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PA-MSC-1288R0: PWR Materials Assessment Results

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Background

- A/LAI 7 – Requires additional analysis for CASS RV Internals components
- RAIs received on many A/LAI 7 responses
- CMTR data for CASS RV Internals are not always readily available or retained under individual component tracking documentation
- Margin and uncertainty have been challenged

Background

- PWROG PA-MSC-1288 developed a statistical approach for determining and assessing material or fabrication factors for PWR internals components
- PA pilot application addresses TE of CASS material as a fleet demonstration of statistically based assessments of material properties
  - Analyzed existing accessed CMTR data on a statistical basis

Process

- Used CMTR data to calculate ferrite content and fracture toughness
- Used statistical approach to analyze data
  - Used normal or lognormal distributions to model datasets, as appropriate
- Developed 95/95 upper bounds for ferrite content
  - Allows for prediction of ferrite content without 100% of CMTRs
- Developed 95/95 lower bounds for fracture toughness
  - Demonstrates high remaining toughnesses after TE effects have saturated

Process

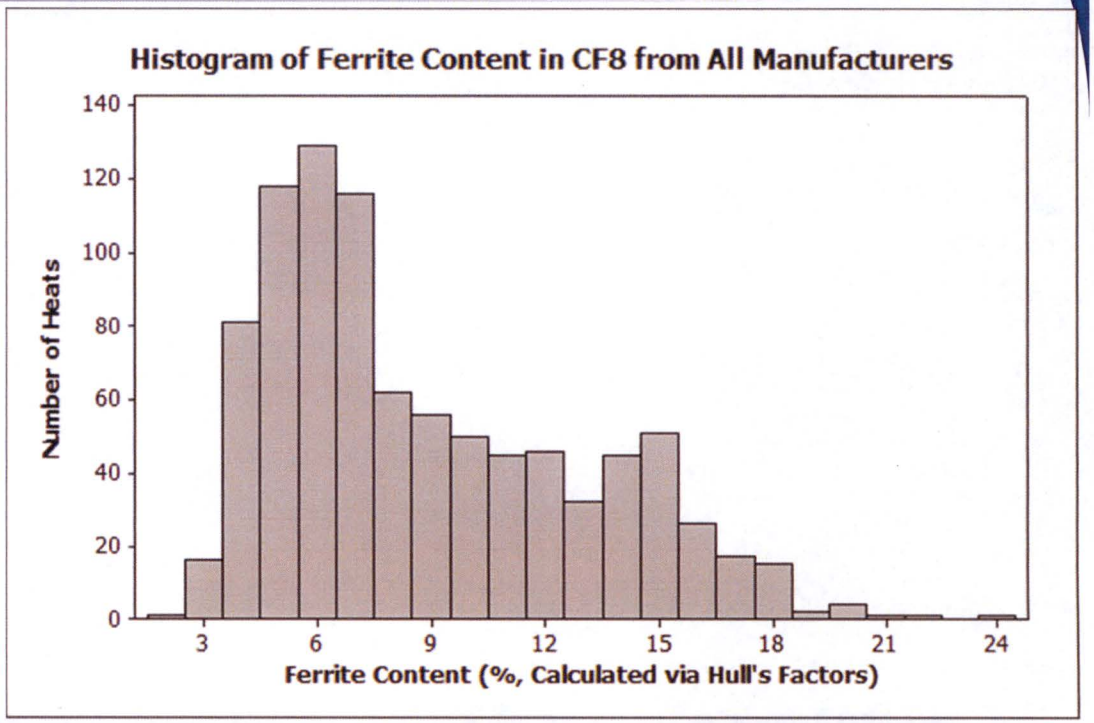
- Approach evaluated by PWROG expert panel composed of utility personnel
- Approach presented to NRC (5/27/15)
- Draft report with PWROG utility members for review
- Final report can be made available to the Staff for information only
- Will be referenced in subsequent A/LAI 7 responses, CASS-related RAI responses

