Fabrication Records Review

U.S.NRC
UNITED STATES NUCLEAR REGULATORY COMMISSION
Protecting People and the Environment

Al Csontos, RES

June 19, 2007

Background

- On Friday June 8, 2007, Cameron Martin facilitated the NRC review of the as-built fabrication drawings from the ten plants under evaluation.
- Cameron identified and described the various fabrication processes as found in the drawings and answered NRC questions.
- An issue was identified by the NRC during the review that could affect the WRS models and the resulting Phase II crack growth calculations
  - Potentially reducing WRS.

Summary

- The majority of fabrication information was verified by the NRC reviewers except for the following:
- For Westinghouse surge nozzles:
  - Fill-in welds after the back chip step were confirmed to be 0.3" as previously identified and modeled.
  - The fill-in welds were 1-2" wide.
- For 1 out of 3 Westinghouse spray nozzle designs:
  - Weld fabrication steps were more akin to a "CE" type design with wider lands and a final machining step.
  - This may reduce ID WRS for this specific design.

Recommendations

- Determine if the findings need to be considered in the Phase II crack growth calculations.
- With regards to the fabrication tables from past industry presentations, add an additional column for:
  - Land thickness for Westinghouse nozzles
  - Fill-in weld thickness for Westinghouse surge nozzles
  - Fill-in weld widths for Westinghouse surge nozzles.

Pressurizer Nozzle Fabrication Detail

Cameron Martin

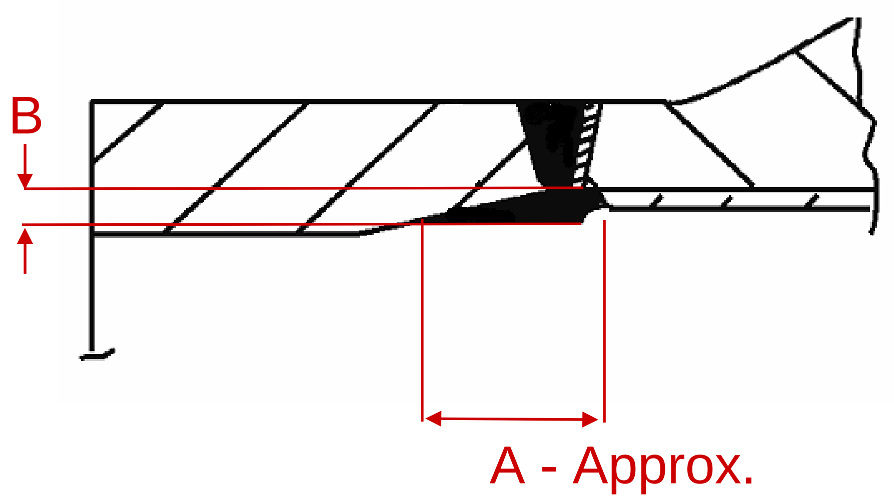
Wolf Creek Task Group Meeting
June 19 -20, 2007

Westinghouse

Thermal Sleeve Fill-In Weld Design Detail

(Approximate Dimensions)

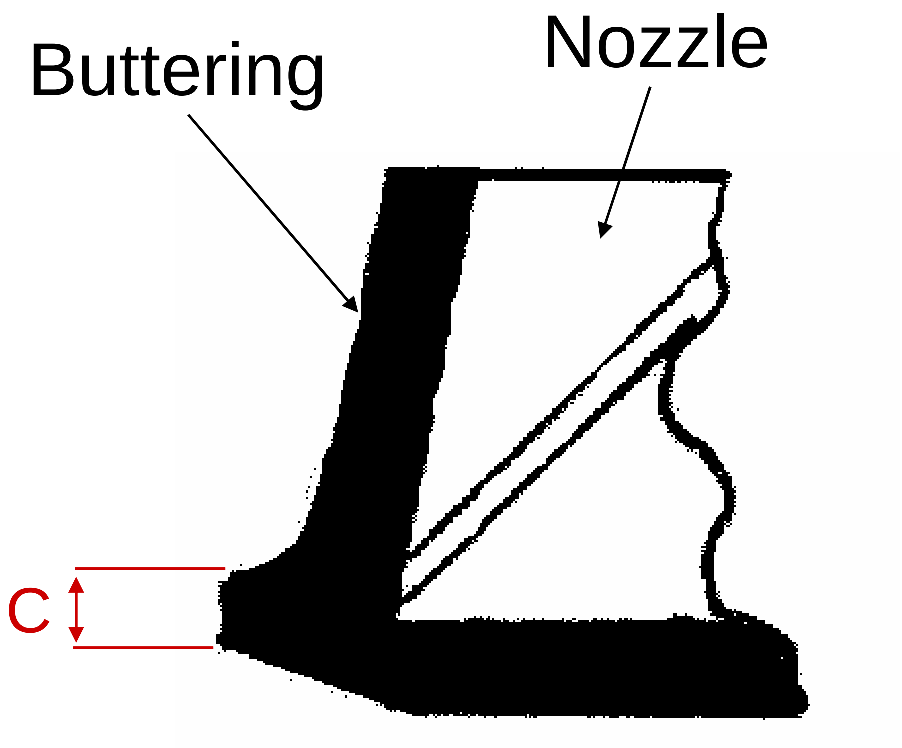
Plant	"A"	"B"
A	2.05	0.30
B	2.10	0.30
C	2.00	0.29
D	N/A	
E	N/A – Machined Fit	
F	N/A	
G	2.10	0.30
H	N/A – Machined Fit	
I	N/A	
J	2.10	TBD



Nozzle Buttering - Weld Land Detail

Plant	Location	"C" (in)
B	SURGE NOZZLE	0.06
	SPRAY NOZZLE	0.06
	SAFETY/RELIEF NOZZLE	0.06
C	SURGE NOZZLE	0.06
	SPRAY NOZZLE	0.06
	SAFETY/RELIEF NOZZLE	0.06
D	SURGE NOZZLE	0.10*
	SPRAY NOZZLE	0.10*
	SAFETY/RELIEF NOZZLE	0.10*
E	SURGE NOZZLE	N/A
	SPRAY NOZZLE	0.06
	SAFETY/RELIEF NOZZLE	0.06

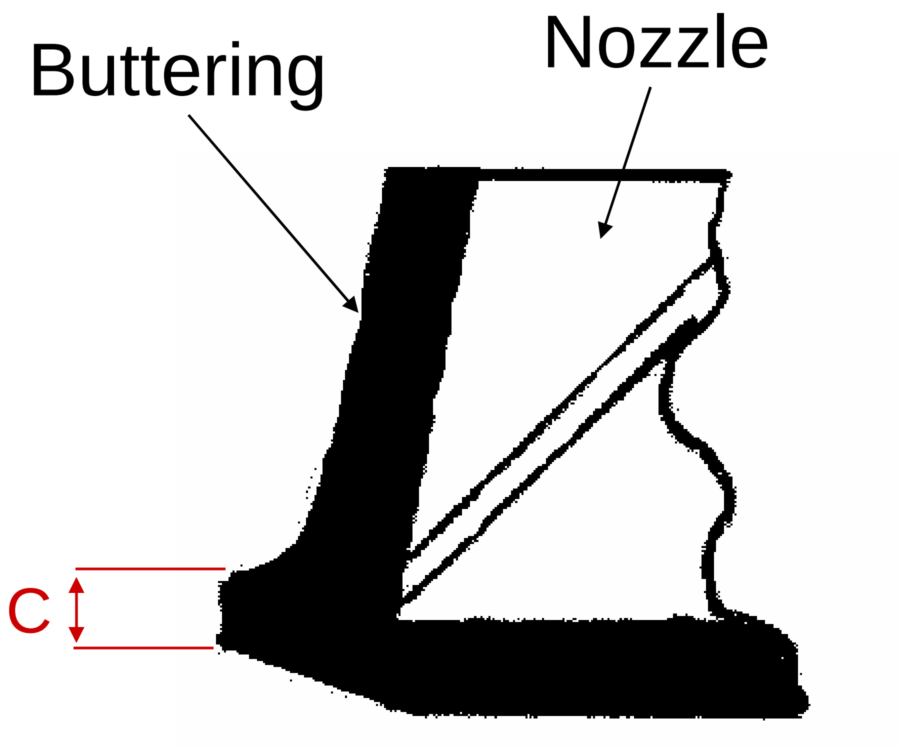
* Machined



Nozzle Buttering - Weld Land Detail

Plant	Location	"C" (in)
G	SURGE NOZZLE	0.06
	SPRAY NOZZLE	0.06
	SAFETY/RELIEF NOZZLE	0.06
H	SURGE NOZZLE	0.10*
	SPRAY NOZZLE	0.10*
	SAFETY/RELIEF NOZZLE	0.10*
J	SURGE NOZZLE	0.06
	SPRAY NOZZLE	0.06
	SAFETY/RELIEF NOZZLE	0.06

* Machined



Westinghouse

Advanced FEA Crack Growth Calculations for Evaluation of PWR Pressurizer Nozzle Dissimilar Metal Weld Circumferential PWSCC

Sponsored by: EPRI Materials Reliability Program

Dominion Engineering, Inc.

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Reston, VA 20190
703.437.1155
www.domeng.com

Presented To:

Expert Review Panel for Advanced FEA Crack Growth Calculations

Presented By:

Glenn White
John Broussard
Jean Collin
Matthew Klug
Dominion Engineering, Inc.

Tuesday and Wednesday, June 19 and 20, 2007
Meeting on Implications of Wolf Creek Dissimilar Metal Weld Inspections
DEI Offices, Reston, Virginia

Tuesday Agenda

- Introductions – Industry and NRC
- Fabrication Records Meeting Update – NRC
- Status Update – Industry
  - WRS Modeling
    - Axisymmetric & 3-D WRS Results
    - Typical Fabrication Steps
  - Phase II Sensitivity Cases
  - Knockdown Factor Calculations
  - Probabilistic Assessment
- Status of NRC Confirmatory Research – NRC
  - WRS Modeling
  - Phase II Sensitivity Cases
  - K Verification

Wednesday Agenda

- Discussion from Previous Day's Results – Industry & NRC
  - WRS Models
  - Phase II Sensitivity Cases
- Acceptance Criteria and Safety Factors – Industry
  - Revised Proposed Industry Acceptance Criteria & Safety Factors
  - Discussions
- Plans for next meeting(s) – Industry & NRC
  - Project Timeline & Milestones Update
  - Draft/Final Industry Report Update
  - Expert Panel July 10th
  - ACRS July 11th
  - Expert Panel July 12th?
  - End of July Management Meeting?
- Meeting Summary and Conclusions – Industry & NRC

Tuesday Agenda

- Introductions – Industry and NRC
- Fabrication Records Meeting Update – NRC
- Status Update – Industry
- Status of NRC Confirmatory Research – NRC

Principal Meeting Participants

- EPRI Project Management / Support
  - Craig Harrington, EPRI
  - Christine King, EPRI
  - Tim Gilman, Structural Integrity Associates
- Project Team
  - Glenn White, DEI
  - John Broussard, DEI
  - Jean Collin, DEI
  - Matthew Klug, DEI
- Expert Review Panel
  - Ted Anderson, Quest Reliability, LLC
  - Warren Bamford, Westinghouse
  - David Harris, Engineering Mechanics Technology
  - Doug Killian, AREVA
  - Pete Riccardella, Structural Integrity Associates
  - Ken Yoon, AREVA
- NRC Participants
  - Al Csontos, NRC Research
  - Mauricio Gutierrez, NRC NRR
  - Tim Lupold, NRC NRR
  - Dave Rudland, EMC2
  - Simon Sheng, NRC NRR
  - Ted Sullivan, NRC NRR

Fabrication Records Meeting Update

- To be presented by NRC

Status of Industry Work
Topics

- WRS Modeling
  - Axisymmetric & 3-D WRS Results
  - Typical Fabrication Steps
- Phase II Sensitivity Cases
- Knockdown Factor Calculations
- Probabilistic Assessment
- Other Topics

WRS Modeling

WRS Activities Since 5/31 Meeting

- Additional analysis cases
- Comparison between REFT=1800 and REFT=70
- Stress plots of WRS cases with path lines
- Analysis results with and without SS weld
- Analysis results at residual and normal operating temperature (NOT)
- Analysis results for short, deep repair (3D model)

WRS Modeling
WRS Cases Named in Current Case Matrix

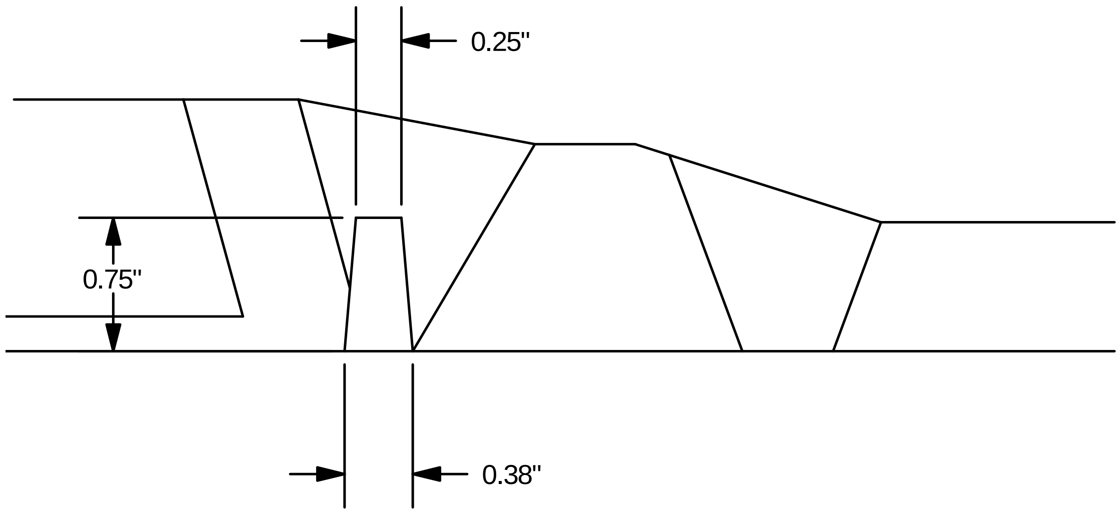
1. S&R No Liner
2. S&R With Liner
3. S&R No Liner, No SS Weld
4. Generic Spray
5. Surge w/ Fill-In Weld
6. Surge No Fill-In Weld
7. S&R Repair No Liner
8. S&R Repair w/ Liner
9. Surge ID Repair w/ Fill-In

WRS Modeling
DEI WRS Cases

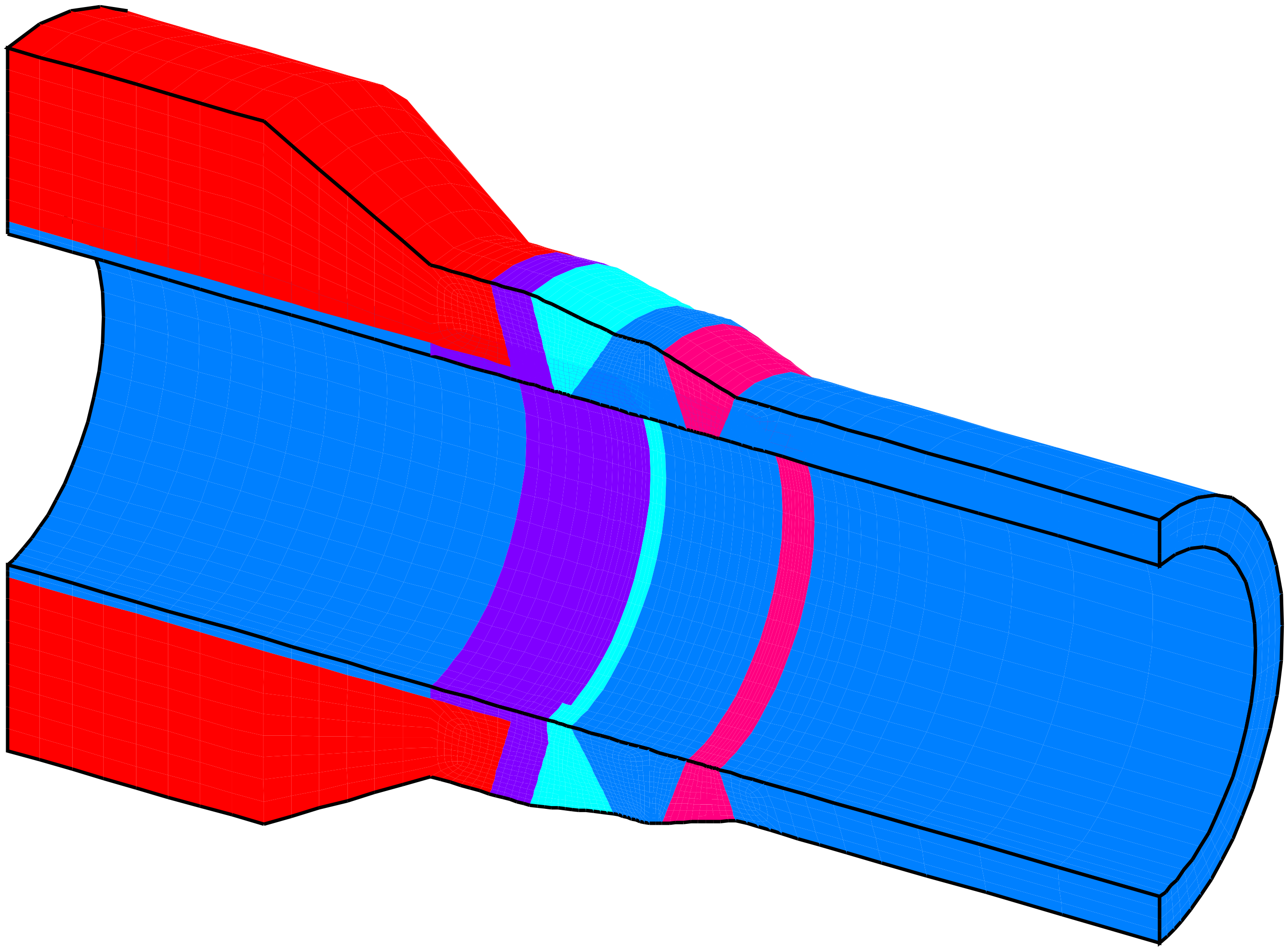
- Type 1a – Safety/Relief No Liner
  - DMW + backweld; with and without SS weld
  - DMW + backweld + safe end ID weld buildup + SS weld
  - DMW + backweld + 0.75-in deep repair, axisymmetric and 0.9-in on ID (3D)
- Type 2b – Safety/Relief w/ Liner
  - DMW + backweld + fillet weld + SS weld
- Type 8 – Surge (W)
  - DMW + backweld + Fill-In; with and without SS weld
  - DMW + repair + Fill-In + SS weld
  - DMW + backweld + 0.6" thick Fill-In
- Type 9 – Surge (CE)
  - DMW + final machining (no SS weld)

Additional WRS Analysis Cases

Safety/Relief with 0.75" Deep Repair

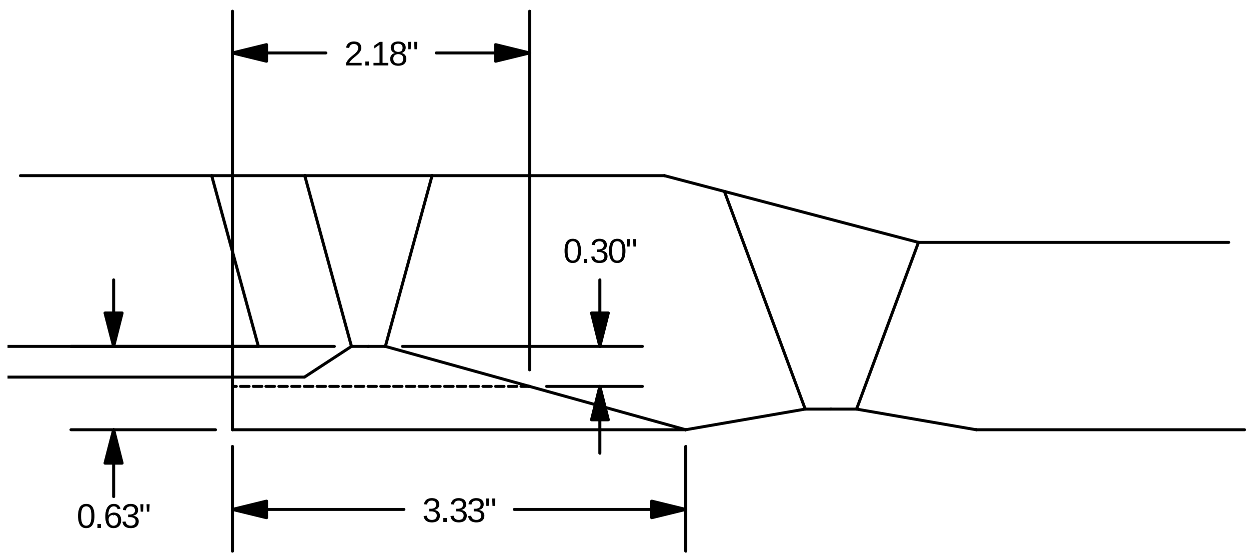


WRS Modeling
3D Model for Safety and Relief Configuration #1a



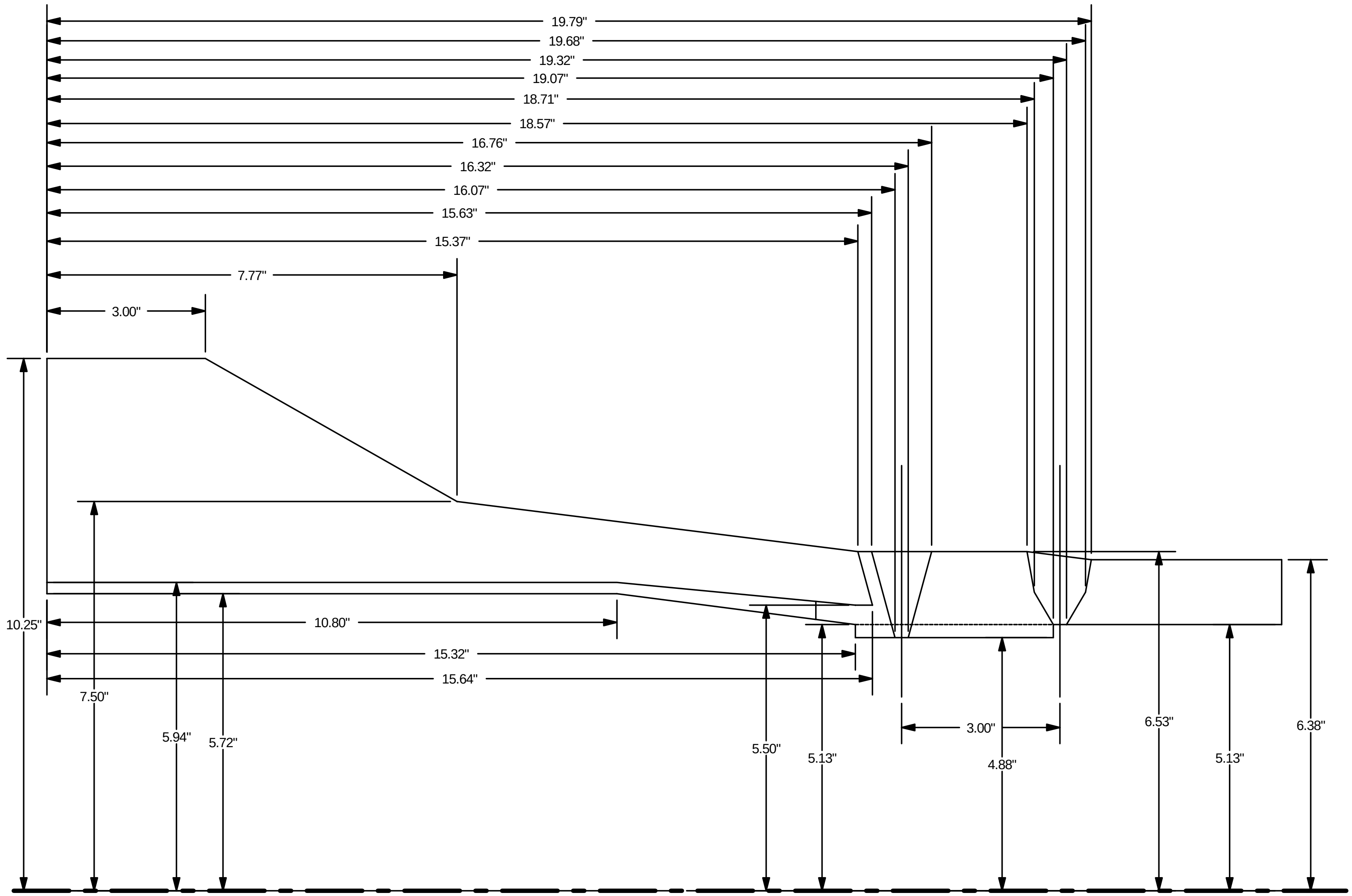
Additional WRS Analysis Cases

Type 8 (W) Surge with 0.6" Fill-In



Additional WRS Analysis Cases

Type 9 (CE) Surge Nozzle



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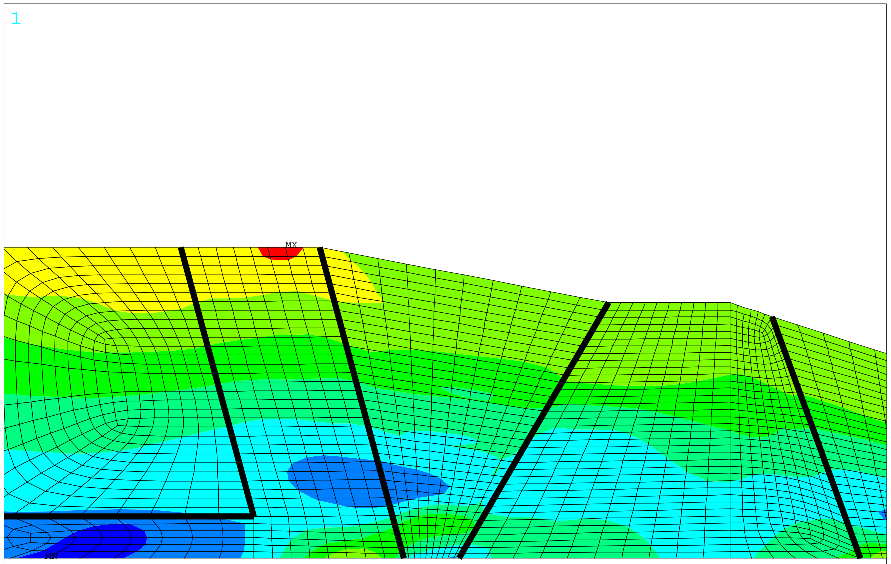
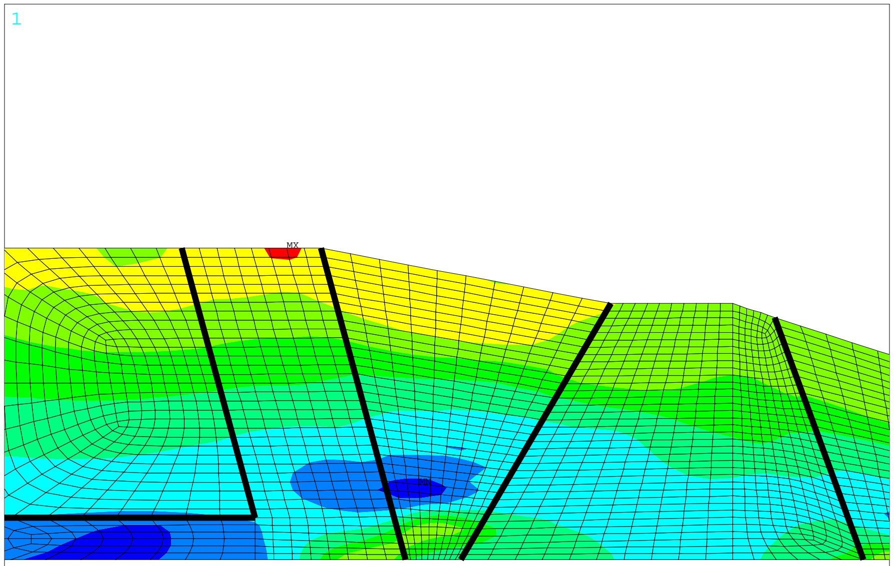
WRS Modeling
Comparison Between REFT=1800 and REFT=70

- Stress paths taken at weld centerline for 5/31 meeting showed significant effect of operating conditions on inside surface axial stress
- Results from modeling choice for zero strain reference temperature of weld metal
- Comparison of stress plots reveals differences limited primarily to weld itself
- All runs performed using REFT=70 to eliminate effect on operating conditions

WRS Modeling
Comparison Between REFT=1800 and REFT=70 – NOPT



REFT=1800



REFT=70

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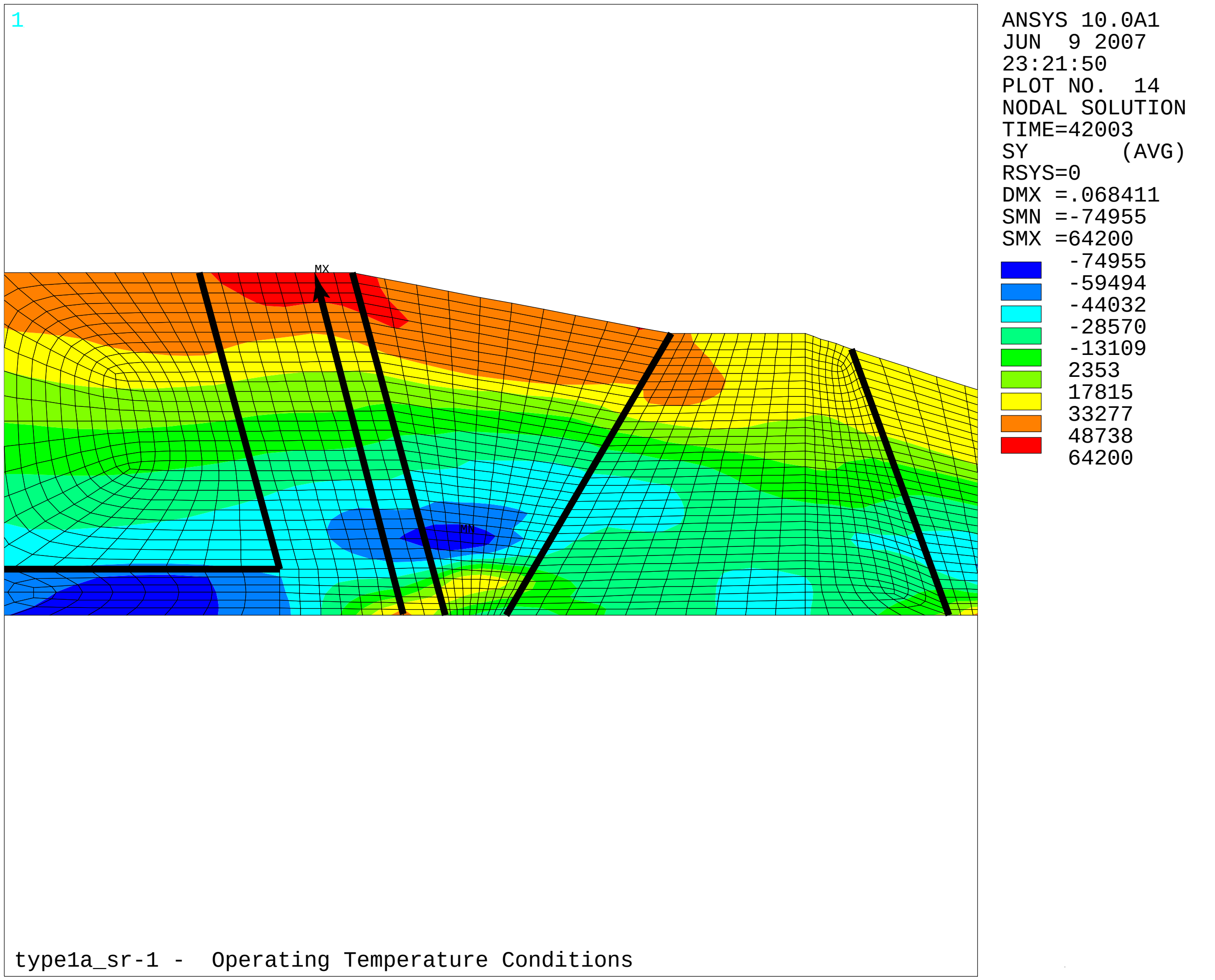
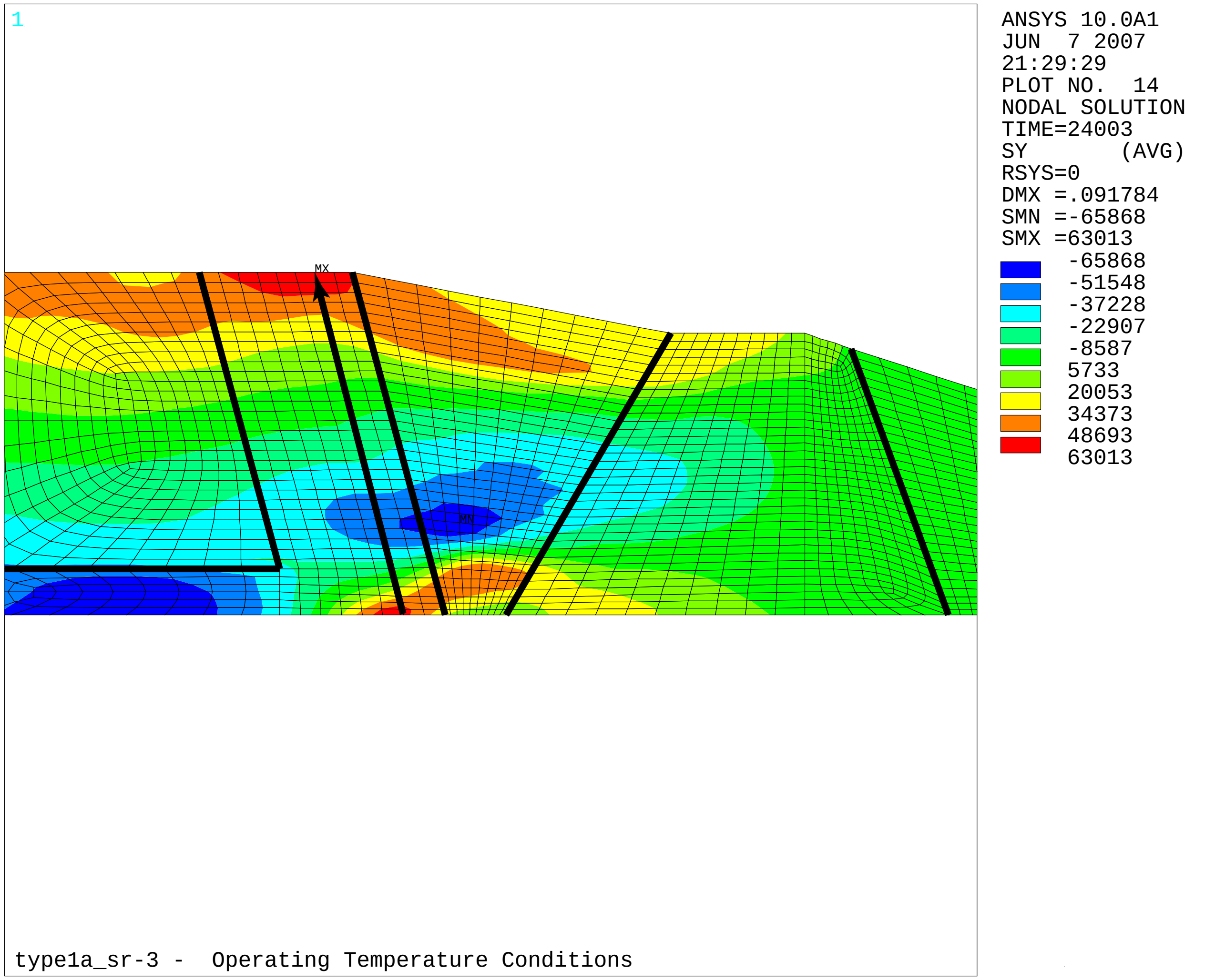
Safety/Relief NOT

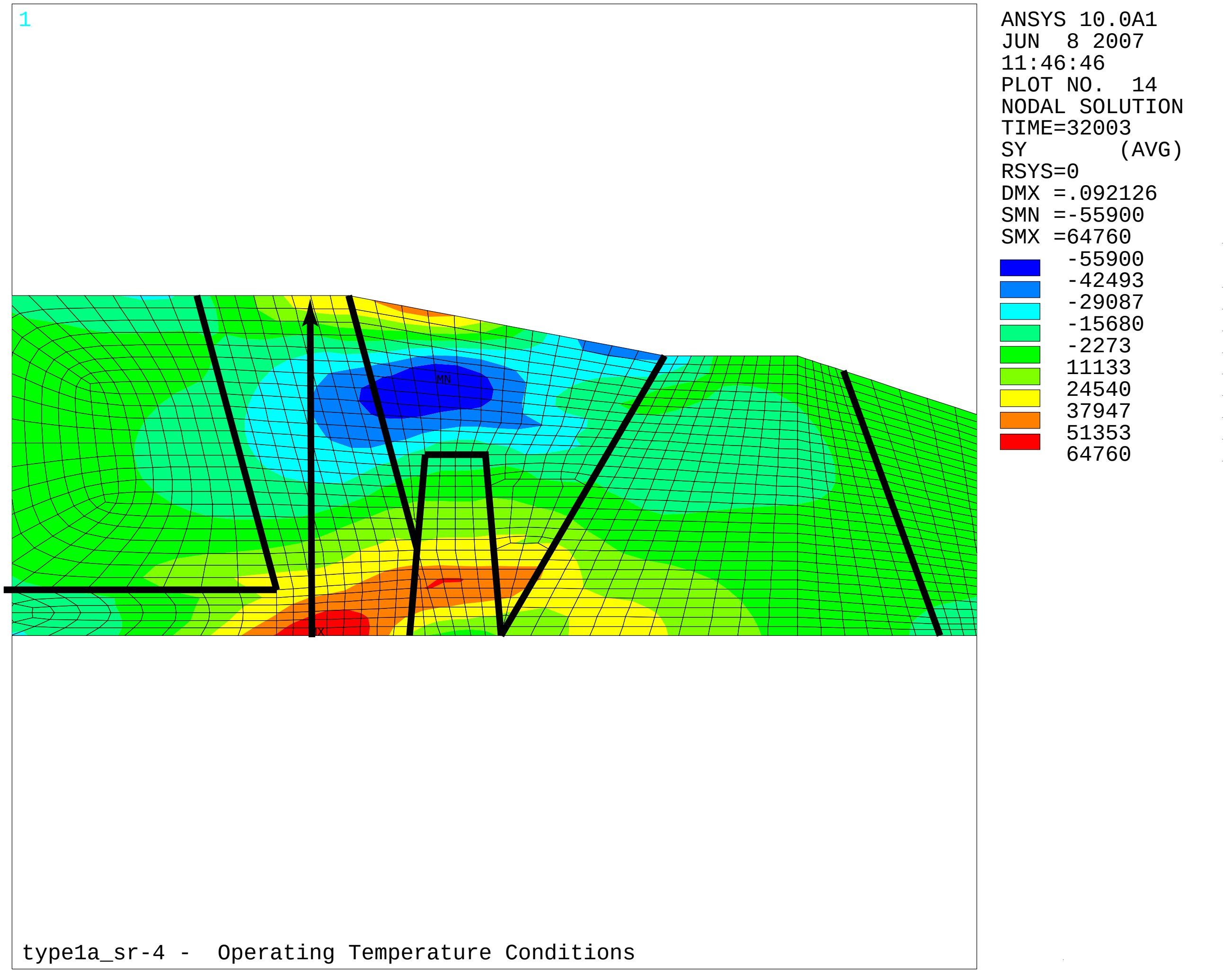
DMW + Backweld + SS Weld



Safety/Relief NOT
DMW + Backweld, No SS Weld

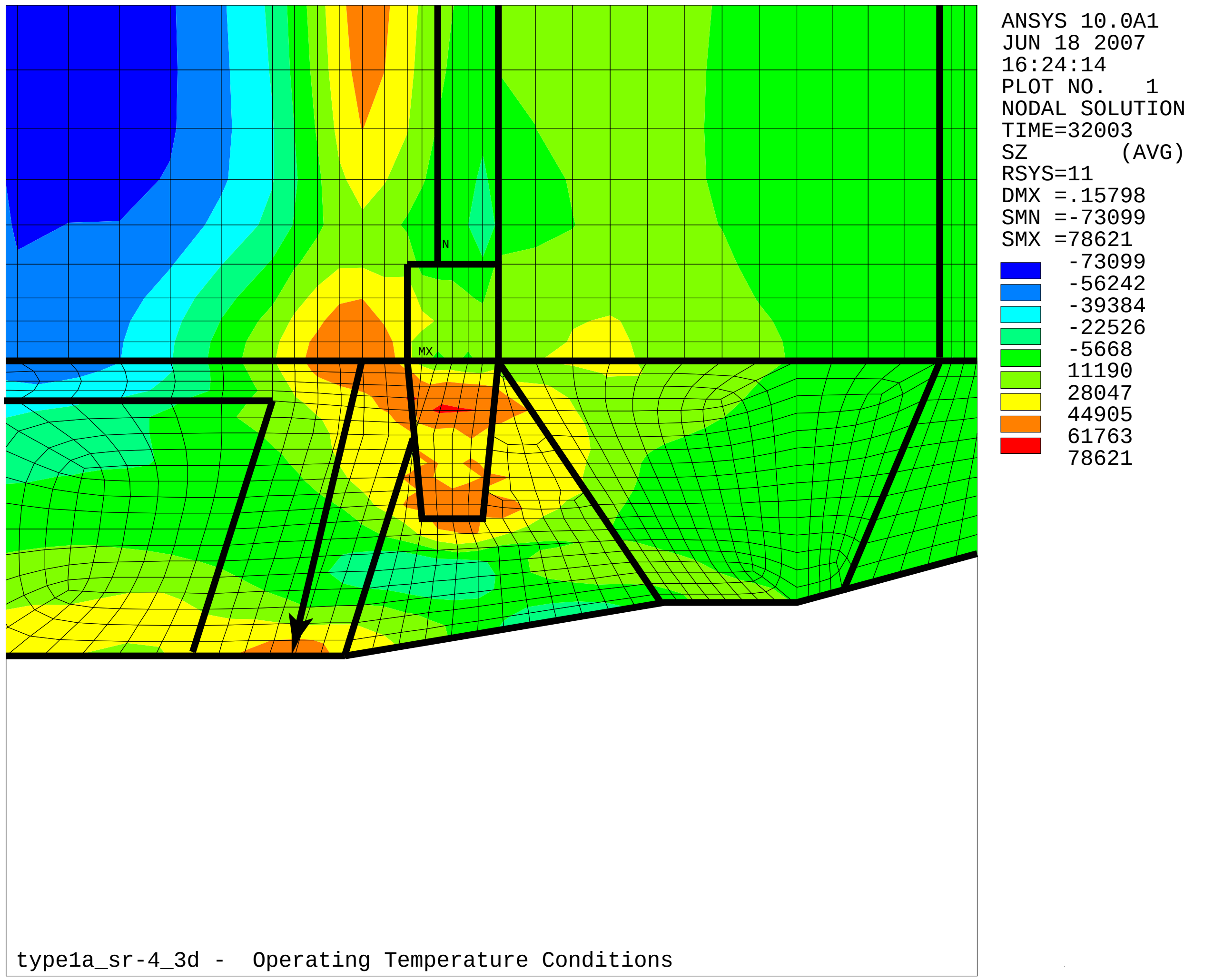


Safety/Relief NOT
DMW + 0.75" Repair, No SS Weld



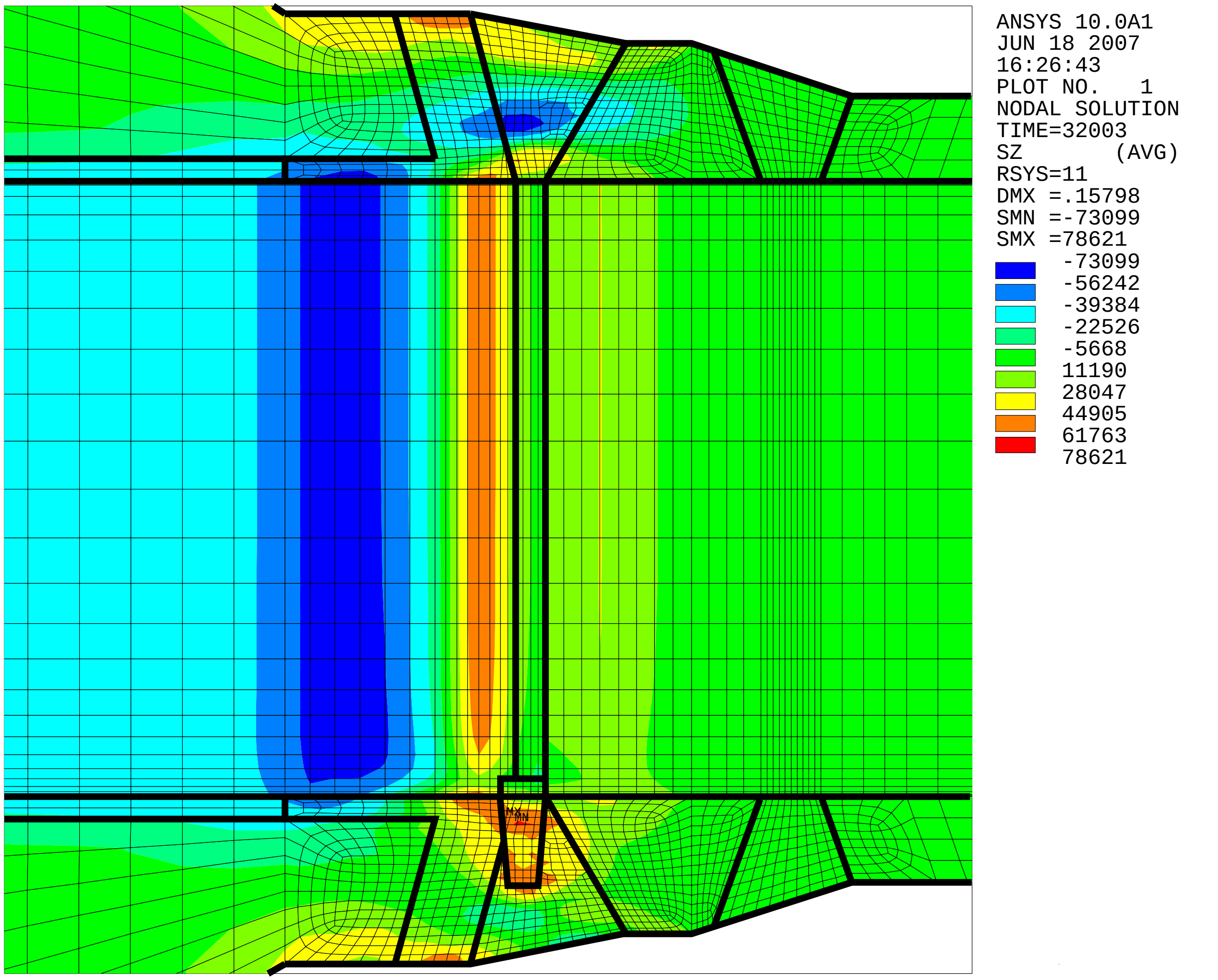
Safety/Relief NOT – 3D Repair

DMW + 0.75" Repair, No SS Weld (1/2)

