June 27, 2001

MEMORANDUM TO: William H. Bateman, Chief
Materials and Chemical Engineering Branch
Division of Engineering

FROM: Matthew A. Mitchell, Materials Engineer ***/ra/***
Materials and Chemical Engineering Branch
Division of Engineering

SUBJECT: MEETING SUMMARY - "LESSONS LEARNED FROM THE EVALUATION OF THE MASTER CURVE SUBMITTAL AND APPROVAL FOR THE KEWAUNEE NUCLEAR POWER PLANT," JUNE 19, 2001

On June 19, 2001, the NRC staff held a meeting with interested stakeholders representing both the industry and the general public (see Attachment 1 for details) regarding "lessons learned" from our recently completed evaluation of the Kewaunee Master Curve submittal (the exemptions and safety evaluation were issued on May 1, 2001 and are documented at ADAMS accession no. ML011210180). At the meeting, the NRC staff made a brief presentation (copies of the overhead slides used are in Attachment 2) which focused on "lessons learned" associated with licensing, regulatory implementation, and technical/programmatic issues which arose as part of our review. Industry representatives actively participated in the meeting by asking questions which sought to relate use of the Master Curve technology to license renewal activities, potential future rulemaking on 10 CFR 50.61, potential staff issuance of generic communications on this subject, etc. The NRC staff provided complete answers to all questions which were posed.

The NRC staff concluded that purpose of this meeting was achieved and that those representatives from the industry and the general public who were in attendance left the meeting with a clear understanding of NRC staff positions regarding use of the Master Curve technology. Further, the staff benefitted from this meeting by confirming the submittals regarding the use of Master Curve technology for reactor pressure vessel (RPV) evaluation will be made by the licensees for Beaver Valley and Point Beach. In addition, the licensee for D.C. Cook and a more generic topical report from Framatome on behalf of Babcock and Wilcox RPV owners may also be made.

Attachments: As stated

CONTACT: Matthew A. Mitchell, EMCB/DE
415-3303

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Discussion of “Lessons Learned” Concerning the Evaluation and Approval of the Kewaunee Master Curve Submittal

Matthew A. Mitchell
Materials and Chemical Engineering Branch
Division of Engineering
Office of Nuclear Reactor Regulation

June 19, 2001

Attachment 2

Introduction and Purpose

- NRC staff approval of the Kewaunee submittal represents a significant change in the regulation of RPV integrity issues
  - First use of fracture toughness data in a “generic methodology” for the purpose of evaluating RPV integrity
  - First approval of analysis based on use of ASME Code Case N-629 (and/or N-631) and ASTM E 1921-97 Master Curve methodology
  - First use of plant-specific fracture toughness data from irradiated specimens for the purpose of evaluating RPV integrity
- The staff recognizes that there is the potential for use of the Master Curve technology throughout the industry and that there is a high level of interest in the outcome of the Kewaunee review process.

Introduction and Purpose

- Based on the above considerations, the staff initiated this meeting to:
  - Discuss licensing-related “lessons learned” from the Kewaunee review
  - Discuss issues of regulatory implementation related the submittal
  - Discuss technical/programmatic issues which were addressed by the staff in the completion of the review
  - Highlight specific staff conclusions/positions in the Kewaunee safety evaluation which may be of general interest
  - Facilitate the efficient review of future licensee Master Curve-based submittals by reducing the need for RAIs to resolve generic issues which have already been addressed in the Kewaunee safety evaluation

Regulatory Implementation

- General Question: What actions must be taken to enable the use of a Master Curve-based methodology for RPV integrity evaluations?
  - Kewaunee submittal requested three exemptions, from 10 CFR 50.61, Appendix G to 10 CFR Part 50, and Appendix H to 10 CFR Part 50
  - The staff agreed that all of these exemptions were necessary for the Kewaunee submittal and would be necessary in general for future licensee applications.
- Exemptions to 10 CFR 50.61 and Appendix G necessary to invoke fracture toughness-based methodology in lieu of Charpy/drop weight-based methodology.
- Exemption from Appendix H necessary to incorporate the acquisition of fracture toughness data at the basis for the facility's RPV surveillance program.

<u>Regulatory Implementation</u>

- "Lessons learned" regarding the exemption requests:

  1. Exemptions which are being sought to the requirements of 10 CFR Part 50 <u>should not</u> refer to the need to address license renewal considerations as part of the basis for requesting the exemption. In fact, the evaluation of the EOLE condition is problematic outside of inclusion in a specific licence renewal submittal.

