NRC-00-010

Public Service

Wisconsin Public Service Corporation
(a subsidiary of WPS Resources Corporation)
Kewaunee Nuclear Power Plant
North 490, Highway 42
Kewaunee, WI 54216-9511
920-388-2560

February 4, 2000

10 CFR 50.12 and
10CFR 50.90

U.S. NRC Nuclear Regulatory Commission
Attention: Document Control Desk
Washington, D.C. 20555

Ladies/Gentlemen:

Docket 50-305
Operating License DPR-43
Kewaunee Nuclear Power Plant
Proposed Technical Specification Change Regarding Heatup and Cooldown Limit Curves and
Request for Exemption to 10 CFR 50.60, 10 CFR 50.61, and Appendices G and H of Part 50

References:
1) Letter from M.L. Marchi (WPSC) to Document Control Desk (NRC) dated June 7, 1999
2) Letter from T.J. Kim (NRC) to M.L. Marchi (WPSC) dated July 16, 1999
3) Letter from C.M. Craig (NRC) to WPSC dated November 16, 1999

In reference 1 Wisconsin Public Service Corporation (WPSC) proposed changes to the heatup and cooldown curves contained in the Kewaunee Nuclear Power Plant (KNPP) Technical Specifications (TS). The reference also requested exemption from the applicable sections of 10CFR50 in order to use the master curve methodology to determine reactor vessel fracture toughness. In reference 2 the NRC staff stated they could not begin their review until WPSC answered additional questions about the margin terms used in our analysis. Reference 3 summarizes a meeting between WPSC and the NRC in which the margin terms were discussed.

The attachment to this letter provides WPSC's response to the questions raised in references 2 and 3. If you have any questions about our response, please contact me or a member of my staff.

Sincerely,

Mark L. Marchi
Vice President-Nuclear

TJW
Attach.
cc - US NRC, Region III
US NRC Senior Resident Inspector
Electric Division, PSCW

A001

ATTACHMENT 1

Letter from Mark L. Marchi (WPSC)

To

Document Control Desk (NRC)

Dated

February 4, 2000

Re:

Response to the NRC's Request for Addition Information on Proposed Amendment 160

EDRE-EMT-1467

RESPONSE TO NRC QUESTIONS REGARDING MARGINS TO BE USED IN MASTER CURVE INTEGRITY ASSESSMENT FOR THE KEWAUNEE NUCLEAR POWER PLANT

January , 2000

Prepared by

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Under the WOG program MUHP 5903

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RESPONSE TO NRC QUESTIONS REGARDING MARGINS TO BE USED IN MASTER CURVE INTEGRITY ASSESSMENT FOR THE KEWAUNEE NUCLEAR POWER PLANT

W. Server, ATI Consulting
Dr. R. Lott, Westinghouse
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Introduction

The Nuclear Regulatory Commission (NRC) issued a letter on July 16, 1999 to Wisconsin Public Service Corporation (WPSC) with regard to their June 7, 1999 submittal for the Kewaunee Nuclear Power Plant (KNPP). The submittal requested NRC approval to use the Master Curve fracture toughness methodology to assess the structural integrity of the critical material in the intermediate to lower shell girth weld of the KNPP reactor vessel. The NRC raised three issues:

- Adequacy of the overall margin included in the submitted analysis considering variability in copper and nickel chemistry;
- Application of the ratio method does not consider the effect of saturation of radiation damage for welds above about 0.3 wt% copper (specifically, applicable to the Maine Yankee surveillance weld); and
- Integrated effect of considering margins and copper saturation on the determination of adjusted reference temperature (ART).

A meeting was held with the NRC on October 6, 1999 to clarify these questions and to present WPSC's proposed approach to address these issues. The NRC Staff posed three new, but related questions/issues:

- Incorporation of the latest understanding of chemistry variability from responses to Generic Letter 92-01 into the margin term;
- Clarification and incorporation of uncertainty of fluence into the margin term for direct fracture toughness measurement; and
- Explanation of how initial properties of the surveillance materials and the actual reactor pressure vessel (RPV) weld need to be compared to assess the contribution of variability to the margin term.

This letter report provides the technical response to these issues. Note, these issues are interrelated and separation into independent variable effects has been attempted, but consideration of individual effects may be misleading at times. It is important to consider the integrated effects on the calculated ART/RT_{PTS} value. Also note that the use of the ratio normalization method was originally termed a heat uncertainty term has been replaced by different terminology more consistent with NRC interpretation and use.

WPSC's original submittal parallels the current regulatory structure in 10CFR 50.61 and Appendices G and H for dealing with the effects of irradiation on vessel toughness. The current regulatory structure is based upon the sum of:

(1) an unirradiated value,
(2) an estimated mean value of shift, and
(3) a margin term.

Fundamental to the Master Curve fracture toughness methodology is a process to directly measure the toughness at the fluence level of interest. Direct measurement of fracture toughness at a fluence level of interest reduces or eliminates the uncertainty associated with initial properties, transition temperature shift, and fluence (if conservatively calculated). The ability to make relevant fracture toughness measurements directly on irradiated material at the fluence of interest is a primary advantage of the proposed Master Curve methodology used in the WPSC submittal.

In the current regulatory methodology, three separate mechanical property measurements are required:

(1) unirradiated nil-ductility transition temperature (NDTT) per ASTM E 208,
(2) unirradiated Charpy V-notch (CVN) results per ASTM E 23 to determine the 30 ft-lb transition temperature (T_{30}) and the acceptance for a valid RT_{NDT} determination, and
(3) irradiated CVN T_{30}.

The combination of these three measurements produces a larger uncertainty than the proposed Master Curve direct measurement methodology. As stated previously, the Master Curve technology is based on a single determination at the fluence level of interest. Therefore, the overall uncertainty and margin term is smaller than the currently approved methodology.

The issues raised by the NRC in the July 16th letter and October 6th meeting have been condensed into the following six questions/issues:

QUESTION 1: How are uncertainties in initial properties, copper, nickel, fluence, and calculation method included in the proposed margin term?

QUESTION 2: If the embrittlement due to copper saturates at a level of 0.30 wt%, what effect does this saturation have on the ratio method used for estimating the best-estimate values for the Kewaunee vessel weld?

QUESTION 3: What is the uncertainty in fluence to be used for the Kewaunee direct fracture toughness measurement methodology?

QUESTION 4: What is the effect of the latest understanding of chemistry variability from responses to Generic Letter 92-01 on the margin term?

QUESTION 5: What are the integrated effects when considering margins and copper saturation?

QUESTION 6: How can the initial properties of the surveillance materials and the actual RPV weld be compared to assess variability and potential contribution to the margin term?

Each of these six specific questions/issues is addressed. The questions have been arranged by subject, which allows technical flow and linkage between the issues. Each question is stated and a summary response is presented. The technical details supporting the summary response are then provided before addressing the next question. All of the figures and tables are positioned at the end of this report.

All six questions address the relationship between the uncertainty in the determination of the fracture toughness reference temperature from surveillance welds and the margin required for application to the RPV weld. Uncertainty from many sources must be considered, including: initial RT_{NDT} or $RT_{NDT(u)}$, copper content, nickel content, fluence, and calculation procedure. The variability in $RT_{NDT(u)}$ is addressed in the response to Question 1. Uncertainty due to calculation procedure is also addressed in the response to Question 1. The copper and nickel variability issues are addressed in detail in the response to Questions 2, 4 and 5, and the evaluations include use of all of the extensive information available on 1P3571 welds. Uncertainty in fluence is addressed in the response to Question 3. Variability between the 1P3571 surveillance weld materials and the Kewaunee reactor vessel weld is not an issue since the two key surveillance welds (Kewaunee and Maine Yankee) and the KNPP vessel girth weld are identical as described in the response to Question 6. The technical basis for the uncertainty analysis to determine margin terms for the KNPP vessel weld is briefly summarized in the following bullet items:

- T_o values have been measured for both the Maine Yankee and KNPP surveillance capsule materials. These test specimens sampled a representative variation in copper content, nickel content, and potential cleavage initiation sites (such as carbides) as discussed in WCAP-15074. The T_o, and subsequent RT_{To}, results of this testing indicate that these two sources of 1P3571 weld material produce essentially identical initial properties. This equivalence of results is expected because these weld materials are judged to be identical to each other and normal variations in toughness measurements are included in the T_o definition. Similarly, the KNPP vessel weld has been judged to be identical to the surveillance capsule materials and an uncertainty term specific to initial property variations is not required. Furthermore, since initial properties are not used directly in the Master Curve direct fracture toughness methodology, there is no need to consider any uncertainties in initial properties.

- The projected fluence used to estimate extended end of life ART is bounding due to the assumption of a capacity factor of 95-97% throughout the current and extended life of the KNPP reactor vessel. Due to this level of conservatism in the projected fluence, there is no need to include a specific fluence uncertainty for the margin term.
- The chemical composition, specifically copper and nickel content, for many sources of weld heat 1P3571 have been measured extensively since the early 1970's. The preponderance of test data is documented in WCAP-15074. These data involve a statistically significant number of measurements, and additional measurements on 1P3571 weldments will not alter the distributions that have now been characterized. The potential variability of the KNPP vessel weld is known. The impact of this variability has been assessed and included in the margin term used to determine ART.
- The submitted direct measurement process is not based upon a correlation of Charpy V-notch impact transition temperature shift measurements. Thus, there is no need to include a specific calculation procedure uncertainty in the margin term.

