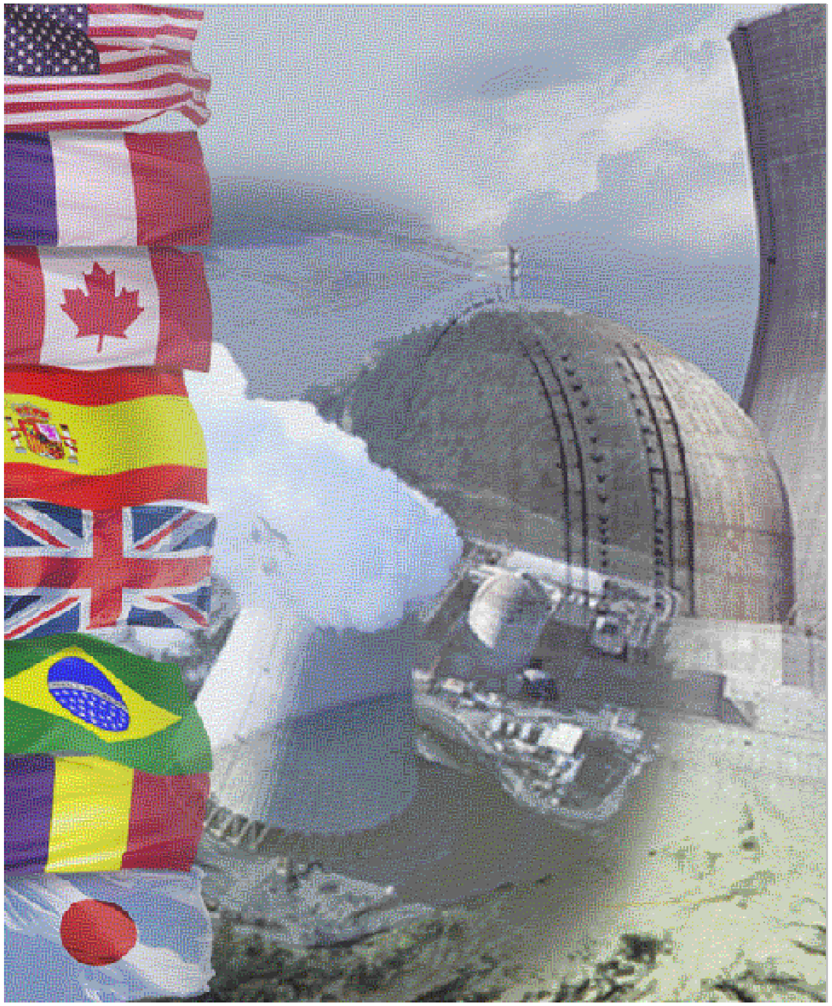


Alloy 82/182 Pipe Butt Weld Safety Assessment
MRP-113

MRP / NRC

July 30, 2004

Alloy 600 Issue Task Group (ITG)

Larry Mathews, Southern Nuclear, Chairman

Butt Weld Working Group

Dana Covill, Progress Energy, Chairman

Agenda

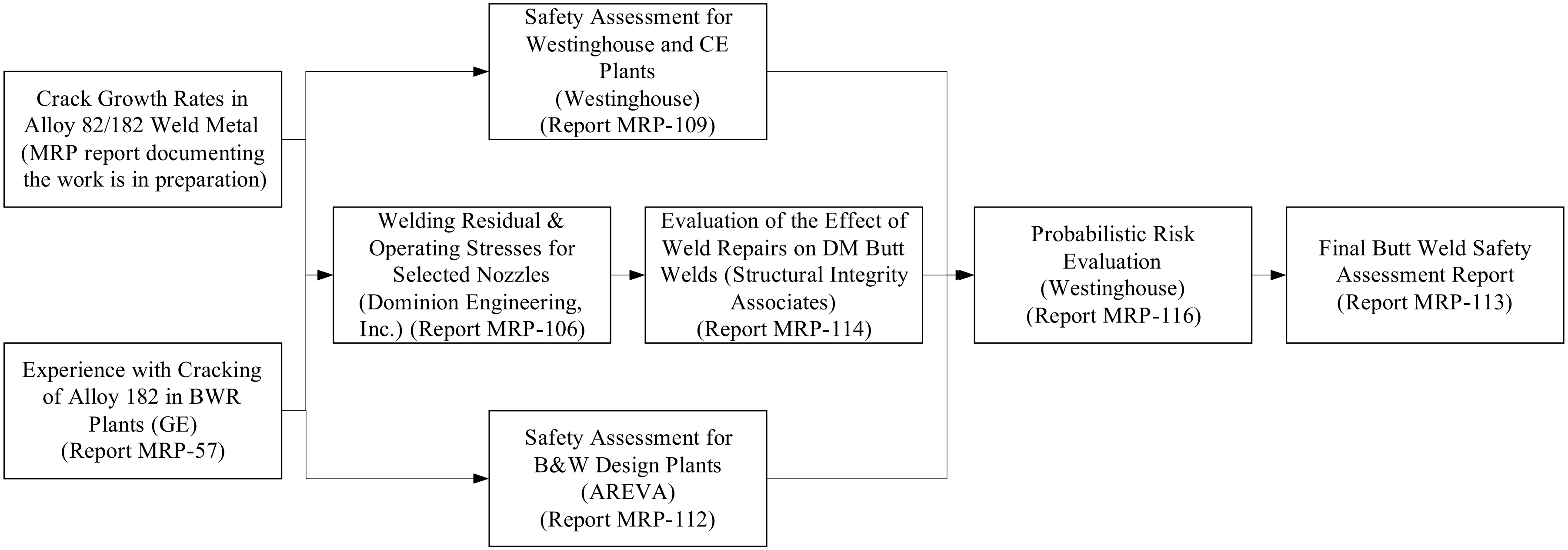
- MRP-113 Overview
- Butt Weld Locations
- Field Experience
- Safety Assessment Calculations
- Safety Assessment Conclusions
- Leak Before Break Strategy
- Butt Weld I&E Guidelines
- Summary

Roadmap to Documents

- Cover report and seven supporting documents

– Summary report	MRP-113
– BWR experience	MRP-57
– Crack growth	in preparation
– Welding residual stresses	MRP-106
– Westinghouse & CE deterministic	MRP-109
– B&W deterministic	MRP-112
– Weld repair analysis	MRP-114
– Probabilistic analysis	MRP-116

