NRC Staff Compiled Comments on Industry CASS Screening Position

Summary – General Comments

1. There is very little data for CASS subject to both thermal aging and irradiation representative of reactor vessel internals operating conditions.

2. There is almost no IE+TE fracture toughness data for CASS in the 0.5 dpa-2 dpa transition range of interest.

3. NRC screening criteria are similar, but a little more conservative than industry's.

4. The staff feels that erring on the conservative side is appropriate, particularly when there is a lack of data to support either position.

5. Industry should develop analyses supporting a lower fracture toughness basis for the screening criteria, such as generic flaw tolerance analyses.

6. NRC staff is not convinced that industry's mechanistic argument regarding austenite controlled or ferrite controlled CASS toughness is valid. I.e., staff does not believe ferrite toughness has no effect on bulk toughness just because ferrite is below 20%.

7. Some data does show toughness can be lower for CASS with IE+TE, than that caused by IE or TE alone.[1]

8. Lower fluence screening criteria and adjustments to ferrite screening criteria above this fluence are intended to make address uncertainties in behavior of CASS under IE+TE.

Staff Interpretation of Industry position

- Toughness drops due to ferrite embrittlement and austenite embrittlement – **Staff agrees**.
- Screen on thermal, everything with high ferrite is in – **Staff agrees**.
- For high dpa, everything screens in – **Staff agrees**.
- For those things not already in, screen for IE – **Staff agrees**
- Set IE screening level so that (effectively) most things screen out
- Recognize that chosen level is beyond where embrittlement starts, i.e., chosen level is where degradation in toughness is significant – **Staff agrees**

[1] See Figure A-2 of 2014-086 (Fig. 60 of NUREG/CR-7027, for Heat 75 – J @ 2.5 for fully aged + irradiated ~ 125 kJ/M^2 vs. same heat, fully aged and unirradiated, from Table 7 of the Supplemental Information in 2014-086, J@ 2.5 is 418 kJ/m^2.

- For those things that are embrittled by IE, but not fully embrittled, screen them out because they have adequate toughness because not much toughness is needed. Even the NRC admits that the 255 kJ/m^2 J value at 2.5 mm is conservative, but NRC has not quantified what the conservatism means, so NRC should just let us screen everything out because these components really don't need to be tough.
- Industry doesn't like the NRC screening because some things might screen in, and then the industry would need to perform analyses to show how much toughness is required, and that is hard and expensive.
- If there is less than 20 volume percent of a microstructural component, changes in material properties of that component has zero effect on the bulk properties.

<u>NRC Staff Response to Industry Comments on Staff Position Dated 7-10-14</u>

Industry Comment 2

The current NRC position observes correctly that the 255 kJ/m^2 J value at 2.5 mm of crack extension was based on elastic-plastic fracture toughness assessment of simplified CASS piping components. This is likely overly conservative for RVI CASS components that are largely subjected to compressive stresses, which may be configured within a redundant structural system, and whose functionality does not include pressure boundary functions. From this observation, one might have expected a slightly less conservative set of screening criteria, more along the lines of the industry position. That is not the case. The level of required technical demonstration for CASS RVI component locations will be substantial.

Staff Response

Staff and industry agree in principle that 255 kJ/m^2 is probably too conservative, but this needs to be demonstrated via generic flaw tolerance evaluations of RVI components justifying a lower toughness to be used as a basis for the revised screening levels. Industry needs to perform this work not NRC instead of asking NRC to rely on engineering judgment with regard to an appropriate toughness level. (EPRI TR-112718 appears to show that this type of work has already been done for certain cases.)

Industry Comment 4

Given the original arguments put forth supporting the 255 kJ/m^2 toughness arguments presented in BWRVIP-234 and supported in detail by the latest RAI-9a response, it is important to affirm that the BWR components listed in Table 6-1 of BWRVIP-234 do not require any augmented inspections. We believe that these data provide sufficient technical bases to allow the NRC to accept this position. The discussion that the toughness requirement is very likely conservative and was generated for piping further supports this position. If the NRC position is that inspections are required with the current data, it would be beneficial to understand the safety benefit of inspections when the expected variation in toughness is small. Further, it will be necessary to understand whether and what type of generic calculations can be used to justify a lower required value of J that will still demonstrate adequate fracture toughness for a component.

Staff Response

See staff response to Comment 2. Also, the staff observes there are only a couple of components in BWRVIP-234 Table 6-1 that would exceed 0.45 dpa. A component-specific fracture toughness basis could be developed for these components (fleet generic flaw tolerance evaluation for specific components).

