Received by OSTI

JAN 25 1993

NUREG/CR-5914
ORNL-6740

Chemical Composition and RT_{NDT} Determinations for Midland Weld WF-70

Prepared by
R. K. Nanstad, D. E. McCabe, R. L. Swain, M. K. Miller

Oak Ridge National Laboratory

Prepared for
U.S. Nuclear Regulatory Commission

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

AVAILABILITY NOTICE

Availability of Reference Materials Cited in NRC Publications

Most documents cited in NRC publications will be available from one of the following sources:

1. The NRC Public Document Room, 2120 L Street, NW., Lower Level, Washington, DC 20555
2. The Superintendent of Documents, U.S. Government Printing Office, P.O. Box 37082, Washington, DC 20013-7082
3. The National Technical Information Service, Springfield, VA 22161

Although the listing that follows represents the majority of documents cited in NRC publications, it is not intended to be exhaustive.

Referenced documents available for inspection and copying for a fee from the NRC Public Document Room include NRC correspondence and internal NRC memoranda; NRC bulletins, circulars, information notices, inspection and investigation notices; licensee event reports; vendor reports and correspondence; Commission papers; and applicant and licensee documents and correspondence.

The following documents in the NUREG series are available for purchase from the GPO Sales Program: formal NRC staff and contractor reports, NRC-sponsored conference proceedings, international agreement reports, grant publications, and NRC booklets and brochures. Also available are regulatory guides, NRC regulations in the *Code of Federal Regulations*, and *Nuclear Regulatory Commission Issuances*.

Documents available from the National Technical Information Service include NUREG-series reports and technical reports prepared by other Federal agencies and reports prepared by the Atomic Energy Commission, forerunner agency to the Nuclear Regulatory Commission.

Documents available from public and special technical libraries include all open literature items, such as books, journal articles, and transactions. *Federal Register* notices, Federal and State legislation, and congressional reports can usually be obtained from these libraries.

Documents such as theses, dissertations, foreign reports and translations, and non-NRC conference proceedings are available for purchase from the organization sponsoring the publication cited.

Single copies of NRC draft reports are available free, to the extent of supply, upon written request to the Office of Administration, Distribution and Mail Services Section, U.S. Nuclear Regulatory Commission, Washington, DC 20555.

Copies of industry codes and standards used in a substantive manner in the NRC regulatory process are maintained at the NRC Library, 7920 Norfolk Avenue, Bethesda, Maryland, for use by the public. Codes and standards are usually copyrighted and may be purchased from the originating organization or, if they are American National Standards, from the American National Standards Institute, 1430 Broadway, New York, NY 10018.

DISCLAIMER NOTICE

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, or any of their employees, makes any warranty, expressed or implied, or assumes any legal liability of responsibility for any third party's use, or the results of such use, of any information, apparatus, product or process disclosed in this report, or represents that its use by such third party would not infringe privately owned rights.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

Chemical Composition and RT_{NDT} Determinations for Midland Weld WF-70

Manuscript Completed: July 1992
Date Published: December 1992

Prepared by
R. K. Nanstad, D. E. McCabe, R. L. Swain, M. K. Miller

Oak Ridge National Laboratory
Managed by Martin Marietta Energy Systems, Inc.

Oak Ridge National Laboratory
Oak Ridge, TN 37831-6285

Prepared for
Division of Engineering
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, DC 20555
NRC FIN L1098
Under Contract No. DE-AC05-84OR21400

MASTER

EB

Abstract

The Heavy-Section Steel Irradiation (HSSI) Program at Oak Ridge National Laboratory (ORNL) includes a task, the Tenth Irradiation Series, to investigate the effects of radiation on the fracture toughness of the low-upper-shelf (LUS) submerged-arc welds in the reactor pressure vessel (RPV) of the canceled Midland Unit 1 nuclear plant. The welds carry the Babcock and Wilcox Co. (B&W) designation WF-70, a specific combination of weld wire (heat 72105) and welding flux (lot 8669), which exists in many commercial pressurized-water reactors. Part of the study involves the determination of variations in chemical composition and reference temperature (RT_{NDT}) throughout the welds. Four 1.17-m-long (46-in.) sections of beltline weld and two similar sections of nozzle course weld have been examined. One of the beltline sections contains a repair weld in the fabrication weld along about 150 mm (6 in.) of its length.

For each section, drop-weight specimens were machined from two locations through the weld thickness, while Charpy V-Notch (CVN) impact specimens were machined from five locations in the beltline weld and three locations in the nozzle course weld. The nil-ductility transition (NDT)

temperatures ranged from -40 to -60°C (-40 and -76°F). Because the Charpy impact energy did not achieve 68 J (50 ft-lb) at $NDT + 33^{\circ}\text{C}$ (60°F) at any of the locations, the RT_{NDT} s are all controlled by the Charpy behavior. The RT_{NDT} s vary from -20 to 37°C (-4 to 99°F), while the upper-shelf energies varied from 77 to 108 J (57 to 80 ft-lb). Analysis of the combined data revealed a mean 41-J (30-ft-lb) temperature of -8°C (17°F) with a mean upper-shelf energy of 88 J (65 ft-lb). The tested Charpy specimens were used to determine chemical composition at each location. Even though all the welds carry the WF-70 designation, the bulk copper contents range from 0.21 to 0.34 wt % in the beltline weld and from 0.37 to 0.46 wt % in the nozzle course weld. Atom probe analyses of the matrix copper content in one beltline section gave an average of about 0.11 wt %, indicating substantial depletion of copper in the matrix as a result of precipitation during the postweld heat treatment. Field ion micrographs, however, showed no evidence of copper clustering. Statistical analyses of the Charpy and chemical composition results are discussed. Interpretation of the American Society of Mechanical Engineers (ASME) procedures for RT_{NDT} determination is also discussed.

Contents

	Page
Abstract	iii
List of Figures	v
List of Tables	viii
Acknowledgments	xi
Previous Reports in Series	xiii
Introduction	1
Description of Weldments	1
Drop-Weight Tests	4
CVN Impact Tests	4
CVN Test Results	20
Statistical Analyses of CVN Test Results	32
Chemical Composition	61
Bulk Analyses	61
Electron Microprobe Analyses	71
Atom Probe-Field Ion Microscope Analyses	71
Discussion	79
Observations and Conclusions	81
References	82
Appendix A: B&W "Record of Filler Wire Qualification Test" - Weld Wire 72105	A-1
Appendix B: Charpy V-Notch Impact Data For Unirradiated Midland Reactor Vessel Welds	B-1
Appendix C: Results of Chemical Analyses of Unirradiated Midland Reactor Vessel Welds	C-1
Appendix D: Hyperbolic Tangent Curve Fits With 68 and 95% Confidence Bounds for Individual Data Sets Unirradiated Midland Reactor Vessel Welds	D-1
Appendix E: Hyperbolic Tangent Curve Fits With 68 and 95% Confidence Bounds for Combined Data Sets Unirradiated Midland Reactor Vessel Welds	E-1

Figures

1 Schematic diagram of Midland Unit 1 reactor vessel showing plan for sectioning beltline and nozzle course welds	2
--	---

	Page
2 Macrograph at end of Midland beltline weld section 1-13 shows large amount of manual metal-arc weld repair from clad surface of vessel	5
3 Macrograph of Midland beltline weld section 1-13 about 70 mm (~2.75 in.) from macrograph shown in Figure 2	6
4 Macrograph of Midland beltline weld section 1-13 about 140 mm (~5.50 in.) from macrograph shown in Figure 2	7
5 Macrograph of Midland beltline weld section 1-13 about 210 mm (~8.25 in.) from macrograph shown in Figure 2	8
6 Typical macrostructures and microstructures of the manual metal-arc repair weld in Midland beltline weld section 1-13: (a) low magnification showing individual weld passes and regions with coarse solidification structure, (b) somewhat higher magnification showing mixture of coarse and fine structure, (c) higher magnification showing region of fine microstructure, and (d) same magnification as (c), showing region of coarse microstructure.	9
7 Macrograph showing locations through the thickness of Midland beltline weld section 1-13 from which microscopy, chemistry, Charpy impact, and drop-weight specimens were machined . .	11
8 Typical microstructures through the thickness (from the inside surface) of the submerged-arc weld WF-70 in the beltline region (see Figure 7): (a) 1/4 thickness (region 1), (b) 1/2 thickness (region 2D), (c) 1/2 thickness (region 2E), (d) 5/8 thickness (region 3), and (e) 3/4 thickness (region 4)	12
9 Macrograph of Midland nozzle course weld section 3-1; weld WF-67 comprises approximately the inner half of the weld thickness, while WF-70 comprises approximately the outer half	15
10 Typical microstructures through the thickness (from the root of the weld joining WF-67 and WF-70) of the submerged-arc weld WF-70 in the nozzle course region (see Figure 9): (a) 1/2 thickness, (b) 3/4 thickness, and (c) 7/8 thickness	16
11 Charpy V-notch impact energy versus test temperature for specimens machined from the various regions through the thickness of the Midland weld section 1-13 shown in Figure 7: (a) Region 1, (b) Region 2 (2D and 2E combined), (c) Region 2D, (d) Region 2E, (e) Region 3, and (f) Region 4	21
12 Charpy V-notch lateral expansion versus test temperature for specimens machined from the various regions through the thickness of the Midland beltline weld section 1-13 shown in Figure 7: (a) Region 1, (b) Region 2 (2D and 2E combined), (c) Region 2D, (d) Region 2E, (e) Region 3, and (f) Region 4	24
13 Charpy V-notch percent shear fracture versus test temperature for specimens machined from the various regions through the thickness of the Midland beltline weld section 1-13 shown in Figure 7: (a) Region 1, (b) Region 2 (2D and 2E combined), (c) Region 2D, (d) Region 2E, (e) Region 3, and (f) Region 4	27

14	Charpy V-notch impact energy versus test temperature for specimens from the 1/2 thickness location in Midland beltline weld section 1-13. The solid curve represents the mean hyperbolic tangent curve fit to all the data, while the dashed curve represents a similar fit using the minimum datum at each test temperature. The third curve represents a lower-bound curve to all the data. The reference temperature analysis is given at the bottom of the figure	31
15	Charpy V-notch impact energy versus test temperature for all tests of beltline and nozzle course welds of the Midland reactor vessel; the solid curve represents the mean hyperbolic tangent curve fit, while the dashed curves represent upper and lower 68% confidence bounds on the predicted value	39
16	Charpy V-notch impact energy versus test temperature for all tests of beltline and nozzle course welds of the Midland reactor vessel; the solid curve represents the mean hyperbolic tangent curve fit, while the dashed curves represent upper and lower 90% confidence bounds on the predicted value	40
17	Charpy V-notch impact energy versus test temperature for all tests of beltline and nozzle course welds of the Midland reactor vessel; the solid curve represents the mean hyperbolic tangent curve fit, while the dashed curves represent upper and lower 95% confidence bounds on the predicted value	41
18	Charpy V-notch impact energy versus test temperature for all tests of beltline and nozzle course welds of the Midland reactor vessel; the solid curve represents the mean hyperbolic tangent curve fit, while the dashed curves represent upper and lower 99% confidence bounds on the predicted value	42
19	Charpy V-notch impact energy versus test temperature for all tests of beltline and nozzle course welds of the Midland reactor vessel. The solid curve represents the mean hyperbolic tangent curve fit, while the dashed and dotted curves show a comparison of 95% confidence bounds on the mean and on the predicted value	44
20	Charpy V-notch impact energy versus test temperature for tests at the 7/8 thickness location in section 1-11 of the Midland reactor vessel beltline weld. The solid curve represents the mean hyperbolic tangent curve fit, while the dashed curves show a comparison of the 95% confidence bounds on the mean and on the predicted value: (a) shows curves plotted only to 0 J, while (b) shows the symmetric nature of the confidence curves and is shown only for illustrative purposes. The confidence on the mean value for a small data set can be compared with that for the large data set shown in Figure 19	45
21	Charpy V-notch impact energy versus test temperature for all tests of the beltline weld from the Midland reactor vessel; the solid curve represents the mean hyperbolic tangent curve fit, while the dashed curves represent upper and lower 68 and 95% confidence bounds on the predicted value	46
22	Charpy V-notch impact energy versus test temperature for all tests of the nozzle course weld from the Midland reactor vessel; the solid curve represents the mean hyperbolic tangent curve fit, while the dashed curves represent upper and lower 68 and 95% confidence bounds on the predicted value	47

23	Charpy V-notch impact energy versus test temperature for tests at the 1/2 thickness location of the nozzle course weld from the Midland reactor vessel: (a) all data, lower shelf not held fixed; (b) same as in (a) but lower shelf held fixed at 2.7 J; (c) higher energy result at -50°C excluded, lower shelf not held fixed; (d) same as (c) but lower shelf held fixed at 2.7 J; (e) lower energy result at -50°C excluded, lower shelf not held fixed; and (f) same as (e) but lower shelf held fixed at 2.7 J. The large dashed curve represents the mean hyperbolic tangent curve fit, while the small, dashed curves represent upper and lower 95% confidence bounds	48
24	Plots of through-thickness Charpy impact results for the Midland beltline weld sections: (a) 41-J temperature, (b) upper-shelf energy, and (c) RT_{NDT}	64
25	Plots of through-thickness Charpy impact results for the Midland nozzle course weld sections. (a) 41-J temperature, (b) upper-shelf energy, and (c) RT_{NDT}	66
26	Plots of through-thickness copper content for the Midland reactor WF-70 welds: (a) beltline weld sections and (b) nozzle course weld sections	70
27	Plots of through-thickness copper content for a nozzle dropout with WF-70 weld as reported in BAW-1799	72
28	Field-ion micrographs of Midland beltline weld section 1-13 at the various through-thickness regions shown in Figure 7: (a) Region 1, (b) Region 2D, (c) Region 2E, (d) Region 3, and (e) Region 4. Ultrafine, brightly imaging refractory carbides, roughly spherical and approximately 1 nm in diameter, were observed in all five samples but are only evident (indicated by arrows) in the micrographs shown in (c) and (e)	74
29	Comparison of various curve fits to the Charpy impact data from the 7/8 thickness location of Midland beltline weld section 1-11. Shown are the hyperbolic tangent curve fits to all the data and to the minimum data points, a curve constructed as a lower boundary to all the data, and the 68 and 95% confidence bounds on the predicted value	80

Tables

1	Drop-weight test results for Midland beltline weld section 1-9	18
2	Drop-weight test results for Midland beltline weld section 1-11	18
3	Drop-weight test results for Midland beltline weld section 1-13	18
4	Drop-weight test results for Midland beltline weld section 1-15	19
5	Drop-weight test results for Midland nozzle course weld section 3-1	19
6	Drop-weight test results for Midland nozzle course weld section 3-4	19
7	Summary of Charpy impact results for Midland reactor beltline weld section 1-13	30
8	Summary of Charpy impact results for Midland reactor beltline weld section 1-9	33
9	Summary of Charpy impact results for Midland reactor beltline weld section 1-11	34

	Page
10 Summary of Charpy impact results for Midland reactor beltline weld section 1-15	35
11 Summary of Charpy impact results for Midland reactor nozzle course weld section 3-1	36
12 Summary of Charpy impact results for Midland reactor nozzle course weld section 3-4	36
13 Summary of Charpy impact results for Midland Unit 1 reactor vessel beltline weld sections	37
14 Summary of Charpy impact results for Midland Unit 1 reactor vessel nozzle course weld sections	38
15 Comparison of mean hyperbolic tangent curve fits and 95% confidence bounds on predicted value using lower shelf fixed at 2.7 J and unfixed for the combined beltline and nozzle course welds	51
16 Summary of mean hyperbolic tangent curve fits and 68% confidence bounds on predicted value for Charpy energy, RT_{NDT} , and RT_M results for the Midland reactor beltline weld at various through-thickness locations	52
17 Summary of mean hyperbolic tangent curve fits and 95% confidence bounds on predicted value for Charpy energy, RT_{NDT} , and RT_M results for the Midland reactor beltline weld at various through-thickness locations	53
18 Summary of mean hyperbolic tangent curve fits and 68% confidence bounds on predicted value for Charpy energy, RT_{NDT} , and RT_M results of four Midland reactor beltline weld sections	54
19 Summary of mean hyperbolic tangent curve fits and 95% confidence bounds on predicted value for Charpy energy, RT_{NDT} , and RT_M results of four Midland reactor beltline weld sections	55
20 Summary of mean hyperbolic tangent curve fit results and 68% confidence bounds on predicted value for Charpy energy, RT_{NDT} , and RT_M results for the Midland reactor nozzle course weld at various through-thickness locations	56
21 Summary of mean hyperbolic tangent curve fit results and 95% confidence bounds on predicted value for Charpy energy, RT_{NDT} , and RT_M results for the Midland reactor nozzle course weld at various through-thickness locations	57
22 Summary of mean hyperbolic tangent curve fit results and 68% confidence bounds on predicted value for Charpy energy, RT_{NDT} , and RT_M results for two sections of the Midland reactor nozzle course weld	58
23 Summary of mean hyperbolic tangent curve fit results and 95% confidence bounds on predicted value for Charpy energy, RT_{NDT} , and RT_M results for two sections of the Midland reactor nozzle course weld	59
24 Summary of mean hyperbolic tangent curve fits and 95% confidence bounds on predicted value for Charpy energy, RT_{NDT} , and RT_M results for the beltline and nozzle course welds and for the combined data set	60
25 Summary of mean hyperbolic tangent curve fits and various confidence bounds on predicted value for Charpy energy, RT_{NDT} , and RT_M results for the combined beltline and nozzle course welds	62

	Page
26 Comparison of mean hyperbolic tangent curve fits and 95% confidence bounds on predicted value for combined Midland beltline and nozzle course welds (MW) with welds 72W and 73W from HSSI Fifth Irradiation Series	63
27 Chemical composition of Midland reactor weld section 1-13	68
28 Summary of major radiation sensitive elements for Midland Unit 1 reactor vessel welds	69
29 Results of electron microprobe analyses of Midland Unit 1 reactor vessel welds	73
30 Atom probe analysis of the matrix composition for Midland reactor weld section 1-13	77
31 Significances of the mean separation of copper atoms	78

Acknowledgments

The authors express their appreciation to Eric Manneschildt and John Henry for the Charpy and drop-weight testing, and to Tom Hutton for Charpy analysis software development. We also gratefully acknowledge Julia Bishop for manuscript preparation, Shafik Iskander and Bill Corwin for helpful comments in review, Marcia Hodges for preparation of the final report, and Kathy Spence for editing.

We also appreciate the programmatic support from Al Taboada and Ed Hackett, former and current NRC Technical Monitors, respectively, and Bill Corwin, Heavy-Section Steel Irradiation Program Manager.

Previous Reports In Series

The work reported here was performed at Oak Ridge National Laboratory (ORNL) under the Heavy-Section Steel Irradiation (HSSI) Program, W. R. Corwin, Program Manager. The program is sponsored by the Office of Nuclear Regulatory Research of the U.S. Nuclear Regulatory Commission (NRC). The former and current technical monitors for the NRC are A. Taboada and E. M. Hackett, respectively.

This report is designated HSSI Report 6. Reports in this series are listed below:

1. F. M. Haggag, W. R. Corwin, and R. K. Nanstad, Martin Marietta Energy Systems, Inc., Oak Ridge Natl. Lab., Oak Ridge, Tenn., *Irradiation Effects on Strength and Toughness of Three-Wire Series-Arc Stainless Steel Weld Overlay Cladding*, NUREG/CR-5511 (ORNL/TM-11439), February 1990.
2. L. F. Miller, C. A. Baldwin, F. W. Stallman, and F. B. K. Kam, Martin Marietta Energy Systems, Inc., Oak Ridge Natl. Lab., Oak Ridge, Tenn., *Neutron Exposure Parameters for the Metallurgical Test Specimens in the Sixth Heavy-Section Steel Irradiation Series*, NUREG/CR-5409 (ORNL/TM-11267), March 1990.
3. S. K. Iskander, W. R. Corwin, and R. K. Nanstad, Martin Marietta Energy Systems, Inc., Oak Ridge Natl. Lab., Oak Ridge, Tenn., *Results of Crack-Arrest Tests on Two Irradiated High-Copper Welds*, NUREG/CR-5584 (ORNL/TM-11575), December 1990.
4. R. K. Nanstad and R. G. Berggren, Martin Marietta Energy Systems, Inc., Oak Ridge Natl. Lab., *Irradiation Effects on Charpy Impact and Tensile Properties of Low-Upper-Shelf Welds, HSSI Series 2 and 3*, USNRC Report NUREG/CR-5696 (ORNL/TM-11804), August 1991.
5. R. E. Stoller, Martin Marietta Energy Systems, Inc., Oak Ridge Natl. Lab., *Modeling the*

Influence of Irradiation Temperature and Displacement Rate on Radiation-Induced Hardening in Ferritic Steels, USNRC Report NUREG/CR-5859 (ORNL/TM-12073), August 1992.

6. This report.
7. R. K. Nanstad, F. M. Haggag, D. E. McCabe, S. K. Iskander, and K. O. Bowman, *Irradiation Effects on Fracture Toughness of Two High-Copper Submerged-Arc Welds, HSSI Series 5*, USNRC Report NUREG/CR-5913 (ORNL/TM-12156), October 1992.

The HSSI Program includes both follow-on and the direct continuation of work that was performed under the Heavy-Section Steel Technology (HSST) Program. The HSST reports related to irradiation effects in pressure vessel materials and those containing unirradiated properties of materials used in HSSI and HSST irradiation programs are tabulated below as a convenience to the reader.

C. E. Childress, Union Carbide Corp. Nuclear Div., Oak Ridge Natl. Lab., Oak Ridge, Tenn., *Fabrication History of the First Two 12-in.-Thick A-533 Grade B, Class 1 Steel Plates of the Heavy Section Steel Technology Program*, ORNL-4313, February 1969.

T. R. Mager and F. O. Thomas, Westinghouse Electric Corporation, PWR Systems Division, Pittsburgh, Pa., *Evaluation by Linear Elastic Fracture Mechanics of Radiation Damage to Pressure Vessel Steels*, WCAP-7328 (Rev.), October 1969.

P. N. Randall, TRW Systems Group, Redondo Beach, Calif., *Gross Strain Measure of Fracture Toughness of Steels*, HSSTP-TR-3, Nov. 1, 1969.

L. W. Loechel, Martin Marietta Corporation, Denver, Colo., *The Effect of Testing Variables on the Transition Temperature in Steel*, MCR-69-189, November 20, 1969.

W. O. Shabbits, W. H. Pryle, and E. T. Wessel, Westinghouse Electric Corporation, PWR Systems Division, Pittsburgh, Pa., *Heavy-Section Fracture Toughness Properties of A533 Grade B Class 1 Steel Plate and Submerged-Arc Weldment*, WCAP-7414, December 1969.

C. E. Childress, Union Carbide Corp. Nuclear Div., Oak Ridge Natl. Lab., Oak Ridge, Tenn., *Fabrication History of the Third and Fourth ASTM A-533 Steel Plates of the Heavy Section Steel Technology Program*, ORNL-4313-2, February 1970.

P. B. Crosley and E. J. Ripling, Materials Research Laboratory, Inc., Glenwood, Ill., *Crack Arrest Fracture Toughness of A533 Grade B Class 1 Pressure Vessel Steel*, HSSTP-TR-8, March 1970.

F. J. Loss, Naval Research Laboratory, Washington, D.C., *Dynamic Tear Test Investigations of the Fracture Toughness of Thick-Section Steel*, NRL-7056, May 14, 1970.

T. R. Mager, Westinghouse Electric Corporation, PWR Systems Div., Pittsburgh, Pa., *Post-Irradiation Testing of 2T Compact Tension Specimens*, WCAP-7561, August 1970.

F. J. Witt and R. G. Berggren, Union Carbide Corp. Nuclear Div., Oak Ridge Natl. Lab., Oak Ridge, Tenn., *Size Effects and Energy Disposition in Impact Specimen Testing of ASTM A533, Grade B Steel*, ORNL/TM-3030, August 1970.

D. A. Canonico, Union Carbide Corp. Nuclear Div., Oak Ridge Natl. Lab., Oak Ridge, Tenn., *Transition Temperature Considerations for Thick-Wall Nuclear Pressure Vessels*, ORNL/TM-3114, October 1970.

T. R. Mager, Westinghouse Electric Corporation, PWR Systems Div., Pittsburgh, Pa., *Fracture Toughness Characterization Study of A533, Grade B, Class 1 Steel*, WCAP-7578, October 1970.

W. O. Shabbits, Westinghouse Electric Corp., PWR Systems Div., Pittsburgh, Pa., *Dynamic Fracture Toughness Properties of Heavy-Section A533, Grade B, Class 1 Steel Plate*, WCAP-7623, December 1970.

C. E. Childress, Union Carbide Corp. Nuclear Div., Oak Ridge Natl. Lab., Oak Ridge, Tenn., *Fabrication Procedures and Acceptance Data for ASTM A-533 Welds and a 10-in.-Thick ASTM A-543 Plate of the Heavy Section Steel Technology Program*, ORNL-TM-4313-3, January 1971.

D. A. Canonico and R. G. Berggren, Union Carbide Corp. Nuclear Div., Oak Ridge Natl. Lab., Oak Ridge, Tenn., *Tensile and Impact Properties of Thick-Section Plate and Weldments*, ORNL/TM 3211, January 1971.

C. W. Hunter and J. A. Williams, Hanford Eng. Dev. Lab., Richland, Wash., *Fracture and Tensile Behavior of Neutron-Irradiated A533-B Pressure Vessel Steel*, HEDL-TME-71-76, February 6, 1971.

C. E. Childress, Union Carbide Corp. Nuclear Div., Oak Ridge Natl. Lab., Oak Ridge, Tenn., *Manual for ASTM A533, Grade B, Class 1 Steel (HSST Plate 03) Provided to the International Atomic Energy Agency*, ORNL/TM-3193, March 1971.

P. N. Randall, TRW Systems Group, Redondo Beach, Calif., *Gross Strain Crack Tolerance of A533-B Steel*, HSSTP-TR-14, May 1, 1971.

C. L. Segaser, Union Carbide Corp. Nuclear Div., Oak Ridge Natl. Lab., Oak Ridge, Tenn., *Feasibility Study, Irradiation of Heavy-Section Steel Specimens in the South Test Facility of the Oak Ridge Research Reactor*, ORNL/TM-3234, May 1971.

H. T. Corten and R. H. Sailors, University of Illinois, Urbana, Ill., *Relationship Between Material Fracture Toughness Using Fracture Mechanics and Transition Temperature Tests*, T&AM Report 346, August 1, 1971.

L. A. James and J. A. Williams, Hanford Eng. Dev. Lab., Richland, Wash., *Heavy Section Steel Technology Program Technical Report No. 21, The Effect of Temperature and Neutron Irradiation Upon the Fatigue-Crack Propagation Behavior of ASTM A533 Grade B, Class 1 Steel*, HEDL-TME 72-132, September 1972.

P. B. Crosley and E. J. Ripling, Materials Research Laboratory, Inc., Glenwood, Ill., *Crack Arrest in an Increasing K-Field*, HSSTP-TR-27, January 1973.

W. J. Stelzman and R. G. Berggren, Union Carbide Corp. Nuclear Div., Oak Ridge Natl. Lab., Oak Ridge, Tenn., *Radiation Strengthening and Embrittlement in Heavy-Section Steel Plates and Welds*, ORNL-4871, June 1973.

J. M. Steichen and J. A. Williams, Hanford Eng. Dev. Lab., Richland, Wash., *High Strain Rate Tensile Properties of Irradiated ASTM A533 Grade B Class 1 Pressure Vessel Steel*, HEDL-TME 73-74, July 1973.

J. A. Williams, Hanford Eng. Dev. Lab., Richland, Wash., *The Irradiation and Temperature Dependence of Tensile and Fracture Properties of ASTM A533, Grade B, Class 1 Steel Plate and Weldment*, HEDL-TME 73-75, August 1973.

J. A. Williams, Hanford Eng. Dev. Lab., Richland, Wash., *Some Comments Related to the Effect of Rate on the Fracture Toughness of Irradiated ASTM A553-B Steel Based on Yield Strength Behavior*, HEDL-SA 797, December 1974.

J. A. Williams, Hanford Eng. Dev. Lab., Richland, Wash., *The Irradiated Fracture Toughness of ASTM A533, Grade B, Class 1 Steel Measured with a Four-Inch-Thick Compact Tension Specimen*, HEDL-TME 75-10, January 1975.

J. G. Merkle, G. D. Whitman, and R. H. Bryan, Union Carbide Corp. Nuclear Div., Oak Ridge Natl. Lab., Oak Ridge, Tenn., *An Evaluation of the HSST Program Intermediate Pressure Vessel Tests in Terms of Light-Water-Reactor Pressure Vessel Safety*, ORNL/TM-5090, November 1975.

J. A. Davidson, L. J. Ceschini, R. P. Shogan, and G. V. Rao, Westinghouse Electric Corporation, Pittsburgh, Pa., *The Irradiated Dynamic Fracture Toughness of ASTM A533, Grade B, Class 1 Steel Plate and Submerged Arc Weldment*, WCAP-8775, October 1976.

J. A. Williams, Hanford Eng. Dev. Lab., Richland, Wash., *Tensile Properties of Irradiated and Unirradiated Welds of A533 Steel Plate and A508 Forgings*, NUREG/CR-1158 (ORNL/SUB-79/50917/2), July 1979.

J. A. Williams, Hanford Eng. Dev. Lab., Richland, Wash., *The Ductile Fracture Toughness of Heavy Section Steel Plate*, NUREG/CR-0859, September 1979.

K. W. Carlson and J. A. Williams, Hanford Eng. Dev. Lab., Richland, Wash., *The Effect of Crack Length and Side Grooves on the Ductile Fracture Toughness Properties of ASTM A533 Steel*, NUREG/CR-1171 (ORNL/SUB-79/50917/3), October 1979.

G. A. Clarke, Westinghouse Electric Corp., Pittsburgh, Pa., *An Evaluation of the Unloading Compliance Procedure for J-Integral Testing in the Hot Cell*, Final Report, NUREG/CR-1070 (ORNL/Sub-7394/1), October 1979.

P. B. Crosley and E. J. Ripling, Materials Research Laboratory, Inc., Glenwood, Ill., *Development of a Standard Test for Measuring K_{Ia} with a Modified Compact Specimen*, NUREG/CR-2294 (ORNL/SUB-81/7755/1), August 1981.

H. A. Domian, Babcock and Wilcox Company, Alliance, Ohio, *Vessel V-8 Repair and Preparation of Low-Upper-Shelf Weldment*, NUREG/CR-2676 (ORNL/Sub/81-85813/1), June 1982.

R. D. Cheverton, S. K. Iskander, and D. G. Ball, Union Carbide Corp. Nuclear Div., Oak Ridge Natl. Lab., Oak Ridge, Tenn., *PWR Pressure Vessel Integrity During Overcooling Accidents: A Parametric Analysis*, NUREG/CR-2895 (ORNL/TM-7931), February 1983.

J. G. Merkle, Union Carbide Corp. Nuclear Div., Oak Ridge Natl. Lab., Oak Ridge, Tenn., *An Examination of the Size Effects and Data Scatter Observed in Small Specimen Cleavage Fracture Toughness Testing*, NUREG/CR-3672 (ORNL/TM-9088), April 1984.

W. R. Corwin, Martin Marietta Energy Systems, Inc., Oak Ridge Natl. Lab., Oak Ridge, Tenn., *Assessment of Radiation Effects Relating to Reactor Pressure Vessel Cladding*, NUREG/CR-3671 (ORNL-6047), July 1984.

W. R. Corwin, R. G. Berggren, and R. K. Nanstad, Martin Marietta Energy Systems, Inc., Oak Ridge Natl. Lab., Oak Ridge, Tenn., *Charpy Toughness and Tensile Properties of a Neutron Irradiated Stainless Steel Submerged-Arc Weld Cladding Overlay*, NUREG/CR-3927 (ORNL/TM-9709), September 1984.

J. J. McGowan, Martin Marietta Energy Systems, Inc., Oak Ridge Natl. Lab., Oak Ridge, Tenn., *Tensile Properties of Irradiated Nuclear-Grade Pressure Vessel Plate and Welds for the Fourth HSST Irradiation Series*, NUREG/CR-3978 (ORNL/TM-9516), January 1985.

J. J. McGowan, Martin Marietta Energy Systems, Inc., Oak Ridge Natl. Lab., Oak Ridge, Tenn., *Tensile Properties of Irradiated Nuclear-Grade*

Pressure Vessel Welds for the Third HSST Irradiation Series, NUREG/CR-4086 (ORNL/TM 9477), March 1985.

W. R. Corwin, G. C. Robinson, R. K. Nanstad, J. G. Merkle, R. G. Berggren, G. M. Goodwin, R. L. Swain, and T. D. Owings, Martin Marietta Energy Systems, Inc., Oak Ridge Natl. Lab., Oak Ridge, Tenn., *Effects of Stainless Steel Weld Overlay Cladding on the Structural Integrity of Flawed Steel Plates in Bending, Series 1*, NUREG/CR-4015 (ORNL/TM-9390), April 1985.

W. J. Stelzman, R. G. Berggren, and T. N. Jones, Martin Marietta Energy Systems, Inc., Oak Ridge Natl. Lab., Oak Ridge, Tenn., *ORNL Characterization of Heavy-Section Steel Technology Program Plates 01, 02, and 03*, NUREG/CR-4092 (ORNL/TM-9491), April 1985.

G. D. Whitman, Martin Marietta Energy Systems, Inc., Oak Ridge Natl. Lab., Oak Ridge, Tenn., *Historical Summary of the Heavy-Section Steel Technology Program and Some Related Activities in Light-Water Reactor Pressure Vessel Safety Research*, NUREG/CR-4489 (ORNL-6259), March 1986.

R. H. Bryan, B. R. Bass, S. E. Bolt, J. W. Bryson, J. G. Merkle, R. K. Nanstad, and G. C. Robinson, Martin Marietta Energy Systems, Inc., Oak Ridge Natl. Lab., Oak Ridge, Tenn., *Test of 6-in.-Thick Pressure Vessels. Series 3: Intermediate Test Vessel V-8A — Tearing Behavior of Low Upper-Shelf Material*, NUREG-CR-4760 (ORNL-6187), May 1987.

D. B. Barker, R. Chona, W. L. Fournay, and G. R. Irwin, University of Maryland, College Park, Md., *A Report on the Round Robin Program Conducted to Evaluate the Proposed ASTM Standard Test Method for Determining the*

Plane Strain Crack Arrest Fracture Toughness K_{Ia} of Ferritic Materials, NUREG/CR-4966 (ORNL/Sub/79-7778/4), January 1988.

L. F. Miller, C. A. Baldwin, F. W. Stallman, and F. B. K. Kam, Martin Marietta Energy Systems, Inc., Oak Ridge Natl. Lab., Oak Ridge, Tenn., *Neutron Exposure Parameters for the Metallurgical Test Specimens in the Fifth Heavy-Section Steel Technology Irradiation Series Capsules*, NUREG/CR-5019 (ORNL/TM-10582), March 1988.

J. J. McGowan, R. K. Nanstad, and K. R. Thoms, Martin Marietta Energy Systems, Inc., Oak Ridge Natl. Lab., Oak Ridge, Tenn., *Characterization of Irradiated Current-Practice Welds and A533 Grade B, Class 1 Plate for Nuclear Pressure Vessel Service*, NUREG/CR-4880 (ORNL-6484/V1 and V2), July 1988.

R. D. Cheverton, W. E. Pennell, G. C. Robinson, and R. K. Nanstad, Martin Marietta Energy Systems, Inc., Oak Ridge Natl. Lab., Oak Ridge, Tenn., *Impact of Radiation Embrittlement on Integrity of Pressure Vessel Supports for Two PWR Plants*, NUREG/CR-5320 (ORNL/TM-10966), February 1989.

J. G. Merkle, Martin Marietta Energy Systems, Inc., Oak Ridge Natl. Lab., Oak Ridge, Tenn., *An Overview of the Low-Upper-Shelf Toughness Safety Margin Issue*, NUREG/CR-5552 (ORNL/TM-11314), August 1990.

R. D. Cheverton, T. L. Dickson, J. G. Merkle, R. K. Nanstad, Martin Marietta Energy Systems, Inc., Oak Ridge Natl. Lab., Oak Ridge, Tenn., *Review of Reactor Pressure Vessel Evaluation Report for Yankee Rowe Nuclear Power Station (YAEC No. 1735)*, NUREG/CR-5799 (ORNL/TM-11982), March 1992.

Chemical Composition and RT_{NDT} Determinations For Midland Weld WF-70*

R. K. Nanstad, D. E. McCabe, R. L. Swain, and M. K. Miller

Introduction

The primary objective of the Heavy-Section Steel Irradiation (HSSI) Program Tenth Irradiation Series is to investigate the postirradiation fracture toughness of the submerged-arc weld from the Midland Unit 1 reactor vessel. The reactor is a pressurized-water reactor owned by Consumers Power Company and was canceled prior to startup. The weld from that vessel is of considerable interest because it carries the Babcock and Wilcox Co. (B&W) designation WF-70, a submerged-arc weld fabricated with a specific heat of weld wire (heat 72105) and specific lot of flux (lot 8669). Welds with the WF-70 designation are contained in the beltline region of at least six operating nuclear reactor vessels and are the limiting materials (regarding irradiation effects) in at least two of those vessels.¹ The WF-70 weld was fabricated using copper-coated wire and Linde 80 flux and is known to be a low-upper-shelf (LUS), high-copper weld. The fact that this particular weld exists in numerous operating reactors is the primary motivation for this irradiation series. An important supporting objective is the determination of copper variation throughout the welds. Another specific supporting objective is a complete unirradiated characterization to include determination of the RT_{NDT} and the Charpy V-Notch (CVN) upper-shelf energy. As will be shown, even though they are designated WF-70, the beltline weld and the WF-70 portion of the nozzle course weld have distinctly different copper contents, which will require the irradiation program to consider the welds as two different materials.

For surveillance purposes, the Power Reactor Embrittlement Data Base (PR-EDB)² gives the carbon content for the WF-70 weld in Midland Unit 1 as 0.42 wt %. For licensing purposes, the copper content for WF-70 is given as 0.35 wt % in BAW-1799 (ref. 3). No value of RT_{NDT} is given in the PR-EDB. However, Lowe⁴ provided three different values of RT_{NDT} for three different WF-70 weldments, 14, 23, and 51°C (58, 74, and 123°F, respectively). In Part 50 of Title 10, *Code of Federal Regulations* (10CFR50) [ref. 5], it states that measured values of RT_{NDT} must be used if credible values are available; if not, a generic mean value of 0°F (-18°C) must be used for welds made with Linde 80 flux.

This report presents the results of Charpy impact and drop-weight tests, RT_{NDT} determinations, and chemical composition analyses for the beltline and nozzle course welds of the Midland Unit 1 reactor vessel. Evaluations of the chemical composition, CVN impact behavior, and RT_{NDT} were selected for the initial testing phase not only because they are important to the overall evaluation of this weld but also to provide information crucial to the conduct of the irradiation program. Other mechanical properties, fracture toughness, and irradiation effects on all those properties will be reported separately.

Description of Weldments

The first beltline section, 1.17 m long (46 in.), of weldment received at Oak Ridge National Laboratory (ORNL) was designated 1-13 according to the section removal plan detailed by B&W in BAW-2070 (ref. 6). In addition to 1-13, beltline sections 1-9, 1-11, and 1-15 were received. The thickness of the beltline weld is about 216 mm (8.5 in.). Figure 1 is a schematic diagram from that document showing the sectioning plan for the vessel. Initial examination of section 1-13 revealed

*Research sponsored by the Office of Nuclear Regulatory Commission, under Interagency Agreement DOE 1886-8109-8L with the U.S. Department of Energy under contract DE-AC05-84OR21400 with Martin Marietta Energy Systems, Inc.

NUREG/CR-5914

2

Figure 1. Schematic diagram of Midland Unit 1 reactor vessel showing plan for sectioning beltline and nozzle course welds.
Source: The Babcock & Wilcox Company, Lynchburg, Virginia.

(b)

* SUPPORT LOCATION SPACED APPROX. 5'-7" APART. (SEE DETAIL A FOR ASSEMBLY)

- ① SUPPORT SPACER (4" THICK)
 - ② SUPPORT SPACER (1" THICK)
 - ③ SUPPORT SPACER (1/2" THICK)
- MATERIAL: A36

DETAIL A
TYPICAL SUPPORT ASSEMBLY

Figure 1. cont.

an anomalous weld macrostructure which indicated a repair weld. The BAW-2070 report stated that:

"When fit-up of P/N 165 to P/N 166 shells occurred, a mismatch existed between the 3/16" noses of the weld grooves and MMA weld build-up repair was made to the offset areas on the inside of the weld prep, at the nose, to provide a flush surface for subsequent circle seam automatic sub-arc welding. MMA electrodes from Lot #818-026343 were used for the repair."

Presumably, that information was gleaned from the original fabrication records for the vessel. A series of photomicrographs is shown in Figures 2 through 5, representing cross-sectional views separated by about 69.8 mm (2.75 in.). Thus, in section 1-13, the repair weld extends only about 150 mm (6 in.) or so. Figure 2 was taken at one end of the section, and the extent of the repair into the adjoining section (not included in the portion of the weldment received by ORNL) is not yet known. Figure 6 shows a typical micrograph of the repair weld. Figure 7 shows a macrograph of the submerged-arc weld WF-70 with regions designated 1 through 4 from which specimens were removed for optical microscopy, chemical analysis, Charpy impact tests, and drop-weight tests. Figures 8(a) through (e) show typical microstructures through the thickness of the submerged-arc beltline weld. The weld metal is largely acicular ferrite but with highly decorated grain boundaries and a high inclusion content.

From the nozzle course weld, sections 3-1 and 3-4 were received and examined. The thickness of the nozzle course is about 305 mm (12 in.). Figure 9 is a macrograph from section 3-1 and shows that weld WF-70 comprises that portion of the weld from approximately midthickness to the outer surface of the vessel; B&W weld WF-67 comprises approximately the other half of the weld thickness. Figures 10(a) through (c) show typical microstructures, similar to the beltline weld, through the thickness of weld WF-70 in the nozzle course weld section 3-1. The report BAW-2070 states that the Midland beltline weld received 22 h and 36 min at $1125 \pm 25^\circ\text{F}$ ($607 \pm 14^\circ\text{C}$) as a postweld heat treatment, while the nozzle course weld received 25 h and 31 min at the same temperature. That report also provides the B&W "Record of Filler Wire

Qualification Test," which shows the qualification weld was postweld heat treated at 1100 to 1150°F (593 to 621°C) for 48 h (see Appendix A). The room-temperature tensile test results of the qualification weld give room-temperature yield strength as 69.0 ksi (475 MPa) and ultimate strength as 85.5 ksi (589 MPa). Preliminary results from tensile tests and automated ball indentation⁷ tests of the Midland welds indicate room-temperature yield strengths of about 545 MPa (79 ksi) for the nozzle course weld. The automated ball indentation tests of the beltline weld gave about 450 MPa (65 ksi) for the beltline weld yield strength. These results will be confirmed during the course of unirradiated tensile tests yet to be conducted.

Drop-Weight Tests

Figure 7 shows the locations through the thickness of beltline section 1-13 (in a region of the weldment with no repair weld) where material was removed for machining of Charpy and drop-weight specimens in the TL orientation. The intent was that one set of drop-weight specimens would be used for RT_{NDT} determinations for locations 1 and 2 (about 1/4t), while the second set would apply to locations 3 and 4 (about 3/4t). Similar removal plans were used for the other three beltline sections and the WF-70 portion of the nozzle course weld. Type P-3 drop-weight specimens were fabricated using a single-weld pass and tested according to American Society for Testing and Materials (ASTM) E 208-87, *Standard Test Method for Conducting Drop-Weight Test to Determine Nil-Ductility Transition Temperature of Ferritic Steels*.⁸ Tables 1 through 6 give the drop-weight results for all six sections. The nil-ductility transition (NDT) temperatures range from -60 to -45°C (-76 to -49°F) in the beltline weld and from -55 to -40°C (-67 to -40°F) in the nozzle course weld. No clear pattern is evident regarding consistency of NDT temperatures with position in the weld thickness.

CVN Impact Tests

CVN impact tests were conducted at various temperatures to obtain a full curve of absorbed energy and lateral expansion versus test

YP8886

Figure 2. Macrograph at end of Midland beltline weld section 1-13 shows large amount of manual metal-arc weld repair from clad surface of vessel.

YP8661

Figure 3. Macrograph of Midland beltline weld section 1-13 about 70 mm (~2.75 in.) from macrograph shown in Figure 2.

YP8663

Figure 4. Macrograph of Midland beltline weld section 1-13 about 140 mm (~5.50 in.) from macrograph shown in Figure 2.

YP8664

Figure 5. Macrograph of Midland beltline weld section 1-13 about 210 mm (~8.25 in.) from macrograph shown in Figure 2.

Y218150

(a)

Y218151

(b)

Figure 6.

Typical macrostructures and microstructures of the manual metal-arc repair weld in Midland beltline weld section 1-13: (a) low magnification showing individual weld passes and regions with coarse solidification structure, (b) somewhat higher magnification showing mixture of coarse and fine structure, (c) higher magnification showing region of fine microstructure, and (d) same magnification as (c), showing region of coarse microstructure.

Y218152

Y218154

Figure 6. contd.

Figure 7. Macrograph showing locations through the thickness of Midland beltline weld section 1-13 from which microscopy, chemistry, Charpy impact, and drop-weight specimens were machined.

(a)

91-0464-1

(b)

Figure 8. Typical microstructures through the thickness (from the inside surface) of the submerged-arc weld WF-70 in the beltline region (see Figure 7): (a) 1/4 thickness (region 1), (b) 1/2 thickness (region 2D), (c) 1/2 thickness (region 2E), (d) 5/8 thickness (region 3), and (e) 3/4 thickness (region 4).

91-0465-1

(c)

91-0466-1

(d)

Figure 8. contd.

(e)

Figure 8. contd.

Figure 9. Macrograph of Midland nozzle course weld section 3-1; weld WF-67 comprises approximately the inner half of the weld thickness, while WF-70 comprises approximately the outer half.

(a)

80 μm

250X

(b)

80 μm

250X

Figure 10. Typical microstructures through the thickness (from the root of the weld joining WF-67 and WF-70) of the submerged-arc weld WF-70 in the nozzle course region (see Figure 9):
(a) 1/2 thickness, (b) 3/4 thickness, and (c) 7/8 thickness.

(c)

Figure 10. contd.

Table 1. Drop-weight test results for
Midland beltline weld section 1-9

Location	Test temperature ^a (°C)						NDT (°C)
	-60	-55	-50	-45	-40	-35	
1/4t	X,X	O,O	O	-	-	-	-60
3/4t	-	-	X	O,O	O	-	-50

^aX = break, O = no break.

Table 2. Drop-weight test results for
Midland beltline weld section 1-11

Location	Test temperature ^a (°C)						NDT (°C)
	-60	-55	-50	-45	-40	-35	
1/4t	X	O,O	-	-	-	-	-60
3/4t	-	X	X,O	O,O	-	-	-50

^aX = break, O = no break.

Table 3. Drop-weight test results for
Midland beltline weld section 1-13

Location	Test temperature ^a (°C)						NDT (°C)
	-60	-55	-50	-45	-40	-35	
1/4t	X	O,O	O	-	O	-	-60
3/4t	X	X	X	O,X	O,O	-	-45

^aX = break, O = no break.

Table 4. Drop-weight test results for
Midland beltline weld section 1-15

Location	Test temperature ^a (°C)						NDT (°C)
	-60	-55	-50	-45	-40	-35	
1/4t	X	X	X	X	O,O	-	-45
3/4t	X	X	O,O	O	-	-	-55

^aX = break, O = no break.

Table 5. Drop-weight test results for Midland
nozzle course weld section 3-1

Location	Test temperature ^a (°C)						NDT (°C)
	-60	-55	-50	-45	-40	-35	
3/4t	X	-	X	X	X,O	O,O	-40
7/8t	X	X	X	X,O	O,O	-	-45

^aX = break, O = no break.

Table 6. Drop-weight test results for Midland
nozzle course weld section 3-4

Location	Test temperature ^a (°C)						NDT (°C)
	-60	-55	-50	-45	-40	-35	
3/4t	-	X	X,O	O,O	-	-	-50
7/8t	X	X	O,O	-	-	-	-55

^aX = break, O = no break.

temperature. Tests were conducted in general accordance with ASTM E 23-91, *Standard Test Methods for Notched Bar Impact Testing of Metallic Materials*, and ASTM E 184-79, *Standard Practice for Effects of High-Energy Neutron Irradiation on the Mechanical Properties of Metallic Materials, E 706 (IB)*.^{9,10} The primary emphases are on determination of the RT_{NDT} and the upper-shelf energy. Additionally, fracture appearance was determined for all specimens. All specimens were machined with the TL orientation (specimen major axis across the weld and crack propagation in the direction of welding). Initial CVN tests were conducted after the NDT temperatures had been determined so that tests could be performed at $NDT + 60^{\circ}F$ ($33^{\circ}C$) as required by the ASME Code Section III (ref. 11) for determination of the RT_{NDT} . In all cases examined, tests at $NDT + 60^{\circ}F$ ($33^{\circ}C$) did not meet the minimum requirements for the RT_{NDT} to equal the NDT. Thus, the RT_{NDT} is higher than the NDT in every case and, for this material, is controlled by the CVN behavior.

CVN Test Results

Figures 11(a) through (f) show plots of the absorbed energy versus test temperature for the four regions shown in Figure 7. At region 2, it was apparent from the data that specimens from the two layers of that region gave consistently different results; thus, the data have been shown as a combined set for region 2 as well as for the two layers designated D and E. The curves represent mean hyperbolic tangent fits to each data set. Figures 12(a) through (f) and 13(a) through (f) show similar series of plots for lateral expansion and fracture appearance, respectively. The scatter in data is considered typical.

Using the mean hyperbolic tangent curve fits, various transition temperatures and upper-shelf energies were determined for each region tested in section 1-13. Table 7 provides a summary of transition temperatures and upper-shelf energies as well as RT_{NDT} s. The upper-shelf energies vary from 90 to 108 J (66 to 80 ft-lb). In paragraph NB 2331, Section III, the ASME Code states:

"When a C_v test has not been performed at $T_{NDT} + 60^{\circ}F$, or when the C_v test at $T_{NDT} + 60^{\circ}F$ does not exhibit a minimum of 50 ft-lb and 35 mils lateral expansion, a

temperature representing a minimum of 50 ft-lb and 35 mils lateral expansion may be obtained from a full C_v impact curve developed from the minimum data points of all the C_v tests performed."

In every case, the 50-ft-lb (68-J) temperature was higher than the 0.035-in. (0.89-mm) lateral expansion temperature; thus, the 50-ft-lb (68-J) temperature controlled the determination of the RT_{NDT} . The precise procedure intended by the code is not clear. The paragraph does not say to develop a curve which bounds all the data obtained, but it does say to develop a full C_v impact curve, presumably meaning one from brittle to ductile fracture. This will be discussed in more detail later. For this study, a procedure was adopted in which values of RT_{NDT} were determined by identifying the data points with the lowest energy value at each test temperature and fitting a hyperbolic tangent curve to those minimum data. The 50-ft-lb (68-J) temperature was determined from that curve, and the RT_{NDT} was then calculated by subtracting $60^{\circ}F$ ($33^{\circ}C$) from the 50-ft-lb (68-J) temperature. For comparison, RT_M values (similar to RT_{NDT} but not determined from the minimum data curve according to ASME Code) were determined by subtracting $60^{\circ}F$ ($33^{\circ}C$) from the 50-ft-lb (68-J) temperature defined by the mean hyperbolic tangent curve fit. Also, for comparison, absolute lower-bound curves were manually constructed to each individual data set and "lower-bound" reference temperatures (RT_{LB}) were determined in the same manner used for the RT_{NDT} and RT_M .

Figure 14 shows an example of these procedures applied to the tests of section 1-13 at the 1/2t location (confidence bounds will be discussed later). The reference temperature analysis appears at the bottom of the figure and shows that the RT_{NDT} is about $7^{\circ}C$ ($12^{\circ}F$) higher than the RT_M . The RT_{LB} is about $15^{\circ}C$ ($27^{\circ}F$) higher than the RT_{NDT} . For beltline weld section 1-13, the RT_{NDT} s vary from $-31^{\circ}C$ to $20^{\circ}C$ (-24 to $68^{\circ}F$) using the minimum data curve fits [the $-31^{\circ}C$ value is from the "D" position at the 1/2t location, while the combined curve for the 1/2t location shows an RT_{NDT} value of $2^{\circ}C$ ($36^{\circ}F$)]. That compares to the drop-weight NDT temperatures of -45 and $-60^{\circ}C$ (-49 and $-67^{\circ}F$). Except for region 2 (combines 2D and 2E) at the 1/2t location, the 41-J (30-ft-lb) temperatures agree with the RT_{NDT} s within $10^{\circ}C$.

Figure 11. Charpy V-notch impact energy versus test temperature for specimens machined from the various regions through the thickness of the Midland weld section 1-13 shown in Figure 7: (a) Region 1, (b) Region 2 (2D and 2E combined), (c) Region 2D, (d) Region 2E, (e) Region 3, and (f) Region 4.

Figure 11. contd.

(e)

(f)

Figure 11. contd.

Figure 12. Charpy V-notch lateral expansion versus test temperature for specimens machined from the various regions through the thickness of the Midland beltline weld section 1-13 shown in Figure 7: (a) Region 1, (b) Region 2 (2D and 2E combined), (c) Region 2D, (d) Region 2E, (e) Region 3, and (f) Region 4.

Figure 12 contd.

Figure 12. contd.

(a)

(b)

Figure 13. Charpy V-notch percent shear fracture versus test temperature for specimens machined from the various regions through the thickness of the Midland beltline weld section 1-13 shown in Figure 7: (a) Region 1, (b) Region 2 (2D and 2E combined), (c) Region 2D, (d) Region 2E, (e) Region 3, and (f) Region 4.

(c)

(d)

Figure 13. contd.

(e)

(f)

Figure 13. contd.

Table 7. Summary of Charpy impact results for Midland reactor beltline weld section 1-13

Location	Charpy Transition Temperature °C (°F)						USE J (ft-lb)	RT _M ^a °C (°F)	RT _{NDT} ^b °C (°F)	RT _{LB} ^c °C (°F)
	Energy J (ft-lb)			Expansion mm (in)		Shear				
	27 (20)	41 (30)	68 (50)	.38 (.015)	.89 (.035)	50%				
1/4 t	-30 (-22)	-11 (12)	21 (69)	-40 (-39)	2 (36)	-9 (15)	101 (75)	-13 (9)	-10 (15)	-11 (12)
1/2 t	-43 (-45)	-16 (4)	29 (84)	-48 (-54)	7 (45)	12 (54)	104 (77)	-5 (24)	2 (36)	17 (63)
1/2t "D"	-41 (-42)	-25 (-12)	3 (37)	-45 (-49)	-9 (15)	4 (40)	104 (77)	-31 (-23)	-31 (-23)	-28 (-18)
1/2t "E"	-23 (-10)	2 (36)	47 (116)	-24 (-11)	24 (75)	19 (66)	98 (72)	13 (55)	20 (68)	15 (59)
5/8 t	-41 (-42)	-22 (-7)	9 (48)	-64 (-83)	-13 (8)	-4 (24)	108 (80)	-25 (-12)	-20 (-3)	-16 (3)
3/4 t	-23 (-10)	-3 (28)	37 (98)	-39 (-37)	9 (48)	2 (36)	90 (66)	3 (38)	6 (43)	12 (54)

NOTE: All temperatures have been rounded to the nearest degree

- ^a Determined from T₅₀ - 60°F (T₆₈ -33°C) using average curve fit, where T₅₀ is the temperature corresponding to 50 ft-lb.
^b Determined from T₅₀ - 60°F (T₆₈ -33°C) using minimum curve fit, where T₅₀ is the temperature corresponding to 50 ft-lb.
^c Determined from T₅₀ - 60°F (T₆₈ -33°C) using lower bound curve, where T₅₀ is the temperature corresponding to 50 ft-lb.

ANALYSIS SETS: MW13_12TD AND MW13_12TE

MODEL PARAMETERS

LOWER SHELF ENERGY [HELD FIXED]: 2.7 (J), 2 (FT-LB)

MID-TRANSITION TEMPERATURE: 4.7 (DEG C), 40.4 (DEG F)

TRANSITION ZONE WIDTH: 164.5 (C DEG), 296.2 (F DEG)

UPPER SHELF ENERGY: 104 (J), 76.7 (FT-LB)

STANDARD MODEL: $ENERGY = A + B \cdot \tanh((TEMPERATURE - T_0) / C)$

A: 53.3 (J), 39.3 (FT-LB)

B: 50.6 (J), 37.4 (FT-LB)

T₀: 4.7 (DEG C), 40.4 (DEG F)

C: 82.3 (C DEG), 148.1 (F DEG)

UPPER SHELF ENERGY: 104 (J), 76.7 (FT-LB)

TEMPERATURE [27 (J), 19.9 (FT-LB) ENERGY]: -42.8 (DEG C), -45 (DEG F)

TEMPERATURE [41 (J), 30.2 (FT-LB) ENERGY]: -15.8 (DEG C), 3.5 (DEG F)

TEMPERATURE [68 (J), 50.2 (FT-LB) ENERGY]: 29.1 (DEG C), 84.5 (DEG F)

REFERENCE TEMPERATURE ANALYSIS

MEAN IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY]-60 (DEG F): -4.5 (DEG C), 23.8 (DEG F)

MINIMUM IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY]-60 (DEG F): 2.2 (DEG C), 35.9 (DEG F)

REMARK: MIDLAND WELD 13, WF70 WELD IN A533B FROM 1/2 THICKNESS

Figure 14. Charpy V-notch impact energy versus test temperature for specimens from the 1/2 thickness location in Midland beltline weld section 1-13. The solid curve represents the mean hyperbolic tangent curve fit to all the data, while the dashed curve represents a similar fit using the minimum datum at each test temperature. The third curve represents a lower-bound curve to all the data. The reference temperature analysis is given at the bottom of the figure.

(18°F). As seen in the table, the RT_M values are lower in most cases and range from -31 to 13°C (-24 to 55°F), which is 0 to 7°C (0 to 13°F) lower than the RT_{NDT} values. For comparison, the RT_{LB} values range from about -28 to 17°C (-18 to 63°F). The difference between these values will depend, of course, on the number of tests and the scatter exhibited by each data set, and this will also be discussed later.

Tables 8 through 10 provide similar information for beltline weld sections 1-9, -11, and -15, respectively. Note that the cutting plans for those three sections included specimens removed from the 7/8 depth location. For the nozzle course weld sections, specimens were removed from the 1/2, 3/4, and 7/8 depth locations, and Tables 11 and 12 provide similar information for nozzle course weld sections 3-1 and -4, respectively. The amount of material available from the nozzle course weld was limited; thus, fewer tests were conducted for that weld than for the beltline weld. Tables 13 and 14 provide overall summaries of the Charpy energy, NDT, RT_{NDT} , RT_M , and RT_{LB} results for the beltline and nozzle course sections, respectively. For all the various locations through the thickness of the beltline weld, the RT_{NDT} values range from -20 to 37°C (-3 to 99°F), while the RT_M values range from -25 to 24°C (-12 to 76°F) and the RT_{LB} values range from -21 to 35°C (-6 to 95°F). For all the individual CVN curves obtained from the nozzle course weld, the RT_{NDT} and RT_M values range from -8 to 18°C (18 to 65°F), while the RT_{LB} values range from -6 to 29°C (21 to 84°F). The maximum difference between RT_M and RT_{NDT} for any one case is 22°C (40°F). A comparison of RT_{NDT} and RT_{LB} values shows that RT_{LB} is 21°C (38°F) greater than RT_{NDT} in one case and 8°C (14°F) less than RT_{NDT} in another case.

Appendix B provides tables of all the raw Charpy results for energy, lateral expansion, and shear fracture versus temperature for the individual data sets. Appendix D provides plots of each of those measurements versus temperature. Each plot includes the appropriate curve-fit coefficients, transition temperatures, and upper-shelf values as well as confidence bounds (discussed in the next section). The 41-J temperatures ranged from -22 to 14°C (-7 to 57°F) for the four beltline sections and from -11 to 5°C (13 to 42°F) for the two nozzle course sections. The upper-shelf energies ranged from 77 to 108 J (57 to 80 ft-lb) for the beltline sections and from 85 to 90 J (63 to

66 ft-lb) for the nozzle course sections. Thus, for both the transition temperatures and upper-shelf energies, the nozzle course weld results fall within the scatter bands exhibited by the beltline welds. Plots of all the various combined data sets with mean curve fits and confidence bounds are given in Appendix E. A mean hyperbolic tangent fit to the entire combined data set reveals 41- and 68-J temperatures of about -8°C (17°F) and 31°C (87°F), respectively. Similarly, the mean 0.89-mm (0.035-in.) lateral expansion temperature is about 5°C (41°F). The mean lateral expansion at the 68-J (30 ft-lb) temperature is about 1.2 mm (0.043 in.), which supports the earlier observation that the absorbed energy results controlled the RT_{NDT} determinations for this material. At the average NDT temperature of -50°C (-58°F), the mean energy is about 16 J (12 ft-lb), while the mean lateral expansion is about 0.31 mm (0.012 in.).

