U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

Technical Basis for CASS Aging Management "Combined effects of TE & IE"

May 5, 2016

Outline

- Review activities related to CASS screening for license renewal aging management.
- Review technical basis that supports screening of CASS for TE alone.
- Goal to create similar screening criteria for TE & IE.
- Present staff's technical basis for BWRs.
- Discuss how this approach affects PWRs.
- Proposed revision to GALL.

Timeline for CASS issues

- Grimes letter (2000)
- GALL (2001, 2005, 2010)
- MRP-175 (2005) & 276 (2007)
- MRP-227 (2009)
- BWRVIP-234 (2009)
- MRP-227-A w/ Action Item 7 (2011)
- Public & closed meetings (2012-2014)

Timeline - continued

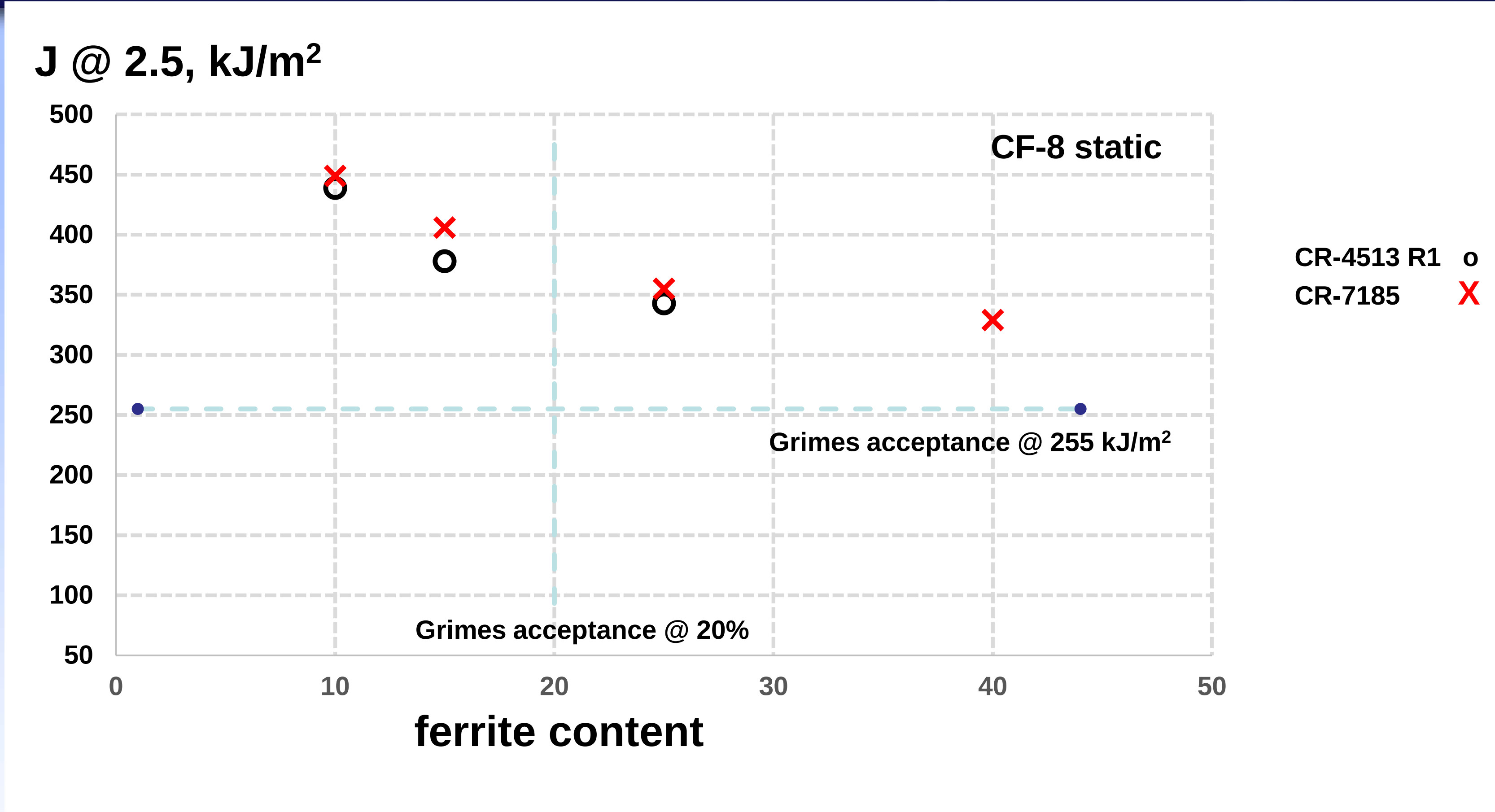
- BWRVIP-234 RAI response (2014)
- NRC draft TE&IE screening (2014)
- MRP 2014-019, industry guidance for RAI response
- PWROG-14048-P (2014), generic LSC
- BWRVIP 2015-025, final industry position
- GALL-SLR (2015)
- MRP-227, Rev. 1 (2015)
- PWROG-15032-NP (2016), statistical analysis of CMTRs
- BWRVIP-234 SE (2016), supersedes 2014 draft TE+IE screening

4

Grimes Letter from 2000

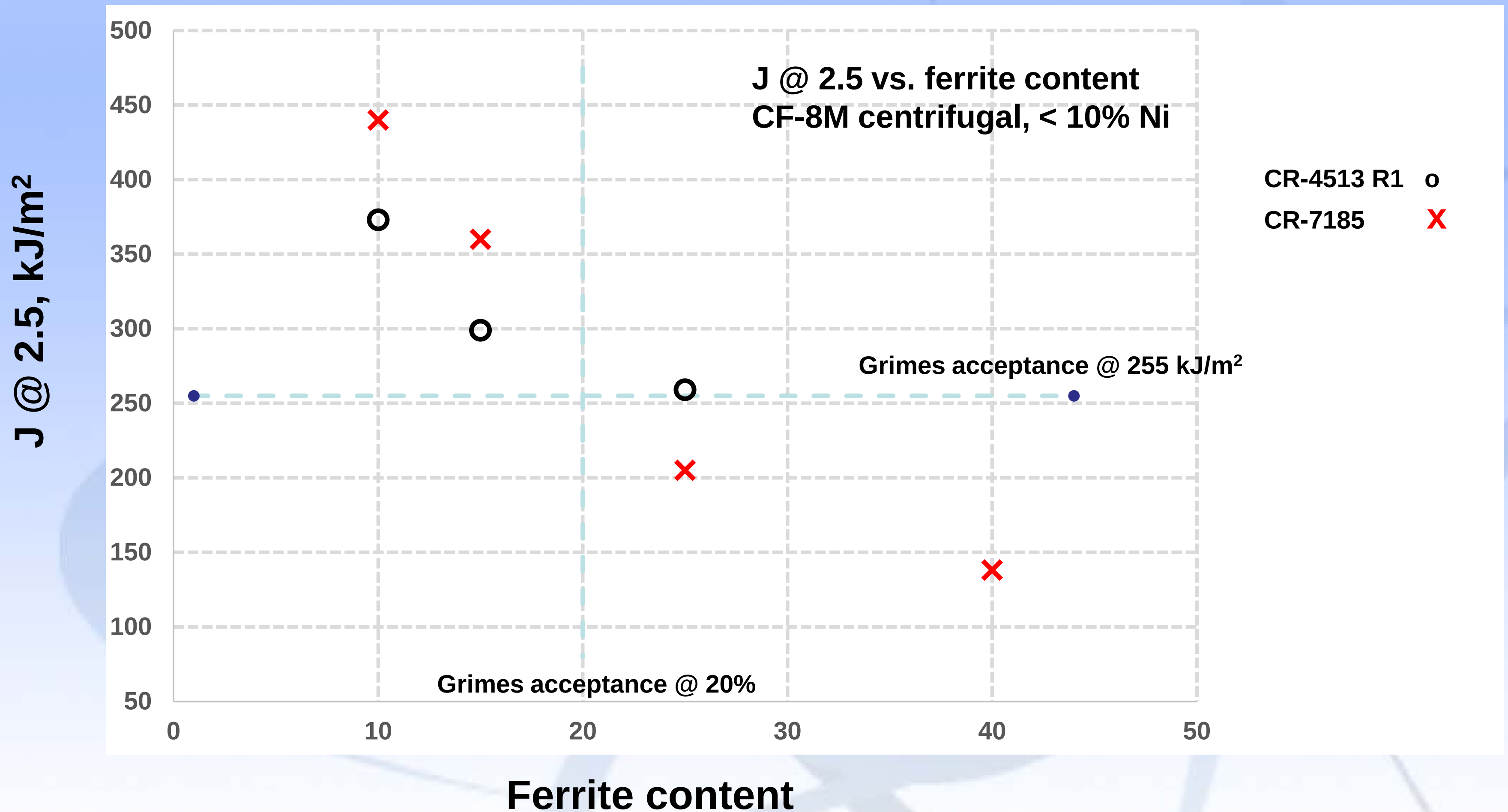
- For TE alone, valid up to $1x10^{17}$ n/cm^2 (0.00015 dpa)
- For CF-8 static cast, NUREG/CR-4513, Rev. 1 lower-bound of measured J2.5
  - 15-25% ferrite 343 kJ/m2
  - 10-15% ferrite 378
  - < 10% ferrite 439
- Screening for CF-8 static cast; ≤ 20% ferrite needs no further evaluation.
- 255 kJ/m^2 value was established as a conservative acceptance criteria for CASS piping based on a generic flaw tolerance analysis for RCS piping elbows.
- Further evaluation required for fluence > 0.00015 dpa

Assessment of CF-8 Static Cast



Screening was conservative in terms of J (margin of 343-255) and ferrite content (margin of 25-20%) for CF-8 static cast materials.