Roadmap to Documents



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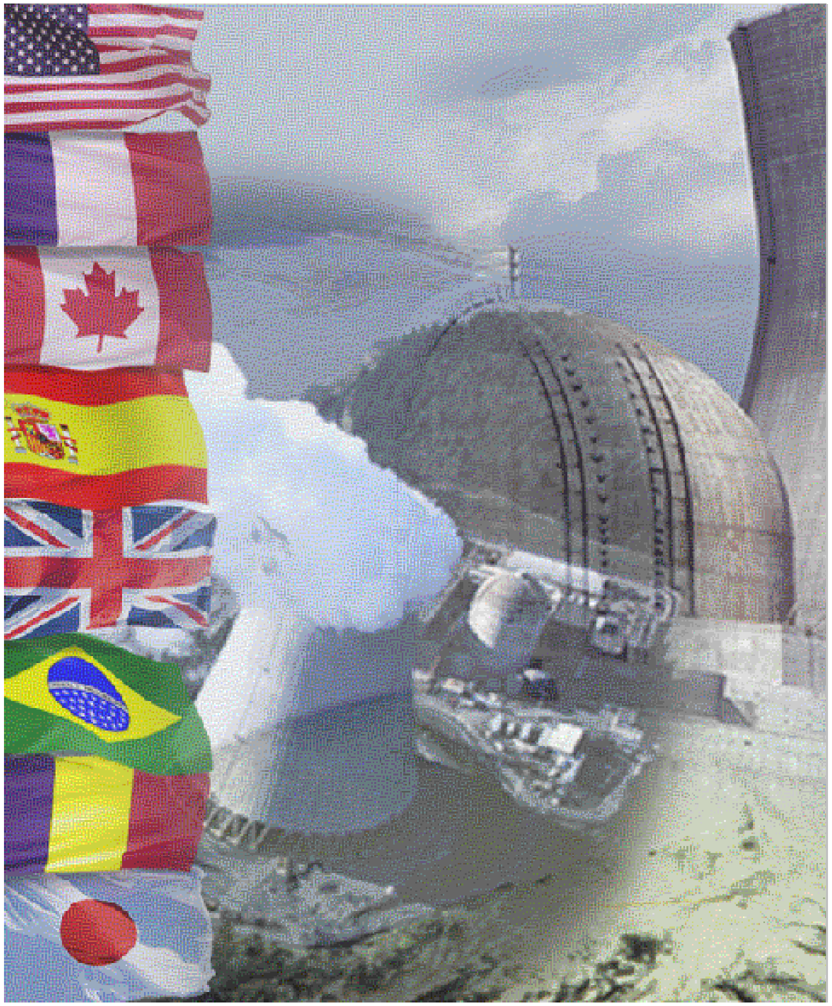


Butt Weld Locations

Larry Mathews, Southern Nuclear

Chairman, Alloy 600 ITG

Butt Weld Locations

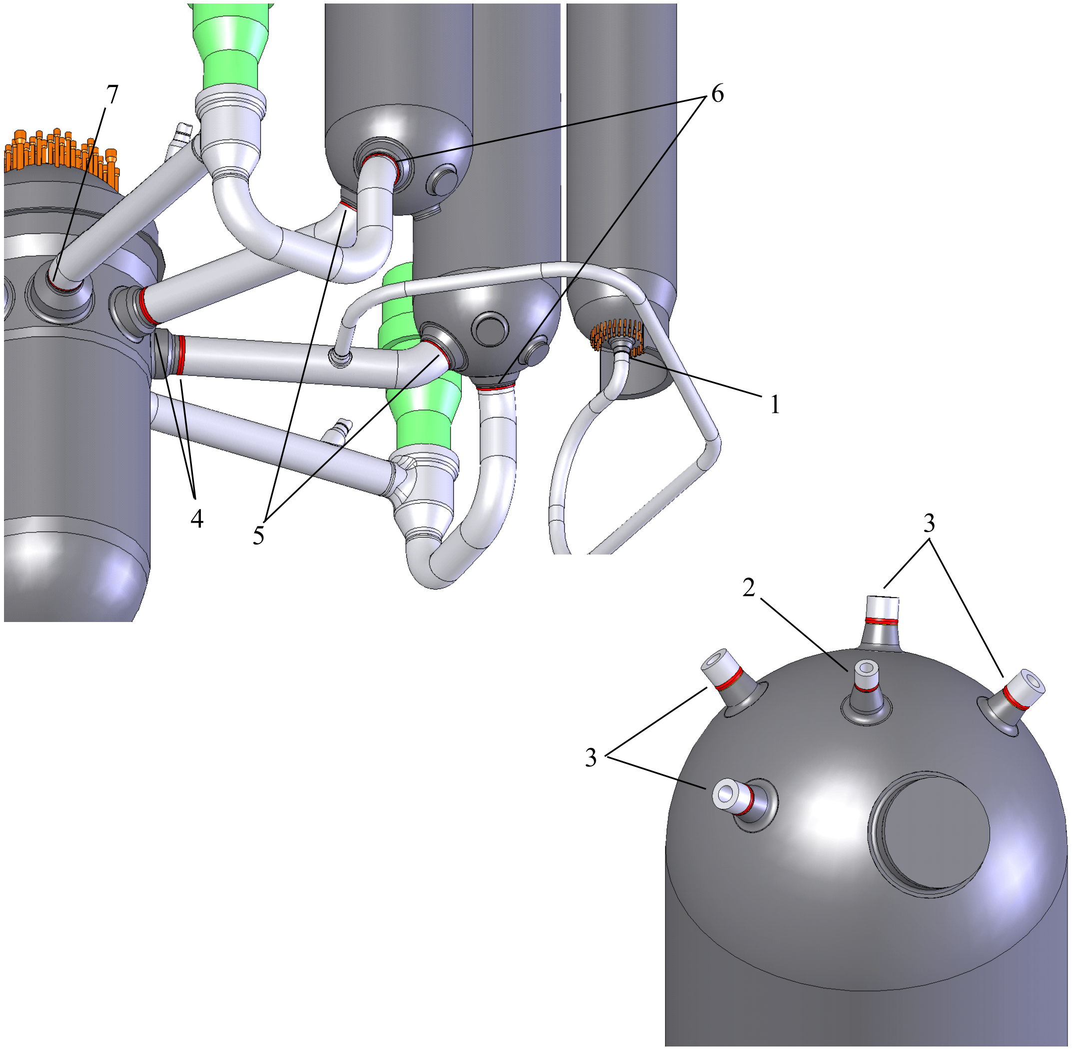
Summary

Location	Westinghouse Design Plants	Combustion Engineering Design Plants	Babcock & Wilcox Design Plants
Reactor Vessels			
- Inlet & Outlet Nozzles	Yes	No[2]	No
- Core Flood Nozzles	No	No	Yes
Pressurizers			
- Surge Line Nozzles	Yes	Yes	Yes
- Spray Nozzles	Yes	Yes	Yes
- Safety & Relief Valve Nozzles	Yes	Yes	Yes
RCS Piping Loop			
- SG Inlet & Outlet Nozzles	No[4]	No	No
- RCP Suction & Discharge Nozzles	No	Yes[3]	Yes
RCS Branch Line Connections			
- HL Pipe to Surge Line Connection	No	Yes	Yes
- Charging Inlet Nozzles	No	Yes	Yes
- Safety Injection and SDC Inlet	No	Yes	Yes
- Shutdown Cooling Outlet Nozzle	No	Yes	Yes
- Pressurizer Spray Nozzles	No	Yes	Yes
- Let-Down and Drain Nozzles	No	Yes	Yes

1. Table does not include butt welds in instrument nozzles 1 inch NPS and smaller, or welds that operate at less than 550°F (CRDM nozzle to flange butt welds, BMI nozzle to pipe butt welds, core flood tank nozzle butt welds).
2. One CE design plant has Alloy 82/182 welds and is evaluated with the Westinghouse design plants.
3. Palo Verde does not have Alloy 82/182 RCP suction and discharge nozzle welds.
4. One plant has Alloy 82/182 butt welds at this location.

