UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001
July 11, 2000

MEMORANDUM TO: Stuart A. Richards, Director
Project Directorate IV & Decommissioning
Division of Licensing Project Management
Office of Nuclear Reactor Regulation

FROM: Stewart N. Bailey, Project Manager, Section 2
Project Directorate III
Division of Licensing Project Management
Office of Nuclear Reactor Regulation

SUBJECT: SUMMARY OF JUNE 20, 2000, MEETING WITH THE BABCOCK AND WILCOX OWNERS GROUP REACTOR VESSEL WORKING GROUP ON APPLICATION OF MASTER CURVE TECHNOLOGY TO LINDE 80 WELDS

On June 20, 2000, the U. S. Nuclear Regulatory Commission (NRC) staff met with the Babcock and Wilcox Owners Group (B&WOG) Reactor Vessel Working Group (RVWG) to discuss their plans to apply Master Curve technology to Linde 80 weld materials. The meeting was held to update the staff on progress since the meeting in 1995 and to obtain staff feedback on the RVWG's proposed documentation.

After introductions, the RVWG discussed their intention to use this technology to demonstrate additional margin of safety in Linde 80 welds, which can then be used to support pressure-temperature curves and plant license renewal. The RVWG stated that Linde 80 welds behave consistently (good uniformity) if welds made with weld wire heat 72105 were separated from the rest of the group. The RVWG stated 72105 welds had significantly different microstructure characteristics (larger inclusion size) than the rest of the Linde 80 welds and this justifies treating them separately. The RVWG intends to use Master Curve technology to determine an initial RT_{NDT} (nil-ductility transition temperature) for Linde 80 welds (minus 72105 welds), and use irradiated specimen data to demonstrate that the shift in RT_{NDT} can be conservatively estimated using the methods in Regulatory Guide (RG) 1.99, Revision 2, "Radiation Embrittlement of Reactor Vessel Materials."

The staff stated that the submittal should provide statistical and physical reasons for separating 72105 welds from the rest of the Linde 80 welds. The staff also stated the submittal should discuss statistical uncertainty in the test data, including any caused by sampling variability. The staff noted that the RVWG had discussed copper saturation in Linde 80 welds, while this is not assumed in RG 1.99, Revision 2, and that the RVWG should be clear in describing their methods and comparisons. There was also a significant discussion about the variation in the determination of T_0 (index temperature determined from Master Curve based testing) when measured using different specimen sizes (Charpy vs. 0.5TCT specimens). The RVWG commented that this phenomenon is known and recognized, and they discussed how they accounted for it in their data reduction. On a related issue, the staff stated the submittal should explain why it is appropriate to normalize the results to 1T (ASTM-E 1921 assumptions) when the data is being applied to reactor vessels.

DF01

A list of those attending the meeting is provided as Attachment 1. The slides used by the B&WOG during the meeting are provided in Attachment 2.

Project No. 693

Attachments: 1. Meeting Attendees
2. Slides

cc w/atts: See next page

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FRAMATOME TECHNOLOGIES, INC.
MEETING ON MASTER CURVE TECHNOLOGY
JUNE 20, 2000

NAME	AFFILIATION
Stewart Bailey	NRC/NRR/DLPM
Edward Andruszkiewicz	NRC/NRR/DE/EMCB
Barry Elliot	NRC/NRR/DE/EMCB
Allen Hiser	NRC/NRR/DE/EMCB
Matthew Mitchell	NRC/NRR/DE/EMCB
Keith Wichman	NRC/NRR/DE/EMCB
Ken Karwoski	NRC/RES/DET/MEB
Mark Kirk	NRC/RES/DET/MEB
Matthew DeVan	FTI
Don Howell	FTI
Ken Moore	FTI
Ken Yoon	FTI
William Brady	Duke Energy
S. D. Leshnoff	PECO Energy
John Harrell	Virginia Power
Daniel Spond	Engerty Operations Inc.
Stephen Collard	FPL
James Pfefferle	Wisconsin Electric Power
Charles Kim	Westinghouse Electric Company
Altheia Wyche	SERCH Licensing/Bechtel

