U.S. NUCLEAR REGULATORY COMMISSION'S

REQUEST FOR ADDITIONAL INFORMATION

BY THE OFFICE OF NUCLEAR REACTOR REGULATION ON

TOPICAL REPORT PWROG-18068-NP, REVISION 1,

"USE OF DIRECT FRACTURE TOUGHNESS FOR EVALUATION OF RPV INTEGRITY,"

FOR THE PRESSURIZED WATER REACTOR OWNERS GROUP

PROJECT NO. 99902037; EPID: L-2021-TOP-0027

BACKGROUND

By letter dated July 27, 2021 (Agencywide Documents Access and Management System Accession (ADAMS) No. ML21209A932), the Pressurized Water Reactor Owners Group (PWROG) submitted Topical Report (TR) PWROG -18068-NP, Revision (Rev.) 1, "Use of Direct Fracture Toughness for Evaluation of [Reactor Pressure Vessel] RPV Integrity" (ADAMS No. ML21209A933), for U.S. Nuclear Regulatory Commission (NRC) staff review and approval. The TR provides an alternative methodology to the RPV material integrity requirements presented in the "Fracture Toughness Requirements" of Appendix G to Part 50 Section 61 of Title 10 of the *Code of Federal Regulations* (10 CFR).

As a result of the review of TR PWROG -18068, Rev. 1, the NRC staff has determined that the request for additional information (RAI) questions provided below are needed to complete the next phase of the review.

REGULATORY BASES

The NRC has established regulatory requirements under 10 CFR Part 50, "Domestic Licensing of Production and Utilization Facilities," to protect the structural integrity of the reactor coolant pressure boundary in nuclear power plants as follows:

10 CFR 50.60, "Acceptance Criteria for Fracture Prevention Measures for Lightwater Nuclear Power Reactors for Normal Operation," states that fracture toughness requirements for RPV materials, which are set forth in Appendix G to 10 CFR Part 50 and "Reactor Vessel Material Surveillance Program Requirements," in Appendix H to 10 CFR Part 50.

10 CFR 50.61, "Fracture Toughness Requirements for Protection Against Pressurized Thermal Shock," requires that the reference temperature of the RPV materials be within specific values to prevent pressurized thermal shock of the RPV materials.

Therefore, the regulatory basis for the following RAI questions is directly related to reasonable assurance for structural integrity of RPV materials in accordance with the regulations listed in this section.

REQUESTS FOR ADDITIONAL INFORMATION

RAI 01 – Section 4.1 of TR – Generation and Validation of Irradiated Data

NRC Comment

Section 4.1 of the TR states that each material irradiated in a high flux test reactor must have at least one validation material in the copper grouping shown in the section. The NRC staff is not clear on what steps will be taken if the material irradiated in a high flux test reactor does not have at least one validation material in the copper grouping.

NRC Request

Clarify/provide the steps that will be taken if the material irradiated in a high flux test reactor does not have at least one validation material in the copper grouping.

RAI 02 – Section 4.0 of the TR – Data Adjustments

NRC Comment

Various subsections in Section 4 of the TR, state that irradiated materials must be from the same heat as the RPV materials of interest. For example, Section 4.3.1 states that irradiated materials must be from the same heat as the RPV materials of interest; therefore, chemistry adjustments should be relatively small.

NRC Request (a, b)

a. If irradiated materials must be from the same heat as the RPV materials of interest, describe whether or not the proposed alternative to the methodology can be used or needs to be modified for use if irradiated materials are not from the same heat as the RPV materials of interest.

b. If the irradiated RPV materials are not from the same heat as the RPV material of interest, describe how the chemistry adjustments are derived.

RAI 03 – Section 4.2 of the TR – Specimen Test Data

NRC Comment

Section 4.2 of the TR states that extra specimens are recommended to be tested to ensure that a valid T_0 is obtained.

NRC Request

Provide information regarding why the minimum specimens required in ASTM E1921 are sufficient to obtain a valid T_0.

RAI 04 – Section 4.2 of the TR – Specimen Test Data

NRC Comment (a, b, c)

a. Section 4.2 of the TR states that for large datasets (20 or more) which are screened as inhomogeneous, regardless of the ASTM E1921-20[1] treatment method used, or the analysis result, the T_0 used does not have to be more conservative than the T_0 corresponding to the least tough datapoint being on the $K_{Jc\text{-}lower95\%}$ curve plus σ_{E1921} ($\sigma°$ value per ASTM E1921-20 paragraph 10.9). The NRC staff is not clear why the T_0 that is used does not have to be more conservative than the T_0 corresponding to the least tough datapoint.

b. The TR does not provide the technical basis for the statement that T_0 does not have to be more conservative than the T_0 corresponding to the least tough datapoint.

c. The NRC staff noted that larger datasets would more likely result in a datapoint lower than the 5th percentile, especially if the material is determined to be significantly inhomogeneous. However, it is also possible that there may not be a large percentage of the lower toughness material within the dataset such that the datapoint may not be representative of the $K_{Jc\text{-}lower95\%}$ curve.