In responding to the six questions, several alternative approaches to setting margins to maintain current levels of confidence were considered, and the overall impact was assessed for use of the Master Curve approach. Several key findings are summarized as follows:

- The original submittal contains two margins, an explicit 24°F margin and an inherent margin of 18°F applicable to the bounding material for the ASME Code K_{IC} curve.
- The definition of RT_{T_0} as an index to a bounding curve does not require any further margin term for measurement uncertainty; the inclusion of the ASTM E 1921-97 standard deviation term in the original submittal exceeds the current standards for conservatism.
- The additional margin necessary to cover normal uncertainties associated with copper and nickel chemistry is comparable to the 24°F margin used in the original submittal.
- Using worst-case assumptions for both copper and nickel effects produces a maximum total margin of 55°F for weld heat 1P3571 without considering saturation effects.
- When copper saturation effects are considered, the ART/RT_{PTS} margin is actually reduced by 28°F from the maximum total margin; this reduction gives a total margin of 27°F.

- When the integrated effects of the broadened Cu distribution and Cu saturation are considered, the overall total margin term is approximately equal to the 24°F margin contained in the original analysis.

These new analyses demonstrate that alternative approaches, including the integrated consideration of copper saturation, have minimal impact on the margin required to maintain the current level of confidence in RPV integrity. These analyses reinforce the use of the 24°F margin term provided in the June 7, 1999 submittal. Therefore, no alterations to the original submittal are required.

QUESTION 1: How are uncertainties in initial properties, copper, nickel, fluence, and calculation method included in the proposed margin term?

RESPONSE

Summary: In the June 7, 1999 submittal, a margin associated with the ratio normalization method and the uncertainty in the measured value of RT_{To} was explicitly described. The inherent margin of 18°F, which is built into the determination of $RT_{To} = T_o + 35°F$, was also presented as an added conservatism to account for other undefined uncertainties. The July 16th letter from the NRC indicated that the margin term from the original submittal might not have included consideration of all pertinent uncertainties. At the October 6th meeting, WPSC explained that the explicit margin associated with the ratio normalization (or heat uncertainty term, as used in the original submittal) closely follows current regulation. The inclusion of the ASTM E 1921-97 standard deviation in the measurement uncertainty in T_o, and subsequently RT_{To}, goes beyond current regulation in that RT_{To} is a bounding value not a best estimate. These three terms (the ratio normalization, the explicit margin on the measured value of RT_{To}, and the implicit margin included in the definition of RT_{To}) constitute a reasonable approach to define an overall margin. These terms account for uncertainties in initial transition temperature, copper, nickel, fluence, and calculation method.

In response to the October 6th presentation, the NRC asked for further clarification on the following issues:

- How will variability in the initial properties affect the overall margin term?
- Does the margin term include uncertainties observed in irradiation-induced shifts?
- In addition, the NRC suggested that it might be helpful to assess the effect of replacing the fracture toughness distributions used to develop the PTS Rule, 10 CFR 50.61, with the Master Curve distribution to determine the effect on conditional RPV failure probability.

Detailed analysis of these concerns demonstrates that:

(1) the variability in initial properties is incorporated in the definition of RT_{To},
(2) the original margin terms (24° F explicit and 18 ° F inherent) adequately cover uncertainties in the radiation induced shifts, and
(3) initial comparisons of fracture toughness distributions indicate that replacing the original toughness distribution assumptions with the more realistic Master Curve distribution (and using RT_{To} to index the K_{IC} curve) reduces the calculated conditional probability of RPV failure.

The proceeding Technical Details Section is arranged as following:

(1) Initial or Unirradiated RT_{NDT}, $RT_{NDT(u)}$
(2) Shift in RT_{NDT} – Correlation Based on Copper, Nickel, and Fluence
(3) Ratio Normalization and Calculation of ART
(4) Margin Assessment
(5) PTS Evaluation Considering Master Curve and RT_{To}

Technical Details: A review was conducted to ascertain the historical basis for the margin term used in 10 CFR 50.61 and Regulatory Guide 1.99, Revision 2. Aspects of this review are presented next as they relate to each specific uncertainty. Copper variability and its role in enhancing radiation embrittlement is a factor in establishing margin. Details of this issue, as addressed in current regulation, are described here; a more technical discussion for application beyond the current regulatory process is given in the response to Question 4.

Initial or Unirradiated RT_{NDT}, $RT_{NDT(u)}$

This section discusses uncertainty associated with initial or unirradiated RT_{NDT}, $RT_{NDT(u)}$, with respect to the KNPP application of the Master Curve fracture toughness methodology. The uncertainty associated with the initial RT_{NDT} is composed of two components:

(1) the measurement process uncertainty, and
(2) the variability in the measured value associated with material inhomogeneity (which is a metallurgical variable related to the distribution of carbides, inclusions, etc.).

ASTM Test Method E23 for Charpy V-notch (CVN) testing and ASTM Test Method E 208 are used in the measurement of $RT_{NDT(u)}$. Using ASTM E 208, typically results in a bounding value with 10°F precision. These standards assure a repeatable measurement. Variability is primarily due to material variations. The current regulatory process is summarized in Table 1. The standard deviation term, σ_I, associated with the initial RT_{NDT}, is taken as zero for a value measured in accordance with ASME NB 2300. This practice is acceptable because $RT_{NDT(u)}$ is an empirically determined bound (not a mean value) to a combined set of drop-weight NDTT and CVN results. Therefore, variability/uncertainty is already included in the bounding definition of $RT_{NDT(u)}$, when measured. When estimated values are used in place of a measurement, the regulation calls for an additional uncertainty. Adding uncertainty to a mean value is reasonable since the specific property is not measured directly and the potential variability in $RT_{NDT(u)}$ is much larger. For non-Linde 80 welds, which include Linde 1092 welds, the generic value of –56°F is generally used, and the corresponding σ_i term is 17°F. The 17°F uncertainty represents the material variability for Combustion Engineering fabricated welds.

Since the Master Curve technology directly measures the properties of an irradiated material, it does not require measurements of unirradiated material properties to determine fracture toughness. The only place initial properties are used is in the ratio procedure; note that any variation in initial properties has little effect on the ratio procedure as used in the WPSC evaluation. Therefore, uncertainties associated with the measurement of initial properties do not affect the calculation of RT_{To}. The potential material variability in the irradiated RT_{To} determination has been considered. RT_{To} is defined as T_o+35°F and is an empirical bound. RT_{To} is similar to RT_{NDT} in that it is also a bounding value. As such, material uncertainty is inherent in its definition. In fact, there is an inherent margin of 18°F on the most-limiting lower bound material, HSST Plate 02, when using the RT_{To} approach. As the most limiting material in the original database, HSST Plate 02 establishes the standard for the minimum acceptable spacing between the fracture toughness values and the reference fracture toughness curve (see Figure 1 for illustration). The use of RT_{To} provides a more consistent relationship between the data and the curve and increases the minimum acceptable spacing. The implied relationship between the fracture toughness data and the reference toughness curve is illustrated in Figure 1.

ASTM Test Method E 1921-97 has been used for testing and evaluation, and the uncertainty associated with the measurement process has been included in the KNPP submittal. The ASTM E 1921-97 standard deviation in T_o defines the overall uncertainty needed for the direct measurement of reference temperature, RT_{To}. The use of this uncertainty term represents a level of conservatism that *exceeds* current requirements since the regulations do not require an uncertainty for a bounding measurement of reference temperature.

A measured RT_{To} is equivalent in application to a measured value of RT_{NDT}. RT_{NDT} is a bounding value and no additional margin is needed to cover uncertainty when the quantity is measured. RT_{To} also is a defined bounding value. But, in the June 7, 1999 submittal, RT_{To} was conservatively treated as a mean value, and the uncertainty in the measurement, due primarily to the known statistical distribution of the fracture toughness data, was added. Given the more appropriate use of the direct measurement methodology, it is expected that measurement uncertainties for T_o, and hence RT_{To}, are smaller than real measurement uncertainties for RT_{NDT}.

Table 2 illustrates that the unirradiated RT_{To} value for the Maine Yankee surveillance weld is slightly lower than that for the Kewaunee surveillance weld (i.e., -123°F vs. -109°F), although within the typical range of expected repeat determinations. These results are in contrast to the reversed results for initial (unirradiated) RT_{NDT} of -30°F vs. -50°F for the Maine Yankee and Kewaunee surveillance welds, respectively. These initial property results are within expected data scatter and property precision for the initial RT_{NDT} and RT_{To} measurements for the Kewaunee and Maine Yankee weldments.

Shift in RT_{NDT} – Correlation Based on Copper, Nickel, and Fluence

This section discusses the uncertainties associated with the estimation of shift in RT_{NDT}. The shift in RT_{NDT} is determined using procedures outlined in 10CFR 50.61/Regulatory Guide 1.99, Rev. 2. These procedures rely on determinations and/or estimates of the shift in Charpy 30 ft-lb transition temperature. The estimate of the transition temperature is based on a correlation involving three independent variables: Cu content, Ni content, and irradiation fluence. There are two types of contribution to the uncertainty in the determination of the transition temperature shift:

(1) Uncertainty in the measurement/correlation process, and
(2) Uncertainty in the knowledge of the independent variables.