Attachment 1

APPLICATION OF MASTER CURVE TECHNOLOGY TO LINDE 80 WELD MATERIALS

JAMES PFEFFERLE
WISCONSIN ELECTRIC
CHAIRMAN
B&W OWNERS GROUP
REACTOR VESSEL WORKING GROUP

B&WOG-NRC MEETING
ROCKVILLE, MARYLAND
JUNE 20, 2000

B&WOG REACTOR VESSEL WORKING GROUP PARTICIPANTS

❑ *AmerGen Energy Company*	*TMI-1*
❑ *Duke Energy Company*	*Oconee-1, 2, 3*
❑ *Entergy Operations, Inc.*	*ANO-1*
❑ *FirstEnergy Nuclear Operating Co.*	*Davis Besse*
❑ *Florida Power Corporation*	*Crystal River-3*
❑ *Florida Power & Light Co.*	*Turkey Point-1, 2*
❑ *Virginia Power Company*	*Surry-1, 2*
❑ *Wisconsin Electric Power Co.*	*Point Beach-1, 2*

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Attachment 2

MEETING PURPOSE

- *Provide staff with progress and results of Master Curve and Microstructure work since last meeting in 1995*
- *Provide feedback on open issues from previous meeting*
  - *Technical basis for use of Master Curve*
  - *Alternative Code rule to NB 2300*
  - *Additional fracture toughness data*
- *Summarize B&WOG proposed documentation of results and obtain feedback and direction*

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AGENDA

- *Results of Microstructural Studies and Tensile Properties* - *Ken Moore*
- *Application of Master Curve Technology to Linde 80 Weld Materials* - *Ken Yoon*
- *Proposed Topical Report* - *Ken Yoon*
- *Feedback* - *Staff*

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LINDE 80 WELDS

Mechanical Properties and Microstructure

K. E. MOORE
FRAMATOME TECHNOLOGIES

FOR
B&W OWNERS GROUP
REACTOR VESSEL WORKING GROUP

BWOG-NRC MEETING
Rockville, Maryland
June 20, 2000

BACKGROUND

- *Linde 80 Welds have been the subject of 25 years of testing and analysis in work sponsored by the B&WOG and the NRC*
- *Very well characterized material*
- *Chemistry, properties and their variabilities are narrowly defined within the Linde 80 class of welds*

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BACKGROUND

- *Microstructural characterization provides additional basis for understanding Linde 80 weld metal properties and variabilities*
- *Results demonstrate that weld wire heat 72105 has microstructural characteristics that are significantly different than the remainder of Linde 80 welds*

BACKGROUND

- *These differences provide the basis for understanding the impact and fracture toughness data*
  - **The fracture toughness data set for welds made with weld wire heat 72105 are treated separately from the remainder of the "Linde 80" welds.**

TOPICS

- *General description of Linde 80 welds*
- *Mechanical properties*
- *Summary of quantitative metallographic and microchemical analysis*
  - **Linde 80 and weld wire 72105 subset**
  - **Significance**

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GENERAL DESCRIPTION OF LINDE 80 WELDS

- *Welds produced using submerged arc process*
  - **Consumables: Mn-Mo-Ni weld filler wire**
    - Typical wire composition: .12 C, 2.0 Mn, .010 P, .015 S, .10 Si, .65 Ni, .39 Mo, .07 Cr
    - Sources of copper: plating and base alloy
    - Linde 80: neutral calcium silicate flux rich in silica with 8-10 w/o MnO
- *General Characteristics: ASA welds made with Linde 80 contain relatively large oxide inclusions. Result is relatively low initial toughness.*

