NRC Advanced FEA Confirmatory Project

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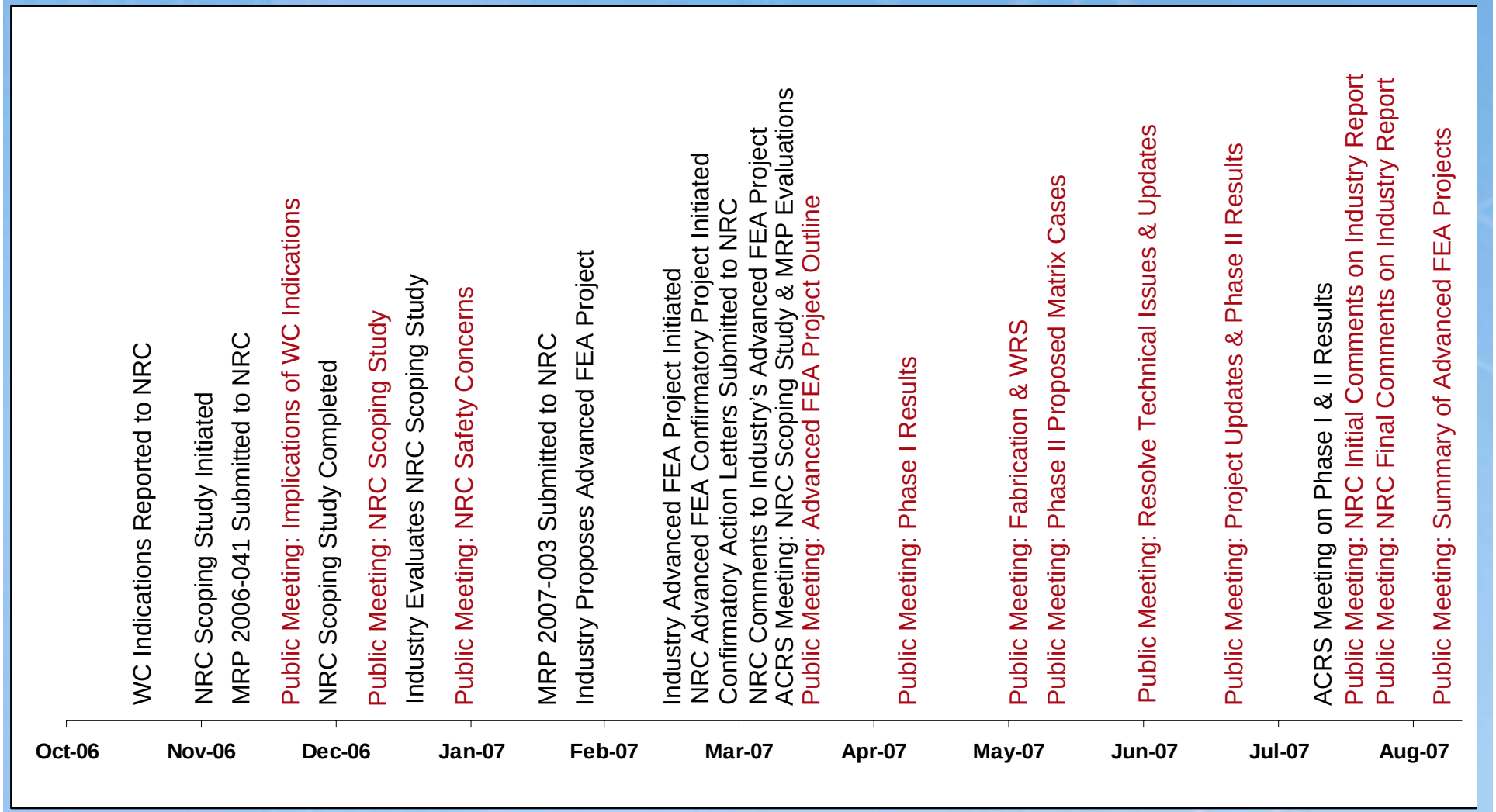
Advanced FEA Project: Chronology



