Butt Weld Safety Assessment Meeting

MRP / NRC
September 11, 2003

Alloy 600 Issue Task Group (ITG)
Butt Weld Working Group

Dana Covill, Progress Energy, Chairman

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Butt Weld Safety Assessment Meeting
MRP / NRC

- Other Industry participants
  - Larry Mathews, SNC, Alloy 600 ITG Chairman
  - Patrick O'Regan, EPRI
  - Steve Hunt, DEI
  - Ken Yoon, Framatome ANP
  - Warren Bamford, Westinghouse
  - Jim Riley, NEI
  - Frank Ammirato, EPRI NDE Center

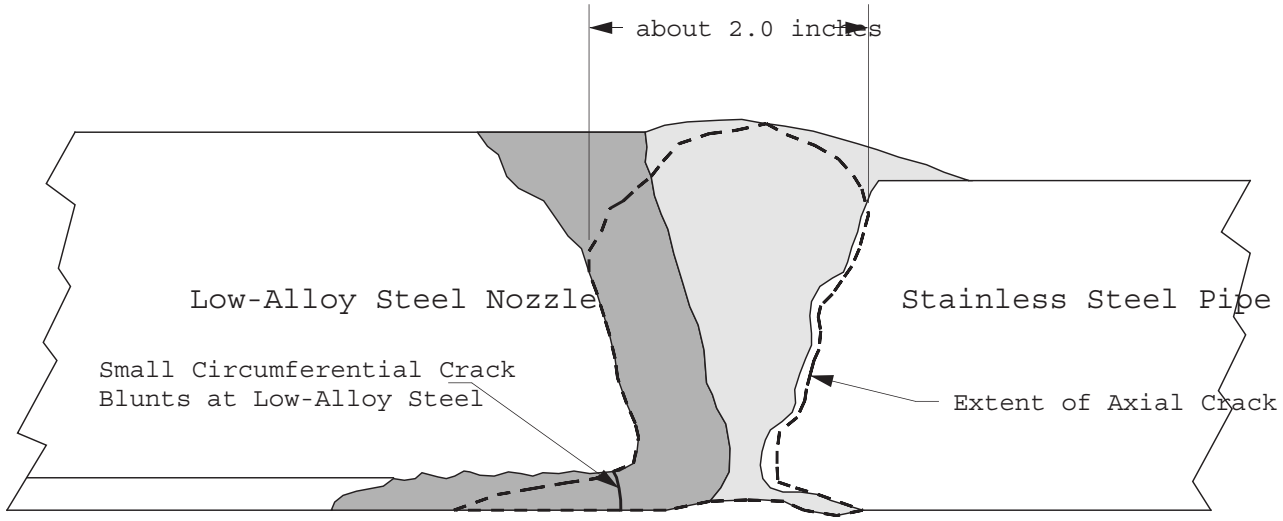
Agenda

- Review of Interim Butt Weld Safety Assessment (MRP-44, Part 1)
- Recent Inspections and Results
- NRC Comments on MRP-44, Part 1 and MRP Responses
- Final Safety Assessment – Contents and Schedule
- Future Activities

Interim Butt Weld Safety Assessment – MRP-44, Part 1
Contents

- Interim Safety Assessment submitted April 2001
- Main body of report
  - Background of VC Summer and Ringhals RPV nozzle cracks
  - Important butt weld locations
  - Assessment methodology
  - Interim safety assessment results
  - Interim recommendations
- Appendices
  - Evaluation of limiting locations in Westinghouse design plants (reactor vessel outlet nozzle) and CE design plants (pressurizer surge line nozzle)
  - Locations of Alloy 82/182 butt welds in B&W design plants
  - Welding residual stress analysis for VC Summer and Ringhals RV outlet nozzle welds

Interim Butt Weld Safety Assessment - MRP-44, Part 1
VC Summer Cracks



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Interim Butt Weld Safety Assessment - MRP-44, Part 1 *Important Butt Weld Locations*