Statistical Analyses of CVN Test Results

The Charpy impact results were also statistically analyzed to determine confidence intervals for the individual data sets and for combined data sets, including each section, each thickness location, all beltline tests, all nozzle course tests, and all tests. The confidence interval on the mean represents the confidence that the true mean value of energy at a given temperature lies between the bounds. The confidence interval on the predicted value represents the confidence that another observation will lie between the bounds. The hyperbolic tangent curve fit and confidence bounds were determined using nonlinear regression analysis. Figures 15 through 18 are plots of Charpy impact energy versus test temperature for all the tests performed (279 individual Charpy impact tests) and show the mean hyperbolic tangent curve fits with 68, 90, 95, and 99% upper and lower confidence bounds on the predicted values, respectively. The 68 and 95% confidence bounds represent approximately 1 and 2 standard deviations on energy, respectively. The figures also give the temperature intervals in the transition region corresponding to various energy levels and the energy bounds for the upper-shelf energy. As shown, the mean 41-J temperature is -8°C (17°F) with 68% confidence bounds from -21 to 4°C (-6 to 39°F) and 95% bounds from -36 to 17°C (-32 to 62°F). On the upper shelf, the overall mean energy is 88 J (65 ft-lb) with variations of

Table 8. Summary of Charpy impact results for Midland reactor beltline weld section 1-9

Location	Charpy Transition Temperature °C (°F)						USE J (ft-lb)	RT _M ^a °C (°F)	RT _{NDT} ^b °C (°F)	RT _{LB} ^c °C (°F)
	Energy J (ft-lb)			Expansion mm (in)		Shear				
	27 (20)	41 (30)	68 (50)	.38 (.015)	.89 (.035)	50%				
1/4 t	-24 (-10)	-6 (21)	37 (98)	-38 (-36)	5 (42)	-10 (13)	77 (57)	3 (37)	14 (57)	35 (95)
1/2 t	-28 (-18)	-11 (13)	25 (77)	-47 (-53)	-5 (23)	-2 (28)	83 (61)	-9 (17)	-9 (17)	12 (54)
5/8 t	-36 (-33)	-18 (0)	18 (64)	-55 (-66)	-12 (10)	-23 (-9)	88 (65)	-16 (3)	-16 (3)	-21 (-6)
3/4 t	-19 (-3)	4 (38)	53 (128)	-40 (-40)	10 (50)	6 (43)	81 (60)	19 (67)	19 (67)	15 (59)
7/8 t	-24 (-12)	-3 (26)	47 (116)	-54 (-64)	1 (34)	-19 (-1)	78 (58)	13 (55)	13 (55)	24 (75)

NOTE: All temperatures have been rounded to the nearest degree

- ^a Determined from T₅₀ - 60°F (T₆₈ - 33°C) using average curve fit, where T₅₀ is the temperature corresponding to 50 ft-lb.
^b Determined from T₅₀ - 60°F (T₆₈ - 33°C) using minimum curve fit, where T₅₀ is the temperature corresponding to 50 ft-lb.
^c Determined from T₅₀ - 60°F (T₆₈ - 33°C) using lower bound curve, where T₅₀ is the temperature corresponding to 50 ft-lb.

Table 9. Summary of Charpy impact results for Midland reactor beltline weld section 1-11

Location	Charpy Transition Temperature °C (°F)						USE J (ft-lb)	RT _M ^a °C (°F)	RT _{NDT} ^b °C (°F)	RT _{LB} ^c °C (°F)
	Energy J (ft-lb)			Expansion mm (in)		Shear				
	27 (20)	41 (30)	68 (50)	38 (015)	89 (035)	50%				
1/4 t	-34 (-28)	-13 (8)	25 (76)	-54 (-65)	-10 (14)	2 (36)	91 (67)	-9 (16)	-9 (16)	7 (45)
1/2 t	-19 (-1)	-4 (25)	24 (74)	-17 (2)	7 (45)	6 (42)	91 (67)	-10 (14)	-10 (14)	-8 (18)
5/8 t	-25 (-13)	-10 (13)	17 (63)	-37 (-35)	-2 (28)	-3 (27)	90 (67)	-16 (3)	-16 (3)	-18 (0)
3/4 t	-7 (19)	14 (57)	58 (137)	-44 (-47)	11 (52)	18 (64)	85 (62)	24 (76)	37 (99)	29 (84)
7/8 t	-32 (-26)	-14 (8)	30 (86)	-68 (-91)	-18 (0)	-9 (16)	79 (58)	-4 (25)	19 (65)	29 (84)

NOTE. All temperatures have been rounded to the nearest degree

- ^a Determined from T₅₀ - 60°F (T₆₈ -33°C) using average curve fit, where T₅₀ is the temperature corresponding to 50 ft-lb
- ^b Determined from T₅₀ - 60°F (T₆₈ -33°C) using minimum curve fit, where T₅₀ is the temperature corresponding to 50 ft-lb
- ^c Determined from T₅₀ - 60°F (T₆₈ -33°C) using lower bound curve, where T₅₀ is the temperature corresponding to 50 ft-lb

Table 10. Summary of Charpy impact results for Midland reactor beltline weld section 1-15

Location	Charpy Transition Temperature °C (°F)						USE J (ft-lb)	RT _M ^a °C (°F)	RT _{NDT} ^b °C (°F)	RT _{LB} ^c °C (°F)
	Energy J (ft-lb)			Expansion mm (in)		Shear				
	27 (20)	41 (30)	68 (50)	.38 (.015)	.89 (.035)	50%				
1/4 t	-17 (1)	4 (40)	50 (122)	-25 (-12)	25 (77)	21 (70)	83 (61)	16 (61)	16 (61)	17 (63)
1/2 t	-23 (-10)	-10 (15)	17 (63)	-30 (-23)	5 (41)	-8 (18)	88 (65)	-16 (2)	-15 (4)	-13 (9)
5/8 t	-20 (-4)	3 (37)	49 (121)	-20 (-4)	25 (76)	17 (62)	85 (63)	15 (60)	8 (47)	27 (81)
3/4 t	-24 (-11)	-6 (21)	28 (82)	-30 (-22)	6 (43)	-8 (18)	89 (66)	-6 (22)	-5 (22)	12 (54)
7/8 t	-22 (-8)	-8 (18)	22 (72)	-27 (-16)	4 (40)	-1 (31)	83 (61)	-12 (11)	-3 (26)	-8 (18)

NOTE: All temperatures have been rounded to the nearest degree

^a Determined from T₅₀ - 60°F (T₆₈ -33°C) using average curve fit, where T₅₀ is the temperature corresponding to 50 ft-lb.

^b Determined from T₅₀ - 60°F (T₆₈ -33°C) using minimum curve fit, where T₅₀ is the temperature corresponding to 50 ft-lb.

^c Determined from T₅₀ - 60°F (T₆₈ -33°C) using lower bound curve, where T₅₀ is the temperature corresponding to 50 ft-lb.

Table 11. Summary of Charpy impact results for Midland reactor nozzle course weld section 3-1

Location	Charpy Transition Temperature °C (°F)						USE J (ft-lb)	RT _M ^a °C (°F)	RT _{NDT} ^b °C (°F)	RT _{LB} ^c °C (°F)
	Energy J (ft-lb)			Expansion mm (in)		Shear				
	27 (20)	41 (30)	68 (50)	.38 (.015)	.89 (.035)	50%				
1/2 t	-16 (4)	5 (42)	47 (117)	-14 (8)	25 (76)	15 (59)	86 (63)	14 (56)	14 (56)	17 (63)
3/4 t	-23 (-9)	2 (35)	49 (121)	-16 (4)	28 (82)	29 (84)	89 (65)	15 (60)	12 (53)	12 (54)
7/8 t	-28 (-19)	-10 (15)	26 (78)	-35 (-31)	1 (34)	7 (45)	90 (66)	-8 (17)	-8 (17)	-6 (21)

NOTE: All temperatures have been rounded to the nearest degree

- ^a Determined from T₅₀ - 60°F (T₆₈ -33°C) using average curve fit, where T₅₀ is the temperature corresponding to 50 ft-lb.
^b Determined from T₅₀ - 60°F (T₆₈ -33°C) using minimum curve fit, where T₅₀ is the temperature corresponding to 50 ft-lb.
^c Determined from T₅₀ - 60°F (T₆₈ -33°C) using lower bound curve, where T₅₀ is the temperature corresponding to 50 ft-lb.

Table 12. Summary of Charpy impact results for Midland reactor nozzle course weld section 3-4

Location	Charpy Transition Temperature °C (°F)						USE J (ft-lb)	RT _M ^a °C (°F)	RT _{NDT} ^b °C (°F)	RT _{LB} ^c °C (°F)
	Energy J (ft-lb)			Expansion mm (in)		Shear				
	27 (20)	41 (30)	68 (50)	.38 (.015)	.89 (.035)	50%				
1/2 t	-43 (-45)	-11 (13)	52 (125)	-33 (-28)	20 (68)	16 (61)	88 (65)	18 (64)	18 (64)	29 (84)
3/4 t	-23 (-10)	-1 (30)	45 (112)	-37 (-35)	18 (65)	25 (77)	85 (63)	11 (51)	11 (51)	10 (50)
7/8 t	-16 (3)	5 (42)	47 (116)	-21 (-5)	17 (63)	20 (68)	89 (66)	13 (56)	13 (56)	12 (54)

NOTE: All temperatures have been rounded to the nearest degree

- ^a Determined from T₅₀ - 60°F (T₆₈ -33°C) using average curve fit, where T₅₀ is the temperature corresponding to 50 ft-lb.
^b Determined from T₅₀ - 60°F (T₆₈ -33°C) using minimum curve fit, where T₅₀ is the temperature corresponding to 50 ft-lb.
^c Determined from T₅₀ - 60°F (T₆₈ -33°C) using lower bound curve, where T₅₀ is the temperature corresponding to 50 ft-lb.

Table 13. Summary of Charpy impact results for Midland Unit 1 reactor vessel beltline weld sections

Through-thickness position	Charpy V-notch tests												RT _M ^a °C (°F), at weld section				RT _{NDT} ^b °C (°F), at weld section			
	41-J temperature, °C (°F), at weld section				68-J temperature, °C (°F), at weld section				Upper-shelf energy, J (ft-lb), at weld section											
	1-13	1-9	1-11	1-15	1-13	1-9	1-11	1-15	1-13	1-9	1-11	1-15	1-13	1-9	1-11	1-15	1-13	1-9	1-11	1-15
1/4t	-11 (12)	-6 (21)	-13 (8)	4 (39)	21 (69)	37 (98)	25 (76)	50 (122)	101 (74)	77 (57)	91 (67)	82 (60)	-9 (15)	3 (37)	-9 (16)	16 (61)	-13 (9)	14 (57)	-9 (16)	16 (61)
1/2t	-16 (3)	-11 (13)	-4 (25)	-9 (15)	29 (84)	25 (77)	23 (74)	17 (63)	104 (77)	83 (61)	91 (67)	88 (65)	-5 (24)	-8 (17)	-10 (14)	-16 (3)	2 (36)	-8 (17)	-10 (14)	-15 (5)
5/8t	-22 (-7)	-18 (0)	-10 (13)	3 (37)	9 (48)	18 (64)	17 (63)	49 (121)	108 (80)	88 (65)	90 (66)	85 (62)	-25 (-12)	-16 (3)	-16 (3)	15 (60)	-20 (-3)	-16 (3)	-16 (3)	8 (47)
3/4t	-2 (27)	3 (38)	14 (57)	-6 (21)	37 (98)	53 (128)	58 (136)	28 (82)	90 (66)	81 (60)	84 (62)	89 (66)	3 (37)	20 (68)	24 (76)	-6 (21)	6 (43)	20 (68)	37 (99)	-6 (22)
7/8t		-3 (26)	-13 (8)	-8 (18)		46 (116)	30 (86)	22 (72)		78 (57)	79 (58)	83 (61)		13 (55)	-4 (25)	-12 (11)		13 (56)	18 (65)	-3 (26)

^aDetermined from T₅₀ - 60°F (T₈₈ - 33°C) using average curve fit, where T₅₀ is the temperature corresponding to 50 ft-lb.

^bDetermined from T₅₀ - 60°F (T₈₈ - 33°C) using minimum curve fit, where T₅₀ is the temperature corresponding to 50 ft-lb.

Table 14. Summary of Charpy impact results for Midland Unit 1 reactor vessel nozzle course weld sections

Through-thickness position	Charpy V-notch tests						RT _M ^a °C (°F), at weld section		RT _{NDT} ^b °C (°F), at weld section	
	41-J temperature, °C (°F), at weld section		68-J temperature, °C (°F), at weld section		Upper-shelf energy, J (ft-lb), at weld section					
	3-1	3-4	3-1	3-4	3-1	3-4	3-1	3-4	3-1	3-4
1/2t	5 (42)	-11 (13)	47 (117)	51 (125)	86 (63)	88 (65)	14 (57)	18 (65)	14 (57)	18 (65)
3/4t	2 (35)	-1 (30)	49 (120)	45 (112)	89 (65)	85 (63)	16 (61)	11 (52)	16 (61)	11 (52)
7/8t	-10 (15)	5 (42)	26 (78)	47 (116)	90 (66)	89 (66)	-8 (18)	14 (57)	-8 (18)	14 (57)

^aDetermined from T₅₀ - 60°F (T₈₈ - 33°C) using average curve fit.^bDetermined from T₅₀ - 60°F (T₈₈ - 33°C) using minimum curve fit.

ANALYSIS SET: MWALL

MODEL PARAMETERS

LOWER SHELF ENERGY [HELD FIXED]: 2.7 (J), 2 (FT-LB)
 MID-TRANSITION TEMPERATURE: -2.1 (DEG C), 28.3 (DEG F)
 TRANSITION ZONE WIDTH: 112.7 (C DEG), 202.8 (F DEG)
 UPPER SHELF ENERGY: 88.5 (J), 65.3 (FT-LB)
 STANDARD MODEL: $ENERGY = A + B \cdot \tanh((TEMPERATURE - T_0) / C)$
 A: 45.6 (J), 33.6 (FT-LB)
 B: 42.9 (J), 31.6 (FT-LB)
 T₀: -2.1 (DEG C), 28.3 (DEG F)
 C: 56.3 (C DEG), 101.4 (F DEG)
 UPPER SHELF ENERGY: 88.5 (J), 65.3 (FT-LB)
 CONFIDENCE INTERVAL ON PREDICTED VALUE
 68 PERCENT: 79.2 TO 97.8 (J), 58.4 TO 72.1 (FT-LB)
 TEMPERATURE [27 (J), 19.9 (FT-LB) ENERGY]: -28.2 (DEG C), -18.8 (DEG F)
 CONFIDENCE INTERVAL ON PREDICTED VALUE
 68 PERCENT: -45.7 TO -14.5 (DEG C), -50.3 TO 5.9 (DEG F)
 TEMPERATURE [41 (J), 30.2 (FT-LB) ENERGY]: -8.1 (DEG C), 17.4 (DEG F)
 CONFIDENCE INTERVAL ON PREDICTED VALUE
 68 PERCENT: -21 TO 4.1 (DEG C), -5.7 TO 39.4 (DEG F)
 TEMPERATURE [68 (J), 50.2 (FT-LB) ENERGY]: 30.6 (DEG C), 87.1 (DEG F)
 CONFIDENCE INTERVAL ON PREDICTED VALUE
 68 PERCENT: 15.8 TO 51.3 (DEG C), 60.4 TO 124.3 (DEG F)
 REFERENCE TEMPERATURE ANALYSIS
 MEAN IMPACT CURVE
 TEMPERATURE [50 (FT-LB) ENERGY] -60 (DEG F): -3.1 (DEG C), 26.4 (DEG F)
 MINIMUM IMPACT CURVE
 TEMPERATURE [50 (FT-LB) ENERGY] -60 (DEG F): 15 (DEG C), 58.9 (DEG F)
 REMARK: MIDLAND WELD ALL LAYERS & THICKNESSES

Figure 15. Charpy V-notch impact energy versus test temperature for all tests of beltline and nozzle course welds of the Midland reactor vessel; the solid curve represents the mean hyperbolic tangent curve fit, while the dashed curves represent upper and lower 68% confidence bounds on the predicted value.

ANALYSIS SET: MWall

MODEL PARAMETERS

LOWER SHELF ENERGY [HELD FIXED]: 2.7 (J), 2 (FT-LB)

MID-TRANSITION TEMPERATURE:-2.1 (DEG C), 28.3 (DEG F)

TRANSITION ZONE WIDTH: 112.7 (C DEG), 202.8 (F DEG)

UPPER SHELF ENERGY: 88.5 (J), 65.3 (FT-LB)

STANDARD MODEL: $ENERGY = A + B \cdot \tanh((TEMPERATURE - T_0) / C)$

A: 45.6 (J), 33.6 (FT-LB)

B: 42.9 (J), 31.6 (FT-LB)

T₀: -2.1 (DEG C), 28.3 (DEG F)

C: 56.3 (C DEG), 101.4 (F DEG)

UPPER SHELF ENERGY: 88.5 (J), 65.3 (FT-LB)

CONFIDENCE INTERVAL ON PREDICTED VALUE

90 PERCENT: 73.1 TO 103.9 (J), 53.9 TO 76.6 (FT-LB)

TEMPERATURE [27 (J), 19.9 (FT-LB) ENERGY]: -28.2 (DEG C), -18.8 (DEG F)

CONFIDENCE INTERVAL ON PREDICTED VALUE

90 PERCENT: -62.6 TO -6.3 (DEG C), -80.7 TO 20.6 (DEG F)

TEMPERATURE [41 (J), 30.2 (FT-LB) ENERGY]: -8.1 (DEG C), 17.4 (DEG F)

CONFIDENCE INTERVAL ON PREDICTED VALUE

90 PERCENT: -30.5 TO 12.4 (DEG C), -22.9 TO 54.3 (DEG F)

TEMPERATURE [68 (J), 50.2 (FT-LB) ENERGY]: 30.6 (DEG C), 87.1 (DEG F)

CONFIDENCE INTERVAL ON PREDICTED VALUE

90 PERCENT: 7.3 TO 75.4 (DEG C), 45.2 TO 167.7 (DEG F)

REFERENCE TEMPERATURE ANALYSIS

MEAN IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY]-60 (DEG F): -3.1 (DEG C), 26.4 (DEG F)

MINIMUM IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY]-60 (DEG F): 15 (DEG C), 58.9 (DEG F)

REMARK: MIDLAND WELD ALL LAYERS & THICKNESSES

Figure 16.

Charpy V-notch impact energy versus test temperature for all tests of beltline and nozzle course welds of the Midland reactor vessel; the solid curve represents the mean hyperbolic tangent curve fit, while the dashed curves represent upper and lower 90% confidence bounds on the predicted value.

ANALYSIS SET: MWALL

MODEL PARAMETERS

LOWER SHELF ENERGY [HELD FIXED]: 2.7 (J), 2 (FT-LB)

MID-TRANSITION TEMPERATURE: -2.1 (DEG C), 28.3 (DEG F)

TRANSITION ZONE WIDTH: 112.7 (C DEG), 202.8 (F DEG)

UPPER SHELF ENERGY: 88.5 (J), 65.3 (FT-LB)

STANDARD MODEL: $ENERGY = A + B \cdot \tanh((TEMPERATURE - T_0) / C)$

A: 45.6 (J), 33.6 (FT-LB)

B: 42.9 (J), 31.6 (FT-LB)

T₀: -2.1 (DEG C), 28.3 (DEG F)

C: 56.3 (C DEG), 101.4 (F DEG)

UPPER SHELF ENERGY: 88.5 (J), 65.3 (FT-LB)

CONFIDENCE INTERVAL ON PREDICTED VALUE

95 PERCENT: 70.1 TO 106.8 (J), 51.7 TO 78.8 (FT-LB)

TEMPERATURE [27 (J), 19.9 (FT-LB) ENERGY]: -28.2 (DEG C), -18.8 (DEG F)

CONFIDENCE INTERVAL ON PREDICTED VALUE

95 PERCENT: -74.8 TO -2.4 (DEG C), -102.7 TO 27.6 (DEG F)

TEMPERATURE [41 (J), 30.2 (FT-LB) ENERGY]: -8.1 (DEG C), 17.4 (DEG F)

CONFIDENCE INTERVAL ON PREDICTED VALUE

95 PERCENT: -35.7 TO 16.6 (DEG C), -32.3 TO 61.9 (DEG F)

TEMPERATURE [68 (J), 50.2 (FT-LB) ENERGY]: 30.6 (DEG C), 87.1 (DEG F)

CONFIDENCE INTERVAL ON PREDICTED VALUE

95 PERCENT: 3.4 TO 100.5 (DEG C), 38 TO 212.8 (DEG F)

REFERENCE TEMPERATURE ANALYSIS

MEAN IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY] -60 (DEG F): -3.1 (DEG C), 26.4 (DEG F)

MINIMUM IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY] -60 (DEG F): 15 (DEG C), 58.9 (DEG F)

REMARK: MIDLAND WELD ALL LAYERS & THICKNESSES

Figure 17. Charpy V-notch impact energy versus test temperature for all tests of beltline and nozzle course welds of the Midland reactor vessel; the solid curve represents the mean hyperbolic tangent curve fit, while the dashed curves represent upper and lower 95% confidence bounds on the predicted value.

ANALYSIS SET: MWALL

MODEL PARAMETERS

LOWER SHELF ENERGY [HELD FIXED]: 2.7 (J), 2 (FT-LB)

MID-TRANSITION TEMPERATURE: -2.1 (DEG C), 28.3 (DEG F)

TRANSITION ZONE WIDTH: 112.7 (C DEG), 202.8 (F DEG)

UPPER SHELF ENERGY: 88.5 (J), 65.3 (FT-LB)

STANDARD MODEL: $ENERGY = A + B \cdot \tanh((TEMPERATURE - T_0) / C)$

A: 45.6 (J), 33.6 (FT-LB)

B: 42.9 (J), 31.6 (FT-LB)

T₀: -2.1 (DEG C), 28.3 (DEG F)

C: 56.3 (C DEG), 101.4 (F DEG)

UPPER SHELF ENERGY: 88.5 (J), 65.3 (FT-LB)

CONFIDENCE INTERVAL ON PREDICTED VALUE

99 PERCENT: 64.3 TO 112.7 (J), 47.4 TO 83.1 (FT-LB)

TEMPERATURE [27 (J), 19.9 (FT-LB) ENERGY]: -28.2 (DEG C), -18.8 (DEG F)

CONFIDENCE INTERVAL ON PREDICTED VALUE

99 PERCENT: -160.3 TO 5.2 (DEG C), -256.6 TO 41.4 (DEG F)

TEMPERATURE [41 (J), 30.2 (FT-LB) ENERGY]: -8.1 (DEG C), 17.4 (DEG F)

CONFIDENCE INTERVAL ON PREDICTED VALUE

99 PERCENT: -47.8 TO 25.6 (DEG C), -54 TO 78.2 (DEG F)

TEMPERATURE [68 (J), 50.2 (FT-LB) ENERGY]: 30.6 (DEG C), 87.1 (DEG F)

CONFIDENCE INTERVAL ON PREDICTED VALUE

99 PERCENT: -4.3 TO UNDEFINED (DEG C), 24.3 TO UNDEFINED (DEG F)

REFERENCE TEMPERATURE ANALYSIS

MEAN IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY] -60 (DEG F): -3.1 (DEG C), 26.4 (DEG F)

MINIMUM IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY] -60 (DEG F): 15 (DEG C), 58.9 (DEG F)

REMARK: MIDLAND WELD ALL LAYERS & THICKNESSES

Figure 18. Charpy V-notch impact energy versus test temperature for all tests of beltline and nozzle course welds of the Midland reactor vessel; the solid curve represents the mean hyperbolic tangent curve fit, while the dashed curves represent upper and lower 99% confidence bounds on the predicted value.

about ± 9 J (± 7 ft-lb) for the 68% level and about ± 18 J (± 13 ft-lb) for the 95% level. Figure 19 shows a comparison of the 95% confidence bounds on the mean and on the predicted value for the same data set; at the 41-J (30-ft-lb) level, the 95% confidence intervals are about 5°C (9°F) wide on the mean and about 53°C (94°F) wide on the predicted value. Although the scatter is large, the mean value is known with high confidence because the data set is large. On the other hand, Figure 20 shows a smaller data set. At the 41-J level, the 95% confidence intervals are about 55°C (98°F) wide on the mean and about 130°C (234°F) wide on the predicted value. The confidence intervals for a small data set will, of course, be affected by the goodness of fit to the data as well as by the number of observations. Further reference to confidence bounds will refer to those on the predicted value unless confidence bounds on the mean are specifically noted.

Figures 21 and 22 show the Charpy energy results for all the tests of the beltline weld and those for the nozzle course weld, respectively. The number of tests of the beltline weld is at least four times that of the nozzle course weld. That is likely the primary reason that the 95% confidence intervals for the beltline weld are larger than those for the nozzle course weld. Plots of all the various combined data sets with mean curve fits and confidence bounds are given in Appendix E.

The initial analyses performed with the individual data sets showed substantial differences in the mean curve fit and confidence bounds, especially in the lower-shelf region for data sets which appeared similar. The reason for that was the sparse number of test results obtained in the lower-shelf region in most cases. Thus, five CVN tests were conducted at liquid nitrogen temperature, -196°C (-320°F), to provide values at which the lower shelves could be fixed. The tests resulted in averages of 2.7 J (1.9 ft-lb), 0.061-mm (0.0024-in.) lateral expansion, and 0% ductile fracture. Figures 23(a) through (f) show a series of analysis results with 95% confidence bounds obtained for the nozzle course weld at the 1/2t location (16 test results). Figure 23(a) represents the entire data set and the hyperbolic tangent fit with the lower-shelf energy not fixed, while Figure 23(b) represents the lower-shelf energy fixed at 2.7 J. In this case, the mean curve fits are about the same. The confidence bounds are different in the lower-shelf region because the mean value is fixed and, therefore, known exactly.

If only one test had been conducted at -50°C, the fits and confidence intervals, with and without fixing the lower-shelf energy, would be affected as shown in Figures 23(c) through (f). Elimination of either the upper or lower data point at -50°C significantly affects both the confidence intervals and the mean curve fits (mean curve goes negative in the former case), especially in the lower-shelf region, when the lower shelf is not fixed. Fixing the lower-shelf energy, especially for data sets with sparse data in the lower-shelf region, provides a more reasonable overall result and does not degrade the fit to the rest of the data. Thus, all hyperbolic tangent analyses were performed with the lower-shelf values fixed at the values given above. Furthermore, the upper-shelf value for the percent shear fits was fixed at 100%.

Shown in Table 15 is a comparison of results obtained when the lower-shelf energy for the mean hyperbolic tangent curve fit to the entire data set is held fixed at 2.7 J (1.9 ft-lb) versus unfixed. Except for the upper confidence bound at 27 J (20 ft-lb), there are only small differences for the total combined data set because there are sufficient data in the lower-shelf region with which to obtain a representative fit.

Tables 16 and 17 give the various Charpy transition temperatures, upper-shelf energies, RT_{NDT} , and RT_M values, with 68 and 95% confidence bounds, respectively, from the hyperbolic tangent curve fits for the beltline weld by thickness location. Tables 18 and 19 give similar information by each beltline weld section. Tables 20 through 23 provide similar results for the nozzle course weld, while Table 24 provides a comparison of the beltline and nozzle course welds with the total combined data set. Examination of Table 24 shows generally good correspondence between the Charpy results of the beltline and nozzle course welds, with the observation that the nozzle course weld mean curve is somewhat more shallow in the transition region (the temperature interval from 41 to 68 J is greater for the nozzle course weld).

A comparison of confidence intervals, 68, 90, 95, and 99%, for the analyses of the total combined data set is given in Table 25. It is interesting to note that the mean 68-J (50 ft-lb) temperature, 31°C (87°F), is about 39°C (70°F) above the mean 41-J (30 ft-lb) temperature, -8°C (17°F), but that the 95% lower confidence bound 68-J temperature is about 84°C (151°F) above the

Figure 19. Charpy V-notch impact energy versus test temperature for all tests of beltline and nozzle course welds of the Midland reactor vessel. The solid curve represents the mean hyperbolic tangent curve fit, while the dashed curves show a comparison of 95% confidence bounds on the mean and on the predicted value.

Figure 20. Charpy V-notch impact energy versus test temperature for tests at the 7/8 thickness location in section 1-11 of the Midland reactor vessel beltline weld. The solid curve represents the mean hyperbolic tangent curve fit, while the dashed curves show a comparison of the 95% confidence bounds on the mean and on the predicted value: (a) shows curves plotted only to 0 J, while (b) shows the symmetric nature of the confidence curves and is shown only for illustrative purposes. The confidence on the mean value for a small data set can be compared with that for the large data set shown in Figure 19.

ANALYSIS SET: MWBELTALL

MODEL PARAMETERS

LOWER SHELF ENERGY [HELD FIXED]: 2.7 (J), 2 (FT-LB)
 MID-TRANSITION TEMPERATURE: -3.2 (DEG C), 26.2 (DEG F)
 TRANSITION ZONE WIDTH: 109 (C DEG), 196.2 (F DEG)
 UPPER SHELF ENERGY: 88.9 (J), 65.5 (FT-LB)

STANDARD MODEL: $ENERGY = A + B \cdot \tanh((TEMPERATURE - T_0) / C)$

A: 45.8 (J), 33.8 (FT-LB)
 B: 43.1 (J), 31.8 (FT-LB)
 T₀: -3.2 (DEG C), 26.2 (DEG F)
 C: 54.5 (C DEG), 98.1 (F DEG)

UPPER SHELF ENERGY: 88.9 (J), 65.5 (FT-LB)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 79.2 TO 98.5 (J), 58.4 TO 72.7 (FT-LB)

95 PERCENT: 69.8 TO 107.9 (J), 51.5 TO 79.6 (FT-LB)

TEMPERATURE [27 (J), 19.9 (FT-LB) ENERGY]: -28.7 (DEG C), -19.7 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -46.4 TO -15 (DEG C), -51.6 TO 5 (DEG F)

95 PERCENT: -77.2 TO -3 (DEG C), -107 TO 26.6 (DEG F)

TEMPERATURE [41 (J), 30.2 (FT-LB) ENERGY]: -9.3 (DEG C), 15.2 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -22.2 TO 2.9 (DEG C), -8 TO 37.2 (DEG F)

95 PERCENT: -37.2 TO 15.4 (DEG C), -35 TO 59.8 (DEG F)

TEMPERATURE [68 (J), 50.2 (FT-LB) ENERGY]: 27.8 (DEG C), 82.1 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 13.2 TO 48.4 (DEG C), 55.7 TO 119.1 (DEG F)

95 PERCENT: 0.8 TO 100.3 (DEG C), 33.5 TO 212.5 (DEG F)

REFERENCE TEMPERATURE ANALYSIS

MEAN IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY] -60 (DEG F): -5.9 (DEG C), 21.4 (DEG F)

MINIMUM IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY] -60 (DEG F): 14.5 (DEG C), 58.2 (DEG F)

REMARK: MIDLAND WELD BELTLINE ALL SECTIONS & THICKNESSES

Figure 21. Charpy V-notch impact energy versus test temperature for all tests of the beltline weld from the Midland reactor vessel; the solid curve represents the mean hyperbolic tangent curve fit, while the dashed curves represent upper and lower 68 and 95% confidence bounds on the predicted value.

ANALYSIS SET: MWNCALL

MODEL PARAMETERS

LOWER SHELF ENERGY [HELD FIXED]: 2.7 (J), 2 (FT-LB)
 MID-TRANSITION TEMPERATURE: 5.2 (DEG C), 41.4 (DEG F)
 TRANSITION ZONE WIDTH: 130.1 (C DEG), 234.1 (F DEG)
 UPPER SHELF ENERGY: 87.7 (J), 64.7 (FT-LB)

STANDARD MODEL: $ENERGY = A + B \cdot \tanh((TEMPERATURE - T_0) / C)$

A: 45.2 (J), 33.3 (FT-LB)
 B: 42.5 (J), 31.3 (FT-LB)
 T₀: 5.2 (DEG C), 41.4 (DEG F)
 C: 65 (C DEG), 117 (F DEG)

UPPER SHELF ENERGY: 87.7 (J), 64.7 (FT-LB)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 81.4 TO 94 (J), 60.1 TO 69.3 (FT-LB)

95 PERCENT: 75.2 TO 100.2 (J), 55.4 TO 73.9 (FT-LB)

TEMPERATURE [27 (J), 19.9 (FT-LB) ENERGY]: -24.5 (DEG C), -12.2 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -37.1 TO -13.9 (DEG C), -34.7 TO 7 (DEG F)

95 PERCENT: -53.1 TO -4.2 (DEG C), -63.6 TO 24.5 (DEG F)

TEMPERATURE [41 (J), 30.2 (FT-LB) ENERGY]: -1.2 (DEG C), 29.8 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -10.8 TO 8.1 (DEG C), 12.6 TO 46.5 (DEG F)

95 PERCENT: -21.2 TO 17.5 (DEG C), -6.2 TO 63.5 (DEG F)

TEMPERATURE [68 (J), 50.2 (FT-LB) ENERGY]: 44.2 (DEG C), 111.5 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 32.3 TO 59 (DEG C), 90.1 TO 138.2 (DEG F)

95 PERCENT: 21.9 TO 80.5 (DEG C), 71.4 TO 176.9 (DEG F)

REFERENCE TEMPERATURE ANALYSIS

MEAN IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY]-60 (DEG F): 10.4 (DEG C), 50.7 (DEG F)

MINIMUM IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY]-60 (DEG F): 24.6 (DEG C), 76.2 (DEG F)

Figure 22. Charpy V-notch impact energy versus test temperature for all tests of the nozzle course weld from the Midland reactor vessel; the solid curve represents the mean hyperbolic tangent curve fit, while the dashed curves represent upper and lower 68 and 95% confidence bounds on the predicted value.

Figure 23. Charpy V-notch impact energy versus test temperature for tests at the 1/2 thickness location of the nozzle course weld from the Midland reactor vessel: (a) all data, lower shelf not held fixed; (b) same as in (a) but lower shelf held fixed at 2.7 J; (c) higher energy result at -50°C excluded, lower shelf not held fixed; (d) same as (c) but lower shelf held fixed at 2.7 J; (e) lower energy result at -50°C excluded, lower shelf not held fixed; and (f) same as (e) but lower shelf held fixed at 2.7 J. The large dashed curve represents the mean hyperbolic tangent curve fit, while the small, dashed curves represent upper and lower 95% confidence bounds.

(c)

(d)

Figure 23. contd.

Figure 23. contd.

Table 15. Comparison of mean hyperbolic tangent curve fits and 95% confidence bounds on predicted value using lower shelf fixed at 2.7 J and unfixed for the combined beltline and nozzle course welds

	Charpy Transition Temperature °C (°F) for Given Energy									Upper-shelf energy J (ft-lb)			RT _M ^a °C (°F)			RT _{NDT} ^b °C (°F)	RT _{LB} ^c °C (°F)
	27J (20ft-lb)			41J (30 ft-lb)			68J (50 ft-lb)									Min	Min
	-95%	Model	95%	-95%	Model	95%	-95%	Model	95%	-95%	Model	95%	-95%	Model	95%		
Fixed	-75 (-103)	-28 (-19)	-2 (28)	-36 (-32)	-8 (17)	17 (62)	3 (38)	31 (87)	101 (213)	70 (52)	89 (65)	107 (79)	-30 (-22)	-3 (27)	67 (153)	15 (59)	35 (95)
Unfixed	-89 (-129)	-27 (-17)	-2 (29)	-35 (-31)	-7 (19)	17 (62)	4 (39)	30 (86)	101 (213)	70 (51)	88 (65)	106 (78)	-30 (-21)	-3 (26)	67 (153)	16 (60)	35 (95)

NOTE: All temperatures have been rounded to the nearest degree.

^a Determined from T₆₀ - 60°F (T₆₈ -33°C) using average curve fit, where T₆₀ is the temperature corresponding to 50 ft-lb.

^b Determined from T₅₀ - 60°F (T₆₈ -33°C) using minimum curve fit, where T₅₀ is the temperature corresponding to 50 ft-lb.

^c Determined from T₆₀ - 60°F (T₆₈ -33°C) using lower bound curve fit, where T₅₀ is the temperature corresponding to 50 ft-lb.

Table 16. Summary of mean hyperbolic tangent curve fits and 68% confidence bounds on predicted value for Charpy energy, RT_{NDT} , and RT_M results for the Midland reactor beltline weld at various through-thickness locations

Location	Charpy Transition Temperature °C (°F) for Given Energy									Upper-shelf energy J (ft-lb)			RT_M , ^a °C (°F)			RT_{NDT} , ^b °C (°F)
	27J (20ft-lb)			41J (30 ft-lb)			68J (50 ft-lb)			-68%	Model	68%	-68%	Model	68%	Min
	-68%	Model	68%	-68%	Model	68%	-68%	Model	68%							
1/4 t	-45 (-48)	-28 (-18)	-18 (6)	-21 (-5)	-8 (17)	4 (38)	15 (59)	29 (84)	48 (118)	80 (59)	89 (66)	98 (73)	-18 (1)	-4 (24)	15 (58)	11 (52)
1/2 t	-51 (-59)	-33 (-27)	-19 (-2)	-25 (-12)	-12 (11)	0 (33)	13 (56)	27 (80)	44 (111)	85 (62)	93 (69)	102 (76)	-20 (-4)	-6 (20)	10 (51)	23 (74)
5/8 t	-54 (-65)	-34 (-29)	-19 (-2)	-12 (10)	-16 (4)	-3 (28)	3 (37)	18 (64)	37 (98)	82 (61)	94 (69)	105 (77)	-30 (-23)	-16 (4)	3 (38)	-13 (8)
3/4 t	-33 (-27)	-19 (-2)	-8 (18)	-9 (16)	1 (34)	11 (52)	28 (83)	41 (106)	58 (137)	79 (58)	87 (64)	94 (69)	-5 (23)	8 (46)	25 (77)	18 (64)
7/8 t	-40 (-40)	-27 (-16)	-16 (3)	-20 (-5)	-10 (14)	0 (32)	12 (54)	28 (83)	65 (150)	70 (52)	79 (58)	88 (65)	-21 (-6)	-5 (23)	32 (90)	29 (84)

^a Determined from $T_{50} - 60^\circ\text{F}$ ($T_{68} - 33^\circ\text{C}$) using average curve fit, where T_{50} is the temperature corresponding to 50 ft-lb.

^b Determined from $T_{50} - 60^\circ\text{F}$ ($T_{68} - 33^\circ\text{C}$) using minimum curve fit, where T_{50} is the temperature corresponding to 50 ft-lb.

Table 17. Summary of mean hyperbolic tangent curve fits and 95% confidence bounds on predicted value for Charpy energy, RT_{NDT} , and RT_M results for the Midland reactor beltline weld at various through-thickness locations

Location	Charpy Transition Temperature °C (°F) for Given Energy									Upper-shelf energy J (ft-lb)			RT_M , ^a °C (°F)			RT_{NDT} , ^b °C (°F)
	27J (20ft-lb)			41J (30 ft-lb)			68J (50 ft-lb)			-95%	Model	95%	-95%	Model	95%	Min
	-95%	Model	95%	-95%	Model	95%	-95%	Model	95%							
1/4 t	-72 (-97)	-28 (-18)	-3 (27)	-35 (-31)	-8 (17)	16 (60)	3 (37)	29 (84)	88 (191)	71 (52)	89 (66)	108 (79)	-30 (-23)	-4 (24)	55 (131)	11 (52)
1/2 t	-79 (-110)	-33 (-27)	-7 (20)	-40 (-40)	-12 (11)	13 (55)	1 (34)	27 (80)	70 (158)	76 (56)	93 (69)	111 (82)	-32 (-26)	-6 (20)	36 (98)	23 (74)
5/8 t	-101 (-149)	-34 (-29)	-6 (22)	-48 (-54)	-16 (4)	11 (53)	-10 (14)	18 (64)	79 (173)	71 (52)	94 (69)	116 (86)	-43 (-46)	-16 (4)	45 (113)	3 (38)
3/4 t	-52 (-61)	-19 (-2)	3 (37)	-21 (-5)	1 (34)	22 (71)	17 (63)	41 (106)	92 (197)	71 (53)	87 (64)	102 (75)	-16 (3)	8 (46)	58 (137)	18 (64)
7/8 t	-61 (-78)	-27 (-16)	-6 (22)	-32 (-26)	-10 (14)	12 (54)	0 (33)	28 (83)	undefined undefined	61 (45)	79 (58)	97 (71)	-33 (-27)	-5 (23)	undefined undefined	29 (84)

^a Determined from $T_{50} - 60^\circ\text{F}$ ($T_{68} - 33^\circ\text{C}$) using average curve fit, where T_{50} is the temperature corresponding to 50 ft-lb.

^b Determined from $T_{50} - 60^\circ\text{F}$ ($T_{68} - 33^\circ\text{C}$) using minimum curve fit, where T_{50} is the temperature corresponding to 50 ft-lb.

Table 18. Summary of mean hyperbolic tangent curve fits and 68% confidence bounds on predicted value for Charpy energy, RT_{NDT} , and RT_M results of four Midland reactor beltline weld sections

Section	Charpy Transition Temperature °C (°F) for Given Energy									Upper-shell energy J (ft-lb)			RT_M , ^a °C (°F)			RT_{NDT} , ^b °C (°F)
	27J (20ft-lb)			41J (30 ft-lb)			68J (50 ft-lb)			-68%	Model	68%	-68%	Model	68%	Min
	-68%	Model	68%	-68%	Model	68%	-68%	Model	68%							
1 - 9	-38 (-36)	-27 (-17)	-18 (1)	-17 (2)	-9 (17)	0 (32)	20 (69)	34 (92)	54 (129)	74 (55)	80 (59)	87 (64)	-13 (9)	0 (32)	21 (69)	23 (74)
1 - 11	-44 (-47)	-25 (-13)	-11 (13)	-20 (-3)	-6 (21)	7 (44)	15 (59)	31 (87)	53 (128)	78 (58)	88 (65)	99 (73)	-18 (1)	-3 (27)	20 (68)	9 (48)
1 - 13	-58 (-72)	-37 (-35)	-21 (-7)	-30 (-22)	-15 (4)	-2 (28)	8 (47)	22 (71)	38 (101)	30 (66)	99 (73)	109 (81)	-25 (-13)	-11 (11)	5 (41)	6 (43)
1 - 15	-37 (-34)	-23 (-10)	-13 (10)	-15 (5)	-5 (23)	5 (41)	20 (67)	33 (91)	51 (124)	77 (57)	85 (63)	93 (69)	-14 (7)	-1 (31)	18 (64)	21 (70)

^a Determined from $T_{50} - 60^\circ\text{F}$ ($T_{68} - 33^\circ\text{C}$) using average curve fit, where T_{50} is the temperature corresponding to 50 ft-lb.

^b Determined from $T_{50} - 60^\circ\text{F}$ ($T_{68} - 33^\circ\text{C}$) using minimum curve fit, where T_{50} is the temperature corresponding to 50 ft-lb.

Table 19. Summary of mean hyperbolic tangent curve fits and 95% confidence bounds on predicted value for Charpy energy, RT_{NDT} , and RT_M results of four Midland reactor beltline weld sections

Section	Charpy Transition Temperature °C (°F) for Given Energy									Upper-shelf energy J (ft-lb)			RT_M , ^a °C (°F)			RT_{NDT} , ^b °C (°F)
	27J (20ft-lb)			41J (30 ft-lb)			68J (50 ft-lb)			-95%	Model	95%	-95%	Model	95%	Min
	-95%	Model	95%	-95%	Model	95%	-95%	Model	95%							
1 - 9	-52 (-61)	-27 (-17)	-10 (14)	-26 (-14)	-9 (17)	9 (48)	10 (50)	34 (92)	undefined undefined	68 (50)	80 (59)	93 (69)	-23 (-10)	0 (32)	undefined undefined	23 (74)
1 - 11	-80 (-113)	-25 (-13)	2 (36)	-37 (-34)	-6 (21)	21 (69)	2 (36)	31 (87)	undefined undefined	68 (50)	88 (65)	109 (80)	-31 (-24)	-3 (27)	undefined undefined	9 (48)
1 - 13	-95 (-138)	-37 (-34)	-8 (18)	-48 (-54)	-15 (4)	11 (51)	-5 (23)	22 (71)	61 (142)	80 (59)	99 (73)	119 (88)	-38 (-37)	-11 (11)	28 (82)	6 (43)
1 - 15	-56 (-69)	-23 (-10)	3 (37)	-27 (-16)	-5 (23)	15 (59)	9 (48)	33 (91)	109 (229)	69 (51)	85 (63)	101 (74)	-25 (-12)	-1 (31)	76 (169)	21 (70)

^a Determined from $T_{50} - 60^\circ\text{F}$ ($T_{68} - 33^\circ\text{C}$) using average curve fit, where T_{50} is the temperature corresponding to 50 ft-lb.

^b Determined from $T_{50} - 60^\circ\text{F}$ ($T_{68} - 33^\circ\text{C}$) using minimum curve fit, where T_{50} is the temperature corresponding to 50 ft-lb.

Table 20. Summary of mean hyperbolic tangent curve fit results and 68% confidence bounds on predicted value for Charpy energy, RT_{NDT} , and RT_M results for the Midland reactor nozzle course weld at various through-thickness locations

Location	Charpy Transition Temperature °C (°F) for Given Energy									Upper-shelf energy J (ft-lb)			RT_M , ^a °C (°F)			RT_{NDT} , ^b °C (°F)
	27J (20ft-lb)			41J (30 ft-lb)			68J (50 ft-lb)			-68%	Model	68%	-68%	Model	68%	Min
	-68%	Model	68%	-68%	Model	68%	-68%	Model	68%							
1/2 t	-43 (-46)	-27 (-17)	-14 (6)	-14 (8)	-2 (29)	10 (50)	34 (94)	50 (121)	69 (156)	79 (58)	87 (64)	94 (70)	1 (34)	16 (61)	35 (96)	24 (76)
3/4 t	-35 (-31)	-23 (-9)	-13 (9)	-8 (17)	1 (33)	9 (49)	36 (96)	47 (117)	61 (143)	81 (60)	87 (64)	93 (69)	2 (36)	14 (57)	28 ³ (83)	16 (60)
7/8 t	-38 (-36)	-24 (-10)	-12 (11)	-13 (8)	-3 (27)	7 (45)	25 (76)	37 (98)	52 (126)	82 (60)	90 (66)	98 (72)	-9 (16)	4 (38)	19 (66)	13 (55)

^a Determined from $T_{50} - 60^\circ\text{F}$ ($T_{68} - 33^\circ\text{C}$) using average curve fit, where T_{50} is the temperature corresponding to 50 ft-lb.

^b Determined from $T_{50} - 60^\circ\text{F}$ ($T_{68} - 33^\circ\text{C}$) using minimum curve fit, where T_{50} is the temperature corresponding to 50 ft-lb.

Table 21. Summary of mean hyperbolic tangent curve fit results and 95% confidence bounds on predicted value for Charpy energy, RT_{NOT} , and RT_M results for the Midland reactor nozzle course weld at various through-thickness locations

Location	Charpy Transition Temperature °C (°F) for Given Energy									Upper-shelf energy J (ft-lb)			RT_M , ^a °C (°F)			RT_{NOT} , ^b °C (°F)
	27J (20ft-lb)			41J (30 ft-lb)			68J (50 ft-lb)			-95%	Model	95%	-95%	Model	95%	Min
1/2 t	-66 (-88)	-27 (-17)	-2 (29)	-28 (-19)	-2 (29)	23 (73)	21 (69)	50 (121)	106 (223)	71 (52)	87 (64)	103 (76)	-13 (9)	16 (61)	73 (163)	24 (76)
3/4 t	-51 (-60)	-23 (-9)	-3 (27)	-19 (-2)	1 (33)	19 (66)	25 (76)	47 (117)	84 (183)	74 (55)	87 (64)	100 (74)	-9 (16)	14 (57)	50 (123)	16 (60)
7/8 t	-59 (-75)	-24 (-10)	-1 (31)	-27 (-16)	-3 (27)	19 (66)	13 (55)	37 (98)	78 (173)	73 (54)	90 (66)	106 (78)	-20 (-5)	4 (38)	45 (113)	13 (55)

^a Determined from $T_{50} - 60^\circ\text{F}$ ($T_{68} - 33^\circ\text{C}$) using average curve fit, where T_{50} is the temperature corresponding to 50 ft-lb.

^b Determined from $T_{50} - 60^\circ\text{F}$ ($T_{68} - 33^\circ\text{C}$) using minimum curve fit, where T_{50} is the temperature corresponding to 50 ft-lb.

Table 22. Summary of mean hyperbolic tangent curve fit results and 68% confidence bounds on predicted value for Charpy energy, RT_{NDT} , and RT_M results for two sections of the Midland reactor nozzle course weld

Section	Charpy Transition Temperature °C (°F) for Given Energy									Upper-shelf energy J (ft-lb)			RT_M , ^a °C (°F)			RT_{NDT} , ^b °C (°F)
	27J (20ft-lb)			41J (30 ft-lb)			68J (50 ft-lb)			-68%	Model	68%	-68%	Model	68%	Min
	-68%	Model	68%	-68%	Model	68%	-68%	Model	68%							
3-1	-36 (-33)	-23 (-9)	-12 (11)	-11 (13)	-1 (31)	9 (48)	30 (85)	42 (107)	57 (134)	81 (60)	88 (65)	95 (70)	-4 (25)	8 (47)	23 (74)	16 (62)
3-4	-40 (-40)	-27 (-16)	-15 (5)	-12 (10)	-2 (29)	8 (47)	34 (94)	47 (117)	64 (147)	81 (59)	87 (64)	94 (69)	1 (34)	14 (58)	31 (87)	26 (79)

^a Determined from $T_{50} - 60^\circ\text{F}$ ($T_{68} - 33^\circ\text{C}$) using average curve fit, where T_{50} is the temperature corresponding to 50 ft-lb.

^b Determined from $T_{50} - 60^\circ\text{F}$ ($T_{68} - 33^\circ\text{C}$) using minimum curve fit, where T_{50} is the temperature corresponding to 50 ft-lb.

Table 23. Summary of mean hyperbolic tangent curve fit results and 95% confidence bounds on predicted value for Charpy energy, RT_{NDT} , and RT_M results for two sections of the Midland reactor nozzle course weld

Section	Charpy Transition Temperature °C (°F) for Given Energy									Upper-shelf energy J (ft-lb)			RT_M , ^a °C (°F)			RT_{NDT} , ^b °C (°F)
	27J (20ft-lb)			41J (30 ft-lb)			68J (50 ft-lb)			-95%	Model	95%	-95%	Model	95%	Min
	-95%	Model	95%	-95%	Model	95%	-95%	Model	95%							
3-1	-54 (-65)	-23 (-9)	-2 (29)	-22 (-8)	-1 (31)	19 (66)	19 (66)	42 (107)	80 (176)	74 (55)	88 (65)	103 (76)	-15 (6)	8 (47)	47 (116)	16 (62)
3-4	-58 (-73)	-27 (-16)	-4 (24)	-24 (-11)	-2 (29)	19 (66)	22 (72)	47 (117)	90 (193)	74 (54)	87 (64)	100 (74)	-11 (12)	14 (57)	56 (133)	26 (79)

^a Determined from $T_{50} - 60^\circ\text{F}$ ($T_{68} - 33^\circ\text{C}$) using average curve fit, where T_{50} is the temperature corresponding to 50 ft-lb.

^b Determined from $T_{50} - 60^\circ\text{F}$ ($T_{68} - 33^\circ\text{C}$) using minimum curve fit, where T_{50} is the temperature corresponding to 50 ft-lb.

Table 24. Summary of mean hyperbolic tangent curve fits and 95% confidence bounds on predicted value for Charpy energy, RT_{NDT} , and RT_M results for the beltline and nozzle course welds and for the combined data set

Section	Charpy Transition Temperature °C (°F) for Given Energy									Upper-shelf energy J (ft-lb)			RT_M ^a °C (°F)			RT_{NDT} ^b °C (°F)	RT_{LB} ^c °C (°F)
	27J (20ft-lb)			41J (30 ft-lb)			68J (50 ft-lb)									Min	Min
	-95%	Model	95%	-95%	Model	95%	-95%	Model	95%	-95%	Model	95%	-95%	Model	95%		
Beltline	-77 (-107)	-29 (-20)	-3 (27)	-37 (-35)	-9 (15)	15 (60)	1 (33)	28 (82)	100 (213)	70 (51)	89 (66)	108 (80)	-33 (-27)	-6 (22)	67 (153)	15 (58)	35 (95)
Nozzle	-53 (-64)	-25 (-12)	-4 (24)	-21 (-6)	-1 (30)	18 (64)	22 (71)	44 (112)	81 (177)	75 (55)	88 (65)	100 (74)	-11 (11)	11 (52)	47 (117)	25 (76)	29 (84)
All	-75 (-103)	-28 (-19)	-2 (28)	-36 (-32)	-8 (17)	17 (62)	3 (38)	31 (87)	101 (213)	70 (52)	89 (65)	107 (79)	-30 (-27) 2	-3 (27)	67 (153)	15 (59)	35 (95)

NOTE: All temperatures have been rounded to the nearest degree.

^a Determined from $T_{50} - 60^\circ\text{F}$ ($T_{68} - 33^\circ\text{C}$) using average curve fit, where T_{50} is the temperature corresponding to 50 ft-lb.

^b Determined from $T_{50} - 60^\circ\text{F}$ ($T_{68} - 33^\circ\text{C}$) using minimum curve fit, where T_{50} is the temperature corresponding to 50 ft-lb.

^c Determined from $T_{50} - 60^\circ\text{F}$ ($T_{68} - 33^\circ\text{C}$) using lower bound curve fit, where T_{50} is the temperature corresponding to 50 ft-lb.

corresponding 41-J temperature. It is also interesting that the RT_{NDT} , 15°C (59°F), is at a lower temperature than even the 68% lower confidence bound for RT_M , 18°C (64°F), and far lower than the 95% lower confidence bound for RT_M , 67°C (153°F).

The variations shown by the 95% confidence bounds are compared in Table 26 to those from welds 72W and 73W tested in the HSSI Fifth Irradiation Series,^{12,13} a high upper-shelf submerged-arc weld, using weld wire fabricated with copper in the melt, not a copper-coated wire. The 41-J (30 ft-lb) temperature interval of 53°C (94°F) for the Midland weld compares with intervals of 76 and 54°C (136 and 97°F) for welds 72W and 73W, respectively, while the upper-shelf energy bounds are very similar in terms of percent of mean upper-shelf energy.

Figures 24(a) through (c) graphically depict the through-thickness variation of the 41-J (30 ft-lb) temperature, upper-shelf energy, and RT_{NDT} , respectively, for the beltline weld sections, while Figures 25(a) through (c) show the same series for the nozzle course weld sections. There does not appear to be a consistent trend of through-thickness behavior in either case.

Chemical Composition

Bulk Analyses

Regarding chemical composition, fracture surfaces were cut off CVN specimens from the various locations and submitted for chemical analyses to Combustion Engineering, Inc., Chattanooga, Tennessee, or MQS Inspection, Inc., Woodlawn, Ohio. The first section to be analyzed was beltline weld section 1-13, and the results are shown in Table 27. The carbon contents at 2D and 2E are higher than for the other locations. Those locations are in the root region of the weld where manual metal-arc welding (MMA) was performed prior to grinding and submerged-arc welding (SAW). The MMA electrodes have lower carbon content than does the wire used for the SAW welds, and the higher carbon contents at those locations are likely the result of carbon pickup from the higher carbon base metal. The other major

alloying elements are present in typical amounts and are fairly consistent through the weld thickness.

The copper contents in section 1-13 range from 0.21 to 0.32 wt % (mean value of 0.25 wt %). Those values are substantially lower than those reported by B&W in BAW-1799 for WF-70. They are, however, consistent with the copper content reported in the weld wire qualification record, 0.27 wt %. Both of those B&W reported analyses for WF-70 are shown in Table 27 for comparison. As mentioned earlier, the PR-EDB gives 0.42 wt % for the WF-70 weld of Midland Unit 1. Because the copper contents obtained for section 1-13 in this study were relatively low, Combustion Engineering was asked to recheck them. Their recheck procedure incorporated two different measurement techniques, optical emission spectrometry and X-ray fluorescence, as well as measurements on five different National Institute of Standards and Technology (NIST) standards. The recheck analyses validated the original copper determinations.

Subsequent analyses of the other three beltline weld sections confirmed the relatively low mean copper contents in the beltline region, while analyses of the two nozzle course sections confirmed the higher copper contents reported by B&W and given in the PR-EDB. The B&W analyses were conducted with material removed from nozzle course dropouts, so their analyses also represented the nozzle course weld. Appendix C provides tables of all the chemical analysis results, while Table 28 gives a summary of the analyses for the beltline and nozzle welds. Table 28 shows that the copper content ranges from 0.21 to 0.34% in the beltline weld, and from 0.37 to 0.46% in the nozzle course weld. The results shown are all in good agreement with those reported by Moore, Heller, and Lowe¹⁴ for a WF-70 nozzle belt dropout, except that the copper content in the beltline weld is substantially less than their value of 0.42%. Except for section 1-15, Figure 26(a) shows that there does appear to be a trend of increasing copper content through the thickness of the beltline weld. Figure 26(b) shows the disparity in copper contents between welds WF-67 and WF-70 in the nozzle course weld, but the through-thickness trend in the WF-70 portion is relatively constant in spite of the fairly wide range shown by

Table 25. Summary of mean hyperbolic tangent curve fits and various confidence bounds on predicted value for Charpy energy, RT_{NDT} , and RT_M results for the combined beltline and nozzle course welds

Conf. Interval	Charpy Transition Temperature °C (°F) for Given Energy									Upper-shelf energy J (ft-lb)			RT_M , ^a °C (°F)			RT_{NDT} , ^b °C (°F)
	27J (20ft-lb)			41J (30 ft-lb)			68J (50 ft-lb)			-CI	Model	+CI	-CI	Model	+CI	Min
	-CI	Model	+CI	-CI	Model	+CI	-CI	Model	+CI							
68%	-46 (-50)	-28 (-19)	-15 (6)	-21 (-6)	-8 (17)	4 (39)	16 (60)	31 (87)	51 (124)	79 (58)	89 (65)	98 (72)	-18 (0)	-3 (27)	18 (64)	15 (59)
90%	-63 (-81)	-28 (-19)	-6 (21)	-31 (-23)	-8 (17)	12 (54)	7 (45)	31 (87)	75 (168)	73 (54)	89 (65)	104 (77)	-26 (-15)	-3 (27)	42 (108)	15 (59)
95%	-75 (-103)	-28 (-19)	-2 (28)	-36 (-32)	-8 (17)	17 (62)	3 (38)	31 (87)	101 (213)	70 (52)	89 (65)	107 (79)	-30 (-22)	-3 (27)	67 (153)	15 (59)
99%	-160 (-257)	-28 (-19)	5 (41)	-48 (-54)	-8 (17)	26 (78)	-4 (24)	31 (87)	Undefined Undefined	64 (47)	89 (65)	113 (83)	-38 (-36)	-3 (27)	Undefined Undefined	15 (59)

^a Determined from $T_{50} - 60^\circ\text{F}$ ($T_{68} - 33^\circ\text{C}$) using average curve fit, where T_{50} is the temperature corresponding to 50 ft-lb.

^b Determined from $T_{50} - 60^\circ\text{F}$ ($T_{68} - 33^\circ\text{C}$) using minimum curve fit, where T_{50} is the temperature corresponding to 50 ft-lb.

Table 26. Comparison of mean hyperbolic tangent curve fits and 95% confidence bounds on predicted value for combined Midland beltline and nozzle course welds (MW) with welds 72W and 73W from HSSI Fifth Irradiation Series

Section	Charpy Transition Temperature °C (°F) for Given Energy									Upper-shelf energy J (ft-lb)			RT _M ^a °C (°F)			RT _{NDT} ^b °C (°F)
	27J (20ft-lb)			41J (30 ft-lb)			68J (50 ft-lb)			-95%	Model	95%	-95%	Model	95%	Min
	-95%	Model	95%	-95%	Model	95%	-95%	Model	95%							
MW	-75 (-103)	-28 (-19)	-2 (28)	-36 (-32)	-8 (17)	17 (62)	3 (38)	31 (87)	101 (213)	70 (52)	89 (65)	107 (79)	-30 (-22)	-3 (27)	67 (153)	15 (59)
72W	Undefined Undefined	-43 (-46)	-13 (8)	-78 (-108)	-28 (-18)	-2 (28)	-32 (-26)	-6 (22)	21 (69)	105 (78)	136 (101)	168 (124)	-66 (-86)	-39 (-38)	-13 (9)	-32 (-25)
73W	Undefined Undefined	-54 (-66)	-30 (-21)	-73 (-99)	-39 (-39)	-19 (-2)	-38 (-36)	-17 (1)	3 (38)	109 (81)	135 (99)	160 (118)	-71 (-96)	-51 (-59)	-30 (-22)	-48 (-54)

^a Determined from T₅₀ - 60°F (T₆₈ -33°C) using average curve fit, where T₅₀ is the temperature corresponding to 50 ft-lb.

^b Determined from T₅₀ - 60°F (T₆₈ -33°C) using minimum curve fit, where T₅₀ is the temperature corresponding to 50 ft-lb.

Figure 24. Plots of through-thickness Charpy impact results for the Midland beltline weld sections: (a) 41-J temperature, (b) upper-shelf energy, and (c) RT_{NDT} .

Figure 24. contd.

Figure 25. Plots of through-thickness Charpy impact results for the Midland nozzle course weld sections: (a) 41-J temperature, (b) upper-shelf energy, and (c) RT_{NDT} .

Figure 25. contd.