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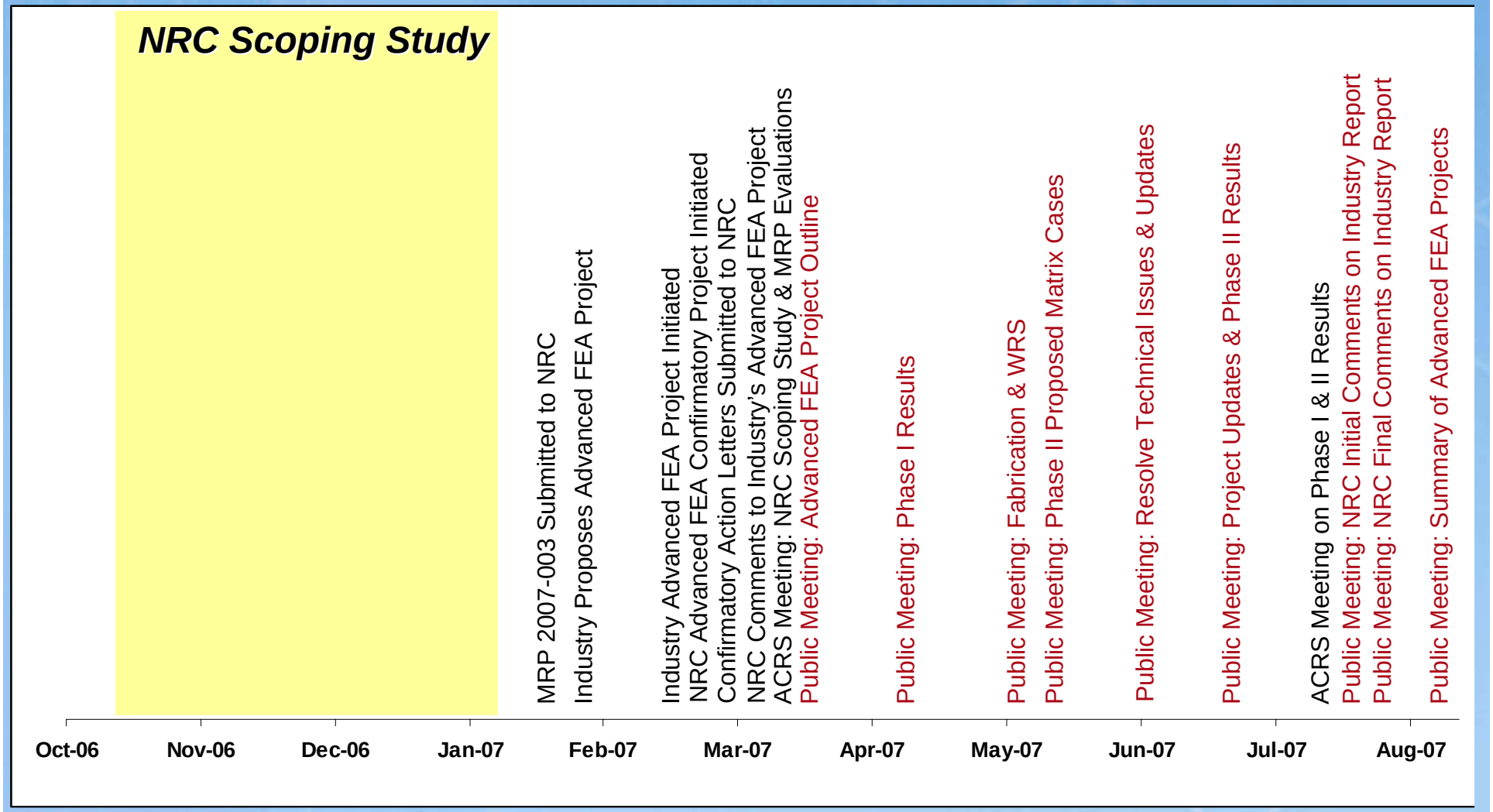

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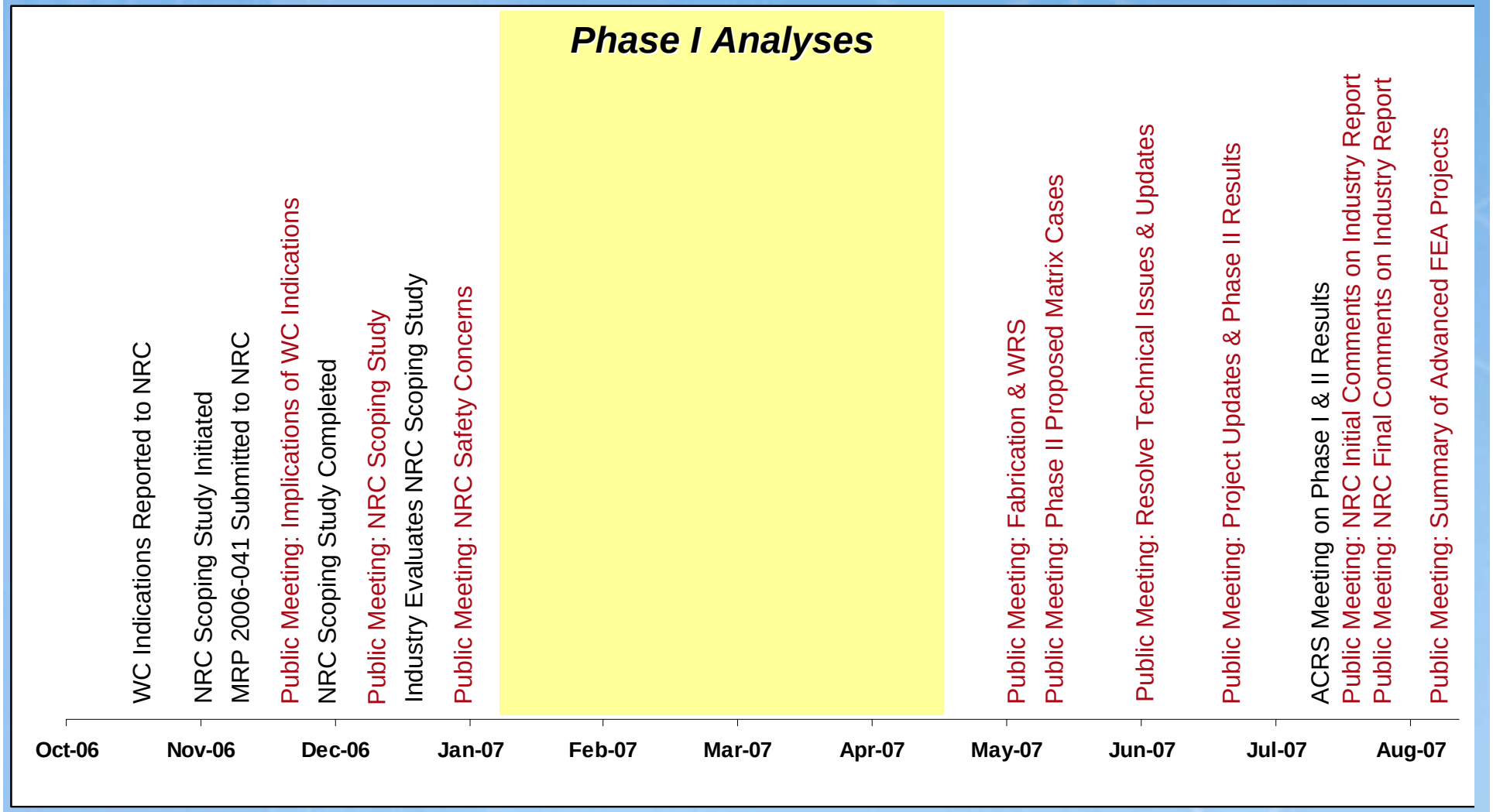