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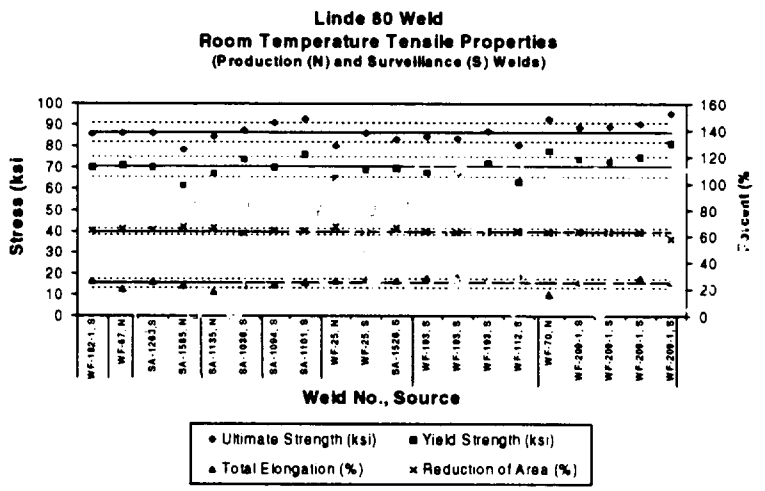
MECHANICAL PROPERTIES

Room Temperature Tensile Properties For Linde 80 Welds

TENSILE PROPERTIES



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MICROSTRUCTURE

Summary of Quantitative Metallographic
and Microchemical Analysis

MICROSTRUCTURAL STUDIES

- *Quantitative image analysis method used to systematically measure precipitate size and distribution*
  - **multiple locations sampled in each of 30 specimens obtained from 11 Linde 80 welds**
- *Microchemical analysis performed using energy dispersive spectroscopy on large surface areas of all specimens*
  - **the composition of precipitates systematically analyzed and categorized**

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MICROSTRUCTURAL STUDIES

- *Results of Microchemical Analysis*
  - Mn-Si, Mn-Si-S, and Mn-Si-Al are predominent compositions; some precipitates are Cu rich
  - Inclusion spacing consistent for all welds
  - Average inclusion size significantly larger in welds made with weld wire 72105

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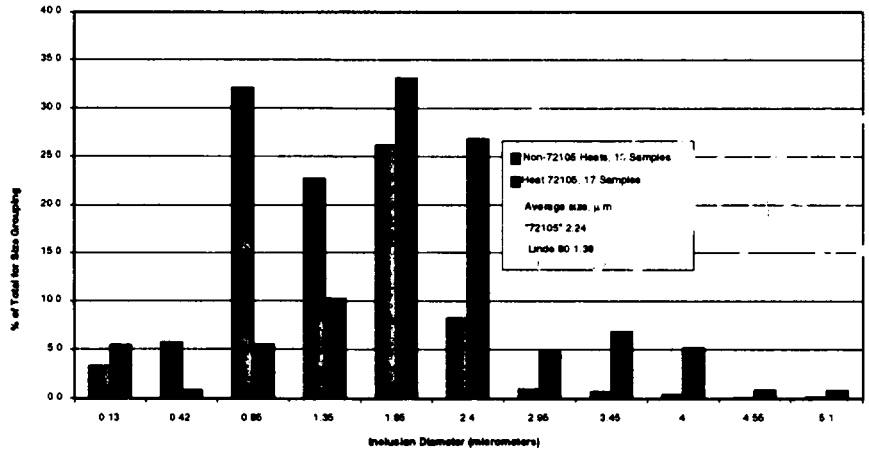
INCLUSION SIZE

HISTOGRAMS FOR 72105 AND NON-72105 LINDE 80 WELD WIRE HEATS



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MICROSTURCTURE

Significance of Results

MICROSTRUCTURE

- *According to Anderson, Stienstra and Dodds*
  - Cleavage fracture initiates at inclusions
  - The largest or most favorably located inclusion ahead of the crack tip often controls the overall toughness in the transition region
  - "This" inclusion is referred to as a cleavage trigger
- *Wallin, et.al., provided a relationship to describe the significance of the size of potential cleavage trigger.*
  - r_0, critical inclusion radius, is a function of "work" divided by tensile stress

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THEORETICAL MODEL FOR CRITICAL INCLUSION RADIUS

- Cleavage fracture will initiate when the radius of an inclusion exceeds r_0.
- Material with larger inclusions will likely exhibit cleavage at a lower level of stress in the transition range and thus lower fracture toughness.
- Welds made with wire heat 72105 have significantly larger inclusions than other Linde 80 weld class.

