NUREG/CR-2676
ORNL/Sub/81-85813/1

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Vessel V-8 Repair and Preparation of Low Upper-Shelf Weldment

H. A. Domian

Prepared for the U.S. Nuclear Regulatory Commission
Office of Nuclear Regulatory Research
Under Interagency Agreements DOE 40-551-75 and 40-552-75

OPERATED BY
UNION CARBIDE CORPORATION
FOR THE UNITED STATES
DEPARTMENT OF ENERGY

Printed in the United States of America. Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road, Springfield, Virginia 22161

Available from
GPO Sales Program
Division of Technical Information and Document Control
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

NUREG/CR-2676
ORNL/Sub/81-85813/1
Dist. Category AN
Final Report

VESSEL V-8 REPAIR AND PREPARATION OF LOW UPPER-SHELF WELDMENT

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Manuscript Completed: March 1982

Date Published: June 1982

Report prepared by
Research and Development Division
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Submitted by
Contract Research Division
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UCC-ND Subcontract Nos. 76Y-57301C and 76Y-85813V
B&W Contract Nos. CRD-1055 and CRD-1078

Work funded by
U.S. Nuclear Regulatory Commission
Office of Nuclear Regulatory Research
Under Interagency Agreements 40-551-75 and 40-552-75
NRC FIN No. B0119

Prepared for
OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37830
operated by
UNION CARBIDE CORPORATION
for the
DEPARTMENT OF ENERGY

Contract No. W-7405-eng-26

CONTENTS

CONTENTS (Cont'd)

ILLUSTRATIONS

ILLUSTRATIONS (Cont'd)

TABLES

SUMMARY

This report describes the weld repair of the Heavy Section Steel Technology (HSST) Program Intermediate Test Vessel V-8 and the making of a submerged-arc low upper-shelf test weld as a long seam in the vessel. The development of the low upper-shelf weld metal and its mechanical property characterization, including fracture toughness, is reported.

From replicate characterization weld test results it is expected that the vessel seam test weld properties are likely to have the following values:

Room temperature yield strength (YS)	$\geq$66.3 ksi
Upper-shelf energies (USE)	$\leq$43.5 ft-lbs
J_{1c}	$\leq$0.335 Kip/in. at 300°F
J = 50T	$\leq$1.131 Kip/in. at 300°F

These values are not far different than those reported for some irradiated welds.

1. INTRODUCTION

Intermediate Test Vessel V-8, shown in Figure 1, was tested hydrostatically to failure at about -10°F by the Oak Ridge National Laboratory (ORNL) as part of the Heavy Section Steel Technology (HSST) Program. The test vessel contained a fatigue-sharpened, part-circular surface flaw in a weld repair region where residual stresses were high. The maximum test pressure was about 9470 psi, slightly below the ASME Code design pressure of 9710 psi. The crack propagated until it penetrated the wall and attained a length of about 20 inches. The flawed region was subsequently cut from the vessel, leaving a cavity as shown in Figure 2.

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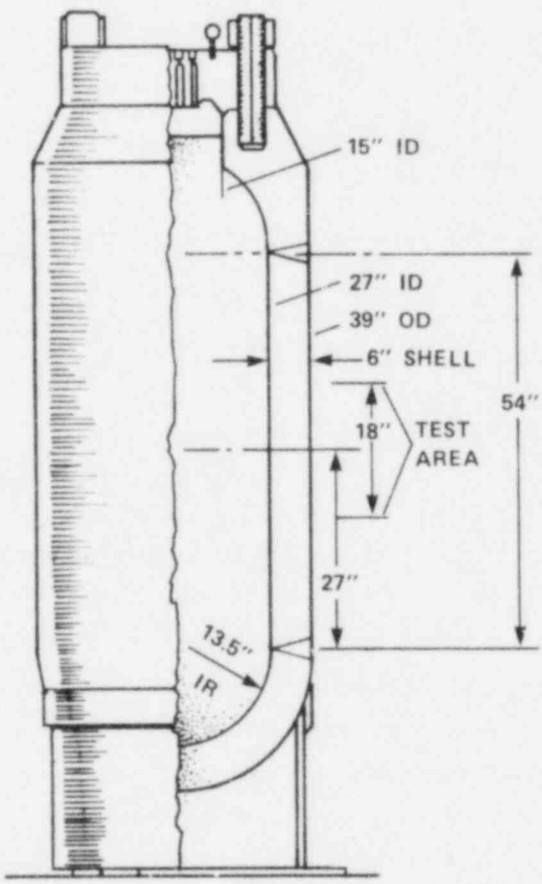

Figure 1 Intermediate Test Vessel V-8

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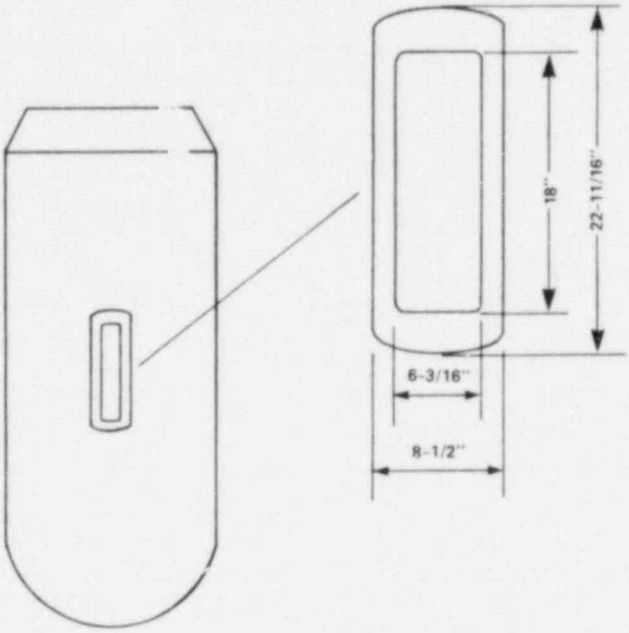

Figure 2   Cavity to be Repaired on Vessel V-8

This report describes the work done to repair that cavity and make a submerged-arc long seam weld having low upper-shelf properties for another test of the vessel, V8A. The purpose of this test is to study crack growth in material with low upper-shelf toughness, particularly material with Charpy V-notch upper-shelf energy (USE) and yield strength (YS) similar to that found in some irradiated weld metal. In addition to the vessel welds, replicates of the long seam weld were made and tested to characterize the mechanical properties of the low upper-shelf weldment.

This program consisted of three principal phases of work:

Phase 1 -- Attainment of Properties in a Trial Weld
(Illustrated in Figure 3)

This consisted of making three submerged-arc welds with the same Mn-Mo-Ni welding wire with different mixtures of Linde 60 and Linde 80 flux. One-third of each weldment was then given a different post weld heat treatment (PWHT). After tensile and impact testing, the optimum condition from the combination of nine was selected to make a trial weld for evaluation of mechanical properties.

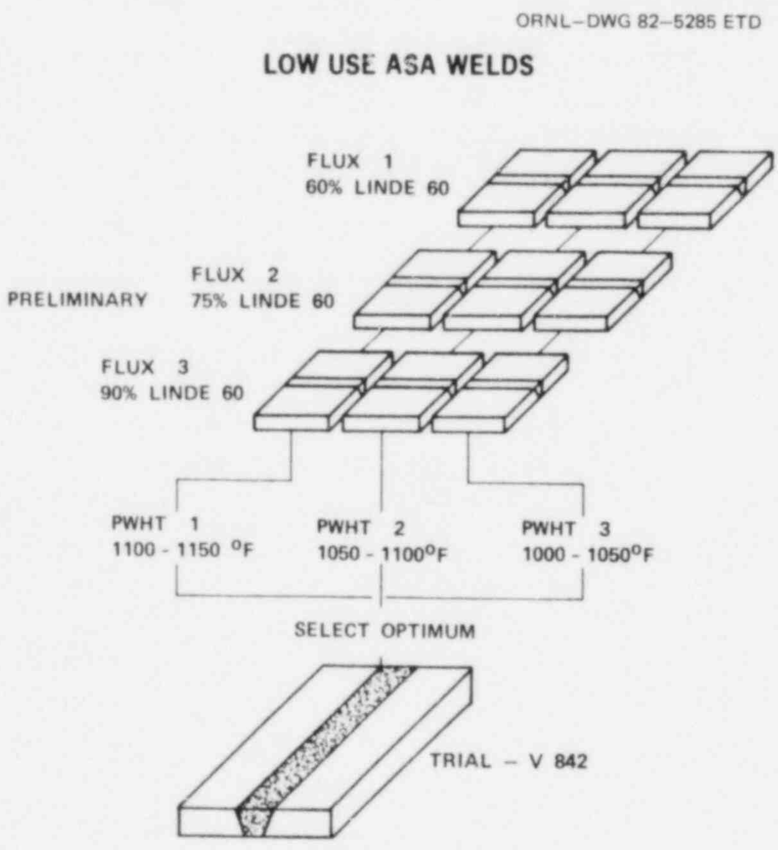

Figure 3 Preliminary and Trail Welds

Phase 2 Making and Testing of Characterization Welds (Illustrated in Figures 4, 5, and 6)

Five characterization and one flawing practice submerged-arc welds were made with the same conditions as those used for the trial and vessel long seam test weld. Four of the characterization welds were made in Vessel V-10 (SA533-B1 steel) prolongation as shown in Figure 4.

The fifth characterization weld was made from pieces of 6-inch thick SA533-B1 steel plate (Heat No. C6200-4) as shown in Figure 5.

The flawing practice weld -- to be used by Union Carbide Corporation - Nuclear Division (UCC-ND) in setting the flawing parameters for the vessel long seam test weld -- was made with pieces of SA533-B1 steel plate (Heat No. C6200-4) as shown in Figure 6.

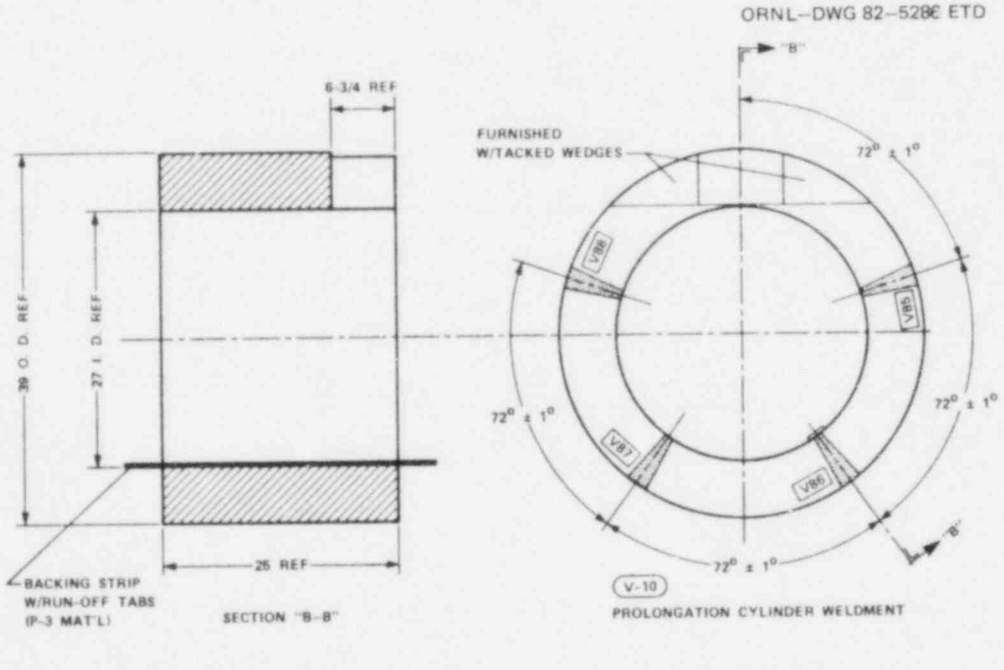

Figure 4 Characterization Welds Made in Vessel V-10 Prolongation (Welds V852, V862, V872, and V882)

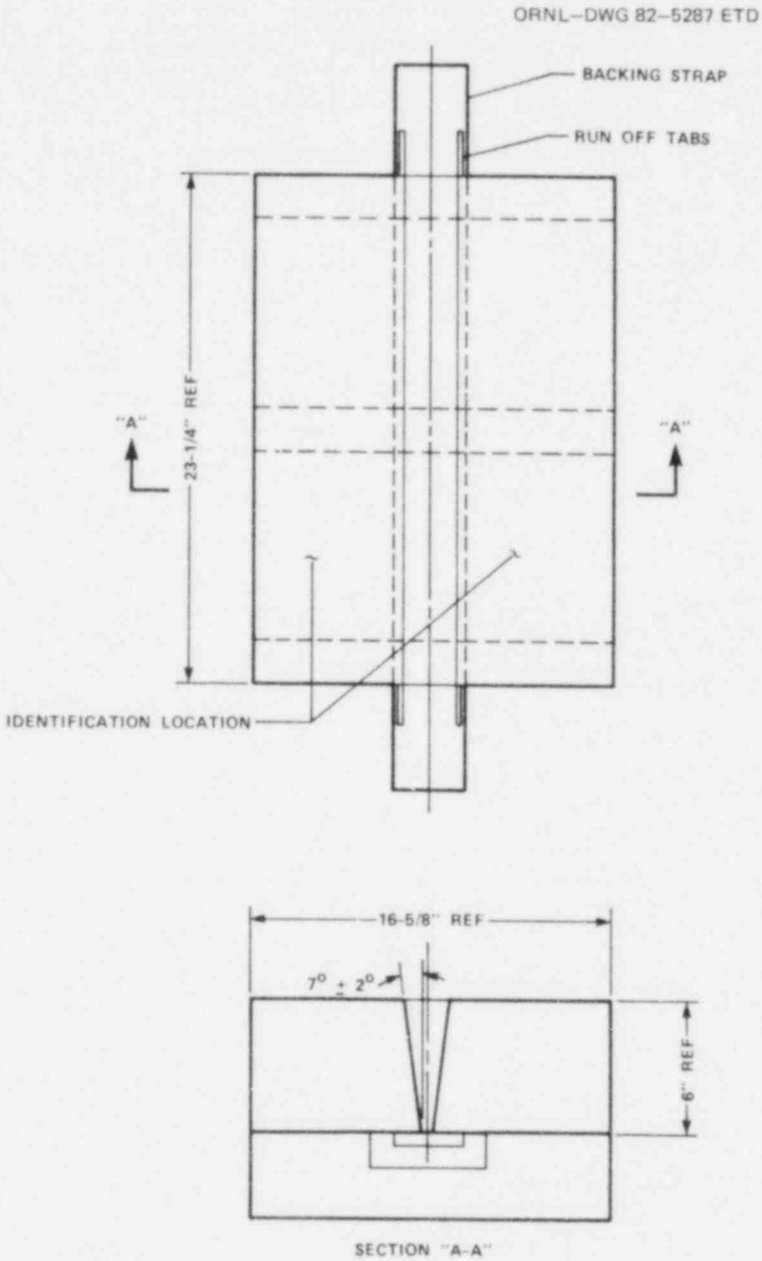

Figure 5 Fifth Characteristic Weld (V8102)

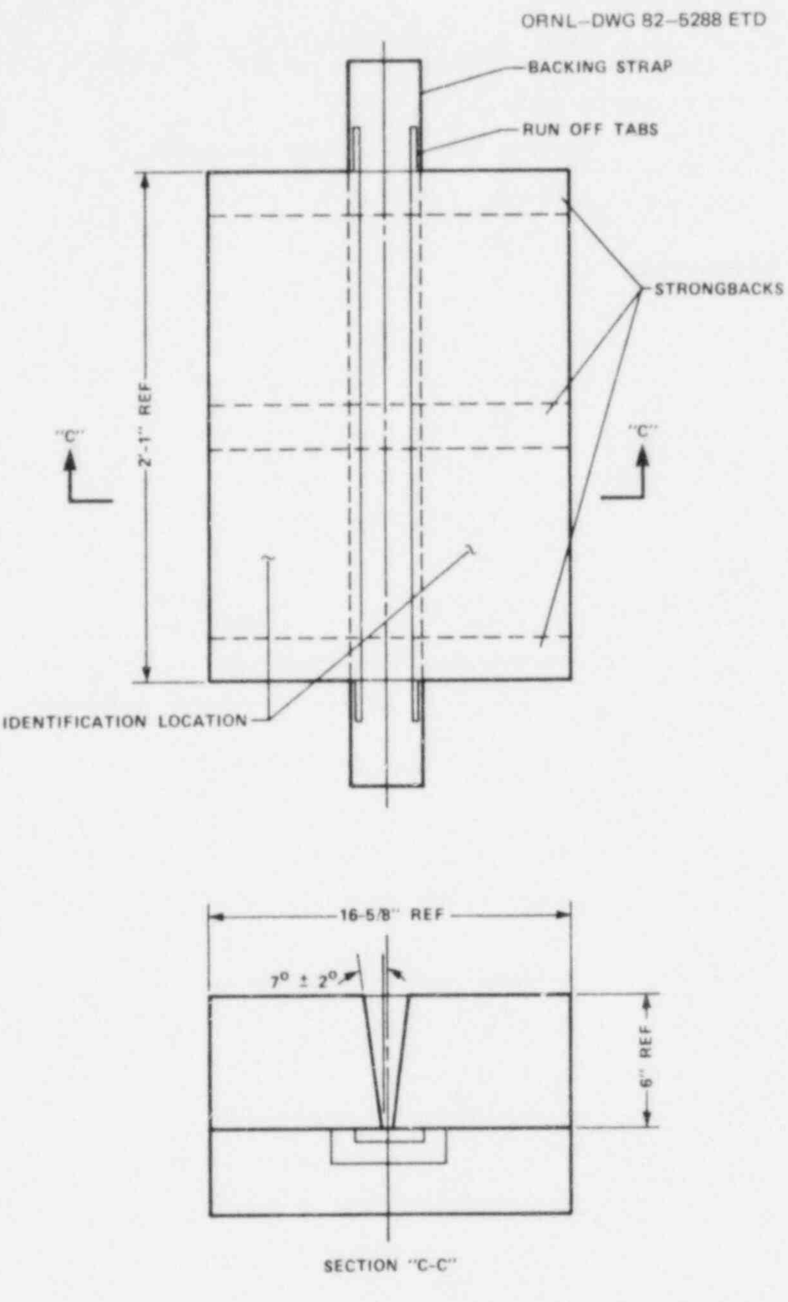

Figure 6 Flawing Practice Weld (V892)

Phase 3 -- Repair of Vessel and Making of Long Seam Test Weld
(Illustrated in Figure 7)

The repair to the vessel cavity was accomplished by manual metal arc (MMA) welding of a plug insert. The long seam test weld was done by making a submerged-arc weld with the same conditions as the trial weld except that it had MMA welds on the ends.

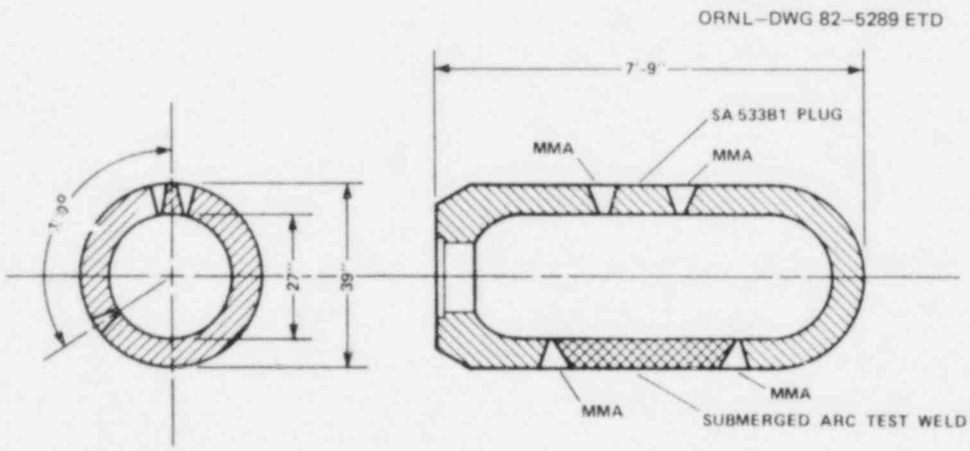

Figure 7 Vessel Repair and Long Seam Test Weld

2. PHASE 1 -- TRIAL WELDS

2.1 PRELIMINARY WELDS AND THEIR TESTS

The effects of submerged-arc welding flux basicity and post weld heat treatment (PWHT) temperatures on tensile and impact properties were determined with three weldments made in 3-3/4-inch thick SA533-B1 steel plate for a combination of nine conditions. The making of these weldments and their test results are given in Appendix A.

The nine combinations, shown previously in Figure 3, are identified as follows:

Flux Mixture, %		Calculated Nominal BN*	Mean PWHT Hold Temperature, °F		
			1135	1075	1025
Linde 60	Linde 80		Weld Designations		
60	40	0.75	V811	V812	V813
75	25	0.70	V821	V822	V823
90	10	0.65	V831	V832	V833

* Basicity number (BN) = $\frac{CaO + MgO + CaF_2 + 1/2\ MnO}{SiO_2 + 1/2\ Al_2O_3}$ (All wt %)

Increasing the proportion of Linde 60 flux decreases the basicity of the flux and this results in both lower upper-shelf energies (USE) and yield strength (YS).

The effects of flux mixture composition (Basicity Number - BN) and PWHT on the impact properties and tensile properties are summarized in Figures 8 and 9.

Based on these results, the optimum conditions for low impact transition temperature, low USE, and high YS were obtained with the mid-range conditions of the test matrix, namely:

- Flux Mixture -- 75% Linde 60 - 25% Linde 80
- PWHT Hold Temperature -- 1050° - 1100°F

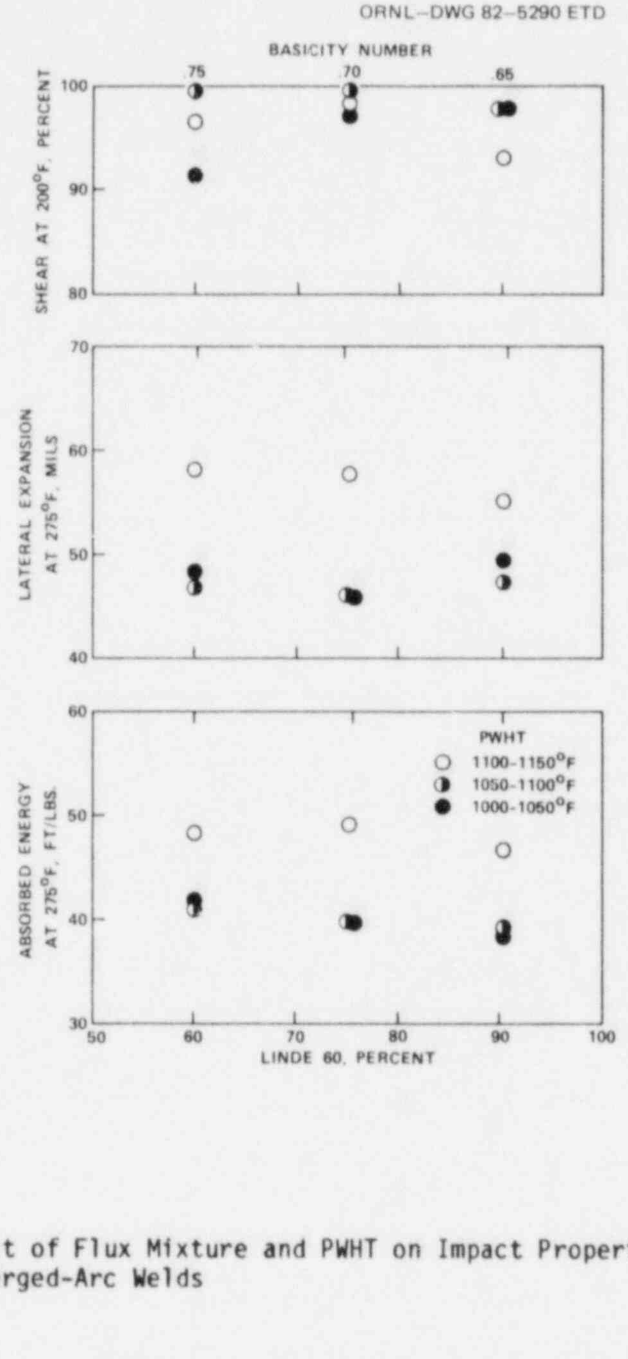

Figure 8 Effect of Flux Mixture and PWHT on Impact Properties of Mn-Mo-Ni Submerged-Arc Welds

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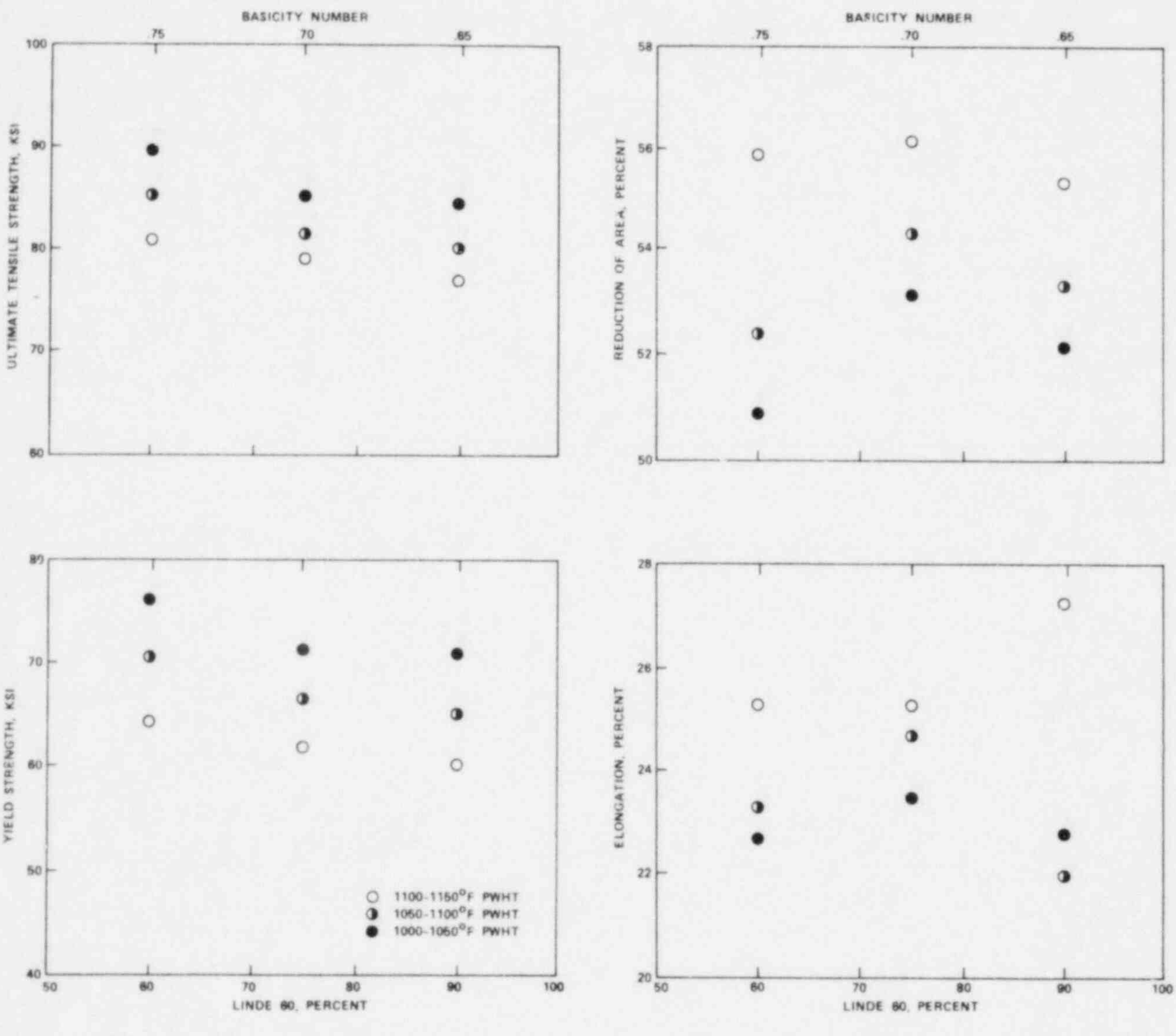

Figure 9   Effect of Flux Mixture and PWHT on Tensile Properties of Mn-Mo-Ni Submerged-Arc Welds

These conditions were used for Weld V822 and were also used to make a trial weld. A brief attempt was made to reduce the impact transition temperature so that the upper-shelf start temperature would be below 200°F. This was done with a different heat of welding wire. An attempt at using a lower heat input (70 - 85 kJ/in.) for the larger diameter (5/32") wire was unsuccessful. The result at higher heat input is summarized below with details in Appendix B.

2.2 DIFFERENT WIRE HEAT

The effect of making a wire heat change on impact properties are shown in Figures 10 and B-2 (Appendix B) by comparison with the results of Weld V822 -- the optimum of the preliminary welds. The effect on impact transition temperature is illustrated in Figure 10 with a plot of shear versus test temperature for specimens having less than 100% shear. There was apparently no benefit in making the welding wire change and the trial weld was therefore made with the same conditions as Preliminary Weld V822 except that a lower heat input (~76 versus 92 kJ/in.) was used.

2.3 TRIAL WELD

This weldment, with the same thickness (6 inches) as the Vessel V-8 wall, was to serve as a qualification weld for the vessel test seam and is described in detail in Appendix C together with test results. Comparisons of the trial weld (V842) and its precursor (V822) are shown in Table 1. The difference in heat inputs between the two welds did not apparently have a significant effect. The difference in manganese content between the two welds may be significant but this is not reflected in the measured mechanical properties.

The objectives of 65 ksi minimum YS and USE value of 35 - 55 ft-lbs were achieved with the trial weld.

Three of the four 1T compact tension J-integral tests performed on WL orientation specimens gave valid results and these are shown in Figure 11. Good agreement and little effect due to test temperature differences was obtained.