Assessment of CF-8M Centrifugal Cast



Grimes provides a margin on ferrite, but not on J @ 2.5

Screening Process

- Both industry and NRC want a screening process for TE&IE that that covers RVIs.
- All agree > 0.00015 dpa is too conservative for fluence screening.
- Initially BWRVIP had more conservative fluence threshold than MRP, but now has adopted same as MRP.
- 1 dpa is consistent with IE screening criterion for PWRs and bounds expected fluence for BWR CASS RVIs after 60 years of service.
- Need to reevaluate toughness screening level for RVIs

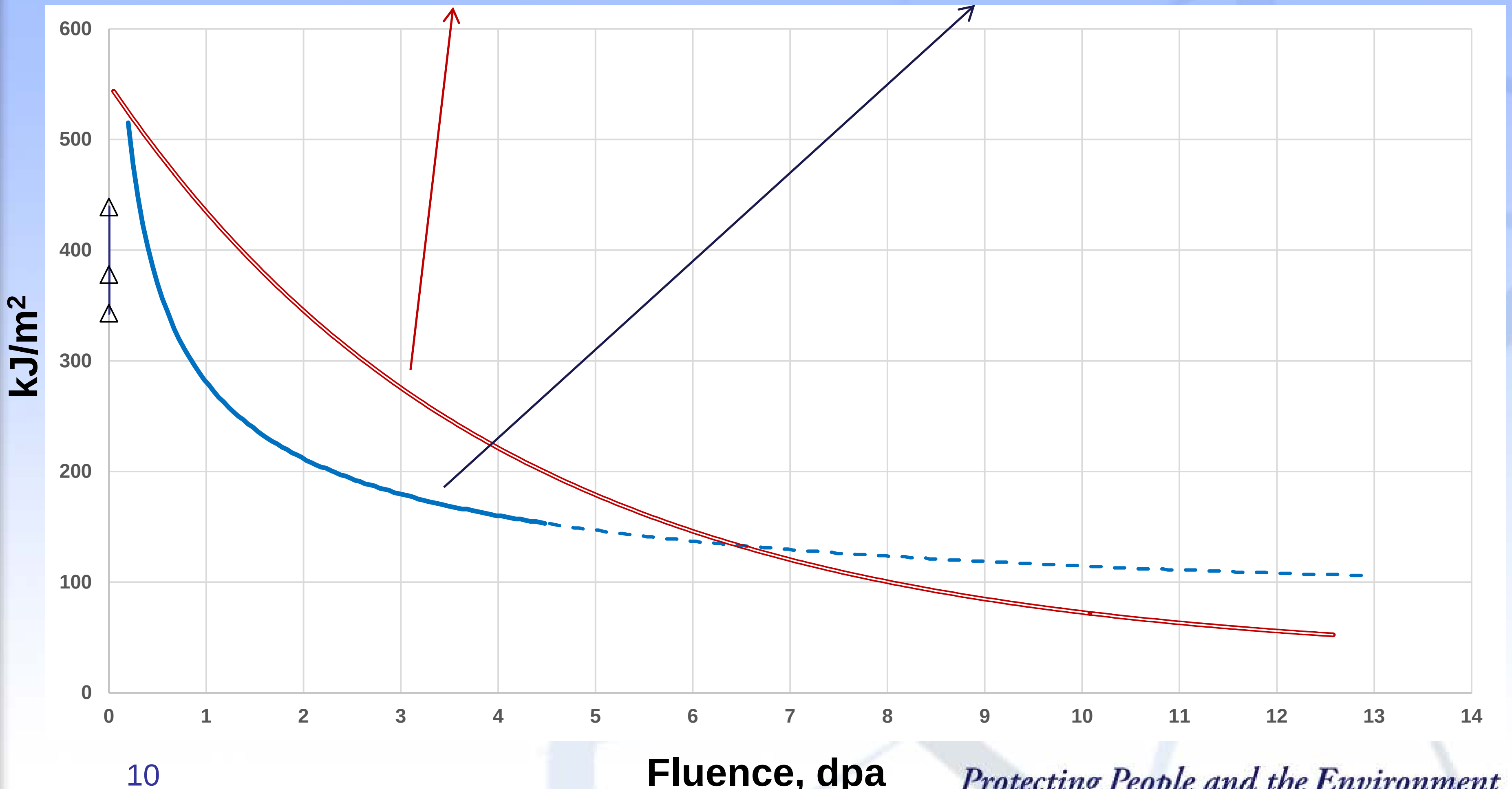
TE & IE

- Possible synergistic effect? Little database to evaluate.
- BWRVIP-234 estimates toughness without explicitly considering TE alone or ferrite content.
  - Z-factor from ASME Code and
  - BWRVIP-100 EPFM methodology
- MRP-276 does not consider synergistic effect.
- These approaches are not consistent with tech basis for Grimes letter screening.
- BWRVIP 2015-025 proposes lower-bound toughness of CF-3/8 as a function of dpa, but depends on RT tests and doesn't bound TE alone.
- Prediction of δ_c by Hull has its own uncertainty.