Results of Ferrite Content Analysis – Summary

- Population of CASS heats grouped by manufacturer because that division of the data resulted in the most credible analytical subsets
- Knowledge of manufacturer (and component) provides a reasonable means of predicting maximum ferrite content in the absence of component or part specific data
  - Screening to 20% at 95/95 confidence ferrite content would screen out compositions of concern
    - Use of "by manufacturer" statistics would provide reasonably assured approach for not exceeding 20% screening criteria
- Implementation strategy flow chart provides options for plant specific use in A/LAI 7 response

Results of Ferrite Content Analysis – Overall Population

- Shows majority of CF8 heats are low ferrite
- Lognormal distribution used to model data
- Randomly selected component has a low probability of being over 20% ferrite
  - 0.5% of population over 20% ferrite



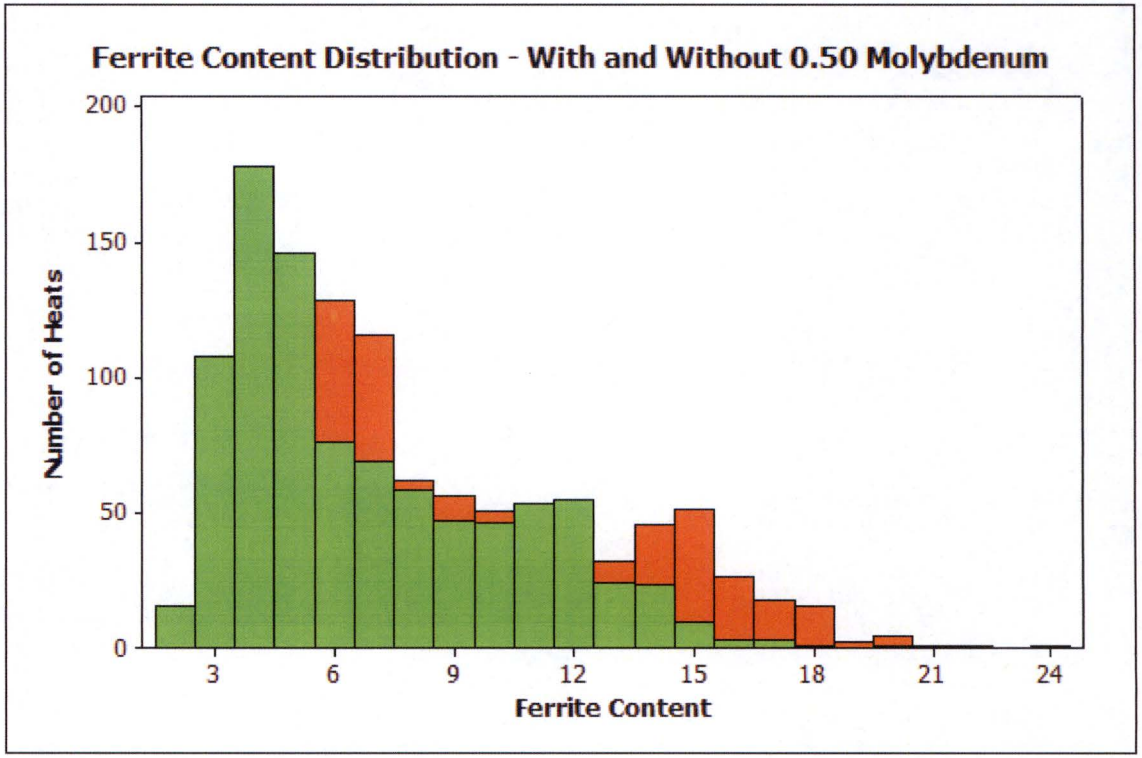
Total Heats	Mean	Standard Deviation	Minimum Ferrite Content	Maximum Ferrite Content	Heats Over 15% Ferrite	Heats Over 20% Ferrite	95/95 Upper Bound
915	8.8%	4.1%	2.5%	23.8%	90	5	17.5%

