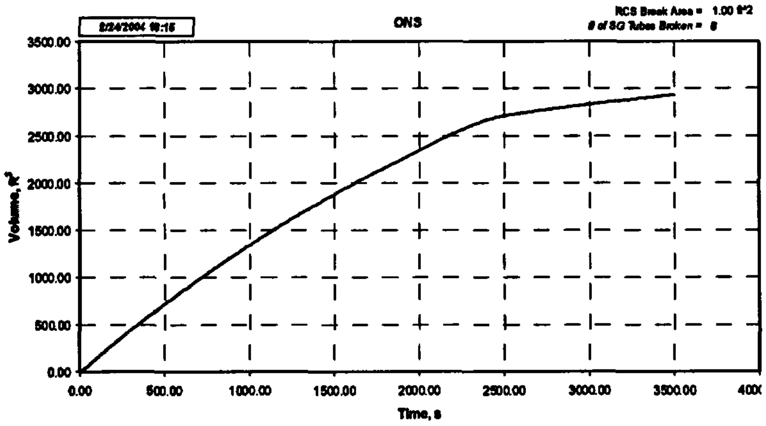


Time to Reach NPSH Limit (cont)

- Results of benchmark – 1.0-ft² case – Liquid Ht on Secondary Side

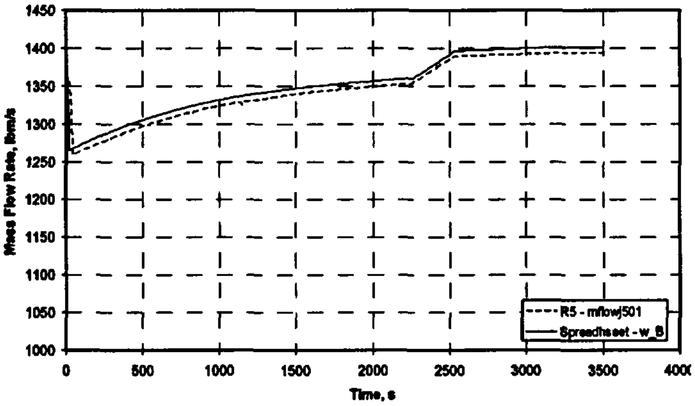
Time to Reach NPSH Limit (cont)

- Results of benchmark – 1.0-ft^2 case – Liquid Lost to Secondary



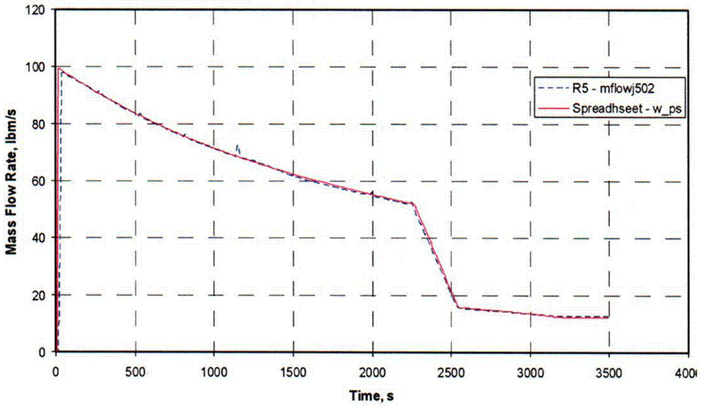
Time to Reach NPSH Limit (cont)

- Results of benchmark – 1.0-ft² case – Comparison of Break Mass Flow Rate



Time to Reach NPSH Limit (cont)

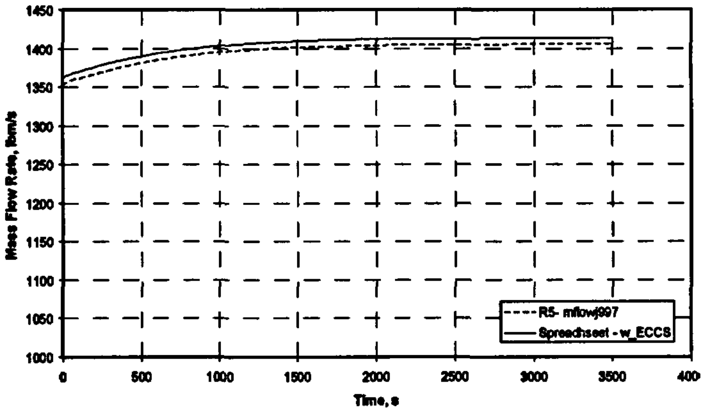
- Results of benchmark – 1.0-ft^2 case – Comparison of P-to-S Mass Flow Rate