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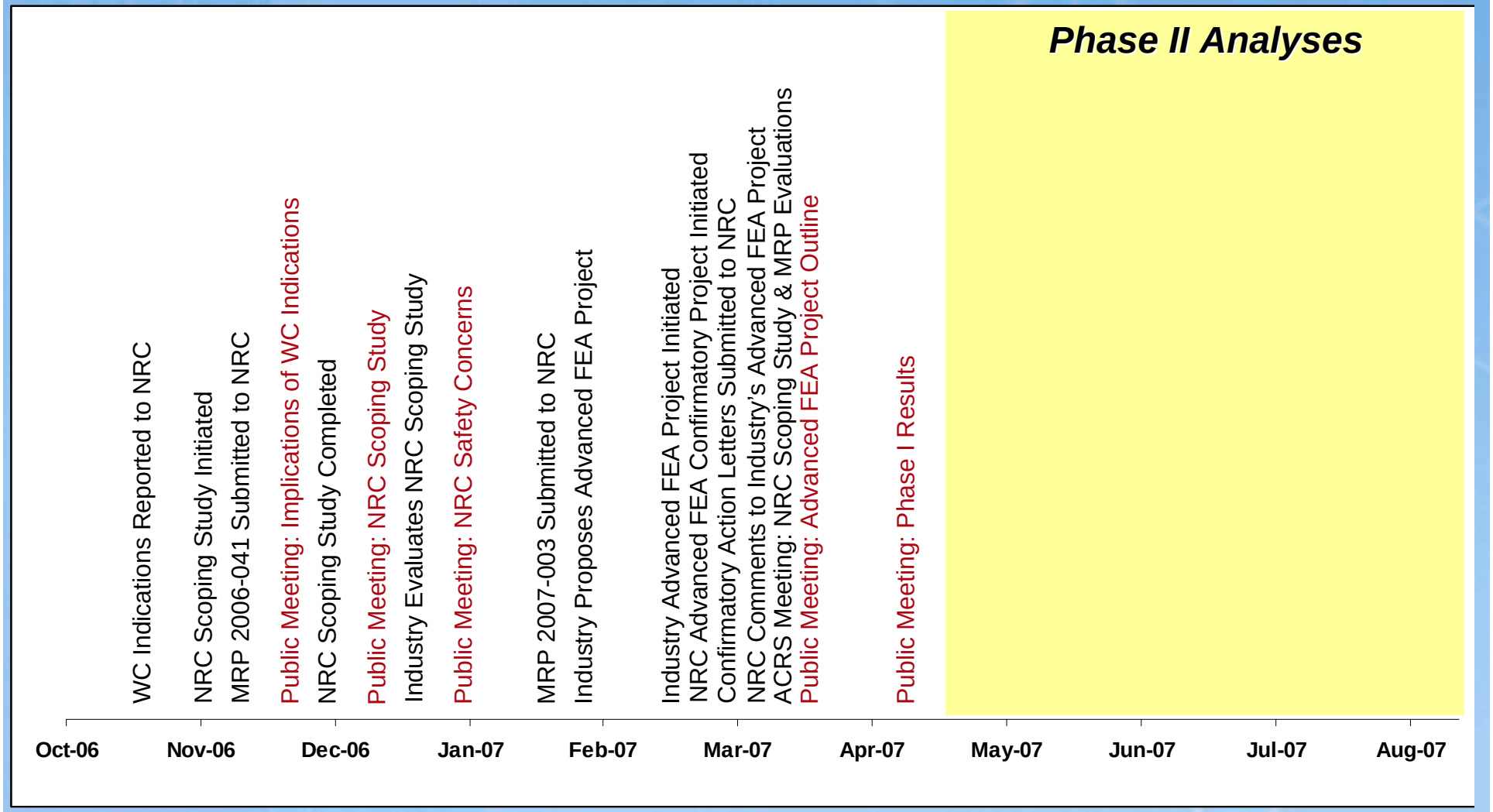

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Advanced FEA Project: Background

- Purpose:
  - Evaluate the component integrity of the pressurizer nozzle welds with new advanced FEA software for circumferential flaws that removes artificial conservatisms found in NRC Wolf Creek Scoping Analysis and ASME Section XI Code.
    - artificial constraint of the semi-elliptical crack shape
    - allow the crack to grow in a more realistic manner as a function of the stress intensity factor
- Objective:
  - Evaluate viability of through-wall leakage prior to rupture for the pressurizer nozzle-to-safe end dissimilar metal welds for the 9 PWRs that had planned to perform inspection/mitigation during the spring 2008 outage season

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Advanced FEA Project: NRC Confirmatory Program

- NRC confirmatory program developed to benchmark, verify, and evaluate industry's analyses and results
- NRC staff interacted with the industry to provide timely input on the project analytical approach, modeling methodologies, and sensitivity study
- NRC provided comments by letter dated Mar 5, 2007
- NRC staff reached agreement with the industry on the analytical approach, modeling methodologies, and matrix of sensitivity cases used in their analyses
- NRC and industry conducted a WRS validation study