NRC Request (a, b, c)

a. Clarify if the requirement in part a of the comment above means that the analysis T_0 value (i.e., $T_0 + \sigma_{E1921}$) does not have to be greater than a value which would cause the least tough datapoint to fall exactly on the associated $K_{Jc\text{-}lower95\%}$ curve, or if another interpretation is intended by this statement.

b. Discuss the technical basis for the statement that T_0 does not have to be more conservative than the T_0 corresponding to the least tough datapoint.

c. Provide details on why the proposed treatment of large, inhomogeneous datasets is more appropriate, or more conservative, than the method required in E1921 to characterize both the material toughness and the uncertainty in the toughness value.

RAI 05 – Section 4.3 of the TR – Data Adjustments

NRC Comment (a, b, c, d)

a. Section 4.3 of the TR states that for adjustments that are within the uncertainty of the embrittlement trend correlation (ETC), because the difference in the ETC prediction of the irradiated test material and the RPV is relatively small, any systemic errors in the ETC model (model uncertainty) would be negligible. The TR does not provide data to show that difference in the ETC prediction of the irradiated test material and the RPV is small. The NRC staff is not clear how small of a difference the systemic errors would need to be in order to be considered negligible.

[1] *Standard Test Method for Determination of Reference Temperature, T_0, for Ferritic Steels in the Transition Range*

b. The NRC staff is not clear why the "predicted ΔT_{30} of the irradiated tested material" term within the parentheses in Equation 4 in Section 4.3 of the TR is not called "**measured** ΔT_{30} of the irradiated tested material" instead (emphasis added) because ΔT_{30} values from tested materials should have measured ΔT_{30} values by definition, not predicted ΔT_{30} values.

c. With respect to the Part b question above, if the intent of Equation 4 is to calculate the ΔT_{30} value of the irradiated test material predicted by E900-15, the NRC staff is not clear why the measured ΔT_{30} value of the irradiated test material is not used.

d. The NRC staff is not clear whether the statement after Equation 4 should state "The **predicted** ΔT_{30} above…" (emphasis added).

<u>NRC Request (a, b, c, d)</u>

a. Provide data to show that the difference in the ETC prediction of the irradiated test material and the RPV is relatively small so that any systemic errors in the ETC model (model uncertainty) would be consider negligible.

b. Clarify why the "predicted ΔT_{30} of the irradiated tested material" term within the parentheses in Equation 4 in Section 4.3 of the TR is called "predicted ΔT_{30} of the irradiated tested material" instead of "**measured** ΔT_{30} of the irradiated tested material."

c. Clarify why the measured ΔT_{30} value of the irradiated test material is not used in Equation 4.

d. Clarify whether the statement after Equation 4 should state "The **predicted** ΔT_{30} above…"

RAI 06 – Section 4.3.2 – Data Adjustments – Temperature

<u>NRC Comment</u>

Section 4.3.2 of the TR states that for pressure-temperature (P-T) limit calculations the temperature at the ¼ or ¾T crack tip can be used in the ETC calculation. Alternatively, if a simplified conservative approach is used, the value of average cold leg temperature (T_{cold}) can be used in the ETC, which will over-estimate the effect of embrittlement on ΔT_{30}. Section 4.3.2 further states that gamma heating of the RPV in the beltline region increases the RPV wall temperature relative to T_{cold} at the wetted surface during normal operation, and a lower embrittlement shift occurs at higher irradiation temperatures. Section 4.3.2 indicates that T_{cold} should be used for PTS calculations which are performed for the clad/low alloy steel interface where the irradiation temperature would be very close to T_{cold}.

<u>NRC Request</u>

Describe why T_{cold} should be used for PTS calculations which are performed for the clad/low alloy steel interface where the irradiation temperature would be very close to T_{cold}.