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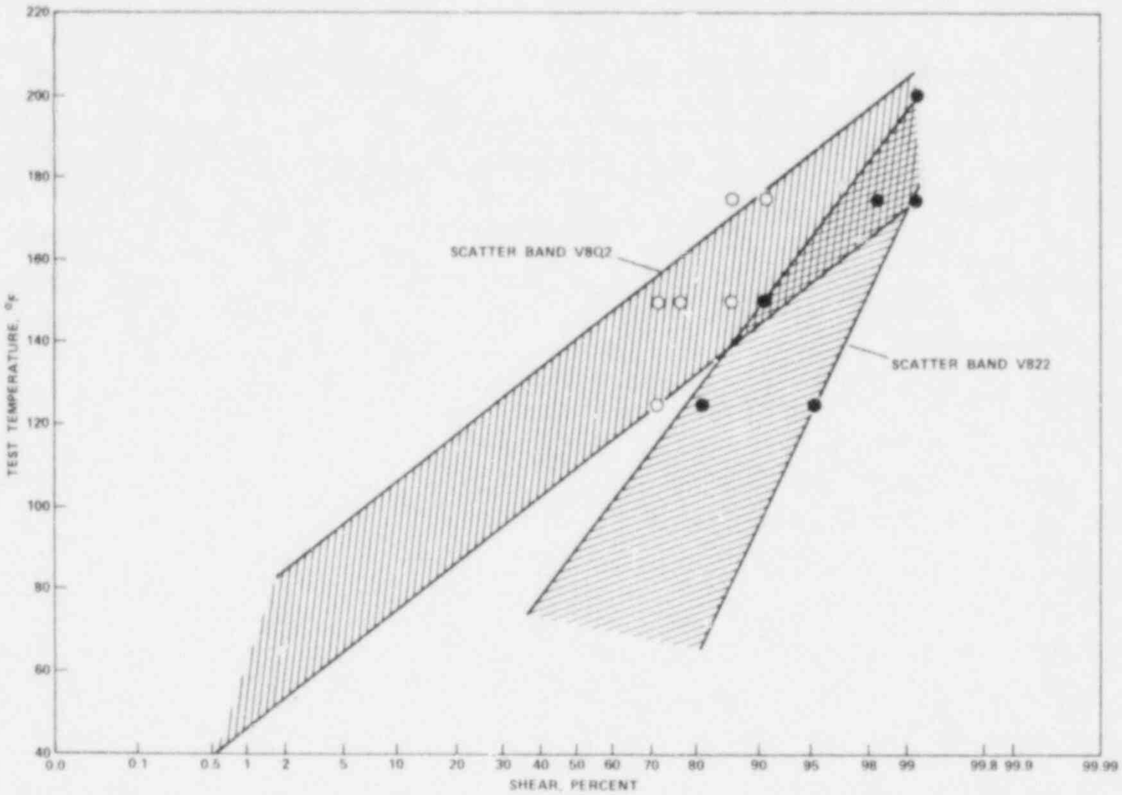

Figure 10 Comparison of Impact Test Results for Welds V8Q2 and V822 in the Transition Region

Table 1

COMPARISONS OF AVERAGE VALUES

	Weld	
Weld Chemistry, %	V822	V842
C	0.06	0.05
Mn	1.61	1.50
P	0.024	0.028
S	0.017	0.016
Si	0.65	0.66
Ni	0.61	0.62
Mo	0.48	0.45
Cu	0.29	0.27
Plate (Weld) Thickness, in.	3-3/4	6
Heat Input, kJ/in.	92	76
PWHT		
Heating Rate, °F/hr	59.4	148.0
Hold Time, hours	50	52
Hold Temperature, °F	1075	1083
Cooling Rate, °F/hr	12.2	10.2
Room Temperature Tension Test		
Yield Strength, ksi	66.87	66.74
Ultimate Tensile Strength, ksi	81.87	82.39
Elongation, %	24.7	25.8
Reduction of Area, %	54.4	55.3
Charpy V-Notch Tests		
USE, ft-lbs (200° - 300°F)	42.2	42.8
LE, mils (200° - 300°F)	47.9	49.5

2.4 BASE METAL TENSION TEST RESULTS

A partial cylindrical piece, approximately 6" thick x 12-7/8" wide and 38-1/2" long, from Vessel V-8 was received from UCC-ND. About 9 inches was cut off each end of the long dimension. The remainde s given the following PWHT together with the weld designated as V8Q2.

2.4.1 Post Weld Heat Treatment (PWHT)

The following PWHT was achieved for the base metal designated as V802:

Heating rate - 600° to 1050°F: 140°F/hr
Hold time at 1050° - 1100°F : 58 hours
Cooling rate - 1050° to 600°F: 13.8°F/hr

The intended 100°F/hr maximum heating rate and 52-hour maximum hold time were exceeded, but these are not significant.

2.4.2 Specimen Locations

Figure 12 shows the general location and orientation of the tension test specimens.

2.4.3 Tension Test Results

Three specimens each were tested at room temperature and at 250°F. These results are given in Table 2.

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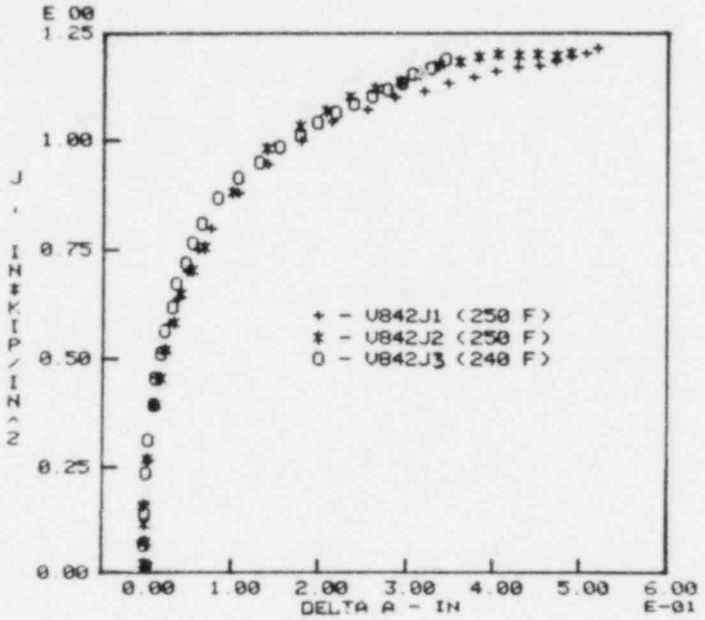

Figure 11 J-R Curves for Trial Weld Test Specimens (V842J1/J2/J3)

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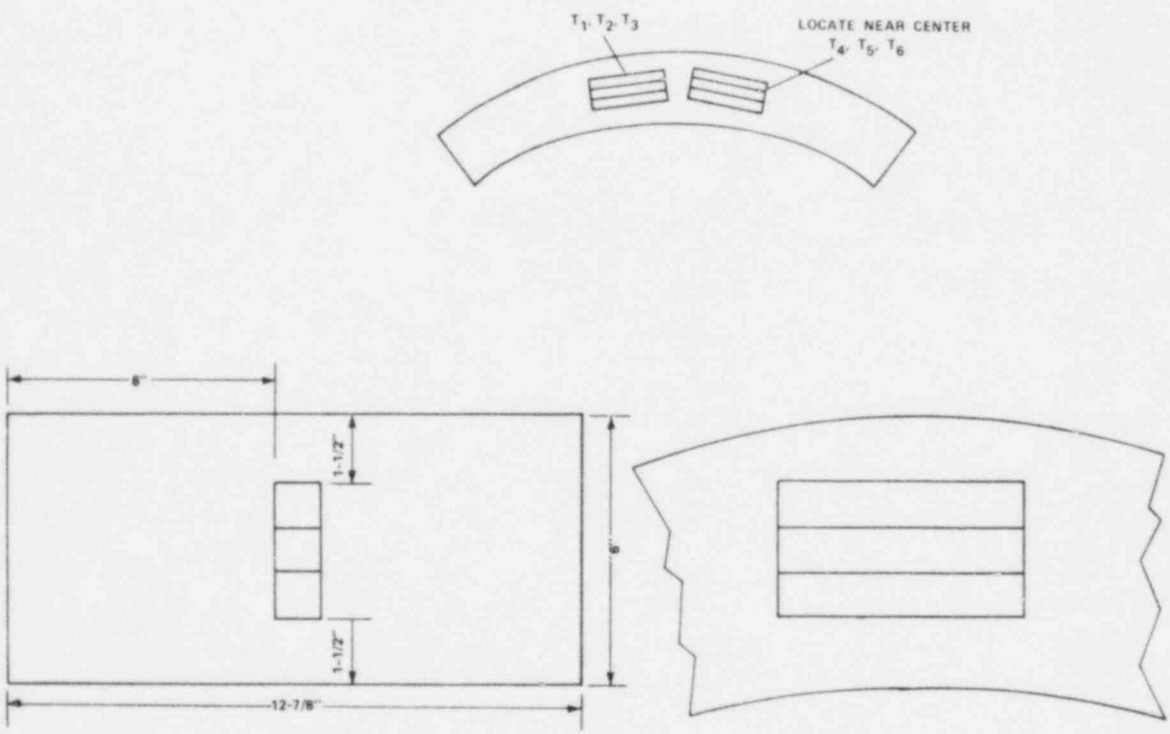


Figure 12 Cutting Diagram for the V802 Base Metal Tension Tests

Table 2

BASE METAL (V802) TENSION TEST RESULTS

Specimen Number	Yield Strength ksi	Ultimate Tensile Strength, ksi	Elongation, %	Reduction of Area, %
		Room Temperature		
V802T1	65.10	86.31	28.0	70.2
2	65.74	87.10	28.0	70.6
3	65.90	87.07	27.5	70.4
		SA 533 B1 Specification		
	50.0 Min.	80.0 - 100.0	18.0 Min.	---
		250°F Test Temperature		
4	60.18	79.62	25.0	69.5
5	60.13	80.10	26.0	69.9
6	59.88	79.30	26.0	70.7

3. PHASE 2 -- FLAWING PRACTICE AND CHARACTERIZATION WELDS

Testing was performed in accordance with the requirements of the following specifications:

- Tension Testing - ASTM E-8-80 or E-21-80
- Charpy V-Notch Impact Testing - ASTM E-23-72
- Plane Strain Fracture Toughness - ASTM E-399-78
- J-Integral - Charpy V-Notch - ASTM E-813-81 (except that specimens contained side grooves)
- J-Integral - Compact Tension - B&W's Single Specimen J-Test (TP 367)
- Drop Weight - ASTM E-208-69
- Weld Bend Tests - SFA 5.17, Section II, ASME BPVC
- Chemical Analysis - NB 2432, Section III, ASME BPVC
- Radiography - Section III, ASME BPVC (except indications up to twice that allowed by Section III are acceptable)
- Macrostructure - Surface grinding followed by etching in 10% nitric acid-ethanol solution

One flawing practice and five material characterization welds were made at The Babcock & Wilcox Company's (B&W) Nuclear Equipment Division (NED) production shops with the same conditions of electrode wire heat, flux mixture, welding parameters, and post weld heat treatment (PWHT) temperature as those used for the trial weld. The flawing practice weld was used by Union Carbide Corporation - Nuclear Division (UCC-ND) to evaluate the flawing procedure to be used on the Vessel V-8A seam test weld.

The characterization welds consisted of four welds made in Vessel V-10 prolongation and one weld made in plate material. Details of the welding conditions are given in Appendix D together with test results.

Figure 13 shows the cutting diagrams for four of the welds (designated V852, V862, V882, and V8102). The first three were made in the prolongation and Weld V8102 was made in plate material. Weld V872 was intended for material characterization tests but instead was used by UCC-ND for a second flawing practice trial.

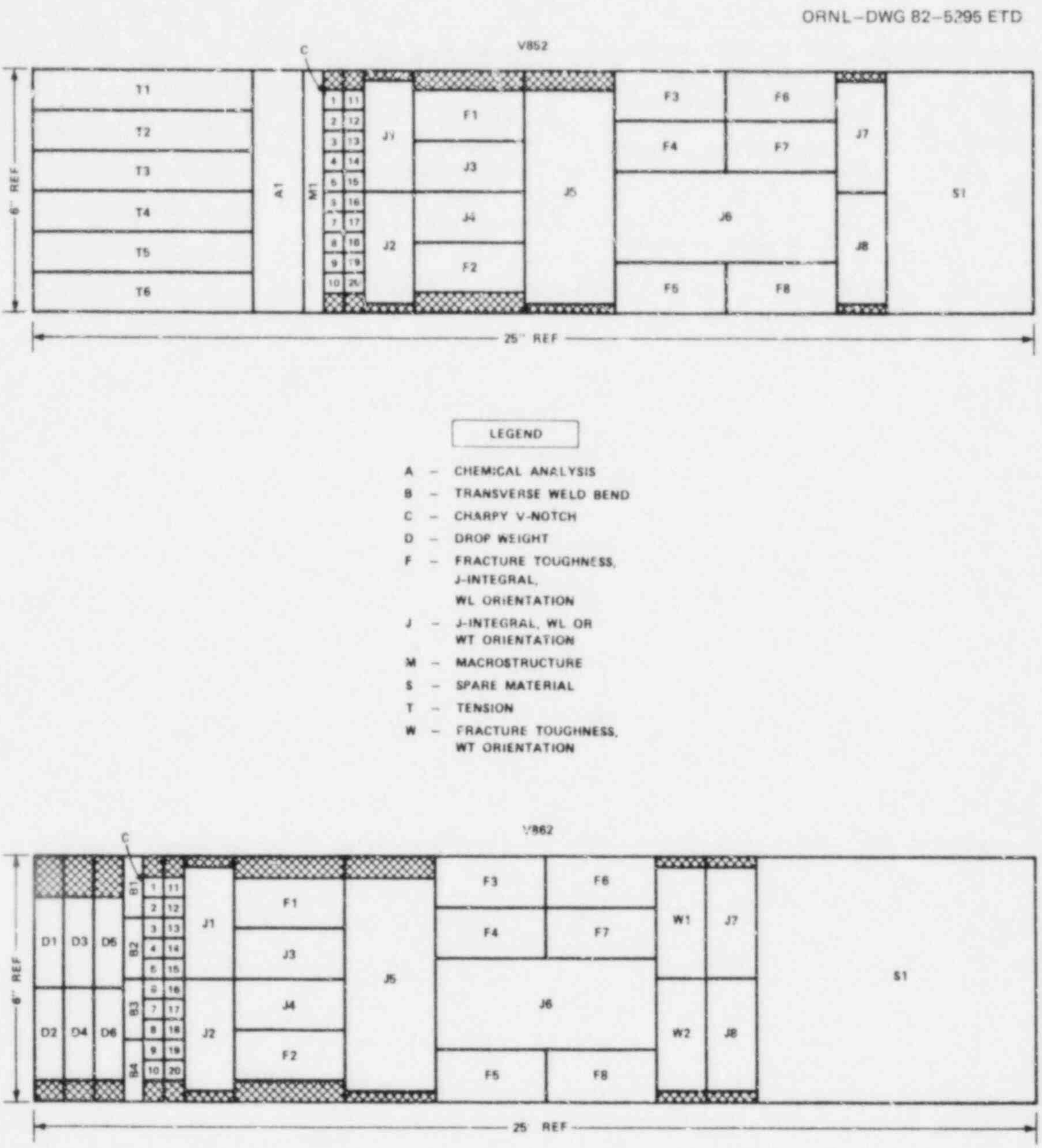
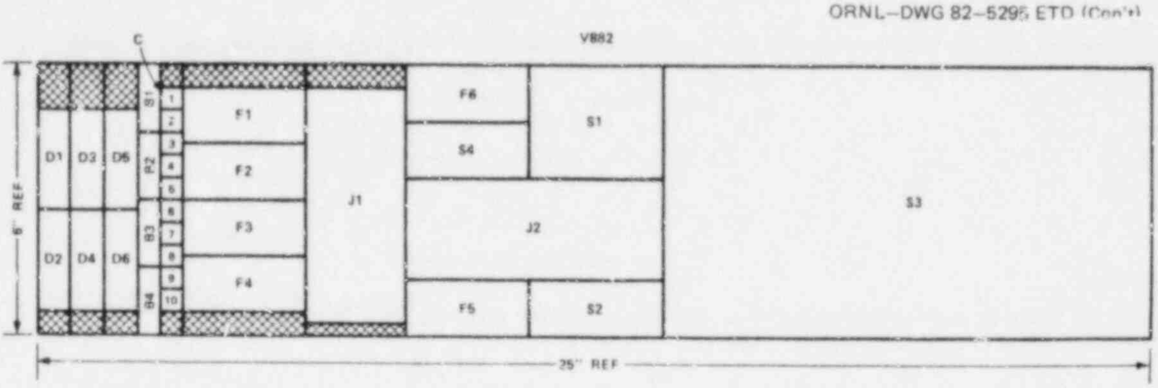


Figure 13 Side-View Cutting Diagrams for Characterization Welds V852, V862, V882, and V8102



LEGEND

A – CHEMICAL ANALYSIS
B – TRANSVERSE WELD BEND
C – CHARPY V-NOTCH
D – DROP WEIGHT
F – FRACTURE TOUGHNESS, J-INTEGRAL, WL ORIENTATION
J – J-INTEGRAL, WL OR WT ORIENTATION
M – MACROSTRUCTURE
S – SPARE MATERIAL
T – TENSION
W – FRACTURE TOUGHNESS, WT ORIENTATION

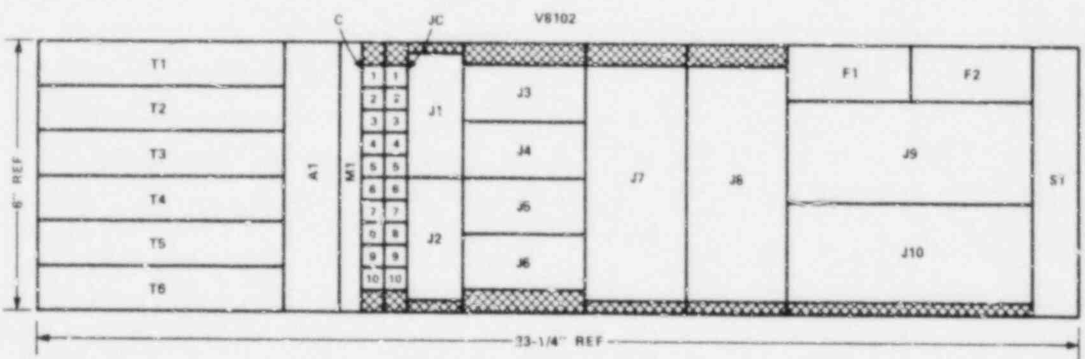


Figure 13 Side-View Cutting Diagrams for Characterization Welds V852, V862, V882, and V8102 (Cont'd)

3.1 TENSION TEST RESULTS

Six room temperature and elevated temperature (300°F) tension tests each were performed on Welds V852 and V8102. These results are given in Table 3.

Table 3

ALL WELD METAL TENSILE TEST RESULTS

Specimen Identification	Test Temp. °F	Yield Strength ksi	Ultimate Strength ksi	Elongation %	Reduction of Area %
		Weld V852			
T1	75	61.0	78.0	27.0	58.5
T3	75	62.0	78.5	28.0	57.5
T5	75	64.0	81.5	25.5	57.5
Average		62.3	79.3	26.8	57.8
T2	300	53.5	69.5	24.0	55.5
T4	300	58.0	73.5	22.5	54.0
T6	300	58.5	74.0	21.5	50.5
Average		56.7	72.3	22.7	53.3
		Weld V8102			
T1	75	68.0	82.5	24.0	55.0
T3	75	69.5	84.5	23.0	53.5
T5	75	70.5	86.0	21.5	51.5
Average		69.3	84.3	22.8	53.3
T2	300	62.0	76.0	20.0	51.5
T4	300	63.0	77.0	19.5	49.5
T6	300	65.5	79.5	18.5	50.0
Average		63.5	77.5	19.3	50.3

3.2 CHARPY V-NOTCH IMPACT TEST RESULTS

These results are shown in Figures 14, 15, and 16 for welds V852, V862, V882, and V8102. The variability at one test temperature is mainly due to the depth position within the weld.

The mean upper-shelf energies (USE) values calculated from specimens that exhibit 100% shear regardless of test temperature or location in the weld are given in Table 4.

3.3 FRACTURE TOUGHNESS PROPERTIES

3.3.1 Plane Strain Fracture Toughness Tests

Tests were performed near 0°F and ambient temperature (~75°F) with 1T compact tension test specimens having 20% side grooves*. These results are summarized in Table 5. Values for K_Q were not calculated since $P_{max}/P_Q > 1.10$. Valid equivalent energy (K_{EQ}), fracture toughness from J-integral (K_J) and J-integral values at maximum load were derived.

3.3.2 J-Integral Tests

J-Integral tests were performed with 20% side-grooved 3-point bend Charpy V-notch, 1TCT, and 2TCT specimens at temperatures of 73°, 150°, 200°, 250°, and 300°F. These test results are summarized in Table 6 and the J-R curves shown in Figures 17 through 23.

Additional tests were performed on Weld V8102 with J-Integral tests of 3-point bend Charpy V-notch specimens having 5% and 10% side grooves; these test results are given in Appendix E.

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* Side grooves are in nonconformance with ASTM E-399-78 thereby producing invalid plane strain fracture toughness results. This occurred because of a mistake in machining instructions.

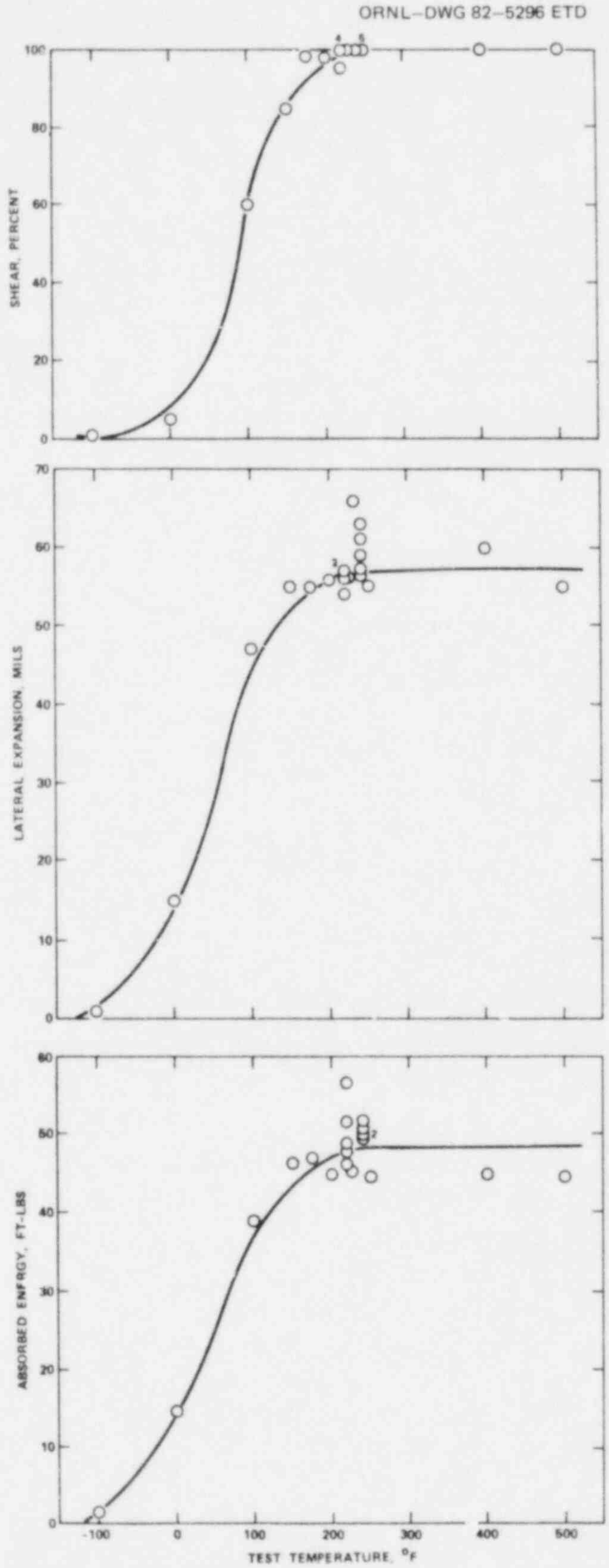

Figure 14 Charpy V-Notch Impact Test Results for Weld V852

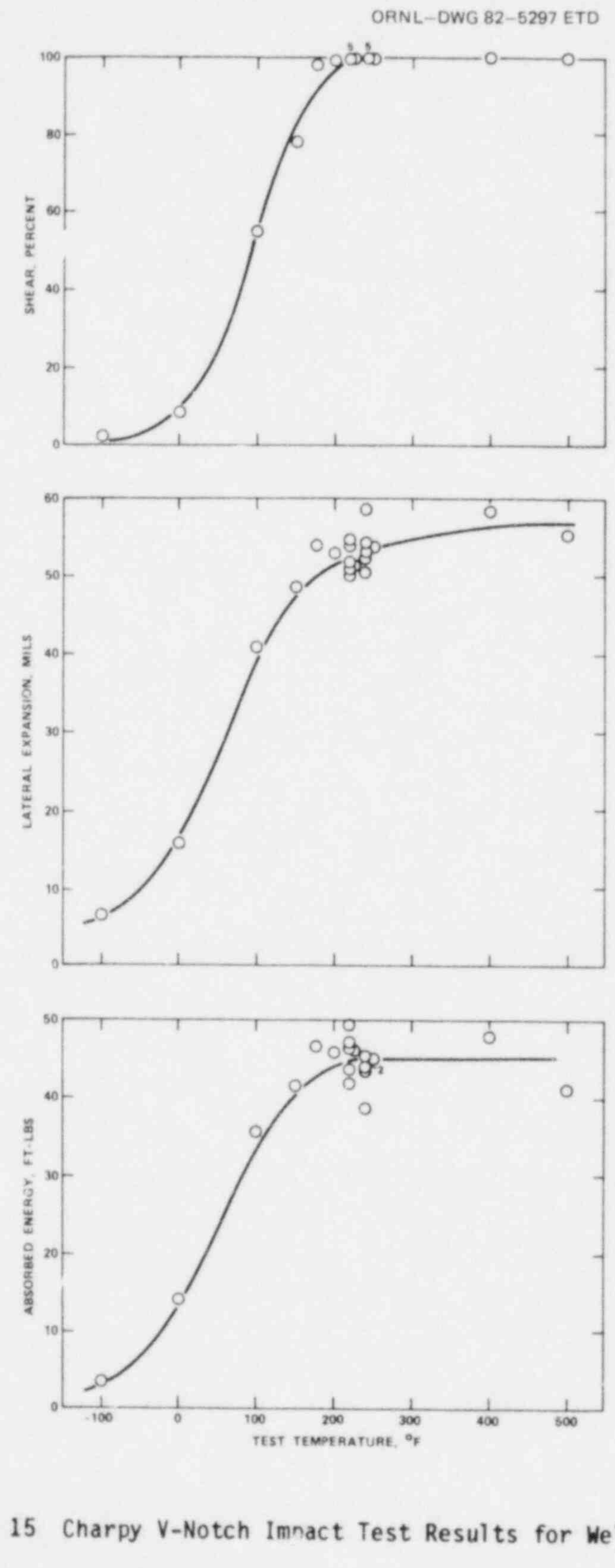

Figure 15 Charpy V-Notch Impact Test Results for Weld V862

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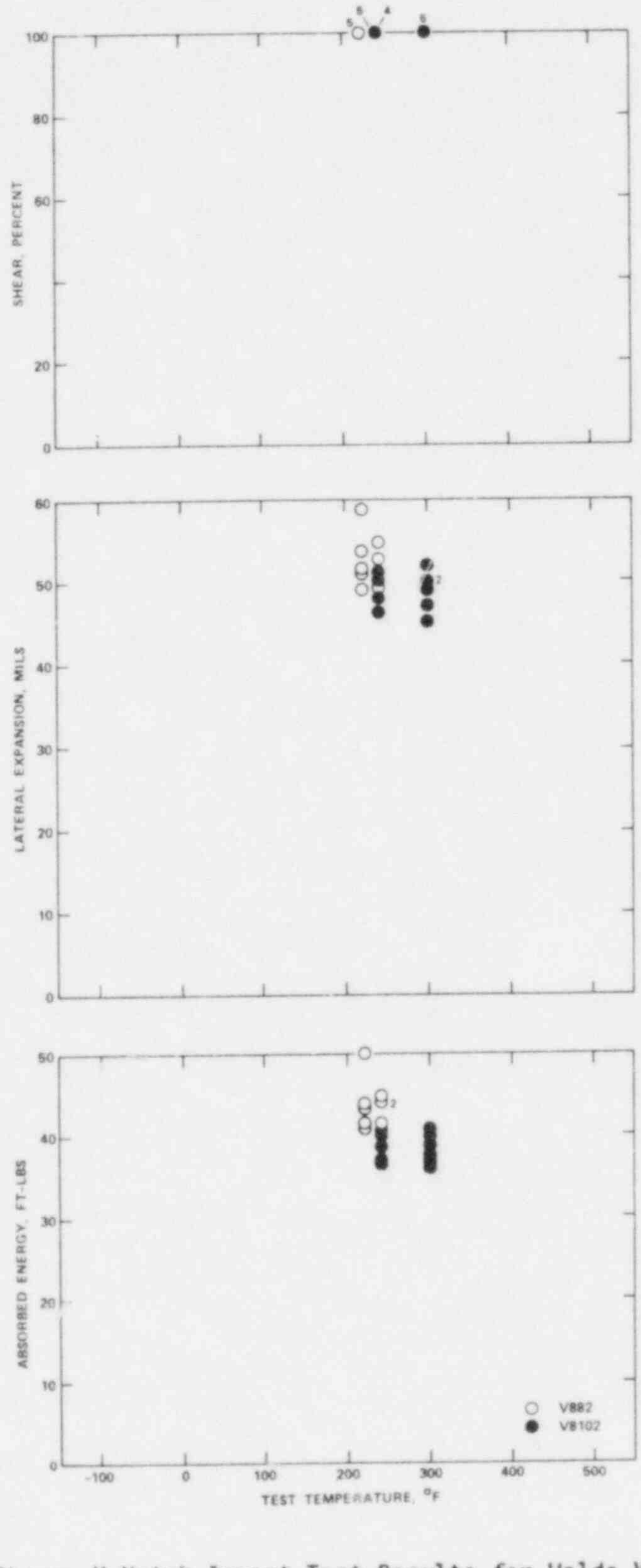


Figure 16 Charpy V-Notch Impact Test Results for Welds V882 and V8102

Table 4

MEAN UPPER-SHELF ENERGIES (USE) VALUES

Weld	Specimen Orientation	No. of Specimens Having 100% Shear	Average Test Temp., °F	USE, ft-lbs Mean	USE, ft-lbs ±1 SD
V852	WL	13	266	48.9	3.5
V862	WL	13	265	45.6	2.9
V882	WL	10	230	43.5	2.7
V8102	WL	5	276	37.4	1.1
	WT	5	276	38.9	1.8
	WL or WT	10	276	38.1	1.6
All 4 combined	WL or WT	46	260	44.1	4.7

Table 5

PLANE STRAIN FRACTURE TOUGHNESS RESULTS

Specimen Identification	Test Temp.* °F	K_{EQ}, ksi $\sqrt{in.}$	K_J, ksi $\sqrt{in.}$	J**, Kip/in.
V852F4	7	169	151	0.763
V852F5	4	183	164	0.899
V852F7	5	142	92	0.512
V852F8	5	182	159	0.847
V862W1	71	226	204	1.39
V862W2	71	221	199	1.32
V8102F1	5	105	124	0.282

* Average of start and finish temperatures.
** At maximum load. Some crack extension may have occurred.