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Advanced FEA Project: NRC Confirmatory Program

- Industry & NRC independently developed:
  - Separate fracture mechanics based advanced FEA models that evaluate crack growth at each point on the crack front as a function of the stress intensity factor at that point
  - Separate axisymmetric WRS models for the various nozzle types, geometries, and fabrication processes
- Industry & NRC benchmarked:
  - Calculated K-solutions for arbitrary cracks to prove the advanced FEA models produced comparable K-solutions
  - Axisymmetric WRS models for the various nozzles
  - Crack growth methodologies through the Phase I effort
- K-solutions and WRSs benchmarking showed good agreement between industry's and NRC's models

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Advanced FEA Project: NRC Confirmatory Program

- NRC reviewed the fabrication drawings for the 9 PWRs scheduled to perform inspections/mitigations in the spring 2008 outage season
- Typical fabrication steps were shown to affect WRS:
  - Backchipping and last past 360^{o} ID welds at certain Westinghouse plants produced tensile ID axial stresses
  - Stainless steel safe end welds generally reduced the ID tensile stresses when modeled with the last pass 360^{o} weld
- Industry and NRC WRS models were validated using an EU round robin study on dissimilar metal butt weld WRS modeling and measurements

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Advanced FEA Project: NRC Confirmatory Program

- Advanced FEA project evaluated in two parts
- Phase I Wolf Creek relief nozzle reevaluation:
  - Reevaluate scoping analysis results with new model
  - Good agreement between industry & NRC model results
  - Unlike the NRC Wolf Creek scoping study results, margins were predicted for the time between leak and rupture
- Phase II parametric sensitivity study:
  - Develop a matrix of sensitivity and bounding cases with plant specific nozzle geometries, loads, & WRS
  - Evaluate the margins between detectable leakage and rupture for the 51 DM butt welds in 8 plants susceptible to PWSCC

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Advanced FEA Project: Phase I Results

- Phase I Wolf Creek relief nozzle reevaluation:
  - 26% flaw depth
  - 21:1 c/a flaw ratio
  - ASME Section XI WRS
- Semi-elliptical assumption proved to be conservative for this ASME Section XI type flaw evaluation

Time to First Leakage (yrs)			
Scoping Study		Phase I	
NRC	MRP	NRC	MRP
1.9 - 2.6	4.4	5.40	5.36

Time Margin b/w Leak & Rupture (days)			
Scoping Study		Phase I	
NRC	MRP	NRC	MRP
-	-	105	152

Leak Rate (gpm)			
Scoping Study		Phase I	
NRC	MRP	NRC	MRP
Rupture	Rupture	0.4 - 6.9	0.38 - 7.9

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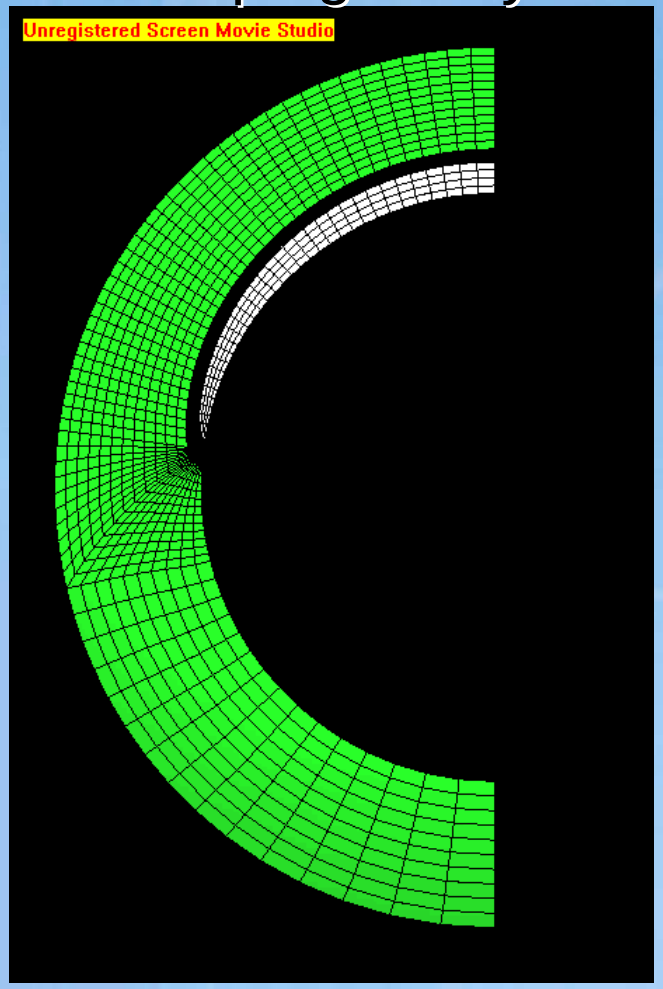
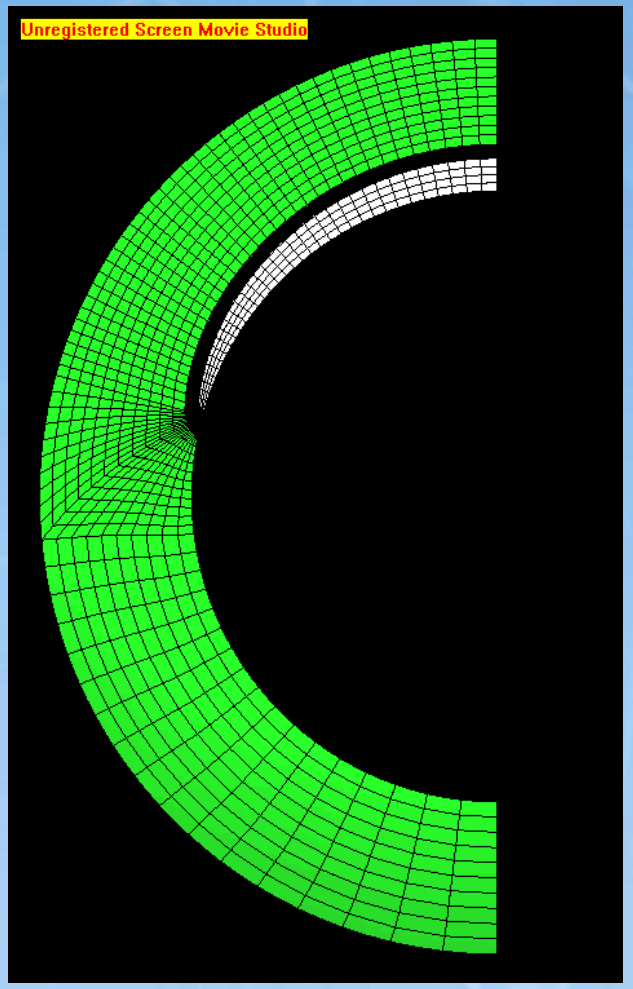
Advanced FEA Project: Phase I Results

