Omaha Public Power District

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July 16, 1982
LIC-82-259

Dr. Stephen H. Hanauer, Director
Division of Safety Technology
U. S. Nuclear Regulatory Commission
Washington, D.C. 20555

Reference: Docket No. 50-285

Dear Dr. Hanauer:

Pressurized Thermal Shock (PTS)

In the District's previous letters, we have made a number of recommendations regarding the long-term resolution of the PTS issue. One area where we made specific recommendations was in the method used to determine the RT_{NDT} value for the reactor vessels under consideration. Our basic recommendation for high copper-high nickel vessels was to use a best estimate value in the initial determination of RT_{NDT} and to predict the RT_{NDT} shift using the curves in Regulatory Guide 1.99, which would result in an upper bound value of current RT_{NDT}.

In the June 23, 1982 meeting with the CE Owners Group, the NRC staff also presented a method for determining plant values of RT_{NDT}. It is our understanding that the method proposed would use a best estimate value of initial RT_{NDT}, predict the shift in RT_{NDT} using the Guthrie equation, and then add an additional factor of 59°F which is based on the standard deviation of generic initial RT_{NDT} data and the standard deviation of the Guthrie equation. It is our understanding that this method would also consider Regulatory Guide 1.99 as an upper bound for the shift prediction.

We have reviewed the staff's method and believe that it is compatible with the method we have proposed, particuarly in the area of predicting the RT_{NDT} shift. However, the District also believes that the 2 sigma uncertainty factor included in the staff's calculation is not applicable to the Fort Calhoun Station. It is our understanding that this uncertainty factor would be applied to all plants for which drop weight test data does not exist. While drop weight test data does not exist for Fort Calhoun's reactor vessel welds, a significant amount of Charpy test data does exist. Using this Charpy test data, a best estimate initial RT_{NDT} can be determined. Two methods for a more accurate determination of initial RT_{NDT} from this Charpy data have previously been presented in CEN-189 and at the June 23, 1982 meeting.

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Both of these methods justify the use of the best estimate value of initial RT_{NDT} as presented in CEN-189 without adding an uncertainty factor. Both of these methods are summarized in the enclosures to this letter. We request that these methods be considered together as a justification for the use of a best estimate value of initial RT_{NDT} for the Fort Calhoun reactor vessel material.

The value of RT_{NDT} for the Fort Calhoun reactor vessel as of December 31, 1981 is given by the equation:

$$RT_{NDT} = RT_{NDT_i} + RT_{NDT_{1.99}}$$

$$RT_{NDT} = -50 + 263 = 213^{o}F$$

where RT_{NDT_i} is the best estimate initial value of RT_{NDT} and $RT_{NDT_{1.99}}$ is the RT_{NDT} shift value as determined by the upper bound curve of Regulatory Guide 1.99.

Detailed summaries of the two methods used to establish the initial value of RT_{NDT} for Fort Calhoun form the enclosures to this letter.

Sincerely,

W. C. Jones
Division Manager
Production Operations

cc: LeBoeuf, Lamb, Leiby & MacRae
1333 New Hampshire Avenue, N.W.
Washington, D.C. 20036

Enclosure (A)

At the June 23, 1982 meeting with the CEOG, the NRC staff proposed a new method to calculate RT_{NDT}. This enclosure provides our comments based on a brief review of the proposed method. As you recall, the CEOG presented our recommended method of predicting current and future RT_{NDT} values at the June 23 meeting, which was basically to use best estimate initial RT_{NDT} and the Reg. Guide 1.99 shift as an absolute upper bound shift.

The proposed NRC method, to be applied to plants for which drop weight test data is not available for definition of initial RT_{NDT} is understood to be as follows:

$$RT_{NDT} = \overline{RT}_{NDTi} + \Delta RT_{NDTG} + 2\sqrt{\sigma i^2 + \sigma g^2}$$

where: RT_{NDT} = adjusted value

$\overline{RT}_{NDTi}$ = -56^oF (mean value of all data)

ΔRT_{NDTG} = Guthrie shift prediction value

σi = 17^oF (std. dev. of RT_{NDTi})

σg = 24^oF (std. dev. of Guthrie shift)

The value of the term $2\sqrt{\sigma i^2 + \sigma g^2}$ is + 59^oF.

The proposed NRC method does not recognize the two-slope characteristic of Reg. Guide 1.99 which distinguishes between low and high fluence shift rates, however, this proposed NRC method does consider the high fluence upper bound aspects of Reg. Guide 1.99. If the Guthrie shift prediction value is greater than Reg. Guide 1.99 in the high fluence region, then the Reg. Guide value is to be used and the standard deviation of the Guthrie formulation is eliminated,

i.e.: if: $\Delta RT_{NDTG} > \Delta RT_{NDT}\text{-}1.99$

then: $RT_{NDT} = \overline{RT}_{NDTi} + \Delta RT_{NDT}\text{-}1.99 + 2\sigma i$

For example, using the current (12/31/81) fluence value and materials chemistry for Fort Calhoun:

$$\Delta RT_{NDTG} = 241^oF$$

$$\Delta RT_{NDT}\text{-}1.99 = 263^{o}F$$

Therefore: $\Delta RT_{NDTG} < \Delta RT_{NDT}\text{-}1.99$

so that: $RT_{NDT} = (-56^{o}F) + (241^{o}F) + (59^{o}F) = 244^{o}F$
by the proposed NRC method.