Table 6

J-TEST RESULTS

Specimen Identification	Size	Orientation	Approximate Depth in Weld, in.	Net Thickness, in.	Crack Length, in. Initial	Crack Length, in. Final	Corrected Modulus 10^6 psi	Test Temp. °F	J_{1c}, Kip/in.* 1	2	3	Mean	±1 SD	J = 50T Kip/in.	T = J/50
V842/J1	1TCT	WL	1.5 - 2.8	.791	1.004	1.529	32.00	250	.374	.376	.383	.378	.005	.857	17.137
/J2	1TCT	WL	3.5 - 4.5	.797	1.003	1.496	31.75	250	.372	.350	.346	.356	.014	.906	18.120
/J3	1TCT	WL	1.5 - 2.8	.790	1.113	1.465	31.35	240	.403	.401	.393	.399	.005	.899	17.982
/J4	1TCT	WL			Invalid Test - Irregular Initial Crack Front										
V852/F1	1TCT	WL	.5 - 1.8	.798	1.053	1.383	30.43	250	.417	.419	.423	.420	.003	1.428	28.556
/F2	1TCT	WL	4.3 - 5.5	.800	1.065	1.483	30.58	200	.427	.423	.422	.424	.003	1.167	23.342
/F3	1TCT	WL	0 - 1.3	.797	1.048	1.369	29.48	200	.278	.293	.307	.293	.015	1.543	30.869
/F6	1TCT	WL	0 - 1.3	.799	1.048	1.367	29.62	200	.483	.491	.497	.490	.007	1.492	29.846
/J1	1TCT	WT			Fractured at Load Line During Fatigue Precracking										
/J2	1TCT	WT			Fractured at Load Line During Fatigue Precracking										
/J3	1TCT	WL	1.8 - 3.0	.800	1.055	1.540	30.52	300	.408	.405	.408	.407	.002	1.313	26.250
/J4	1TCT	WL	3.0 - 4.3	.803	1.054	1.473	30.63	300	.660	.653	.657	.657	.004	1.216	24.323
/J5	2TCT	WT	3.5 - 4.5	1.614	2.130	2.985	30.05	300	.281	.272	.289	.281	.009	1.430	28.607
/J6	2TCT	WL	2.5 - 4.8	1.618	2.101	2.883	30.24	300	.422	.367	.422	.404	.032	1.315	26.300
/J7	1TCT	WT			Test not Completed - Machine Malfunctioned										
/J8	1TCT	WT	4.5 - 5.0	.798	1.107	1.578	30.79	300	.234	.250	.245	.273	.044	1.330	26.596
V862/F1	1TCT	WL	.5 - 1.8	.792	1.047	1.362	29.63	250	.443	.431	.437	.437	.006	1.411	28.223
/F2	1TCT	WL	4.3 - 5.5	.799	1.057	1.433	29.49	250	.402	.396	.402	.400	.003	1.318	26.366
/F3	1TCT	WL	0 - 1.3	.798	1.042	1.311	29.80	200	.462	.390	.392	.415	.041	1.711	34.229
/F4	1TCT	WL	1.3 - 2.5	.794	1.172	1.364	30.20	73	.450	.445	.450	.448	.003	1.747	34.942
/F5	1TCT	WL	4.8 - 6.0	.798	1.068	1.425	30.54	73	.399	.329	.398	.375	.040	1.372	27.431
/F7	1TCT	WL	1.3 - 2.5	.803	1.052	1.288	30.88	73	.545	.540	.553	.546	.007	1.888	37.755
/F8	1TCT	WL	4.8 - 6.0	.799	1.062	1.433	30.74	73	.466	.463	.459	.463	.004	1.303	26.068
/J1	1TCT	WT			Fractured at Load Line During Fatigue Precracking										
/J2	1TCT	WT			Fractured at Load Line During Fatigue Precracking										
/J3	1TCT	WL	1.8 - 3.0	.808	1.105	1.416	30.22	300	.310	.325	.347	.327	.019	1.368	27.360
/J4	1TCT	WL	3.0 - 4.3	.802	1.044	1.437	30.45	300	.439	.446	.445	.443	.004	1.260	25.205
/J5	2TCT	WT	3.5 - 4.5	1.614	2.219	2.972	30.08	300	.264	.274	.274	.271	.006	1.335	26.701
/J6	2TCT	WL	2.5 - 4.8	1.609	2.166	2.949	30.38	300	.426	.415	.410	.417	.008	1.361	27.226
/J7	1TCT	WT	1.8 - 2.3	.805	1.093	1.534	30.14	300	.346	.363	.352	.354	.008	1.666	33.321
/J8	1TCT	WT	4.5 - 5.0	.800	1.140	1.523	29.92	300	.270	.270	.348	.296	.045	1.388	27.768

* J_{1c} was determined by three independent operators.

Table 6

J-TEST RESULTS (Cont'd)

Specimen Identification	Size	Orientation	Approximate Depth in Weld, in.	Net Thickness, in.	Crack Length, in. Initial	Crack Length, in. Final	Corrected Modulus 10^6 psi	Test Temp. °F	J_{Ic}, Kip/in.* 1	2	3	Mean	±1 SD	J = 50T Kip/in.	T = J/50
V882/F1	1TCT	WL	.5 - 1.8	.788	1.046	1.340	30.65	150	.434	.383	.394	.404	.027	1.656	33.126
/F2	1TCT	WL	1.8 - 3.0	.798	1.046	1.378	30.81	150	.357	.354	.343	.351	.007	1.206	24.120
/F3	1TCT	WL	3.0 - 4.3	.801	1.063	1.512	30.47	150	.411	.335	.341	.362	.042	1.196	23.922
/F4	1TCT	WL	4.3 - 5.5	.799	1.040	1.427	30.50	150	.442	.428	.428	.433	.008	1.381	27.610
/F5	1TCT	WL	4.3 - 5.5	.799	1.070	1.476	30.89	150	.453	.447	.447	.449	.003	1.254	25.071
/F6	1TCT	WL	0 - 1.3	.808	1.084	1.468	30.57	200	.425	.413	.413	.417	.007	1.268	25.356
/J1	2TCT	WT	3.5 - 4.5	1.617	2.244	3.155	30.00	300	.279	.284	.353	.305	.041	1.127	22.534
/J2	2TCT	WL	2.5 - 4.8	1.618	2.263	3.131	30.38	300	.373	.365	.368	.369	.004	1.058	21.163
V8102/F2	1TCT	WL			Specimen Broke During Test			73							
/J1	1TCT	WT	1.8 - 2.3	.800	1.104	1.578	30.14	300	.156	.150	.177	.161	.014	.735	14.691
/J2	1TCT	WT	4.5 - 5.0	.797	1.095	1.592	30.34	300	.339	.336	.285	.320	.030	.651	13.012
/J3	1TCT	WL	.5 - 1.8	.801	1.064	1.531	30.93	300	.269	.273	.274	.272	.003	.723	14.453
/J4	1TCT	WL	1.8 - 3.0	.805	1.073	1.521	31.21	300	.256	.257	.260	.258	.002	.753	15.054
/J5	1TCT	WL	3.0 - 4.3	.795	1.062	1.565	31.43	300	.188	.192	.196	.192	.004	.675	13.500
/J6	1TCT	WL	4.3 - 5.5	.800	1.068	1.570	31.25	300	.273	.238	.240	.250	.020	.684	13.678
/J7	2TCT	WT	3.5 - 4.5	1.628	2.276	3.197	29.67	300	.262	.259	.262	.261	.002	.662	13.232
/J8	2TCT	WT	3.5 - 4.5	1.616	2.333	3.098	30.49	300	.261	.258	.269	.263	.006	.696	13.923
/J9	2TCT	WL	1.3 - 3.5	1.617	2.153	3.056	29.93	300	.264	.262	.260	.262	.002	.815	16.290
/J10	2TCT	WL	3.5 - 5.8	1.618	2.147	3.265	30.00	300	.217	.237	.236	.230	.011	.734	14.679
/JC1	Cv	WL	.5 - 1.0	.306	.201	.258	28.00	300	.153	--	--	--	--	.374	7.475
/JC2	Cv	WT	1.0 - 1.2	.311	.192	.275	28.00	300	.171	--	--	--	--	.456	9.1[illegible]9
/JC3	Cv	WL	1.5 - 2.0		Fractured During Fatigue Precracking										
/JC4	Cv	WT	2.1 - 2.2	.311	.203	.283	28.00	300	.206	--	--	--	--	.405	8.108
/JC5	Cv	WL	2.5 - 3.0	.307	.200	.280	28.00	300	.157	--	--	--	--	.356	7.116
/JC6	Cv	WT	3.1 - 3.2	.309	.199	.281	28.00	300	.127	--	--	--	--	.397	7.933
/JC7	Cv	WL	3.5 - 4.0	.311	.197	.282	28.00	300	.182	--	--	--	--	.377	7.549
/JC8	Cv	WT	4.1 - 4.2	.310	.225	.284	28.00	300	.135	--	--	--	--	.391	7.821
/JC9	Cv	WL	4.5 - 5.0	.310	.187	.271	28.00	300	.179	--	--	--	--	.412	8.244
/JC10	Cv	WT	5.1 - 5.2	.311	.221	.297	28.00	300	.181	--	--	--	--	.411	8.214

* J_{Ic} was determined by three independent operators.

