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Pressurizer Alloy 600 Weld Inspection Program Overview

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Chairman, EPRI PMMP Executive Committee & NEI MEOG

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Presentation Scope

- Pressurizer Butt Weld Inspection/Mitigation
  - Industry Initiative (MRP-139)
  - Impact of Wolf Creek Inspection Findings
  - Conclusions

Industry Initiative Addressing Butt Weld Integrity

- MRP-139 is a proactive industry inspection program issued in 2005 under the materials initiative, NEI 03-08
  - Pressurizer weld requirements consistent with approach used for BWR piping in GL 88-01 (NUREG 0313)
  - Prior to MRP-139, ASME Code inspections
- Industry is ensuring weld integrity
  - Over 50% of the pressurizer welds will be inspected and/or mitigated by Spring 2007
  - All US PWR plant pressurizer welds will be inspected per MRP-139 or mitigated by the end of Spring 2008

Immediate Industry Actions

- Mobilized industry expertise to evaluate program guidance and safety assessment
- Documented industry inspection/mitigation plans
- Conducted analysis of the Wolf Creek inspection findings
- Assessed current leakage monitoring capabilities
- Evaluated industry's ability to accelerate inspection schedule

Industry Perspective on Wolf Creek Indications

- Industry's inspection plan per MRP-139 guidance assures continued safe operation. Evaluations included:
  - Flaw tolerance and growth
  - Probability of rupture
  - Leakage monitoring
- Existing safety analysis conclusions remain valid after consideration of Wolf Creek indications.

Effect of Wolf Creek Inspection Findings on Pressurizer Inspection/Mitigation Plans

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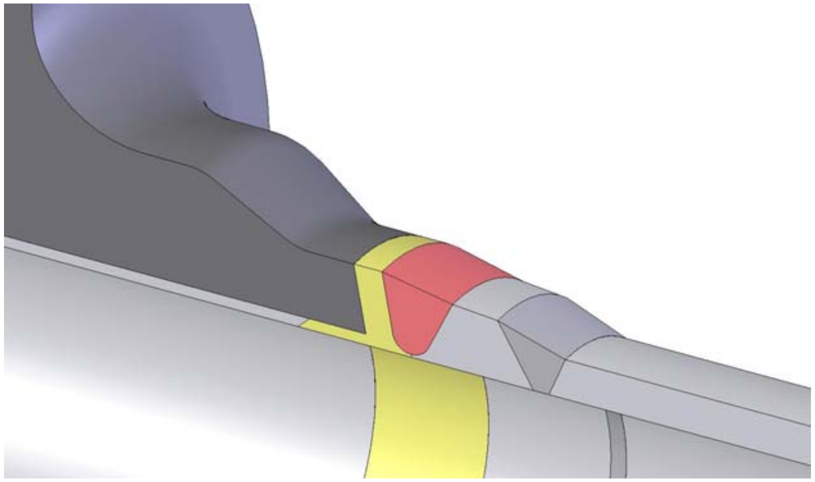
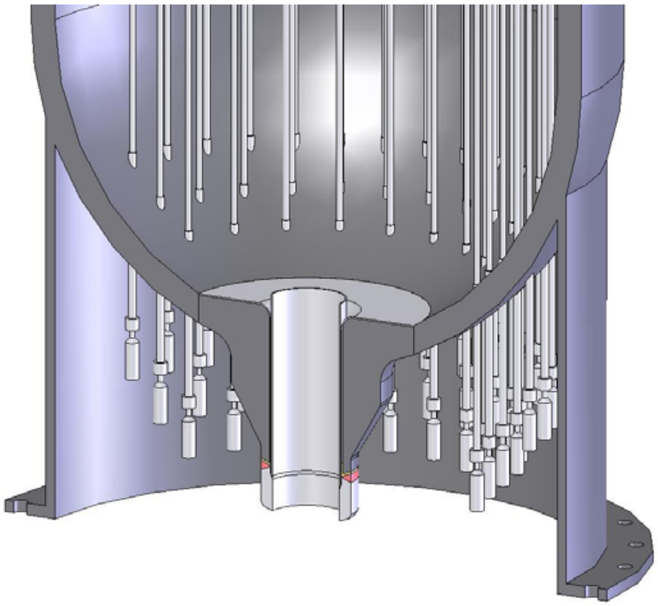
Outline

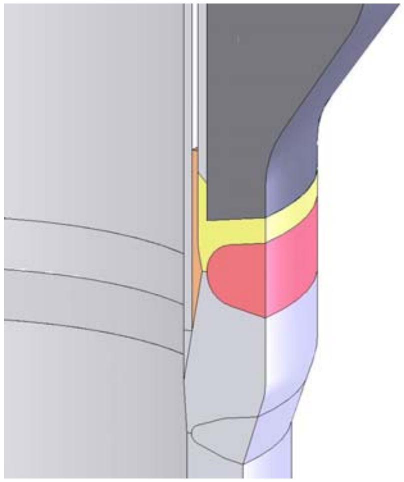
- Background
- Wolf Creek Inspection Results and Evaluation
- Industry Inspection and Mitigation Plans
- Flaw Tolerance and Growth
- Probability of Critical Size Flaws in PZR Welds
- Leakage Monitoring
- Conclusions

Background
Pressurizer Top Head Nozzles



Background
Pressurizer Bottom Head Nozzles





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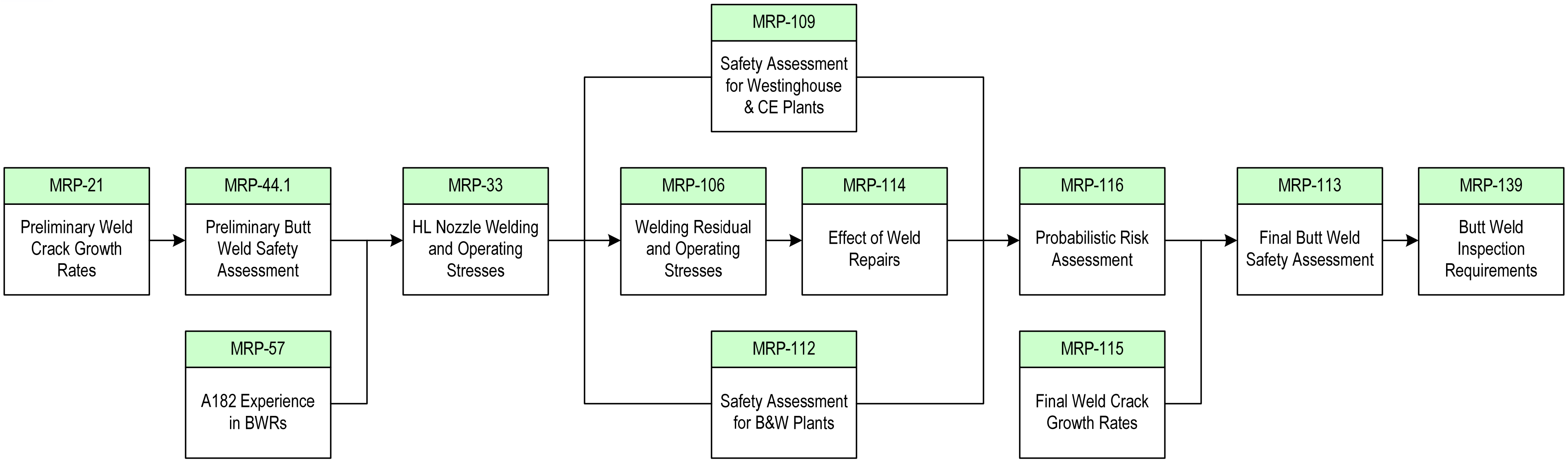
Background