C07

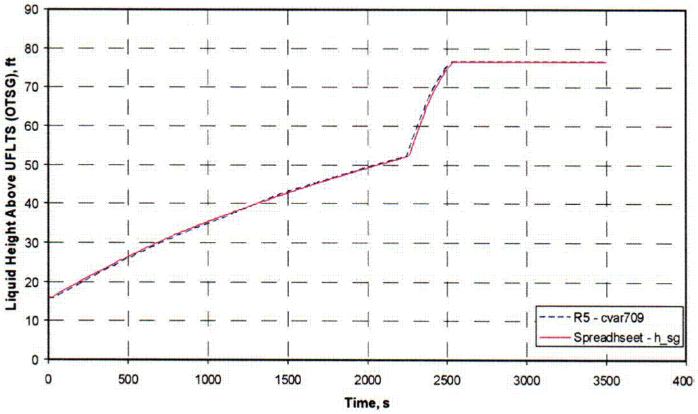
Time to Reach NPSH Limit (cont)

- Results of benchmark – 1.0-ft² case – Comparison of ECCS Mass Flow Rate



Time to Reach NPSH Limit (cont)

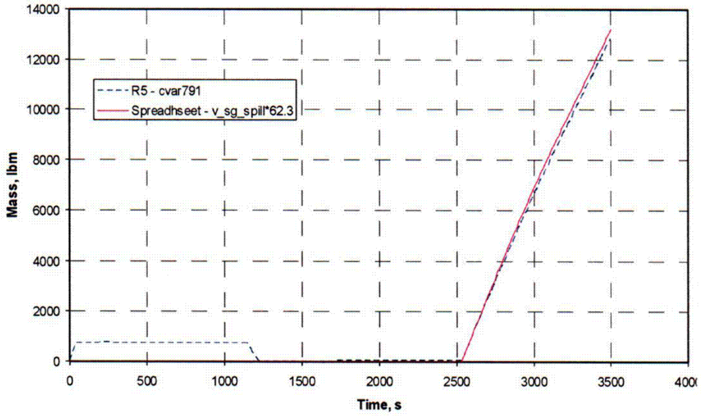
- Results of benchmark – 1.0-ft^2 case – Comparison of SG Liquid Height



C08

Time to Reach NPSH Limit (cont)

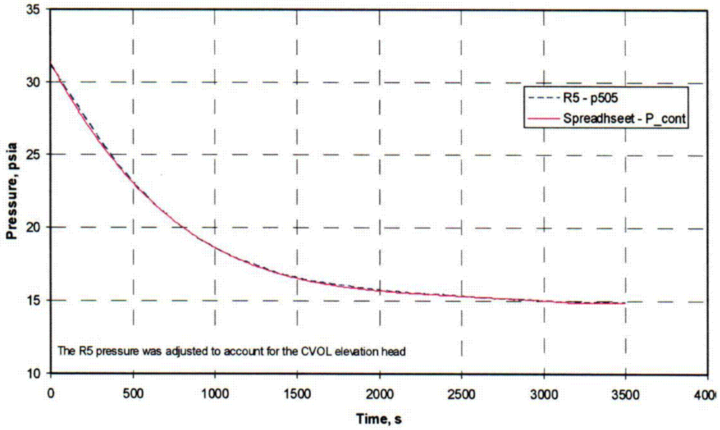
- Results of benchmark – 1.0-ft^2 case – Comparison of Liquid Lost to SG & SL



C09

Time to Reach NPSH Limit (cont)

- Results of benchmark – 1.0-ft^2 case – Comparison of Containment Pressure

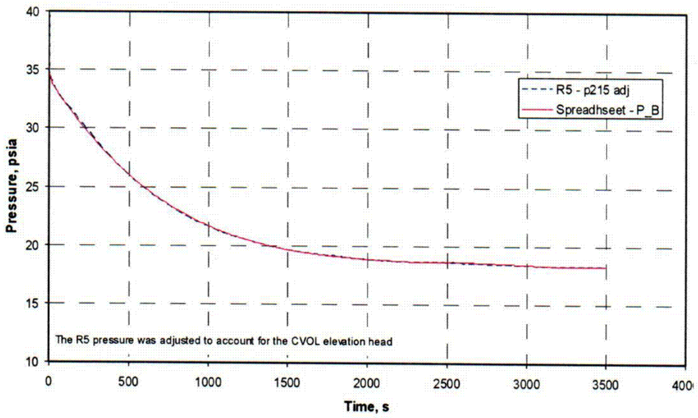


The R5 pressure was adjusted to account for the CVOL elevation head

C10

Time to Reach NPSH Limit (cont)