However, we believe we have demonstrated that the Reg. Guide 1.99 shift prediction is more of an absolute upper bound than merely an upper bound of the Mean, as illustrated by the data ploted in Enclosure (B). This plot was presented at the June 23, 1982 CEOG/NRC meeting. Therefore, the proper comparison should be between $\Delta RT_{NDT}\text{-}1.99$ and $(\Delta RT_{NDTG} + 2\sigma g)$ in order to compare upper bound values. Using this approach with the Fort Calhoun parameters would yield:

$$\Delta RT_{NDTG} + 2\sigma g = (241 + 48) = 289$$

$$\text{Therefore, } RT_{NDTG} + 2\sigma g > RT_{NDT_{1.99}}$$

$$\text{so that: } RT_{NDT} = (-56) + (263) + 2(17) = 241^{o}F$$

This $241^{o}F$ is not very different than the $244^{o}F$ value calculated by the proposed NRC method, but it clearly identifies the area of uncertainty to be the initial RT_{NDT} value, not the shift prediction method. Too much attention has been focused on the shift prediction methodology in the least susceptible copper and fluence ranges.

Turning attention now to the initial RT_{NDT} value, it is understood that the mean-plus-2σ initial RT_{NDT} value is meant to apply to materials for which insufficient test data exists to define a more accurate value. Although drop weight test data for the Fort Calhoun weld materials do not exist, Charpy impact test data are available which exhibit excellent toughness characteristics. The Charpy test data have been used to calculate effective initial RT_{NDT} values of lower than $-50^{o}F$ by two independent methods. We therefore believe that there is sufficient test data available to define initial RT_{NDT} values more precisely than the proposed 2σ uncertainty band for the Fort Calhoun vessel materials.

The first method of defining the initial RT_{NDT} was reported in CEN-189. This method utilizes the ASME Code (NB 2330) approach to establish a Charpy 50 ft-lb, 35 mils lateral expansion temperature (T_{cv}) and then subtracts 60°F to define RT_{NDT}.