Industry Butt Weld Integrity Management Activities



< 2000	2000-2001	2002-2003	2004	2005

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WC Inspection Results and Evaluation

Indication Characterization

Nozzle	Circumference (in)	Outside Diameter (in)	Thickness (in)	Inside Diameter (in)	2006 Indications				
					OD Lemgth (inches)	Arc Length (2) (deg)	Maximum Depth (1) (%)	Depth (in)	Aspect Ratio (3)
Safety C	25.0	7.96	1.32	5.32	3.75	54	23	0.30	8
Relief	25.0	7.96	1.32	5.32	11.50	166	26	0.34	22
Surge	47.0	14.96	1.45	12.06	1.00	8	<10 (4)	---	---
	47.0	14.96	1.45	12.06	2.75	21	25	0.36	6
	47.0	14.96	1.45	12.06	5.00	38	31	0.45	9
				Surge Nozzle Totals =>	8.75	67			

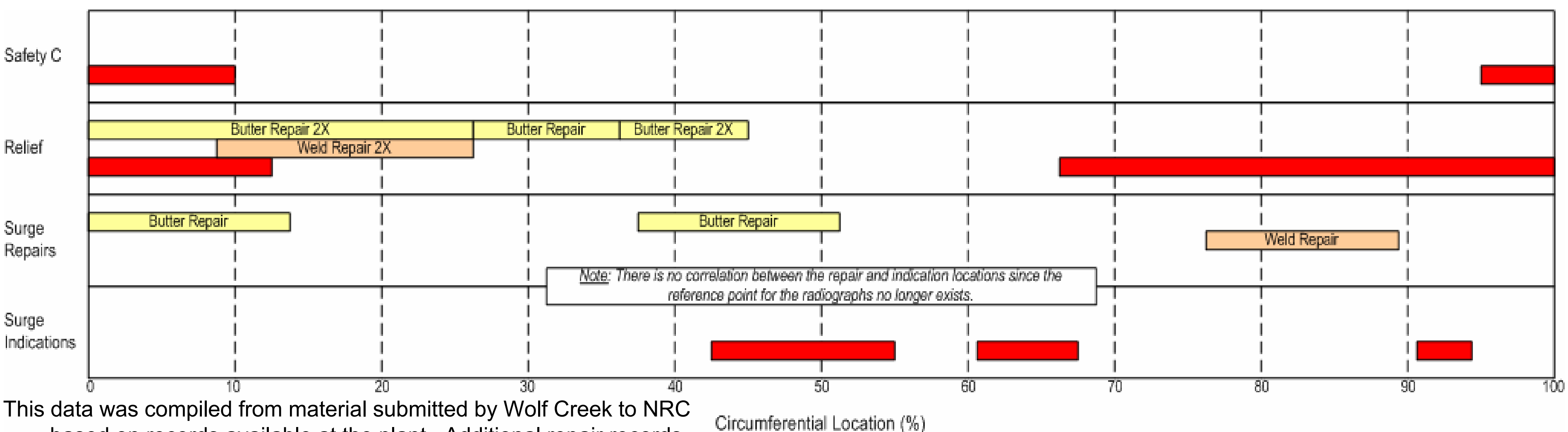
Highlighted data represents values reported to the NRC by Wolf Creek. Other values are calculated by geometry.

(1) Average depth from 45 and 60 degree angle UT probes at maximum depth location.

(2) Calculated from OD length and circumference.

(3) Calculated from ID arc length and depth.

(4) Indication found but no measurable depth could be determined.