ORNL-DWG 82-5299 ETD

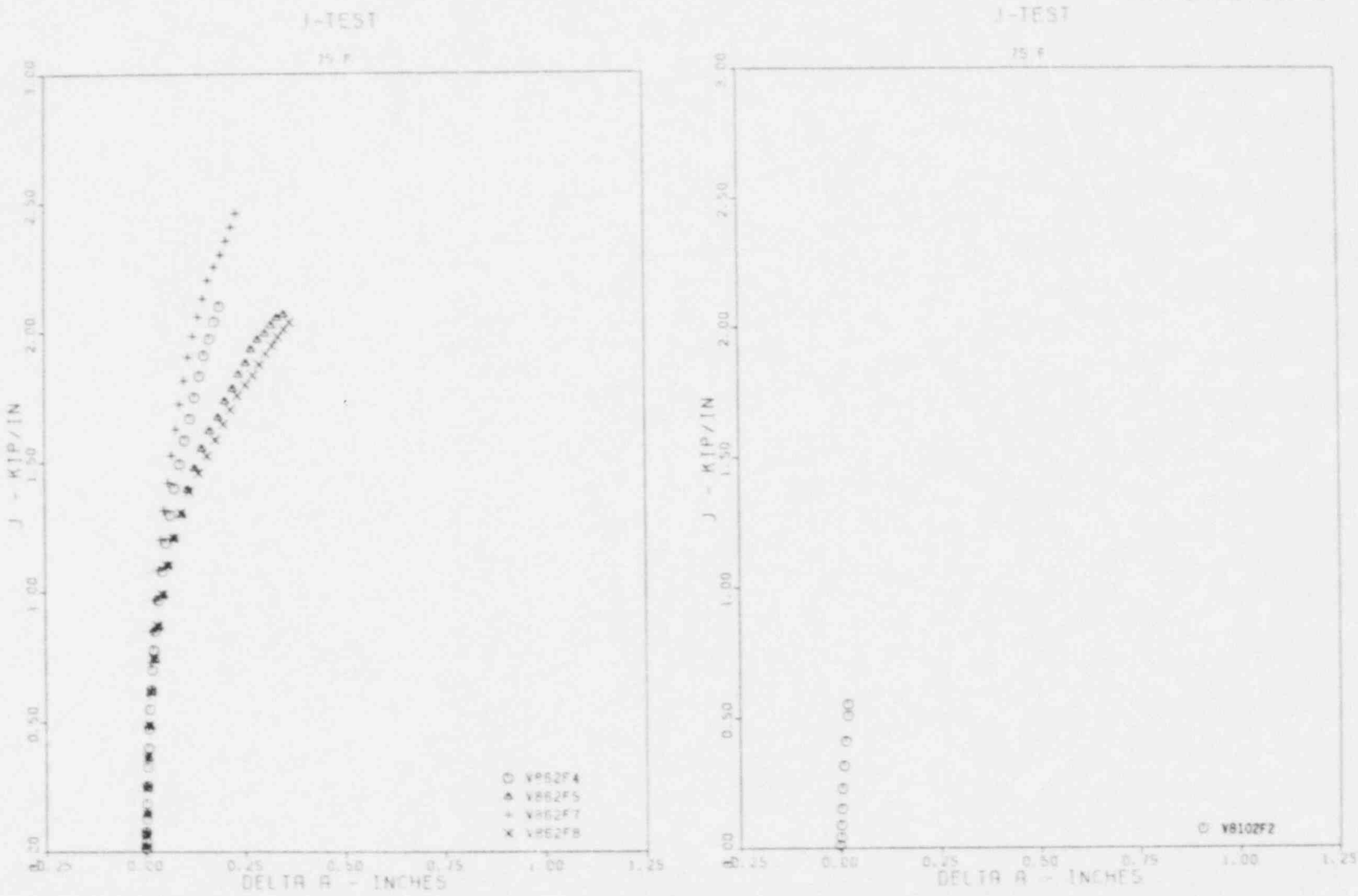


Figure 17 J-R Curves

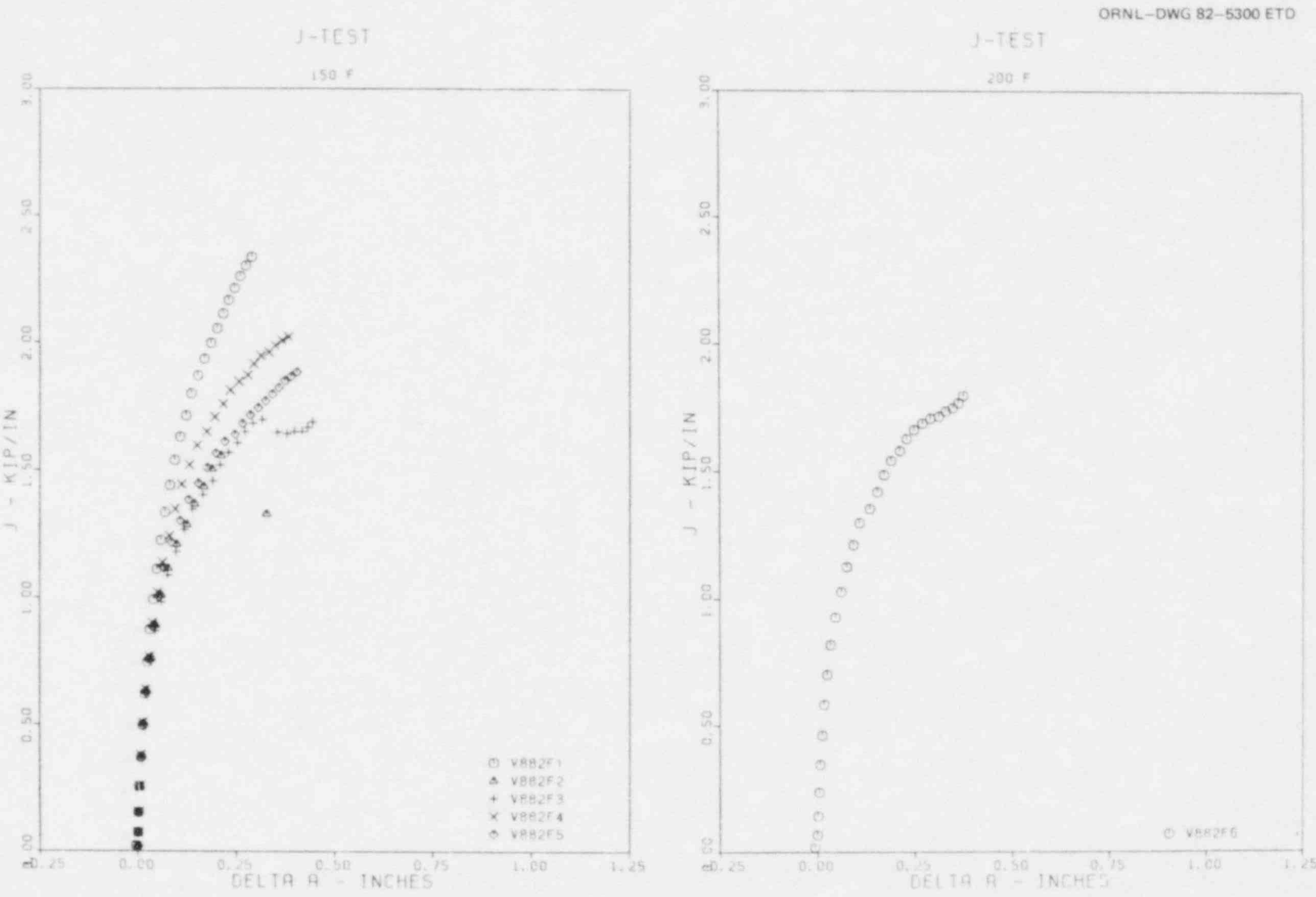


Figure 18 J-R Curves

ORNL-DWG 82-5301 ETD

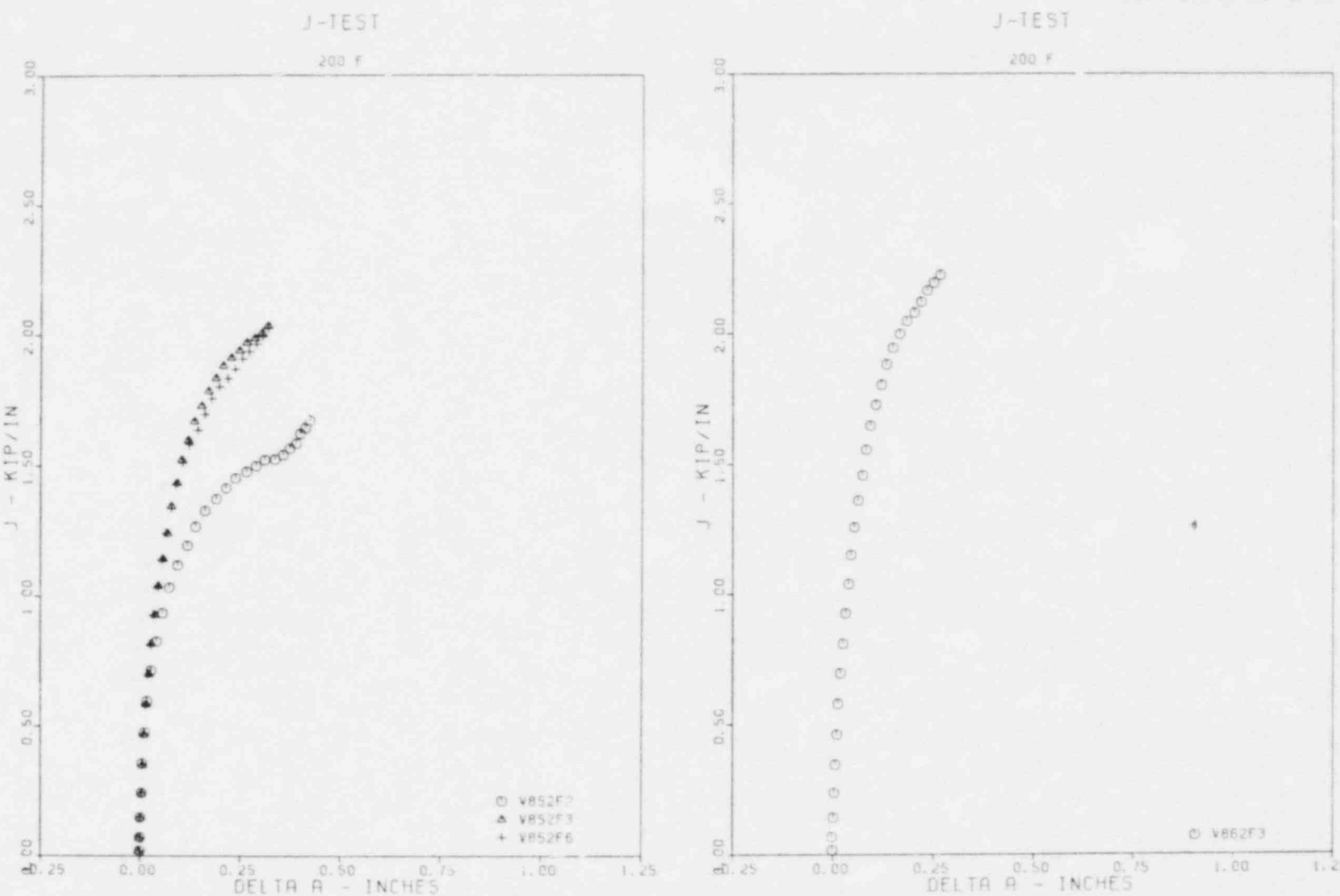


Figure 19 J-R Curves

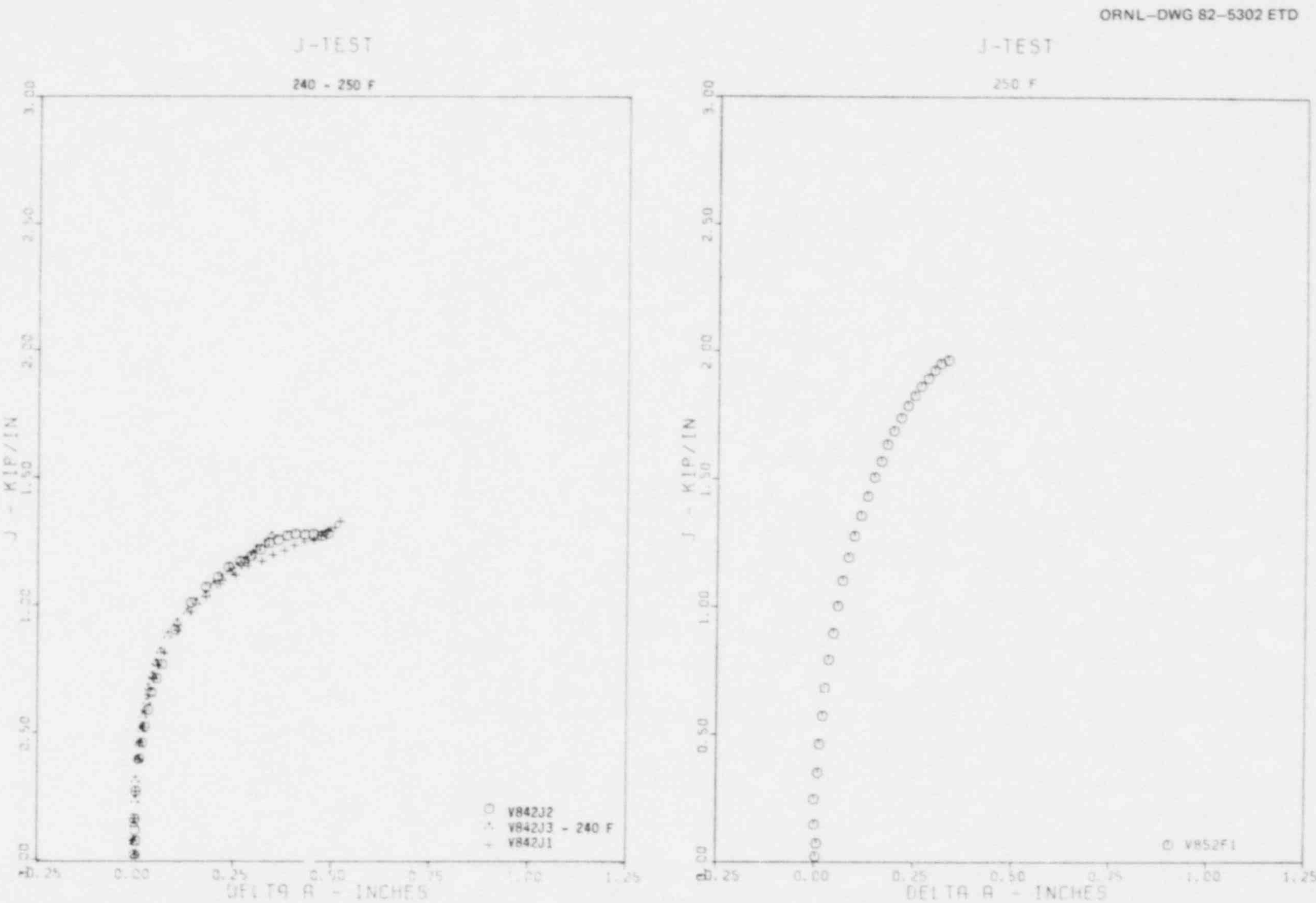


Figure 20 J-R Curves

ORNL-DWG 82-5303 ETD

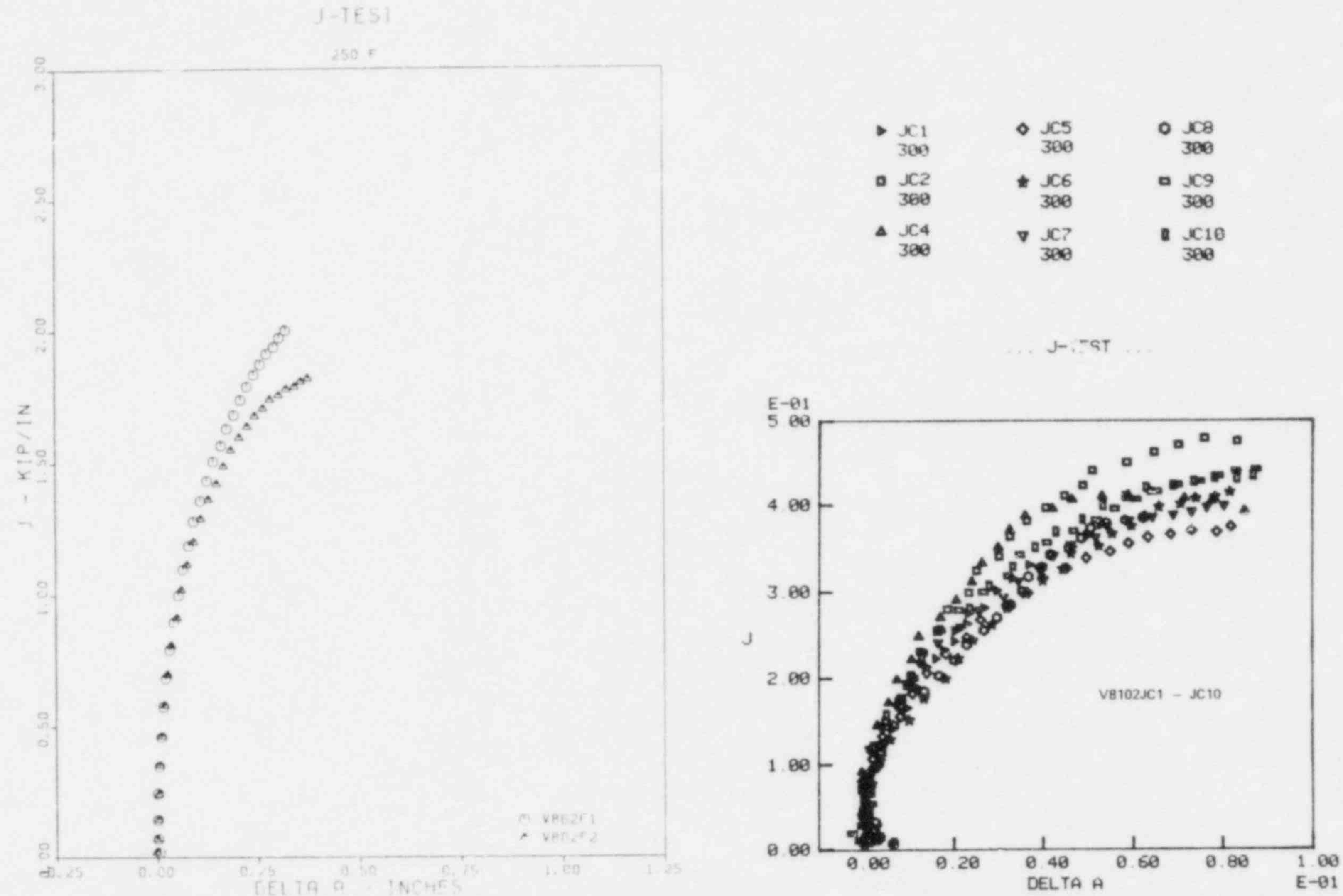


Figure 21 J-R Curves

ORNL-DWG 82-5304 ETD

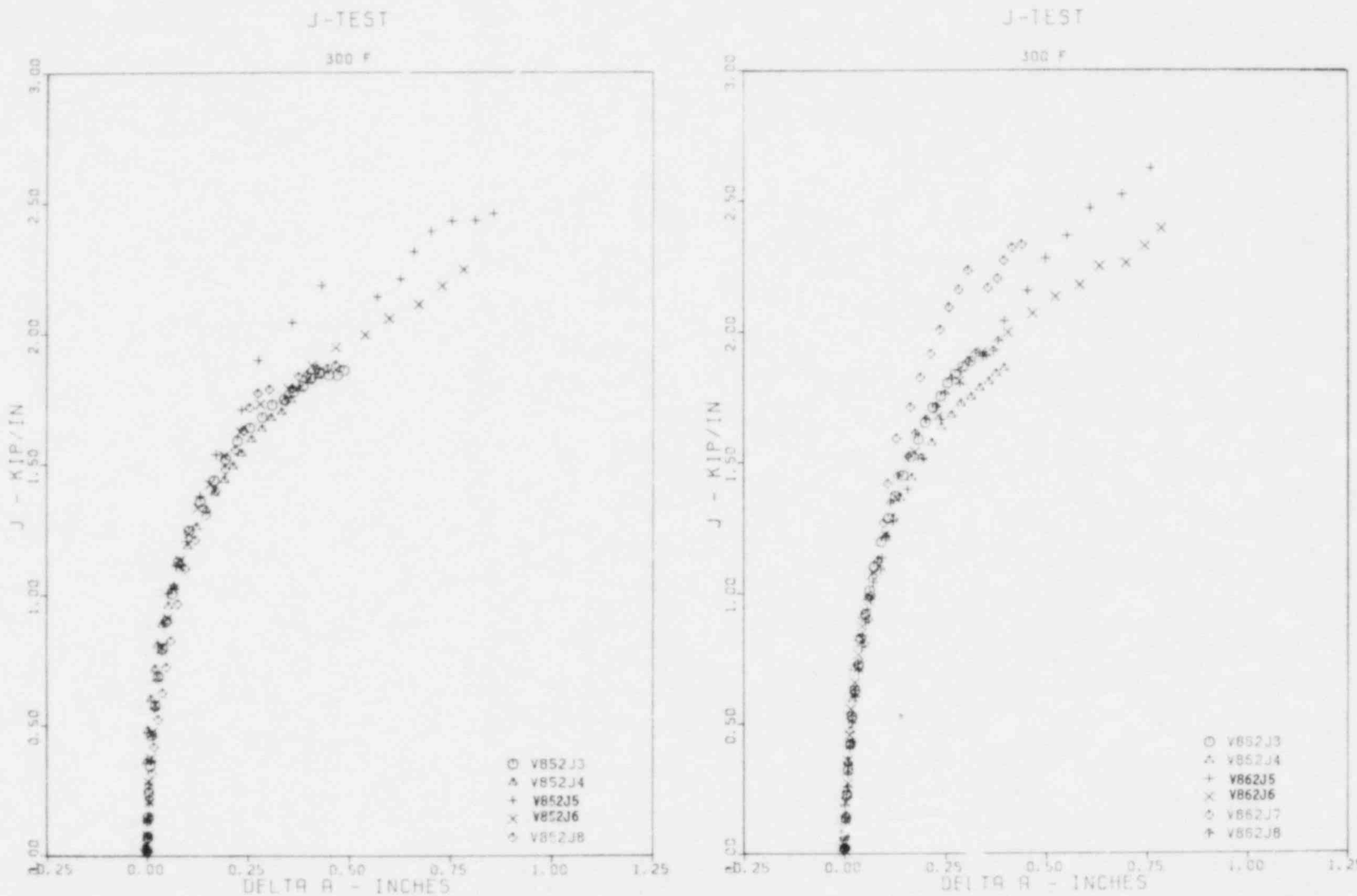


Figure 22 J-R Curves

ORNL–DWG 82–5305 ETD

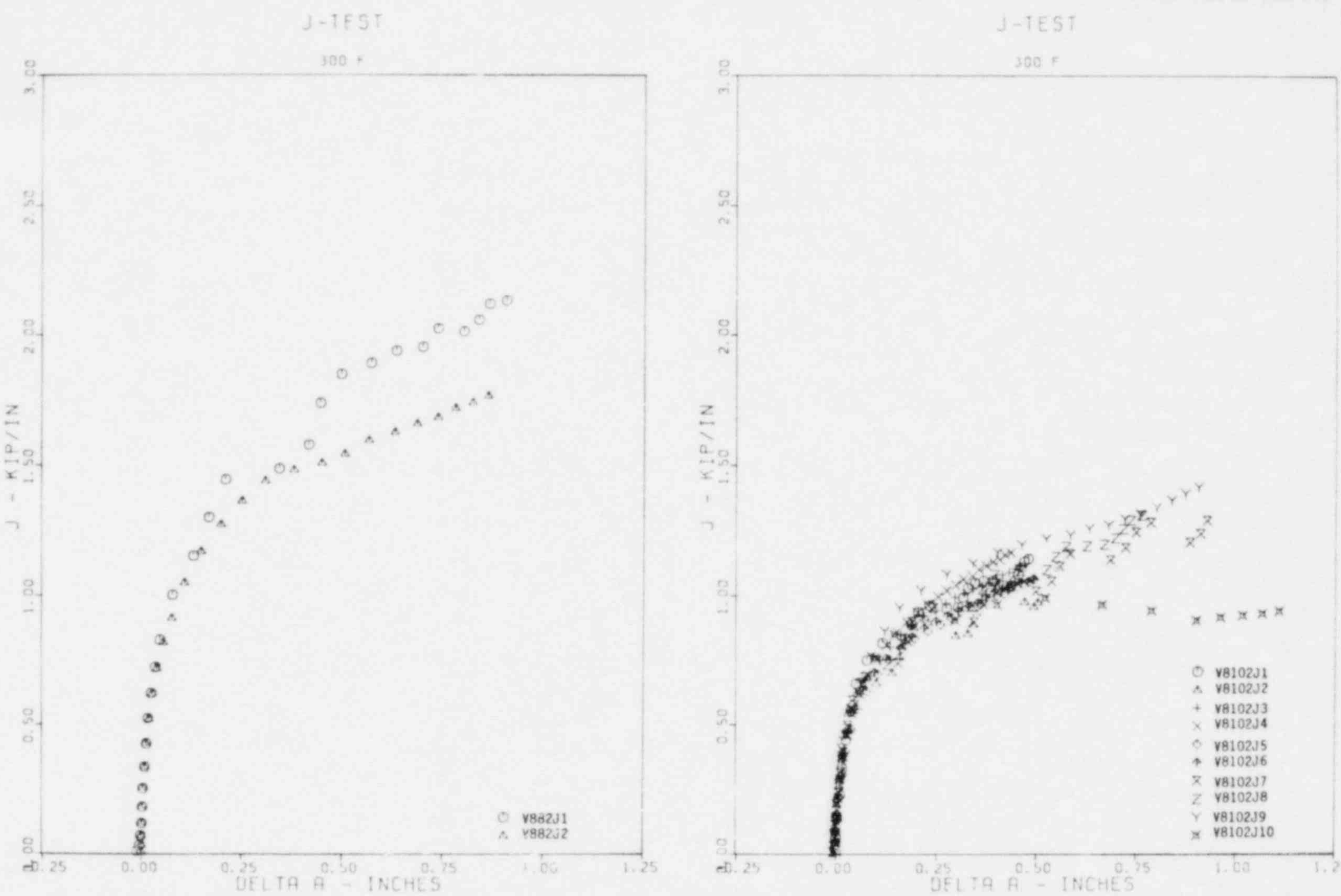


Figure 23 J-R Curves

4. PHASE 3 -- VESSEL V-8 REPAIR AND LOW UPPER-SHELF TEST WELD

4.1 VESSEL WELDING

The through-wall cavity in the vessel (approximately 8-1/2" wide by 22-3/4" long), which was the result of removal of the test section of the Vessel V-8 test, was repaired by manual metal arc (MMA) (E8015 electrodes) welding in a plug made from a V-9 prolongation. The submerged-arc (SA) long seam test weld, located about 130° from the plug weld, was made in a slot as previously indicated in Figure 7 with the same conditions that were used for the trial weld. The SA weld was cut back on the ends to form weld cavities for MMA welds. This procedure was adopted because of the great possibility of weld defects at the starts and stops of the SA weld.

The plug repair, test weld, post weld heat treatment (PWHT), and radiographic inspection were completed when an unacceptable defect was found at the vessel open end MMA portion of the test weld. This required that the seam test weld be remade. Figure 24 shows the completed SA portion of the seam test weld and MMA cavities on the second attempt which was acceptable.

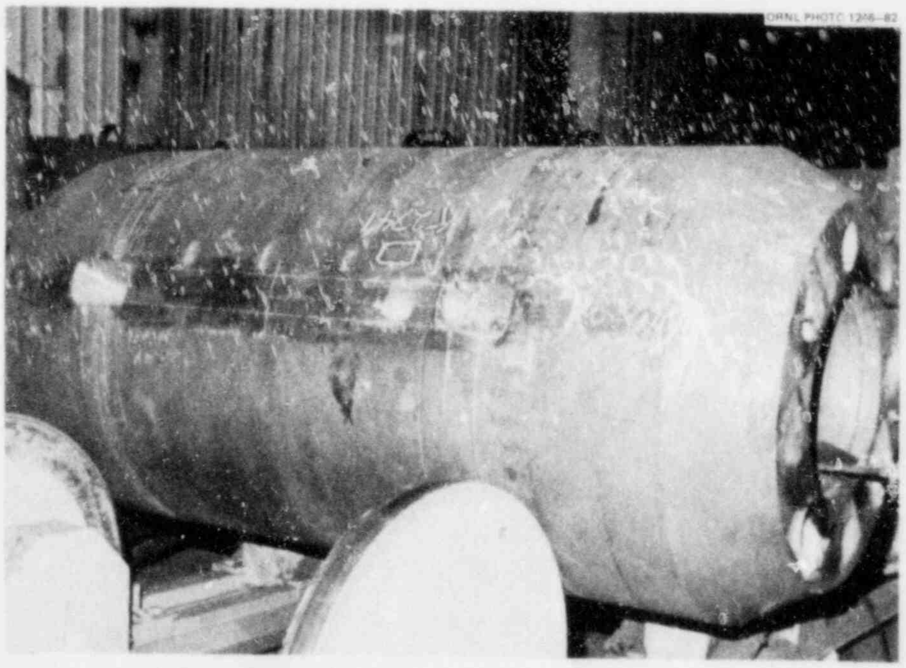


Figure 24 Completed Submerged-Arc (SA) Portion of the Seam Test Weld and Manual Metal Arc (MMA) Weld Cavities of the Vessel

The final dimensions achieved for the vessel seam test weld are given in Figure 25.

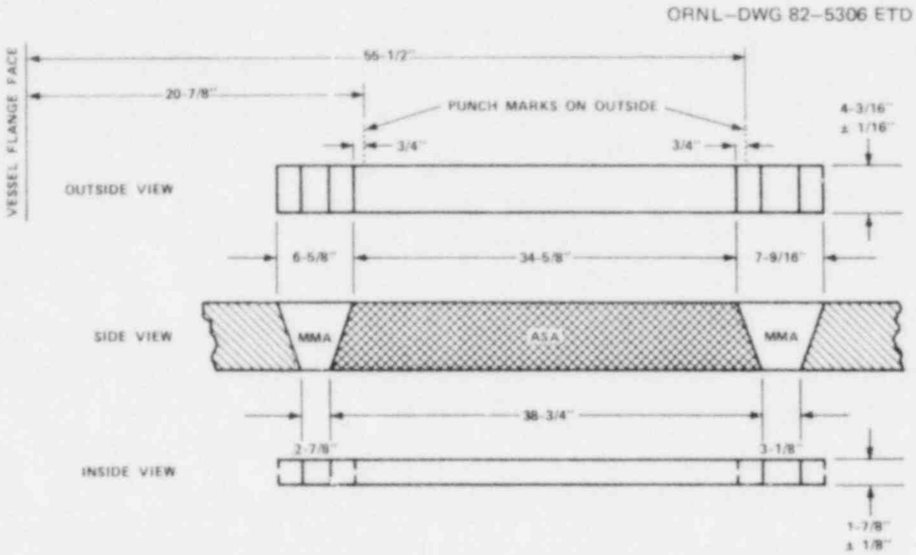


Figure 25 Dimensions at the Seam Test Weld of the Vessel

4.2 POST WELD HEAT TREATMENT

The original and second (final) PWHT conditions achieved are given in Table 7.

Table 7

PWHT CONDITIONS FOR VESSEL V-8

		Original	Final
Heating Rate - 600° to 1050°F	:	56.3°F/hr	40.9°F/hr
Hold Time at 1050° - 1100°F	:	50.5 hours	49.8 hours
Average Hold Temperature	:	1081°F	1077°F
Cooling Rate - 1050° to 600°F	:	12.3°F/hr	12.0°F/hr

These values (Table 7) are the averages of four thermocouples located around the seam test weld. These thermocouple locations are as shown in Figure 26. Other thermocouple locations monitored during PWHT conditions are shown in Figures 27 and 28. Thermocouple No. 8 was attached to a test piece (designated V10S1) taken from the V-10 prolongation which formerly contained Characterization Welds V852 through V882. Therefore, it was also subjected to two PWHT cycles as was the vessel and its repair weld.

4.3 SEAL LEAK TESTING

Prior to shipment to Union Carbide Corporation - Nuclear Division (UCC-ND), the head and its seal were mounted on the vessel and a helium leak test was performed. No leaks were detected; the sensitivity of the Vickers Leak Detector used was demonstrated and verified by use of a probe sniffing and observing a calibration standard helium leak of 5.2×10^{-7} standard cc/sec.

ORNL PHOTO 1247-82

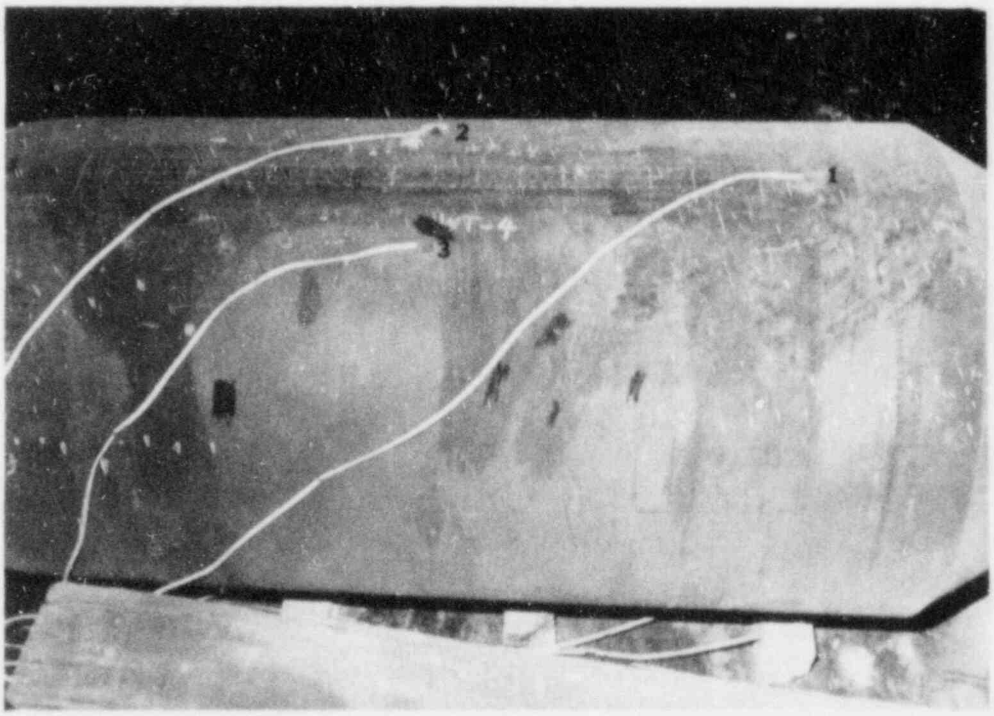


Figure 26 Thermocouple Locations Around the Vessel Seam Test Weld

ORNL PHOTO 1248-82

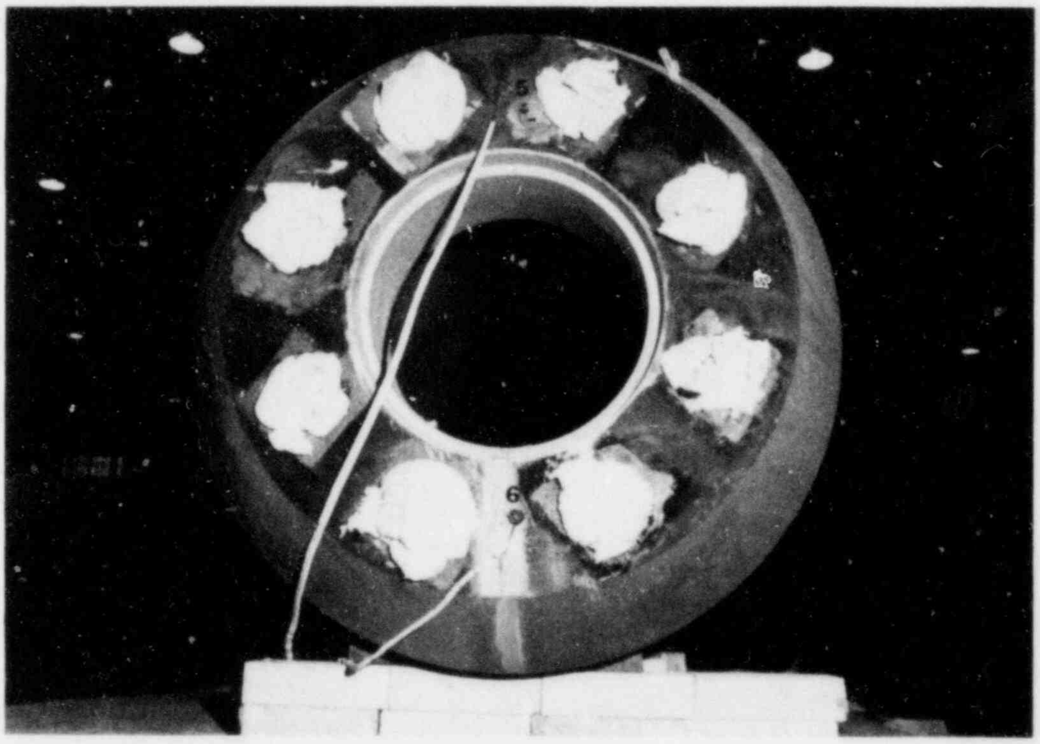


Figure 27 Overall View of Vessel During the PWHT Cycle with Thermocouple Locations

ORNL PHOTO 1249-82

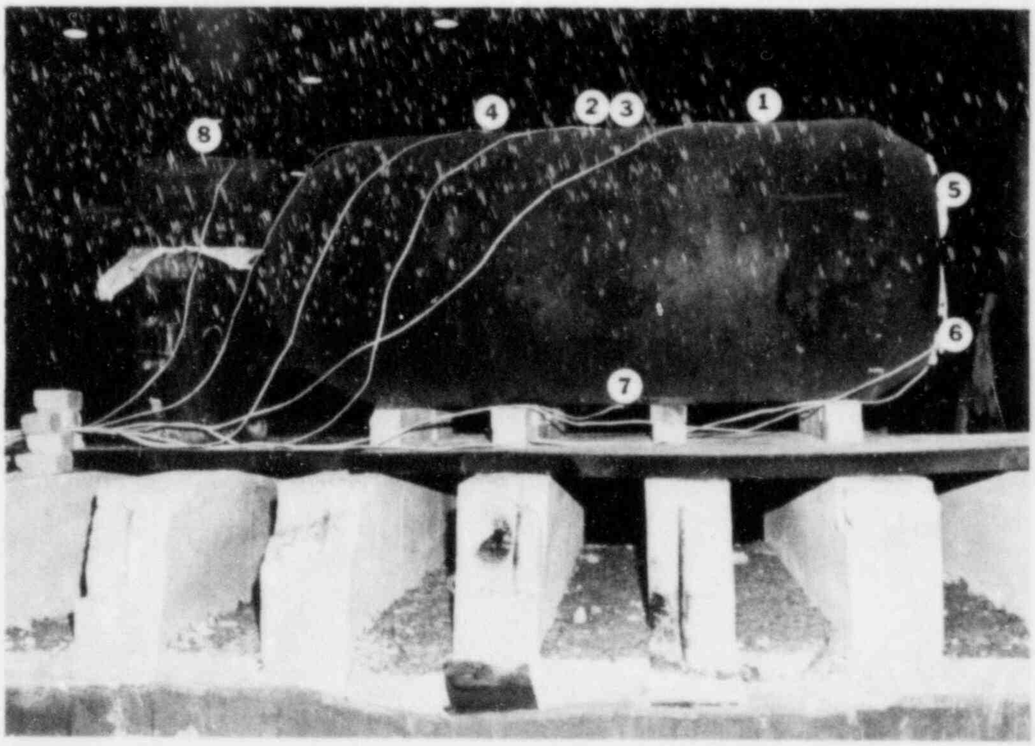


Figure 28 Thermocouple Locations No. 5 and 6 on the Vessel

4.4 COMPARISONS OF VESSEL V-8A TEST WELD TO OTHER TEST WELDS

Average values for welds made with the same conditions used for the Vessel V-8A test weld are given in Table 8.

Table 8

COMPARISONS OF AVERAGE VALUES

	Weld						
	V822	V842	V852	V862	V882	V8102	Vessel V-8A
Weld Chemistry, %							
C	0.06	0.05	0.06	--	--	0.06	--
Mn	1.61	1.50	1.56	--	--	1.52	--
P	0.024	0.028	0.031	--	--	0.026	--
S	0.017	0.016	0.016	--	--	0.014	--
Si	0.65	0.66	0.71	--	--	0.62	--
Ni	0.61	0.62	0.63	--	--	0.63	--
Mo	0.48	0.45	0.48	--	--	0.47	--
Cu	0.29	0.27	0.25	--	--	0.17	--
O	0.143	0.143	0.147	0.153	0.147	0.147	--
Plate (Weld) Thickness, in.	3-3/4	6	6	6	6	6	6
Heat Input, kJ/in.	92	76	76	76	76	76	76
PWHT							
Heating Rate, °F/hr	59.4	148.0	--------	37.0	--------	50.0	40.9
Hold Time, hours	50.0	52.0	--------	50.0	--------	48.5	49.8
Hold Temperature, °F	1075	1083	--------	1071	--------	1068	1077
Cooling Rate, °F/hr	12.2	10.2	--------	15.5	--------	12.4	12.0
Room Temperature Tension Test							
Yield Strength, ksi	66.9	56.[illegible]	62.3	--	--	69.3	--
Ultimate Tensile Strength, ksi	81.9	82.4	79.3	--	--	84.3	--
Elongation, %	24.7	25.8	26.8	--	--	22.8	--
Reduction of Area, %	54.4	55.3	57.8	--	--	53.3	--
Charpy V-Notch Tests							
USE, ft-lbs (200° - 300°F)	42.2	42.8	48.9	45.6	43.5	38.1	--
LE, mils (200° - 300°F)	47.9	49.5	53.0	53.7	52.1	48.1	--
J_{Ic}, Kip/in. (300°F, 1TCT, 2TCT)	--	0.378 (240°, 250°F)	0.404	0.351	0.337	0.24[illegible]	--

5. DISCUSSION OF TEST RESULTS

5.1 EFFECT OF SPECIMEN DEPTH LOCATION WITHIN THE WELD

In testing the preliminary welds, it was noticed that there was a variation in mechanical properties according to position in the weld. Figures 29 and 30 show the trends for upper-shelf energies (USE) and yield strength (YS). In general, it was observed that higher USE and lower YS values were obtained for bead overlap regions where there was more grain refinement and tempering. The general trend of decreased USE and increased YS with increasing depth within the welds may be due to increased tempering because of lower heat transfer conditions as the weld cavity is filled.

The apparent effect of depth in the weld on impact energy is apparently larger than for the tensile properties and this attributed to the greater sensitivity of fracture on micro-macrostructure as compared to tensile yielding.

The effect of weld depth on the fracture toughness predicted from the relationship:

$$J_{1c} = \frac{5\sigma y^2}{E} (1 - \nu^2) (\frac{USE}{\sigma y} - 0.05)$$

as shown in Figure 31 is seen to be small. The variation of test results is seen to be greater than the total range of the predicted weld depth effect. Apparently the predicted relationship gives an upper bound for the experimentally determined values. The J_{1c} value obtained for Specimen V852J4 is apparently too high when compared to all of the other test results.

For the general case shown in Figure 32 (obtained by normalizing the WL-oriented specimen J_{1c} values to their averages for each weld and test temperature), the scatter is seen to be too great to demonstrate any trend of weld depth.

ORNL-DWG 82-5307 ETD

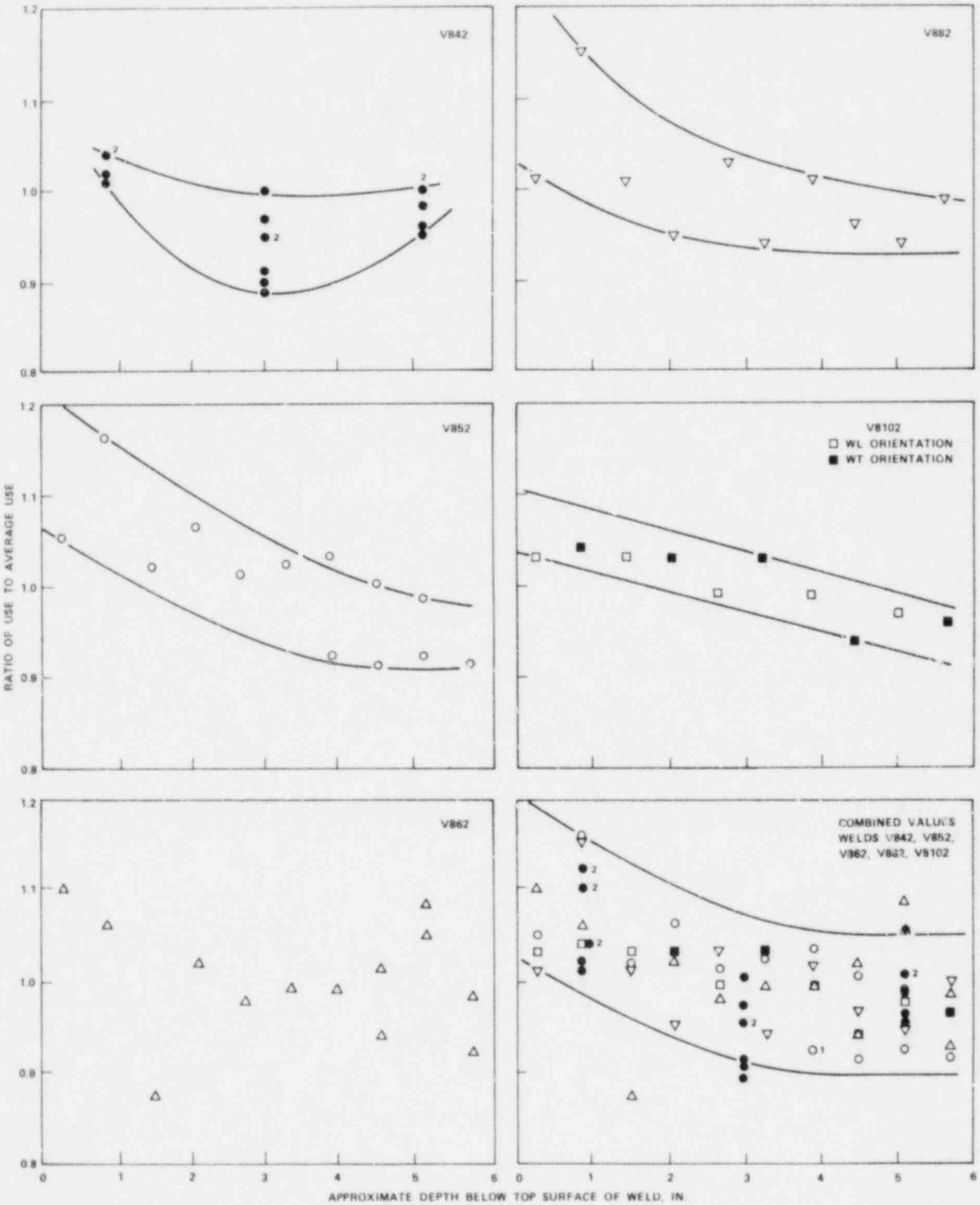


Figure 29 Plots of Normalized USE Values for the Trial and Characterization Welds