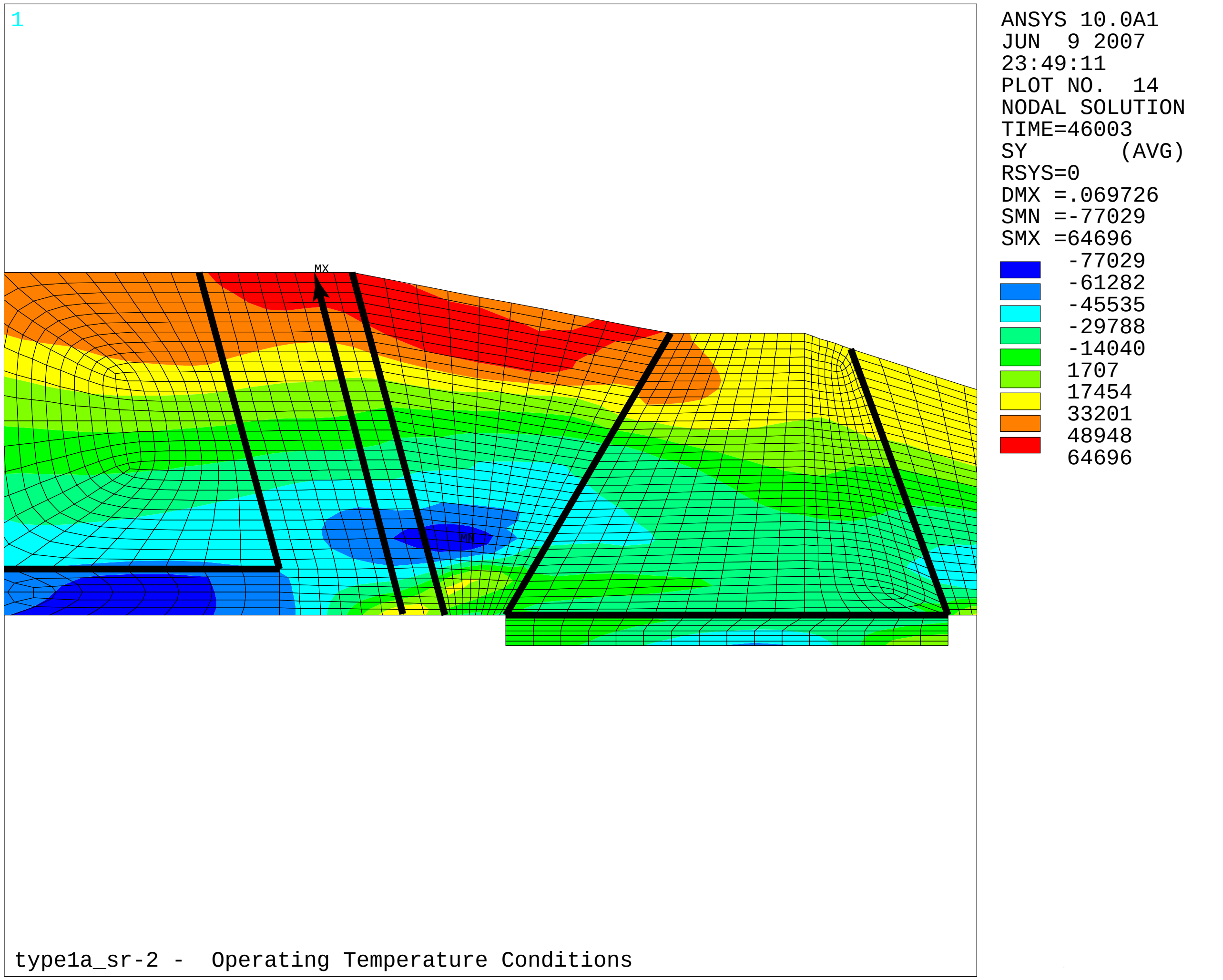


Safety/Relief NOT – 3D Repair

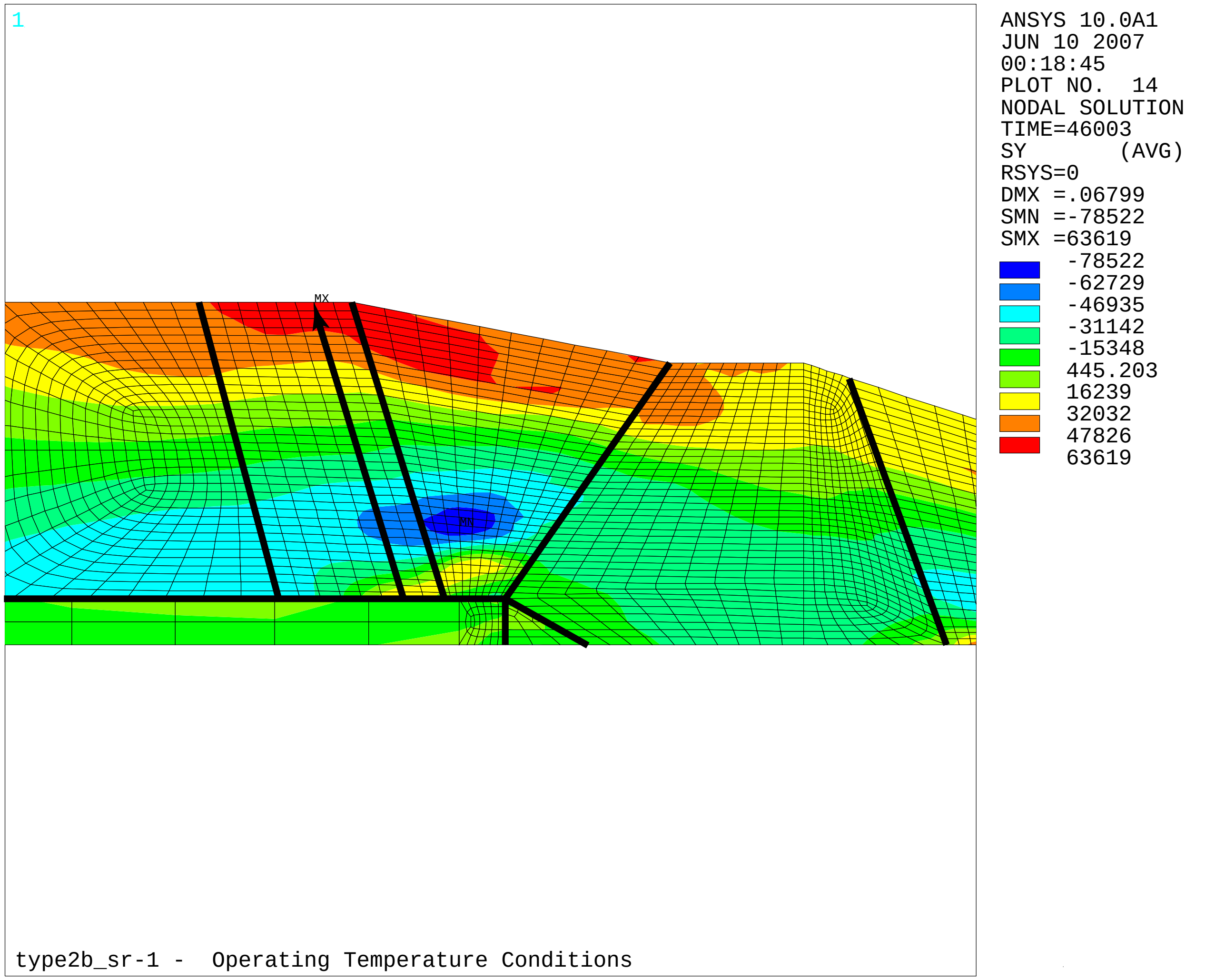
DMW + 0.75" Repair, No SS Weld (2/2)



Safety/Relief NOT
DMW + Backweld + Safe End ID + SS Weld



Safety/Relief NOT
DMW + Backweld + Liner + SS Weld



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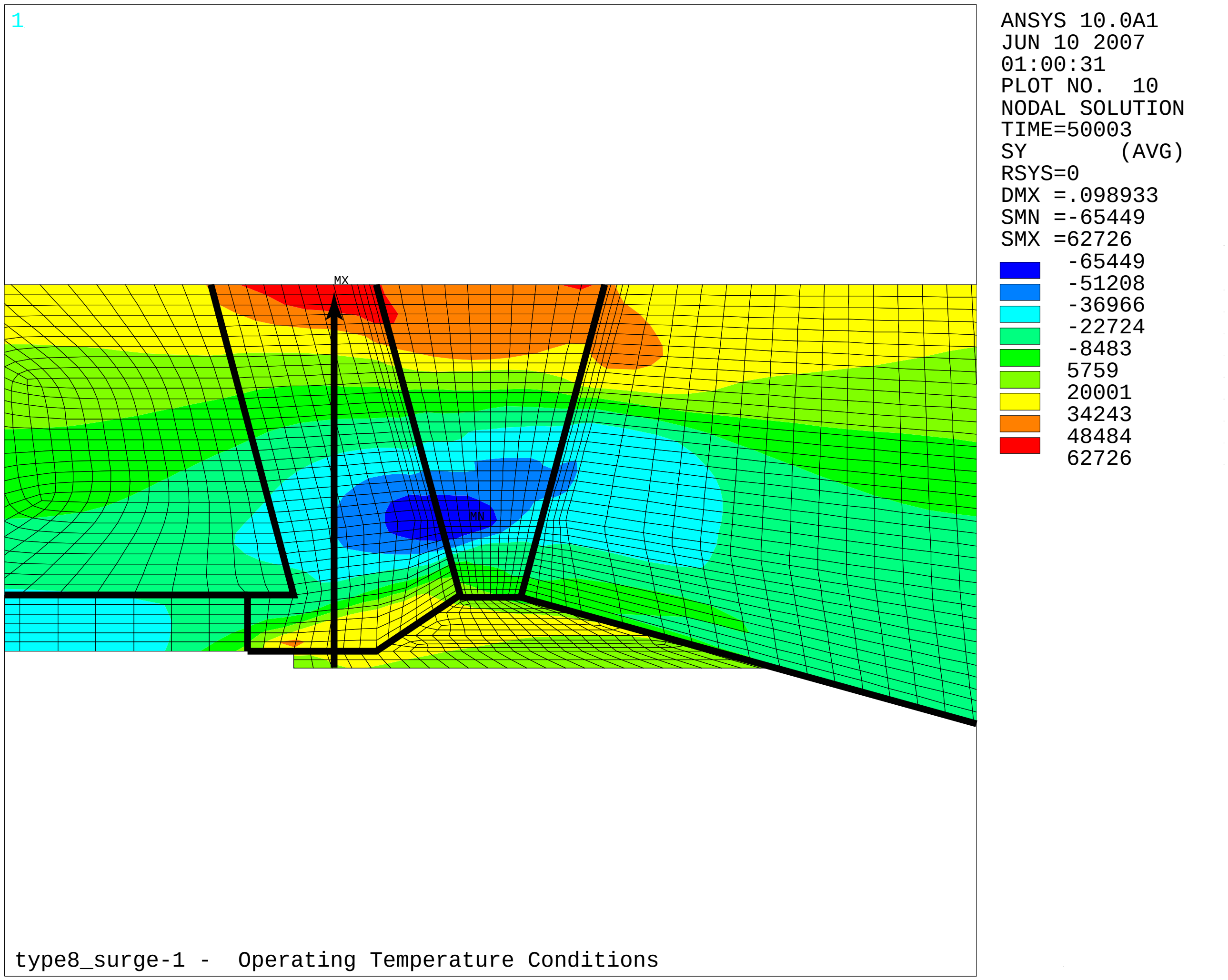
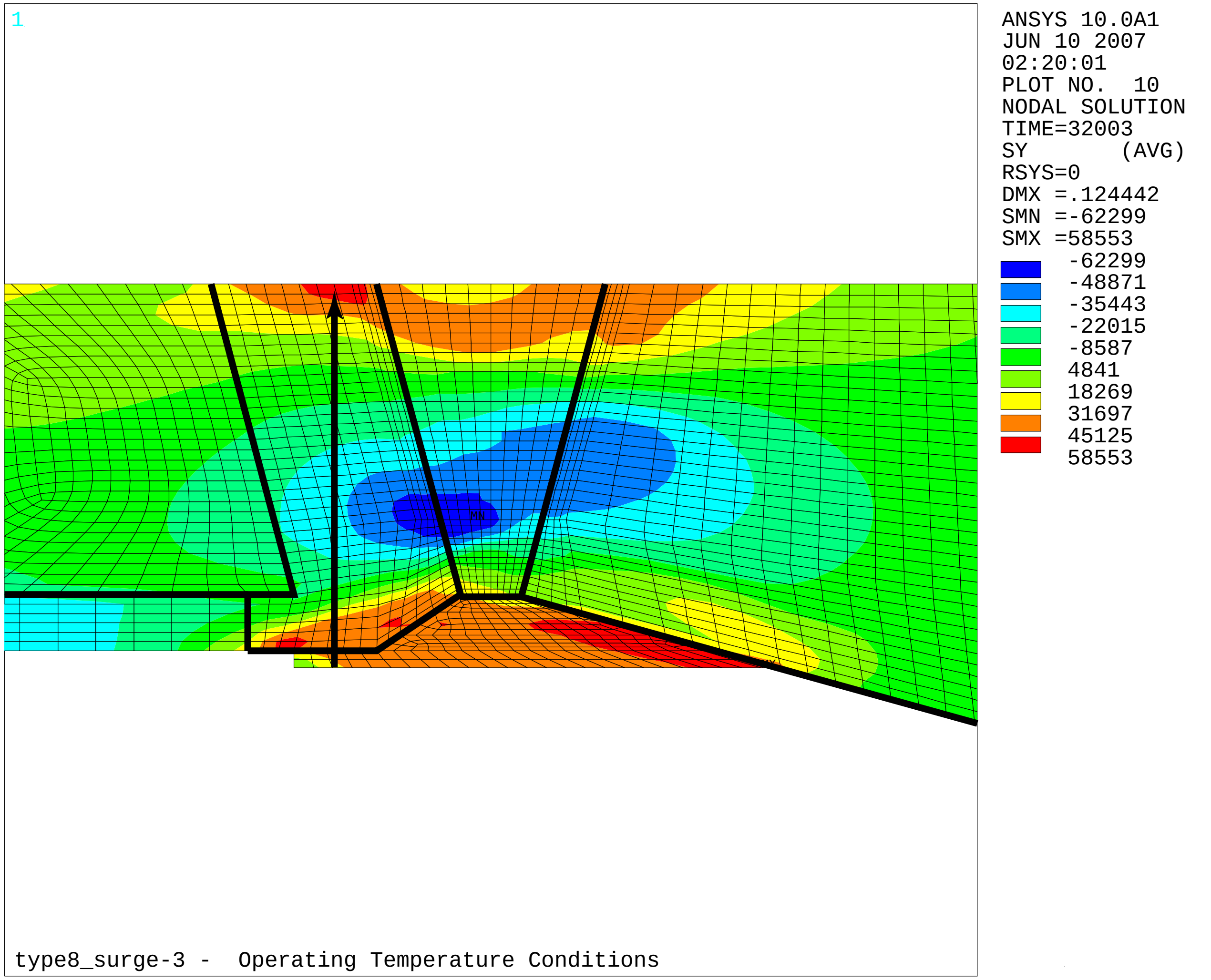
W Surge NOT
DMW + Backweld + Fill-In + SS Weld

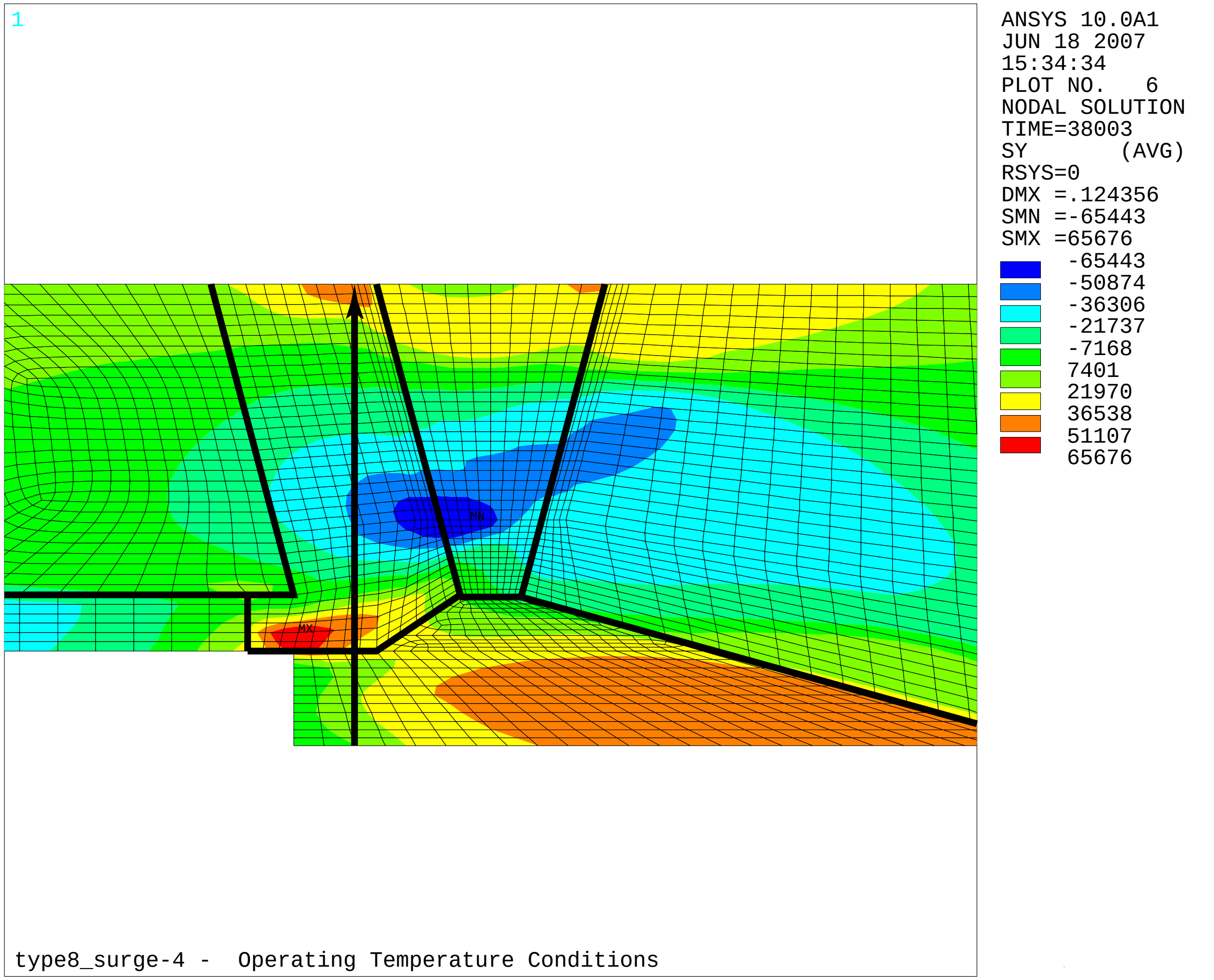


W Surge NOT
DMW + Backweld + Fill-In, No SS Weld



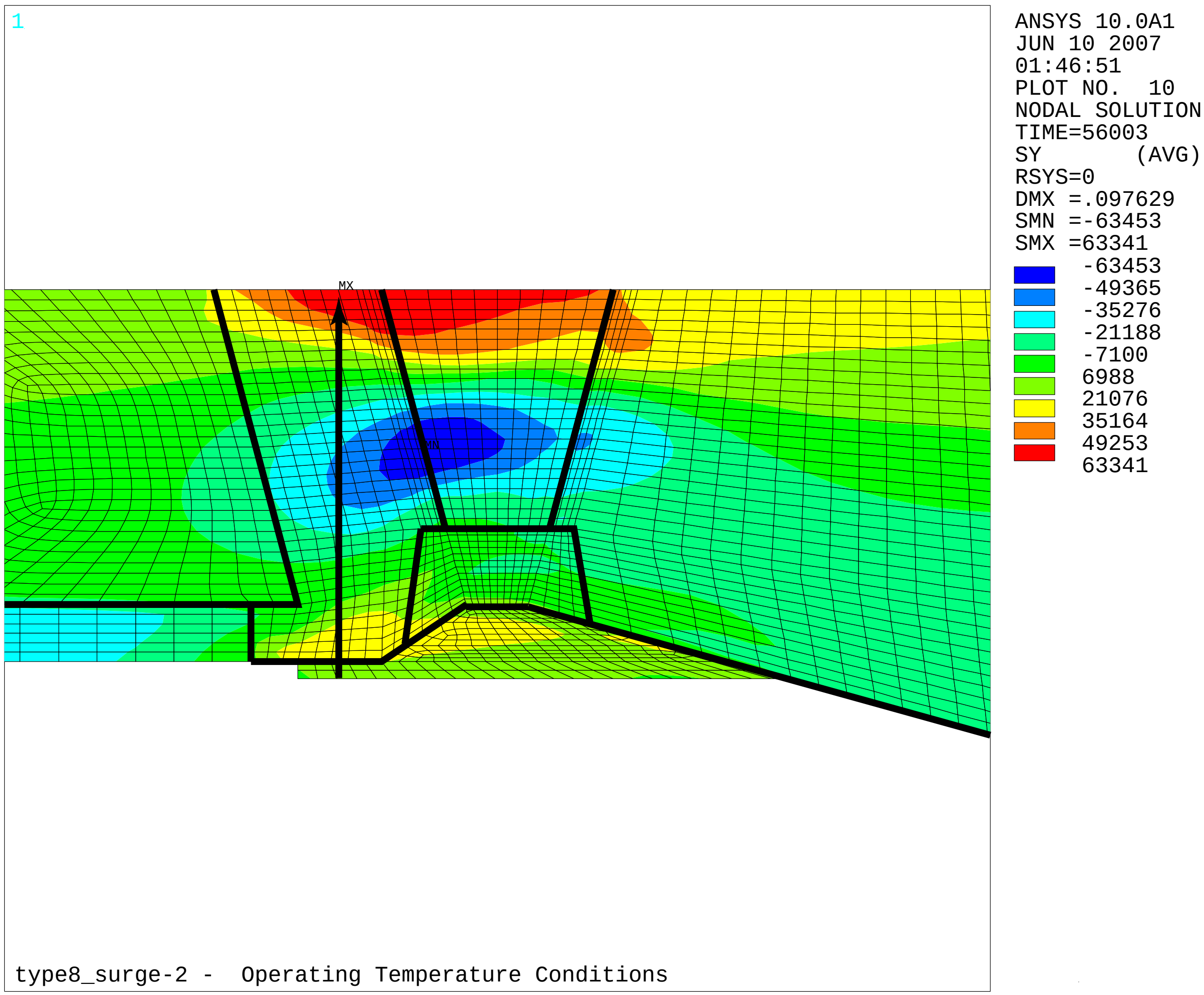
W Surge NOT

DMW + Backweld + Repair + 0.6″ Fill-In, no SS Weld

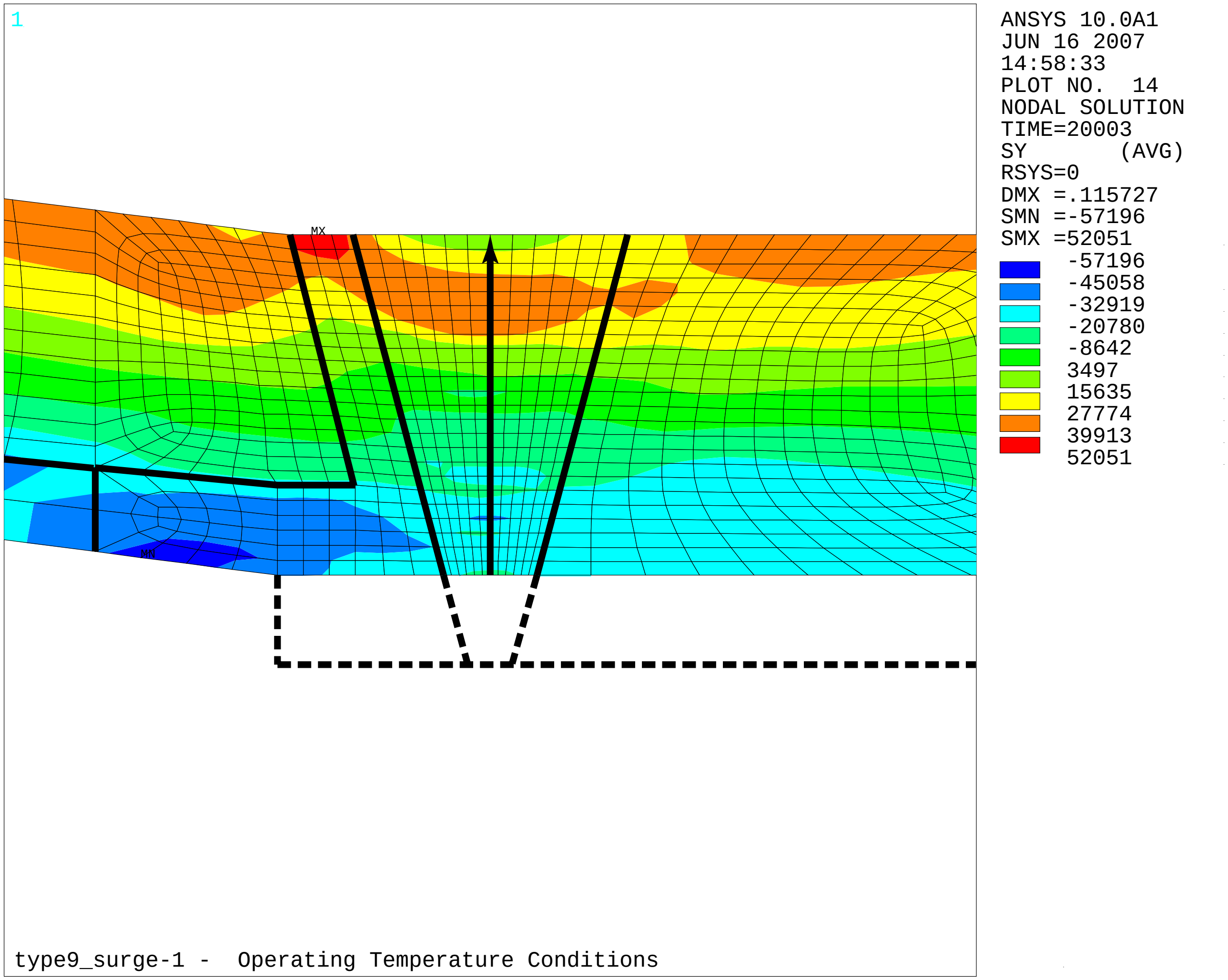


W Surge NOT

DMW + Backweld + Repair + Fill-In + SS Weld

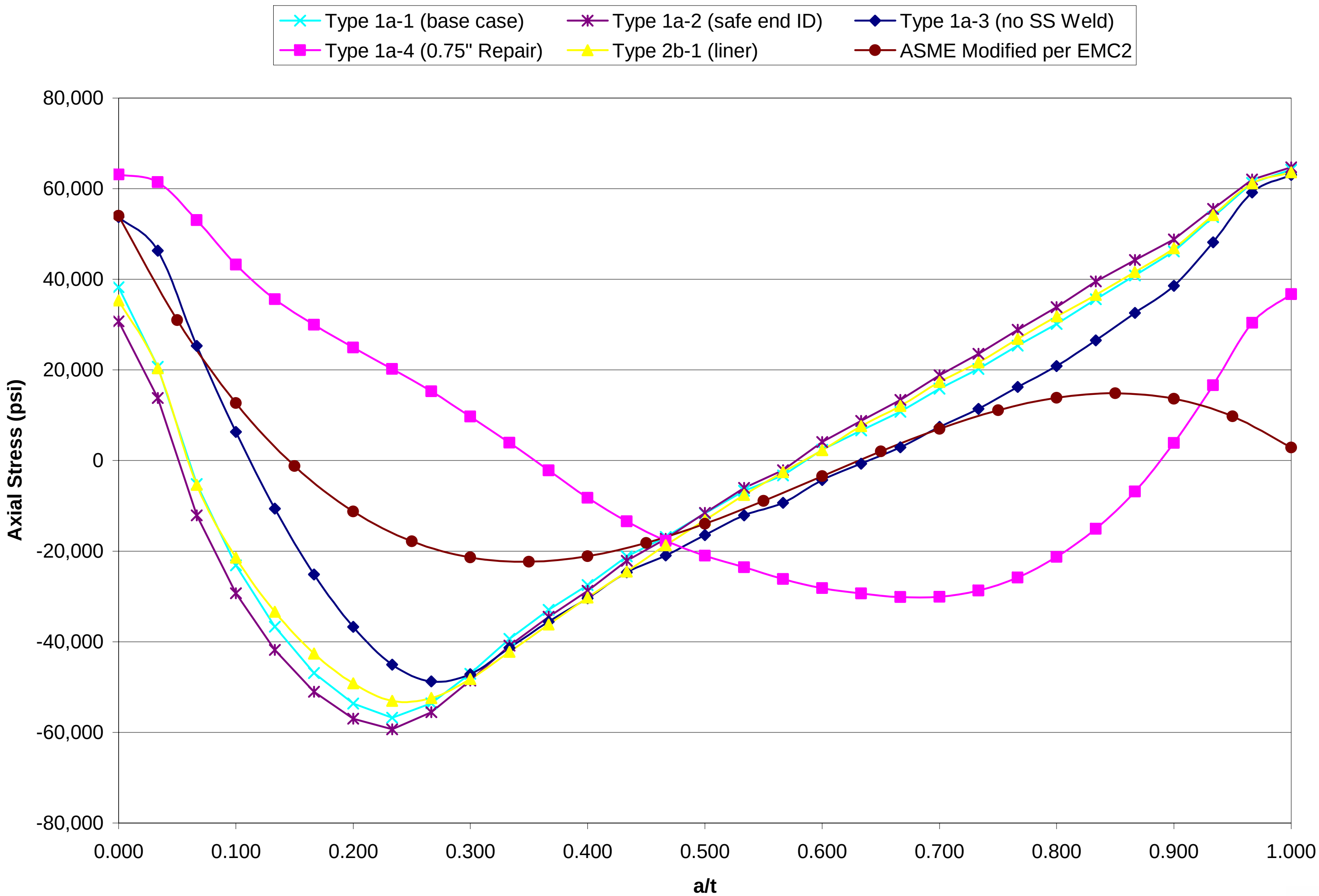


CE Surge NOT
DMW + Final Machining, No SS Weld



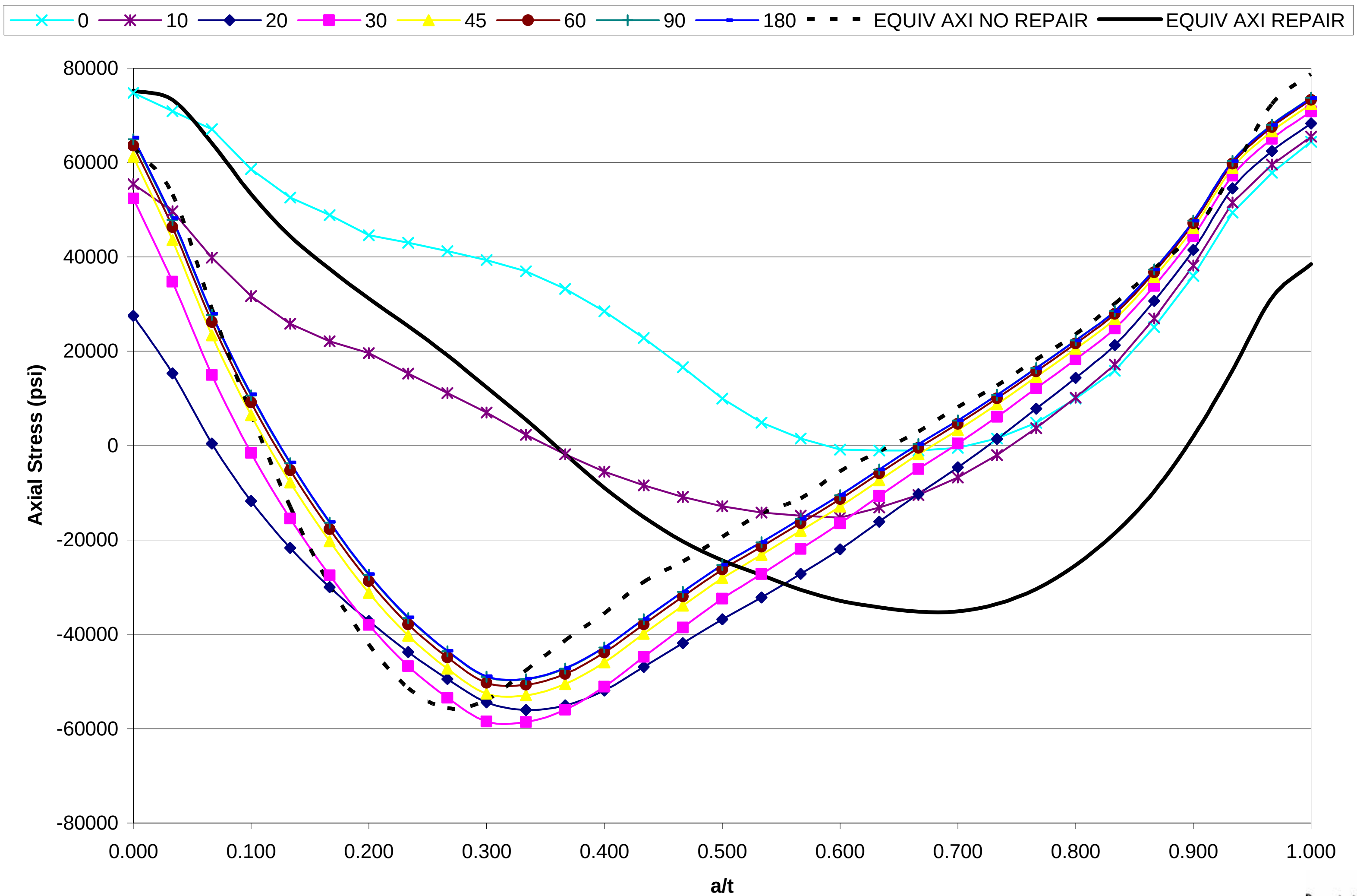
WRS Analysis Results

Safety/Relief – Normal Operating Temperature

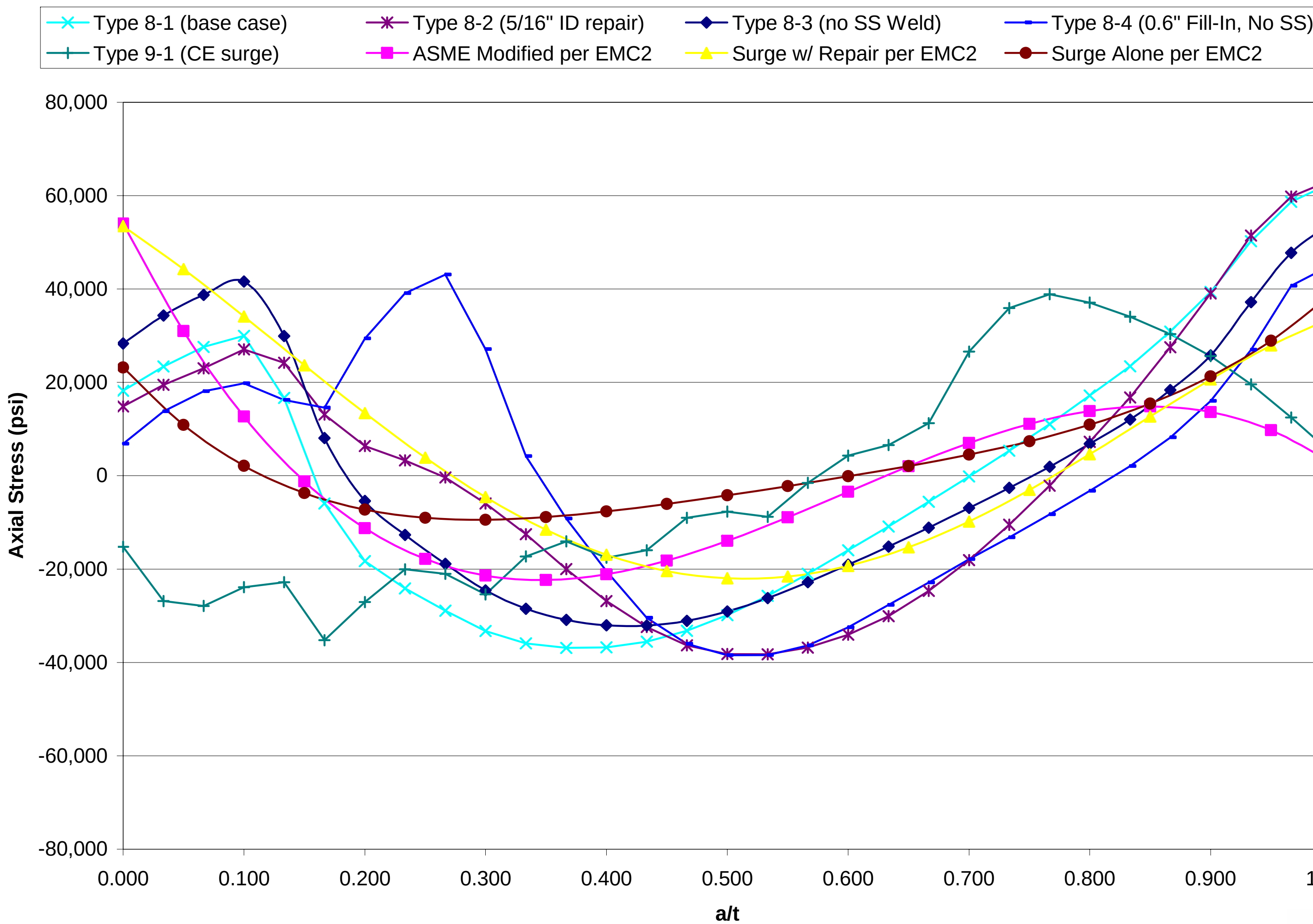


WRS Analysis Results

Safety/Relief 3D Repair – Normal Operating Temperature



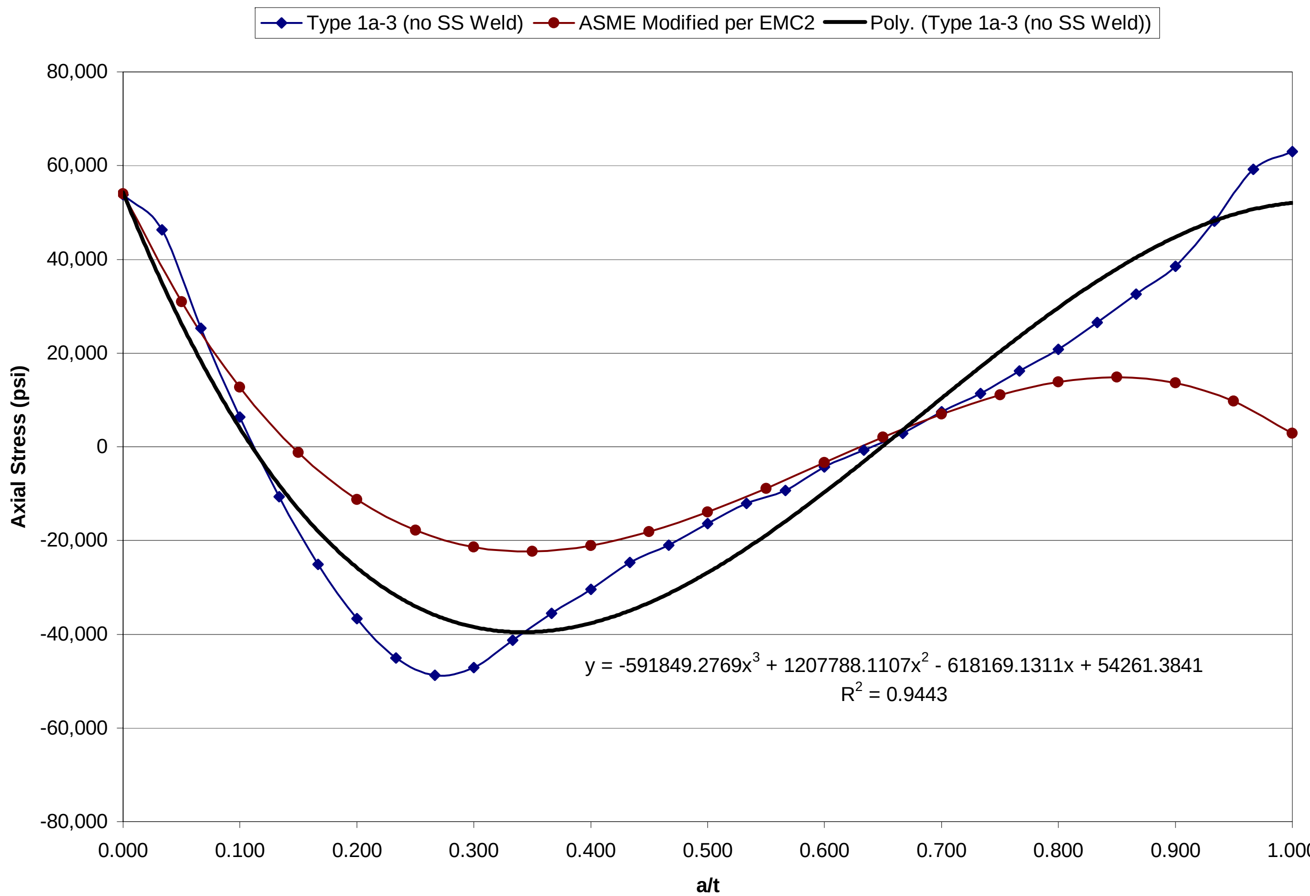
WRS Analysis Results
Surge – Normal Operating Temperature



Stress Distributions Used in Case Matrix

Type 1 Safety and Relief Nozzle – Cubic Fit

- Crack arrest is predicted for matrix Cases 1 through 16
- Therefore, 3/30 ASME WRS was conservatively applied for these matrix cases



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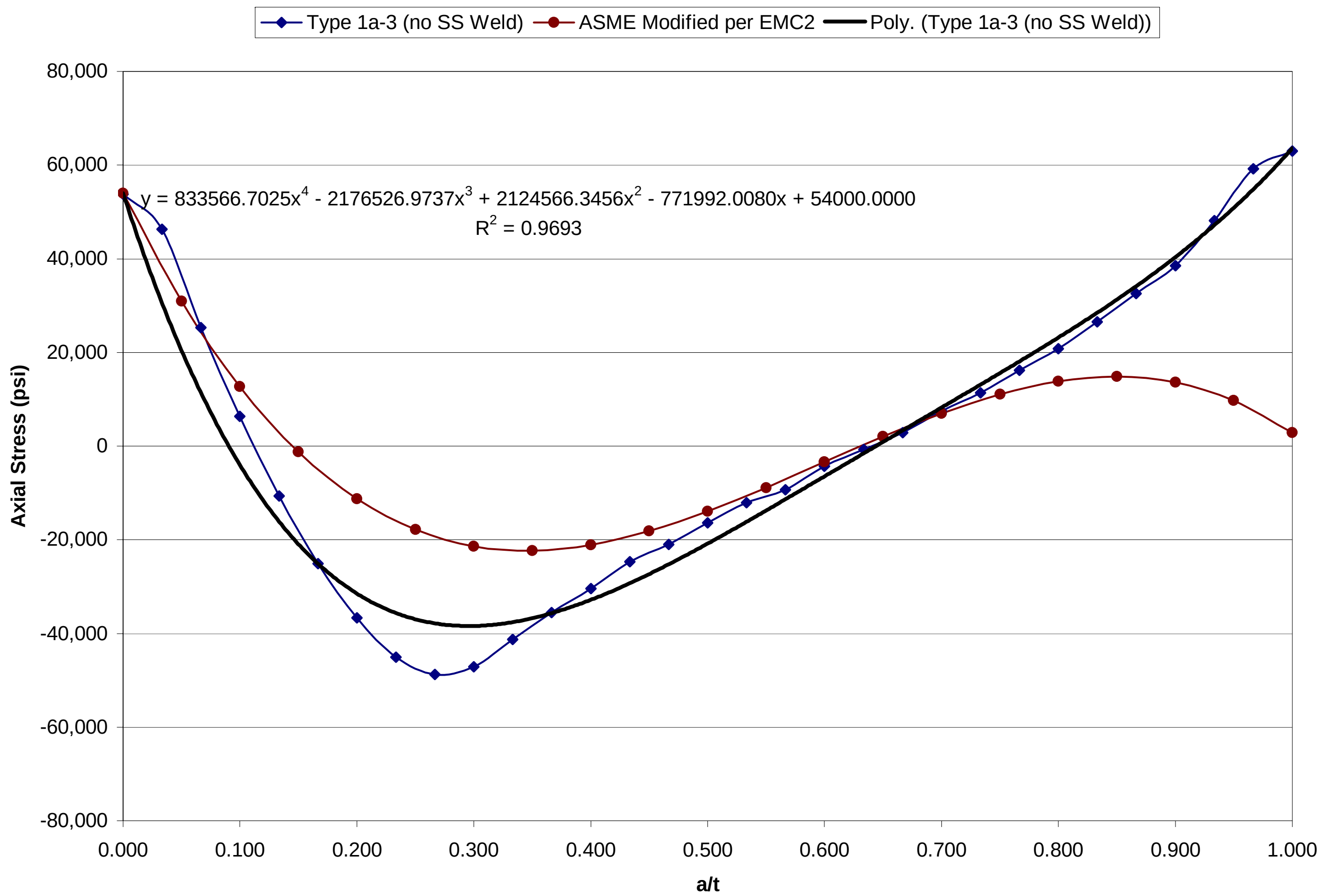
Stress Distributions Used in Case Matrix

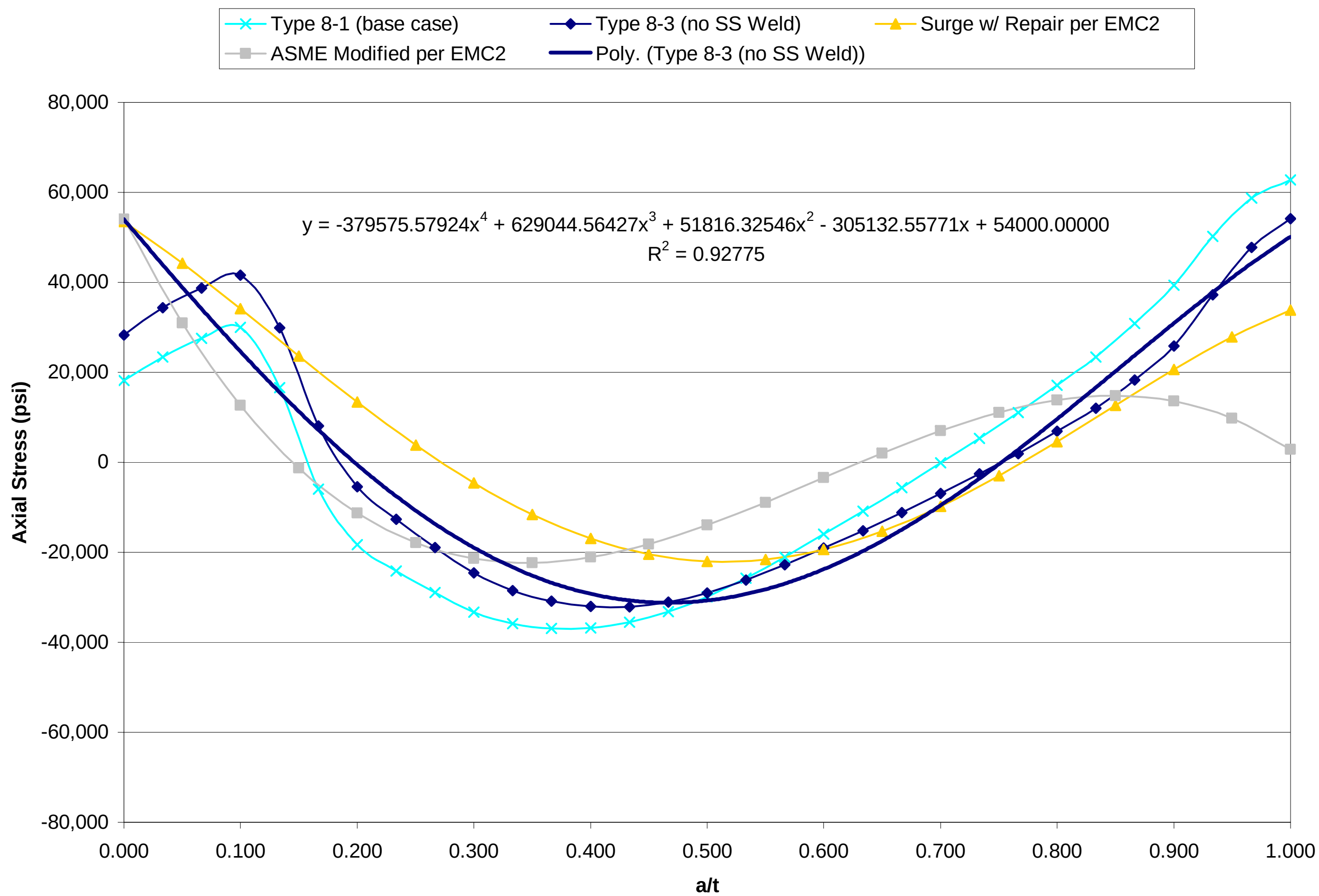
Type 1 Safety and Relief Nozzle – Quartic Fit (σ_0 = 54 ksi)

- Crack arrest is predicted for matrix Cases 1 through 16
- Therefore, 3/30 ASME WRS was conservatively applied for these matrix cases



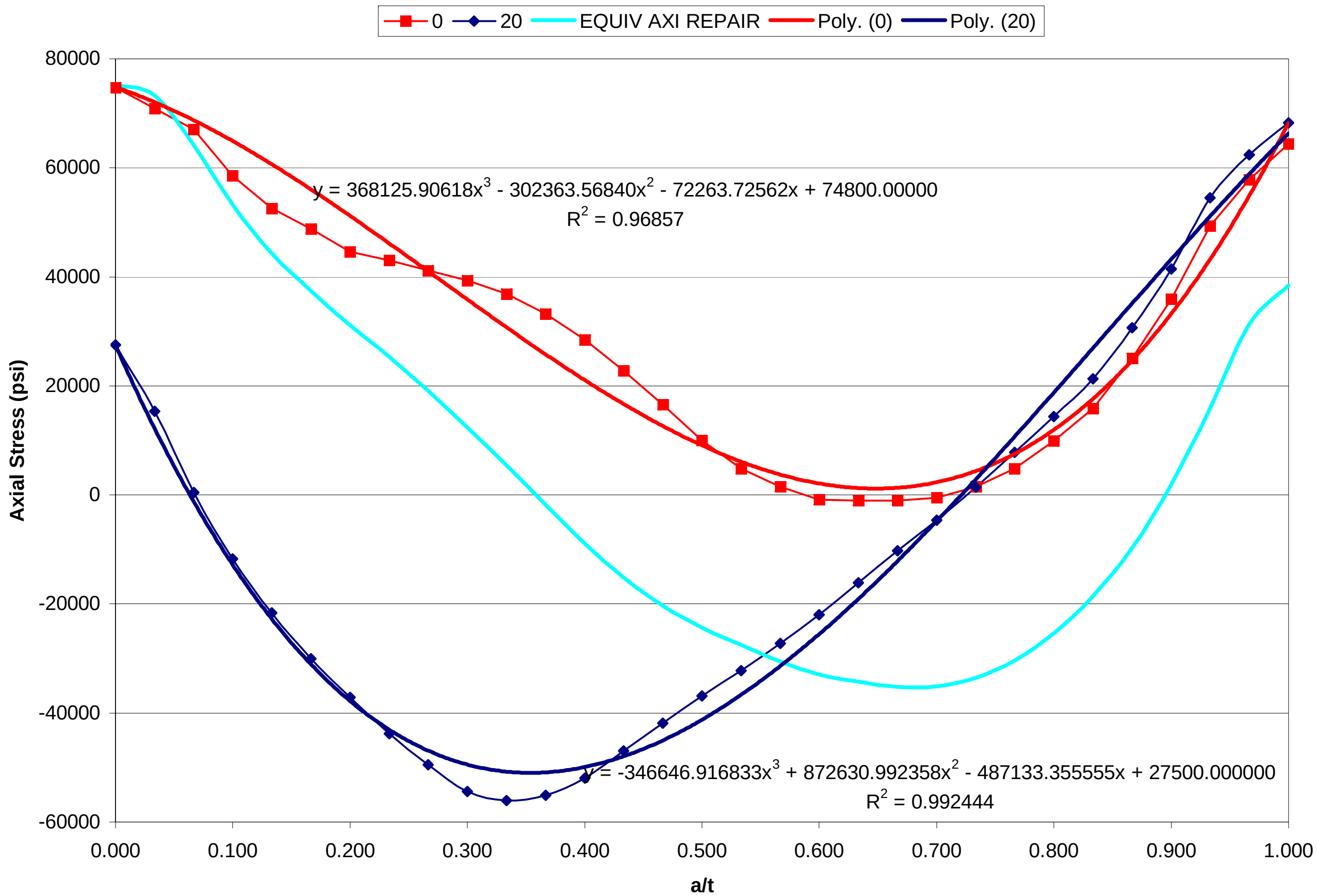
Stress Distributions Used in Case Matrix
Type 8 Surge Nozzle – Quartic Fit (σ_0 = 54 ksi)

- Distribution for Type 8 with no SS weld conservatively applied for matrix Cases 17 through 20



Stress Distributions Used in Case Matrix
Type 1 Surge Nozzle with 3D Repair

- Upper fit with σ_0 = 74.8 ksi applied for repair zone
- Lower fit with σ_0 = 27.5 ksi applied for transition zone
- Quartic fit for axisymmetric Type 1 case applied for remainder



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Phase II Sensitivity Cases

- Sensitivity results are available for the following cases:
  - Base cases for safety and relief nozzle configurations (Cases 1 through 9)
  - Base cases for spray nozzle configurations (Cases 10 through 16)
  - Base cases for surge nozzle configurations (Cases 17 through 20)
- Results presented include:
  - Profile at time of through-wall penetration
  - Time from initial flaw to through-wall penetration
  - Stability margin at time of through-wall penetration
  - Time from detectable leakage to critical crack
- Additional results for Phase 1 relief nozzle case with varying moment
  - Assumes initial uniform 10% deep 360° flaw
  - Profile at time of through-wall penetration

Phase II Sensitivity Cases
Outputs

- Time from detectable leakage to rupture
  - Key parameter
  - Assuming normal loads
  - Assuming faulted loads for select cases
- Time from through-wall penetration to rupture
  - Can be compared to time of most recent bare metal visual examination
- Total time from initial flaw to rupture
  - Can be compared to operating age of each subject plant
- For some key cases, complete output parameters will be displayed in the report, as in the Phase 1 calculation

Phase II Sensitivity Cases

Geometry and Load Combinations

Note: Pm in this table based on pressure stress $pD_o/4t$. Pressure stress $pD_i^2/(D_o^2 - D_i^2)$ plus deadweight and secondary piping axial force and pressure on crack face to be used for crack growth.