RAI 07 – Section 4.0 of TR – Master Curve Set Data

NRC Comment (a, b, c)

a. Section 4 of the TR, page 4-1, states that if multiple datasets are available for the heat of interest, the dataset with the irradiation conditions most similar to the reactor vessel may be used alone. The NRC staff is not clear regarding the acceptance criteria that will be used to permit the use of the irradiated dataset.

b. Section 4 of the TR further states that alternatively, the "T_0 (or RT_{T0}) + adjustment + margin" values can be averaged using the respective adjustment and margin for each dataset available. The NRC staff is not clear how the above values can be averaged to result in an appropriate T_0.

c. Section 4 of the TR states that if unirradiated data is also available, this data does not have to be combined with irradiated data because the irradiated T_0 provides the measured effect of embrittlement without the need for the full prediction of uncertainty. Section 4 indicates that if only unirradiated T_0 is available, the approach discussed can also be used. The NRC staff is not clear whether or not the adjustment term and margin term in Equations 1, 2 and 3 are needed to calculate T_0, specifically, if irradiated and unirradiated data are available..

NRC Request (a, b, c)

a. Describe the acceptance criteria that will be used to decide the irradiation conditions that are most similar to the reactor vessel in question such that the irradiation data could be used alone. Discuss the need for acceptance criteria to demonstrate that a dataset is sufficiently representative of the conditions to be evaluated and, if it cannot be demonstrated, that such criteria are not needed, describe the appropriate criteria that could be used to appropriately select datasets.

b. Describe how the "T_0 (or RT_{T0}) + adjustment + margin" values can be averaged using the respective adjustment and margin for each dataset available. Discuss why a bounding "T_0 (or RT_{T0}) + adjustment + margin" value from the multiple datasets is not a more appropriate approach to ensure reasonable conservatism instead of the proposed averaged value. Discuss why the "T_0 (or RT_{T0}) + adjustment + margin" values are not weight-averaged by criteria such as the number of data or the similarity of the dataset to the evaluated conditions instead of simply averaged.

c. Clarify if the adjustment term and margin term in Equations 1, 2, and 3 of the TR are needed to calculate the T_0 (or RT_{T0}) value if unirradiated data for the reactor vessel in question are available in addition to irradiated data.

RAI 08 – Section 4.0 of TR – 10 CFR 50.55a Condition on Use of Irradiated T_0

NRC Comment

Section 4 of the TR states that Equation 2 is one of the options for development of Appendix G P-T curves. Equation 2 is based on the K_{IC} equation from Appendix G of Section XI of the 2017 Edition of the ASME Code. G-2212 of Section XI of the ASME Code refers to A-4400 of Section

XI of the ASME Code, which is subject to 10 CFR 50.55a condition regarding the use of irradiated T_0 data, as given below:

(xxxvi) *Section XI condition: Fracture toughness of irradiated materials*. When using the 2013 through 2017 Editions of the ASME BPV Code, Section XI, Appendix A paragraph A–4400, the licensee shall obtain NRC approval under paragraph (z) of this section before using irradiated T_0 and the associated RT_{T0}.

The TR does not explain how this condition will be met when using the methodology described in the TR.

NRC Request

Explain how the referenced 10 CFR 50.55a condition will be met when using the methodology described in the TR.

RAI 09 – Section 4.0 of TR – Use of Master Curve Approach When Only Unirradiated T_0 Data is Available

NRC Comment

Section 4 of the TR states that "if only unirradiated T_0 is available, the approach discussed herein can also be used." The TR does not discuss the approach or methodology for determining irradiated T_0 if only unirradiated T_0 data is available.

NRC Request

Describe the approach or methodology for the "adjustment" and "margin" terms in Equations 1, 2, and 3 of the TR if only unirradiated T_0 data is available for determining irradiated T_0.

RAI 10 – Section 4.2 of the TR – Specimen Test Data

NRC Comment

The last paragraph of Section 4.2 of the TR states: "Test data from three-point bend (3PB) Charpy 10 x 10 mm size specimen is acceptable, if a bias correction addition of 18°F (10°C) [3 and 31] is included. If there is a mixture of Charpy 3PB and C(T) specimens, the bias correction can be prorated based on the proportion of Charpy 3PB specimens." Also, the last paragraph on page A-3 of the TR states: "The uncertainty per ASTM E1921 for the mini-C(T) T_0 values shown in Table A-1 would be expected to range from approximately 4°C through 8°C." The NRC staff is not clear whether the bias correction and/or the uncertainty for the mini-C(T) specimens are incorporated into the data adjustment or margin terms in Equations 1, 2, and 3 of the TR. The NRC staff also noted that the master curve is essentially a nonlinear fitting method, and data below T_0 have a stronger effect on the T_0 value than data above T_0. Therefore, the weight is a function of the relative test temperatures, and that a more consistent, and simpler, approach would be to shift the test temperature of all 3PB data (even if mixed with C(T) specimens) by +18°F (+10°C) in determining T_0.