ORNL–DWG 82–5308 ETD

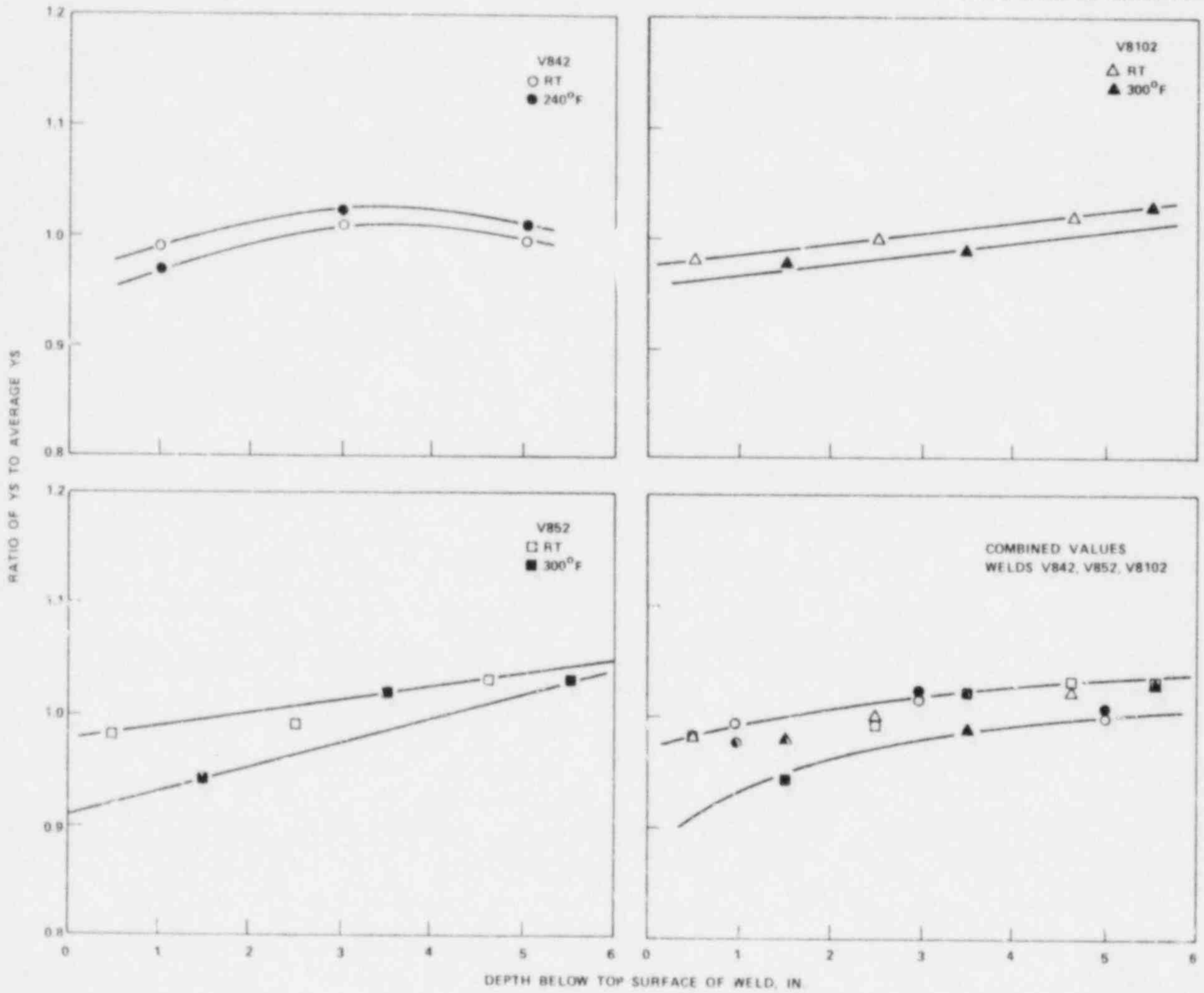


Figure 30 Plots of Normalized YS Values for the Trial and Characterization Welds

ORNL-DWG 82-5309 ETD

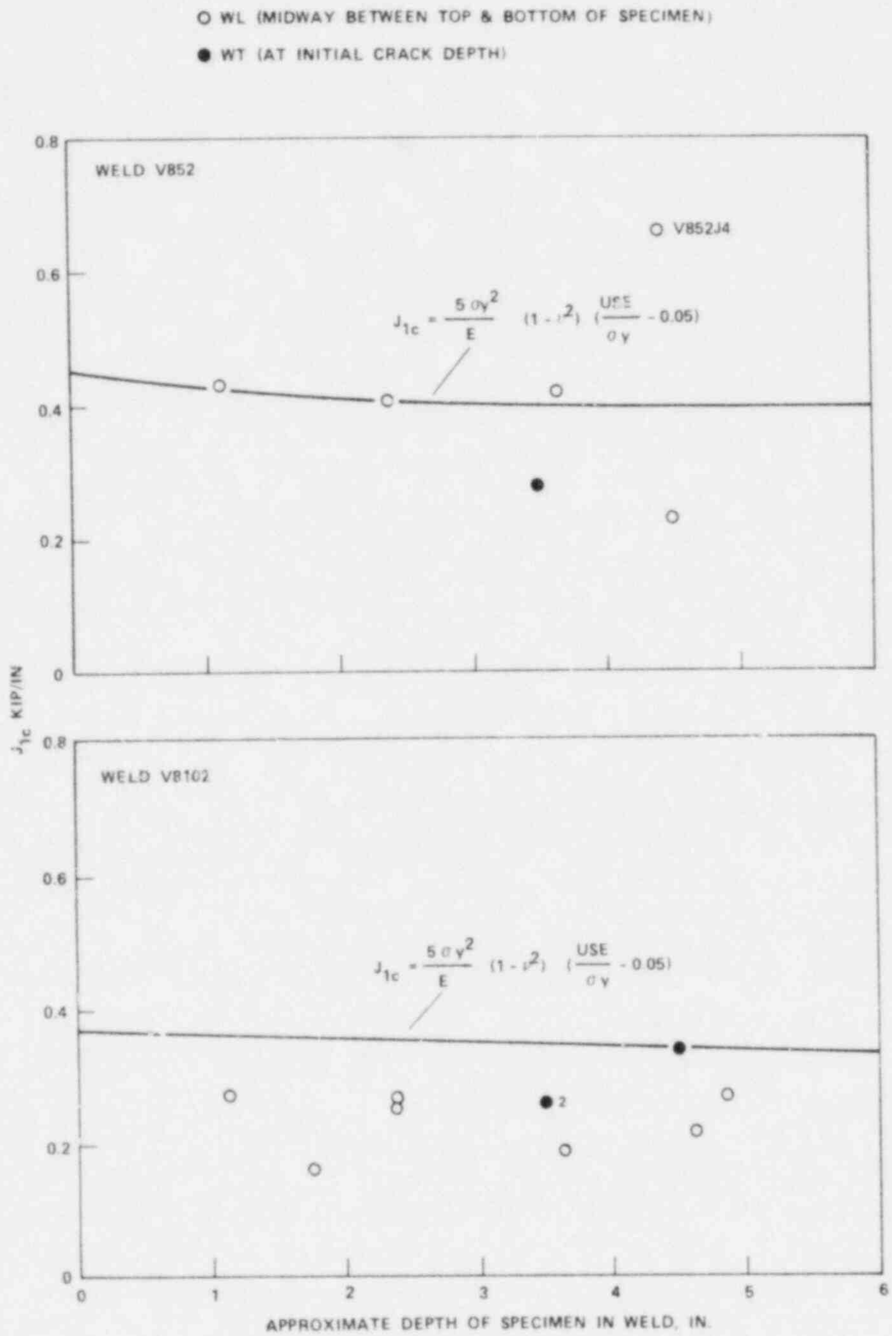


Figure 31 Effect of Weld Depth on J_{1c} for Welds V852 and V8102 at 300°F

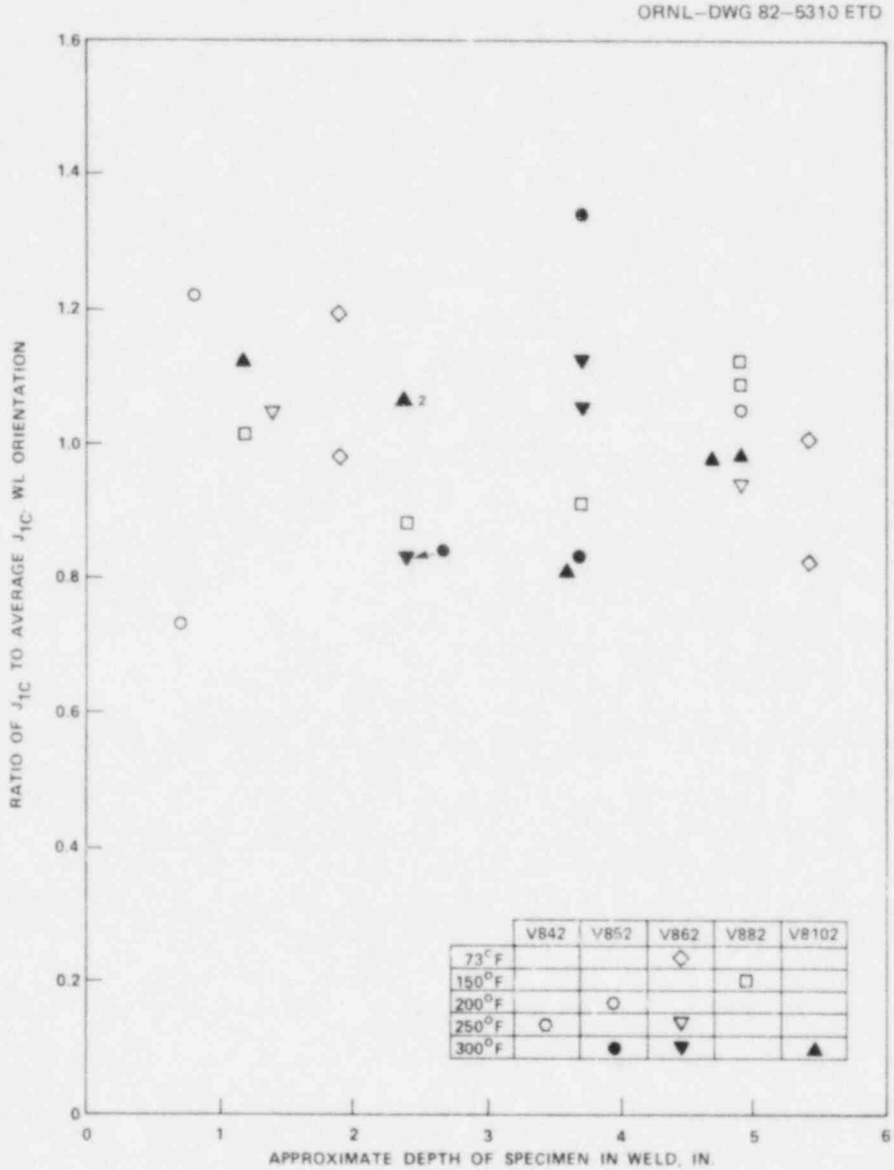


Figure 32 Plot of Normalized J_{1c} With Respect to the Average for Each Weld and Test Temperature in the WL Orientation

On the other hand, the toughness at some crack extension does show a trend of decreasing toughness with increasing depth. Figure 33 shows the trend for J at J/T = 50. This trend is proportional to USE and inversely proportional to YS trends.

ORNL-DWG 82-5311 ETD

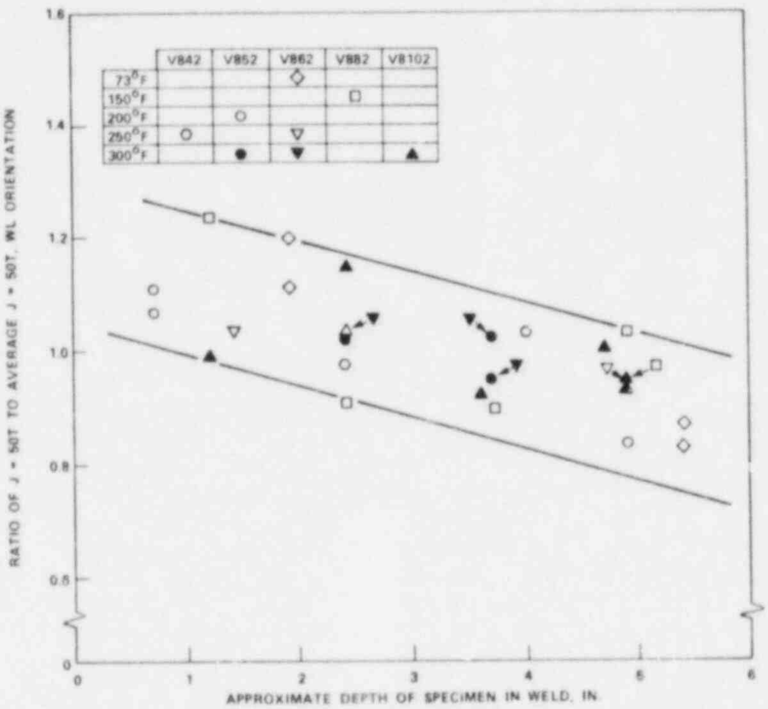
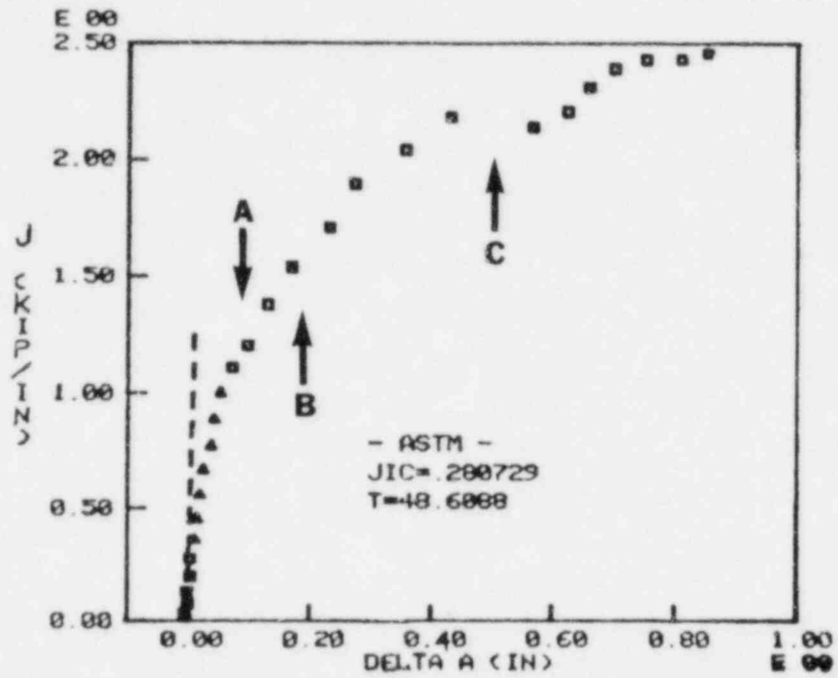


Figure 33 Plot of Normalized J = 50T With Respect to the Average for Each Weld and Test Temperature in the WL Orientation

5.2 EFFECT OF MICRO-MACROSTRUCTURE

The effect of macrostructural variations is evident from the Charpy and J-Integral fractures. For instance, Figures 34 and 35 show distinct examples of the weld bead effects on fracture appearance and their relationship with J-R curves. In general, specimens with WT orientation display less smoothness in the load-displacement and J-R curves as compared to those with WL orientation. In most cases, the instantaneous changes in shape of the load displacement and J-R curves can be related to fracture topography.

ORNL PHOTO 1250-82



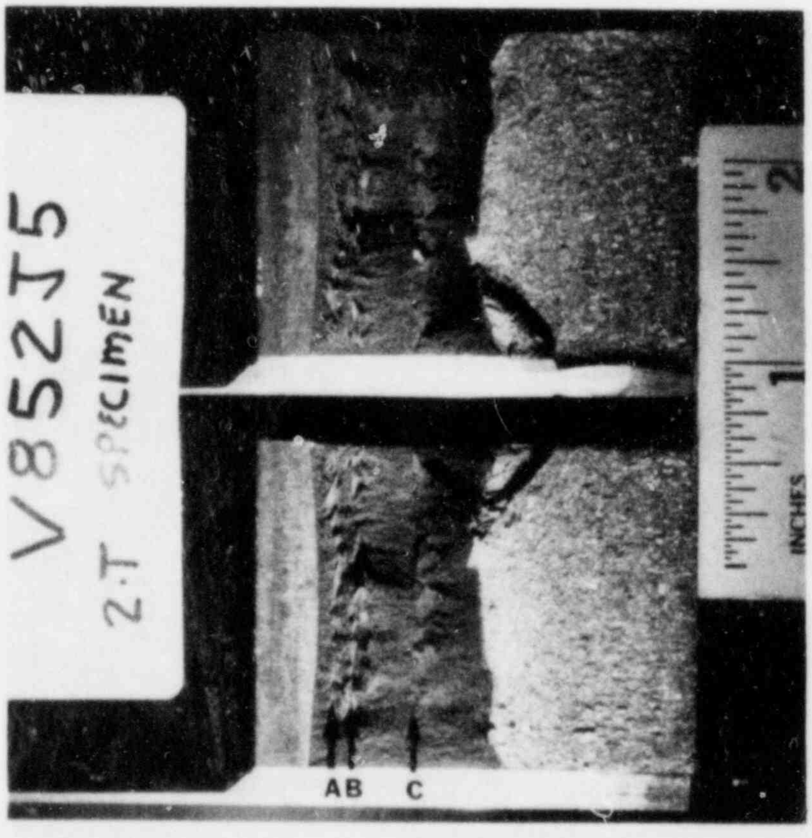


Figure 34 Fracture Surface of J-Integral Test Specimen V852J5 and the Relationship of Fracture Features With J-R Curve Test Results

ORNL PHOTO 1251-82

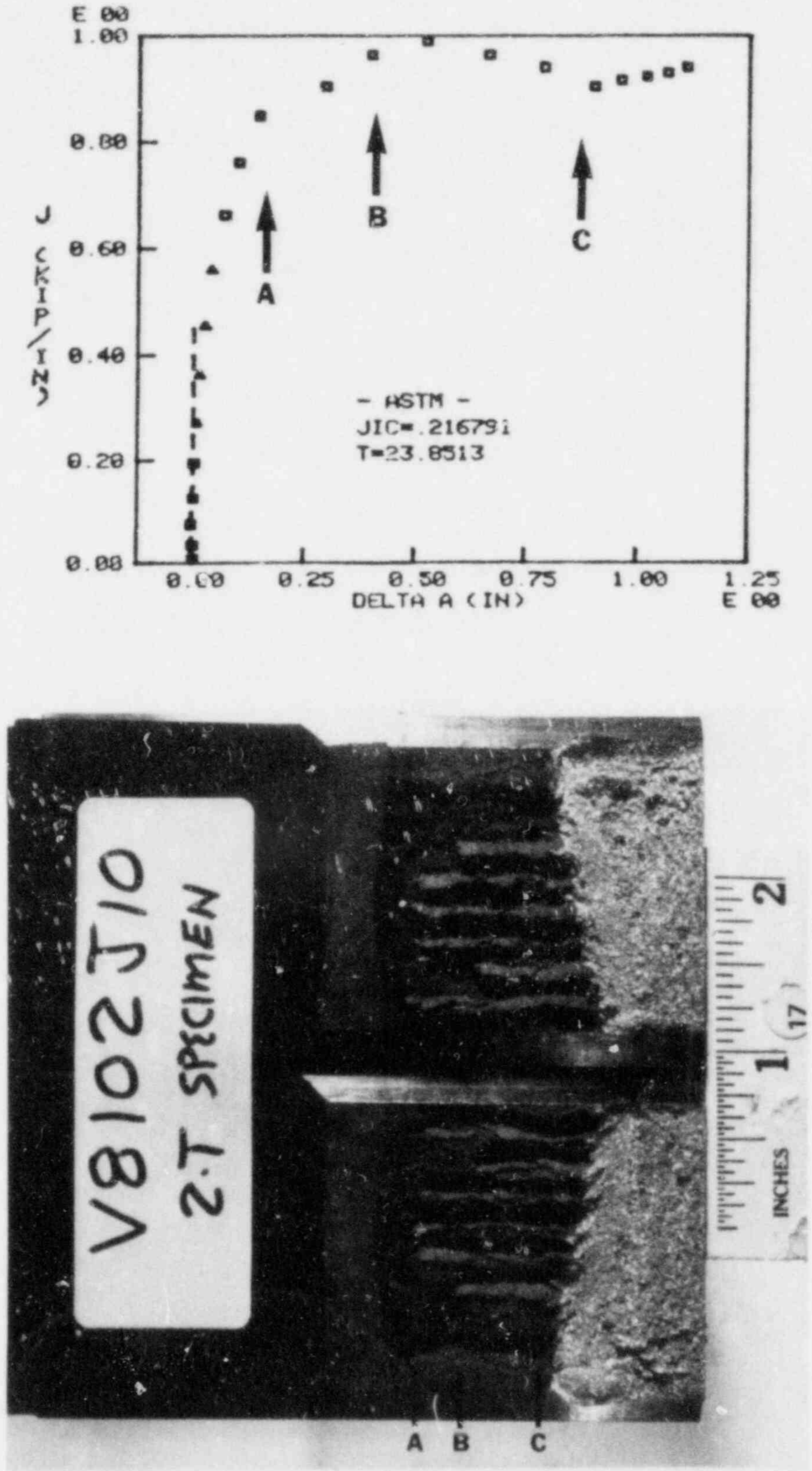


Figure 35 Fracture Surface of J-Integral Test Specimen V8102J10 and the Relationship of Fracture Features With J-R Curve Test Results

5.3 EFFECT OF SPECIMEN ORIENTATION

The effect of orientation on Charpy V-notch results determined with specimens from Weld V8102 tested at 240° and 300°F is not significant as indicated in Table 9.

Table 9

CHARPY V-NOTCH TEST RESULTS FOR WELD V8102

		USE, ft-lbs	
Orientation	No. of Specimens	Mean	S.D.
WL	5	37.4	1.1
WT	5	38.9	1.8

The effect of specimen orientation on fracture toughness is shown in Table 10.

Table 10

EFFECT OF SPECIMEN ORIENTATION ON FRACTURE TOUGHNESS

		J_{1c}, Kip/in.							
	Test Temp.	WL Orientation			WT Orientation			Difference	
Weld	°F	No. of Tests	Mean	±1 SD	No. of Tests	Mean	±1 SD	(WL) - (WT)	Significance
V852	300	3	0.489	0.145	2	0.277	0.006	0.212	NS
V862	300	3	0.396	0.061	3	0.307	0.043	0.089	NS
V882	300	1	0.369	---	1	0.305	---	0.064	--
V8102-CT	300	6	0.244	0.029	4	0.251	0.066	-0.007	NS
V8102-JC	300	4	0.168	0.015	5	0.164	0.033	0.004	NS
		J = 50T, Kip/in.							
V852	300	3	1.281	0.056	2	1.380	0.071	-0.099	NS
V862	300	3	1.330	0.060	3	1.463	0.178	-0.133	NS
V882	300	1	1.058	---	1	1.127	---	-0.069	--
V8102-CT	300	6	0.731	0.051	4	0.686	0.038	0.045	NS
V8102-JC	300	4	0.380	0.023	5	0.412	0.026	-0.032	NS

Although these differences are not statistically significant, it appears that the WL orientation gives higher values for J_{1c} and lower J = 50T values -- particularly as the general toughness of the weld increases. For the low toughness welds, orientation of the specimen has little significance.

5.4 EFFECT OF TEST TEMPERATURE ON FRACTURE TOUGHNESS

The effect of test temperature on fracture toughness determined with compact tension specimens is illustrated in Figures 36 and 37. It is assumed that specimen size, specimen location within the weld, and level of toughness for each weld is not significant.

One notable result is that obtained for Specimen V8102F2 tested at room temperature. It fractured in half during J-Integral testing at "maximum load". Apparently the toughness of this weld was low enough that this test was conducted below the ductile transition temperature for the loading rate employed. In addition, Figure D-33 (Appendix D) shows the obvious load drop associated with the "pop-in" of Specimen V882F2 tested at 150°F. Specimen V882F3, also tested at 150°F, demonstrated a like "pop-in".

The other results indicate a slowly decreasing toughness with increasing temperature with the 250°F values being near those obtained at 300°F.

5.5 COMPUTATION REPRODUCIBILITY OF J_{1c}

It was noticed that when the J-R curve analysis was performed for some tests, the reproducibility of the J_{1c} calculation, which is dependent on where the origin of the blunting line is placed, was sometimes poorer. This operation was performed three times by independent operators and these results are as previously reported in Table 6. The range of reproducibility of the 1T and 2TCT specimen tests is shown in Figure 38.

Inspection of the results shows that in general for the larger deviations two operators gave nearly equivalent results with the third being much further away. There was no apparent consistency of which operator was further away from the other two. In any case, it would appear that the analysis would normally give about a reproducibility of about 4%.

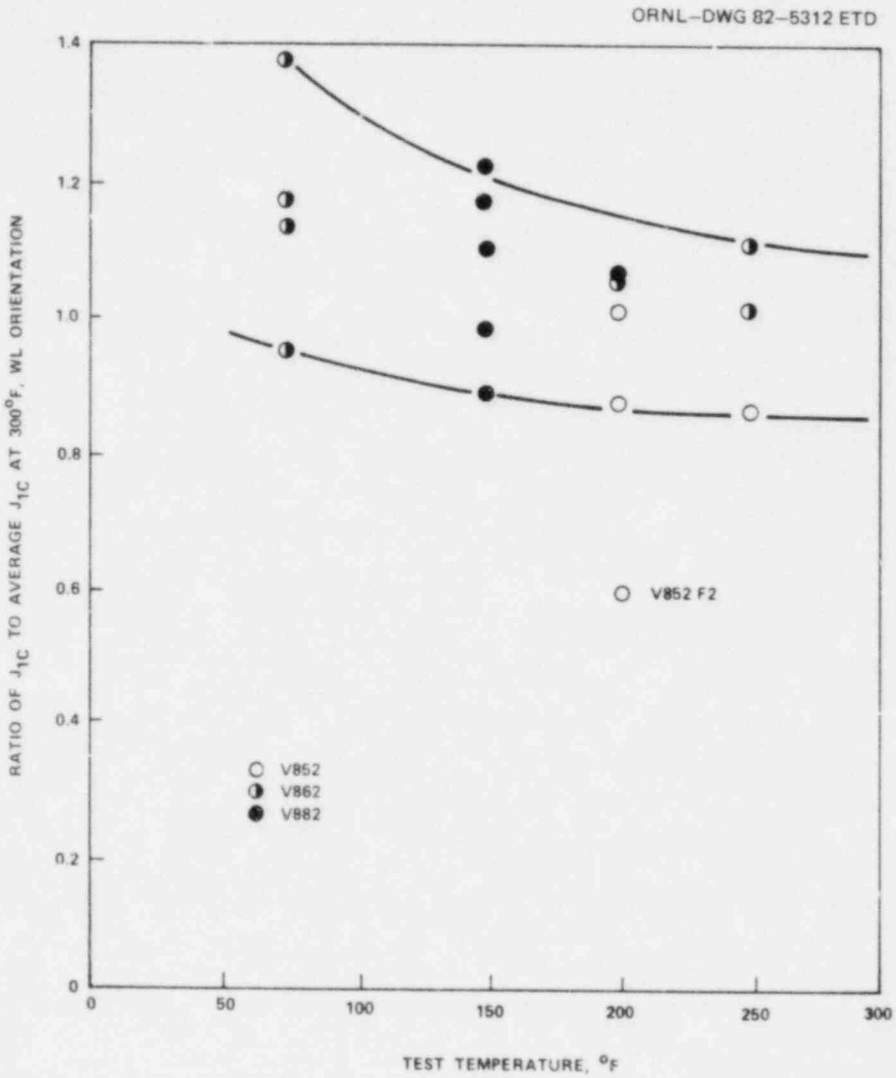


Figure 36 Effect of Test Temperature on J_{1c}

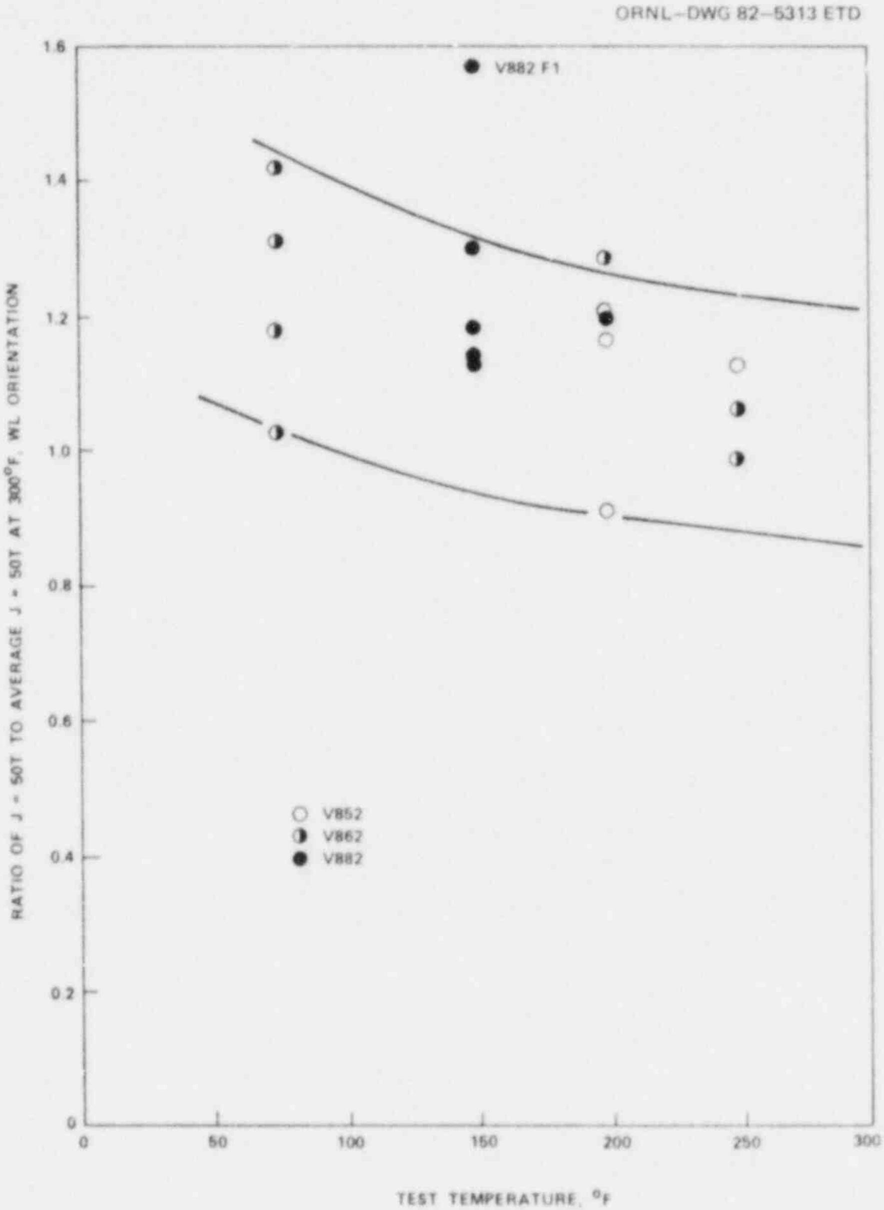


Figure 37 Effect of Test Temperature on J = 50T

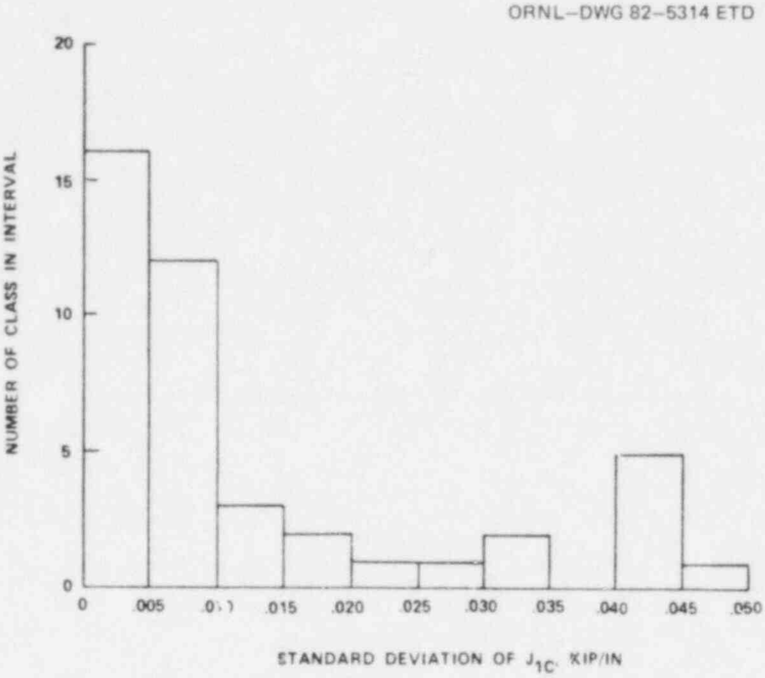


Figure 38 Histogram of Standard Deviations (3 Determinations Each) for 1T and 2TCT J_{1c}

5.6 SPECIMEN SIZE EFFECTS

The results of tests performed on Weld V8102 (Table 11) show that there is little difference between 1T and 2T compact tension specimens while there is about a 30% difference in J_{1c} values for the 3-point bend and compact tension specimens, respectively.