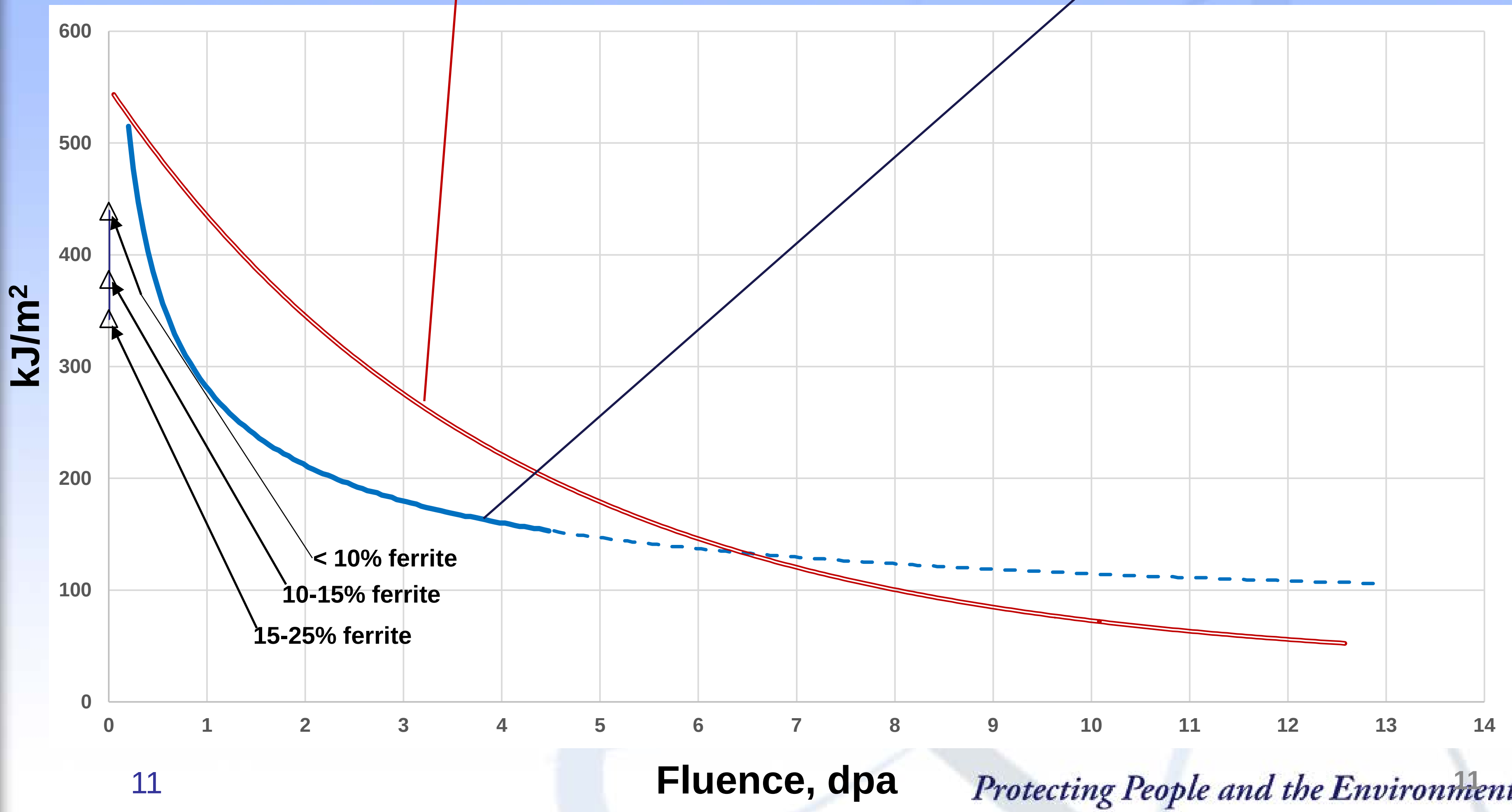
Prediction of toughness vs. dpa

CF-3/8; ≥ 0.02 dpa; @ RT

BWRVIP 2015-025 vs. BWRVIP-100

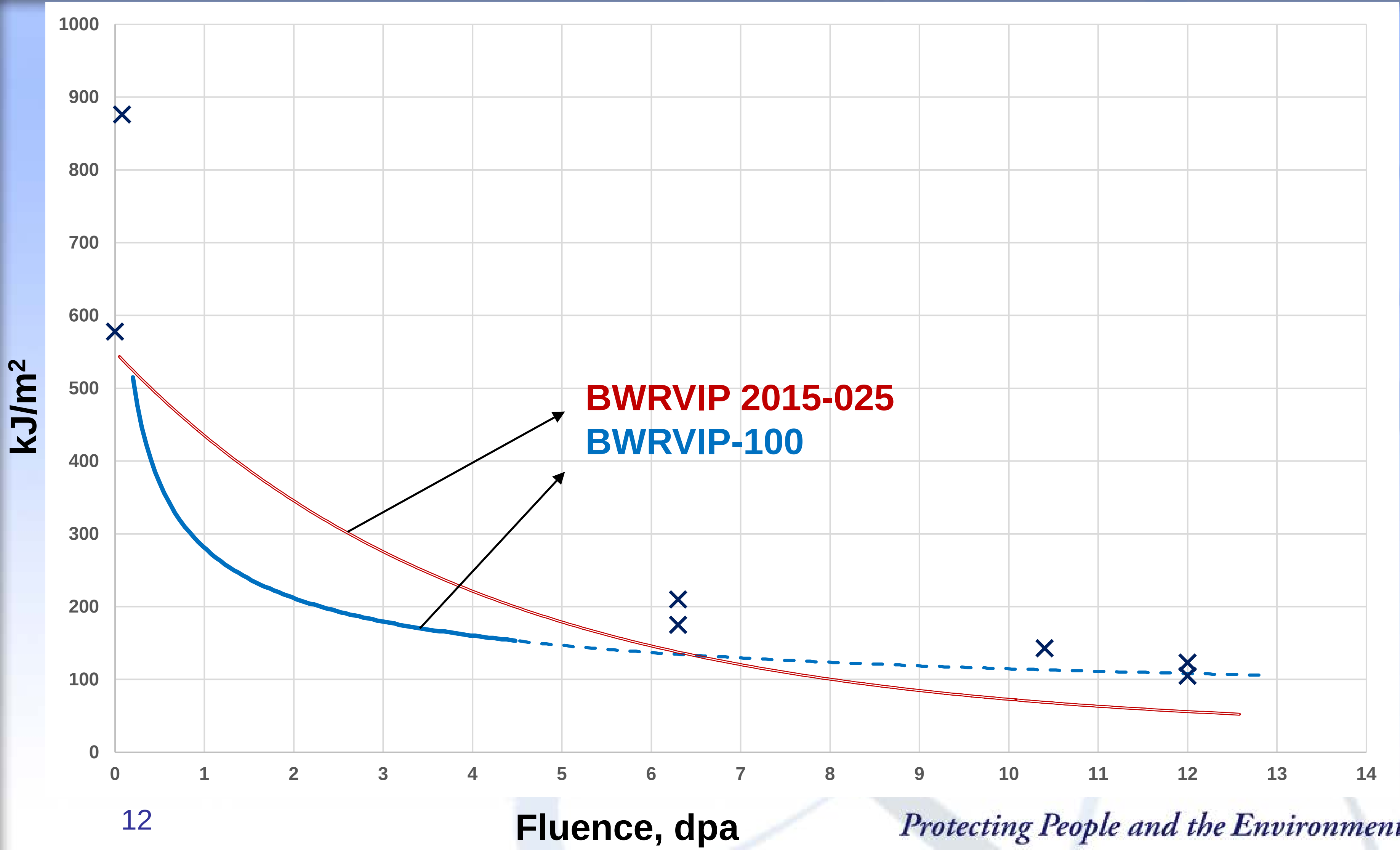


BWRVIP 2015-025 vs. BWRVIP-100



11

Kim Data for J@2.5, RT Tests Including TE Alone



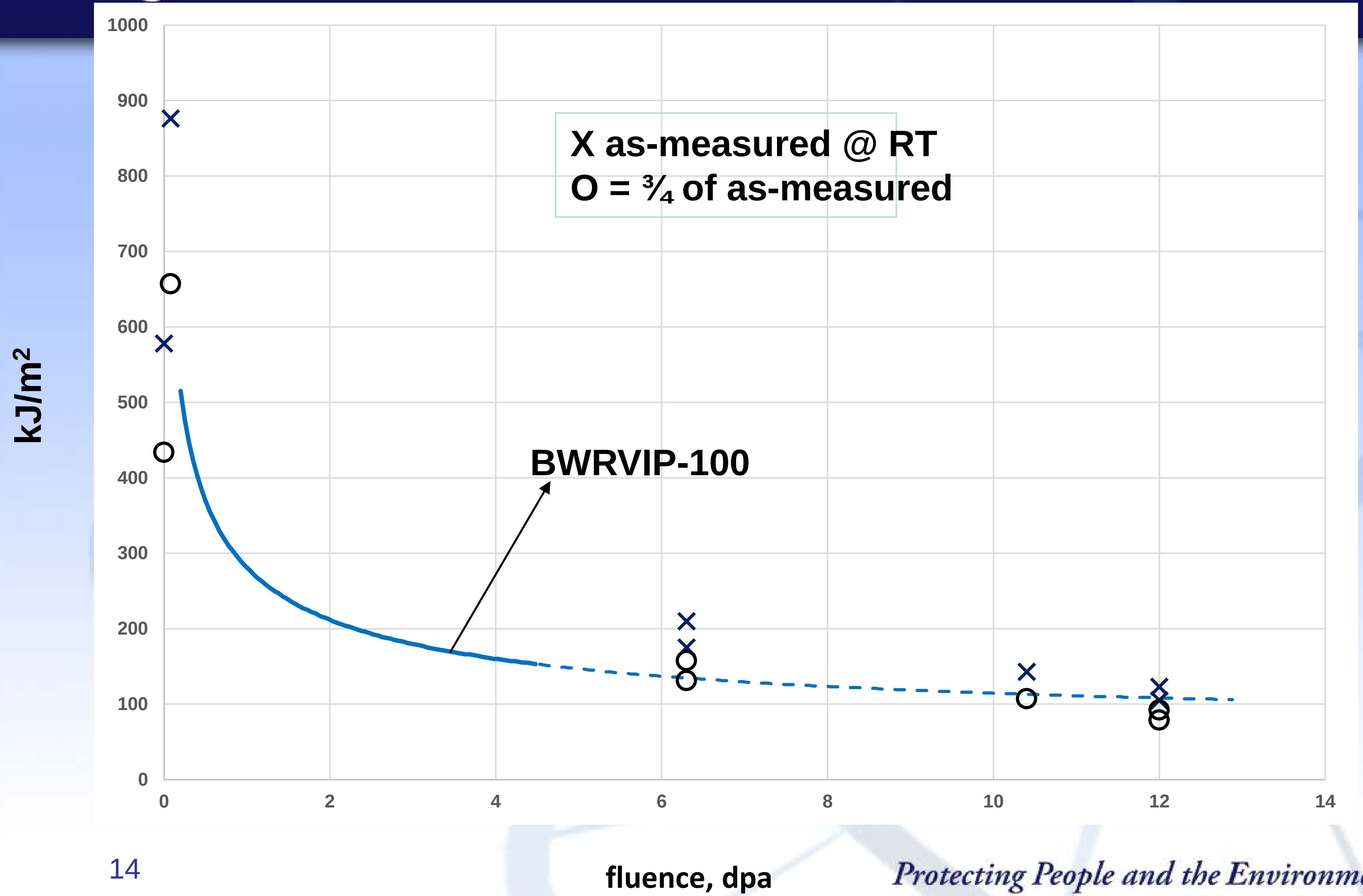
Temperature correction: from BWRVIP 2015-025 & NUREG/CR