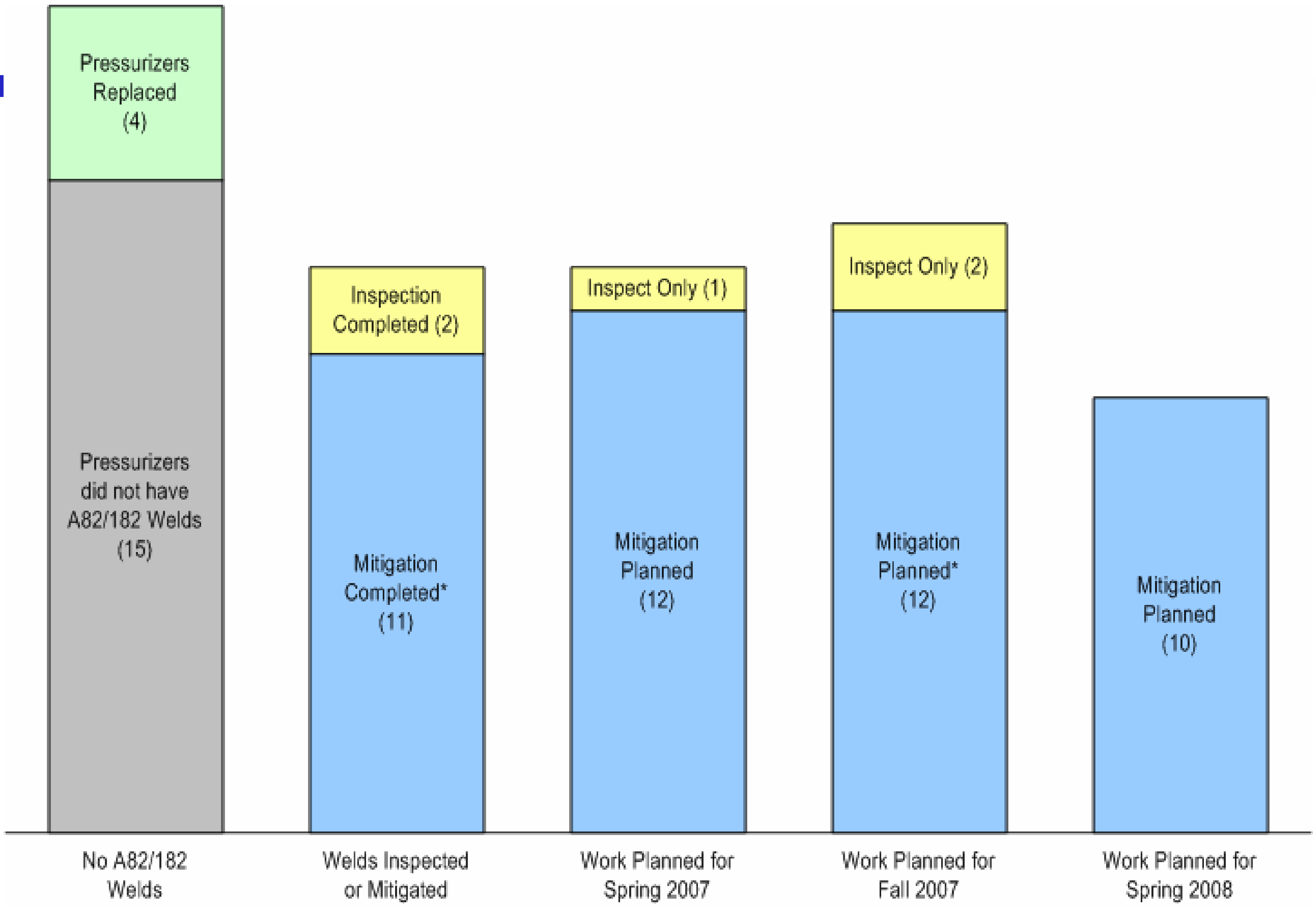


This data was compiled from material submitted by Wolf Creek to NRC based on records available at the plant. Additional repair records have been compiled from Westinghouse fabrication records.

Past and Future Inspections

- Total population of pressurizer DM 82/182 welds: 275
- Butt welds inspected or mitigated
  - 2005 and 2006: 79 (29% complete)
  - Spring 2007: 71 (55% complete)
  - Fall 2007: 66 (79% complete)
  - Spring 2008: 57 (99% complete)
- Inspections or mitigations occur during plants' next scheduled refueling outages
  - Over 95% mitigations by Spring 2008

Inspection/Mitigation Plans by Plant



* Two plants have individual nozzles with deviations to the above schedule

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Flaw Tolerance and Crack Growth

Flaw Tolerance & Growth Conclusions

- Tests and analysis show that very large flaws can be tolerated and lead to tearing and leakage not rupture (NUREG/CR-4687)
- Refined analysis indicates flaws the size of Wolf Creek would not grow through-wall between now and end of industry's implementation schedule.
- Flaw growth will lead to localized penetration and leakage under realistic assumptions

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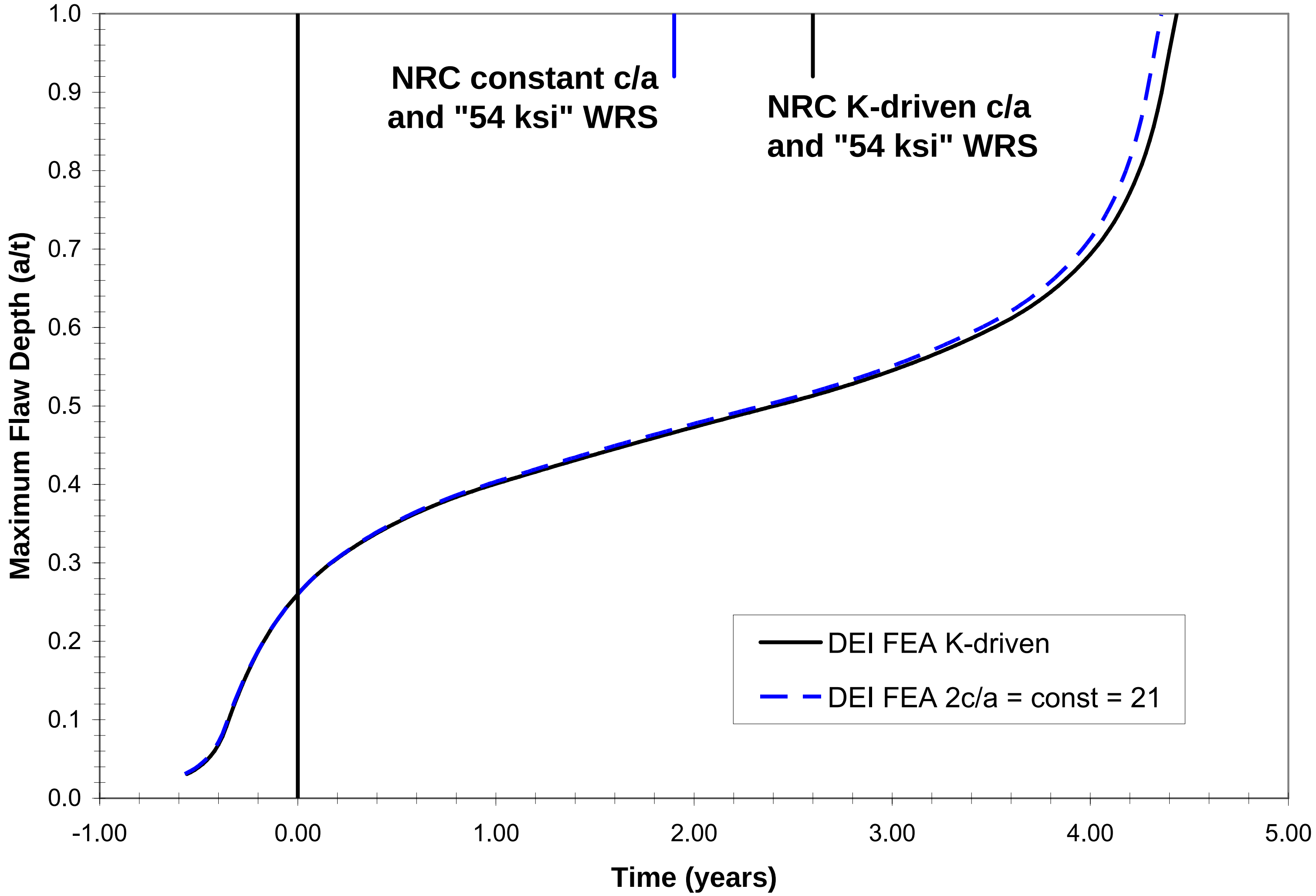
Flaw Tolerance & Growth: New Work