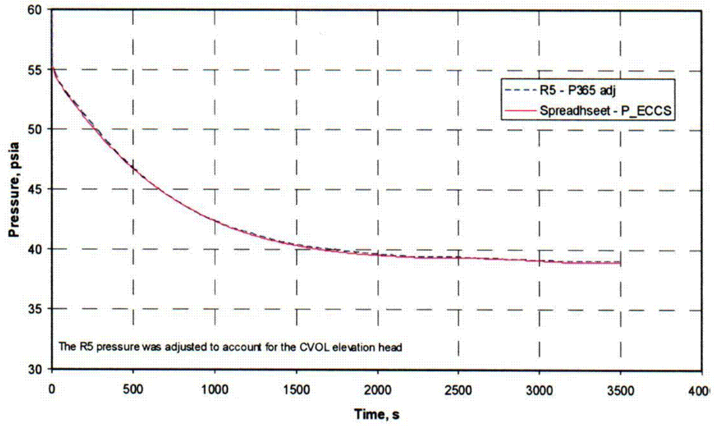
- Results of benchmark – 1.0-ft^2 case – Comparison of Break Pressure



C11

Time to Reach NPSH Limit (cont)

- Results of benchmark – 1.0-ft^2 case – Comparison of ECCS Pressure

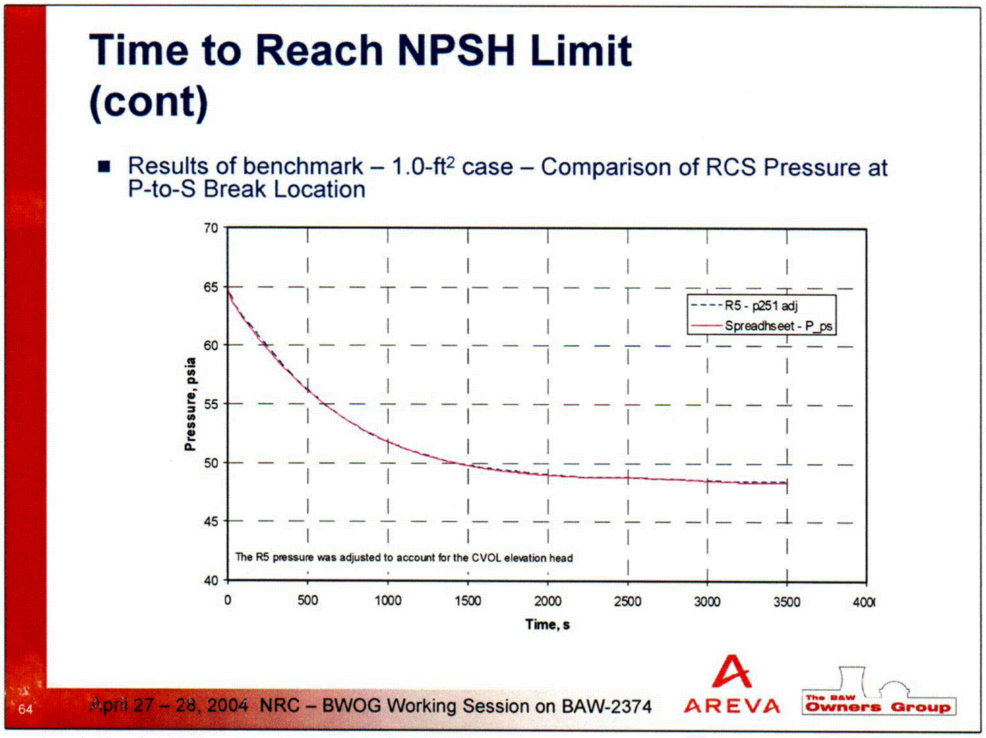


The R5 pressure was adjusted to account for the CVOL elevation head

C12

Time to Reach NPSH Limit (cont)