J @ 1 mm for saturation from Fig. 14, NUREG/CR-4513, Rev 1				
	% ferrite	J @ 1 RT	J @ 1 290 C	Ratio 290 C/RT
CF-3	21	504	358	71.0%
CF-3 impeller	20	533	369	69.2%
CF-8	15	354	296	83.6%
				average about 75%

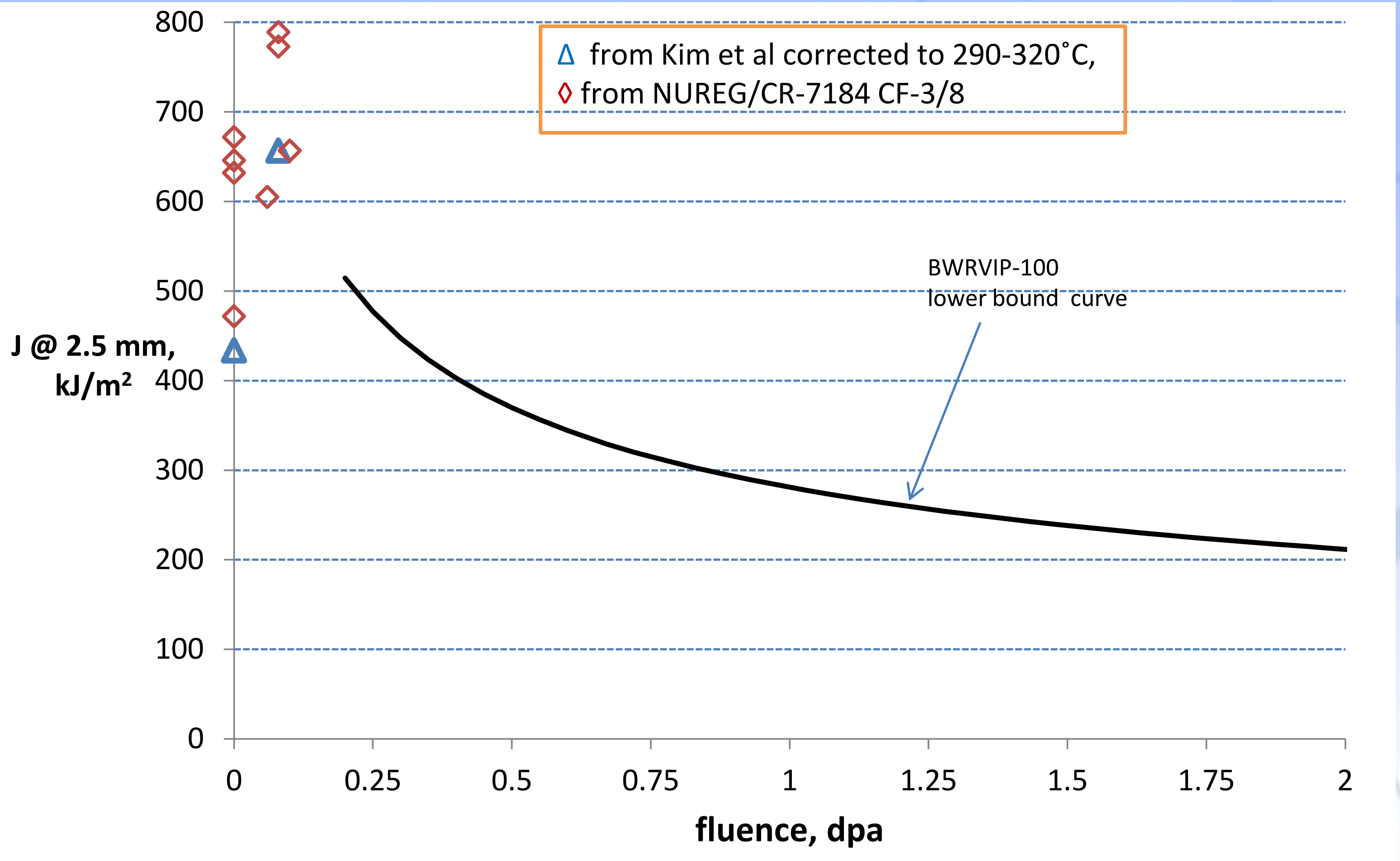
J @ 2.5 mm for saturation from Fig. 14, NUREG/CR-4513, Rev 1				
	% ferrite	J @ 2.5 RT	J @ 2.5 290 C	Ratio 290 C/RT
CF-3	21	768	516	67.2%
CF-3 impeller	20	820	537	65.5%
CF-8	15	511	412	80.6%
				average about 71%

Correction is considered OK when RT and 290° C are both 100% ductile, may not hold for higher ferrite or Mo-containing CASS.