- Considerable new work performed to evaluate the impact of Wolf Creek indications on MRP-139 inspection recommendations
  - Reassessed crack growth
  - Reassessed critical flaw sizes
  - Reviewed NRC sponsored pipe rupture tests
  - Updated Leak Rate Calculations

MRP Crack Growth Evaluation Wolf Creek Relief Nozzle

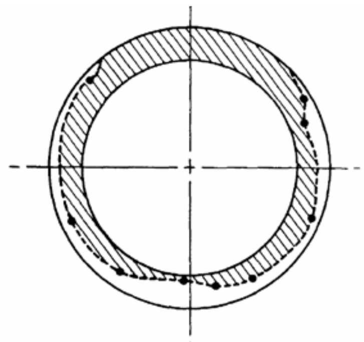
- Created finite element model with assumed Wolf Creek crack
  - Validated Model with respect to Published Solutions
  - Used NRC Residual Stresses, Loads and Dimensions
- Computed crack growth using MRP-115 crack growth rate
- Results:
  - 4.4 years to through-wall (NRC 1.9-2.6 years) primarily due to refinement of stress intensity factor solution in FEM
  - Due to semi-elliptical flaw and axisymmetric residual stress assumption, calculations show little margin between onset of leakage and rupture
- Realistic treatment of residual stress distribution and crack shape would result in significant time between leakage and rupture

Predicted Growth in Depth Direction of Relief Nozzle Indication

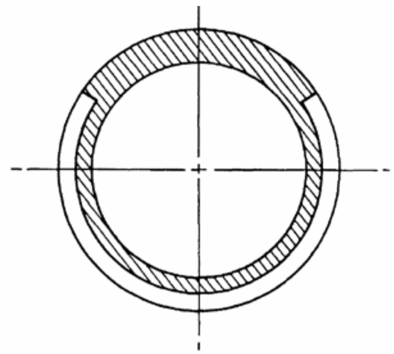


Critical Flaw Size
NUREG/CR-4687 Tests of Complex Crack

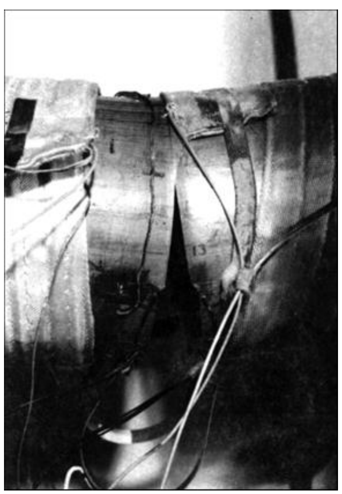
- Full scale tests of "complex flaws" sponsored by NRC

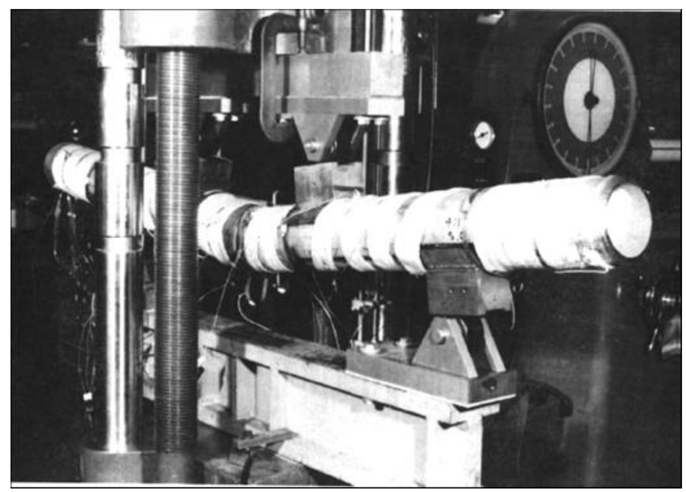


Duane-Arnold Crack Found in Service



Simulated Complex Crack





Critical Flaw Size

NUREG/CR-4687 Test Results for Complex Cracks

- Tests for Alloy 600 material at 550F with simulated 360 degree crack showed very large crack opening angle, crack opening area and kink angle in pipe
- Significant ductility in pipes with large 360 degree cracks (60% and 80% lost cross sectional area)
- Failure loads were typical of plant loadings on pressurizer dissimilar metal welds
- Confirms that these types of cracks in a ductile material would result in tearing and gradually increasing leakage, not instantaneous guillotine rupture when critical flaw size reached

Critical Flaw Size
NUREG/CR-4687 Test Results for Complex Cracks

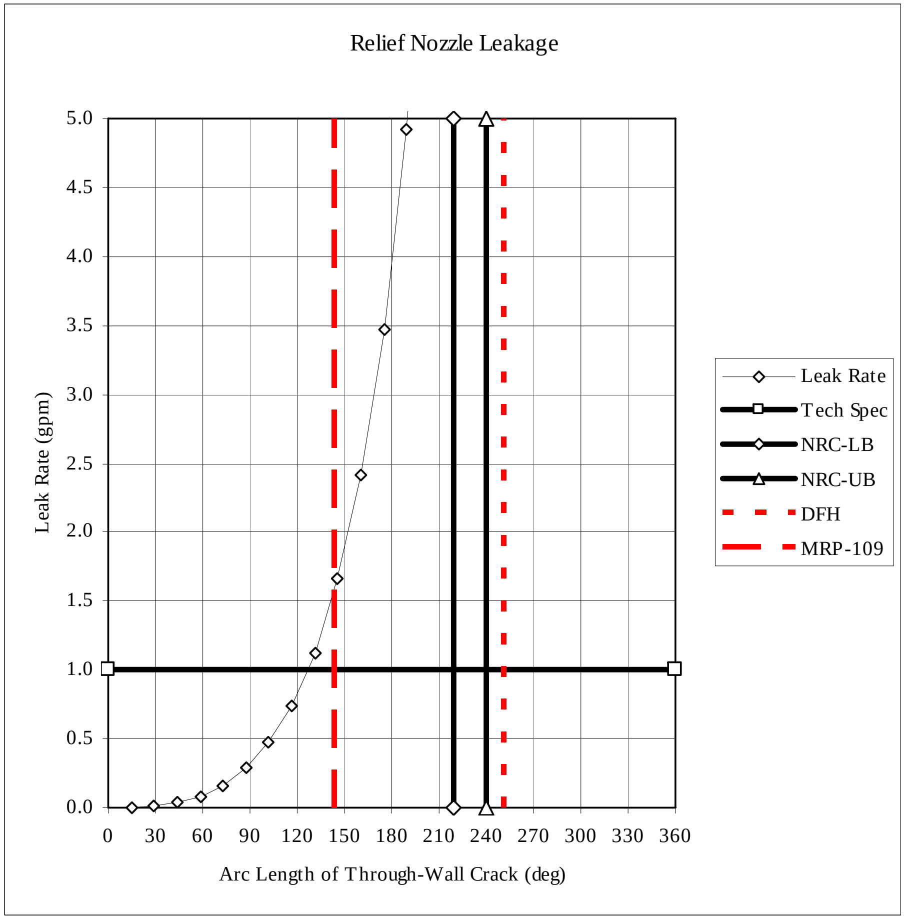
	"Small" Flaws	"Large" Flaws
Test Samples		
Depth of part thru-wall portion of flaw (a/t)	0.34	0.61
Length of thru-wall portion of flaw (deg)	133	133
Cracked area (% of cross section)	60%	79%
Test Results		
Critical stress at rupture (Pb/Sm)	0.97	0.59
Crack opening angle (deg)	18	12~15
Pipe kink angle (deg)	9	7
Crack opening area (in^2)	16.5	14.7