Scoping Study



Advanced FEA



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Advanced FEA Project: Phase II Results

- Industry evaluated 121 sensitivity cases
- NRC evaluated 30 cases:
  - Directly confirmed 7 safety/relief, 3 spray, & 6 surge nozzle cases from the industry matrix cases
  - Remaining 14 cases evaluated cases not directly addressed by the industry matrix cases
- Phase II results show generally good agreement between the independently developed industry and NRC advanced FEA models

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Advanced FEA Project: Phase II Safety/Relief Results

Case #	DEI Case #	Time at first leakage (yr)		Margin at 1gpm leak		Time since 1gpm leak to 1.2 margin (Month)	
		DEI	Emc2	DEI	Emc2	DEI	Emc2
1	1c	17.4	20.16	2.24	2.46	3.63	2.18
1-1	1b	Arrest	Arrest	Arrest	Arrest	Arrest	Arrest
3	3c	26.3	29.40	2.40	2.55	4.17	2.42
6	6c	3.4	4.13	1.70	1.79	1.37	1.13
6-4	35c	2.9	3.26	1.62	1.81	1.07	0.70
9-1	9c	32.2	119.18	2.50	2.50	4.80	2.90

- In addition to the Phase I relief line results, the Phase II results for the safety/relief lines confirm the industry results that margins between leak and rupture

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Advanced FEA Project: Phase II Spray Line Results

Case #	DEI Case #	Time at first leakage (yr)		Margin at 1gpm leak		Time since 1gpm leak to 1.2 margin (Month)	
		DEI	Emc2	DEI	Emc2	DEI	Emc2
10	10c	21.2	51.36	2.07	2.48	2.43	1.85
11-1	11c	25.3	Arrest	2.08	Arrest	2.43	Arrest
15	15c	Arrest	Arrest	Arrest	Arrest	Arrest	Arrest

- Phase II results for the spray lines confirm the industry results that margins exist between leak and rupture
- Results also indicate significantly long times for leakage to occur or complete crack arrest

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Advanced FEA Project: Phase II Surge Line Results

Case #	DEI Case #	Time at first leakage (yr)		Margin at 1gpm leak		Time since 1gpm leak to 1.2 margin (Month)	
		DEI	Emc2	DEI	Emc2	DEI	Emc2
17-1	S1b	1.2	1.30	1.03	1.00	0.00	0.00
17-2	17b	1.2	1.36	1.71	1.80	1.17	N/A
17-8	17a	Arrest	6.15	Arrest	1.58	Arrest	N/A
19-1	19b	Arrest	9.50	Arrest	1.58	Arrest	1.18
20	20b	Arrest	Arrest	Arrest	Arrest	Arrest	Arrest
17-11	25b	0.50	0.86	1.36	1.37	0.43	0.31

- Surge lines results confirm industry results cases 17-1/S1b, 17-2/17b, 20/20b, and 17-11/25b
- Some divergence occurred for cases 17-8/17a & 19-1/19b, but, substantial margins exist

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Advanced FEA Project: Phase II Result Summary

- Of the 30 cases in the NRC confirmatory program,
  - All 11 safety/relief cases showed either arrest or substantial margin between leakage and rupture
  - 3 out of 4 spray cases showed crack arrest with the final case predicting >50 years to leakage with substantial margins between leakage and rupture
  - 6 out of 15 surge line cases show little margin due to multiple conservatisms used in the analysis
  - 9 out of 15 surge line cases show either arrest or some margin between leakage and rupture

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Advanced FEA Project: WRS Validation

- Crack growth modeling in DM butt welds is highly dependent upon WRS distributions
- Changes in WRS profiles have a large effect on crack growth behavior, i.e. arrest or rupture predicted for certain surge line cases
- Therefore, WRS model validation undertaken
- Model results in good agreement for the butter centerline considering WRS model assumptions