Type	Design	# of nozzles	Loads P_m (ksi) Min	Loads P_m (ksi) Max	P_b (ksi) Min	P_b (ksi) Max	$P_b/(P_m+P_b)$ - Min	$P_b/(P_m+P_b)$ - Max
Safety and Relief Nozzles	1a	12	3.17	3.45	0.07	5.71	0.02	0.64
	1b	4	3.20	3.71	0.78	5.74	0.20	0.63
	2a	8	3.93	4.29	1.04	7.63	0.21	0.64
	2b	4	3.57	3.90	2.35	4.78	0.38	0.57
	3	7	3.16	3.24	0.00	6.70	0.00	0.67
Spray Nozzles	4	2	3.45	3.58	1.38	4.89	0.28	0.59
	5	3	4.00	4.20	1.12	4.75	0.21	0.54
	6	1	3.84	3.84	0.75	0.75	0.16	0.16
	7	2	2.76	3.05	1.16	4.80	0.30	0.61
Surge Nozzles	8	6	5.24	5.43	4.04	13.58	0.43	0.72
	9	2	4.92	5.06	6.65	14.55	0.57	0.74

Phase II Sensitivity Cases
Current Planned Matrix (slide 1/2)

		Geometry Case							Load Case									Initial Flaw		
Prelim Case #	Model Type	Nozzle Type	Geometry Configuration	D_o (in)	D_i (in)	t (in)	R_i/t	TW Z-factor per PVP	Pm Case	Pm (ksi)	max Code Total Pm (ksi)	Pb Case	Pb (thick) (ksi)	Pb/7.51 (thick)	Pb/(Pm+Pb)	WRS Case	CGR Expon. n	2c/a	Shape Factor	Depth (%tw)
1	cylinder	S&R	Config 1a	7.750	5.170	1.290	2.004	1.170	typical	1.74	3.45	high	5.71	76.0%	0.60	S&R no liner	1.6	21 or 360°	natural	26% or 10%
2	cylinder	S&R	Config 1a	7.750	5.170	1.290	2.004	1.170	typical	1.74	3.45	intermed	5.30	70.5%	0.58	S&R no liner	1.6	21 or 360°	natural	26% or 10%
3	cylinder	S&R	Config 1a	7.750	5.170	1.290	2.004	1.170	typical	1.74	3.45	above arrest	4.88	65.0%	0.56	S&R no liner	1.6	21 or 360°	natural	26% or 10%
4	cylinder	S&R	Config 1b	8.000	5.190	1.405	1.847	1.171	typical	1.90	3.71	high	5.74	76.4%	0.59	S&R no liner	1.6	21 or 360°	natural	26% or 10%
5	cylinder	S&R	Config 1b	8.000	5.190	1.405	1.847	1.171	typical	1.90	3.71	above arrest	4.88	65.0%	0.55	S&R no liner	1.6	21 or 360°	natural	26% or 10%
6	cylinder	S&R	Config 2a/2b	7.750	5.620	1.065	2.638	1.170	typical	2.34	4.29	high	7.63	101.5%	0.63	S&R with liner	1.6	21 or 360°	natural	26% or 10%
7	cylinder	S&R	Config 2a/2b	7.750	5.620	1.065	2.638	1.170	typical	2.34	4.29	above arrest	4.88	65.0%	0.52	S&R with liner	1.6	21 or 360°	natural	26% or 10%
8	cylinder	S&R	Config 3	8.000	5.190	1.405	1.847	1.171	typical	1.65	3.24	high	6.70	89.2%	0.64	S&R no liner (no SS weld)	1.6	21 or 360°	natural	26% or 10%
9	cylinder	S&R	Config 3	8.000	5.190	1.405	1.847	1.171	typical	1.65	3.24	above arrest	4.88	65.0%	0.57	S&R no liner (no SS weld)	1.6	21 or 360°	natural	26% or 10%
10	cylinder	spray	Config 4	5.810	4.010	0.900	2.228	1.156	typical	1.94	3.58	high	4.89	65.1%	0.55	generic spray	1.6	21 or 360°	natural	26% or 10%
11	cylinder	spray	Config 4	5.810	4.010	0.900	2.228	1.156	typical	1.94	3.58	above arrest	4.13	55.0%	0.51	generic spray	1.6	21 or 360°	natural	26% or 10%
12	cylinder	spray	Config 5	5.810	4.250	0.780	2.724	1.156	typical	2.51	4.20	high	4.75	63.3%	0.51	generic spray	1.6	21 or 360°	natural	26% or 10%
13	cylinder	spray	Config 5	5.810	4.250	0.780	2.724	1.156	typical	2.51	4.20	above arrest	4.13	55.0%	0.47	generic spray	1.6	21 or 360°	natural	26% or 10%
14	cylinder	spray	Config 6	8.000	5.700	1.150	2.478	1.171	typical	2.27	3.85	high	0.75	10.0%	0.15	generic spray	1.6	21 or 360°	natural	26% or 10%
15	cylinder	spray	Config 7	5.190	3.100	1.045	1.483	1.147	typical	1.29	2.83	high	4.65	61.9%	0.58	generic spray	1.6	21 or 360°	natural	26% or 10%
16	cylinder	spray	Config 7	5.190	3.100	1.045	1.483	1.147	typical	1.29	2.83	above arrest	4.13	55.0%	0.55	generic spray	1.6	21 or 360°	natural	26% or 10%
17	cylinder	surge	Config 8	15.000	11.840	1.580	3.747	1.194	typical	3.72	5.43	high	13.57	180.7%	0.70	surge with fill-in weld	1.6	21 or 360°	natural	26% or 10%
18	cylinder	surge	Config 8	15.000	11.840	1.580	3.747	1.194	typical	3.72	5.43	above arrest	4.88	65.0%	0.45	surge with fill-in weld	1.6	21 or 360°	natural	26% or 10%
19	cylinder	surge	Config 9	13.060	10.120	1.470	3.442	1.189	typical	3.38	5.06	high	14.55	193.7%	0.72	surge no fill-in weld	1.6	21 or 360°	natural	26% or 10%
20	cylinder	surge	Config 9	13.060	10.120	1.470	3.442	1.189	typical	3.38	5.06	above arrest	4.88	65.0%	0.47	surge no fill-in weld	1.6	21 or 360°	natural	26% or 10%
21	cylinder	S&R	Config 1a	7.750	5.170	1.290	2.004	1.170	typical	1.74	3.45	high	5.71	76.0%	0.60	S&R ID repair no liner	1.6	21 or 360°	natural	26% or 10%
22	cylinder	S&R	Config 1a	7.750	5.170	1.290	2.004	1.170	typical	1.74	3.45	above arrest	4.88	65.0%	0.56	S&R ID repair no liner	1.6	21 or 360°	natural	26% or 10%
23	cylinder	S&R	Config 2a/2b	7.750	5.620	1.065	2.638	1.170	typical	2.34	4.29	high	7.63	101.5%	0.63	S&R ID repair with liner	1.6	21 or 360°	natural	26% or 10%
24	cylinder	S&R	Config 2a/2b	7.750	5.620	1.065	2.638	1.170	typical	2.34	4.29	above arrest	4.88	65.0%	0.52	S&R ID repair with liner	1.6	21 or 360°	natural	26% or 10%
25	cylinder	surge	Config 8	15.000	11.840	1.580	3.747	1.194	typical	3.72	5.43	high	13.57	180.7%	0.70	surge ID repair with fill-in	1.6	21 or 360°	natural	26% or 10%
26	cylinder	surge	Config 8	15.000	11.840	1.580	3.747	1.194	typical	3.72	5.43	above arrest	4.88	65.0%	0.45	surge ID repair with fill-in	1.6	21 or 360°	natural	26% or 10%

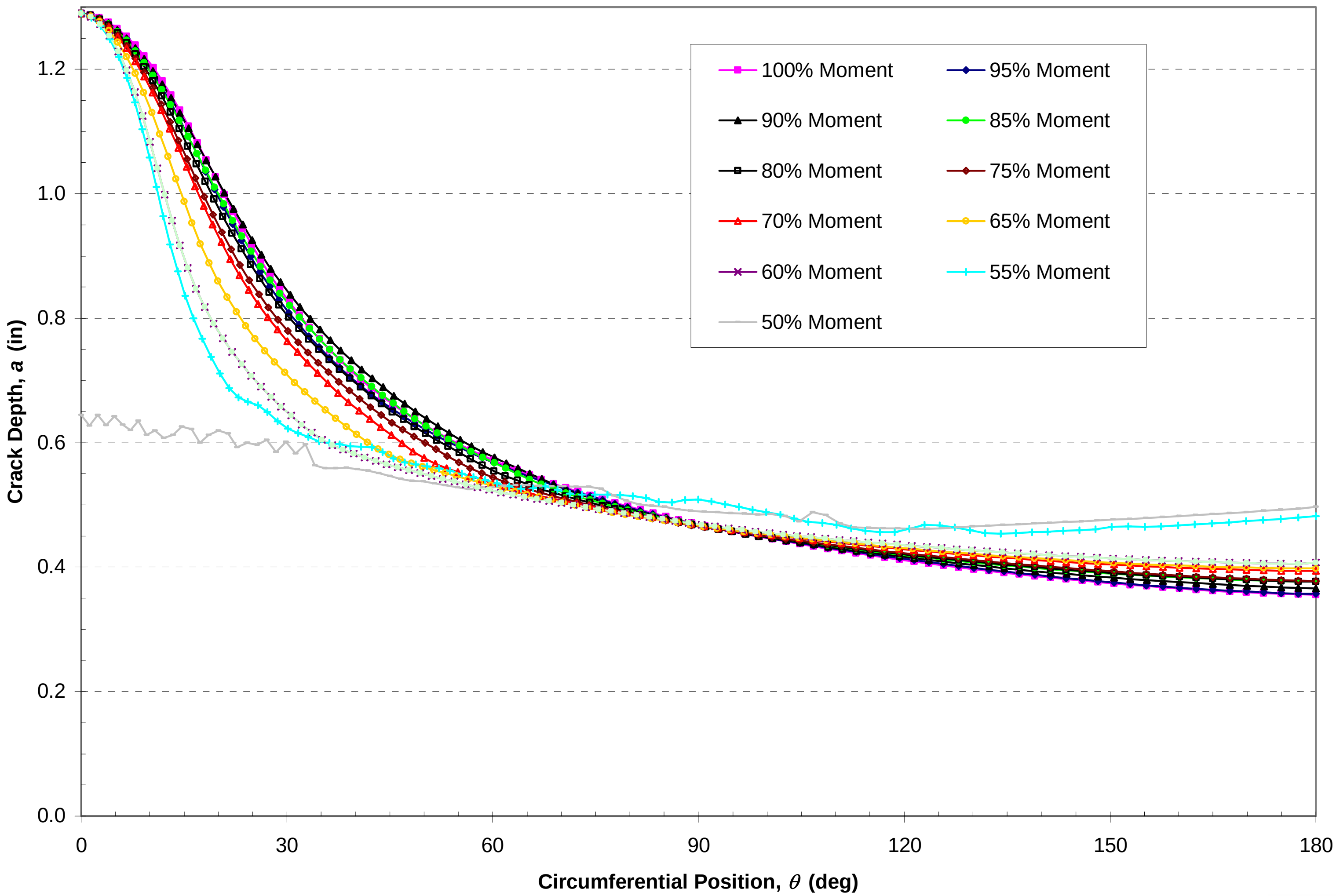
Phase II Sensitivity Cases

Current Planned Matrix (slide 2/2)

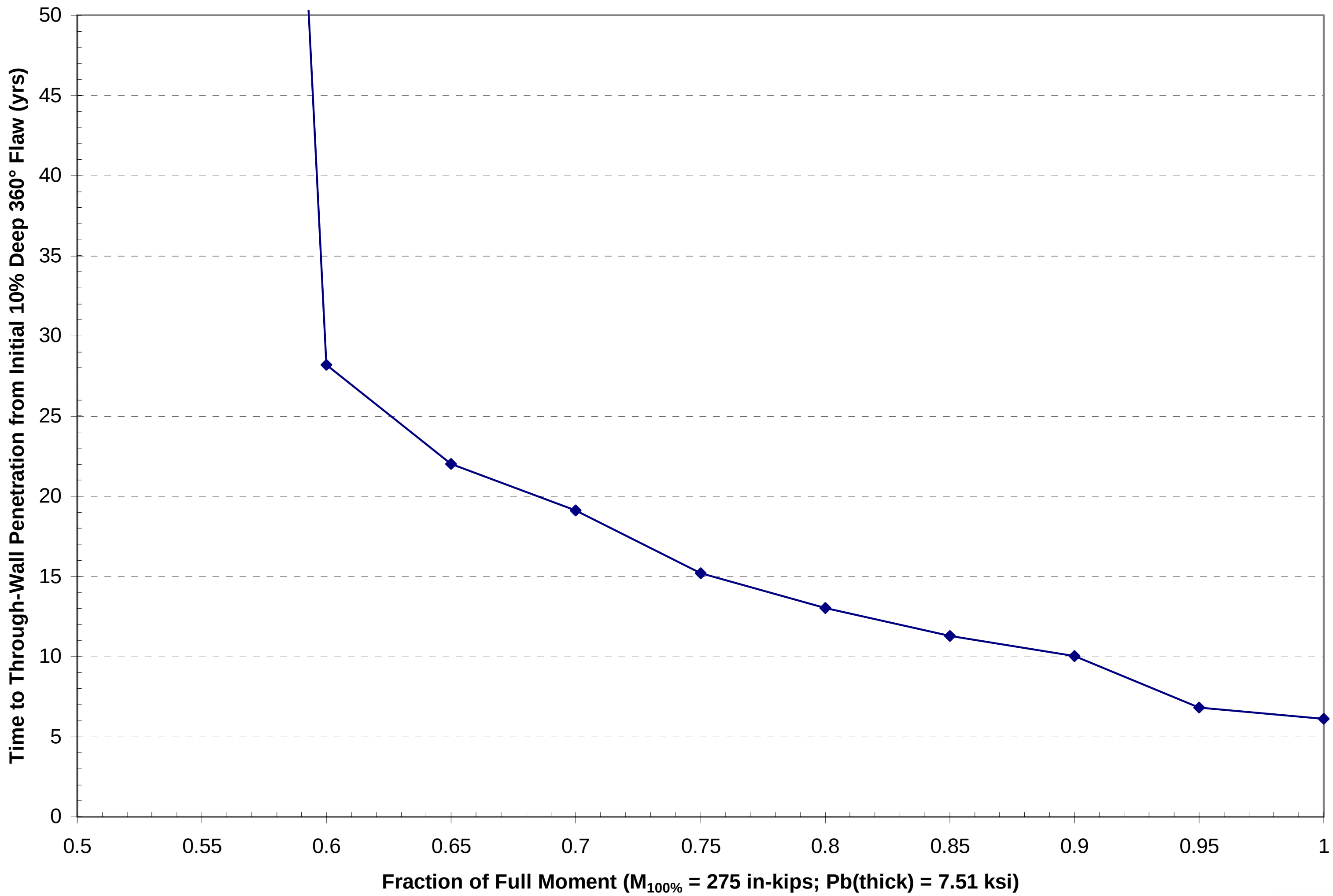
		Geometry Case							Load Case									Initial Flaw		
Prelim Case #	Model Type	Nozzle Type	Geometry Configuration	D_o (in)	D_i (in)	t (in)	R_i/t	TW Z-factor per PVP	Pm Case	Pm (ksi)	max Code Total Pm (ksi)	Pb Case	Pb (thick) (ksi)	Pb/7.51 (thick)	Pb/(Pm+Pb)	WRS Case	CGR Expon. n	2c/a	Shape Factor	Depth (%tw)
27	cylinder	bound	bounding						typical			sens 1				bounding	1.6	21 or 360°	natural	26% or 10%
28	cylinder	bound	bounding						typical			sens 2				bounding	1.6	21 or 360°	natural	26% or 10%
29	cylinder	bound	bounding						typical			sens 3				bounding	1.6	21 or 360°	natural	26% or 10%
30	cylinder	bound	bounding						typical			sens 4				bounding	1.6	21 or 360°	natural	26% or 10%
31	cylinder	S&R	as-built 1						typical			bounding				bounding	1.6	21 or 360°	natural	26% or 10%
32	cylinder	S&R	as-built 2						typical			bounding				bounding	1.6	21 or 360°	natural	26% or 10%
33	cylinder	S&R	bounding S&R						low			bounding				bounding	1.6	21 or 360°	natural	26% or 10%
34	cylinder	S&R	bounding S&R						high			bounding				bounding	1.6	21 or 360°	natural	26% or 10%
35	cylinder	TBD	TBD						typical			bounding				effect of SS weld	1.6	21 or 360°	natural	26% or 10%
36	cylinder	S&R	bounding S&R						typical			bounding				safe end ID buildup	1.6	21 or 360°	natural	26% or 10%
37	cylinder	S&R	bounding S&R						typical			bounding				tweaked axisymmetric	1.6	21 or 360°	natural	26% or 10%
38	cylinder	S&R	bounding S&R						typical			bounding				tweaked ID repair	1.6	21 or 360°	natural	26% or 10%
39	cylinder	S&R	bounding S&R						typical			bounding				multiple ID repairs	1.6	21 or 360°	natural	26% or 10%
40	cylinder	spray	bounding spray						typical			bounding				tweaked axisymmetric	1.6	21 or 360°	natural	26% or 10%
41	cylinder	surge	bounding surge						typical			bounding				tweaked axisymmetric	1.6	21 or 360°	natural	26% or 10%
42	cylinder	surge	bounding surge						typical			bounding				tweaked ID repair	1.6	21 or 360°	natural	26% or 10%
43	cylinder	S&R	bounding S&R						typical			bounding				shortened "weld"	1.6	21 or 360°	natural	26% or 10%
44	cylinder	S&R	bounding S&R						typical			bounding				simulate e-p redistrib.	1.6	21 or 360°	natural	26% or 10%
45	cylinder	S&R	bounding S&R						typical			bounding				bounding	1.6	2	natural	26%
46	cylinder	S&R	bounding S&R						typical			bounding				bounding	1.6	6	natural	26%
47	cylinder	S&R	bounding S&R						typical			bounding				bounding	1.6	21	low	26%
48	cylinder	S&R	bounding S&R						typical			bounding				bounding	1.6	21	semi-ellipse	26%
49	cylinder	S&R	bounding S&R						typical			bounding				bounding	1.6	21	high	26%
50	cylinder	S&R	bounding S&R						typical			bounding				bounding	1.6	21	natural	15%
51	cylinder	S&R	bounding S&R						typical			bounding				bounding	1.6	21	natural	40%
52	cylinder	S&R	bounding S&R						typical			bounding				bounding	low	21 or 360°	natural	26% or 10%
53	cylinder	S&R	bounding S&R						typical			bounding				bounding	high	21 or 360°	natural	26% or 10%
54	cylinder	spray	bounding spray						typical			bounding				bounding	low	21 or 360°	natural	26% or 10%
55	cylinder	spray	bounding spray						typical			bounding				bounding	high	21 or 360°	natural	26% or 10%
56	cylinder	surge	bounding surge						typical			bounding				bounding	low	21 or 360°	natural	26% or 10%
57	cylinder	surge	bounding surge						typical			bounding				bounding	high	21 or 360°	natural	26% or 10%
58	nozzle	S&R	bounding S&R						typical			bounding				axsymmetric	1.6	21 or 360°	natural	26% or 10%
59	nozzle	S&R	bounding S&R						typical			bounding				ID repair case	1.6	21 or 360°	natural	26% or 10%
60	nozzle	surge	bounding surge						typical			bounding				axsymmetric	1.6	21 or 360°	natural	26% or 10%
61	nozzle	surge	bounding surge						typical			bounding				ID repair case	1.6	21 or 360°	natural	26% or 10%

Phase II Sensitivity Cases

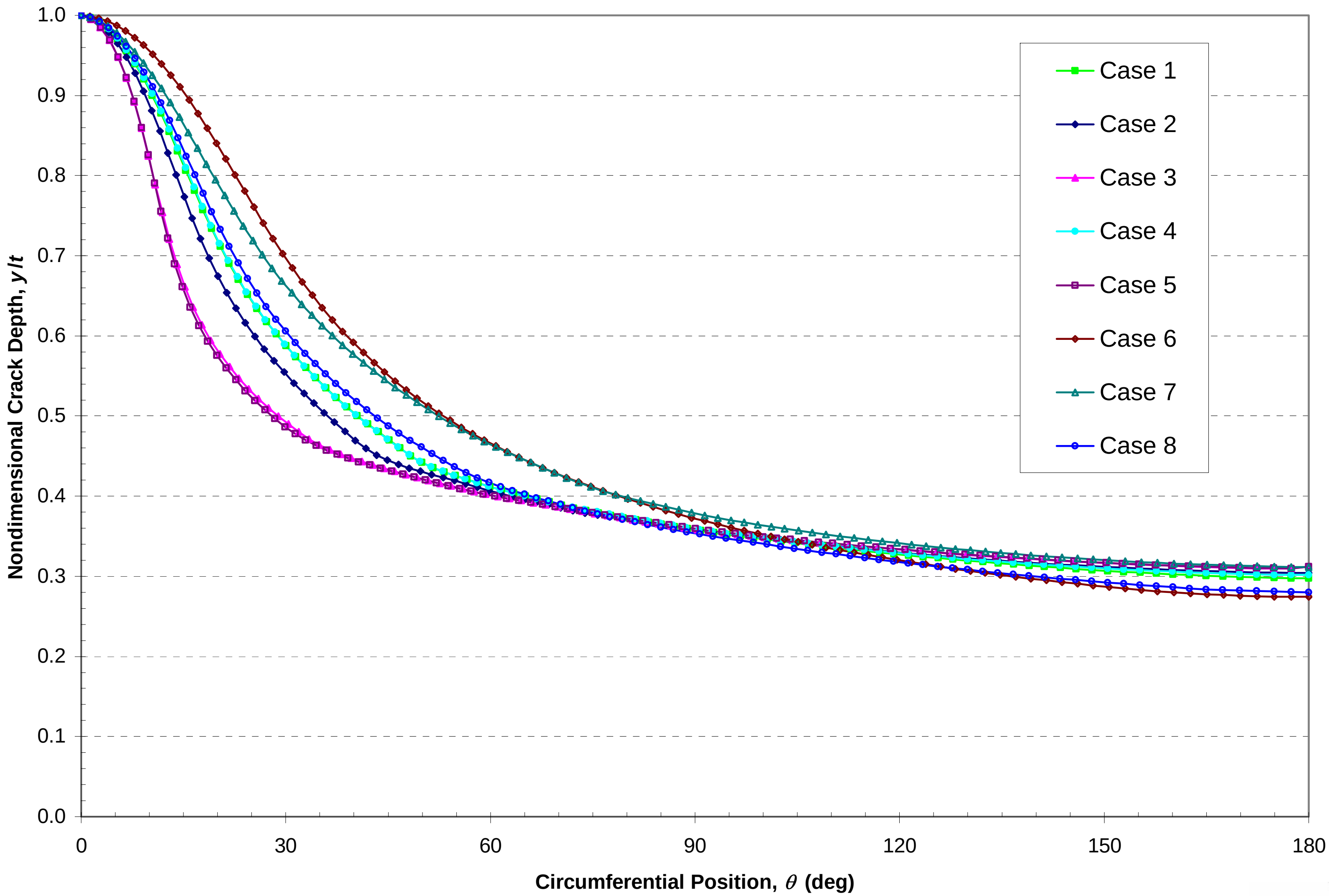
Results for Phase 1 Inputs – TW Profiles



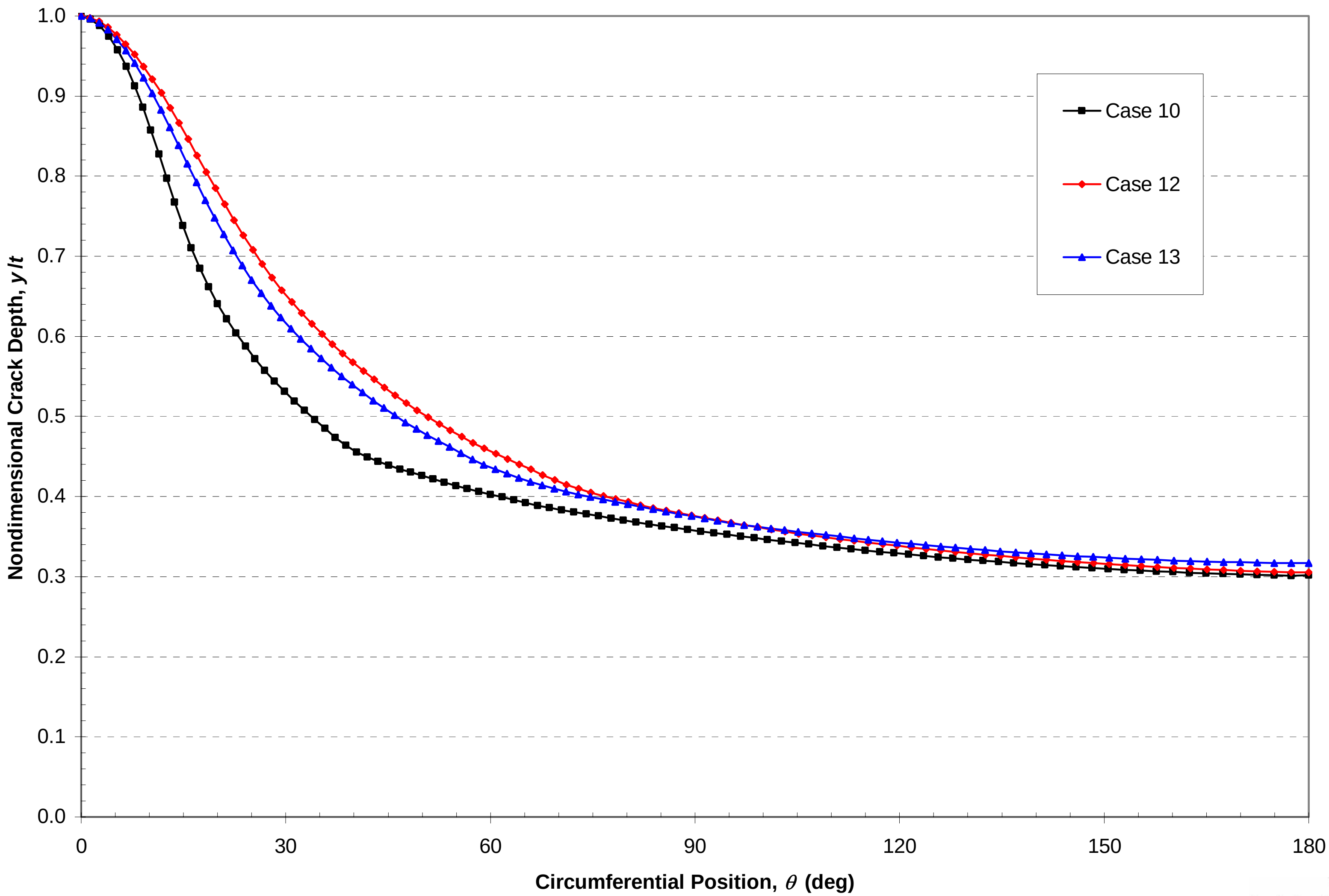
Phase II Sensitivity Cases
Results for Phase 1 Inputs – Time to TW



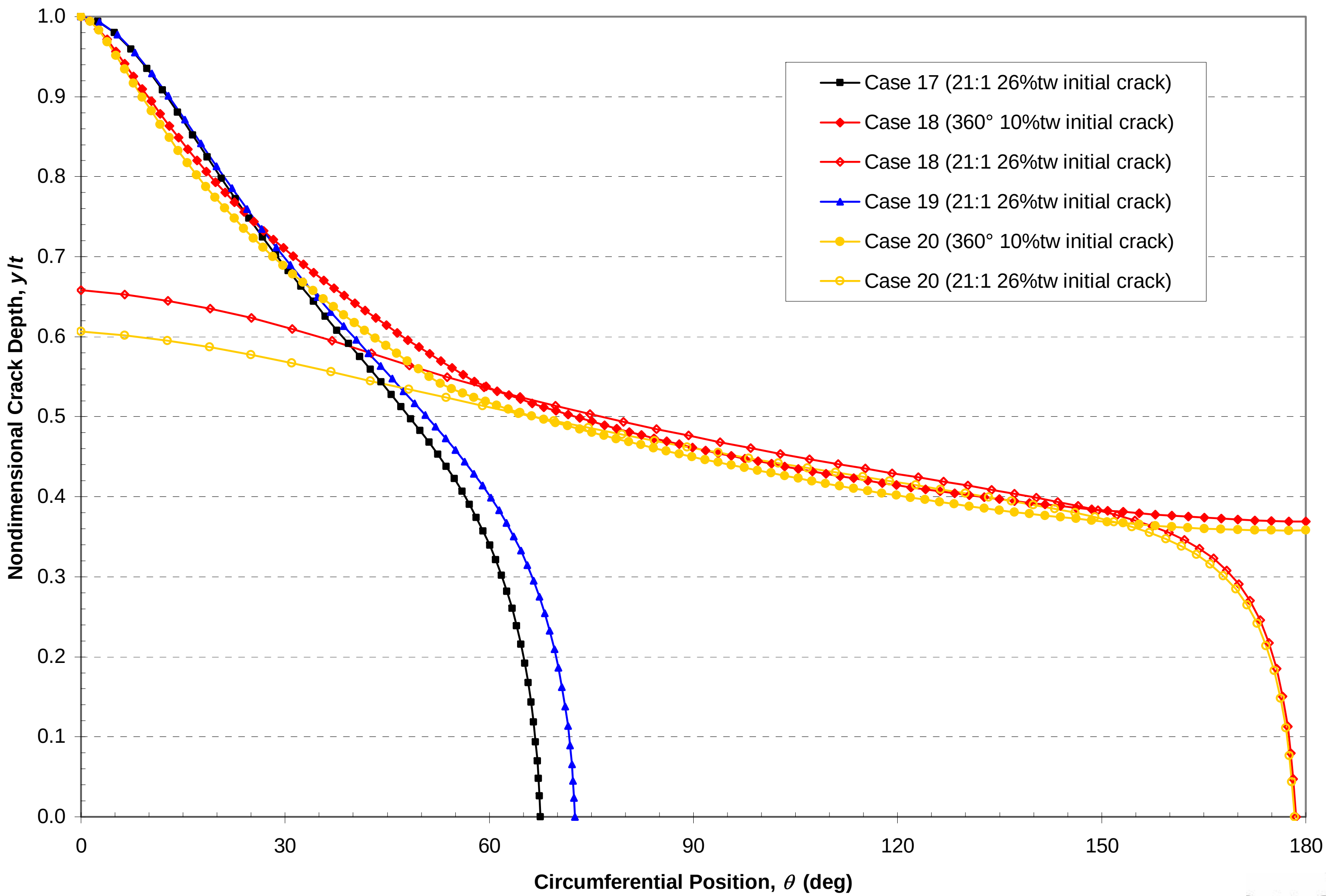
Phase II Sensitivity Cases
TW Profile for S&R Nozzles – 360° Initial Flaw



Phase II Sensitivity Cases
TW Profile for Spray Nozzles – 360° Initial Flaw



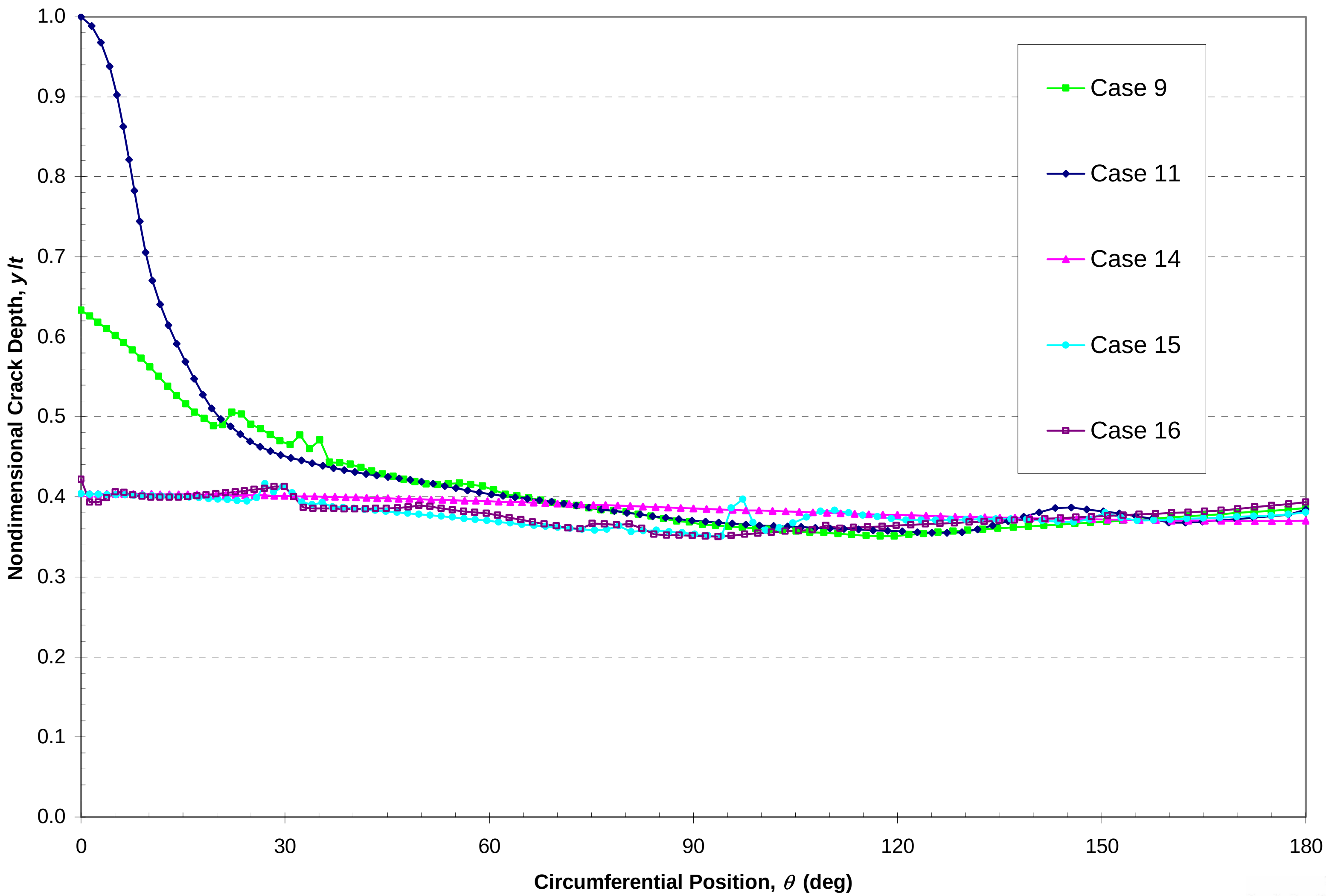
Phase II Sensitivity Cases
TW Profile for Surge Nozzles – 21:1 26% Initial Flaw



Dominion Engineering, Inc.

Phase II Sensitivity Cases

Final Profile for Arrested Cracks – 360° Initial Flaw



Dominion Engineering, Inc.

Phase II Sensitivity Cases

Prelim Summary Results for Surface Crack Cases (1/2)

	Geometry Case				Load Case								Initial Flaw		
Prelim Case #	Nozzle Type	Geometry Configuration	R_i (in)	t (in)	Pm Case	Pm (ksi)	max Code Total Pm (ksi)	Pb Case	Pb (thick) (ksi)	Pb/7.51 (thick)	WRS Case	CGR Exp. n	2c/a	Shape Factor	Depth (%tw)
1	S&R	Config 1a	2.585	1.290	typical	1.74	3.45	high	5.71	76.0%	ASME (3/30 version)	1.6	360°	uniform	10%
2	S&R	Config 1a	2.585	1.290	typical	1.74	3.45	intermed	5.30	70.5%	ASME (3/30 version)	1.6	360°	uniform	10%
3	S&R	Config 1a	2.585	1.290	typical	1.74	3.45	above arrest	4.88	65.0%	ASME (3/30 version)	1.6	360°	uniform	10%
4	S&R	Config 1b	2.595	1.405	typical	1.90	3.71	high	5.74	76.4%	ASME (3/30 version)	1.6	360°	uniform	10%
5	S&R	Config 1b	2.595	1.405	typical	1.90	3.71	above arrest	4.88	65.0%	ASME (3/30 version)	1.6	360°	uniform	10%
6	S&R	Config 2a/2b	2.810	1.065	typical	2.34	4.29	high	7.63	101.5%	ASME (3/30 version)	1.6	360°	uniform	10%
7	S&R	Config 2a/2b	2.810	1.065	typical	2.34	4.29	above arrest	4.88	65.0%	ASME (3/30 version)	1.6	360°	uniform	10%
8	S&R	Config 3	2.595	1.405	typical	1.65	3.24	high	6.70	89.2%	ASME (3/30 version)	1.6	360°	uniform	10%
9	S&R	Config 3	2.595	1.405	typical	1.65	3.24	above arrest	4.88	65.0%	ASME (3/30 version)	1.6	360°	uniform	10%
10	spray	Config 4	2.005	0.900	typical	1.94	3.58	high	4.89	65.1%	ASME (3/30 version)	1.6	360°	uniform	10%
11	spray	Config 4	2.005	0.900	typical	1.94	3.58	above arrest	4.13	55.0%	ASME (3/30 version)	1.6	360°	uniform	10%
12	spray	Config 5	2.125	0.780	typical	2.51	4.20	high	4.75	63.3%	ASME (3/30 version)	1.6	360°	uniform	10%
13	spray	Config 5	2.125	0.780	typical	2.51	4.20	above arrest	4.13	55.0%	ASME (3/30 version)	1.6	360°	uniform	10%
14	spray	Config 6	2.850	1.150	typical	2.27	3.85	high	0.75	10.0%	ASME (3/30 version)	1.6	360°	uniform	10%
15	spray	Config 7	1.550	1.045	typical	1.29	2.83	high	4.65	61.9%	ASME (3/30 version)	1.6	360°	uniform	10%
16	spray	Config 7	1.550	1.045	typical	1.29	2.83	above arrest	4.13	55.0%	ASME (3/30 version)	1.6	360°	uniform	10%
17	surge	Config 8	5.920	1.580	typical	3.72	5.43	high	13.57	180.7%	surge w/ fill-in weld (no SS weld)	1.6	21	natural	26%
18	surge	Config 8	5.920	1.580	typical	3.72	5.43	above arrest	4.88	65.0%	surge w/ fill-in weld (no SS weld)	1.6	360°	uniform	10%
19	surge	Config 9	5.060	1.470	typical	3.38	5.06	high	14.55	193.7%	surge w/ fill-in weld (no SS weld)	1.6	21	natural	26%
20	surge	Config 9	5.060	1.470	typical	3.38	5.06	above arrest	4.88	65.0%	surge w/ fill-in weld (no SS weld)	1.6	360°	uniform	10%

Phase II Sensitivity Cases

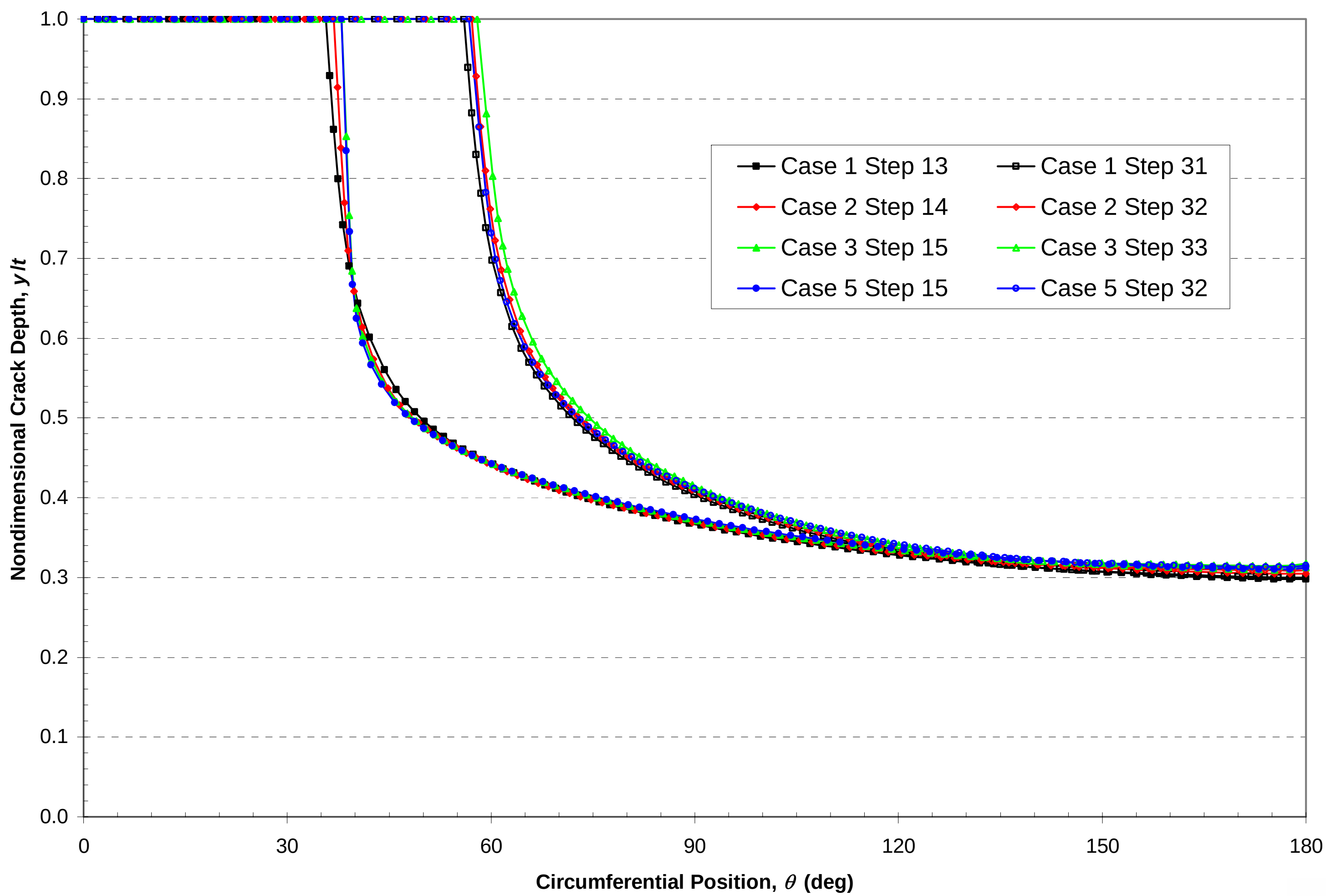
Prelim Summary Results for Surface Crack Cases (2/2)