Location	Westinghouse Design Plants	Combustion Engineering Design Plants	Babcock & Wilcox Design Plants
Reactor Vessels			
- Inlet & Outlet Nozzles	Yes	No*	No
- CRDM Motor Housing	No	Yes	Yes
- Core Flood Nozzle	NA	?	Yes
Pressurizers			
- Surge Line Nozzles	Yes	Yes	Yes
- Spray Nozzles	Yes	Yes	Yes
- Safety & Relief Valve Nozzles	Yes	Yes	Yes
Main Coolant Piping Loop			
- SG Inlet & Outlet Nozzles	Yes	No*	No
- RCP Suction & Discharge Nozzles	No	Yes	Yes
Branch Line Connections			
- Pipe to Surge Nozzle Connection	Yes	Yes	Yes
- Charging Inlet Nozzles	No	Yes	Yes
- Safety Injection and SDC Inlet	No	Yes	Yes
- Shutdown Cooling Outlet Nozzle	No	Yes	Yes
- Spray Nozzles	No	Yes	Yes
- Let-Down and Drain Nozzles	No	Yes	Yes
- Core Flood Tank Nozzle	NA	?	Yes

*One CE design plant has Alloy 82/182 welds and is evaluated with the Westinghouse design plants

Interim Butt Weld Safety Assessment - MRP-44, Part 1 *Assessment Methodology*

- Crack orientation
  - Most cracks expected to be axial based on experience and FEA of butt welds
  - Potential for circumferential cracks is small (potential is increased for cases involving ID surface weld repairs)
- Leak detection and structural margin
  - Axial cracks will arrest when they reach carbon steel nozzle or stainless steel pipe
  - Partial-arc through wall cracks will exhibit leaks while there is still significant margin (Example: Palisades pressurizer safe end, 1993)
  - Low probability of rupture due to part-depth 360° circumferential flaw
    - Experience in BWRs and PWRs has shown few long partial depth flaws at butt welds
    - External moments and weld pass sequencing tend to drive cracks to partial-arc
    - Circumferential cracks starting in cladding under base metal will arrest

Interim Butt Weld Safety Assessment - MRP-44, Part 1 *Assessment Methodology (cont.)*

- Defense-in-depth
  - Analyses demonstrate cracks do not significantly increase Core Damage Frequency
  - Instantaneous pipe rupture is analyzed accident per FSAR
- Operational experience
  - Many inspections performed
  - Lack of significant findings suggests no widespread problems
  - VC Summer cracks discovered by boric acid residue from leakage long before there was any safety risk
  - Inspections at several plants during 2001 showed no problems

Interim Butt Weld Safety Assessment - MRP-44, Part 1 *Conclusions*

- Most cracks are expected to be axial
- Axial cracks are limited to width of the weld
- Partial-arc circ cracks should exhibit leak before break
- Part-depth 360° circumferential cracks are unlikely in moment loaded applications
- There is significant defense-in-depth
- There is no history of widespread problems despite 88-05 walkdowns and 10 year ISI inspections
- There is no concern with boric acid corrosion