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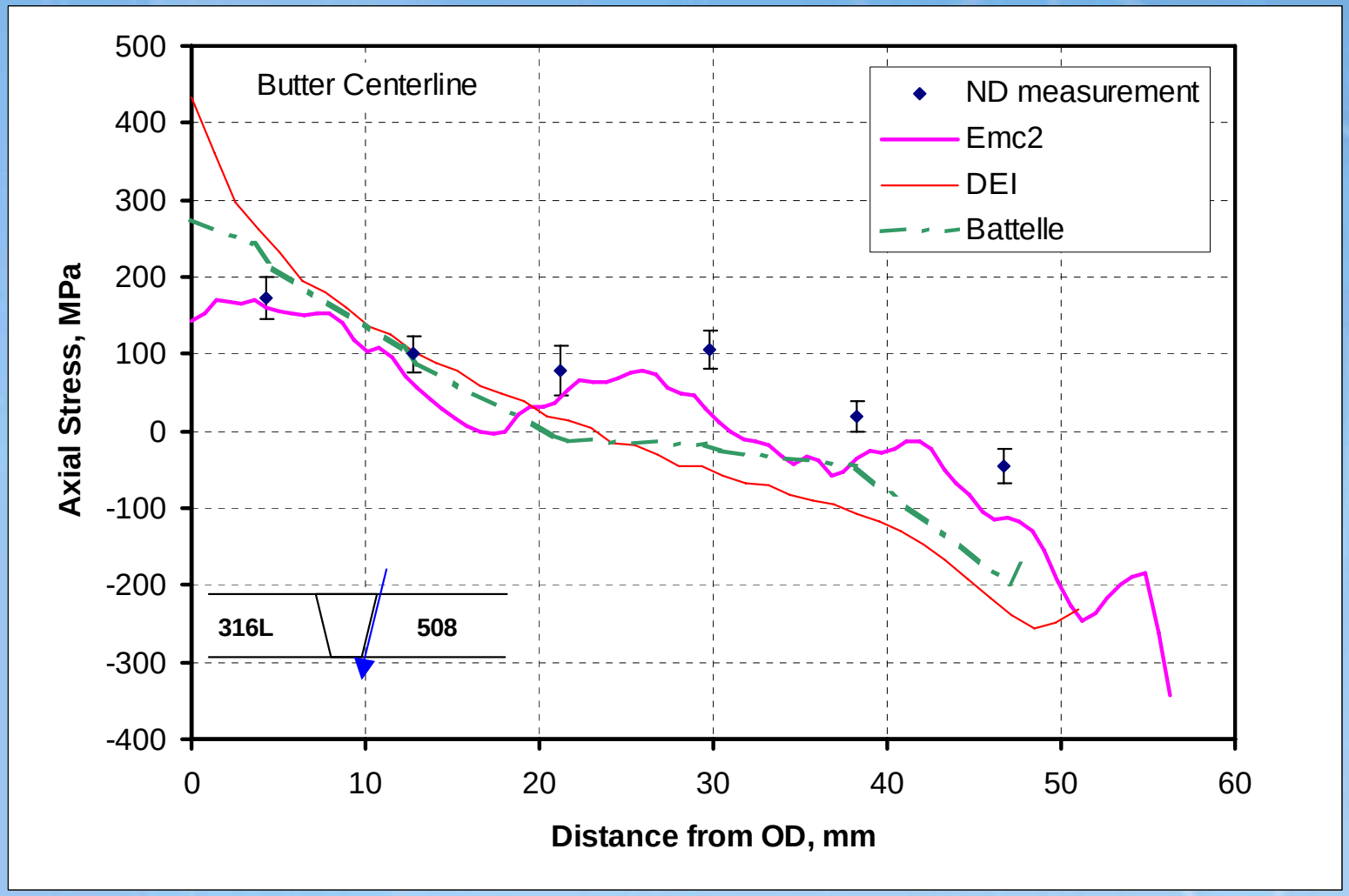
Advanced FEA Project: WRS Validation



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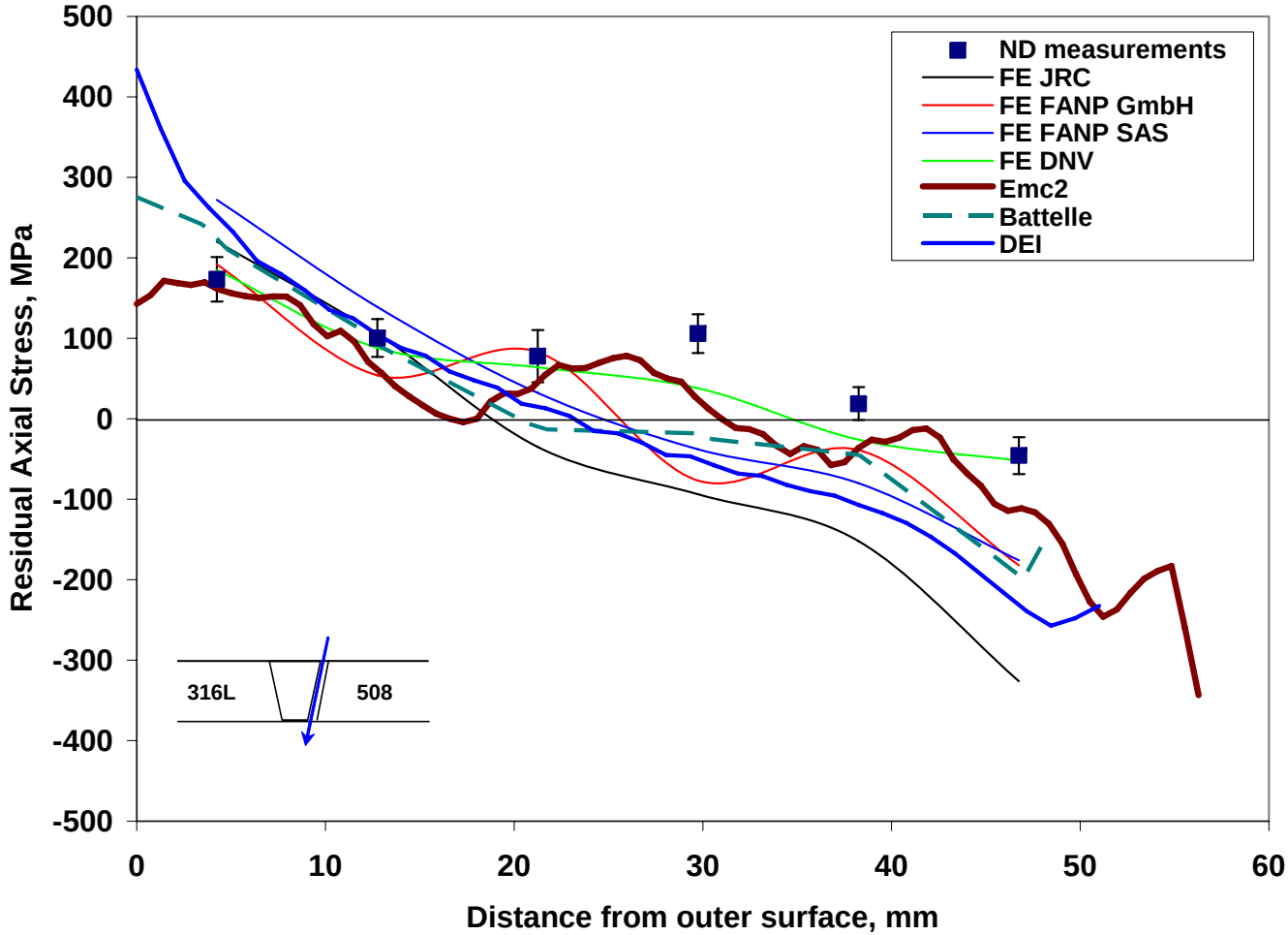