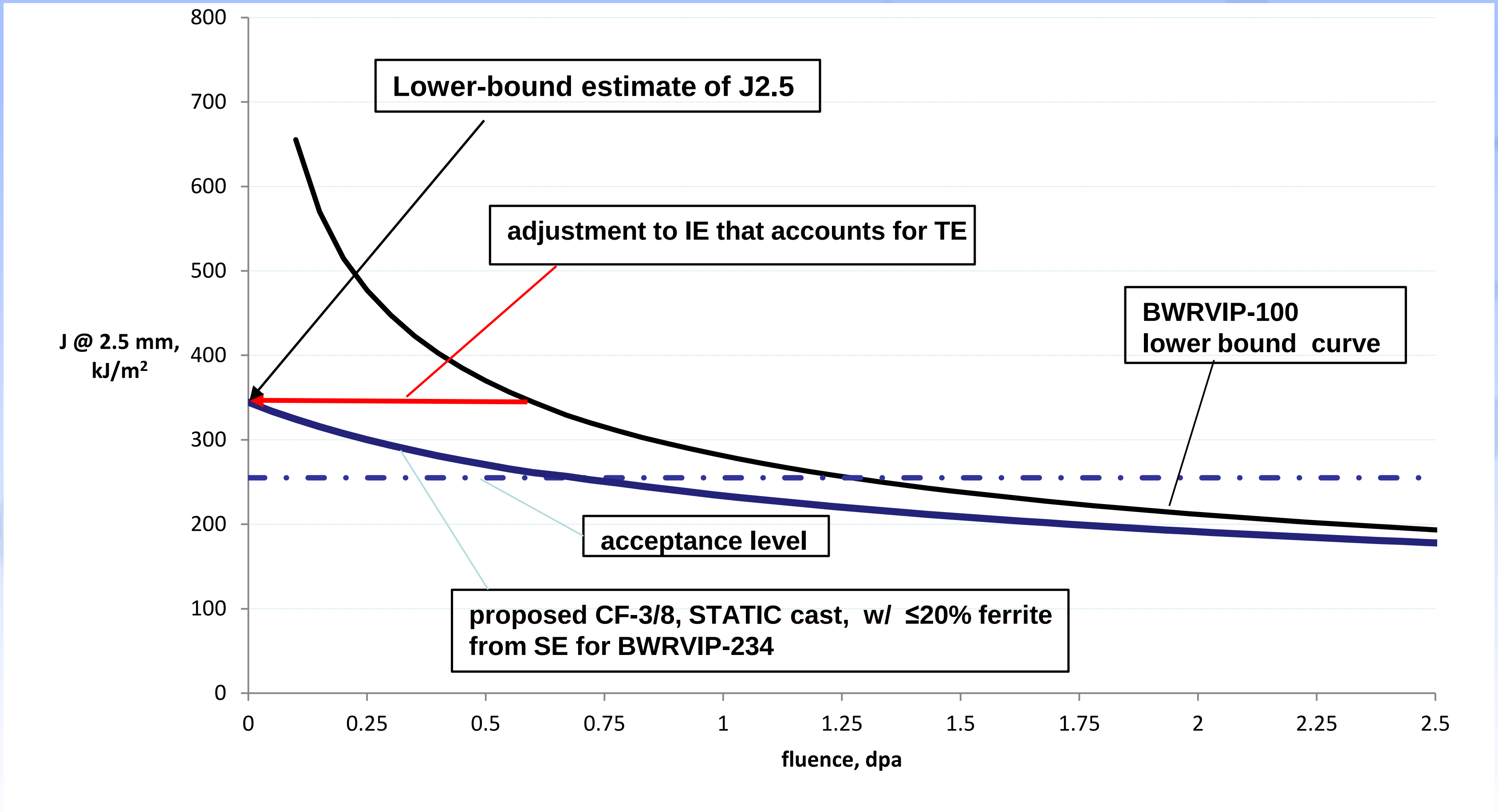
J@2.5 Corrected for Temperature



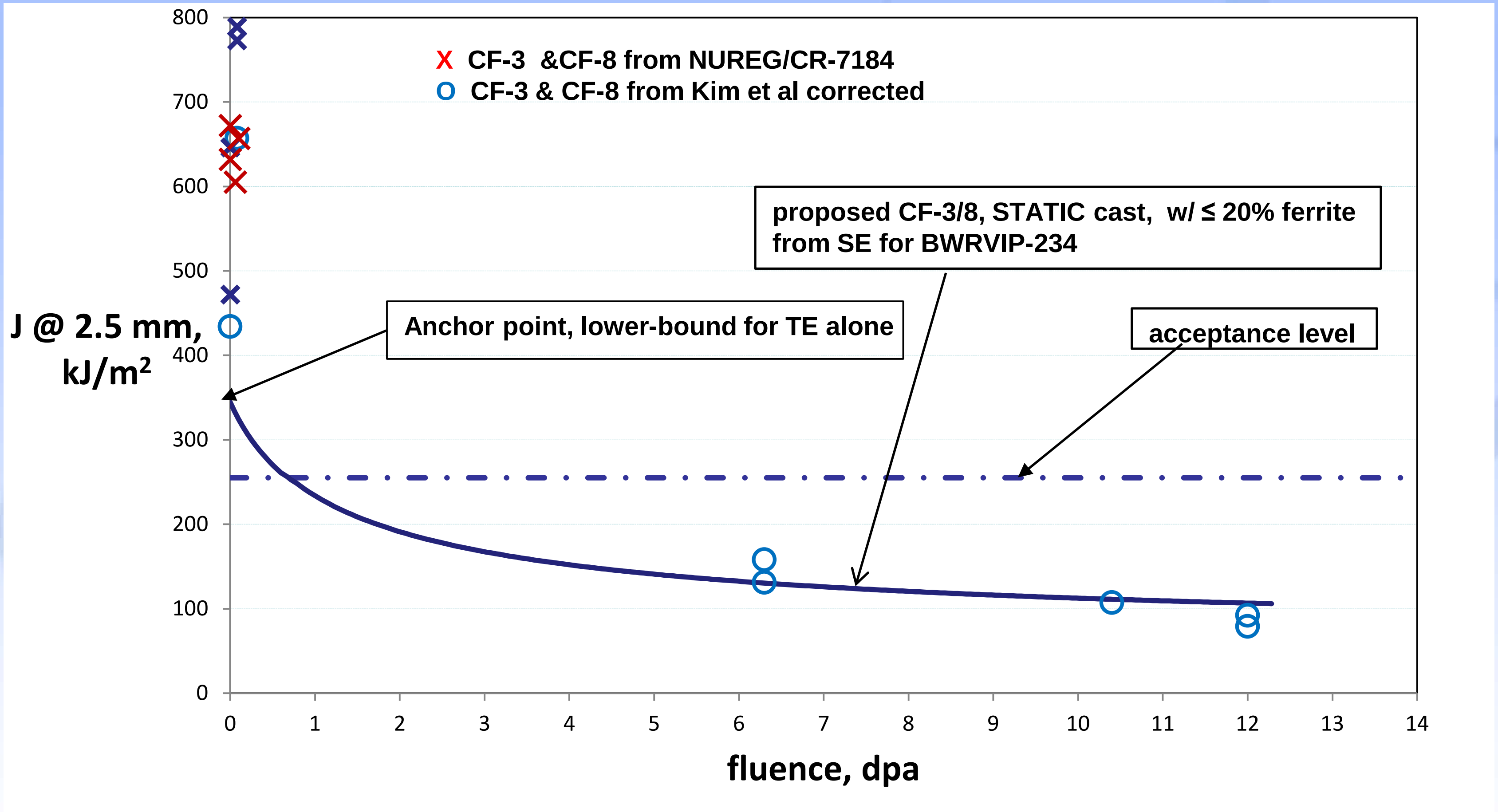
Focus on Low dpa, add NUREG/CR-7184



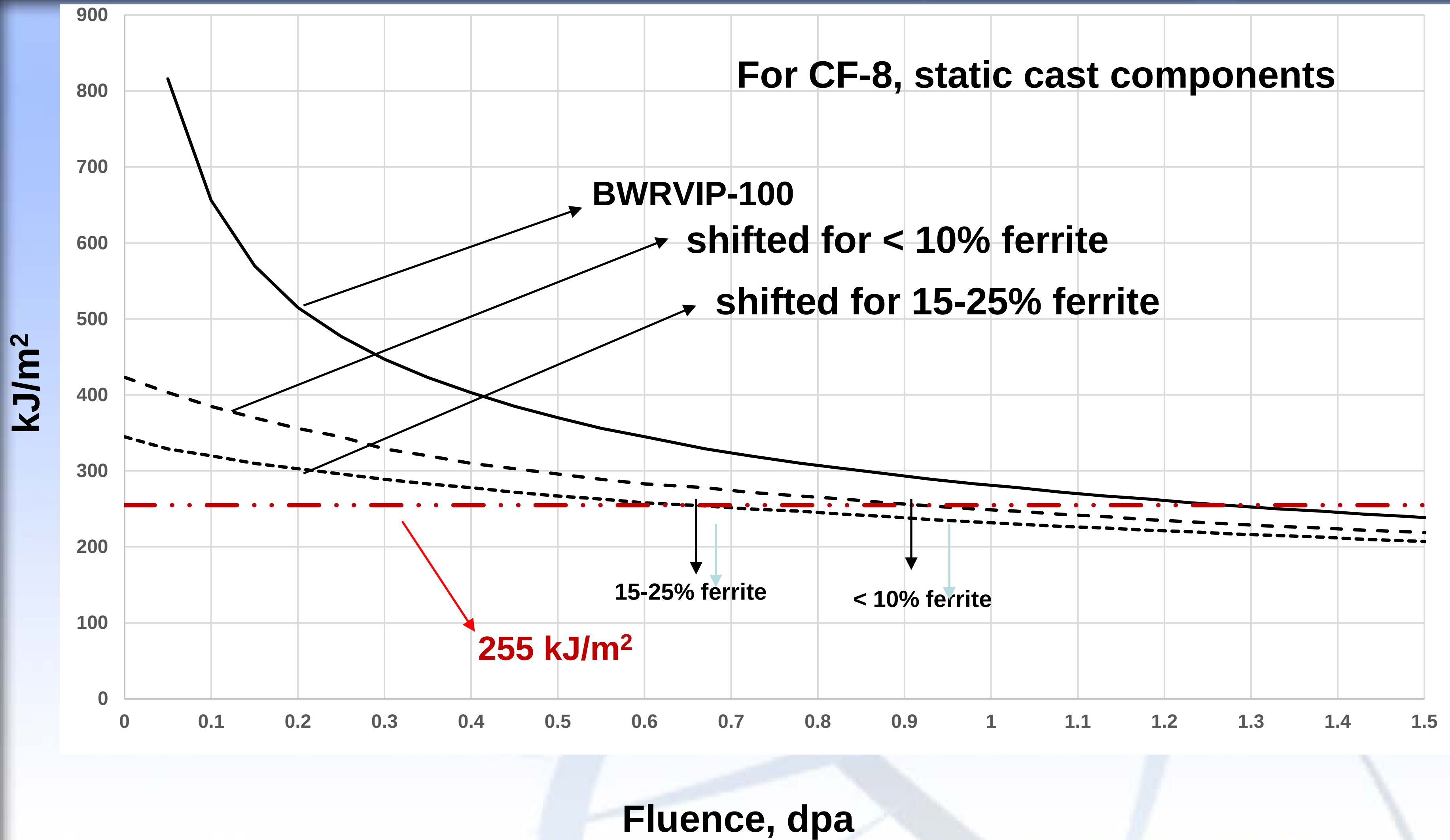
Shift BWRVIP-100 to include TE



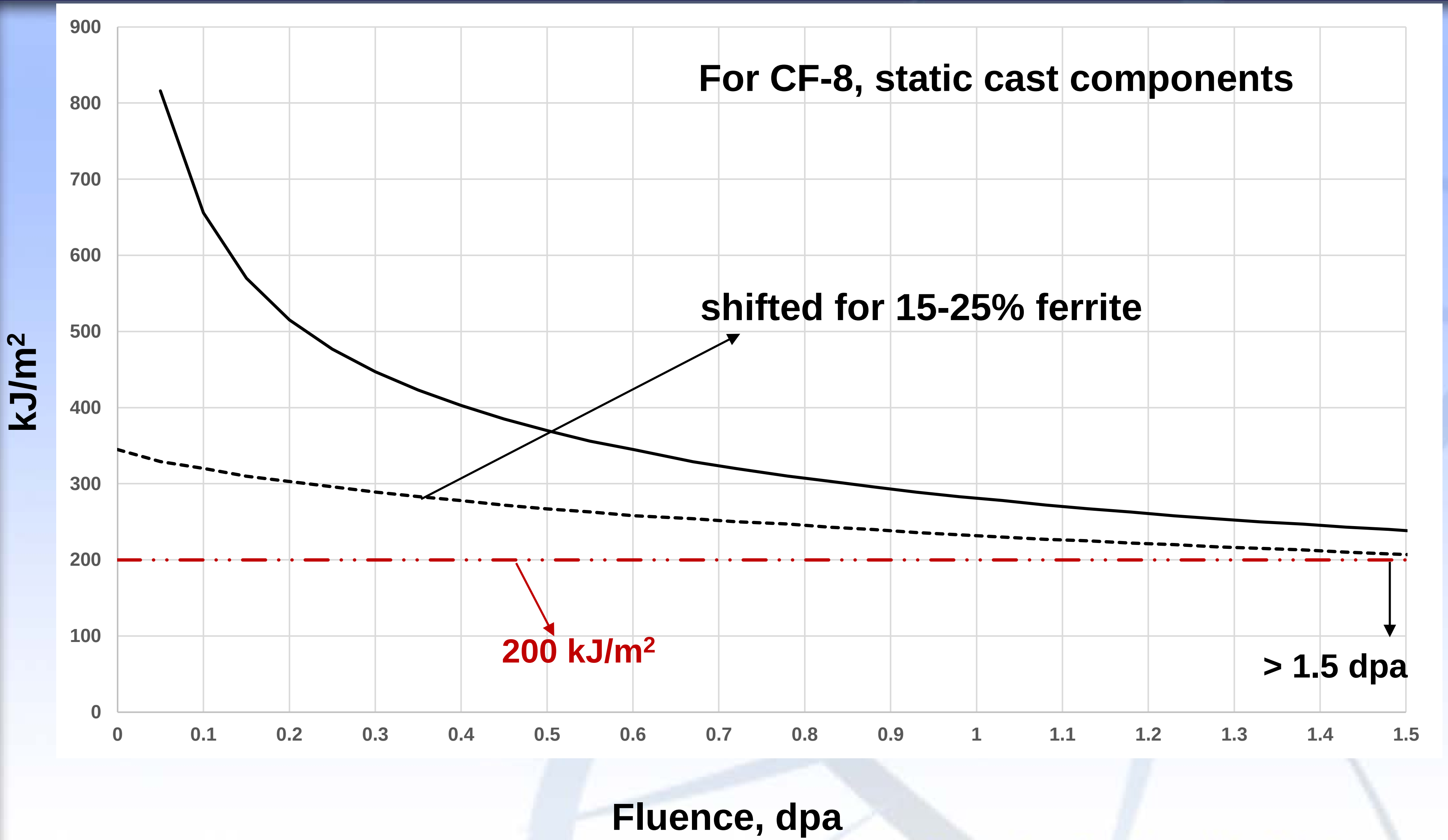
Proposed J @ 2.5 vs. measured



Depends on Anchor Point



Depends on Acceptance Criteria



19

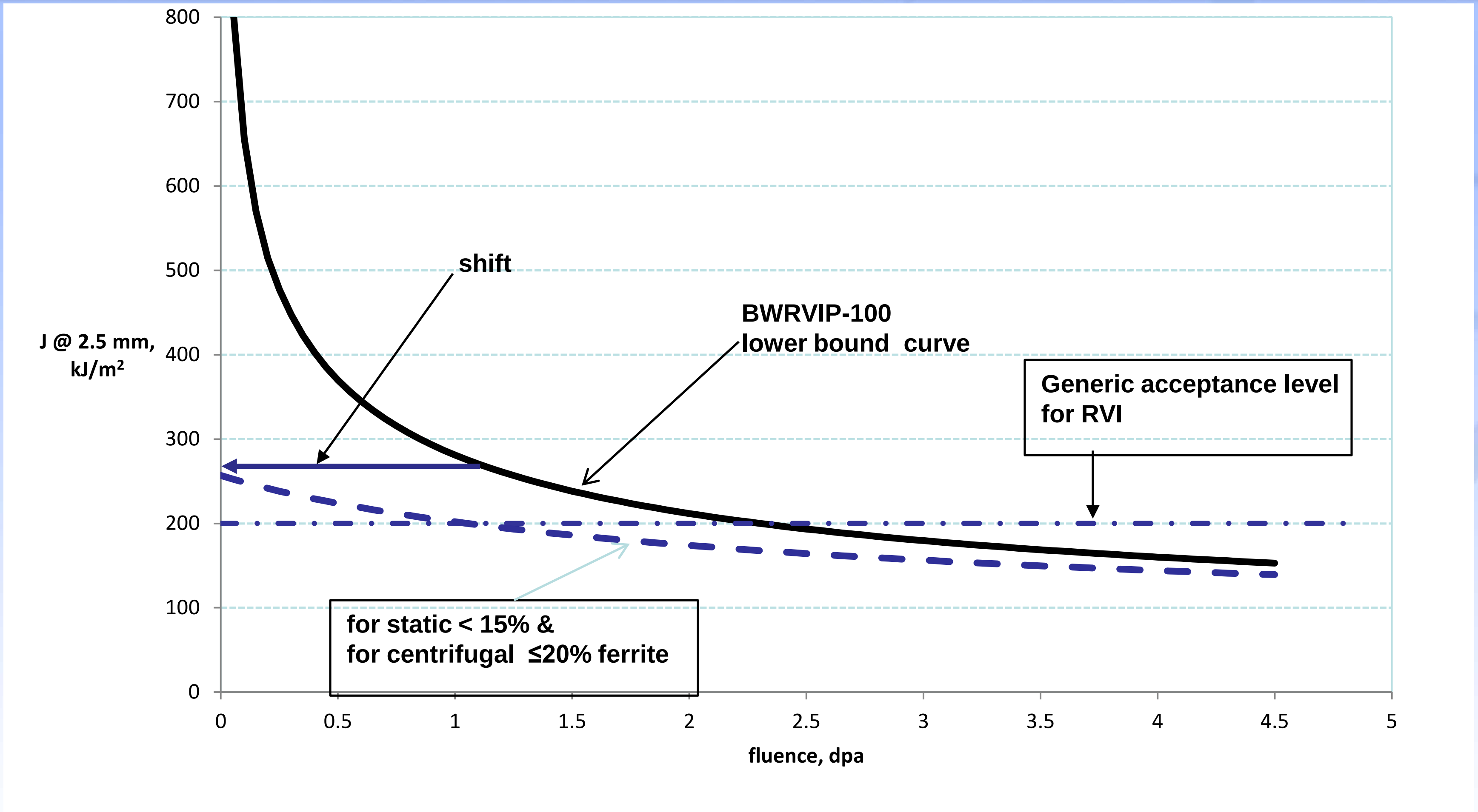
Acceptance criteria

- MRP based fluence and ferrite screening limits to correlate with $J_{2.5}$ > 255 kJ/m^2, consistent with criteria established by generic piping component flaw tolerance analysis.
- For RVIs, Attachment C to BWRVIP 2015-025 cites three generic cases that suggest the crack driving forces are much lower, 4 to 83 kJ/m^2.
- Given the lower generic driving forces, the staff recommends the toughness basis for the screening criteria be reduced from 255 to 200 kJ/m^2.

Consideration for PWRs

- Revised NRC screening is consistent with MRP-175.
- Allows PWRs to screen CF-3/8 materials at 1 dpa and 20% ferrite, but provides NRC-approved method to estimate toughness for functionality analyses, e.g. lower support columns for Westinghouse .
- Use similar approach for CF-3M/8M with component-specific basis for acceptance criteria & appropriate anchor for TE alone.
- Some plant-specific AMPs include new CF-3/8 components. Must be considered in response to Action Item 2 and 7.