Industry Comment 5

The "TE" section of the current NRC position notes that NUREG/CR-4513, Rev. 1 provides lower-bound fracture toughness J-R curves for aged CASS materials in three categories (<10%, 10-15%, and >15% delta ferrite contents) and that it also correlates with molybdenum contents and casting method (centrifugal vs. static). It also notes that the Grimes letter provides screening criteria correlated with J-R curves exhibiting a minimum J value at 2.5 mm crack extension of 255 kJ/m^2. However, it does not provide any discussion of the industry's approach for addressing TE relative to austenite control versus ferrite control.

Staff Response

Addressing TE via "austenite control" requires acceptance of the mechanistic theory that if the ferrite volume fraction is 20% or less, the toughness of the ferrite phase does not affect the bulk toughness. The NRC staff does not believe there is no effect on bulk toughness no matter how brittle the ferrite becomes, and is not aware of data that support the industry's position.

Industry Comment 6

The "IE" section of the current NRC position notes that fracture toughness for CASS materials decreased due to neutron irradiation above about 0.3 dpa, and considers this level as a threshold for changes in the measured fracture toughness. But, NRC notes also that embrittlement becomes significant at slightly higher fluence levels, 0.5-2 dpa, depending on the material. However, there is no discussion of the industry's evaluation of data that was reported in MRP-276 or the screening criterion and its basis developed in MRP-175.

Staff Response

Dated evaluated in MRP-276 was the Kim et. al data. The staff feels this data is of limited value because it was tested at room temperature, used small specimens, and lacks data in the transition fluence range of 0.5-2 dpa.

Industry Comment 7

The “NRC staff’s position” section notes that the 0.45 dpa fluence selection correlates to a fracture toughness of 255 kJ/m^2 when toughness is predicted with Equation 25 from NUREG/CR-7027. It is not clear how 0.45 dpa is chosen since, as is stated in NUREG/CR-7027 (page 78, paragraph below Figure 64), “the lower bound curve indicates that for cast SSs and welds irradiated **<u>up to 1.0 dpa</u>**, the predicted J at 2.5 mm is above the screening value of 255 kJ/m^2 (1456 in.-lb/$in.^2$).” (Note: bolded text and underline added for emphasis)

Staff Response

The statement in the NUREG text is not accurate. When J@2.5 is calculated using 1 dpa in equation 25, the actual value is 208 kJ/m^2.

Industry Comment 8

The “NRC staff’s position” section also notes that the staff applies criteria to two different ferrite screening levels depending on neutron “exposure”. The staff suggests changing the ferrite screening to the levels described in NUREG/CR-4513, Rev. 1 (10% and 15% ferrite) from the current ferrite screening levels (14% and 20%) accepted both by the staff and industry for license renewal (e.g., the Grimes letter, MRP-175, and MRP-227-A) without a described technical basis. The basis data for the 14% and 20% screening levels of ferrite are established in industry documentation that clearly states the conservatism used in determining these values and thus it is not clear why additional conservatism (i.e., decreasing the ferrite screening levels to 10% and 15%) is required.

Staff Response

- Basis for Reduced Ferrite Screening Levels at > 0.45 dpa
    - NRC reduced ferrite content
        - Accounts for uncertainty of end state toughness due to IE+TE
        - NUREG/CR-4513 J-R curves for TE alone show significant margin above 255 kJ/m^2 at 2.5 mm crack extension at:
            - 10-15% ferrite for low-moly
            - <10% ferrite for high-moly
    - This provides margin for uncertainty wrt additional embrittlement due to fluence

See Figure 1 below for an illustration of the principle. The figure shows there is considerable margin for the lower bound curves for CF-3 and CF-8 above the 255 kJ/m^2 toughness level at

2.5 mm crack extension. However, for the CF-8M with the same ferrite range, the toughness is right around 255 kJ/m^2. Therefore, for the CF-8M there is no additional margin for reductions in toughness due to irradiation effects. Figure 2 shows a similar plot for <10 ferrite, which shows even CF-8M has some margin of toughness above 255 kJ/m^2 at 2.5 mm crack extension.