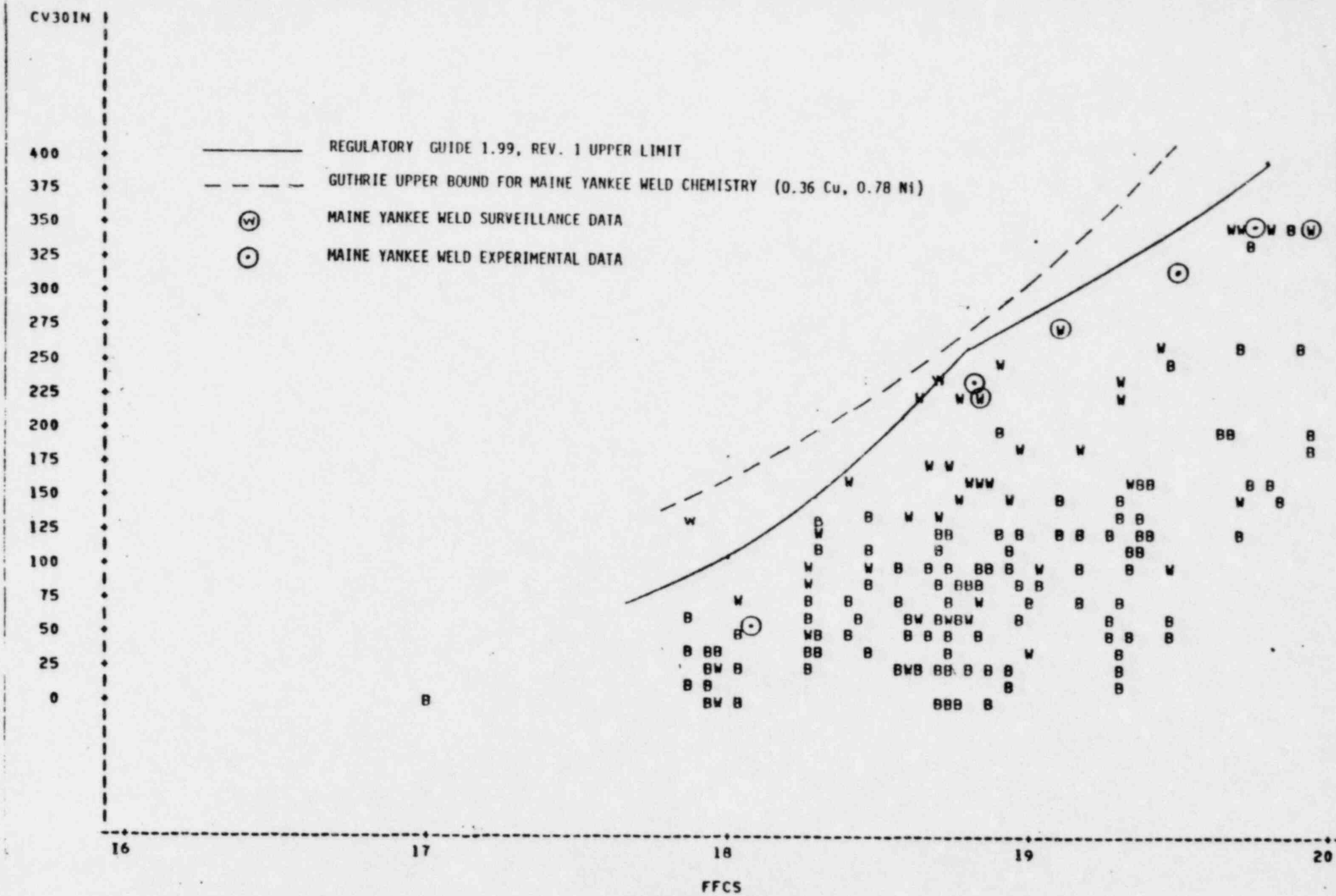
$$RT_{NDT} = T_{cv} - 60^{o}F$$

The Fort Calhoun vessel weld materials exhibited greater than 50 ft.-lbs (61 ft-lbs and 57 ft-lbs) at + 10°F. Using + 10°F as T_{cv} and subtracting 60°F results in an effective initial RT_{NDT} of -50°F.

The second method used to define the initial RT_{NDT} for Fort Calhoun is based on using the Rolfe/Novak/Barsom relationship to calculate the effective K_{IC} value from the Charpy energy at 10°F, and then calculating RT_{NDT} from the ASME-XI curves of RT_{NDT} versus K_{IC}. The RT_{NDT} versus K_{IC} curves used were developed for weld materials, as described in Enclosure (C). The Rolfe/Novak/Barsom methodology was presented at the June 23, 1982 CEOG/NRC meeting, as summarized in Enclosure (D). Using this method, the 10°F Charpy test data (61 ft-lbs and 57 ft-lbs) equate to initial RT_{NDT} values of - -54°F and -50°F for the controlling welds in the Fort Calhoun reactor vessel.

Based on this work, we continue to recommend the use of an initial RT_{NDT} value of -50°F for the Fort Calhoun vessel welds. This combined with the Reg. Guide 1.99 upper bound shift prediction value of 263°F results in a current (12/31/81) RT_{NDT} value of 213°F for the Fort Calhoun vessel welds.

Enclosure (B)


CV30IN
400
375
350
325
300
275
250
225
200
175
150
125
100
75
50
25
0
REGULATORY GUIDE 1.99, REV. 1 UPPER LIMIT
GUTHRIE UPPER BOUND FOR MAINE YANKEE WELD CHEMISTRY (0.36 Cu, 0.78 Ni)
MAINE YANKEE WELD SURVEILLANCE DATA
MAINE YANKEE WELD EXPERIMENTAL DATA
16
17
18
19
20
FFCS

Enclosure (C)

A review of the ASME Section XI K_{IC} and K_{Ia} curves was performed by C-E with regard to the existing fracture toughness data base and to available data on C-E reactor pressure vessel materials. Figures 1 and 2 are displays of the K_{Ia} and K_{IC} curves, respectively, with supporting data, as shown in Figures C-1 and C-2 of EPRI NP-719-SR (Reference 1), a report describing the original data base and lower-bound curve methodology.

In Figure 2 (K_{IC} lower bound toughness curve), a distinction between plate and weld materials is apparent, with weld material consistently conservatively estimated by the Section XI K_{IC} curve (above -150F ($T-RT_{NDT}$)). When examining the original sources for the data in Reference 1, it was discovered that all non-HSST02 data in Figure 2 were erroneously plotted. In an effort to make a correction to Figure C-2 in Reference 1 (Errata for Subject Report, April 14, 1980), the authors made an error which shifted all data to the right by +40F. This error in no way affects the derived K_{IC} reference curve since the HSST02 data is correct. The weld data in Figure 2, is therefore, really 40F further to the left, thereby demonstrating the conservatism of the K_{IC} lower bound curve for weld data. The distinction between plate and weld data and the conservatism of the K_{IC} curve to weld data can also be found in the data reported in Reference 2.