Table 27. Chemical composition of Midland reactor weld section 1-13

Set	Chemical composition (wt %)																				
	C	Mn	P	S	Si	Cr	Ni	Mo	Cu	V	Nb	Ti	Co	Al	B	W	Sb	As	Sn	Zr	N
1	0.074	1.60	0.015	0.008	0.58	0.11	0.58	0.40	0.24	0.005	0.002	<0.001	0.015	0.020	<0.001	<0.01	-	0.003	0.003	<0.001	0.017
2D	0.11	1.45	0.018	0.008	0.65	0.14	0.61	0.42	0.21	0.005	0.003	<0.001	0.015	0.008	<0.001	<0.01	-	0.007	0.004	<0.001	0.016
2E	0.11	1.49	0.016	0.008	0.57	0.14	0.63	0.43	0.22	0.005	0.003	<0.001	0.014	0.013	<0.001	<0.01	-	0.007	0.004	<0.001	0.015
3	0.075	1.60	0.018	0.009	0.65	0.11	0.60	0.41	0.25	0.005	0.003	<0.001	0.015	0.017	<0.001	<0.01	-	0.006	0.004	<0.001	0.019
4	0.079	1.61	0.022	0.010	0.67	0.11	0.60	0.41	0.32	0.005	0.003	<0.001	0.016	0.015	<0.001	<0.01	-	0.007	0.004	<0.001	0.018
WQ ^a	0.070	1.60	0.014	0.011	0.48		0.46	0.40	0.27												
BW ^b	0.09	1.63	0.018	0.009	0.54	0.11	0.59	0.40	0.42												

^aFrom B&W weld wire qualification report^bFrom BAW-1799 giving extensive chemical analyses

Table 28. Summary of major radiation sensitive elements for Midland Unit 1 reactor vessel welds

Section number	n ^a	Element, wt % ± 1σ				
		Cu ^b	Ni	P	Mn	Si
<u>Beltline weld</u>						
1-9	8	0.26 ± 0.041 (0.22-0.34)	0.566 ± 0.031	0.016 ± 0.0013	1.629 ± 0.050	0.605 ± 0.031
1-11	8	0.258 ± 0.027 (0.23-0.31)	0.57 ± 0.007	0.016 ± 0.0014	1.615 ± 0.015	0.62 ± 0.029
1-13	5	0.248 ± 0.039 (0.21-0.32)	0.604 ± 0.016	0.018 ± 0.002	1.55 ± 0.067	0.62 ± 0.041
1-15	7	0.254 ± 0.026 (0.22-0.29)	0.567 ± 0.009	0.018 ± 0.0013	1.614 ± 0.014	0.644 ± 0.016
Average	28	0.256 ± 0.034 (0.21-0.34)	0.574 ± 0.023	0.017 ± 0.0019	1.607 ± 0.049	0.622 ± 0.033
<u>Nozzle course weld</u>						
3-1	4	0.398 ± 0.034 (0.37-0.46)	0.576 ± 0.021	0.015 ± 0.001	1.59 ± 0.045	0.548 ± 0.051
3-4	5	0.392 ± 0.016 (0.38-0.42)	0.567 ± 0.008	0.015 ± 0.002	1.61 ± 0.018	0.55 ± 0.043
Average	9	0.396 ± 0.028 (0.37-0.46)	0.572 ± 0.017	0.015 ± 0.002	1.59 ± 0.037	0.55 ± 0.048
Total average	37	0.290 ± 0.068 (0.21-0.46)	0.574 ± 0.022	0.016 ± 0.002	1.604 ± 0.046	0.605 ± 0.048

^aNumber of measurements.

^bRange of copper shown in parentheses.

Figure 26. Plots of through-thickness copper content for the Midland reactor WF-70 welds: (a) beltline weld sections and (b) nozzle course weld sections.

the individual measurements. Figure 27 is reproduced from BAW-1799 (ref. 3), in which a large number of chemical composition analyses of various LUS welds were reported, and shows results for WF-70 similar to those obtained in this study for the nozzle course weld.

Electron Microprobe Analyses

Electron microprobe analyses were conducted to examine elemental variation across the width of the weld. The beltline weld was examined at the 1/4t and 1/2t locations, while the nozzle course weld was examined at the 3/4t location. A 10- μm spot was used at 200- μm intervals across the weld; thus, nearly 100 measurements were made in each case. The results are summarized in Table 29. In the beltline weld, at the 1/4t location, 88 measurements showed a range of copper from 0.09 to 0.40% with a mean copper content of 0.238% and a standard deviation of 0.061%. Similarly, at the 1/2t depth, the mean copper content was 0.243 with similar standard deviation and range of values. The mean values are in good agreement with the bulk analyses given in Table 28 but do emphasize the variation that exists on the microstructural level. For the nozzle course weld, the mean copper level of 0.340 is somewhat below the 0.396% observed with bulk analyses but does confirm the higher copper in the nozzle course weld. In both welds, the nickel contents are in reasonably good agreement with the bulk analyses. The microprobe analyses of P, Mn, and Si are also in reasonably good agreement with those from the bulk analyses.

Atom Probe-Field Ion Microscope Analyses

In addition to the optical microscopy, bulk chemical analyses, and microprobe analyses reported above, atom probe field ion microscopy (APFIM) analysis of the beltline weld was performed. The APFIM analyses were conducted to characterize the nature of precipitates or clusters, especially those of copper, in the microstructure and to compare the matrix copper content with the bulk content. Similar APFIM analyses will be conducted with the nozzle course welds and with both welds in the post-irradiated condition. High-quality field ion micrographs of the

weld were obtained as shown in Figures 28(a) through (e). No evidence of darkly imaging copper precipitates or clusters was observed in any of the weld samples. Some ultrafine, brightly imaging refractory carbides were observed, as shown in Figures 28(c) and (e); these carbides were observed in all five samples, but the field ion micrographs which were printed did not always have them in the field of view. The carbides were roughly spherical and approximately 1 nm in diameter. Similar ultrafine carbides have been observed in irradiated A 302, grade B steel¹⁵ and irradiated A 533, grade B, class 1 steel.¹⁶

The average composition of the five beltline weld samples (from the regions of section 1-13 identified in Figure 7) were determined in the ORNL energy-compensated atom probe and are summarized in Table 30. The matrix copper ranges from about 0.07 to 0.13 wt % with a mean value of 0.11 wt%. The results indicate that there was generally a substantial depletion in the copper in the matrix over the bulk chemical analysis (which ranged from 0.21 to 0.32 wt %). This behavior has been observed previously in other reactor steels and is due to copper precipitation at grain boundaries and other microstructural features during the postweld heat treatment.¹⁶ The Midland reactor vessel beltline weld was given a postweld heat treatment at 607°C (1125°F) for about 22.5 h (ref. 5).

The atom probe composition data were subjected to statistical analysis to determine whether the copper was in random solid solution in the matrix or whether clustering had occurred. The results of the significance of the mean separation of the copper atoms in the atom probe ion-by-ion data chain is given in Table 31. Two results are given for each specimen. In this type of analysis, significance of greater than 2.0 indicates that clustering had occurred. In these Midland beltline weld samples, no deviation from a random solid solution was detected. The atom probe data were also analyzed in terms of the Johnston and Klotz order parameter, and, again, the results indicated no deviation from a random solid solution. Thus, because the matrix is substantially depleted in copper, fine copper precipitation occurred during the PWHT but, as shown in the field ion micrographs, copper clustering did not.

Figure 27. Plots of through-thickness copper content for a nozzle dropout with WF-70 weld as reported in BAW-1799.

Table 29. Results of electron microprobe analyses
of Midland Unit 1 reactor vessel welds

	Beltline weld 1/4t (wt %)		Beltline weld 1/2t (wt %)		Nozzle weld 3/4t (wt %)	
	Cu	Ni	Cu	Ni	Cu	Ni
Mean	0.238	0.514	0.243	0.567	0.340	0.541
Standard deviation	0.061	0.056	0.057	0.053	0.045	0.045
Min	0.09	0.39	0.11	0.45	0.21	0.34
Max	0.40	0.65	0.37	0.68	0.43	0.66
Number of measurements	88	88	74	74	96	96

Table 29. Results of electron microprobe analyses
of Midland Unit 1 reactor vessel welds

	Beltline weld 1/4t (wt %)		Beltline weld 1/2t (wt %)		Nozzle weld 3/4t (wt %)	
	Cu	Ni	Cu	Ni	Cu	Ni
Mean	0.238	0.514	0.243	0.567	0.340	0.541
Standard deviation	0.061	0.056	0.057	0.053	0.045	0.045
Min	0.09	0.39	0.11	0.45	0.21	0.34
Max	0.40	0.65	0.37	0.68	0.43	0.66
Number of measurements	88	88	74	74	96	96

(a)

Figure 28. Field-ion micrographs of Midland beltline weld section 1-13 at the various through-thickness regions shown in Figure 7: (a) Region 1, (b) Region 2D, (c) Region 2E, (d) Region 3, and (e) Region 4. Ultrafine, brightly imaging refractory carbides, roughly spherical and approximately 1 nm in diameter, were observed in all five samples but are only evident (indicated by arrows) in the micrographs shown in (c) and (e).

L653-25

(b)

L626-7

(c)

Figure 28. contd.

L645-5

(d)

L624.1-12

(e)

Figure 28. contd.

**Table 30. Atom probe analysis of the matrix composition
for Midland reactor weld section 1-13**

Material	Composition (at. %)									
	Cu	Ni	Mn	Mo	Cr	Co	Si	P	C	Fe
1	0.09	0.49	1.45	0.14	0.28	0.01	1.16	0.01	0.05	bal
error	0.04	0.09	0.16	0.04	0.09	0.01	0.15	0.01	0.03	
2D	0.11	0.59	1.39	0.23	0.08	0.02	1.57	0.06	0.02	bal
error	0.02	0.06	0.09	0.04	0.02	0.01	0.09	0.02	0.01	
2E	0.11	0.64	1.38	0.15	0.07	0.01	1.25	0.03	0.01	bal
error	0.04	0.08	0.12	0.04	0.03	0.01	0.12	0.01	0.01	
3	0.06	0.45	1.22	0.36	0.18	0.04	1.60	0.05	0.16	bal
error	0.06	0.17	0.29	0.16	0.11	0.02	0.32	0.04	0.09	
4	0.11	0.58	1.28	0.12	0.05	0.02	1.35	0.004	0.004	bal
error	0.02	0.05	0.07	0.02	0.01	0.01	0.07	0.003	0.003	

Material	Composition (wt %)									
	Cu	Ni	Mn	Mo	Cr	Co	Si	P	C	Fe
1	0.10	0.52	1.43	0.24	0.26	0.01	0.59	0.006	0.011	bal
error	±0.04	0.09	0.16	0.08	0.09	0.01	0.07	0.006	0.006	
2D	0.13	0.62	1.38	0.40	0.08	0.02	0.80	0.033	0.004	bal
error	±0.02	0.06	0.09	0.08	0.02	0.01	0.04	0.01	0.002	
2E	0.13	0.68	1.37	0.26	0.07	0.01	0.63	0.017	0.002	bal
error	±0.04	0.08	0.12	0.08	0.03	0.01	0.06	0.006	0.002	
3	0.07	0.48	1.21	0.62	0.17	0.04	0.81	0.028	0.035	bal
error	±0.06	0.17	0.29	0.32	0.11	0.02	0.16	0.02	0.020	
4	0.13	0.61	1.27	0.21	0.05	0.02	0.68	0.002	0.001	bal
error	±0.02	0.05	0.07	0.02	0.01	0.01	0.07	0.003	0.003	

Table 31. Significances of the mean
separation of copper atoms

Material	Separation significance (Johnson/Klotz order parameter)
1	0.29 (-0.55)
2D	-0.81 (0.19)
2E	0.26 (-0.64)
3	-0.35 (-0.50)
4	0.18 (0)

Discussion

The B&W "Record of Filler Wire Qualification Test" is given in Appendix A. It shows results of CVN testing at 10°F (-12°C) as 35, 39, and 44 ft-lb (47, 53, and 60 J). Those results are somewhat above most of the curves reported here. The qualification record shows the qualification weld was postweld heat treated at 1100 to 1150°F (593 to 621°C) for 48 h. BAW-2070 reports that the Midland beltline weld received 22 h and 36 min at 1125 ± 25°F (607 ± 14°C), while the nozzle course weld received 25 h and 31 min at the same temperature. The slight differences between the Midland weld results obtained in this study and the weld qualification results would likely be mitigated if the Midland weld received a total of 48-h heat treatment. The shorter postweld heat treatment (PWHT) given the vessel welds would likely result in somewhat higher strength and higher transition temperature than that reported in the qualification tests (see the earlier section on Description of Weldments), and that is borne out by the nozzle course weld, which has a higher yield strength than reported in the weld qualification, but is similar to that reported by Lowe⁴ for one WF-70 weld. It is not clear, however, why the beltline weld, which received a PWHT only 3 h less than that of the nozzle course weld, would have a yield strength significantly less than that of the nozzle course weld. As stated earlier, this observation will be verified with tensile tests of the beltline weld.

The issue of RT_{NDT} determination is important for steels like the WF-70 weld because the RT_{NDT} is defined by the CVN toughness rather than the drop-weight NDT. The ASME Code paragraph discussed earlier is not perfectly clear as to the procedure to be used for such a determination. It requires the construction of a full Charpy curve from the minimum data points of all the C_v tests conducted. Strictly speaking, because Para. NB-2321 in the code defines a C_v test as three tested specimens, the above paragraph would require one to use the minimum value from each of those groups of three specimens; however, since it only requires C_v tests at $NDT + 60^\circ\text{F}$ or higher, one could not really develop a full C_v impact curve. On the other hand, the code allows determination of the RT_{NDT} when a C_v test has not been conducted at $NDT + 60^\circ\text{F}$. It also is not clear how one should develop a curve from the minimum data points. It could be

interpreted to be a best fit or an absolute lower bound. For consistency of RT_{NDT} determination, a clearer procedure needs to be developed and incorporated into relevant regulatory documents. Even from the analyses of the individual data sets, it is clear that substantial differences in RT_{NDT} can result depending on individual interpretation of the intended procedure. The data from the 7/8t location in beltline weld section 1-11 provide one example of this; Figure 29 shows the curve fits to all the data, to the minimum data as discussed previously, and a lower boundary curve. The lower boundary curve is about midway between the lower 68 and 95% confidence bounds. If the code paragraph is interpreted to mean the construction of a curve which encompasses all the data, the RT_{LB} for the data in Figure 29 would be about 29°C (84°F). That compares to an RT_{NDT} value of about 18°C (65°F) using the curve fit to the minimum data. The result depends, of course, on the actual construction of the lower boundary curve (e.g., smooth curve or point to point) as well, in that there is no guidance regarding its shape and, therefore, the 50-ft-lb (68-J) temperature could vary widely. For the individual beltline data sets, the RT_M ranged from 23°C (42°F) lower to 7°C (13°F) higher than the corresponding values of RT_{NDT} . For the individual nozzle course data sets, which generally had even fewer test results in each data set, there were no differences. A comparison of RT_{NDT} and RT_{LB} values shows that RT_{LB} ranged from 21°C (38°F) higher to 8°C (14°F) lower than the corresponding values of RT_{NDT} . Thus, the method used for determination of such an index is also dependent on the number of test results in the data set.

As seen in this study, small data sets for the same weld can result in substantial differences in determination of a transition temperature. The incorporation of statistical methods such as confidence bounds to be applied to the data would require a more well-defined prescription for the selection of test temperatures and number of tests. On the other hand, one could prescribe a value of deviation, based on documented behavior of welds and of base metals, which could be added to the mean value determined from a curve fit to the data. The prescription must be chosen, of course, based on the desired confidence level, such as 95%. There are other potential methods, but they are dependent on various judgments that can result in significantly different results.

ANALYSIS SET: MW11_78T

MODEL PARAMETERS

LOWER SHELF ENERGY [HELD FIXED]: 2.7 (J), 2 (FT-LB)

MID-TRANSITION TEMPERATURE: -14 (DEG C), 6.8 (DEG F)

TRANSITION ZONE WIDTH: 96.8 (C DEG), 174.3 (F DEG)

UPPER SHELF ENERGY: 78.5 (J), 57.9 (FT-LB)

STANDARD MODEL: $\text{ENERGY} = A + B \cdot \tanh((\text{TEMPERATURE} - T_0) / C)$

A: 40.6 (J), 30 (FT-LB)

B: 37.9 (J), 28 (FT-LB)

T0: -14 (DEG C), 6.8 (DEG F)

C: 48.4 (C DEG), 87.1 (F DEG)

UPPER SHELF ENERGY: 78.5 (J), 57.9 (FT-LB)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 62.7 TO 94.4 (J), 46.3 TO 69.6 (FT-LB)

95 PERCENT: 43.6 TO 113.5 (J), 32.2 TO 83.7 (FT-LB)

TEMPERATURE [27 (J), 19.9 (FT-LB) ENERGY]: -32.2 (DEG C), -26 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -65.4 TO -12.1 (DEG C), -85.8 TO 10.2 (DEG F)

95 PERCENT: UNDEFINED TO 13.9 (DEG C), UNDEFINED TO 57 (DEG F)

TEMPERATURE [41 (J), 30.2 (FT-LB) ENERGY]: -13.5 (DEG C), 7.6 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -37.1 TO 6.8 (DEG C), -34.8 TO 44.2 (DEG F)

95 PERCENT: -78.8 TO 51.5 (DEG C), -109.8 TO 124.7 (DEG F)

TEMPERATURE [68 (J), 50.2 (FT-LB) ENERGY]: 30.1 (DEG C), 86.2 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 2.6 TO UNDEFINED (DEG C), 36.6 TO UNDEFINED (DEG F)

95 PERCENT: -25.2 TO UNDEFINED (DEG C), -13.4 TO UNDEFINED (DEG F)

REFERENCE TEMPERATURE ANALYSIS

MEAN IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY] -60 (DEG F): -3.8 (DEG C), 25.2 (DEG F)

MINIMUM IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY] -60 (DEG F): 18.5 (DEG C), 65.2 (DEG F)

REMARK: MIDLAND WELD BELTLINE 1-11, FROM 7/8 THICKNESS OF WELD

Figure 29. Comparison of various curve fits to the Charpy impact data from the 7/8 thickness location of Midland beltline weld section 1-11. Shown are the hyperbolic tangent curve fits to all the data and to the minimum data points, and a curve constructed as a lower boundary to all the data, and the 68 and 95% confidence bounds on the predicted value.

As pointed out earlier, 10CFR50 states that a value of 0°F (-18°C) must be used as the RT_{NDT} for a Linde 80 weld if no credible measured value is available. For the three WF-70 welds referred to by Lowe,⁴ the RT_{NDT} values are 14, 23, and 51°C (58, 74, and 123°F, respectively). In this study of the Midland Unit 1 WF-70 welds, the RT_{NDT} (determined from a hyperbolic tangent curve fit to the minimum data points) varied from -20 to 37°C (-3 to 99°F) for the 25 individual Charpy impact curves examined. For the same 25 data sets, the RT_{LB} (determined from the absolute lower bound to the data) varied from -21 to 35°C (-6 to 95°F). In SECY-82-465 (ref. 17), a standard deviation of 17°F (9°C) is given for Linde 80 welds. For the 25 values of RT_{NDT} in this study, the mean value is about 4°C (39°F) with a standard deviation of 14°C (25°F). Similarly, the mean value of upper-shelf energy is 88 J (65 ft-lb) with a standard deviation of 7.3 J (5.4 ft-lb). Using a curve fit to the minimum data for the entire midland weld data set, the RT_{NDT} would be 15°C (59°F). Using the absolute lower bound, the RT_{LB} would be 35°C (95°F), about midway in the range reported by Lowe.⁴ Using a mean curve fit to the entire data set, the RT_M would be -3°C (27°F) with lower 68 and 95% confidence values of 18°C (64°F) and 67°C (153°F) respectively. Thus, the temperature interval between the mean and lower confidence bound associated with one standard deviation on energy is about 21°C (37°F). The RT_{NDT} value of 15°C (59°F) is similar to the 68% confidence bound on the mean curve, 18°C (64°F). Similarly, the overall RT_{LB} value of 35°C (95°F) is close to the 90% confidence bound on the mean curve, 42°C (108°F). Regarding the 41-J (30 ft-lb) and 68-J (50 ft-lb) temperatures of -8°C (17°F) and 31°C (87°F), respectively, for the mean curve to the total data set, they are less than all the values reported by Lowe.⁴ His reported values, however, are within the 95% confidence bounds for the Midland data reported here.

The fact that the RT_{NDT} values vary from -20 to 37°C (-3 to 99°F) warrants further consideration relative to both the unirradiated and irradiated test programs. The testing of multiple specimens to allow for statistical analyses is an integral part of the current planned program as is the testing and irradiation of fairly large specimens. The location in the weld from which specimens are machined will, of course, influence the unirradiated properties; however, because there was not a

consistent trend of RT_{NDT} , 41-J temperature, or upper-shelf energy with depth in the welds, one reference RT_{NDT} and 41-J temperature for the beltline weld and one of each for the nozzle weld will be used. It is very interesting that, despite the large scatter in these welds, the 95% confidence interval is similar to the relatively homogenous welds 72W and 73W that were fabricated with copper contained in the weld wire and not as a coating as was used for the Midland welds.

The wide variation in copper content, however, will further complicate the analysis of radiation effects. This is particularly true regarding the differences between the beltline and nozzle course welds. Those differences will require the irradiation program to consider the welds as two different materials. Additionally, if 4T compact specimens are used in the program, the mechanical property and copper variations present in the weld will exist in individual specimens. The fact that this weld represents a real reactor vessel was the primary motivation for the study, yet the apparent variation in properties and copper content will only exacerbate the large variations already observed in relatively homogeneous materials. This does not necessarily render the study less useful, but it does require a different approach to the conduct of the program.

Observations and Conclusions

The major observations and conclusions from this study are as follows:

1. Drop-weight NDT temperatures from various through-thickness positions in the beltline and nozzle course welds varied from -40 to -60°C (-49 to -67°F).
2. The RT_{NDT} values (determined from a hyperbolic tangent fit to the minimum data in each case) in all 25 individual cases are controlled by the CVN impact energy and vary from -20 to 37°C (-4 to 99°F), with a mean value of about 4°C (39°F) and a standard deviation of 14°C (25°F). From a mean curve fit to the entire data set, the RT_M is -3°C (27°F) with a temperature interval between the mean and lower confidence bound associated with one standard deviation on energy of about 21°C (37°F). For the same 25 data sets, the

RT_{LB} values (determined from the absolute lower bound in each case) vary from -21 to 35°C (-6 to 95°F) with a mean value of about 9°C (47°F) and a standard deviation of 16°C (29°F).

3. Analysis of the combined data from both beltline and nozzle course welds revealed a mean 41-J temperature of -8°C (17°F). Statistical analyses of the combined data (279 tests) show a 95% confidence temperature interval from -36 to 17°C (-32 to 62°F) at the 41-J energy level; that 53°C (94°F) interval width is similar to those observed for welds 72W and 73W in the HSSI Fifth Irradiation Series.
4. Analysis of the combined data set for the beltline and nozzle course welds (279 Charpy impact tests) gives a RT_M [50 ft-lb (68-J) temperature from the mean curve fit less 60°F (33°C)] result of -3°C (27°F) with lower 68 and 95% confidence bounds of 18 and 67°C (64 and 153°F), respectively.
5. The ASME Code procedure for determination of RT_{NDT} is unclear, and different interpretations can result in substantially different results, depending on the nature of the data.
6. Upper-shelf energies for 25 data sets vary from 77 to 108 J (57 to 80 ft-lb) with a mean value of 88 J (65 ft-lb) and a standard deviation of 7.3 J (5.4 ft-lb). Analysis of the combined data from both beltline and nozzle course welds revealed a mean upper-shelf energy of 89 J (65 ft-lb) with 95% confidence bounds from 70 to 107 J (52 to 79 ft-lb).
7. Bulk copper contents range from 0.21 to 0.34% in the beltline weld (average is 0.26%) and from 0.37 to 0.46 wt % in the nozzle course weld (average is 0.40%); the overall average is 0.29% with a standard deviation of ±0.07%.
8. APFIM revealed no evidence of detectable (darkly imaging) copper precipitates or clusters but did indicate substantial depletion of copper in the matrix over the bulk chemical analysis. Thus, copper precipitation occurred on a very fine scale as a result of the PWHT, but copper clustering did not occur.

References

1. M. J. DeVan, L. B. Gross, and A. L. Lowe, Jr., *B&W Owner's Group Response to Generic Letter 92-01*, BAW-2166, B&W Nuclear Service Co., Lynchburg, Va., June 1992.*
2. F. W. Stallmann, F. B. K. Kam, and B. J. Taylor, Martin Marietta Energy Systems, Inc., Oak Ridge Natl. Lab., *PR-EDB: Power Reactor Embrittlement Data Base, Version 1*, USNRC Report NUREG/CR-4816 (ORNL/TM-10328), June 1990.*
3. K. E. Moore and A. S. Heller, *B&W 177-FA Reactor Vessel Beltline Weld Chemistry Study*, BAW-1799, B&W Company, Utility Power Generation Division, Lynchburg, Va., July 1983.*
4. A. L. Lowe, Jr., "Irradiation Characteristics of Weld Wire Heat Number 72105," pp. 292-308 in *Effects of Radiation on Materials: 15th International Symposium, ASTM STP 1125*, ed. R. E. Stoller, A. S. Kumar, and D. S. Gelles, American Society for Testing and Materials, Philadelphia, 1992.†
5. "Title 10," *Code of Federal Regulations*, Parts 0 to 50, U.S. Government Printing Office, Washington, D.C., January 1992.†
6. *Material Documentation Report for the Weld Material Removed From the Consumers Power (Midland) Reactor Vessel (620-0012-1)*, BAW-2070, B&W Company, Nuclear Power Division, Lynchburg, Va., January 1989.*
7. F. M. Haggag, R. K. Nanstad, J. T. Hutton, D. L. Thomas, and R. L. Swain, "Use of Automated Ball Indentation Testing to Measure Flow Properties and Estimate Fracture Toughness in Metallic Materials," pp. 188-208 in *Applications of Automation Technology to Fatigue and Fracture Testing, ASTM STP 1092*, ed. A. A. Braun, N. E. Ashbaugh, and F. M. Smith, American Society for Testing and Materials, Philadelphia, 1990.†

*Available in the NRC Public Document Room for inspection and copying for a fee.

†Available from public technical libraries.

*Available for purchase from National Technical Information Service, Springfield, VA 22161.

8. *Standard Test Method for Conducting Drop-Weight Test to Determine Nil-Ductility Transition Temperature of Ferritic Steels*, ASTM E 208-87, American Society for Testing and Materials, Philadelphia, 1990.[†]

9. *Standard Test Methods for Notched-Bar Impact Testing of Metallic Materials*, ASTM E 23-91, American Society for Testing and Materials, Philadelphia, 1991.[†]

10. *Standard Practice for Effects of High-Energy Neutron Irradiation on the Mechanical Properties of Metallic Materials*, E 706 (IB), ASTM E 184-79, American Society for Testing and Materials, Philadelphia, 1990.[†]

11. *ASME Boiler and Pressure Vessel Code. An American National Standard*, Section III, American Society of Mechanical Engineers, New York, 1989.[†]

12. R. K. Nanstad et al., "Effects of Radiation on K_{Ic} Curves for High-Copper Welds," pp. 214-33 in *Effects of Radiation on Materials: 14th International Symposium (Volume II)*, ASTM STP 1046, ed. N. H. Packan, R. E. Stoller, and A. S. Kumar, American Society for Testing and Materials, Philadelphia, 1990.[†]

13. R. K. Nanstad et al., Martin Marietta Energy Systems, Inc., Oak Ridge Natl. Lab., *Irradiation Effects on Fracture Toughness of Two High-Copper*

Submerged-Arc Welds, HSSI Series 5, USNRC Report NUREG/CR-5913 (ORNL/TM-12156), October 1992.*

14. K. E. Moore, A. S. Heller, and A. L. Lowe, Jr., "Chemical Composition of Nuclear Reactor Vessel Welds," pp. 1046-58 in *Effects of Radiation on Materials: Twelfth International Symposium*, ASTM STP 870, ed. F. A. Garner and J. S. Perrin, American Society for Testing and Materials, Philadelphia, 1985.[†]

15. M. K. Miller et al., pp. 523-28 in *Proceedings of the Second International Symposium on Environmental Degradation of Materials in Nuclear Power Systems-Water Reactors, Monterey 1985*, ed. J. T. A. Robert, J. R. Weeks, and G. Theus, American Nuclear Society, Hinsdale, Ill., 1985.[†]

16. M. K. Miller and M. G. Burke, "Microstructural Characterization of Irradiated PWR Steels Using the Atom Probe Field-Ion Microscope," pp. 143-49 in *Proceedings of the Third International Symposium on Environmental Degradation of Materials in Nuclear Power Systems - Water Reactors*, ed. G. J. Theus and J. R. Weeks, The Metallurgical Society, Inc., New York, 1987.[†]

17. USNRC, "Pressurized Thermal Shock (PTS)," SECY-82-465, Washington, D.C., November 23, 1982.*

*Available in the NRC Public Document Room for inspection and copying for a fee.

[†]Available from public technical libraries.

*Available for purchase from National Technical Information Service, Springfield, VA 22161.

[†]Available from public technical libraries.

APPENDIX A

B&W "RECORD OF FILLER WIRE QUALIFICATION TEST" - WELD WIRE 72105

REPORT OF FILLER WIRE QUALIFICATION TEST

TEST NO. WF-70

AMETER:	ELECTRODE SPECIFICATION AND WELDING PROCESS	FILLER WIRE IDENTIFICATION AND/OR FLUX	CORE WIRE HEAT NO.
1/8	Submerged Arc 2E4-142-6 & 156-6	AM Cham & Cable Mn-Mo-Ni GK 80 48xD Lot 8669	72105
P. ORDER NUMBER	TYPE OF CURRENT		AMPERES

WET BATCH EQUIVALENCY CHEMICAL ANALYSIS TESTS

[illegible]

TENSILE PROPERTIES

TEST NO.	HEAT TREATMENT	ULT. TEN. STR. PSI	YIELD POINT PSI	E-LONG IN 2" %	RED OF AREA %
WF-70	48 Hrs. at 1100-1150°F.	85,500	69,000	25.8	64.7

ARPY V-Notch IMPACT TEST @ ± 10 OF 240 FT/LB. ENERGY LOAD

HEAT TREATMENT	TEST NO.	FT/LB.	TEST NO.	FT. LB.
48 Hrs. at 1100-1150°F.	WF-70	39		
		35		
		44		

GUIDED BEND TESTS

GUIDED BEND TESTS		
FACE	ROOT	SIDE
N.R.	N.R.	N.R.

**MICRO OR MACRO
FISSURE ANALYSIS.**

N.R.

WE HEREBY CERTIFY THAT THE ABOVE MATERIAL HAS BEEN
TESTED IN ACCORDANCE WITH THE ABOVE LISTED SPECIFICA-
TION AND IS IN CONFORMANCE WITH ALL REQUIREMENTS.

MATERIAL APPROVAL

MATERIAL	APPROVAL	APPROVED	REJECTED
NAVSHIPS - 250/1500-1		X	
ASME - COMM'L NUCLEAR		X	
STEAM GENERATORS		N/A	

GROOVE WELD TEST

RADIOGRAPHIC EXAMINATION

FIRE FOLIO NO. 504-223
 LUX FOLIO NO. 499-063
 WORKS Mt. Vernon
 CONTRACT NO. _____

DATE 10/21/69
SIGNED Babcock & Wilcox Co.
INSPECTION AGENCY _____
INSPECTOR J. B. Toon
J. B. Toon

APPENDIX B

CHARPY V-NOTCH IMPACT DATA FOR UNIRRADIATED MIDLAND REACTOR VESSEL WELDS

APPENDIX B

CHARPY V-NOTCH IMPACT DATA FOR UNIRRADIATED MIDLAND REACTOR VESSEL WELDS

The Charpy V-Notch impact data for each individual test set are provided in separate tables in this appendix. The tables provide the specimen identification, absorbed energy, lateral expansion, and percent shear for each specimen at the indicated test temperature. The location in the vessel from which the specimens were removed is indicated in the identification of the Analysis Set given in the heading for each table. The following is an example of the code used in that identification:

ANALYSIS SET: MW914T

MW = Midland Weld Beltline Weld (NC = Nozzle Course)

9 = Weld Section (Sections 9, 11, 13, and 15 Are Beltline Welds; Sections 31 and 34 Are Nozzle Course Welds)

14 = Fractional Depth In Thickness From Inner Surface
In This Case It Is The 1/4 Depth

NOTE: Ignore any underline (e.g. MW15_78T).

SOURCE ■ ANALYSIS SET

ANALYSIS SETS

SET 1 ■ MW914T

SET 2 ■ NONE

SET ■ MW914T

REMARK ■ MIDLAND WELD, FROM 1/4 THICKNESS OF WELD

NMBR	IDENT	TEMPERATURE		ENERGY	(FT-LB)	EXPANSION		SHEAR
		(DEG C)	(DEG F)			(MM)	(IN)	
1	MW9BB1	-75	-103	11.5	8.5	0.305	0.012	0
2	MW9AA2	-50	-58	8.9	6.6	0.254	0.01	10
3	MW9BA5	-25	-13	23	17	0.381	0.015	20
4	MW9BB5	0	32	52.3	38.6	0.965	0.038	75
5	MW9AA4	25	77	56.1	41.4	0.991	0.039	85
6	MW9AB2	50	122	84.1	62	1.626	0.064	100
7	MW9BA4	50	122	64.4	47.5	1.321	0.052	90
8	MW9BA1	75	167	72.5	53.5	1.575	0.062	95
9	MW9AA3	100	212	74.7	55.1	1.524	0.06	99
10	MW9AA1	100	212	73.6	54.3	1.524	0.06	100
11	MW9BA3	150	302	81.1	59.8	1.778	0.07	100

SOURCE ■ ANALYSIS SET

ANALYSIS SETS

SET 1 ■ MW912T

SET 2 ■ NONE

SET ■ MW912T

REMARK ■ MIDLAND WELD WF70 IN A533B, FROM 1/2 THICKNESS OF WELD

NMBR	IDENT	TEMPERATURE		ENERGY	(FT-LB)	EXPANSION		SHEAR
		(DEG C)	(DEG F)			(MM)	(IN)	
1	MW9AD2	-100	-148	3.7	2.7	0.203	0.008	0
2	MW9AD1	-75	-103	6.2	4.6	0.127	0.005	0
3	MW9BE4	-50	-58	16.7	12.3	0.381	0.015	10
4	MW9BE5	-25	-13	26.2	19.3	0.584	0.023	25
5	MW9AD5	0	32	50.4	37.2	0.991	0.039	55
6	MW9AD3	25	77	71.7	52.9	1.321	0.052	75
7	MW9BE1	50	122	74	54.6	1.499	0.059	95
8	MW9BE2	75	167	73.5	54.2	1.575	0.062	97
9	MW9AD4	100	212	93	68.6	1.778	0.07	100
10	MW9BE3	150	302	80	59	1.753	0.069	100

SOURCE ■ ANALYSIS SET

ANALYSIS SETS

SET 1 ■ MW958T

SET 2 ■ NONE

SET ■ MW958T

REMARK ■ MIDLAND WELD WF70 IN A533B, SPEC. FROM 5/8 THICKNESS OF WELD

NMBR	IDENT	TEMPERATURE		ENERGY	(FT-LB)	EXPANSION		SHEAR
		(DEG C)	(DEG F)			(MM)	(IN)	
1	MW9AF3	-100	-148	5.6	4.1	0.127	0.005	0
2	MW9AF1	-75	-103	17.1	12.6	0.33	0.013	10
3	MW9BC5	-50	-58	21.7	16	0.483	0.019	25
4	MW9AF5	-25	-13	33.9	25	0.686	0.027	40
5	MW9BC2	-10	14	38.5	28.4	0.838	0.033	65
6	MW9AF4	0	32	58	42.8	1.016	0.04	80
7	MW9BC3	25	77	77.1	56.9	1.499	0.059	100
8	MW9AF2	50	122	85.7	63.2	1.676	0.066	100
9	MW9BC4	100	212	85.4	63	1.753	0.069	100
10	MW9BC1	150	302	84.5	62.3	1.829	0.072	100

SOURCE ■ ANALYSIS SET

ANALYSIS SETS

SET 1 ■ MW934T

SET 2 ■ NONE

SET ■ MW934T

REMARK ■ MIDLAND WELD WF70 IN A533B, FROM 3/4 THICKNESS OF WELD

NMBR	IDENT	TEMPERATURE		ENERGY	EXPANSION			SHEAR
		(DEG C)	(DEG F)		(FT-LB)	(MM)	(IN)	
1	MW9BI1	-100	-148	3.9	2.9	0.127	0.005	0
2	MW9AJ1	-50	-58	11.4	8.4	0.279	0.011	5
3	MW9BI2	-25	-13	28.7	21.2	0.584	0.023	25
4	MW9BI3	0	32	36.2	26.7	0.737	0.029	40
5	MW9BI5	25	77	52.9	39	0.991	0.039	65
6	MW9AJ4	50	122	69.1	51	1.422	0.056	99
7	MW9AJ5	100	212	77.1	56.9	1.6	0.063	100
8	MW9BI4	150	302	83.7	61.7	1.702	0.067	100
9	MW9AJ3	200	392	79	58.3	1.803	0.071	100
10	MW9AJ2	250	482	79.6	58.7	1.727	0.068	100

SOURCE ■ ANALYSIS SET

ANALYSIS SETS

SET 1 ■ MW978T

SET 2 ■ NONE

SET ■ MW978T

REMARK ■ MIDLAND WELD WF70 IN A533B, SPEC. FROM 7/8 THICKNESS OF WELD

NMBR	IDENT	TEMPERATURE		ENERGY	EXPANSION			SHEAR
		(DEG C)	(DEG F)		(FT-LB)	(MM)	(IN)	
1	MW9BK3	-75	-103	9.5	7	0.279	0.011	0
2	MW9DE5	-50	-58	8.3	6.1	0.254	0.01	10
3	MW9DE1	-35	-31	19.9	14.7	0.508	0.02	30
4	MW9BK5	-25	-13	30.4	22.4	0.686	0.027	40
5	MW9BK4	0	32	45.3	33.4	0.991	0.039	75
6	MW9BK2	50	122	64.8	47.8	1.245	0.049	97
7	MW9DE4	75	167	74.7	55.1	1.575	0.062	99
8	MW9DE3	100	212	76.7	56.6	1.676	0.066	100
9	MW9DE2	150	302	80	59	1.651	0.065	100
10	MW9BK1	250	482	77.8	57.4	1.829	0.072	100

SOURCE ■ ANALYSIS SET

ANALYSIS SETS

SET 1 ■ MW11_14T

SET 2 ■ NONE

SET ■ MW11_14T

REMARK ■ HSST - MIDLAND WELD 11, FROM 1/4 THICKNESS

NMBR	IDENT	TEMPERATURE		ENERGY	EXPANSION			SHEAR
		(DEG C)	(DEG F)		(FT-LB)	(MM)	(IN)	
1	MW11AB1	-50	-58	22.2	16.4	0.406	0.016	10
2	MW11BB3	-25	-13	34.6	25.5	0.787	0.031	25
3	MW11AA5	0	32	45.6	33.6	0.965	0.038	50
4	MW11BA4	25	77	67.7	49.9	1.194	0.047	65
5	MW11AA4	40	104	68.7	50.7	1.372	0.054	80
6	MW11BB2	50	122	88.8	65.5	1.727	0.068	100
7	MW11AB5	75	167	93.4	68.9	1.778	0.07	100
8	MW11AB3	100	212	91.2	67.3	1.778	0.07	100
9	MW11BA3	125	257	84.7	62.5	1.651	0.065	100
10	MW11BA2	175	347	85	62.7	1.651	0.065	100

SOURCE ■ ANALYSIS SET

ANALYSIS SETS

SET 1 ■ MW11_12T

SET 2 ■ NONE

SET ■ MW11_12T

REMARK ■ HSST - MIDLAND WELD 11, FROM 1/2 THICKNESS

NMBR	IDENT	TEMPERATURE		ENERGY	(FT-LB)	EXPANSION		SHEAR
		(DEG C)	(DEG F)			(MM)	(IN)	
1	MW11ED5	-75	-103	13.3	9.8	0.127	0.005	3
2	MW11BE1	-25	-13	23.7	17.5	0.254	0.01	7
3	MW11BD1	0	32	44.9	33.1	0.762	0.03	40
4	MW11AE2	0	32	40	29.5	0.686	0.027	35
5	MW11BE3	25	77	72.5	53.5	1.27	0.05	85
6	MW11AE5	50	122	86.1	63.5	1.448	0.057	99
7	MW11BD4	75	167	86.6	63.9	1.575	0.062	100
8	MW11BD3	125	257	90	66.4	1.448	0.057	100
9	MW11AE3	175	347	86.1	63.5	1.575	0.062	100
10	MW11AD2	225	437	96.4	71.1	1.676	0.066	100

SOURCE ■ ANALYSIS SET

ANALYSIS SETS

SET 1 ■ MW11_58T

SET 2 ■ NONE

SET ■ MW11_58T

REMARK ■ HSST - MIDLAND WELD 11, FROM 5/8 THICKNESS

NMBR	IDENT	TEMPERATURE		ENERGY	(FT-LB)	EXPANSION		SHEAR
		(DEG C)	(DEG F)			(MM)	(IN)	
1	MW11AF3	-50	-58	18.3	13.5	0.33	0.013	10
2	MW11BG2	-25	-13	27.4	20.2	0.508	0.02	25
3	MW11AF4	0	32	42.3	31.2	0.813	0.032	40
4	MW11AG3	10	50	64.3	47.4	1.143	0.045	80
5	MW11BG5	25	77	80.1	59.1	1.397	0.055	100
6	MW11AG1	50	122	86.2	63.6	1.473	0.058	100
7	MW11BG1	75	167	85.7	63.2	1.626	0.064	100
8	MW11AG2	100	212	88.3	65.1	1.651	0.065	100
9	MW11BG4	125	257	90.4	66.7	1.676	0.066	100
10	MW11BF2	200	392	89.5	66	1.753	0.069	100

SOURCE ■ ANALYSIS SET

ANALYSIS SETS

SET 1 ■ MW11_34T

SET 2 ■ NONE

SET ■ MW11_34T

REMARK ■ HSST - MIDLAND WELD 11, FROM 3/4 THICKNESS

NMBR	IDENT	TEMPERATURE		ENERGY	(FT-LB)	EXPANSION		SHEAR
		(DEG C)	(DEG F)			(MM)	(IN)	
1	MW11BI1	-75	-103	5.8	4.3	0.279	0.011	0
2	MW11AI2	-50	-58	9.1	6.7	0.203	0.008	0
3	MW11BJ3	-25	-13	30.6	22.6	0.635	0.025	35
4	MW11AI1	0	32	27	19.9	0.584	0.023	20
5	MW11AI3	0	32	24.8	18.3	1.041	0.041	25
6	MW11BJ4	25	77	66.2	48.8	1.092	0.043	75
7	MW11AI4	25	77	31.9	23.5	0.787	0.031	45
8	MW11AJ4	75	167	79.3	58.5	1.524	0.06	100
9	MW11AJ1	125	257	81.8	60.3	1.549	0.061	100
10	MW11AJ5	200	392	81.8	60.3	1.549	0.061	100

SOURCE ■ ANALYSIS SET

ANALYSIS SETS

SET 1 ■ MW11_78T

SET 2 ■ NONE

SET ■ MW11_78T

REMARK ■ HSST - MIDLAND WELD 11, FROM 7/8 THICKNESS

NMBR	IDENT	TEMPERATURE		ENERGY		EXPANSION		SHEAR
		(DEG C)	(DEG F)			(MM)	(IN)	
1	MW11BK3	-75	-103	4.7	3.5	0.279	0.011	5
2	MW11CE5	-25	-13	29.7	21.9	0.711	0.028	20
3	MW11AK3	-10	14	33.6	24.8	0.991	0.039	40
4	MW11BK4	0	32	61.1	45.1	1.245	0.049	90
5	MW11BK5	0	32	66.4	49	1.27	0.05	95
6	MW11EE1	25	77	41.6	30.7	0.864	0.034	55
7	MW11BK2	25	77	72.8	53.7	1.473	0.058	98
8	MW11DE3	75	167	76.9	56.7	1.549	0.061	100
9	MW11DE5	125	257	82.2	60.6	1.626	0.064	100
10	MW11DE4	200	392	79.7	58.8	1.676	0.066	100

SOURCE ■ ANALYSIS SET

ANALYSIS SETS

SET 1 ■ MW13_14T

SET 2 ■ NONE

SET ■ MW13_14T

REMARK ■ MIDLAND WELD 13, WF70 WELD IN A533B FROM 1/4 THICKNESS

NMBR	IDENT	TEMPERATURE		ENERGY		EXPANSION		SHEAR
		(DEG C)	(DEG F)			(MM)	(IN)	
1	MW1GA5	-100	-148	5	3.7	0.064	0.0025	1
2	MW1GB1	-100	-148	5.8	4.3	0.064	0.0025	1
3	MW1GB2	-75	-103	10.7	7.9	0.178	0.007	10
4	MW1GB3	-75	-103	13.6	10	0.241	0.0095	10
5	MW1GA1	-50	-58	25.6	18.9	0.406	0.016	15
6	MW1GA2	-50	-58	22.4	16.5	0.356	0.014	15
7	MW1GA3	0	32	40.4	29.8	0.737	0.029	50
8	MW1GA4	0	32	32.7	24.1	0.635	0.025	45
9	MWIHB2	0	32	56.1	41.4	0.876	0.0345	75
10	MWIHA4	25	77	73.3	54.1	1.359	0.0535	90
11	MWIHA5	25	77	73.5	54.2	1.283	0.0505	90
12	MWIHB1	25	77	74.4	54.9	1.27	0.05	90
13	MW1HA1	42.8	109	85.3	62.9	1.41	0.0555	95
14	MW1GB4	50	122	89.9	66.3	1.461	0.0575	99
15	MW1GB5	50	122	94.1	69.4	1.486	0.0585	99
16	MWIHB3	100	212	94.9	70	1.689	0.0665	100
17	MWIHB4	100	212	96.1	70.9	1.638	0.0645	100
18	MW1HA2	150	302	98.7	72.8	1.638	0.0645	100
19	MW1HA3	250	482	99.5	73.4	1.753	0.069	100
20	MWIHB5	287.8	550	100.7	74.3	1.956	0.077	100

SOURCE ■ ANALYSIS SET

ANALYSIS SETS

SET 1 ■ MW13_12TD

SET 2 ■ NONE

SET ■ MW13_12TD

REMARK ■ MIDLAND WELD 13, WF70 WELD IN A533B FROM 1/2 THICK "D" LAYER

NMBR	IDENT	TEMPERATURE		ENERGY	EXPANSION			SHEAR
		(DEG C)	(DEG F)		(FT-LB)	(MM)	(IN)	
1	MWIGD3	-50	-58	19.9	14.7	0.318	0.0125	10
2	MWIGD4	-50	-58	23.6	17.4	0.368	0.0145	10
3	MWIGD5	-25	-13	39.3	29	0.648	0.0255	25
4	MWIGD1	0	32	65.5	48.3	1.054	0.0415	40
5	MWIGD2	0	32	65.2	48.1	1.003	0.0395	40
6	MWIHD1	50	122	97.2	71.7	1.727	0.068	100
7	MWIHD3	75	167	101.8	75.1	1.816	0.0715	100
8	MWIHD5	100	212	99.4	73.3	1.765	0.0695	100
9	MWIHD2	150	302	105.6	77.9	1.867	0.0735	100
10	MWIHD4	287.8	550	105.1	77.5	1.88	0.074	100

SOURCE ■ ANALYSIS SET

ANALYSIS SETS

SET 1 ■ MW13_12TE

SET 2 ■ NONE

SET ■ MW13_12TE

REMARK ■ MIDLAND WELD 13, WF70 WELD IN A533B FROM 1/2 THICK "E" LAYER

NMBR	IDENT	TEMPERATURE		ENERGY	EXPANSION			SHEAR
		(DEG C)	(DEG F)		(FT-LB)	(MM)	(IN)	
1	MWIGE2	-100	-148	8	5.9	0.076	0.003	1
2	MWIGE3	-100	-148	9.2	6.8	0.191	0.0075	1
3	MWIGE1	-25	-13	28.1	20.7	0.457	0.018	20
4	MWIGE4	25	77	43.7	32.2	0.686	0.027	40
5	MWIGE5	25	77	57.5	42.4	0.864	0.034	65
6	MWIHE1	50	122	73.3	54.1	1.308	0.0515	80
7	MWIHE2	50	122	73.1	53.9	1.321	0.052	80
8	MWIHE3	50	122	72.3	53.3	1.232	0.0485	75
9	MWIHE4	100	212	86.9	64.1	1.461	0.0575	99
10	MWIHE5	150	302	93.8	69.2	1.715	0.0675	100

SOURCE ■ ANALYSIS SET

ANALYSIS SETS

SET 1 ■ MW13_58T

SET 2 ■ NONE

SET ■ MW13_58T

REMARK ■ MIDLAND WELD 13, WF70 WELD IN A533B FROM 5/8 THICKNESS

NMBR	IDENT	TEMPERATURE		ENERGY	EXPANSION			SHEAR
		(DEG C)	(DEG F)		(FT-LB)	(MM)	(IN)	
1	MWIGG4	-100	-148	6.5	4.8	0.064	0.0025	1
2	MWIHF1	-50	-58	31	22.9	0.521	0.0205	20
3	MW1HG5	-50	-58	23.5	17.3	0.406	0.016	15
4	MWIHF3	-25	-13	39.7	29.3	1.168	0.046	35
5	MW1HG4	-25	-13	32.1	23.7	0.584	0.023	25
6	MWIHF5	0	32	50.8	37.5	0.864	0.034	40
7	MWIGG5	12.8	55	68.9	50.8	1.118	0.044	35
8	MWIHF2	12.8	55	72.7	53.6	1.207	0.0475	70
9	MWIHF4	12.8	55	63.6	46.9	1.067	0.042	60
10	MW1HG1	17.8	64	83.9	61.9	1.384	0.0545	95
11	MW1HG2	17.8	64	73.3	54.1	1.194	0.047	85
12	MW1HG3	17.8	64	69.4	51.2	1.143	0.045	75
13	MWIGF5	25	77	91.4	67.4	1.448	0.057	99
14	MWIGG1	25	77	87.9	64.8	1.397	0.055	99
15	MWIGF1	50	122	97.9	72.2	1.562	0.0615	100
16	MWIGF2	50	122	94.9	70	1.499	0.059	100
17	MWIGF3	100	212	97.3	71.8	1.588	0.0625	100
18	MWIGF4	100	212	97.2	71.7	1.473	0.058	100
19	MWIGG2	150	302	111.2	82	1.854	0.073	100
20	MWIGG3	250	482	113.1	83.4	1.842	0.0725	100

SOURCE ■ ANALYSIS SET

ANALYSIS SETS

SET 1 ■ MW13_34T

SET 2 ■ NONE

SET ■ MW13_34T

REMARK ■ MIDLAND WELD 13, WF70 WELD IN A533B FROM 3/4 THICKNESS

NMBR	IDENT	TEMPERATURE		ENERGY	EXPANSION			SHEAR
		(DEG C)	(DEG F)		(FT-LB)	(MM)	(IN)	
1	MWIHJ1	-100	-148	4.3	3.2	0.114	0.0045	1
2	MWIHI4	-50	-58	18.4	13.6	0.33	0.013	15
3	MW1HI5	-50	-58	23.5	17.3	0.394	0.0155	15
4	MWIHI2	-25	-13	20.5	15.1	0.381	0.015	25
5	MW1HI3	-25	-13	27.5	20.3	0.483	0.019	25
6	MWIGI5	0	32	42.2	31.1	0.914	0.036	40
7	MWIGJ1	0	32	33.5	24.7	0.597	0.0235	45
8	MWIGI3	25	77	62.4	46	1.257	0.0495	75
9	MWIGI4	25	77	66.3	48.9	1.194	0.047	75
10	MWIGJ2	32.8	91	64	47.2	1.016	0.04	65
11	MWIGJ3	37.8	100	66.8	49.3	1.156	0.0455	90
12	MWIGJ4	42.8	109	70.1	51.7	1.219	0.048	90
13	MWIGJ5	42.8	109	67.8	50	1.118	0.044	85
14	MWIHI1	42.8	109	80.1	59.1	1.486	0.0585	95
15	MW1HJ4	75	167	86.2	63.6	1.575	0.062	95
16	MWIGI1	100	212	85.6	63.1	1.524	0.06	100
17	MWIGI2	100	212	86	63.4	1.511	0.0595	100
18	MWIHJ3	150	302	83.9	61.9	1.422	0.056	100
19	MW1HJ2	150	302	86.9	64.1	1.702	0.067	100
20	MW1HJ5	287.8	550	95.2	70.2	1.803	0.071	100

SOURCE ■ ANALYSIS SET
 ANALYSIS SETS
 SET 1 ■ MW15_14TR
 SET 2 ■ NONE

SET ■ MW15_14TR

REMARK ■ MIDLAND WELD 15, FROM 1/4 THICKNESS REVISED

NMBR	IDENT	TEMPERATURE (DEG C) (DEG F)		ENERGY (J)	(FT-LB)	EXPANSION (MM) (IN)		SHEAR (PERCENT)
1	MW15BB5	-50	-58	10.8	8	0.178	0.007	5
2	MW15BB2	-25	-13	25.8	19	0.432	0.017	10
3	MW15AA3	0	32	38	28	0.584	0.023	35
4	MW15BA3	22.2	72	49.5	36.5	0.838	0.033	40
5	MW15AB1	50	122	70.5	52	1.168	0.046	85
6	MW15AA4	75	167	75.9	56	1.321	0.052	95
7	MW15AA1	100	212	81.1	59.8	1.346	0.053	100
8	MW15BA1	200	392	81.1	59.8	1.549	0.061	100
9	MW15BA2	200	392	81.8	60.3	1.473	0.058	100

SOURCE ■ ANALYSIS SET
 ANALYSIS SETS
 SET 1 ■ MW15_12T
 SET 2 ■ NONE

SET ■ MW15_12T

REMARK ■ MIDLAND WELD 15, FROM 1/2 THICKNESS

NMBR	IDENT	TEMPERATURE (DEG C) (DEG F)		ENERGY (J)	(FT-LB)	EXPANSION (MM) (IN)		SHEAR (PERCENT)
1	MW15BE2	-75	-103	14.2	10.5	0.127	0.005	3
2	MW15BE3	-25	-13	21.4	15.8	0.432	0.017	20
3	MW15AE1	0	32	51.5	38	0.838	0.033	55
4	MW15AD2	0	32	53.7	39.6	0.787	0.031	75
5	MW15BE4	25	77	74.3	54.8	1.168	0.046	85
6	MW15AD5	50	122	82.7	61	1.524	0.06	100
7	MW15BD3	75	167	83.7	61.7	1.524	0.06	100
8	MW15BD2	125	257	83.5	61.6	1.499	0.059	100
9	MW15AD3	175	347	89.8	66.2	1.702	0.067	100
10	MW15AD1	225	437	91.5	67.5	1.727	0.068	100

SOURCE ■ ANALYSIS SET
 ANALYSIS SETS
 SET 1 ■ MW15_58T
 SET 2 ■ NONE

SET ■ MW15_58T

REMARK ■ HSST - MIDLAND WELD 15, FROM 5/8 THICKNESS

NMBR	IDENT	TEMPERATURE (DEG C) (DEG F)		ENERGY (J)	(FT-LB)	EXPANSION (MM) (IN)		SHEAR (PERCENT)
1	MW15AG2	-50	-58	16.9	12.5	0.279	0.011	5
2	MW15BG5	-25	-13	24.1	17.8	0.305	0.012	10
3	MW15BF1	0	32	27.8	20.5	0.432	0.017	25
4	MW15AG4	10	50	52.7	38.9	0.864	0.034	45
5	MW15BG4	25	77	69.3	51.1	0.965	0.038	75
6	MW15AF5	50	122	57.8	42.6	1.067	0.042	70
7	MW15AF1	50	122	57.2	42.2	1.143	0.045	75
8	MW15BG1	75	167	87.2	64.3	1.524	0.06	99
9	MW15BG2	125	257	91.2	67.3	1.753	0.069	100
10	MW15BF5	200	392	76.6	56.5	1.549	0.061	100

SOURCE ■ ANALYSIS SET

ANALYSIS SETS

SET 1 ■ MW15_34T

SET 2 ■ NONE

SET ■ MW15_34T

REMARK ■ HSST - MIDLAND WELD 15, FROM 3/4 THICKNESS

NMBR	IDENT	TEMPERATURE		ENERGY	EXPANSION			SHEAR
		(DEG C)	(DEG F)		(MM)	(IN)	(PERCENT)	
1	MW15BJ1	-75	-103	5.7	4.2	0.051	0.002	5
2	MW15BJ5	-25	-13	24.5	18.1	0.457	0.018	25
3	MW15AJ3	-10	14	40.1	29.6	0.61	0.024	35
4	MW15AJ2	0	32	49.8	36.7	0.864	0.034	75
5	MW15BJ3	25	77	56.7	41.8	1.041	0.041	85
6	MW15AI1	50	122	86.5	63.8	1.524	0.06	99
7	MW15BI4	75	167	83.9	61.9	1.549	0.061	100
8	MW15BI2	75	167	85.8	63.3	1.524	0.06	100
9	MW15AJ5	125	257	86.6	63.9	1.473	0.058	100
10	MW15AJ4	200	392	88.5	65.3	1.702	0.067	100

SOURCE ■ ANALYSIS SET

ANALYSIS SETS

SET 1 ■ MW15_78T

SET 2 ■ NONE

SET ■ MW15_78T

REMARK ■ HSST - MIDLAND WELD15, FROM 7/8 THICKNESS

NMBR	IDENT	TEMPERATURE		ENERGY	EXPANSION			SHEAR
		(DEG C)	(DEG F)		(MM)	(IN)	(PERCENT)	
1	MW15CE3	-75	-103	7.6	5.6	0.076	0.003	0
2	MW15CE5	-50	-58	15.9	11.7	0.203	0.008	5
3	MW15DE5	-25	-13	23.3	17.2	0.381	0.015	15
4	MW15AK5	-10	14	46.1	34	0.838	0.033	60
5	MW15CE4	0	32	34	25.1	0.559	0.022	20
6	MW15EE2	25	77	80.4	59.3	1.346	0.053	95
7	MW15CE2	25	77	71.5	52.7	1.219	0.048	90
8	MW15EE4	75	167	80.5	59.4	1.524	0.06	100
9	MW15DE3	125	257	82.7	61	1.626	0.064	100
10	MW15DE4	200	392	79.2	58.4	1.549	0.061	100

SOURCE ■ ANALYSIS SET

ANALYSIS SETS

SET 1 ■ NC31_50T

SET 2 ■ NONE

SET ■ NC31_50T

REMARK ■ MIDLAND WELD NOZZEL COURSE 3-1, FROM 1/2 THICKNESS

NMBR	IDENT	TEMPERATURE		ENERGY	EXPANSION			SHEAR
		(DEG C)	(DEG F)		(MM)	(IN)	(PERCENT)	
1	NC31AA1	-50	-58	8.1	6	0.102	0.004	0
2	NC31AA3	-25	-13	28.5	21	0.406	0.016	15
3	NC31AA5	0	32	33.2	24.5	0.483	0.019	25
4	NC31BA1	22.2	72	50.4	37.2	0.787	0.031	60
5	NC31AB4	50	122	75.9	56	1.27	0.05	95
6	NC31BA3	75	167	75.9	56	1.27	0.05	100
7	NC31BA5	100	212	77.3	57	1.245	0.049	100
8	NC31BB2	150	302	88.1	65	1.295	0.051	100

SOURCE ■ ANALYSIS SET
 ANALYSIS SETS
 SET 1 ■ NC31_75T
 SET 2 ■ NONE

SET ■ NC31_75T

REMARK ■ MIDLAND WELD NOZZLE COURSE 3-1, FROM 3/4 THICKNESS

NMBR	IDENT	TEMPERATURE (DEG C) (DEG F)		ENERGY (J)	(FT-LB)	EXPANSION (MM) (IN)		SHEAR (PERCENT)
1	NC31BE1	-50	-58	19	14	0.229	0.009	0
2	NC31BE3	-25	-13	21.7	16	0.254	0.01	5
3	NC31BF2	0	32	48.8	36	0.711	0.028	35
4	NC31BE5	22.2	72	47.5	35	0.711	0.028	30
5	NC31BE5	22.2	72	47.5	35	0.711	0.028	30
6	NC31AE1	50	122	72.5	53.5	1.194	0.047	90
7	NC31AF2	75	167	81.3	60	1.372	0.054	99
8	NC31AE5	100	212	82.7	61	1.549	0.061	100
9	NC31AE3	150	302	84.7	62.5	1.346	0.053	100

SOURCE ■ ANALYSIS SET
 ANALYSIS SETS
 SET 1 ■ NC31_78T
 SET 2 ■ NONE

SET ■ NC31_78T

REMARK ■ MIDLAND WELD NOZZLE COURSE 3-1 FROM 7/8 THICKNESS

NMBR	IDENT	TEMPERATURE (DEG C) (DEG F)		ENERGY (J)	(FT-LB)	EXPANSION (MM) (IN)		SHEAR (PERCENT)
1	NC31AH5	-50	-58	15.6	11.5	0.254	0.01	5
2	NC31AH1	-25	-13	28.5	21	0.533	0.021	10
3	NC31AH3	0	32	48.8	36	0.813	0.032	35
4	NC31DF2	22.2	72	66.4	49	1.219	0.048	75
5	NC31BH4	50	122	80.7	59.5	1.524	0.06	100
6	NC31CF3	75	167	85.8	63.3	1.575	0.062	100
7	NC31CF5	100	212	81.3	60	1.499	0.059	100
8	NC31CF1	150	302	94.9	70	1.702	0.067	100

SOURCE ■ ANALYSIS SET
 ANALYSIS SETS
 SET 1 ■ NC34_50T
 SET 2 ■ NONE

SET ■ NC34_50T

REMARK ■ MIDLAND WELD - NOZZLE COURSE 34 1/2T (6")

NMBR	IDENT	TEMPERATURE (DEG C) (DEG F)		ENERGY (J)	(FT-LB)	EXPANSION (MM) (IN)		SHEAR (PERCENT)
1	NC34BB1	-50	-58	26.8	19.8	0.305	0.012	10
2	NC34AA4	-25	-13	29.8	22	0.432	0.017	15
3	NC34AB3	0	32	44.7	33	0.686	0.027	40
4	NC34AB5	22.2	72	63.5	46.8	0.914	0.036	45
5	NC34BA2	50	122	63	46.5	1.041	0.041	85
6	NC34BA4	75	167	76.6	56.5	1.397	0.055	100
7	NC34BB3	100	212	78	57.5	1.295	0.051	100
8	NC34AB1	200	392	88.1	65	1.346	0.053	100

SOURCE ■ ANALYSIS SET

ANALYSIS SETS

SET 1 ■ NC34_75T

SET 2 ■ NONE

SET ■ NC34_75T

REMARK ■ MIDLAND WELD - NOZZLE COURSE 34 3/4T (2.5")

NMBR	IDENT	TEMPERATURE (DEG C) (DEG F)		ENERGY (J)	(FT-LB)	EXPANSION (MM) (IN)		SHEAR (PERCENT)
1	NC34BE2	-50	-58	20.3	15	0.279	0.011	3
2	NC34BF5	-25	-13	28.5	21	0.61	0.024	5
3	NC34BF3	0	32	33.9	25	0.559	0.022	20
4	NC34BF1	22.2	72	55.6	41	0.914	0.036	45
5	NC34BE4	50	122	74.6	55	1.245	0.049	80
6	NC34AE2	75	167	80	59	1.321	0.052	100
7	NC34AF3	100	212	82.7	61	1.422	0.056	100
8	NC34AF5	200	392	81.3	60	1.499	0.059	100

SOURCE ■ ANALYSIS SET

ANALYSIS SETS

SET 1 ■ NC34_78T

SET 2 ■ NONE

SET ■ NC34_78T

REMARK ■ MIDLAND WELD - NOZZLE COURSE 34 7/8T (1/2")

NMBR	IDENT	TEMPERATURE (DEG C) (DEG F)		ENERGY (J)	(FT-LB)	EXPANSION (MM) (IN)		SHEAR (PERCENT)
1	NC34DF1	-50	-58	10.2	7.5	0.102	0.004	0
2	NC34BH5	-25	-13	32.5	24	0.508	0.02	15
3	NC34BH1	0	32	31.2	23	0.508	0.02	30
4	NC34BH3	22.2	72	47.5	35	0.991	0.039	45
5	NC34DF4	50	122	75.2	55.5	1.27	0.05	85
6	NC34CF2	75	167	82.7	61	1.575	0.062	100
7	NC34AH1	100	212	81.3	60	1.346	0.053	100
8	NC34AH3	200	392	87.5	64.5	1.549	0.061	100

APPENDIX C

RESULTS OF CHEMICAL ANALYSES OF UNIRRADIATED MIDLAND REACTOR VESSEL WELDS

Table C1. Chemical composition of Midland reactor beltline section 1-9

Location	Chemical composition																					
	(wt %)																					
	C	Mn	P	S	Si	Cr	Ni	Mo	Cu	V	Nb	Ti	Co	Al	B	W	Cb	As	Sn	Zr	N	O
1/8 t	0.082	1.67	0.015	0.008	0.57	0.11	0.58	0.40	0.24	0.005	-	<.001	0.015	0.017	<.001	<.01	0.003	0.008	0.003	<.001	0.016	0.082
1/4 t	0.087	1.65	0.015	0.008	0.61	0.09	0.56	0.41	0.22	0.001												
	0.080	1.59	0.016	0.008	0.62	0.11	0.57	0.40	0.27	0.005	-	<.001	0.015	0.015	<.001	<.01	0.003	0.007	0.003	<.001	0.015	0.078
	0.076	1.66	0.018	0.005	0.62	0.09	0.57	0.41	0.22	0.002												
1/2 t	0.095	1.51	0.014	0.008	0.55	0.15	0.62	0.44	0.22	0.005	-	<.001	0.014	0.015	<.001		0.003	0.005	0.003	<.001	0.013	0.075
3/4 t	0.078	1.64	0.016	0.007	0.61	0.11	0.58	0.40	0.30	0.005	-	<.001	0.015	0.015	<.001	<.01	0.003	0.004	0.003	<.001	0.018	0.080
	0.089	1.65	0.018	0.008	0.66	0.09	0.56	0.41	0.27	0.004												
7/8 t	0.086	1.66	0.016	0.007	0.60	0.10	0.57	0.39	0.34	0.005	-	<.001	0.015	0.016	<.001	<.01	0.003	0.006	0.003	<.001	0.018	0.080

Source: Combustion engineering

Table C2. Chemical composition of Midland reactor beltline section 1-11

Location	Chemical composition																					
	(wt %)																					
C	Mn	P	S	Si	Cr	Ni	Mo	Cu	V	Nb	Ti	Co	Al	B	W	Cb	As	Sn	Zr	N	O	
1/4 t	0.083	1.610	0.013	0.006	0.59	0.10	0.57	0.41	0.23	0.006	-	<0.01	0.04	0.04	0.002	0.04	<0.05	0.06	-	0.02	0.018	0.065
	0.078	1.650	0.018	0.005	0.59	0.10	0.57	0.41	0.23	0.005												
1/2 t	0.088	1.600	0.017	0.006	0.60	0.11	0.58	0.42	0.24	0.005	-	<0.01	0.04	0.03	0.002	0.03	<0.05	0.06	-	0.02	0.014	0.068
	0.084	1.620	0.016	0.006	0.59	0.10	0.58	0.42	0.25	0.005												
5/8 t	0.079	1.610	0.017	0.006	0.63	0.10	0.56	0.41	0.26	0.005	-	<0.01	0.04	0.06	0.002	0.02	<0.05	0.09	-	0.02	0.018	0.068
	0.080	1.620	0.016	0.006	0.65	0.09	0.57	0.41	0.25	0.005												
3/4 t	0.083	1.610	0.015	0.007	0.66	0.10	0.57	0.41	0.29	0.004	-	<0.01	0.04	0.04	0.002	0.02	<0.05	0.06	-	0.02	0.019	0.063
	0.083	1.600	0.016	0.007	0.65	0.10	0.56	0.41	0.31	0.006												

Source: Combustion Engineering for C through V,
MQS Inspection Inc. for Ti through O

Table C3. Chemical composition of Midland reactor beltline section 1-13

Location	Chemical composition																					
	(wt %)																					
C	Mn	P	S	Si	Cr	Ni	Mo	Cu	V	Nb	Ti	Co	Al	B	W	Cb	As	Sn	Zr	N	O	
1/4 t	0.074	1.600	0.015	0.008	0.58	0.11	0.58	0.40	0.24	0.005	0.002	<0.001	0.015	0.020	<0.001	<.01	-	0.003	0.003	<0.001	0.017	-
1/2 t"D"	0.110	1.450	0.018	0.008	0.65	0.14	0.61	0.42	0.21	0.005	0.003	<0.001	0.015	0.008	<0.001	<.01	-	0.007	0.004	<0.001	0.016	-
1/2 t"E"	0.110	1.490	0.016	0.008	0.57	0.14	0.63	0.43	0.22	0.005	0.003	<0.001	0.014	0.013	<0.001	<.01	-	0.007	0.004	<0.001	0.015	-
5/8 t	0.075	1.600	0.018	0.009	0.65	0.11	0.60	0.41	0.25	0.005	0.003	<0.001	0.015	0.017	<0.001	<.01	-	0.006	0.004	<0.001	0.019	-
3/4 t	0.079	1.610	0.022	0.010	0.67	0.11	0.60	0.41	0.32	0.005	0.003	<0.001	0.016	0.015	<0.001	<.01	-	0.007	0.004	<0.001	0.018	-
WQa	0.070	1.600	0.014	0.011	0.48		0.46	0.40	0.27													
WQb	0.090	1.630	0.018	0.009	0.54	0.11	0.59	0.40	0.42													

Source: a from B&W weld wire qualification report.

b from BAN-1799 giving extensive chemical analyses.