❒ *Welds made with wire heat 72105 are justifiably separated from the overall population of Linde 80 welds*

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APPLICATION OF MASTER CURVE TECHNOLOGY TO LINDE 80 WELD MATERIALS

K. K. YOON
FRAMATOME TECHNOLOGIES

FOR
B&W OWNERS GROUP
REACTOR VESSEL WORKING GROUP

BWOG-NRC MEETING
ROCKVILLE, MARYLAND
JUNE 20, 2000

NEED

- *Some B&WOG plants may be close to the PTS screening criteria in the license renewal operating period.*
- *These utilities need to address this problem in the short term to make financial decisions regarding license renewal.*
- *Additional relief in the construction of P/T curves would be a significant benefit to all B&WOG RVWG plants*

OBJECTIVES

- *Since Charpy based IRT_{NDT} are not true measures of fracture toughness, need to establish alternative values.*
- *Demonstrate similarities among Linde 80 welds based on microstructures and tensile properties.*
- *Establish alternative* "common initial RT_{NDT}" *values for two subgroups of Linde 80 weld materials based on ASTM E 1921 and ASME Code Case N-631.*
- *Feedback and direction on this approach for lead plant license renewal applications.*

TO ACCOMPLISH OUR OBJECTIVES

Need fracture toughness data
Need ASTM and ASME procedures
Need an approach

- BWOG has a substantial fracture toughness database
- ASTM Standard E 1921 and ASME Code Case N-631
- Two possible approaches

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APPROACHES

1. *Approach I*
   - *Determine ART using T_0 from irradiated specimen testing and E1921 - similar to Kewaunee submittal*

- *Approach II*
  - *Determine IRT_{NDT} by T_0 using Code Case N-631*
  - *Validate this approach with irradiated specimen data*

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B&WOG ELECTED THE SECOND APPROAC

Why ?

Ease of compliance with existing regulations

Fracture toughness database available

Reduced uncertainties dealing with only unirradiated specimen data

Flux is neutral and only variable is copper content among Linde 80 welds. Since copper effect has been shown to saturate at 0.25wt%, it is appropriate to treat all Linde 80 welds as groups.

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HISTORICAL BACKGROUND

- *First Application of Master Curve Technology BAW-2202 "Fracture Toughness Characterization of WF-70 Weld Metal," September 1993 for Zion*
- *What was the issue?*
  - Inadequacy of Charpy transition temperature based RT_{NDT}
- *Resolution*
  - Used T_{NDT} based RT_{NDT}
  - Validated by Master Curve Method/Data

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WHAT'S NEW SINCE 1995

- *Additional technical basis developed*
- *Additional fracture toughness data made available*
- *Utilization of microstructural studies*
- *ASME Code Cases N-629 and N-631*
- *EPRI MRP Program*

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TECHICAL BASIS FOR MASTER CURVE

- *ASTM Standard E 1921-97 and E 1921-00*
- *NUREG/CR-5504 Technical Basis*
- *EPRI TR-108390-R1 Application of Master Curve Fracture Toughness Methodology for Ferritic Steels, Rev. 1*
- *FAW-2318 Fracture Toughness of Ferritic Steels and ASTM Reference Temperature (T_0) – B&WOG and PVRC Fracture Toughness Database*
- *Japanese TENPES Data Analysis*
- *Dynamic Fracture Toughness Data Analysis*

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SIMILARITIES IN MATERIAL PARAMETERS

- ***Weld-wire Heat Flux Combinations (WWH) in Beltline Regions of B&WOG RVWG Plants - 15***
  - Weld-wire heat introduces copper variation
  - Importance of copper variation diminished in view of copper saturation level of 0.25 for Linde 80 welds
  - Nickel content has very narrow scatter band~0.6 wt%
- ***Among 15 WWHs***
  - 4 WWH are located in low fluence region
  - 3 WWH have low copper (<0.2)
  - 6 WWH have MC data
  - 2 in medium copper range (0.23 and 0.26) no data