Figure 3 summarizes the lower bound data trends in Reference 2 for 5 heats of C-E A533B-Class 1 plates (approximately 45 data), 4 heats of C-E submerged-arc welds (approximately 24 data) and 4 heats of C-E consumable electrode weld materials (approximately 22 data). Above $-60^{o}F$ ($T-RT_{NDT}$) all weld data had consistently greater fracture toughness than plate, with manual welds greater at all temperatures. The Section XI K_{IC} curve was also conservative with respect to the 5 heats of representative C-E A533B-Class 1 plate.

Figure 4 displays pertinent submerged-arc weld data with respect to the ASME Section XI K_{IC} lower bound curve. Only selected data are plotted to ensure the clarity of the presentation. Data include the lower bound weld data (originally 21 data total) used in the K_{IC} curve derivation (from Figure 2 corrected by 40F), C-E submerged-arc welds deposited with Linde 0091 and Linde 80 weld flux types (from Reference 3, 9 data total). No significant variation in fracture toughness is apparent within the linear-elastic region between

welds of Linde 0091 or Linde 80 flux types (as also concluded in Reference 3), nor is there significant variation between C-E and B&W welds. However, one B&W weld (37 ksi$\sqrt{in}$ at -100F) is most limiting with respect to ASME Section XI K_{IC} lower bound curve and to the remaining weld data population. Two lower bound K_{IC} curves can be derived from the weld data. Ignoring the most limiting B&W weld data point and curve fitting the remaining lower bound data, a weld K_{IC} lower bound curve is derived by computer regression analysis:

$$K_{IC} = 30.0 + 2.780 \exp [0.0128 (T-RT_{NDT} + 244^{o}F)] \quad \text{Eq. 1}$$

The weld K_{IC} lower bound curve would exhibit a 100 KSI$\sqrt{in}$ crack initiation toughness approximately 40°F ($T-RT_{NDT}$) less than the "plate" K_{IC} reference curve. By taking into account the most limiting B&W weld, a second weld K_{IC} lower bound curve can also be derived using computer regression analysis:

$$K_{IC} = 30.1 + 1.675 \exp [0.0171 (T-RT_{NDT} + 195^{o}F)] \quad \text{Eq. 2,}$$

resulting in a weld 100 KSI $\sqrt{in}$ initial toughness approximately 30°F ($T - RT_{NDT}$) less than the "plate" Section XI K_{iC} reference curve. Equation 1 can be supported over Equation 2 because:

1. Equation 1 is most representative of the weld data population, and

2. The derivation of the "plate" Section XI K_{IC} lower bound curve (Figure 2) also allowed one data at -150F $T-RT_{NDT}$ temperature to fall below the curve.

REFERENCES

1. T.U. Marston, "Flaw Evaluation Procedures & ASME Section XI," EPRI NP-719-SR, August, 1978, Errata for Subject Report, April 14, 1980.

2. T.U. Marston, Fracture Toughness of Ferritic Materials in Light Water Nuclear Reactor Vessels, October 13, 1975, MM1-75-152.

3. W.A. Van Der Sluys, et al, Determining Fracture Properties of Reactor Vessel Forging Materials, Weldments and Bolting Materials, EPRI NP-122, July, 1976.