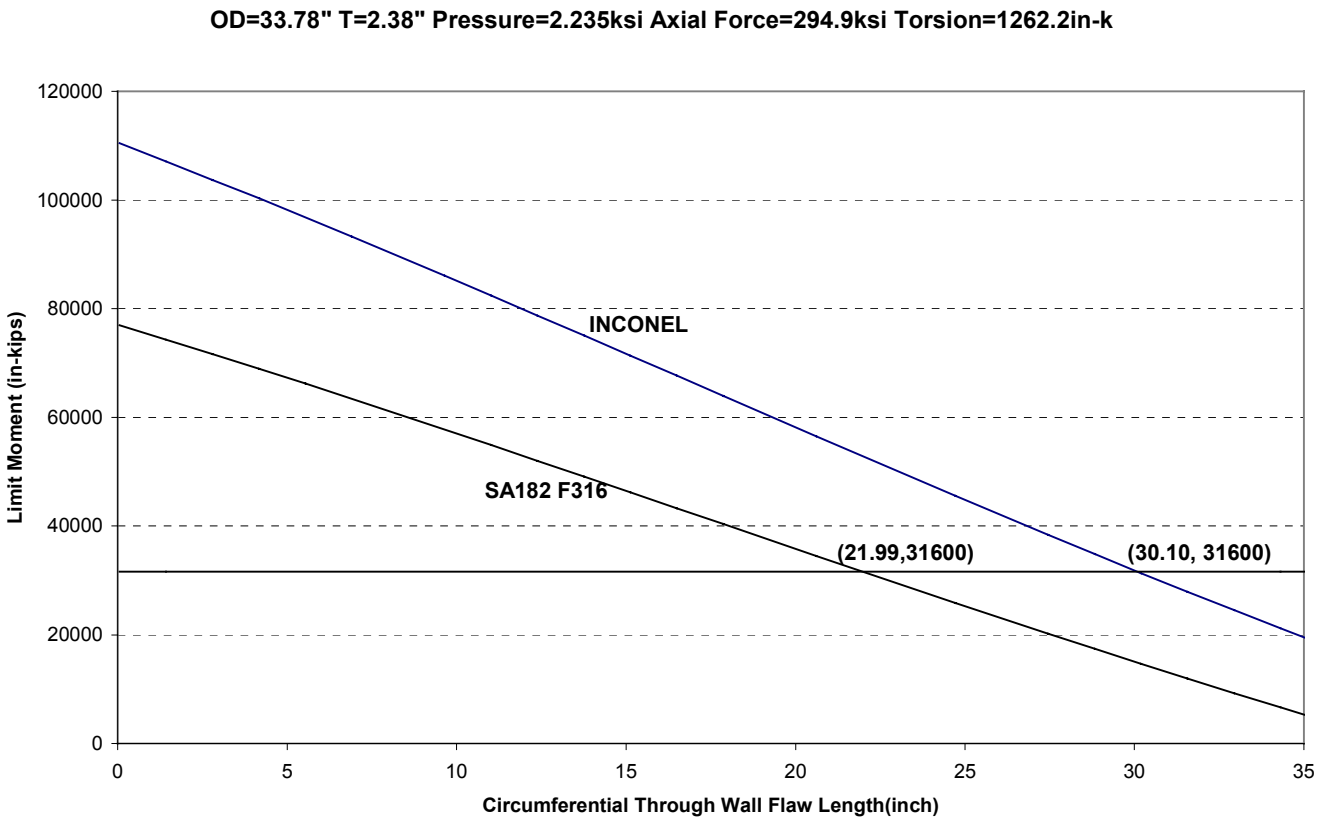
Interim Butt Weld Safety Assessment - MRP-44, Part 1 *Recommendations*

- Enhance sensitivity of personnel performing 88-05 boric acid walkdowns
- Enhance sensitivity of NDE personnel to inspection capabilities, limitations and results
- Enhance sensitivity of operations personnel to small changes in containment leak rates
- Encourage use of mockups to demonstrate NDE capabilities

Interim Butt Weld Safety Assessment - MRP-44, Part 1 *Appendix A: Westinghouse and CE Design Plants*

- Selection of most important locations
  - Westinghouse plants: reactor vessel outlet nozzles
  - CE plants: pressurizer surge line nozzles
- Most probable flaw orientations are axial based on service experience and stress analysis
- Limit load analyses for most important locations
- Leak-before-break assessment for most important locations
- Risk evaluation shows the change in core damage frequency due to stress corrosion to be about 4x10-8 per year

Interim Butt Weld Safety Assessment - MRP-44, Part 1 *Appendix A: Westinghouse and CE Design Plants*



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Interim Butt Weld Safety Assessment - MRP-44, Part 1 *Appendix B: B&W Design Plants*

- Provided a compilation of butt weld locations by plant
- Provided current basis for there being no immediate safety problem
  - B&W plants do not have the type of weld joints used at VC Summer
  - B&W vessel nozzle-to-pipe shop and field butt welds were heat treated to relieve welding residual stresses
- Additional evaluations are underway to assess the safety significance of other Alloy 82/182 weld locations

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Interim Butt Weld Safety Assessment - MRP-44, Part 1 *Appendix C: Welding Residual Stress Analysis*

- Welding residual stress analyses performed for VC Summer and Ringhals nozzle-to-pipe butt welds
- Analyses show that hoop stresses exceed axial stresses under most conditions
- Axial stresses can exceed hoop stresses locally on the ID surface for cases of weld repairs performed on the pipe ID surface
- Analysis results are consistent with field experience to date

Recent Inspections and Results
US Experience

- No leaks detected by visual methods
- About 150 dissimilar metal butt welds UT inspected since 2001
  - About 140 before Appendix VIII qualification required
  - About 10 qualified to Appendix VIII
  - No indications detected