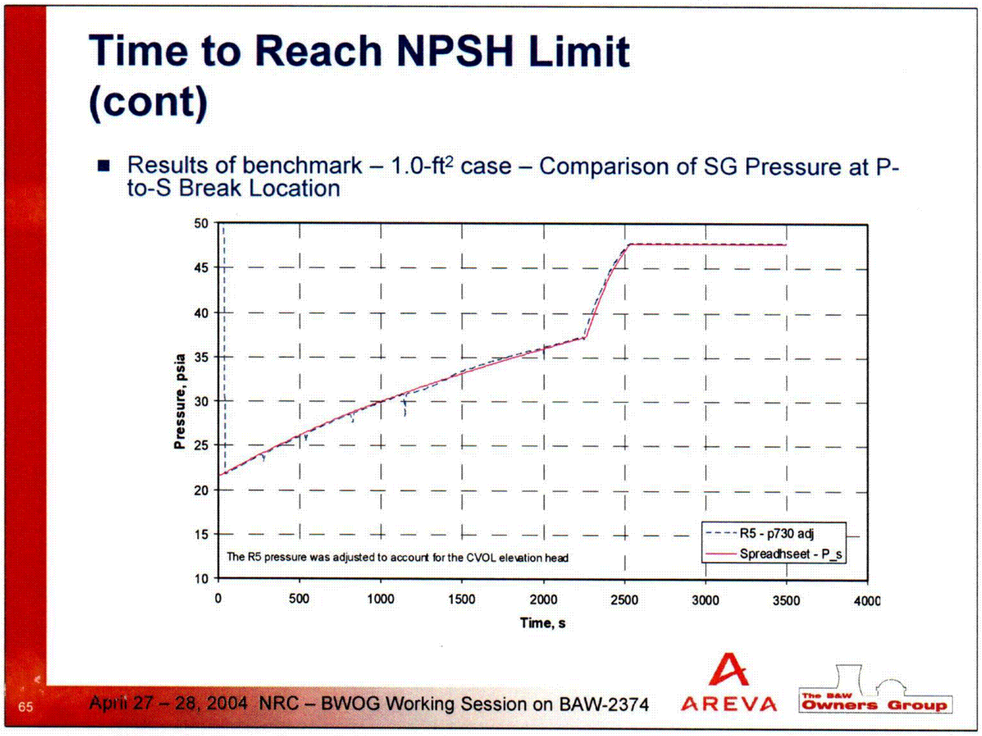
- Results of benchmark – 1.0-ft^2 case – Comparison of RCS Pressure at P-to-S Break Location



C 13

Time to Reach NPSH Limit (cont)

- Results of benchmark – 1.0-ft^2 case – Comparison of SG Pressure at P-to-S Break Location

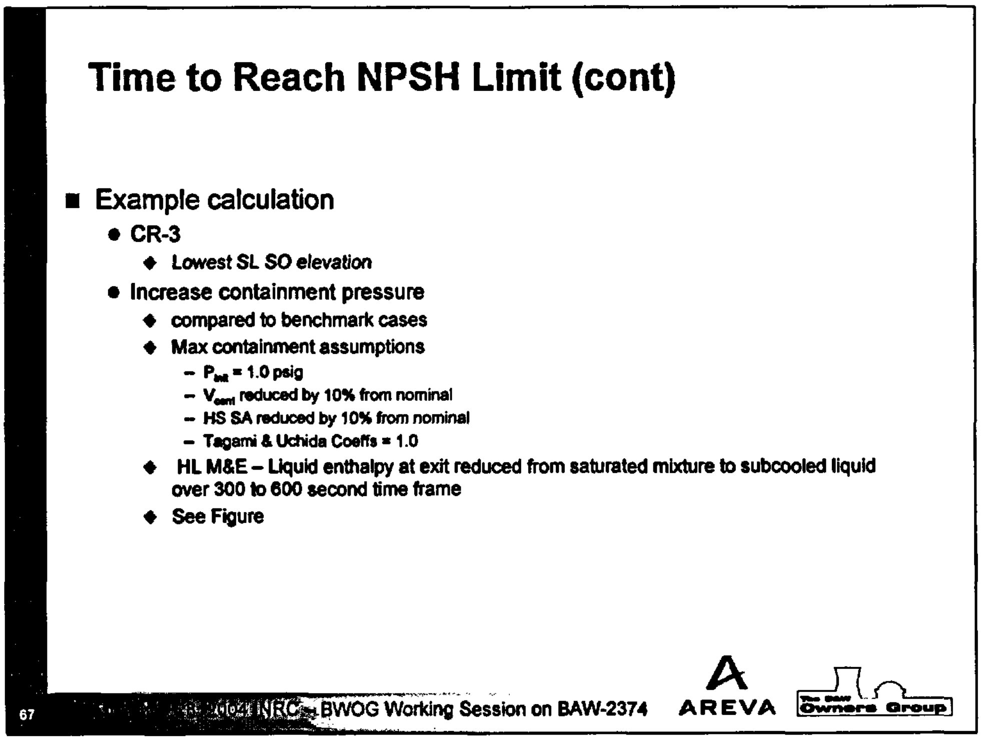


The R5 pressure was adjusted to account for the CVOL elevation head

C14

Time to Reach NPSH Limit (cont)