K_{Ia} REFERENCE TOUGHNESS CURVE WITH SUPPORTING DATA

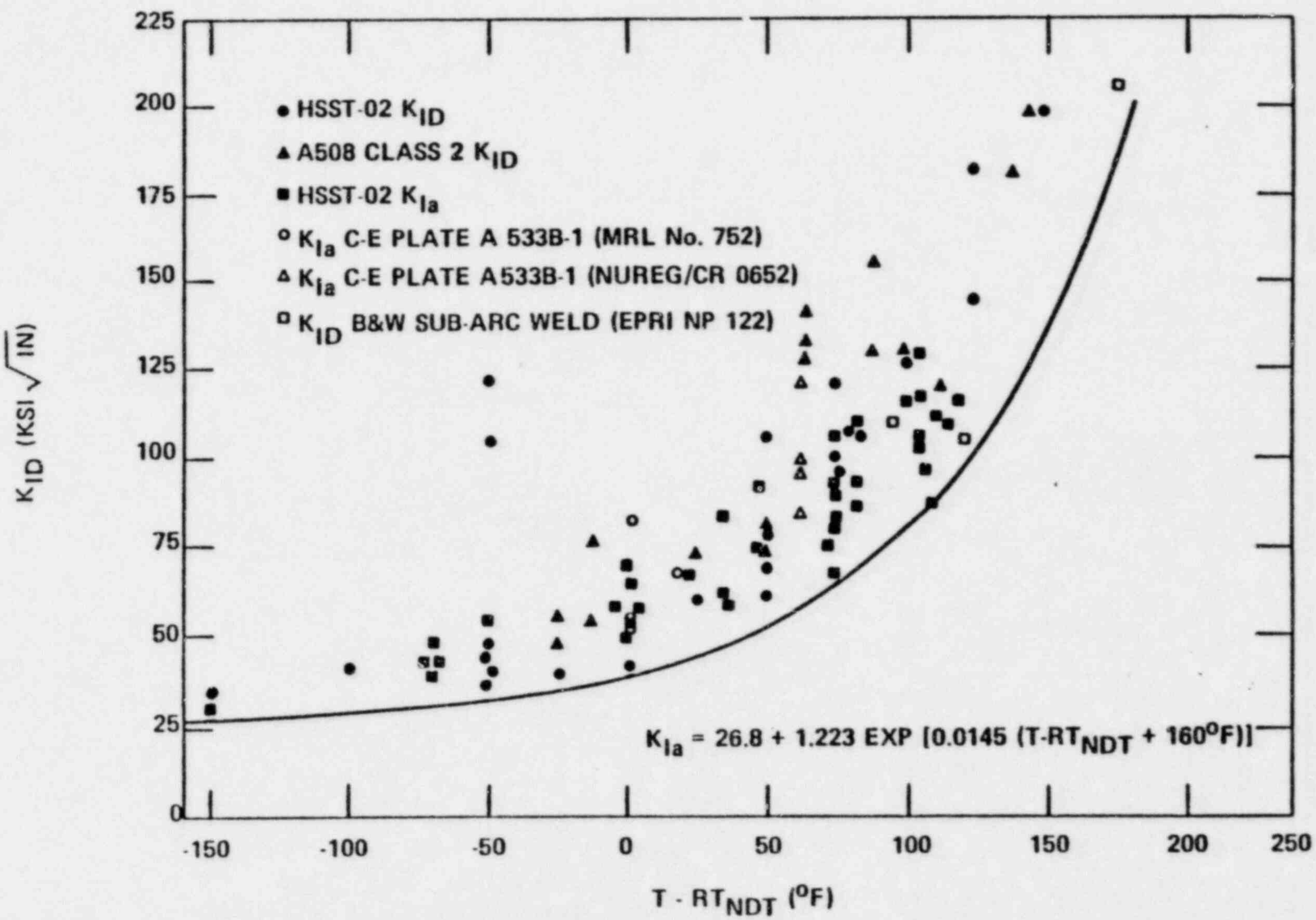