Within these two types of uncertainty, there are six components of the uncertainty:

Measurement/Correlation

- Measurement Process
- Material Variability
- Correlation Inaccuracy

Independent Variables

- Cu Uncertainty
- Ni Uncertainty
- Fluence Uncertainty

The assigned overall uncertainty in shift (σ_Δ) is 28°F for weld metals. Given known uncertainties in the independent variables and the correlation model, the last three components of the overall uncertainty can be determined. This determination was accomplished using a spreadsheet to perform a simplified Monte Carlo analysis. Inputs to the Monte Carlo analysis include the historical estimated standard deviation for Cu (σ_{Cu}) of 0.03 wt%, the 1P3571 measured standard deviation for Ni (σ_{Ni}) of 0.042 wt% Ni (the historical value being either assumed as 0.05 wt% or 10%), and a standard deviation of 20% for fluence ($\sigma_{\phi t}$).

The three measurement/correlation components of uncertainty are combined into a single term (σ_{err}) since it is difficult to separate them explicitly. The measurement process is based upon ASTM Test Method E 23 measurements of CVN energy evaluated to give the mean 30 ft-lb transition temperature shift from an unirradiated (U) state to an irradiated (I) condition. Variability in material properties is sampled by the various CVN test specimens used to derive the 30 ft-lb temperatures. The balance of the σ_{err} is due to the correlation process used in the calculation following the current regulatory methodology. This material and process combined term (i.e., the standard deviation estimate, σ_{err} = 19°F) was determined by calculation assuming the overall variability of 28°F as shown in

Table 3. The temperature shift uncertainty results for copper, nickel and fluence are listed in Table 3.

Each of these uncertainties as they relate to the KNPP submittal is discussed in the following paragraphs. When surveillance measurements are deemed credible by the regulatory process, then the overall standard deviation value (σ_Δ) can be reduced in half. Note that both the Kewaunee and Maine Yankee surveillance programs have been deemed credible. Margin is then assessed using a square-root sum of the squares (SRSS) combination of individual standard deviation terms.

For an application where shift and a correlation are not needed, such as application of Master Curve data measured at the extended end-of-life (EOLE) fluence, the SRSS combination of copper and nickel standard deviations alone gives 17°F ($[13^2 + 11^2]^{1/2} = 17$). The σ_{err} term is set to zero since no correlation or shift measurement is used. The $\sigma_{\phi t}$ term is not needed because the peak fluence in the vessel is assessed from dosimetry measurements higher than physics calculations and a very conservative capacity factor. Additionally, the uncertainty in fluence for the Kewaunee vessel application is less than the 20% uncertainty assumed in the Table 3 analyses. The response to Question 3 discusses fluence uncertainty in more detail.

One key area for evaluation of the Kewaunee reactor vessel is copper variability. Weld metal heat number 1P3571 is common for the Kewaunee and Maine Yankee reactor vessels. To date, two surveillance welds of heat 1P3571 for Kewaunee and Maine Yankee reactor vessels have been analyzed extensively, as have other weldments fabricated using weld wire 1P3571. The most obvious difference between the Maine Yankee and Kewaunee surveillance welds is the Cu content. Repeated chemistry measurements on these two weldments indicate that they represent distinctly different distributions of Cu levels. Combining the two data sets results in a Cu distribution that is much broader than typically observed in historical distributions of weld metal heats (but there are other weld heats besides heat 1P3571 that exhibit wide Cu distributions). Based on a sample-weighted mean, the standard deviation of Cu in the entire 1P3571 database is about 0.08 wt%. According to the NRC evaluation of the PTS Rule*, the standard deviation in Cu determination is expected to be 0.03 wt%; it is this 0.03 wt% level of Cu uncertainty that is currently built into the current regulatory margin term as shown in Table 3. In summary, as stated above, an overall uncertainty of 17°F is adequate, which is based on the 0.03 wt% Cu and 0.042 wt% Ni corresponding to individual temperature uncertainties of 13° F and 11 ° F for Cu and Ni, respectively. The effect of the wider Cu distribution is further addressed in the response to Question 4.

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* Draft NRC Staff Evaluation of Pressurized Thermal Shock, September 13, 1982.

Ratio Normalization and Calculation of ART

This section discusses the use of the ratio normalization process and the combination of using it in calculating ART. The only adjustment in the current regulatory process for multiple weld wire coils is contained in the ratio method, which the NRC has appropriately pointed out is a normalization procedure, not a true margin. The ratio method normalizes surveillance capsule data from multiple sources to obtain the best estimate Cu and Ni values for the reactor vessel. These best estimate values are based upon a broader range of information about the specific weld wire heat. This normalization process reflects the difference in chemistry between the surveillance welds and the best estimate for the reactor vessel weld. This additional term was called a "heat uncertainty term" in the June 7, 1999 submittal. In this letter, the term is called a ratio adjustment (R). Note that in the June 7, 1999 submittal, the heat uncertainty term (hence, ratio adjustment) was not treated as a standard deviation type of uncertainty which can use SRSS combination; it was treated as a simple additive term, consistent with Regulatory Guide 1.99, Rev. 2.

The equation for calculating adjusted reference temperature, ART (or RT_{PTS}), using the Charpy-based methodology can be stated as:

$$ART = IRT + (\Delta RT + R) + M$$

where,

- IRT is the initial RT_{NDT} which is sometime termed $RT_{NDT(u)}$,
- ΔRT is the shift in RT_{NDT} with fluence, and
- M is the margin term that is typically a two standard deviation value of the SRSS of the assigned uncertainties.

For the direct measurement Master Curve fracture toughness methodology, the ART is:

$$ART = RT_{To} + R + M$$

where,

RT_{To} is the reference temperature measured near the EOLE fluence. RT_{To} is determined following Code Case N-629: $RT_{To} = T_o + 35°F$. T_o is determined following ASTM Test Method E 1921. The 35°F increase above T_o includes the inherent margin of approximately 18°F that is applicable to the HSST Plate 02 bounding material for the ASME Code K_{IC} curve.

R is the ratio adjustment using RT_{T0} values from the Kewaunee and Maine Yankee surveillance welds. This adjustment accounts for the difference in wt% Cu and wt% Ni observed in the surveillance welds and the best-estimate reactor vessel weld (similar to the Charpy-based approach).

M is the two standard deviation margin that combines independent uncertainties using the SRSS method. In the June 7, 1999 submittal, the standard deviation associated with the Weibull determination uncertainty in RT_{T0} ($\sigma_{T0} = 12°F$) was used to define M. As indicated earlier, this uncertainty is not required following the current regulatory process, but it is a reasonable term to cover uncertainty in the RT_{T0} determination and other unspecified uncertainties.

The value of R from the Charpy-based approach is an adjustment upward of 39°F above the Kewaunee surveillance weld projections (or equivalently, 32°F below the Maine Yankee surveillance weld projections). Using the measured RT_{T0} values for the two surveillance welds, instead of Charpy data, results in a ratio adjustment of 37°F above the Kewaunee surveillance weld projections (or equivalently 32°F below the Maine Yankee surveillance weld projections). The higher level of variation in copper for weld wire heat 1P3571 is partially taken into account by the ratio normalization method. In particular, the Maine Yankee surveillance weld exhibits the highest overall mean for copper; the Kewaunee surveillance weld shows the lowest mean level for copper for the 1P3571 heat. The best-estimate copper content for the Kewaunee vessel (using the coil-weighted average of all of the industry data on weld wire heat 1P3571) is essentially midway between the Kewaunee and Maine Yankee surveillance weld mean values. The calculated ratio corresponds to 0.54 between the Kewaunee and Maine Yankee surveillance weld data as shown in Figure 2.

Margin Assessment

This section compares and contrasts margin included in the June 7, 1999 submittal, with margin derived consistent with the PTS rule, and margin derived in response to question 1.

Following the current regulatory practice as closely as possible allows a comparison of the uncertainties that explicitly cover the key parameters of interest: initial RT_{NDT}, copper content, nickel content, fluence, and calculation method. In the June 7, 1999 submittal, an explicit margin of 24°F, based on the uncertainty in RT_{T0} was included, which was intended to cover other possible uncertainties in the process. Additionally, there is the implicit uncertainty of 18°F that is built into the RT_{T0} definition (Code Case N-629). The total maximum margin is the sum of the explicit and implicit terms, which is 42°F (an explicit margin of 24°F from original submittal plus an implicit margin of 18°F). Two alternative methods for determining explicit margin for the direct measurement of fracture toughness are compared to the original submittal value in Table 4. The first alternative approach uses the current regulatory process for Charpy technology and is listed as "PTS Rule Margin." The second alternative approach follows the evaluation presented earlier to combine the portion of σ_Δ directly attributable to Cu and Ni uncertainty with the measurement uncertainty. In all cases, the additional uncertainty terms associated with Cu and Ni chemistry are treated as a credible σ_Δ.

As shown in Table 4, an increase of only 4-5°F in the explicit margin conservatively covers other uncertainties associated with Cu, Ni, fluence, and calculation process. This difference is easily accounted for by the 18°F implicit margin included in the RT_{To} definition. Therefore, the original submittal has a reasonable amount of margin included to accommodate specific uncertainties that are needed for the direct fracture toughness measurement approach.