							Surface Crack Results (Press + Deadweight + Normal Thermal loads and Z-factor for critical size)									
	Geometry Case						Pm Based on $pD_o/4t$			Pm Based on ID Area plus Crack Face Area						
Prelim Case #	Nozzle Type	Geometry Configuration	R_i (in)	t (in)	Time to TW (yr)	Fraction Xsection Cracked	Stability Margin Factor	Support. Code Pm (ksi)	Support. Pb (thick) (ksi)	Crack Face F (kips)	Max tot Faxial (kips)	Max Pm Based on CF (ksi)	Stability Margin Factor	Support. Pm (ksi)	Support. Pb (thick) (ksi)
1	S&R	Config 1a	2.585	1.290	18.4	0.40	2.8	9.8	16.3	23.18	72.52	2.77	3.2	8.8	18.1
2	S&R	Config 1a	2.585	1.290	23.0	0.39	3.1	10.5	16.2	22.76	72.09	2.75	3.4	9.4	18.1
3	S&R	Config 1a	2.585	1.290	27.0	0.38	3.4	11.6	16.4	21.96	71.30	2.72	3.8	10.4	18.6
4	S&R	Config 1b	2.595	1.405	19.4	0.39	2.7	10.1	15.7	25.68	88.33	3.03	3.0	9.2	17.4
5	S&R	Config 1b	2.595	1.405	28.3	0.37	3.2	12.0	15.8	24.18	86.83	2.98	3.7	10.9	17.9
6	S&R	Config 2a/2b	2.810	1.065	3.5	0.43	1.9	8.2	14.6	21.58	82.00	3.67	2.1	7.6	15.7
7	S&R	Config 2a/2b	2.810	1.065	10.6	0.44	2.4	10.3	11.7	21.82	82.24	3.68	2.6	9.7	12.9
8	S&R	Config 3	2.595	1.405	14.2	0.39	2.7	8.6	17.8	25.56	74.58	2.56	2.9	7.5	19.7
9	S&R	Config 3	2.595	1.405	Arrest	0.36	3.9	12.6	19.0	23.31	72.33	2.48	4.5	11.1	21.8
10	spray	Config 4	2.005	0.900	21.6	0.39	3.2	11.5	15.7	11.96	39.84	2.87	3.6	10.4	17.7
11	spray	Config 4	2.005	0.900	479	0.39	3.7	13.3	15.3	11.96	39.83	2.87	4.2	12.1	17.5
12	spray	Config 5	2.125	0.780	10.5	0.43	2.5	10.6	12.0	11.89	44.06	3.57	2.8	10.0	13.2
13	spray	Config 5	2.125	0.780	13.5	0.42	2.8	11.6	11.5	11.69	43.86	3.56	3.1	11.0	12.7
14	spray	Config 6	2.850	1.150	Arrest	0.35	5.6	21.7	4.2	19.16	75.35	3.04	7.0	21.3	5.2
15	spray	Config 7	1.550	1.045	Arrest	0.32	4.9	14.0	22.9	9.67	27.35	2.01	5.8	11.7	27.0
16	spray	Config 7	1.550	1.045	Arrest	0.32	5.2	14.7	21.5	9.68	27.36	2.01	6.2	12.4	25.6
17	surge	Config 8	5.920	1.580	1.2	0.23	1.6	8.9	22.1	34.81	288.93	4.34	1.8	7.6	23.9
18	surge	Config 8	5.920	1.580	9.1	0.50	1.8	9.6	8.7	74.77	328.88	4.94	1.9	9.3	9.2
19	surge	Config 9	5.060	1.470	1.2	0.25	1.5	7.8	22.5	29.56	214.31	4.00	1.7	6.7	24.2
20	surge	Config 9	5.060	1.470	11.0	0.48	2.0	9.9	9.6	57.99	242.74	4.54	2.1	9.5	10.3

Phase II Sensitivity Cases

Pairs of Complex Crack Profiles for Time w/ Detectable Leakage

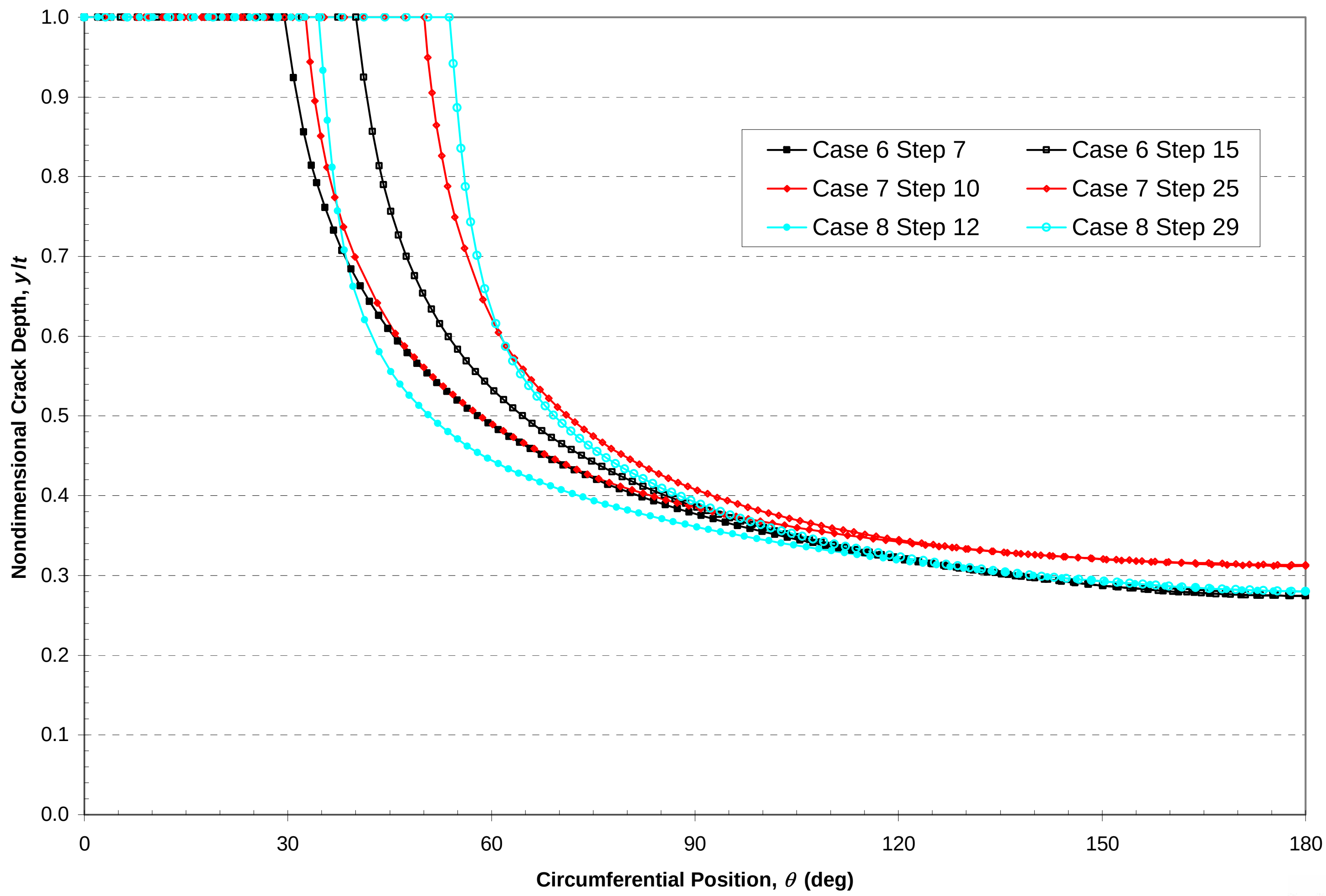
Safety and Relief nozzle cases: 1 gpm to critical for 1.4 factor on load



Phase II Sensitivity Cases

Pairs of Complex Crack Profiles for Time w/ Detectable Leakage

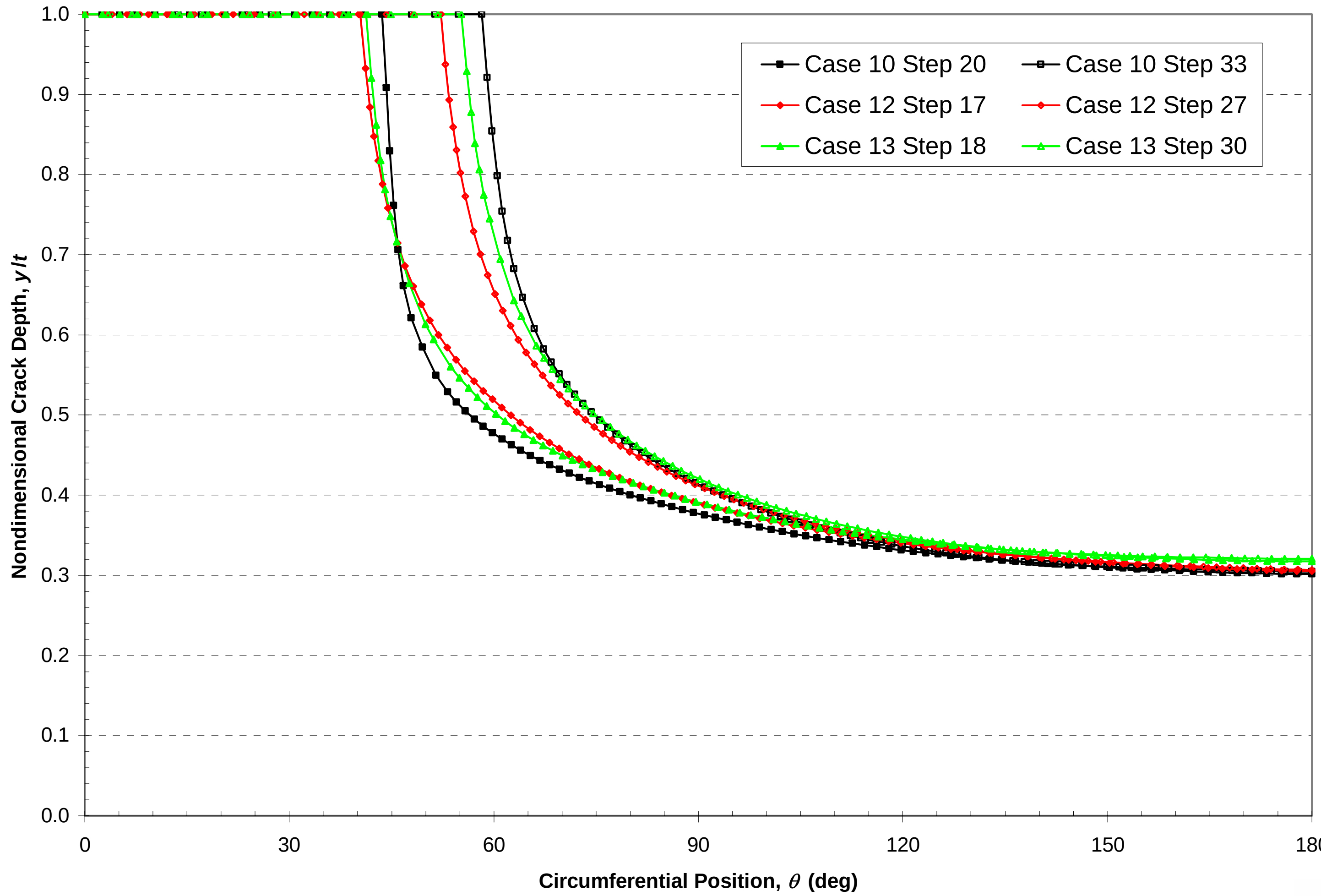
Safety and Relief nozzle cases: 1 gpm to critical for 1.4 factor on load



Phase II Sensitivity Cases

Pairs of Complex Crack Profiles for Time w/ Detectable Leakage

Spray nozzle cases: 1 gpm to critical for 1.4 factor on load



Phase II Sensitivity Cases
Prelim Summary Results for Complex Crack Cases (1/3)

Crack Stability Results - 1 gpm Calculated Leak Rate								
Case and Step	Fraction Xsection Cracked	Crack Face Force (kips)	Max tot Faxial (kips)	Max Pm Based on CF (ksi)	Support. Pm (ksi)	Support. Pb (thick) (ksi)	Stability Margin Factor	Complex Crack Time* (h)
C1S13	0.466	27.24	76.58	2.92	6.62	12.92	2.26	2,888
C2S14	0.468	27.38	76.72	2.93	6.86	12.39	2.34	3,654
C3S15	0.472	27.62	76.96	2.94	7.07	11.74	2.41	4,873
C5S15	0.470	30.55	93.20	3.20	7.39	11.27	2.31	5,009
C6S7	0.470	23.48	83.90	3.75	6.38	12.96	1.70	825
C7S10	0.488	24.38	84.80	3.79	7.64	9.84	2.01	1,651
C8S12	0.456	29.68	78.70	2.70	5.86	14.52	2.17	2,386
C10S20	0.497	15.42	43.30	3.12	6.46	10.13	2.07	4,642
C12S17	0.509	14.03	46.20	3.75	6.89	8.74	1.84	2,423
C13S18	0.511	14.08	46.26	3.75	7.31	8.05	1.95	3,163

*Initial complex crack assumed to have total through-wall crack circumferential extent of 42°

Phase II Sensitivity Cases

Prelim Summary Results for Complex Crack Cases (2/3)

Crack Stability Results - 1.4 Factor on Pm and Pb Loads										
Case and Step	Fraction Xsection Cracked	Crack Face Force (kips)	Max tot Faxial (kips)	Max Pm Based on CF (ksi)	Support. Pm (ksi)	Support. Pb (thick) (ksi)	Stability Margin Factor	Complex Crack Time (h)	Time since 1 gpm (days)	Time since 1 gpm (years)
C1S31	0.546	31.94	81.27	3.10	4.38	8.06	1.41	5,208	96.7	0.26
C2S32	0.552	32.29	81.63	3.12	4.44	7.54	1.42	6,185	105.4	0.29
C3S33	0.558	32.66	81.99	3.13	4.49	7.00	1.43	7,585	113.0	0.31
C5S32	0.551	35.86	98.50	3.38	4.81	6.94	1.42	7,690	111.7	0.31
C6S15	0.501	25.07	85.49	3.82	5.44	10.86	1.42	1,463	26.6	0.07
C7S25	0.545	27.25	87.67	3.92	5.60	6.97	1.43	3,015	56.9	0.16
C8S29	0.529	34.42	83.44	2.87	4.10	9.59	1.43	4,442	85.7	0.23
C10S33	0.559	17.34	45.22	3.26	4.60	6.90	1.41	6,059	59.1	0.16
C12S27	0.551	15.17	47.34	3.84	5.46	6.76	1.42	3,207	32.7	0.09
C13S30	0.564	15.53	47.70	3.87	5.42	5.78	1.40	4,205	43.4	0.12

Phase II Sensitivity Cases

Prelim Summary Results for Complex Crack Cases (3/3)

Crack Stability Results - 1.0 Factor on Pm and Pb Loads										
Case and Step	Fraction Xsection Cracked	Crack Face Force (kips)	Max tot Faxial (kips)	Max Pm Based on CF (ksi)	Support. Pm (ksi)	Support. Pb (thick) (ksi)	Stability Margin Factor	Complex Crack Time (h)	Time since 1 gpm (days)	Time since 1 gpm (years)
C6S28	0.557	27.85	88.28	3.95	3.97	7.67	1.01	2,152	55.3	0.15
C12S38	0.599	16.51	48.68	3.95	4.00	4.81	1.01	3,753	55.4	0.15
C13S40	0.610	16.81	48.98	3.97	3.98	4.14	1.00	4,722	65.0	0.18

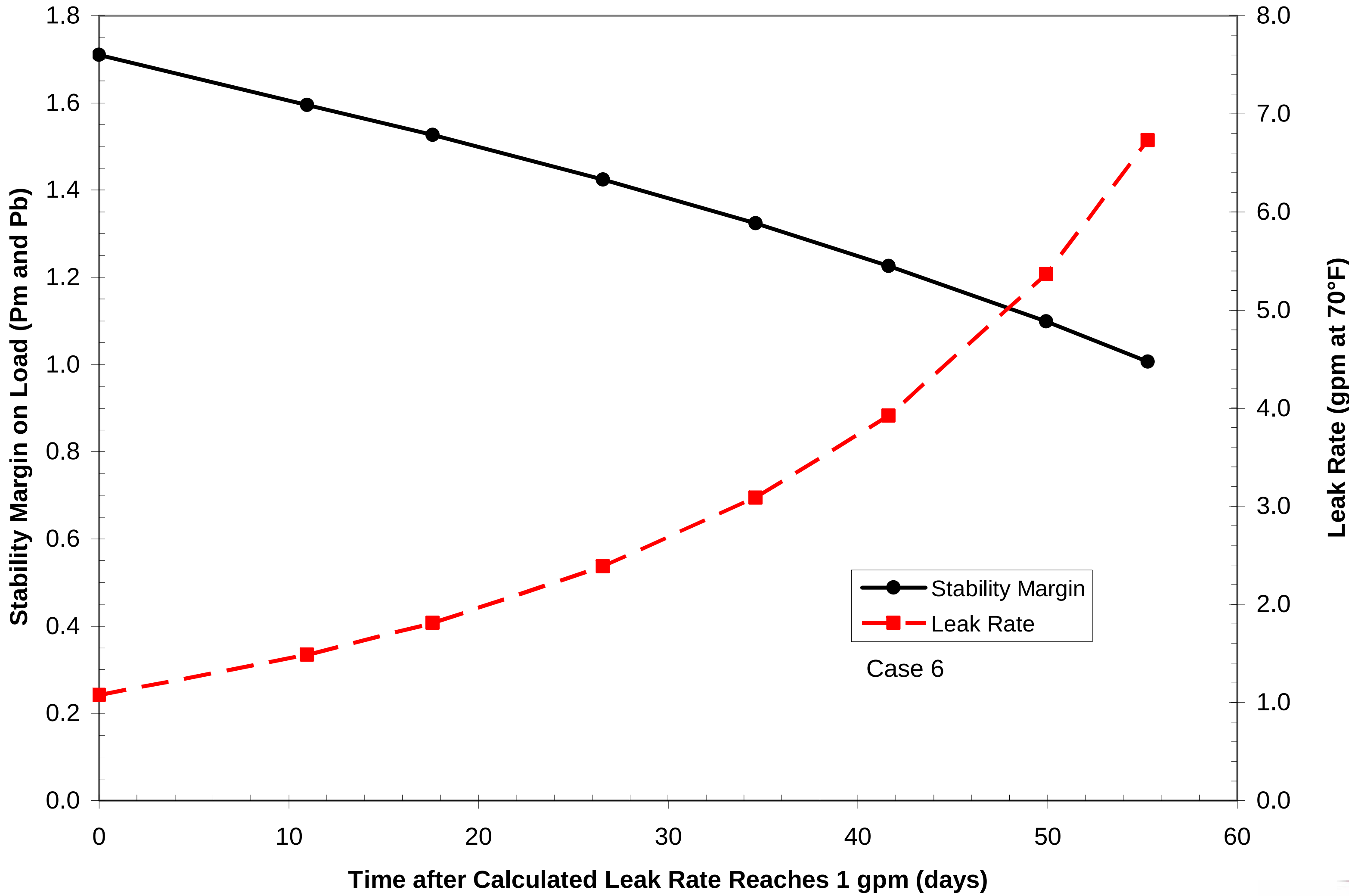
Phase II Sensitivity Cases

Prelim PICEP Leak Rate Calc for Complex Crack Cases

Matrix Case #	Nozzle Type	OD (in)	t (in)	Area (in^2)	COD (in)	$2c_{OD}$ (in)	Quality	Roughness (in)	# Turns	Leak Rate (gpm @ 70°F)
1	S&R	7.750	1.290	0.0236	0.0062	4.812	1.00	3.9370E-04	31	1.02
1	S&R	7.750	1.290	0.0785	0.0132	7.566	1.00	3.9370E-04	31	4.05
2	S&R	7.750	1.290	0.0239	0.0061	4.969	1.00	3.9370E-04	31	1.03
2	S&R	7.750	1.290	0.0802	0.0132	7.713	1.00	3.9370E-04	31	4.14
3	S&R	7.750	1.290	0.0241	0.0060	5.121	1.00	3.9370E-04	31	1.03
3	S&R	7.750	1.290	0.0813	0.0132	7.825	1.00	3.9370E-04	31	4.20
5	S&R	8.000	1.405	0.0257	0.0062	5.285	1.00	3.9370E-04	34	1.07
5	S&R	8.000	1.405	0.0813	0.0131	7.909	1.00	3.9370E-04	34	4.03
6	S&R	7.750	1.065	0.0222	0.0071	3.976	1.00	3.9370E-04	26	1.08
6	S&R	7.750	1.065	0.0448	0.0106	5.407	1.00	3.9370E-04	26	2.38
6	S&R	7.750	1.065	0.0295	0.0083	4.525	1.00	3.9370E-04	26	1.49
6	S&R	7.750	1.065	0.0351	0.0092	4.882	1.00	3.9370E-04	26	1.81
6	S&R	7.750	1.065	0.0564	0.0121	5.925	1.00	3.9370E-04	26	3.08
6	S&R	7.750	1.065	0.0698	0.0138	6.426	1.00	3.9370E-04	26	3.92
6	S&R	7.750	1.065	0.0924	0.0166	7.105	1.00	3.9370E-04	26	5.36
6	S&R	7.750	1.065	0.1132	0.0189	7.612	1.00	3.9370E-04	26	6.73
7	S&R	7.750	1.065	0.0217	0.0063	4.399	1.00	3.9370E-04	26	1.02
7	S&R	7.750	1.065	0.0639	0.0120	6.763	1.00	3.9370E-04	26	3.49
8	S&R	8.000	1.405	0.0252	0.0067	4.810	1.00	3.9370E-04	34	1.07
8	S&R	8.000	1.405	0.0783	0.0133	7.498	1.00	3.9370E-04	34	3.89
10	Spray	5.810	0.900	0.0204	0.0059	4.415	1.00	3.9370E-04	22	1.01
10	Spray	5.810	0.900	0.0476	0.0103	5.895	1.00	3.9370E-04	22	2.70
12	Spray	5.810	0.780	0.0199	0.0062	4.090	1.00	3.9370E-04	19	1.07
12	Spray	5.810	0.780	0.0394	0.0095	5.290	1.00	3.9370E-04	19	2.34
13	Spray	5.810	0.780	0.0194	0.0059	4.173	1.00	3.9370E-04	19	1.03
13	Spray	5.810	0.780	0.0436	0.0099	5.595	1.00	3.9370E-04	19	2.61

Phase II Sensitivity Cases

Leak Rate and Crack Stability vs. Time for Example Case



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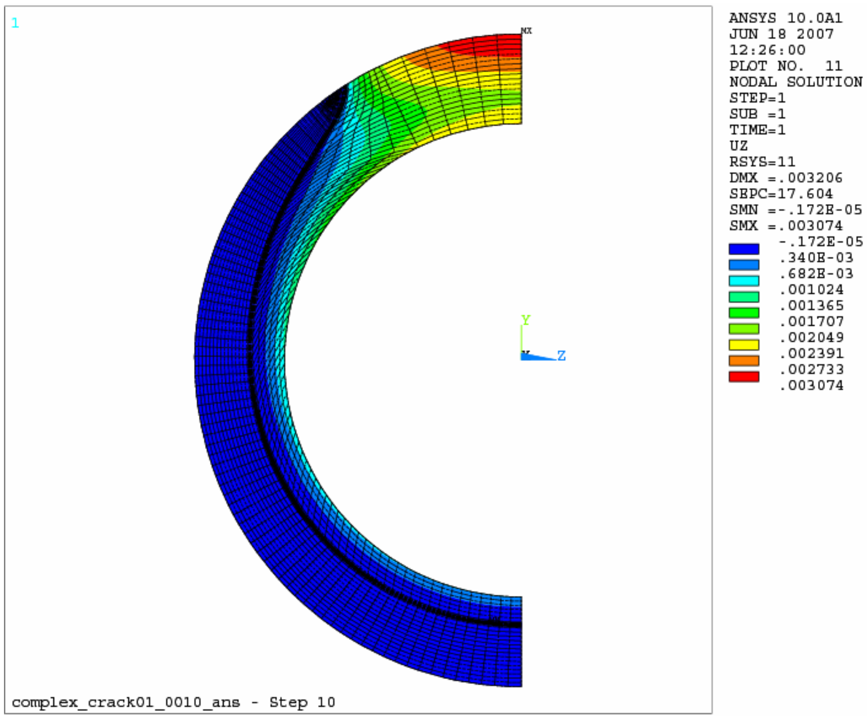
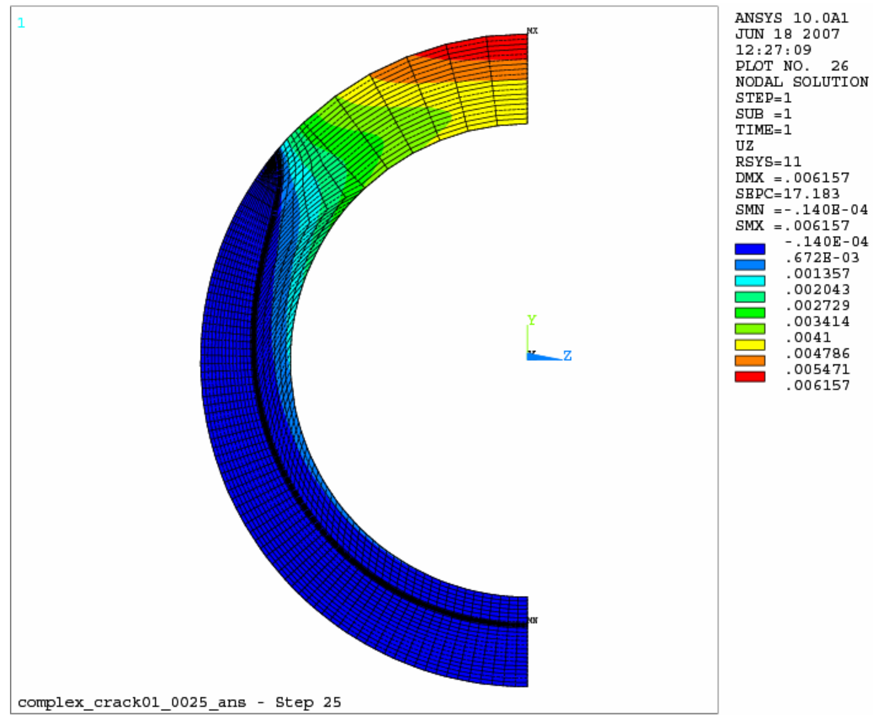
Leak Rate Calculation
Crack Opening Displacements (Half COD)



Case 7 – 1 gpm leak rate



Case 7 – Critical for 1.4 Factor on Loading

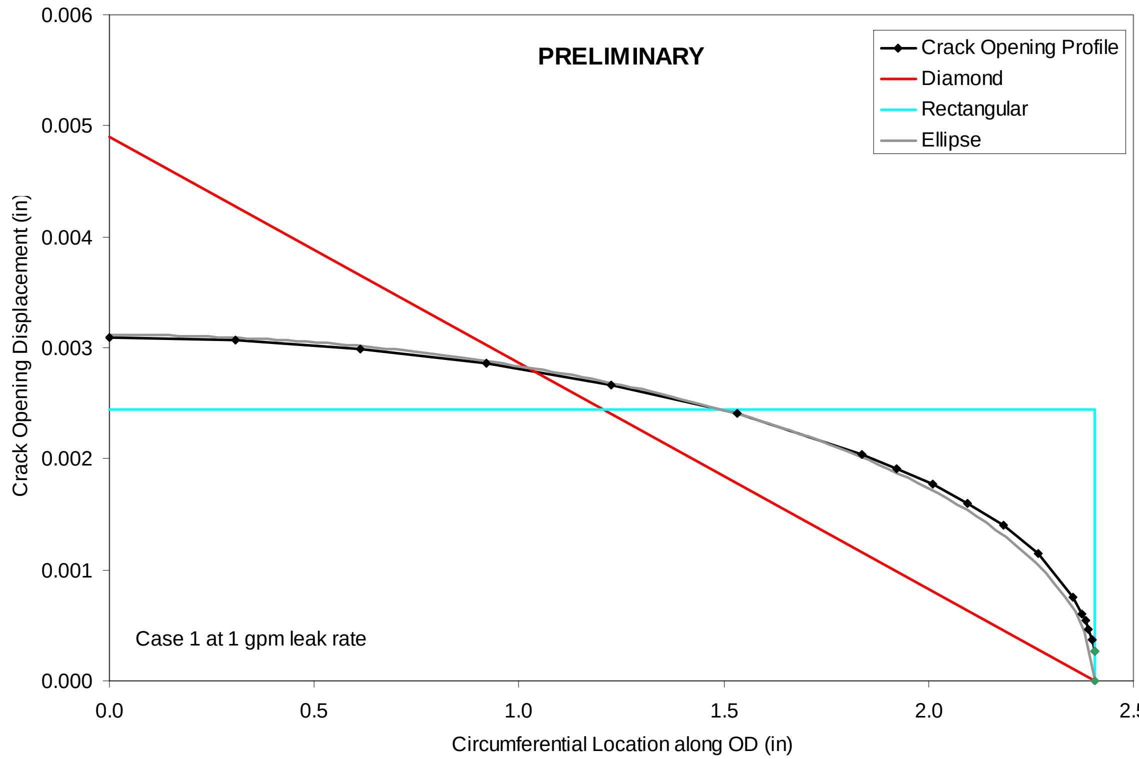
Leak Rate Calculation
Effect of Variation in COD with Radial Position

- Crack opening area (COA) and crack length at OD applied in leak rate results presented above
  - Circumferential extent of crack assumed to be same on ID as given by crack growth calculation for OD
- COA at OD approximately 1.5 times that at the mid-radius
- Approximately 20% reduction in flow rate when model the area expansion (from mid-radius to OD) using PICEP

Leak Rate Calculation

Effect of Assumed Crack Shape on Calculated Leak Rate

- Crack opening at OD from FEA closely approximated by ellipse
- Ellipse selected as default crack shape
- Rectangular and diamond crack shapes both resulted in 2% increase in predicted leak rate for the same COA



Knockdown Factor Calculations

- See separate presentation by Ted Anderson of Quest Reliability, LLC

Probabilistic Assessment

- See separate presentation by Pete Riccardella of Structural Integrity Associates

Status of Industry Work
Other Topics

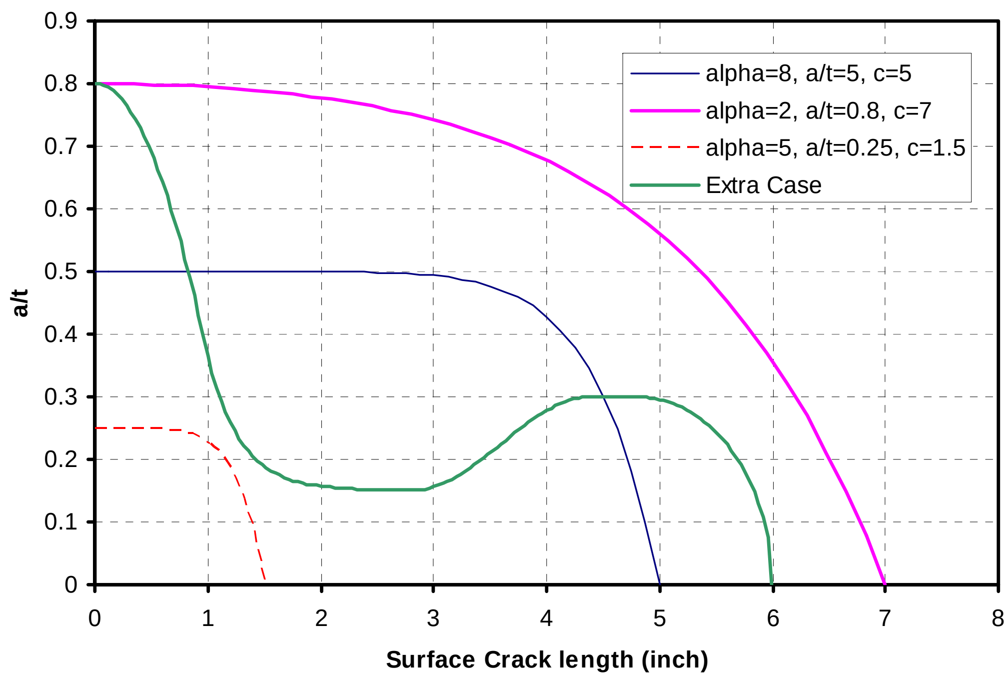
- K Verification
- Model convergence
  - Effect of time step on crack growth solution
- Nozzle-to-safe-end geometry cases
- Validation work
  - EU mockup
  - Battelle mockup with weld repairs
- Final report

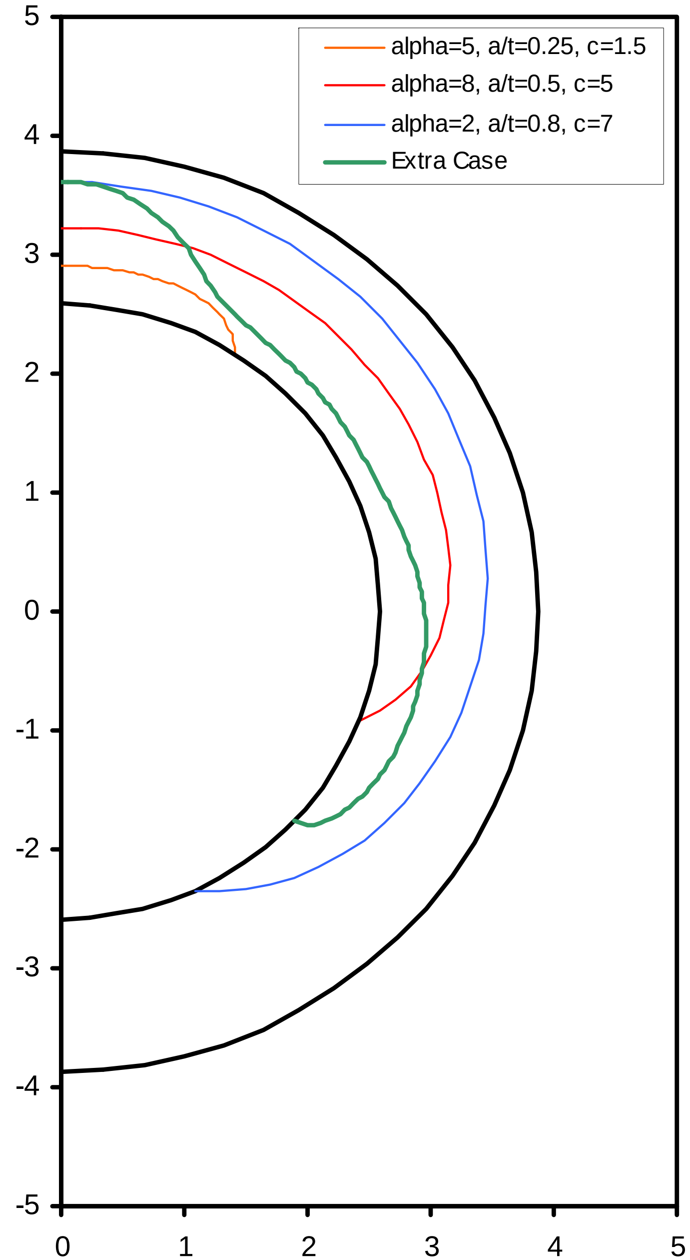
K Verification
Introduction

- Previously FEACrack has been applied to generate K solutions for the three custom crack profiles suggested by EMC2
  - EMC2's solutions closely matched the DEI results for these cases
- Results are now available for the fourth profile, which was suggested by DEI

K Verification

Test Crack Profiles





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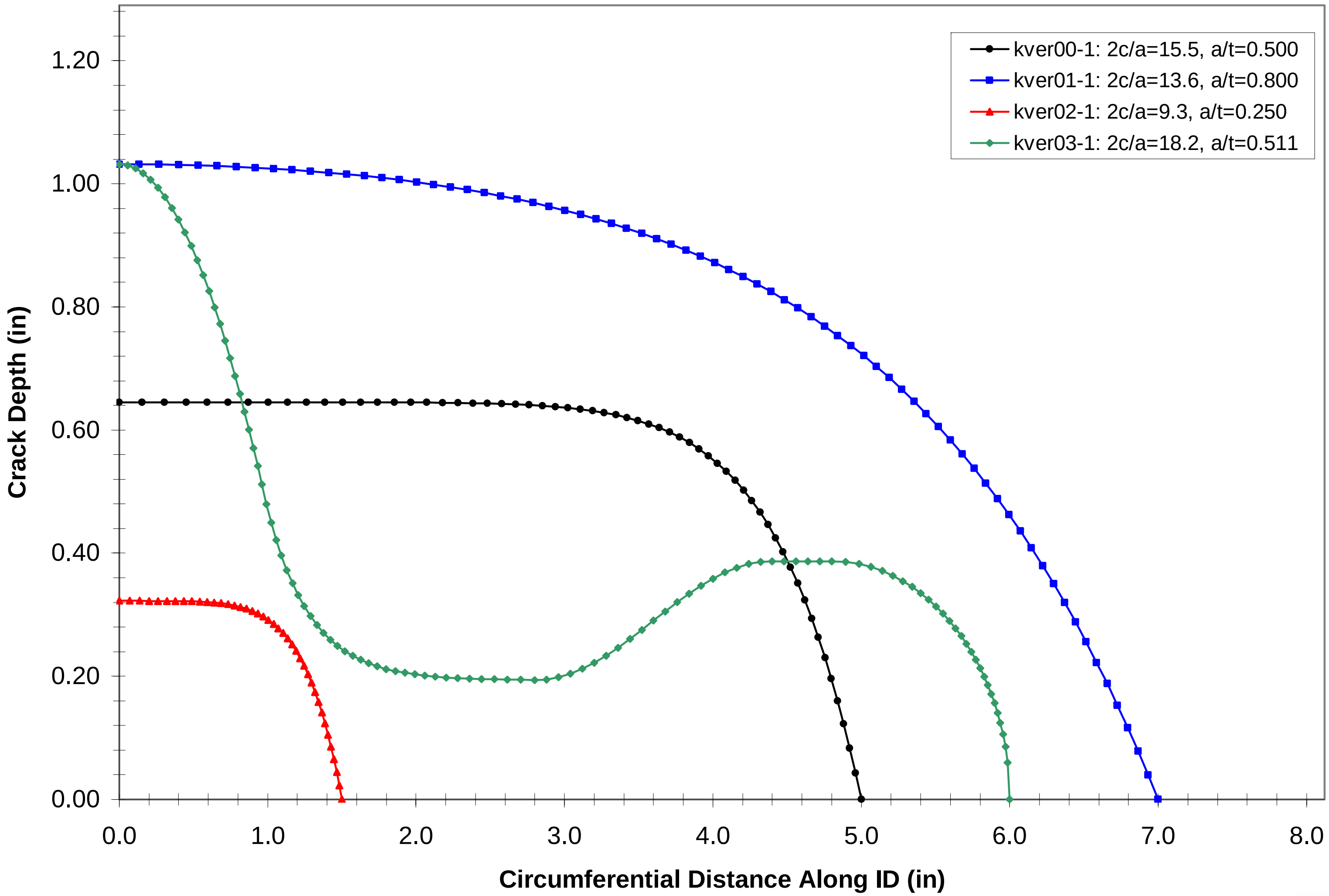
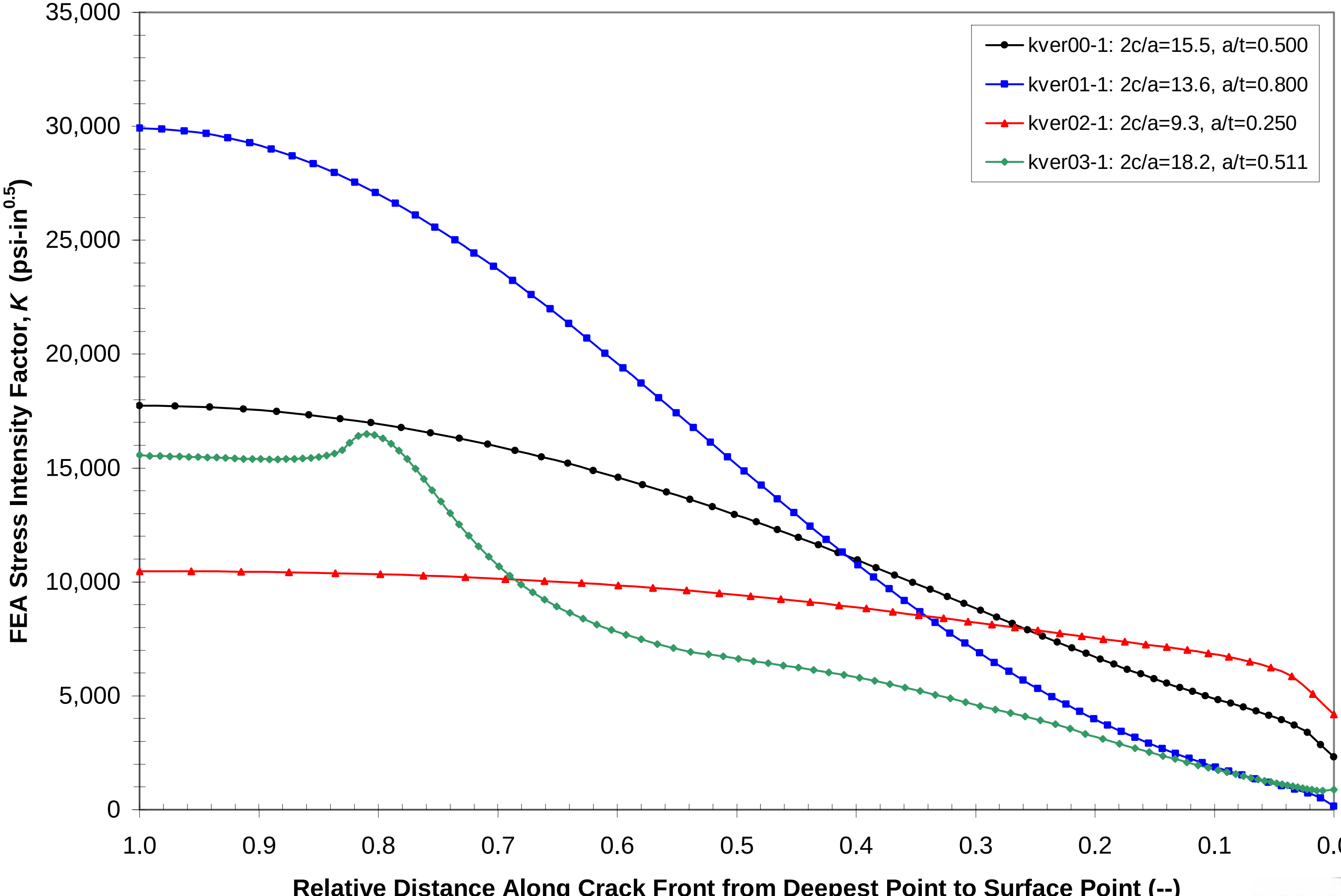
K Verification

Corner Node Positions Along Crack Front

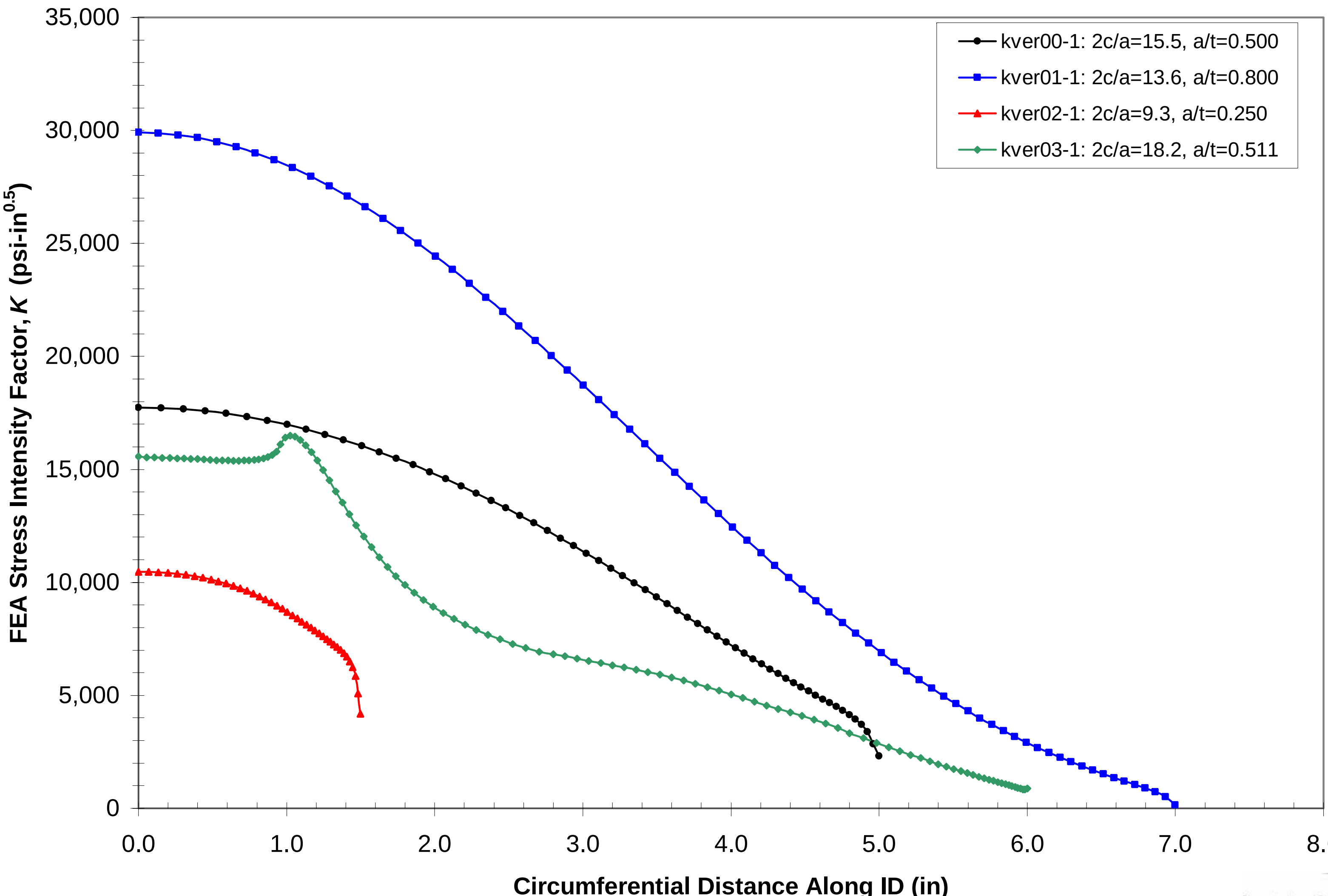


K Verification

K Result as Function of Relative Crack Front Position



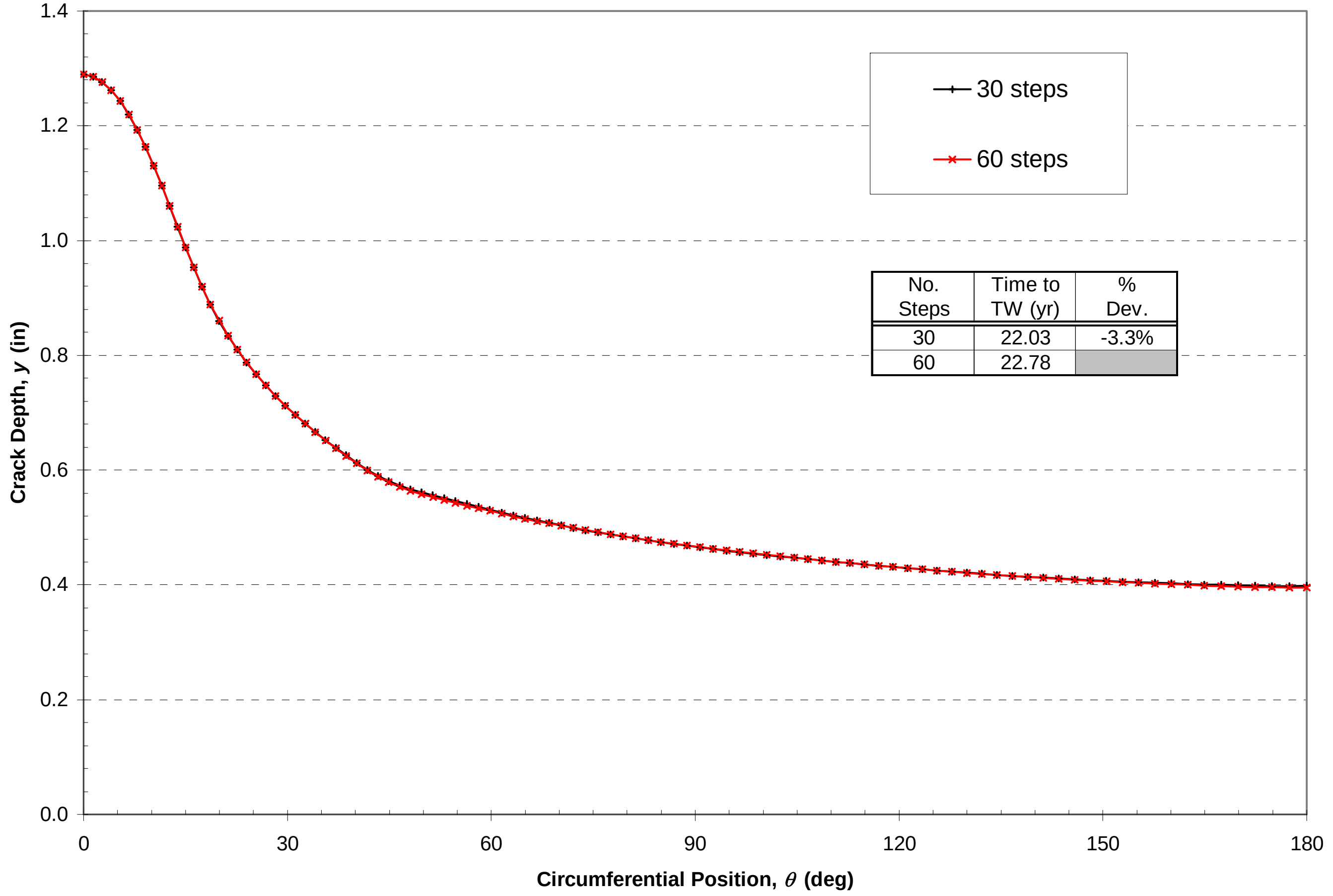
K Verification
K Result as Function of Circumferential Position on ID



Model Convergence

Investigation of Effect of Time Step

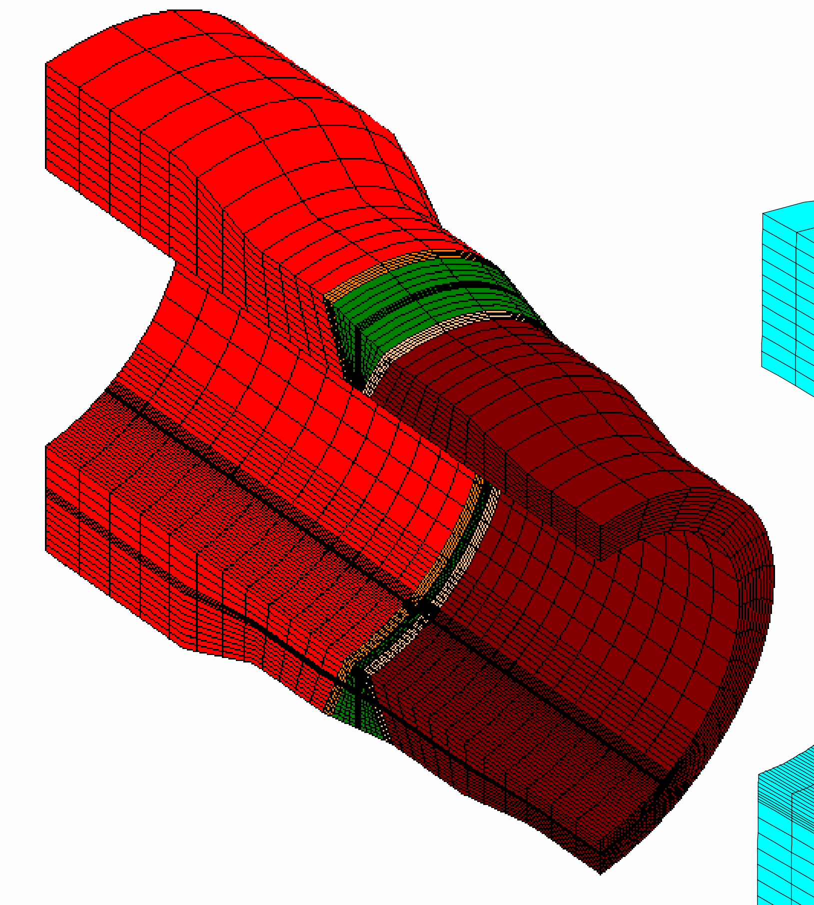
- For the Phase 1 set of inputs and an initial 10% deep 360° surface flaw, the through-wall profile and time to through-wall were checked for 30 and 60 growth steps

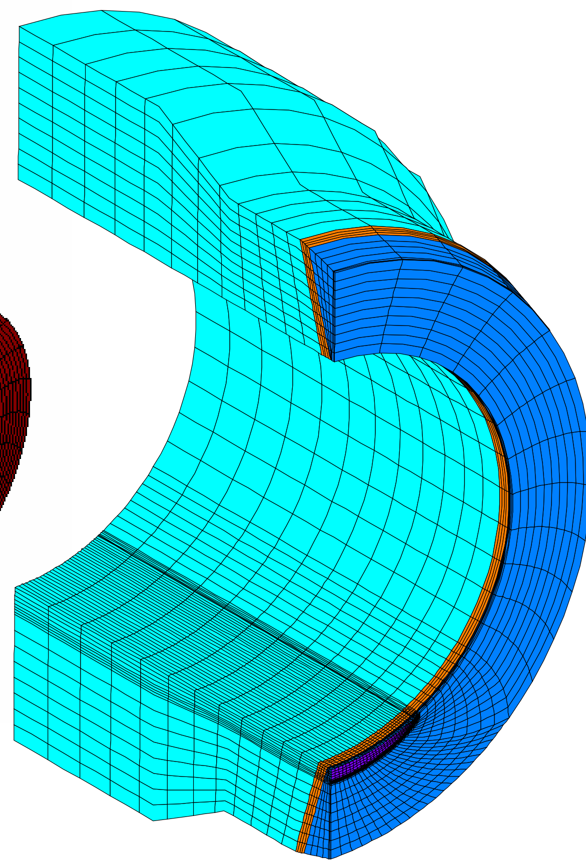


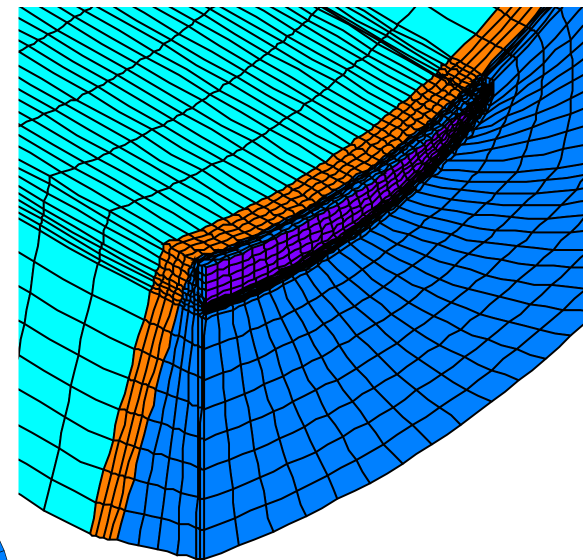
No. Steps	Time to TW (yr)	% Dev.
30	22.03	-3.3%
60	22.78	

Dominion Engineering, Inc.