     – "The NRC staff did not evaluate the condition of the KNPP RPV at EOLE fluence for the purpose of justifying the integrity of the RPV to that fluence value. Rather, the NRC staff evaluated the $ART_{T0\text{-}EOLE\text{-}ID}$ value of the KNPP RPV using the NRC staff's methodology only for comparison to the value determined from the licensee's methodology. This comparison was necessary to determine whether the licensee's proposed methodology was at least as conservative as the NRC staff's methodology."

     – Resolving this issue with the Kewaunee submittal caused a delay of at least 3 months in the issuance of the staff's approval.

Regulatory Implementation

2. Exemptions to apply the methodology should be noted as necessary since the regulations would not otherwise permit the methodology to be used.

3. Exemption requests for Kewaunee were found to be appropriately processed under 10 CFR 50.12(a)(2)(ii) - special circumstances present such that application of the regulation is not necessary to achieve the underlying purpose of the rule.

   – Special circumstance - availability of an alternate, acceptable methodology

   – Therefore, application of the specific methodology proscribed in the regulation is not necessary to achieve the underlying purpose of the rule (to maintain RPV integrity)

Licensing Issues

- Along with the exemption requests, the Kewaunee submittal included a requested licensee amendment to revise the facility’s pressure-temperature limit curves based on use of the Master Curve-based methodology.

- This request was subsequently withdrawn by the licensee since the methodology on which the NRC staff could base its approval did not provide results which supported the P-T limit curves which were submitted by the licensee.

- “Lesson learned” - in order to not require extensive rework, it may be advisable to seek approval of a methodology first, obtain the applicable results, and then submit any subsequent license amendments as part of a separate action.

Surveillance Program Technical/Programmatic Issues

- RPV surveillance program provisions should be considered given the need to supply data to support the proposed methodology and to address other regulatory concerns.
  - Adequacy of data should consider number of T_0 data points available, exposure level of irradiated materials in comparison to the RPV, etc.
  - Surveillance program requirements should also consider the need to continue to address USE drop concerns.
  - “The NRC staff’s review was predicated on determining the minimum acceptable KNPP surveillance program to adequately monitor radiation damage...through the end of the current operating license.”
- Regarding surveillance program reporting requirements, “the NRC staff requires that all information specified in paragraphs 11.1 through 11.2.3 of ASTM E 1921-97 be reported for the surveillance weld fracture toughness testing performed on sample from the next KNPP surveillance capsule.”

Surveillance Program Technical/Programmatic Issues

- Surveillance Program Miscellaneous Notes
  - Staff endorsed use of ASTM E 1253 for Charpy reconstitution
  - Staff permitted Kewaunee to stop testing HAZ specimens. These specimens will be used instead to provide weld metal for reconstituted CVN specimens
  - Staff agreed the Kewaunee could use original (whole) CVN specimens from the next surveillance capsule as PCVN Master Curve fracture toughness specimens and reconstituted specimens for establishing “partial” CVN curve and an estimate of the USE drop.

<u>Technical Issues With A Master Curve-Based Methodology</u>

- As expected, many technical issues related to the effective <u>implementation</u> of a Master Curve-based methodology had to be resolved as part of the Kewaunee review.

- These issues included the appropriate consideration of margins, the need for a bias term to account for the use of PCVN test data, adjustments to normalize available data relative to the RPV based on best-estimate chemistry and fluence differences, etc.

  "...the staff acknowledges that the state of knowledge regarding some specific technical topics associated with this application may be improved upon in the future....RPV material property uncertainty, fluence uncertainty, and potential biases due to the use of PCVN testing, for example,...are subjects on which the existing state of knowledge could be improved upon. Hence, while the methodology discussed in this SE is acceptable, the staff acknowledges that it reflects a technical approach which is still under development. Additional "conservatisms" in this methodology may be identified in the future and...may be reduced/removed provided that a sufficient technical justification can be made for their reduction/removal."

Technical Issues With A Master Curve-Based Methodology

Issue #1: Normalization of available data to reflect best-estimate chemistry and fluence of the RPV material.

- Corrections for systematic chemistry and fluence differences (the "ratio procedure") are normalization procedures not uncertainty evaluations.
- To understand the adjustments that are made to achieve this normalization, it is necessary to recognize that although the methodology submitted by the licensee (and the one acceptable to the staff) was discussed in terms of "direct measurement of fracture toughness properties in the irradiated condition," in reality it entailed a "initial property + shift" methodology similar to that used in the current regulations.
- However, the licencee's methodology attempted to adjust one data point (KNPP Capsule S) to RPV EOL conditions and the other (MY Capsule A-35) to RPV EOLE conditions. The staff's methodology was constructed so that both data points could be used together to assess any RPV condition.