PTS Evaluation Considering Master Curve and RT_{To}

This section discusses the impact of using the Master Curve and RT_{To} in probabilistic fracture mechanics evaluations in lieu of the past, more traditional RT_{NDT}-K_{IC} curve and data. The evaluation performed in the June 7, 1999 submittal used the new definition of RT_{To} and an explicit margin of 24°F to determine the EOLE RT_{PTS} (ART at EOLE) value. In the presentation made to the NRC on June 10, 1999, a qualitative comparison of the current RT_{NDT} approach versus the Master Curve method was made to illustrate that the RT_{To} methodology would be conservative in assessing conditional failure probability. This qualitative evaluation is described next. The 18°F margin implicit in the RT_{To} definition contributes to the conservatism of the RT_{To} methodology and therefore is included in the conditional failure probability. The explicit margin term provides an additional level of conservatism that is outside this comparison, since this comparison sets RT_{To} equal to RT_{NDT}.

As described in the technical basis document for ASME Code Case N-629 (EPRI TR - 108390-R1) and in WCAP 15075, the RT_{To} methodology is based on a clearly defined relationship between the Master Curve confidence bounds and the measured fracture toughness values. Use of RT_{To} as an alternative indexing temperature defines a relationship between the expected distribution of fracture toughness values and the ASME K_{IC} toughness curve. This relationship is supported by the demonstrated validity of the entire Master Curve approach.

The analysis that established the basis for the PTS Rule, 10 CFR 50.61, was based on an empirical relationship between the ASME K_{IC} toughness curve as indexed by RT_{NDT} and a limited set of fracture toughness data. These distributions may be described in terms of their median values and confidence/tolerance bounds. This comparison is illustrated in Figure 3. Both the mean and the lower (5%) bound curves of the Master Curve exceed the corresponding mean and 5% lower bound for the distribution used in developing the original PTS Rule determination. Substituting RT_{To} for RT_{NDT} in the PTS evaluation results in the relationship between the two distributions illustrated in Figure 3. The range of toughness values indicated by Master Curve confidence bounds is significantly broader than the corresponding range indicated by the confidence bounds used for the PTS Rule. Recent advances in the understanding of the statistical nature of cleavage fracture initiation indicate that the broader Master Curve distribution is more realistic. This distribution is inherent in the definition of T_O as outlined in ASTM E 1921-97. Therefore, for any measured value of T_o, the fracture toughness data must lie in the Master Curve range described in Figure 3. The distribution used for the original PTS Rule determination is narrower and concentrates the toughness values nearer the lower bound. The fracture toughness values used to evaluate conditional probabilities of failure in the PTS screening criteria analysis were drawn from this narrower distribution. Fracture toughness values sampled from the PTS distribution are generally low as compared to the more realistic Master Curve distribution. Use of these low values results in an overestimate of the conditional probability of failure. The use of RT_{To} in place of RT_{PTS} implies a level of conservatism that exceeds the level implicit in the current PTS screening criteria. This additional conservatism in the analysis is a manifestation of the inherent margin in the RT_{To} definition.

QUESTION 2: If the embrittlement due to copper saturates at a level of 0.30 wt%, what effect does this saturation have on the ratio method used for estimating the best-estimate values for the Kewaunee vessel weld?

RESPONSE

Summary: Copper saturation at a level near 0.30 wt% recently has been assessed in Charpy embrittlement trend equations developed under contract to NRC Research (Eason et al., NUREG/CR-6551). However, no current regulations use copper saturation in assessing structural integrity, and this effect was not included in the June 7, 1999 submittal. If copper saturation at 0.30 wt% is included, the relative normalization ratio value changes from 0.54 to 0.81, which changes R from 32°F to 14°F below the Maine Yankee prediction. This change would raise the value of ART for the Kewaunee vessel by a maximum of 18°F. If copper saturation is applied, and this more conservative value of R used, the explicit margin term is overstated and should be reduced. The embrittlement concern relative to copper chemistry variability is eliminated because of saturation very near the best-estimate value of 0.287 wt% Cu for the Kewaunee vessel.

Technical Approach: Copper saturation is an expected phenomenon for a heat of material that is dominated by an embrittlement mechanism involving precipitation of copper–rich particles. The level at which saturation occurs has been measured experimentally on a few vessel steels. The experimental results indicate a saturation level ranging from 0.25 to 0.35 wt% depending upon the material and the post-weld heat treatment conditions. The recent Charpy embrittlement correlation by Eason et al. in NUREG/CR-6551 indicates saturation at 0.30 wt% copper for the entirety of the surveillance material database.

In assessing copper saturation at 0.30 wt%, both the use of the weld chemistry factor tables (with copper set at a maximum of 0.30 wt%) in 10CFR50.61/ Regulatory Guide 1.99, Revision 2 and the proposed equations in NUREG/CR-6551were examined. The change in the ratio normalization increases from 0.54 to 0.81 using either approach. The impact of changing the ratio normalization from 0.54 to 0.81 is an increase of 18°F. The shift of the predicted Kewaunee vessel curve towards the higher Maine Yankee surveillance weld projection is illustrated in Figure 4. Instead of being 32°F below the Maine Yankee projection at EOLE, the copper saturation would occur 14°F below the Maine Yankee projection. Copper saturation, however, also results in a bias reduction in the mean copper estimate for the Kewaunee vessel. This bias adjustment greatly reduces this apparent increase as discussed in response to Question 5.

If copper saturation is included in the direct fracture toughness analysis, the concern for high copper variability in the 1P3571 welds is eliminated. In particular for the Kewaunee vessel, the best-estimate copper content is 0.287 wt%. This value is nearly equivalent to the saturation limit of 0.30 wt%. The difference is only 0.013 wt%, which is much less than the 0.03wt% standard deviation assumed earlier in the analysis to address Question

1. Thus, if the full effect of copper saturation is included in the ratio adjustment then determination of the margin term based upon uncertainties requires careful scrutiny so that the effects of copper are not double counted. The integrated effect of considering margins, ratio adjustment, and copper saturation on the determination of adjusted reference temperature are discussed in response to Question 5.

QUESTION 3: What is the uncertainty in fluence to be used for the Kewaunee direct fracture toughness measurement methodology?

RESPONSE

Summary: The uncertainty in fluence that was assumed in developing the PTS Rule was ± 20%. The evaluations of fluence for the Kewaunee capsules, the Maine Yankee A-35 capsule, and the Kewaunee vessel were reported in the June 7, 1999 submittal. The values reported have 1σ uncertainties of about 8% for the capsules and less than 15% for the Kewaunee vessel wall. The fluences are quoted as best-estimate values, and the overall bias between Kewaunee physics calculations and dosimetry measurements is 5.6% higher for the measurements; the reported fluence values are based on an upward adjustment of the physics calculations to the measured results. The projection calculations for fluence on the Kewaunee vessel are bounding due to the assumption of a capacity factor of 95-97% throughout the current and extended life of the Kewaunee vessel. Due to this level of conservatism in the projected fluence, there is no need to add fluence uncertainty in the margin term.

Technical Approach: WCAP-14279, Rev. 1 has details on the DORT calculations and the dosimetry analyses for the Kewaunee surveillance capsules, the Maine Yankee A-35 capsule, and the Kewaunee vessel projections. The uncertainties in flux and fluence are well within the range typically assigned for such determinations and well below the 20% uncertainty assumed in the development of the PTS Rule (10CFR50.61). Three key aspects relative to the Kewaunee vessel are:

- Very conservative capacity factors have been assumed for the projected life of the Kewaunee vessel (i.e., 95-97% capacity over the current license period and beyond);
- The capsule and Kewaunee vessel calculations have been adjusted to account for the measured dosimetry – this is an overall upward bias of 5.6% above the straight DORT calculated fluences; and
- The peak fluence value is assumed for the entire girth weld fabricated using the 1P3571 weld wire heat.

The key factor for assessing the need for a fluence uncertainty term in the margin value for the Kewaunee application is the bounding value for EOLE fluence. There is no realistic way that the Kewaunee vessel will ever see an EOLE peak fluence of 5.1×10^{19} n/cm^2 (E > 1 MeV). A more realistic capacity factor of about 85% would put the EOLE fluence near 4.7×10^{19} n/cm^2. Thus, the projected fluence is a bounding value and there is no need to add a fluence uncertainty in the margin term for the direct fracture toughness measurement approach for the Kewaunee vessel.

QUESTION 4: What is the effect of the latest understanding of chemistry variability from responses to Generic Letter 92-01 on the margin term?

RESPONSE

Summary: The Kewaunee Master Curve submittal paralleled current regulations. The margin term included in both NRC Regulatory Guide 1.99, Rev. 2 and 10 CFR 50.61 (the PTS Rule) were derived from the standard deviation of the residuals of the trend curve data fits. Therefore, the margin term reflects uncertainties in the input parameters from the original dataset, as described in the answer to Question 1. Subsequent to the development of Regulatory Guide 1.99, Rev. 2 and 10 CFR 50.61, new concerns about higher than expected variability in the input parameters (particularly Cu and Ni) have been raised by the NRC. These concerns were originally expressed in NRC Generic Letter 92-01. The industry response to Generic Letter 92-01 and the resolution of related issues are described in NUREG 1511. In response to the June 7, 1999 submittal and the October 6, 1999 presentation, the NRC questioned whether or not the proposed approach adequately accounted for chemistry variability. The NRC noted that the proposed approach should address both the intent of the current regulatory process and any new issues identified in the response to GL 92-01. It was shown in the response to Question 1 that these chemistry concerns were adequately covered by the margin term in the original submittal. Additional studies to illustrate the effects of chemistry variability on margin values have been completed to answer the NRC question. These studies demonstrate that inclusion of a broader Cu distribution, that represents the complete weld 1P3571 data set, results in a larger variability in the predicted Charpy shift. If the broader Cu distribution were applied, the effect would be to require a higher margin.