BWOG FRACTURE TOUGHNESS DATA

- *K_{Jc} DATA FOR UNIRRADITED LINDE 80 WELDS*
  - **7 different welds - 84 data points plus ORNL data**
  - **Used to determine initial RT_{NDT}**

- *K_{Jc} DATA FOR IRRADIATED LINDE 80 WELDS*
  - **10 welds - 58 data points**
  - **Used to validate ART resulting from Master Curve based IRT_{NDT} and RG199 R2 shift**

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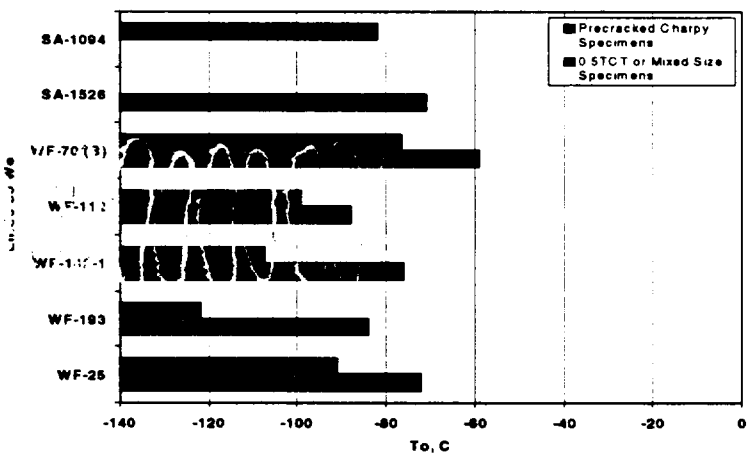
LINDE 80 T_0 DATA - UNIRRADIATED



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RG 1.99 REV. 2

- $ART = I\,RT_{NDT} + \Delta RT_{NDT} + M$
  - $M = 2\sqrt{\sigma_I^2 + \sigma_\Delta^2}$
  - σ_Δ = 28°F for welds
  - σ_I = 0 for credible data

BAW-2202 WF-70

- BAW-2202
  $RT_{NDT\,(MEAN)}$ = -56 °F (T_{NDT})
  σ_I = 14.8 °F
  $IRT_{NDT} = RT_{NDT\,(MEAN)} + 2\,\sigma_I$ = - 27 °F

  M = 56 °F
- Correct method

  $IRT_{NDT} = RT_{NDT\,(MEAN)}$ = -56

  σ_I = 14.3 °F

  $M = 2\sqrt{\sigma_I^2 + \sigma_\Delta^2}$ = 66.3

NON-72105 GROUP

- $RT_{NDT\,(MEAN)} = -82.7°F$

  $\sigma_I = 21.1°F$

  $IRT_{NDT} = RT_{NDT\,(MEAN)}$

  $M = 2 / \quad 21.1^2 + 28^2$

  $M = 70.1\ °F$

  Unirradiated Welds

  $IRT_{NDT} = RT_{NDT\,(MEAN)} + 2x21.1 = -40.5°F$

RT_{NDT} FOR LINDE 80 WELDS

Linde 80 Weld Group	RT_{NDT} (MEAN)	σ_I	$RT_{NDT} + 2\sigma$	Remarks
Weld-wire heat 72105	-56	14.8	-26.4	BAW-2202
Weld-wire heat Non-72105	-82.7	21.1	-40.5	BAW-2308