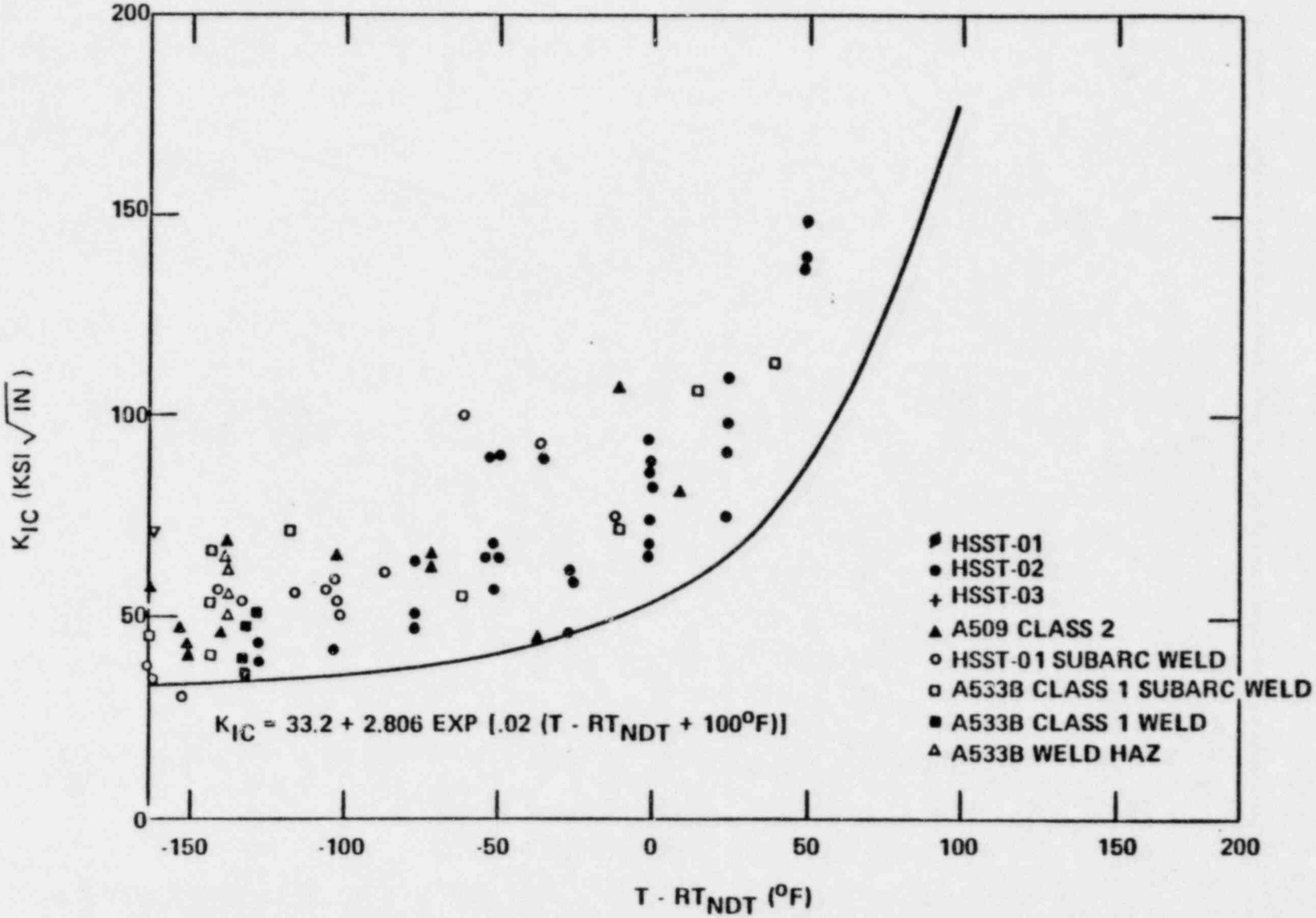
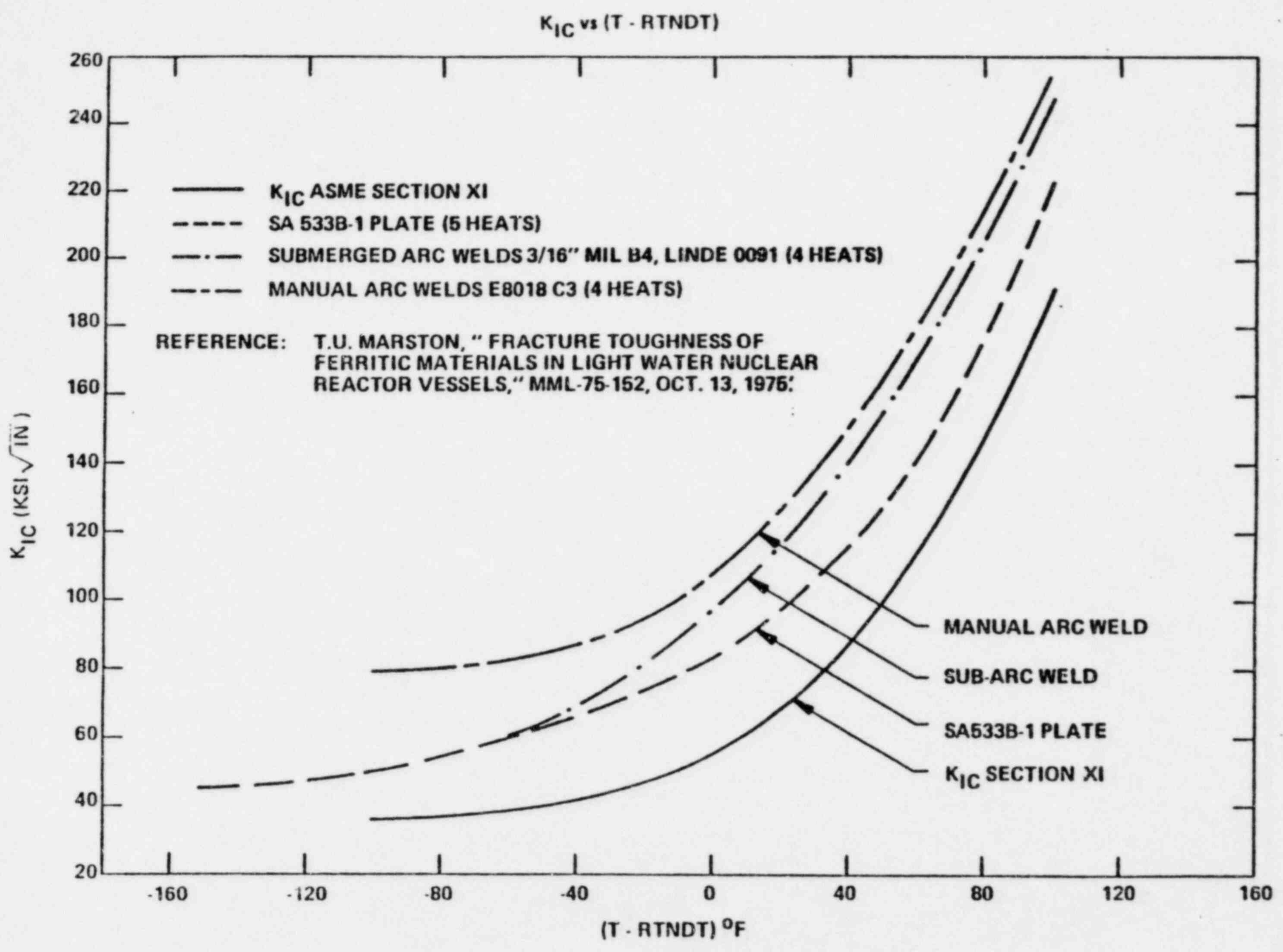