Technical Approach: The set of chemistry data for welds fabricated from wire heat 1P3571 contains information from six different weldments. These weldments include the Kewaunee, Maine Yankee, LaSalle-1 and Hatch-1 surveillance welds as well as two qualification welds (see Figure 5). These welds were all included in the determination of the coil-weighted average composition, using a weighting scheme that is related to the composition of the weld (see WCAP-15074). As previously indicated, the Kewaunee and Maine Yankee surveillance welds of heat 1P3571 have been analyzed extensively. These two materials exhibit distinctly different Cu distributions. Although the other 1P3571 data sets are smaller it appears that the remaining materials also exhibit characteristic distributions. The ratio method normalizes the measured Charpy shift to the mean behavior of the combined distribution. The mean Cu concentration for this distribution is 0.287 wt% and the standard deviation is 0.08 wt%. The distinct nature of the underlying distributions is clearly evident in the distribution. The width of the $\pm 2\sigma$ band ($\pm$0.16 wt%) in the distribution is also indicated in Figure 5.

The effect of the broadened Cu distribution on the standard deviation of the prediction was evaluated by performing a Monte Carlo simulation process using Regulatory Guide 1.99, Rev. 2 (similar to the previous evaluation of the uncertainty contributions to the current regulatory margin generated in response to Question 1). 5000 random samples were selected from the illustrated Cu distribution. For this broadened distribution, the Cu portion of the standard deviation of the predicted Charpy shift is increased to 36°F. As indicated in the answer to Question 1, the 0.03 wt% standard deviation on Cu content assumed in the current regulations corresponds to a standard deviation of 13°F in Charpy shift. The factor of 2.8 increase in standard deviation is to be expected given the wide range of Cu levels included in this analysis. The impact on the overall margin term would not be as great since the other key uncertainties are combined using SRSS.

The ratio normalization adjustment (R) that is applied in the determination of ART accommodates much of this uncertainty. The application of copper saturation to R (discussed in response to Question 2) is a further indication that these projected effects are unreasonable. Note that the variability issue is closely related to the copper saturation issue. For clarity these issues have been separated as much as possible, however it must be understood that these effects are compensating and may not be used independently without considering the integrated effects, which are presented in response to Question 5.

QUESTION 5: What are the integrated effects when considering margins and copper saturation?

RESPONSE

Summary: The effect of large Cu variability is offset by the copper saturation effect. As previously described, recent studies of embrittlement in high copper weldments indicate that the Cu contribution to embrittlement saturates near 0.3 wt%. Thus, only the effective Cu concentration (or Cu in solution) needs to be considered in the embrittlement predictions. If this saturation effect is applied to the ratio adjustment without first calculating the distribution of effective Cu values, the vessel prediction curve would be expected to move closer to the Maine Yankee measured curve, as discussed in the response to Question 2. However, the distribution of effective concentrations is much narrower than the distribution of total Cu concentrations. This narrower distribution has both a lower mean value and a smaller standard deviation than the coil-weighted distribution. The lower mean value is a bias that offsets the ratio penalty presented earlier for Question 2. The smaller standard deviation offsets the Cu variability effects. ART will be over-estimated if the synergistic effects of copper saturation and applicable uncertainties are ignored. The overall integrated effects are comparable to the margins included in the June 7, 1999 submittal.

Technical Approach: The revised distribution of effective Cu concentrations due to copper saturation is illustrated in Figure 6. In this case, all 1P3571 weld metals with a Cu concentration greater than 0.3 wt% (as shown in Figure 4) are assumed to have an effective Cu concentration of 0.3 wt%. Compressing the high end of the distribution results in a lower mean value and a smaller standard deviation. These effects are obvious in Figure 6.

The intent of the ratio procedure is to normalize the surveillance data to the best-estimate chemistry for the reactor pressure vessel weld. Standard practice for calculating ratio adjustments do not generally account for saturation effects beyond the modest effect that is built into the Reg. Guide 1.99 Rev. 2 embrittlement equation. The ratio adjustment included in the original submittal, which is summarized in Table 5, was based on paralleling standard regulatory procedures and did not contain any adjustment for saturation. In response to the NRC question concerning the impact of Cu saturation on the ratio adjustment (see Question 2), an upper estimate of the effect was estimated by substituting the effective Cu concentration of 0.3 wt% for the Maine Yankee surveillance weld in the standard procedure. As indicated in Table 5, this "saturated ratio procedure" produced a maximum adjustment of 18°F (i.e., -32°F-(-14°F))= -18°F) beyond the standard procedure. However, a reduction in this adjustment is required, as no credit has been taken for the change in the shape of the Cu distribution.

Use of saturated or effective Cu concentrations with the Regulatory Guide 1.99, Rev. 2 and 10CFR50.61 embrittlement curve is misleading because the curve was developed using non-saturated Cu levels. The effect of the saturated copper distribution on radiation embrittlement has been evaluated using an embrittlement correlation that includes a saturation term. The embrittlement trend curves provided by Eason et al. in NUREG/CR-6551 do contain a defined saturation effect. The distribution of predicted Charpy shifts illustrated in Figure 7 was developed by randomly sampling 5000 Cu values from the Cu distribution (illustrated in Figure 5) and 5000 Ni values from a similar set of measurements. WCAP-15074 contains a detailed listing of the individual Cu and Ni measurements. The randomly sampled values were processed through the NUREG/CR-6551 prediction equation. As illustrated in Figure 6, the mean of the predicted shifts is lower than the values calculated in the answer to Question 2, which used a *mean total Cu* combined with a saturated upper bound. In reality, the mean predicted shift corresponds closely to the predicted shift for the *mean effective Cu* level. These results indicate that the mean behavior of the material is best described by the mean effective Cu concentration (as opposed to the mean total Cu concentration). The effect of the compressed Cu distribution on the mean behavior of the material more than offsets the original saturation adjustment of 18°F. These results are also summarized in Table 5.

The Cu contribution to the standard deviation of the Charpy shift predictions using the broad 1P3571 distribution shown in Figure 5 with the NUREG/CR-6551 equation is 30°F. This value corresponds to the Cu contribution to the uncertainty in the shift prediction. It is smaller than the 36°F standard deviation calculated using a similar procedure with the Reg. Guide 1.99, Rev. 2 equation (see the response to Question 4). If Ni uncertainty is factored into the same estimate, the standard deviation becomes 38°F. The distribution of predicted Charpy shifts is also highly asymmetric, with the two standard deviation bound significantly exceeding the upper limit of the distribution. Approximately one-half of the values in the fracture toughness distribution correspond to the saturated Cu level. In this case, the conservative estimate of Charpy shift would clearly require that the mean plus margin equal the saturated value. Any larger margin for Cu uncertainty would exceed the maximum possible shift. The mean predicted Charpy shift for the distribution in Figure 7 is 247°F. The maximum predicted shift is 302°F. The difference between the mean and maximum Charpy shifts represents a maximum total margin of 55°F. This margin includes both Cu and Ni effects and is conservative with respect to current practice in that it encompasses all combinations of these variables. The ratio-adjusted value for the EOLE RT_{T_0} based on the saturated distribution would be 217°F (257°F @ EOLE for Maine Yankee –40°F ratio adjustment.). The original submittal contained a 24°F margin on a base (ratio adjusted) RT_{T_0} value of 225°F. When the base value and margin are summed, the net difference between this new analysis, which contains the effects of both a broadened Cu distribution and Cu saturation, and the original submittal is 23°F. Note, current regulatory practice (including post GL 92-01 submittals) has not generally required either a specific analysis of increased Cu variability or Cu saturation.

The only adjustment in the current regulatory methodology for multiple weld wire coils is contained in the ratio method, which normalizes a set of data to the best estimate value for the vessel based upon a broader range of information about the specific weld wire heat. The higher level of uncertainty in copper for weld wire heat 1P3571 is accounted for using a ratio method applied to the measured RT_{To} values from the Kewaunee and Maine Yankee surveillance welds. During the October 6, 1999 meeting, the NRC inquired as to whether or not the overall effect of this broad range of copper variability was included in the margin used in the June 7, 1999 submittal. Applying a larger margin associated with this broad range of Cu variability forces the prediction towards the Maine Yankee surveillance weld projections. In essence, the procedure becomes a "worst observation" analysis. The current PTS Rule clearly does not require this level of conservatism in the calculation of the RT_{PTS} value. Current practice allows for a factor of two reduction in the σ_{Δ} term when the RT_{PTS} value is based on credible surveillance data. Applying this same logic reduces the margin by 28°F and produces an RT_{PTS} value that is virtually identical to the original submittal. Thus, the integrated effects of these phenomena are comparable to the margins included in the original June 7, 1999 submittal.

QUESTION 6: How can the initial properties of the surveillance materials and the actual RPV weld be compared to assess variability and potential contribution to the margin term?

RESPONSE

Summary: This question is difficult to paraphrase in a succinct manner since it potentially encompasses a broad range of issues. Never the less, WPSC understands this question to be based on the discussion that occurred at the October 6th meeting, plus other discussions and correspondence. The NRC staff has expressed related concerns that can be summarized in terms of three underlying issues:

- Is it reasonable to expect that the behavior of the surveillance weld (or other material) will adequately represent the response of the reactor vessel material?
- How do initial properties and scatter relate to the reactor vessel?
- How does the margin included in the KNPP submittal address or account for variability or uncertainty throughout the reactor vessel weld.