Results of Ferrite Content Analysis by Manufacturer

- Analysis by manufacturer indicates that they practiced effective statistical process control
  - Allows prediction of ferrite upper bound
- Distributions stable over time
  - Same manufacturer, same process, similar compositions
- Correlation between ferrite and manufacturer is strongest
- Possibility of using statistical distributions by manufacturer to justify predicting maximum expected ferrite content to be below screening criteria

Results of Ferrite Content Analysis by Manufacturer

- When not reported, molybdenum is assumed to be 0.50 weight percent in ferrite calculations
  - 0.50 is maximum allowed by ASTM A351 specification
  - Adds conservatism to ferrite content calculation



When zero molybdenum is assumed in the calculations – no heats would be over 20% ferrite

Results of Ferrite Content Analysis by Manufacturer

Manufacturer	Count	Mean	Standard Deviation	Distribution	95/95 Upper Bound
Static-Cast CF8					
AMP	14	6.2	1.7	Lognormal	11.9
CSF	15	10.0	3.6	Normal	19.3
Esco	23	10.7	3.3	Normal	18.4
Kearsarge	498	6.2	1.7	Lognormal	9.7
PF	10	10.7	4.8	Normal	24.3
QACC	24	9.4	4.0	Normal	18.7
Valcast	16	5.6	2.0	Lognormal	13.4
Waukesha	263	13.3	3.0	Normal	18.7
Wollaston	39	12.0	4.5	Lognormal	24.5
Centrifugally-Cast CF8					
Kearsarge	90	5.5	1.4	Lognormal	8.3
WC (Ladle Analysis)	185	16.3	3.5	Normal	22.7
WC (Product Analysis)	185	14.2	3.6	Normal	20.8
Static-Cast CF3M					
Wollaston	227	18.4	4.7	Normal	27.0

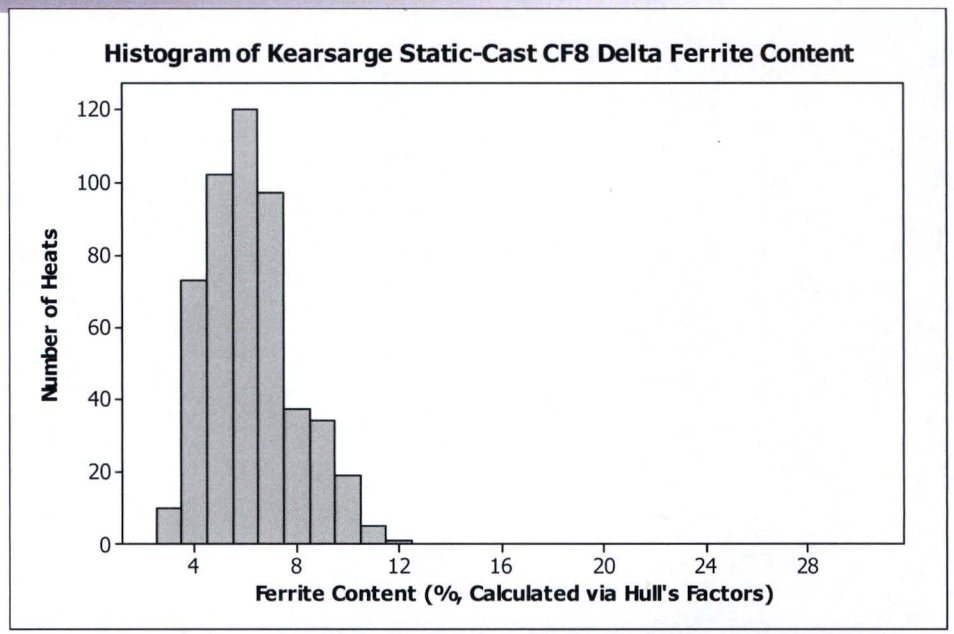
* *Ferrite content calculated via Hull's factors*

Identification of manufacturer can provide an increased precision prediction of CASS ferrite content