Example for CF-3M/8M



22

GALL Revision

- Incorporate changes for CF-3/8 into XI.M9 with ISG, allows for public comment.
- BWRVIP-100 shift can be applied on as-needed basis to CF-3M/8M, but not included in ISG.
- Provides technical basis that can be revised with new test results.
- MRP could follow BWRVIP-234 SE.

NRC Staff Review of PWROG-15032-NP, Statistical Assessment of PWR RV Internals CASS Materials

May 5, 2016

Overview

- Statistical analysis of CMTRs for PWR RVIs,
- Calculated ferrite content from Hull's factors,
- Provides tech basis for screening according to Grimes letter without CMTRs.
- Based on data for around 1500 CASS heats,
  - static and centrifugally cast low-molybdenum CF8,
  - high molybdenum static cast CF3M
- Does not consider irradiation effects.

Staff Observations

- Large and representative data set
- TR uses methods endorsed in NRC guidance to estimate ferrite (NUREG/CR-4513 Rev. 1)
- For ferrite, statistical (95/95) upper bounds determined for each vendor and overall population
- For fracture toughness, 95/95 upper bounds determined for each vendor only
- Statistical approach seems generally sound
  - Some issues with toughness goodness-of-fit

Issue: Statistical Method

- Most vendor ferrite distributions (11 of 13) passed tests for normality/lognormality
- Only 6 of 13 toughness distributions passed the normality/lognormality tests (why?)
- Are deviations from normality/lognormality conservative?
- Were other distributions tried for toughness?
- Method of determining p-values needs better explanation (Draft RAI 3)

Issue: Irradiation Effects

- PWROG-15032-NP does not address effects of irradiation
- However, report is specifically intended for application to RVI components
- Does not affect TE screening, since this may be done before IE screening
- Other guidance needed for IE screening
- Staff may restrict use of $J_{2.5}$ values to fluence < $1x10^{17}$ n/cm^2.

Issue: Use of PWROG-15032-NP to Estimate Ferrite (Draft RAI 1)

- **Large sample of heats in dataset**
- **Use 95/95 upper bound ferrite (manufacturer or overall population) only if plant material untraceable to a specific CMTR?**
- **Use of overall population 95/95 upper bound ferrite versus most conservative 95/95 upper bound ferrite**
- **Does it matter since even the manufacturer with highest 95/95 ferrite would still have adequate toughness for TE alone?**

Effect of Kearsarge (Draft RAI 5)

- **Kearsarge accounts for > 50% of heats in dataset**
- **Kearsarge has low 95/95 upper bound ferrite (9.7%),**
- **Overall population 95/95 upper bound ferrite is thus biased toward a lower value**
- **Appropriate to use overall population 95/95 upper bound rather than most conservative, if manufacturer unknown?**
- **More conservative to use largest 95/95 upper bound ferrite for subset of manufacturers known to produce component of interest**
- **What is the 95/95 upper bound ferrite for the population excluding Kearsarge?**

Example

- Both Kearsarge and Waukesha made lower support columns for Westinghouse RVI.
  - Kearsarge
    - 95/95 upper bound ferrite = 9.7%
    - 95/95 lower bond toughness = 527 kJ/m^2
  - Waukesha
    - 95/95 upper bound ferrite = 18.7%
    - 95/95 lower bound toughness = 398 kJ/m^2
- If manufacturer unknown, use Waukesha 95/95?
- Could make a difference if toughness estimate needed, or adjustment for irradiation.

Issue: Use of PWROG-15032-NP to Estimate Fracture Toughness

- TR determined 95/95 lower bound $J_{2.5}$ fracture toughness for each manufacturer
- No overall population lower bound $J_{2.5}$ in TR
- What $J_{2.5}$ would be used if manufacturer unknown?
- Appendix D to TR estimated minimum $J_{2.5}$ based on composition – 340 kJ/m^2
- What would statistically determined lower bound $J_{2.5}$ be?

Issue: Use of PWROG-15032-NP to Estimate Fracture Toughness

- **Since virtually all CF8 materials could be screened out for TE using the TR, how would 95/95 lower bound $J_{2.5}$ values be used?**
  - **Use in flaw tolerance or functionality evaluations?**
  - **Use to show margin to account for additional loss of toughness due to irradiation?**
  - **Support for adequacy of existing CASS screening criteria for TE?**
- **CF3M material $J_{2.5}$ < 255 kJ/m^2 – Use 95/95 $J_{2.5}$ in flaw tolerance or functionality evaluation?**

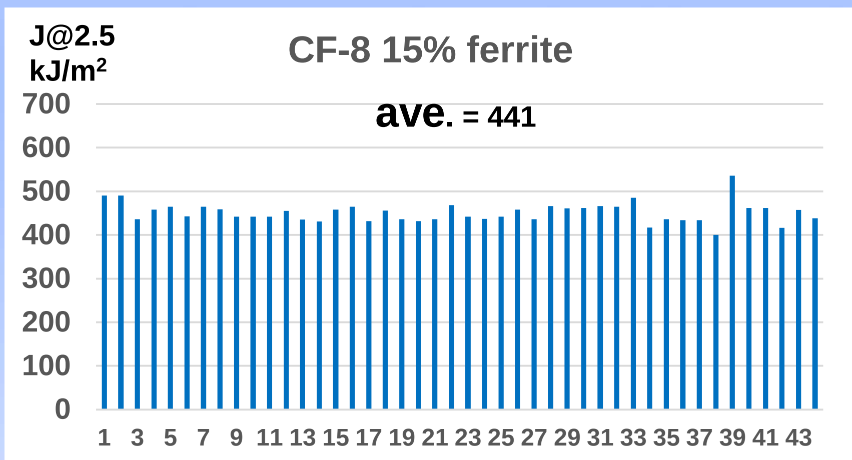
Issue: Conservatism of 95/95 Fracture Toughness Values

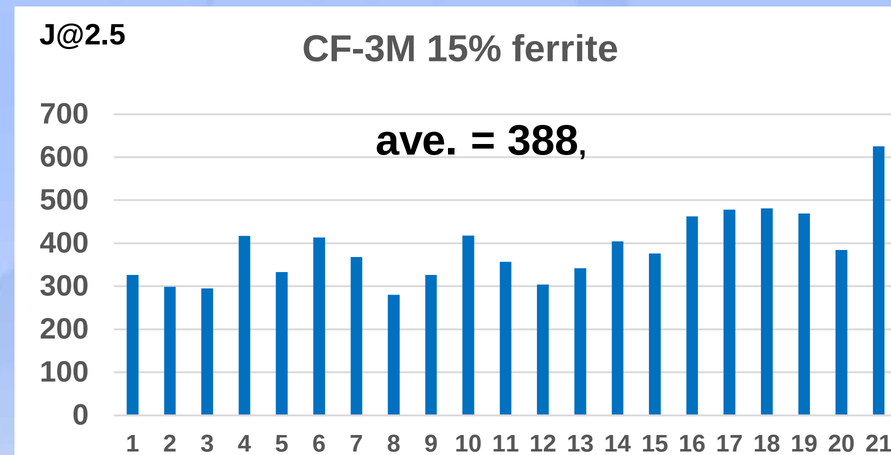
- For each heat, fracture toughness ($J_{2.5}$) estimated using NUREG/CR-4513 and NUREG/CR-7185 equations for known composition
- 95/95 lower bound toughness then determined from these $J_{2.5}$ estimates
- Manufacturer 95/95 lower bound $J_{2.5}$ determined this way are higher than if $J_{2.5}$ determined using equations for known ferrite, unknown composition. (Draft RAI 4)
- For heats of same material grade and casting method with the same estimated ferrite, toughness varies widely

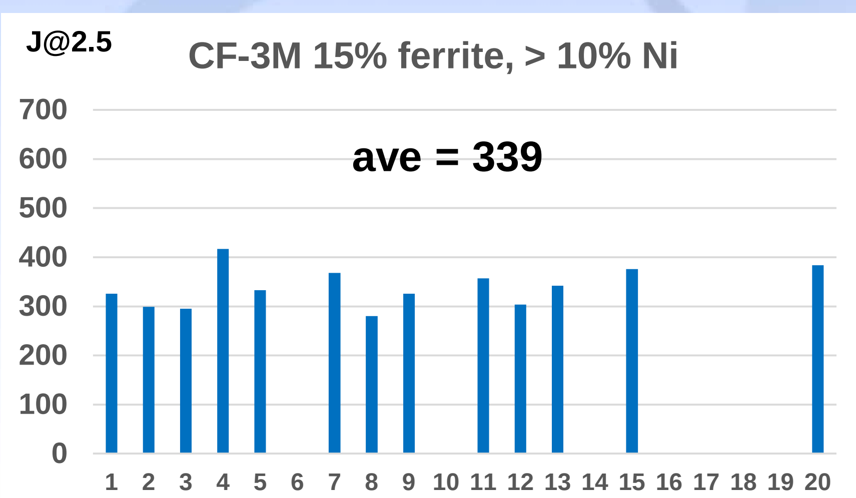
Lower Bound $J_{2.5}$ - TR Method vs. NUREG Comp. Unknown Eqns.