NRC Requests (a, b, c)

a. Describe whether a bias correction addition of +18°F (+10°C) is appropriate for adding to all 3PB specimen data when calculating the adjustment or margin terms in Equations 1, 2, and 3 of the TR. If not, provide an explanation for when it is not needed.

b. Regarding the uncertainty for mini-C(T) of 4°C to 8°C discussed in Appendix A of the TR, clarify if the uncertainty value of 4°C to 8°C is added to the adjustment or margin terms and discuss if additional uncertainty for mini-C(T) specimen data (i.e., uncertainly greater than what would be applied for larger C(T) specimens) would be included in the adjustment or margin terms. If not, provide justification.

c. Justify the proposed method for linearly prorating the bias when there is a mixture of Charpy 3PB and C(T) specimens.

RAI 11 – Section 4.3 of the TR – MTR Flux

NRC Comment

The NRC staff is not clear on the derivation, definition of certain terms, or application of Material Test Reactor (MTR) flux validation (i.e., Equation 7 of the TR) and adjustment (i.e., Equation 8 of the TR) as discussed in Section 4.3.4.2 of the TR. First, the NRC staff is not clear how Equation 7 and Equation 8 were derived. With respect to Equation 7, the NRC staff noted that it may not be an appropriately conservative criterion. For example, if the σ terms are equal, Equation 7 only requires that the "$AdjustedT_{0highfluxVM}$" value be greater than approximately the 0.2% probability curve of the data (i.e., $Z = -2*\sqrt{(2)}$ or -2.82). Therefore, this criterion appears to be not sufficient to judge that the high-flux dataset is representative, or conservatively bound, the T_{0PWRVM} conditions. The NRC staff also noted that a t-test (with classical 5% alpha-acceptance criteria) could be a better criterion to demonstrate that "$AdjustedT_{0highfluxVM}$" can be considered to be equivalent to or greater than "T_{0PWRVM}." With respect to Equation 8, the NRC staff is not clear how it is representative of the conservative approach compared to PWR flux, as discussed in Section 4.3.4.2. Finally, the NRC staff noted that the numerator within the brackets in Equation 8 should be "$AdjustedT_{0highfluxVM} – T_{0PWRVM}$" or the absolute value of "$AdjustedT_{0highfluxVM} – T_{0PWRVM}$" instead of "$T_{0PWRVM} – AdjustedT_{0highfluxVM}$".

NRC Requests (a, b, c, d, e, f, g)

a. Provide a clear derivation and description of Equation 7 and Equation 8. Also, clarify, as part of the description of this derivation, if these equations should only be used with T_0 and ΔT_0 data or if T_{30} and ΔT_{30} (along with the $\Delta T_0/ \Delta T_{30}$ correction ratio) data can be used in this assessment.

b. Explain why a t-test is not used to infer that "$AdjustedT_{0highfluxVM}$" is equivalent to or greater than "T_{0PWRVM}."

c. Clarify the definition of the "$AdjustedT_{0highfluxVM}$" term that is used in Equation 7. Clarify if only $T_{0highfluxVM}$ that gets adjusted to the PWR VM conditions (i.e., fluence, chemistry, temperature) or if both $T_{0highfluxVM}$ and T_{0PWRVM} get adjusted to the conditions of interest for the limiting material.

d. Clarify and justify how Equation 7 should be applied with multiple datasets. Specifically, justify why it is more appropriate for multiple datasets to be considered collectively (i.e., by adding both sides of the inequalities using all that data) rather than to independently judge each dataset on its representativeness, such that only datasets which have demonstrated representativeness would be used within the TR methodology.

e. Clarify how the Equation 8 would lead to an irradiated T_0 value that is representative or conservative compared to a PWR-irradiated T_0 value.

f. Clearly describe how multiple datasets are to be treated within Equation 8 and provide the basis supporting the proposed treatment, including the appropriateness of averaging multiple datasets for the variables contained within the Equation 8 brackets.

g. Clarify the baseline or reference condition for the "$\Delta T_{\text{high flux VM}}$" and "$\Delta T_{\text{high flux}}$" terms; specifically, explain if these terms are intended to represent the difference between the test condition fluence and the evaluated (e.g., end-of-life) fluence, the predicted ΔT_0 (or ΔT_{30}) value for the "PWR VM" experiments starting from unirradiated or whatever initial state of the material was, or is a different interpretation of these terms intended. If a different interpretation is intended, please clarify their definitions.