Results of Ferrite Content Analysis by Manufacturer

Kearsarge

- Provided 588 heats out of the 1410 analyzed
- Both static and centrifugal CF8 castings
- 50% of all centrifugal castings, 55% of all static castings
- Very similar compositions for centrifugal and static cast ferrite content
- Very low ferrite content
- Modeled well by a lognormal distribution

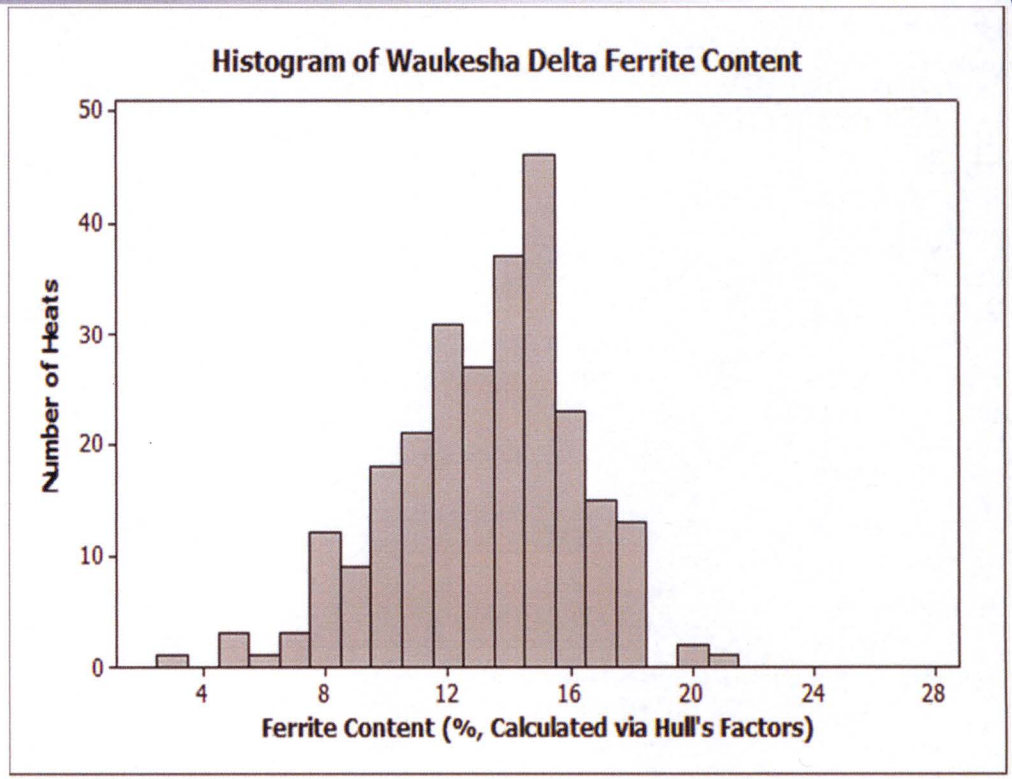


Casting Type	Count	Mean Ferrite	Standard Deviation
Static	498	6.2	1.7
Centrifugal	90	5.5	1.4

Results of Ferrite Content Analysis by Manufacturer

Waukesha

- Provided 263 heats out of the 1410 analyzed
- All static CF8 castings
- 18% of all castings, 29% of CF8 static castings
- Moderate ferrite content
  - 3 heats above 20%