Topical Report BAW-2308

Based on microstructures, divide Linde 80 weld materials into two groups

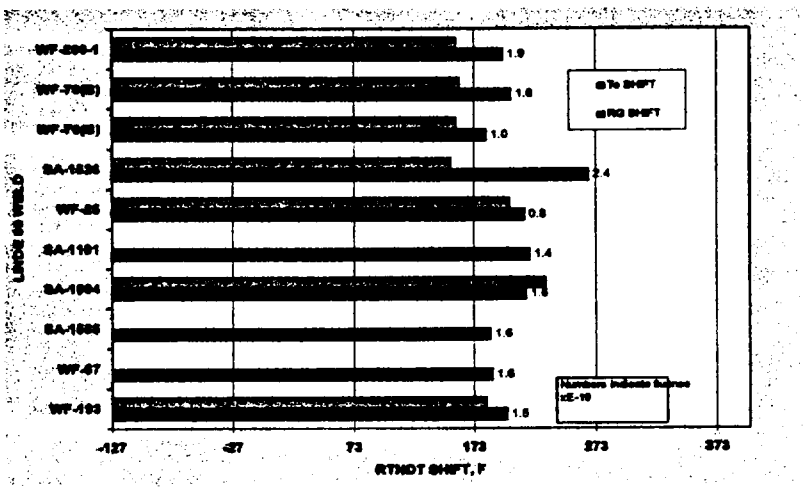
1. *Group L80-1 : Weld Wire 72105*
   Initial RT_{NDT} of -27°F as per BAW-2202

2. *Group L80-2: Mean Initial RT_{T0} = -82.7°F*
   σ_I = 21.1 F
   Code Case N-631 Initial RT_{T0} = -40.5°F

VALIDATION BY IRRADIATED SPECIMEN DATA

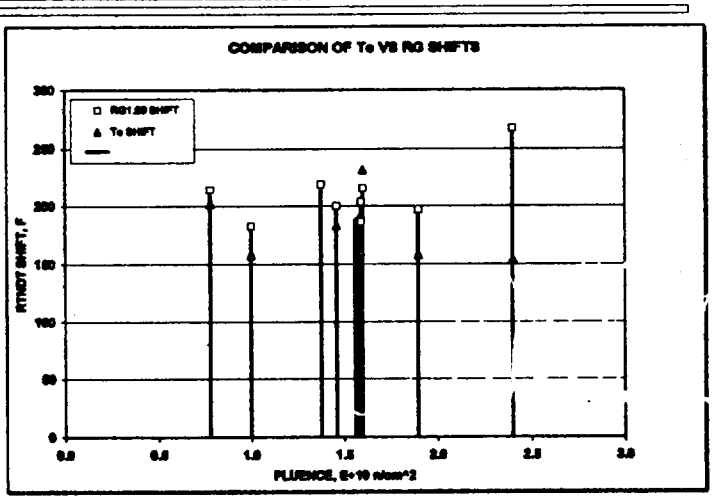
- *Comparison of RG 1.99 R2 Shift vs. T_0 Shift*
  - A total of seven lots of measured fracture toughness of irradiated weld materials
  - Predicted RT_{NDT} shift compared with measured shift in T_0
- *Actual T_0 shifts are less than RG shift predictions (except one)*