<u>Technical Issues With A Master Curve-Based Methodology</u>

Issue #1: Normalization of available data to reflect best-estimate chemistry and fluence of the RPV material.

- Staff accepts the use of the functional form from RG 1.99, Revision 2, the fluence factor formula, for defining the variation in fracture toughness <u>shift</u> with increasing fluence level.

- Normalization formula includes factors which permit adjustment for irradiation temperature, fluence, and chemical composition.

$$\Delta T_{0\text{-time X-location Y-[cap]}} = [\Delta T_{0\text{-[cap]}} - (t_{irr\text{-}RPV} - t_{irr\text{-[cap]}})] * [(FF_{X\text{-}Y} / FF_{[cap]}) * (CF_{RPV} / CF_{[cap]})]$$

- For analyzing throughwall locations, RG 1.99, Revision 2 attenuation function may be used to obtain fluence-at-depth and, thereby, the appropriate FF value.

Technical Issues With A Master Curve-Based Methodology

Issue #1: Normalization of available data to reflect best-estimate chemistry and fluence of the RPV material. Why?

"The staff has concluded...that "direct measurement" of fracture toughness properties in the irradiated condition is, in theory, an acceptable basis upon which to utilize the Master Curve technology to evaluate the material properties of RPVs....However,...the concept of "direct measurement" of RPV material properties must be clearly understood if it is to applied in an acceptable manner. The NRC staff's position is that "direct measurement," in its strictest sense, results from obtaining and testing material samples from the RPV material itself. Fracture toughness data derived from other sources (in the KNPP submittal, data obtained from the testing of irradiated samples of surveillance welds made with the same weld wire heat as the RPV weld) does not represent "direct measurement" of RPV material properties in the irradiated condition. Testing of surveillance weld materials which are linked to the RPV weld in question by the same weld wire heat number is considered by the staff to be an application of "surrogate" material testing."

Technical Issues With A Master Curve-Based Methodology

Issue #2: Assessment of explicit and implicit margins

- The staff anticipates that this will continue to be the most significant issue to be resolved in future Master Curve-based applications.

- Licensee proposed that the explicit margins be based solely on the uncertainty associated with the Master Curve test procedure (ASTM E1921-97).

  - 16 °F for EOL evaluation
  - 24 °F for EOLE evaluation

- Licensee proposed that 18 °F of implicit margin existed in their methodology based on the use of the relationship $RT_{T0} = T_0 + 35$ °F from ASME Code Case N-629.

Technical Issues With A Master Curve-Based Methodology

Issue #2: Assessment of explicit and implicit margins

- The staff concluded that only 2 °F of implicit margin existed in the $RT_{T0} = T_0 + 35$ °F relationship.

- The staff concluded that variability in initial material properties, chemical composition, and fluence had to be explicitly accounted for when determining the margin to be applied.

- Monte Carlo simulations were used by the staff to assess the effects of chemistry variability and initial material property (fracture toughness) uncertainty.

  – Staff determined 28 °F to be the 1σ uncertainty contribution from chemical composition variability and fluence uncertainty (σ_{Δ}).

  – Staff determined 14 °F to be the 1σ uncertainty contribution from initial material property/test method uncertainty (σ_{IT0}).

  – Therefore, 62.5 °F of total, explicit margin was applied in the staff's evaluation.

Comparison of Implicit and Explicit Components Used to Determine ART Values for the KNPP RPV Circumferential Weld at the Clad-to-Base Metal Interface Via the NRC and WPSC Methodologies

	At EOL Conditions		At EOLE Conditions[9]	
	NRC	WPSC	NRC	WPSC
T_0[1]	167 °F[2]	183 °F[3]	184 °F[2]	190 °F[4]
RT_{T0}	T_0 + 33 °F[5]	T_0 + 35 °F[6]	T_0 + 33 °F	T_0 + 35 °F
Explicit Margin	62.5 °F	16 °F	62.5 °F	24 °F
PCVN Bias	8.5 °F[7]	0 °F[8]	8.5 °F	0 °F
ART_{T0}	271 °F	234 °F	288 °F	249 °F

[1] "T_0" in this table refers to the estimated value of T_0 for the RPV weld at the specified condition after all chemistry and fluence adjustments were made to the data sets of interest.