Table 11

EFFECT OF SPECIMEN SIZE ON FRACTURE TOUGHNESS RESULTS
(Weld V8102 - 300°F - WL and WT Orientations)

Specimen Size	No. of Tests	J_{1c}, Kip/in.		J = 50T, Kip/in.	
		Mean	±1 SD	Mean	±1 SD
C_v	9	0.166	0.025	0.398	0.029
1TCT	6	0.242	0.057	0.687	0.063
2TCT	4	0.254	0.016	0.727	0.066

5.7 WELD TO WELD VARIABILITY

The use of low flux basicity and PWHT temperature was found to provide weld metal having low USE values at a reasonable YS value. The optimum condition selected -- 75% Linde 60 - 25% Linde 80 flux mixture and 1050° - 1100°F PWHT temperature -- used for the trial and subsequent welds gave the following properties (Table 12):

Table 12

AVERAGE VALUES FOR WELDS

	V842	V852	V862	V882	V8102
USE, ft-lbs	42.8	48.9	45.6	43.5	38.1
RT Yield Strength, ksi	66.7	62.3	--	--	69.3
J_{Ic} at 300°F, Kip/in.	0.378 (240° - 250°F)	0.404	0.351	0.337	0.247*
J - 50T at 300°F, Kip/in.	0.887 (240° - 250°F)	1.319	1.396	1.0925	0.713*

* Excluding 3-point bend C_v test specimen results

The reasons for differences in the mechanical properties between welds, although within the range of normal scatter of ±5 ft-lbs for USE, are not understood. The effects of variations in welding conditions within the controlled parameters were probably not significant. Oxygen analyses made on specimens from the preliminary and characterization welds (given in Table 13) show that the effective flux basicity for welds made with the 75% Linde 60 - 25% Linde 80 flux mixture (i.e., Welds V822, V842, V852, V862, V882, and V8102) was about the same.

Table 13

TOTAL OXYGEN CONTENTS OF WELDS

	Oxygen, Wt. %							
	V812	V822	V832	V842	V852	V862	V882	V8102
% Linde 60 →	50	75	90	75	75	75	75	75
Position in Weld								
Top	.13	.15	.16	.15	.14	.15	.15	.15
Middle	.13	.14	.15	.15	.15	.16	.14	.14
Bottom	.12	.14	---	.13	.15	.15	.15	.15
Average	.127	.143	.155	.143	.147	.153	.147	.147

The other important controlling variable, PWHT, was about the same for the welds made with 75% Linde 60 flux mixture as shown in Table 14.

Table 14

PWHT CONDITIONS FOR WELDS

		V822	V842	V852 - V882	V8102
Heating Rate - 600° to 1050°F, °F/hr	:	59.4	148.0	37.0	50.0
Hold Time at 1050° - 1100°F, hours	:	50.0	52.0	50.0	48.5
Average Hold Temperature, °F	:	1075	1083	1071	1068
Cooling Rate - 1050° to 600°F, °F/hr	:	12.2	10.2	15.5	12.4

The higher heating rate for Weld V842 and the higher cooling rate for Welds V852 - V882 are considered to be insignificant.

If we take the average USE values for the six welds -- including Preliminary Weld V822 made with the 75% Linde 60 flux mixture and 1050° - 1100°F PWHT, we obtain an average value of 43.5 [±3.6 (±1 SD)] ft-lbs with the result for Weld V852 being furthest away (48.9 ft-lbs or about 1.5 standard deviations away). It has the largest, and perhaps undue, effect on the mean. This deviation is not sufficient to call it an outlier, but it does suggest the average weld made with these conditions will probably lie on the lower side of the mean. For this reason, the following values are taken as the most likely for the submerged-arc (SA) test weld made in the vessel:

Room temperature YS (Average of V822, V842, V852, and V8102)	$\geq$66.3 ksi
USE (Average of V822, V842, V852, V862, V882, and V8102)	$\leq$43.5 ft-lbs
J_{Ic} at 300°F (Average of V852, V862, V882, and V8102)	$\leq$0.335 Kip/in.
J = 50T (Average of V852, V862, V882, and V8102)	$\leq$1.13[illegible] Kip/in.

5.8 COMPARISON TO IRRADIATED AND OTHER WELD TEST RESULTS

A thorough discussion of the relationship of the properties obtained for the vessel SA test weld and irradiated welds is beyond this investigation. However, Figure 39 is included as an attempt to place these test results in perspective with respect to the fracture toughness of irradiated welds.

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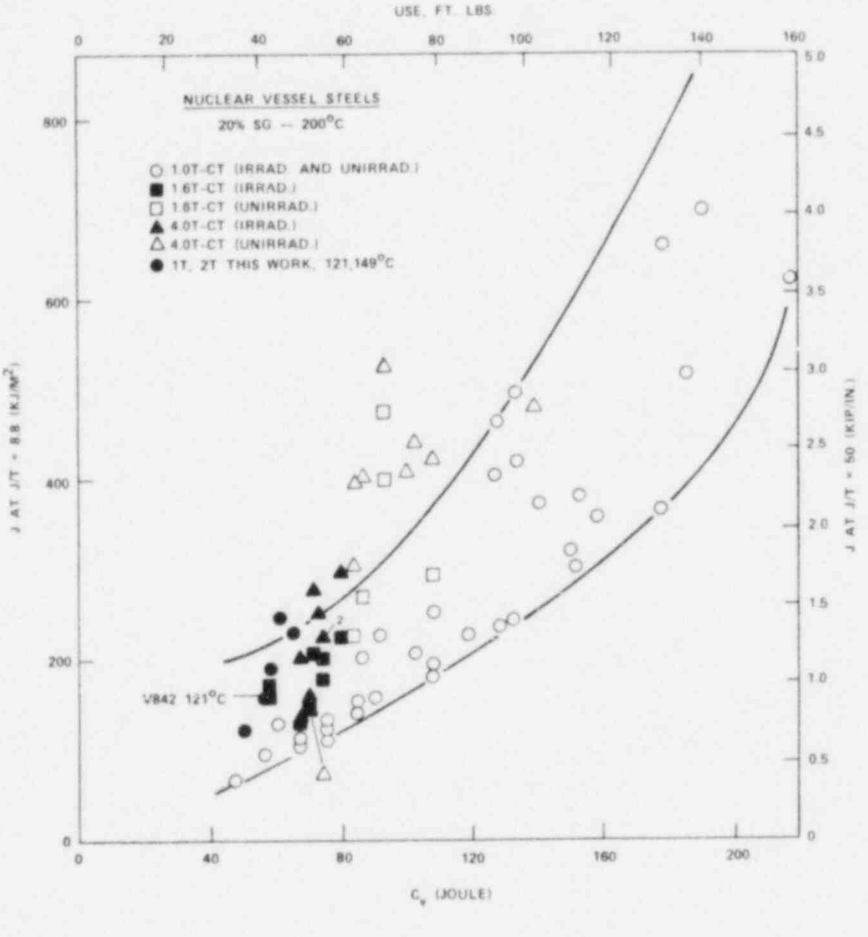

Figure 39 Correlation of C_v, USE, and J at a Fixed Value of J/T (After Loss)

6. CONCLUSIONS

1) The properties of the vessel seam test weld are likely to have the following values:

- Room temperature yield strength (YS)	≥66.3 ksi
- Upper-shelf energies (USE)	≤43.5 ft-lbs
- J_{1c}	≤0.335 Kip/in. at 300°F
- J = 50T	≤1.131 Kip/in. at 300°F

2) The J_{1c} fracture toughness values determined with 1T and 2TCT specimens are about equal. The values obtained with 3-point bend Charpy V-Notch specimens were about 30% less than the compact tension specimens. The results of a few 3-point bend Charpy V-Notch specimens having 5% or 10% side grooves indicate close agreement to the 1T and 2TCT specimens with 20% side grooves.

3) The yield strength, ultimate tensile strength, J_{1c}, and J-R curves can be correlated with USE values.

4) The fracture toughness values obtained for these welds are not far different than those reported for some irradiated welds.

5) In general, YS increases, USE decreases, and the fracture toughness decreases with increasing weld depth. There is no apparent consistent change in J_{1c} with weld depth.

6) The WL-oriented specimens may give higher J_{1c} and lower J = 50T results as compared to specimens of WT orientation. This effect apparently diminishes with decreasing toughness.

7) Crack propagation is apparently more sensitive to macrostructure in the thickness orientation as compared to the longitudinal weld direction as evidenced by the variations in load-deflection curves during J-Integral tests.

8) Toughness decreases slightly with increasing temperature over the range of 75° to 300°F. The toughness at 250°F is nearly the same as at 300°F.

9) Apparently, if USE is low enough (such as 38 ft-lbs for Weld V8102), fast fracture is possible at room temperature with the loading rate used in J-Integral testing.

7. RECOMMENDATIONS

- The YS, USE, and fracture toughness values should be determined for the vessel test weld after Vessel V-8A test is completed. This should increase the precision of predicting crack growth from laboratory specimen tests.

- If vessel and characterization welds are to be made in the future, they should be made simultaneously to increase the precision of predictions made from characterization test specimens.

8. ACKNOWLEDGMENTS

This project was accomplished with the assistance of the following persons at B&W:

P. S. Ayres	- Project Management
C. M. Coleman	- Contract Administration at Barberton
W. L. Coler	- Contract Management - Contract Research Division
J. G. Feldstein	- Welding at Alliance Research Center
R. J. Futato	- Mechanical Testing at Alliance Research Center
V. J. Hudacko	- Mechanical Testing and Chemical Analysis at Barberton
B. E. Irwin	- Welding at Barberton
W. A. Pavinich	- Mechanical Testing at Lynchburg Research Center
D. E. Young	- PWHT of Vessel
W. A. VanDerSluys	- Project Management

The cooperation and assistance of Union Carbide Corporation - Nuclear Division (UCC-ND) through the efforts of R. H. Bryan, R. J. Lynn, and P. P. Holz are greatly appreciated.

9. QUALITY ASSURANCE

This work was performed under two contracts. Phase 1, done under Contract 76Y-57301 C, did not require a formal quality assurance program while Phases 2 and 3, performed under Contract 76Y-85813 V, were accomplished using quality assurance plans. The equipment and nominal procedures used for Phase 1 were the same as those for Phases 2 and 3, and the results are judged to be comparable.

Three tasks performed in Phase 2 were done outside of the contract and quality assurance requirements:

1) Oxygen Analyses (Table 13)

2) Computer Computations of:

- $J = C_1 (C_2 + \Delta a)^{C_3} + C_4 \Delta a + C_5$
- Tearing Modulus, $T = K\, dJ/da$
- $J = 50T$

3) Tests of 5% and 10% Side-Grooved C_v J-Integral Specimens (Appendix E)

The results of these tasks are provided for information only.

The plane strain fracture toughness tests were performed on side-grooved specimens in nonconformance to the requirements of ASTM E-399-78. The results obtained indicate that the toughness of the specimens would preclude obtaining valid K_Q values regardless of whether or not the specimens were side grooved.

The calibration of displacement gauges used for the plane strain and J-Integral fracture specimens was done in a manner that is not traceable to appropriate standards of the National Bureau of Standards (NBS).

One of the gauges used for the J-Integral tests was in-calibration (by the procedure used) before the start of testing and out-of-calibration by as much as 2.5% after testing the following specimens:

1TCT	2TCT
V852/F1, /F2	V852/J5, /J6
V852/J3	V862/J5, /J6
V852/J7, /J8	V882/J1, /J2
V862/F1, /F2	V8102/J7 - /J10
V862/J7, /J8	
V8102/J1 - /J6	

The J values for these tests may be as much as 2.5% too low. Inspection of the test results does not indicate when the drift in calibration occurred and it is not possible to determine which of these test results should be adjusted accordingly.

Comparison of compliance-determined initial and final crack lengths to the ones measured on the specimen fractured faces (with a procedure that was traceable to the appropriate NBS standards) showed that all of the J-Integral test results met the validity criteria of ASTM E-813-81. The J_{1c} results are therefore judged to be acceptable.

To the best of my knowledge and belief, and noting the above exceptions, the work for Phases 2 and 3 was completed in accordance with the Quality Assurance Plan.

[signature] 2.26.82

G. W. Roberts
Quality Assurance Manager,
Alliance Research Center

APPENDIX A

PRELIMINARY WELDS AND THEIR TESTS

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PRELIMINARY WELDS AND THEIR TESTS

A.1 MAKING OF WELDMENTS

Six pieces of 3-3/4" thick x 8" wide x 36" long SA533-B1 steel plate were flame cut from a larger piece. Two pieces each were assembled with three equally spaced strongbacks and 1/4" thick SA302-B steel backing straps to form a single (7°/side) groove with a nominal 7/8" root opening. The following conditions and parameters were achieved:

Base Metal: SA 533 B1 Steel, Heat C4173-3

Backing Strap: SA 302 B Steel, Heat 37388-43

Welding Electrode: 1/8" Diameter, SFA 5.23, EF-2,
Mn-Mo-Ni, Heat F60853

Welding Flux:
- Mixture No. 1 - 60% Linde 60 - 40% Linde 80
- No. 2 - 75% Linde 60 - 25% Linde 80
- No. 3 - 90% Linde 60 - 10% Linde 80

(These mixtures were made by Rectron, Inc., from Lot 0894, Linde 60, which was ground to 48XD particle size and mixed with Lot 0592, Linde 80, to these proportions.)

Welding Parameters:
- Preheat: 300°F Minimum
- Interpass Temperature: 500°F Maximum
- Current: 575 ± 15A
- Voltage: 32 ± 2 VAC
- Travel Speed: 12 IPM

One weldment each was made with the same nominal conditions except that the flux mixture was changed for each weld as follows:

Weld Description	Welding Flux Mixture
V81	1 - 6060 (0894) 4080 (0592)
V82	2 - 7560 (0894) 2580 (0592)
V83	3 - 9060 (0894) 1080 (0592)

At the completion of welding, the preheat was maintained for a minimum of 16 hours. The strongbacks and backing straps were removed and the welds were then each cut into three 12-inch pieces.

A.2 POST WELD HEAT TREATMENTS

One-third of each weld was given the following PWHTs:

	PWHT		
	#1	#2	#3
Heating Rate			
600°F to Hold Temp., °F/Hr.	53.5	59.4	42.5
Hold Temperature, °F	1135	1075	1025
Hold Time, Hours	50	50	50
Cooling Rate			
Hold Temp. to 600°F, °F/Hr.	13.0	12.2	11.5
Flux	Weld Designations		
6060 (0894) - 4080 (0592)	V811	V812	V813
7560 (0894) - 2580 (0592)	V821	V822	V823
9060 (0894) - 1080 (0592)	V831	V832	V833

A.3 NONDESTRUCTIVE EXAMINATION RESULTS

This examination consisted of radiography of the three weldments after cutting into three equal lengths and milling of the top and bottom surfaces. Its purpose was to locate sound material for specimen cutting. The results are given in Table A-1 and Figure A-1. No interpretation of the indications was made (slag, lack of fusion, porosity, cracks, etc.).

A.4 MECHANICAL PROPERTY AND OTHER TESTS

Each of the test plates was cut by sawing to provide test specimen blanks in the general relationship shown on Figure A-2. The orientation of the test specimens with respect to the weld are shown in Figure A-3. In those cases where extra Charpy V-Notch tests were performed, the spare material was used to produce specimens continuing with the same numbering sequence. The specimen numbering system adopted for the subcontract is given in Table A-2.

Table A-1

SUMMARY OF RADIOGRAPHIC EXAMINATIONS

Weld	Indications
V811	None
12	Two - Short transverse in weld metal
13	None
V821	None
22	None
23	One - Long longitudinal 1/4 to 1/2" deep
V831	Two - Long longitudinal 1/4 to 1/2" deep
	- Transverse in base metal
32	Two - Longitudinal in weld metal
33	None

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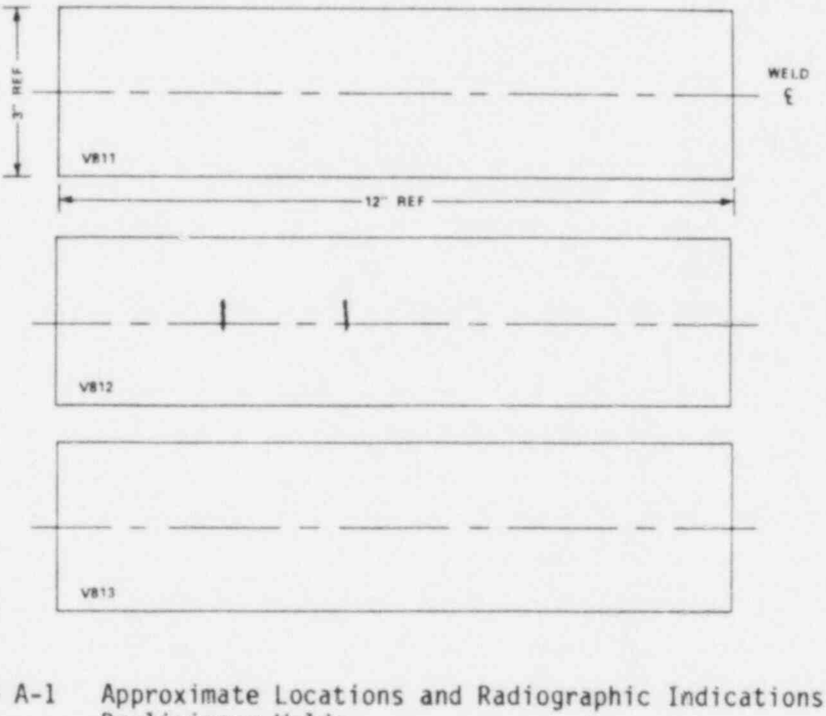

Figure A-1 Approximate Locations and Radiographic Indications for Preliminary Welds

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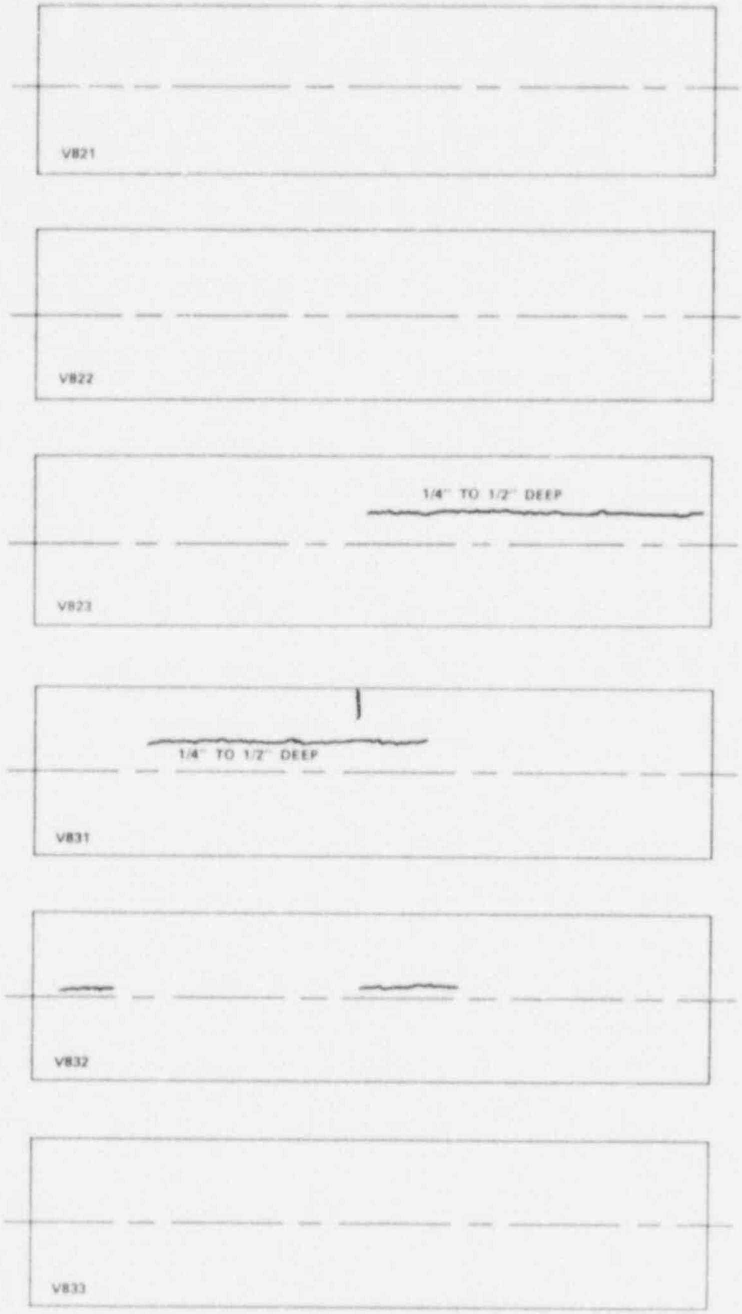

Figure A-1 Approximate Locations and Radiographic Indications for Preliminary Welds (Cont'd)

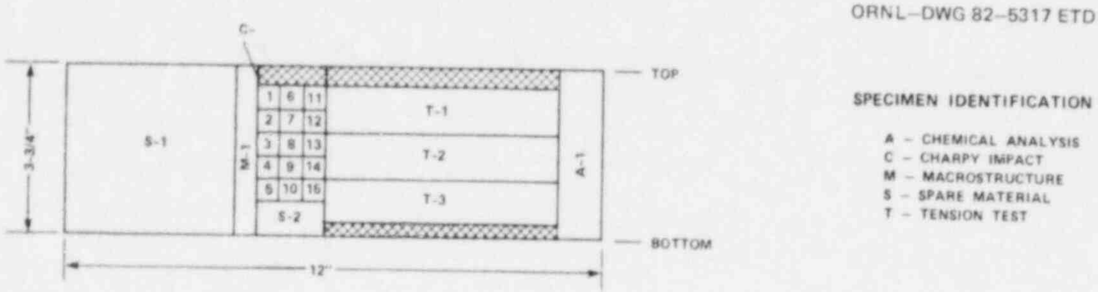

Figure A-2 Side-View Cutting Diagram for Welds V811 Through V833

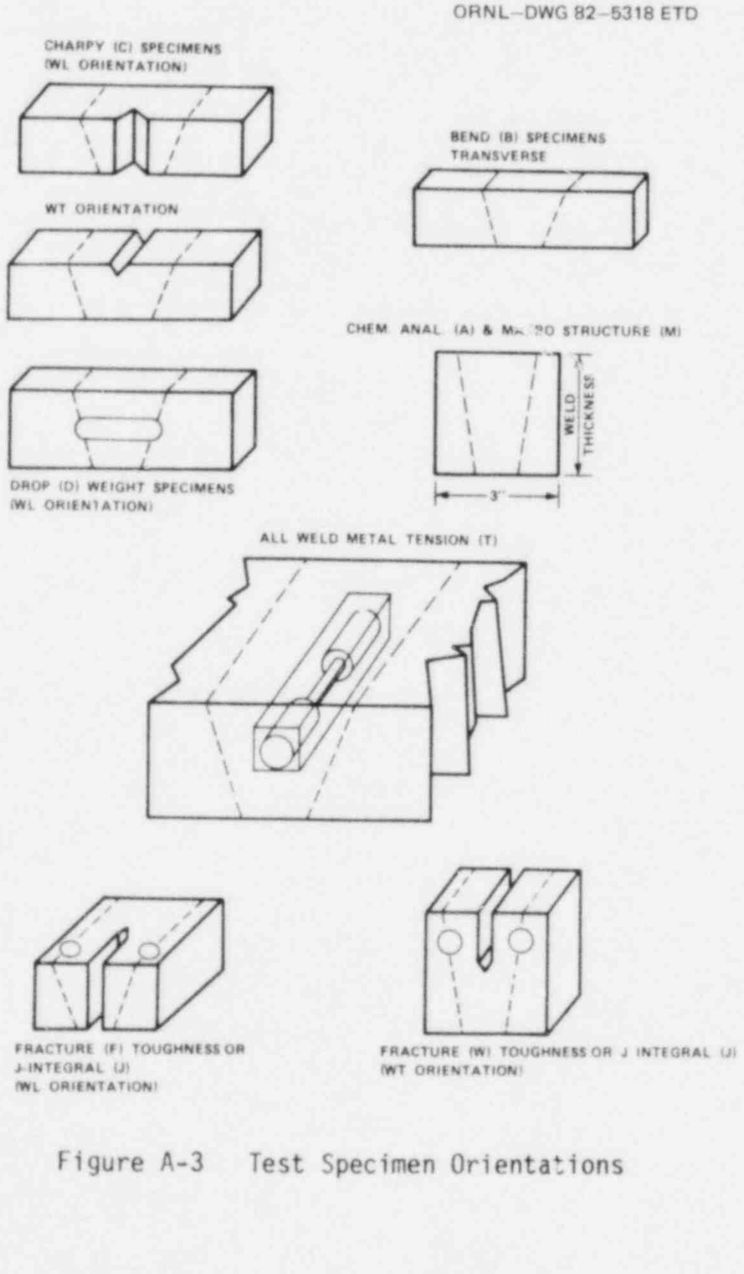

Figure A-3 Test Specimen Orientations

Table A-2

V-8 VESSEL CONTRACT SPECIMEN IDENTIFICATION SYSTEM

```
V 8 W P T N
    | | | |
    | | | |______ Specimen in series (1, 2, 3,...)
    | | |
    | | |________ Type of Test Specimen
    | |             A - Chemical Analysis
    | |             B - Transverse Weld Bend
    | |             C - Charpy V-Notch
    | |             D - Drop Weight
    | |             F - Fracture Toughness or
    | |                   J-Integral, WL Orientation
    | |             J - J-Integral, WL or WT Orientation
    | |             M - Macrostructure
    | |             S - Spare Material
    | |             T - Tension
    | |             W - Fracture Toughness, WT Orientation
    | |__________ Post Weld Heat Treatment (1, 2, or 3)
    |
    |____________ Weld
                    0 - Base Metal
                    1 - Preliminary Weld #1
                    2 - Preliminary Weld #2
                    3 - Preliminary Weld #3
                    4 - Trial Weld
                    5 - Characterization Weld #1
                    6 - Characterization Weld #2
                    7 - Characterization Weld #3
                    8 - Characterization Weld #4
                    9 - Flawing Practice Weld
                   10 - Characterization Weld #5
                    P - Preliminary Weld #4
                    Q - Preliminary Weld #5
```

A.4.1 Macrostructure

A macroetched cross-section of each of the welds is shown in Figures A-4, A-5, and A-6. A visual examination of these sections performed at 10X magnification did not reveal any discontinuities in the weld metal or base metal heat affected zones (HAZ).

A.4.2 Chemical Analysis

Spectrographic chemical analyses were performed in accordance with ASME NB2432, Section III, of the weld cross-sections at the top, middle, and root locations. These results are given in Table A-3.