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Recent Inspections and Results
Tihange Unit 2 Surge Nozzle Indications

- Axial and circumferential indications were discovered in the safe end Alloy 182 weld of the surge nozzle
- Axial flaw, 28 mm (1.10 in) long x 8 mm (0.31 in) deep, entirely in the weld
- The plant is a three loop, 900 Mwt, Framatome plant, built by Cockerill. The weld was stress relieved with the vessel
- Inspection done by AIB Vincottes, of Belgium, a well-qualified vendor.
- Indications were reinspected after six months
  - No growth detected
- Utility is evaluating the source of the indications. May be
  - PWSCC at stage of slow growth
  - Subsurface fabrication defects

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NRC Comments on MRP-44, Part 1 and Response
General Findings

- NRC letter of June 14, 2001 provided comments on MRP-44, Part 1
- *The general findings were:*
  - *Cracking observed to date has been predominantly axial*
  - *Pipe weld axial crack growth is bounded by the low-alloy steel or stainless steel materials at each end*
  - *The critical flaw size for axial rupture is several times larger than the weld width*
  - *No significant concern exists for boric acid corrosion*
- *The above findings provide a basis for continued safe operation while additional analyses and inspections are performed*
- *Additional work is necessary to understand the potential for significant circumferential cracking*

NRC Comments on MRP-44, Part 1 and Response
Staff Expectations

- NRC letter of June 14, 2001 provided staff expectations that the final report will address:
  - Potential for multiple initiation sites in single weld
  - Need to augment visual inspections or employ augmented leak detection capabilities
  - Need to develop generic susceptibility ranking and proposed inspection scope and schedule
  - Other items discussed in NRC/MRP meetings

NRC Comments on MRP-44, Part 1 and Response
Visual Inspection for Leaks - 1

- *The expected leakage levels, considering experience which has shown very low volumes of leakage from tight cracks in combination with the dendritic nature of welds, should be addressed*
- Response:
  - The SA report will address the issue of small amounts of leakage from butt weld cracks
  - Small amounts of leakage are detectable by bare metal visual inspections at all locations
  - Leakage will be detectable by on-line means for locations of greatest concern, i.e., through wall partial-arc circumferential cracks in large diameter RPV and pressurizer surge nozzles

NRC Comments on MRP-44, Part 1 and Response
Visual Inspection for Leaks - 2

- *The ability of current leakage detection systems (inventory makeup, radiation monitoring, sumps, etc.) to detect small volumes of leakage should be addressed*
- Response:
  - The ability of current systems to detect small leaks will be addressed in the SA report

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NRC Comments on MRP-44, Part 1 and Response
Visual Inspection for Leaks - 3

- *Plant-specific factors such as insulation or other obstructions that may limit the effectiveness of visual examinations need to be addressed*
- Response:
  - The SA report will include a discussion of the typical insulation at each type of butt weld and how this insulation affects the ability to find small leaks
  - The need to remove insulation to provide access for direct visual inspections will be addressed

NRC Comments on MRP-44, Part 1 and Response
ISI Capability - 1

- *Presently required ISI examinations need to be augmented*
  - *UT examinations do not appear to be effective in detecting all cases of PWSCC*
  - *Specifically, UT missed cracks at VC Summer during 10-year ISI program that were detected by leakage*
- Response:
  - The SA report will address need to augment ISI
  - The reasons for the missed detections at VC Summer are understood. Modifications to inspection tooling and procedures are being qualified through Appendix VIII
  - The SA report will recommend the type(s) of inspection and inspection intervals that will ensure a suitably low risk of Core Damage per Reg. Guide 1.174

NRC Comments on MRP-44, Part 1 and Response
ISI Capability - 2

- *The report concludes an absence of widespread problems based on ISI inspections*
  - *Is it possible that the absence of problems is really just a reflection of poor inspectability by UT?*
- Response:
  - Inspection techniques now required to meet Appendix VIII, Supplement 10
  - The effectiveness of inspections will be addressed in the SA report