Butt Weld Locations

Westinghouse Design Plants



Butt Weld Locations

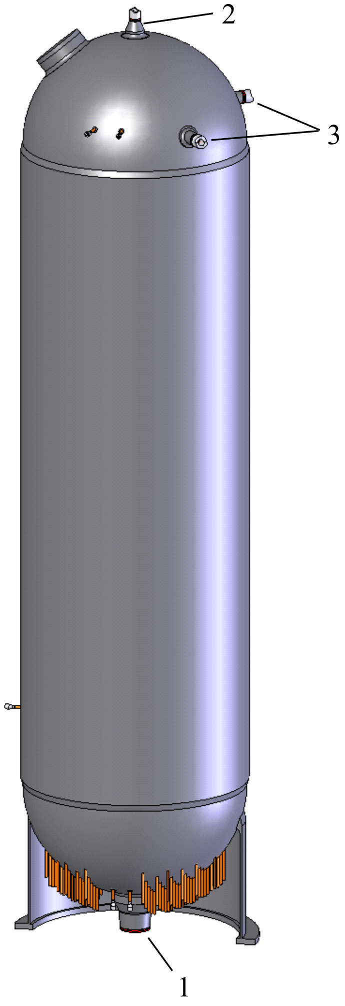
Westinghouse Design Plants

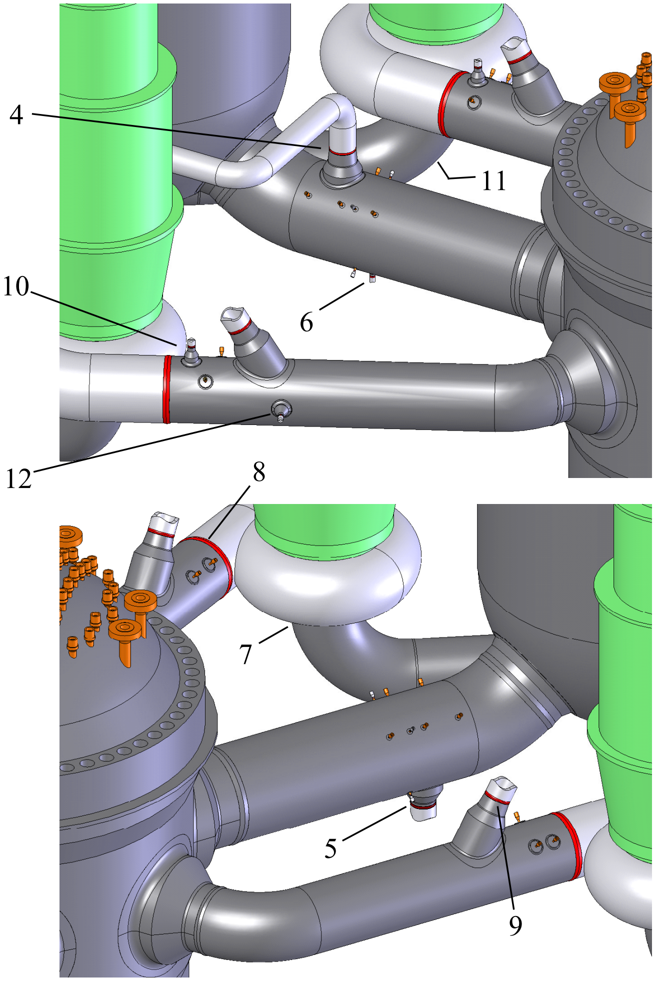
Application	Identification Number	Typical Temperature (°F)	Typical ID (inches)	Typ. Number (3 Loop Plant)
Pressurizer		653		
- Surge Line Nozzle	1		10	1
- Spray Nozzle	2		4	1
- Safety/Relief Nozzles	3		5	4
RCS Hot Leg Pipe				
- Reactor Vessel Outlet Nozzles[3]	4	600-620	29	3
- Steam Generator Inlet Nozzles[4]	5		--	--
RCS Cold Leg Pipe				
- Steam Generator Outlet Nozzles[4]	6	550-560	--	--
- Reactor Vessel Inlet Nozzles[3]	7		27.5	3

1. Figures only show locations in pipes greater than 1" NPS and operating at temperatures greater than about 550°F.
2. Plants with original reactor vessel closure heads have CRDM nozzles with Alloy 82/182 nozzle-to-flange butt welds (4" diameter).
3. There are no Alloy 82/182 RPV nozzle welds in Westinghouse 2-loop plants and some early Westinghouse 3-loop plants.
4. One plant has Alloy 82/182 butt welds between the reactor coolant piping and steam generator nozzles.