RAI 12 – Section 4.3.4.2 of the TR – MTR Flux Adjustment

NRC Comment

Page 4-8 of the TR shows the following definition of $\Delta T_{\textit{high flux VM}}$:

$\Delta T_{\textit{high flux VM}}$ = Predicted shift of the PWR flux validation material using the ASTM E900-15 ETC

The NRC staff is not clear whether the definition should be:

"Predicted shift of the **high flux validation** material using the ASTM E900-15 ETC"

NRC Request

Clarify whether the definition of $\Delta T_{\textit{high flux VM}}$ should be:

"Predicted shift of the high flux validation material using the ASTM E900-15 ETC"

RAI 13 – Section 4.3.5 of the TR – Correlation between ΔT_{30} and ΔT_0

NRC Comment

The NRC staff noted that the discussion of the correlation between ΔT_{30} and ΔT_0 (shown in Figure 6 of the TR) does not include model uncertainty (i.e., uncertainty in the correlation). Regardless of the basis as used in NUREG-1807, "Probabilistic Fracture Mechanics – Models, Parameters, and Uncertainty Treatment Used in FAVOR Version 04.1", the NRC staff is not clear that this precedent should apply in the methodology as used in the TR. Therefore, some basis for not considering model uncertainty should be provided. For a given ΔT_0, the NRC staff noted that the spread in observed ΔT_{30} values can easily be greater than 100°F. Thus, there are other factors contributing to this scatter in the ΔT_{30} and ΔT_0 relationship than just measurement uncertainty associated with individual values. Also, the correlation between ΔT_{30}

and ΔT_0 is an assumed linear model where all the measurement points come from comparing an irradiated to unirradiated measurement, but in the TR, the correlation is used to adjust between two irradiation levels. Further, it appears from Figure 6 of the TR that the R-value associated with the linear fit is not particularly high, which would mean that a linear correlation may not be the best assumption.

<u>NRC Request (a, b, c, d)</u>

Provide additional justification to support the proposed use and treatment of the model uncertainty in the correlation between ΔT_{30} and ΔT_0 as applied in the methodology in the TR. This justification should:

a. Address other sources of uncertainty in this relationship, including the uncertainty associated with individual measurement values.

b. Address differences between the data in Figure 6, which use unirradiated data as the reference state and the intended use of this correlation in the TR, which principally uses irradiated data as the reference state.

c. Demonstrate the continued applicability of this correlation given the differences in the initial material reference state.

d. Demonstrate the appropriateness of applying the rationale from NUREG-1807 Section 4.2.3.4.2.

RAI 14 – Section 4.4.3 of the TR – Determination of σtempspecimen and σtempRPV

<u>NRC Comment</u>

Section 4.4.3 of the TR provides the following equation for the term σtempRPV:
σtempRPV = The effect of the uncertainty of the RPV irradiation temperature on embrittlement using the ETC ***** (ΔT_0 / ΔT_{30} Slope) at the RPV best estimate condition. Additionally, Section 4.4.3 states that "…the uncertainty of the average (standard error) irradiation temperature is less than or equal to 2°F after averaging at least four cycles of data. There may be some unique situations (i.e., short irradiation time), but 2°F for the uncertainty in the time weighted average irradiation temperature can be used conservatively for surveillance capsule and RPV wall irradiations…" The NRC staff is not clear on how 2°F was derived based on the information above.

<u>NRC Request</u>

Describe how the 2°F is derived.

RAI 15 – Sections 4.4.3 and 4.4.4 of the TR - Determination of σtempspecimen, σtempRPV, σfluencespecimen, and σfluenceRPV

<u>NRC Comment</u>

The last paragraphs of Sections 4.4.3 and 4.4.4 of the TR states that the uncertainty values related to temperature (Section 4.4.3) or fluence (Section 4.4.4) are the effect on the ETC prediction as a result of the temperature or fluence uncertainty. The NRC staff needs confirmation on the understanding of the referenced paragraphs.

NRC Request

Confirm that one would calculate the change in ETC for a given temperature uncertainty or fluence uncertainty applied in the conservative direction, then multiply by ΔT_0 / Δ T_{30} slope to calculate the corresponding uncertainty value. Provide an example.

RAI 16 – Section 4.5 – Uncertainty due to Material Variability

NRC Comment

The second paragraph of Section 4.5 of the TR states that "…Data sets that fail the [homogeneity] screening criterion, regardless of the reason, are evaluated in accordance with Appendix X5 of ASTM E1921-20…," but does not state that these data would be submitted to the NRC for review and approval. The NRC staff is not clear whether data sets evaluated in accordance with Appendix X5 of ASTM E1921-20 will be sent for NRC review and approval.