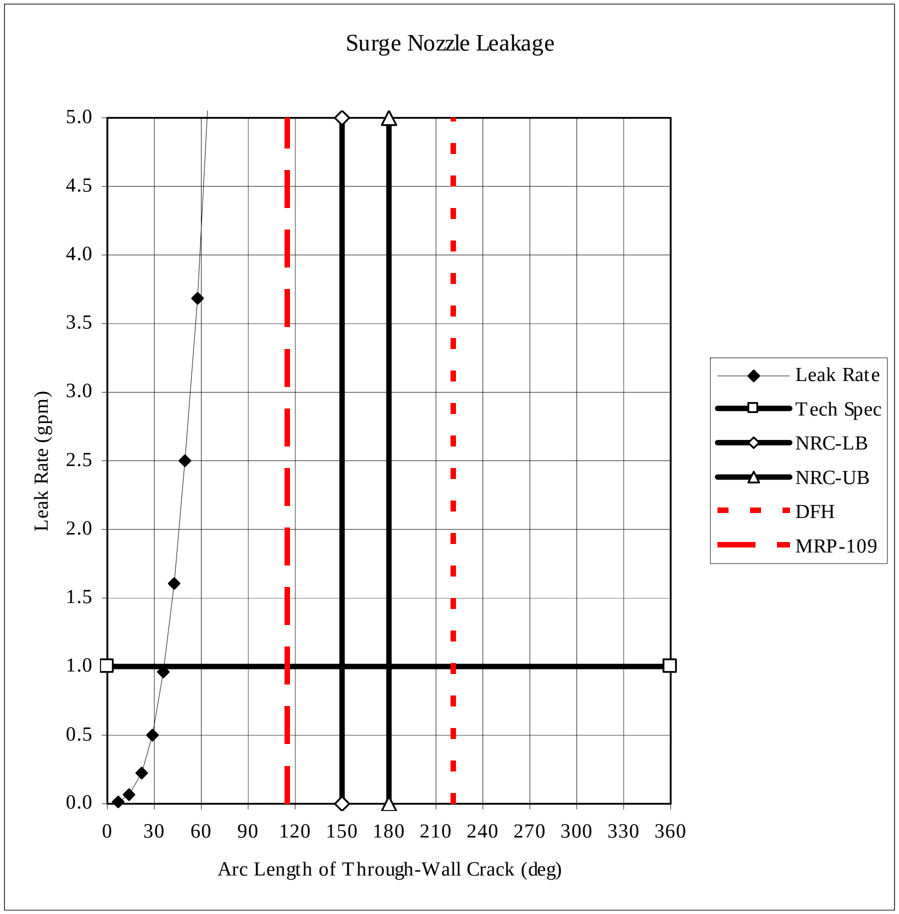
Critical Flaw Size and Leak Detection

Partial-Arc Through-Wall Cracks

- Leak rate calculations have been updated using PICEP with PWSCC morphology
- Critical flaw sizes from MRP-109, NRC, and recent EPRI Ductile Fracture Handbook methods
- Leakage monitoring action levels range 0.1-0.3 gpm
- Calculations show large critical flaw sizes and significant margin between leakage and critical size

Critical Flaw Size and Leak Detection
Partial-Arc Through-Wall Cracks





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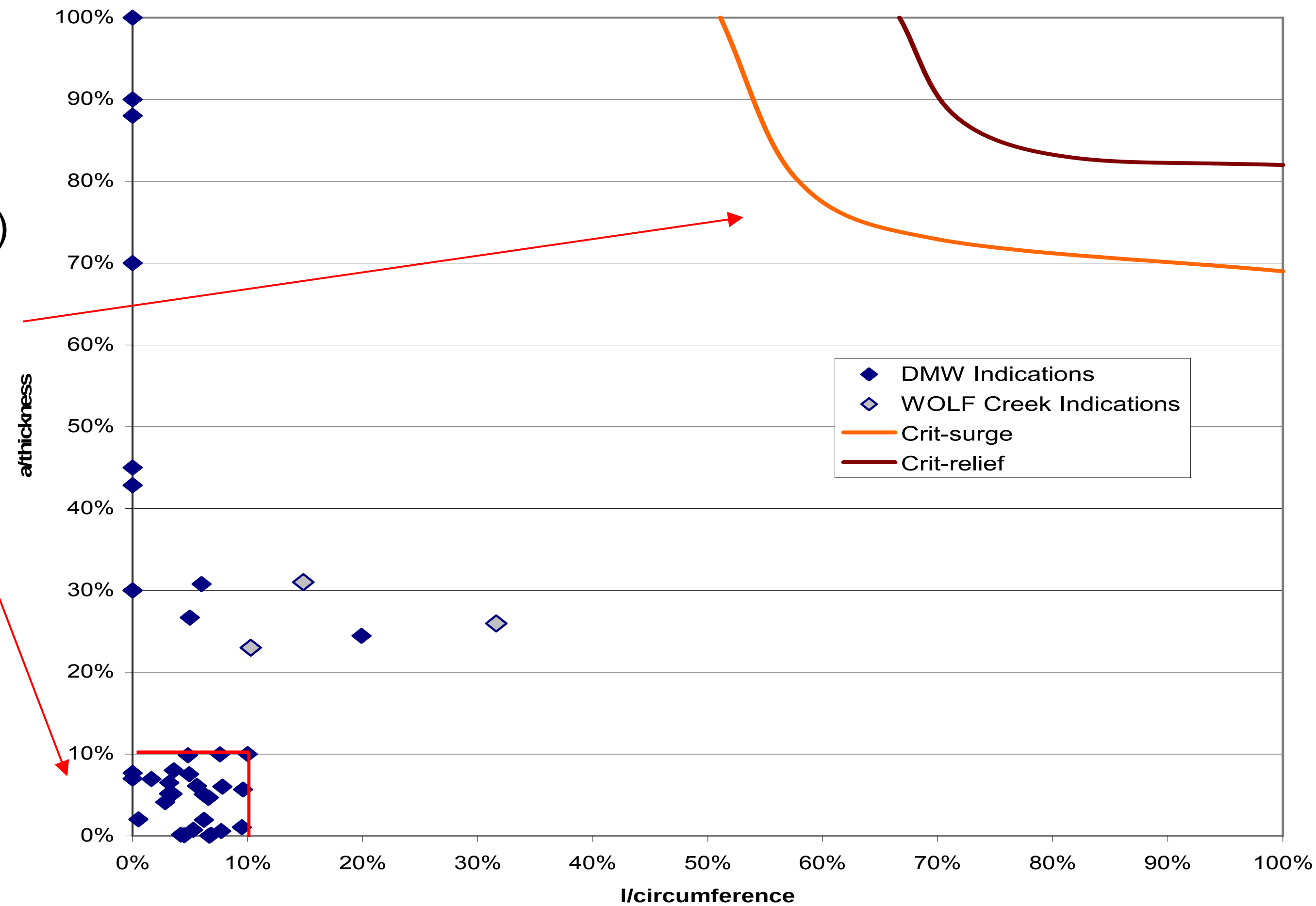
Probability of Critical Flaws in Uninspected Pressurizer Welds