The first issue is addressed here. The second issue is covered in our response to Question 1 in the section entitled "Initial or Unirradiated RT_{NDT}, $RT_{NDT(u)}$." The third issue is addressed in our responses to Questions 1-5; the effects of copper and nickel are addressed in great detail in Questions 1, 2, 4, and 5; the fluence uncertainty issue is primarily discussed in Question 3.

The first issue regards the fundamental premise of all surveillance programs, whether the licensee is using the Master Curve methodology or the current regulatory process. Therefore, review and resolution of this potential issue is generic to all plants and should not delay NRC review of WPSC's application to use the Master Curve methodology. Toughness tests (either fracture toughness or Charpy V-notch), that are inherently destructive, cannot be performed directly on the vessel material. Fracture toughness values using the Master Curve approach used in vessel analysis are based on testing of weld specimens made with the weld wire heat that matches the critical vessel weld. The adequacy of the surveillance weld specimens must be judged on the basis of the similarity between the surveillance material and the vessel material. For reactor pressure steels, similarity may be defined in terms of the input materials, the welding (or fabrication) procedures, and the post-weld heat treatment. If the surveillance material matches these characteristics of the vessel material, then it can be judged as being identical and not a surrogate.

The Kewaunee reactor vessel weld, Maine Yankee reactor vessel weld, and corresponding 1P3571 surveillance capsule weldments meet all of these similarity criteria and are therefore judged as being identical.

The copper variability issue, which is inherent for all welds fabricated using copper-coated electrodes, has been extensively addressed for the various weldments in Questions 4 and 5.

Technical Approach: As indicated in WCAP-15074, the Kewaunee surveillance weld, the Kewaunee vessel girth weld, and the Maine Yankee surveillance weld are identical. A comparison is presented in Table 6 (which was taken from WCAP-15074). The key aspects for all of the weldments are summarized next:

- All were fabricated using the same weld wire heat, flux type and flux lot;
- The same welding procedures were used for all weldments;
- All weldments were fabricated within months of each other;
- Post-weld heat treatments were similar for all weldments and meet all ASME Code requirements; and
- Operating temperatures and spectrum are very similar between the Kewaunee and Maine Yankee vessels.

Details of the fabrication for all of the weldments and operating conditions are available for review. Based upon extensive review of all of the weldments, the Kewaunee and Maine Yankee surveillance welds have been shown to be identical to the Kewaunee vessel girth weld. Therefore, the surrogate issue is not relevant to the Kewaunee reactor vessel. However, copper variation between and among the weldments must be addressed for these equivalent welds. See the responses to Questions 4 and 5, which address measured copper variation and its impact. This issue regards a fundamental premise of all surveillance programs, regardless of the integrity evaluation methodology. Therefore, any review and disposition of the surrogate issue (if deemed necessary) is expected to progress independent of NRC review of the WPSC submittal to use the Master Curve methodology to assess reactor pressure vessel integrity for KNPP.

Since these welds are identical and the surveillance welds have been evaluated so extensively (and the welds sample a good portion of the coils used to fabricate all of the 1P3571 welds), there is no additional margin needed to cover variability between the surveillance welds and KNPP vessel girth weld. The effects of copper (and nickel) variability have been thoroughly evaluated. The magnitude of the margin included in the WPSC submittal is large enough to account for this known copper variability.

Table 1. Current Regulatory Method for Use of Initial RT_{NDT} for Non-Linde 80 Welds

Quantity	σ_I (°F)	Application	Remarks
Measured RT_{NDT}	0	Use when CVN T_{50} & NDTT are measured	Bounding value
Material Variability as Defined by Generic RT_{NDT} Data	17	Use when using generic value of −56°F	Statistical Mean

Table 2. Variation of Unirradiated Transition Temperature Measurements

Material	RT_{To}	RT_{NDT}
Kewaunee Surveillance Weld	-123°F	-30°F
Maine Yankee Surveillance Weld	-109°F	-50°F
Difference (MY – KNPP)	14°F	-20°F

Table 3. Uncertainty Components in Current Regulatory Method for Assessing ΔRT_{NDT} and Contributions Derived by Sensitivity Analysis

Measurement Process	Material Variability	Correlation Process	Copper	Nickel	Fluence
CVN T_{30} (U&I); negligible or in correlation	Built into correlation; many test specimens	Overall σ_Δ = 28°F assigned	σ_{Cu} = 0.03 wt% with possible adjustment in CF	σ_{Ni} = 0.042 wt%; others used 0.05 or 10%	$\sigma_{\phi t}$ = 20%
σ_{err} = 19°F			σ_{Cu} = 13°F	σ_{Ni} = 11°F	$\sigma_{\phi t}$ = 11°F

Table 4. Comparison of Explicit Margins Following Current Regulatory Process

Margin Analysis	Base σ_{Δ}, °F	Credible Data, $\sigma_{\Delta}/2$, °F	Measured σ_i or σ_{To}, °F	2SRSS Margin $2(\sigma_{\Delta}^2+\sigma_i^2)^{1/2}$, °F
June 7, 1999 Submittal	0	0	12	24
PTS Rule Margin	28	14	0	28
$\sigma_{Cu} = 0.03$ wt% and $\sigma_{Ni} = 0.042$ wt%	17	8.5	12	29

Table 5. Comparison of Ratio Adjustment Procedures

Ratio Analysis	Kewaunee Effective % Cu	Maine Yankee Effective % Cu	1P3571 Coil-Weighted % Cu	Ratio	R (°F) wrt MY
Standard (No Saturation)	0.219	0.351	0.287	0.54	-32
Saturation – Original Distribution	0.219	0.3	0.287	0.81	-14
Saturation – Distribution-Adjusted	0.219	0.3	0.254	0.43	-40

Table 6. Comparison of Kewaunee and Maine Yankee RPV and Surveillance Welds

Comparison of Kewaunee / Maine Yankee RPV and Surveillance Welds			
Topic	**Kewaunee Weld**	**Maine Yankee Weld**	**Comments**
Weld wire heat	1P3571	1P3571; RPV seam 9-203 also had some 33A277 as TSAA	Same
Flux type	Linde 1092	Linde 1092	Same
Flux lot/size	3958 (65 x 200)	3958 (65 x 200) except for TSAA on RPV weld	Same
Surveillance weld fabrication dates	October 9 – 16, 1970	September 19 – 23, 1970	Only a few weeks apart and after RPV welds
RPV fabrication dates	Seam 11-766, July 7 – 12, 1970	Seam 9-203, August 4 – 15, 1970	Approximately one month apart
RPV weld post-weld heat treatment	1150±25°F for 16.5 h	1125±25°F for 40 h	Longer PWHT for Maine Yankee
Surveillance weld post-weld heat treatment	1150±25°F for 19.25 h; closely matches RPV weld PWHT	1100-1175 for 40.5 h; PWHT had to be requalified – furnace malfunction caused block to be heated second time to reach total PWHT time	Effect of longer, two-stage heat treatment on MY surveillance weld could result in differences
Surveillance weld interpass temperatures	Pre-heat at 250°F; interpass at 300°F	Pre-heat at 250°F; interpass at 300°-400°F	Essentially the same
Surveillance weld repairs	None reported	3 repair areas that were extracted	Specimens are not taken from repaired regions
Specimen location in surveillance welds	All CVNs came from a 2.5-in. thickness of weld metal	All CVNs were taken from the full thickness of weld seam	MY weld CVNs sample more coils of wire than Kewaunee weld
Welding procedures	SAA-MA-500-0	SAA-MA-500-0	Same
Surveillance weld thickness	8.25-in. trimmed	8.125-in. trimmed	Similar
RPV weld thickness	6.5-in.	8.625-in. min. specified	Kewaunee vessel is thinner