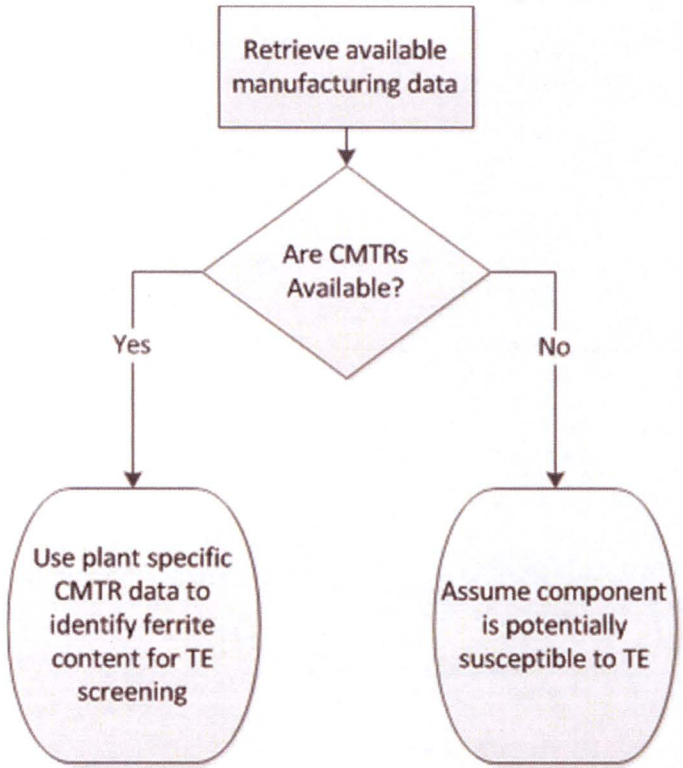
Results Summary

- Analysis of ferrite content by manufacturer indicates that they practiced effective statistical process control
  - Allows prediction of ferrite upper bound
- Statistical approach provides reasonable assurance that CASS RV internals materials are below 20% ferrite content
- Knowledge of manufacturer of a given component provides a more precise means of predicting maximum ferrite content in the absence of concise documentation of plant specific data

Implementation

Key use of this statistical methodology is for prediction of ferrite content in the absence of detailed fabrication records…

- Current practice has been that a component be assumed potentially susceptible to TE when plant-specific data is not readily available
  - Based on assuming worst-case allowed by material specification
- Example: Component without readily available component specific CMTR effectively screens in for TE automatically



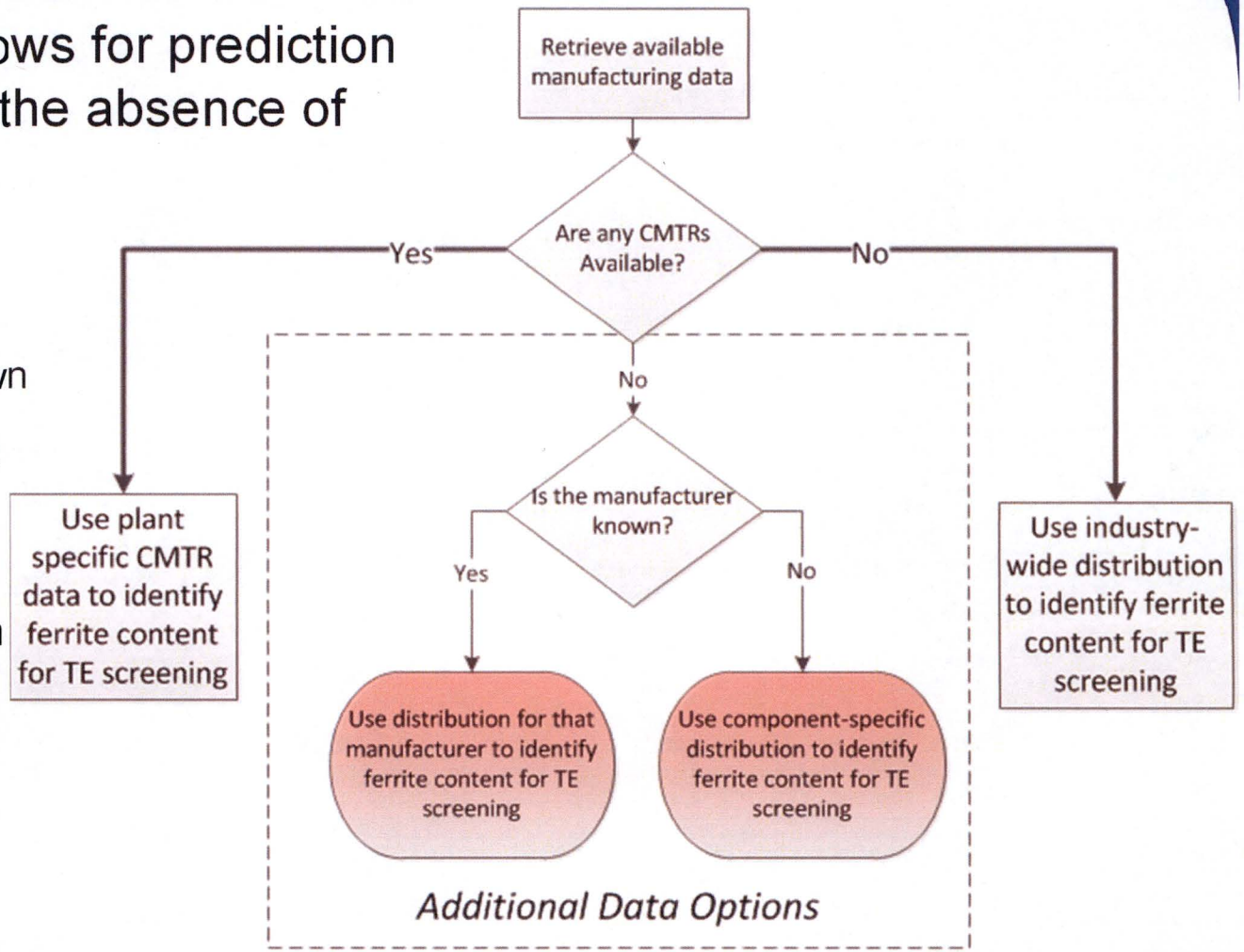
Implementation – Statistically-based Process