Table C4. Chemical composition of Midland reactor beltline section 1-15

Location	Chemical composition (wt %)																					
	C	Mn	P	S	Si	Cr	Ni	Mo	Cu	V	Nb	Ti	Co	Al	B	W	Cb	As	Sn	Zr	N	O
1/4 t	0.092	1.620	0.017	0.006	0.65	0.11	0.58	0.41	0.29	0.002	-	<0.01	0.04	0.03	0.002	0.02	<0.05	0.09	0.03	0.02	0.018	0.087
	0.090	1.600	0.018	0.006	0.66	0.11	0.57	0.42	0.28	0.004												
1/2 t	0.083	1.620	0.021	0.006	0.66	0.09	0.57	0.41	0.25	0.001	-	<0.01	0.04	0.03	0.002	0.01	<0.05	0.09	0.03	0.02	0.019	0.100
3/4 t	0.077	1.600	0.017	0.005	0.64	0.10	0.56	0.41	0.22	0.003	-	<0.01	0.05	0.03	0.002	0.01	<0.05	0.08	0.03	0.03	0.016	0.085
	0.077	1.600	0.017	0.005	0.61	0.11	0.57	0.41	0.22	0.002												
7/8 t	0.086	1.640	0.017	0.006	0.64	0.09	0.55	0.40	0.27	0.002	-	<0.01	0.06	0.03	0.002	0.01	<0.05	0.08	0.03	0.04	0.015	0.090
	0.080	1.620	0.018	0.006	0.65	0.10	0.57	0.41	0.25	0.002												

Source: Combustion Engineering for C through V,
MQS Inspection Inc. for Ti through O

Table C5. Chemical composition of Midland reactor nozzle course section 3-1

Location	Chemical composition (wt %)																					
	C	Mn	P	S	Si	Cr	Ni	Mo	Cu	V	Nb	Ti	Co	Al	B	W	Cb	As	Sn	Zr	N	O
0.07 t	0.087	1.60	0.018	0.009	0.68	0.10	0.56	0.38	0.29	0.006	-	<0.001	0.014	0.016	<0.001	<0.01	0.003	0.006	0.004	<0.001	0.015	0.080
0.2t	0.071	1.53	0.017	0.017	0.55	0.09	0.58	0.37	0.20	0.005	-	<0.001	0.009	0.007	<0.001	<0.01	0.003	0.006	0.008	<0.001	0.012	0.053
0.4t	0.081	1.47	0.016	0.016	0.54	0.11	0.59	0.39	0.15	0.008	-	<0.001	0.010	0.008	<0.001	<0.01	0.003	0.006	0.007	<0.001	0.010	0.054
0.5t	0.110	1.50	0.014	0.008	0.50	0.14	0.61	0.42	0.37	0.012	-	<0.001	0.016	0.021	<0.001	<0.01	0.003	0.006	0.005	<0.001	0.011	0.084
0.54t	0.100	1.60	0.014	0.008	0.50	0.14	0.59	0.41	0.46	0.010	-	<0.001	0.016	0.019	<0.001	<0.01	0.003	0.006	0.005	<0.001	0.011	0.087
0.7t	0.092	1.61	0.014	0.006	0.55	0.11	0.56	0.39	0.37	0.008	-	<0.001	0.015	0.020	<0.001	<0.01	0.003	0.006	0.004	<0.001	0.012	0.084
0.8t	0.078	1.63	0.015	0.007	0.55	0.11	0.56	0.39	0.38	0.006	-	<0.001	0.015	0.018	<0.001	<0.01	0.003	0.006	0.003	<0.001	0.015	0.074
0.95t	0.080	1.59	0.017	0.007	0.64	0.10	0.56	0.38	0.41	0.006	-	<0.001	0.015	0.015	<0.001	<0.01	0.003	0.007	0.004	<0.001	0.015	0.074

Source: Combustion engineering

Table C6. Chemical composition of Midland reactor nozzle course section 3-4

Location	Chemical composition (wt %)																					
	C	Mn	P	S	Si	Cr	Ni	Mo	Cu	V	Nb	Ti	Co	Al	B	W	Cb	As	Sn	Zr	N	O
0.07 t	0.091	1.65	0.018	0.007	0.63	0.10	0.56	0.39	0.30	0.007	-	<0.001	0.015	0.019	<0.001	<0.01	0.002	0.006	0.004	<0.001	0.017	0.063
0.2t	0.070	1.52	0.016	0.016	0.54	0.09	0.58	0.38	0.19	0.006	-	<0.001	0.009	0.008	<0.001	<0.01	0.003	0.005	0.007	<0.001	0.016	0.066
0.4t	0.082	1.48	0.016	0.016	0.53	0.11	0.58	0.38	0.14	0.007	-	<0.001	0.009	0.008	<0.001	<0.01	0.002	0.005	0.007	<0.001	0.010	0.068
0.5t	0.110	1.44	0.013	0.009	0.50	0.15	0.60	0.43	0.23	0.014	-	<0.001	0.014	0.021	<0.001	<0.01	0.003	0.005	0.006	<0.001	0.009	0.011
0.54t	0.100	1.61	0.012	0.006	0.49	0.13	0.58	0.41	0.42	0.010	-	<0.001	0.015	0.019	<0.001	<0.01	0.002	0.003	0.004	<0.001	0.012	0.068
0.7t	0.097	1.58	0.015	0.007	0.55	0.12	0.57	0.40	0.38	0.009	-	<0.001	0.016	0.018	<0.001	<0.01	0.003	0.005	0.004	<0.001	0.012	0.064
0.8t	0.084	1.63	0.015	0.006	0.56	0.11	0.56	0.39	0.39	0.007	-	<0.001	0.015	0.021	<0.001	<0.01	0.003	0.007	0.004	<0.001	0.013	0.064
0.95t	0.074	1.61	0.017	0.007	0.61	0.10	0.56	0.39	0.38	0.006	-	<0.001	0.015	0.015	<0.001	<0.01	0.003	0.007	0.004	<0.001	0.015	0.073

Source: Combustion engineering

APPENDIX D

HYPERBOLIC TANGENT CURVE FITS WITH 68 AND 95% CONFIDENCE BOUNDS FOR INDIVIDUAL DATA SETS UNIRRADIATED MIDLAND REACTOR VESSEL WELDS

APPENDIX D

HYPERBOLIC TANGENT CURVE FITS WITH 68% AND 95% CONFIDENCE BOUNDS FOR INDIVIDUAL DATA SETS UNIRRADIATED MIDLAND REACTOR VESSEL WELDS

Hyperbolic tangent curve fits to the Charpy V-notch impact data for each individual test set are provided in separate plots in this appendix. Plots of absorbed energy, lateral expansion, and percent shear vs test temperature are provided. Separate plots are provided for the 68% and 95% confidence bounds. Additionally, each plot also gives the fitting constants for the mean hyperbolic tangent curve fit for the equation:

$$\text{Energy} = (\text{USE} + \text{LSE})/2 + (\text{USE} - \text{LSE})/2 * \tanh[(T - T_0)/(TZW/2)],$$

where USE and LSE are upper shelf energy and lower shelf energy, respectively; T is test temperature, T_0 is the mid-transition temperature, and TZW is the transition zone width.

The location in the vessel from which the specimens were removed is indicated in the identification of the Analysis Set given in the heading for each plot. The following is an example of the code used in that identification:

ANALYSIS SET: MW914T

MW $\equiv$ Midland Weld Beltline Weld (NC $\equiv$ Nozzle Course)

9 $\equiv$ Weld Section (Sections 9, 11, 13, and 15 Are Beltline Welds; Sections 31 and 34 Are Nozzle Course Welds)

14T $\equiv$ Fractional Depth In Thickness From Inner Surface
In This Case It Is The 1/4 Depth

NOTE: Ignore any underline (e.g. MW15_78T).

APPENDIX D

HYPERBOLIC TANGENT CURVE FITS WITH 68% AND 95% CONFIDENCE BOUNDS FOR INDIVIDUAL DATA SETS UNIRRADIATED MIDLAND REACTOR VESSEL WELDS

PLOTS FOR BELTLINE WELD SECTION 1-9

ANALYSIS SET: MW914T

MODEL PARAMETERS

LOWER SHELF ENERGY [HELD FIXED]: 2.7 (J), 2 (FT-LB)

MID-TRANSITION TEMPERATURE: -7.7 (DEG C), 18.2 (DEG F)

TRANSITION ZONE WIDTH: 88.5 (C DEG), 159.2 (F DEG)

UPPER SHELF ENERGY: 76.7 (J), 56.6 (FT-LB)

STANDARD MODEL: $ENERGY = A + B \cdot \tanh((TEMPERATURE - T_0) / C)$

A: 39.7 (J), 29.3 (FT-LB)

B: 37 (J), 27.3 (FT-LB)

T0: -7.7 (DEG C), 18.2 (DEG F)

C: 44.2 (C DEG), 79.6 (F DEG)

ORNL-DWG 92-11680

UPPER SHELF ENERGY: 76.7 (J), 56.6 (FT-LB)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 68.5 TO 84.9 (J), 50.5 TO 62.6 (FT-LB)

95 PERCENT: 58.8 TO 94.6 (J), 43.4 TO 69.8 (FT-LB)

TEMPERATURE [27 (J), 19.9 (FT-LB) ENERGY]: -23.5 (DEG C), -10.3 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -37 TO -12.5 (DEG C), -34.6 TO 9.6 (DEG F)

95 PERCENT: -59.1 TO 0 (DEG C), -74.3 TO 32 (DEG F)

TEMPERATURE [41 (J), 30.2 (FT-LB) ENERGY]: -6.1 (DEG C), 21 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -16.7 TO 4.7 (DEG C), 2 TO 40.5 (DEG F)

95 PERCENT: -31 TO 19.4 (DEG C), -23.8 TO 66.9 (DEG F)
TEMPERATURE [68 (J), 50.2 (FT-LB) ENERGY]: 36.9 (DEG C), 98.4 (DEG F)
CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 18.4 TO 94.6 (DEG C), 65.1 TO 202.2 (DEG F)

95 PERCENT: 3.6 TO UNDEFINED (DEG C), 38.4 TO UNDEFINED (DEG F)

REFERENCE TEMPERATURE ANALYSIS

MEAN IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY] -60 (DEG F): 3 (DEG C), 37.3 (DEG F)

MINIMUM IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY] -60 (DEG F): 13.9 (DEG C), 57 (DEG F)

REMARK: MIDLAND WELD BELTLINE 1-9, FROM 1/4 THICKNESS OF WELD

ANALYSIS SET: MW914T

MODEL PARAMETERS

LOWER SHELF EXPANSION [HELD FIXED]: 0.061 (MM),0.0024 (IN)

MID-TRANSITION TEMPERATURE: 4.2 (DEG C),39.6 (DEG F)

TRANSITION ZONE WIDTH: 119.8 (C DEG),215.6 (F DEG)

UPPER SHELF EXPANSION: 1.687 (MM),0.0664 (IN)

STANDARD MODEL: $EXPANSION = A + B * \tanh((TEMPERATURE - T_0) / C)$

A: 0.874 (MM),0.0344 (IN)

B: 0.813 (MM),0.032 (IN)

T0: 4.2 (DEG C),39.6 (DEG F)

C: 59.9 (C DEG),107.8 (F DEG)

ORNL-DWG 92-11681

UPPER SHELF EXPANSION: 1.687 (MM),0.0664 (IN)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 1.495 TO 1.879 (MM),0.0588 TO 0.074 (IN)

95 PERCENT: 1.269 TO 2.104 (MM),0.05 TO 0.0829 (IN)

TEMPERATURE [0.38 (MM),0.015 (IN) EXPANSION]: -38 (DEG C),-36.4 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -64.6 TO -20.1 (DEG C),-84.3 TO -4.2 (DEG F)

95 PERCENT: UNDEFINED TO -3.7 (DEG C),UNDEFINED TO 25.4 (DEG F)

TEMPERATURE [0.89 (MM),0.035 (IN) EXPANSION]: 5.4 (DEG C),41.8 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -7.9 TO 18.8 (DEG C),17.8 TO 65.9 (DEG F)

MIDLAND BELTLINE WELD 1-9, 1/4 THICKNESS

95 PERCENT:-25.9 TO 36.5 (DEG C), -14.6 TO 97.7 (DEG F)

REFERENCE TEMPERATURE ANALYSIS

MEAN IMPACT CURVE

TEMPERATURE [0.035 (IN) EXPANSION]-60 (DEG F):-28 (DEG C), -18.4 (DEG F)

MINIMUM IMPACT CURVE

TEMPERATURE [0.035 (IN) EXPANSION]-60 (DEG F):-23.7 (DEG C), -10.7 (DEG F)

REMARK: MIDLAND WELD BELTLINE 1-9, FROM 1/4 THICKNESS OF WELD

ANALYSIS SET: MW914T

MODEL PARAMETERS

LOWER SHELF SHEAR [HELD FIXED]: 0 (PERCENT)
MID-TRANSITION TEMPERATURE: -10.4 (DEG C), 13.3 (DEG F)
TRANSITION ZONE WIDTH: 56.2 (C DEG), 101.2 (F DEG)
UPPER SHELF SHEAR [HELD FIXED]: 100 (PERCENT)

STANDARD MODEL: $SHEAR = A + B \cdot \tanh((TEMPERATURE - T_0) / C)$

A: 50 (PERCENT)
B: 50 (PERCENT)
T0: -10.4 (DEG C), 13.3 (DEG F)
C: 28.1 (C DEG), 50.6 (F DEG)

ORNL-DWG 92-11682

UPPER SHELF SHEAR: 100 (PERCENT)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 94.3 TO 105.7 (PERCENT)

95 PERCENT: 87.6 TO 112.4 (PERCENT)

TEMPERATURE [50 (PERCENT), 50 (PERCENT) SHEAR]: -10.4 (DEG C), 13.3 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -14.6 TO -6.2 (DEG C), 5.7 TO 20.9 (DEG F)

95 PERCENT: -19.9 TO -1 (DEG C), -3.8 TO 30.2 (DEG F)

REMARK: MIDLAND WELD BELTLINE 1-9, FROM 1/4 THICKNESS OF WELD

ANALYSIS SET: MW912T

MODEL PARAMETERS

LOWER SHELF ENERGY [HELD FIXED]: 2.7 (J), 2 (FT-LB)

MID-TRANSITION TEMPERATURE: -8.5 (DEG C), 16.7 (DEG F)

TRANSITION ZONE WIDTH: 91.3 (C DEG), 164.3 (F DEG)

UPPER SHELF ENERGY: 83 (J), 61.2 (FT-LB)

STANDARD MODEL: $ENERGY = A + B \cdot \tanh((TEMPERATURE - T_0) / C)$

A: 42.8 (J), 31.6 (FT-LB)

B: 40.1 (J), 29.6 (FT-LB)

T₀: -8.5 (DEG C), 16.7 (DEG F)

C: 45.6 (C DEG), 82.1 (F DEG)

ORNL-DWG 92-11683

UPPER SHELF ENERGY: 83 (J), 61.2 (FT-LB)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 75.9 TO 90 (J), 56 TO 66.4 (FT-LB)

95 PERCENT: 67.4 TO 98.6 (J), 49.7 TO 72.7 (FT-LB)

TEMPERATURE [27 (J), 19.9 (FT-LB) ENERGY]: -27.5 (DEG C), -17.6 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -38.4 TO -18.5 (DEG C), -37.1 TO -1.3 (DEG F)

95 PERCENT: -55.4 TO -8.5 (DEG C), -67.8 TO 16.7 (DEG F)

TEMPERATURE [41 (J), 30.2 (FT-LB) ENERGY]: -10.6 (DEG C), 12.9 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -18.9 TO -2.3 (DEG C), -2.1 TO 27.8 (DEG F)

95 PERCENT: -30.3 TO 8.6 (DEG C), -22.6 TO 47.4 (DEG F)
TEMPERATURE [68 (J), 50.2 (FT-LB) ENERGY]: 25.1 (DEG C), 77.1 (DEG F)
CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 13.3 TO 41 (DEG C), 56 TO 105.8 (DEG F)

95 PERCENT: 2 TO UNDEFINED (DEG C), 35.6 TO UNDEFINED (DEG F)

REFERENCE TEMPERATURE ANALYSIS

MEAN IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY] -60 (DEG F): -8.6 (DEG C), 16.4 (DEG F)

MINIMUM IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY] -60 (DEG F): -8.6 (DEG C), 16.4 (DEG F)

REMARK: MIDLAND WELD BELTLINE 1-9, FROM 1/2 THICKNESS OF WELD

ANALYSIS SET: MW912T

MODEL PARAMETERS

LOWER SHELF EXPANSION [HELD FIXED]: 0.061 (MM), 0.0024 (IN)

MID-TRANSITION TEMPERATURE: -3.7 (DEG C), 25.4 (DEG F)

TRANSITION ZONE WIDTH: 118.8 (C DEG), 213.7 (F DEG)

UPPER SHELF EXPANSION: 1.762 (MM), 0.0694 (IN)

STANDARD MODEL: $\text{EXPANSION} = A + B \cdot \tanh((\text{TEMPERATURE} - T_0) / C)$

A: 0.911 (MM), 0.0359 (IN)

B: 0.85 (MM), 0.0335 (IN)

T0: -3.7 (DEG C), 25.4 (DEG F)

C: 59.4 (C DEG), 106.9 (F DEG)

ORNL-DWG 92-11684

UPPER SHELF EXPANSION: 1.762 (MM), 0.0694 (IN)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 1.68 TO 1.843 (MM), 0.0662 TO 0.0726 (IN)

95 PERCENT: 1.582 TO 1.941 (MM), 0.0623 TO 0.0764 (IN)

TEMPERATURE [0.38 (MM), 0.015 (IN) EXPANSION]: -47.2 (DEG C), -52.9 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -56.6 TO -39.2 (DEG C), -69.8 TO -38.6 (DEG F)

95 PERCENT: -70.8 TO -30.9 (DEG C), -95.4 TO -23.6 (DEG F)

TEMPERATURE [0.89 (MM), 0.035 (IN) EXPANSION]: -5.2 (DEG C), 22.7 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -10.4 TO 0.1 (DEG C), 13.3 TO 32.2 (DEG F)

95 PERCENT:-16.9 TO 6.7 (DEG C), 1.5 TO 44 (DEG F)
REFERENCE TEMPERATURE ANALYSIS
MEAN IMPACT CURVE
TEMPERATURE [0.035 (IN) EXPANSION]-60 (DEG F):-38.6 (DEG C), -37.4 (DEG F)
MINIMUM IMPACT CURVE
TEMPERATURE [0.035 (IN) EXPANSION]-60 (DEG F):-38.6 (DEG C), -37.4 (DEG F)
REMARK: MIDLAND WELD BELTLINE 1-9, FROM 1/2 THICKNESS OF WELD

ANALYSIS SET: MW912T

MODEL PARAMETERS

LOWER SHELF SHEAR [HELD FIXED]: 0 (PERCENT)
MID-TRANSITION TEMPERATURE: -2.4 (DEG C), 27.8 (DEG F)
TRANSITION ZONE WIDTH: 83.9 (C DEG), 151 (F DEG)
UPPER SHELF SHEAR [HELD FIXED]: 100 (PERCENT)

STANDARD MODEL: $SHEAR = A + B \cdot \tanh((TEMPERATURE - T_0) / C)$

A: 50 (PERCENT)
B: 50 (PERCENT)
T0: -2.4 (DEG C), 27.8 (DEG F)
C: 42 (C DEG), 75.5 (F DEG)

ORNL-DWG 92-11685

UPPER SHELF SHEAR: 100 (PERCENT)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 97.7 TO 102.3 (PERCENT)

95 PERCENT: 95.1 TO 104.9 (PERCENT)

TEMPERATURE [50 (PERCENT), 50 (PERCENT) SHEAR]: -2.4 (DEG C), 27.8 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -4.6 TO -0.1 (DEG C), 23.6 TO 31.9 (DEG F)

95 PERCENT: -7.4 TO 2.7 (DEG C), 18.7 TO 36.8 (DEG F)

REMARK: MIDLAND WELD BELTLINE 1-9, FROM 1/2 THICKNESS OF WELD

ANALYSIS SET: MW958T

MODEL PARAMETERS

LOWER SHELF ENERGY [HELD FIXED]: 2.7 (J), 2 (FT-LB)

MID-TRANSITION TEMPERATURE: -12.6 (DEG C), 9.4 (DEG F)

TRANSITION ZONE WIDTH: 102.9 (C DEG), 185.3 (F DEG)

UPPER SHELF ENERGY: 88.2 (J), 65.1 (FT-LB)

STANDARD MODEL: $ENERGY = A + B \cdot \tanh((TEMPERATURE - T_0) / C)$

A: 45.5 (J), 33.5 (FT-LB)

B: 42.8 (J), 31.5 (FT-LB)

T0: -12.6 (DEG C), 9.4 (DEG F)

C: 51.5 (C DEG), 92.7 (F DEG)

ORNL-DWG 92-11686

UPPER SHELF ENERGY: 88.2 (J), 65.1 (FT-LB)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 81 TO 95.5 (J), 59.8 TO 70.4 (FT-LB)

95 PERCENT: 72.3 TO 104.2 (J), 53.3 TO 76.9 (FT-LB)

TEMPERATURE [27 (J), 19.9 (FT-LB) ENERGY]: -36.3 (DEG C), -33.4 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -47.8 TO -27 (DEG C), -54 TO -16.6 (DEG F)

95 PERCENT: -66 TO -17 (DEG C), -86.9 TO 1.4 (DEG F)

TEMPERATURE [41 (J), 30.2 (FT-LB) ENERGY]: -18 (DEG C), -0.3 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -26.4 TO -9.9 (DEG C), -15.6 TO 14.2 (DEG F)

MIDLAND BELTLINE WELD 1-9, 5/8 THICKNESS

95 PERCENT:-38.3 TO 0.4 (DEG C), -36.9 TO 32.8 (DEG F)

TEMPERATURE [68 (J), 50.2 (FT-LB) ENERGY]: 17.6 (DEG C), 63.7 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 7.2 TO 30.7 (DEG C), 45 TO 87.2 (DEG F)

95 PERCENT:-3.3 TO 55.9 (DEG C), 26 TO 132.6 (DEG F)

REFERENCE TEMPERATURE ANALYSIS

MEAN IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY]-60 (DEG F):-16.1 (DEG C), 3 (DEG F)

MINIMUM IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY]-60 (DEG F):-16.1 (DEG C), 3 (DEG F)

REMARK: MIDLAND WELD BELTLINE 1-9, FROM 5/8 THICKNESS OF WELD

ANALYSIS SET: MW958T

MODEL PARAMETERS

LOWER SHELF EXPANSION [HELD FIXED]: 0.061 (MM),0.0024 (IN)

MID-TRANSITION TEMPERATURE:-7.8 (DEG C),17.9 (DEG F)

TRANSITION ZONE WIDTH: 122.2 (C DEG),219.9 (F DEG)

UPPER SHELF EXPANSION: 1.854 (MM),0.073 (IN)

STANDARD MODEL: $\text{EXPANSION} = A + B \cdot \tanh((\text{TEMPERATURE} - T_0) / C)$

A: 0.957 (MM),0.0377 (IN)

B: 0.896 (MM),0.0353 (IN)

T0:-7.8 (DEG C),17.9 (DEG F)

C: 61.1 (C DEG),109.9 (F DEG)

ORNL-DWG 92-11687

UPPER SHELF EXPANSION: 1.854 (MM),0.073 (IN)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 1.751 TO 1.956 (MM),0.0689 TO 0.077 (IN)

95 PERCENT: 1.626 TO 2.081 (MM),0.064 TO 0.0819 (IN)

TEMPERATURE [0.38 (MM),0.015 (IN) EXPANSION]:-54.6 (DEG C),-66.2 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT:-66.7 TO -44.8 (DEG C),-88 TO -48.6 (DEG F)

95 PERCENT:-86.6 TO -35 (DEG C),-123.8 TO -30.9 (DEG F)

TEMPERATURE [0.89 (MM),0.035 (IN) EXPANSION]:-12.4 (DEG C),9.6 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT:-18.7 TO -6.2 (DEG C),-1.6 TO 20.8 (DEG F)

95 PERCENT:-26.7 TO 1.4 (DEG C), -16.1 TO 34.6 (DEG F)
REFERENCE TEMPERATURE ANALYSIS
MEAN IMPACT CURVE
TEMPERATURE [0.035 (IN) EXPANSION]-60 (DEG F):-45.8 (DEG C), -50.5 (DEG F)
MINIMUM IMPACT CURVE
TEMPERATURE [0.035 (IN) EXPANSION]-60 (DEG F):-45.8 (DEG C), -50.5 (DEG F)
REMARK: MIDLAND WELD BELTLINE 1-9, FROM 5/8 THICKNESS OF WELD

ANALYSIS SET: MW958T

MODEL PARAMETERS

LOWER SHELF SHEAR [HELD FIXED]: 0 (PERCENT)
MID-TRANSITION TEMPERATURE:-22.8 (DEG C), -9.1 (DEG F)
TRANSITION ZONE WIDTH: 74.6 (C DEG), 134.2 (F DEG)
UPPER SHELF SHEAR [HELD FIXED]: 100 (PERCENT)
STANDARD MODEL: $SHEAR = A + B * \tanh((TEMPERATURE - T_0) / C)$
A: 50 (PERCENT)
B: 50 (PERCENT)
T0: -22.8 (DEG C), -9.1 (DEG F)
C: 37.3 (C DEG), 67.1 (F DEG)

ORNL-DWG 92-11688

UPPER SHELF SHEAR: 100 (PERCENT)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 95.1 TO 104.9 (PERCENT)

95 PERCENT: 89.3 TO 110.7 (PERCENT)

TEMPERATURE [50 (PERCENT), 50 (PERCENT) SHEAR]: -22.8 (DEG C), -9.1 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -27.2 TO -18.6 (DEG C), -17 TO -1.4 (DEG F)

95 PERCENT: -32.8 TO -13.4 (DEG C), -27.1 TO 8 (DEG F)

REMARK: MIDLAND WELD BELTLINE 1-9, FROM 5/8 THICKNESS OF WELD

ANALYSIS SET: MW934T

MODEL PARAMETERS

LOWER SHELF ENERGY [HELD FIXED]: 2.7 (J), 2 (FT-LB)

MID-TRANSITION TEMPERATURE: 4.7 (DEG C), 40.5 (DEG F)

TRANSITION ZONE WIDTH: 119.8 (C DEG), 215.7 (F DEG)

UPPER SHELF ENERGY: 81 (J), 59.7 (FT-LB)

STANDARD MODEL: $ENERGY = A + B * \tanh((TEMPERATURE - T_0) / C)$

A: 41.8 (J), 30.9 (FT-LB)

B: 39.1 (J), 28.9 (FT-LB)

T₀: 4.7 (DEG C), 40.5 (DEG F)

C: 59.9 (C DEG), 107.8 (F DEG)

ORNL-DWG 92-11689

UPPER SHELF ENERGY: 81 (J), 59.7 (FT-LB)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 77.4 TO 84.6 (J), 57.1 TO 62.4 (FT-LB)

95 PERCENT: 73 TO 88.9 (J), 53.8 TO 65.6 (FT-LB)

TEMPERATURE [27 (J), 19.9 (FT-LB) ENERGY]: -19.2 (DEG C), -2.5 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -26.2 TO -12.8 (DEG C), -15.1 TO 8.9 (DEG F)

95 PERCENT: -35.9 TO -5.7 (DEG C), -32.6 TO 21.8 (DEG F)

TEMPERATURE [41 (J), 30.2 (FT-LB) ENERGY]: 3.5 (DEG C), 38.2 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -2.2 TO 9.1 (DEG C), 28.1 TO 48.4 (DEG F)

95 PERCENT: -9.2 TO 16.1 (DEG C), 15.4 TO 61 (DEG F)
TEMPERATURE [68 (J), 50.2 (FT-LB) ENERGY]: 53.2 (DEG C), 127.7 (DEG F)
CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 43.8 TO 64.6 (DEG C), 110.8 TO 148.2 (DEG F)

95 PERCENT: 34.2 TO 83.7 (DEG C), 93.5 TO 182.7 (DEG F)

REFERENCE TEMPERATURE ANALYSIS

MEAN IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY] -60 (DEG F): 19.2 (DEG C), 66.6 (DEG F)

MINIMUM IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY] -60 (DEG F): 19.2 (DEG C), 66.6 (DEG F)

REMARK: MIDLAND BELTLINE WELD 1-9, FROM 3/4 THICKNESS OF WELD

ANALYSIS SET: MW934T

MODEL PARAMETERS

LOWER SHELF EXPANSION [HELD FIXED]: 0.061 (MM), 0.0024 (IN)

MID-TRANSITION TEMPERATURE: 11.7 (DEG C), 53.1 (DEG F)

TRANSITION ZONE WIDTH: 140.9 (C DEG), 253.6 (F DEG)

UPPER SHELF EXPANSION: 1.758 (MM), 0.0692 (IN)

STANDARD MODEL: $\text{EXPANSION} = A + B \cdot \tanh((\text{TEMPERATURE} - T_0) / C)$

A: 0.91 (MM), 0.0358 (IN)

B: 0.849 (MM), 0.0334 (IN)

T₀: 11.7 (DEG C), 53.1 (DEG F)

C: 70.5 (C DEG), 126.8 (F DEG)

ORNL-DWG 92-11690

UPPER SHELF EXPANSION: 1.758 (MM), 0.0692 (IN)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 1.679 TO 1.837 (MM), 0.0661 TO 0.0723 (IN)

95 PERCENT: 1.583 TO 1.933 (MM), 0.0623 TO 0.0761 (IN)

TEMPERATURE [0.38 (MM), 0.015 (IN) EXPANSION]: -39.8 (DEG C), -39.7 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -51.7 TO -29.9 (DEG C), -61 TO -21.8 (DEG F)

95 PERCENT: -69.8 TO -19.7 (DEG C), -93.6 TO -3.5 (DEG F)

TEMPERATURE [0.89 (MM), 0.035 (IN) EXPANSION]: 10.1 (DEG C), 50.2 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 3.6 TO 16.6 (DEG C), 38.5 TO 61.9 (DEG F)

MIDLAND BELTLINE WELD 1-9, 3/4 THICKNESS

95 PERCENT:-4.4 TO 24.8 (DEG C), 24 TO 76.6 (DEG F)

REFERENCE TEMPERATURE ANALYSIS

MEAN IMPACT CURVE

TEMPERATURE [0.035 (IN) EXPANSION]-60 (DEG F):-23.3 (DEG C), -10 (DEG F)

MINIMUM IMPACT CURVE

TEMPERATURE [0.035 (IN) EXPANSION]-60 (DEG F):-23.3 (DEG C), -10 (DEG F)

REMARK: MIDLAND WELD BELTLINE 1-9, FROM 3/4 THICKNESS OF WELD

ANALYSIS SET: MW934T

MODEL PARAMETERS

LOWER SHELF SHEAR [HELD FIXED]: 0 (PERCENT)

MID-TRANSITION TEMPERATURE: 6.2 (DEG C), 43.1 (DEG F)

TRANSITION ZONE WIDTH: 84 (C DEG), 151.2 (F DEG)

UPPER SHELF SHEAR [HELD FIXED]: 100 (PERCENT)

STANDARD MODEL: $SHEAR = A + B \cdot \tanh((TEMPERATURE - T_0) / C)$

A: 50 (PERCENT)

B: 50 (PERCENT)

T0: 6.2 (DEG C), 43.1 (DEG F)

C: 42 (C DEG), 75.6 (F DEG)

ORNL-DWG 92-11691

UPPER SHELF SHEAR: 100 (PERCENT)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 94.8 TO 105.2 (PERCENT)

95 PERCENT: 88.7 TO 111.3 (PERCENT)

TEMPERATURE [50 (PERCENT), 50 (PERCENT) SHEAR]: 6.2 (DEG C), 43.1 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 0.9 TO 11.5 (DEG C), 33.6 TO 52.7 (DEG F)

95 PERCENT: -5.7 TO 18.1 (DEG C), 21.8 TO 64.6 (DEG F)

REMARK: MIDLAND WELD BELTLINE 1-9, FROM 3/4 THICKNESS OF WELD

ANALYSIS SET: MW978T

MODEL PARAMETERS

LOWER SHELF ENERGY [HELD FIXED]: 2.7 (J), 2 (FT-LB)
MID-TRANSITION TEMPERATURE: -4.2 (DEG C), 24.5 (DEG F)
TRANSITION ZONE WIDTH: 108.5 (C DEG), 195.2 (F DEG)
UPPER SHELF ENERGY: 78.1 (J), 57.6 (FT-LB)

STANDARD MODEL: $ENERGY = A + B \cdot \tanh((TEMPERATURE - T_0) / C)$

A: 40.4 (J), 29.8 (FT-LB)
B: 37.7 (J), 27.8 (FT-LB)
T0: -4.2 (DEG C), 24.5 (DEG F)
C: 54.2 (C DEG), 97.6 (F DEG)

ORNL-DWG 92-11692

UPPER SHELF ENERGY: 78.1 (J), 57.6 (FT-LB)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 73.8 TO 82.4 (J), 54.4 TO 60.8 (FT-LB)

95 PERCENT: 68.6 TO 87.6 (J), 50.6 TO 64.6 (FT-LB)

TEMPERATURE [27 (J), 19.9 (FT-LB) ENERGY]: -24.3 (DEG C), -11.8 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -31.6 TO -17.6 (DEG C), -24.9 TO 0.3 (DEG F)

95 PERCENT: -41.8 TO -9.6 (DEG C), -43.3 TO 14.7 (DEG F)

TEMPERATURE [41 (J), 30.2 (FT-LB) ENERGY]: -3.3 (DEG C), 26.1 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -9.6 TO 3.4 (DEG C), 14.8 TO 38.1 (DEG F)

MIDLAND BELTLINE WELD 1-9, 7/8 THICKNESS

95 PERCENT: -17.1 TO 12.4 (DEG C), 1.3 TO 54.3 (DEG F)

TEMPERATURE [68 (J), 50.2 (FT-LB) ENERGY]: 46.5 (DEG C), 115.7 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 34.1 TO 62.7 (DEG C), 93.4 TO 144.8 (DEG F)

95 PERCENT: 22.2 TO 113.6 (DEG C), 71.9 TO 236.6 (DEG F)

REFERENCE TEMPERATURE ANALYSIS

MEAN IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY]-60 (DEG F): 12.5 (DEG C), 54.5 (DEG F)

MINIMUM IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY]-60 (DEG F): 12.5 (DEG C), 54.5 (DEG F)

REMARK: MIDLAND WELD BELTLINE 1-9, FROM 7/8 THICKNESS OF WELD

ANALYSIS SET: MW978T

MODEL PARAMETERS

LOWER SHELF EXPANSION [HELD FIXED]: 0.061 (MM),0.0024 (IN)

MID-TRANSITION TEMPERATURE: 3.1 (DEG C),37.5 (DEG F)

TRANSITION ZONE WIDTH: 154.2 (C DEG),277.6 (F DEG)

UPPER SHELF EXPANSION: 1.766 (MM),0.0695 (IN)

STANDARD MODEL: $\text{EXPANSION} = A + B \cdot \text{TANH}((\text{TEMPERATURE} - T_0) / C)$

A: 0.913 (MM),0.036 (IN)

B: 0.852 (MM),0.0336 (IN)

T0: 3.1 (DEG C),37.5 (DEG F)

C: 77.1 (C DEG),138.8 (F DEG)

ORNL-DWG 92-11693

UPPER SHELF EXPANSION: 1.766 (MM),0.0695 (IN)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 1.631 TO 1.9 (MM),0.0642 TO 0.0748 (IN)

95 PERCENT: 1.469 TO 2.062 (MM),0.0578 TO 0.0812 (IN)

TEMPERATURE [0.38 (MM),0.015 (IN) EXPANSION]: -53.6 (DEG C),-64.4 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -74.6 TO -37.7 (DEG C),-102.2 TO -35.9 (DEG F)

95 PERCENT: -117.4 TO -21.9 (DEG C),-179.3 TO -7.5 (DEG F)

TEMPERATURE [0.89 (MM),0.035 (IN) EXPANSION]: 1 (DEG C),33.7 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -10.2 TO 12.4 (DEG C),13.7 TO 54.4 (DEG F)

MIDLAND BELTLINE WELD 1-9, 7/8 THICKNESS

95 PERCENT:-24.2 TO 27.6 (DEG C), -11.6 TO 81.7 (DEG F)

REFERENCE TEMPERATURE ANALYSIS

MEAN IMPACT CURVE

TEMPERATURE [0.035 (IN) EXPANSION]-60 (DEG F):-32.5 (DEG C), -26.4 (DEG F)

MINIMUM IMPACT CURVE

TEMPERATURE [0.035 (IN) EXPANSION]-60 (DEG F):-32.5 (DEG C), -26.4 (DEG F)

REMARK: MIDLAND WELD BELTLINE 1-9, FROM 7/8 THICKNESS OF WELD

ANALYSIS SET: MW978T

MODEL PARAMETERS

LOWER SHELF SHEAR [HELD FIXED]: 0 (PERCENT)
MID-TRANSITION TEMPERATURE: -18.6 (DEG C), -1.5 (DEG F)
TRANSITION ZONE WIDTH: 65.1 (C DEG), 117.3 (F DEG)
UPPER SHELF SHEAR [HELD FIXED]: 100 (PERCENT)
STANDARD MODEL: $SHEAR = A + B \cdot \tanh((TEMPERATURE - T_0) / C)$
A: 50 (PERCENT)
B: 50 (PERCENT)
T0: -18.6 (DEG C), -1.5 (DEG F)
C: 32.6 (C DEG), 58.6 (F DEG)

ORNL-DWG 92-11694

UPPER SHELF SHEAR: 100 (PERCENT)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 97.9 TO 102.1 (PERCENT)

95 PERCENT: 95.5 TO 104.5 (PERCENT)

TEMPERATURE [50 (PERCENT), 50 (PERCENT) SHEAR]: -18.6 (DEG C), -1.5 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -20.2 TO -16.9 (DEG C), -4.4 TO 1.5 (DEG F)

95 PERCENT: -22.1 TO -14.9 (DEG C), -7.9 TO 5.2 (DEG F)

REMARK: MIDLAND WELD BELTLINE 1-9, FROM 7/8 THICKNESS OF WELD

APPENDIX D

HYPERBOLIC TANGENT CURVE FITS WITH 68% AND 95% CONFIDENCE BOUNDS FOR INDIVIDUAL DATA SETS UNIRRADIATED MIDLAND REACTOR VESSEL WELDS

PLOTS FOR BELTLINE WELD SECTION 1-11

ANALYSIS SET: MW11_14T

MODEL PARAMETERS

LOWER SHELF ENERGY [HELD FIXED]: 2.7 (J), 2 (FT-LB)
MID-TRANSITION TEMPERATURE: -5.9 (DEG C), 21.4 (DEG F)
TRANSITION ZONE WIDTH: 115.4 (C DEG), 207.8 (F DEG)
UPPER SHELF ENERGY: 90.6 (J), 66.8 (FT-LB)

STANDARD MODEL: $ENERGY = A + B * \tanh((TEMPERATURE - T_0) / C)$

A: 46.7 (J), 34.4 (FT-LB)
B: 44 (J), 32.4 (FT-LB)
T0: -5.9 (DEG C), 21.4 (DEG F)
C: 57.7 (C DEG), 103.9 (F DEG)

ORNL-DWG 92-11695

UPPER SHELF ENERGY: 90.6 (J), 66.8 (FT-LB)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 82.2 TO 99 (J), 60.7 TO 73 (FT-LB)

95 PERCENT: 72.1 TO 109.1 (J), 53.2 TO 80.5 (FT-LB)

TEMPERATURE [27 (J), 19.9 (FT-LB) ENERGY]: -33.6 (DEG C), -28.6 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -49.8 TO -21 (DEG C), -57.6 TO -5.7 (DEG F)

95 PERCENT: -77 TO -7.8 (DEG C), -106.7 TO 17.9 (DEG F)

TEMPERATURE [41 (J), 30.2 (FT-LB) ENERGY]: -13.3 (DEG C), 8 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -25.1 TO -2.6 (DEG C), -13.3 TO 27.4 (DEG F)

MIDLAND BELTLINE WELD 1-11, 1/4 THICKNESS

95 PERCENT:-42.5 TO 10.8 (DEG C), -44.5 TO 51.5 (DEG F)

TEMPERATURE [68 (J), 50.2 (FT-LB) ENERGY]: 24.7 (DEG C), 76.5 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 12 TO 40.5 (DEG C), 53.6 TO 104.9 (DEG F)

95 PERCENT:-1.6 TO 71.1 (DEG C), 29.2 TO 160 (DEG F)

REFERENCE TEMPERATURE ANALYSIS

MEAN IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY]-60 (DEG F):-9 (DEG C), 15.8 (DEG F)

MINIMUM IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY]-60 (DEG F):-9 (DEG C), 15.8 (DEG F)

REMARK: MIDLAND WELD BELTLINE 1-11, FROM 1/4 THICKNESS OF WELD

ANALYSIS SET: MW11_14T

MODEL PARAMETERS

LOWER SHELF EXPANSION [HELD FIXED]: 0.061 (MM), 0.0024 (IN)

MID-TRANSITION TEMPERATURE: -8.4 (DEG C), 16.8 (DEG F)

TRANSITION ZONE WIDTH: 123.8 (C DEG), 222.9 (F DEG)

UPPER SHELF EXPANSION: 1.757 (MM), 0.0692 (IN)

STANDARD MODEL: $\text{EXPANSION} = A + B \cdot \text{TANH}((\text{TEMPERATURE} - T_0) / C)$

A: 0.909 (MM), 0.0358 (IN)

B: 0.848 (MM), 0.0334 (IN)

T0: -8.4 (DEG C), 16.8 (DEG F)

C: 61.9 (C DEG), 111.5 (F DEG)

ORNL-DWG 92-11696

UPPER SHELF EXPANSION: 1.757 (MM), 0.0692 (IN)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 1.593 TO 1.921 (MM), 0.0627 TO 0.0756 (IN)

95 PERCENT: 1.395 TO 2.119 (MM), 0.0549 TO 0.0834 (IN)

TEMPERATURE [0.38 (MM), 0.015 (IN) EXPANSION]: -53.7 (DEG C), -64.7 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -78 TO -36.7 (DEG C), -108.4 TO -34 (DEG F)

95 PERCENT: -158.2 TO -21.1 (DEG C), -252.7 TO -6 (DEG F)

TEMPERATURE [0.89 (MM), 0.035 (IN) EXPANSION]: -9.8 (DEG C), 14.3 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -21.9 TO 1.8 (DEG C), -7.4 TO 35.2 (DEG F)

MIDLAND BELTLINE WELD 1-11, 1/4 THICKNESS

95 PERCENT:-39.1 TO 16.9 (DEG C), -38.5 TO 62.4 (DEG F)

REFERENCE TEMPERATURE ANALYSIS

MEAN IMPACT CURVE

TEMPERATURE [0.035 (IN) EXPANSION]-60 (DEG F):-43.2 (DEG C), -45.8 (DEG F)

MINIMUM IMPACT CURVE

TEMPERATURE [0.035 (IN) EXPANSION]-60 (DEG F):-43.2 (DEG C), -45.8 (DEG F)

REMARK: MIDLAND WELD BELTLINE 1-11, FROM 1/4 THICKNESS OF WELD

ANALYSIS SET: MW11_14T

MODEL PARAMETERS

LOWER SHELF SHEAR [HELD FIXED]: 0 (PERCENT)
MID-TRANSITION TEMPERATURE: 2 (DEG C), 35.6 (DEG F)
TRANSITION ZONE WIDTH: 92.2 (C DEG), 166 (F DEG)
UPPER SHELF SHEAR [HELD FIXED]: 100 (PERCENT)

STANDARD MODEL: $SHEAR = A + B * \tanh((TEMPERATURE - T_0) / C)$

A: 50 (PERCENT)
B: 50 (PERCENT)
T0: 2 (DEG C), 35.6 (DEG F)
C: 46.1 (C DEG), 83 (F DEG)

ORNL-DWG 92-11697

UPPER SHELF SHEAR: 100 (PERCENT)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 94.3 TO 105.7 (PERCENT)

95 PERCENT: 87.7 TO 112.3 (PERCENT)

TEMPERATURE [50 (PERCENT), 50 (PERCENT) SHEAR]: 2 (DEG C), 35.6 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -4.2 TO 8.1 (DEG C), 24.4 TO 46.6 (DEG F)

95 PERCENT: -12.1 TO 15.6 (DEG C), 10.2 TO 60 (DEG F)

REMARK: MIDLAND WELD BELTLINE 1-11, FROM 1/4 THICKNESS OF WELD

ANALYSIS SET: MW11_12T

MODEL PARAMETERS

LOWER SHELF ENERGY [HELD FIXED]: 2.7 (J), 2 (FT-LB)

MID-TRANSITION TEMPERATURE: 1.9 (DEG C), 35.4 (DEG F)

TRANSITION ZONE WIDTH: 84.1 (C DEG), 151.4 (F DEG)

UPPER SHELF ENERGY: 91.3 (J), 67.4 (FT-LB)

STANDARD MODEL: $ENERGY = A + B \cdot \tanh((TEMPERATURE - T_0) / C)$

A: 47 (J), 34.7 (FT-LB)

B: 44.3 (J), 32.7 (FT-LB)

T0: 1.9 (DEG C), 35.4 (DEG F)

C: 42 (C DEG), 75.7 (F DEG)

ORNL-DWG 92-11698

UPPER SHELF ENERGY: 91.3 (J), 67.4 (FT-LB)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 85.3 TO 97.4 (J), 62.9 TO 71.9 (FT-LB)

95 PERCENT: 77.9 TO 104.8 (J), 57.5 TO 77.3 (FT-LB)

TEMPERATURE [27 (J), 19.9 (FT-LB) ENERGY]: -18.6 (DEG C), -1.5 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -27.3 TO -11.5 (DEG C), -17.2 TO 11.3 (DEG F)

95 PERCENT: -40.9 TO -4.1 (DEG C), -41.5 TO 24.6 (DEG F)

TEMPERATURE [41 (J), 30.2 (FT-LB) ENERGY]: -3.9 (DEG C), 25 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -10.2 TO 2 (DEG C), 13.6 TO 35.6 (DEG F)

95 PERCENT: -19.2 TO 9.3 (DEG C), -2.6 TO 48.8 (DEG F)
TEMPERATURE [68 (J), 50.2 (FT-LB) ENERGY]: 23.5 (DEG C), 74.3 (DEG F)
CONFIDENCE INTERVALS ON PREDICTED VALUE
68 PERCENT: 16.3 TO 32.3 (DEG C), 61.3 TO 90.1 (DEG F)
95 PERCENT: 8.8 TO 46 (DEG C), 47.8 TO 114.9 (DEG F)

REFERENCE TEMPERATURE ANALYSIS

MEAN IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY] -60 (DEG F): -10.1 (DEG C), 13.9 (DEG F)

MINIMUM IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY] -60 (DEG F): -10.1 (DEG C), 13.8 (DEG F)

REMARK: MIDLAND WELD BELTLINE 1-11, FROM 1/2 THICKNESS OF WELD

ANALYSIS SET: MW11_12T

MODEL PARAMETERS

LOWER SHELF EXPANSION [HELD FIXED]: 0.061 (MM), 0.0024 (IN)

MID-TRANSITION TEMPERATURE: 3.8 (DEG C), 38.9 (DEG F)

TRANSITION ZONE WIDTH: 63.2 (C DEG), 113.7 (F DEG)

UPPER SHELF EXPANSION: 1.566 (MM), 0.0617 (IN)

STANDARD MODEL: $\text{EXPANSION} = A + B \cdot \tanh((\text{TEMPERATURE} - T_0) / C)$

A: 0.813 (MM), 0.032 (IN)

B: 0.752 (MM), 0.0296 (IN)

T0: 3.8 (DEG C), 38.9 (DEG F)

C: 31.6 (C DEG), 56.9 (F DEG)

ORNL-DWG 92-11699

UPPER SHELF EXPANSION: 1.566 (MM), 0.0617 (IN)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 1.482 TO 1.65 (MM), 0.0583 TO 0.065 (IN)

95 PERCENT: 1.379 TO 1.752 (MM), 0.0543 TO 0.069 (IN)

TEMPERATURE [0.38 (MM), 0.015 (IN) EXPANSION]: -16.9 (DEG C), 1.6 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -23.5 TO -11.6 (DEG C), -10.3 TO 11.1 (DEG F)

95 PERCENT: -33.8 TO -6.3 (DEG C), -28.8 TO 20.7 (DEG F)

TEMPERATURE [0.89 (MM), 0.035 (IN) EXPANSION]: 7.1 (DEG C), 44.7 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 3.3 TO 11.1 (DEG C), 37.9 TO 51.9 (DEG F)

MIDLAND BELTLINE WELD 1-11, 1/2 THICKNESS

95 PERCENT:-1.3 TO 16.5 (DEG C), 29.7 TO 61.7 (DEG F)

REFERENCE TEMPERATURE ANALYSIS

MEAN IMPACT CURVE

TEMPERATURE [0.035 (IN) EXPANSION]-60 (DEG F):-26.3 (DEG C), -15.4 (DEG F)

MINIMUM IMPACT CURVE

TEMPERATURE [0.035 (IN) EXPANSION]-60 (DEG F):-25.4 (DEG C), -13.7 (DEG F)

REMARK: MIDLAND WELD BELTLINE 1-11, FROM 1/2 THICKNESS OF WELD

ANALYSIS SET: MW11_12T

MODEL PARAMETERS

LOWER SHELF SHEAR [HELD FIXED]: 0 (PERCENT)

MID-TRANSITION TEMPERATURE: 5.6 (DEG C), 42.2 (DEG F)

TRANSITION ZONE WIDTH: 45 (C DEG), 80.9 (F DEG)

UPPER SHELF SHEAR [HELD FIXED]: 100 (PERCENT)

STANDARD MODEL: $SHEAR = A + B * \tanh((TEMPERATURE - T_0) / C)$

A: 50 (PERCENT)

B: 50 (PERCENT)

T0: 5.6 (DEG C), 42.2 (DEG F)

C: 22.5 (C DEG), 40.5 (F DEG)

ORNL-DWG 92-11700

UPPER SHELF SHEAR: 100 (PERCENT)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 98.2 TO 101.8 (PERCENT)

95 PERCENT: 96.1 TO 103.9 (PERCENT)

TEMPERATURE [50 (PERCENT), 50 (PERCENT) SHEAR]: 5.6 (DEG C), 42.2 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 4.7 TO 6.7 (DEG C), 40.4 TO 44 (DEG F)

95 PERCENT: 3.5 TO 7.9 (DEG C), 38.3 TO 46.2 (DEG F)

REMARK: MIDLAND WELD 1-11, FROM 1/2 THICKNESS OF WELD

ANALYSIS SET: MW11_58T

MODEL PARAMETERS

LOWER SHELF ENERGY [HELD FIXED]: 2.7 (J), 2 (FT-LB)
MID-TRANSITION TEMPERATURE: -5.1 (DEG C), 22.8 (DEG F)
TRANSITION ZONE WIDTH: 83.4 (C DEG), 150.1 (F DEG)
UPPER SHELF ENERGY: 90.2 (J), 66.5 (FT-LB)

STANDARD MODEL: $ENERGY = A + B * \tanh((TEMPERATURE - T_0) / C)$

A: 46.5 (J), 34.3 (FT-LB)
B: 43.8 (J), 32.3 (FT-LB)
T₀: -5.1 (DEG C), 22.8 (DEG F)
C: 41.7 (C DEG), 75 (F DEG)

ORNL-DWG 92-11701

UPPER SHELF ENERGY: 90.2 (J), 66.5 (FT-LB)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 83.8 TO 96.6 (J), 61.8 TO 71.2 (FT-LB)

95 PERCENT: 76.1 TO 104.3 (J), 56.1 TO 76.9 (FT-LB)

TEMPERATURE [27 (J), 19.9 (FT-LB) ENERGY]: -25 (DEG C), -13 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -34.3 TO -17.4 (DEG C), -29.7 TO 0.6 (DEG F)

95 PERCENT: -48.5 TO -9.6 (DEG C), -55.3 TO 14.8 (DEG F)

TEMPERATURE [41 (J), 30.2 (FT-LB) ENERGY]: -10.3 (DEG C), 13.4 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -17.2 TO -4 (DEG C), 1.1 TO 24.8 (DEG F)

MIDLAND BELTLINE WELD 1-11, 5/8 THICKNESS

95 PERCENT: -26.9 TO 3.6 (DEG C), -16.3 TO 38.5 (DEG F)
TEMPERATURE [68 (J), 50.2 (FT-LB) ENERGY]: 17.4 (DEG C), 63.3 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 9.8 TO 26.6 (DEG C), 49.6 TO 79.9 (DEG F)

95 PERCENT: 1.7 TO 41.9 (DEG C), 35.1 TO 107.4 (DEG F)

REFERENCE TEMPERATURE ANALYSIS

MEAN IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY] -60 (DEG F): -16.2 (DEG C), 2.8 (DEG F)

MINIMUM IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY] -60 (DEG F): -16.2 (DEG C), 2.8 (DEG F)

REMARK: MIDLAND WELD BELTLINE 1-11, FROM 5/8 THICKNESS OF WELD

ANALYSIS SET: MW11_58T

MODEL PARAMETERS

LOWER SHELF EXPANSION [HELD FIXED]: 0.061 (MM), 0.0024 (IN)

MID-TRANSITION TEMPERATURE: -2.5 (DEG C), 27.5 (DEG F)

TRANSITION ZONE WIDTH: 97.9 (C DEG), 176.2 (F DEG)

UPPER SHELF EXPANSION: 1.702 (MM), 0.067 (IN)

STANDARD MODEL: $\text{EXPANSION} = A + B \cdot \tanh((\text{TEMPERATURE} - T_0) / C)$

A: 0.882 (MM), 0.0347 (IN)

B: 0.821 (MM), 0.0323 (IN)

T0: -2.5 (DEG C), 27.5 (DEG F)

C: 49 (C DEG), 88.1 (F DEG)

ORNL-DWG 92-11702

UPPER SHELF EXPANSION: 1.702 (MM), 0.067 (IN)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 1.613 TO 1.791 (MM), 0.0635 TO 0.0705 (IN)

95 PERCENT: 1.507 TO 1.898 (MM), 0.0593 TO 0.0747 (IN)

TEMPERATURE [0.38 (MM), 0.015 (IN) EXPANSION]: -37.3 (DEG C), -35.2 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -47.2 TO -29.2 (DEG C), -52.9 TO -20.6 (DEG F)

95 PERCENT: -62.7 TO -21.1 (DEG C), -80.9 TO -6 (DEG F)

TEMPERATURE [0.89 (MM), 0.035 (IN) EXPANSION]: -2 (DEG C), 28.4 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -7.3 TO 3.3 (DEG C), 18.8 TO 37.9 (DEG F)

MIDLAND BELTLINE WELD 1-11, 5/8 THICKNESS

95 PERCENT:-14.2 TO 9.9 (DEG C), 6.5 TO 49.8 (DEG F)

REFERENCE TEMPERATURE ANALYSIS

MEAN IMPACT CURVE

TEMPERATURE [0.035 (IN) EXPANSION]-60 (DEG F):-35.4 (DEG C), -31.7 (DEG F)

MINIMUM IMPACT CURVE

TEMPERATURE [0.035 (IN) EXPANSION]-60 (DEG F):-35.4 (DEG C), -31.7 (DEG F)

REMARK: MIDLAND WELD BELTLINE 1-11, FROM 5/8 THICKNESS OF WELD

ANALYSIS SET: MW11_58T

MODEL PARAMETERS

LOWER SHELF SHEAR [HELD FIXED]: 0 (PERCENT)
MID-TRANSITION TEMPERATURE:-3 (DEG C), 26.7 (DEG F)
TRANSITION ZONE WIDTH: 52.3 (C DEG), 94.2 (F DEG)

UPPER SHELF SHEAR [HELD FIXED]: 100 (PERCENT)

STANDARD MODEL: $SHEAR = A + B \cdot \tanh((TEMPERATURE - T_0) / C)$

A: 50 (PERCENT)

B: 50 (PERCENT)

T0:-3 (DEG C), 26.7 (DEG F)