RG199 SHIFT vs. T_0 SHIFT

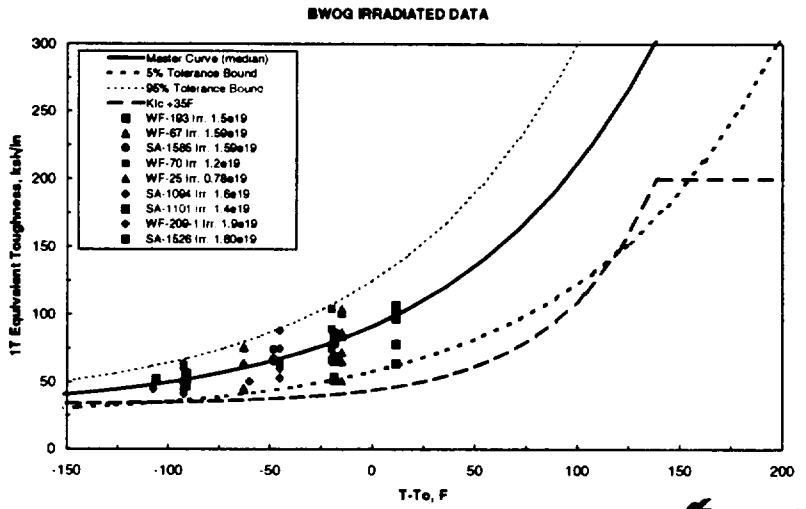


RG1.99 PREDICTED SHIFT VS. MEASURED T_0 SHIFT

- *T_0 shift is less than RG1.99 predicted shift except one*



BWOG IRRADIATED LINDE 80 DATA



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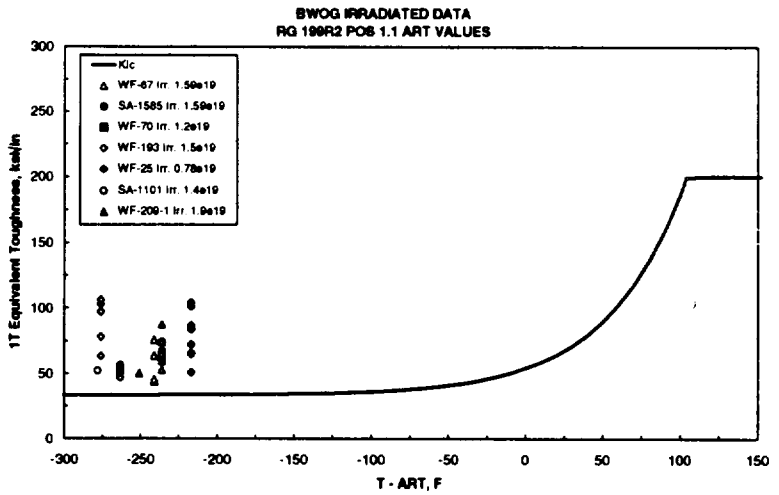
RG199 PREDICTED ART VS DATA



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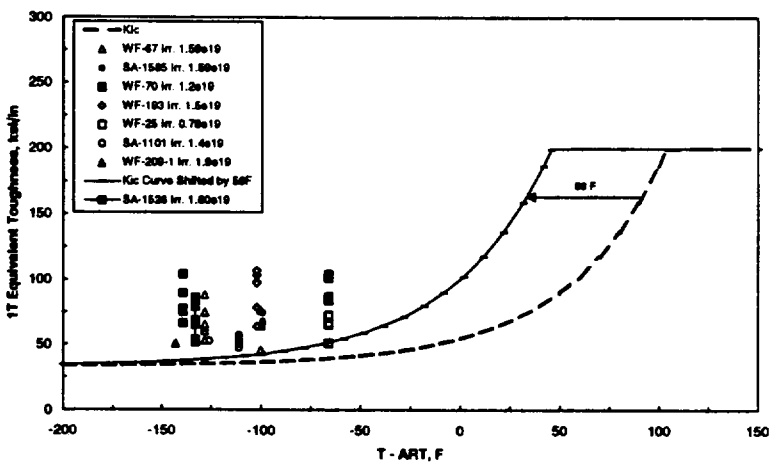
ADDITIONAL MARGIN BEYOND RG



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CONCLUSIONS

- *BWOG has a large K_{Jc} data set on Linde 80 welds.*
- *Based on microstructural data, Linde 80 welds are divided into two groups; 72105 weld-wire heat group and non-72105 weld-wire heat group.*
- *Established alternative* "**common initial RT_{NDT}**" *values for two subgroups of Linde 80 weld materials using ASTM E 1921 and ASME Code Case N-631.*
- *Irradiated Linde 80 weld data show that RG1.99 shifts are more conservative than T_0 shifts. Combining initial RT_{NDT} with RG1.99 RT_{NDT} shift is conservative.*

CONCLUSIONS (CONT'D)

- *The following* "**common initial RT_{NDT}**" *values are established:*
  - Group 1: Weld wire heat 72105
    Initial RT_{NDT} of -27°F as per BAW-2202
  - Group 2:Non-72105 weld wire heat
    Mean Initial RT_{T0} = -82.7°F
    σ_I = 21.1 F
    Initial RT_{T0} = -40.5°F