NRC Comments on MRP-44, Part 1 and Response
ISI Capability - 3

- *Inspection improvements are necessary*
  - *Use the best available techniques*
  - *Address known concerns such as susceptibility to ID surface conditions*
  - *Include real PWSCC cracks in NDE qualification mockups*
- Response:
  - Inspection techniques now required to meet Appendix VIII, Supplement 10
  - The effectiveness of inspections will be addressed in the SA report
  - ISI vendors have modified transducer sleds to address the ID surface contour issue identified at VC Summer
  - The Appendix VIII qualification program for dissimilar metal welds has included mockups with surface conditions representative of VC Summer
  - The NRC has reviewed the process used to produce mockups with flaws for qualification of dissimilar metal weld inspections
  - It is understood that there are no open issues pertaining to flaws used in mockups

NRC Comments on MRP-44, Part 1 and Response
Fracture Evaluation and Leak-Before-Break - 1

- *The staff agrees that axial cracks are not a safety concern*
- *MRP-44 does not adequately substantiate that large part-depth 360° flaws may not develop in service*
  - *Analyses need to show that large part-depth circumferential flaws cannot develop*
  - *Analysis must consider effects such as multiple flaw initiation*
- Response:
  - The technical case for showing that PWSCC should be predominantly short and axial or partial-arc circumferential is being improved
  - Finite element modeling and fracture mechanics analysis are being used to support the technical case
  - The analytical case is being supplemented by inspection results for both PWR and BWR plants

NRC Comments on MRP-44, Part 1 and Response
Fracture Evaluation and Leak-Before-Break - 2

- *More detail is required regarding leakage calculations*
  - *Crack surface roughness, number of 45 ° & 90 ° turns, uncertainties, etc.*
  - *Licensing basis calculations for approving LBB for piping systems include a factor of safety of 10 on leakage*
- Response:
  - Leakage calculations are being refined
  - The probability of leakage detection is being included in the probabilistic fracture mechanics analysis used to establish the effect of butt weld PWSCC on Core damage

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NRC Comments on MRP-44, Part 1 and Response
Fracture Evaluation and Leak-Before-Break - 3

- *More detail is required regarding the critical flaw size, including assumed material properties and loadings*
- Response:
  - Critical flaw size calculations will provide the requested information

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NRC Comments on MRP-44, Part 1 and Response
Cracking Phenomenon - 1

- *The potential for circumferential cracking developing at a location where the entire cross section is Alloy 82/182 needs to be addressed*
- Response:
  - The potential for circumferential cracking is being addressed through
    - Field experience with PWR and BWR welds
    - Finite element analysis including welding residual stresses, operating pressure and temperature and other piping loads
    - Deterministic and probabilistic fracture mechanics analyses
  - Analyses are expected to show that the increase in risk due to an undetected circumferential flaw is within the criteria specified by Reg. Guide 1.174

NRC Comments on MRP-44, Part 1 and Response
Cracking Phenomenon - 2

- *The following factors should be addressed regarding predicted cracking*
  - *Type of cracks: axial vs. circumferential*
  - *Nature of cracks: through-wall vs. 360° part depth, multiple initiation*
  - *Stresses: orientations and magnitudes of welding residual and operating stresses*
  - *Repairs: extent and nature*
  - *Weld structure: micro- and macro-*
  - *Operating conditions: time and temperature*
  - *Crack growth rates*
- Response:
  - The above issues are being addressed in the SA report

NRC Comments on MRP-44, Part 1 and Response
Weld Residual Stress Evaluation - 1

- *Analyses of Appendix C were useful in understanding specific issues associated with VC Summer and foreign experience*
- *Several items of interest were not included in Appendix C*
  - *Through-wall thickness profiles showing welding/repair residual stresses and superimposed operating condition stresses*
  - *Investigation into the adequacy of axi-symmetric modeling and elastic-perfectly plastic material properties*
  - *Details of ANSYS thermal and residual stress analysis models such as mesh refinement studies, and a description of how properties of previous weld passes were changed during re-melting and solidification due to new passes being deposited*
- Response:
  - Appendix C provided sample results to help understand the VC Summer cracking
  - A more complete stress analysis report is being prepared addressing the other issues