C: 26.2 (C DEG), 47.1 (F DEG)

ORNL-DWG 92-11703

UPPER SHELF SHEAR: 100 (PERCENT)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 91.2 TO 108.8 (PERCENT)

95 PERCENT: 80.9 TO 119.1 (PERCENT)

TEMPERATURE [50 (PERCENT), 50 (PERCENT) SHEAR]: -3 (DEG C), 26.7 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -9.1 TO 2.7 (DEG C), 15.7 TO 36.8 (DEG F)

95 PERCENT: -17.9 TO 10 (DEG C), -0.1 TO 50 (DEG F)

REMARK: MIDLAND WELD BELTLINE 1-11, FROM 5/8 THICKNESS OF WELD

ANALYSIS SET: MW11_34T

MODEL PARAMETERS

LOWER SHELF ENERGY [HELD FIXED]: 2.7 (J), 2 (FT-LB)
MID-TRANSITION TEMPERATURE: 17.8 (DEG C), 64 (DEG F)
TRANSITION ZONE WIDTH: 117.2 (C DEG), 211 (F DEG)
UPPER SHELF ENERGY: 84.5 (J), 62.3 (FT-LB)

STANDARD MODEL: $ENERGY = A + B \cdot \tanh((TEMPERATURE - T_0) / C)$

A: 43.6 (J), 32.1 (FT-LB)
B: 40.9 (J), 30.2 (FT-LB)
T0: 17.8 (DEG C), 64 (DEG F)
C: 58.6 (C DEG), 105.5 (F DEG)

ORNL-DWG 92-11704

UPPER SHELF ENERGY: 84.5 (J), 62.3 (FT-LB)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 69.7 TO 99.2 (J), 51.4 TO 73.2 (FT-LB)

95 PERCENT: 51.9 TO 117.1 (J), 38.2 TO 86.4 (FT-LB)

TEMPERATURE [27 (J), 19.9 (FT-LB) ENERGY]: -7.4 (DEG C), 18.6 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -36.6 TO 12.7 (DEG C), -33.9 TO 54.9 (DEG F)

95 PERCENT: UNDEFINED TO 39.7 (DEG C), UNDEFINED TO 103.4 (DEG F)

TEMPERATURE [41 (J), 30.2 (FT-LB) ENERGY]: 14.1 (DEG C), 57.4 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -6 TO 34.5 (DEG C), 21.2 TO 94.1 (DEG F)

95 PERCENT: -42.3 TO 67.7 (DEG C), -44.2 TO 153.8 (DEG F)
TEMPERATURE [68 (J), 50.2 (FT-LB) ENERGY]: 58.2 (DEG C), 136.7 (DEG F)
CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 33.3 TO 115.4 (DEG C), 91.9 TO 239.7 (DEG F)

95 PERCENT: 11.4 TO UNDEFINED (DEG C), 52.6 TO UNDEFINED (DEG F)

REFERENCE TEMPERATURE ANALYSIS

MEAN IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY]-60 (DEG F): 24.4 (DEG C), 75.9 (DEG F)

MINIMUM IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY]-60 (DEG F): 37 (DEG C), 98.6 (DEG F)

REMARK: MIDLAND WELD BELTLINE 1-11, FROM 3/4 THICKNESS OF WELD

ANALYSIS SET: MW11_34T

MODEL PARAMETERS

LOWER SHELF EXPANSION [HELD FIXED]: 0.061 (MM), 0.0024 (IN)

MID-TRANSITION TEMPERATURE: 5.8 (DEG C), 42.4 (DEG F)

TRANSITION ZONE WIDTH: 147.5 (C DEG), 265.6 (F DEG)

UPPER SHELF EXPANSION: 1.605 (MM), 0.0632 (IN)

STANDARD MODEL: $\text{EXPANSION} = A + B \cdot \tanh((\text{TEMPERATURE} - T_0) / C)$

A: 0.833 (MM), 0.0328 (IN)

B: 0.772 (MM), 0.0304 (IN)

T₀: 5.8 (DEG C), 42.4 (DEG F)

C: 73.8 (C DEG), 132.8 (F DEG)

ORNL-DWG 92-11705

UPPER SHELF EXPANSION: 1.605 (MM), 0.0632 (IN)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 1.36 TO 1.851 (MM), 0.0536 TO 0.0729 (IN)

95 PERCENT: 1.064 TO 2.147 (MM), 0.0419 TO 0.0845 (IN)

TEMPERATURE [0.38 (MM), 0.015 (IN) EXPANSION]: -43.8 (DEG C), -46.9 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -88.1 TO -18 (DEG C), -126.6 TO -0.4 (DEG F)

95 PERCENT: UNDEFINED TO 6.7 (DEG C), UNDEFINED TO 44.1 (DEG F)

TEMPERATURE [0.89 (MM), 0.035 (IN) EXPANSION]: 11.2 (DEG C), 52.2 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -9 TO 33.3 (DEG C), 15.8 TO 91.9 (DEG F)

MIDLAND BELTLINE WELD 1-11, 3/4 THICKNESS

95 PERCENT:-39.9 TO 69.5 (DEG C), -39.8 TO 157.1 (DEG F)

REFERENCE TEMPERATURE ANALYSIS

MEAN IMPACT CURVE

TEMPERATURE [0.035 (IN) EXPANSION]-60 (DEG F):-22.2 (DEG C), -8 (DEG F)

MINIMUM IMPACT CURVE

TEMPERATURE [0.035 (IN) EXPANSION]-60 (DEG F):-12.2 (DEG C), 10.1 (DEG F)

REMARK: MIDLAND WELD BELTLINE 1-11, FROM 3/4 THICKNESS OF WELD

ANALYSIS SET: MW11_34T

MODEL PARAMETERS

LOWER SHELF SHEAR [HELD FIXED]: 0 (PERCENT)
MID-TRANSITION TEMPERATURE: 17.7 (DEG C), 63.8 (DEG F)
TRANSITION ZONE WIDTH: 86.7 (C DEG), 156 (F DEG)
UPPER SHELF SHEAR [HELD FIXED]: 100 (PERCENT)
STANDARD MODEL: $SHEAR = A + B \cdot \tanh((TEMPERATURE - T_0) / C)$
A: 50 (PERCENT)
B: 50 (PERCENT)
T0: 17.7 (DEG C), 63.8 (DEG F)
C: 43.3 (C DEG), 78 (F DEG)

ORNL-DWG 92-11706

UPPER SHELF SHEAR: 100 (PERCENT)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 87.1 TO 112.9 (PERCENT)

95 PERCENT: 72 TO 128 (PERCENT)

TEMPERATURE [50 (PERCENT), 50 (PERCENT) SHEAR]: 17.7 (DEG C), 63.8 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 4.7 TO 31.8 (DEG C), 40.4 TO 89.2 (DEG F)

95 PERCENT: -15.7 TO 54.1 (DEG C), 3.8 TO 129.3 (DEG F)

REMARK: MIDLAND WELD BELTLINE 1-11, FROM 3/4 THICKNESS OF WELD

ANALYSIS SET: MW11_78T

MODEL PARAMETERS

LOWER SHELF ENERGY [HELD FIXED]: 2.7 (J), 2 (FT-LB)

MID-TRANSITION TEMPERATURE: -14 (DEG C), 6.8 (DEG F)

TRANSITION ZONE WIDTH: 96.8 (C DEG), 174.3 (F DEG)

UPPER SHELF ENERGY: 78.5 (J), 57.9 (FT-LB)

STANDARD MODEL: $ENERGY = A + B * \tanh((TEMPERATURE - T_0) / C)$

A: 40.6 (J), 30 (FT-LB)

B: 37.9 (J), 28 (FT-LB)

T0: -14 (DEG C), 6.8 (DEG F)

C: 48.4 (C DEG), 87.1 (F DEG)

ORNL-DWG 92-11707

UPPER SHELF ENERGY: 78.5 (J), 57.9 (FT-LB)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 62.7 TO 94.4 (J), 46.3 TO 69.6 (FT-LB)

95 PERCENT: 43.6 TO 113.5 (J), 32.2 TO 83.7 (FT-LB)

TEMPERATURE [27 (J), 19.9 (FT-LB) ENERGY]: -32.2 (DEG C), -26 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -65.4 TO -12.1 (DEG C), -85.8 TO 10.2 (DEG F)

95 PERCENT: UNDEFINED TO 13.9 (DEG C), UNDEFINED TO 57 (DEG F)

TEMPERATURE [41 (J), 30.2 (FT-LB) ENERGY]: -13.5 (DEG C), 7.6 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -37.1 TO 6.8 (DEG C), -34.8 TO 44.2 (DEG F)

MIDLAND BELTLINE WELD 1-11, 7/8 THICKNESS

95 PERCENT:-78.8 TO 51.5 (DEG C), -109.8 TO 124.7 (DEG F)

TEMPERATURE [68 (J), 50.2 (FT-LB) ENERGY]: 30.1 (DEG C), 86.2 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 2.6 TO UNDEFINED (DEG C), 36.6 TO UNDEFINED (DEG F)

95 PERCENT:-25.2 TO UNDEFINED (DEG C), -13.4 TO UNDEFINED (DEG F)

REFERENCE TEMPERATURE ANALYSIS

MEAN IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY]-60 (DEG F):-3.8 (DEG C), 25.2 (DEG F)

MINIMUM IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY]-60 (DEG F): 18.5 (DEG C), 65.2 (DEG F)

REMARK: MIDLAND WELD BELTLINE 1-11, FROM 7/8 THICKNESS OF WELD

ANALYSIS SET: MW11_78T

MODEL PARAMETERS

LOWER SHELF EXPANSION [HELD FIXED]: 0.061 (MM),0.0024 (IN)

MID-TRANSITION TEMPERATURE:-21.7 (DEG C),-7 (DEG F)

TRANSITION ZONE WIDTH: 135.7 (C DEG),244.2 (F DEG)

UPPER SHELF EXPANSION: 1.632 (MM),0.0643 (IN)

STANDARD MODEL: $\text{EXPANSION} = A + B \cdot \tanh((\text{TEMPERATURE} - T_0) / C)$

A: 0.846 (MM),0.0333 (IN)

B: 0.785 (MM),0.0309 (IN)

T0:-21.7 (DEG C),-7 (DEG F)

C: 67.8 (C DEG),122.1 (F DEG)

ORNL-DWG 92-11708

UPPER SHELF EXPANSION: 1.632 (MM),0.0643 (IN)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 1.363 TO 1.901 (MM),0.0536 TO 0.0749 (IN)

95 PERCENT: 1.037 TO 2.227 (MM),0.0408 TO 0.0877 (IN)

TEMPERATURE [0.38 (MM),0.015 (IN) EXPANSION]:-68.1 (DEG C),-90.5 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT:-122.1 TO -39.1 (DEG C),-187.7 TO -38.3 (DEG F)

95 PERCENT: UNDEFINED TO -15.1 (DEG C),UNDEFINED TO 4.9 (DEG F)

TEMPERATURE [0.89 (MM),0.035 (IN) EXPANSION]:-17.9 (DEG C),-0.3 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT:-42.1 TO 4.2 (DEG C),-43.8 TO 39.6 (DEG F)

MIDLAND BELTLINE WELD 1-11, 7/8 THICKNESS

95 PERCENT:-83.2 TO 43.5 (DEG C), -117.7 TO 110.3 (DEG F)

REFERENCE TEMPERATURE ANALYSIS

MEAN IMPACT CURVE

TEMPERATURE [0.035 (IN) EXPANSION]-60 (DEG F):-51.3 (DEG C), -60.4 (DEG F)

MINIMUM IMPACT CURVE

TEMPERATURE [0.035 (IN) EXPANSION]-60 (DEG F):-43.7 (DEG C), -46.7 (DEG F)

REMARK: MIDLAND WELD BELTLINE 1-11, FROM 7/8 THICKNESS OF WELD

ANALYSIS SET: MW11_78T

MODEL PARAMETERS

LOWER SHELF SHEAR [HELD FIXED]: 0 (PERCENT)
MID-TRANSITION TEMPERATURE: -9 (DEG C), 15.8 (DEG F)

TRANSITION ZONE WIDTH: 17.3 (C DEG), 31.1 (F DEG)

UPPER SHELF SHEAR [HELD FIXED]: 100 (PERCENT)

STANDARD MODEL: $SHEAR = A + B * \tanh((TEMPERATURE - T_0) / C)$

A: 50 (PERCENT)

B: 50 (PERCENT)

T0: -9 (DEG C), 15.8 (DEG F)

C: 8.6 (C DEG), 15.5 (F DEG)

ORNL-DWG 92-11709

UPPER SHELF SHEAR: 100 (PERCENT)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 81.6 TO 118.4 (PERCENT)

95 PERCENT: 59.9 TO 140.1 (PERCENT)

TEMPERATURE [50 (PERCENT), 50 (PERCENT) SHEAR]: -9 (DEG C), 15.8 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -14.3 TO -4.4 (DEG C), 6.2 TO 24 (DEG F)

95 PERCENT: -22.2 TO 3.4 (DEG C), -7.9 TO 38.2 (DEG F)

REMARK: MIDLAND WELD BELTLINE 1-11, FROM 7/8 THICKNESS OF WELD

APPENDIX D

HYPERBOLIC TANGENT CURVE FITS WITH 68% AND 95% CONFIDENCE BOUNDS FOR INDIVIDUAL DATA SETS UNIRRADIATED MIDLAND REACTOR VESSEL WELDS

PLOTS FOR BELTLINE WELD SECTION 1-13

ANALYSIS SET: MW13_14T

MODEL PARAMETERS

LOWER SHELF ENERGY [HELD FIXED]: 2.7 (J), 2 (FT-LB)

MID-TRANSITION TEMPERATURE: 1.6 (DEG C), 34.8 (DEG F)

TRANSITION ZONE WIDTH: 113.7 (C DEG), 204.6 (F DEG)

UPPER SHELF ENERGY: 101.2 (J), 74.6 (FT-LB)

STANDARD MODEL: $ENERGY = A + B \cdot \tanh((TEMPERATURE - T_0) / C)$

A: 51.9 (J), 38.3 (FT-LB)

B: 49.2 (J), 36.3 (FT-LB)

T₀: 1.6 (DEG C), 34.8 (DEG F)

C: 56.8 (C DEG), 102.3 (F DEG)

ORNL-DWG 92-11710

UPPER SHELF ENERGY: 101.2 (J), 74.6 (FT-LB)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 93.7 TO 108.6 (J), 69.1 TO 80.1 (FT-LB)

95 PERCENT: 85.8 TO 116.5 (J), 63.3 TO 85.9 (FT-LB)

TEMPERATURE [27 (J), 19.9 (FT-LB) ENERGY]: -30.2 (DEG C), -22.3 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -43.3 TO -19.5 (DEG C), -46 TO -3.1 (DEG F)

95 PERCENT: -62.1 TO -9.9 (DEG C), -79.8 TO 14.3 (DEG F)

TEMPERATURE [41 (J), 30.2 (FT-LB) ENERGY]: -11.3 (DEG C), 11.7 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -20.8 TO -2.7 (DEG C), -5.4 TO 27.2 (DEG F)

MIDLAND BELTLINE WELD 1-13, 1/4 THICKNESS

95 PERCENT: -32.6 TO 6.1 (DEG C), -26.6 TO 42.9 (DEG F)

TEMPERATURE [68 (J), 50.2 (FT-LB) ENERGY]: 20.8 (DEG C), 69.4 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 11.9 TO 30.7 (DEG C), 53.5 TO 87.3 (DEG F)

95 PERCENT: 2.9 TO 43.3 (DEG C), 37.3 TO 109.9 (DEG F)

REFERENCE TEMPERATURE ANALYSIS

MEAN IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY] -60 (DEG F): -12.8 (DEG C), 9 (DEG F)

MINIMUM IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY] -60 (DEG F): -9.5 (DEG C), 14.8 (DEG F)

REMARK: MIDLAND WELD BELTLINE 1-13, FROM 1/4 THICKNESS OF WELD

ANALYSIS SET: MW13_14T

MODEL PARAMETERS

LOWER SHELF EXPANSION [HELD FIXED]: 0.061 (MM), 0.0024 (IN)

MID-TRANSITION TEMPERATURE: 4.3 (DEG C), 39.7 (DEG F)

TRANSITION ZONE WIDTH: 118.5 (C DEG), 213.3 (F DEG)

UPPER SHELF EXPANSION: 1.777 (MM), 0.07 (IN)

STANDARD MODEL: $\text{EXPANSION} = A + B \cdot \tanh((\text{TEMPERATURE} - T_0) / C)$

A: 0.919 (MM), 0.0362 (IN)

B: 0.858 (MM), 0.0338 (IN)

T0: 4.3 (DEG C), 39.7 (DEG F)

C: 59.2 (C DEG), 106.6 (F DEG)

ORNL-DWG 92-11711

UPPER SHELF EXPANSION: 1.777 (MM), 0.07 (IN)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 1.661 TO 1.894 (MM), 0.0654 TO 0.0745 (IN)

95 PERCENT: 1.537 TO 2.017 (MM), 0.0605 TO 0.0794 (IN)

TEMPERATURE [0.38 (MM), 0.015 (IN) EXPANSION]: -39.5 (DEG C), -39.1 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -54.8 TO -27.7 (DEG C), -66.6 TO -17.9 (DEG F)

95 PERCENT: -79.5 TO -17.4 (DEG C), -111.2 TO 0.6 (DEG F)

TEMPERATURE [0.89 (MM), 0.035 (IN) EXPANSION]: 2.3 (DEG C), 36.1 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -5.7 TO 10 (DEG C), 21.8 TO 50 (DEG F)

MIDLAND BELTLINE WELD 1-13, 1/4 THICKNESS

95 PERCENT:-14.7 TO 18.4 (DEG C), 5.5 TO 65 (DEG F)

REFERENCE TEMPERATURE ANALYSIS

MEAN IMPACT CURVE

TEMPERATURE [0.035 (IN) EXPANSION]-60 (DEG F):-31.1 (DEG C), -24 (DEG F)

MINIMUM IMPACT CURVE

TEMPERATURE [0.035 (IN) EXPANSION]-60 (DEG F):-26.9 (DEG C), -16.4 (DEG F)

REMARK: MIDLAND WELD BELTLINE 1-13, FROM 1/4 THICKNESS OF WELD

ANALYSIS SET: MW13_14T

MODEL PARAMETERS

LOWER SHELF SHEAR [HELD FIXED]: 0 (PERCENT)
MID-TRANSITION TEMPERATURE:-9.4 (DEG C),15.1 (DEG F)
TRANSITION ZONE WIDTH: 79.2 (C DEG),142.6 (F DEG)
UPPER SHELF SHEAR [HELD FIXED]: 100 (PERCENT)

STANDARD MODEL: $SHEAR = A + B \cdot \tanh((TEMPERATURE - T_0) / C)$

A: 50 (PERCENT)
B: 50 (PERCENT)
T0:-9.4 (DEG C),15.1 (DEG F)
C: 39.6 (C DEG),71.3 (F DEG)

ORNL-DWG 92-11712

UPPER SHELF SHEAR: 100 (PERCENT)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 93.2 TO 106.8 (PERCENT)

95 PERCENT: 85.9 TO 114.1 (PERCENT)

TEMPERATURE [50 (PERCENT),50 (PERCENT) SHEAR]:-9.4 (DEG C),15.1 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT:-15.9 TO -3.3 (DEG C),3.5 TO 26.1 (DEG F)

95 PERCENT:-23.4 TO 3.3 (DEG C),-10.2 TO 37.9 (DEG F)

REMARK: MIDLAND WELD BELTLINE 1-13, FROM 1/4 THICKNESS OF WELD

ANALYSIS SET: MW13_12TD

MODEL PARAMETERS

LOWER SHELF ENERGY [HELD FIXED]: 2.7 (J), 2 (FT-LB)

MID-TRANSITION TEMPERATURE: -11.9 (DEG C), 10.7 (DEG F)

TRANSITION ZONE WIDTH: 101.4 (C DEG), 182.5 (F DEG)

UPPER SHELF ENERGY: 104.3 (J), 77 (FT-LB)

STANDARD MODEL: $ENERGY = A + B \cdot \tanh((TEMPERATURE - T_0) / C)$

A: 53.5 (J), 39.5 (FT-LB)

B: 50.8 (J), 37.5 (FT-LB)

T₀: -11.9 (DEG C), 10.7 (DEG F)

C: 50.7 (C DEG), 91.2 (F DEG)

ORNL-DWG 92-11713

UPPER SHELF ENERGY: 104.3 (J), 77 (FT-LB)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 101.9 TO 106.7 (J), 75.2 TO 78.7 (FT-LB)

95 PERCENT: 99 TO 109.6 (J), 73 TO 80.9 (FT-LB)

TEMPERATURE [27 (J), 19.9 (FT-LB) ENERGY]: -41.2 (DEG C), -42.1 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -44.7 TO -37.9 (DEG C), -48.5 TO -36.3 (DEG F)

95 PERCENT: -49.4 TO -34.3 (DEG C), -56.9 TO -29.7 (DEG F)

TEMPERATURE [41 (J), 30.2 (FT-LB) ENERGY]: -24.6 (DEG C), -12.3 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -27.2 TO -22.1 (DEG C), -17 TO -7.8 (DEG F)

95 PERCENT: -30.5 TO -19.1 (DEG C), -22.9 TO -2.4 (DEG F)
TEMPERATURE [68 (J), 50.2 (FT-LB) ENERGY]: 3 (DEG C), 37.4 (DEG F)
CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 0.3 TO 5.8 (DEG C), 32.6 TO 42.4 (DEG F)

95 PERCENT: -2.8 TO 9.4 (DEG C), 27 TO 48.9 (DEG F)

REFERENCE TEMPERATURE ANALYSIS

MEAN IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY] -60 (DEG F): -30.6 (DEG C), -23 (DEG F)

MINIMUM IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY] -60 (DEG F): -30.6 (DEG C), -23.1 (DEG F)

REMARK: MIDLAND WELD BELTLINE 1-13, FROM 1/2 THICKNESS OF D LAYER

ANALYSIS SET: MW13_12TD

MODEL PARAMETERS

LOWER SHELF EXPANSION [HELD FIXED]: 0.061 (MM), 0.0024 (IN)

MID-TRANSITION TEMPERATURE: -5 (DEG C), 23.1 (DEG F)

TRANSITION ZONE WIDTH: 103.9 (C DEG), 187 (F DEG)

UPPER SHELF EXPANSION: 1.868 (MM), 0.0736 (IN)

STANDARD MODEL: $\text{EXPANSION} = A + B \cdot \tanh((\text{TEMPERATURE} - T_0) / C)$

A: 0.965 (MM), 0.038 (IN)

B: 0.904 (MM), 0.0356 (IN)

T0: -5 (DEG C), 23.1 (DEG F)

C: 51.9 (C DEG), 93.5 (F DEG)

ORNL-DWG 92-11714

UPPER SHELF EXPANSION: 1.868 (MM), 0.0736 (IN)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 1.816 TO 1.921 (MM), 0.0715 TO 0.0756 (IN)

95 PERCENT: 1.752 TO 1.985 (MM), 0.069 TO 0.0781 (IN)

TEMPERATURE [0.38 (MM), 0.015 (IN) EXPANSION]: -45 (DEG C), -48.9 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -50.5 TO -40 (DEG C), -59 TO -40.1 (DEG F)

95 PERCENT: -58.4 TO -34.7 (DEG C), -73.1 TO -30.5 (DEG F)

TEMPERATURE [0.89 (MM), 0.035 (IN) EXPANSION]: -9.3 (DEG C), 15.3 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -12.3 TO -6.2 (DEG C), 9.8 TO 20.8 (DEG F)

MIDLAND BELTLINE WELD 1-13, 1/2 D THICKNESS

95 PERCENT: -16 TO -2.5 (DEG C), 3.1 TO 27.5 (DEG F)

REFERENCE TEMPERATURE ANALYSIS

MEAN IMPACT CURVE

TEMPERATURE [0.035 (IN) EXPANSION] -60 (DEG F): -42.7 (DEG C), -44.8 (DEG F)

MINIMUM IMPACT CURVE

TEMPERATURE [0.035 (IN) EXPANSION] -60 (DEG F): -42.1 (DEG C), -43.9 (DEG F)

REMARK: MIDLAND WELD BELTLINE 1-13, FROM 1/2 THICKNESS OF D LAYER

ANALYSIS SET: MW13_12TD

MODEL PARAMETERS

LOWER SHELF SHEAR [HELD FIXED]: 0 (PERCENT)

MID-TRANSITION TEMPERATURE: 4.4 (DEG C), 39.9 (DEG F)

TRANSITION ZONE WIDTH: 80.2 (C DEG), 144.3 (F DEG)

UPPER SHELF SHEAR [HELD FIXED]: 100 (PERCENT)

STANDARD MODEL: $SHEAR = A + B * \tanh((TEMPERATURE - T_0) / C)$

A: 50 (PERCENT)

B: 50 (PERCENT)

T₀: 4.4 (DEG C), 39.9 (DEG F)

C: 40.1 (C DEG), 72.1 (F DEG)

ORNL-DWG 92-11715

UPPER SHELF SHEAR: 100 (PERCENT)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 94.6 TO 105.4 (PERCENT)

95 PERCENT: 88.3 TO 111.7 (PERCENT)

TEMPERATURE [50 (PERCENT), 50 (PERCENT) SHEAR]: 4.4 (DEG C), 39.9 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -0.7 TO 9.8 (DEG C), 30.7 TO 49.6 (DEG F)

95 PERCENT: -6.8 TO 17 (DEG C), 19.8 TO 62.6 (DEG F)

REMARK: MIDLAND WELD BELTLINE 1-13, FROM 1/2 THICKNESS OF D LAYER

ANALYSIS SET: MW13_12TE

MODEL PARAMETERS

LOWER SHELF ENERGY [HELD FIXED]: 2.7 (J), 2 (FT-LB)

MID-TRANSITION TEMPERATURE: 16.8 (DEG C), 62.2 (DEG F)

TRANSITION ZONE WIDTH: 150.2 (C DEG), 270.4 (F DEG)

UPPER SHELF ENERGY: 97.5 (J), 71.9 (FT-LB)

STANDARD MODEL: $ENERGY = A + B \cdot \tanh((TEMPERATURE - T_0) / C)$

A: 50.1 (J), 36.9 (FT-LB)

B: 47.4 (J), 34.9 (FT-LB)

T₀: 16.8 (DEG C), 62.2 (DEG F)

C: 75.1 (C DEG), 135.2 (F DEG)

ORNL-DWG 92-11716

UPPER SHELF ENERGY: 97.5 (J), 71.9 (FT-LB)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 89.3 TO 105.7 (J), 65.9 TO 77.9 (FT-LB)

95 PERCENT: 79.4 TO 115.5 (J), 58.6 TO 85.2 (FT-LB)

TEMPERATURE [27 (J), 19.9 (FT-LB) ENERGY]: -23.2 (DEG C), -9.8 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -39.1 TO -10.4 (DEG C), -38.4 TO 13.4 (DEG F)

95 PERCENT: -63.7 TO 2.5 (DEG C), -82.6 TO 36.5 (DEG F)

TEMPERATURE [41 (J), 30.2 (FT-LB) ENERGY]: 2.2 (DEG C), 36 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -9.2 TO 12.2 (DEG C), 15.5 TO 54 (DEG F)

MIDLAND BELTLINE WELD 1-13, 1/2" THICKNESS

95 PERCENT: -25.7 TO 23.7 (DEG C), -14.2 TO 74.6 (DEG F)
 TEMPERATURE [68 (J), 50.2 (FT-LB) ENERGY]: 46.7 (DEG C), 116 (DEG F)
 CONFIDENCE INTERVALS ON PREDICTED VALUE
 68 PERCENT: 36.1 TO 58.6 (DEG C), 96.9 TO 137.5 (DEG F)
 95 PERCENT: 23.9 TO 76.6 (DEG C), 75.1 TO 170 (DEG F)

REFERENCE TEMPERATURE ANALYSIS

MEAN IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY]-60 (DEG F): 12.9 (DEG C), 55.3 (DEG F)

MINIMUM IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY]-60 (DEG F): 20 (DEG C), 68 (DEG F)

REMARK: MIDLAND WELD BELTLINE 1-13, FROM 1/2" THICKNESS OF E LAYER

ANALYSIS SET: MW13_12TE

MODEL PARAMETERS

LOWER SHELF EXPANSION [HELD FIXED]: 0.061 (MM), 0.0024 (IN)

MID-TRANSITION TEMPERATURE: 24.3 (DEG C), 75.7 (DEG F)

TRANSITION ZONE WIDTH: 134.3 (C DEG), 241.8 (F DEG)

UPPER SHELF EXPANSION: 1.726 (MM), 0.068 (IN)

STANDARD MODEL: $\text{EXPANSION} = A + B \cdot \tanh((\text{TEMPERATURE} - T_0) / C)$

A: 0.894 (MM), 0.0352 (IN)

B: 0.833 (MM), 0.0328 (IN)

T₀: 24.3 (DEG C), 75.7 (DEG F)

C: 67.2 (C DEG), 120.9 (F DEG)

ORNL-DWG 92-11717

UPPER SHELF EXPANSION: 1.726 (MM), 0.068 (IN)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 1.534 TO 1.919 (MM), 0.0604 TO 0.0755 (IN)

95 PERCENT: 1.301 TO 2.152 (MM), 0.0512 TO 0.0847 (IN)

TEMPERATURE [0.38 (MM), 0.015 (IN) EXPANSION]: -24 (DEG C), -11.3 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -50.2 TO -5.8 (DEG C), -58.4 TO 21.5 (DEG F)

95 PERCENT: -117.4 TO 10.1 (DEG C), -179.2 TO 50.2 (DEG F)

TEMPERATURE [0.89 (MM), 0.035 (IN) EXPANSION]: 24 (DEG C), 75.2 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 11.5 TO 35.8 (DEG C), 52.7 TO 96.4 (DEG F)

MIDLAND BELTLINE WELD 1-13, 1/2 THICKNESS

95 PERCENT: -7.3 TO 51.3 (DEG C), 18.8 TO 124.4 (DEG F)

REFERENCE TEMPERATURE ANALYSIS

MEAN IMPACT CURVE

TEMPERATURE [0.035 (IN) EXPANSION] -60 (DEG F): -9.4 (DEG C), 15.1 (DEG F)

MINIMUM IMPACT CURVE

TEMPERATURE [0.035 (IN) EXPANSION] -60 (DEG F): -2.9 (DEG C), 26.8 (DEG F)

REMARK: MIDLAND WELD BELTLINE 1-13, FROM 1/2 THICKNESS OF E LAYER

ANALYSIS SET: MW13_12TE

MODEL PARAMETERS

LOWER SHELF SHEAR [HELD FIXED]: 0 (PERCENT)

MID-TRANSITION TEMPERATURE: 19.1 (DEG C), 66.4 (DEG F)

TRANSITION ZONE WIDTH: 103.2 (C DEG), 185.7 (F DEG)

UPPER SHELF SHEAR [HELD FIXED]: 100 (PERCENT)

STANDARD MODEL: $SHEAR = A + B * \tanh((TEMPERATURE - T_0) / C)$

A: 50 (PERCENT)

B: 50 (PERCENT)

T0: 19.1 (DEG C), 66.4 (DEG F)

C: 51.6 (C DEG), 92.8 (F DEG)

ORNL-DWG 92-11718

UPPER SHELF SHEAR: 100 (PERCENT)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 92.6 TO 107.4 (PERCENT)

95 PERCENT: 83.9 TO 116.1 (PERCENT)

TEMPERATURE [50 (PERCENT), 50 (PERCENT) SHEAR]: 19.1 (DEG C), 66.4 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 9.6 TO 27.8 (DEG C), 49.2 TO 82 (DEG F)

95 PERCENT: -4 TO 38.3 (DEG C), 24.8 TO 100.9 (DEG F)

REMARK: MIDLAND WELD BELTLINE 1-13, FROM 1/2 THICKNESS OF E LAYER

ANALYSIS SETS: MW13_12TD AND MW13_12TE

MODEL PARAMETERS

LOWER SHELF ENERGY [HELD FIXED]: 2.7 (J), 2 (FT-LB)

MID-TRANSITION TEMPERATURE: 4.7 (DEG C), 40.4 (DEG F)

TRANSITION ZONE WIDTH: 164.5 (C DEG), 296.2 (F DEG)

UPPER SHELF ENERGY: 104 (J), 76.7 (FT-LB)

STANDARD MODEL: $ENERGY = A + B \cdot \tanh((TEMPERATURE - T_0) / C)$

A: 53.3 (J), 39.3 (FT-LB)

B: 50.6 (J), 37.4 (FT-LB)

T₀: 4.7 (DEG C), 40.4 (DEG F)

C: 82.3 (C DEG), 148.1 (F DEG)

ORNL-DWG 92-11719

UPPER SHELF ENERGY: 104 (J), 76.7 (FT-LB)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 91.4 TO 116.6 (J), 67.4 TO 86 (FT-LB)

95 PERCENT: 78 TO 130 (J), 57.5 TO 95.9 (FT-LB)

TEMPERATURE [27 (J), 19.9 (FT-LB) ENERGY]: -42.8 (DEG C), -45 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -74.8 TO -20.2 (DEG C), -102.7 TO -4.3 (DEG F)

95 PERCENT: -155.7 TO -0.1 (DEG C), -248.4 TO 31.8 (DEG F)

TEMPERATURE [41 (J), 30.2 (FT-LB) ENERGY]: -15.8 (DEG C), 3.5 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -37.7 TO 3.1 (DEG C), -35.8 TO 37.5 (DEG F)

95 PERCENT:-68.9 TO 22.9 (DEG C), -91.9 TO 73.3 (DEG F)
TEMPERATURE [68 (J), 50.2 (FT-LB) ENERGY]: 29.1 (DEG C), 84.5 (DEG F)
CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 10 TO 51.4 (DEG C), 50 TO 124.5 (DEG F)
95 PERCENT:-9.9 TO 84.5 (DEG C), 14.1 TO 184 (DEG F)

REFERENCE TEMPERATURE ANALYSIS

MEAN IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY]-60 (DEG F): -4.6 (DEG C), 23.8 (DEG F)

MINIMUM IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY]-60 (DEG F): 2.2 (DEG C), 35.9 (DEG F)

REMARK: MIDLAND WELD BELTLINE 1-13, FROM 1/2 THICKNESS COMB.D&ELAYER

ANALYSIS SETS: MW13_12TD AND MW13_12TE

MODEL PARAMETERS

LOWER SHELF EXPANSION [HELD FIXED]: 0.061 (MM), 0.0024 (IN)

MID-TRANSITION TEMPERATURE: 13.6 (DEG C), 56.4 (DEG F)

TRANSITION ZONE WIDTH: 159.1 (C DEG), 286.3 (F DEG)

UPPER SHELF EXPANSION: 1.868 (MM), 0.0735 (IN)

STANDARD MODEL: $\text{EXPANSION} = A + B \cdot \tanh((\text{TEMPERATURE} - T_0) / C)$

A: 0.964 (MM), 0.038 (IN)

B: 0.903 (MM), 0.0356 (IN)

T₀: 13.6 (DEG C), 56.4 (DEG F)

C: 79.5 (C DEG), 143.1 (F DEG)

ORNL-DWG 92-11720

UPPER SHELF EXPANSION: 1.868 (MM), 0.0735 (IN)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 1.632 TO 2.103 (MM), 0.0643 TO 0.0828 (IN)

95 PERCENT: 1.383 TO 2.353 (MM), 0.0544 TO 0.0926 (IN)

TEMPERATURE [0.38 (MM), 0.015 (IN) EXPANSION]: -47.7 (DEG C), -53.8 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -94.1 TO -21.1 (DEG C), -137.4 TO -5.9 (DEG F)

95 PERCENT: UNDEFINED TO 0.3 (DEG C), UNDEFINED TO 32.6 (DEG F)

TEMPERATURE [0.89 (MM), 0.035 (IN) EXPANSION]: 7 (DEG C), 44.6 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -12.6 TO 25.7 (DEG C), 9.2 TO 78.2 (DEG F)

MIDLAND BELTLINE WELD 1-13, 1/2 THICKNESS

95 PERCENT:-38.2 TO 47.3 (DEG C), -36.8 TO 117.1 (DEG F)

REFERENCE TEMPERATURE ANALYSIS

MEAN IMPACT CURVE

TEMPERATURE [0.035 (IN) EXPANSION]-60 (DEG F):-26.4 (DEG C), -15.5 (DEG F)

MINIMUM IMPACT CURVE

TEMPERATURE [0.035 (IN) EXPANSION]-60 (DEG F):-18.7 (DEG C), -1.7 (DEG F)

REMARK: MIDLAND WELD BELTLINE 1-13, FROM 1/2 THICKNESS COMB.D&ELAYER

ANALYSIS SETS: MW13_12TD AND MW13_12TE

MODEL PARAMETERS

LOWER SHELF SHEAR [HELD FIXED]: 0 (PERCENT)

MID-TRANSITION TEMPERATURE: 12.3 (DEG C), 54.1 (DEG F)

TRANSITION ZONE WIDTH: 104 (C DEG), 187.2 (F DEG)

UPPER SHELF SHEAR [HELD FIXED]: 100 (PERCENT)

STANDARD MODEL: $SHEAR = A + B \cdot \tanh((TEMPERATURE - T_0) / C)$

A: 50 (PERCENT)

B: 50 (PERCENT)

T0: 12.3 (DEG C), 54.1 (DEG F)

C: 52 (C DEG), 93.6 (F DEG)

ORNL-DWG 92-11721

UPPER SHELF SHEAR: 100 (PERCENT)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 92.3 TO 107.7 (PERCENT)

95 PERCENT: 84.2 TO 115.8 (PERCENT)

TEMPERATURE [50 (PERCENT), 50 (PERCENT) SHEAR]: 12.3 (DEG C), 54.1 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 3.5 TO 21 (DEG C), 38.2 TO 69.7 (DEG F)

95 PERCENT: -6.6 TO 30.7 (DEG C), 20.2 TO 87.3 (DEG F)

REMARK: MIDLAND WELD BELTLINE 1-13, FROM 1/2 THICKNESS COMB.D&ELAYER

ANALYSIS SET: MW13_58T

MODEL PARAMETERS

LOWER SHELF ENERGY [HELD FIXED]: 2.7 (J), 2 (FT-LB)

MID-TRANSITION TEMPERATURE: -5.3 (DEG C), 22.5 (DEG F)

TRANSITION ZONE WIDTH: 118.1 (C DEG), 212.5 (F DEG)

UPPER SHELF ENERGY: 108.2 (J), 79.8 (FT-LB)

STANDARD MODEL: $ENERGY = A + B \cdot \tanh((TEMPERATURE - T_0) / C)$

A: 55.5 (J), 40.9 (FT-LB)

B: 52.8 (J), 38.9 (FT-LB)

T₀: -5.3 (DEG C), 22.5 (DEG F)

C: 59 (C DEG), 106.3 (F DEG)

ORNL-DWG 92-11722

UPPER SHELF ENERGY: 108.2 (J), 79.8 (FT-LB)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 100.5 TO 116 (J), 74.1 TO 85.6 (FT-LB)

95 PERCENT: 92.2 TO 124.3 (J), 68 TO 91.7 (FT-LB)

TEMPERATURE [27 (J), 19.9 (FT-LB) ENERGY]: -40.9 (DEG C), -41.7 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -54.5 TO -30.1 (DEG C), -66.1 TO -22.1 (DEG F)

95 PERCENT: -74.3 TO -20.3 (DEG C), -101.7 TO -4.6 (DEG F)

TEMPERATURE [41 (J), 30.2 (FT-LB) ENERGY]: -21.9 (DEG C), -7.4 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -31.6 TO -13.3 (DEG C), -24.8 TO 8 (DEG F)

95 PERCENT:-43.6 TO -4.8 (DEG C), -46.5 TO 23.3 (DEG F)
TEMPERATURE [68 (J), 50.2 (FT-LB) ENERGY]: 9 (DEG C), 48.2 (DEG F)
CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 0.7 TO 17.9 (DEG C), 33.2 TO 64.1 (DEG F)

95 PERCENT:-8 TO 28.6 (DEG C), 17.5 TO 83.4 (DEG F)

REFERENCE TEMPERATURE ANALYSIS

MEAN IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY]-60 (DEG F):-24.6 (DEG C), -12.3 (DEG F)

MINIMUM IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY]-60 (DEG F):-19.7 (DEG C), -3.4 (DEG F)

REMARK: MIDLAND WELD BELTLINE 1-13, FROM 5/8 THICKNESS OF WELD

ANALYSIS SET: MW13_58T
MODEL PARAMETERS

LOWER SHELF EXPANSION [HELD FIXED]: 0.061 (MM), 0.0024 (IN)

MID-TRANSITION TEMPERATURE: -11.7 (DEG C), 10.9 (DEG F)

TRANSITION ZONE WIDTH: 142.9 (C DEG), 257.3 (F DEG)

UPPER SHELF EXPANSION: 1.753 (MM), 0.069 (IN)

STANDARD MODEL: $\text{EXPANSION} = A + B \cdot \tanh((\text{TEMPERATURE} - T_0) / C)$

A: 0.907 (MM), 0.0357 (IN)

B: 0.846 (MM), 0.0333 (IN)

T0: -11.7 (DEG C), 10.9 (DEG F)

C: 71.5 (C DEG), 128.6 (F DEG)

ORNL-DWG 92-11723

UPPER SHELF EXPANSION: 1.753 (MM), 0.069 (IN)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 1.566 TO 1.94 (MM), 0.0617 TO 0.0764 (IN)

95 PERCENT: 1.368 TO 2.138 (MM), 0.0539 TO 0.0842 (IN)

TEMPERATURE [0.38 (MM), 0.015 (IN) EXPANSION]: -63.9 (DEG C), -82.9 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -95.8 TO -43 (DEG C), -140.4 TO -45.4 (DEG F)

95 PERCENT: UNDEFINED TO -26.1 (DEG C), UNDEFINED TO -15 (DEG F)

TEMPERATURE [0.89 (MM), 0.035 (IN) EXPANSION]: -13.1 (DEG C), 8.3 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -28.2 TO 1.2 (DEG C), -18.8 TO 34.2 (DEG F)

MIDLAND BELTLINE WELD 1-13, 5/8 THICKNESS

95 PERCENT:-47 TO 17.7 (DEG C), -52.6 TO 63.8 (DEG F)

REFERENCE TEMPERATURE ANALYSIS

MEAN IMPACT CURVE

TEMPERATURE [0.035 (IN) EXPANSION]-60 (DEG F):-46.6 (DEG C), -51.8 (DEG F)

MINIMUM IMPACT CURVE

TEMPERATURE [0.035 (IN) EXPANSION]-60 (DEG F):-36 (DEG C), -32.7 (DEG F)

REMARK: MIDLAND WELD BELTLINE 1-13, FROM 5/8 THICKNESS OF WELD

ANALYSIS SET: MW13_58T

MODEL PARAMETERS

LOWER SHELF SHEAR [HELD FIXED]: 0 (PERCENT)
MID-TRANSITION TEMPERATURE: -4.2 (DEG C), 24.5 (DEG F)
TRANSITION ZONE WIDTH: 76.8 (C DEG), 138.3 (F DEG)

UPPER SHELF SHEAR [HELD FIXED]: 100 (PERCENT)

STANDARD MODEL: $SHEAR = A + B \cdot \tanh((TEMPERATURE - T_0) / C)$

A: 50 (PERCENT)

B: 50 (PERCENT)

T0: -4.2 (DEG C), 24.5 (DEG F)

C: 38.4 (C DEG), 69.1 (F DEG)

ORNL-DWG 92-11724

UPPER SHELF SHEAR: 100 (PERCENT)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 86.8 TO 113.2 (PERCENT)

95 PERCENT: 72.9 TO 127.1 (PERCENT)

TEMPERATURE [50 (PERCENT), 50 (PERCENT) SHEAR]: -4.2 (DEG C), 24.5 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -16 TO 6.9 (DEG C), 3.1 TO 44.4 (DEG F)

95 PERCENT: -31.6 TO 20.8 (DEG C), -24.9 TO 69.4 (DEG F)

REMARK: MIDLAND WELD BELTLINE 1-13, FROM 5/8 THICKNESS OF WELD

ANALYSIS SET: MW13_34T

MODEL PARAMETERS

LOWER SHELF ENERGY [HELD FIXED]: 2.7 (J), 2 (FT-LB)

MID-TRANSITION TEMPERATURE: 4.9 (DEG C), 40.8 (DEG F)

TRANSITION ZONE WIDTH: 118.4 (C DEG), 213.1 (F DEG)

UPPER SHELF ENERGY: 90.1 (J), 66.5 (FT-LB)

STANDARD MODEL: $ENERGY = A + B \cdot \tanh((TEMPERATURE - T_0) / C)$

A: 46.4 (J), 34.2 (FT-LB)

B: 43.7 (J), 32.2 (FT-LB)

T₀: 4.9 (DEG C), 40.8 (DEG F)

C: 59.2 (C DEG), 106.6 (F DEG)

ORNL-DWG 92-11725

UPPER SHELF ENERGY: 90.1 (J), 66.5 (FT-LB)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 84.4 TO 95.9 (J), 62.2 TO 70.7 (FT-LB)

95 PERCENT: 78.3 TO 102 (J), 57.7 TO 75.2 (FT-LB)

TEMPERATURE [27 (J), 19.9 (FT-LB) ENERGY]: -23.4 (DEG C), -10.1 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -33.7 TO -14.5 (DEG C), -28.7 TO 5.9 (DEG F)

95 PERCENT: -47.2 TO -6.1 (DEG C), -53 TO 21 (DEG F)

TEMPERATURE [41 (J), 30.2 (FT-LB) ENERGY]: -2.5 (DEG C), 27.5 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -10.3 TO 5 (DEG C), 13.4 TO 40.9 (DEG F)

95 PERCENT: -19.4 TO 12.8 (DEG C), -3 TO 55 (DEG F)
TEMPERATURE [68 (J), 50.2 (FT-LB) ENERGY]: 36.9 (DEG C), 98.4 (DEG F)
CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 27.8 TO 47.6 (DEG C), 82.1 TO 117.7 (DEG F)

95 PERCENT: 19.2 TO 62.2 (DEG C), 66.5 TO 144 (DEG F)

REFERENCE TEMPERATURE ANALYSIS

MEAN IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY] -60 (DEG F): 3.2 (DEG C), 37.8 (DEG F)

MINIMUM IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY] -60 (DEG F): 6.3 (DEG C), 43.3 (DEG F)

REMARK: MIDLAND WELD BELTLINE 1-13, FROM 3/4 THICKNESS OF WELD

ANALYSIS SET: MW13_34T

MODEL PARAMETERS

LOWER SHELF EXPANSION [HELD FIXED]: 0.061 (MM), 0.0024 (IN)

MID-TRANSITION TEMPERATURE: 5.9 (DEG C), 42.6 (DEG F)

TRANSITION ZONE WIDTH: 128.5 (C DEG), 231.3 (F DEG)

UPPER SHELF EXPANSION: 1.649 (MM), 0.0649 (IN)

STANDARD MODEL: $\text{EXPANSION} = A + B \cdot \tanh((\text{TEMPERATURE} - T_0) / C)$

A: 0.855 (MM), 0.0337 (IN)

B: 0.794 (MM), 0.0313 (IN)

T0: 5.9 (DEG C), 42.6 (DEG F)

C: 64.2 (C DEG), 115.6 (F DEG)

ORNL-DWG 92-11726

UPPER SHELF EXPANSION: 1.649 (MM), 0.0649 (IN)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 1.493 TO 1.804 (MM), 0.0588 TO 0.071 (IN)

95 PERCENT: 1.328 TO 1.969 (MM), 0.0523 TO 0.0775 (IN)

TEMPERATURE [0.38 (MM), 0.015 (IN) EXPANSION]: -38.5 (DEG C), -37.2 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -61.7 TO -22 (DEG C), -79.1 TO -7.7 (DEG F)

95 PERCENT: -117.4 TO -8.1 (DEG C), -179.3 TO 17.4 (DEG F)

TEMPERATURE [0.89 (MM), 0.035 (IN) EXPANSION]: 8.7 (DEG C), 47.7 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -3.2 TO 20.8 (DEG C), 26.2 TO 69.4 (DEG F)

95 PERCENT:-17.1 TO 34.8 (DEG C), 1.2 TO 94.6 (DEG F)
REFERENCE TEMPERATURE ANALYSIS
MEAN IMPACT CURVE
TEMPERATURE [0.035 (IN) EXPANSION]-60 (DEG F):-24.7 (DEG C), -12.4 (DEG F)
MINIMUM IMPACT CURVE
TEMPERATURE [0.035 (IN) EXPANSION]-60 (DEG F):-17.3 (DEG C), 0.8 (DEG F)
REMARK: MIDLAND WELD BELTLINE 1-13, FROM 3/4 THICKNESS OF WELD

ANALYSIS SET: MW13_34T

MODEL PARAMETERS

LOWER SHELF SHEAR [HELD FIXED]: 0 (PERCENT)
MID-TRANSITION TEMPERATURE: 2 (DEG C), 35.7 (DEG F)
TRANSITION ZONE WIDTH: 92.6 (C DEG), 166.7 (F DEG)
UPPER SHELF SHEAR [HELD FIXED]: 100 (PERCENT)
STANDARD MODEL: $SHEAR = A + B \cdot \tanh((TEMPERATURE - T_0) / C)$
A: 50 (PERCENT)
B: 50 (PERCENT)
T0: 2 (DEG C), 35.7 (DEG F)
C: 46.3 (C DEG), 83.3 (F DEG)

ORNL-DWG 92-11727

UPPER SHELF SHEAR: 100 (PERCENT)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 94.5 TO 105.5 (PERCENT)

95 PERCENT: 88.8 TO 111.2 (PERCENT)

TEMPERATURE [50 (PERCENT), 50 (PERCENT) SHEAR]: 2 (DEG C), 35.7 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -3.5 TO 7.5 (DEG C), 25.6 TO 45.5 (DEG F)

95 PERCENT: -9.7 TO 13.4 (DEG C), 14.5 TO 56.2 (DEG F)

REMARK: MIDLAND WELD BELTLINE 1-13, FROM 3/4 THICKNESS OF WELD

APPENDIX D

HYPERBOLIC TANGENT CURVE FITS WITH 68% AND 95% CONFIDENCE BOUNDS FOR INDIVIDUAL DATA SETS UNIRRADIATED MIDLAND REACTOR VESSEL WELDS

PLOTS FOR BELTLINE WELD SECTION 1-15

ANALYSIS SET: MW15_14TR

MODEL PARAMETERS

LOWER SHELF ENERGY [HELD FIXED]: 2.7 (J), 2 (FT-LB)
MID-TRANSITION TEMPERATURE: 6.6 (DEG C), 43.9 (DEG F)
TRANSITION ZONE WIDTH: 114.9 (C DEG), 206.8 (F DEG)
UPPER SHELF ENERGY: 82.5 (J), 60.8 (FT-LB)
STANDARD MODEL: $ENERGY = A + B \cdot \tanh((TEMPERATURE - T_0) / C)$
A: 42.6 (J), 31.4 (FT-LB)
B: 39.9 (J), 29.4 (FT-LB)
T₀: 6.6 (DEG C), 43.9 (DEG F)
C: 57.5 (C DEG), 103.4 (F DEG)

ORNL-DWG 92-11728

UPPER SHELF ENERGY: 82.5 (J), 60.8 (FT-LB)
CONFIDENCE INTERVALS ON PREDICTED VALUE
68 PERCENT: 79.4 TO 85.6 (J), 58.6 TO 63.1 (FT-LB)
95 PERCENT: 75.5 TO 89.5 (J), 55.7 TO 66 (FT-LB)
TEMPERATURE [27 (J), 19.9 (FT-LB) ENERGY]: -17.1 (DEG C), 1.2 (DEG F)
CONFIDENCE INTERVALS ON PREDICTED VALUE
68 PERCENT: -22.7 TO -12 (DEG C), -8.8 TO 10.4 (DEG F)
95 PERCENT: -30.5 TO -6 (DEG C), -22.9 TO 21.1 (DEG F)
TEMPERATURE [41 (J), 30.2 (FT-LB) ENERGY]: 4.3 (DEG C), 39.8 (DEG F)
CONFIDENCE INTERVALS ON PREDICTED VALUE
68 PERCENT: -0.1 TO 8.7 (DEG C), 31.8 TO 47.7 (DEG F)

95 PERCENT: -5.9 TO 14.4 (DEG C), 21.4 TO 57.9 (DEG F)
TEMPERATURE [68 (J), 50.2 (FT-LB) ENERGY]: 49.8 (DEG C), 121.7 (DEG F)
CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 42.9 TO 57.9 (DEG C), 109.2 TO 136.2 (DEG F)

95 PERCENT: 35.1 TO 70.3 (DEG C), 95.3 TO 158.5 (DEG F)

REFERENCE TEMPERATURE ANALYSIS

MEAN IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY]-60 (DEG F): 16 (DEG C), 60.8 (DEG F)

MINIMUM IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY]-60 (DEG F): 16 (DEG C), 60.8 (DEG F)

REMARK: MIDLAND WELD BELTLINE 1-15, FROM 1/4 THICKNESS

ANALYSIS SET: MW15_14TR

REGRESSION NOT CONVERGING AFTER 6 ITERATION(S)

REGRESSION NOT CONVERGING AFTER 4 ITERATION(S)

REGRESSION NOT CONVERGING AFTER 4 ITERATION(S)

MODEL PARAMETERS

LOWER SHELF EXPANSION: 0 (MM), 0 (IN)

MID-TRANSITION TEMPERATURE: 12.7 (DEG C), 54.9 (DEG F)

TRANSITION ZONE WIDTH: 137 (C DEG), 246.5 (F DEG)

UPPER SHELF EXPANSION: 1.51 (MM), 0.0594 (IN)

STANDARD MODEL: $\text{EXPANSION} = A + B \cdot \tanh((\text{TEMPERATURE} - T_0) / C)$

A: 0.755 (MM), 0.0297 (IN)

B: 0.755 (MM), 0.0297 (IN)

T0: 12.7 (DEG C), 54.9 (DEG F)

C: 68.5 (C DEG), 123.3 (F DEG)

UPPER SHELF EXPANSION: 1.51 (MM), 0.0594 (IN)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 1.453 TO 1.567 (MM), 0.0572 TO 0.0617 (IN)

95 PERCENT: 1.377 TO 1.642 (MM), 0.0542 TO 0.0647 (IN)

TEMPERATURE [0.38 (MM), 0.015 (IN) EXPANSION]: -24.6 (DEG C), -12.3 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -31.8 TO -18.1 (DEG C), -25.3 TO -0.5 (DEG F)

95 PERCENT: -43.1 TO -10.1 (DEG C), -45.6 TO 13.8 (DEG F)

MIDLAND BELTLINE WELD 1-15, 1/4 THICKNESS

TEMPERATURE [0.89 (MM), 0.035 (IN) EXPANSION]: 25.1 (DEG C), 77.2 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 19.8 TO 30.5 (DEG C), 67.7 TO 87 (DEG F)

95 PERCENT: 12.9 TO 38.1 (DEG C), 55.3 TO 100.6 (DEG F)

REFERENCE TEMPERATURE ANALYSIS

MEAN IMPACT CURVE

TEMPERATURE [0.035 (IN) EXPANSION]-60 (DEG F): -8.3 (DEG C), 17 (DEG F)

MINIMUM IMPACT CURVE

TEMPERATURE [0.035 (IN) EXPANSION]-60 (DEG F): -9.1 (DEG C), 15.7 (DEG F)

REMARK: MIDLAND WELD BELTLINE 1-15, FROM 1/4 THICKNESS

ANALYSIS SET: MW15_14TR

MODEL PARAMETERS

LOWER SHELF SHEAR [HELD FIXED]: 0 (PERCENT)
MID-TRANSITION TEMPERATURE: 21.2 (DEG C), 70.2 (DEG F)
TRANSITION ZONE WIDTH: 84.9 (C DEG), 152.9 (F DEG)
UPPER SHELF SHEAR [HELD FIXED]: 100 (PERCENT)
STANDARD MODEL: $SHEAR = A + B * \tanh((TEMPERATURE - T_0) / C)$
A: 50 (PERCENT)
B: 50 (PERCENT)
T₀: 21.2 (DEG C), 70.2 (DEG F)
C: 42.5 (C DEG), 76.4 (F DEG)

ORNL-DWG 92-11730

UPPER SHELF SHEAR: 100 (PERCENT)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 93.9 TO 106.1 (PERCENT)

95 PERCENT: 86.5 TO 113.5 (PERCENT)

TEMPERATURE [50 (PERCENT), 50 (PERCENT) SHEAR]: 21.2 (DEG C), 70.2 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 14.9 TO 27.5 (DEG C), 58.8 TO 81.6 (DEG F)

95 PERCENT: 6.8 TO 35.9 (DEG C), 44.2 TO 96.5 (DEG F)

REMARK: MIDLAND WELD BELTLINE 1-15, FROM 1/4 THICKNESS

ANALYSIS SET: MW15_12T

MODEL PARAMETERS

LOWER SHELF ENERGY [HELD FIXED]: 2.7 (J), 2 (FT-LB)
MID-TRANSITION TEMPERATURE: -5.8 (DEG C), 21.5 (DEG F)
TRANSITION ZONE WIDTH: 76.3 (C DEG), 137.3 (F DEG)
UPPER SHELF ENERGY: 87.6 (J), 64.6 (FT-LB)

STANDARD MODEL: $ENERGY = A + B * \tanh((TEMPERATURE - T_0) / C)$

A: 45.1 (J), 33.3 (FT-LB)
B: 42.4 (J), 31.3 (FT-LB)
T0: -5.8 (DEG C), 21.5 (DEG F)
C: 38.1 (C DEG), 68.7 (F DEG)

ORNL-DWG 92-11731

UPPER SHELF ENERGY: 87.6 (J), 64.6 (FT-LB)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 82 TO 93.2 (J), 60.5 TO 68.7 (FT-LB)

95 PERCENT: 75.3 TO 99.9 (J), 55.5 TO 73.7 (FT-LB)

TEMPERATURE [27 (J), 19.9 (FT-LB) ENERGY]: -23.2 (DEG C), -9.8 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -31.1 TO -16.8 (DEG C), -24 TO 1.7 (DEG F)

95 PERCENT: -43 TO -10.3 (DEG C), -45.3 TO 13.4 (DEG F)

TEMPERATURE [41 (J), 30.2 (FT-LB) ENERGY]: -9.6 (DEG C), 14.8 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -15.3 TO -4.3 (DEG C), 4.5 TO 24.2 (DEG F)

MIDLAND BELTLINE WELD 1-15, 1/2 THICKNESS

95 PERCENT: -23.5 TO 2.1 (DEG C), -10.3 TO 35.8 (DEG F)
TEMPERATURE [68 (J), 50.2 (FT-LB) ENERGY]: 17.2 (DEG C), 62.9 (DEG F)
CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 10.3 TO 25.7 (DEG C), 50.5 TO 78.3 (DEG F)

95 PERCENT: 3.3 TO 39.8 (DEG C), 38 TO 103.7 (DEG F)

REFERENCE TEMPERATURE ANALYSIS

MEAN IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY]-60 (DEG F): -16.4 (DEG C), 2.4 (DEG F)

MINIMUM IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY]-60 (DEG F): -15.3 (DEG C), 4.5 (DEG F)

REMARK: MIDLAND WELD BELTLINE 1-15, FROM 1/2 THICKNESS

ANALYSIS SET: MW15_12T

MODEL PARAMETERS

LOWER SHELF EXPANSION [HELD FIXED]: 0.061 (MM), 0.0024 (IN)

MID-TRANSITION TEMPERATURE: 2.7 (DEG C), 36.9 (DEG F)

TRANSITION ZONE WIDTH: 95.8 (C DEG), 172.5 (F DEG)

UPPER SHELF EXPANSION: 1.646 (MM), 0.0648 (IN)

STANDARD MODEL: $\text{EXPANSION} = A + B \cdot \tanh((\text{TEMPERATURE} - T_0) / C)$

A: 0.854 (MM), 0.0336 (IN)

B: 0.793 (MM), 0.0312 (IN)

T0: 2.7 (DEG C), 36.9 (DEG F)

C: 47.9 (C DEG), 86.2 (F DEG)

ORNL-DWG 92-11732

UPPER SHELF EXPANSION: 1.646 (MM), 0.0648 (IN)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 1.555 TO 1.737 (MM), 0.0612 TO 0.0684 (IN)

95 PERCENT: 1.446 TO 1.847 (MM), 0.0569 TO 0.0727 (IN)

TEMPERATURE [0.38 (MM), 0.015 (IN) EXPANSION]: -30.3 (DEG C), -22.5 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -40.5 TO -22.1 (DEG C), -40.9 TO -7.7 (DEG F)

95 PERCENT: -56.7 TO -13.9 (DEG C), -70.1 TO 6.9 (DEG F)

TEMPERATURE [0.89 (MM), 0.035 (IN) EXPANSION]: 5 (DEG C), 40.9 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -0.5 TO 10.5 (DEG C), 31 TO 51 (DEG F)

MIDLAND BELTLINE WELD 1-15, 1/2 THICKNESS

95 PERCENT:-7.5 TO 17.9 (DEG C), 18.4 TO 64.2 (DEG F)

REFERENCE TEMPERATURE ANALYSIS

MEAN IMPACT CURVE

TEMPERATURE [0.035 (IN) EXPANSION]-60 (DEG F):-28.4 (DEG C), -19.2 (DEG F)

MINIMUM IMPACT CURVE

TEMPERATURE [0.035 (IN) EXPANSION]-60 (DEG F):-27.7 (DEG C), -17.8 (DEG F)

REMARK: MIDLAND WELD BELTLINE 1-15, FROM 1/2 THICKNESS

ANALYSIS SET: MW15_12T

MODEL PARAMETERS

LOWER SHELF SHEAR [HELD FIXED]: 0 (PERCENT)

MID-TRANSITION TEMPERATURE: -7.6 (DEG C), 18.3 (DEG F)

TRANSITION ZONE WIDTH: 56.9 (C DEG), 102.4 (F DEG)

UPPER SHELF SHEAR [HELD FIXED]: 100 (PERCENT)

STANDARD MODEL: $SHEAR = A + B * \tanh((TEMPERATURE - T_0) / C)$

A: 50 (PERCENT)

B: 50 (PERCENT)

T0: -7.6 (DEG C), 18.3 (DEG F)

C: 28.5 (C DEG), 51.2 (F DEG)