NRC Request

Clarify whether or not a data set fails the homogeneity screening criterion, whether the data set will be evaluated according to ASTM E1921-20 without NRC review and approval. If yes, discuss how the evaluation of the data set in accordance with Appendix X5 of ASTM E1921-20 for inhomogeneous data sets will be documented.

RAI 17 – Section 4.3 of the TR – Data Adjustments

NRC Comment

Section 4.3 of the TR states that "if the calculated adjustment exceeds the prediction model uncertainty (SDETC) shown in Equation 5 of the TR, then additional margin is added as described in Section 4.4." The NRC staff noted that while the uncertainty should clearly be a function of the amount of adjustment, there is no basis provided for why it should be zero until the adjustment exceeds the standard deviation of the ETC model. The implication of this approach is that the larger the standard deviation of the ETC model, the larger the adjustment has to be before margin is added. This logic appears counterintuitive.

NRC Request

Provide the basis for why there is no ETC model uncertainty until the adjustment exceeds the standard deviation of the ETC model, and why a gradual increase of the standard deviation that, in the limit of a large enough adjustment, would be equal to the E900-15 SD_{ETC}, is not more appropriate.

RAI 18 – Section 4.3.3 of the TR – Fluence

NRC Comment

Section 4.3.3 of the TR states: "The ratio of dpa at the postulated flaw depth to dpa at the inner surface may be substituted for the exponential attenuation factor in Equation 6." The NRC staff noted that either the dpa or fluence at crack depth location is required to predict the other, unknown variable (from a single equation). Therefore, it's not clear how the dpa ratio alone provides that information.

NRC Request

Clarify how the approach cited above can be used to determine the fluence at the depth of the postulated flaw tip using Equation 6 of the TR.

RAI 19 – Section 4.4.1 of the TR – Determination of σtest

NRC Comment

In Section 4.4.1 of the TR, the PWROG discussed the determination of the uncertainty due to specimen testing, σ_{test}. The NRC staff also noted that there are several examples in Appendix C of the TR where the T_0 uncertainty of smaller data sets is less than the uncertainty of larger datasets. It is not clear why the uncertainty is less when material inhomogeneity has been detected. The NRC staff noted that the ASTM E1921 T_0 uncertainty is based on the "r" value and for T_{0IN}, the "r" value is typically less than 50% of the total data set. When T_{0max} is calculated, r = 1. The NRC staff also noted that a datapoint based on a single toughness measurement does not necessarily mean there is no uncertainty in the associated T_{0max} value. Also, the NRC staff is not clear about the basis for the uncertainty being a function of the difference between T_{0max} and T_{0IN}, which seems to imply that T_{0max} be calculated for any number of specimens (N) of less than 20, when it is only a specified ASTM E1921 calculation if N is less than 10. Finally, staff is also not clear why the uncertainty measure prescribed for homogeneous data sets in E1921 Section 10.9 is appropriate for inhomogeneous materials.

NRC Request (a, b, c, d, e)

Provide the basis for the determination of σ_{test} in Section 4.4.1 of the TR as summarized in Table 3 of the TR, addressing the following issues:

a. Basis for small, or zero, T_0 uncertainty when the data set is small.

b. Basis for small, or zero, T_0 uncertainty when material inhomogeneity has been detected.

c. Basis for the uncertainty being a function of the difference between T_{0max} and T_{0IN} in Table 3.

d. Clarification and justification for both the calculation and use of T_{0max} for $10 < N < 20$.

e. Basis for assigning $\sigma_{test} = \sigma_{E1921}$ for inhomogeneous datasets, instead of the σ values prescribed in ASTM E1921 Appendix X5 or other possibly appropriate measures.

RAI 20 – Section 4.4.2 of the TR – Determination of $\sigma_{additional}$

NRC Comment (a, b, c, d)

a. In Section 4.4.2 of the TR, the PWROG discussed the determination of the uncertainty term, $\sigma_{additional}$. Similar to the development and use of Equation 5 (and RAI-17) for calculating SDETC, the NRC staff noted that any additional margin should be a function of the amount of ETC shift between the test data and application and not solely a function of the standard deviation of the ETC. A bigger shift between the RPV and specimen should have more uncertainty. Equation 10 of the TR does not account for the amount of shift at all. The NRC staff also noted that the additional margin should exactly equal the ETC standard deviation if one of the conditions is the unirradiated state. Equation 10 of the TR does not approach that standard deviation in the limit.