NRC Comments on MRP-44, Part 1 and Response
Weld Residual Stress Evaluation - 2

- *Work should be expanded to cover a full range of designs and fabrications, including outliers to provide a more balanced assessment of stresses*
- Response:
  - The final stress analysis report has been expanded to cover
    - RPV inlet/outlet nozzles
    - Pressurizer sure nozzles
    - Pressurizer spray nozzles
    - Pressurizer safety relief nozzles
  - The analyses include
    - Welding residual stresses, operating pressure and temperature, other piping loads
    - A range of weld repairs from full 360º to 30º, 60º and 90º partial arcs

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NRC Comments on MRP-44, Part 1 and Response
Risk Assessment - 1

- *Appendix A, Section 7, "Risk Evaluation" concludes that risk of core damage due to PWSCC related large leaks is expected to remain insignificant, and that a number of potential actions are available to reduce uncertainty and manage PWSCC degradation*
- *Staff requests that further technical justification for the core damage risk assessment be provided based on*
  - *Realistic initiating event frequencies*
  - *Bounded by technically-justified uncertainty bands for all three types of NSSS designs*
- Response:
  - The risk assessment is being refined by a probabilistic fracture mechanics analysis that addresses all the key geometries on the previous slide

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NRC Comments on MRP-44, Part 1 and Response
Risk Assessment - 2

- *Risk-informed assessments should provide sufficient details that the staff can verify risk-informed results*
- Response:
  - Details of the risk evaluation will be included

NRC Comments on MRP-44, Part 1 and Response
Boric Acid Corrosion

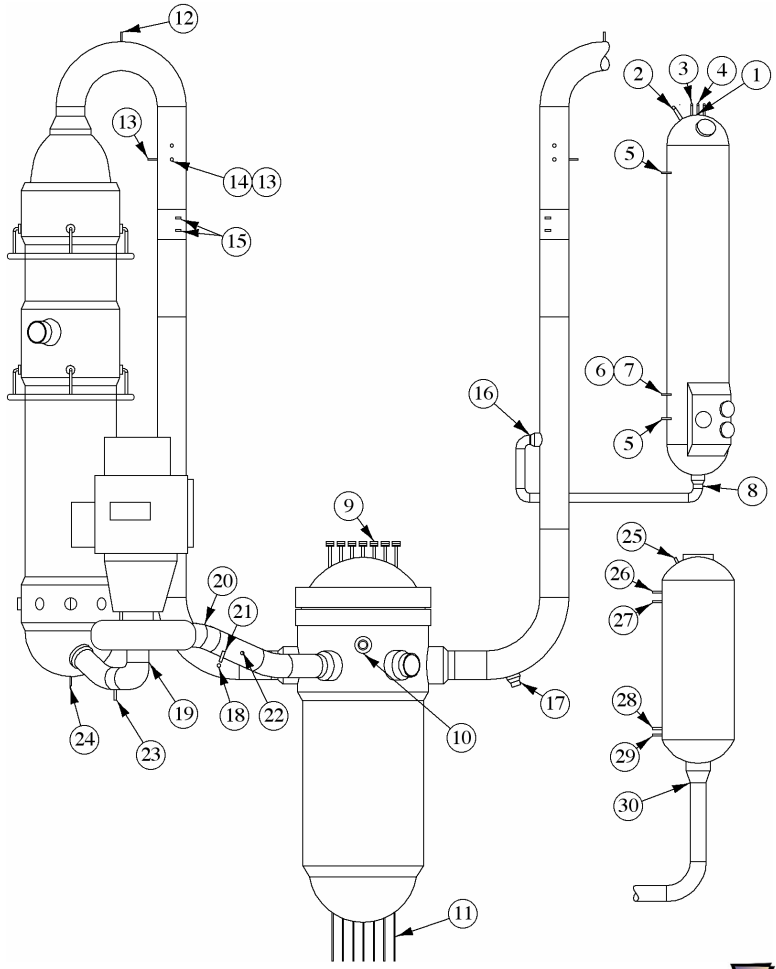
- *By letter from Sheron (NRC) to Marion (NEI) dated April 22, 2003, the NRC has questioned the conclusion that there is no concern with boric acid corrosion due to low leak rates from PWSCC cracks and high temperatures*
- Response:
  - The SA will address the issue of boric acid corrosion based on field experience and current analytical knowledge