ORNL-DWG 92-11733

UPPER SHELF SHEAR: 100 (PERCENT)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 94 TO 106 (PERCENT)

95 PERCENT: 86.9 TO 113.1 (PERCENT)

TEMPERATURE [50 (PERCENT), 50 (PERCENT) SHEAR]: -7.6 (DEG C), 18.3 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -11.9 TO -3.5 (DEG C), 10.6 TO 25.7 (DEG F)

95 PERCENT: -17.8 TO 1.6 (DEG C), -0.1 TO 34.8 (DEG F)

REMARK: MIDLAND WELD BELTLINE 1-15, FROM 1/2 THICKNESS

ANALYSIS SET: MW15_58T

MODEL PARAMETERS

LOWER SHELF ENERGY [HELD FIXED]: 2.7 (J), 2 (FT-LB)

MID-TRANSITION TEMPERATURE: 6.8 (DEG C), 44.3 (DEG F)

TRANSITION ZONE WIDTH: 124.9 (C DEG), 224.9 (F DEG)

UPPER SHELF ENERGY: 84.8 (J), 62.6 (FT-LB)

STANDARD MODEL: $ENERGY = A + B \cdot \tanh((TEMPERATURE - T_0) / C)$

A: 43.8 (J), 32.3 (FT-LB)

B: 41.1 (J), 30.3 (FT-LB)

T0: 6.8 (DEG C), 44.3 (DEG F)

C: 62.5 (C DEG), 112.4 (F DEG)

ORNL-DWG 92-11734

UPPER SHELF ENERGY: 84.8 (J), 62.6 (FT-LB)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 69.9 TO 99.7 (J), 51.6 TO 73.5 (FT-LB)

95 PERCENT: 51.9 TO 117.7 (J), 38.3 TO 86.8 (FT-LB)

TEMPERATURE [27 (J), 19.9 (FT-LB) ENERGY]: -20.2 (DEG C), -4.4 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -52.5 TO 1.5 (DEG C), -62.5 TO 34.7 (DEG F)

95 PERCENT: UNDEFINED TO 26.5 (DEG C), UNDEFINED TO 79.7 (DEG F)

TEMPERATURE [41 (J), 30.2 (FT-LB) ENERGY]: 2.6 (DEG C), 36.7 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -19.9 TO 23.1 (DEG C), -3.8 TO 73.6 (DEG F)

95 PERCENT:-59.6 TO 54.6 (DEG C), -75.3 TO 130.3 (DEG F)
TEMPERATURE [68 (J), 50.2 (FT-LB) ENERGY]: 49.2 (DEG C), 120.6 (DEG F)
CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 24 TO 105.2 (DEG C), 75.2 TO 221.4 (DEG F)

95 PERCENT:-1.1 TO UNDEFINED (DEG C), 30 TO UNDEFINED (DEG F)

REFERENCE TEMPERATURE ANALYSIS

MEAN IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY]-60 (DEG F): 15.4 (DEG C), 59.7 (DEG F)

MINIMUM IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY]-60 (DEG F): 8.3 (DEG C), 46.9 (DEG F)

REMARK: MIDLAND WELD BELTLINE 1-15, FROM 5/8 THICKNESS

ANALYSIS SET: MW15_58T

MODEL PARAMETERS

LOWER SHELF EXPANSION [HELD FIXED]: 0.061 (MM), 0.0024 (IN)

MID-TRANSITION TEMPERATURE: 22.9 (DEG C), 73.1 (DEG F)

TRANSITION ZONE WIDTH: 122.6 (C DEG), 220.7 (F DEG)

UPPER SHELF EXPANSION: 1.676 (MM), 0.066 (IN)

STANDARD MODEL: $\text{EXPANSION} = A + B \cdot \tanh((\text{TEMPERATURE} - T_0) / C)$

A: 0.869 (MM), 0.0342 (IN)

B: 0.808 (MM), 0.0318 (IN)

T0: 22.9 (DEG C), 73.1 (DEG F)

C: 61.3 (C DEG), 110.4 (F DEG)

ORNL-DWG 92-11735

UPPER SHELF EXPANSION: 1.676 (MM), 0.066 (IN)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 1.492 TO 1.86 (MM), 0.0588 TO 0.0732 (IN)

95 PERCENT: 1.27 TO 2.082 (MM), 0.05 TO 0.082 (IN)

TEMPERATURE [0.38 (MM), 0.015 (IN) EXPANSION]: -20.1 (DEG C), -4.2 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -44.6 TO -3.4 (DEG C), -48.3 TO 25.9 (DEG F)

95 PERCENT: UNDEFINED TO 12.3 (DEG C), UNDEFINED TO 54.2 (DEG F)

TEMPERATURE [0.89 (MM), 0.035 (IN) EXPANSION]: 24.5 (DEG C), 76.1 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 12.3 TO 36.9 (DEG C), 54.1 TO 98.4 (DEG F)

MIDLAND BELTLINE WELD 1-15, 5/8 THICKNESS

95 PERCENT:-4.5 TO 54.2 (DEG C), 23.9 TO 129.5 (DEG F)

REFERENCE TEMPERATURE ANALYSIS

MEAN IMPACT CURVE

TEMPERATURE [0.035 (IN) EXPANSION]-60 (DEG F):-8.9 (DEG C), 15.9 (DEG F)

MINIMUM IMPACT CURVE

TEMPERATURE [0.035 (IN) EXPANSION]-60 (DEG F):-10 (DEG C), 13.9 (DEG F)

REMARK: MIDLAND WELD BELTLINE 1-15, FROM 5/8 THICKNESS

MIDLAND BELTLINE WELD 1-15, 5/8 THICKNESS

ANALYSIS SET: MW15_58T

MODEL PARAMETERS

LOWER SHELF SHEAR [HELD FIXED]: 0 (PERCENT)

MID-TRANSITION TEMPERATURE: 16.6 (DEG C), 61.8 (DEG F)

TRANSITION ZONE WIDTH: 89.2 (C DEG), 160.6 (F DEG)

UPPER SHELF SHEAR [HELD FIXED]: 100 (PERCENT)

STANDARD MODEL: $SHEAR = A + B * \tanh((TEMPERATURE - T_0) / C)$

A: 50 (PERCENT)

B: 50 (PERCENT)

T0: 16.6 (DEG C), 61.8 (DEG F)

C: 44.6 (C DEG), 80.3 (F DEG)

ORNL-DWG 92-11736

UPPER SHELF SHEAR: 100 (PERCENT)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 91.4 TO 108.6 (PERCENT)

95 PERCENT: 81.2 TO 118.8 (PERCENT)

TEMPERATURE [50 (PERCENT), 50 (PERCENT) SHEAR]: 16.6 (DEG C), 61.8 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 7.7 TO 25.4 (DEG C), 45.8 TO 77.8 (DEG F)

95 PERCENT: -4.4 TO 37.1 (DEG C), 24.2 TO 98.8 (DEG F)

REMARK: MIDLAND WELD BELTLINE 1-15, FROM 5/8 THICKNESS

ANALYSIS SET: MW15_34T

MODEL PARAMETERS

LOWER SHELF ENERGY [HELD FIXED]: 2.7 (J), 2 (FT-LB)

MID-TRANSITION TEMPERATURE: -0.5 (DEG C), 31.1 (DEG F)

TRANSITION ZONE WIDTH: 100.3 (C DEG), 180.5 (F DEG)

UPPER SHELF ENERGY: 88.9 (J), 65.6 (FT-LB)

STANDARD MODEL: $ENERGY = A + B \cdot \tanh((TEMPERATURE - T_0) / C)$

A: 45.8 (J), 33.8 (FT-LB)

B: 43.1 (J), 31.8 (FT-LB)

T₀: -0.5 (DEG C), 31.1 (DEG F)

C: 50.1 (C DEG), 90.3 (F DEG)

ORNL-DWG 92-11737

UPPER SHELF ENERGY: 88.9 (J), 65.6 (FT-LB)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 82.6 TO 95.3 (J), 60.9 TO 70.3 (FT-LB)

95 PERCENT: 75 TO 102.9 (J), 55.3 TO 75.9 (FT-LB)

TEMPERATURE [27 (J), 19.9 (FT-LB) ENERGY]: -24 (DEG C), -11.2 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -34.2 TO -15.6 (DEG C), -29.5 TO 3.9 (DEG F)

95 PERCENT: -50.1 TO -6.7 (DEG C), -58.2 TO 19.9 (DEG F)

TEMPERATURE [41 (J), 30.2 (FT-LB) ENERGY]: -6.1 (DEG C), 20.9 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -13.6 TO 1 (DEG C), 7.5 TO 33.8 (DEG F)

MIDLAND BELTLINE WELD 1-15, 3/4 THICKNESS

95 PERCENT: -24.1 TO 10 (DEG C), -11.4 TO 50 (DEG F)
TEMPERATURE [68 (J), 50.2 (FT-LB) ENERGY]: 28 (DEG C), 82.4 (DEG F)
CONFIDENCE INTERVALS ON PREDICTED VALUE
68 PERCENT: 18.8 TO 39.2 (DEG C), 65.9 TO 102.5 (DEG F)
95 PERCENT: 9.4 TO 57.3 (DEG C), 49 TO 135.1 (DEG F)

REFERENCE TEMPERATURE ANALYSIS

MEAN IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY]-60 (DEG F): -5.7 (DEG C), 21.8 (DEG F)

MINIMUM IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY]-60 (DEG F): -5.4 (DEG C), 22.2 (DEG F)

REMARK: MIDLAND WELD BELTLINE 1-15, FROM 3/4 THICKNESS

ANALYSIS SET: MW15_34T

MODEL PARAMETERS

LOWER SHELF EXPANSION [HELD FIXED]: 0.061 (MM), 0.0024 (IN)

MID-TRANSITION TEMPERATURE: 2.9 (DEG C), 37.2 (DEG F)

TRANSITION ZONE WIDTH: 96.9 (C DEG), 174.4 (F DEG)

UPPER SHELF EXPANSION: 1.611 (MM), 0.0634 (IN)

STANDARD MODEL: $\text{EXPANSION} = A + B \cdot \text{TANH}((\text{TEMPERATURE} - T_0) / C)$

A: 0.836 (MM), 0.0329 (IN)

B: 0.775 (MM), 0.0305 (IN)

T0: 2.9 (DEG C), 37.2 (DEG F)

C: 48.5 (C DEG), 87.2 (F DEG)

ORNL-DWG 92-11738

UPPER SHELF EXPANSION: 1.611 (MM), 0.0634 (IN)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 1.49 TO 1.732 (MM), 0.0587 TO 0.0682 (IN)

95 PERCENT: 1.344 TO 1.878 (MM), 0.0529 TO 0.0739 (IN)

TEMPERATURE [0.38 (MM), 0.015 (IN) EXPANSION]: -29.8 (DEG C), -21.6 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -43.3 TO -19.6 (DEG C), -46 TO -3.2 (DEG F)

95 PERCENT: -68.4 TO -9.6 (DEG C), -91.1 TO 14.7 (DEG F)

TEMPERATURE [0.89 (MM), 0.035 (IN) EXPANSION]: 6.3 (DEG C), 43.3 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -1 TO 14 (DEG C), 30.2 TO 57.2 (DEG F)

MIDLAND BELTLINE WELD 1-15, 3/4 THICKNESS

95 PERCENT:-10.3 TO 24.6 (DEG C), 13.4 TO 76.2 (DEG F)

REFERENCE TEMPERATURE ANALYSIS

MEAN IMPACT CURVE

TEMPERATURE [0.035 (IN) EXPANSION]-60 (DEG F):-27.1 (DEG C), -16.8 (DEG F)

MINIMUM IMPACT CURVE

TEMPERATURE [0.035 (IN) EXPANSION]-60 (DEG F):-27.1 (DEG C), -16.7 (DEG F)

REMARK: MIDLAND WELD BELTLINE 1-15, FROM 3/4 THICKNESS

ANALYSIS SET: MW15_34T

MODEL PARAMETERS

LOWER SHELF SHEAR [HELD FIXED]: 0 (PERCENT)

MID-TRANSITION TEMPERATURE: -7.7 (DEG C), 18.2 (DEG F)

TRANSITION ZONE WIDTH: 55.2 (C DEG), 99.3 (F DEG)

UPPER SHELF SHEAR [HELD FIXED]: 100 (PERCENT)

STANDARD MODEL: $SHEAR = A + B * \tanh((TEMPERATURE - T_0) / C)$

A: 50 (PERCENT)

B: 50 (PERCENT)

T0: -7.7 (DEG C), 18.2 (DEG F)

C: 27.6 (C DEG), 49.7 (F DEG)

ORNL-DWG 92-11739

UPPER SHELF SHEAR: 100 (PERCENT)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 93.3 TO 106.7 (PERCENT)

95 PERCENT: 85.5 TO 114.5 (PERCENT)

TEMPERATURE [50 (PERCENT), 50 (PERCENT) SHEAR]: -7.7 (DEG C), 18.2 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -12.1 TO -3.2 (DEG C), 10.2 TO 26.3 (DEG F)

95 PERCENT: -18.1 TO 2.9 (DEG C), -0.6 TO 37.2 (DEG F)

REMARK: MIDLAND WELD BELTLINE 1-15, FROM 3/4 THICKNESS

ANALYSIS SET: MW15_78T

MODEL PARAMETERS

LOWER SHELF ENERGY [HELD FIXED]: 2.7 (J), 2 (FT-LB)
MID-TRANSITION TEMPERATURE: -6.3 (DEG C), 20.6 (DEG F)
TRANSITION ZONE WIDTH: 76.6 (C DEG), 137.8 (F DEG)
UPPER SHELF ENERGY: 82.8 (J), 61.1 (FT-LB)

STANDARD MODEL: $ENERGY = A + B \cdot \tanh((TEMPERATURE - T_0) / C)$

A: 42.8 (J), 31.5 (FT-LB)
B: 40.1 (J), 29.6 (FT-LB)
T₀: -6.3 (DEG C), 20.6 (DEG F)
C: 38.3 (C DEG), 68.9 (F DEG)

ORNL-DWG 92-11740

UPPER SHELF ENERGY: 82.8 (J), 61.1 (FT-LB)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 72.8 TO 92.9 (J), 53.7 TO 68.5 (FT-LB)

95 PERCENT: 60.6 TO 105.1 (J), 44.7 TO 77.5 (FT-LB)

TEMPERATURE [27 (J), 19.9 (FT-LB) ENERGY]: -22.3 (DEG C), -8.1 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -36 TO -11.9 (DEG C), -32.7 TO 10.6 (DEG F)

95 PERCENT: -62.8 TO -0.3 (DEG C), -81 TO 31.4 (DEG F)

TEMPERATURE [41 (J), 30.2 (FT-LB) ENERGY]: -8 (DEG C), 17.6 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -18.1 TO 1.6 (DEG C), -0.5 TO 35 (DEG F)

MIDLAND BELTLINE WELD 1-15, 7/8 THICKNESS

95 PERCENT:-33.5 TO 15.5 (DEG C), -28.4 TO 59.8 (DEG F)

TEMPERATURE [68 (J), 50.2 (FT-LB) ENERGY]: 22 (DEG C), 71.7 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 8.9 TO 44.6 (DEG C), 48 TO 112.3 (DEG F)

95 PERCENT:-3.2 TO UNDEFINED (DEG C), 26.3 TO UNDEFINED (DEG F)

REFERENCE TEMPERATURE ANALYSIS

MEAN IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY]-60 (DEG F):-11.6 (DEG C), 11.1 (DEG F)

MINIMUM IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY]-60 (DEG F):-3.2 (DEG C), 26.3 (DEG F)

REMARK: MIDLAND WELD BELTLINE 1-15, FROM 7/8 THICKNESS

ANALYSIS SET: MW15_78T

MODEL PARAMETERS

LOWER SHELF EXPANSION [HELD FIXED]: 0.061 (MM), 0.0024 (IN)

MID-TRANSITION TEMPERATURE: 0.7 (DEG C), 33.2 (DEG F)

TRANSITION ZONE WIDTH: 82.4 (C DEG), 148.4 (F DEG)

UPPER SHELF EXPANSION: 1.59 (MM), 0.0626 (IN)

STANDARD MODEL: $\text{EXPANSION} = A + B \cdot \tanh((\text{TEMPERATURE} - T_0) / C)$

A: 0.826 (MM), 0.0325 (IN)

B: 0.765 (MM), 0.0301 (IN)

T₀: 0.7 (DEG C), 33.2 (DEG F)

C: 41.2 (C DEG), 74.2 (F DEG)

ORNL-DWG 92-11741

UPPER SHELF EXPANSION: 1.59 (MM), 0.0626 (IN)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 1.421 TO 1.759 (MM), 0.056 TO 0.0693 (IN)

95 PERCENT: 1.217 TO 1.964 (MM), 0.0479 TO 0.0773 (IN)

TEMPERATURE [0.38 (MM), 0.015 (IN) EXPANSION]: -26.8 (DEG C), -16.2 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -43.8 TO -15.1 (DEG C), -46.9 TO 4.8 (DEG F)

95 PERCENT: -139.1 TO -3.9 (DEG C), -218.3 TO 25 (DEG F)

TEMPERATURE [0.89 (MM), 0.035 (IN) EXPANSION]: 4.2 (DEG C), 39.5 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -4.7 TO 13.6 (DEG C), 23.5 TO 56.4 (DEG F)

95 PERCENT: -16.7 TO 27.4 (DEG C), 1.9 TO 81.4 (DEG F)

REFERENCE TEMPERATURE ANALYSIS

MEAN IMPACT CURVE

TEMPERATURE [0.035 (IN) EXPANSION]-60 (DEG F):-29.2 (DEG C), -20.6 (DEG F)

MINIMUM IMPACT CURVE

TEMPERATURE [0.035 (IN) EXPANSION]-60 (DEG F):-26.6 (DEG C), -15.9 (DEG F)

REMARK: MIDLAND WELD BELTLINE 1-15, FROM 7/8 THICKNESS

ANALYSIS SET: MW15_78T

MODEL PARAMETERS

LOWER SHELF SHEAR [HELD FIXED]: 0 (PERCENT)
MID-TRANSITION TEMPERATURE:-0.5 (DEG C), 31.1 (DEG F)
TRANSITION ZONE WIDTH: 60.5 (C DEG), 108.9 (F DEG)
UPPER SHELF SHEAR [HELD FIXED]: 100 (PERCENT)
STANDARD MODEL: $SHEAR = A + B * \tanh((TEMPERATURE - T_0) / C)$
A: 50 (PERCENT)
B: 50 (PERCENT)
T₀: -0.5 (DEG C), 31.1 (DEG F)
C: 30.2 (C DEG), 54.5 (F DEG)

ORNL-DWG 92-11742

UPPER SHELF SHEAR: 100 (PERCENT)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 84.4 TO 115.6 (PERCENT)

95 PERCENT: 66 TO 134 (PERCENT)

TEMPERATURE [50 (PERCENT), 50 (PERCENT) SHEAR]: -0.5 (DEG C), 31.1 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -12.3 TO 11.5 (DEG C), 9.9 TO 52.6 (DEG F)

95 PERCENT: -31.4 TO 30.7 (DEG C), -24.5 TO 87.3 (DEG F)

REMARK: MIDLAND WELD BELTLINE 1-15, FROM 7/8 THICKNESS

APPENDIX D

HYPERBOLIC TANGENT CURVE FITS WITH 68% AND 95% CONFIDENCE BOUNDS FOR INDIVIDUAL DATA SETS UNIRRADIATED MIDLAND REACTOR VESSEL WELDS

PLOTS FOR NOZZLE COURSE WELD SECTION 3-1

ANALYSIS SET: NC31_50T

MODEL PARAMETERS

LOWER SHELF ENERGY [HELD FIXED]: 2.7 (J), 2 (FT-LB)
MID-TRANSITION TEMPERATURE: 9.7 (DEG C), 49.4 (DEG F)
TRANSITION ZONE WIDTH: 114.5 (C DEG), 206.1 (F DEG)
UPPER SHELF ENERGY: 85.6 (J), 63.1 (FT-LB)

STANDARD MODEL: $ENERGY = A + B * \tanh((TEMPERATURE - T_0) / C)$

A: 44.1 (J), 32.6 (FT-LB)
B: 41.4 (J), 30.6 (FT-LB)
T₀: 9.7 (DEG C), 49.4 (DEG F)
C: 57.3 (C DEG), 103.1 (F DEG)

ORNL-DWG 92-11743

UPPER SHELF ENERGY: 85.6 (J), 63.1 (FT-LB)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 77.4 TO 93.8 (J), 57.1 TO 69.2 (FT-LB)

95 PERCENT: 66.4 TO 104.7 (J), 49 TO 77.3 (FT-LB)

TEMPERATURE [27 (J), 19.9 (FT-LB) ENERGY]: -15.5 (DEG C), 4.1 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -29.5 TO -4.1 (DEG C), -21.2 TO 24.6 (DEG F)

95 PERCENT: -55.4 TO 9.7 (DEG C), -67.7 TO 49.4 (DEG F)

TEMPERATURE [41 (J), 30.2 (FT-LB) ENERGY]: 5.3 (DEG C), 41.6 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -5.1 TO 15.6 (DEG C), 22.7 TO 60.1 (DEG F)

MIDLAND NOZZLE WELD 3-31, 1/2 THICKNESS

95 PERCENT:-21.6 TO 30.5 (DEG C),-6.8 TO 86.9 (DEG F)
TEMPERATURE [68 (J),50.2 (FT-LB) ENERGY]: 47.3 (DEG C),117.1 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 33.5 TO 65.2 (DEG C),92.3 TO 149.3 (DEG F)

95 PERCENT: 18.8 TO UNDEFINED (DEG C),65.8 TO UNDEFINED (DEG F)

REFERENCE TEMPERATURE ANALYSIS

MEAN IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY]-60 (DEG F): 13.5 (DEG C),56.3 (DEG F)

MINIMUM IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY]-60 (DEG F): 13.5 (DEG C),56.3 (DEG F)

REMARK: MIDLAND WELD NOZZLE COURSE 3-31, FROM 1/2 THICKNESS

ANALYSIS SET: NC31_50T

MODEL PARAMETERS

LOWER SHELF EXPANSION [HELD FIXED]: 0.061 (MM), 0.0024 (IN)

MID-TRANSITION TEMPERATURE: 10.1 (DEG C), 50.1 (DEG F)

TRANSITION ZONE WIDTH: 87.8 (C DEG), 158 (F DEG)

UPPER SHELF EXPANSION: 1.318 (MM), 0.0519 (IN)

STANDARD MODEL: $\text{EXPANSION} = A + B \cdot \tanh((\text{TEMPERATURE} - T_0) / C)$

A: 0.69 (MM), 0.0272 (IN)

B: 0.629 (MM), 0.0248 (IN)

T₀: 10.1 (DEG C), 50.1 (DEG F)

C: 43.9 (C DEG), 79 (F DEG)

ORNL-DWG 92-11744

UPPER SHELF EXPANSION: 1.318 (MM), 0.0519 (IN)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 1.187 TO 1.45 (MM), 0.0467 TO 0.0571 (IN)

95 PERCENT: 1.012 TO 1.625 (MM), 0.0398 TO 0.064 (IN)

TEMPERATURE [0.38 (MM), 0.015 (IN) EXPANSION]: -13.6 (DEG C), 7.5 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -27.8 TO -2.9 (DEG C), -18.1 TO 26.8 (DEG F)

95 PERCENT: -58.7 TO 9.5 (DEG C), -73.6 TO 49.1 (DEG F)

TEMPERATURE [0.89 (MM), 0.035 (IN) EXPANSION]: 24.5 (DEG C), 76.2 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 14.9 TO 36 (DEG C), 58.9 TO 96.7 (DEG F)

MIDLAND NOZZLE WELD 3-31, 1/2 THICKNESS

95 PERCENT: 3 TO 55.8 (DEG C), 37.3 TO 132.4 (DEG F)

REFERENCE TEMPERATURE ANALYSIS

MEAN IMPACT CURVE

TEMPERATURE [0.035 (IN) EXPANSION]-60 (DEG F):-8.9 (DEG C), 16 (DEG F)

MINIMUM IMPACT CURVE

TEMPERATURE [0.035 (IN) EXPANSION]-60 (DEG F):-8.9 (DEG C), 16.1 (DEG F)

REMARK: MIDLAND WELD NOZZLE COURSE 3-31, FROM 1/2 THICKNESS

MIDLAND NOZZLE WELD 3-31, 1/2 THICKNESS

ANALYSIS SET: NC31_50T

MODEL PARAMETERS

LOWER SHELF SHEAR [HELD FIXED]: 0 (PERCENT)

MID-TRANSITION TEMPERATURE: 14.8 (DEG C), 58.6 (DEG F)

TRANSITION ZONE WIDTH: 61.3 (C DEG), 110.3 (F DEG)

UPPER SHELF SHEAR [HELD FIXED]: 100 (PERCENT)

STANDARD MODEL: $SHEAR = A + B * \tanh((TEMPERATURE - T_0) / C)$

A: 50 (PERCENT)

B: 50 (PERCENT)

T0: 14.8 (DEG C), 58.6 (DEG F)

C: 30.7 (C DEG), 55.2 (F DEG)

ORNL-DWG 92-11745

UPPER SHELF SHEAR: 100 (PERCENT)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 95.6 TO 104.4 (PERCENT)

95 PERCENT: 90.2 TO 109.8 (PERCENT)

TEMPERATURE [50 (PERCENT), 50 (PERCENT) SHEAR]: 14.8 (DEG C), 58.6 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 11.4 TO 18.2 (DEG C), 52.5 TO 64.8 (DEG F)

95 PERCENT: 7 TO 22.8 (DEG C), 44.6 TO 73 (DEG F)

REMARK: MIDLAND WELD NOZZLE COURSE 3-31, FROM 1/2 THICKNESS

ANALYSIS SET: NC31_75T

MODEL PARAMETERS

LOWER SHELF ENERGY [HELD FIXED]: 2.7 (J), 2 (FT-LB)

MID-TRANSITION TEMPERATURE: 9.4 (DEG C), 49 (DEG F)

TRANSITION ZONE WIDTH: 138.6 (C DEG), 249.5 (F DEG)

UPPER SHELF ENERGY: 88.8 (J), 65.5 (FT-LB)

STANDARD MODEL: $ENERGY = A + B \cdot \tanh((TEMPERATURE - T_0) / C)$

A: 45.7 (J), 33.7 (FT-LB)

B: 43 (J), 31.7 (FT-LB)

T0: 9.4 (DEG C), 49 (DEG F)

C: 69.3 (C DEG), 124.7 (F DEG)

ORNL-DWG 92-11746

UPPER SHELF ENERGY: 88.8 (J), 65.5 (FT-LB)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 79.6 TO 97.9 (J), 58.7 TO 72.2 (FT-LB)

95 PERCENT: 68.2 TO 109.3 (J), 50.3 TO 80.6 (FT-LB)

TEMPERATURE [27 (J), 19.9 (FT-LB) ENERGY]: -22.9 (DEG C), -9.2 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -40.3 TO -9.2 (DEG C), -40.5 TO 15.5 (DEG F)

95 PERCENT: -71 TO 5.8 (DEG C), -95.8 TO 42.4 (DEG F)

TEMPERATURE [41 (J), 30.2 (FT-LB) ENERGY]: 1.8 (DEG C), 35.2 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -10.7 TO 13.6 (DEG C), 12.7 TO 56.4 (DEG F)

95 PERCENT:-30 TO 29.2 (DEG C),-22.1 TO 84.6 (DEG F)
TEMPERATURE [68 (J),50.2 (FT-LB) ENERGY]: 49.2 (DEG C),120.5 (DEG F)
CONFIDENCE INTERVALS ON PREDICTED VALUE
68 PERCENT: 34.4 TO 67.9 (DEG C),93.9 TO 154.2 (DEG F)
95 PERCENT: 18.8 TO 125.8 (DEG C),65.8 TO 258.5 (DEG F)

REFERENCE TEMPERATURE ANALYSIS

MEAN IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY]-60 (DEG F): 15.4 (DEG C),59.7 (DEG F)

MINIMUM IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY]-60 (DEG F): 11.5 (DEG C),52.7 (DEG F)

REMARK: MIDLAND WELD NOZZLE COURSE 3-31, FROM 3/4 THICKNESS

ANALYSIS SET: NC31_75T

MODEL PARAMETERS

LOWER SHELF EXPANSION [HELD FIXED]: 0.061 (MM), 0.0024 (IN)

MID-TRANSITION TEMPERATURE: 18.9 (DEG C), 66 (DEG F)

TRANSITION ZONE WIDTH: 110.2 (C DEG), 198.3 (F DEG)

UPPER SHELF EXPANSION: 1.494 (MM), 0.0588 (IN)

STANDARD MODEL: $\text{EXPANSION} = A + B \cdot \tanh((\text{TEMPERATURE} - T_0) / C)$

A: 0.778 (MM), 0.0306 (IN)

B: 0.717 (MM), 0.0282 (IN)

T0: 18.9 (DEG C), 66 (DEG F)

C: 55.1 (C DEG), 99.1 (F DEG)

ORNL-DWG 92-11747

UPPER SHELF EXPANSION: 1.494 (MM), 0.0588 (IN)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 1.313 TO 1.676 (MM), 0.0517 TO 0.066 (IN)

95 PERCENT: 1.084 TO 1.905 (MM), 0.0427 TO 0.075 (IN)

TEMPERATURE [0.38 (MM), 0.015 (IN) EXPANSION]: -15.6 (DEG C), 4 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -37.8 TO -0.3 (DEG C), -36 TO 31.5 (DEG F)

95 PERCENT: -124.4 TO 15.2 (DEG C), -192 TO 59.3 (DEG F)

TEMPERATURE [0.89 (MM), 0.035 (IN) EXPANSION]: 27.6 (DEG C), 81.6 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 15.6 TO 40.9 (DEG C), 60.1 TO 105.6 (DEG F)

MIDLAND NOZZLE WELD 3-31, 3/4 THICKNESS

95 PERCENT:-0.7 TO 61.9 (DEG C),30.7 TO 143.4 (DEG F)

REFERENCE TEMPERATURE ANALYSIS

MEAN IMPACT CURVE

TEMPERATURE [0.035 (IN) EXPANSION]-60 (DEG F):-5.8 (DEG C),21.5 (DEG F)

MINIMUM IMPACT CURVE

TEMPERATURE [0.035 (IN) EXPANSION]-60 (DEG F):-8.9 (DEG C),15.9 (DEG F)

REMARK: MIDLAND WELD NOZZLE COURSE 3-31, FROM 3/4 THICKNESS

ANALYSIS SET: NC31_75T

MODEL PARAMETERS

LOWER SHELF SHEAR [HELD FIXED]: 0 (PERCENT)

MID-TRANSITION TEMPERATURE: 28.8 (DEG C), 83.8 (DEG F)

TRANSITION ZONE WIDTH: 62.4 (C DEG), 112.3 (F DEG)

UPPER SHELF SHEAR [HELD FIXED]: 100 (PERCENT)

STANDARD MODEL: $SHEAR = A + B * \tanh((TEMPERATURE - T_0) / C)$

A: 50 (PERCENT)

B: 50 (PERCENT)

T0: 28.8 (DEG C), 83.8 (DEG F)

C: 31.2 (C DEG), 56.2 (F DEG)

ORNL-DWG 92-11748

UPPER SHELF SHEAR: 100 (PERCENT)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 88.9 TO 111.1 (PERCENT)

95 PERCENT: 75.4 TO 124.6 (PERCENT)

TEMPERATURE [50 (PERCENT), 50 (PERCENT) SHEAR]: 28.8 (DEG C), 83.8 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 20.4 TO 37.7 (DEG C), 68.7 TO 99.9 (DEG F)

95 PERCENT: 7.9 TO 51.6 (DEG C), 46.2 TO 125 (DEG F)

REMARK: MIDLAND WELD NOZZLE COURSE 3-31, FROM 3/4 THICKNESS

ANALYSIS SET: NC31_78T

MODEL PARAMETERS

LOWER SHELF ENERGY [HELD FIXED]: 2.7 (J), 2 (FT-LB)

MID-TRANSITION TEMPERATURE: -3.2 (DEG C), 26.2 (DEG F)

TRANSITION ZONE WIDTH: 105 (C DEG), 189 (F DEG)

UPPER SHELF ENERGY: 89.8 (J), 66.2 (FT-LB)

STANDARD MODEL: $ENERGY = A + B \cdot \tanh((TEMPERATURE - T_0) / C)$

A: 46.3 (J), 34.1 (FT-LB)

B: 43.6 (J), 32.1 (FT-LB)

T₀: -3.2 (DEG C), 26.2 (DEG F)

C: 52.5 (C DEG), 94.5 (F DEG)

ORNL-DWG 92-11749

UPPER SHELF ENERGY: 89.8 (J), 66.2 (FT-LB)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 84.5 TO 95.1 (J), 62.3 TO 70.1 (FT-LB)

95 PERCENT: 77.4 TO 102.2 (J), 57.1 TO 75.4 (FT-LB)

TEMPERATURE [27 (J), 19.9 (FT-LB) ENERGY]: -28.2 (DEG C), -18.7 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -36.7 TO -20.8 (DEG C), -34.1 TO -5.5 (DEG F)

95 PERCENT: -50.6 TO -12.2 (DEG C), -59.1 TO 10 (DEG F)

TEMPERATURE [41 (J), 30.2 (FT-LB) ENERGY]: -9.6 (DEG C), 14.7 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -16 TO -3.5 (DEG C), 3.2 TO 25.8 (DEG F)

MIDLAND NOZZLE WELD 3-31, 7/8 THICKNESS

95 PERCENT:-25.5 TO 4.9 (DEG C),-13.9 TO 40.8 (DEG F)

TEMPERATURE [68 (J),50.2 (FT-LB) ENERGY]: 25.5 (DEG C),78 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 17.8 TO 34.6 (DEG C),64 TO 94.2 (DEG F)

95 PERCENT: 8.7 TO 49.3 (DEG C),47.7 TO 120.8 (DEG F)

REFERENCE TEMPERATURE ANALYSIS

MEAN IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY]-60 (DEG F):-8.1 (DEG C),17.4 (DEG F)

MINIMUM IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY]-60 (DEG F):-8.1 (DEG C),17.4 (DEG F)

REMARK: MIDLAND WELD NOZZLE COURSE 3-31, FROM 7/8 THICKNESS

ANALYSIS SET: NC31_78T

MODEL PARAMETERS

LOWER SHELF EXPANSION [HELD FIXED]: 0.061 (MM), 0.0024 (IN)

MID-TRANSITION TEMPERATURE: -1.5 (DEG C), 29.3 (DEG F)

TRANSITION ZONE WIDTH: 97.5 (C DEG), 175.5 (F DEG)

UPPER SHELF EXPANSION: 1.637 (MM), 0.0645 (IN)

STANDARD MODEL: $\text{EXPANSION} = A + B \cdot \tanh((\text{TEMPERATURE} - T_0) / C)$

A: 0.849 (MM), 0.0334 (IN)

B: 0.788 (MM), 0.031 (IN)

T0: -1.5 (DEG C), 29.3 (DEG F)

C: 48.7 (C DEG), 87.7 (F DEG)

ORNL-DWG 92-11750

UPPER SHELF EXPANSION: 1.637 (MM), 0.0645 (IN)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 1.54 TO 1.734 (MM), 0.0606 TO 0.0683 (IN)

95 PERCENT: 1.412 TO 1.863 (MM), 0.0556 TO 0.0733 (IN)

TEMPERATURE [0.38 (MM), 0.015 (IN) EXPANSION]: -34.9 (DEG C), -30.9 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -45.4 TO -26.5 (DEG C), -49.6 TO -15.7 (DEG F)

95 PERCENT: -64.1 TO -17.2 (DEG C), -83.4 TO 1.1 (DEG F)

TEMPERATURE [0.89 (MM), 0.035 (IN) EXPANSION]: 1 (DEG C), 33.8 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -4.8 TO 7 (DEG C), 23.3 TO 44.6 (DEG F)

MIDLAND NOZZLE WELD 3-31, 7/8 THICKNESS

95 PERCENT:-12.9 TO 15.7 (DEG C),8.7 TO 60.2 (DEG F)

REFERENCE TEMPERATURE ANALYSIS

MEAN IMPACT CURVE

TEMPERATURE [0.035 (IN) EXPANSION]-60 (DEG F):-32.4 (DEG C),-26.3 (DEG F)

MINIMUM IMPACT CURVE

TEMPERATURE [0.035 (IN) EXPANSION]-60 (DEG F):-32.4 (DEG C),-26.3 (DEG F)

REMARK: MIDLAND WELD NOZZLE COURSE 3-31, FROM 7/8 THICKNESS

ANALYSIS SET: NC31_78T

MODEL PARAMETERS

LOWER SHELF SHEAR [HELD FIXED]: 0 (PERCENT)

MID-TRANSITION TEMPERATURE: 7.4 (DEG C), 45.3 (DEG F)

TRANSITION ZONE WIDTH: 52.6 (C DEG), 94.7 (F DEG)

UPPER SHELF SHEAR [HELD FIXED]: 100 (PERCENT)

STANDARD MODEL: $SHEAR = A + B \cdot \tanh((TEMPERATURE - T_0) / C)$

A: 50 (PERCENT)

B: 50 (PERCENT)

T0: 7.4 (DEG C), 45.3 (DEG F)

C: 26.3 (C DEG), 47.4 (F DEG)

ORNL-DWG 92-11751

UPPER SHELF SHEAR: 100 (PERCENT)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 97.4 TO 102.6 (PERCENT)

95 PERCENT: 94.1 TO 105.9 (PERCENT)

TEMPERATURE [50 (PERCENT), 50 (PERCENT) SHEAR]: 7.4 (DEG C), 45.3 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 5.6 TO 9.2 (DEG C), 42.1 TO 48.5 (DEG F)

95 PERCENT: 3.3 TO 11.5 (DEG C), 38 TO 52.6 (DEG F)

REMARK: MIDLAND WELD NOZZLE COURSE 3-31, FROM 7/8 THICKNESS

APPENDIX D

HYPERBOLIC TANGENT CURVE FITS WITH 68% AND 95% CONFIDENCE BOUNDS FOR INDIVIDUAL DATA SETS UNIRRADIATED MIDLAND REACTOR VESSEL WELDS

PLOTS FOR NOZZLE COURSE WELD SECTION 3-4

ANALYSIS SET: NC34_50T
MODEL PARAMETERS

LOWER SHELF ENERGY [HELD FIXED]: 2.7 (J), 2 (FT-LB)
MID-TRANSITION TEMPERATURE: -1.4 (DEG C), 29.4 (DEG F)
TRANSITION ZONE WIDTH: 179.1 (C DEG), 322.3 (F DEG)
UPPER SHELF ENERGY: 88 (J), 64.9 (FT-LB)

STANDARD MODEL: $ENERGY = A + B \cdot \tanh((TEMPERATURE - T_0) / C)$

A: 45.4 (J), 33.5 (FT-LB)
B: 42.7 (J), 31.5 (FT-LB)
T₀: -1.4 (DEG C), 29.4 (DEG F)
C: 89.5 (C DEG), 161.2 (F DEG)

ORNL-DWG 92-11752

UPPER SHELF ENERGY: 88 (J), 64.9 (FT-LB)
CONFIDENCE INTERVALS ON PREDICTED VALUE
68 PERCENT: 80.7 TO 95.3 (J), 59.5 TO 70.3 (FT-LB)
95 PERCENT: 71 TO 105.1 (J), 52.4 TO 77.5 (FT-LB)
TEMPERATURE [27 (J), 19.9 (FT-LB) ENERGY]: -42.6 (DEG C), -44.7 (DEG F)
CONFIDENCE INTERVALS ON PREDICTED VALUE
68 PERCENT: -60.4 TO -28.2 (DEG C), -76.6 TO -18.7 (DEG F)
95 PERCENT: -91 TO -11.7 (DEG C), -131.8 TO 10.9 (DEG F)
TEMPERATURE [41 (J), 30.2 (FT-LB) ENERGY]: -10.6 (DEG C), 12.9 (DEG F)
CONFIDENCE INTERVALS ON PREDICTED VALUE
68 PERCENT: -23.4 TO 1.4 (DEG C), -10.1 TO 34.6 (DEG F)

95 PERCENT:-43.6 TO 17.9 (DEG C),-46.4 TO 64.2 (DEG F)
TEMPERATURE [68 (J),50.2 (FT-LB) ENERGY]: 51.5 (DEG C),124.7 (DEG F)
CONFIDENCE INTERVALS ON PREDICTED VALUE
68 PERCENT: 35.9 TO 70.5 (DEG C),96.6 TO 158.9 (DEG F)
95 PERCENT: 18.2 TO 110.9 (DEG C),64.8 TO 231.5 (DEG F)
REFERENCE TEMPERATURE ANALYSIS
MEAN IMPACT CURVE
TEMPERATURE [50 (FT-LB) ENERGY]-60 (DEG F): 17.6 (DEG C),63.6 (DEG F)
MINIMUM IMPACT CURVE
TEMPERATURE [50 (FT-LB) ENERGY]-60 (DEG F): 17.6 (DEG C),63.6 (DEG F)
REMARK: MIDLAND NOZZLE WELD 3-34, FROM 1/2 THICKNESS

ANALYSIS SET: NC34_50T

MODEL PARAMETERS

LOWER SHELF EXPANSION [HELD FIXED]: 0.061 (MM), 0.0024 (IN)

MID-TRANSITION TEMPERATURE: 3.5 (DEG C), 38.3 (DEG F)

TRANSITION ZONE WIDTH: 128.7 (C DEG), 231.6 (F DEG)

UPPER SHELF EXPANSION: 1.384 (MM), 0.0545 (IN)

STANDARD MODEL: $\text{EXPANSION} = A + B \cdot \tanh((\text{TEMPERATURE} - T_0) / C)$

A: 0.723 (MM), 0.0285 (IN)

B: 0.662 (MM), 0.026 (IN)

T0: 3.5 (DEG C), 38.3 (DEG F)

C: 64.3 (C DEG), 115.8 (F DEG)

ORNL-DWG 92-11753

UPPER SHELF EXPANSION: 1.384 (MM), 0.0545 (IN)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 1.27 TO 1.498 (MM), 0.05 TO 0.059 (IN)

95 PERCENT: 1.119 TO 1.65 (MM), 0.0441 TO 0.0649 (IN)

TEMPERATURE [0.38 (MM), 0.015 (IN) EXPANSION]: -33.4 (DEG C), -28.1 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -49.2 TO -20.9 (DEG C), -56.6 TO -5.5 (DEG F)

95 PERCENT: -79.2 TO -6.9 (DEG C), -110.6 TO 19.5 (DEG F)

TEMPERATURE [0.89 (MM), 0.035 (IN) EXPANSION]: 20.2 (DEG C), 68.3 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 10 TO 31.5 (DEG C), 49.9 TO 88.7 (DEG F)

MIDLAND NOZZLE WELD 3-34, 1/2 THICKNESS

95 PERCENT:-3.1 TO 49.2 (DEG C),26.4 TO 120.6 (DEG F)

REFERENCE TEMPERATURE ANALYSIS

MEAN IMPACT CURVE

TEMPERATURE [0.035 (IN) EXPANSION]-60 (DEG F):-13.3 (DEG C),8.1 (DEG F)

MINIMUM IMPACT CURVE

TEMPERATURE [0.035 (IN) EXPANSION]-60 (DEG F):-13.3 (DEG C),8.1 (DEG F)

REMARK: MIDLAND NOZZLE WELD 3-34, FROM 1/2 THICKNESS

ANALYSIS SET: NC34_50T

MODEL PARAMETERS

LOWER SHELF SHEAR [HELD FIXED]: 0 (PERCENT)

MID-TRANSITION TEMPERATURE: 15.9 (DEG C), 60.6 (DEG F)

TRANSITION ZONE WIDTH: 93.6 (C DEG), 168.4 (F DEG)

UPPER SHELF SHEAR [HELD FIXED]: 100 (PERCENT)

STANDARD MODEL: $SHEAR = A + B \cdot \tanh((TEMPERATURE - T_0) / C)$

A: 50 (PERCENT)

B: 50 (PERCENT)

T0: 15.9 (DEG C), 60.6 (DEG F)

C: 46.8 (C DEG), 84.2 (F DEG)

ORNL-DWG 92-11754

UPPER SHELF SHEAR: 100 (PERCENT)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 92.7 TO 107.3 (PERCENT)

95 PERCENT: 83.6 TO 116.4 (PERCENT)

TEMPERATURE [50 (PERCENT), 50 (PERCENT) SHEAR]: 15.9 (DEG C), 60.6 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 7.7 TO 24 (DEG C), 45.9 TO 75.2 (DEG F)

95 PERCENT: -3.5 TO 35.5 (DEG C), 25.7 TO 95.8 (DEG F)

REMARK: MIDLAND NOZZLE WELD 3-34, FROM 1/2 THICKNESS

ANALYSIS SET: NC34_75T

MODEL PARAMETERS

LOWER SHELF ENERGY [HELD FIXED]: 2.7 (J), 2 (FT-LB)

MID-TRANSITION TEMPERATURE: 3.7 (DEG C), 38.6 (DEG F)

TRANSITION ZONE WIDTH: 123.6 (C DEG), 222.5 (F DEG)

UPPER SHELF ENERGY: 85.4 (J), 63 (FT-LB)

STANDARD MODEL: $ENERGY = A + B \cdot \tanh((TEMPERATURE - T_0) / C)$

A: 44 (J), 32.5 (FT-LB)

B: 41.3 (J), 30.5 (FT-LB)

T0: 3.7 (DEG C), 38.6 (DEG F)

C: 61.8 (C DEG), 111.3 (F DEG)

ORNL-DWG 92-11755

UPPER SHELF ENERGY: 85.4 (J), 63 (FT-LB)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 78.1 TO 92.6 (J), 57.6 TO 68.3 (FT-LB)

95 PERCENT: 68.5 TO 102.3 (J), 50.5 TO 75.4 (FT-LB)

TEMPERATURE [27 (J), 19.9 (FT-LB) ENERGY]: -23.4 (DEG C), -10.1 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -36.8 TO -12.3 (DEG C), -34.3 TO 9.9 (DEG F)

95 PERCENT: -60.5 TO 0.9 (DEG C), -77 TO 33.6 (DEG F)

TEMPERATURE [41 (J), 30.2 (FT-LB) ENERGY]: -0.9 (DEG C), 30.5 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -10.9 TO 8.9 (DEG C), 12.3 TO 48.1 (DEG F)

MIDLAND NOZZLE WELD 3-34, 3/4 THICKNESS

95 PERCENT:-26.4 TO 22.9 (DEG C),-15.6 TO 73.2 (DEG F)
 TEMPERATURE [68 (J),50.2 (FT-LB) ENERGY]: 44.6 (DEG C),112.3 (DEG F)
 CONFIDENCE INTERVALS ON PREDICTED VALUE
 68 PERCENT: 31.3 TO 61.7 (DEG C),88.3 TO 143.1 (DEG F)
 95 PERCENT: 16.7 TO 120.1 (DEG C),62.1 TO 248.2 (DEG F)

REFERENCE TEMPERATURE ANALYSIS

MEAN IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY]-60 (DEG F): 10.8 (DEG C),51.5 (DEG F)

MINIMUM IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY]-60 (DEG F): 10.8 (DEG C),51.5 (DEG F)

REMARK: MIDLAND NOZZLE WELD 3-34, FROM 3/4 THICKNESS

ANALYSIS SET: NC34_75T

MODEL PARAMETERS

LOWER SHELF EXPANSION [HELD FIXED]: 0.061 (MM), 0.0024 (IN)

MID-TRANSITION TEMPERATURE: 8.9 (DEG C), 48.1 (DEG F)

TRANSITION ZONE WIDTH: 143.6 (C DEG), 258.4 (F DEG)

UPPER SHELF EXPANSION: 1.526 (MM), 0.0601 (IN)

STANDARD MODEL: $\text{EXPANSION} = A + B \cdot \text{TANH}((\text{TEMPERATURE} - T_0) / C)$

A: 0.794 (MM), 0.0312 (IN)

B: 0.733 (MM), 0.0288 (IN)

T0: 8.9 (DEG C), 48.1 (DEG F)

C: 71.8 (C DEG), 129.2 (F DEG)

ORNL-DWG 92-11756

UPPER SHELF EXPANSION: 1.526 (MM), 0.0601 (IN)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 1.382 TO 1.67 (MM), 0.0544 TO 0.0657 (IN)

95 PERCENT: 1.192 TO 1.86 (MM), 0.0469 TO 0.0732 (IN)

TEMPERATURE [0.38 (MM), 0.015 (IN) EXPANSION]: -37 (DEG C), -34.6 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -58.1 TO -21.1 (DEG C), -72.5 TO -6 (DEG F)

95 PERCENT: -104.7 TO -4.1 (DEG C), -156.4 TO 24.6 (DEG F)

TEMPERATURE [0.89 (MM), 0.035 (IN) EXPANSION]: 18.4 (DEG C), 65.2 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 6.6 TO 31.1 (DEG C), 43.8 TO 88 (DEG F)

MIDLAND NOZZLE WELD 3-34, 3/4 THICKNESS

95 PERCENT:-9.9 TO 50.5 (DEG C),14.2 TO 123 (DEG F)

REFERENCE TEMPERATURE ANALYSIS

MEAN IMPACT CURVE

TEMPERATURE [0.035 (IN) EXPANSION]-60 (DEG F):-15 (DEG C),5 (DEG F)

MINIMUM IMPACT CURVE

TEMPERATURE [0.035 (IN) EXPANSION]-60 (DEG F):-15 (DEG C),5 (DEG F)

REMARK: MIDLAND NOZZLE WELD 3-34, FROM 3/4 THICKNESS

ANALYSIS SET: NC34_75T

MODEL PARAMETERS

LOWER SHELF SHEAR [HELD FIXED]: 0 (PERCENT)

MID-TRANSITION TEMPERATURE: 24.8 (DEG C), 76.7 (DEG F)

TRANSITION ZONE WIDTH: 67.5 (C DEG), 121.5 (F DEG)

UPPER SHELF SHEAR [HELD FIXED]: 100 (PERCENT)

STANDARD MODEL: $SHEAR = A + B * \tanh((TEMPERATURE - T_0) / C)$

A: 50 (PERCENT)

B: 50 (PERCENT)

T0: 24.8 (DEG C), 76.7 (DEG F)

C: 33.7 (C DEG), 60.7 (F DEG)

ORNL-DWG 92-11757

UPPER SHELF SHEAR: 100 (PERCENT)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 97.4 TO 102.6 (PERCENT)

95 PERCENT: 94.2 TO 105.8 (PERCENT)

TEMPERATURE [50 (PERCENT), 50 (PERCENT) SHEAR]: 24.8 (DEG C), 76.7 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 22.6 TO 27 (DEG C), 72.8 TO 80.6 (DEG F)

95 PERCENT: 19.9 TO 29.8 (DEG C), 67.8 TO 85.6 (DEG F)

REMARK: MIDLAND NOZZLE WELD 3-34, FROM 3/4 THICKNESS

ANALYSIS SET: NC34_78T

MODEL PARAMETERS

LOWER SHELF ENERGY [HELD FIXED]: 2.7 (J), 2 (FT-LB)
MID-TRANSITION TEMPERATURE: 12.2 (DEG C), 54 (DEG F)
TRANSITION ZONE WIDTH: 121.9 (C DEG), 219.4 (F DEG)
UPPER SHELF ENERGY: 88.9 (J), 65.6 (FT-LB)

STANDARD MODEL: $ENERGY = A + B \cdot \tanh((TEMPERATURE - T_0) / C)$

A: 45.8 (J), 33.8 (FT-LB)
B: 43.1 (J), 31.8 (FT-LB)
T₀: 12.2 (DEG C), 54 (DEG F)
C: 61 (C DEG), 109.7 (F DEG)

ORNL-DWG 92-11758

UPPER SHELF ENERGY: 88.9 (J), 65.6 (FT-LB)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 79.1 TO 98.7 (J), 58.4 TO 72.8 (FT-LB)

95 PERCENT: 66.2 TO 111.7 (J), 48.8 TO 82.4 (FT-LB)

TEMPERATURE [27 (J), 19.9 (FT-LB) ENERGY]: -16.3 (DEG C), 2.7 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -34 TO -2.4 (DEG C), -29.2 TO 27.7 (DEG F)

95 PERCENT: -70 TO 14.2 (DEG C), -93.9 TO 57.5 (DEG F)

TEMPERATURE [41 (J), 30.2 (FT-LB) ENERGY]: 5.4 (DEG C), 41.7 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -7.6 TO 17.7 (DEG C), 18.4 TO 63.9 (DEG F)

MIDLAND NOZZLE WELD 3-34, 7/8 THICKNESS

95 PERCENT:-28.9 TO 35.7 (DEG C),-20.1 TO 96.2 (DEG F)

TEMPERATURE [68 (J),50.2 (FT-LB) ENERGY]: 46.9 (DEG C),116.4 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 31.7 TO 66.7 (DEG C),89.1 TO 152 (DEG F)

95 PERCENT: 15 TO UNDEFINED (DEG C),59.1 TO UNDEFINED (DEG F)

REFERENCE TEMPERATURE ANALYSIS

MEAN IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY]-60 (DEG F): 13.2 (DEG C),55.7 (DEG F)

MINIMUM IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY]-60 (DEG F): 13.2 (DEG C),55.7 (DEG F)

REMARK: MIDLAND NOZZLE WELD 3-34, FROM 7/8 THICKNESS

ANALYSIS SET: NC34_78T

MODEL PARAMETERS

LOWER SHELF EXPANSION [HELD FIXED]: 0.061 (MM),0.0024 (IN)

MID-TRANSITION TEMPERATURE: 10.5 (DEG C),51 (DEG F)

TRANSITION ZONE WIDTH: 97.9 (C DEG),176.2 (F DEG)

UPPER SHELF EXPANSION: 1.527 (MM),0.0601 (IN)

STANDARD MODEL: $\text{EXPANSION} = A + B * \text{TANH}((\text{TEMPERATURE} - T_0) / C)$

A: 0.794 (MM),0.0313 (IN)

B: 0.733 (MM),0.0289 (IN)

T0: 10.5 (DEG C),51 (DEG F)

C: 48.9 (C DEG),88.1 (F DEG)

ORNL-DWG 92-11759

UPPER SHELF EXPANSION: 1.527 (MM),0.0601 (IN)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 1.339 TO 1.715 (MM),0.0527 TO 0.0675 (IN)

95 PERCENT: 1.089 TO 1.965 (MM),0.0429 TO 0.0774 (IN)

TEMPERATURE [0.38 (MM),0.015 (IN) EXPANSION]: -20.8 (DEG C),-5.4 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -43.2 TO -5.6 (DEG C),-45.8 TO 21.9 (DEG F)

95 PERCENT: UNDEFINED TO 10.9 (DEG C),UNDEFINED TO 51.6 (DEG F)

TEMPERATURE [0.89 (MM),0.035 (IN) EXPANSION]: 17 (DEG C),62.6 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 5 TO 30.3 (DEG C),40.9 TO 86.5 (DEG F)

95 PERCENT:-13 TO 52.4 (DEG C),8.5 TO 126.4 (DEG F)
REFERENCE TEMPERATURE ANALYSIS

MEAN IMPACT CURVE

TEMPERATURE [0.035 (IN) EXPANSION]-60 (DEG F):-16.4 (DEG C),2.5 (DEG F)

MINIMUM IMPACT CURVE

TEMPERATURE [0.035 (IN) EXPANSION]-60 (DEG F):-16.4 (DEG C),2.5 (DEG F)

REMARK: MIDLAND NOZZLE WELD 3-34, FROM 7/8 THICKNESS

ANALYSIS SET: NC34_78T

MODEL PARAMETERS

LOWER SHELF SHEAR [HELD FIXED]: 0 (PERCENT)

MID-TRANSITION TEMPERATURE: 20.1 (DEG C), 68.1 (DEG F)

TRANSITION ZONE WIDTH: 79 (C DEG), 142.3 (F DEG)

UPPER SHELF SHEAR [HELD FIXED]: 100 (PERCENT)

STANDARD MODEL: $SHEAR = A + B \cdot \tanh((TEMPERATURE - T_0) / C)$

A: 50 (PERCENT)

B: 50 (PERCENT)

T0: 20.1 (DEG C), 68.1 (DEG F)

C: 39.5 (C DEG), 71.1 (F DEG)

ORNL-DWG 92-11760

UPPER SHELF SHEAR: 100 (PERCENT)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 94.5 TO 105.5 (PERCENT)

95 PERCENT: 87.6 TO 112.4 (PERCENT)

TEMPERATURE [50 (PERCENT), 50 (PERCENT) SHEAR]: 20.1 (DEG C), 68.1 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 14.8 TO 25.4 (DEG C), 58.6 TO 77.7 (DEG F)

95 PERCENT: 7.7 TO 32.6 (DEG C), 45.9 TO 90.7 (DEG F)

REMARK: MIDLAND NOZZLE WELD 3-34, FROM 7/8 THICKNESS

APPENDIX E

HYPERBOLIC TANGENT CURVE FITS WITH 68 AND 95% CONFIDENCE BOUNDS FOR COMBINED DATA SETS UNIRRADIATED MIDLAND REACTOR VESSEL WELDS

APPENDIX E

HYPERBOLIC TANGENT CURVE FITS WITH 68% AND 95% CONFIDENCE BOUNDS FOR COMBINED DATA SETS UNIRRADIATED MIDLAND REACTOR VESSEL WELDS

Hyperbolic tangent curve fits to the Charpy V-notch impact data for various combined data sets are provided in separate plots in this appendix. Plots of absorbed energy, lateral expansion, and percent shear vs test temperature are provided. Separate plots are provided for the 68% and 95% confidence bounds. Additionally, each plot also gives the fitting constants for the mean hyperbolic tangent curve fit for the equation:

$$\text{Energy} = (\text{USE} + \text{LSE})/2 + (\text{USE} - \text{LSE})/2 * \tanh[(T - T_0)/(TZW/2)],$$

where USE and LSE are upper shelf energy and lower shelf energy, respectively; T is test temperature, T_0 is the mid-transition temperature, and TZW is the transition zone width.