Butt Weld Locations

Combustion Engineering Design Plants





Butt Weld Locations

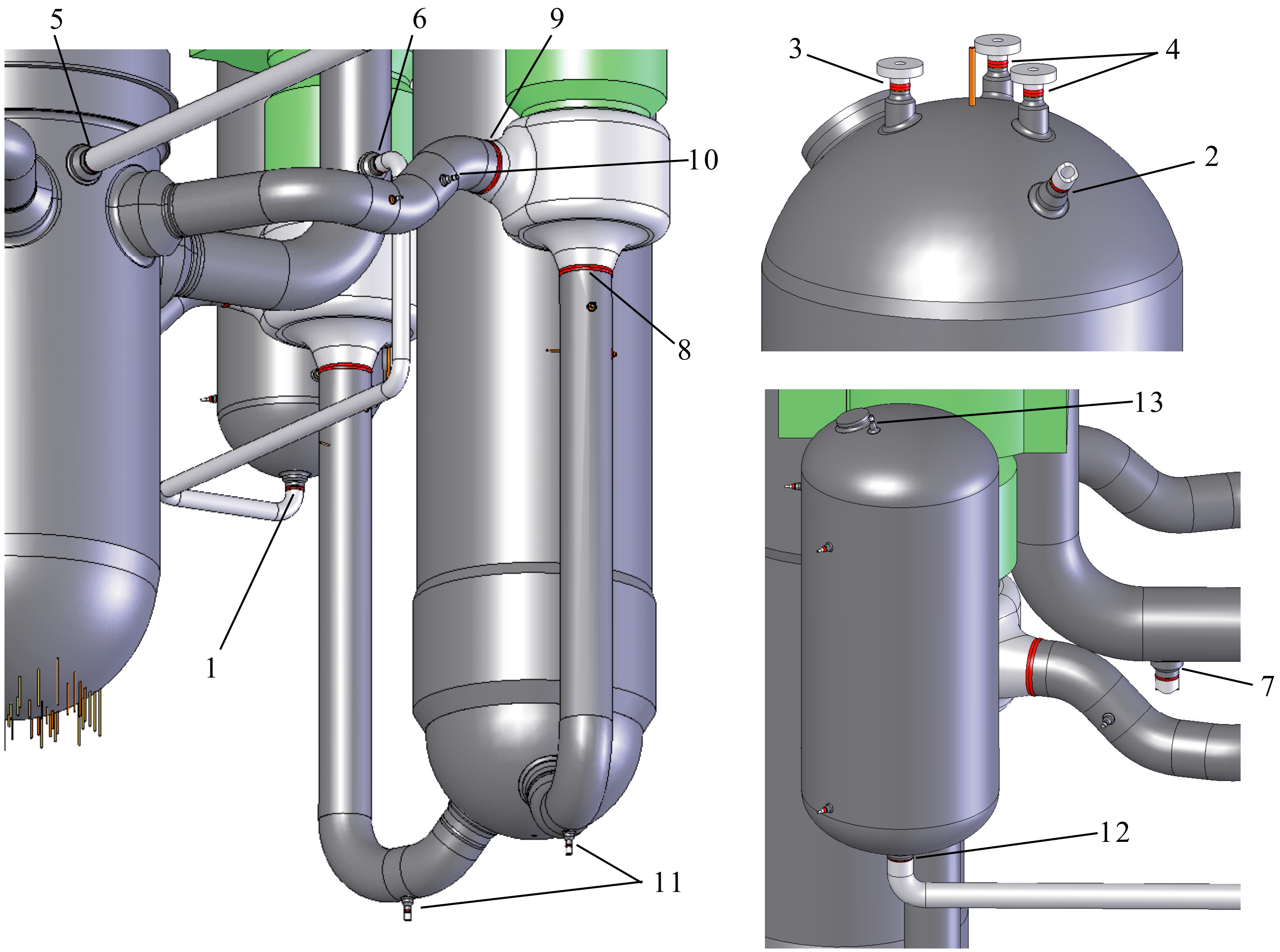
Combustion Engineering Design Plants

Application	Identification Number	Typical Temperature (°F)	Typical ID (inches)	Typical Number
Pressurizer		643-653		
- Surge Line Nozzle	1		10	1
- Spray Nozzle	2		3	1
- Safety/Relief Nozzles	3		5	2-3
RCS Hot Leg Pipe		600		
- Surge Line Nozzle	4		10	1
- Shutdown Cooling Outlet Nozzle	5		10	1
- Drain Nozzle	6		2	1
RCS Cold Leg Pipe		549-560		
- RCP Inlet Nozzles	7[3]		30	4
- RCP Outlet Nozzles	8[3]		30	4
- Safety Injection	9		10	4
- Pressurizer Spray Nozzles	10		2.25	2
- Letdown/Drain Nozzles	11		1.3	4[4]
- Charging Inlet Nozzle	12		1.3	2

1. Figures only show locations in pipes greater than 1" NPS and operating at temperatures greater than about 550°F.
2. Some plants with original reactor vessel closure heads have CEDM/ICI nozzles with Alloy 82/182 nozzle-to-flange butt welds.
3. One plant does not have Alloy 82/182 welds at reactor coolant pump.
4. One plant has 8 cold leg letdown/drain nozzles.

Butt Weld Locations

B&W Design Plants

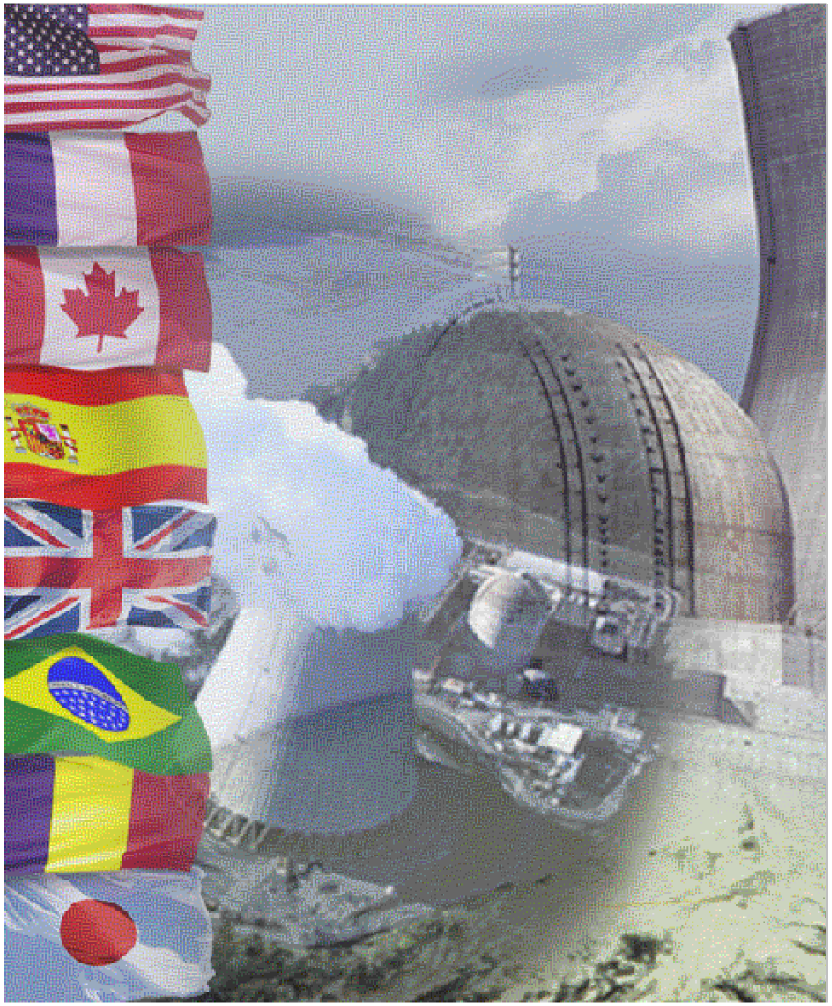


Butt Weld Locations

B&W Design Plants

Application	Identification Number	Typical Temperature (°F)	Typical ID (inches)	Typical Number
Pressurizer				
- Surge Line Nozzle	1	650	10	1
- Spray Nozzle	2		4	1
- PORV Nozzle	3		2.5	1
- Safety Relief Nozzles	4		2.5-3	2
Reactor Vessel[2]				
- Core Flood Nozzle	5	577	14	2
RCS Hot Leg Pipe				
- Surge Line Nozzle	6	601-605	10	1
- Decay Heat Nozzle	7		12	1
RCS Cold Leg Pipe				
- RCP Inlet Nozzles	8	557	28	4
- RCP Outlet Nozzles	9		28	4
- High Pressure Injection Nozzles	10		2.5	4
- Letdown/Drain Nozzles	11		1.5-2.5	4
Core Flood Tanks				
- Outlet Nozzle	12	RT	14	2
- Pressure Relief	13		2	2

1. Figures only show locations in pipes greater than 1" NPS and operating at temperatures greater than about 550°F.
2. As of July 2004, there are two remaining B&W plants that have reactor vessel closure heads with Alloy 600 CRDM nozzles and Alloy 82 nozzle-to-flange butt welds (69 4" welds at temperature < 605°F).