FIGURE 2

K_{IC} REFERENCE TOUGHNESS CURVE WITH SUPPORTING DATA

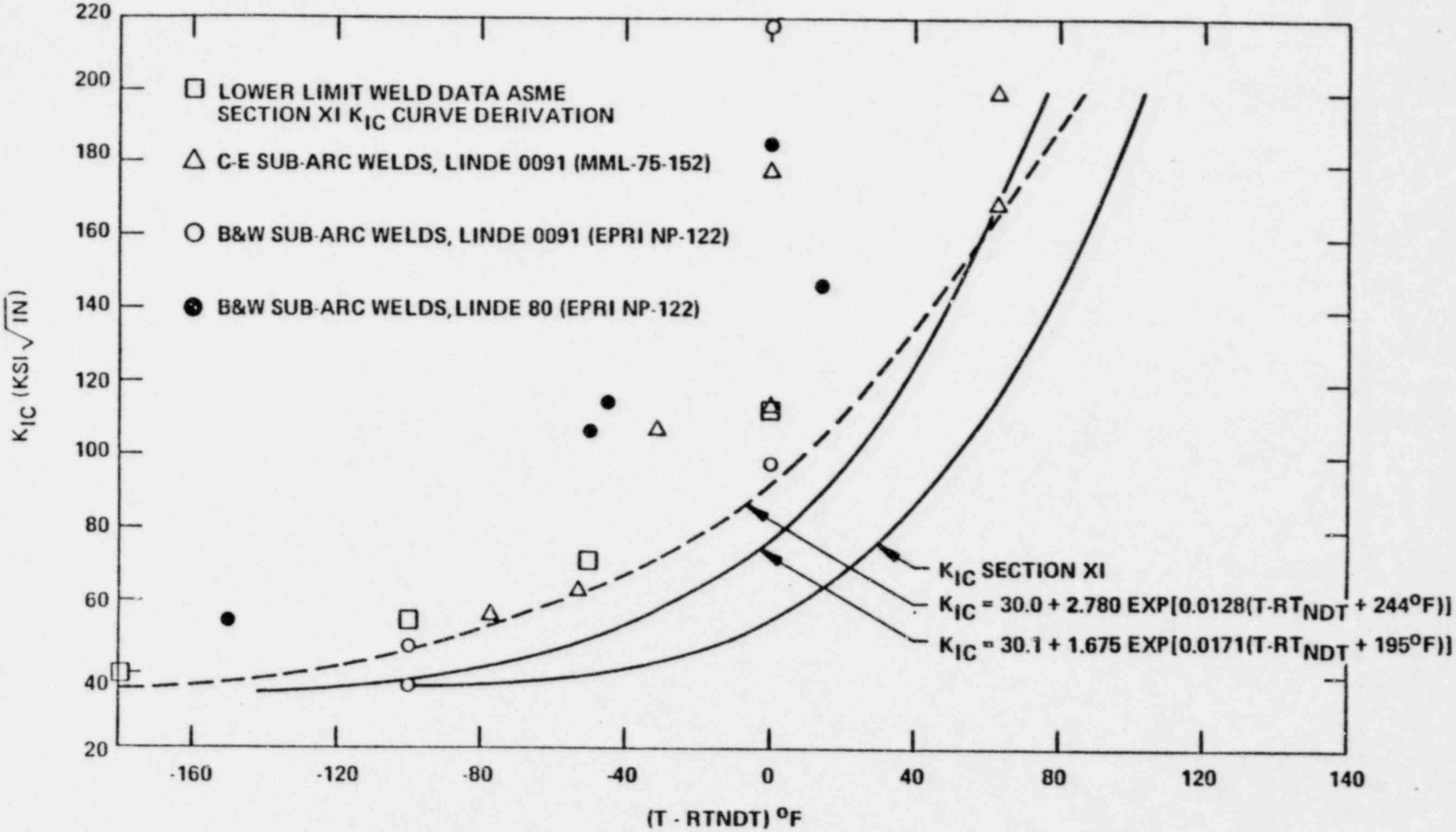




K_{IC} vs (T - RTNDT)
K_{IC} ASME SECTION XI
SA 533B-1 PLATE (5 HEATS)
SUBMERGED ARC WELDS 3/16" MIL B4, LINDE 0091 (4 HEATS)
MANUAL ARC WELDS E8018 C3 (4 HEATS)
REFERENCE: T.U. MARSTON, " FRACTURE TOUGHNESS OF FERRITIC MATERIALS IN LIGHT WATER NUCLEAR REACTOR VESSELS," MML-75-152, OCT. 13, 1975.
MANUAL ARC WELD
SUB-ARC WELD
SA533B-1 PLATE
K_{IC} SECTION XI
K_{IC} (KSI $\sqrt{IN}$)
(T - RTNDT) °F
260
240
220
200
180
160
140
120
100
80
60
40
20
-160
-120
-80
-40
0
40
80
120
160