Nozzle-to-safe-end Geometry Cases
Example Cracked Model







Status of NRC Confirmatory Research

- To be presented by NRC
  - WRS Modeling
  - Phase II Sensitivity Cases
  - K Verification

Wednesday Agenda

- Discussion from Previous Day's Results – Industry & NRC
- Acceptance Criteria and Safety Factors – Industry
- Plans for next meeting(s) – Industry & NRC
- Meeting Summary and Conclusions – Industry & NRC

Discussion from Previous Day's Results

- WRS Models
- Phase II Sensitivity Cases

Acceptance Criteria and Safety Factors – Industry

- Revised Proposed Industry Acceptance Criteria & Safety Factors
- Discussions

Acceptance Criteria and Safety Factors

Conclusions from June 1 Presentation – Summary

- It is appropriate that analyses demonstrate a high and sufficient level of assurance given possibility of circumferential flaws
- This short-term implementation issue is different than long-term safety evaluations or disposition of actual detected growing flaws
- Extensive consideration of analysis uncertainties and modeling conservatisms reduce the effect of analysis uncertainties
- Operating ages of subject plants are generally less than that for Wolf Creek
  - This effect tends to lower probability of crack initiation in subject plants
  - However, time for crack initiation not explicitly credited in the type of leakage prior to rupture calculation being performed

Acceptance Criteria and Safety Factors

Conclusions from June 1 Presentation – Acceptance Criteria Under Development

- Acceptance criteria are currently under development for this project:
  - Calculated time between leak detection and critical crack is main assessment parameter
  - There is a high confidence of leak detection and plant shutdown within 7 days after the leak rate reaches 0.25 gpm
  - A margin factor >1 on the calculated leak rate is under consideration to address the uncertainty in the best-estimate leak rate predicted by the leak rate codes
  - Given extensive consideration of analysis uncertainties and modeling conservatisms, a margin factor of 1 on critical crack size may be appropriate
  - A secondary assessment parameter is the time between the initial crack and the critical crack, which can be compared to the operating age of each subject weld

Plans for Next Meeting(s)

- Project Timeline & Milestones Update
- Draft/Final Industry Report Update
- Expert Panel July 10th
- ACRS July 11th
- Expert Panel July 12th?
- End of July Management Meeting?

Meeting Summary and Conclusions

- Industry
- NRC

Final Report on Secondary Stress Study

Ted Anderson, Ph.D., P.E.

Eric Scheibler

Greg Thorwald, Ph.D.

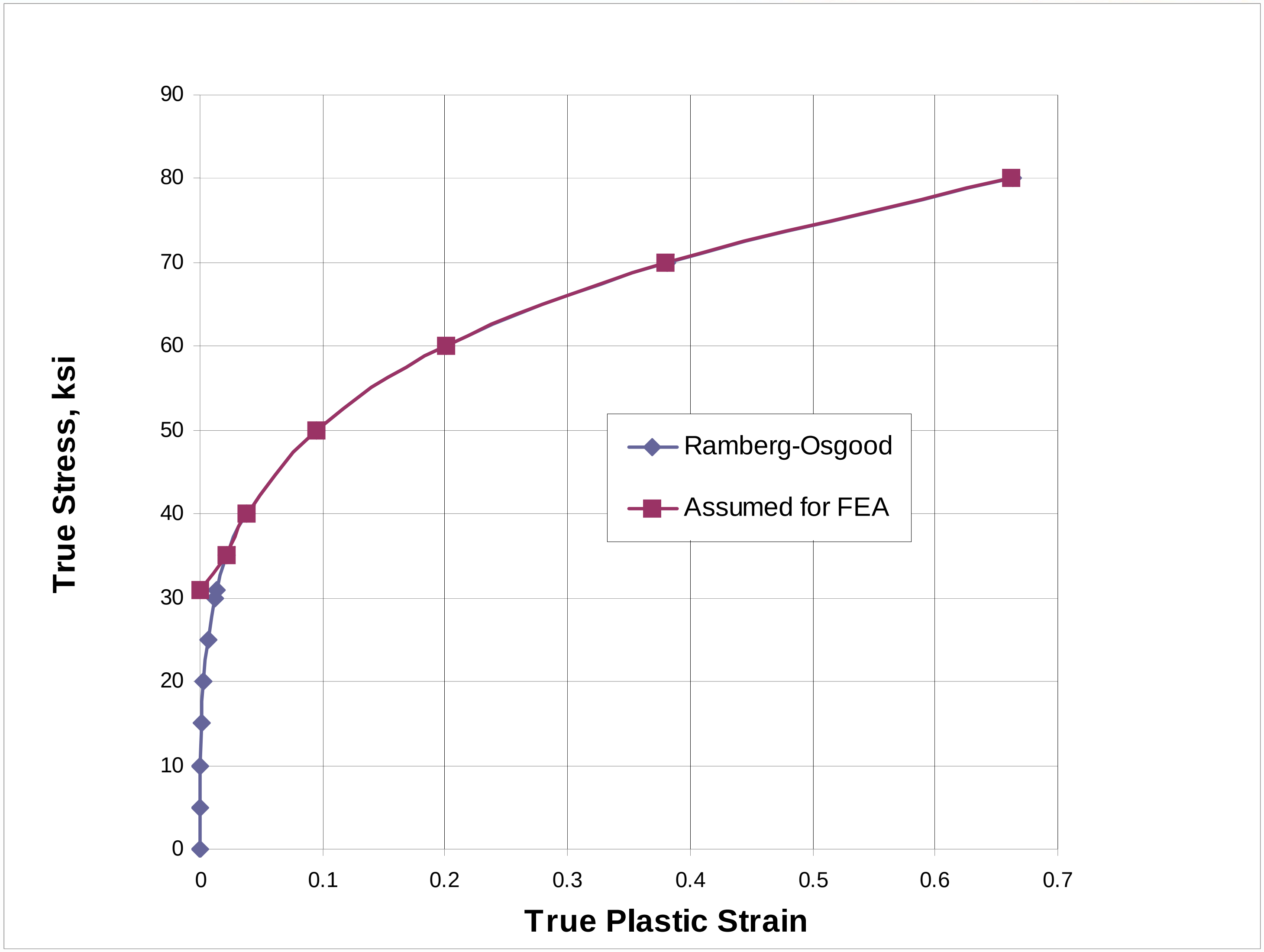
Overview

- Elastic and elastic-plastic finite element analysis to determine the effect of an imposed end rotation on bending moment and crack driving force.
  - Total pipe length (2L) = 60 in & 60 ft (L corresponds to the length of the model due to symmetry conditions).
  - Initial (uncracked) bending stress = 25 ksi
  - Through-wall cracks of various lengths.

Calculated Results

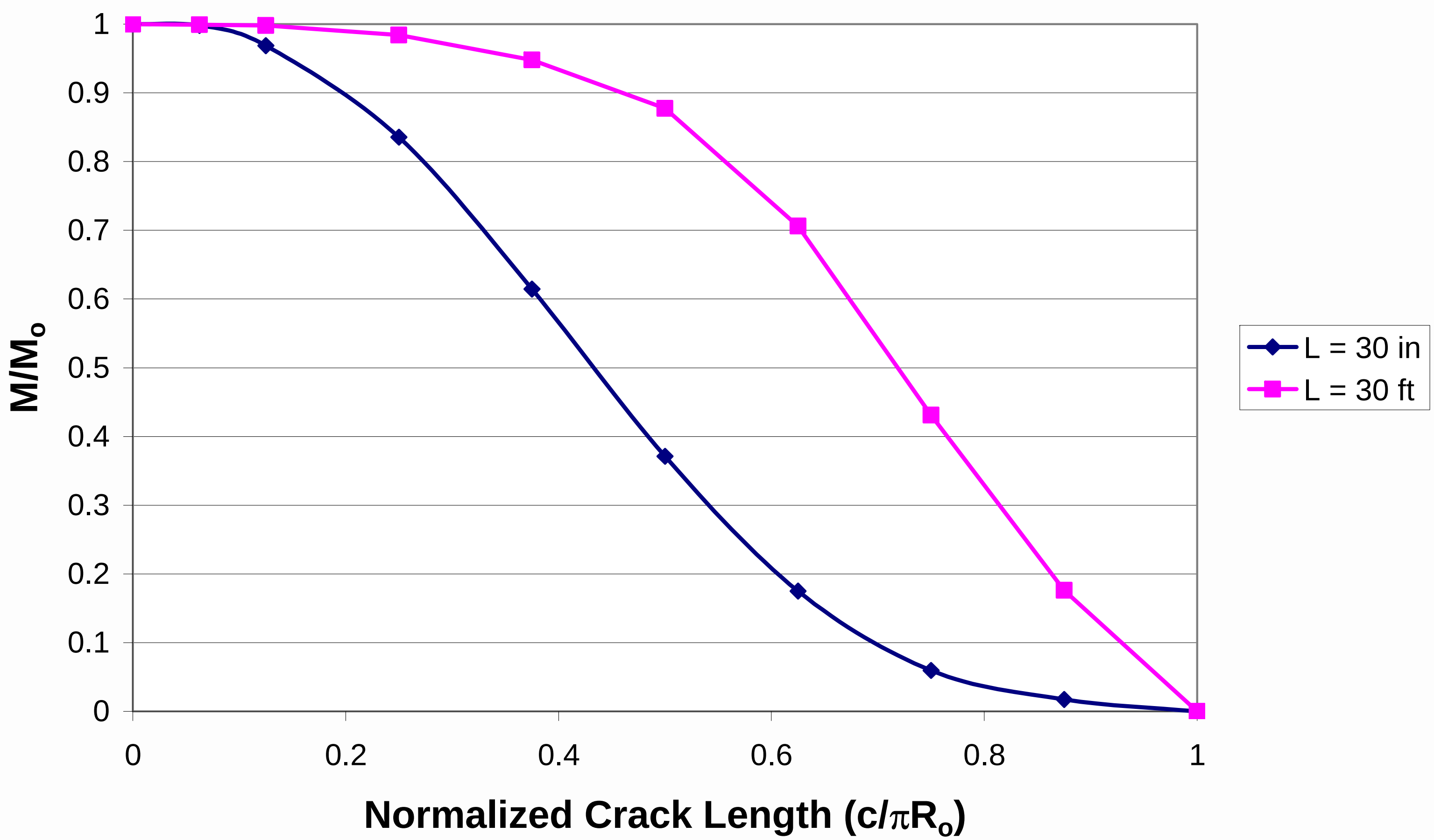
- Moment knock-down factor (M/M_o) for a fixed rotation (θ):
  - Ratio of the bending moment of the cracked pipe to that of the uncracked pipe.
- J-integral knock-down factor (J_θ/J_M):
  - Ratio of crack driving force for a fixed rotation to that for fixed applied moment.

Stress-Strain Curve



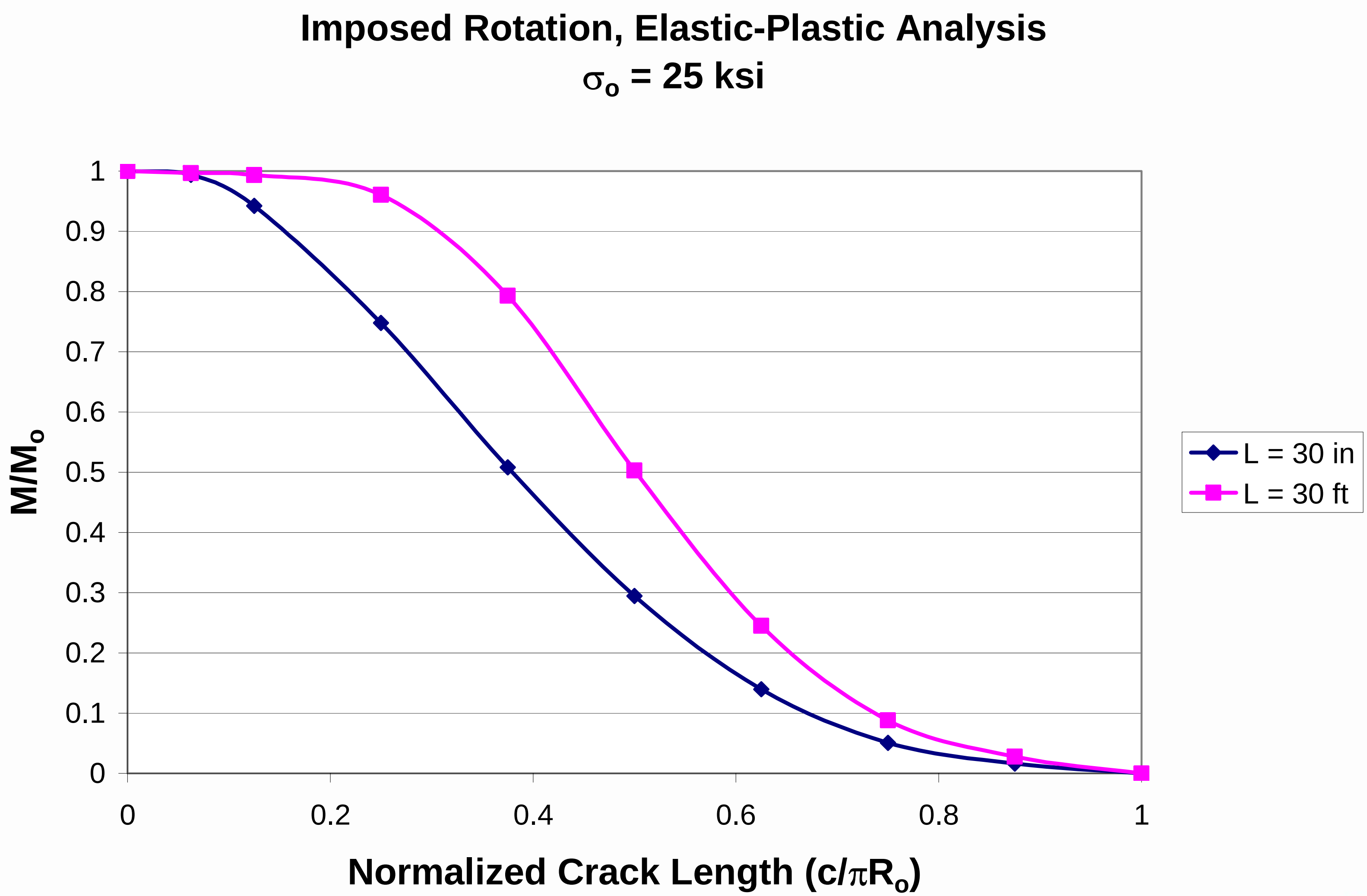
Moment Knock-Down Factors
Elastic Analysis

Imposed Rotation, Elastic Analysis



Asset Longevity | Plant Performance

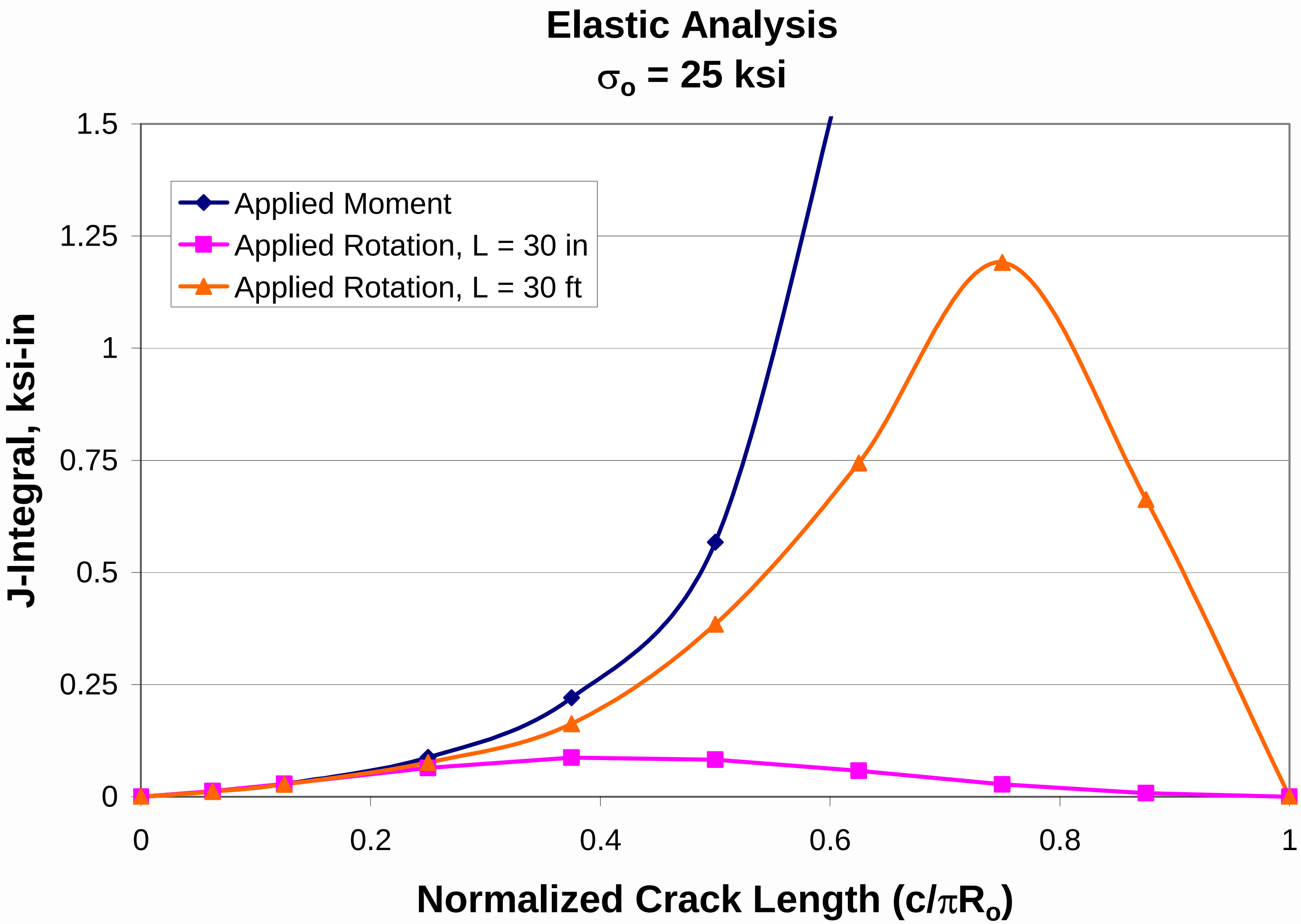
Moment Knock-Down Factors
Elastic-Plastic Analysis



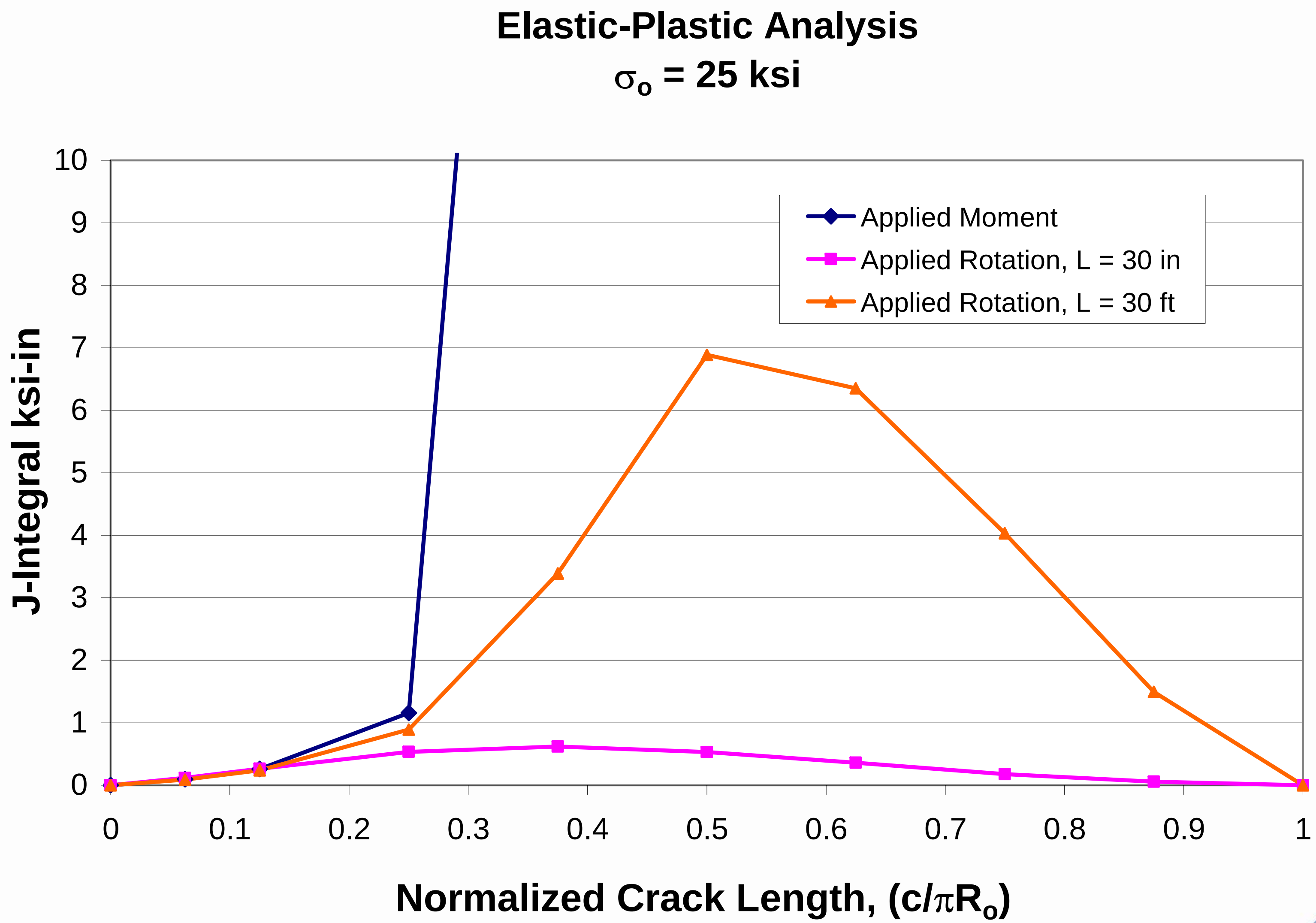
Imposed angle at free end is 0.1987 degrees for L = 30 in and 2.291 degrees for L = 30 ft

Asset Longevity | Plant Performance

Elastic Crack Driving Force

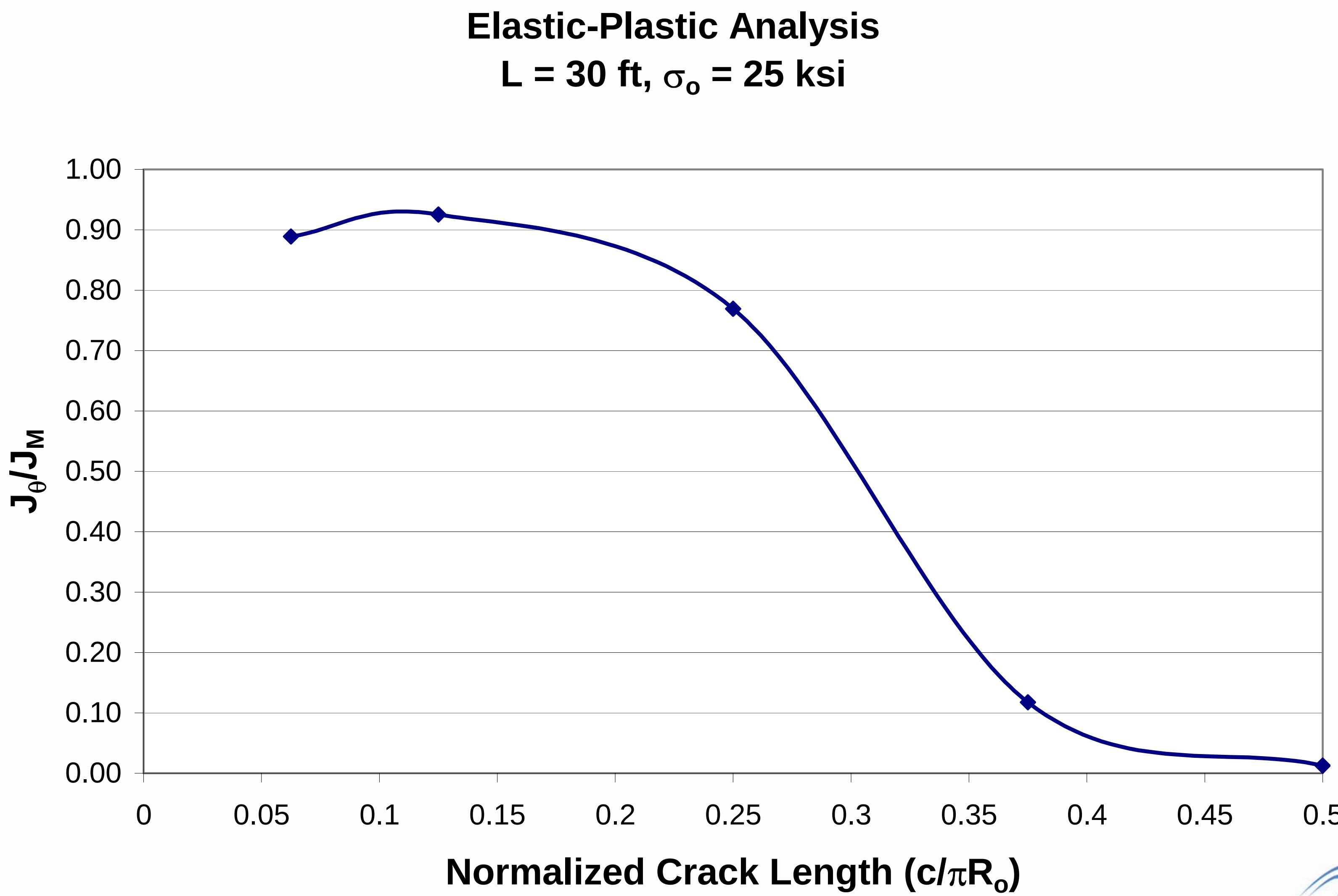


Elastic-Plastic Crack Driving Force



Asset Longevity | Plant Performance

J-Integral Knock-Down Factor
Elastic-Plastic Analysis



Asset Longevity | Plant Performance

QUEST RELIABILITY

Emc^2 Verification and Confirmatory Analyses

David Rudland, Do-Jun Shim, Tao Zhang and Gery Wilkowski

Engineering Mechanics Corporation of Columbus

June 19, 2007

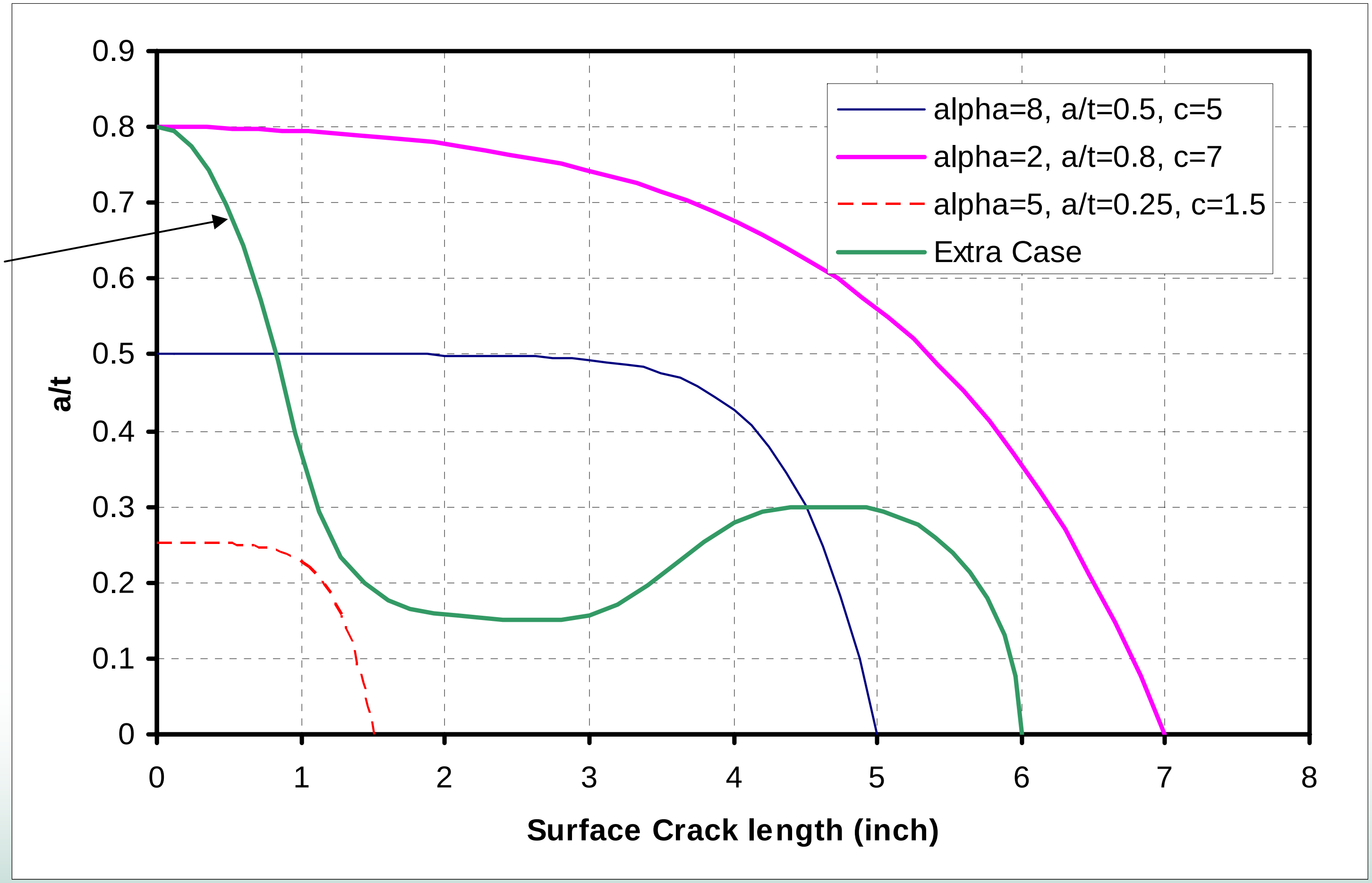
Outline

- ***K-Verification***
- ***Welding Residual Stress***
- ***Confirmatory Sensitivity Analyses***

Continuous Arbitrary Surface Cracks

Modified Bessel of the first kind

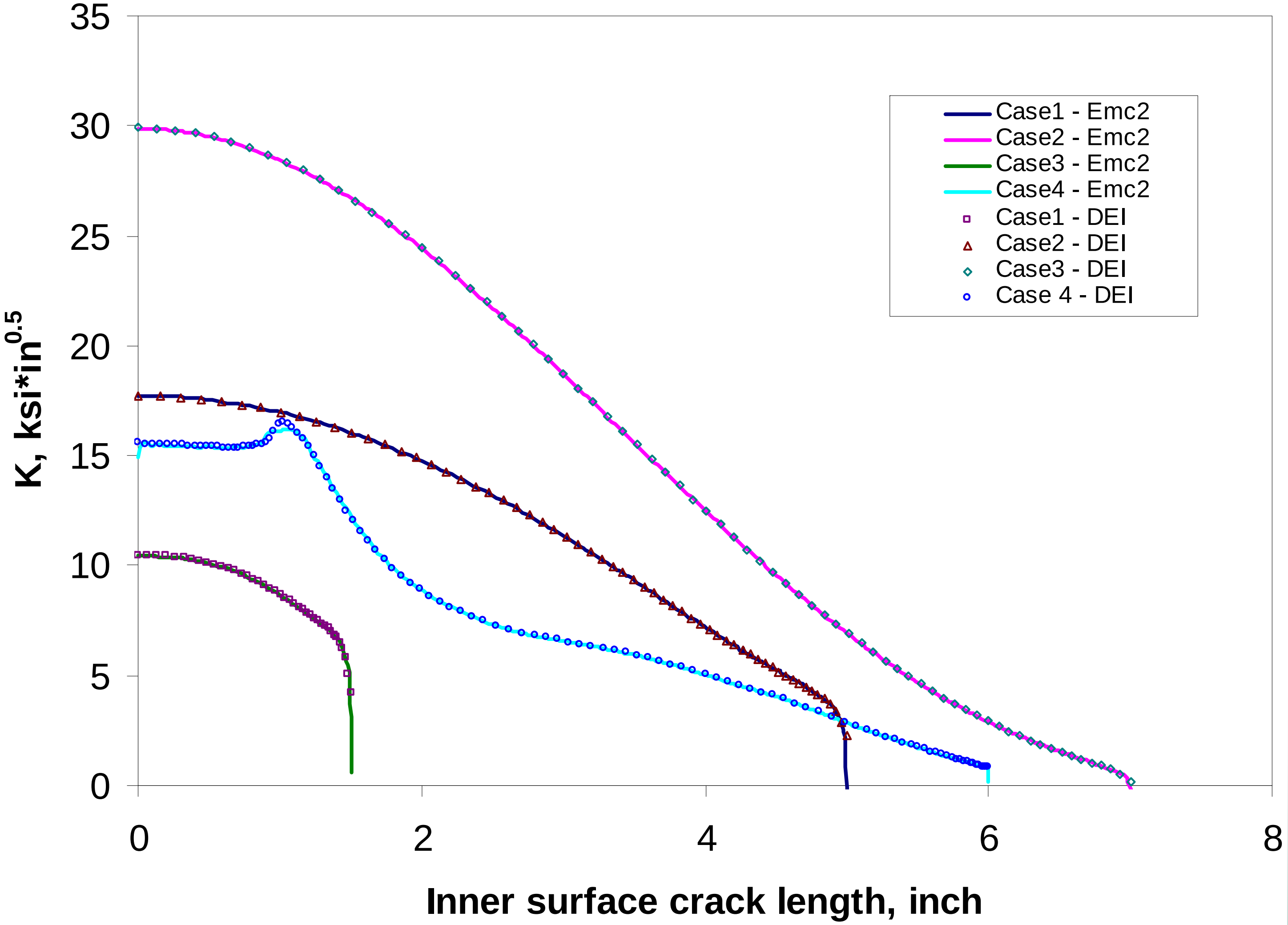
Developed by DEI



$$I_\alpha(x) = i^{-\alpha} J_\alpha(ix)$$

$$J_\alpha(x) = \frac{1}{2\pi}\int_0^{2\pi} \cos(\alpha\tau - x\sin\tau)\,d\tau$$

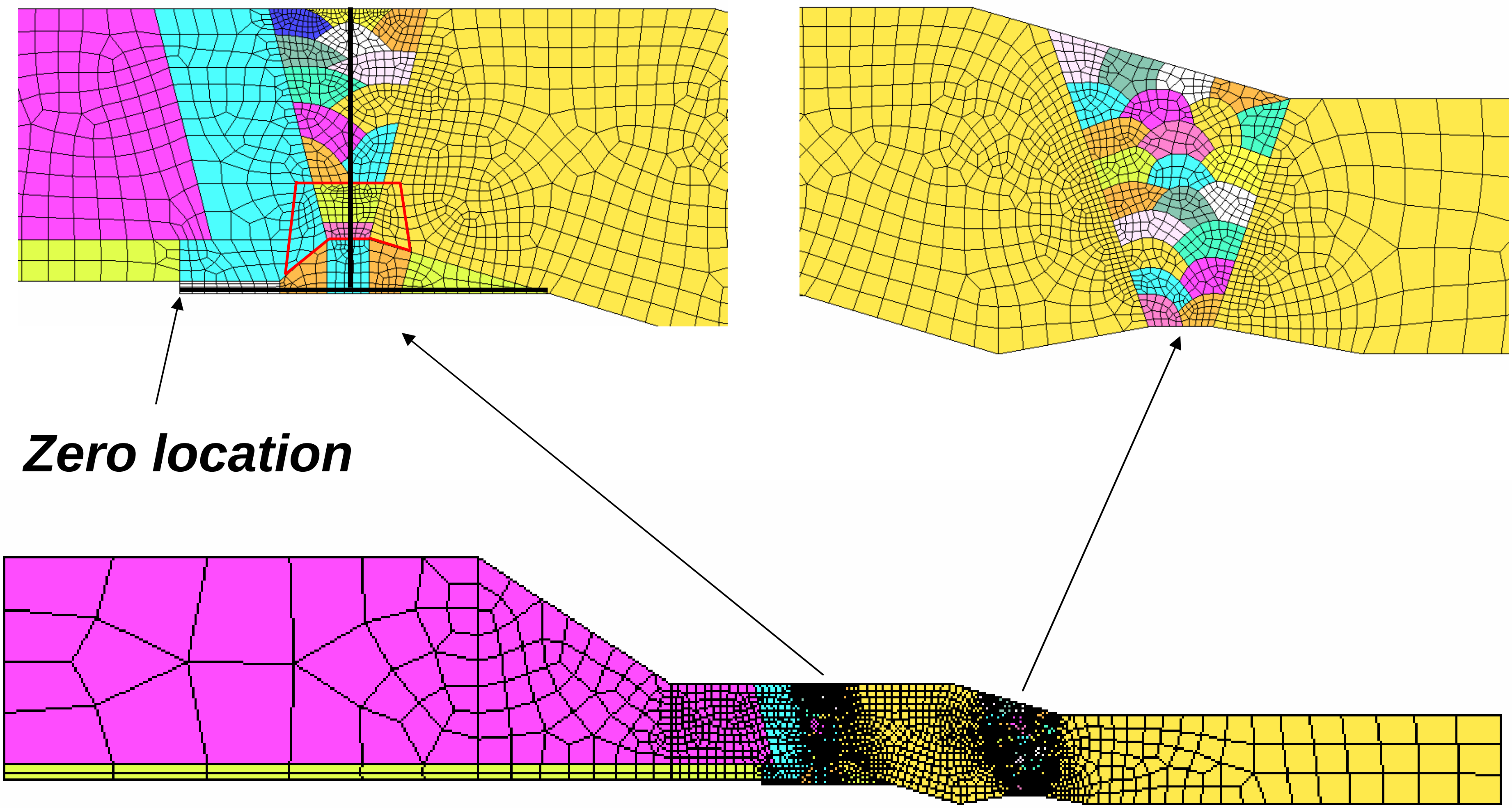
K Verification



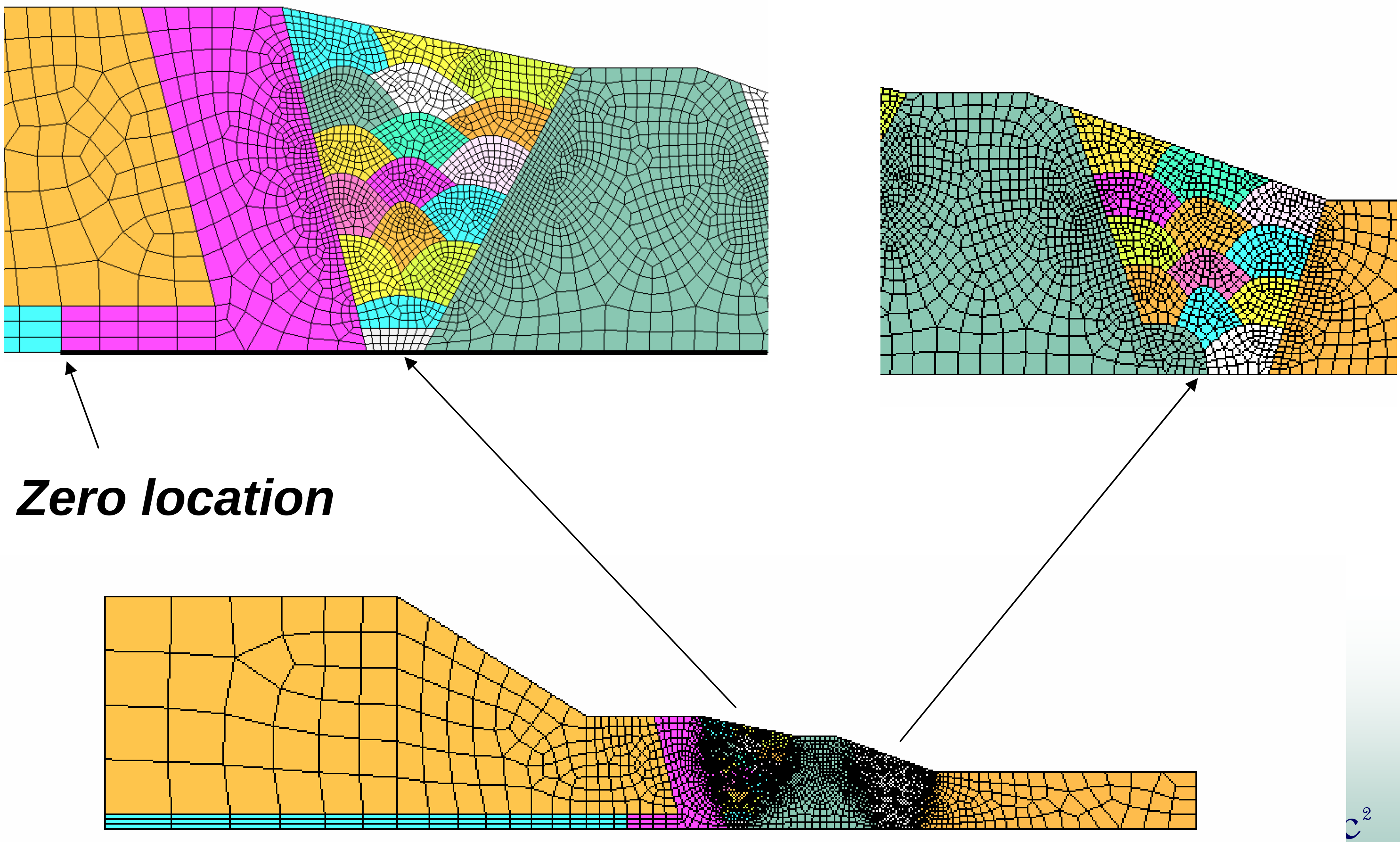
Excellent Agreement

Innovative Structural Integrity Solutions

Surge Nozzle Welding Residual Stress Model



Relief Nozzle Welding Residual Stress Model

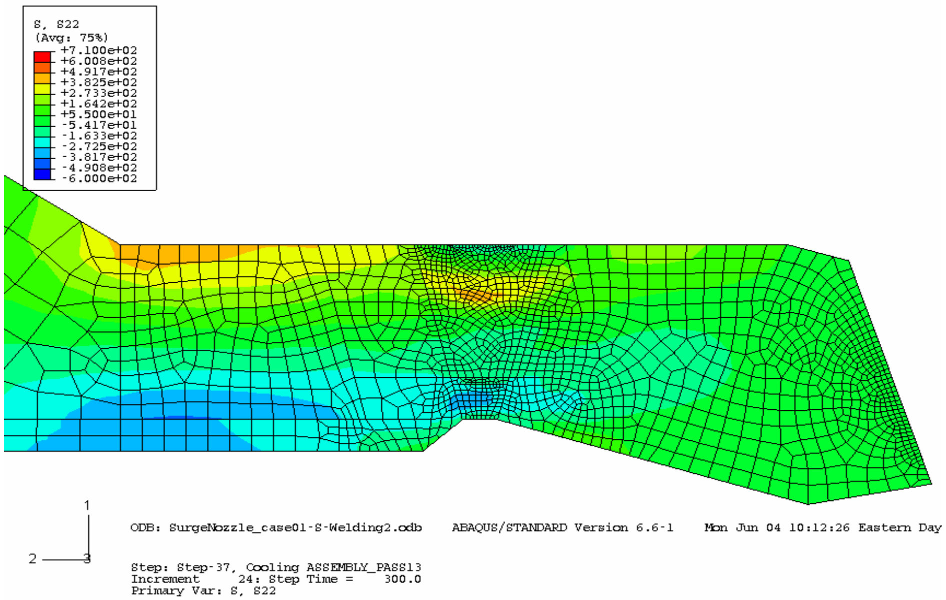


Zero location

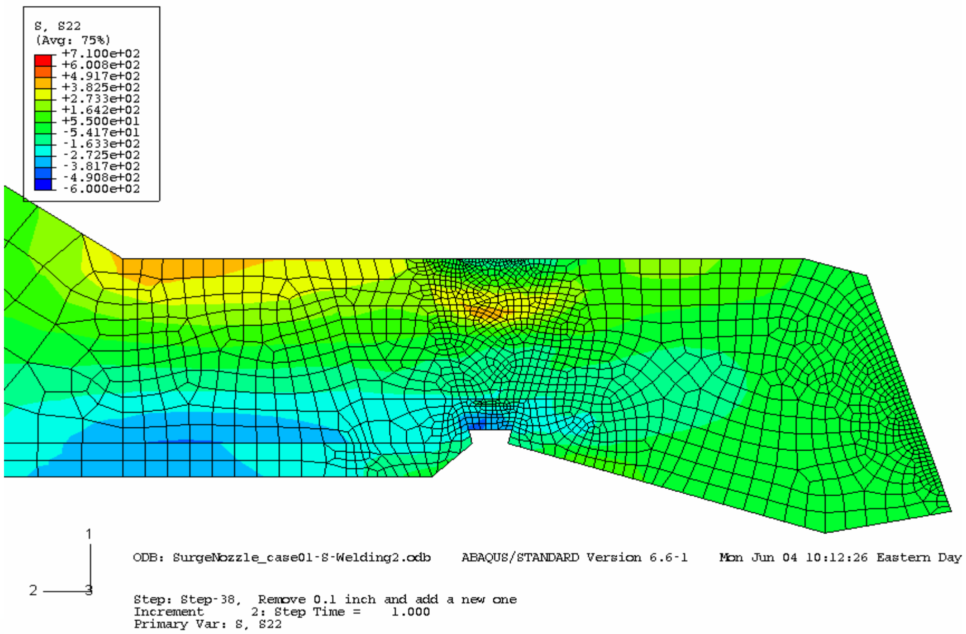
WRS Cases Run

- ***Surge Nozzle – Operating Temperature Only***
  - ***With safe-end weld***
    - ***With no repair (0.1” last pass) - left to right sequence***
    - ***With no repair (0.1” last pass) - right to left sequence***
    - ***With repair (5/16”) – left to right sequence***
    - ***With repair (5/16”) – right to left sequence***
  - ***Without safe-end weld***
    - ***With no repair (0.1” last pass) - left to right sequence***
    - ***With no repair (0.1” last pass) - right to left sequence***
    - ***With repair (5/16”) – left to right sequence***
    - ***With repair (5/16”) – right to left sequence***
- ***Relief Nozzle - Operating Temperature Only***
  - ***With safe-end weld***
  - ***Without safe-end weld***