Butt Weld Field Experience

Larry Mathews, Southern Nuclear

Chairman, Alloy 600 ITG

Butt Weld Field Experience

Summary Status

- Plants with leaks
  - VC Summer — associated with repairs
  - Tsuruga 2 — associated with repairs
- Plants with cracks/indications
  - Ringhals 3 & 4
  - VC Summer
  - Tsuruga 2
  - TMI-1 — associated with repairs
  - Tihange 2
- Plants with related cracks (circ cracks in HAZ of A600 components)
  - Palisades
  - Advanced Test Reactor (ATR)

Butt Weld Field Experience

- About 1,150 welds have been inspected per ASME XI
- About 1,038 butt welds require volumetric inspection per ASME XI
  - Most include direct visual and surface exams
- Recent US inspection experience
  - No leaks detected by visual methods since VC Summer
  - About 150 dissimilar metal butt welds UT inspected since 2001
    - About 140 before Appendix VIII qualification required
    - About 10 qualified to Appendix VIII
    - One weld with an axial indication
- In 2004 and 2005, about 190 more welds will be inspected per ASME XI

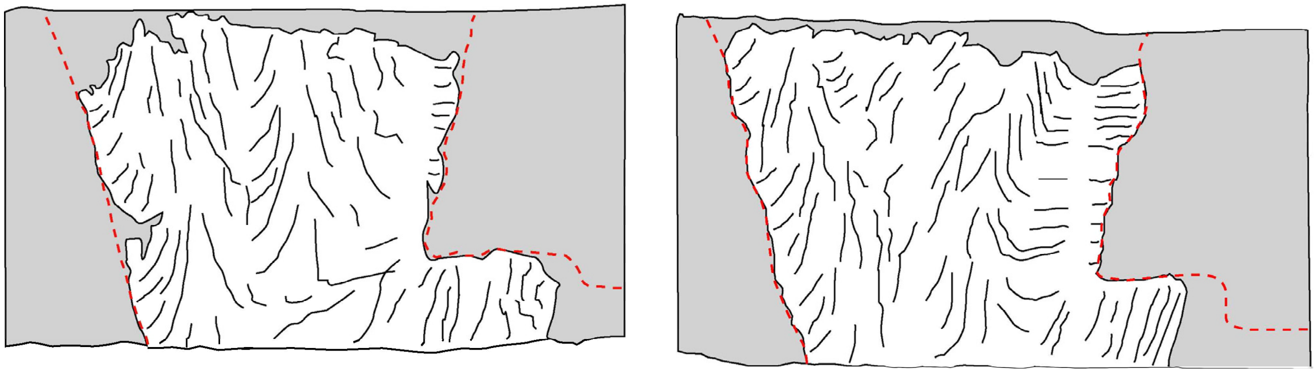
Field Experience (cont'd)

- Butt welds locations are inspected during leakage and pressure tests (insulated) and will be inspected (bare metal) for borated water leaks.
  - MRP letter 2003-039, January 20, 2004
  - MRP letter 2004-05, April 2, 2004
- Butt weld PWSCC is not widespread.
- Numerous leaks from other sources have not resulted in structurally significant wastage (excluding DB).

Butt Weld Field Experience

Characterization of Cracks

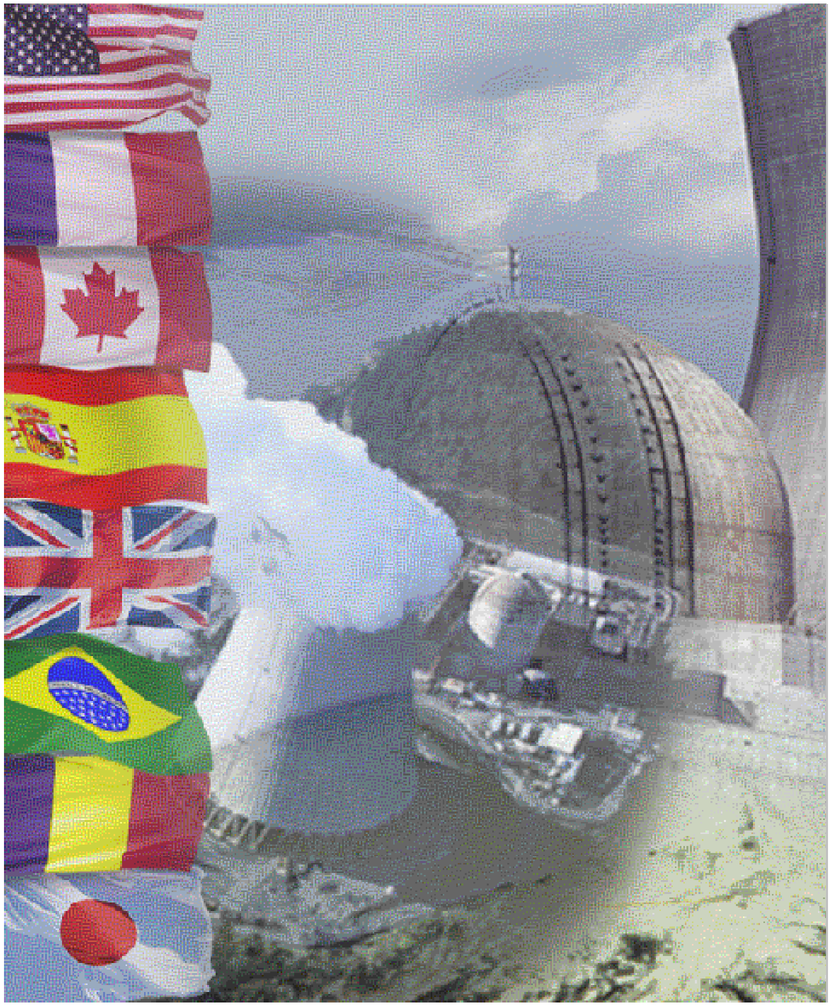
- Most cracks axial and limited to length of weld (Tsuruga 2 shown)
  - Axial crack growth into Alloy 600 safe ends
    - Crack growth rate lower in Alloy 600
    - Length of weld plus safe end less than critical flaw length



b. Cross Section at Leak (90º)

c. Cross Section at Crack (315º)