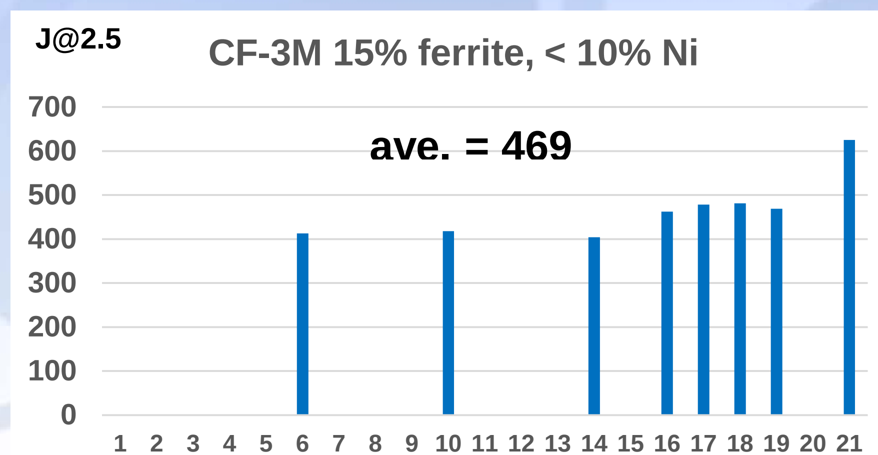
Manufacturer	Grade	Casting Method	95/95 Ferrite, %	95/95 $J_{2.5}$, kJ/m^2	NUREG/CR Lower Bound $J_{2.5}$, kJ/m^2
AMP	CF8	Static	11.9	505	378
CSF	CF8	Static	19.3	364	364
ESCO	CF8	Static	18.4	397	364
Kearsarge	CF8	Static	9.7	527	439
PF	CF8	Static	24.7	364	364
QACC	CF8	Static	18.7	378	364
Valcast	CF8	Static	13.4	496	378
Waukesha	CF8	Static	18.7	398	364
Wollaston	CF8	Static	24.5	448	364
Kearsarge	CF8	Centrifugal	8.3	711	578
WC(Ladle)	CF8	Centrifugal	22.7	487	450
WC(Product)	CF8	Centrifugal	20.8	488	450
Wollaston	CF3M	Static	27.0	141	78

Fracture Toughness - Variability at 15% ferrite

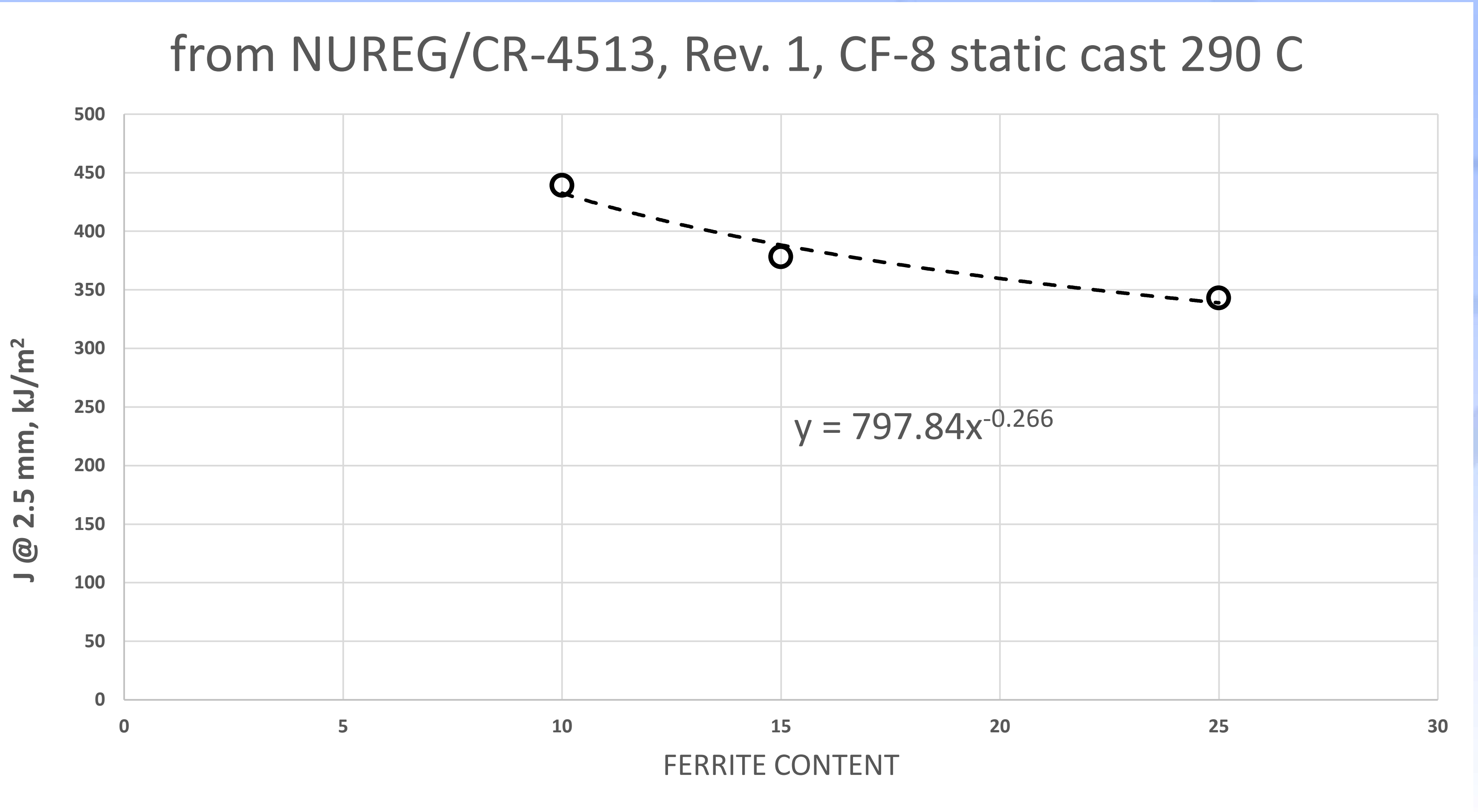








Method to Determine $J_{2.5}$ Based on NUREG Unknown Composition Eqns.



Issue: Saturation

- "Saturated" toughness means it has essentially reached a minimum value and will decrease very slowly, if at all after
- NUREG/CR-4513 R1 predicts "saturated" toughness, based on aging at 400ºC for 10,000 hours
- Time/temperature for accelerated aging depends on assumed activation energy, which various researchers calculated between 100-200 kJ/mole
- TR asserts CASS components may not have reached saturation in 60 years, therefore using saturated toughness estimates is conservative
- Due to uncertainty in activation energy, staff does not agree this can be considered a conservatism
- Staff may need to reevaluate if NUREG/CR-4513 is adequate for SLR

Issue: Saturation and IE Effects

- NUREG/CR-4513 methodology is for TE alone.
- Kinetics of embrittlement expected to be affected by irradiation
- With IE, toughness may not saturate even for low ferrite CASS

Summary

- For low-molybdenum CF8 material, TE alone is not an issue for RVIs
- Plant-specific TE screening can probably be eliminated for fluence < 1×10^{17} n/cm^2
- Estimate of saturation toughness needed if IE is applicable
- Some issues remain related to method of estimating toughness

United States Nuclear Regulatory Commission
Protecting People and the Environment

Staff Assessment of PWROG-14048-P

Functionality Analysis: Lower Support Columns

May 5, 2016

Staff Assessment of PWROG-14048-P

- Analyses of Lower Support Column (LSC) functionality presented to the NRC on October 2014

- PWROG-14048-P was sent to the NRC for information in early 2015

- Staff issued a non-proprietary assessment of the report on December 2015: ADAMS Accession No. ML15334A462

Major Parts of PWROG-14048-NP

- Evaluation of likelihood of failure of LSCs using stress analysis and fracture mechanics analysis
- Evaluation of structural redundancy

Staff Assessment of PWROG-14048-P - Conclusions

- Failure likelihood evaluation used conservative inputs
  - Critical flaw sizes were much larger than the largest acceptable pre-service flaws
- Redundancy analysis used a reasonable approach
- Potential for buckling needs to be considered; change in modal characteristics needs detailed evaluation
- To use methodology, licensees must show plant-specific parameters and loading conditions are bounded by report assumptions
- Follow-on report expected to generically demonstrate this