b. Section 4.4.2 of the TR states: "Furthermore, any chemistry variation is considered indirectly through the homogeneity screening, which identifies atypical toughness variation." The NRC staff noted that the TR documents need to correct for chemistry differences between test data and the application of interest. Therefore, it is not clear if the chemistry variation discussed in this section refers to these bulk chemistry differences or local differences in the test material or the application of interest that vary from the bulk chemistry.

c. Section 4.4.2 of the TR states: "The uncertainty of the ASTM E900-15 prediction within a specific heat (after the heat bias has been compensated for) is less than SDETC." The NRC staff noted that it is reasonable to suggest that a smaller standard deviation of the ETC curve exists within a specific heat of material. However, that doesn't imply that the standard deviation should be simply equal to the standard deviation differences between the RPV and test specimens as proposed in Equation 10. The implication is that if σ_{ETCRPV} and $\sigma_{ETCspecimen}$ are the same, then $\sigma_{additional}$ is zero. The NRC staff is not clear why the TR does not evaluate both σ_{ETCRPV} and $\sigma_{ETCspecimen}$ and choose the greatest uncertainty value in this situation.

d. Section 4.4.2 of the TR states that the term $\sigma_{additional}$ double counts several of the uncertainties that are explicitly included in the margin term (Equation 9) of the TR but is not clear about what other terms in Equation 9 of the TR the $\sigma_{additional}$ term double counts for and why or how it double counts. Clarification and explanation of what margin terms the $\sigma_{additional}$ term double counts for will help the NRC staff determine if the uncertainties are reasonably accounted.

NRC Request (a, b, c, d)

a. Justify Equation 10 of the TR associated with $\sigma_{additional}$ and specifically why, if adjustments do not exceed the standard deviation of the ETC, that $\sigma_{additional}$ should be set to zero.

b. Clarify the statement in Part b of the issue above because the NRC staff noted that the methodology described in the TR appears to adjust for known chemistry differences.

c. Demonstrate that Equation 10 is appropriate for calculating $\sigma_{additional}$ for a specific heat of material. Clarify why σ_{ETCPRV} and $\sigma_{ETCspecimen}$ are not evaluated, and then $\sigma_{additional}$ set to the maximum uncertainty value.

d. Clarify which margin terms in Equation 9 of the TR the $\sigma_{additional}$ term double counts for and explain why or how the term double counts the other margin terms.

RAI 21– Section 4.5 – Uncertainty due to Material Variability

NRC Comment (a, b)

a. In Section 4.5 of the TR, the PWROG discussed the uncertainty due to material variability, (i.e., uncertainty due to variability within the same material heat). The PWROG stated that "no explicit uncertainties are required to consider material variability aside from those associated with the homogeneity screening." The NRC staff noted that, in principle, if all limiting materials could be completely tested, there would be no epistemic uncertainty due to material variability, and it would be appropriate not to consider additional uncertainty to address possible material variability. However, because only a relatively small amount of representative (and not the actual) limiting materials can be evaluated using the TR methodology, the uncertainty in whether the limiting material condition has been evaluated increases. The NRC staff also noted that the ASME Code addresses some of these uncertainties for plates and forgings by requiring, for example, testing at the quarter-wall thickness locations, but no such stipulation exists for the weld materials. The TR does not provide sufficient information to demonstrate that material variability does not need to be considered in the TR methodology.

b. In Section 4.5 of the TR, the PWROG stated:" measurement of irradiated fracture toughness near the condition of interest removes uncertainty associated with embrittlement prediction..." Similar to the issue associated with RAI-7, the TR does not appear to clearly articulate the criteria and/or limitations that assure that the condition in the measurement of irradiated fracture toughness is sufficiently "near the condition of interest."

NRC Request (a, b)

a. Provide further justification that demonstrates that material variability does not need to be considered in the TR methodology and that the uncertainty that the limiting condition has been appropriately evaluated is not a function of both the amount of representative material tested and the degree to which it can be demonstrated that the representative material appropriately represents, or bounds, the limiting material.

b. Describe the criteria and/or limitations with the TR methodology that assure that the condition in the measurement of irradiated fracture toughness is sufficiently "near the condition of interest."

RAI 22 – Figures B-1 and B-2 of the TR – Flux Effect on Welds and Forgings

NRC Comment (a, b)

a. In Figures B-1 and B-2 of the TR, the PWROG showed plots of the effect of flux on RPV welds and forgings. The NRC staff noted that the correlation between ΔT_{41J} and ΔT_0 in Figures B-1 and B-2 does not appear to be as close to the nearly 1-to-1 general correlation illustrated in Figure 6 of the TR. The data in these figures seems to imply that the ΔT_0 shift is higher than the ΔT_{41J} shift and that this disparity increases with fluence.

b. The NRC staff also noted that Figures B-1 and B-2 contain limited high-flux data, especially at high fluences (i.e., above 1E+20 n/cm^2).