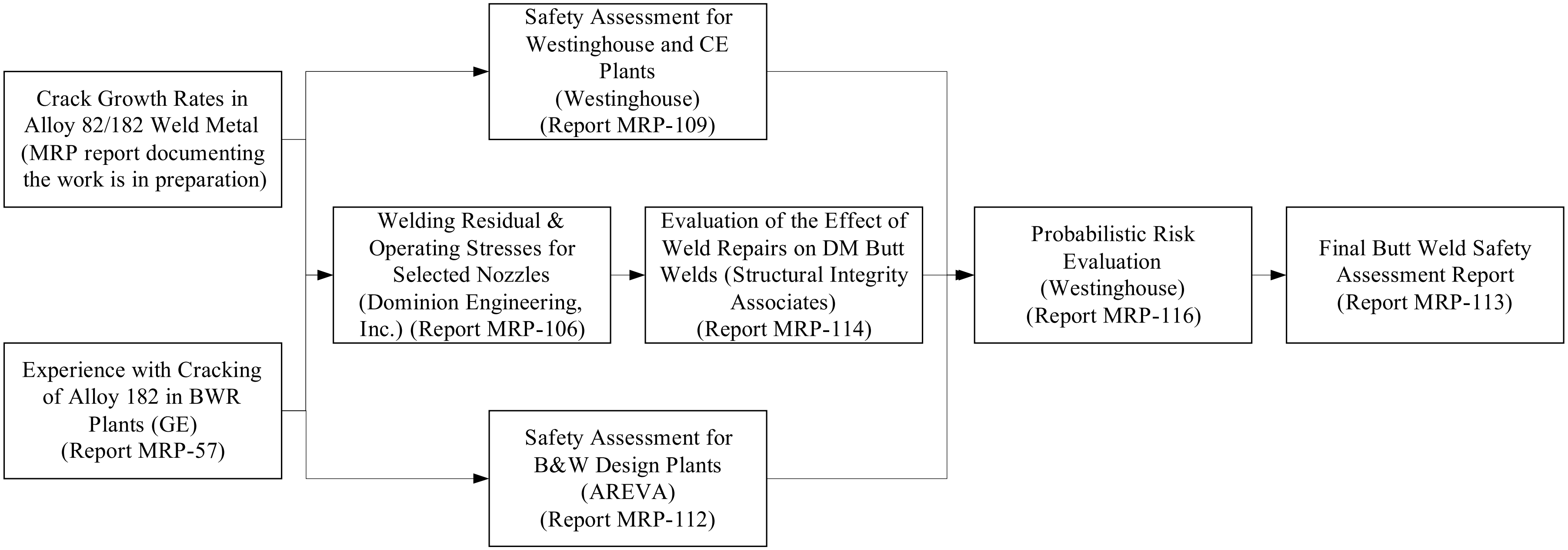
- One short shallow circumferential crack at VC Summer
- None of the above cracks posed significant safety risk at discovery
  - Two (VC Summer and Tsuruga 2) were detected by visual inspections
  - Others were detected by NDE (only TMI was Appendix VIII)



Butt Weld Safety Assessment Calculations

Dana Covill, Progress Energy

Roadmap to Documents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Final Butt Weld Safety Assessment Report (Report MRP-113)

Deterministic Analyses

- Primary objective was to address the safety significance of postulated flaws in Alloy 82/182 butt welds
- Specific analyses included
  - Critical flaw size
  - Time to through wall leak
  - Time between 1 gpm/10 gpm and failure
  - Leak rate as function of flaw size
  - Margin between leak and failure

Deterministic Analyses

Westinghouse and AREVA Analyses

- Axial flaws
  - Axial cracks limited to length of welds
  - Critical length of axial flaws is greater than the length of the weld (and safe end as applicable)
- Circumferential flaws
  - Large critical arc length for through-wall circumferential flaws
  - More than 2 years from 1 gpm leak to critical length for most locations
  - Leakage associated with critical flaw greater than maximum TS leakage for all but one small diameter location

Deterministic Analyses

Westinghouse and AREVA Analyses

Location	NSSS	Plant	Burst Pressure for 2.5" Long Through-Wall Axial Flaw (ksi)	Critical Through-Wall Axial Flaw Length(1) (in)	Critical Through-Wall Circ Flaw Length (deg)	Critical 360° Part Depth a/t Ratio
PZR - Surge Line	W	F	9.9	20.5	115	.69
	CE	K	11.8	23.0	126	.71
	B&W	C	---	16.7	93	.57
PZR - Spray	W	H	10.1	13.4	144	.82
	CE	R	5.7	7.2	72	.44
	B&W	A	---	11.4	211	.75
PZR - Safety/Relief	W	E	15.2	24.2	144	.82
	W	I	11.5	17.4	166	.85
	CE	N	18.1	24.0	130	.82
	CE	P	6.7	8.1	158	.85
	B&W	A	---	18.0	188	.75
HL – RPV Outlet	W	C	7.8	27.4	86	.54
HL – SG Inlet	W	D	8.6	38.5	148	.76
HL – Shutdown Cooling	CE	L	10.3	21.4	133	.74
	CE	M	10.3	23.0	126	.72
HL – Surge Line	CE	K	9.1	17.3	104	.63
	CE	M	10.3	19.5	90	.56
HL – Decay Heat	B&W	B	---	12.3	132	.72
CL – RPV Inlet	W	B	8.2	28.1	115	.66
	W	C	7.7	25.9	130	.67
CL – RPV Core Flood	B&W	A	---	22.3	194	.75
CL – SG Outlet	W	D	8.8	30.0	155	.77
CL – RCP Suction	CE	J	9.4	38.2	115	.62
CL – RCP Discharge	CE	J	9.4	38.2	104	.56

(1) These critical axial flaw lengths are much greater than the width of the Alloy 82/182 butt welds.
(2) PZR = Pressurizer, CL = Cold Leg, HL = Hot Leg

Deterministic Analysis

Westinghouse Analyses

Location	NSSS	Plant	Time to Through-Wall 6:1 Aspect Ratio (years)	Time to Through-Wall 2:1 Aspect Ratio (years)	Time from 1 GPM to Critical Flaw Size (years)	Time from 10 GPM to Critical Flaw Size (years)
PZR - Surge Line	W	F	1.4	3.9	2.6	1.1
	CE	N	3.9	6.5	5.3	1.6
PZR - Spray	W	H	1.1	2.6(1)	2.6	<1
	CE	O	<1	>40	2.0	<1
PZR - Safety/Relief	W	E	4.1(2)	5.2(2)	5.6	<1
	W	I	3.5(3)	4.2(3)	4.8	1.2
	CE	P	1.1	>40	2.1	<1
HL – RPV Outlet	W	A	2.0	6.5	8.3	4.1
HL – SG Inlet	W	D	11.8	35.7	>40	18.3
HL – Shutdown Cooling	CE	L	3.3	10.5	8.3	3.7
HL – Surge Line	CE	M	8.8	13.8	14.2	2.7
CL – RPV Inlet	W	A	23.5	>40	>40	>40
CL – SG Outlet	W	D	>40	>40	>40	>40
CL – RCP Suction	CE	J	27	>40	>40	>40
CL – RCP Discharge	CE	J	19.7	>40	>40	38.5