- Conclusions of benchmark
  - RELAP5 & Excel calculations match
  - Excel calculation valid for
    - A wide range of RCS break areas
    - A wide range of SG tube failures
  - Excel calculations should be reasonable for exploratory analyses to define "final" full RELAP5 case to be examined



Time to Reach NPSH Limit (cont)

- Example calculation
  - CR-3
    - *Lowest SL SO elevation*
  - Increase containment pressure
    - compared to benchmark cases
    - Max containment assumptions
      - P_{init} = 1.0 psig
      - V_{cont} reduced by 10% from nominal
      - HS SA reduced by 10% from nominal
      - Tagami & Uchida Coeffs = 1.0
    - HL M&E – Liquid enthalpy at exit reduced from saturated mixture to subcooled liquid over 300 to 600 second time frame
    - See Figure

AREVA

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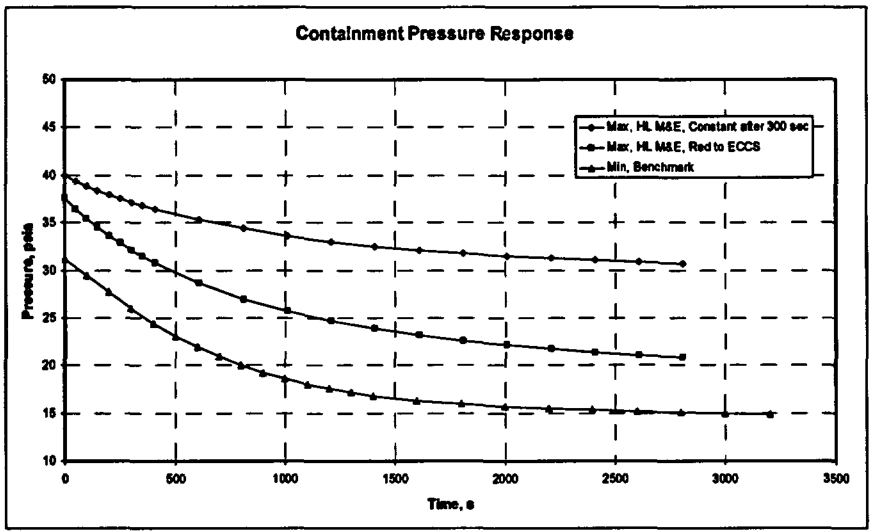
Time to Reach NPSH Limit (cont)



Time to Reach NPSH Limit (cont)

- Example calculation (cont)
  - Maximum ECCS
    - 2 trains of unthrottled LPI
  - Vary number of failed tubes – 1, 6, 10, 15, 20, 50
  - Determine time to reach 5,000 ft^3 of liquid lost, which corresponds to ~0.5 feet of liquid in containment

Time to Reach NPSH Limit (cont)

- Example calculation (cont)
  - Time after SG tube failure to reach 5,000 ft^3 of lost liquid (~0.5 feet of liquid in containment sump)

1 tube	>333.0 min (~8.2 hrs)
2 tubes	243.0 min (~4.1 hrs)
4 tubes	119.5 min (~2.0 hrs)
6 tubes	78.0 min (~1.3 hrs)
10 tubes	44.5 min
15 tubes	28.2 min
20 tubes	20.3 min
50 tubes	12.5 min

Time to Reach NPSH Limit (cont)

- The RCS break size determines the SG tube loads, which helps to define the number of failed SG tubes, which defines the rate of RCS liquid lost to secondary side, which can be used to determine the time to reach the NPSH limit.
- The time to reach NPSH limit is highly plant dependent
  - Single failure assumption
  - Isolation capabilities
  - NPSH margin and calculation assumptions
  - ECCS/CS flow rates

Dose Evaluation

- Later (Eric's slides)

General Observations

- The solution to the SG tube loads problem involves many, separate but related tasks to determine
  - the maximum TTS ΔT
  - fuel failure and related dose
  - number of SG tube failures
  - primary-to-secondary leakage
  - ECCS pump NPSH
  - etc.
- Each of these tasks requires selection of initial and boundary conditions to ensure conservative results
- However, each one plays a different role for each task...

General Observations (cont)

- Furthermore, the conclusions of each task affect and are affected by the subsequent and previous tasks (i.e. an iterative process)