Probability of Critical Flaws in PZR Welds

Data Base Evaluated

- PDI qualified inspection data & other meaningful data plotted as a/t vs. l/circumference
  - 41 data points, 7 w/ circ indications
  - Axial indications (10) lie on axis
- Critical flaw sizes plotted
- Cases with no reported flaws plotted in box suggesting uncertainty
- Distance between data points and critical size indicates margin



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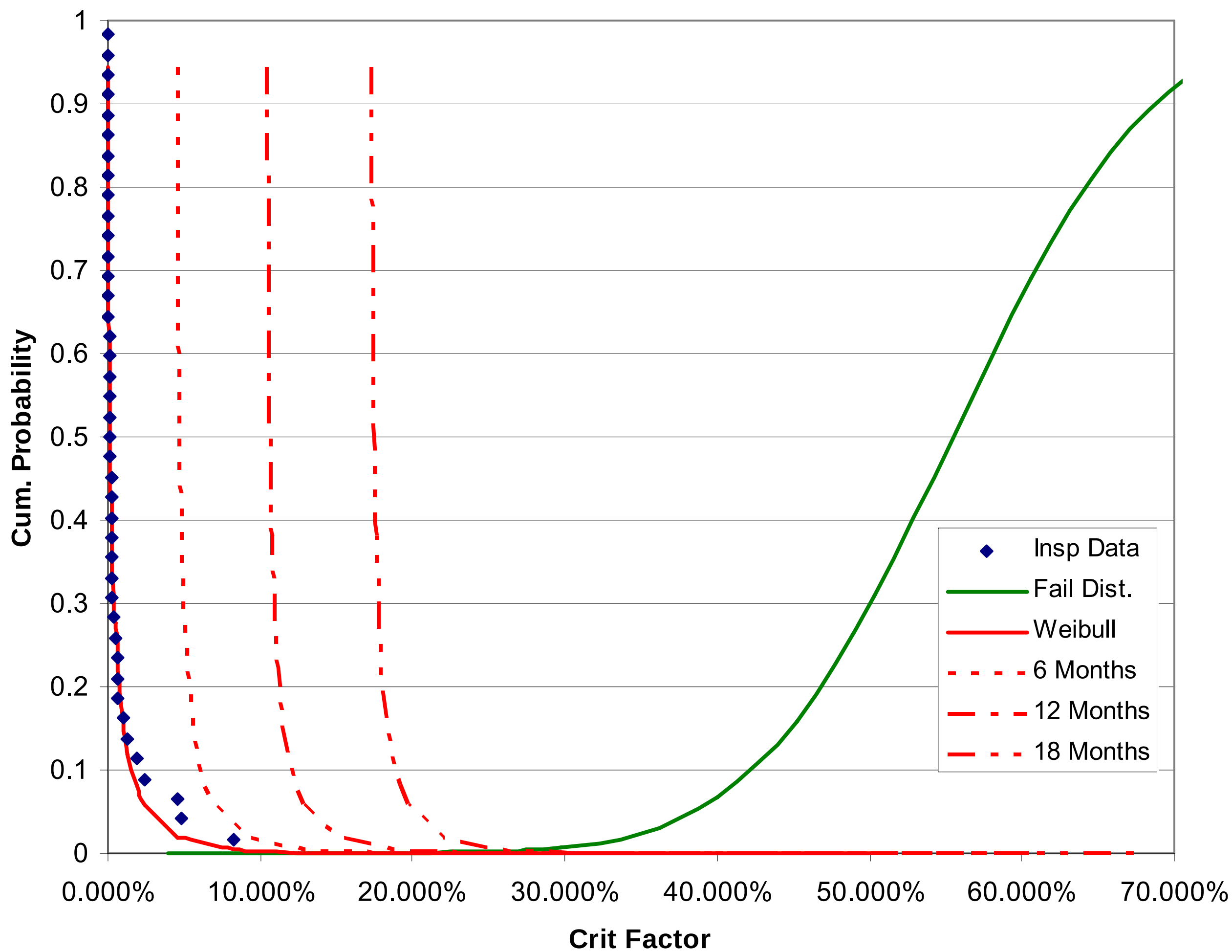
Probability of Critical Flaws in PZR Welds
Probability of Rupture

- Cumulative probability of defect size and critical flaw size plotted vs. "Criticality Factor"
  - Criticality factor is the percentage of the nozzle cross section area lost to the crack
- Very conservative estimate of increase in criticality factor of flaws to account for flaw growth
- "Failure" represented by overlap of tails



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Probability of Critical Flaws in PZR Welds