(1) SCC initiates at a/t = 0.78 based on crack tip stress intensity factor threshold
(2) SCC initiates at a/t = 0.33 for aspect ratio = 6:1 and a/t = 0.62 for aspect ratio = 2:1
(3) SCC initiates at a/t = 0.35 for aspect ratio = 6:1 and a/t = 0.70 for aspect ratio = 2:1

Deterministic Analysis

AREVA Analyses

Location	NSSS	Plant	Time from Initiation to 75% Through-Wall (years)	Time from 1 GPM to Critical Flaw Size (years)
PZR - Surge Line	B&W	C	3.5	0.9
PZR – Spray	B&W	A	>40	1.8
PZR – Relief	B&W	A	>40	See Note(1)
HL - Decay Heat	B&W	B	>40	7.1
CL – RPV Core Flood	B&W	A	>40	>70

(1) Critical flaw size predicted to occur at less than 1 gpm leakage.

Summary of Deterministic Results

Circumferential PWSCC

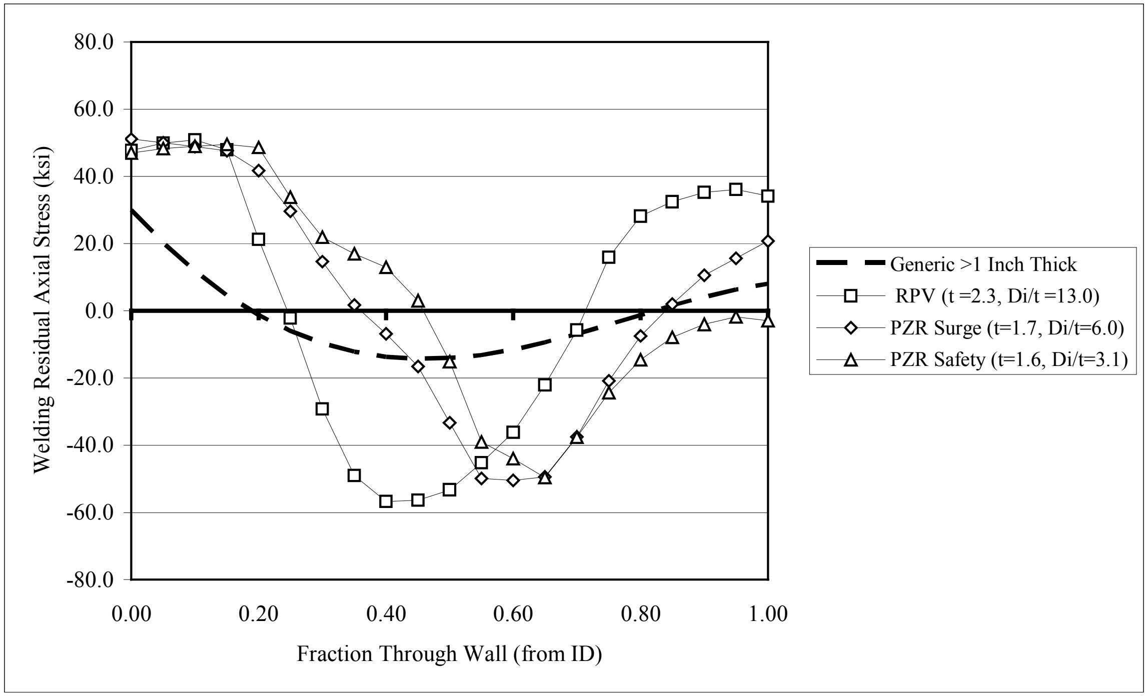
- Large Bore Piping
  - Primary loop nozzle welds (SG, RCP, RV) have large margins from leakage to break
- Pressurizer Nozzle Welds and Safe Ends
  - Time between leakage and break is less than the 10 year ISI interval
- Small Bore Pipes
  - Time between leakage and break is less than the 10-year ISI interval
- Deterministic results were as expected
  - Primary factors: crack growth rate in weld material and assumed circumferential flaws

Deterministic Analysis

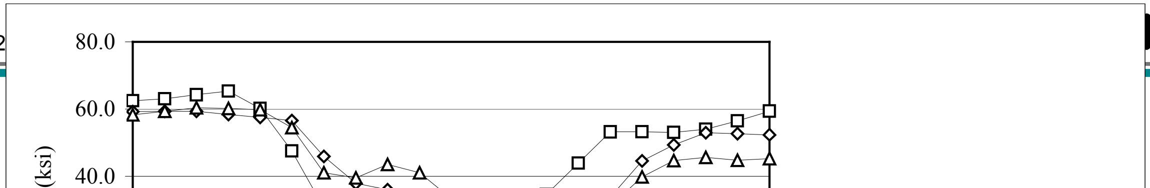
Effect of Weld Repairs on Residual Stress

- Purpose was to evaluate the effect of weld repairs on potential crack growth
- Weld repairs may be common
- Weld repairs from ID or OD may change residual stress distribution relative to generic curves (i.e. Section XI basis)

Axial Stress



Hoop Stress



Deterministic Analysis

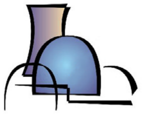
Effect of Weld Repairs on Crack Growth

- However, deterministic treatment of weld repairs does not alter our ultimate conclusion of the deterministic part of Safety Assessment
  - Analyses show that through-wall growth of circumferential cracks should be limited to approximately the weld repaired region
    - Higher residual stresses from weld repair are limited to the repaired region
  - Circumferential crack expected to grow through-wall more rapidly than around the circumference
  - Also, residual stresses associated with weld repairs indicate that axial flaws are more likely.

Probabilistic Analysis

Overview

- Probabilistic analyses performed for several limiting locations in Westinghouse, CE, and B&W design plants
  - Locations with shortest time from leak to critical flaw
  - Locations with largest consequences (core damage)
- Addresses the probability that a flaw could grow through the wall and result in core damage
  - Quantify the probability of leakage from circumferential flaws
  - Axial flaw contribution to core damage frequency is not significant
  - Evaluate the change in core damage frequency
  - Assess various inspection frequencies from a risk perspective
- Take advantage of existing approved approaches (e.g., piping risk informed inspection basis)



Probabilistic Analysis

- Key inputs include
  - Crack initiation
  - Crack growth
  - Criteria for failure of the pipe is initiation of a leak
  - Probability of leak initiating is higher (i.e. bounding) than probability for small and medium LOCA
- Benchmarked to VC Summer and TMI-1 (included weld repair residual stresses from MRP-106)
- CDF calculations for this assessment did not include weld repair residual stresses; however, the stress distribution was assumed to be constant through the wall