Use of statistics allows for prediction of ferrite content in the absence of CMTRs

Supplement overall dataset when:

- Manufacturer is known
- Component is known

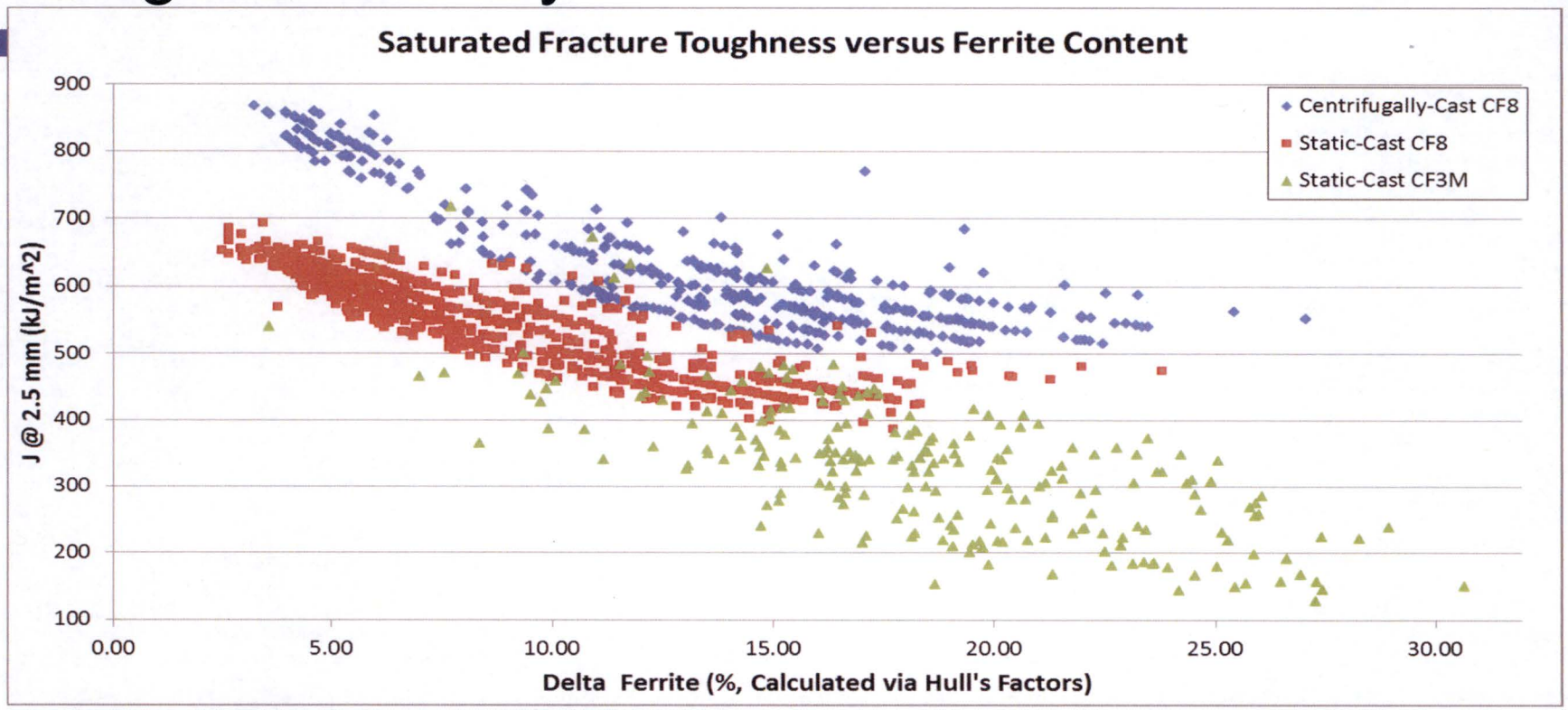
Potential to identify "maximum expected ferrite content less than 20% screening criteria" for plant components