FIGURE 4

K_{IC} vs (T – RTNDT)



Enclosure (D)

The following slides were presented at the June 23, 1982 CEOG meeting with the NRC, showing the method to convert available Charpy impact data to equivalent RT_{NDT} based on the work of Rolfe/Novak/Barsom.[1, 2] Use of this conversion method yielded estimated RT_{NDT} values equal to or better than those derived using the method described in CEN-189. Furthermore, the variation of RT_{NDT} between materials was consistent for both conversion methods. Based on the excellent agreement between these two independent estimation methods, the estimated initial RT_{NDT} values are sufficiently accurate to obviate the need for applying additional conservatism in the form of the 2σ uncertainty factor.

1. ASTM STP 466, June 1969.

2. EPRI NP-372, May 1977.

RT_{NDT} SHIFT PREDICTIONS

WELD METAL BEST

ESTIMATE RT_{NDT} APPROACH

- ROLFE/NOVAK/BARSOM RELATIONSHIP

  $(K_{IC})^2 = 2\ E\ (CVN)^{3/2}$

  E = ELASTIC MODULUS $\approx 30.2 \times 10^6 - 0.46 \times 10^4 T$

  CVN = CHARPY ENERGY AT 10F FROM
  WELD QUAL RESULTS

- ASME CODE SECTION XI KIC RELATIONSHIP

  $KIC = 33.2 + 2.806\ EXP\left[0.2\ (T - RT_{NDT} + 100)\right]$

- WELD SPECIFIC KIC RELATIONSHIP (CEOG)

  $KIC = 30.1 + 1.675\ EXP\left[0.0171\left(T - RT_{NDT} + 195\right)\right]$

- SUMMARY OF APPROACH

  AVG CVN FROM WELD QUAL RESULTS AT 10F

  ESTIMATE KIC AT 10F USING ROLFE/NOVAK/
  BARSOM RELATION

  ESTIMATE RT_{NDT} FROM ASME CODE AND CEOG RELATIONSHIPS

VESSEL	AVG. CVN ENERY AT 10F (FT-LB)	R/M/R KIC AT 10F (KSI $\sqrt{in}$)	ESTIMATED RT_{NDT} (°F) ASME SEC. XI (ALL DATA)	CEOG/WELDS (WELDS ONLY)	CEN-189 (ASME NB 2330)
FORT CALHOUN	61.0 (IS)*	169.4	- 84	- 54	- 50
	57.3 (LS)*	161.6	- 81	- 50	- 50
CALVERT CLIFFS #1	44.3 (IS)	133.2	- 69	- 36	- 30
	57.0 (LS)	161.0	- 81	- 50	- 50
CALVERT CLIFFS #2	73.0 (IS)	193.8	- 92	- 63	- 50
	131.7 (LS)	301.6	-118	- 93	- 80
MAINE YANKEE	61.0 (IS)	169.4	- 84	- 54	- 50
	57.0 (LS)	161.0	- 81	- 50	- 40
PALISADES	40.7 (IS)	125.0	- 64	- 31	- 25
	53.7 (LS)	153.9	- 78	- 47	- 45
MILLSTONE #2	73.0 (IS)	193.8	- 92	- 63	- 50
	73.0 (LS)	193.8	- 92	- 63	- 50
ST. LUCIE #1	67.3 (IS)	182.3	- 89	- 59	- 50
	87.0 (LS)	221.0	-100	- 72	- 50

* IS - INTERMEDIATE SHELL LONG SEAM WELD

* LS - LOWER SHELL LONG SEAM WELD

RT_{NDT} SHIFT PREDICTIONS

BEST ESTIMATE RT_{NDT} FOR WELDS

- CONCLUSIONS -

  - USE OF R/N/B RELATIONSHIP AND SECTION XI K_{IC} CURVES YIELDS VERY LOW RT_{NDT} ESTIMATES

  - USE OF R/N/B PLUS WELD SPECIFIC K_{IC} CURVES YIELDS RT_{NDT} ESTIMATES CONSISTENT WITH CEN-189 RT_{NDT} ESTIMATES

  - USE OF -20F RT_{NDT} FOR INITIAL WELD TOUGHNESS WILL YIELD SIGNIFICANT UNDER-ESTIMATE OF CRACK INITIATION TOUGHNESS

  - CEN-189 BEST ESTIMATE INITIAL RT_{NDT} VALUES USED IN CONJUNCTION WITH ASME CODE, SECTION XI CURVES WILL YIELD CONSERVATIVE ESTIMATES OF CRACK INITIATION TOUGHNESS PROPERTIES

RECOMMENDATION

- USE CEN-189 BEST ESTIMATE INITIAL RT_{NDT} VALUES FOR EVALUATING C-E VESSEL PROPERTIES RELATIVE TO REGULATORY POSITION RT_{NDT} LIMITS