[2] Although this value is not explicitly calculated in the NRC methodology, it represents the "average" T_0 which would be calculated from the KNPP and Maine Yankee PCVN data using the NRC methodology.

[3] Value based on all KNPP surveillance weld fracture toughness data alone.

[4] Value based on all Maine Yankee surveillance weld fracture toughness data alone.

[5] Based on ASME Code Case N-629 definition of RT_{T0} with 2 °F of implicit margin removed.

[6] WPSC claims that this relationship contains 18 °F of implicit margin relative to the current impact test-based approach.

[7] As with note [1], "average" bias adjustment applied to the KNPP and Maine Yankee surveillance data.

[8] WPSC claimed that no bias term was required for their methodology, but noted that a 4 °F bias term might be necessary for the NRC methodology which is based on only the available PCVN fracture toughness test data.

[9] The EOLE fluence chosen by WPSC was 5.1 x 10^{19} n/cm^2 based on assuming a conservative future capacity factor of 97 percent. The EOLE fluence chosen by the NRC was 4.7 x 10^{19} n/cm^2 based on a 85 percent future capacity factor.

Technical Issues With A Master Curve-Based Methodology

Issue #3: Assessment of PCVN testing bias

- The staff concluded that, based on a comparison of PCVN T_0 results to those obtained from the testing of 1T or larger CT specimens, a bias value of 8.5 °F should be applied to all data sets of interest in the Kewaunee evaluation.

"The staff acknowledges that the lack of a definable trend [in observed bias with respect to the M_0 constraint parameter of the PCVN data set] calls into question whether the observed bias from PCVN test results can be simply addressed as a matter of specimen constraint....The staff recognizes that additional research in this area may help to better define this issue and modify the conclusions of this SE. However, the staff concludes, at this time, that the assumption of a 8.5 °F bias in PCVN-based T_0 values relative to values obtained from larger size CT specimens...is adequate to address this potential source of non-conservatism..."

- Therefore, the staff's general conclusion is that an 8.5 °F should be applied to PCVN data sets unless additional technical justification is provided to modify this position.

Technical Issues With A Master Curve-Based Methodology

Issue #4: The methodology discussed as part of the Kewaunee submittal is acceptable because it is based on an indexing method that is traceable back to the use of K_{Ic} fracture toughness data.

"...the methodology...uses fracture toughness data to establish an indexing parameter, RT_{T0}, to position the K_{Ic} (static, plane strain, lower bound) fracture toughness curve from the ASME Code. The NRC staff finds that this is a generally acceptable approach for utilizing fracture toughness data within the current regulatory framework (i.e., 10 CFR 50.61, Appendix G to 10 CFR Part 50, etc.). This would be as opposed to a methodology which could be proposed to directly utilize not only the T_0 parameter, but also the general Master Curve "shape" through the fracture toughness transition region; a proposal which would require significant additional evaluation to understand the relation of such an approach to the current regulatory structure."

$$T_{0(RPV)} = T_{0(capsule)} - (\Delta T_{0(capsule)} - \Delta T_{0(RPV)})$$

$$T_{0(RPV)} = T_{0(capsule)} - (\Delta T_{0(capsule)} - [\Delta T_{0(capsule)} * (FF_{RPV}/FF_{capsule}) * (CF_{RPV}/CF_{capsule})])$$

$$T_{0(RPV)} = T_{0(capsule)} - (\Delta T_{0(capsule)} * [1 - (FF_{RPV}/FF_{capsule}) * (CF_{RPV}/CF_{capsule})])$$

Notes: In this form of the equation, the only place where the unirradiated surveillance material test results contribute is in the determination of $\Delta T_{0(capsule)}$. Hence, use of a higher unirradiated T_0 value serves to minimize $\Delta T_{0(capsule)}$.

The $[1 - (FF_{RPV}/FF_{capsule}) * (CF_{RPV}/CF_{capsule})]$ term represents the normalization of surveillance data to the RPV condition of interest.

If $[(FF_{RPV}/FF_{capsule}) * (CF_{RPV}/CF_{capsule})]$ is < 1, then the data is being "interpolated" to the RPV condition.

If $[(FF_{RPV}/FF_{capsule}) * (CF_{RPV}/CF_{capsule})]$ is > 1, then the data is being "extrapolated" to the RPV condition.

Minimizing $\Delta T_{0(capsule)}$ may be "conservative" when "interpolating", but may be "non-conservative" when "extrapolating."