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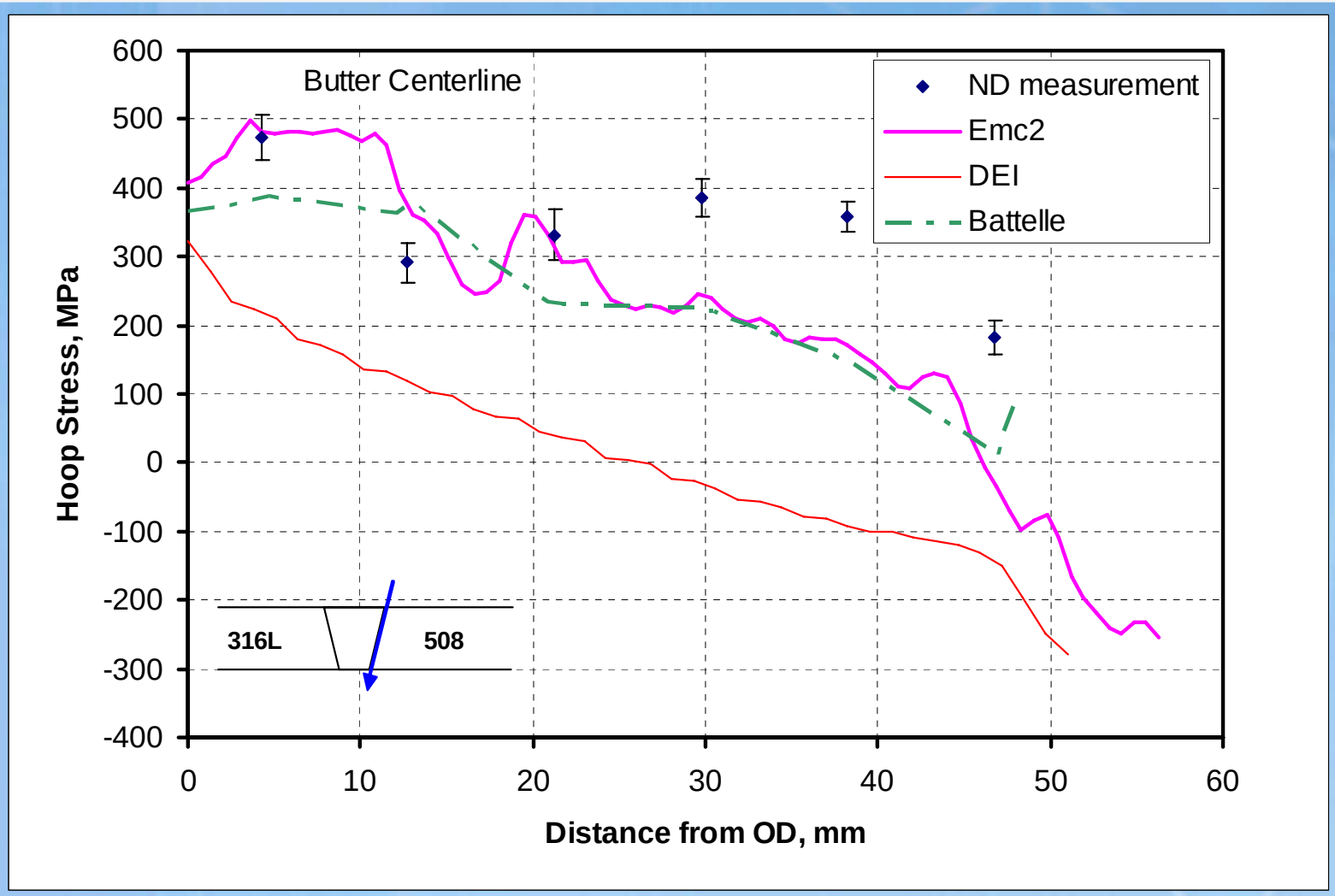