Summary of Monte Carlo Results

	Probabilities of Rupture	
Time	Cumulative	Incremental
Current	3.27 E-06	
6 Months	6.78 E-06	3.51 E-06
12 Months	1.65 E-05	9.76 E-06
18 Months	6.24 E-05	4.59 E-05

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Probability of Critical Flaws in PZR Welds
Summary of Key Results

	Fall 2006	Spring 2007	Fall 2007	Spring 2008
Number of Uninspected Welds Through Indicated Date	279	195	121	53
Number of Plants with uninspected nozzles	50	34	21	9
Planned Nozzle Inspections/ Mitigations at Indicated Date	84	74	68	53
Number of Plants with Planned Nozzle Inspections/Mitigations	16	13	12	9
Nozzle Rupture Frequency - all plants in category, per 6 months	N/A	6.84E-04	1.18E-03	2.43E-03
Nozzle Rupture Frequency (per plant year)	N/A	3.26E-05	8.09E-05	2.70E-04
Core Damage Frequency (per plant year)[1]	N/A	3.26E-08	8.09E-08	2.70E-07

1. CCDP assumed = 1 E-3

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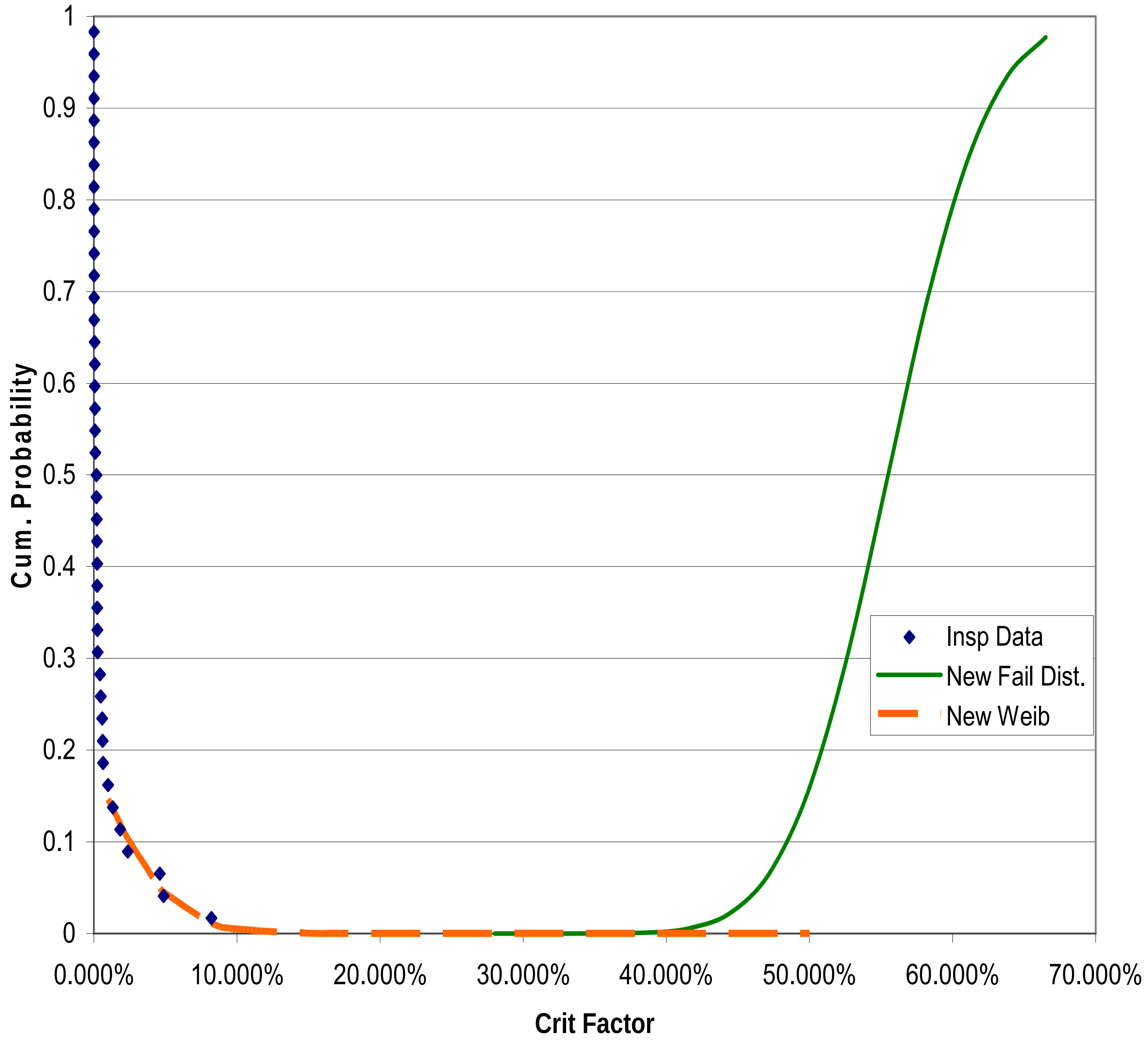
Probability of Critical Flaws in PZR Welds
Sensitivity Evaluation

- Revised distributions considered based in discussion with NRC Expert
- Flaw distribution developed based only on nozzles w/ circ indications (factored by circ indication frequency)
- Less conservative fragility curve assumed
- Results yield lower probabilities than original calculation



Probability of Critical Flaws in PZR Welds *Conclusions*

- Significant sample of Alloy-600 Butt-welded nozzles examined (41 vs 279)
- Inspection results indicate Wolf Creek indications are in tail of distribution
- Critical flaw size for rupture is large, even considering seismic loads
- Rupture and core damage frequencies under industry inspection plans are small
- Sensitivity evaluation indicates results conservative