The plots are grouped in four sections in the following order:

1. Combined data by depth in the beltline weld
2. Combined data by depth in the nozzle course weld
3. Combined data by weld section
4. Combined data for the beltline weld, nozzle course weld, and all data combined

APPENDIX E

HYPERBOLIC TANGENT CURVE FITS WITH 68% AND 95% CONFIDENCE BOUNDS FOR COMBINED DATA SETS UNIRRADIATED MIDLAND REACTOR VESSEL WELDS

The location in the vessel from which the specimens were removed is indicated in the identification of the Analysis Set given in the heading for each plot. The following is an example of the code used in that identification:

ANALYSIS SET: MW14TALL

MW $\equiv$ Midland Beltline Weld (NC $\equiv$ Nozzle Course Weld)

14T $\equiv$ Fractional Depth In Thickness From Inner Surface
In This Case It Is The 1/4 Depth

ALL $\equiv$ All data from the indicated location

ANALYSIS SET: MW9ALL

9 $\equiv$ Weld Section (Sections 1-9, 1-11, 1-13, and 1-15 Are Beltline Welds; Sections 3-1 and 3-4 Are Nozzle Course Welds)

APPENDIX E

HYPERBOLIC TANGENT CURVE FITS WITH 68% AND 95% CONFIDENCE BOUNDS FOR COMBINED DATA SETS UNIRRADIATED MIDLAND REACTOR VESSEL WELDS

COMBINED DATA BY DEPTH IN THE BELTLINE WELD

ANALYSIS SET: MWB14TALL

MODEL PARAMETERS

LOWER SHELF ENERGY [HELD FIXED]: 2.7 (J), 2 (FT-LB)
MID-TRANSITION TEMPERATURE: -1.8 (DEG C), 28.7 (DEG F)
TRANSITION ZONE WIDTH: 109.8 (C DEG), 197.7 (F DEG)
UPPER SHELF ENERGY: 89.2 (J), 65.8 (FT-LB)
STANDARD MODEL: $ENERGY = A + B \cdot \tanh((TEMPERATURE - T_0) / C)$
A: 46 (J), 33.9 (FT-LB)
B: 43.3 (J), 31.9 (FT-LB)
T₀: -1.8 (DEG C), 28.7 (DEG F)
C: 54.9 (C DEG), 98.8 (F DEG)

ORNL-DWG 92-11761

UPPER SHELF ENERGY: 89.2 (J), 65.8 (FT-LB)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 80 TO 98.4 (J), 59 TO 72.6 (FT-LB)

95 PERCENT: 70.8 TO 107.6 (J), 52.2 TO 79.4 (FT-LB)

TEMPERATURE [27 (J), 19.9 (FT-LB) ENERGY]: -27.6 (DEG C), -17.7 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -44.5 TO -14.4 (DEG C), -48.1 TO 6 (DEG F)

95 PERCENT: -71.9 TO -2.6 (DEG C), -97.5 TO 27.2 (DEG F)

TEMPERATURE [41 (J), 30.2 (FT-LB) ENERGY]: -8.1 (DEG C), 17.4 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -20.5 TO 3.5 (DEG C), -4.9 TO 38.3 (DEG F)

95 PERCENT:-35.2 TO 15.6 (DEG C),-31.3 TO 60.2 (DEG F)
TEMPERATURE [68 (J),50.2 (FT-LB) ENERGY]: 29.1 (DEG C),84.3 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 15.1 TO 47.9 (DEG C),59.2 TO 118.2 (DEG F)

95 PERCENT: 3 TO 88.1 (DEG C),37.4 TO 190.7 (DEG F)

REFERENCE TEMPERATURE ANALYSIS

MEAN IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY]-60 (DEG F):-4.6 (DEG C),23.7 (DEG F)

MINIMUM IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY]-60 (DEG F): 11.3 (DEG C),52.4 (DEG F)

REMARK: MIDLAND WELD BELTLINE, ALL SECTIONS, FROM 1/4 THICKNESS

ANALYSIS SET: MWB14TALL

MODEL PARAMETERS

LOWER SHELF EXPANSION [HELD FIXED]: 0.061 (MM), 0.0024 (IN)

MID-TRANSITION TEMPERATURE: 2.3 (DEG C), 36.2 (DEG F)

TRANSITION ZONE WIDTH: 117.7 (C DEG), 211.8 (F DEG)

UPPER SHELF EXPANSION: 1.683 (MM), 0.0663 (IN)

STANDARD MODEL: $\text{EXPANSION} = A + B \cdot \tanh((\text{TEMPERATURE} - T_0) / C)$

A: 0.872 (MM), 0.0343 (IN)

B: 0.811 (MM), 0.0319 (IN)

T₀: 2.3 (DEG C), 36.2 (DEG F)

C: 58.8 (C DEG), 105.9 (F DEG)

ORNL-DWG 92-11762

UPPER SHELF EXPANSION: 1.683 (MM), 0.0663 (IN)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 1.522 TO 1.844 (MM), 0.0599 TO 0.0726 (IN)

95 PERCENT: 1.361 TO 2.005 (MM), 0.0536 TO 0.0789 (IN)

TEMPERATURE [0.38 (MM), 0.015 (IN) EXPANSION]: -39.1 (DEG C), -38.3 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -62.7 TO -23.2 (DEG C), -80.8 TO -9.8 (DEG F)

95 PERCENT: -146.8 TO -10.4 (DEG C), -232.3 TO 13.3 (DEG F)

TEMPERATURE [0.89 (MM), 0.035 (IN) EXPANSION]: 3.6 (DEG C), 38.5 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -8.1 TO 15.4 (DEG C), 17.5 TO 59.7 (DEG F)

95 PERCENT:-20.8 TO 28.3 (DEG C),-5.5 TO 82.9 (DEG F)

REFERENCE TEMPERATURE ANALYSIS

MEAN IMPACT CURVE

TEMPERATURE [0.035 (IN) EXPANSION]-60 (DEG F):-29.8 (DEG C),-21.6 (DEG F)

MINIMUM IMPACT CURVE

TEMPERATURE [0.035 (IN) EXPANSION]-60 (DEG F):-15.1 (DEG C),4.7 (DEG F)

REMARK: MIDLAND WELD BELTLINE, ALL SECTIONS, FROM 1/4 THICKNESS

ANALYSIS SET: MWB14TALL

MODEL PARAMETERS

LOWER SHELF SHEAR [HELD FIXED]: 0 (PERCENT)
MID-TRANSITION TEMPERATURE: -1.9 (DEG C), 28.5 (DEG F)
TRANSITION ZONE WIDTH: 81 (C DEG), 145.9 (F DEG)
UPPER SHELF SHEAR [HELD FIXED]: 100 (PERCENT)

STANDARD MODEL: $SHEAR = A + B \cdot \tanh((TEMPERATURE - T_0) / C)$

A: 50 (PERCENT)
B: 50 (PERCENT)
T₀: -1.9 (DEG C), 28.5 (DEG F)
C: 40.5 (C DEG), 72.9 (F DEG)

ORNL-DWG 92-11763

UPPER SHELF SHEAR: 100 (PERCENT)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 90.7 TO 109.3 (PERCENT)

95 PERCENT: 81.4 TO 118.6 (PERCENT)

TEMPERATURE [50 (PERCENT), 50 (PERCENT) SHEAR]: -1.9 (DEG C), 28.5 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -10 TO 6 (DEG C), 14 TO 42.9 (DEG F)

95 PERCENT: -18.9 TO 14.6 (DEG C), -2 TO 58.4 (DEG F)

REMARK: MIDLAND WELD BELTLINE, ALL SECTIONS, FROM 1/4 THICKNESS

ANALYSIS SET: MWBALL12T

MODEL PARAMETERS

LOWER SHELF ENERGY [HELD FIXED]: 2.7 (J), 2 (FT-LB)

MID-TRANSITION TEMPERATURE:-2 (DEG C), 28.3 (DEG F)

TRANSITION ZONE WIDTH: 122.8 (C DEG), 221.1 (F DEG)

UPPER SHELF ENERGY: 93.4 (J), 68.9 (FT-LB)

STANDARD MODEL: $ENERGY = A + B \cdot \tanh((TEMPERATURE - T_0) / C)$

A: 48.1 (J), 35.5 (FT-LB)

B: 45.4 (J), 33.5 (FT-LB)

T₀: -2 (DEG C), 28.3 (DEG F)

C: 61.4 (C DEG), 110.5 (F DEG)

ORNL-DWG 92-11764

UPPER SHELF ENERGY: 93.4 (J), 68.9 (FT-LB)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 84.5 TO 102.4 (J), 62.3 TO 75.5 (FT-LB)

95 PERCENT: 75.6 TO 111.3 (J), 55.8 TO 82.1 (FT-LB)

TEMPERATURE [27 (J), 19.9 (FT-LB) ENERGY]: -32.9 (DEG C), -27.3 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -50.7 TO -19 (DEG C), -59.3 TO -2.2 (DEG F)

95 PERCENT: -79 TO -6.7 (DEG C), -110.2 TO 19.9 (DEG F)

TEMPERATURE [41 (J), 30.2 (FT-LB) ENERGY]: -11.7 (DEG C), 11 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -24.6 TO 0.3 (DEG C), -12.2 TO 32.5 (DEG F)

95 PERCENT:-39.9 TO 12.5 (DEG C),-39.8 TO 54.5 (DEG F)
TEMPERATURE [68 (J),50.2 (FT-LB) ENERGY]: 26.9 (DEG C),80.4 (DEG F)
CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 13.3 TO 43.8 (DEG C),56 TO 110.9 (DEG F)

95 PERCENT: 1.1 TO 69.8 (DEG C),34 TO 157.7 (DEG F)

REFERENCE TEMPERATURE ANALYSIS

MEAN IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY]-60 (DEG F):-6.8 (DEG C),19.8 (DEG F)

MINIMUM IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY]-60 (DEG F): 23.1 (DEG C),73.6 (DEG F)

REMARK: MIDLAND BELTLINE ALL SECTIONS, FROM 1/2 THICKNESS

ANALYSIS SET: MWBALL12T

MODEL PARAMETERS

LOWER SHELF EXPANSION [HELD FIXED]: 0.061 (MM), 0.0024 (IN)

MID-TRANSITION TEMPERATURE: 4.9 (DEG C), 40.8 (DEG F)

TRANSITION ZONE WIDTH: 123 (C DEG), 221.4 (F DEG)

UPPER SHELF EXPANSION: 1.721 (MM), 0.0677 (IN)

STANDARD MODEL: $\text{EXPANSION} = A + B \cdot \tanh((\text{TEMPERATURE} - T_0) / C)$

A: 0.891 (MM), 0.0351 (IN)

B: 0.83 (MM), 0.0327 (IN)

T0: 4.9 (DEG C), 40.8 (DEG F)

C: 61.5 (C DEG), 110.7 (F DEG)

ORNL-DWG 92-11765

UPPER SHELF EXPANSION: 1.721 (MM), 0.0677 (IN)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 1.561 TO 1.88 (MM), 0.0614 TO 0.074 (IN)

95 PERCENT: 1.4 TO 2.041 (MM), 0.0551 TO 0.0803 (IN)

TEMPERATURE [0.38 (MM), 0.015 (IN) EXPANSION]: -39.3 (DEG C), -38.7 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -63.5 TO -23 (DEG C), -82.3 TO -9.4 (DEG F)

95 PERCENT: -144.7 TO -9.9 (DEG C), -228.5 TO 14.3 (DEG F)

TEMPERATURE [0.89 (MM), 0.035 (IN) EXPANSION]: 4.8 (DEG C), 40.7 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -7 TO 16.6 (DEG C), 19.4 TO 61.9 (DEG F)

MIDLAND BELTLINE, ALL SECTIONS, 1/2T

95 PERCENT:-20 TO 29.5 (DEG C),-3.9 TO 85 (DEG F)

REFERENCE TEMPERATURE ANALYSIS

MEAN IMPACT CURVE

TEMPERATURE [0.035 (IN) EXPANSION]-60 (DEG F):-28.6 (DEG C),-19.5 (DEG F)

MINIMUM IMPACT CURVE

TEMPERATURE [0.035 (IN) EXPANSION]-60 (DEG F):-5.7 (DEG C),21.7 (DEG F)

REMARK: MIDLAND BELTLINE ALL SECTIONS, FROM 1/2 THICKNESS

ANALYSIS SET: MWBALL12T

MODEL PARAMETERS

LOWER SHELF SHEAR [HELD FIXED]: 0 (PERCENT)
MID-TRANSITION TEMPERATURE: 3.2 (DEG C), 37.7 (DEG F)
TRANSITION ZONE WIDTH: 87.5 (C DEG), 157.4 (F DEG)

UPPER SHELF SHEAR [HELD FIXED]: 100 (PERCENT)

STANDARD MODEL: $SHEAR = A + B \cdot \tanh((TEMPERATURE - T_0) / C)$

A: 50 (PERCENT)

B: 50 (PERCENT)

T0: 3.2 (DEG C), 37.7 (DEG F)

C: 43.7 (C DEG), 78.7 (F DEG)

ORNL-DWG 92-11766

UPPER SHELF SHEAR: 100 (PERCENT)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 91.2 TO 108.8 (PERCENT)

95 PERCENT: 82.3 TO 117.7 (PERCENT)

TEMPERATURE [50 (PERCENT), 50 (PERCENT) SHEAR]: 3.2 (DEG C), 37.7 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -4.9 TO 11.3 (DEG C), 23.1 TO 52.3 (DEG F)

95 PERCENT: -13.7 TO 20 (DEG C), 7.3 TO 68.1 (DEG F)

REMARK: MIDLAND BELTLINE ALL SECTIONS, FROM 1/2 THICKNESS

ANALYSIS SET: MWB58TALL

MODEL PARAMETERS

LOWER SHELF ENERGY [HELD FIXED]: 2.7 (J), 2 (FT-LB)

MID-TRANSITION TEMPERATURE: -7.2 (DEG C), 19 (DEG F)

TRANSITION ZONE WIDTH: 105.3 (C DEG), 189.5 (F DEG)

UPPER SHELF ENERGY: 93.5 (J), 69 (FT-LB)

STANDARD MODEL: $ENERGY = A + B \cdot \tanh((TEMPERATURE - T_0) / C)$

A: 48.1 (J), 35.5 (FT-LB)

B: 45.4 (J), 33.5 (FT-LB)

T₀: -7.2 (DEG C), 19 (DEG F)

C: 52.6 (C DEG), 94.7 (F DEG)

ORNL-DWG 92-11767

UPPER SHELF ENERGY: 93.5 (J), 69 (FT-LB)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 82.2 TO 104.8 (J), 60.7 TO 77.3 (FT-LB)

95 PERCENT: 70.9 TO 116.1 (J), 52.3 TO 85.7 (FT-LB)

TEMPERATURE [27 (J), 19.9 (FT-LB) ENERGY]: -33.7 (DEG C), -28.7 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -53.9 TO -19 (DEG C), -64.9 TO -2.2 (DEG F)

95 PERCENT: -100.6 TO -5.8 (DEG C), -149.1 TO 21.5 (DEG F)

TEMPERATURE [41 (J), 30.2 (FT-LB) ENERGY]: -15.5 (DEG C), 4 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -29.6 TO -2.5 (DEG C), -21.3 TO 27.5 (DEG F)

MIDLAND BELTLINE, ALL SECTIONS, 5/8T

95 PERCENT:-47.7 TO 11.4 (DEG C),-53.9 TO 52.5 (DEG F)

TEMPERATURE [68 (J),50.2 (FT-LB) ENERGY]: 17.5 (DEG C),63.5 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 3 TO 36.8 (DEG C),37.3 TO 98.3 (DEG F)

95 PERCENT:-10 TO 78.5 (DEG C),14 TO 173.3 (DEG F)

REFERENCE TEMPERATURE ANALYSIS

MEAN IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY]-60 (DEG F):-16.1 (DEG C),3 (DEG F)

MINIMUM IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY]-60 (DEG F): 3.3 (DEG C),38 (DEG F)

REMARK: MIDLAND WELD BELTLINE ALL SECTIONS, FROM 5/8 THICKNESS

ANALYSIS SET: MWB58TALL

MODEL PARAMETERS

LOWER SHELF EXPANSION [HELD FIXED]: 0.061 (MM), 0.0024 (IN)

MID-TRANSITION TEMPERATURE: -3 (DEG C), 26.6 (DEG F)

TRANSITION ZONE WIDTH: 133.7 (C DEG), 240.6 (F DEG)

UPPER SHELF EXPANSION: 1.739 (MM), 0.0684 (IN)

STANDARD MODEL: $\text{EXPANSION} = A + B \cdot \tanh((\text{TEMPERATURE} - T_0) / C)$

A: 0.9 (MM), 0.0354 (IN)

B: 0.839 (MM), 0.033 (IN)

T0: -3 (DEG C), 26.6 (DEG F)

C: 66.8 (C DEG), 120.3 (F DEG)

ORNL-DWG 92-11768

UPPER SHELF EXPANSION: 1.739 (MM), 0.0684 (IN)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 1.545 TO 1.932 (MM), 0.0608 TO 0.0761 (IN)

95 PERCENT: 1.351 TO 2.126 (MM), 0.0532 TO 0.0837 (IN)

TEMPERATURE [0.38 (MM), 0.015 (IN) EXPANSION]: -51.5 (DEG C), -60.6 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -84.9 TO -31.1 (DEG C), -120.9 TO -24 (DEG F)

95 PERCENT: UNDEFINED TO -14.7 (DEG C), UNDEFINED TO 5.5 (DEG F)

TEMPERATURE [0.89 (MM), 0.035 (IN) EXPANSION]: -3.8 (DEG C), 25.2 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -19 TO 11.6 (DEG C), -2.2 TO 52.8 (DEG F)

95 PERCENT:-36.1 TO 28.9 (DEG C),-33 TO 84 (DEG F)
REFERENCE TEMPERATURE ANALYSIS
MEAN IMPACT CURVE

TEMPERATURE [0.035 (IN) EXPANSION]-60 (DEG F):-37.2 (DEG C),-35 (DEG F)

MINIMUM IMPACT CURVE

TEMPERATURE [0.035 (IN) EXPANSION]-60 (DEG F):-19.1 (DEG C),-2.4 (DEG F)
REMARK: MIDLAND WELD BELTLINE ALL SECTIONS, FROM 5/8 THICKNESS

ANALYSIS SET: MWB58TALL

MODEL PARAMETERS

LOWER SHELF SHEAR [HELD FIXED]: 0 (PERCENT)
MID-TRANSITION TEMPERATURE:-5.1 (DEG C),22.8 (DEG F)
TRANSITION ZONE WIDTH: 82.5 (C DEG),148.5 (F DEG)
UPPER SHELF SHEAR [HELD FIXED]: 100 (PERCENT)

STANDARD MODEL: $SHEAR = A + B * \tanh((TEMPERATURE - T_0) / C)$

A: 50 (PERCENT)
B: 50 (PERCENT)
T0:-5.1 (DEG C),22.8 (DEG F)
C: 41.3 (C DEG),74.2 (F DEG)

ORNL-DWG 92-11769

UPPER SHELF SHEAR: 100 (PERCENT)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 86.7 TO 113.3 (PERCENT)

95 PERCENT: 73.4 TO 126.6 (PERCENT)

TEMPERATURE [50 (PERCENT),50 (PERCENT) SHEAR]:-5.1 (DEG C),22.8 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT:-16.7 TO 6.7 (DEG C),2 TO 44.1 (DEG F)

95 PERCENT:-30.5 TO 20.9 (DEG C),-22.8 TO 69.7 (DEG F)

REMARK: MIDLAND WELD BELTLINE ALL SECTIONS, FROM 5/8 THICKNESS

ANALYSIS SET: MWB34TALL

MODEL PARAMETERS

LOWER SHELF ENERGY [HELD FIXED]: 2.7 (J), 2 (FT-LB)

MID-TRANSITION TEMPERATURE: 6 (DEG C), 42.8 (DEG F)

TRANSITION ZONE WIDTH: 111 (C DEG), 199.8 (F DEG)

UPPER SHELF ENERGY: 86.6 (J), 63.9 (FT-LB)

STANDARD MODEL: $ENERGY = A + B \cdot \tanh((TEMPERATURE - T_0) / C)$

A: 44.6 (J), 32.9 (FT-LB)

B: 41.9 (J), 30.9 (FT-LB)

T₀: 6 (DEG C), 42.8 (DEG F)

C: 55.5 (C DEG), 99.9 (F DEG)

ORNL-DWG 92-11770

UPPER SHELF ENERGY: 86.6 (J), 63.9 (FT-LB)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 79 TO 94.2 (J), 58.3 TO 69.5 (FT-LB)

95 PERCENT: 71.4 TO 101.8 (J), 52.6 TO 75.1 (FT-LB)

TEMPERATURE [27 (J), 19.9 (FT-LB) ENERGY]: -18.9 (DEG C), -2 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -32.6 TO -7.7 (DEG C), -26.6 TO 18.2 (DEG F)

95 PERCENT: -51.8 TO 2.5 (DEG C), -61.2 TO 36.5 (DEG F)

TEMPERATURE [41 (J), 30.2 (FT-LB) ENERGY]: 1.2 (DEG C), 34.1 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -9.1 TO 11.1 (DEG C), 15.5 TO 52 (DEG F)

MIDLAND BELTLINE, ALL SECTIONS, 3/4T

95 PERCENT:-20.8 TO 21.5 (DEG C),-5.4 TO 70.7 (DEG F)

TEMPERATURE [68 (J),50.2 (FT-LB) ENERGY]: 40.9 (DEG C),105.6 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 28.1 TO 58.2 (DEG C),82.5 TO 136.8 (DEG F)

95 PERCENT: 17.2 TO 91.8 (DEG C),62.9 TO 197.2 (DEG F)

REFERENCE TEMPERATURE ANALYSIS

MEAN IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY]-60 (DEG F): 7.2 (DEG C),44.9 (DEG F)

MINIMUM IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY]-60 (DEG F): 17.9 (DEG C),64.2 (DEG F)

REMARK: MIDLAND WELD BELTLINE,ALL SECTIONS, FROM 3/4 THICKNESS

ANALYSIS SET: MWB34TALL

MODEL PARAMETERS

LOWER SHELF EXPANSION [HELD FIXED]: 0.061 (MM), 0.0024 (IN)

MID-TRANSITION TEMPERATURE: 7.2 (DEG C), 44.9 (DEG F)

TRANSITION ZONE WIDTH: 129.9 (C DEG), 233.8 (F DEG)

UPPER SHELF EXPANSION: 1.67 (MM), 0.0658 (IN)

STANDARD MODEL: $\text{EXPANSION} = A + B \cdot \text{TANH}((\text{TEMPERATURE} - T_0) / C)$

A: 0.866 (MM), 0.0341 (IN)

B: 0.805 (MM), 0.0317 (IN)

T0: 7.2 (DEG C), 44.9 (DEG F)

C: 64.9 (C DEG), 116.9 (F DEG)

ORNL-DWG 92-11771

UPPER SHELF EXPANSION: 1.67 (MM), 0.0658 (IN)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 1.541 TO 1.799 (MM), 0.0607 TO 0.0708 (IN)

95 PERCENT: 1.411 TO 1.929 (MM), 0.0556 TO 0.0759 (IN)

TEMPERATURE [0.38 (MM), 0.015 (IN) EXPANSION]: -38.2 (DEG C), -36.8 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -57.7 TO -23.9 (DEG C), -71.9 TO -11.1 (DEG F)

95 PERCENT: -93.3 TO -12.1 (DEG C), -136 TO 10.3 (DEG F)

TEMPERATURE [0.89 (MM), 0.035 (IN) EXPANSION]: 9.1 (DEG C), 48.4 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -1.1 TO 19.5 (DEG C), 30 TO 67.1 (DEG F)

95 PERCENT:-11.9 TO 30.6 (DEG C),10.5 TO 87.1 (DEG F)
REFERENCE TEMPERATURE ANALYSIS
MEAN IMPACT CURVE
TEMPERATURE [0.035 (IN) EXPANSION]-60 (DEG F):-24.3 (DEG C),-11.7 (DEG F)
MINIMUM IMPACT CURVE
TEMPERATURE [0.035 (IN) EXPANSION]-60 (DEG F):-12.9 (DEG C),8.8 (DEG F)
REMARK: MIDLAND WELD BELTLINE,ALL SECTIONS, FROM 3/4 THICKNESS

ANALYSIS SET: MWB34TALL

MODEL PARAMETERS

LOWER SHELF SHEAR [HELD FIXED]: 0 (PERCENT)

MID-TRANSITION TEMPERATURE: 4.3 (DEG C), 39.8 (DEG F)

TRANSITION ZONE WIDTH: 88.7 (C DEG), 159.6 (F DEG)

UPPER SHELF SHEAR [HELD FIXED]: 100 (PERCENT)

STANDARD MODEL: $SHEAR = A + B \cdot \tanh((TEMPERATURE - T_0) / C)$

A: 50 (PERCENT)

B: 50 (PERCENT)

T0: 4.3 (DEG C), 39.8 (DEG F)

C: 44.3 (C DEG), 79.8 (F DEG)

ORNL-DWG 92-11772

UPPER SHELF SHEAR: 100 (PERCENT)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 90.8 TO 109.2 (PERCENT)

95 PERCENT: 81.6 TO 118.4 (PERCENT)

TEMPERATURE [50 (PERCENT), 50 (PERCENT) SHEAR]: 4.3 (DEG C), 39.8 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -4.3 TO 12.8 (DEG C), 24.3 TO 55.1 (DEG F)

95 PERCENT: -13.6 TO 22.1 (DEG C), 7.5 TO 71.8 (DEG F)

REMARK: MIDLAND WELD BELTLINE, ALL SECTIONS, FROM 3/4 THICKNESS

ANALYSIS SET: MWB78TALL

MODEL PARAMETERS

LOWER SHELF ENERGY [HELD FIXED]: 2.7 (J), 2 (FT-LB)

MID-TRANSITION TEMPERATURE: -10.4 (DEG C), 13.4 (DEG F)

TRANSITION ZONE WIDTH: 86.1 (C DEG), 155 (F DEG)

UPPER SHELF ENERGY: 78.9 (J), 58.2 (FT-LB)

STANDARD MODEL: $ENERGY = A + B * \tanh((TEMPERATURE - T_0) / C)$

A: 40.8 (J), 30.1 (FT-LB)

B: 38.1 (J), 28.1 (FT-LB)

T0: -10.4 (DEG C), 13.4 (DEG F)

C: 43.1 (C DEG), 77.5 (F DEG)

ORNL-DWG 92-11773

UPPER SHELF ENERGY: 78.9 (J), 58.2 (FT-LB)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 70.1 TO 87.7 (J), 51.7 TO 64.7 (FT-LB)

95 PERCENT: 61 TO 96.8 (J), 45 TO 71.4 (FT-LB)

TEMPERATURE [27 (J), 19.9 (FT-LB) ENERGY]: -26.7 (DEG C), -16.1 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -40.1 TO -16 (DEG C), -40.1 TO 3.2 (DEG F)

95 PERCENT: -61.1 TO -5.8 (DEG C), -77.9 TO 21.6 (DEG F)

TEMPERATURE [41 (J), 30.2 (FT-LB) ENERGY]: -10.1 (DEG C), 13.8 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -20.3 TO 0.1 (DEG C), -4.6 TO 32.1 (DEG F)

95 PERCENT:-32.4 TO 12.1 (DEG C),-26.4 TO 53.8 (DEG F)
TEMPERATURE [68 (J),50.2 (FT-LB) ENERGY]: 28.2 (DEG C),82.8 (DEG F)
CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 12.2 TO 65.3 (DEG C),53.9 TO 149.6 (DEG F)

95 PERCENT: 0.4 TO UNDEFINED (DEG C),32.6 TO UNDEFINED (DEG F)

REFERENCE TEMPERATURE ANALYSIS

MEAN IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY]-60 (DEG F):-5.6 (DEG C),21.9 (DEG F)

MINIMUM IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY]-60 (DEG F): 29 (DEG C),84.2 (DEG F)

REMARK: MIDLAND WELD BELTLINE, ALL SECTIONS, FROM 7/8 THICKNESS

ANALYSIS SET: MWB78TALL
MODEL PARAMETERS

LOWER SHELF EXPANSION [HELD FIXED]: 0.061 (MM), 0.0024 (IN)

MID-TRANSITION TEMPERATURE: -7.6 (DEG C), 18.3 (DEG F)

TRANSITION ZONE WIDTH: 115.3 (C DEG), 207.6 (F DEG)

UPPER SHELF EXPANSION: 1.647 (MM), 0.0648 (IN)

STANDARD MODEL: $\text{EXPANSION} = A + B \cdot \tanh((\text{TEMPERATURE} - T_0) / C)$

A: 0.854 (MM), 0.0336 (IN)

B: 0.793 (MM), 0.0312 (IN)

T₀: -7.6 (DEG C), 18.3 (DEG F)

C: 57.7 (C DEG), 103.8 (F DEG)

ORNL-DWG 92-11774

UPPER SHELF EXPANSION: 1.647 (MM), 0.0648 (IN)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 1.46 TO 1.834 (MM), 0.0575 TO 0.0722 (IN)

95 PERCENT: 1.269 TO 2.025 (MM), 0.05 TO 0.0797 (IN)

TEMPERATURE [0.38 (MM), 0.015 (IN) EXPANSION]: -47.4 (DEG C), -53.3 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -75.5 TO -29.7 (DEG C), -103.9 TO -21.4 (DEG F)

95 PERCENT: UNDEFINED TO -15.2 (DEG C), UNDEFINED TO 4.6 (DEG F)

TEMPERATURE [0.89 (MM), 0.035 (IN) EXPANSION]: -5 (DEG C), 23 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -18.4 TO 8.8 (DEG C), -1.1 TO 47.9 (DEG F)

MIDLAND BELTLINE, ALL SECTIONS, 7/8T

95 PERCENT:-33.9 TO 25.5 (DEG C),-29 TO 77.9 (DEG F)

REFERENCE TEMPERATURE ANALYSIS

MEAN IMPACT CURVE

TEMPERATURE [0.035 (IN) EXPANSION]-60 (DEG F):-38.4 (DEG C),-37.1 (DEG F)

MINIMUM IMPACT CURVE

TEMPERATURE [0.035 (IN) EXPANSION]-60 (DEG F):-16.7 (DEG C),2 (DEG F)

REMARK: MIDLAND WELD BELTLINE, ALL SECTIONS, FROM 7/8 THICKNESS

ANALYSIS SET: MWB78TALL

MODEL PARAMETERS

LOWER SHELF SHEAR [HELD FIXED]: 0 (PERCENT)
MID-TRANSITION TEMPERATURE:-10.7 (DEG C),12.6 (DEG F)
TRANSITION ZONE WIDTH: 68 (C DEG),122.4 (F DEG)

UPPER SHELF SHEAR [HELD FIXED]: 100 (PERCENT)

STANDARD MODEL: $SHEAR = A + B * \tanh((TEMPERATURE - T_0) / C)$

A: 50 (PERCENT)

B: 50 (PERCENT)

T0:-10.7 (DEG C),12.6 (DEG F)

C: 34 (C DEG),61.2 (F DEG)

ORNL-DWG 92-11775

UPPER SHELF SHEAR: 100 (PERCENT)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 85.6 TO 114.4 (PERCENT)

95 PERCENT: 70.8 TO 129.2 (PERCENT)

TEMPERATURE [50 (PERCENT),50 (PERCENT) SHEAR]:-10.7 (DEG C),12.6 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT:-21.6 TO 0 (DEG C),-6.9 TO 32.1 (DEG F)

95 PERCENT:-35.8 TO 14.1 (DEG C),-32.5 TO 57.3 (DEG F)

REMARK: MIDLAND WELD BELTLINE, ALL SECTIONS, FROM 7/8 THICKNESS

APPENDIX E

HYPERBOLIC TANGENT CURVE FITS WITH 68% AND 95% CONFIDENCE BOUNDS FOR COMBINED DATA SETS UNIRRADIATED MIDLAND REACTOR VESSEL WELDS

COMBINED DATA BY DEPTH IN THE NOZZLE COURSE WELD

ANALYSIS SET: NCALL12T

MODEL PARAMETERS

LOWER SHELF ENERGY [HELD FIXED]: 2.7 (J), 2 (FT-LB)
MID-TRANSITION TEMPERATURE: 4.8 (DEG C), 40.7 (DEG F)
TRANSITION ZONE WIDTH: 143.2 (C DEG), 257.8 (F DEG)
UPPER SHELF ENERGY: 86.8 (J), 64 (FT-LB)

STANDARD MODEL: $ENERGY = A + B \cdot \tanh((TEMPERATURE - T_0) / C)$

A: 44.7 (J), 33 (FT-LB)
B: 42 (J), 31 (FT-LB)
T₀: 4.8 (DEG C), 40.7 (DEG F)
C: 71.6 (C DEG), 128.9 (F DEG)

ORNL-DWG 92-11776

UPPER SHELF ENERGY: 86.8 (J), 64 (FT-LB)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 79.3 TO 94.3 (J), 58.5 TO 69.6 (FT-LB)

95 PERCENT: 71.1 TO 102.5 (J), 52.4 TO 75.6 (FT-LB)

TEMPERATURE [27 (J), 19.9 (FT-LB) ENERGY]: -27.4 (DEG C), -17.3 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -43.3 TO -14.3 (DEG C), -45.9 TO 6.3 (DEG F)

95 PERCENT: -66.4 TO -1.5 (DEG C), -87.6 TO 29.3 (DEG F)

TEMPERATURE [41 (J), 30.2 (FT-LB) ENERGY]: -1.6 (DEG C), 29.2 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -13.5 TO 9.9 (DEG C), 7.8 TO 49.9 (DEG F)

95 PERCENT:-28.1 TO 23 (DEG C),-18.6 TO 73.4 (DEG F)
TEMPERATURE [68 (J),50.2 (FT-LB) ENERGY]: 49.5 (DEG C),121 (DEG F)
CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 34.4 TO 68.7 (DEG C),94 TO 155.7 (DEG F)

95 PERCENT: 20.6 TO 106.3 (DEG C),69.1 TO 223.3 (DEG F)

REFERENCE TEMPERATURE ANALYSIS

MEAN IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY]-60 (DEG F): 15.6 (DEG C),60.1 (DEG F)

MINIMUM IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY]-60 (DEG F): 24.4 (DEG C),75.9 (DEG F)

REMARK: MIDLAND WELD NOZZLE COURSE, ALL SECTIONS, FROM 1/2 THICKNESS

ANALYSIS SET: NCALL12T

MODEL PARAMETERS

LOWER SHELF EXPANSION [HELD FIXED]: 0.061 (MM), 0.0024 (IN)

MID-TRANSITION TEMPERATURE: 6.9 (DEG C), 44.4 (DEG F)

TRANSITION ZONE WIDTH: 108.1 (C DEG), 194.5 (F DEG)

UPPER SHELF EXPANSION: 1.351 (MM), 0.0532 (IN)

STANDARD MODEL: $\text{EXPANSION} = A + B \cdot \tanh((\text{TEMPERATURE} - T_0) / C)$

A: 0.706 (MM), 0.0278 (IN)

B: 0.645 (MM), 0.0254 (IN)

T0: 6.9 (DEG C), 44.4 (DEG F)

C: 54 (C DEG), 97.2 (F DEG)

ORNL-DWG 92-11777

UPPER SHELF EXPANSION: 1.351 (MM), 0.0532 (IN)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 1.24 TO 1.462 (MM), 0.0488 TO 0.0576 (IN)

95 PERCENT: 1.119 TO 1.583 (MM), 0.0441 TO 0.0623 (IN)

TEMPERATURE [0.38 (MM), 0.015 (IN) EXPANSION]: -23.2 (DEG C), -9.8 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -37 TO -12.3 (DEG C), -34.7 TO 9.9 (DEG F)

95 PERCENT: -59 TO -2 (DEG C), -74.2 TO 28.5 (DEG F)

TEMPERATURE [0.89 (MM), 0.035 (IN) EXPANSION]: 22.7 (DEG C), 72.9 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 13.4 TO 33.2 (DEG C), 56.1 TO 91.8 (DEG F)

95 PERCENT: 3.7 TO 46.9 (DEG C), 38.7 TO 116.4 (DEG F)
REFERENCE TEMPERATURE ANALYSIS

MEAN IMPACT CURVE

TEMPERATURE [0.035 (IN) EXPANSION]-60 (DEG F):-10.7 (DEG C), 12.7 (DEG F)

MINIMUM IMPACT CURVE

TEMPERATURE [0.035 (IN) EXPANSION]-60 (DEG F):-1.9 (DEG C), 28.6 (DEG F)

REMARK: MIDLAND WELD NOZZLE COURSE, ALL SECTIONS, FROM 1/2 THICKNESS

ANALYSIS SET: NCALL12T

MODEL PARAMETERS

LOWER SHELF SHEAR [HELD FIXED]: 0 (PERCENT)

MID-TRANSITION TEMPERATURE: 15.3 (DEG C), 59.6 (DEG F)

TRANSITION ZONE WIDTH: 78.1 (C DEG), 140.6 (F DEG)

UPPER SHELF SHEAR [HELD FIXED]: 100 (PERCENT)

STANDARD MODEL: $SHEAR = A + B \cdot \tanh((TEMPERATURE - T_0) / C)$

A: 50 (PERCENT)

B: 50 (PERCENT)

T0: 15.3 (DEG C), 59.6 (DEG F)

C: 39 (C DEG), 70.3 (F DEG)

ORNL-DWG 92-11778

UPPER SHELF SHEAR: 100 (PERCENT)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 93.7 TO 106.3 (PERCENT)

95 PERCENT: 87 TO 113 (PERCENT)

TEMPERATURE [50 (PERCENT), 50 (PERCENT) SHEAR]: 15.3 (DEG C), 59.6 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 9.9 TO 20.8 (DEG C), 49.8 TO 69.5 (DEG F)

95 PERCENT: 3.6 TO 27.1 (DEG C), 38.5 TO 80.8 (DEG F)

REMARK: MIDLAND WELD NOZZLE COURSE, ALL SECTIONS, FROM 1/2 THICKNESS

ANALYSIS SET: NCALL34T

MODEL PARAMETERS

LOWER SHELF ENERGY [HELD FIXED]: 2.7 (J), 2 (FT-LB)
MID-TRANSITION TEMPERATURE: 6.5 (DEG C), 43.6 (DEG F)
TRANSITION ZONE WIDTH: 130.7 (C DEG), 235.3 (F DEG)
UPPER SHELF ENERGY: 86.8 (J), 64 (FT-LB)

STANDARD MODEL: $ENERGY = A + B \cdot \tanh((TEMPERATURE - T_0) / C)$

A: 44.8 (J), 33 (FT-LB)
B: 42.1 (J), 31 (FT-LB)
T₀: 6.5 (DEG C), 43.6 (DEG F)
C: 65.4 (C DEG), 117.7 (F DEG)

ORNL-DWG 92-11779

UPPER SHELF ENERGY: 86.8 (J), 64 (FT-LB)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 80.7 TO 93 (J), 59.5 TO 68.6 (FT-LB)

95 PERCENT: 74 TO 99.7 (J), 54.6 TO 73.5 (FT-LB)

TEMPERATURE [27 (J), 19.9 (FT-LB) ENERGY]: -23 (DEG C), -9.4 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -34.9 TO -12.9 (DEG C), -30.8 TO 8.8 (DEG F)

95 PERCENT: -51 TO -3 (DEG C), -59.7 TO 26.6 (DEG F)

TEMPERATURE [41 (J), 30.2 (FT-LB) ENERGY]: 0.6 (DEG C), 33.1 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -8.4 TO 9.3 (DEG C), 16.8 TO 48.8 (DEG F)

MIDLAND NOZZLE COURSE ALL SECTIONS, 3/4T

95 PERCENT:-19.1 TO 19 (DEG C),-2.4 TO 66.2 (DEG F)

TEMPERATURE [68 (J),50.2 (FT-LB) ENERGY]: 47.1 (DEG C),116.8 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 35.5 TO 61.4 (DEG C),95.9 TO 142.5 (DEG F)

95 PERCENT: 24.7 TO 83.8 (DEG C),76.5 TO 182.8 (DEG F)

REFERENCE TEMPERATURE ANALYSIS

MEAN IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY]-60 (DEG F): 13.3 (DEG C),55.9 (DEG F)

MINIMUM IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY]-60 (DEG F): 15.8 (DEG C),60.4 (DEG F)

REMARK: MIDLAND WELD NOZZLE COURSE, ALL SECTIONS, FROM 3/4 THICKNESS

ANALYSIS SET: NC34TALL

MODEL PARAMETERS

LOWER SHELF EXPANSION [HELD FIXED]: 0.061 (MM), 0.0024 (IN)

MID-TRANSITION TEMPERATURE: 14.9 (DEG C), 58.9 (DEG F)

TRANSITION ZONE WIDTH: 127.1 (C DEG), 228.8 (F DEG)

UPPER SHELF EXPANSION: 1.514 (MM), 0.0596 (IN)

STANDARD MODEL: $\text{EXPANSION} = A + B \cdot \tanh((\text{TEMPERATURE} - T_0) / C)$

A: 0.787 (MM), 0.031 (IN)

B: 0.726 (MM), 0.0286 (IN)

T0: 14.9 (DEG C), 58.9 (DEG F)

C: 63.6 (C DEG), 114.4 (F DEG)

ORNL-DWG 92-11780

UPPER SHELF EXPANSION: 1.514 (MM), 0.0596 (IN)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 1.373 TO 1.654 (MM), 0.0541 TO 0.0651 (IN)

95 PERCENT: 1.221 TO 1.807 (MM), 0.0481 TO 0.0711 (IN)

TEMPERATURE [0.38 (MM), 0.015 (IN) EXPANSION]: -25.4 (DEG C), -13.7 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -45 TO -10.8 (DEG C), -49 TO 12.5 (DEG F)

95 PERCENT: -82.2 TO 2.2 (DEG C), -116 TO 36 (DEG F)

TEMPERATURE [0.89 (MM), 0.035 (IN) EXPANSION]: 24 (DEG C), 75.2 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 12.8 TO 35.9 (DEG C), 55.1 TO 96.6 (DEG F)

95 PERCENT: 0.5 TO 50.6 (DEG C), 33 TO 123.1 (DEG F)
REFERENCE TEMPERATURE ANALYSIS

MEAN IMPACT CURVE

TEMPERATURE [0.035 (IN) EXPANSION]-60 (DEG F):-9.4 (DEG C), 15 (DEG F)

MINIMUM IMPACT CURVE

TEMPERATURE [0.035 (IN) EXPANSION]-60 (DEG F):-4.7 (DEG C), 23.5 (DEG F)

REMARK: MIDLAND WELD NOZZLE COURSE ALL SECTIONS, FROM 3/4 THICKNESS

ANALYSIS SET: NC34TALL

MODEL PARAMETERS

LOWER SHELF SHEAR [HELD FIXED]: 0 (PERCENT)

MID-TRANSITION TEMPERATURE: 27.2 (DEG C), 80.9 (DEG F)

TRANSITION ZONE WIDTH: 65.9 (C DEG), 118.7 (F DEG)

UPPER SHELF SHEAR [HELD FIXED]: 100 (PERCENT)

STANDARD MODEL: $SHEAR = A + B \cdot \tanh((TEMPERATURE - T_0) / C)$

A: 50 (PERCENT)

B: 50 (PERCENT)

T0: 27.2 (DEG C), 80.9 (DEG F)

C: 33 (C DEG), 59.3 (F DEG)

ORNL-DWG 92-11781

UPPER SHELF SHEAR: 100 (PERCENT)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 92.3 TO 107.7 (PERCENT)

95 PERCENT: 84.1 TO 115.9 (PERCENT)

TEMPERATURE [50 (PERCENT), 50 (PERCENT) SHEAR]: 27.2 (DEG C), 80.9 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 21.5 TO 32.9 (DEG C), 70.8 TO 91.3 (DEG F)

95 PERCENT: 15 TO 39.7 (DEG C), 59.1 TO 103.5 (DEG F)

REMARK: MIDLAND WELD NOZZLE COURSE ALL SECTIONS, FROM 3/4 THICKNESS

ANALYSIS SET: NC78TALL

MODEL PARAMETERS

LOWER SHELF ENERGY [HELD FIXED]: 2.7 (J), 2 (FT-LB)
MID-TRANSITION TEMPERATURE: 4.4 (DEG C), 39.9 (DEG F)
TRANSITION ZONE WIDTH: 117.9 (C DEG), 212.3 (F DEG)
UPPER SHELF ENERGY: 89.7 (J), 66.1 (FT-LB)

STANDARD MODEL: $ENERGY = A + B \cdot \tanh((TEMPERATURE - T_0) / C)$

A: 46.2 (J), 34.1 (FT-LB)
B: 43.5 (J), 32.1 (FT-LB)
T₀: 4.4 (DEG C), 39.9 (DEG F)
C: 59 (C DEG), 106.2 (F DEG)

ORNL-DWG 92-11782

UPPER SHELF ENERGY: 89.7 (J), 66.1 (FT-LB)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 81.8 TO 97.5 (J), 60.3 TO 71.9 (FT-LB)

95 PERCENT: 73.3 TO 106.1 (J), 54 TO 78.2 (FT-LB)

TEMPERATURE [27 (J), 19.9 (FT-LB) ENERGY]: -23.5 (DEG C), -10.4 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -37.8 TO -11.9 (DEG C), -36.1 TO 10.5 (DEG F)

95 PERCENT: -59.3 TO -0.7 (DEG C), -74.8 TO 30.8 (DEG F)

TEMPERATURE [41 (J), 30.2 (FT-LB) ENERGY]: -2.7 (DEG C), 27.2 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -13.2 TO 7.4 (DEG C), 8.2 TO 45.4 (DEG F)

95 PERCENT:-26.5 TO 18.8 (DEG C),-15.7 TO 65.9 (DEG F)
TEMPERATURE [68 (J),50.2 (FT-LB) ENERGY]: 36.9 (DEG C),98.5 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 24.6 TO 52.4 (DEG C),76.2 TO 126.3 (DEG F)

95 PERCENT: 13 TO 78.4 (DEG C),55.4 TO 173.1 (DEG F)

REFERENCE TEMPERATURE ANALYSIS

MEAN IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY]-60 (DEG F): 3.2 (DEG C),37.8 (DEG F)

MINIMUM IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY]-60 (DEG F): 12.9 (DEG C),55.2 (DEG F)

REMARK: MIDLAND WELD NOZZLE COURSE, ALL SECTIONS, FROM 7/8 THICKNESS

ANALYSIS SET: NC78TALL

MODEL PARAMETERS

LOWER SHELF EXPANSION [HELD FIXED]: 0.061 (MM), 0.0024 (IN)

MID-TRANSITION TEMPERATURE: 4.3 (DEG C), 39.7 (DEG F)

TRANSITION ZONE WIDTH: 99.2 (C DEG), 178.6 (F DEG)

UPPER SHELF EXPANSION: 1.583 (MM), 0.0623 (IN)

STANDARD MODEL: $\text{EXPANSION} = A + B \cdot \tanh((\text{TEMPERATURE} - T_0) / C)$

A: 0.822 (MM), 0.0324 (IN)

B: 0.761 (MM), 0.03 (IN)

T₀: 4.3 (DEG C), 39.7 (DEG F)

C: 49.6 (C DEG), 89.3 (F DEG)

ORNL-DWG 92-11783

UPPER SHELF EXPANSION: 1.583 (MM), 0.0623 (IN)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 1.428 TO 1.738 (MM), 0.0562 TO 0.0684 (IN)

95 PERCENT: 1.259 TO 1.907 (MM), 0.0496 TO 0.0751 (IN)

TEMPERATURE [0.38 (MM), 0.015 (IN) EXPANSION]: -28.7 (DEG C), -19.6 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -47.3 TO -15.6 (DEG C), -53.1 TO 4 (DEG F)

95 PERCENT: -95.3 TO -4 (DEG C), -139.5 TO 24.8 (DEG F)

TEMPERATURE [0.89 (MM), 0.035 (IN) EXPANSION]: 8.7 (DEG C), 47.7 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -1.2 TO 19.2 (DEG C), 29.9 TO 66.5 (DEG F)

MIDLAND NOZZLE COURSE ALL SECTIONS, 7/8T

95 PERCENT:-12.7 TO 32.3 (DEG C),9.1 TO 90.1 (DEG F)

REFERENCE TEMPERATURE ANALYSIS

MEAN IMPACT CURVE

TEMPERATURE [0.035 (IN) EXPANSION]-60 (DEG F):-24.7 (DEG C),-12.4 (DEG F)

MINIMUM IMPACT CURVE

TEMPERATURE [0.035 (IN) EXPANSION]-60 (DEG F):-15.4 (DEG C),4.2 (DEG F)

REMARK: MIDLAND WELD NOZZLE COURSE, ALL SECTIONS, FROM 7/8 THICKNESS

ANALYSIS SET: NC78TALL

MODEL PARAMETERS

LOWER SHELF SHEAR [HELD FIXED]: 0 (PERCENT)

MID-TRANSITION TEMPERATURE: 12.9 (DEG C), 55.3 (DEG F)

TRANSITION ZONE WIDTH: 69.2 (C DEG), 124.6 (F DEG)

UPPER SHELF SHEAR [HELD FIXED]: 100 (PERCENT)

STANDARD MODEL: $SHEAR = A + B * \tanh((TEMPERATURE - T_0) / C)$

A: 50 (PERCENT)

B: 50 (PERCENT)

T0: 12.9 (DEG C), 55.3 (DEG F)

C: 34.6 (C DEG), 62.3 (F DEG)

ORNL-DWG 92-11784

UPPER SHELF SHEAR: 100 (PERCENT)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 92.9 TO 107.1 (PERCENT)

95 PERCENT: 85.3 TO 114.7 (PERCENT)

TEMPERATURE [50 (PERCENT), 50 (PERCENT) SHEAR]: 12.9 (DEG C), 55.3 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 7.4 TO 18.5 (DEG C), 45.3 TO 65.3 (DEG F)

95 PERCENT: 0.9 TO 25.1 (DEG C), 33.6 TO 77.1 (DEG F)

REMARK: MIDLAND WELD NOZZLE COURSE, ALL SECTIONS, FROM 7/8 THICKNESS

APPENDIX E

HYPERBOLIC TANGENT CURVE FITS WITH 68% AND 95% CONFIDENCE BOUNDS FOR COMBINED DATA SETS UNIRRADIATED MIDLAND REACTOR VESSEL WELDS

COMBINED DATA BY WELD SECTION

ANALYSIS SET: MW9ALL

MODEL PARAMETERS

LOWER SHELF ENERGY [HELD FIXED]: 2.7 (J), 2 (FT-LB)

MID-TRANSITION TEMPERATURE: -7.9 (DEG C), 17.8 (DEG F)

TRANSITION ZONE WIDTH: 99.4 (C DEG), 179 (F DEG)

UPPER SHELF ENERGY: 80.3 (J), 59.2 (FT-LB)

STANDARD MODEL: $ENERGY = A + B \cdot \tanh((TEMPERATURE - T_0) / C)$

A: 41.5 (J), 30.6 (FT-LB)

B: 38.8 (J), 28.6 (FT-LB)

T₀: -7.9 (DEG C), 17.8 (DEG F)

C: 49.7 (C DEG), 89.5 (F DEG)

ORNL-DWG 92-11785

UPPER SHELF ENERGY: 80.3 (J), 59.2 (FT-LB)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 73.9 TO 86.7 (J), 54.5 TO 64 (FT-LB)

95 PERCENT: 67.5 TO 93.2 (J), 49.8 TO 68.7 (FT-LB)

TEMPERATURE [27 (J), 19.9 (FT-LB) ENERGY]: -27.4 (DEG C), -17.4 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -38 TO -18.4 (DEG C), -36.4 TO -1.1 (DEG F)

95 PERCENT: -51.5 TO -10 (DEG C), -60.8 TO 14 (DEG F)

TEMPERATURE [41 (J), 30.2 (FT-LB) ENERGY]: -8.6 (DEG C), 16.6 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -16.9 TO -0.2 (DEG C), 1.6 TO 31.6 (DEG F)

MW BELTLINE SECTION 1-9, ALL THICKNESSES

95 PERCENT:-25.8 TO 8.7 (DEG C),-14.5 TO 47.6 (DEG F)

TEMPERATURE [68 (J),50.2 (FT-LB) ENERGY]: 33.5 (DEG C),92.4 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 20.4 TO 53.9 (DEG C),68.8 TO 129 (DEG F)

95 PERCENT: 10.1 TO UNDEFINED (DEG C),50.2 TO UNDEFINED (DEG F)

REFERENCE TEMPERATURE ANALYSIS

MEAN IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY]-60 (DEG F):-0.3 (DEG C),31.5 (DEG F)

MINIMUM IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY]-60 (DEG F): 23.2 (DEG C),73.7 (DEG F)

REMARK: MIDLAND WELD BELTLINE SECTION 1-9, ALL THICKNESSES OF WELD

ANALYSIS SET: MW9ALL
MODEL PARAMETERS

LOWER SHELF EXPANSION [HELD FIXED]: 0.061 (MM), 0.0024 (IN)

MID-TRANSITION TEMPERATURE: -0.4 (DEG C), 31.3 (DEG F)

TRANSITION ZONE WIDTH: 132.4 (C DEG), 238.3 (F DEG)

UPPER SHELF EXPANSION: 1.751 (MM), 0.069 (IN)

STANDARD MODEL: $\text{EXPANSION} = A + B \cdot \tanh((\text{TEMPERATURE} - T_0) / C)$

A: 0.906 (MM), 0.0357 (IN)

B: 0.845 (MM), 0.0333 (IN)

T₀: -0.4 (DEG C), 31.3 (DEG F)

C: 66.2 (C DEG), 119.1 (F DEG)

ORNL-DWG 92-11786

UPPER SHELF EXPANSION: 1.751 (MM), 0.069 (IN)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 1.63 TO 1.873 (MM), 0.0642 TO 0.0738 (IN)

95 PERCENT: 1.507 TO 1.995 (MM), 0.0594 TO 0.0786 (IN)

TEMPERATURE [0.38 (MM), 0.015 (IN) EXPANSION]: -48.7 (DEG C), -55.6 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -66.9 TO -35.1 (DEG C), -88.4 TO -31.2 (DEG F)

95 PERCENT: -98 TO -23.8 (DEG C), -144.4 TO -10.9 (DEG F)

TEMPERATURE [0.89 (MM), 0.035 (IN) EXPANSION]: -1.7 (DEG C), 29 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -11.1 TO 7.8 (DEG C), 12 TO 46 (DEG F)

MW BELTLINE SECTION 1-9, ALL THICKNESSES

95 PERCENT:-21.1 TO 17.6 (DEG C),-5.9 TO 63.7 (DEG F)

REFERENCE TEMPERATURE ANALYSIS

MEAN IMPACT CURVE

TEMPERATURE [0.035 (IN) EXPANSION]-60 (DEG F):-35.1 (DEG C),-31.2 (DEG F)

MINIMUM IMPACT CURVE

TEMPERATURE [0.035 (IN) EXPANSION]-60 (DEG F):-21.7 (DEG C),-7 (DEG F)

REMARK: MIDLAND WELD BELTLINE SECTION 1-9, ALL THICKNESSES OF WELD

ANALYSIS SET: MW9ALL

MODEL PARAMETERS

LOWER SHELF SHEAR [HELD FIXED]: 0 (PERCENT)

MID-TRANSITION TEMPERATURE:-11.2 (DEG C),11.9 (DEG F)

TRANSITION ZONE WIDTH: 79.6 (C DEG),143.3 (F DEG)

UPPER SHELF SHEAR [HELD FIXED]: 100 (PERCENT)

STANDARD MODEL: $SHEAR = A + B * \tanh((TEMPERATURE - T_0) / C)$

A: 50 (PERCENT)

B: 50 (PERCENT)

T0:-11.2 (DEG C),11.9 (DEG F)

C: 39.8 (C DEG),71.6 (F DEG)

ORNL-DWG 92-11787

UPPER SHELF SHEAR: 100 (PERCENT)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 92.2 TO 107.8 (PERCENT)

95 PERCENT: 84.3 TO 115.7 (PERCENT)

TEMPERATURE [50 (PERCENT),50 (PERCENT) SHEAR]:-11.2 (DEG C),11.9 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT:-17.7 TO -4.6 (DEG C),0.1 TO 23.8 (DEG F)

95 PERCENT:-24.7 TO 2.4 (DEG C),-12.4 TO 36.4 (DEG F)

REMARK: MIDLAND WELD BELTLINE SECTION 1-9, ALL THICKNESSES OF WELD

ANALYSIS SET: MW11ALL

MODEL PARAMETERS

LOWER SHELF ENERGY [HELD FIXED]: 2.7 (J), 2 (FT-LB)
MID-TRANSITION TEMPERATURE: -0.4 (DEG C), 31.2 (DEG F)
TRANSITION ZONE WIDTH: 106.3 (C DEG), 191.4 (F DEG)
UPPER SHELF ENERGY: 88.3 (J), 65.1 (FT-LB)

STANDARD MODEL: $ENERGY = A + B \cdot \tanh((TEMPERATURE - T_0) / C)$

A: 45.5 (J), 33.6 (FT-LB)
B: 42.8 (J), 31.6 (FT-LB)
T0: -0.4 (DEG C), 31.2 (DEG F)
C: 53.2 (C DEG), 95.7 (F DEG)

ORNL-DWG 92-11788

UPPER SHELF ENERGY: 88.3 (J), 65.1 (FT-LB)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 78 TO 98.7 (J), 57.5 TO 72.8 (FT-LB)

95 PERCENT: 67.6 TO 109.1 (J), 49.8 TO 80.5 (FT-LB)

TEMPERATURE [27 (J), 19.9 (FT-LB) ENERGY]: -25.1 (DEG C), -13.1 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -44.1 TO -10.8 (DEG C), -47.3 TO 12.6 (DEG F)

95 PERCENT: -80.4 TO 2.1 (DEG C), -112.7 TO 35.7 (DEG F)

TEMPERATURE [41 (J), 30.2 (FT-LB) ENERGY]: -6.1 (DEG C), 21.1 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -19.7 TO 6.7 (DEG C), -3.5 TO 44.1 (DEG F)

95 PERCENT:-36.7 TO 20.6 (DEG C),-34 TO 69.1 (DEG F)
TEMPERATURE [68 (J),50.2 (FT-LB) ENERGY]: 30.6 (DEG C),87 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 15.1 TO 53.1 (DEG C),59.3 TO 127.6 (DEG F)

95 PERCENT: 2 TO UNDEFINED (DEG C),35.6 TO UNDEFINED (DEG F)

REFERENCE TEMPERATURE ANALYSIS

MEAN IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY]-60 (DEG F):-3.1 (DEG C),26.4 (DEG F)

MINIMUM IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY]-60 (DEG F): 9 (DEG C),48.1 (DEG F)

REMARK: MIDLAND WELD BELTLINE SECTION 1-11, ALL THICKNESSES OF WELD

ANALYSIS SET: MW11ALL

MODEL PARAMETERS

LOWER SHELF EXPANSION [HELD FIXED]: 0.061 (MM), 0.0024 (IN)

MID-TRANSITION TEMPERATURE: -4.2 (DEG C), 24.5 (DEG F)

TRANSITION ZONE WIDTH: 117.1 (C DEG), 210.8 (F DEG)

UPPER SHELF EXPANSION: 1.666 (MM), 0.0656 (IN)

STANDARD MODEL: $\text{EXPANSION} = A + B \cdot \tanh((\text{TEMPERATURE} - T_0) / C)$

A: 0.863 (MM), 0.034 (IN)

B: 0.802 (MM), 0.0316 (IN)

T0: -4.2 (DEG C), 24.5 (DEG F)

C: 58.6 (C DEG), 105.4 (F DEG)

ORNL-DWG 92-11789

UPPER SHELF EXPANSION: 1.666 (MM), 0.0656 (IN)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 1.486 TO 1.846 (MM), 0.0585 TO 0.0727 (IN)

95 PERCENT: 1.305 TO 2.026 (MM), 0.0514 TO 0.0798 (IN)

TEMPERATURE [0.38 (MM), 0.015 (IN) EXPANSION]: -45 (DEG C), -49 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -72.6 TO -27.5 (DEG C), -98.7 TO -17.5 (DEG F)

95 PERCENT: UNDEFINED TO -13.5 (DEG C), UNDEFINED TO 7.7 (DEG F)

TEMPERATURE [0.89 (MM), 0.035 (IN) EXPANSION]: -2.2 (DEG C), 28 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -15.4 TO 11.1 (DEG C), 4.3 TO 51.9 (DEG F)

MW BELTLINE SECTION 1-11, ALL THICKNESS

95 PERCENT:-30.1 TO 26.3 (DEG C),-22.3 TO 79.3 (DEG F)

REFERENCE TEMPERATURE ANALYSIS

MEAN IMPACT CURVE

TEMPERATURE [0.035 (IN) EXPANSION]-60 (DEG F):-35.6 (DEG C),-32.1 (DEG F)

MINIMUM IMPACT CURVE

TEMPERATURE [0.035 (IN) EXPANSION]-60 (DEG F):-25.8 (DEG C),-14.5 (DEG F)

REMARK: MIDLAND WELD BELTLINE SECTION 1-11, ALL THICKNESSES OF WELD

ANALYSIS SET: MW11ALL

MODEL PARAMETERS

LOWER SHELF SHEAR [HELD FIXED]: 0 (PERCENT)
MID-TRANSITION TEMPERATURE:-0.1 (DEG C),31.8 (DEG F)
TRANSITION ZONE WIDTH: 79.5 (C DEG),143.1 (F DEG)

UPPER SHELF SHEAR [HELD FIXED]: 100 (PERCENT)

STANDARD MODEL: $SHEAR = A + B \cdot \tanh((TEMPERATURE - T_0) / C)$

A: 50 (PERCENT)

B: 50 (PERCENT)

T0:-0.1 (DEG C),31.8 (DEG F)

C: 39.8 (C DEG),71.6 (F DEG)

ORNL-DWG 92-11790

UPPER SHELF SHEAR: 100 (PERCENT)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 86 TO 114 (PERCENT)

95 PERCENT: 71.9 TO 128.1 (PERCENT)

TEMPERATURE [50 (PERCENT),50 (PERCENT) SHEAR]:-0.1 (DEG C),31.8 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT:-12.1 TO 11.8 (DEG C),10.3 TO 53.2 (DEG F)

95 PERCENT:-26.9 TO 26.4 (DEG C),-16.4 TO 79.4 (DEG F)

REMARK: MIDLAND WELD BELTLINE SECTION 1-11, ALL THICKNESSES OF WELD

ANALYSIS SET: MW13ALL

MODEL PARAMETERS

LOWER SHELF ENERGY [HELD FIXED]: 2.7 (J), 2 (FT-LB)

MID-TRANSITION TEMPERATURE: -1.7 (DEG C), 28.9 (DEG F)

TRANSITION ZONE WIDTH: 129.1 (C DEG), 232.4 (F DEG)

UPPER SHELF ENERGY: 99.3 (J), 73.3 (FT-LB)

STANDARD MODEL: $ENERGY = A + B \cdot \tanh((TEMPERATURE - T_0) / C)$

A: 51 (J), 37.6 (FT-LB)

B: 48.3 (J), 35.6 (FT-LB)

T₀: -1.7 (DEG C), 28.9 (DEG F)

C: 64.6 (C DEG), 116.2 (F DEG)

ORNL-DWG 92-11791

UPPER SHELF ENERGY: 99.3 (J), 73.3 (FT-LB)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 89.5 TO 109.2 (J), 66 TO 80.5 (FT-LB)

95 PERCENT: 79.7 TO 119 (J), 58.8 TO 87.7 (FT-LB)

TEMPERATURE [27 (J), 19.9 (FT-LB) ENERGY]: -37 (DEG C), -34.5 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -57.6 TO -21.4 (DEG C), -71.8 TO -6.5 (DEG F)

95 PERCENT: -94.6 TO -8 (DEG C), -138.3 TO 17.5 (DEG F)

TEMPERATURE [41 (J), 30.2 (FT-LB) ENERGY]: -15.3 (DEG C), 4.4 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -29.9 TO -2.2 (DEG C), -21.8 TO 28.1 (DEG F)

95 PERCENT:-47.5 TO 10.8 (DEG C),-53.6 TO 51.4 (DEG F)
TEMPERATURE [68 (J),50.2 (FT-LB) ENERGY]: 21.9 (DEG C),71.5 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 8.1 TO 38.4 (DEG C),46.5 TO 101 (DEG F)

95 PERCENT:-4.9 TO 61 (DEG C),23.2 TO 141.8 (DEG F)

REFERENCE TEMPERATURE ANALYSIS

MEAN IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY]-60 (DEG F):-11.7 (DEG C),10.9 (DEG F)

MINIMUM IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY]-60 (DEG F): 6.2 (DEG C),43.2 (DEG F)

REMARK: MIDLAND WELD BELTLINE SECTION 1-13, ALL THICKNESSES OF WELD

ANALYSIS SET: MW13ALL

MODEL PARAMETERS

LOWER SHELF EXPANSION [HELD FIXED]: 0.061 (MM), 0.0024 (IN)

MID-TRANSITION TEMPERATURE: 1.3 (DEG C), 34.4 (DEG F)

TRANSITION ZONE WIDTH: 139.9 (C DEG), 251.8 (F DEG)

UPPER SHELF EXPANSION: 1.752 (MM), 0.069 (IN)

STANDARD MODEL: $\text{EXPANSION} = A + B * \text{TANH}((\text{TEMPERATURE} - T_0) / C)$

A: 0.907 (MM), 0.0357 (IN)

B: 0.846 (MM), 0.0333 (IN)

T0: 1.3 (DEG C), 34.4 (DEG F)

C: 70 (C DEG), 125.9 (F DEG)

ORNL-DWG 92-11792

UPPER SHELF EXPANSION: 1.752 (MM), 0.069 (IN)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 1.581 TO 1.924 (MM), 0.0623 TO 0.0757 (IN)

95 PERCENT: 1.412 TO 2.093 (MM), 0.0556 TO 0.0824 (IN)

TEMPERATURE [0.38 (MM), 0.015 (IN) EXPANSION]: -49.7 (DEG C), -57.5 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -79.8 TO -30.3 (DEG C), -111.6 TO -22.5 (DEG F)

95 PERCENT: UNDEFINED TO -14.9 (DEG C), UNDEFINED TO 5.2 (DEG F)

TEMPERATURE [0.89 (MM), 0.035 (IN) EXPANSION]: -0.1 (DEG C), 31.9 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -14.2 TO 13.9 (DEG C), 6.4 TO 57 (DEG F)