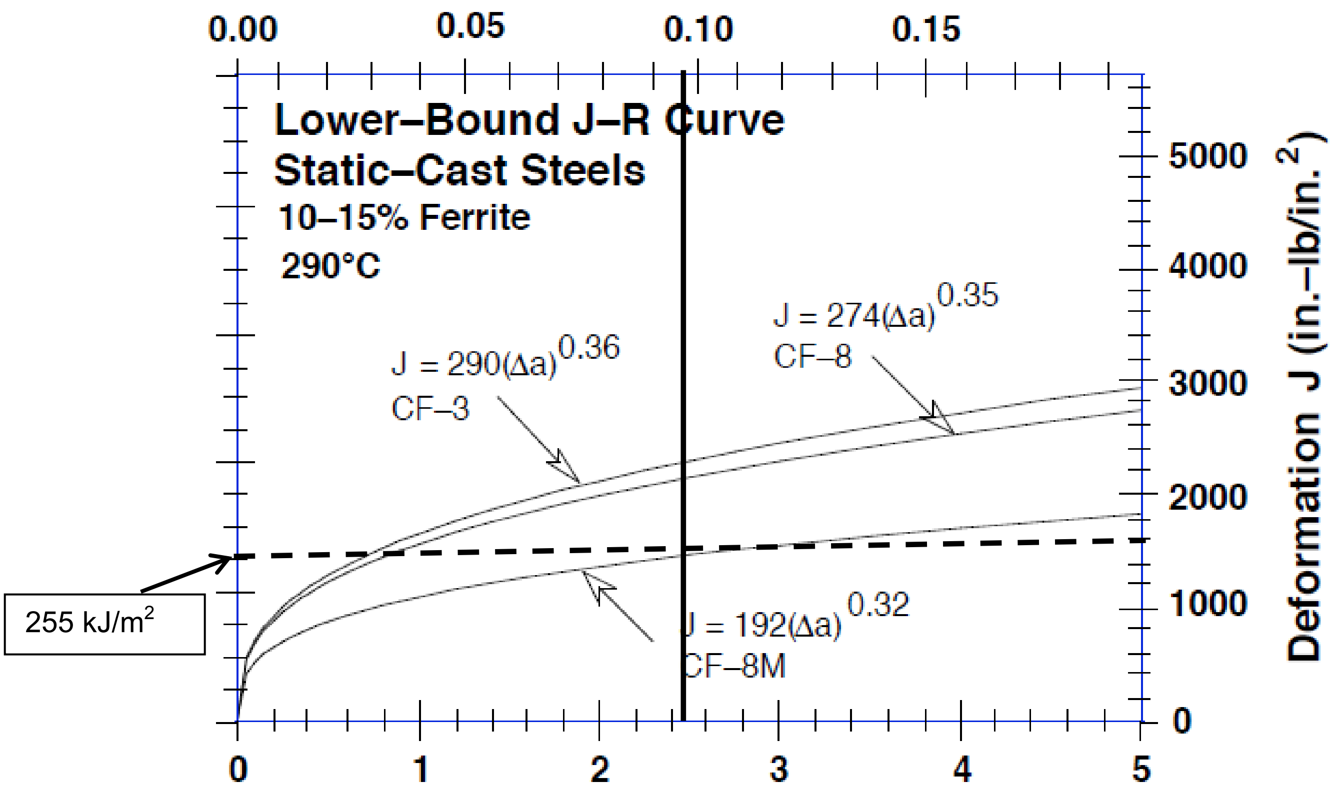

Figure 1 - NUREG/CR-4513 Lower Bound J-R Curves for 10-15% Ferrite Showing Margin Above 255 kJ/m^2 at 2.5 mm for CF-3 and CF-8