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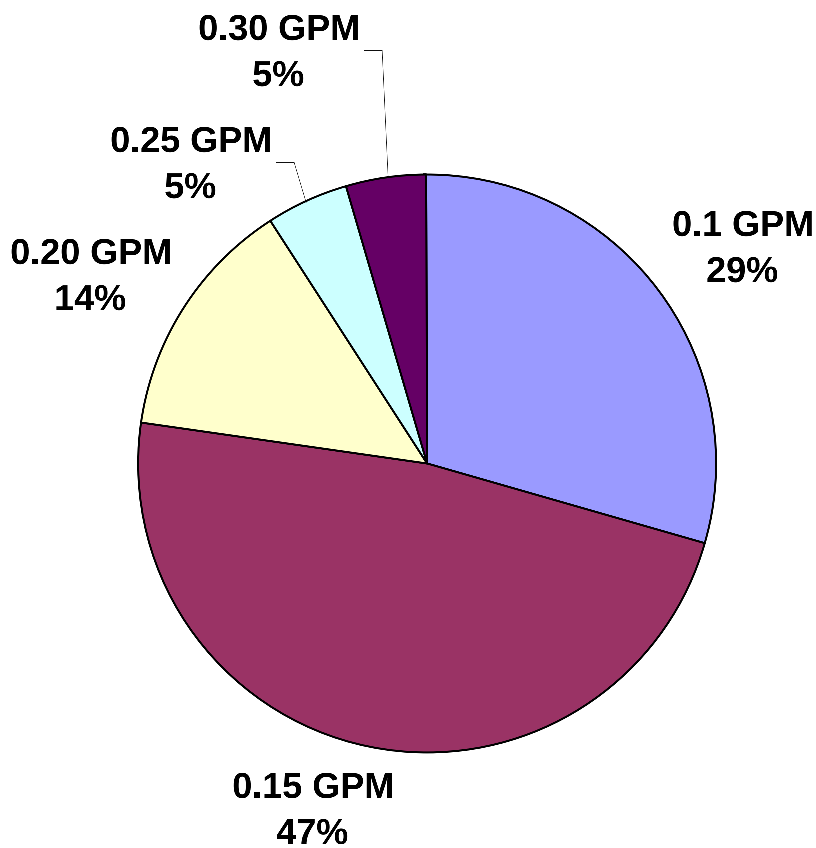
Leakage Monitoring

Leak Monitoring

- It is industry practice to complete bare metal visual inspections each RFO for the pressurizer locations
  - MRP letters
  - Bulletin 2004-01
- INPO review visits confirm that plant operators have high awareness to changes in RCS leak rate.
- PWROG has completed work to standardize the calculation of the leak rate and define action levels
- Currently, all Fall 07 and Spring 08 PWR operators are taking action based on RCS leakage monitoring at 0.3 gpm or less.

Industry Survey - Current RCS Action Levels



44 plants responding - unidentified leak rate or delta above a baseline

PWROG RCS Leakage Guidelines and Action Levels

- Guidelines provide for:
  - Standardized methodology for calculating the unidentified leak rate and leakage
  - Specifies action levels and response with respect to unidentified leakage
    - Absolute Unidentified Leak Rate limits in gpm
    - Deviation from the baseline mean in gpm
    - Total Cumulative Unidentified Leakage limits in gallons
- Status
  - Issued in October 2006 as recommended practice
  - Implementation evaluation in process
- Conclusions:
  - Guidelines are more restrictive than the NRC inspection guidelines (IMC 2215, App. D)

PWROG Leakage Guideline Action Levels

- Tier One Action Levels
  - IF ANY of the following limits are exceeded:
    - One seven {7} day rolling average of daily Unidentified RCS leak rates > 0.1 gpm.
    - Nine (9) consecutive daily Unidentified RCS leak rates > baseline mean [μ].
- Tier Two Action Levels:
  - IF ANY of the following limits are exceeded:
    - Two consecutive daily Unidentified RCS leak rates > 0.15 gpm.
    - Two (2) of three (3) consecutive daily Unidentified RCS leak rates > [$\mu + 2\sigma$].
    - Short Term (30 Day) Total Integrated Unidentified Leakage > 5,000 gallons.
- Tier Three Action Levels:
  - IF ANY of the following limits are exceeded:
    - One daily Unidentified RCS leak rates > 0.3 gpm.
    - One (1) daily Unidentified RCS leak rate > [$\mu + 3\sigma$].
    - Long Term (Operating Cycle) Total Integrated Unidentified RCS Leakage > 50,000 gallons.

Conclusions

- MRP-139 remains a valid approach for inspection and mitigation of pressurizer welds
  - Pressurizer weld requirements consistent with approach used for BWR piping in GL 88-01 (NUREG 0313)
  - Estimated risk within Reg Guide 1.174 limits
- Currently plants perform RCS leakage monitoring at levels significantly below tech spec limits.
- At the next refueling outage, every PWR will have either inspected or mitigated the pressurizer welds.
- This schedule provides adequate assurance of public health and safety.

Consequences of Accelerated Mitigation Schedules

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First Energy

Tasks Required to Overlay

- Site walkdowns
- Engineering Change Package
  - Overlay design (vendor)
  - Design and installation document preparation and issuance
- Pre-outage preparations
  - Weld and NDE process mock-up and demonstration
  - ALARA plans
  - ASME Code relief request
- Welding contractor mobilization
- Weld overlay
- Weld NDE inspection and evaluation
- Re-work (if necessary)
- Welding contractor de-mobilization
- Planning process represents 3-4 manyears of effort

Assumptions

- Critical resources
  - Design engineering support (design of overlay)
  - Qualified welders and NDE personnel
  - Welding engineering support
- Present resources are almost fully allocated for the spring and fall outage seasons
  - Additional campaigns would be challenging
- About 1 month is required between starts of successive overlay campaigns for a given welding team
- Approximately 1 month shutdown to perform an overlay campaign
- At least 12 to 15 Rem exposure for the welding team in each overlay campaign
  - Individual exposure can be on the order of 1.9 Rem

Planned Mitigation Schedules

- 11 overlay projects in Spring of 2007
- 11 overlay projects in Fall of 2007
- 10 overlay projects in Spring of 2008
- 1 overlay project in Fall of 2008
  - already performed a best effort inspection

- Planning cycle for mitigation is typically 18-24 months

Effect of Accelerated Mitigation Schedules

- Inspection or mitigation required before December 31
  - 11 overlay projects in Spring of 2007
  - 11 overlay projects in Fall of 2007
  - 11 unplanned plant shutdowns to perform overlay projects
- 11 months unplanned shutdown time
  - 330 days of lost generation from 11 plants in 2007
    - Each with approximately 1000 megawatts generating capacity
    - 0.7% lost grid capacity for affected months (~3 available months / 3.7 plants per month)
  - Shutdowns will occur in the summer or winter because of resource limitations

Key Challenges

- Above is a best case scenario
  - Does not account for rework and other unforeseen delays
  - Engineering support would be challenged
  - Accelerated schedule will challenge exposure limits and may result in unavailability of critical resources
  - Utilizing inexperienced resources would result in additional rework
  - Will impact other maintenance work that needs welders
  - NRC will need to approve 33 ASME Code relief requests (11 additional in 2007)

Other Considerations

- 4 plants are planning to inspect, not mitigate in the spring and fall of 2007.
  - Mitigation required if indications are identified
- Unplanned shutdown will affect plant fuel reload analysis and efficient fuel usage
- Planning cycle for mitigation is typically 18-24 months