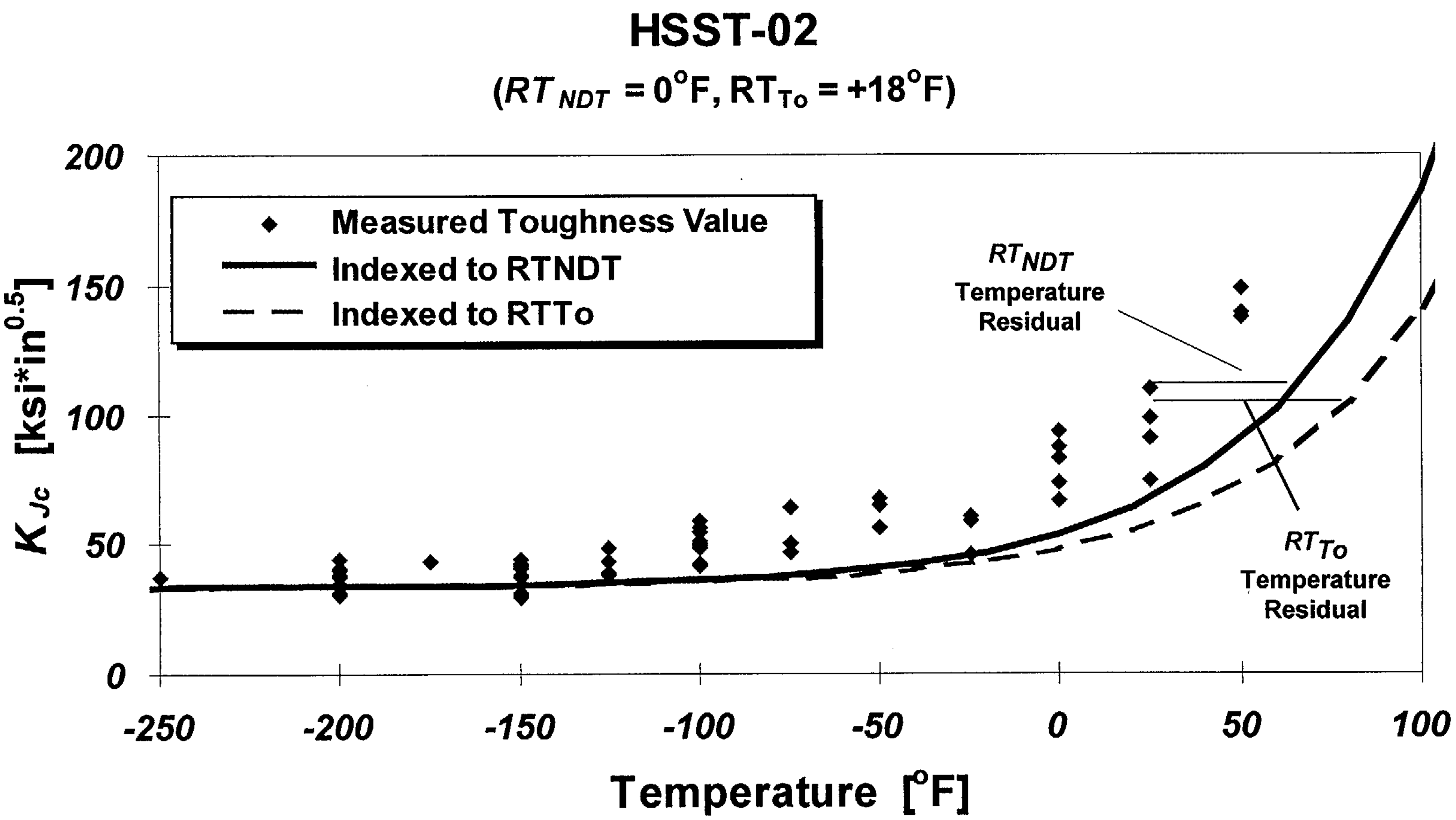

Figure 1. Illustration of Margin in RT_{To} Definition

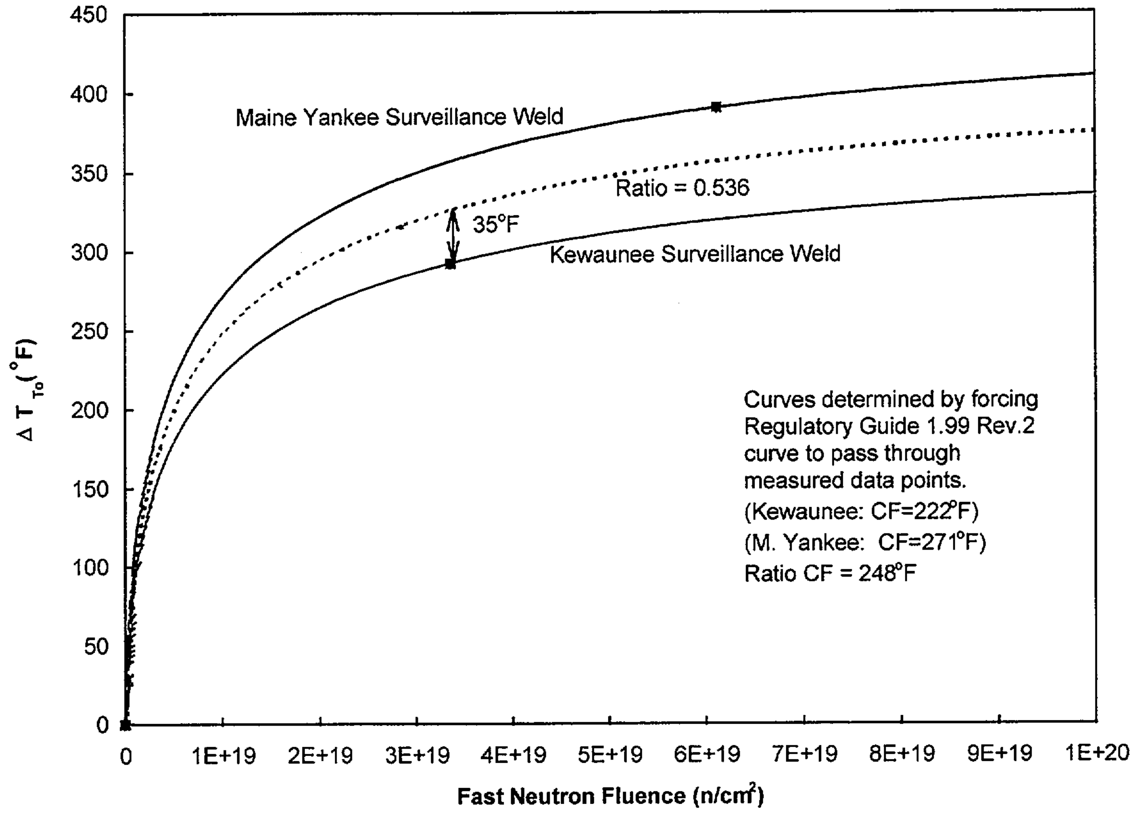

Figure 2. Variation in RT_{To} with Fluence for Kewaunee and Maine Yankee Materials

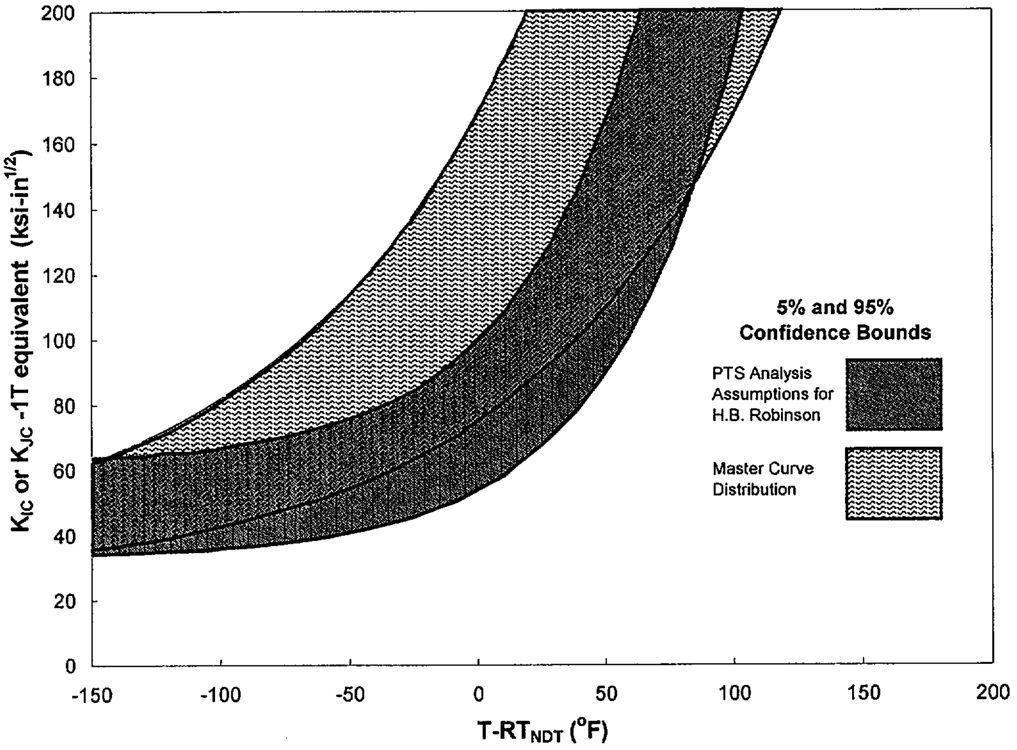

Figure 3. Master Curve Comparison with RT_{NDT} Approach Used to Develop PTS Screening Limits

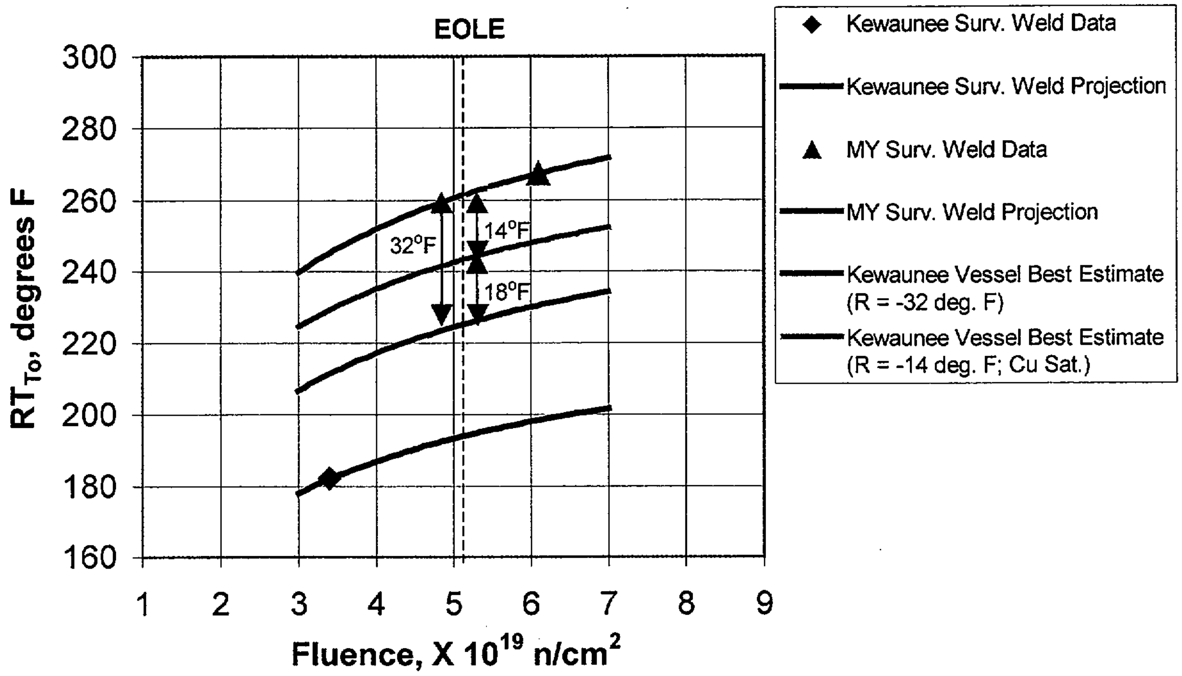

Figure 4. Illustration of Cu Saturation Effect on Original Ratio Adjustment (This adjustment does not account for bias in copper distribution, which is addressed in Question 5).