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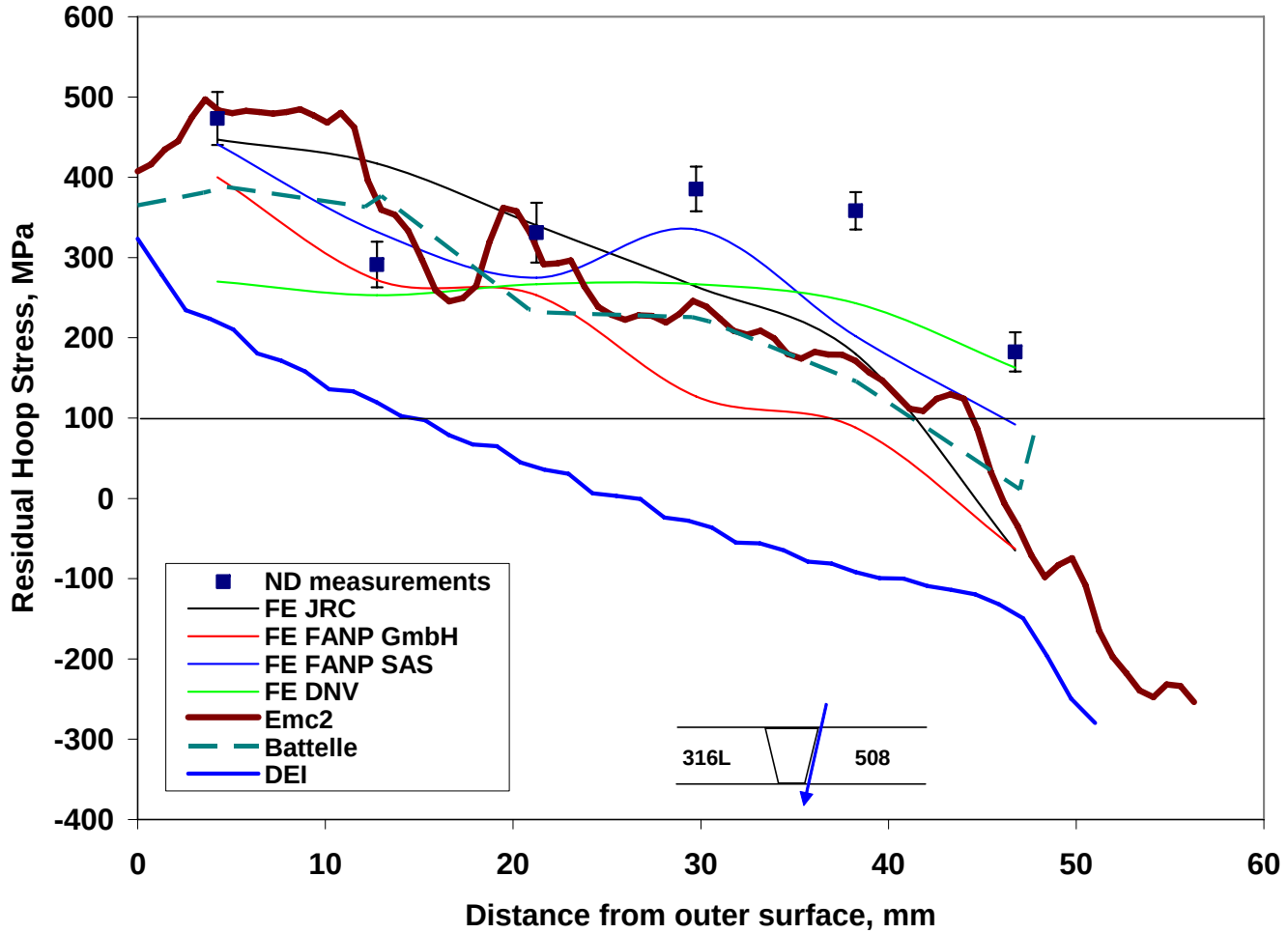

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Summary

- NRC confirmatory program developed to benchmark, verify, and evaluate industry's analyses and results
- Phase I results show good agreement between the industry & NRC advanced FEA model results
- Phase II results show good agreement between the independently developed industry & NRC advanced FEA models
- Validation effort provided useful information for understanding the uncertainties in WRS distributions

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Closing Remarks

- NRC staff appreciates the high level of cooperation while working this issue
- Understanding of PWSCC behavior in pressurizer dissimilar metal nozzle welds greatly increased through AFEA
- Uncertainties still exist in a number of areas
  - Appropriate to continue AFEA-related efforts to narrow uncertainties
- Industry and NRC staff both applying factors of safety to address uncertainties

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Closing Remarks

- Have information we need from AFEA project
- Do not see any significant issues ahead
- Have started to draft safety assessment
- Will be completing written safety assessment by the end of August
- Will issue letters to licensees of nine plants shortly thereafter
- Will provide verbal conclusions before issuing letters

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Closing Remarks

- Pressurizer nozzle weld inspections yield a number of insights
- Aggressive response needed to any findings of PWSCC indications
  - best available NDE
  - destructive examinations, and
  - complete analyses by industry
- NRC staff regards industry “mandatory” inspection schedules in MRP-139 to be appropriate
- Going forward with other inspection locations, staff wants to avoid repeating the pressurizer nozzle welds experience
- Deviations from MRP-139 establishes schedules for pressurizer nozzle welds have been difficult to justify
- Any future exceptions will be difficult to justify to the NRC
  - AFEA may have a number of future applications, but staff would not encourage that AFEA be used to justify future deviations
- Staff will be taking up this message with industry