Results of Saturated Fracture Toughness Analysis

- Chemical composition data used to calculate ferrite content can also be used to calculate saturated fracture toughness (for TE)
  - NUREG/CR-7185 methodology
- Demonstrates conservatism of ferrite screening values
- Large margins against 255 kJ/m^2 criterion

Results of Saturated Fracture Toughness Analysis



- Scatter and low values typically introduced by high Mo CF-3M data
- CF8 materials show saturation fracture toughness much greater than 255kJ/m^2
  - ➢ Inherent conservatism in Grimes letter screening criteria…
    - Indicates excessive conservatism when screening by ferrite content, even at screening criterion greater than 20%

Saturation fracture toughness values calculated via NUREG/CR-7185 methodology

Results of Saturated Fracture Toughness Analysis

Manufacturer	Count	Mean	Standard Deviation	Distribution	95/95 Lower Bound
Static-Cast CF8					
AMP	14	605	38.5	Normal	505
CSF	15	504	54.5	Normal	364
Esco	23	524	54.4	Normal	397
Kearsarge	498	592	36.9	Normal	527
PF	10	547	60.4	Normal	376
QACC	24	545	72.5	Normal	378
Valcast	16	593	38.1	Normal	496
Waukesha	263	462	35.4	Normal	398
Wollaston	39	544	45.1	Normal	448
Centrifugally-Cast CF8					
WC (Ladle Analysis)	185	581	50.7	Normal	487
WC (Product Analysis)	185	590	55.3	Normal	488
Static-Cast CF3M					
Wollaston	227	327	101.7	Normal	141