Initial ID Last Pass Weld

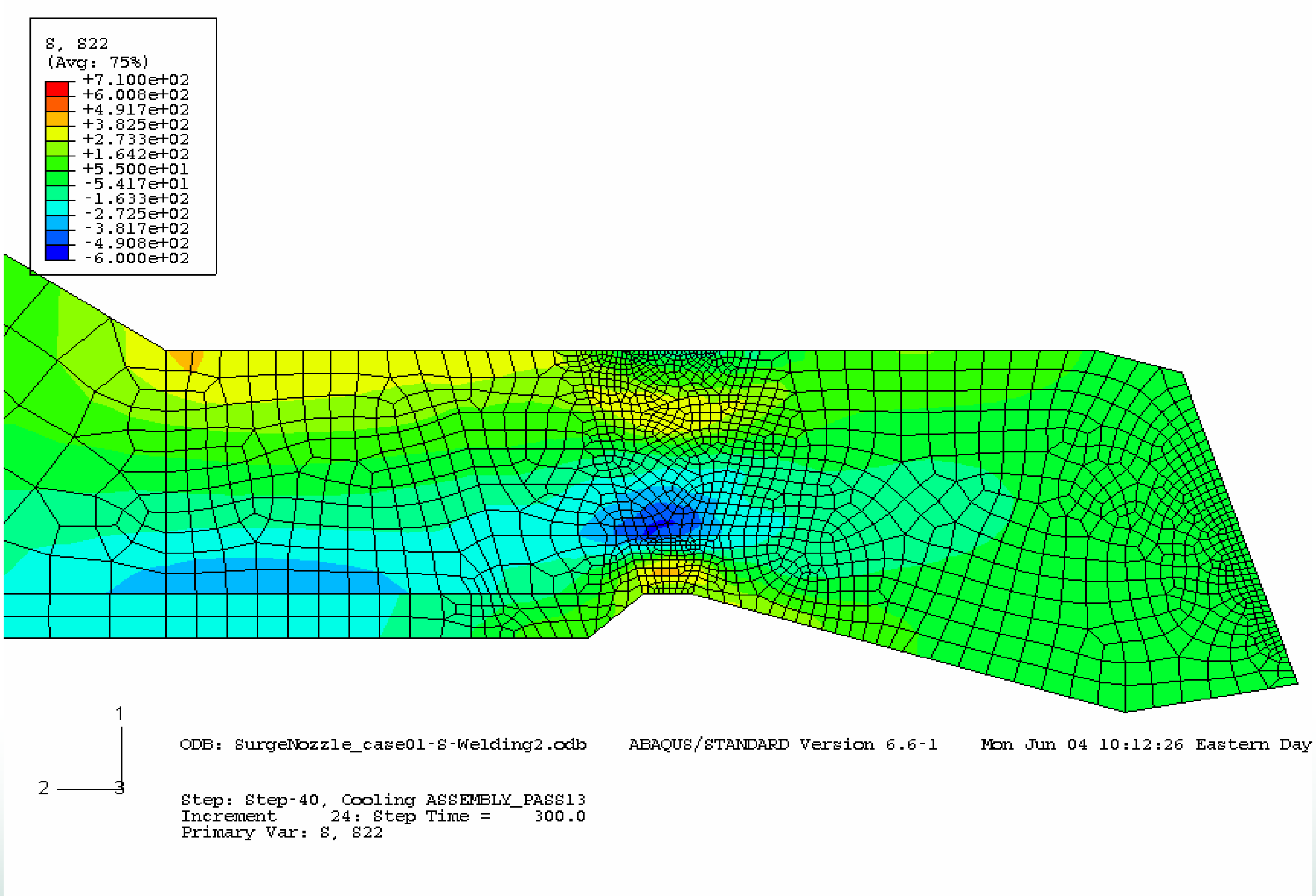


After Original Weld



After 0.1" grind

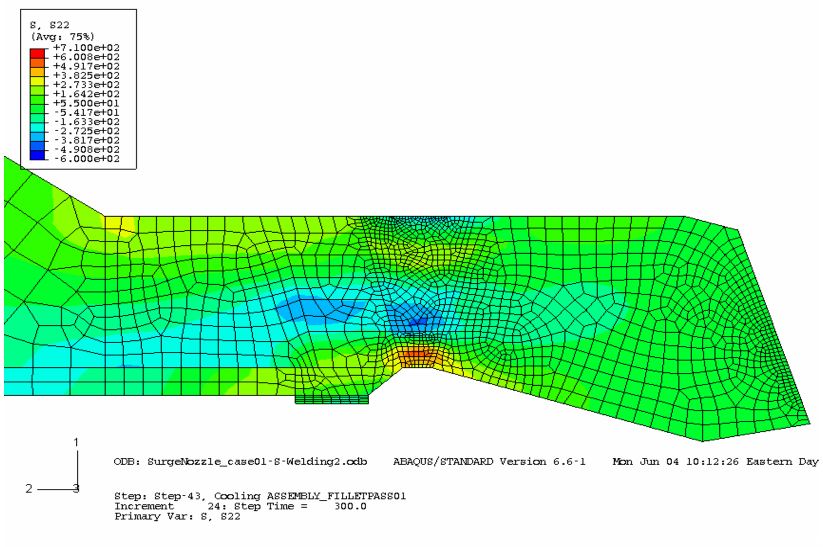
Initial ID Last Pass Weld

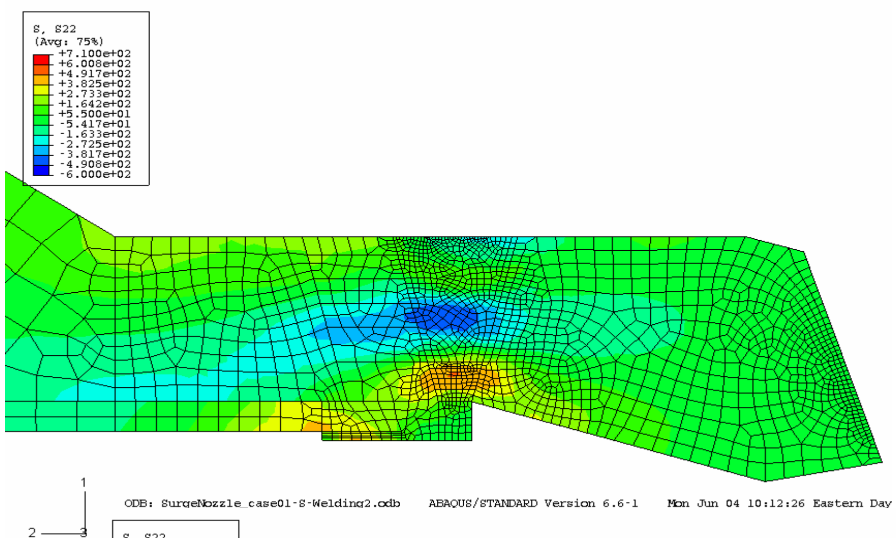


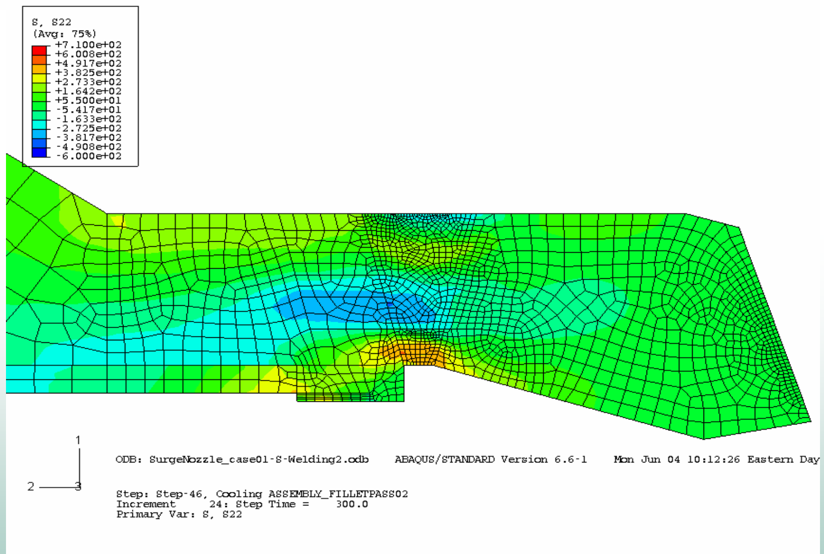
After last pass weld

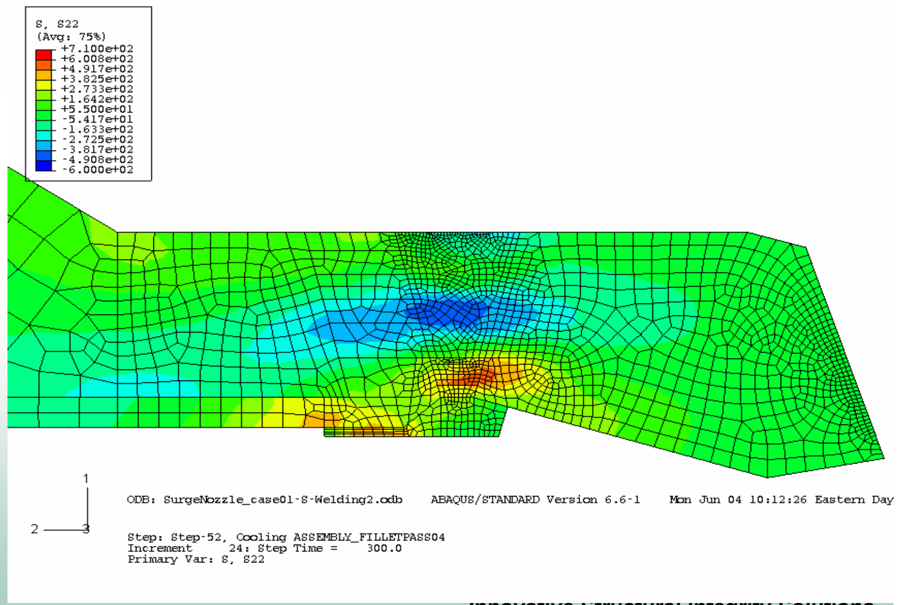
Innovative Structural Integrity Solutions

Fill-in Weld Sequence – Left-to-right

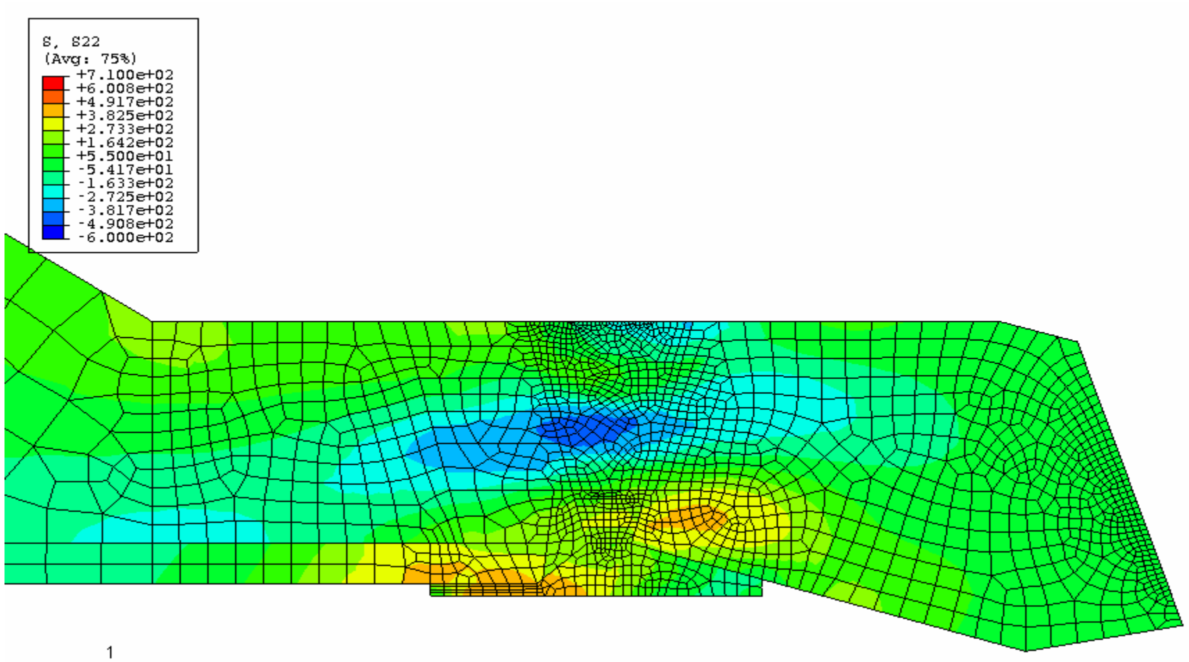


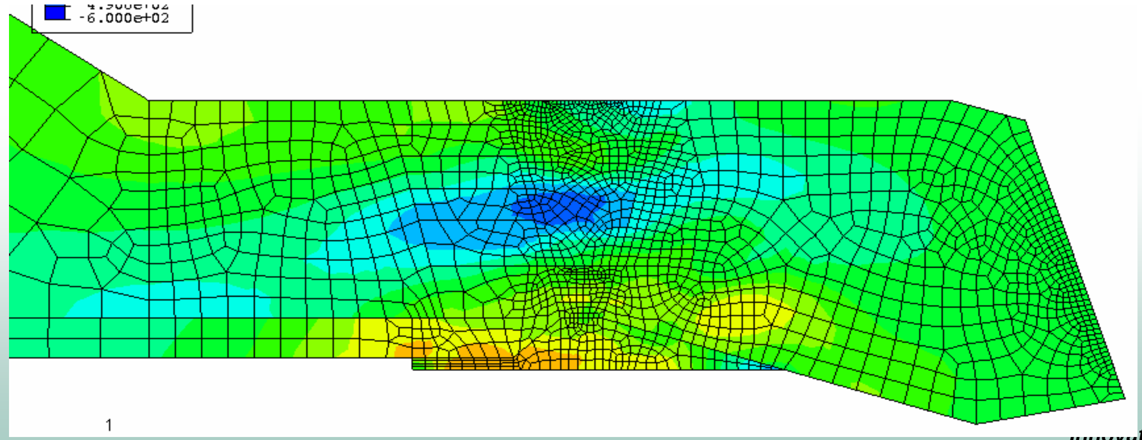






Fill-in Weld Sequence – Left-to-right





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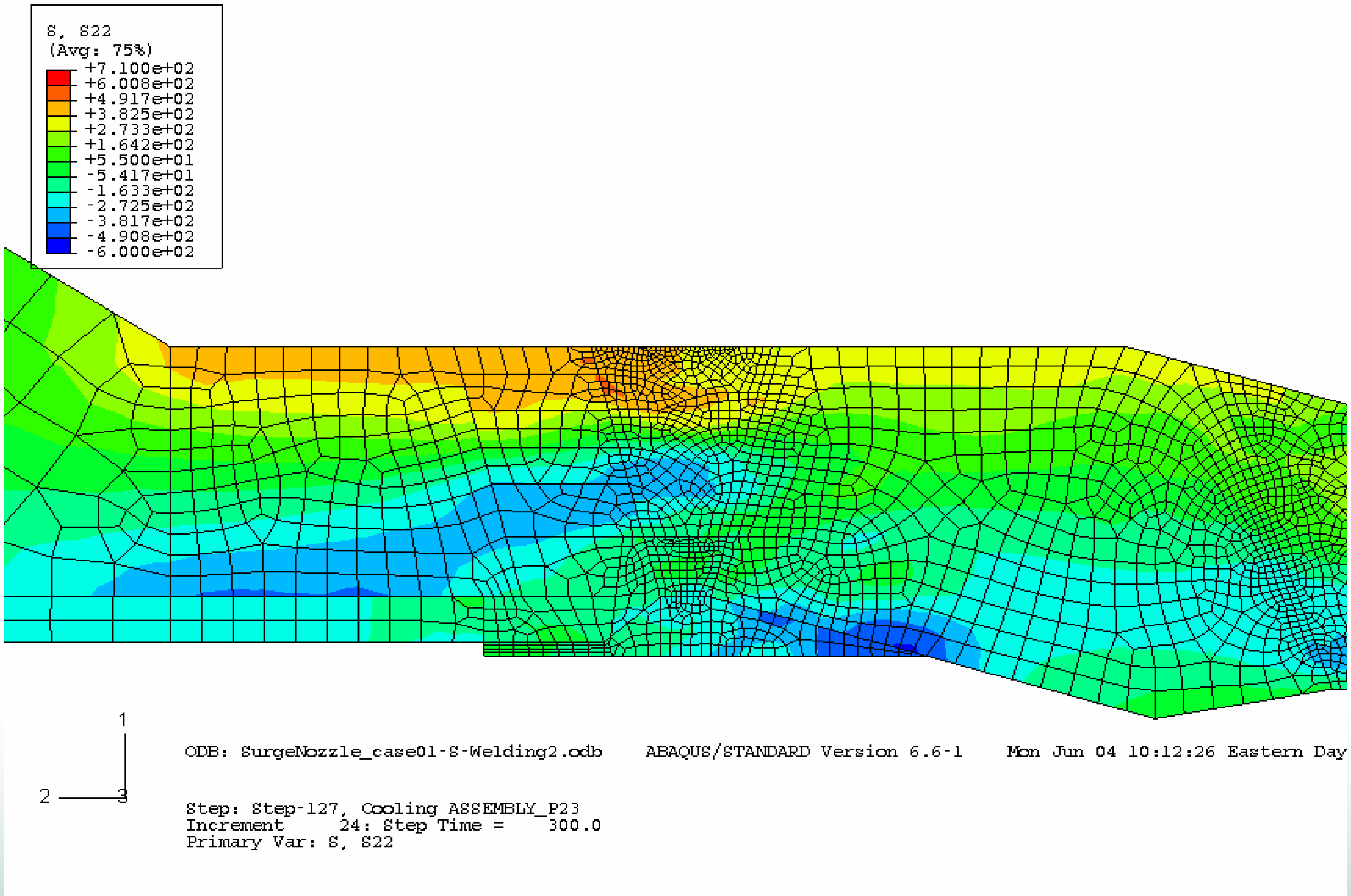
Safe End Weld



After Stainless Weld

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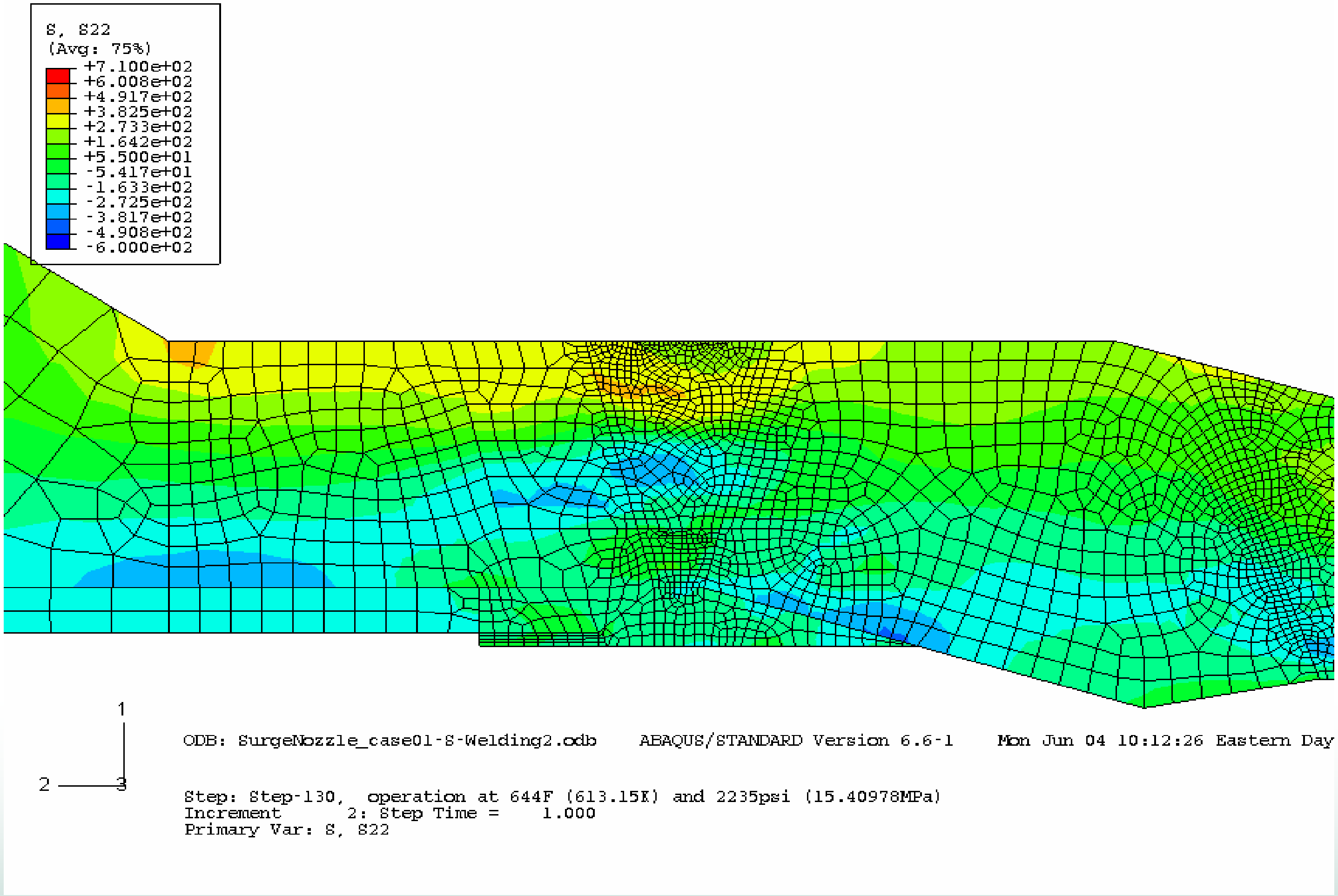
Surge Nozzle DMW at Operating Conditions

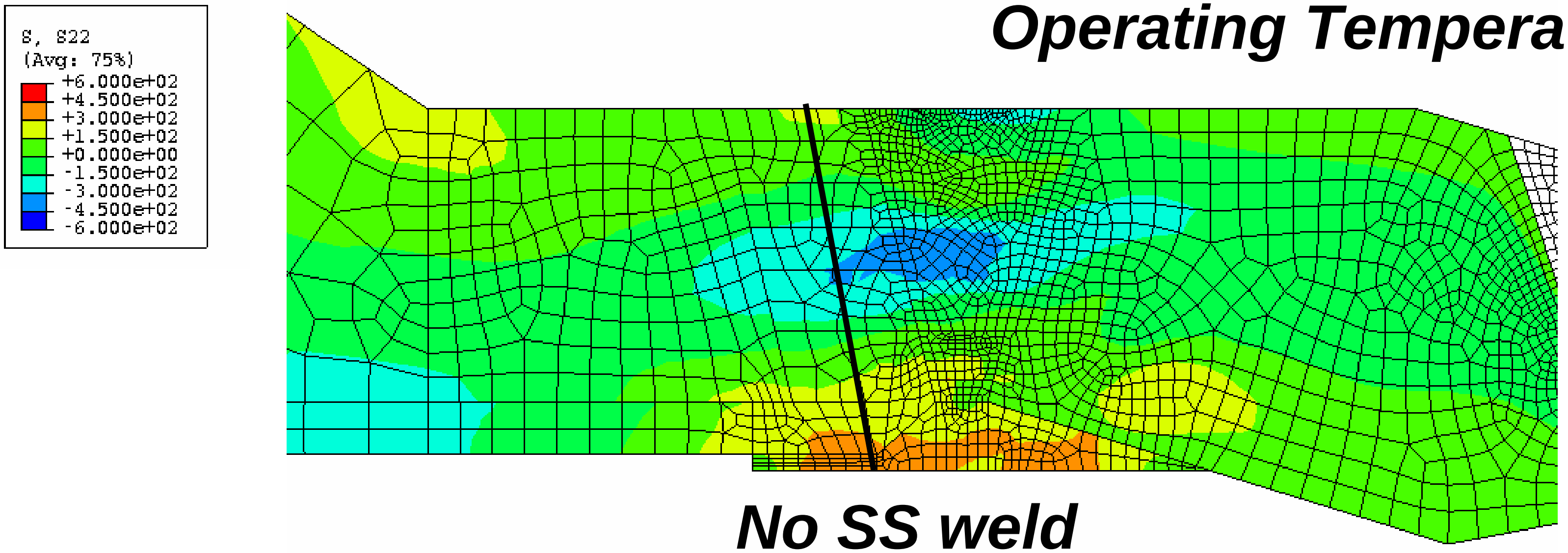


At Operating Conditions
Pressure and Temperature

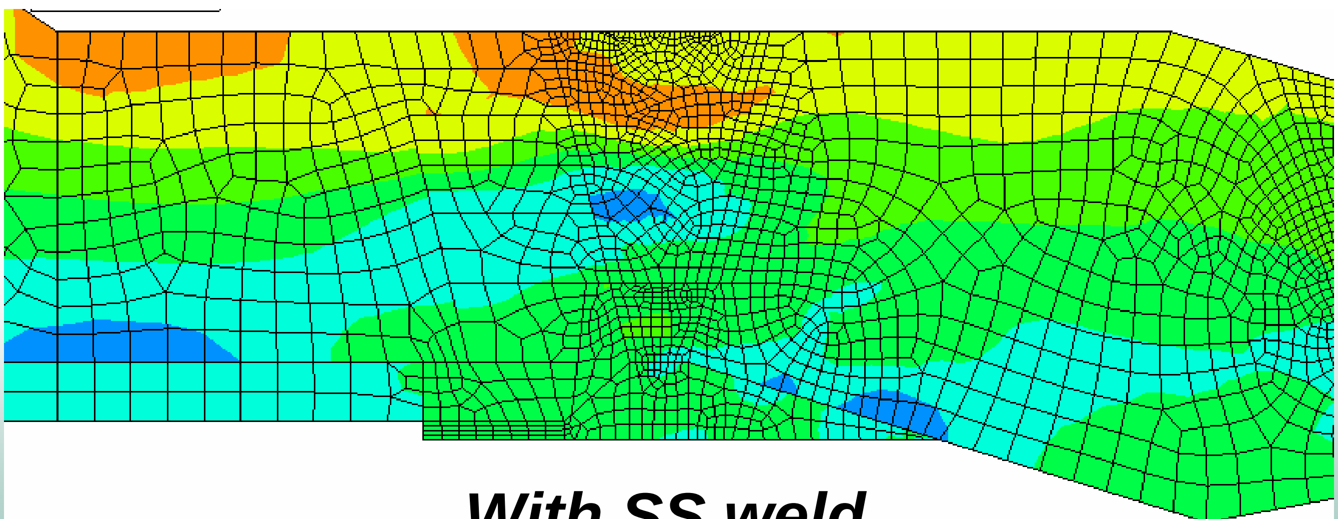
Innovative Structural Integrity Solutions

Surge Nozzle – No Repair – Left-to-right Sequence

Operating Temperature Only



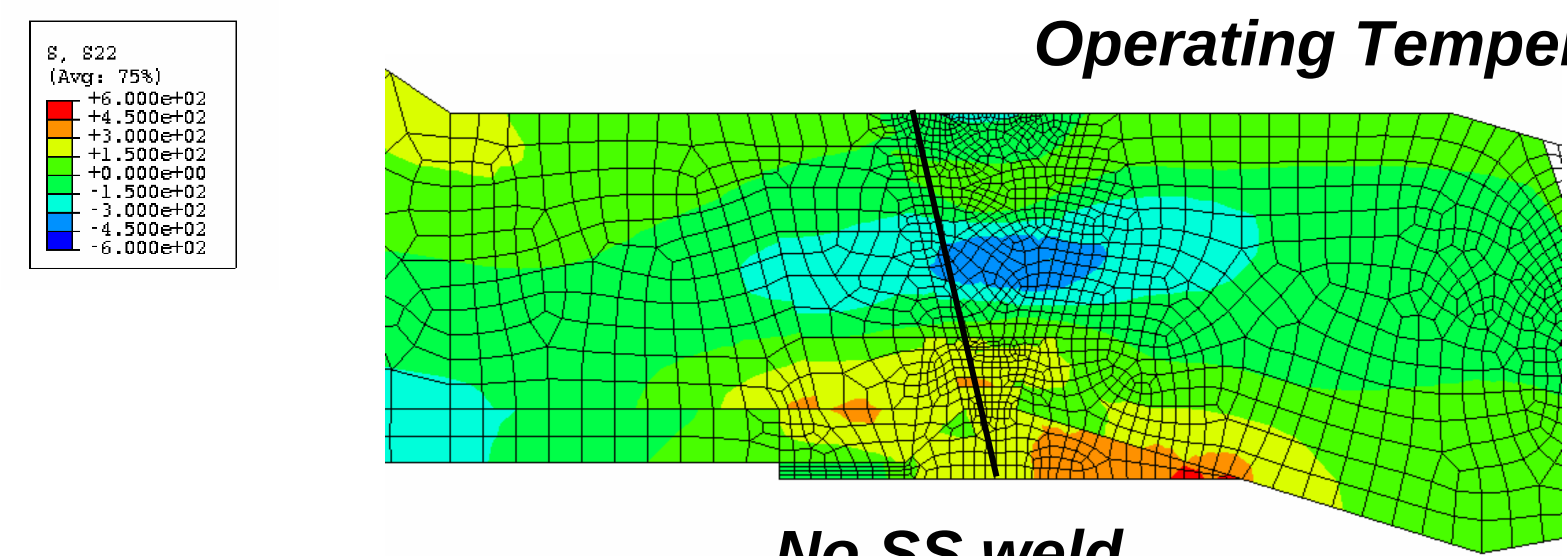
No SS weld



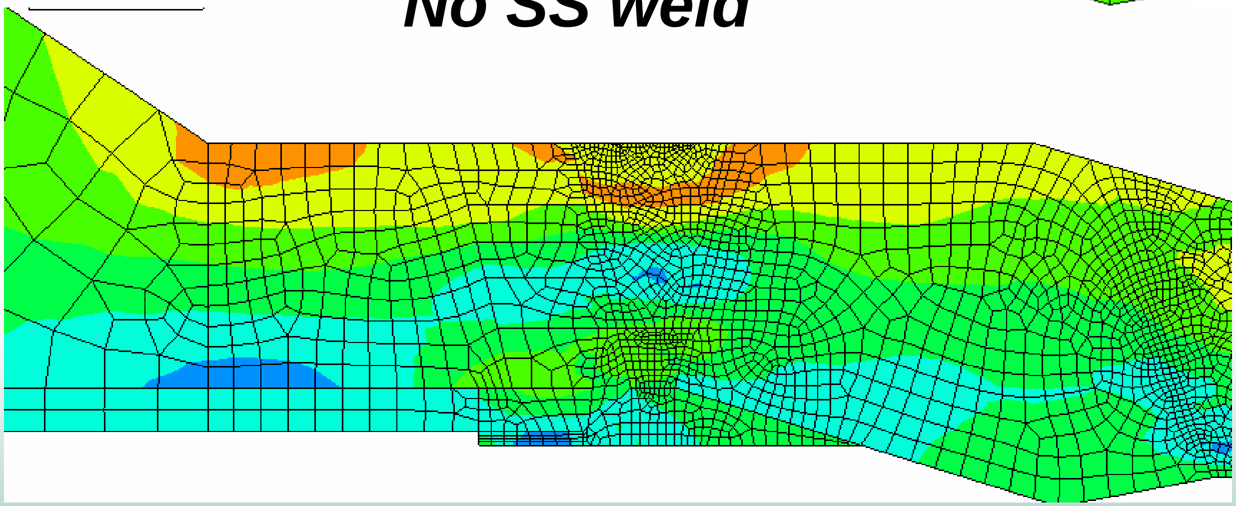
With SS weld

Surge Nozzle – No Repair – Right-to-left Sequence

Operating Temperature Only



No SS weld

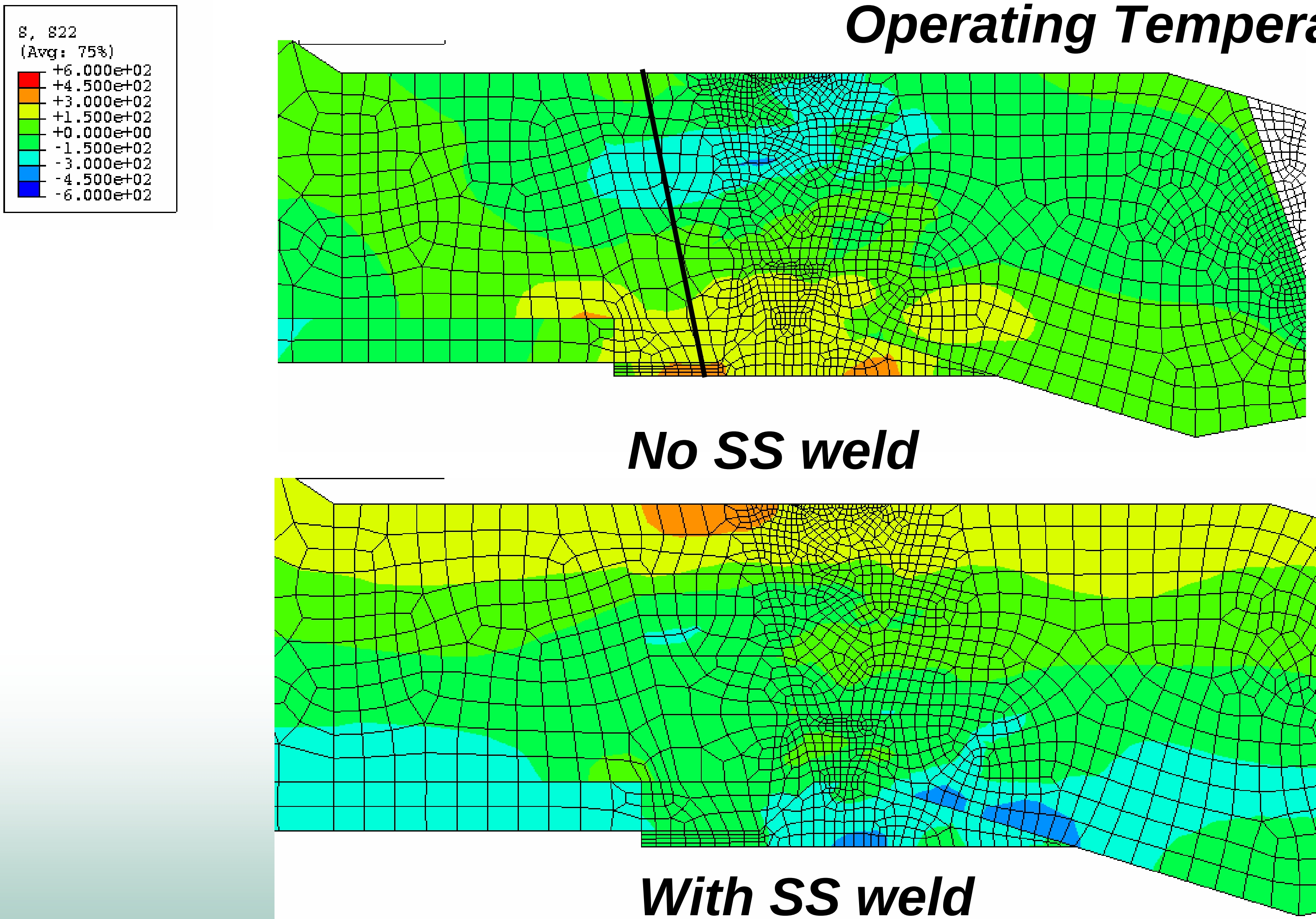


With SS weld

Innovative Structural Integrity Solutions

Surge Nozzle – with Repair – Left-to-right Sequence

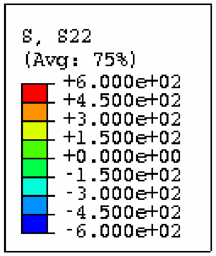
Operating Temperature Only



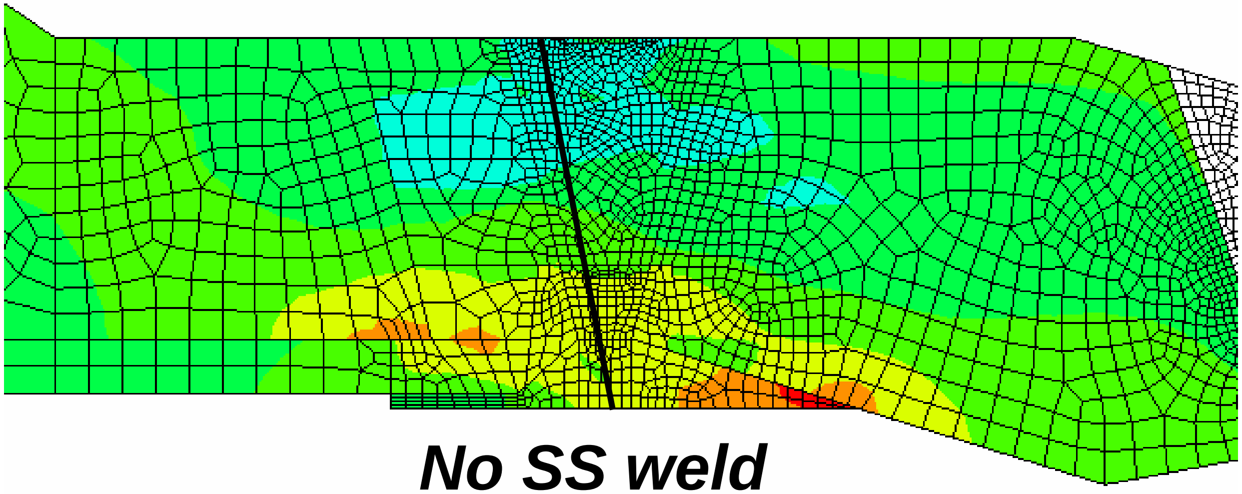
No SS weld

With SS weld

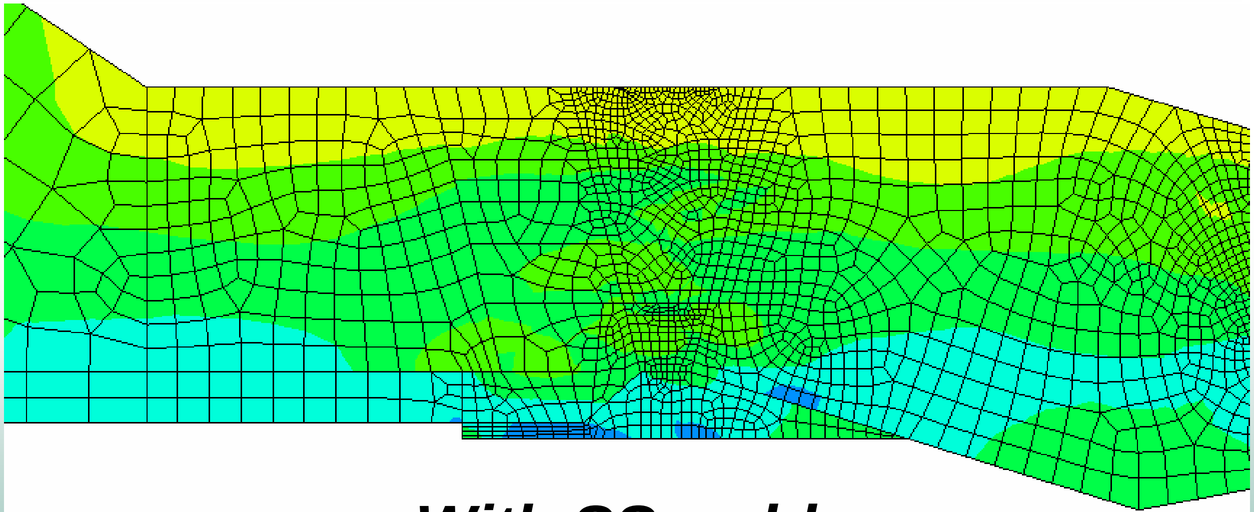
Surge Nozzle – with Repair – Right-to-left Sequence



Operating Temperature Only



No SS weld



With SS weld

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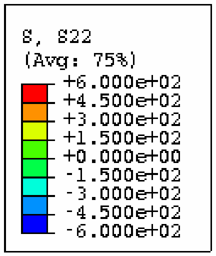
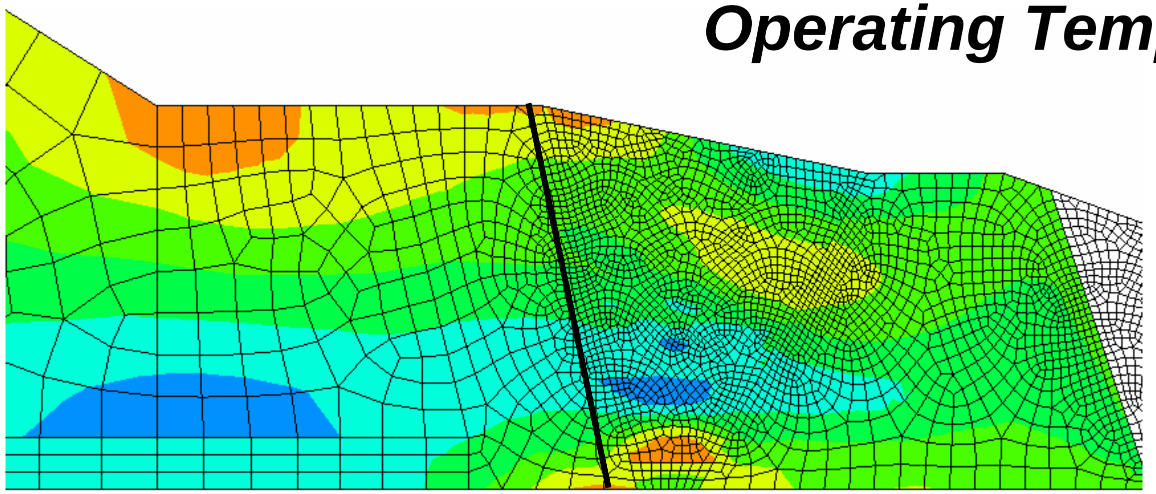
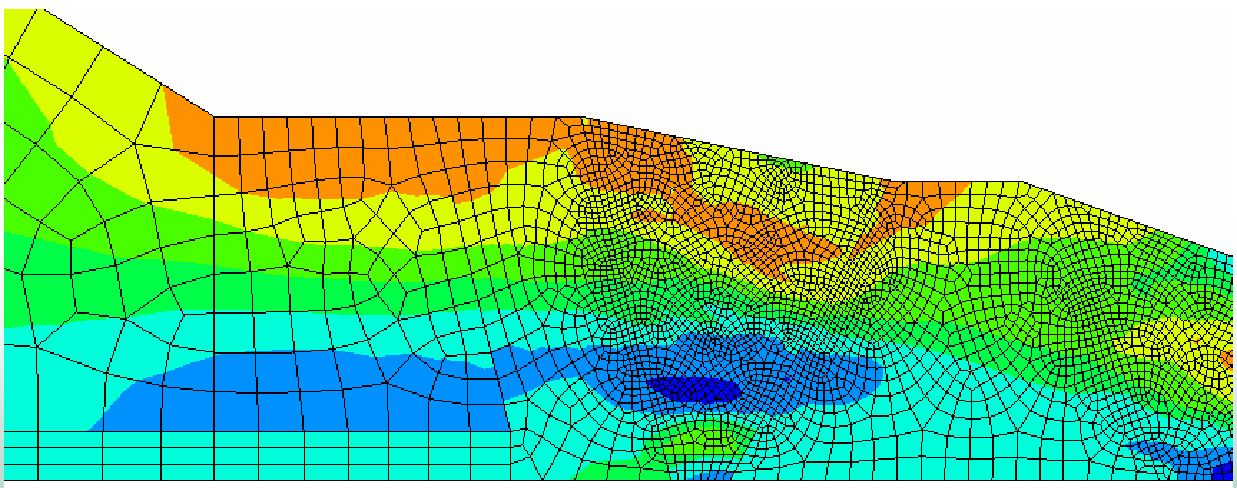
Relief Nozzle Welding Stresses