Final Butt Weld Safety Assessment
Contents

- Overview Safety Assessment Report
  - One overview document to pull together assessment methodology, summary of supporting technical work, conclusions and recommendations
- Supporting Technical Reports
  - Safety Assessment Report for Westinghouse and Combustion Engineering Design Plants
  - Safety Assessment Report for Babcock & Wilcox Design Plants
  - Welding Residual and Operating Stresses for Selected Butt Welds
  - Fracture Mechanics Analyses for Selected Butt Welds
  - Risk Evaluation

Final Butt Weld Safety Assessment
Coverage

- Final assessment addresses the full range of nozzle locations
- Figures shows locations for typical B&W and Westinghouse plants



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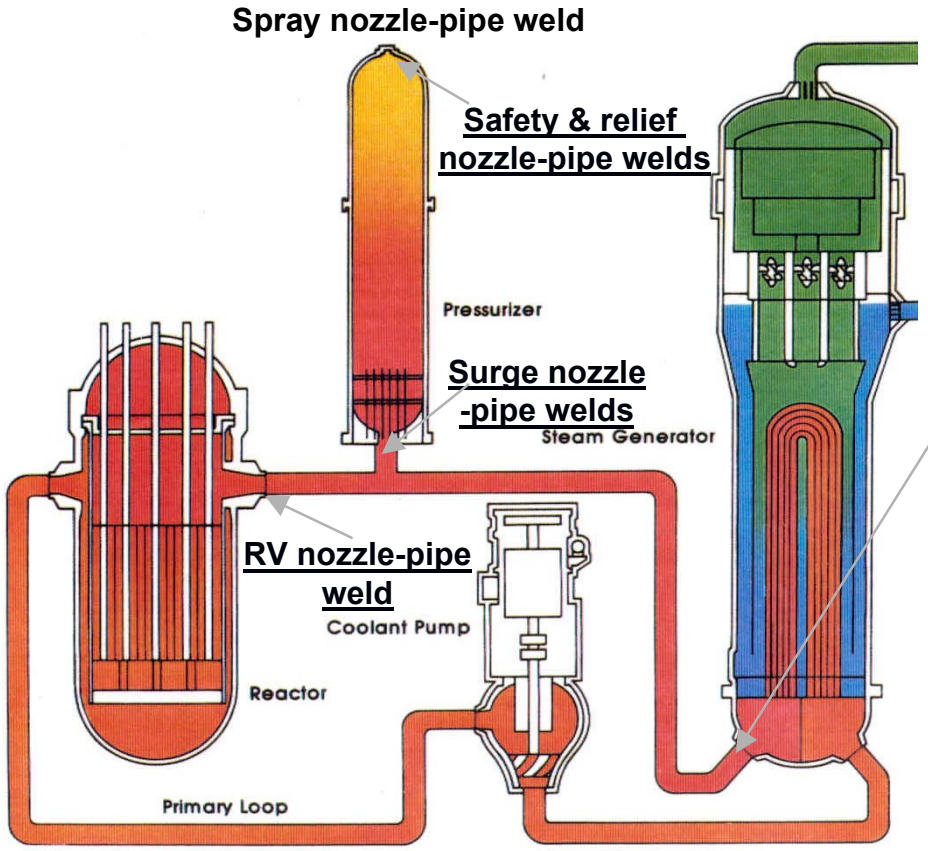
Final Butt Weld Safety Assessment
Coverage

Westinghouse PWRs



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Final Butt Weld Safety Assessment
Schedule

- Submit to NRC by end of first quarter 2004
- Expect to have interim technical exchange meetings with NRC
  - Possibly December and late January

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Final Butt Weld Safety Assessment
Future Activities

- Code activities
  - Recommend Code changes based on results, if appropriate
    - Could be changes to locations inspected, inspection methods and frequencies
    - More comprehensive guidance
- Industry activities
  - Evaluating recommendations for implementation fleet-wide under the NEI Materials Initiative
  - Continue to monitor inspection results and OE

Final Butt Weld Safety Assessment Meeting Summary

- Review of Interim Butt Weld Safety Assessment (MRP-44, Part 1)
- Recent Inspections and Results
  - No new leaks or crack indications in butt welds detected since VC Summer
- NRC Comments on MRP-44, Part 1 and Planned MRP Response
- Final Safety Assessment
  - End of first quarter 2004
- Future Activities
  - Code changes
  - Implementation of recommendations

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