NRC Request (a, b)

a. Explain the apparent differences between the ΔT_{41J} to ΔT_0 correlation implied in Figures B- 1 and B-2 of the TR and the ΔT_{30} to ΔT_0 correlation in Figure 6 of the TR.

b. Explain how this relative lack of high-fluence data, and the associated larger uncertainties have been addressed in the TR methodology (i.e., in both the testing requirements and analysis methods) to properly account for flux effects. As part of this response, address the conditions in the MTR and PWR irradiations that need to be met to assure that these conditions are representative, or conservative, with respect to the intended evaluation conditions. This RAI is related to RAI-11, but the focus here is specifically on the treatment of high-fluence data given its relative paucity.

RAI 23 – ASME Code Cases and Other Regulations

NRC Comment

There are other regulations and ASME Code Cases that could potentially utilize the methods described in the TR. For example, 10 CFR 50.61a requires calculation of RT_{Max} values for the end of the licensed operating period that incorporate an embrittlement trend curve prediction. Also, the TR references use of this method in conjunction with ASME Code Case N-830. The NRC staff noted that ASME Code Case N-830 is referenced in the TR and that it is in the list of currently approved code cases with conditions in Regulatory Guide 1.147, Revision 20. The NRC staff also noted that the ASME Code has recently approved Code Case N-830-1, which is Revision 1 of Code Case N-830. The NRC staff is not clear on how the methodology described in the TR interfaces with either 10 CFR 50.61a or Code Case N-830-1.

NRC Request

Clarify whether or how the methodology described in the TR interfaces with Code Case N- 830- 1. Specifically, explain if the methodology in the TR will be allowed within the framework of Code Case N-830-1. For example, explain if an end-of-life T_0 value using the TR methodology could be determined and applied within Code Case N-830-1 to determine other fracture properties. Additionally, clarify if it is intended that the TR methodology be utilized within 10 CFR 50.61a evaluations and, if so, describe how it would be applied within 10 CFR 50.61a and if, for example, the TR methodology would replace the equations specified in 10 CFR 50.61a to calculate RT_{Max} values, while retaining the 10 CFR 50.61a acceptance criteria.

RAI 24 – Section 4.0 of the TR – Master Curve Approach Process

NRC Comment

The NRC staff noted that, given the complexity of the methodology of applying the master curve approach described in Section 4 of the TR, the process by which the final calculated irradiated T_0 value (with adjustment and margin as specified in the TR) is determined starting from a dataset or multiple datasets of T_0 values (irradiated and/or unirradiated) is not clear for all cases. The NRC staff also noted that while the examples in Appendix C of the TR provide some discussion on how the TR methodology is applied, they do not provide a clear guide on the process steps.

NRC Request

Provide a detailed description of the process by which the final calculated irradiated T_0 value (with adjustment and margin as specified in the TR) is determined starting from a dataset or multiple datasets of T_0 values (irradiated and/or unirradiated).

RAI-25 – Example applications of the TR methodology in Appendix C of the TR

NRC Comment (a, b, c)

a. The NRC staff noted in the example shown in Table C-13 of the TR that the variation in margin using data from representative materials, different test specimen type, etc., is notable. Because of the notable variation in margin values, it is not clear whether there should be a minimum margin value to ensure conservatism in the TR methodology.

b. The NRC staff noted in Table C-9 that the σ_{test} values do not appear to be a function of "r" as required in ASTM E1921. Some description on how the σ_{test} values were assigned for these individual datasets, referencing appropriate sections in the TR as needed, should be provided.

c. Example C.2.2, in Table C-12 provides the ΔT_{30} value for the limiting material (i.e., CR-3 US to LS Circ. weld) but the final predicted (or measured) T_0 and/or RT_{T0} values for the limiting material should also be included in Table C-14 to demonstrate the appropriateness of the individual predictions.

NRC Request (a, b, c)

a. Provide other available data or studies to verify the conservatism in the margin using the methodology proposed in the TR.

b. Provide a description of how each σ_{test} value in Table C-9 was determined for each individual dataset. The section(s) in the TR providing the basis for each selection should be referenced, as appropriate.

c. Provide the final predicted or measured T_0/RT_{T0} values, as appropriate, for the limiting material (i.e., CR-3 US to LS Circ. weld) in Table C-14 and then describe the accuracy and appropriateness of using either individual or average T_0/RT_{T0} values for the four individual datasets in Table C-14 for assessing the limiting material using the TR methodology.