Operating Temperature Only

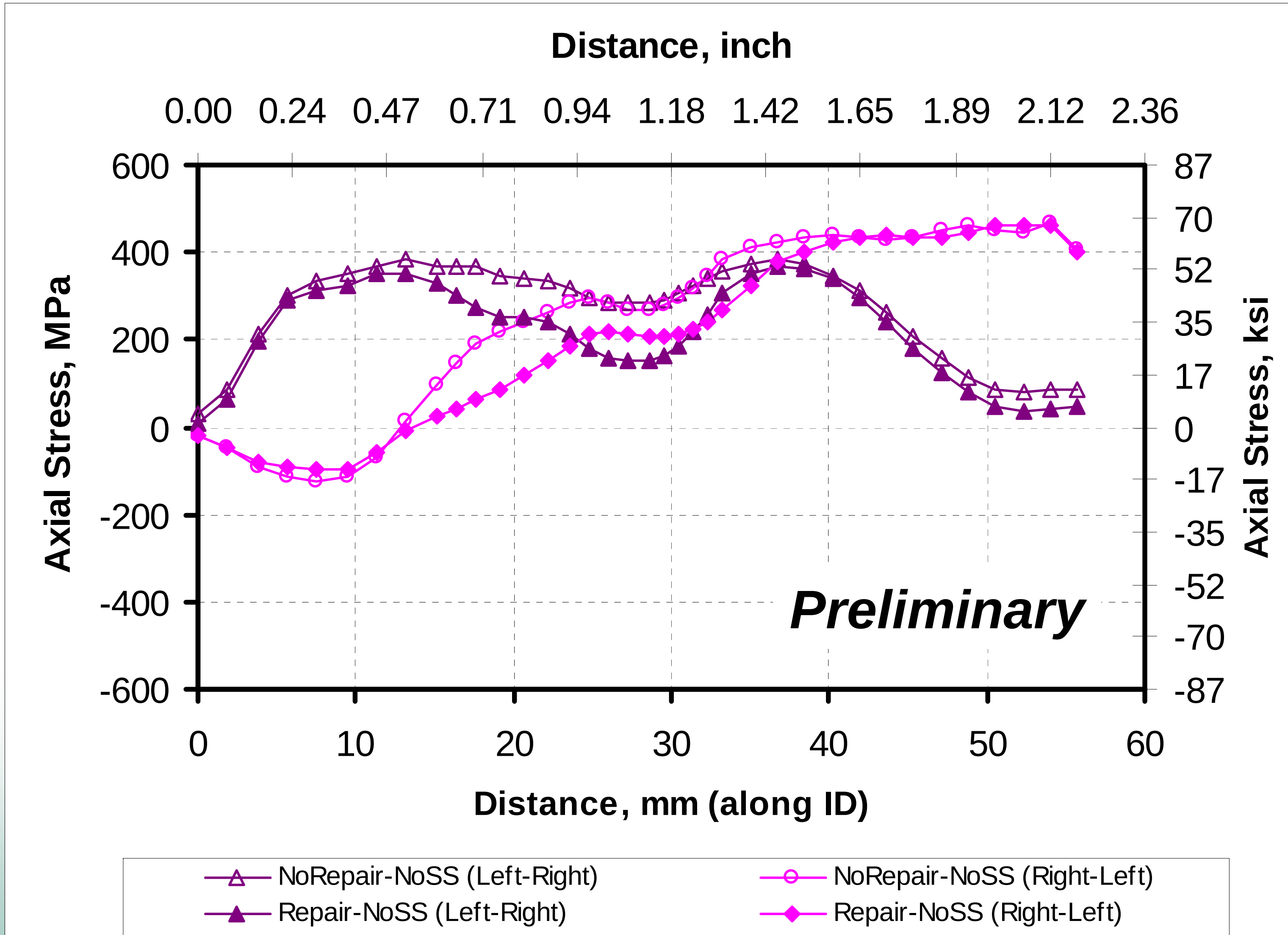


No SS weld

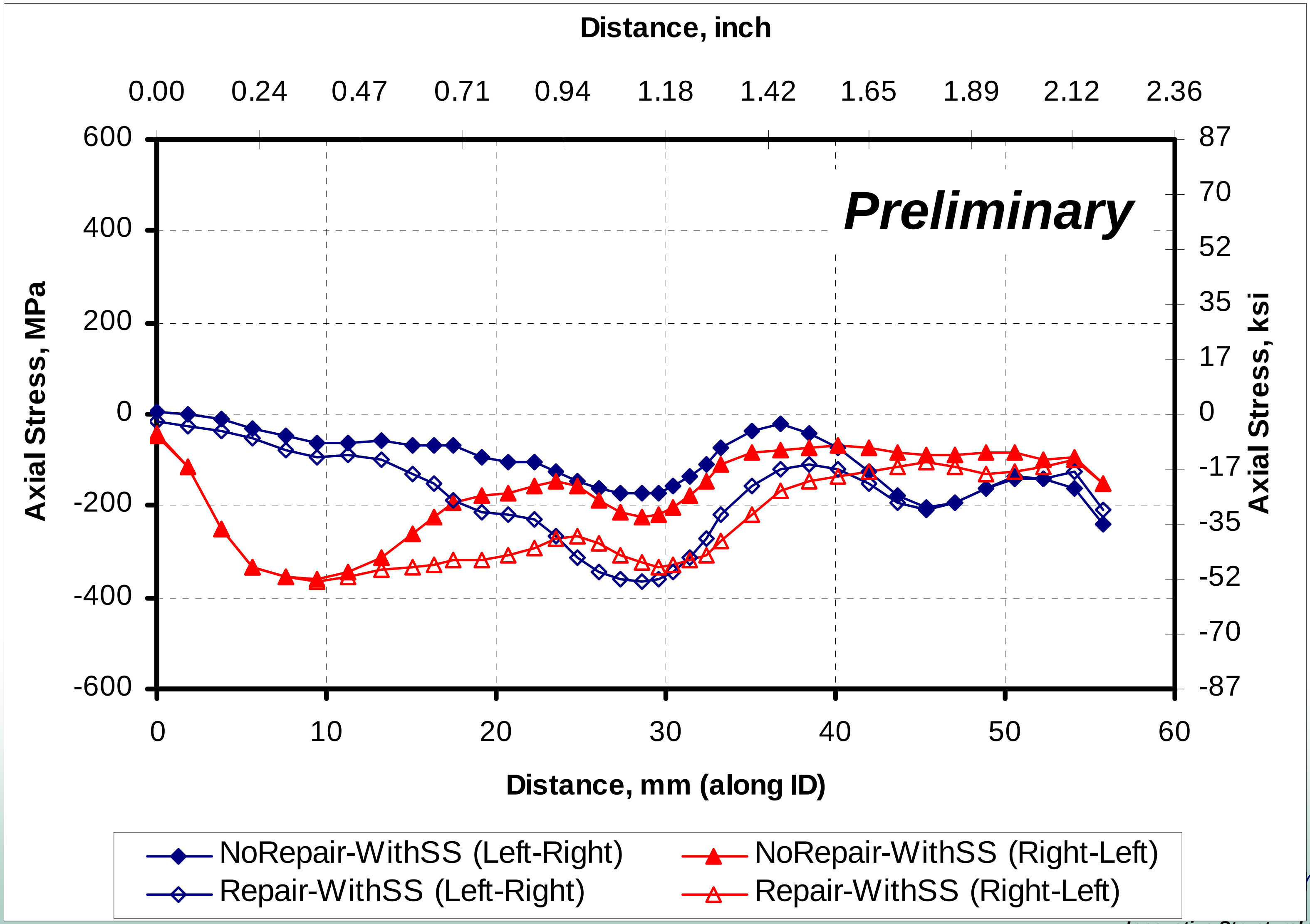


With SS weld

Axial Stress on ID – Surge Nozzle – No SS Weld



Axial Stress on ID – Surge Nozzle – With SS Weld



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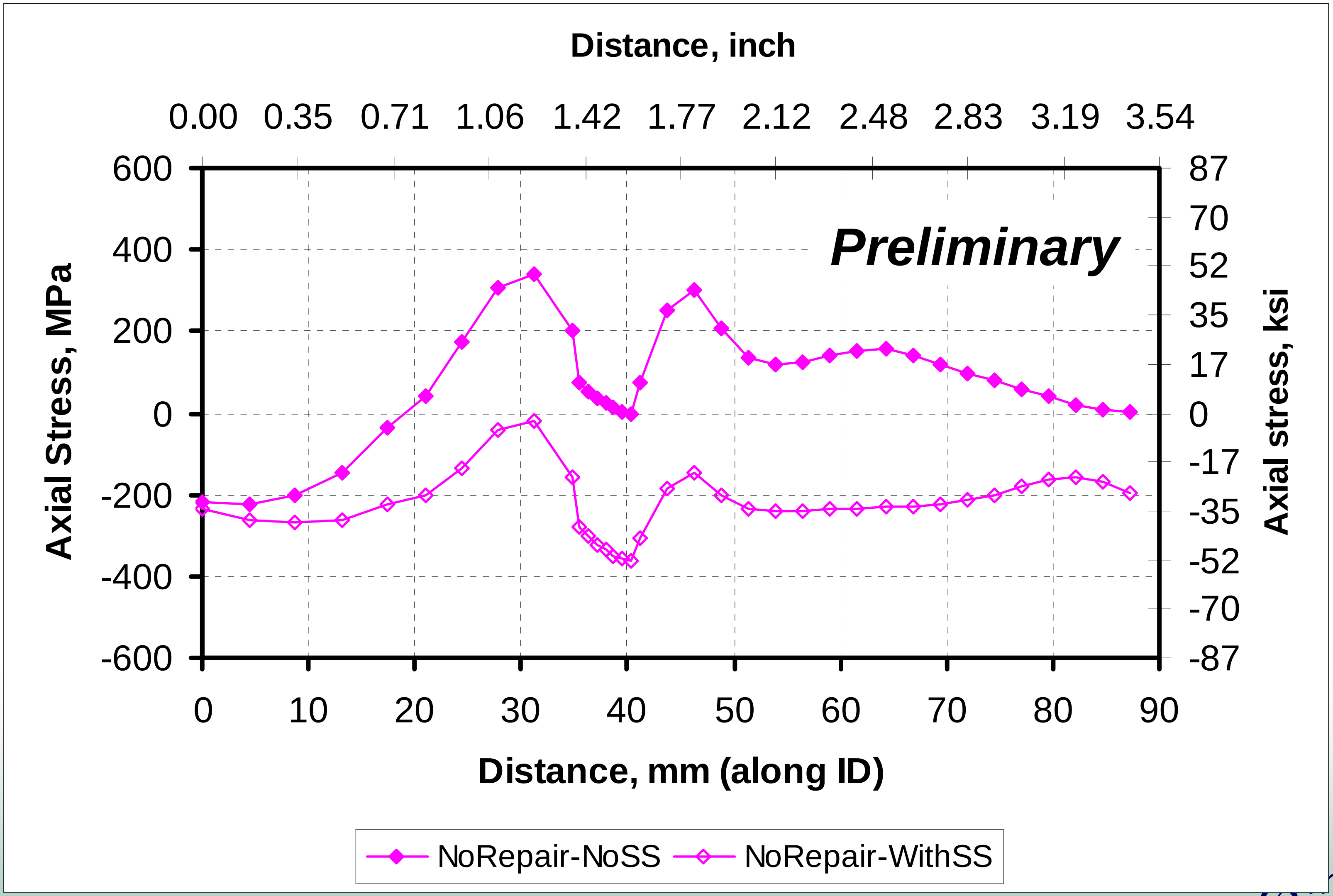
Axial Stress on ID – Relief Nozzle



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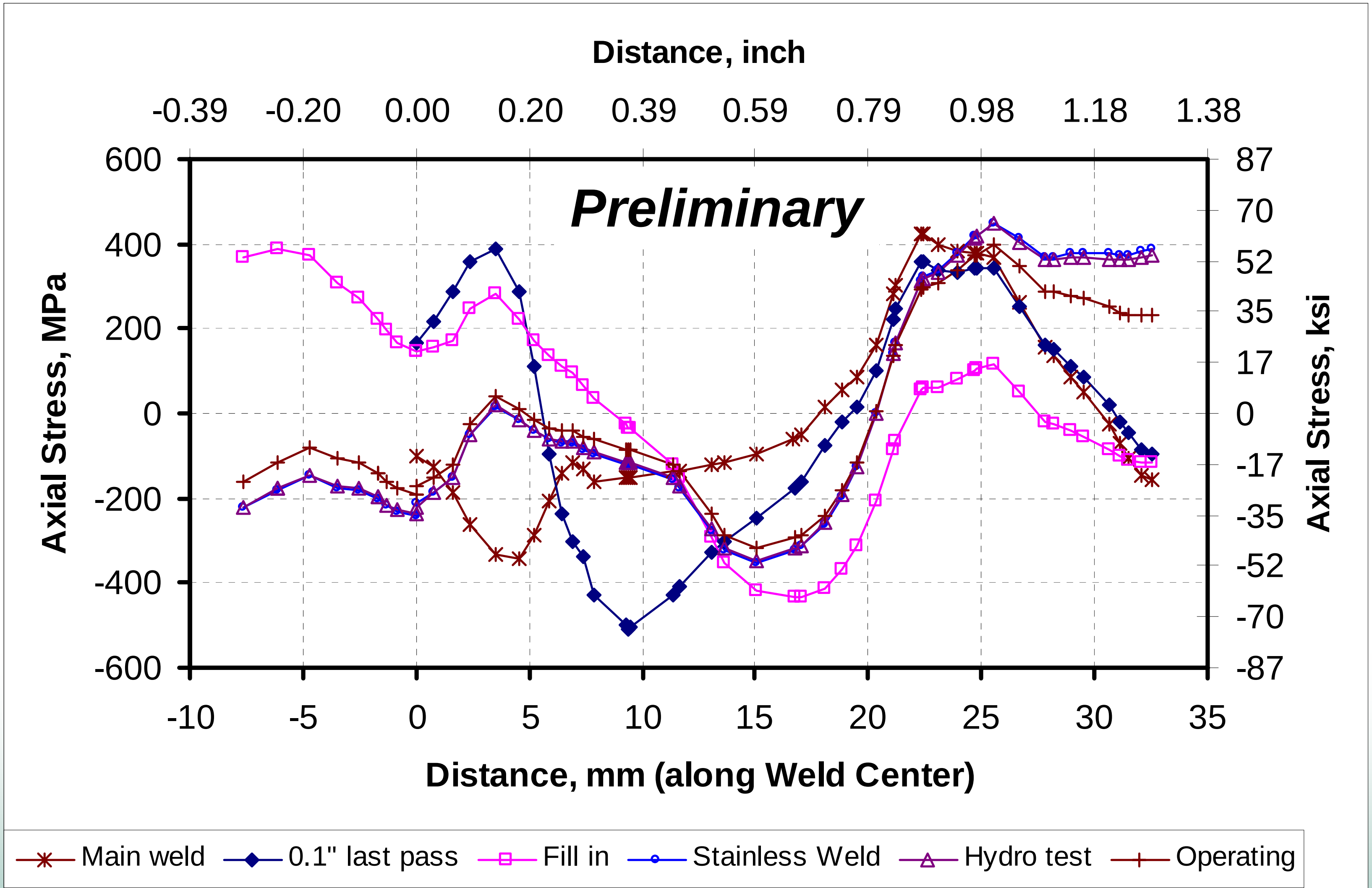
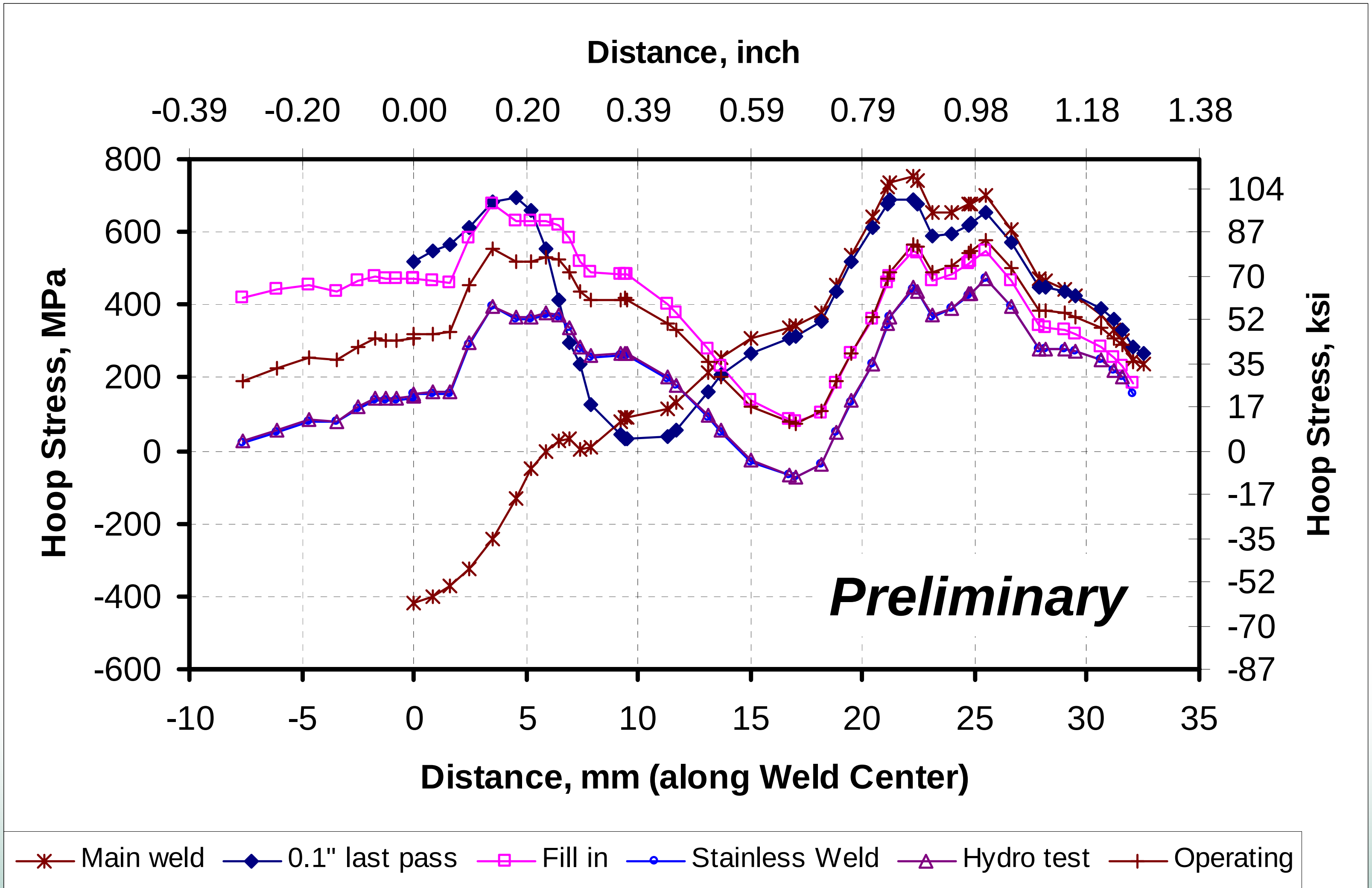
Axial Stress Along Weld Centerline – Surge Nozzle



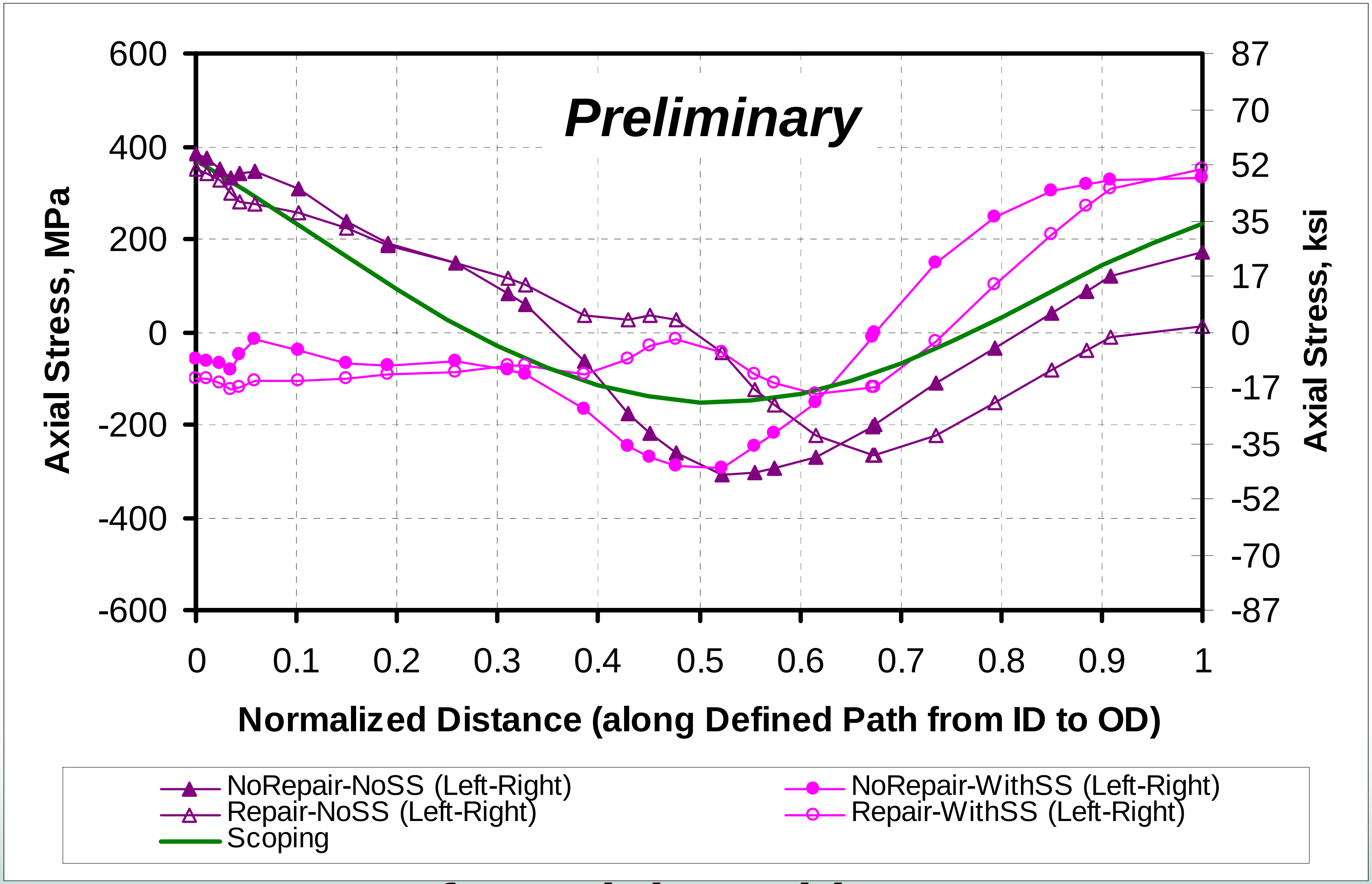
Left-to-right sequence – Operating is pressure + temperature

Hoop Stress Along Weld Center – Surge Nozzle



Left-to-right sequence – Operating is pressure + temperature

Axial Stress Along Maximum Stress Path – Surge Nozzle



Left-to-Right Weld Sequence

Operating Temperature

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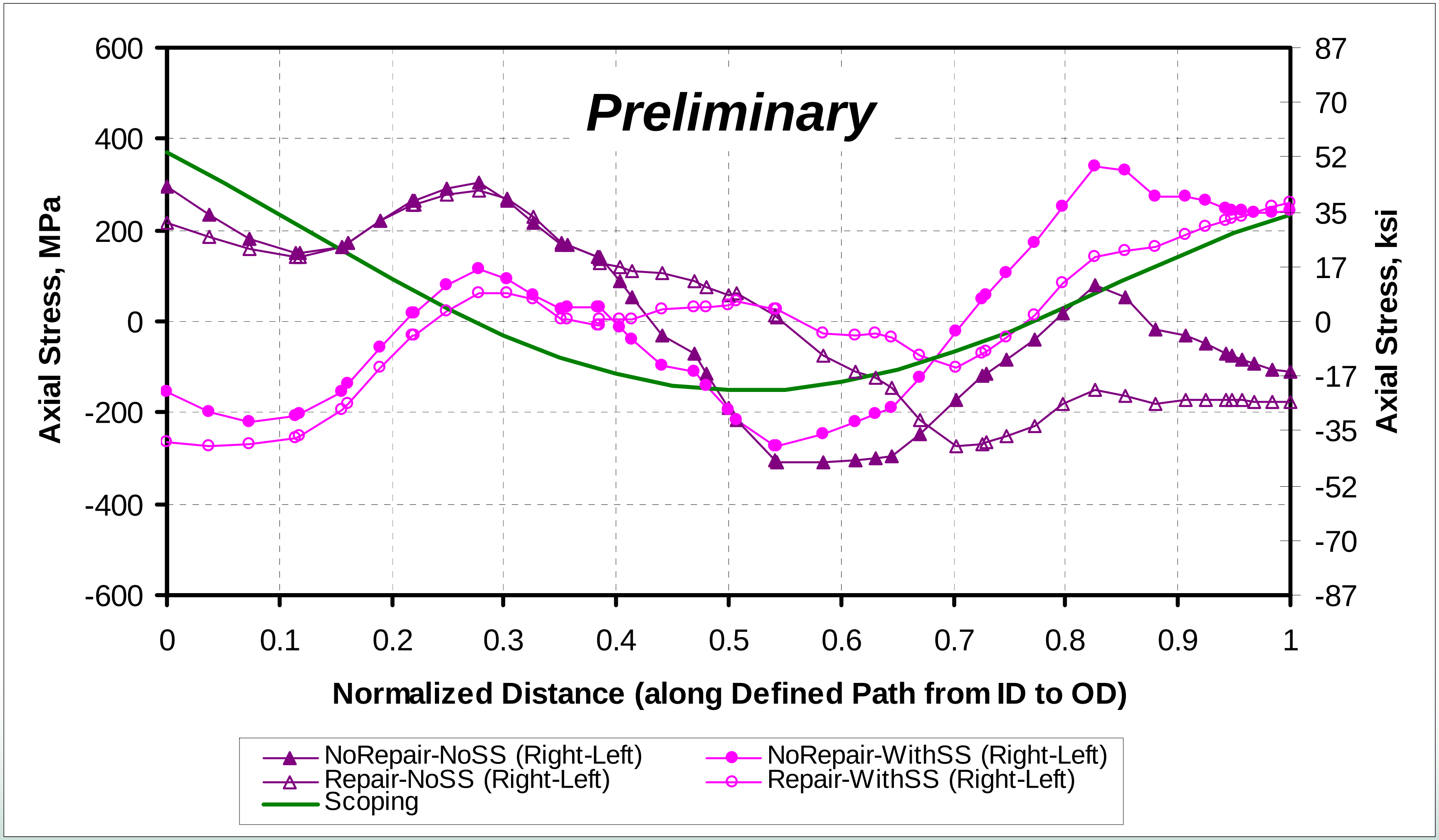
Axial Stress Along Maximum Stress Path – Surge Nozzle



Right-to-Left Sequence

Operating Temperature

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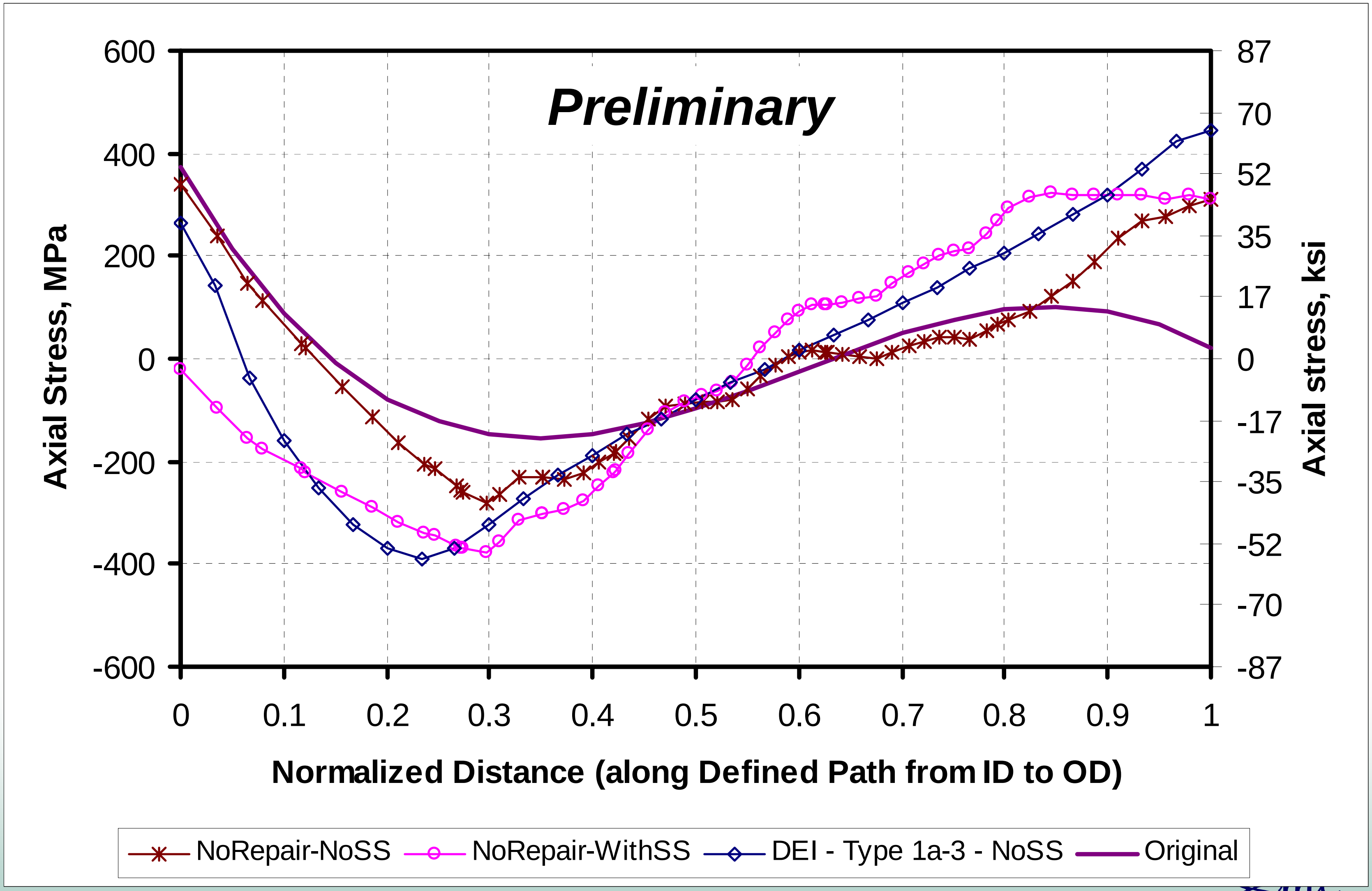
Axial Stress Along Maximum Stress Path – Relief Nozzle



Operating Temperature

Confirmatory Sensitivity Analyses

- ***Purpose of these analyses are to confirm DEI analyses by conducting a selection of cases from the matrix.***

- ***Analyses matrix sent to Emc² on June 13, and relief WRS sent on June 14.***

- ***Initial analyses focuses on original Wolf Creek case (100% + 65% Moment) and Cases 1,3,9,11.***

- ***Analyses conducted with PipeFracCAE + ABAQUS***

Leak and Critical Crack Size Calculations

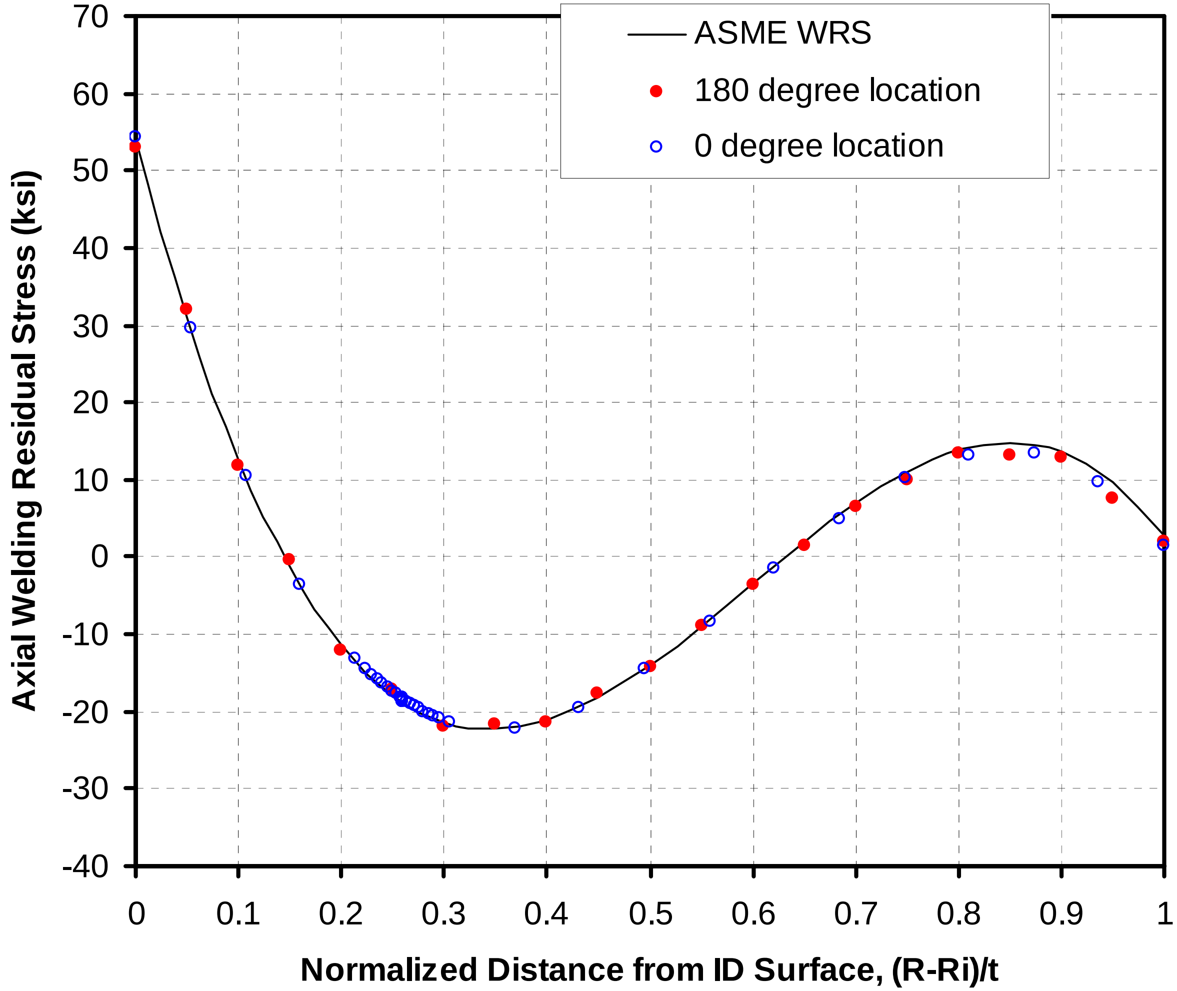
- *For welding residual stress used Emc² fit to WRS from scoping analyses – DEI Relief Nozzle WRS caused arrest!!*

- *Calculated leakage using SQUIRT,*
  - *PWSCC crack morphology parameters, COD dependence*
  - *Assumed elliptical opening*
  - *COD from FEA*
  - *100% quality steam*

- *Used arbitrary NSC analyses with SS flow stress – with no crack closure - Applied appropriate Z factor.*

- *Included all displacement controlled normal operating loads.*

Comparison of WRS



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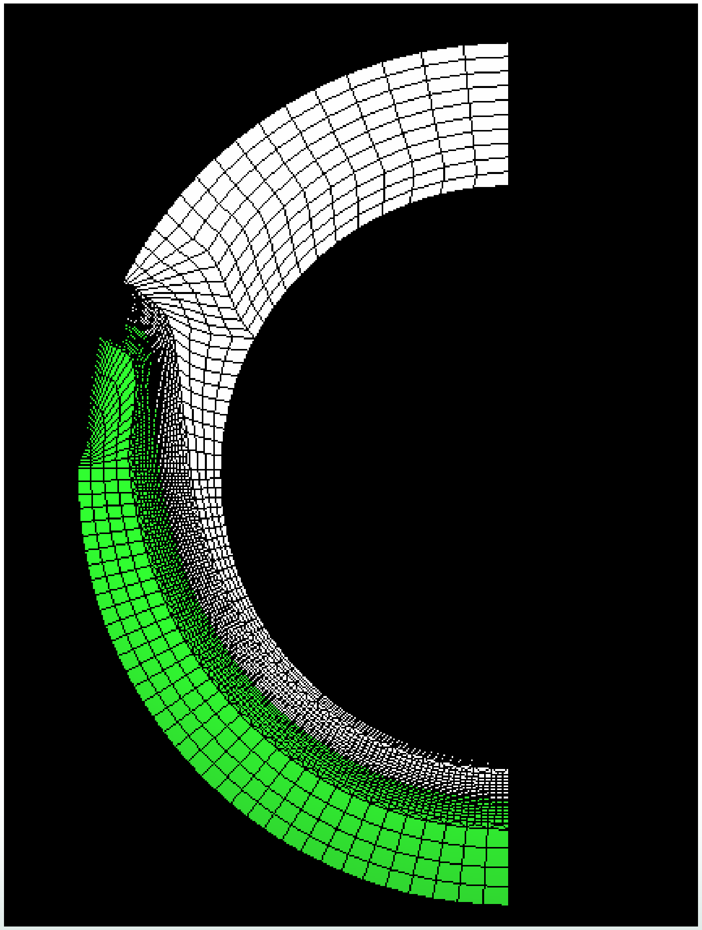
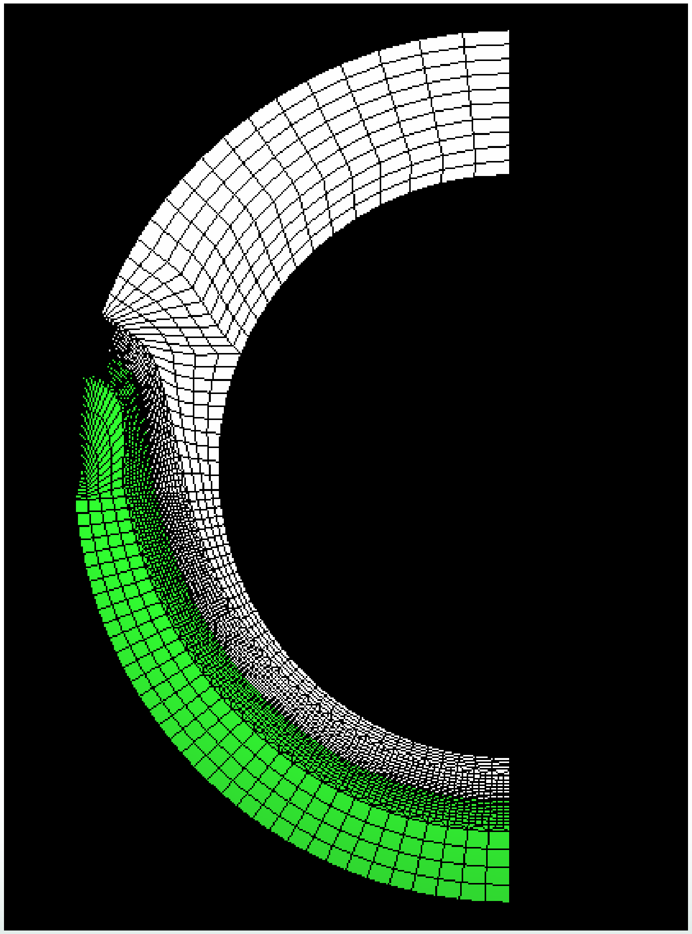
Confirmatory Analyses - Status

- ***Analyses Completed***
  - ***Wolf Creek 100% Moment (leaked in 6.6 years)***
  - ***Wolf Creek 65% Moment (very similar to Case 3 – leaked in 29.4 years)***
  - ***Case 11 (started with 10%, 360 crack – arrest)***
- ***Analyses ongoing (chose cases with low moments)***
  - ***Case 1 (leaked in 19.96 years – Complex crack still growing)***
  - ***Case 1 with DEI WRS - Arrest***
  - ***Case 9 (leaked in 125 years – Complex crack still growing)***
  - ***Case 10 (started with 10%, 360 crack – leaked in ~51years)***
- ***Analyses planned***
  - ***Case 15 (high), 17(high) and 20(low)***
  - ***Selection of 5 or so more cases from Case 27-61 when defined***
  - ***Any bounding cases that seem appropriate***

Wolf Creek Critical Crack Sizes



100% moment



65% Moment

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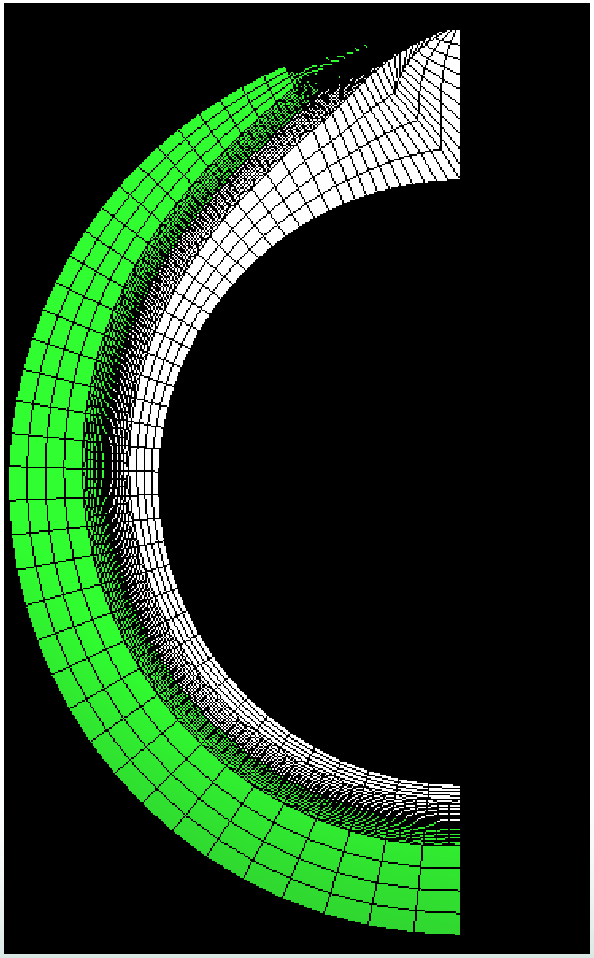
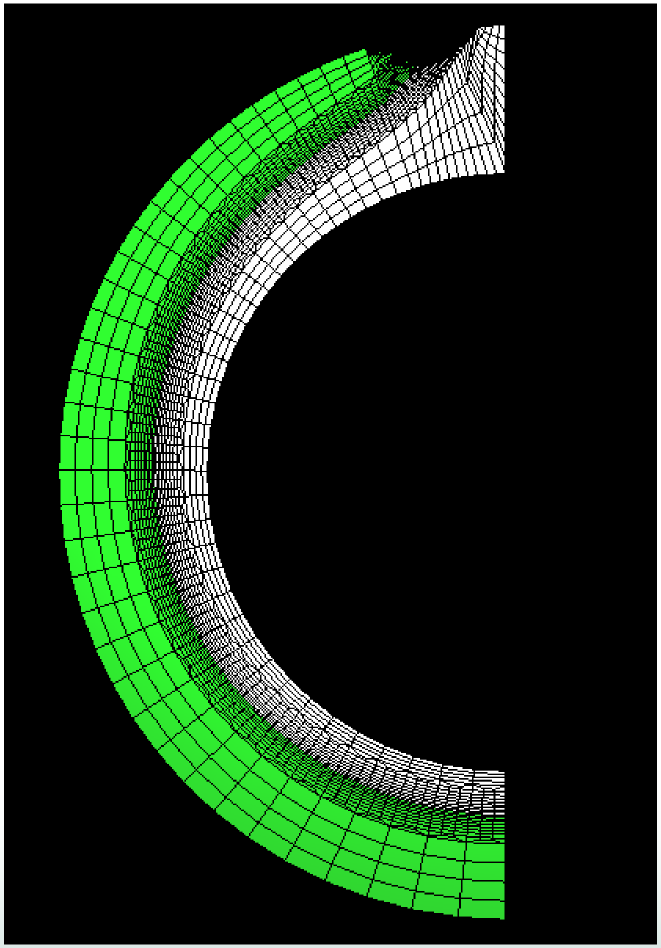
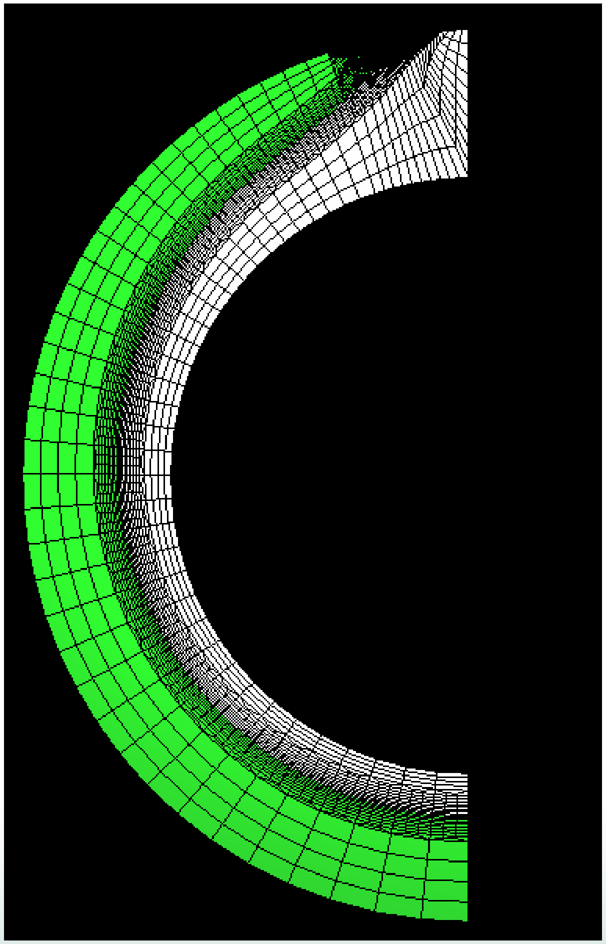
Crack Shape at Leakage



WC 100%

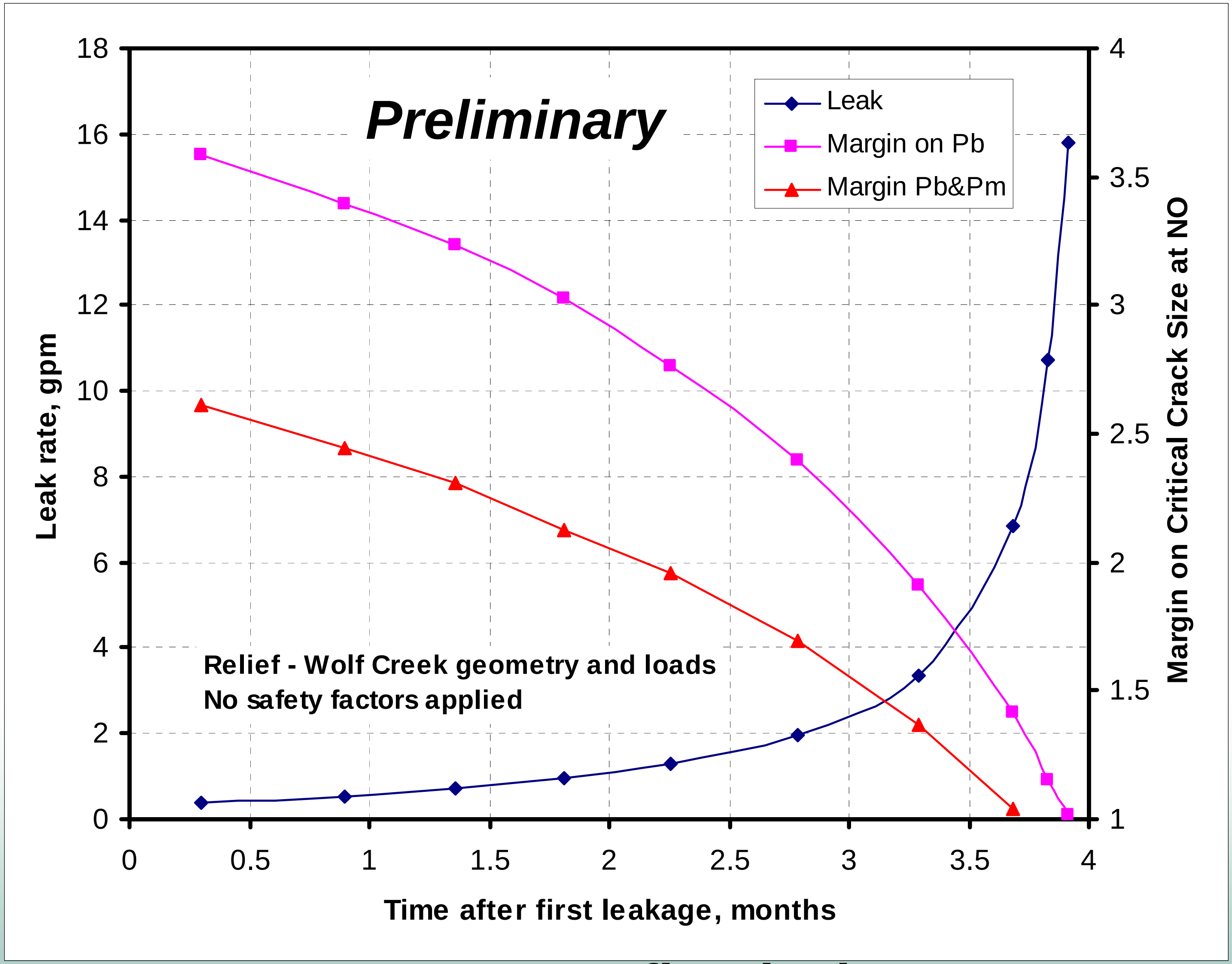


WC 65%



Case 1 – 76%

Wolf Creek Case – 100% Moment



6.6 years at first leakage

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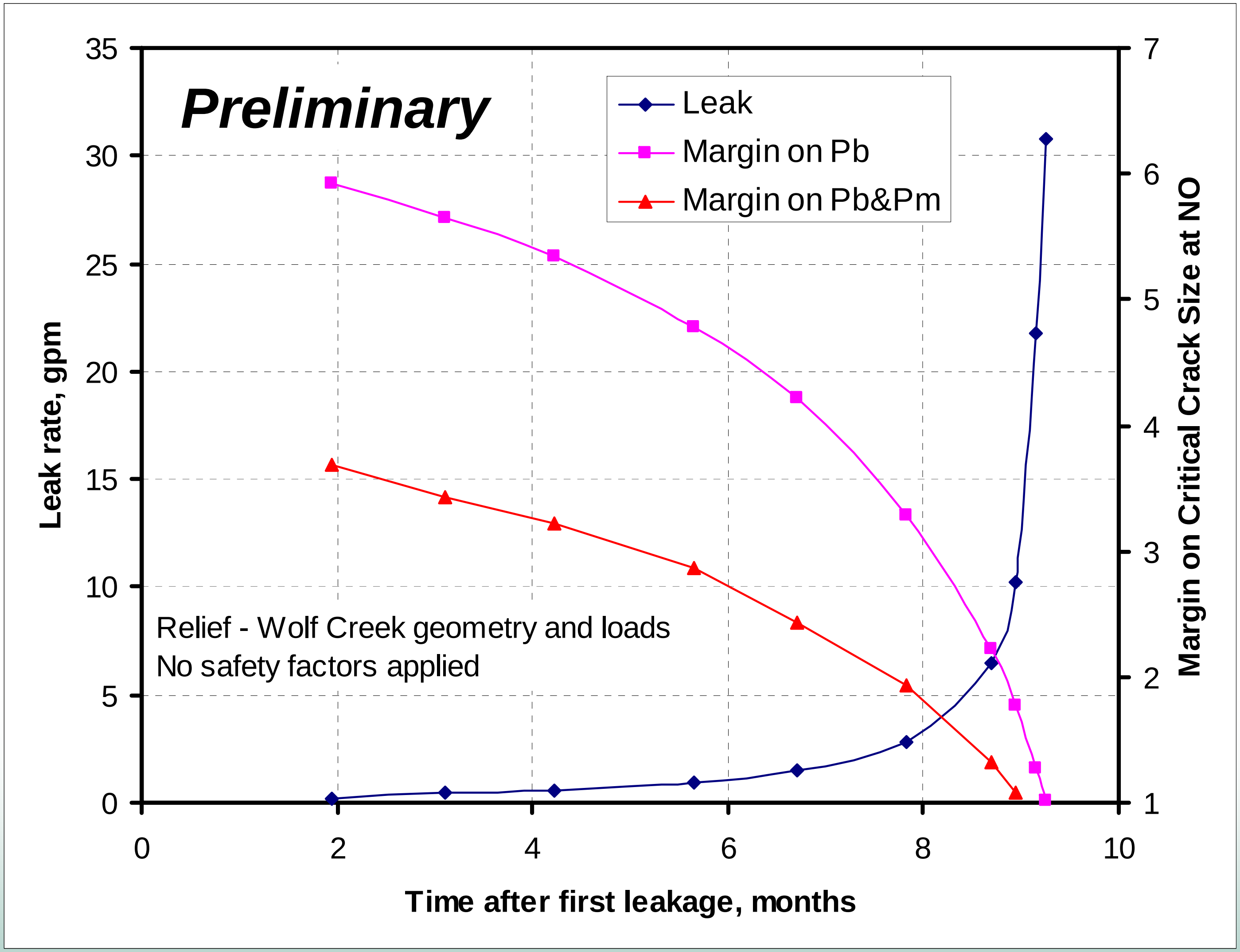
Wolf Creek Case – 65% moment