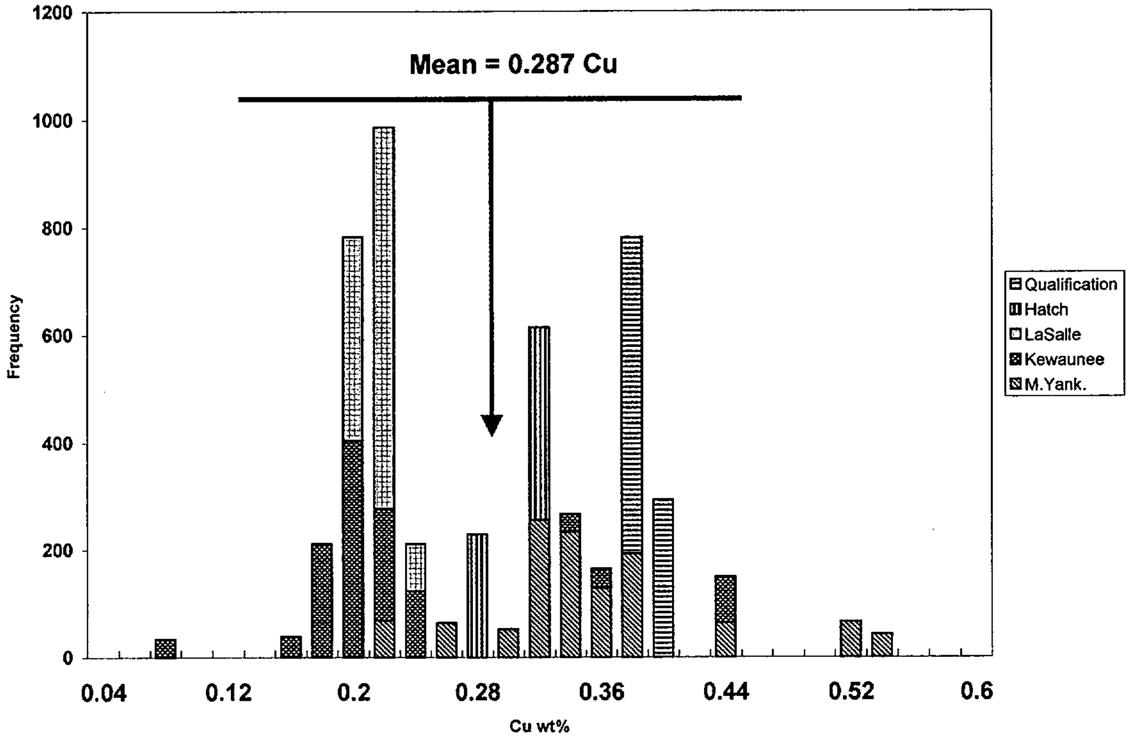

Figure 5. Coil-Adjusted Distribution of Cu Concentrations for Weld 1P3571

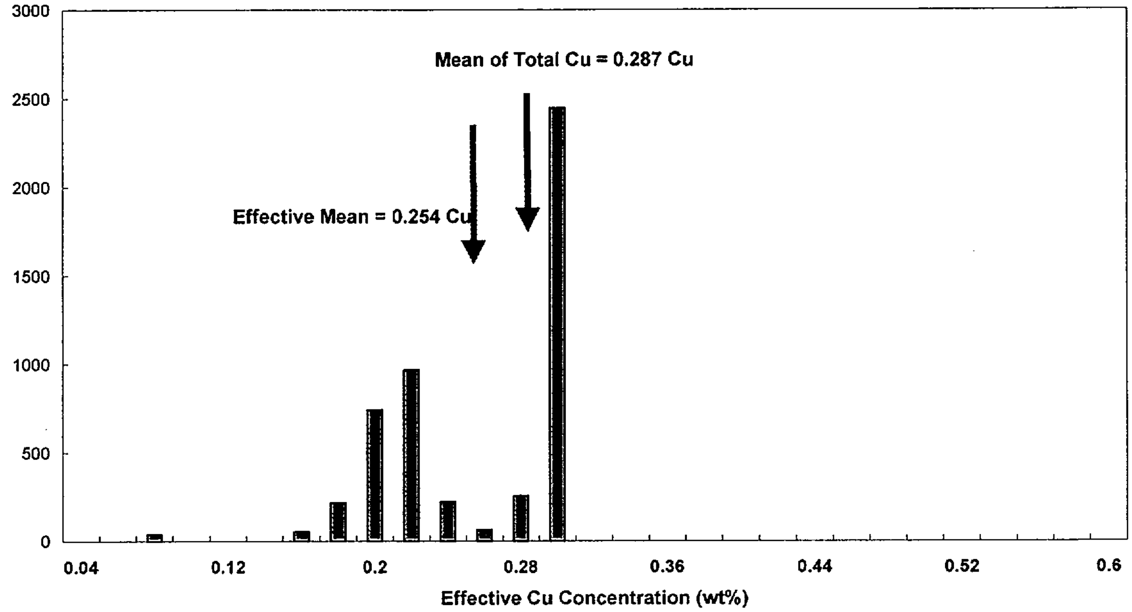

Figure 6. Effective Cu Distribution for Weld Heat 1P3571 Assuming 0.3 wt% Saturation

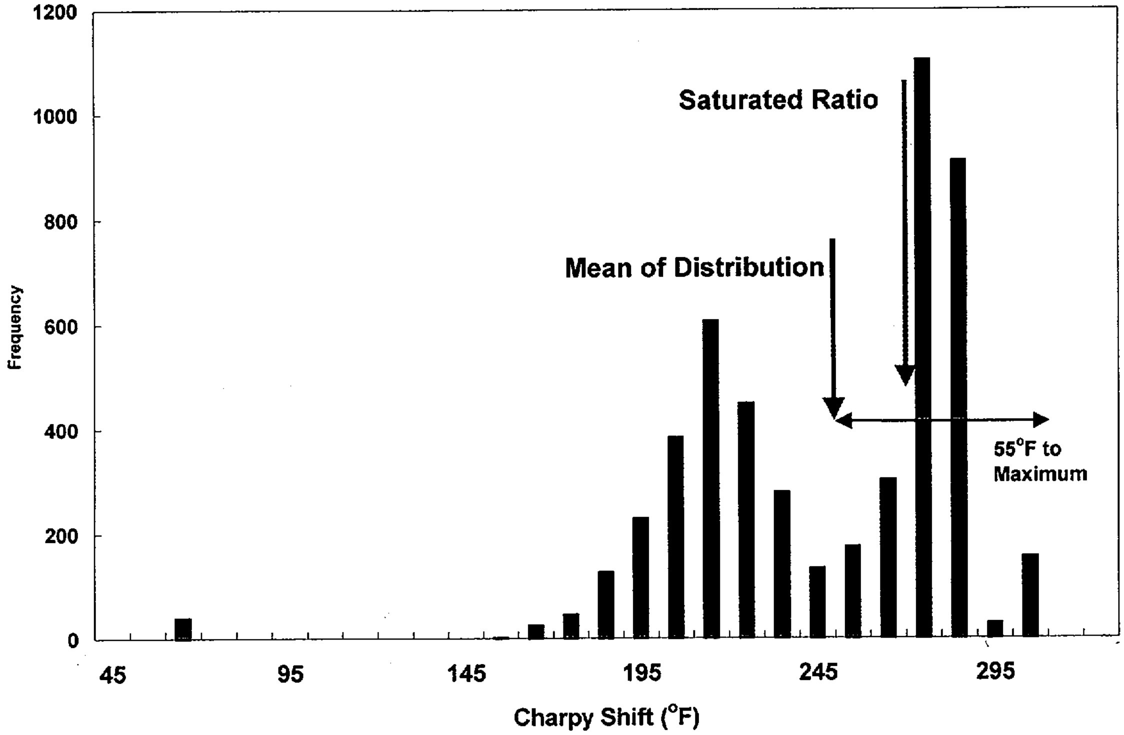

Figure 7. Distribution of Charpy Shifts Derived Using Eason Equation with 1P3571 Chemistries.