MW BELTLINE SECTION 1-13, ALL THICKNESS

95 PERCENT:-29.8 TO 28.8 (DEG C),-21.6 TO 83.9 (DEG F)

REFERENCE TEMPERATURE ANALYSIS

MEAN IMPACT CURVE

TEMPERATURE [0.035 (IN) EXPANSION]-60 (DEG F):-33.5 (DEG C),-28.3 (DEG F)

MINIMUM IMPACT CURVE

TEMPERATURE [0.035 (IN) EXPANSION]-60 (DEG F):-16.4 (DEG C),2.5 (DEG F)

REMARK: MIDLAND WELD BELTLINE SECTION 1-13, ALL THICKNESSES OF WELD

ANALYSIS SET: MW13ALL

MODEL PARAMETERS

LOWER SHELF SHEAR [HELD FIXED]: 0 (PERCENT)

MID-TRANSITION TEMPERATURE:-1.6 (DEG C),29.1 (DEG F)

TRANSITION ZONE WIDTH: 87.8 (C DEG),158.1 (F DEG)

UPPER SHELF SHEAR [HELD FIXED]: 100 (PERCENT)

STANDARD MODEL: $SHEAR = A + B * \tanh((TEMPERATURE - T_0) / C)$

A: 50 (PERCENT)

B: 50 (PERCENT)

T0:-1.6 (DEG C),29.1 (DEG F)

C: 43.9 (C DEG),79.1 (F DEG)

ORNL-DWG 92-11793

UPPER SHELF SHEAR: 100 (PERCENT)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 90 TO 110 (PERCENT)

95 PERCENT: 80.1 TO 119.9 (PERCENT)

TEMPERATURE [50 (PERCENT),50 (PERCENT) SHEAR]:-1.6 (DEG C),29.1 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT:-10.7 TO 7.5 (DEG C),12.7 TO 45.5 (DEG F)

95 PERCENT:-20.7 TO 17.3 (DEG C),-5.3 TO 63.1 (DEG F)

REMARK: MIDLAND WELD BELTLINE SECTION 1-13, ALL THICKNESSES OF WELD

ANALYSIS SET: MW15ALL

MODEL PARAMETERS

LOWER SHELF ENERGY [HELD FIXED]: 2.7 (J), 2 (FT-LB)

MID-TRANSITION TEMPERATURE: -1.5 (DEG C), 29.3 (DEG F)

TRANSITION ZONE WIDTH: 100.6 (C DEG), 181 (F DEG)

UPPER SHELF ENERGY: 84.9 (J), 62.6 (FT-LB)

STANDARD MODEL: $ENERGY = A + B * \tanh((TEMPERATURE - T_0) / C)$

A: 43.8 (J), 32.3 (FT-LB)

B: 41.1 (J), 30.3 (FT-LB)

T₀: -1.5 (DEG C), 29.3 (DEG F)

C: 50.3 (C DEG), 90.5 (F DEG)

ORNL-DWG 92-11794

UPPER SHELF ENERGY: 84.9 (J), 62.6 (FT-LB)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 76.9 TO 92.9 (J), 56.7 TO 68.5 (FT-LB)

95 PERCENT: 68.9 TO 100.9 (J), 50.8 TO 74.4 (FT-LB)

TEMPERATURE [27 (J), 19.9 (FT-LB) ENERGY]: -23.3 (DEG C), -10 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -36.7 TO -12.5 (DEG C), -34.1 TO 9.6 (DEG F)

95 PERCENT: -56.2 TO -2.6 (DEG C), -69.2 TO 27.4 (DEG F)

TEMPERATURE [41 (J), 30.2 (FT-LB) ENERGY]: -4.9 (DEG C), 23.1 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -15 TO 4.9 (DEG C), 4.9 TO 40.7 (DEG F)

MW BELTLINE SECTION 1-15, ALL THICKNESS

95 PERCENT:-26.6 TO 15.2 (DEG C),-15.8 TO 59.4 (DEG F)
TEMPERATURE [68 (J),50.2 (FT-LB) ENERGY]: 32.5 (DEG C),90.5 (DEG F)
CONFIDENCE INTERVALS ON PREDICTED VALUE
68 PERCENT: 19.5 TO 51.3 (DEG C),67.1 TO 124.4 (DEG F)
95 PERCENT: 8.7 TO 109.3 (DEG C),47.7 TO 228.7 (DEG F)
REFERENCE TEMPERATURE ANALYSIS
MEAN IMPACT CURVE
TEMPERATURE [50 (FT-LB) ENERGY]-60 (DEG F):-1.2 (DEG C),29.8 (DEG F)
MINIMUM IMPACT CURVE
TEMPERATURE [50 (FT-LB) ENERGY]-60 (DEG F): 20.9 (DEG C),69.7 (DEG F)
REMARK: MIDLAND WELD BELTLINE SECTION 1-15, ALL THICKNESSES OF WELD

ANALYSIS SET: MW15ALL

MODEL PARAMETERS

LOWER SHELF EXPANSION [HELD FIXED]: 0.061 (MM), 0.0024 (IN)

MID-TRANSITION TEMPERATURE: 7.6 (DEG C), 45.6 (DEG F)

TRANSITION ZONE WIDTH: 108.1 (C DEG), 194.5 (F DEG)

UPPER SHELF EXPANSION: 1.593 (MM), 0.0627 (IN)

STANDARD MODEL: $\text{EXPANSION} = A + B \cdot \tanh((\text{TEMPERATURE} - T_0) / C)$

A: 0.827 (MM), 0.0326 (IN)

B: 0.766 (MM), 0.0302 (IN)

T0: 7.6 (DEG C), 45.6 (DEG F)

C: 54 (C DEG), 97.3 (F DEG)

ORNL-DWG 92-11795

UPPER SHELF EXPANSION: 1.593 (MM), 0.0627 (IN)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 1.454 TO 1.733 (MM), 0.0572 TO 0.0682 (IN)

95 PERCENT: 1.314 TO 1.872 (MM), 0.0517 TO 0.0737 (IN)

TEMPERATURE [0.38 (MM), 0.015 (IN) EXPANSION]: -28.5 (DEG C), -19.3 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -46.7 TO -15.5 (DEG C), -52.1 TO 4.1 (DEG F)

95 PERCENT: -84.6 TO -4.7 (DEG C), -120.2 TO 23.5 (DEG F)

TEMPERATURE [0.89 (MM), 0.035 (IN) EXPANSION]: 12 (DEG C), 53.6 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 2.3 TO 22.1 (DEG C), 36.1 TO 71.8 (DEG F)

MW BELTLINE SECTION 1-15, ALL THICKNESS

95 PERCENT:-7.9 TO 33.4 (DEG C),17.8 TO 92.1 (DEG F)

REFERENCE TEMPERATURE ANALYSIS

MEAN IMPACT CURVE

TEMPERATURE [0.035 (IN) EXPANSION]-60 (DEG F):-21.4 (DEG C),-6.5 (DEG F)

MINIMUM IMPACT CURVE

TEMPERATURE [0.035 (IN) EXPANSION]-60 (DEG F):-6.5 (DEG C),20.4 (DEG F)

REMARK: MIDLAND WELD BELTLINE SECTION 1-15, ALL THICKNESSES OF WELD

ANALYSIS SET: MW15ALL

MODEL PARAMETERS

LOWER SHELF SHEAR [HELD FIXED]: 0 (PERCENT)

MID-TRANSITION TEMPERATURE: 2.3 (DEG C), 36.2 (DEG F)

TRANSITION ZONE WIDTH: 79.4 (C DEG), 142.9 (F DEG)

UPPER SHELF SHEAR [HELD FIXED]: 100 (PERCENT)

STANDARD MODEL: $SHEAR = A + B * \tanh((TEMPERATURE - T_0) / C)$

A: 50 (PERCENT)

B: 50 (PERCENT)

T0: 2.3 (DEG C), 36.2 (DEG F)

C: 39.7 (C DEG), 71.5 (F DEG)

ORNL-DWG 92-11796

UPPER SHELF SHEAR: 100 (PERCENT)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 87.8 TO 112.2 (PERCENT)

95 PERCENT: 75.7 TO 124.3 (PERCENT)

TEMPERATURE [50 (PERCENT), 50 (PERCENT) SHEAR]: 2.3 (DEG C), 36.2 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -7.9 TO 12.6 (DEG C), 17.7 TO 54.6 (DEG F)

95 PERCENT: -19.9 TO 24.5 (DEG C), -3.9 TO 76.1 (DEG F)

REMARK: MIDLAND WELD BELTLINE SECTION 1-15, ALL THICKNESSES OF WELD

ANALYSIS SET: NC31ALL

MODEL PARAMETERS

LOWER SHELF ENERGY [HELD FIXED]: 2.7 (J), 2 (FT-LB)
MID-TRANSITION TEMPERATURE: 5.7 (DEG C), 42.3 (DEG F)
TRANSITION ZONE WIDTH: 122.9 (C DEG), 221.3 (F DEG)
UPPER SHELF ENERGY: 88.3 (J), 65.2 (FT-LB)

STANDARD MODEL: $ENERGY = A + B \cdot \tanh((TEMPERATURE - T_0) / C)$

A: 45.5 (J), 33.6 (FT-LB)
B: 42.8 (J), 31.6 (FT-LB)
T₀: 5.7 (DEG C), 42.3 (DEG F)
C: 61.5 (C DEG), 110.7 (F DEG)

ORNL-DWG 92-11797

UPPER SHELF ENERGY: 88.3 (J), 65.2 (FT-LB)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 81.3 TO 95.4 (J), 60 TO 70.3 (FT-LB)

95 PERCENT: 74 TO 102.6 (J), 54.6 TO 75.7 (FT-LB)

TEMPERATURE [27 (J), 19.9 (FT-LB) ENERGY]: -22.8 (DEG C), -9 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -35.9 TO -11.8 (DEG C), -32.7 TO 10.8 (DEG F)

95 PERCENT: -54 TO -1.6 (DEG C), -65.2 TO 29.1 (DEG F)

TEMPERATURE [41 (J), 30.2 (FT-LB) ENERGY]: -0.8 (DEG C), 30.5 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -10.7 TO 8.7 (DEG C), 12.7 TO 47.7 (DEG F)

MW NOZZLE SECTION 3-31, ALL THICKNESS

95 PERCENT: -22.2 TO 18.8 (DEG C), -7.9 TO 65.9 (DEG F)

TEMPERATURE [68 (J), 50.2 (FT-LB) ENERGY]: 41.6 (DEG C), 106.8 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 29.5 TO 56.6 (DEG C), 85.2 TO 133.8 (DEG F)

95 PERCENT: 18.8 TO 80 (DEG C), 65.8 TO 176.1 (DEG F)

REFERENCE TEMPERATURE ANALYSIS

MEAN IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY]-60 (DEG F): 7.8 (DEG C), 46.1 (DEG F)

MINIMUM IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY]-60 (DEG F): 16.4 (DEG C), 61.6 (DEG F)

REMARK: MIDLAND WELD NOZZLE SECTION 3-31, ALL THICKNESSES OF WELD

ANALYSIS SET: NC31ALL

MODEL PARAMETERS

LOWER SHELF EXPANSION [HELD FIXED]: 0.061 (MM), 0.0024 (IN)

MID-TRANSITION TEMPERATURE: 9.6 (DEG C), 49.3 (DEG F)

TRANSITION ZONE WIDTH: 104.7 (C DEG), 188.5 (F DEG)

UPPER SHELF EXPANSION: 1.489 (MM), 0.0586 (IN)

STANDARD MODEL: $\text{EXPANSION} = A + B \cdot \tanh((\text{TEMPERATURE} - T_0) / C)$

A: 0.775 (MM), 0.0305 (IN)

B: 0.714 (MM), 0.0281 (IN)

T0: 9.6 (DEG C), 49.3 (DEG F)

C: 52.4 (C DEG), 94.2 (F DEG)

ORNL-DWG 92-11798

UPPER SHELF EXPANSION: 1.489 (MM), 0.0586 (IN)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 1.303 TO 1.675 (MM), 0.0513 TO 0.0659 (IN)

95 PERCENT: 1.11 TO 1.868 (MM), 0.0437 TO 0.0735 (IN)

TEMPERATURE [0.38 (MM), 0.015 (IN) EXPANSION]: -23 (DEG C), -9.4 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -48.2 TO -6.6 (DEG C), -54.8 TO 20 (DEG F)

95 PERCENT: UNDEFINED TO 7.4 (DEG C), UNDEFINED TO 45.4 (DEG F)

TEMPERATURE [0.89 (MM), 0.035 (IN) EXPANSION]: 18.1 (DEG C), 64.6 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 4.9 TO 32.7 (DEG C), 40.8 TO 90.9 (DEG F)

95 PERCENT:-9.8 TO 52.3 (DEG C),14.4 TO 126.1 (DEG F)
REFERENCE TEMPERATURE ANALYSIS
MEAN IMPACT CURVE
TEMPERATURE [0.035 (IN) EXPANSION]-60 (DEG F):-15.3 (DEG C),4.5 (DEG F)
MINIMUM IMPACT CURVE
TEMPERATURE [0.035 (IN) EXPANSION]-60 (DEG F):-4.4 (DEG C),24.2 (DEG F)
REMARK: MIDLAND WELD NOZZLE SECTION 3-31, ALL THICKNESSES OF WELD

ANALYSIS SET: NC31ALL

MODEL PARAMETERS

LOWER SHELF SHEAR [HELD FIXED]: 0 (PERCENT)
MID-TRANSITION TEMPERATURE: 18 (DEG C), 64.3 (DEG F)
TRANSITION ZONE WIDTH: 68.2 (C DEG), 122.8 (F DEG)
UPPER SHELF SHEAR [HELD FIXED]: 100 (PERCENT)

STANDARD MODEL: $SHEAR = A + B * \tanh((TEMPERATURE - T_0) / C)$

A: 50 (PERCENT)
B: 50 (PERCENT)
T₀: 18 (DEG C), 64.3 (DEG F)
C: 34.1 (C DEG), 61.4 (F DEG)

ORNL-DWG 92-11799

UPPER SHELF SHEAR: 100 (PERCENT)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 89.9 TO 110.1 (PERCENT)

95 PERCENT: 79.5 TO 120.5 (PERCENT)

TEMPERATURE [50 (PERCENT), 50 (PERCENT) SHEAR]: 18 (DEG C), 64.3 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 10.4 TO 25.5 (DEG C), 50.8 TO 78 (DEG F)

95 PERCENT: 1.6 TO 34.4 (DEG C), 34.9 TO 94 (DEG F)

REMARK: MIDLAND WELD NOZZLE SECTION 3-31, ALL THICKNESSES OF WELD

ANALYSIS SET: NC34ALL

MODEL PARAMETERS

LOWER SHELF ENERGY [HELD FIXED]: 2.7 (J), 2 (FT-LB)

MID-TRANSITION TEMPERATURE: 4.7 (DEG C), 40.4 (DEG F)

TRANSITION ZONE WIDTH: 138.2 (C DEG), 248.8 (F DEG)

UPPER SHELF ENERGY: 87 (J), 64.2 (FT-LB)

STANDARD MODEL: $ENERGY = A + B \cdot \tanh((TEMPERATURE - T_0) / C)$

A: 44.9 (J), 33.1 (FT-LB)

B: 42.2 (J), 31.1 (FT-LB)

T₀: 4.7 (DEG C), 40.4 (DEG F)

C: 69.1 (C DEG), 124.4 (F DEG)

ORNL-DWG 92-11800

UPPER SHELF ENERGY: 87 (J), 64.2 (FT-LB)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 80.5 TO 93.6 (J), 59.4 TO 69 (FT-LB)

95 PERCENT: 73.7 TO 100.4 (J), 54.4 TO 74 (FT-LB)

TEMPERATURE [27 (J), 19.9 (FT-LB) ENERGY]: -26.6 (DEG C), -15.8 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -40.2 TO -15 (DEG C), -40.4 TO 4.9 (DEG F)

95 PERCENT: -58.4 TO -4.2 (DEG C), -73.2 TO 24.5 (DEG F)

TEMPERATURE [41 (J), 30.2 (FT-LB) ENERGY]: -1.7 (DEG C), 29 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -12 TO 8.4 (DEG C), 10.3 TO 47.1 (DEG F)

MW NOZZLE SECTION 3-34, ALL THICKNESS

95 PERCENT:-23.9 TO 19.1 (DEG C),-11 TO 66.4 (DEG F)

TEMPERATURE [68 (J),50.2 (FT-LB) ENERGY]: 47.3 (DEG C),117.1 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 34.2 TO 63.7 (DEG C),93.5 TO 146.7 (DEG F)

95 PERCENT: 22.4 TO 89.7 (DEG C),72.3 TO 193.6 (DEG F)

REFERENCE TEMPERATURE ANALYSIS

MEAN IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY]-60 (DEG F): 13.5 (DEG C),56.2 (DEG F)

MINIMUM IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY]-60 (DEG F): 26.2 (DEG C),79.1 (DEG F)

REMARK: MIDLAND WELD NOZZLE SECTION 3-34, ALL THICKNESSES OF WELD

ANALYSIS SET: NC34ALL

MODEL PARAMETERS

LOWER SHELF EXPANSION [HELD FIXED]: 0.061 (MM), 0.0024 (IN)

MID-TRANSITION TEMPERATURE: 3.5 (DEG C), 38.4 (DEG F)

TRANSITION ZONE WIDTH: 110 (C DEG), 197.9 (F DEG)

UPPER SHELF EXPANSION [HELD FIXED]: 1.4 (MM), 0.0551 (IN)

STANDARD MODEL: $\text{EXPANSION} = A + B \cdot \text{TANH}((\text{TEMPERATURE} - T_0) / C)$

A: 0.731 (MM), 0.0288 (IN)

B: 0.669 (MM), 0.0264 (IN)

T0: 3.5 (DEG C), 38.4 (DEG F)

C: 55 (C DEG), 99 (F DEG)

ORNL-DWG 92-11801

UPPER SHELF EXPANSION: 1.4 (MM), 0.0551 (IN)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 1.285 TO 1.515 (MM), 0.0506 TO 0.0596 (IN)

95 PERCENT: 1.166 TO 1.634 (MM), 0.0459 TO 0.0644 (IN)

TEMPERATURE [0.38 (MM), 0.015 (IN) EXPANSION]: -28.4 (DEG C), -19.1 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -44.7 TO -16 (DEG C), -48.5 TO 3.3 (DEG F)

95 PERCENT: -72.6 TO -4.9 (DEG C), -98.7 TO 23.1 (DEG F)

TEMPERATURE [0.89 (MM), 0.035 (IN) EXPANSION]: 16.9 (DEG C), 62.4 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 6.7 TO 28.2 (DEG C), 44 TO 82.8 (DEG F)

MW NOZZLE SECTION 3-34, ALL THICKNESS

95 PERCENT:-3.8 TO 42.5 (DEG C),25.2 TO 108.5 (DEG F)

REFERENCE TEMPERATURE ANALYSIS

MEAN IMPACT CURVE

TEMPERATURE [0.035 (IN) EXPANSION]-60 (DEG F):-16.5 (DEG C),2.2 (DEG F)

MINIMUM IMPACT CURVE

TEMPERATURE [0.035 (IN) EXPANSION]-60 (DEG F):-6.7 (DEG C),20 (DEG F)

REMARK: MIDLAND WELD NOZZLE SECTION 3-34, ALL THICKNESSES OF WELD

ANALYSIS SET: NC34ALL

MODEL PARAMETERS

LOWER SHELF SHEAR [HELD FIXED]: 0 (PERCENT)
MID-TRANSITION TEMPERATURE: 20.7 (DEG C), 69.2 (DEG F)
TRANSITION ZONE WIDTH: 79.5 (C DEG), 143.2 (F DEG)
UPPER SHELF SHEAR [HELD FIXED]: 100 (PERCENT)

STANDARD MODEL: $SHEAR = A + B * \tanh((TEMPERATURE - T_0) / C)$

A: 50 (PERCENT)
B: 50 (PERCENT)
T0: 20.7 (DEG C), 69.2 (DEG F)
C: 39.8 (C DEG), 71.6 (F DEG)

ORNL-DWG 92-11802

UPPER SHELF SHEAR: 100 (PERCENT)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 94.4 TO 105.6 (PERCENT)

95 PERCENT: 88.5 TO 111.5 (PERCENT)

TEMPERATURE [50 (PERCENT), 50 (PERCENT) SHEAR]: 20.7 (DEG C), 69.2 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 15.8 TO 25.5 (DEG C), 60.5 TO 77.9 (DEG F)

95 PERCENT: 10.6 TO 30.8 (DEG C), 51.1 TO 87.4 (DEG F)

REMARK: MIDLAND WELD NOZZLE SECTION 3-34, ALL THICKNESSES OF WELD

APPENDIX E

HYPERBOLIC TANGENT CURVE FITS WITH 68% AND 95% CONFIDENCE BOUNDS FOR COMBINED DATA SETS UNIRRADIATED MIDLAND REACTOR VESSEL WELDS

COMBINED DATA FOR ENTIRE BELTLINE WELD ENTIRE NOZZLE COURSE WELD AND ALL DATA

ANALYSIS SET: MWBELTALL

MODEL PARAMETERS

LOWER SHELF ENERGY [HELD FIXED]: 2.7 (J), 2 (FT-LB)

MID-TRANSITION TEMPERATURE: -3.2 (DEG C), 26.2 (DEG F)

TRANSITION ZONE WIDTH: 109 (C DEG), 196.2 (F DEG)

UPPER SHELF ENERGY: 88.9 (J), 65.5 (FT-LB)

STANDARD MODEL: $ENERGY = A + B \cdot \tanh((TEMPERATURE - T_0) / C)$

A: 45.8 (J), 33.8 (FT-LB)

B: 43.1 (J), 31.8 (FT-LB)

T₀: -3.2 (DEG C), 26.2 (DEG F)

C: 54.5 (C DEG), 98.1 (F DEG)

ORNL-DWG 92-11803

UPPER SHELF ENERGY: 88.9 (J), 65.5 (FT-LB)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 79.2 TO 98.5 (J), 58.4 TO 72.7 (FT-LB)

95 PERCENT: 69.8 TO 107.9 (J), 51.5 TO 79.6 (FT-LB)

TEMPERATURE [27 (J), 19.9 (FT-LB) ENERGY]: -28.7 (DEG C), -19.7 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -46.4 TO -15 (DEG C), -51.6 TO 5 (DEG F)

95 PERCENT: -77.2 TO -3 (DEG C), -107 TO 26.6 (DEG F)

TEMPERATURE [41 (J), 30.2 (FT-LB) ENERGY]: -9.3 (DEG C), 15.2 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -22.2 TO 2.9 (DEG C), -8 TO 37.2 (DEG F)

MIDLAND WELD BELTLINE ALL MATERIAL

95 PERCENT:-37.2 TO 15.4 (DEG C),-35 TO 59.8 (DEG F)

TEMPERATURE [68 (J),50.2 (FT-LB) ENERGY]: 27.8 (DEG C),82.1 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 13.2 TO 48.4 (DEG C),55.7 TO 119.1 (DEG F)

95 PERCENT: 0.8 TO 100.3 (DEG C),33.5 TO 212.5 (DEG F)

REFERENCE TEMPERATURE ANALYSIS

MEAN IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY]-60 (DEG F):-5.9 (DEG C),21.4 (DEG F)

MINIMUM IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY]-60 (DEG F): 14.5 (DEG C),58.2 (DEG F)

REMARK: MIDLAND WELD BELTLINE ALL SECTIONS & THICKNESSES

ANALYSIS SET: MWBELTALL
MODEL PARAMETERS

LOWER SHELF EXPANSION [HELD FIXED]: 0.061 (MM), 0.0024 (IN)

MID-TRANSITION TEMPERATURE: 1 (DEG C), 33.7 (DEG F)

TRANSITION ZONE WIDTH: 126.2 (C DEG), 227.1 (F DEG)

UPPER SHELF EXPANSION: 1.694 (MM), 0.0667 (IN)

STANDARD MODEL: $\text{EXPANSION} = A + B * \text{TANH}((\text{TEMPERATURE} - T_0) / C)$

A: 0.877 (MM), 0.0345 (IN)

B: 0.816 (MM), 0.0321 (IN)

T0: 1 (DEG C), 33.7 (DEG F)

C: 63.1 (C DEG), 113.6 (F DEG)

ORNL-DWG 92-11804

UPPER SHELF EXPANSION: 1.694 (MM), 0.0667 (IN)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 1.533 TO 1.855 (MM), 0.0604 TO 0.073 (IN)

95 PERCENT: 1.376 TO 2.012 (MM), 0.0542 TO 0.0792 (IN)

TEMPERATURE [0.38 (MM), 0.015 (IN) EXPANSION]: -43.7 (DEG C), -46.7 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -69.3 TO -26.8 (DEG C), -92.7 TO -16.2 (DEG F)

95 PERCENT: UNDEFINED TO -13.3 (DEG C), UNDEFINED TO 8.1 (DEG F)

TEMPERATURE [0.89 (MM), 0.035 (IN) EXPANSION]: 1.9 (DEG C), 35.5 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -10.6 TO 14.5 (DEG C), 13 TO 58.1 (DEG F)

MIDLAND WELD BELTLINE ALL MATERIAL

95 PERCENT:-23.8 TO 27.9 (DEG C),-10.8 TO 82.3 (DEG F)

REFERENCE TEMPERATURE ANALYSIS

MEAN IMPACT CURVE

TEMPERATURE [0.035 (IN) EXPANSION]-60 (DEG F):-31.5 (DEG C),-24.7 (DEG F)

MINIMUM IMPACT CURVE

TEMPERATURE [0.035 (IN) EXPANSION]-60 (DEG F):-14.2 (DEG C),6.4 (DEG F)

REMARK: MIDLAND WELD BELTLINE ALL SECTIONS & THICKNESSES

ANALYSIS SET: MWBELTALL

MODEL PARAMETERS

LOWER SHELF SHEAR [HELD FIXED]: 0 (PERCENT)
MID-TRANSITION TEMPERATURE:-2 (DEG C),28.4 (DEG F)
TRANSITION ZONE WIDTH: 84.9 (C DEG),152.9 (F DEG)
UPPER SHELF SHEAR [HELD FIXED]: 100 (PERCENT)

STANDARD MODEL: $SHEAR = A + B * \tanh((TEMPERATURE - T_0) / C)$

A: 50 (PERCENT)
B: 50 (PERCENT)
T0:-2 (DEG C),28.4 (DEG F)
C: 42.5 (C DEG),76.5 (F DEG)

ORNL-DWG 92-11805

UPPER SHELF SHEAR: 100 (PERCENT)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 88.8 TO 111.2 (PERCENT)

95 PERCENT: 77.8 TO 122.2 (PERCENT)

TEMPERATURE [50 (PERCENT),50 (PERCENT) SHEAR]:-2 (DEG C),28.4 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT:-11.8 TO 7.8 (DEG C),10.8 TO 46.1 (DEG F)

95 PERCENT:-22.5 TO 18.5 (DEG C),-8.6 TO 65.3 (DEG F)

REMARK: MIDLAND WELD BELTLINE ALL SECTIONS & THICKNESSES

ANALYSIS SET: MWNCALL

MODEL PARAMETERS

LOWER SHELF ENERGY [HELD FIXED]: 2.7 (J), 2 (FT-LB)

MID-TRANSITION TEMPERATURE: 5.2 (DEG C), 41.4 (DEG F)

TRANSITION ZONE WIDTH: 130.1 (C DEG), 234.1 (F DEG)

UPPER SHELF ENERGY: 87.7 (J), 64.7 (FT-LB)

STANDARD MODEL: $ENERGY = A + B \cdot \tanh((TEMPERATURE - T_0) / C)$

A: 45.2 (J), 33.3 (FT-LB)

B: 42.5 (J), 31.3 (FT-LB)

T0: 5.2 (DEG C), 41.4 (DEG F)

C: 65 (C DEG), 117 (F DEG)

ORNL-DWG 92-11806

UPPER SHELF ENERGY: 87.7 (J), 64.7 (FT-LB)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 81.4 TO 94 (J), 60.1 TO 69.3 (FT-LB)

95 PERCENT: 75.2 TO 100.2 (J), 55.4 TO 73.9 (FT-LB)

TEMPERATURE [27 (J), 19.9 (FT-LB) ENERGY]: -24.5 (DEG C), -12.2 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -37.1 TO -13.9 (DEG C), -34.7 TO 7 (DEG F)

95 PERCENT: -53.1 TO -4.2 (DEG C), -63.6 TO 24.5 (DEG F)

TEMPERATURE [41 (J), 30.2 (FT-LB) ENERGY]: -1.2 (DEG C), 29.8 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -10.8 TO 8.1 (DEG C), 12.6 TO 46.5 (DEG F)

95 PERCENT:-21.2 TO 17.5 (DEG C),-6.2 TO 63.5 (DEG F)
TEMPERATURE [68 (J),50.2 (FT-LB) ENERGY]: 44.2 (DEG C),111.5 (DEG F)
CONFIDENCE INTERVALS ON PREDICTED VALUE
68 PERCENT: 32.3 TO 59 (DEG C),90.1 TO 138.2 (DEG F)
95 PERCENT: 21.9 TO 80.5 (DEG C),71.4 TO 176.9 (DEG F)

REFERENCE TEMPERATURE ANALYSIS

MEAN IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY]-60 (DEG F): 10.4 (DEG C),50.7 (DEG F)

MINIMUM IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY]-60 (DEG F): 24.6 (DEG C),76.2 (DEG F)

ANALYSIS SET: MWNCALL
MODEL PARAMETERS

LOWER SHELF EXPANSION [HELD FIXED]: 0.061 (MM), 0.0024 (IN)

MID-TRANSITION TEMPERATURE: 8.7 (DEG C), 47.7 (DEG F)

TRANSITION ZONE WIDTH: 112.8 (C DEG), 203.1 (F DEG)

UPPER SHELF EXPANSION: 1.483 (MM), 0.0584 (IN)

STANDARD MODEL: $\text{EXPANSION} = A + B \cdot \tanh((\text{TEMPERATURE} - T_0) / C)$

A: 0.772 (MM), 0.0304 (IN)

B: 0.711 (MM), 0.028 (IN)

T0: 8.7 (DEG C), 47.7 (DEG F)

C: 56.4 (C DEG), 101.5 (F DEG)

ORNL-DWG 92-11807

UPPER SHELF EXPANSION: 1.483 (MM), 0.0584 (IN)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 1.337 TO 1.629 (MM), 0.0526 TO 0.0641 (IN)

95 PERCENT: 1.19 TO 1.776 (MM), 0.0469 TO 0.0699 (IN)

TEMPERATURE [0.38 (MM), 0.015 (IN) EXPANSION]: -26.2 (DEG C), -15.2 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: -46.5 TO -11.8 (DEG C), -51.6 TO 10.7 (DEG F)

95 PERCENT: -91.9 TO 0.3 (DEG C), -133.4 TO 32.5 (DEG F)

TEMPERATURE [0.89 (MM), 0.035 (IN) EXPANSION]: 18.2 (DEG C), 64.8 (DEG F)

CONFIDENCE INTERVALS ON PREDICTED VALUE

68 PERCENT: 6.8 TO 30.5 (DEG C), 44.2 TO 87 (DEG F)

95 PERCENT:-4.9 TO 45.3 (DEG C),23.2 TO 113.5 (DEG F)
REFERENCE TEMPERATURE ANALYSIS

MEAN IMPACT CURVE

TEMPERATURE [0.035 (IN) EXPANSION]-60 (DEG F):-15 (DEG C),5 (DEG F)

MINIMUM IMPACT CURVE

TEMPERATURE [0.035 (IN) EXPANSION]-60 (DEG F): 0.8 (DEG C),33.5 (DEG F)

REMARK: MIDLAND WELD NOZZLE COURSE ALL SECTIONS & THICKNESSES

ANALYSIS SET: MWNCALL
MODEL PARAMETERS

LOWER SHELF SHEAR [HELD FIXED]: 0 (PERCENT)
MID-TRANSITION TEMPERATURE: 19.1 (DEG C), 66.4 (DEG F)
TRANSITION ZONE WIDTH: 73.7 (C DEG), 132.7 (F DEG)
UPPER SHELF SHEAR [HELD FIXED]: 100 (PERCENT)
STANDARD MODEL: $SHEAR = A + B * \tanh((TEMPERATURE - T_0) / C)$
A: 50 (PERCENT)
B: 50 (PERCENT)
T₀: 19.1 (DEG C), 66.4 (DEG F)
C: 36.9 (C DEG), 66.4 (F DEG)

ORNL-DWG 92-11808

UPPER SHELF SHEAR: 100 (PERCENT)
CONFIDENCE INTERVALS ON PREDICTED VALUE
68 PERCENT: 91.9 TO 108.1 (PERCENT)
95 PERCENT: 83.8 TO 116.2 (PERCENT)
TEMPERATURE [50 (PERCENT), 50 (PERCENT) SHEAR]: 19.1 (DEG C), 66.4 (DEG F)
CONFIDENCE INTERVALS ON PREDICTED VALUE
68 PERCENT: 12.8 TO 25.4 (DEG C), 55.1 TO 77.7 (DEG F)
95 PERCENT: 6.1 TO 32.1 (DEG C), 43.1 TO 89.8 (DEG F)
REMARK: MIDLAND WELD NOZZLE COURSE ALL SECTIONS & THICKNESSES

ANALYSIS SET: MWall

MODEL PARAMETERS

LOWER SHELF ENERGY [HELD FIXED]: 2.7 (J), 2 (FT-LB)

MID-TRANSITION TEMPERATURE: -2.1 (DEG C), 28.3 (DEG F)

TRANSITION ZONE WIDTH: 112.7 (C DEG), 202.8 (F DEG)

UPPER SHELF ENERGY: 88.5 (J), 65.3 (FT-LB)

STANDARD MODEL: $ENERGY = A + B \cdot \tanh((TEMPERATURE - T_0) / C)$

A: 45.6 (J), 33.6 (FT-LB)

B: 42.9 (J), 31.6 (FT-LB)

T₀: -2.1 (DEG C), 28.3 (DEG F)

C: 56.3 (C DEG), 101.4 (F DEG)

ORNL-DWG 92-11809

UPPER SHELF ENERGY: 88.5 (J), 65.3 (FT-LB)

CONFIDENCE INTERVAL ON PREDICTED VALUE

68 PERCENT: 79.2 TO 97.8 (J), 58.4 TO 72.1 (FT-LB)

TEMPERATURE [27 (J), 19.9 (FT-LB) ENERGY]: -28.2 (DEG C), -18.8 (DEG F)

CONFIDENCE INTERVAL ON PREDICTED VALUE

68 PERCENT: -45.7 TO -14.5 (DEG C), -50.3 TO 5.9 (DEG F)

TEMPERATURE [41 (J), 30.2 (FT-LB) ENERGY]: -8.1 (DEG C), 17.4 (DEG F)

CONFIDENCE INTERVAL ON PREDICTED VALUE

68 PERCENT: -21 TO 4.1 (DEG C), -5.7 TO 39.4 (DEG F)

TEMPERATURE [68 (J), 50.2 (FT-LB) ENERGY]: 30.6 (DEG C), 87.1 (DEG F)

CONFIDENCE INTERVAL ON PREDICTED VALUE

68 PERCENT: 15.8 TO 51.3 (DEG C), 60.4 TO 124.3 (DEG F)
REFERENCE TEMPERATURE ANALYSIS
MEAN IMPACT CURVE
TEMPERATURE [50 (FT-LB) ENERGY]-60 (DEG F): -3.1 (DEG C), 26.4 (DEG F)
MINIMUM IMPACT CURVE
TEMPERATURE [50 (FT-LB) ENERGY]-60 (DEG F): 15 (DEG C), 58.9 (DEG F)
REMARK: MIDLAND WELD ALL LAYERS & THICKNESSES

ANALYSIS SET: MWall

MODEL PARAMETERS

LOWER SHELF ENERGY [HELD FIXED]: 2.7 (J), 2 (FT-LB)

MID-TRANSITION TEMPERATURE: -2.1 (DEG C), 28.3 (DEG F)

TRANSITION ZONE WIDTH: 112.7 (C DEG), 202.8 (F DEG)

UPPER SHELF ENERGY: 88.5 (J), 65.3 (FT-LB)

STANDARD MODEL: $ENERGY = A + B \cdot \tanh((TEMPERATURE - T_0) / C)$

A: 45.6 (J), 33.6 (FT-LB)

B: 42.9 (J), 31.6 (FT-LB)

T0: -2.1 (DEG C), 28.3 (DEG F)

C: 56.3 (C DEG), 101.4 (F DEG)

ORNL-DWG 92-11810

UPPER SHELF ENERGY: 88.5 (J), 65.3 (FT-LB)

CONFIDENCE INTERVAL ON PREDICTED VALUE

90 PERCENT: 73.1 TO 103.9 (J), 53.9 TO 76.6 (FT-LB)

TEMPERATURE [27 (J), 19.9 (FT-LB) ENERGY]: -28.2 (DEG C), -18.8 (DEG F)

CONFIDENCE INTERVAL ON PREDICTED VALUE

90 PERCENT: -62.6 TO -6.3 (DEG C), -80.7 TO 20.6 (DEG F)

TEMPERATURE [41 (J), 30.2 (FT-LB) ENERGY]: -8.1 (DEG C), 17.4 (DEG F)

CONFIDENCE INTERVAL ON PREDICTED VALUE

90 PERCENT: -30.5 TO 12.4 (DEG C), -22.9 TO 54.3 (DEG F)

TEMPERATURE [68 (J), 50.2 (FT-LB) ENERGY]: 30.6 (DEG C), 87.1 (DEG F)

CONFIDENCE INTERVAL ON PREDICTED VALUE

90 PERCENT: 7.3 TO 75.4 (DEG C), 45.2 TO 167.7 (DEG F)
REFERENCE TEMPERATURE ANALYSIS

MEAN IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY]-60 (DEG F): -3.1 (DEG C), 26.4 (DEG F)

MINIMUM IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY]-60 (DEG F): 15 (DEG C), 58.9 (DEG F)

REMARK: MIDLAND WELD ALL LAYERS & THICKNESSES

ANALYSIS SET: MWALL

MODEL PARAMETERS

LOWER SHELF ENERGY [HELD FIXED]: 2.7 (J), 2 (FT-LB)

MID-TRANSITION TEMPERATURE: -2.1 (DEG C), 28.3 (DEG F)

TRANSITION ZONE WIDTH: 112.7 (C DEG), 202.8 (F DEG)

UPPER SHELF ENERGY: 88.5 (J), 65.3 (FT-LB)

STANDARD MODEL: $ENERGY = A + B \cdot \tanh((TEMPERATURE - T_0) / C)$

A: 45.6 (J), 33.6 (FT-LB)

B: 42.9 (J), 31.6 (FT-LB)

T₀: -2.1 (DEG C), 28.3 (DEG F)

C: 56.3 (C DEG), 101.4 (F DEG)

ORNL-DWG 92-11811

UPPER SHELF ENERGY: 88.5 (J), 65.3 (FT-LB)

CONFIDENCE INTERVAL ON PREDICTED VALUE

95 PERCENT: 70.1 TO 106.8 (J), 51.7 TO 78.8 (FT-LB)

TEMPERATURE [27 (J), 19.9 (FT-LB) ENERGY]: -28.2 (DEG C), -18.8 (DEG F)

CONFIDENCE INTERVAL ON PREDICTED VALUE

95 PERCENT: -74.8 TO -2.4 (DEG C), -102.7 TO 27.6 (DEG F)

TEMPERATURE [41 (J), 30.2 (FT-LB) ENERGY]: -8.1 (DEG C), 17.4 (DEG F)

CONFIDENCE INTERVAL ON PREDICTED VALUE

95 PERCENT: -35.7 TO 16.6 (DEG C), -32.3 TO 61.9 (DEG F)

TEMPERATURE [68 (J), 50.2 (FT-LB) ENERGY]: 30.6 (DEG C), 87.1 (DEG F)

CONFIDENCE INTERVAL ON PREDICTED VALUE

95 PERCENT: 3.4 TO 100.5 (DEG C), 38 TO 212.8 (DEG F)
REFERENCE TEMPERATURE ANALYSIS
MEAN IMPACT CURVE
TEMPERATURE [50 (FT-LB) ENERGY]-60 (DEG F): -3.1 (DEG C), 26.4 (DEG F)
MINIMUM IMPACT CURVE
TEMPERATURE [50 (FT-LB) ENERGY]-60 (DEG F): 15 (DEG C), 58.9 (DEG F)
REMARK: MIDLAND WELD ALL LAYERS & THICKNESSES

ANALYSIS SET: MWALL

MODEL PARAMETERS

LOWER SHELF ENERGY [HELD FIXED]: 2.7 (J), 2 (FT-LB)

MID-TRANSITION TEMPERATURE: -2.1 (DEG C), 28.3 (DEG F)

TRANSITION ZONE WIDTH: 112.7 (C DEG), 202.8 (F DEG)

UPPER SHELF ENERGY: 88.5 (J), 65.3 (FT-LB)

STANDARD MODEL: $ENERGY = A + B \cdot \tanh((TEMPERATURE - T_0) / C)$

A: 45.6 (J), 33.6 (FT-LB)

B: 42.9 (J), 31.6 (FT-LB)

T0: -2.1 (DEG C), 28.3 (DEG F)

C: 56.3 (C DEG), 101.4 (F DEG)

ORNL-DWG 92-11812

UPPER SHELF ENERGY: 88.5 (J), 65.3 (FT-LB)

CONFIDENCE INTERVAL ON PREDICTED VALUE

99 PERCENT: 64.3 TO 112.7 (J), 47.4 TO 83.1 (FT-LB)

TEMPERATURE [27 (J), 19.9 (FT-LB) ENERGY]: -28.2 (DEG C), -18.8 (DEG F)

CONFIDENCE INTERVAL ON PREDICTED VALUE

99 PERCENT: -160.3 TO 5.2 (DEG C), -256.6 TO 41.4 (DEG F)

TEMPERATURE [41 (J), 30.2 (FT-LB) ENERGY]: -8.1 (DEG C), 17.4 (DEG F)

CONFIDENCE INTERVAL ON PREDICTED VALUE

99 PERCENT: -47.8 TO 25.6 (DEG C), -54 TO 78.2 (DEG F)

TEMPERATURE [68 (J), 50.2 (FT-LB) ENERGY]: 30.6 (DEG C), 87.1 (DEG F)

CONFIDENCE INTERVAL ON PREDICTED VALUE

99 PERCENT:-4.3 TO UNDEFINED (DEG C),24.3 TO UNDEFINED (DEG F)
REFERENCE TEMPERATURE ANALYSIS

MEAN IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY]-60 (DEG F):-3.1 (DEG C),26.4 (DEG F)

MINIMUM IMPACT CURVE

TEMPERATURE [50 (FT-LB) ENERGY]-60 (DEG F): 15 (DEG C),58.9 (DEG F)

REMARK: MIDLAND WELD ALL LAYERS & THICKNESSES

ANALYSIS SET: MWall

MODEL PARAMETERS

LOWER SHELF EXPANSION [HELD FIXED]: 0.061 (MM), 0.0024 (IN)

MID-TRANSITION TEMPERATURE: 2.4 (DEG C), 36.2 (DEG F)

TRANSITION ZONE WIDTH: 125.1 (C DEG), 225.2 (F DEG)

UPPER SHELF EXPANSION: 1.657 (MM), 0.0652 (IN)

STANDARD MODEL: $\text{EXPANSION} = A + B \cdot \tanh((\text{TEMPERATURE} - T_0) / C)$

A: 0.859 (MM), 0.0338 (IN)

B: 0.798 (MM), 0.0314 (IN)

T₀: 2.4 (DEG C), 36.2 (DEG F)

C: 62.6 (C DEG), 112.6 (F DEG)

ORNL-DWG 92-11813

UPPER SHELF EXPANSION: 1.657 (MM), 0.0652 (IN)

CONFIDENCE INTERVAL ON PREDICTED VALUE

68 PERCENT: 1.485 TO 1.829 (MM), 0.0585 TO 0.072 (IN)

TEMPERATURE [0.38 (MM), 0.015 (IN) EXPANSION]: -41 (DEG C), -41.9 (DEG F)

CONFIDENCE INTERVAL ON PREDICTED VALUE

68 PERCENT: -69 TO -23.1 (DEG C), -92.2 TO -9.5 (DEG F)

TEMPERATURE [0.89 (MM), 0.035 (IN) EXPANSION]: 4.8 (DEG C), 40.6 (DEG F)

CONFIDENCE INTERVAL ON PREDICTED VALUE

68 PERCENT: -8.8 TO 18.6 (DEG C), 16.2 TO 65.4 (DEG F)

REFERENCE TEMPERATURE ANALYSIS

MEAN IMPACT CURVE

TEMPERATURE [0.035 (IN) EXPANSION]-60 (DEG F):-28.6 (DEG C),-19.5 (DEG F)
MINIMUM IMPACT CURVE

TEMPERATURE [0.035 (IN) EXPANSION]-60 (DEG F):-12.9 (DEG C),8.8 (DEG F)
REMARK: MIDLAND WELD ALL LAYERS & THICKNESSES

ANALYSIS SET: MWALL

MODEL PARAMETERS

LOWER SHELF EXPANSION [HELD FIXED]: 0.061 (MM), 0.0024 (IN)

MID-TRANSITION TEMPERATURE: 2.4 (DEG C), 36.2 (DEG F)

TRANSITION ZONE WIDTH: 125.1 (C DEG), 225.2 (F DEG)

UPPER SHELF EXPANSION: 1.657 (MM), 0.0652 (IN)

STANDARD MODEL: $\text{EXPANSION} = A + B \cdot \text{TANH}((\text{TEMPERATURE} - T_0) / C)$

A: 0.859 (MM), 0.0338 (IN)

B: 0.798 (MM), 0.0314 (IN)

T0: 2.4 (DEG C), 36.2 (DEG F)

C: 62.6 (C DEG), 112.6 (F DEG)

ORNL-DWG 92-11814

UPPER SHELF EXPANSION: 1.657 (MM), 0.0652 (IN)

CONFIDENCE INTERVAL ON PREDICTED VALUE

90 PERCENT: 1.372 TO 1.942 (MM), 0.054 TO 0.0764 (IN)

TEMPERATURE [0.38 (MM), 0.015 (IN) EXPANSION]: -41 (DEG C), -41.9 (DEG F)

CONFIDENCE INTERVAL ON PREDICTED VALUE

90 PERCENT: -115 TO -13.3 (DEG C), -174.9 TO 8.1 (DEG F)

TEMPERATURE [0.89 (MM), 0.035 (IN) EXPANSION]: 4.8 (DEG C), 40.6 (DEG F)

CONFIDENCE INTERVAL ON PREDICTED VALUE

90 PERCENT: -18.2 TO 28.4 (DEG C), -0.7 TO 83.2 (DEG F)

REFERENCE TEMPERATURE ANALYSIS

MEAN IMPACT CURVE

TEMPERATURE [0.035 (IN) EXPANSION]-60 (DEG F):-28.6 (DEG C),-19.5 (DEG F)
MINIMUM IMPACT CURVE

TEMPERATURE [0.035 (IN) EXPANSION]-60 (DEG F):-12.9 (DEG C),8.8 (DEG F)
REMARK: MIDLAND WELD ALL LAYERS & THICKNESSES

ANALYSIS SET: MWALL

MODEL PARAMETERS

LOWER SHELF EXPANSION [HELD FIXED]: 0.061 (MM), 0.0024 (IN)

MID-TRANSITION TEMPERATURE: 2.4 (DEG C), 36.2 (DEG F)

TRANSITION ZONE WIDTH: 125.1 (C DEG), 225.2 (F DEG)

UPPER SHELF EXPANSION: 1.657 (MM), 0.0652 (IN)

STANDARD MODEL: $\text{EXPANSION} = A + B \cdot \tanh((\text{TEMPERATURE} - T_0) / C)$

A: 0.859 (MM), 0.0338 (IN)

B: 0.798 (MM), 0.0314 (IN)

T0: 2.4 (DEG C), 36.2 (DEG F)

C: 62.6 (C DEG), 112.6 (F DEG)

ORNL-DWG 92-11815

UPPER SHELF EXPANSION: 1.657 (MM), 0.0652 (IN)

CONFIDENCE INTERVAL ON PREDICTED VALUE

95 PERCENT: 1.318 TO 1.997 (MM), 0.0519 TO 0.0786 (IN)

TEMPERATURE [0.38 (MM), 0.015 (IN) EXPANSION]: -41 (DEG C), -41.9 (DEG F)

CONFIDENCE INTERVAL ON PREDICTED VALUE

95 PERCENT: UNDEFINED TO -8.8 (DEG C), UNDEFINED TO 16.2 (DEG F)

TEMPERATURE [0.89 (MM), 0.035 (IN) EXPANSION]: 4.8 (DEG C), 40.6 (DEG F)

CONFIDENCE INTERVAL ON PREDICTED VALUE

95 PERCENT: -23.1 TO 33.7 (DEG C), -9.5 TO 92.7 (DEG F)

REFERENCE TEMPERATURE ANALYSIS

MEAN IMPACT CURVE

TEMPERATURE [0.035 (IN) EXPANSION]-60 (DEG F):-28.6 (DEG C),-19.5 (DEG F)
MINIMUM IMPACT CURVE

TEMPERATURE [0.035 (IN) EXPANSION]-60 (DEG F):-12.9 (DEG C),8.8 (DEG F)
REMARK: MIDLAND WELD ALL LAYERS & THICKNESSES

ANALYSIS SET: MWall

MODEL PARAMETERS

LOWER SHELF EXPANSION [HELD FIXED]: 0.061 (MM), 0.0024 (IN)

MID-TRANSITION TEMPERATURE: 2.4 (DEG C), 36.2 (DEG F)

TRANSITION ZONE WIDTH: 125.1 (C DEG), 225.2 (F DEG)

UPPER SHELF EXPANSION: 1.657 (MM), 0.0652 (IN)

STANDARD MODEL: $\text{EXPANSION} = A + B \cdot \tanh((\text{TEMPERATURE} - T_0) / C)$

A: 0.859 (MM), 0.0338 (IN)

B: 0.798 (MM), 0.0314 (IN)

T0: 2.4 (DEG C), 36.2 (DEG F)

C: 62.6 (C DEG), 112.6 (F DEG)

ORNL-DWG 92-11816

UPPER SHELF EXPANSION: 1.657 (MM), 0.0652 (IN)

CONFIDENCE INTERVAL ON PREDICTED VALUE

99 PERCENT: 1.21 TO 2.104 (MM), 0.0476 TO 0.0829 (IN)

TEMPERATURE [0.38 (MM), 0.015 (IN) EXPANSION]: -41 (DEG C), -41.9 (DEG F)

CONFIDENCE INTERVAL ON PREDICTED VALUE

99 PERCENT: UNDEFINED TO -0.3 (DEG C), UNDEFINED TO 31.5 (DEG F)

TEMPERATURE [0.89 (MM), 0.035 (IN) EXPANSION]: 4.8 (DEG C), 40.6 (DEG F)

CONFIDENCE INTERVAL ON PREDICTED VALUE

99 PERCENT: -33.7 TO 45.5 (DEG C), -28.7 TO 113.8 (DEG F)

REFERENCE TEMPERATURE ANALYSIS

MEAN IMPACT CURVE

TEMPERATURE [0.035 (IN) EXPANSION]-60 (DEG F):-28.6 (DEG C),-19.5 (DEG F)
MINIMUM IMPACT CURVE

TEMPERATURE [0.035 (IN) EXPANSION]-60 (DEG F):-12.9 (DEG C),8.8 (DEG F)

REMARK: MIDLAND WELD ALL LAYERS & THICKNESSES

ANALYSIS SET: MWALL

MODEL PARAMETERS

LOWER SHELF SHEAR [HELD FIXED]: 0 (PERCENT)

MID-TRANSITION TEMPERATURE: 1.7 (DEG C), 35.1 (DEG F)

TRANSITION ZONE WIDTH: 85.4 (C DEG), 153.8 (F DEG)

UPPER SHELF SHEAR [HELD FIXED]: 100 (PERCENT)

STANDARD MODEL: $SHEAR = A + B * \tanh((TEMPERATURE - T_0) / C)$

A: 50 (PERCENT)

B: 50 (PERCENT)

T0: 1.7 (DEG C), 35.1 (DEG F)

C: 42.7 (C DEG), 76.9 (F DEG)

ORNL-DWG 92-11817

UPPER SHELF SHEAR: 100 (PERCENT)

CONFIDENCE INTERVAL ON PREDICTED VALUE

68 PERCENT: 88.1 TO 111.9 (PERCENT)

TEMPERATURE [50 (PERCENT), 50 (PERCENT) SHEAR]: 1.7 (DEG C), 35.1 (DEG F)

CONFIDENCE INTERVAL ON PREDICTED VALUE

68 PERCENT: -8.7 TO 12.2 (DEG C), 16.3 TO 54 (DEG F)

REMARK: MIDLAND WELD ALL LAYERS & THICKNESSES

ANALYSIS SET: MWALL

MODEL PARAMETERS

LOWER SHELF SHEAR [HELD FIXED]: 0 (PERCENT)

MID-TRANSITION TEMPERATURE: 1.7 (DEG C), 35.1 (DEG F)

TRANSITION ZONE WIDTH: 85.4 (C DEG), 153.8 (F DEG)

UPPER SHELF SHEAR [HELD FIXED]: 100 (PERCENT)

STANDARD MODEL: $SHEAR = A + B * \tanh((TEMPERATURE - T_0) / C)$

A: 50 (PERCENT)

B: 50 (PERCENT)

T0: 1.7 (DEG C), 35.1 (DEG F)

C: 42.7 (C DEG), 76.9 (F DEG)

ORNL-DWG 92-11818

UPPER SHELF SHEAR: 100 (PERCENT)

CONFIDENCE INTERVAL ON PREDICTED VALUE

90 PERCENT: 80.2 TO 119.8 (PERCENT)

TEMPERATURE [50 (PERCENT), 50 (PERCENT) SHEAR]: 1.7 (DEG C), 35.1 (DEG F)

CONFIDENCE INTERVAL ON PREDICTED VALUE

90 PERCENT: -16.3 TO 19.8 (DEG C), 2.7 TO 67.6 (DEG F)

REMARK: MIDLAND WELD ALL LAYERS & THICKNESSES

ANALYSIS SET: MWall

MODEL PARAMETERS

LOWER SHELF SHEAR [HELD FIXED]: 0 (PERCENT)
MID-TRANSITION TEMPERATURE: 1.7 (DEG C), 35.1 (DEG F)
TRANSITION ZONE WIDTH: 85.4 (C DEG), 153.8 (F DEG)
UPPER SHELF SHEAR [HELD FIXED]: 100 (PERCENT)

STANDARD MODEL: $SHEAR = A + B \cdot \tanh((TEMPERATURE - T_0) / C)$

A: 50 (PERCENT)
B: 50 (PERCENT)
T0: 1.7 (DEG C), 35.1 (DEG F)
C: 42.7 (C DEG), 76.9 (F DEG)

ORNL-DWG 92-11819

UPPER SHELF SHEAR: 100 (PERCENT)

CONFIDENCE INTERVAL ON PREDICTED VALUE

95 PERCENT: 76.4 TO 123.6 (PERCENT)

TEMPERATURE [50 (PERCENT), 50 (PERCENT) SHEAR]: 1.7 (DEG C), 35.1 (DEG F)

CONFIDENCE INTERVAL ON PREDICTED VALUE

95 PERCENT: -20.3 TO 23.8 (DEG C), -4.6 TO 74.8 (DEG F)

REMARK: MIDLAND WELD ALL LAYERS & THICKNESSES

ANALYSIS SET: MWALL

MODEL PARAMETERS

LOWER SHELF SHEAR [HELD FIXED]: 0 (PERCENT)

MID-TRANSITION TEMPERATURE: 1.7 (DEG C), 35.1 (DEG F)

TRANSITION ZONE WIDTH: 85.4 (C DEG), 153.8 (F DEG)

UPPER SHELF SHEAR [HELD FIXED]: 100 (PERCENT)

STANDARD MODEL: $SHEAR = A + B \cdot \tanh((TEMPERATURE - T_0) / C)$

A: 50 (PERCENT)

B: 50 (PERCENT)

T0: 1.7 (DEG C), 35.1 (DEG F)

C: 42.7 (C DEG), 76.9 (F DEG)

ORNL-DWG 92-11820

UPPER SHELF SHEAR: 100 (PERCENT)

CONFIDENCE INTERVAL ON PREDICTED VALUE

99 PERCENT: 68.9 TO 131.1 (PERCENT)

TEMPERATURE [50 (PERCENT), 50 (PERCENT) SHEAR]: 1.7 (DEG C), 35.1 (DEG F)

CONFIDENCE INTERVAL ON PREDICTED VALUE

99 PERCENT: -29.7 TO 33.1 (DEG C), -21.4 TO 91.6 (DEG F)

REMARK: MIDLAND WELD ALL LAYERS & THICKNESSES

INTERNAL DISTRIBUTION

1. D. J. Alexander	26-30. R. K. Nanstad
2. B. R. Bass	31. W. E. Pennell
3. E. E. Bloom	32. C. E. Pugh
4. R. D. Cheverton	33. D. K. Shum
5-10. W. R. Corwin	34. G. M. Slaughter
11. D. F. Craig	35. F. W. Stallman
12. S. A. David	36. R. E. Stoller
13. T. L. Dickson	37-39. R. L. Swain
14. K. Farrell	40. T. J. Theiss
15. F. M. Haggag	41. J. A. Wang
16. S. K. Iskander	42. ORNL Patent Section
17. F. B. Kam	43. Central Research Library
18. J. Keeney-Walker	44. Document Reference Section
19. L. K. Mansur	45-46. Laboratory Records Department
20-22. D. E. McCabe	47. Laboratory Records (RC)
23. J. G. Merkle	48-50. M&C Records Office
24-25. M. K. Miller	

EXTERNAL DISTRIBUTION

51. ABB - Combustion Engineering, Windsor, CT 60695
S. T. Byrne
52. AEA TECHNOLOGY-HARWELL, Thermal Reactor Services, Oxfordshire OX11
ORA Great Britain
S. G. Druce
53. ATI, Suite 160, 2010 Crow Canyon Place, San Ramon, CA 94583
W. L. Server
54. BABCOCK AND WILCOX, B&W R&D Division, 1562 Beeson St., Alliance,
OH 44601
W. A. Van Der Sluys
55. BABCOCK AND WILCOX, 3315 Old Forest Road, Lynchburg, VA 24501
A. Lowe
56. R. G. Berggren, 2021 Woodrow Dr., Knoxville, TN 37918

57. BETTIS ATOMIC POWER LABORATORY, Westinghouse Electric Corp.,
P.O. Box 79, West Mifflin, PA 15122

L. A. James

58. CAROLINA POWER AND LIGHT CO., P.O. Box 1551, Raleigh, NC 27602

S. P. Grant

59. CEGB (NUCLEAR ELECTRIC), BERKELEY NUCLEAR LABS., Berkeley, Gloucestershire
GL 139 PB, United Kingdom

R. B. Jones

60. CEN/SCK, Belgium, Reactor Physics Department, Boeretang 200, B-2400MOL, Belgium

A. Fabry

61. EG&G IDAHO, INC., P.O. Box 1625, Idaho Falls, ID 83415-2406

V. Shah

62. ELECTRIC POWER RESEARCH INSTITUTE, P.O. Box 10412, Palo Alto, CA 94303

T. Griesbach

63. GROVE ENGINEERING, Suite 218, 9040 Executive Park Drive, Knoxville,
TN 37923

W. A. Pavinich

64. HANFORD ENGINEERING DEVELOPMENT LABORATORY, P.O. Box 1970, Richland,
WA 99352

M. L. Hamilton

65. JAPAN ATOMIC ENERGY RESEARCH INSTITUTE, Dept. of Reactor Safety Research,
Tokai-Mura, Ibaraki-ken 319-11, Japan

J. Kohsaka

66. MATERIALS ENGINEERING ASSOCIATES, 9700B Martin Luther King, Jr. Highway, Lanham,
MD 20706

J. R. Hawthorne

67. MITSUBISHI HEAVY INDUSTRIES, LTD., Takasago, R & D Center, 2-1-1 Shinhama,
ARI-CHO, Takasago, 676 Japan

Y. Urabe

68-70. NRC, NRR/Division of Engineering Technology, MS 7D4, Washington, DC 20555

B. J. Elliot
J. R. Strosnider
K. R. Wichman

71-76. NRC, RES/Division of Engineering, Washington, DC 20555

A. Hiser (MS NS 217C)
S. N. Malik (MS NS 217C)
M. E. Mayfield (MS NS 217C)
C. Z. Serpan (MS NS 217C)
L. C. Shao (MS NLS 007)
A. Taboada (MS NS 217C)

77. NRC, RES/Division of Safety Issue Resolution, MS NLS 302, Washington, DC 20555

R. E. Johnson

78. ROLLS-ROYCE AND ASSOCIATES LTD., P.O. Box 31, Raynesway, Derby, England

T. Williams

79. STAATL. MATERIALPRUFUNGSANSTALT, Pfaffenwolding 32, 7000 Stuttgart 80, Germany

J. Fohl

80. TECHNICAL RESEARCH CENTER OF FINLAND, Metals Laboratory, Kemistintie 3,
SF-02150 Espoo, Finland

K. Wallin

81-82. UNIVERSITY OF CALIFORNIA, Department of Chemical and Nuclear Engineering, Ward
Memorial Drive, Santa Barbara, CA 93106

G. E. Lucas
G. R. Odette

83. UNIVERSITY OF MISSOURI-ROLLA, Department of Nuclear Engineering, Rolla,
MO 65401

A. S. Kumar

84. E. T. Wessel, Lake Region Mobile Home Village, 312 Wolverine Lane, Haines City,
FL 33844

85-87. WESTINGHOUSE ELECTRIC CORP., P.O. Box 355, Pittsburgh, PA 15230

W. Bamford
T. Mager
R. C. Shogan

88-89. WESTINGHOUSE R&D CENTER, 1310 Beulah Rd., Pittsburgh, PA 15325

J. A. Begley
R. G. Lott

90. G. D. Whitman, 931 West Outer Drive, Oak Ridge, TN 37830

91. DOE OAK RIDGE FIELD OFFICE, P.O. Box 2001, Oak Ridge, TN 37831-6269

Office of Deputy Assistant Manager for Energy Research and Development

92-93. DOE, OFFICE OF SCIENTIFIC AND TECHNICAL INFORMATION, P.O. Box 62, Oak Ridge,
TN 37831

94-222. Given distribution as shown in category RF (NTIS-10)