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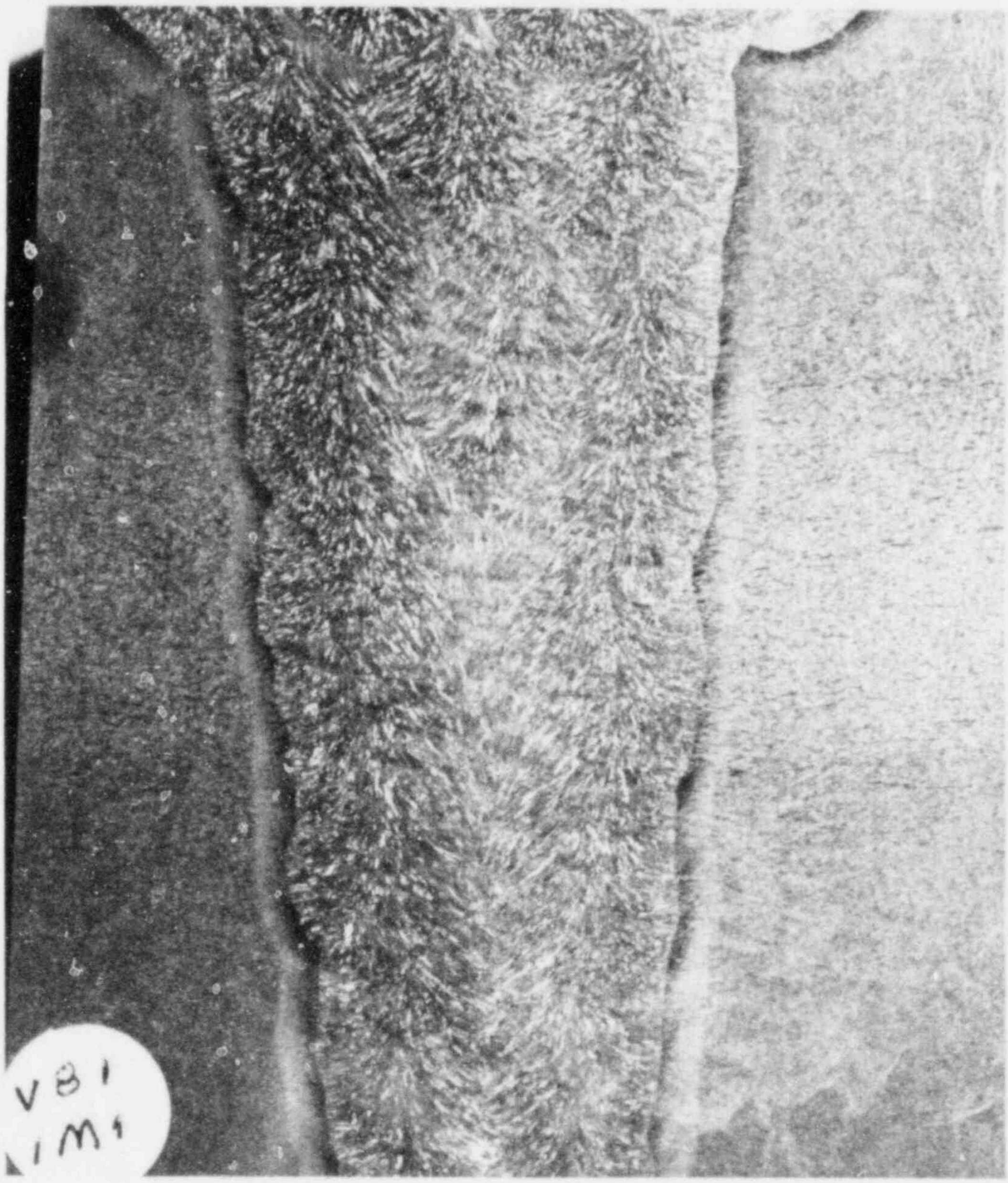

Figure A-4 Photomacrograph of Preliminary Weld V81

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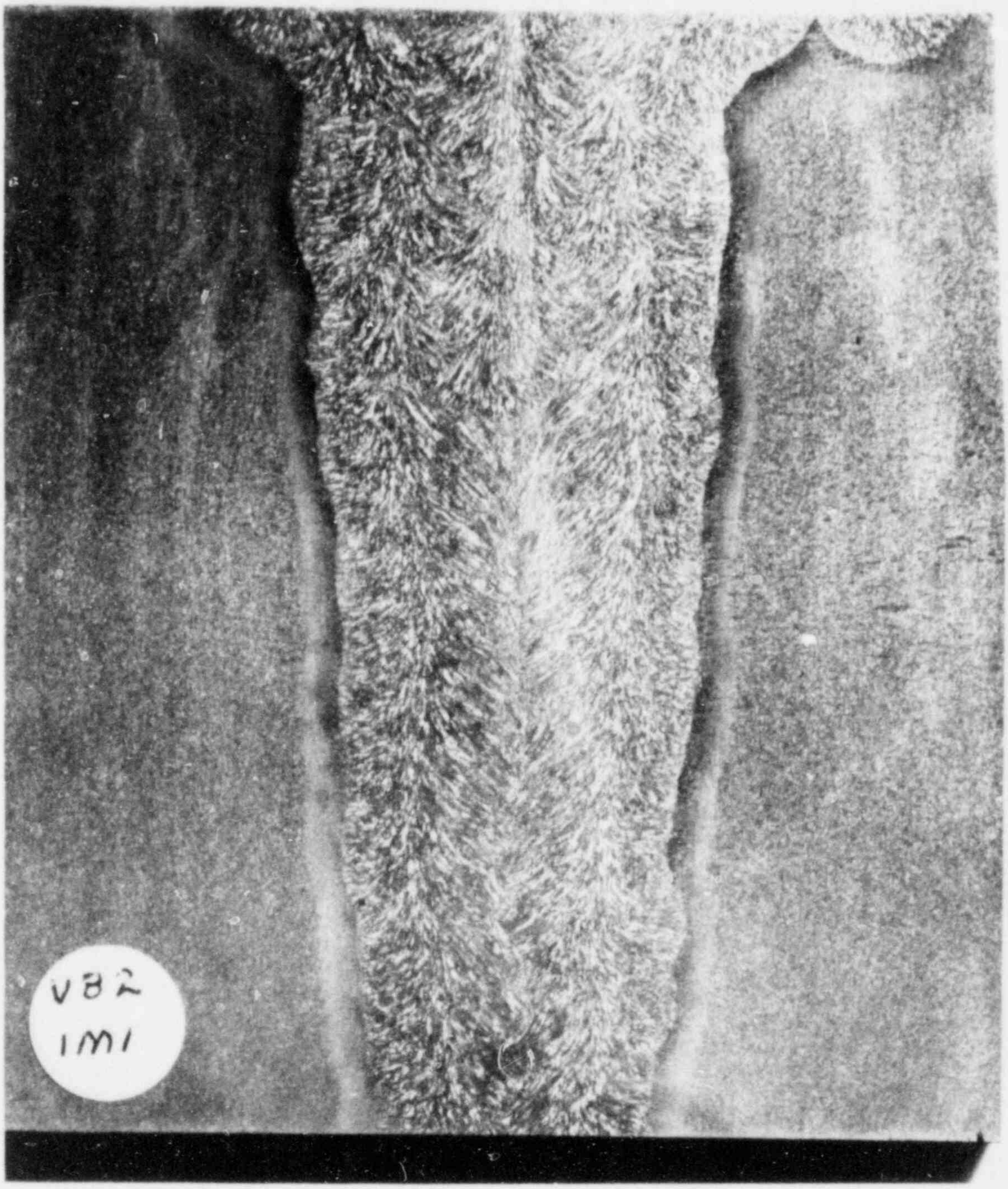

Figure A-5 Photomacrograph of Preliminary Weld V82

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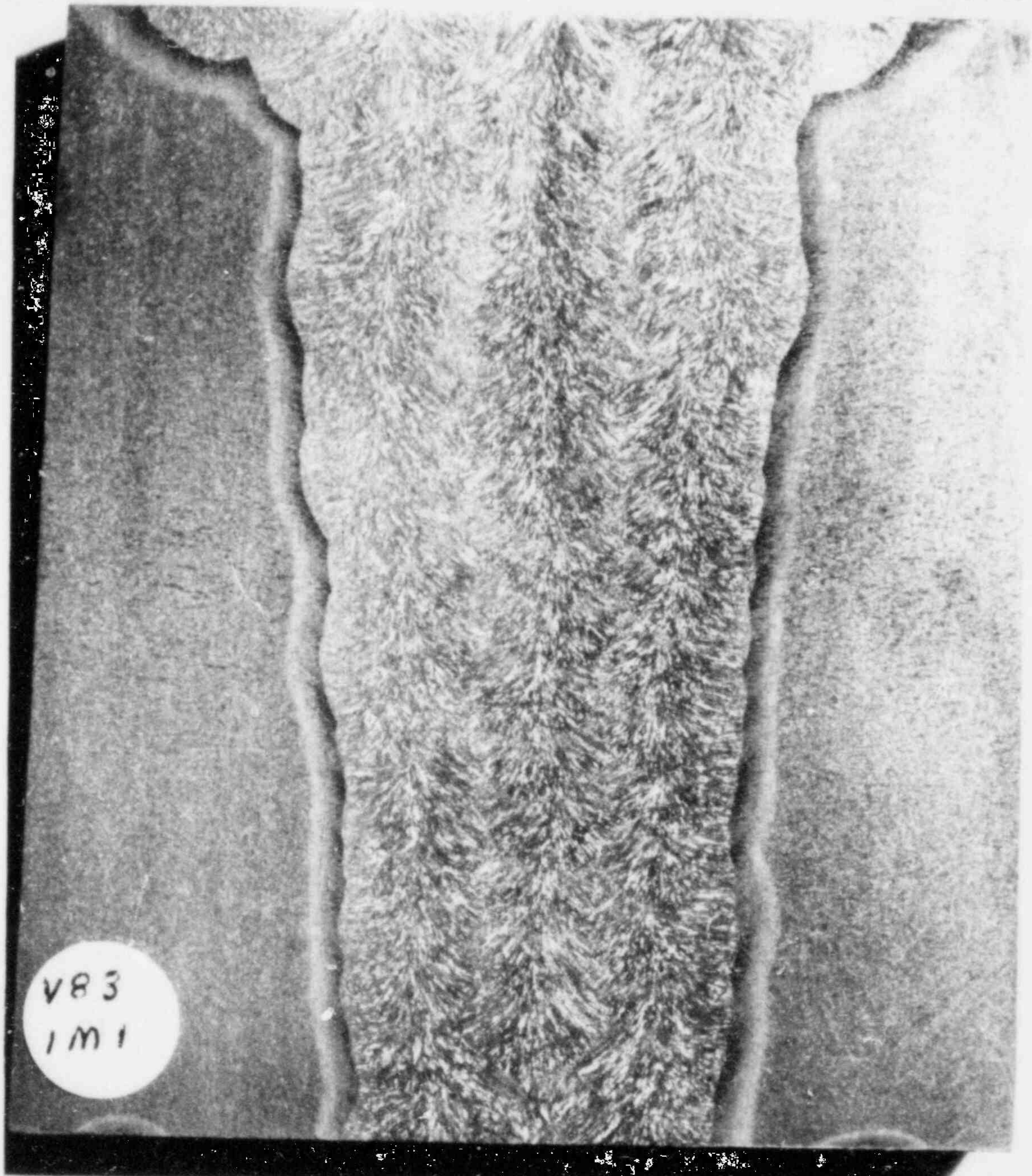


Figure A-6 Photomacrograph of Preliminary Weld V83

Table A-3

CHEMICAL ANALYSIS
(Weight %)

Identity		C	Mn	P	S	Si	Cr	Ni	Mo	Cu	Sn	V	Al
V822A1	Top	.05	1.61	.025	.018	.65	.04	.62	.48	.31	.026	.009	.004
V822A1	Mid	.05	1.61	.024	.016	.65	.04	.61	.48	.29	.025	.009	.003
V822A1	Root	.07	1.60	.023	.017	.65	.05	.59	.49	.28	.023	.008	.003
V812A1	Top	.06	1.62	.026	.020	.67	.04	.62	.49	.27	.027	.009	.004
V812A1	Mid	.07	1.64	.024	.020	.65	.04	.62	.50	.31	.027	.009	.006
V812A1	Root	.07	1.63	.021	.020	.60	.05	.57	.49	.31	.028	.009	.007
V832A1	Top	.05	1.62	.025	.019	.68	.04	.62	.48	.25	.026	.009	.003
V832A1	Mid	.06	1.65	.022	.020	.61	.04	.62	.49	.25	.025	.009	.004
V832A1	Root	.06	1.61	.022	.019	.64	.05	.58	.48	.30	.025	.009	.004

A.4.3 Tensile Tests

Room temperature tensile tests were performed in accordance with ASTM E-8-80. In general, three specimens were tested; one each from the top, middle, and bottom weld. For the V83 weld (made with 90% Linde 60 flux), only two locations -- top and middle -- were tested. These results are given in Table A-4.

A.4.4 Charpy V-Notch Tests

Charpy V-Notch tests were performed over the temperature range of 125° - 275°F in accordance with ASTM E-23-72. The results of these tests are given in Tables A-5 through A-13. These results are also plotted as a function of temperature in Figures A-7 through A-15.

In some cases, instrumented tests were performed to obtain load-time and energy-time recordings. Inspection of these recordings failed to produce any significant improvement in the visual estimation of the amount of shear reported here.

Table A-4

ROOM TEMPERATURE TENSILE TEST RESULTS

Spec. No.	% Linde 60	PWHT Temp., °F	Location In Weld	Y.S., ksi	UTS, ksi	El., %	RA, %
V8111	60	1100-1150	Top	63.72	80.29	26.0	55.2
112	60	1100-1150	Middle	64.54	81.34	25.0	55.9
113	60	1100-1150	Bottom	65.25	81.43	25.0	56.5
			Avg.	64.50	81.02	25.3	55.9
V8121	60	1050-1100	Top	69.07	84.13	24.0	52.5
122	60	1050-1100	Middle	71.08	85.74	24.5	54.6
123	60	1050-1100	Bottom	71.04	85.62	21.5	50.0
			Avg.	70.40	85.16	23.3	52.4
V8131	60	1000-1050	Top	74.41	88.67	23.5	48.3
132	60	1000-1050	Middle	76.47	89.61	24.0	55.0
133	60	1000-1050	Bottom	77.58	90.95	20.5	49.5
			Avg.	76.15	89.74	22.7	50.9
V8211	75	1100-1150	Top	60.78	78.10	25.5	55.4
212	75	1100-1150	Middle	62.50	79.30	25.0	57.3
213	75	1100-1150	Bottom	63.40	80.03	25.5	55.8
			Avg.	62.22	79.14	25.3	56.2
V8221	75	1050-1100	Top	65.49	80.65	24.5	54.6
222	75	1050-1100	Middle	67.32	81.92	25.5	55.1
223	75	1050-1100	Bottom	67.80	83.05	24.0	53.5
			Avg.	66.87	81.87	24.7	54.4
V8231	75	1000-1050	Top	69.46	84.12	24.0	53.5
232	75	1000-1050	Middle	72.66	85.37	23.5	53.0
233	75	1000-1050	Bottom	72.63	86.29	23.0	53.2
			Avg.	71.58	85.26	23.5	53.2
V8311	90	1100-1150	Top	60.14	76.86	27.5	55.1
312	90	1100-1150	Middle	61.23	77.47	27.0	55.7
			Avg.	60.68	77.17	27.3	55.4
V8321	90	1050-1100	Top	65.43	79.88	22.0	53.7
322	90	1050-1100	Middle	65.54	80.55	22.0	53.1
			Avg.	65.48	80.22	22.0	53.4
V8331	90	1000-1050	Top	71.01	84.82	23.0	52.5
332	90	1000-1050	Middle	71.56	84.90	22.5	51.8
			Avg.	71.28	84.86	22.8	52.2

Table A-5

CHARPY V-NOTCH TEST RESULTS

V811 - 60% Linde 60 - 1100-1150°F PWHT

Spec. No.	Test Temp., °F	Energy Ft. Lbs.	Lateral Expansion, Mils	Shear, %
4	125	45.0	50	95
9	125	44.9	53	95
14	125	48.7	55	100
22	125	37.7	39	70
24	125	46.0	47	95
Avg.	125	44.5	48.8	91.0
17	150	42.0	41	65
19	150	48.0	50	95
Avg.	150	45.0	45.5	80.0
2	175	42.7	47	90
7	175	40.8	41	85
12	175	41.9	48	85
16	175	44.9	45	85
18	175	39.1	42	80
20	175	45.0	51	99
Avg.	175	42.4	45.7	87.3
6	200	41.8	48	95
8	200	42.4	44	95
10	200	48.9	57	100
Avg.	200	44.4	49.7	96.7
11	225	47.9	58	98
13	225	46.0	52	95
15	225	48.8	56	100
Avg.	225	47.6	55.3	97.7
1	275	49.2	59	100
3	275	44.5	54	95
5	275	52.0	62	100
Avg.	275	48.6	58.3	98.3

Top

1	6	11	16	21
2	7	12	17	22
3	8	13	18	23
4	9	14	19	24
5	10	15	20	25

Table A-6

CHARPY V-NOTCH TEST RESULTS

Spec. No.	Test Temp., °F	Energy Ft. Lbs.	Lateral Expansion, Mils	Shear, %
	V812 - 60% Linde 60, 1050-1100°F PWHT			
2	125	33.0	33	45
4	125	36.4	43	96
Avg.	125	34.7	38.0	70.5
7	150	35.1	38	65
9	150	35.4	41	98
Avg.	150	35.3	39.5	81.5
1	175	41.5	43	99
3	175	44.0	44	100
5	175	36.0	37	100
Avg.	175	40.5	41.3	99.7
6	200	44.1	46	99
8	200	43.0	46	100
10	200	40.8	44	100
Avg.	200	42.6	45.3	99.7
11	225	41.0	45	100
13	225	44.0	50	100
15	225	38.6	43	100
Avg.	225	41.2	46.0	100.0
12	275	43.5	47	100
14	275	38.7	46	100
Avg.	275	41.1	46.5	100.0

Table A-7

CHARPY V-NOTCH TEST RESULTS

Spec. No.	Test Temp., °F	Energy Ft. Lbs.	Lateral Expansion, Mils	Shear, %
	V813 - 60% Linde 60, 1000-1050°F PWHT			
2	125	28.0	31	65
4	125	37.8	45	99
Avg.	125	32.9	38.0	82.0
7	150	30.5	29	60
9	150	42.0	42	99
Avg.	150	36.3	35.5	79.5
1	175	34.3	37	90
3	175	43.2	45	99
5	175	32.0	35	99
Avg.	175	36.5	39.0	96.0
6	200	35.2	37	95
8	200	36.8	35	80
10	200	36.9	42	100
Avg.	200	36.3	38.0	91.7
11	225	37.7	42	100
13	225	42.7	47	96
15	225	42.0	46	100
Avg.	225	40.8	45.0	98.7
12	275	40.7	46	100
14	275	42.7	51	100
Avg.	275	41.7	48.5	100.0

Table A-8

CHARPY V-NOTCH TEST RESULTS

Spec. No.	Test Temp., °F	Energy Ft. Lbs.	Lateral Expansion, Mils	Shear, %
	V821 - 75% Linde 60, 1100-1150°F PWHT			
4	125	45.0	52.0	95
9	125	40.7	47.0	95
14	125	44.8	56.0	95
22	125	35.0	37.0	75
24	125	41.1	46.0	87
Avg.	125	41.3	47.6	89.4
17	150	34.1	37	70
19	150	42.5	48	98
Avg.	150	38.3	42.5	84.0
2	175	34.8	41	75
7	175	34.6	40	75
12	175	40.[illegible]	44	85
16	175	39.0	41	85
18	175	46.4	49	95
20	175	42.3	50	99
Avg.	175	39.5	44.2	85.7
6	200	42.9	51	98
8	200	47.8	54	98
10	200	50.0	61	100
Avg.	200	46.9	55.3	98.7
11	225	46.9	55	98
13	225	44.8	52	95
15	225	48.8	58	100
Avg.	225	46.8	55.0	97.7
1	275	50.0	54	100
3	275	48.0	61	100
5	275	50.2	59	100
Avg.	275	49.4	58.0	100.0

Table A-9

CHARPY V-NOTCH TEST RESULTS

Spec. No.	Test Temp., °F	Energy Ft. Lbs.	Lateral Expansion, Mils	Shear, %
	V822 - 75% Linde 60, 1050-1100°F PWHT			
2	125	38.0	42	85
4	125	38.0	42	95
Avg.	125	38.0	42	90.0
7	150	37.4	42	90
9	150	42.2	47	100
Avg.	150	39.8	44.5	95.0
1	175	43.0	49	98
3	175	35.0	42	99
5	175	41.8	48	100
Avg.	175	39.9	46.3	99.0
6	200	43.1	48	99
8	200	36.8	42	100
10	200	42.1	48	100
Avg.	200	40.7	46.0	99.7
11	225	46.1	52	100
13	225	45.6	50	100
15	225	43.9	50	100
Avg.	225	45.2	50.7	100.0
12	275	38.5	46	100
14	275	41.6	47	100
Avg.	275	40.1	46.5	100.0

Table A-10

CHARPY V-NOTCH TEST RESULTS

Spec. No.	Test Temp., °F	Energy Ft. Lbs.	Lateral Expansion, Mils	Shear, %
	V823 - 75% Linde 60, 1000-1050°F PWHT			
2	125	29.8	32	60
4	125	31.9	42	99
Avg.	125	30.9	37.0	79.5
7	150	33.0	36	80
9	150	37.9	44	99
Avg.	150	35.5	40.0	89.5
1	175	32.9	39	90
3	175	38.6	44	95
5	175	36.1	38	99
Avg.	175	35.9	40.3	94.7
6	200	33.2	37	95
8	200	37.0	43	98
10	200	37.8	42	100
Avg.	200	36.0	40.7	97.7
11	225	39.0	43	100
13	225	39.3	42	98
15	225	39.0	44	100
Avg.	225	39.1	43.0	99.3
12	275	41.0	46	100
14	275	38.9	45	100
Avg.	275	40.0	45.5	100.0

Table A-11

CHARPY V-NOTCH TEST RESULTS

Spec. No.	Test Temp., °F	Energy Ft. Lbs.	Lateral Expansion, Mils	Shear, %
	V831 - 90% Linde 60, 1100-1150°F PWHT			
5	125	45.4	56	100
7	125	42.2	51	85
9	125	30.0	38	65
Avg.	125	39.2	48.3	83.3
2	175	39.9	46	95
7	175	42.2	51	85
12	175	40.2	44	95
Avg.	175	40.8	47.0	91.7
6	200	40.3	54	91
8	200	43.1	52	98
10	200	41.1	54	92
Avg.	200	41.5	53.3	93.7
11	225	47.9	58	96
13	225	46.2	58	95
15	225	44.1	57	96
Avg.	225	46.0	57.7	95.7
1	275	47.6	56	100
3	275	48.8	55	100
5	275	45.4	56	100
Avg.	275	47.3	55.7	100.0

Table A-12

CHARPY V-NOTCH TEST RESULTS

Spec. No.	Test Temp., °F	Energy Ft. Lbs.	Lateral Expansion, Mils	Shear, %
V832 - 90% Linde 60, 1050-1100°F PWHT				
2	125	35.0	39	88
4	125	31.3	36	99
Avg.	125	33.2	37.5	93.5
7	150	34.1	42	99
9	150	32.9	38	97
Avg.	150	33.5	40.0	98.0
1	175	37.0	41	95
3	175	37.7	44	93
5	175	37.9	46	100
Avg.	175	37.5	43.7	96.0
6	200	37.9	43	95
8	200	42.3	45	100
10	200	40.2	47	100
Avg.	200	40.1	45.0	98.3
11	225	41.1	46	97
13	225	41.0	47	100
15	225	44.2	48	100
Avg.	225	42.1	47.0	99.0
12	275	40.6	50	100
14	275	39.2	46	100
Avg.	275	39.9	48.0	100.0

Table A-13

CHARPY V-NOTCH TEST RESULTS

Spec. No.	Test Temp., °F	Energy Ft. Lbs.	Lateral Expansion, Mils	Shear, %
	V833 - 90% Linde 60, 1000-1050°F PWHT			
2	125	31.9	32	70
4	125	33.9	39	85
Avg.	125	32.9	35.5	77.5
7	150	31.0	36	75
9	150	33.0	38	85
Avg.	150	32.0	37.0	80.0
1	175	36.8	40	95
3	175	34.4	41	95
5	175	36.2	43	99
Avg.	175	35.8	41.3	96.3
6	200	35.1	40	95
8	200	34.3	40	98
10	200	37.2	44	100
Avg.	200	35.5	41.3	97.7
11	225	36.9	42	95
13	225	34.5	42	95
15	225	37.6	45	100
Avg.	225	36.3	43.0	96.7
12	275	40.9	46	100
14	275	37.1	44	100
Avg.	275	39.0	45.0	100.0