29.4 years at first leakage

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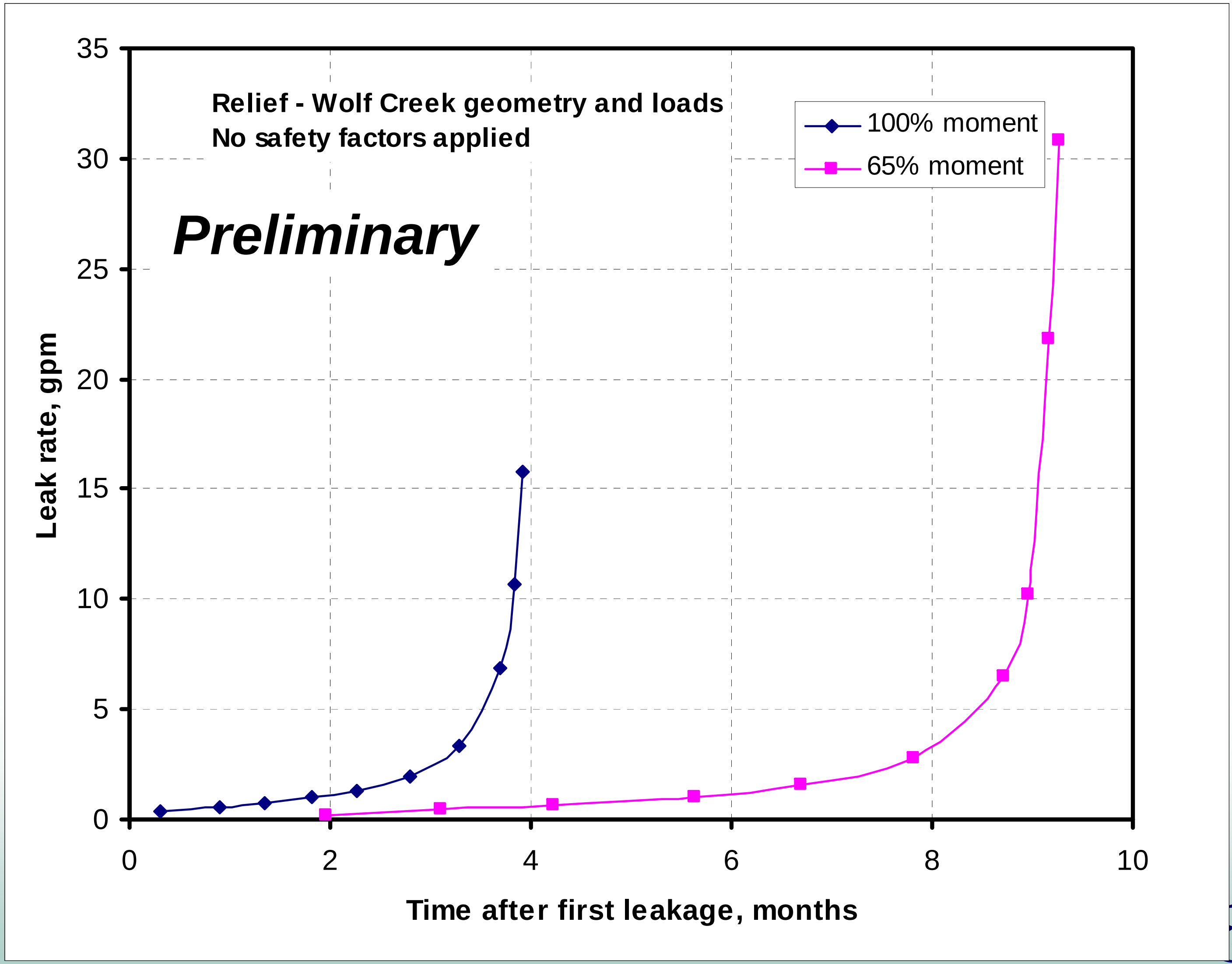
Wolf Creek Comparison



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Plans and Schedule

- ***WRS***
  - ***Conduct comparisons with DEI – DEI to select plane(s) for comparisons***
  - ***Relief Nozzle – conduct deep repair analysis***
  - ***Complete by end of June***
  - ***Validation (EU report, etc) in July***

- ***Confirmatory Sensitivity Analyses***
  - ***Conduct and reduce cases discussed earlier***
  - ***Complete by end of June (or first week in July)***

Evaluation of Pressurizer Alloy 82/182 Nozzle Failure Probability

(Including Effect of Fall-06 Wolf Creek NDE Indications)

By

Peter C. Riccardella

June 19, 2007

Structural Integrity Associates, Inc.

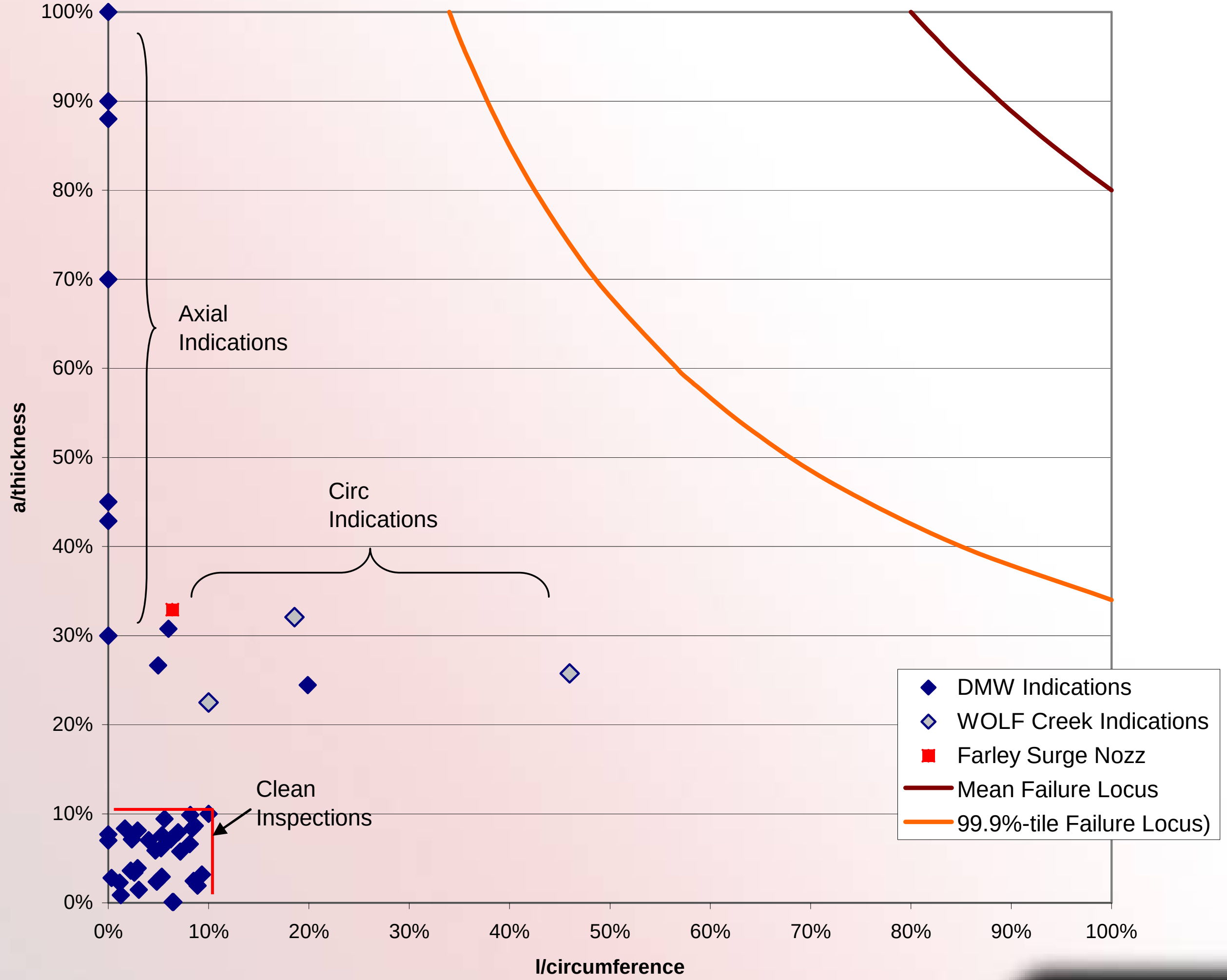
Elements of Analysis

- Flaw Distribution
- Fragility Curve
- Crack Growth
- Monte Carlo Analysis
- Preliminary Results

Flaw Distributions

- Inspection data updated to reflect Spring-07 inspection results
  - ♦ 10 new data points, 9 clean, 1 circ indication
- Incorporated several NRC suggestions in developing flaw distributions from the data
  - ♦ Fitted only inspection results that had circ indications (8 of the 51 data points)
  - ♦ Fitted actual data rather than confidence bounds (i/N vs. MRR)
  - ♦ Employed several distribution types to evaluate extrapolation uncertainties

Inspection Data
(Updated for Spring-07 Inspections)



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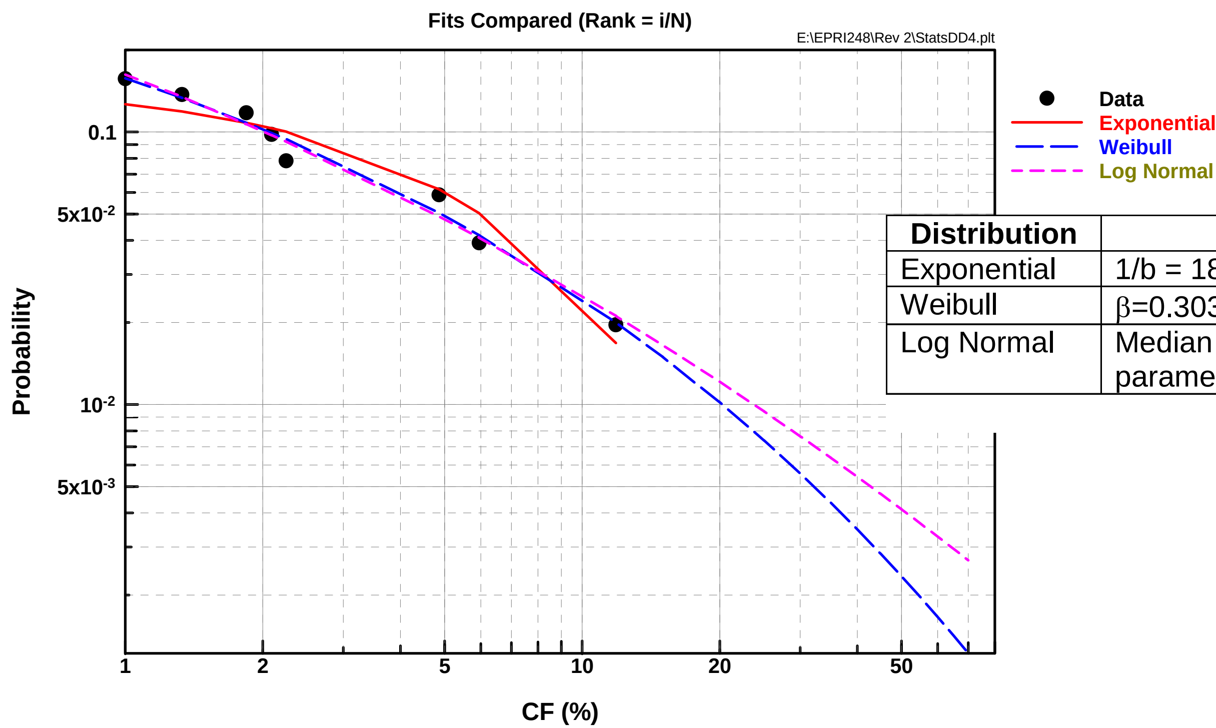
Flaw Distributions fitted to Circ Indication Data (in terms of CF %)



Distribution	Parameters	R^2
Exponential	1/b = 18.608, Cutoff = 0.1524	0.9349
Weibull	β=0.3034 η=0.001321	0.9772
Log Normal	Median = 0.0009785, 2nd parameter = 2.36058	0.9765

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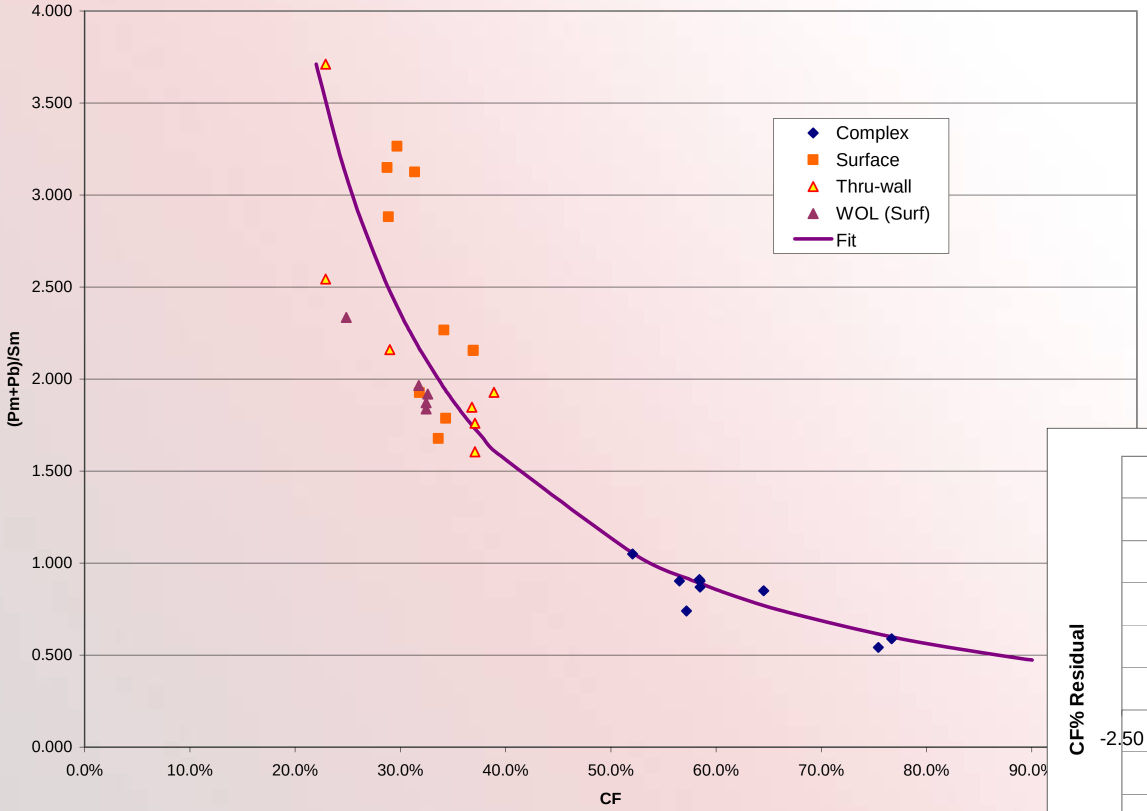
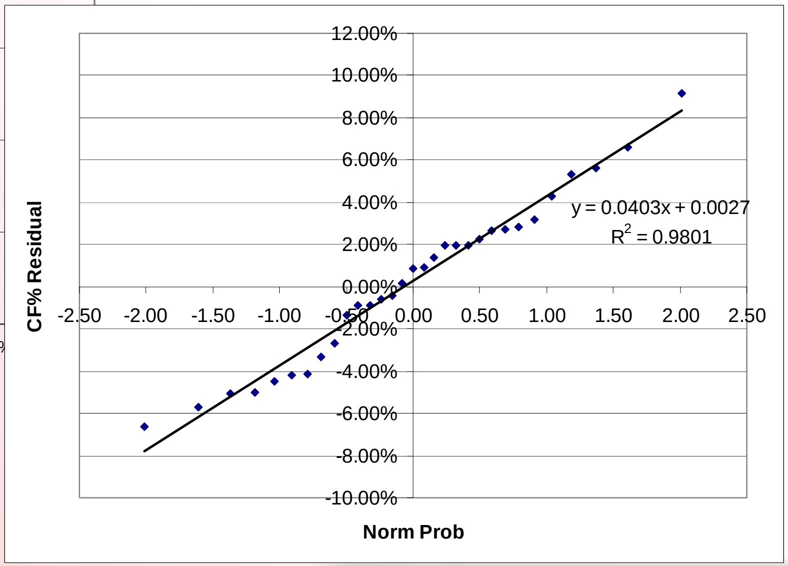
Fragility Curve

- **Completely new approach developed based on:**
  - ♦ **Test data from Degraded Piping Program (DP2) full scale pipe tests**
    - – Z-Factor of 1.17 applied
    - – Adjustment factor used to account for fraction of Pm vs. Pb
  - ♦ **Distribution of actual loads from Spring-08 plant nozzles**
    - – Primary + Thermal
    - – No stratification loads
    - – SSE a non-factor w/ assumed 0.001 frequency of occurrence

Fit of DP2 Full Scale Pipe Test Data (adjusted for fraction Pm vs. Pb)



Residuals well-fit by normal distribution



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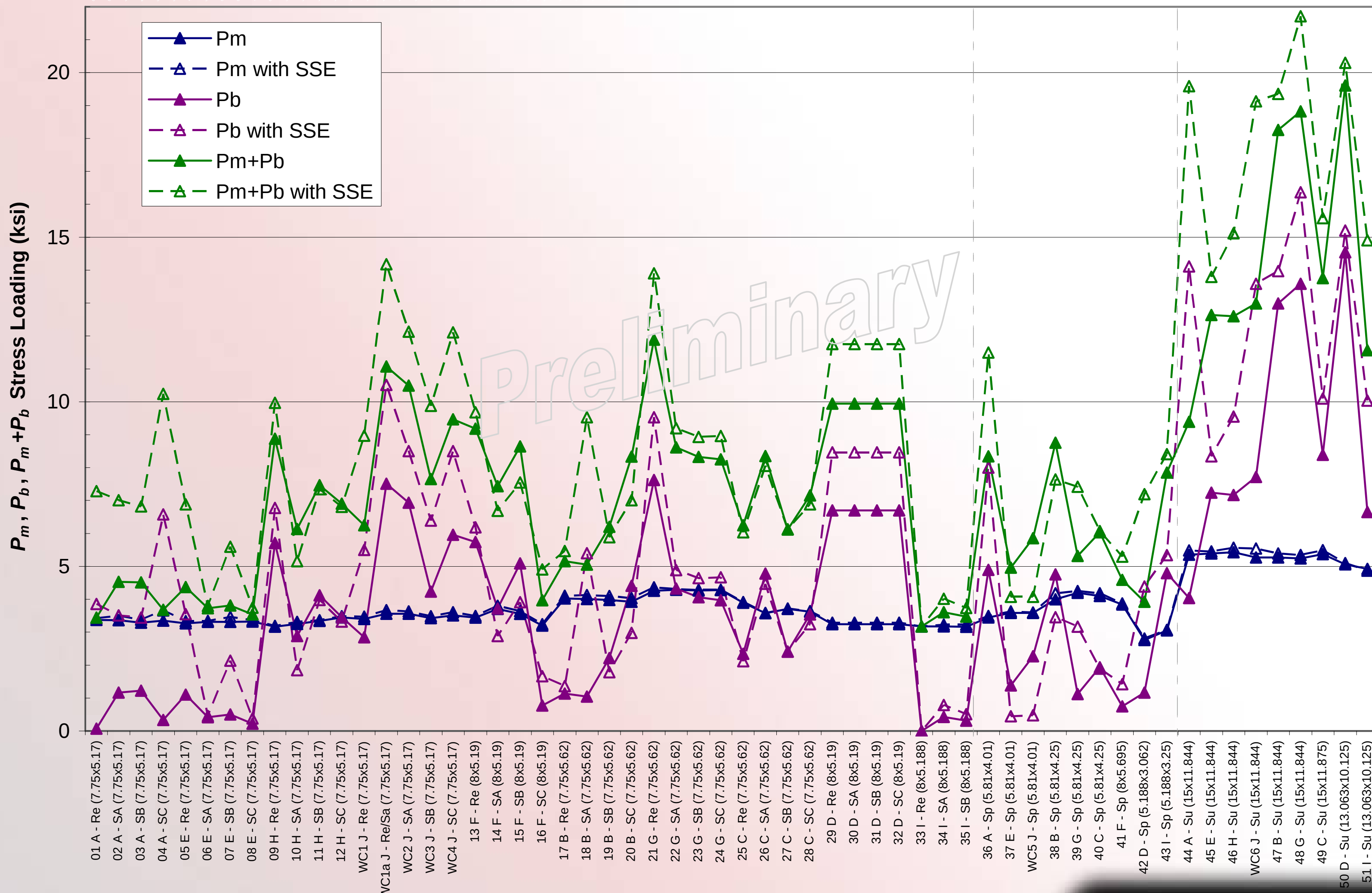
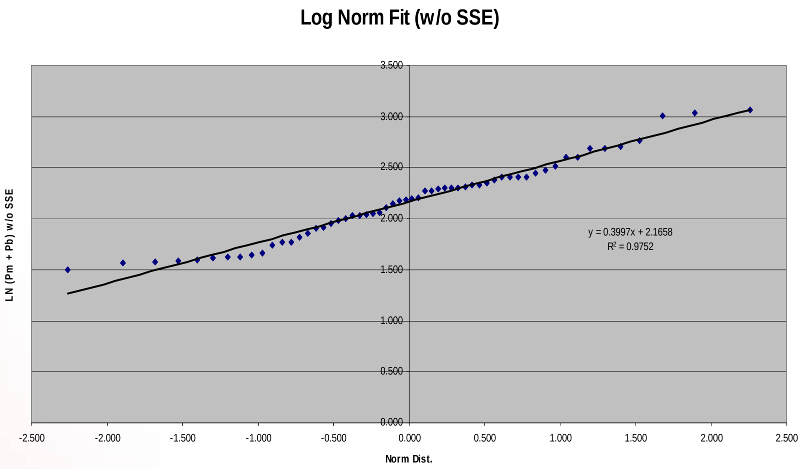
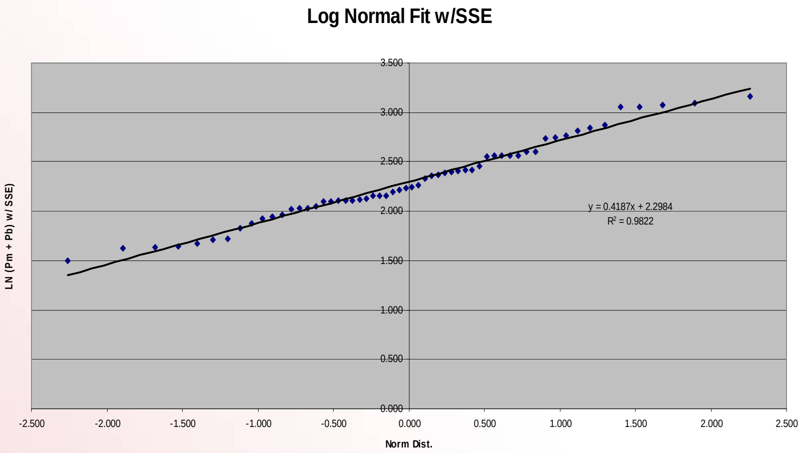
Plant Loading Statistics Provided by DEI



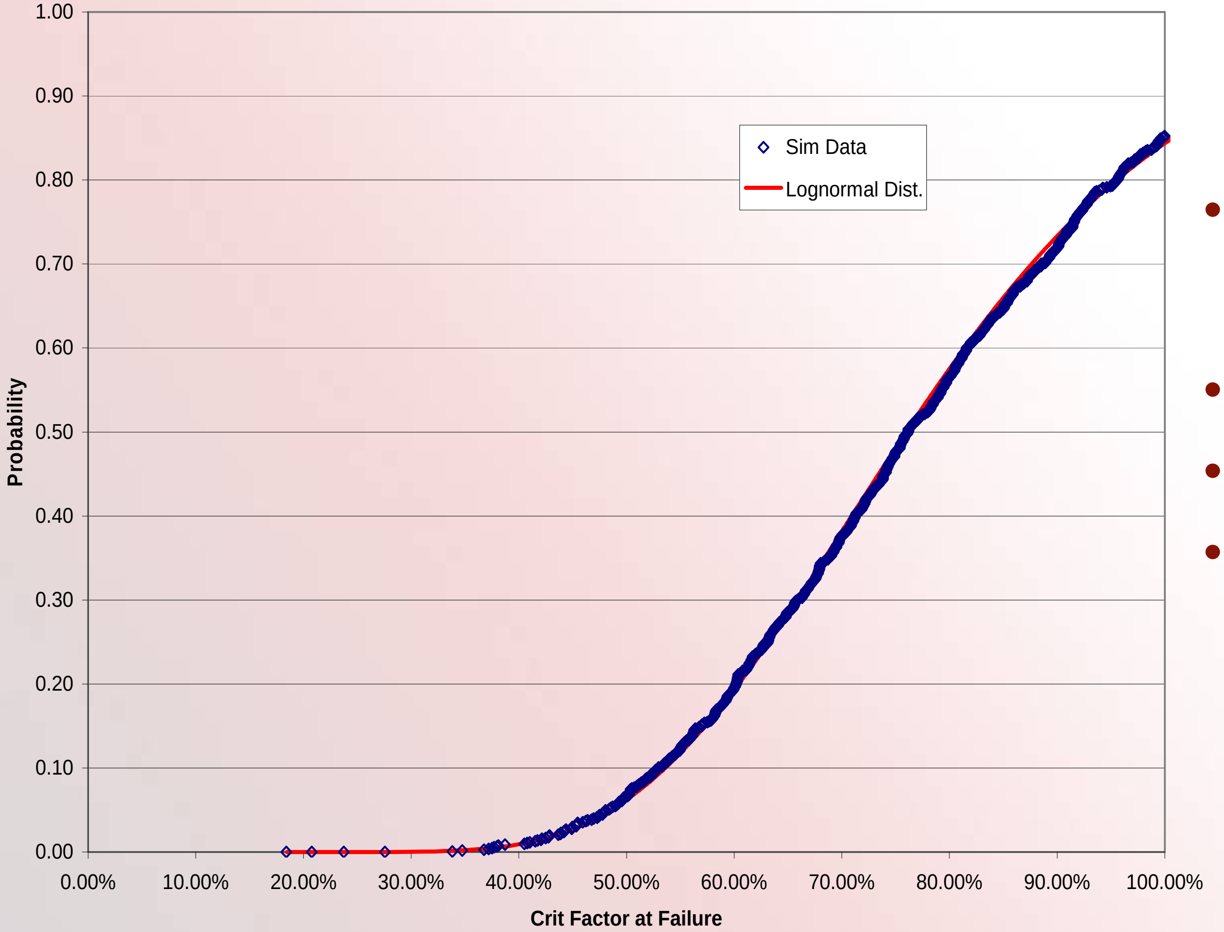
Plant Loading Statistics

- **Data very well fit by Lognormal Distributions**
  - ♦ **Pm + Pb w/o SSE (adjusted for fraction Pm)**
    - – Mean = 9.4 ksi, STD = 4 ksi, Max = 21.4 ksi
    - – R^2 of Lognormal Fit = .9752
  - ♦ **Pm + Pb w/SSE (adjusted for fraction Pm)**
    - – Mean = 10.9 ksi, STD = 4.7 ksi, Max = 23.6 ksi
    - – R^2 of Lognormal Fit = .9822





Test Data + Load Distributions Combined Statistically

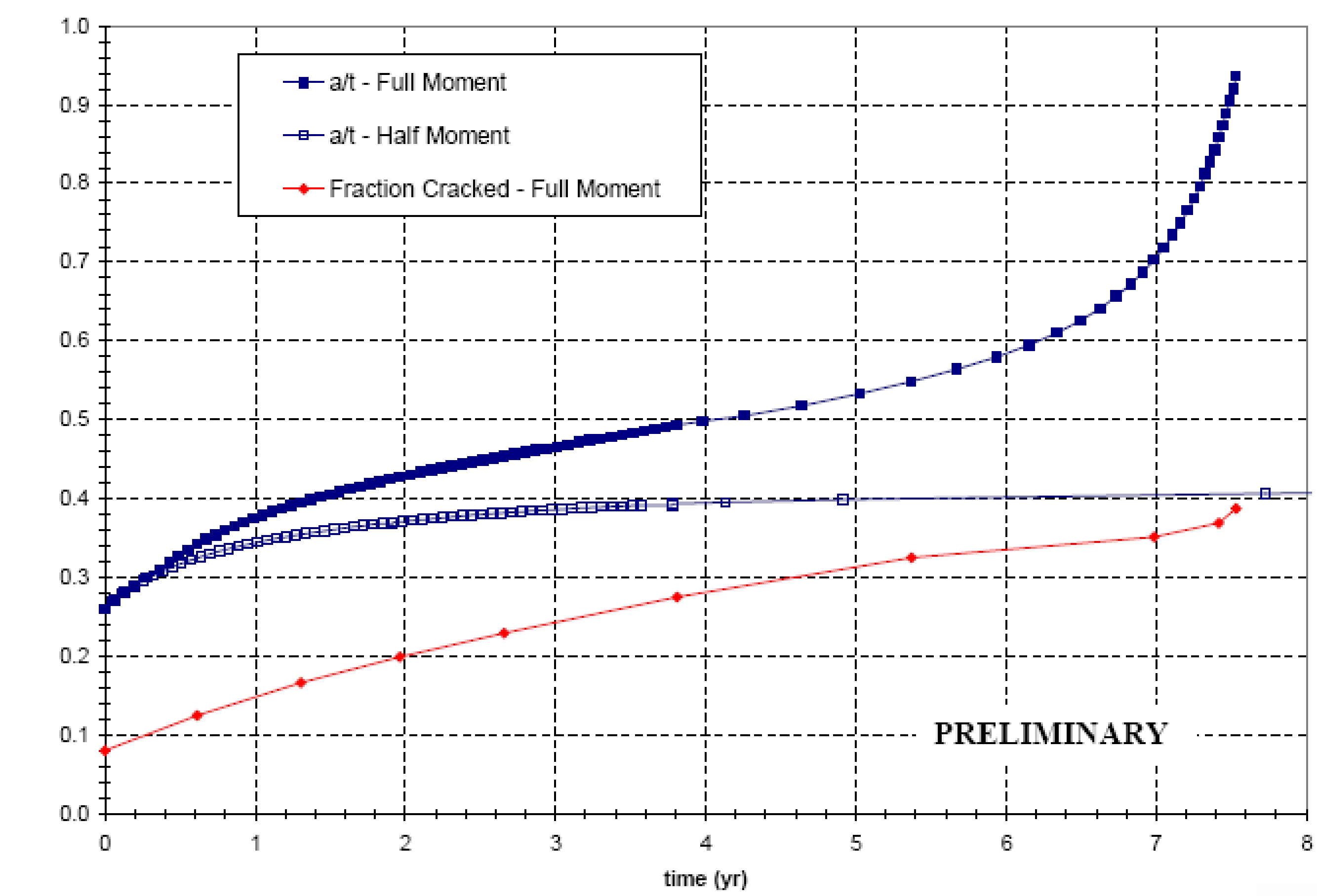


- **Final Fragility Curve very well fit by Lognormal**
- **Mean CF = 76%**
- **99.9%-tile = 34%**
- **R^2 of fit = 0.992**

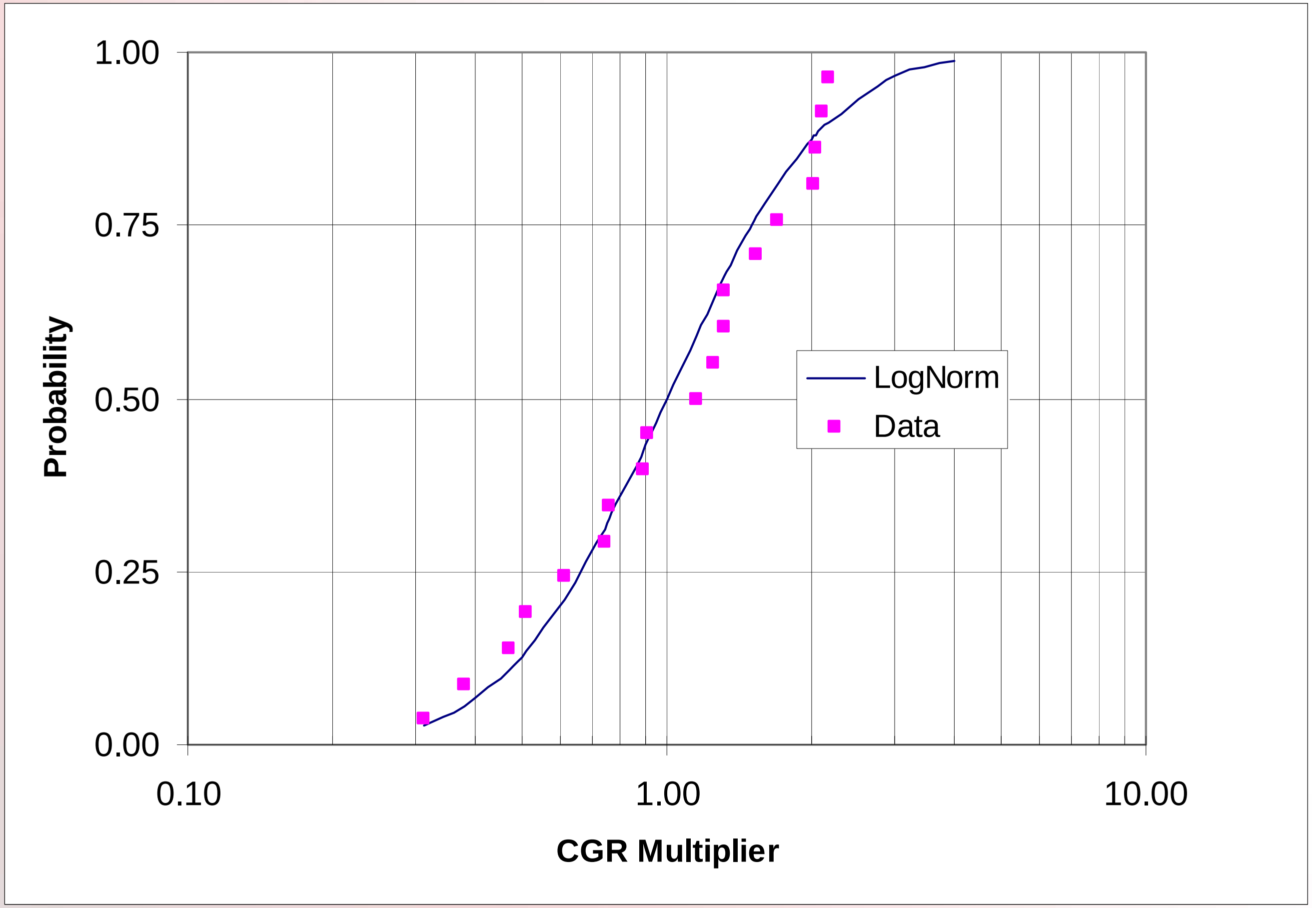
Crack Growth

- Awaiting Results of DEI Matrix runs to obtain distribution of CF% versus time
- In interim, used preliminary results from Phase I calcs
  - ♦ CF% Increases linearly by 3.75% per year from 0 to 40%
  - ♦ Assumed to be 75%-tile, and Lognormal distribution from MRP-115 applied to this value
  - ♦ Turn-up beyond 40% bounded by multipliers of 1 and 10
- Crack growth distribution indexed to same random number as original flaw distribution

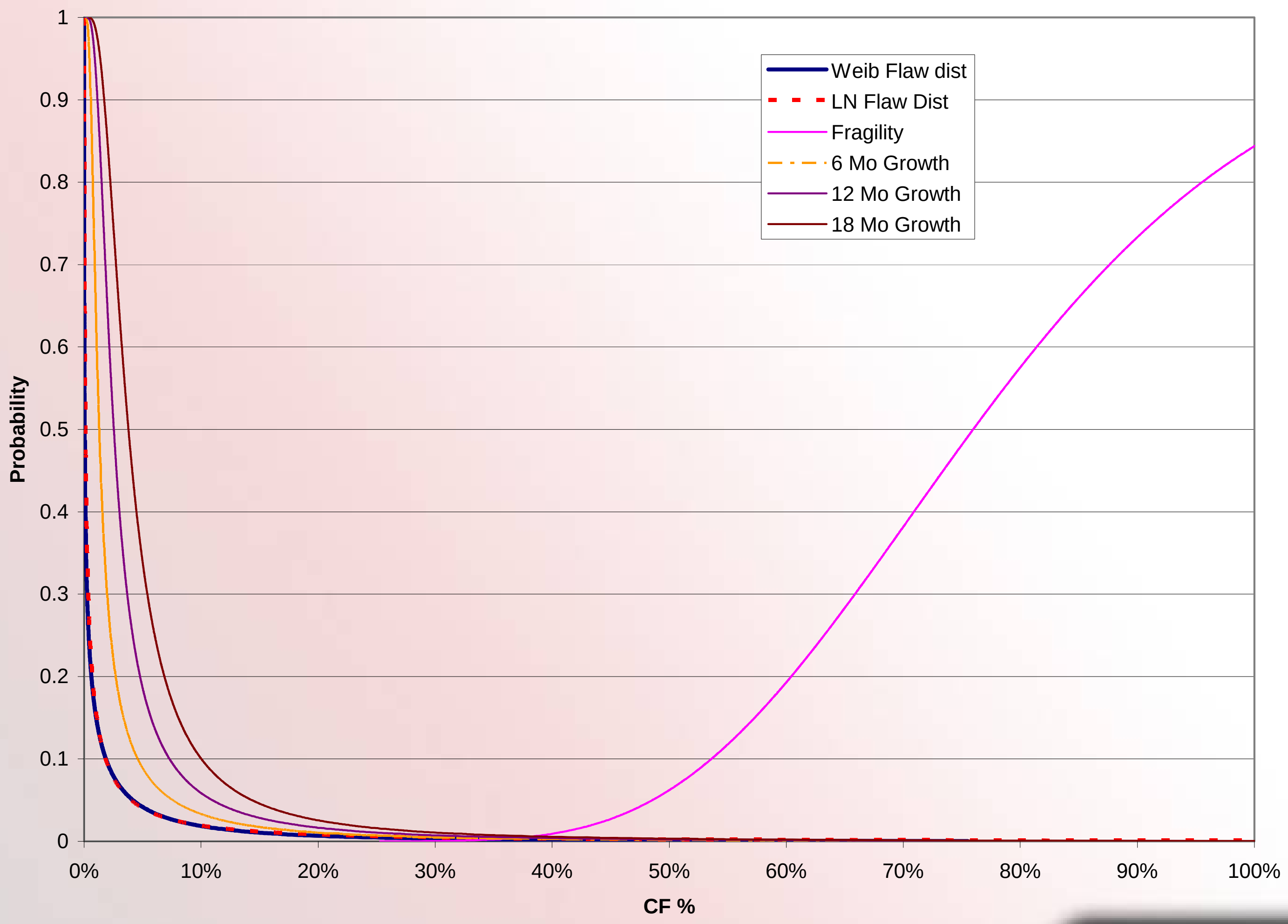
Preliminary Crack Growth Results from DEI Phase I Calcs



Crack Growth Rate distribution from MRP-115



Flaw Distributions w/Growth vs. Fragility Curve



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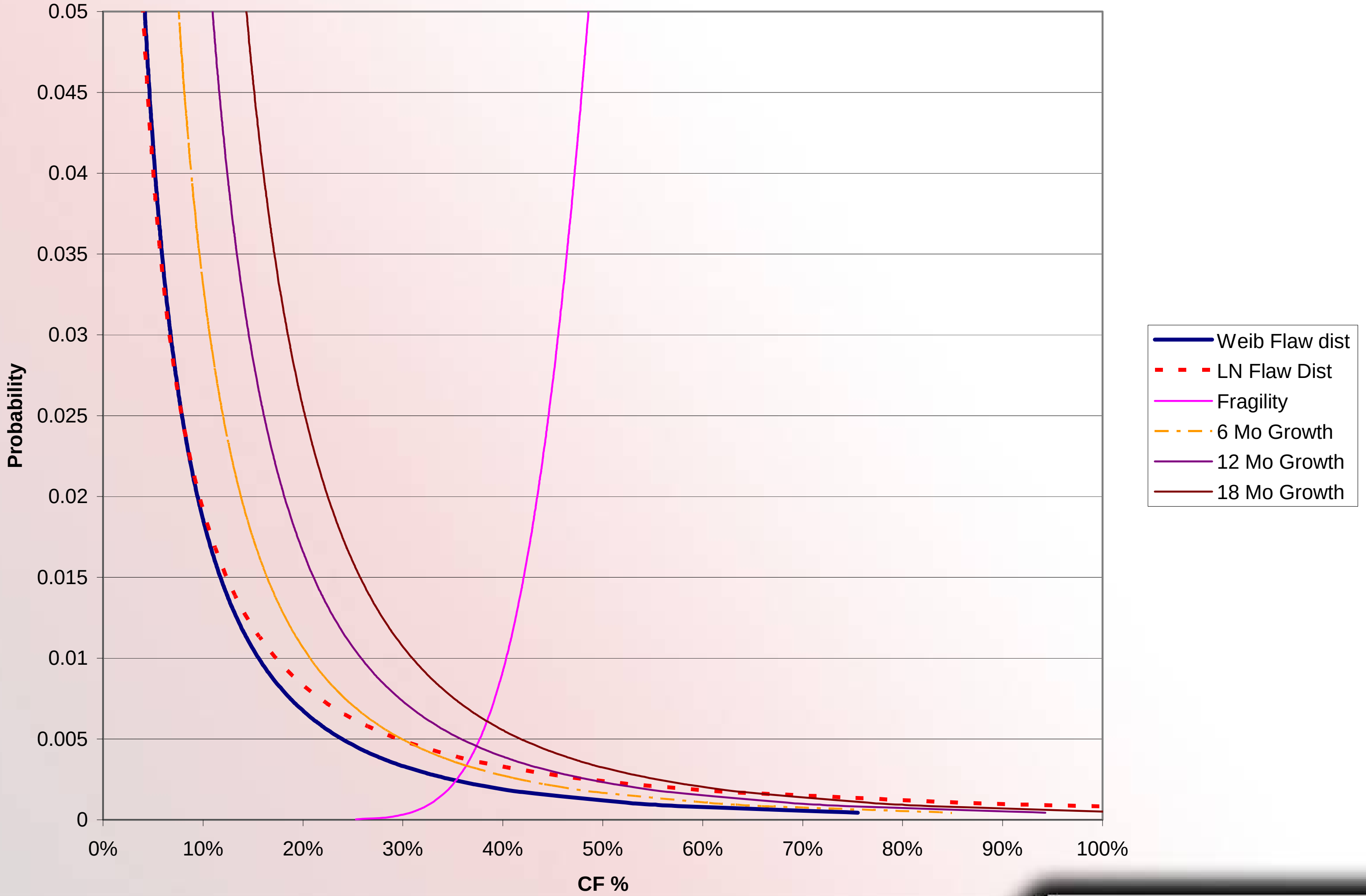
Flaw Distributions w/Growth vs. Fragility Curve (zoomed)



Preliminary Monte Carlo Results (Growth x1 for CF>40%)

	Time (months)	Cumulative Prob.	Incremental Prob. (6 Mo.)	# Nozzles	Nozzle Failure Prob. Total	per Plant
Weibull						
Spring-07	0	1.1869E-03	1.1869E-03	150	0.1632	0.0082
Fall-07	6	1.5012E-03	3.1430E-04	100	0.0309	0.0015
Spring-08	12	1.8903E-03	3.8910E-04	50	0.0193	0.0019
Log Normal						
Spring-07	0	2.5517E-03	2.5517E-03	150	0.3184	0.0159
Fall-07	6	2.9121E-03	3.6040E-04	100	0.0354	0.0018
Spring-08	12	3.3391E-03	4.2700E-04	50	0.0211	0.0021
Exponential						
Spring-07	0	3.4000E-06	3.4000E-06	150	0.0005	0.000025
Fall-07	6	3.0500E-05	2.7100E-05	100	0.0027	0.000135
Spring-08	12	1.2370E-04	9.3200E-05	50	0.0046	0.000465

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Preliminary Monte Carlo Results (Growth x10 for CF>40%)

	Time (months)	Cumulative Prob.	Incremental Prob. (6 Mo.)	# Nozzles	Nozzle Failure Prob. Total	Nozzle Failure Prob. per Plant
Weibull						
Spring-07	0	1.1869E-03	1.1869E-03	150	0.1632	0.0054
Fall-07	6	3.4015E-03	2.2146E-03	100	0.1988	0.0099
Spring-08	12	4.5127E-03	1.1112E-03	50	0.0541	0.0054
Log Normal						
Spring-07	0	2.5517E-03	2.5517E-03	150	0.3184	0.0106
Fall-07	6	5.2430E-03	2.6913E-03	100	0.2362	0.0118
Spring-08	12	6.3873E-03	1.1443E-03	50	0.0556	0.0056
Exponential						
Spring-07	0	3.4000E-06	3.4000E-06	150	0.0005	0.000017
Fall-07	6	1.0640E-04	1.0300E-04	100	0.0102	0.000512
Spring-08	12	5.2640E-04	4.2000E-04	50	0.0208	0.002079

Failure Probabilities per Plant per Year

(Growth x1 for CF>40%)

	Weib	Log Normal	Exponential
2007	0.0070	0.0124	0.0002
2008	0.0019	0.0021	0.0005
2008*	0	0	0

(Growth x10 for CF>40%)

	Weib	Log Normal	Exponential
2007	0.0153	0.0223	0.0005
2008	0.0054	0.0056	0.0021
2008*	0	0	0

* Assuming all plants inspected/mitigated in 2007

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Preliminary Conclusions

- Failure Probabilities (per plant, per year) for Spring-08 Plants generally less than what has existed in these nozzles in 2007
- Greater than generally accepted 1E-3 for the most conservative assumptions
- However, these results assume no leakage or plant response to leakage
  - ♦ They should be factored by probability of non-LBB or failure to react to leakage from DEI study