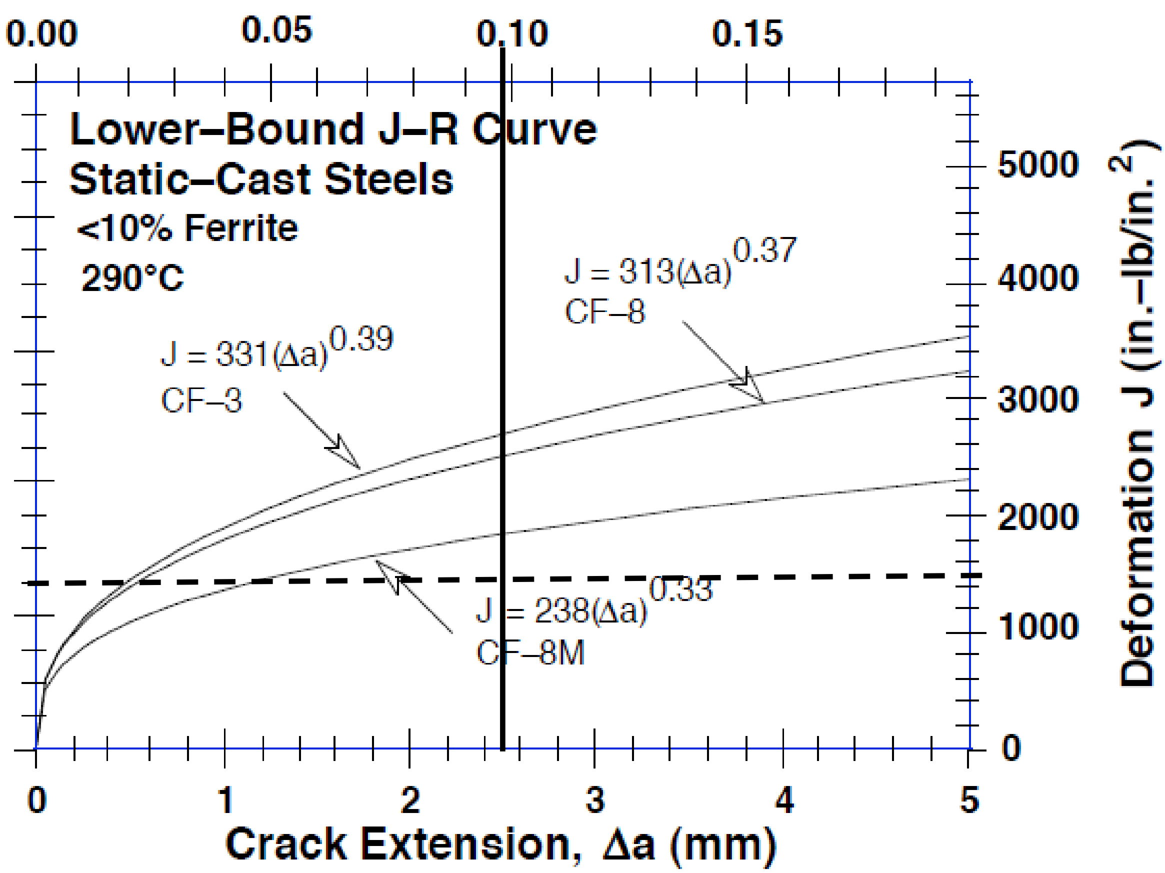

Figure 2 - NUREG/CR-4513 Lower Bound J-R Curves for <10- Ferrite Showing Margin Above 255 kJ/m^2 at 2.5 mm for CF-8M

Industry Comment 9

The “NRC staff’s position” section of the position also notes in item 3 of its numerical summary that “components may also be susceptible to TE…”. It is not clear as to why this statement is necessary. The first sentence (“Above 1.5 dpa, all stainless steel and CASS…”) states it clearly that at high fluence levels loss of fracture toughness requires aging management. The second sentence appears to suggest that embrittlement is additive, which it is not; once the material is embrittled, it is embrittled.

Staff Response

The staff agrees IE and TE may not simply be additive but the potential for a lower end of life toughness should be considered in any evaluation using estimated fracture toughness properties.

Industry Comment 10

Table D has a column listed as “FN.” This is incorrect; the column should correctly be listed as “Delta Ferrite %.”

Staff Response

Noted – the staff made this change.

Industry Comment 11

Under the “NRC Staff’s Position”, it states that the 255 kJ/m^2 may be over-conservative considering non-pressure boundary applications and redundancy of function. It then discounts those conservatisms without providing any discussion as to what the magnitude of the conservatisms might be. The additional information to address the conservatisms is partly available empirically or from structural fundamentals; for example:

- The lack of a credible mechanism that would cause multiple initiations in the PWR environment in a narrow time frame.
- The low probability of any undetected pre-service flaws, and the likely random spacial [sic] distribution of their occurrence in an assembly.
- The lack of observed failures or confirmed cracking in any CASS components after many years of operating experience in PWRs and BWRs.
- Consideration that much of the operational stress loading is secondary; i.e., displacement controlled self-relieving stresses, mostly thermal, and that the sizing of the structural members is conservative for safety function primary loads.

Staff Response

The bullets above are describing elements of what the staff would consider a functionality analysis. This would typically be done for components that did not pass the screening criteria, such as for an MRP-227-A Action Item 7 evaluation. Such elements could be considered in a generic industry evaluation justifying a lower fracture toughness value as the basis for the screening criteria. Quantitative demonstrations are typically more compelling.

Industry Comment 12

No staff response necessary.

Alternate Comparison Table

Molybdenum (wt. %)	Casting Method	% Ferrite	Position	TE Screening Susceptibility Result Yes or No	IE Screening Susceptibility Result Yes or No
High 2.0-3.0% (CF-3M & CF-8M)	static	0-10	NRC Industry	No No	Yes, > 1.5 dpa Yes, > 1 dpa
		11-14	NRC Industry	No No	Yes, > 0.45 dpa Yes, > 1 dpa
		≥ 15	NRC Industry	Yes Yes	N/A N/A
	centrifugal	0-15	NRC Industry	No No	Yes, > 1.5 dpa Yes, > 1 dpa
		16-20	NRC Industry	No No	Yes, > 0.45 dpa Yes, > 1 dpa
		≥ 21	NRC Industry	Yes Yes	N/A N/A
Low 0.5% max (CF-3 & CF-8)	static	0-15	NRC Industry	No No	Yes, > 1.5 dpa Yes, > 1 dpa
		16-20	NRC Industry	No No	Yes, > 0.45 dpa Yes, > 1 dpa
		≥ 21	NRC Industry	Yes Yes	N/A N/A
	centrifugal	All	NRC Industry	No No	Yes, > 1.5 dpa Yes, > 1 dpa