Values in table are saturated fracture toughness given as J at 2.5 mm, in kJ/m^2

Conclusions

- Statistical approach can predict ferrite content with reasonable assurance

95/95 upper bound for ferrite content is below 20% for CF8 materials

- All CF8 material shown to have high remaining toughness after TE

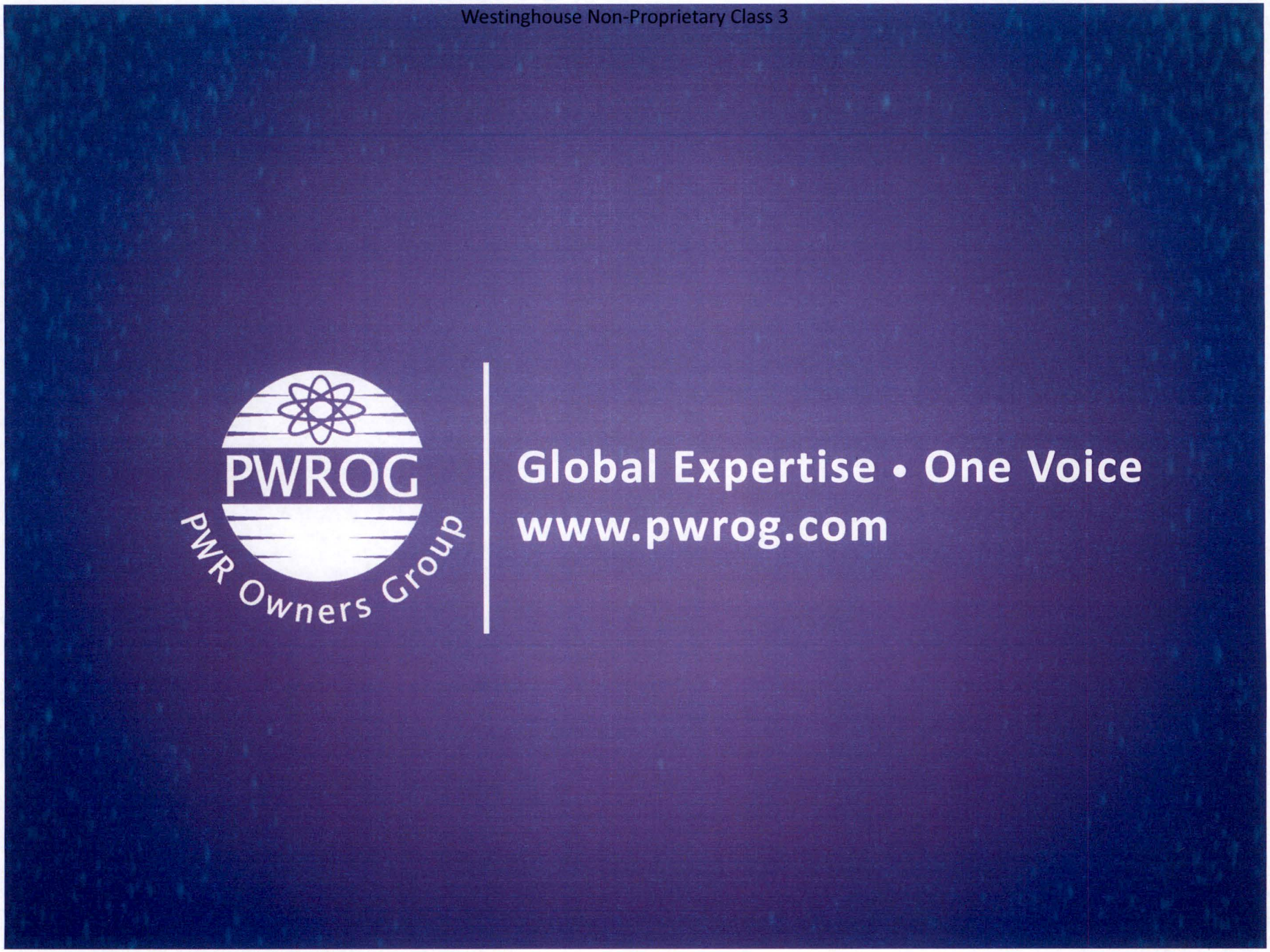
- ***Average saturated fracture toughness of CF8 material is <u>more than double</u> the screening criterion***
- ***Minimum fracture toughness 100 kJ/m2 over screening criterion (255 kJ/m^2)***

Conclusions

- Statistical analysis of data provides a reasonable resolution to generic fleet materials questions
- Plan to use this approach to address A/LAI 7 for CASS internals
- Statistical approach will be carried forward to additional applications as applicable

Questions?

The Materials Committee is established to provide a forum for the identification and resolution of materials issues including their development, modification and implementation to enhance the safe, efficient operation of PWR plants.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