Probabilistic Analysis: Key Conclusions

- Change in core damage frequencies ranged from 1.8 E-8 to 8.7 E-8 per reactor year; therefore, impact of butt weld PWSCC on CDF is insignificant
- Changes in inspection frequency and accuracy have only small impact
- 10 year inspection intervals are adequate from risk perspective

Safety Assessment Conclusions

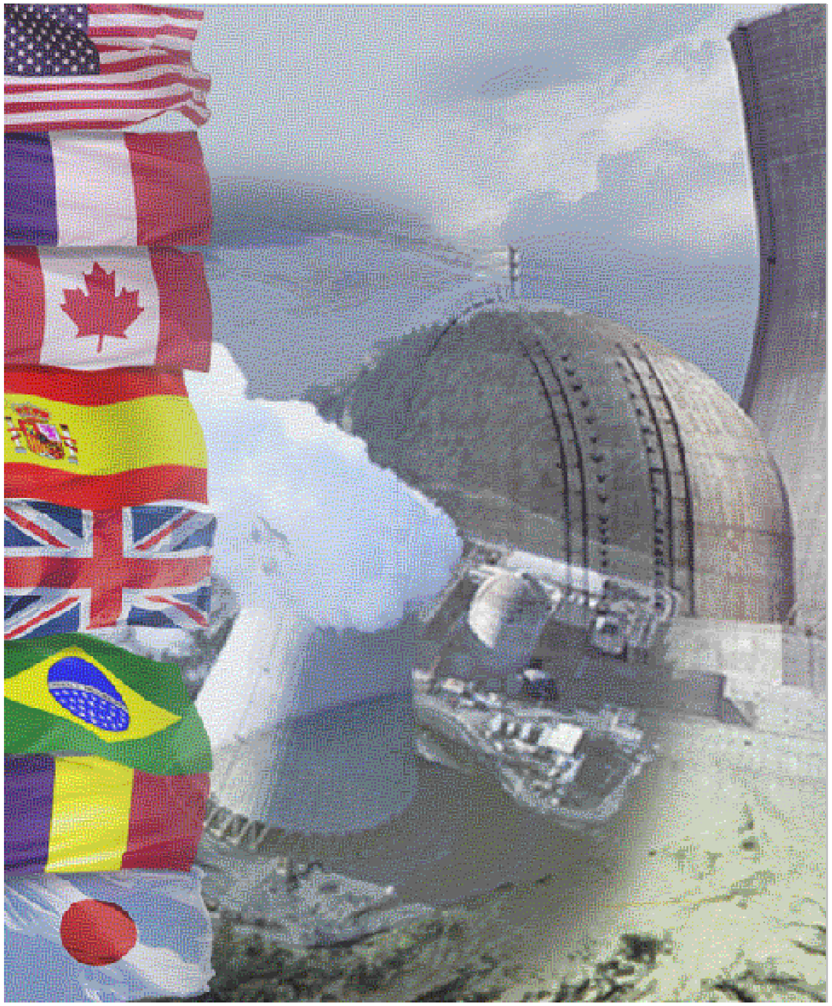
- No Immediate Safety Concern
  - Very small number of leaks/cracks given large numbers of locations worldwide
  - Probabilistic analysis shows impact of butt weld PWSCC on CDF is insignificant
  - Potential for significant BAC considered low
- Supported by
  - Analysis and experience shows most cracks axial and limited to length of weld
    - Exception is for Alloy 600 safe end locations
    - At A600 safe ends, total length of A82/182/600 less than critical length
  - Analyses for circumferential cracks show
    - 360 deg part-depth circ flaws unlikely to occur
    - Through-wall flaws will leak 1 gpm at less than critical size (except for one small diameter location)
    - Through-wall flaws in repaired welds are limited to about repair length
  - All welds are inspected per ASME XI
    - Visual inspections for leakage and BAC
    - Bare metal visual inspections associated with NDE for >1" NPS
    - Volumetric NDE for sizes > 4 inch NPS

LBB & PWSCC

- NRC Has Raised Several Issues Relative to PWSCC and LBB:
  - Application of LBB with potentially active degradation mechanism
  - Leak rate calculations with SCC morphology
- MRP initiating efforts to demonstrate application of LBB to lines with A82/182 welds is appropriate and satisfies requirements of GDC–4
  - "Dynamic effects associated with postulated pipe ruptures in nuclear power units may be excluded from the design basis when analyses reviewed and approved by the Commission demonstrate that the probability of fluid system piping rupture is extremely low under conditions consistent with the design basis for the piping"
    - Statement of consideration "Evaluations of the potential for water hammer, corrosion, creep damage, fatigue, erosion, fatigue, erosion, environmental conditions, indirect failure mechanisms and other degradation sources which could lead to pipe rupture are also required.."

LBB & PWSCC

- MRP Effort Will:
  - Identify ALL LBB applications **with A82/182**
  - Use MRP-113 to address some of the issues
  - Address issues of :
    - Licensing basis for LBB
    - Leak rates
    - Leak detection capability and sensitivity
    - Margins and uncertainties
    - Thermal aging of A600/82/182
    - Overall risk/probability of rupture
- Working with NSSS to develop detailed plans and schedules

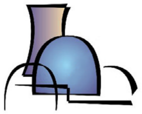


Primary System Piping Butt Weld Inspection and Evaluation Guidelines

Dana Covill, Progress Energy

Primary System Piping Butt Weld I&E Guideline

- MRP is developing an Inspection & Evaluation (I&E) Guideline
- Draft I&E Guideline for primary system piping butt welds will be available for ITG review at end of Summer 2004
  - Augmented inspections (frequency, pipe size, and volume of interest) are likely for some butt weld locations
- In 2004-2005, about 190 DM 82/182 butt welds are scheduled for inspection via UT
  - 69 units (1038 welds total)



Primary System Piping Butt Weld I&E Guideline

- Establish long-term inspection frequencies to effectively manage PWSCC
- Approach similar to GL 88-01
    - Material (resistant or non-resistant)
    - Inspection (by qualified method)
    - Mitigation
    - Temperature (cold leg vs. hot leg)
    - Pipe Size (≥4” OD and <4” OD)
- Alloy 82/182 welds in RI-ISI programs will be re-evaluated

Inspection Recommendation Example

PWSCC Category	Description of Weldments	Inspected? Cracked?
A	Resistant Materials	Yes Uncracked
B	Non-resistant Mat. Reinforced by full structural weld Overlay	Yes Uncracked
C	Non-Resistant Mat. Mitigated by SI	Yes Uncracked

Summary and Conclusion

- No immediate safety concern
- “Needed” Action for Visual Inspection of Alloy 82/182 Butt Welds has been issued under NEI 03-08
- Inspection and Evaluation Guideline being developed
  - Meet with NRC to review approach and obtain feedback in Fall 2004
  - Plan to issue as “Mandatory” requirements under NEI 03-08
  - Not planning to request an SER

Discussion

- NRC Comments