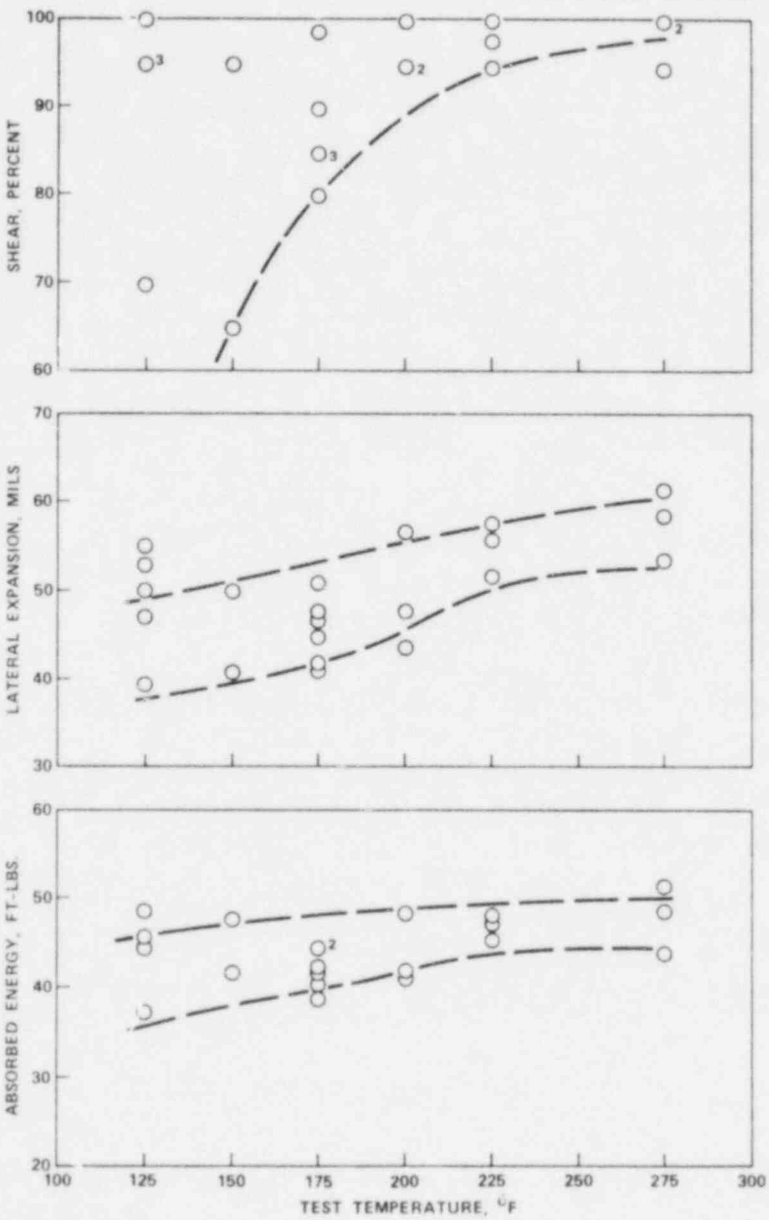


Figure A-7 Charpy V-Notch Test Results for Weld V811

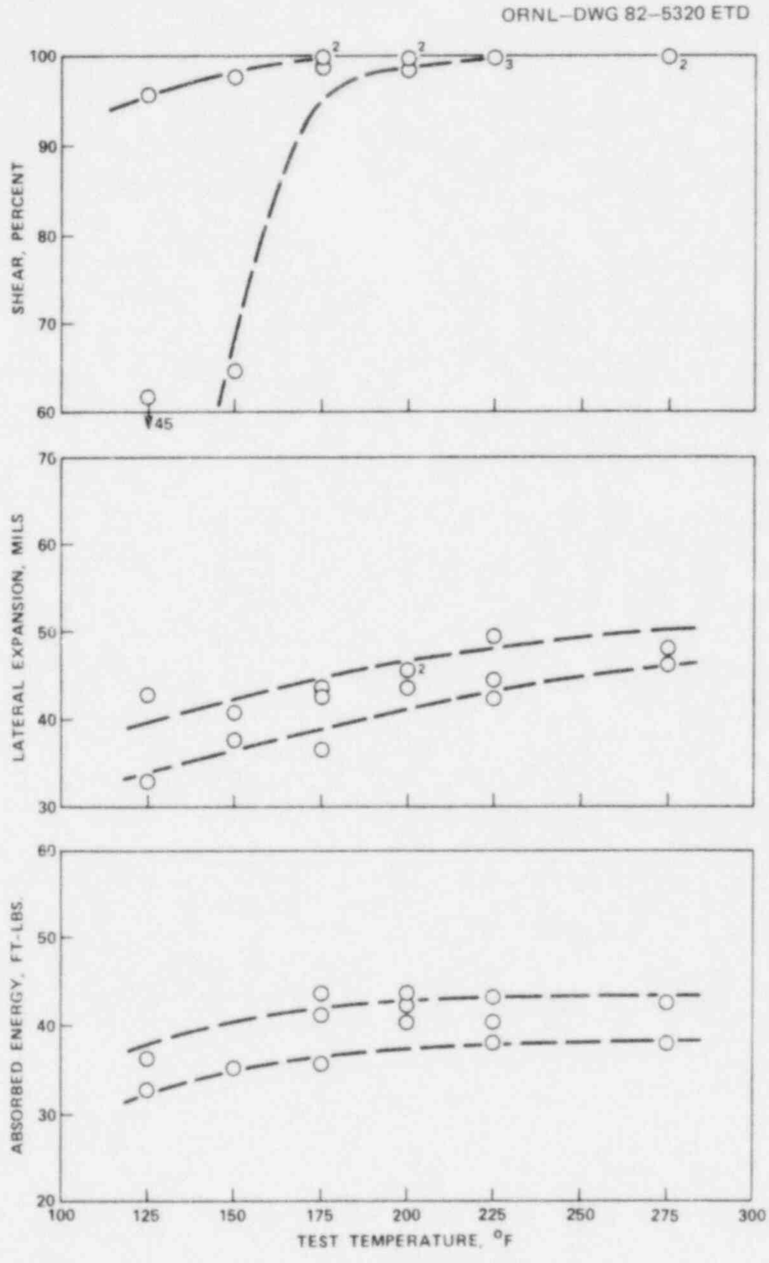


Figure A-8 Charpy V-Notch Test Results for Weld V812

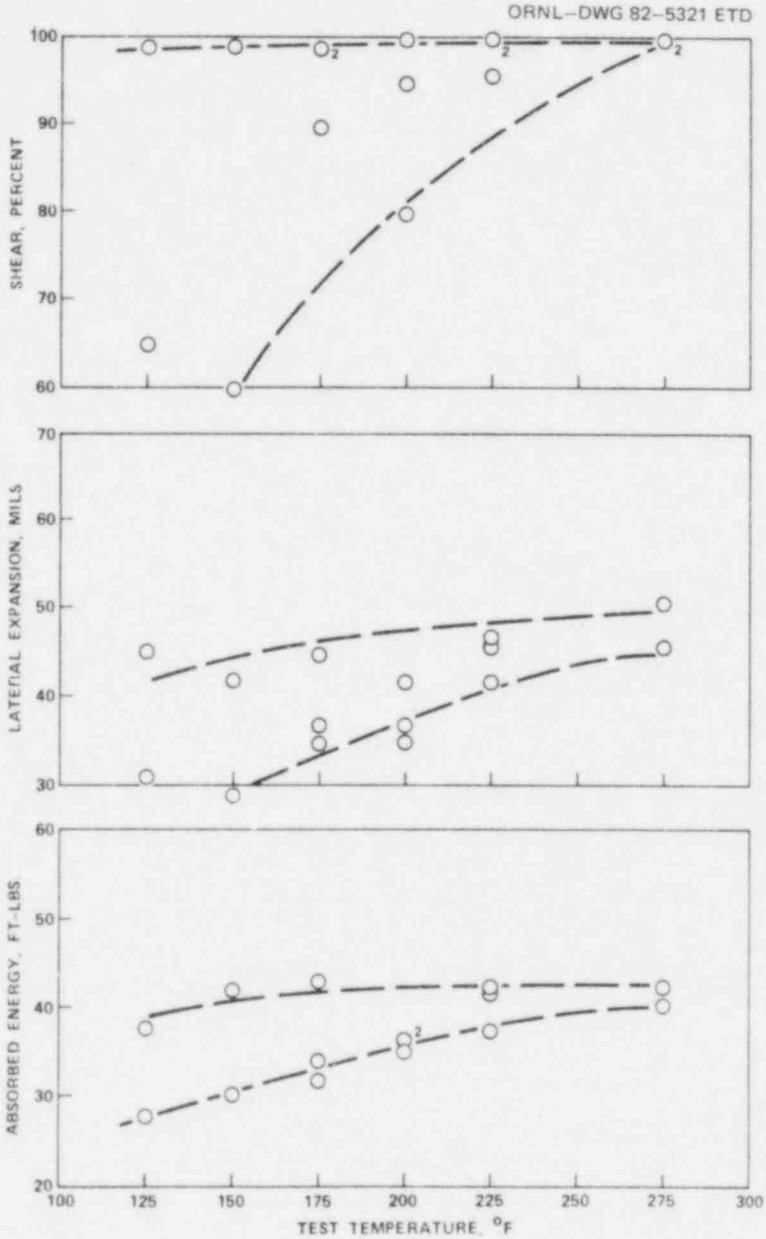


Figure A-9 Charpy V-Notch Test Results for Weld V813

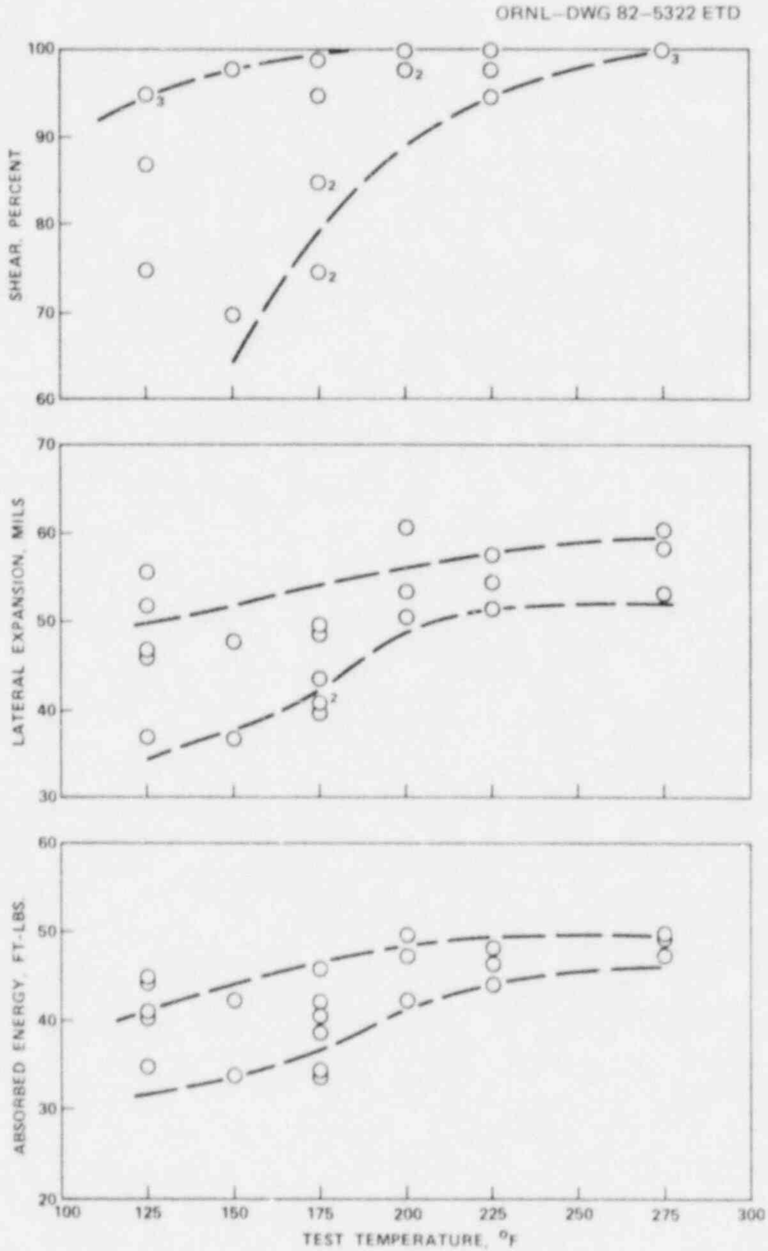


Figure A-10 Charpy V-Notch Test Results for Weld V821

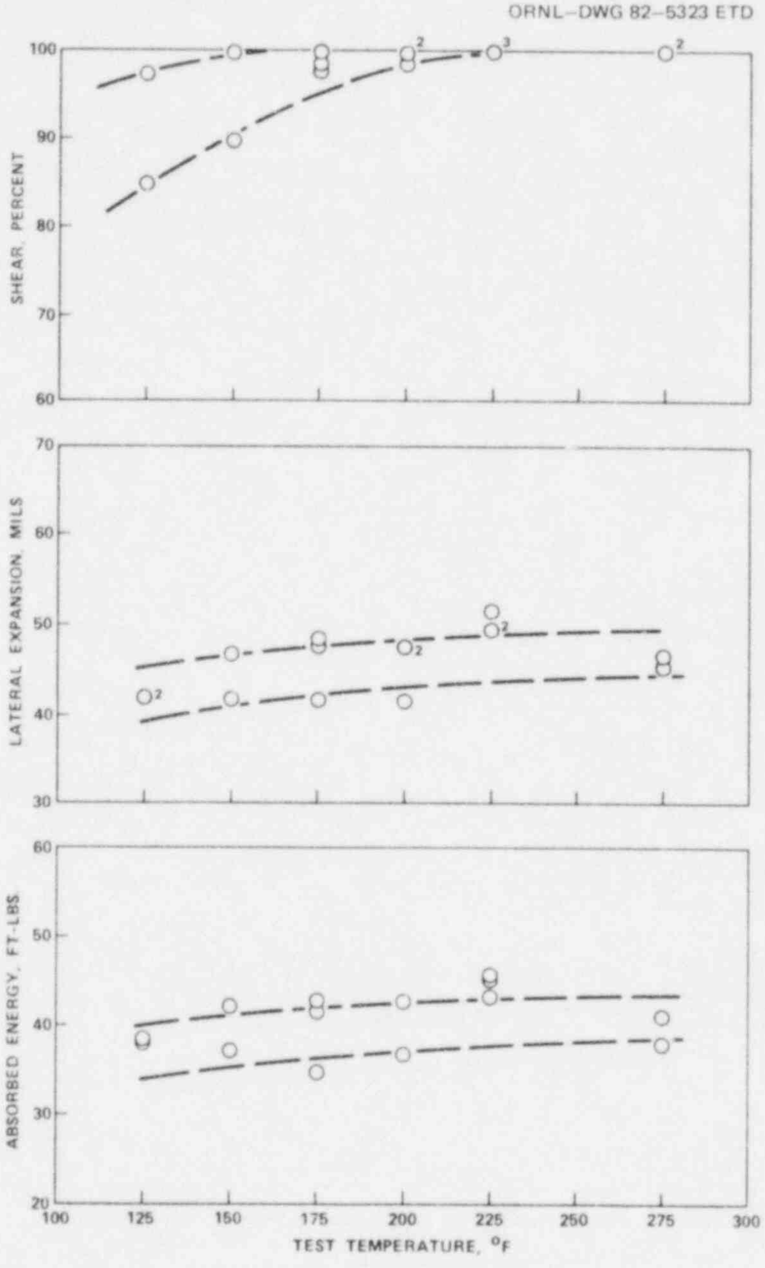


Figure A-11 Charpy V-Notch Test Results for Weld V822

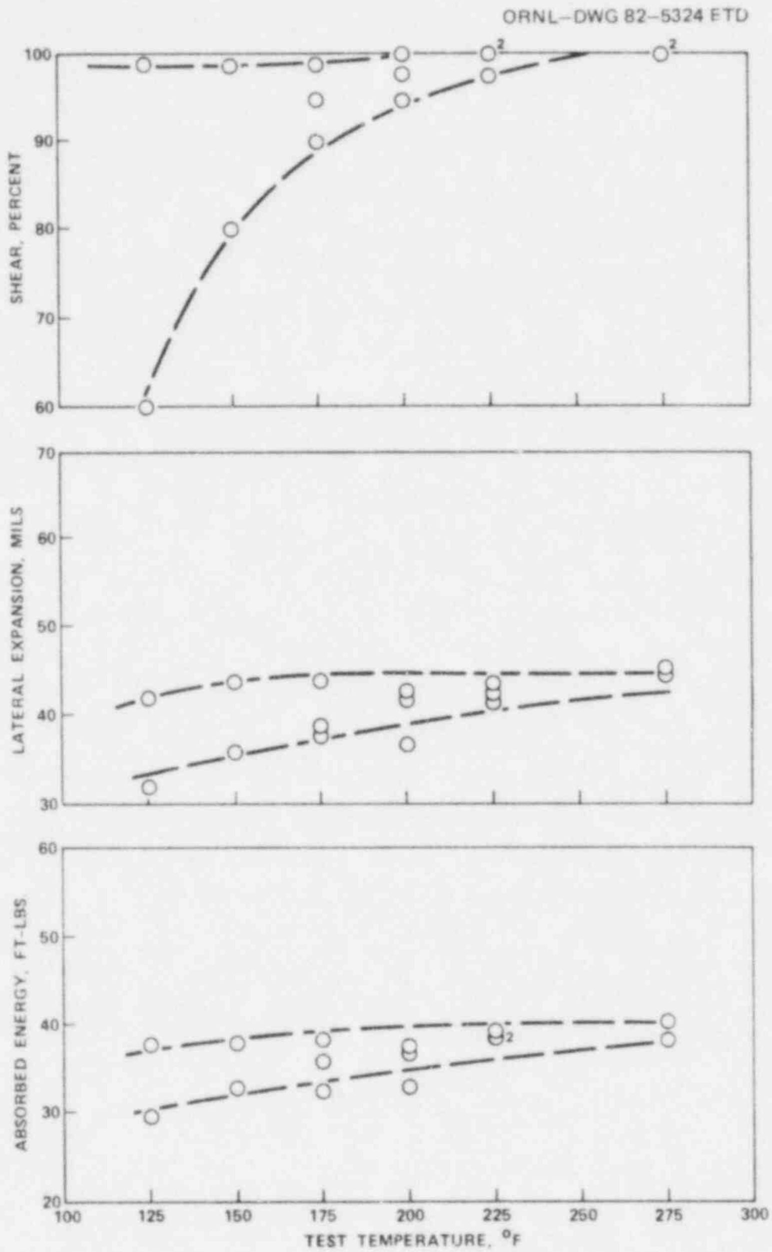


Figure A-12 Charpy V-Notch Test Results for Weld V823

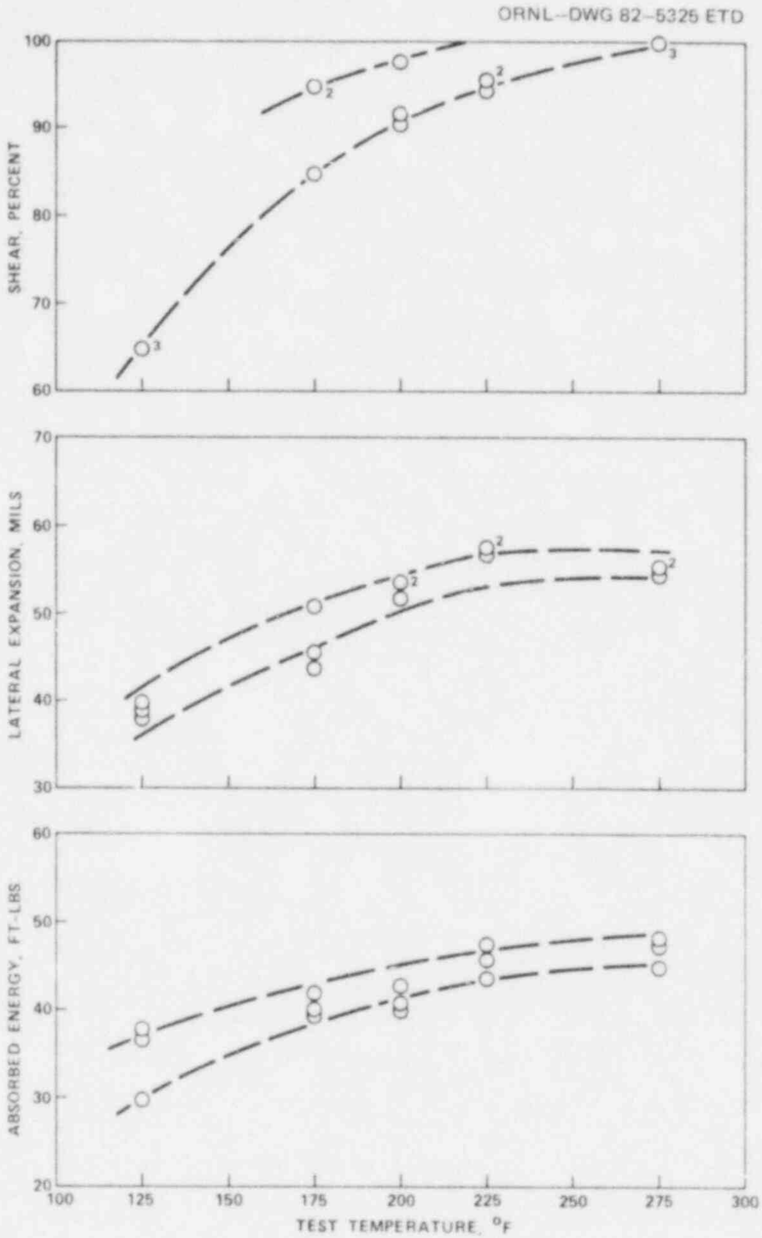


Figure A-13 Charpy V-Notch Test Results for Weld V831

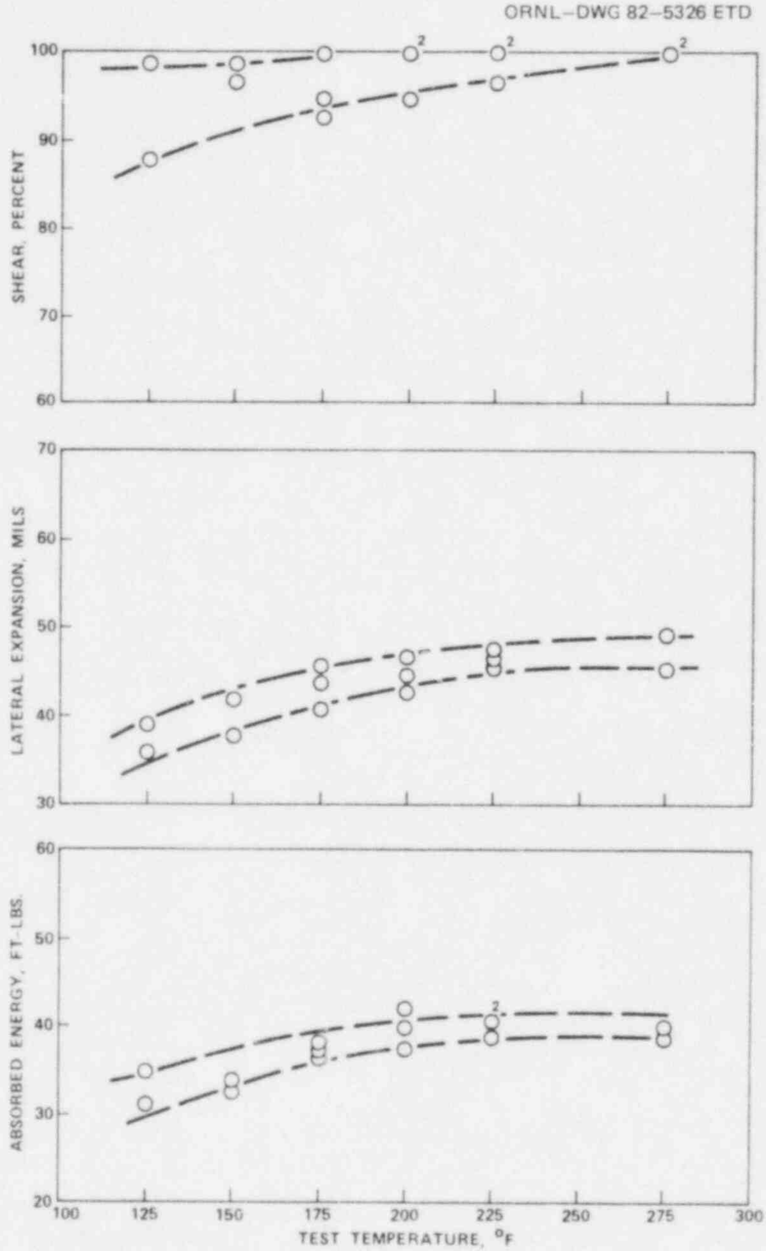


Figure A-14 Charpy V-Notch Test Results for Weld V832

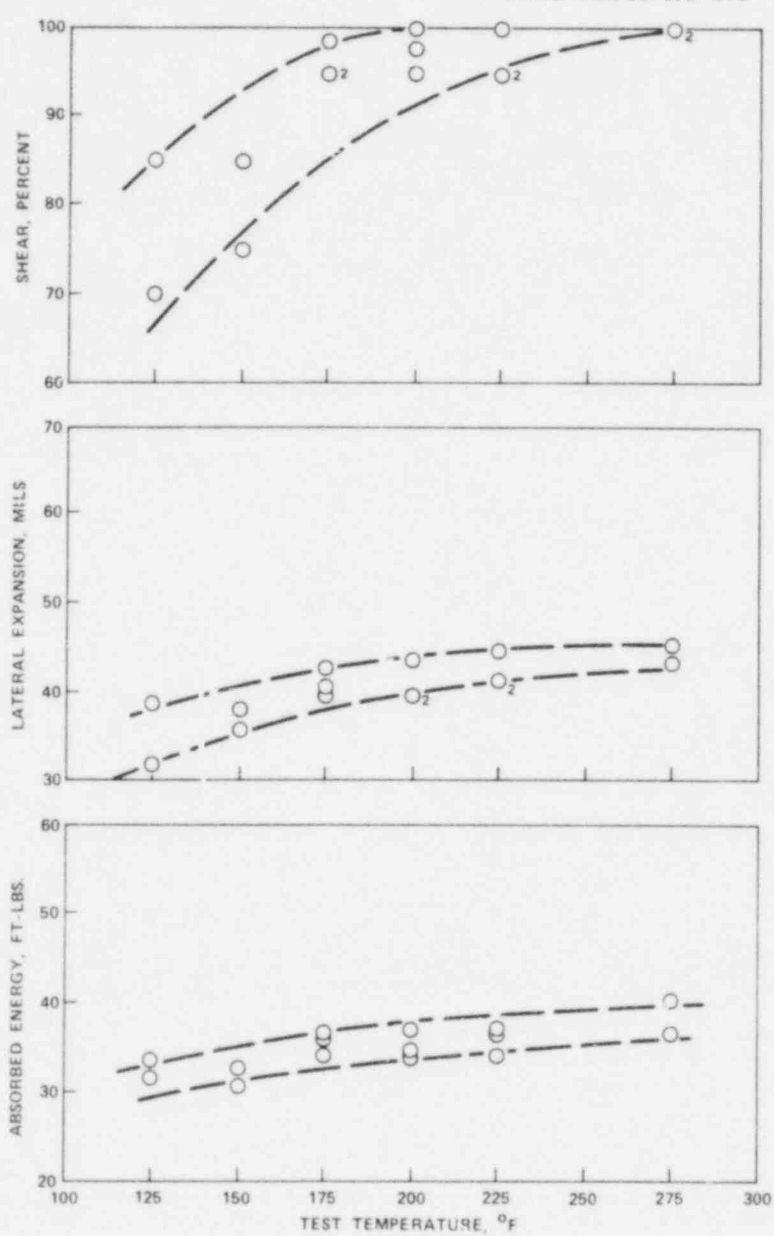


Figure A-15 Charpy V-Notch Test Results for Weld V833

APPENDIX B

WELD V8Q2 AND ITS TEST RESULTS

APPENDIX B

WELD V8Q2 AND ITS TEST RESULTS

After the preliminary weld test results were obtained, it became evident that a lower impact transition temperature was required for the top locations of the weld to achieve 100% shear in the Charpy V-Notch impact tests at 150° or 200°F. This could be done by either using a low heat input during welding or by use of a more favorable welding wire composition. Weld V8P was attempted (but not completed) with another heat of Mn-Mo-Ni wire having a larger diameter (5/32") at a heat input of 70-85 kJ/in., because it was unsatisfactory with respect to weld appearance. A high heat (~100 kJ/in.) input weld with the same wire was made and identified as Weld V8Q.

B.1 MAKING THE WELDMENT

The base metal pieces cut off of the Preliminary Weld V81 were used to make a 12-inch long submerged-arc single V-groove (7°/side) weld with 7/8" root opening as before (see Appendix A) except that the following conditions were used:

Welding Flux Mixture No. 2 -- 7560 (0894) - 2580 (0592)
Welding Wire -- 5/32" diameter, SFA 5.17, EF2, Mn-Mo-Ni, Heat 442010
Current: 610 ± 10A
Voltage: 33 ± 2VAC

Following welding, the strongbacks were removed and the weldment was given the following PWHT. No radiography was performed on this weldment.

B.2 POST WELD HEAT TREATMENT

This weldment, together with the base metal piece designated V80, were given the following PWHT:

Heat up rate - 600° to 1050°F : 140°F/hr
Hold time at 1050° - 1100°F : 58 hours
Cooling rate - 1050° to 600°F : 13.8°F/hr

The intended 100°F/hr maximum heating rate and 52-hour maximum hold time were exceeded but this is not significant.

B.3 TEST RESULTS

Figure B-1 shows the location of Charpy V-Notch test specimens for Weld V8Q2.

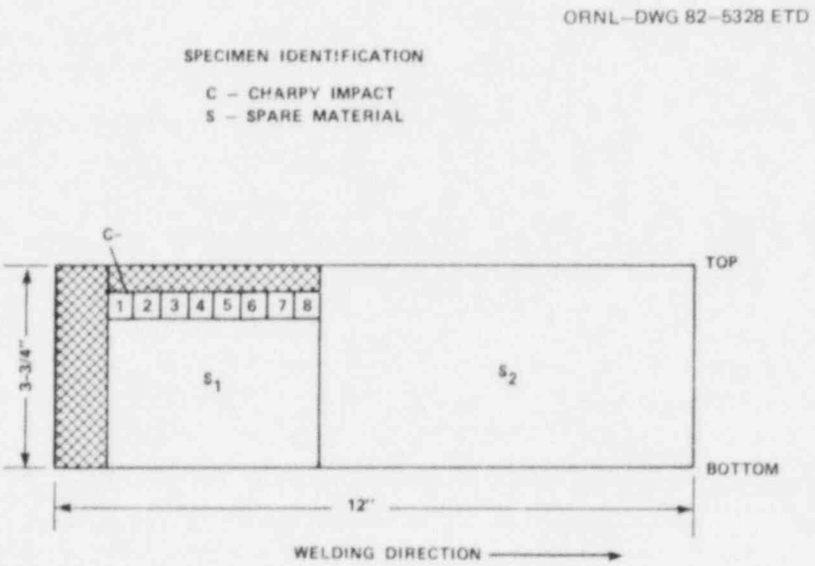


Figure B-1 Side-View Cutting Diagram of Weld V8Q2

The impact test results are given in Table B-1.

Table B-1

CHARPY V-NOTCH IMPACT TEST RESULTS

Specimen No.	Test Temp., °F	Absorbed Energy Ft. Lbs.	Lateral Expansion, Mils	Shear, %
		Weld V8Q2		
V8Q2C1	125	35.6	39	70
2	125	37.0	39	70
Avg.	125	36.3	39.0	70.0
3	150	33.8	37	75
4	150	34.9	36	70
5	150	36.6	42	85
Avg.	150	35.1	38.3	75.7
6	175	41.5	43	99
7	175	38.1	38	85
8	175	34.5	41	90
Avg.	175	38.0	40.7	91.3
9	200	43.0	46	100
10	200	41.3	47	100
Avg.	200	42.2	46.5	100.0

These results are also plotted in Figure B-2 together with those obtained for Weld V822 which was selected as representing the optimum condition for the trial weld. Apparently Weld V8Q2 had about the same upper-shelf start temperature of 200°F but with a higher fracture appearance transition temperature and was therefore no improvement over Weld V822 in the desired results.

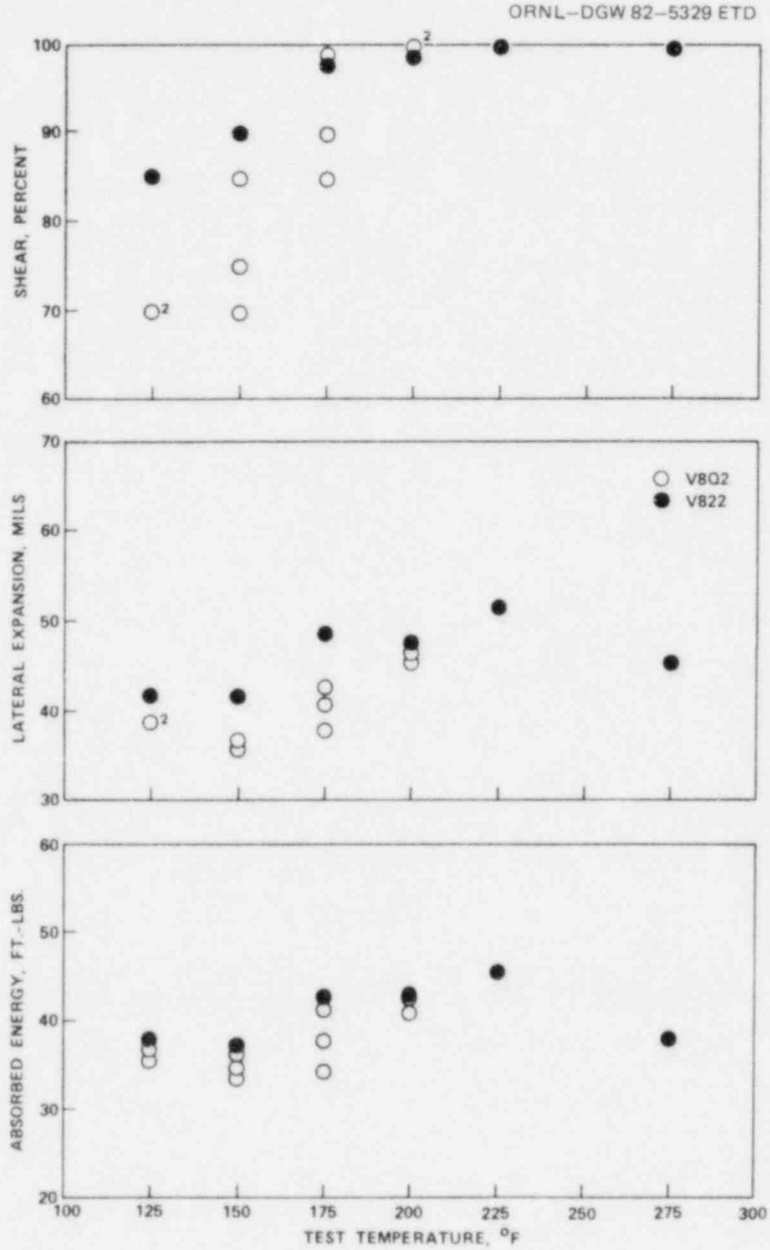


Figure B-2 Plot of Charpy V-Notch Test Results for Welds V822 and V8Q2

APPENDIX C

TRIAL WELD

APPENDIX C

TRIAL WELD

The conditions used to make Weld V822, previously described, were selected to make the trial weld except that it was made at a lower heat input (70 - 85 kJ/in.) in an attempt to lower the impact transition temperature over that obtained with Weld V822.

C.1 MAKING THE WELD

A single-groove submerged-arc weld was made in the Barberton shops with Plate 57E furnished by UCC-ND. This weld was 6" deep by about 25" long and was made with the following conditions:

Weld V842

Base Plate: SA 533 Bl Steel (Heat C6200-4)
Preheat: 300°F Minimum
Interpass Temperature: 500°F Maximum
Current: 450-500A
Voltage: 30-34 VAC
Travel Speed: 11-13 IPM
Flux: 7560 (0894) -2580 (0592)
Electrode: 1/8" Diameter, SFA 5.23, MnMoNi, Heat No. F60853

C.2 POST WELD HEAT TREATMENT

The weldment was given the following PWHT:

Heating Rate, 600-1080°F	:	148°F/hr
Hold Temperature	:	1080-1085°F
Hold Time	:	52 hours
Cooling Rate, 1080 to 600°F	:	10.2°F/hr

The intended 100°F/hr maximum heating rate was exceeded, but this is not significant.

C.3 NON-DESTRUCTIVE EXAMINATION RESULTS

Magnetic particle (MT) and radiographic examinations (RT) were made of the weld prior to the PWHT. The MT results were clear; the RT showed a 1-inch long entrapped slag region at one end of the weld about 1.2 inches below the top surface, apparently at the weld-base metal interface. Other regions of the weld were clear of rejectable indications. Since the indication was in a portion of the weld to be cut off and discarded, it was not repaired; the weld was accepted after PWHT and a second RT showed no further rejectable indications.

A visual examination performed on the macrostructure sample, V842M1, using 10X magnification did not reveal any cracks in the weld or the HAZ.

C.4 MECHANICAL PROPERTY AND OTHER TESTS

Test specimens were machined from the weldment according to Figure C-1 using the same orientations (Figure A-3 - Appendix A) and numbering system (Table A-2 - Appendix A) as previously used.

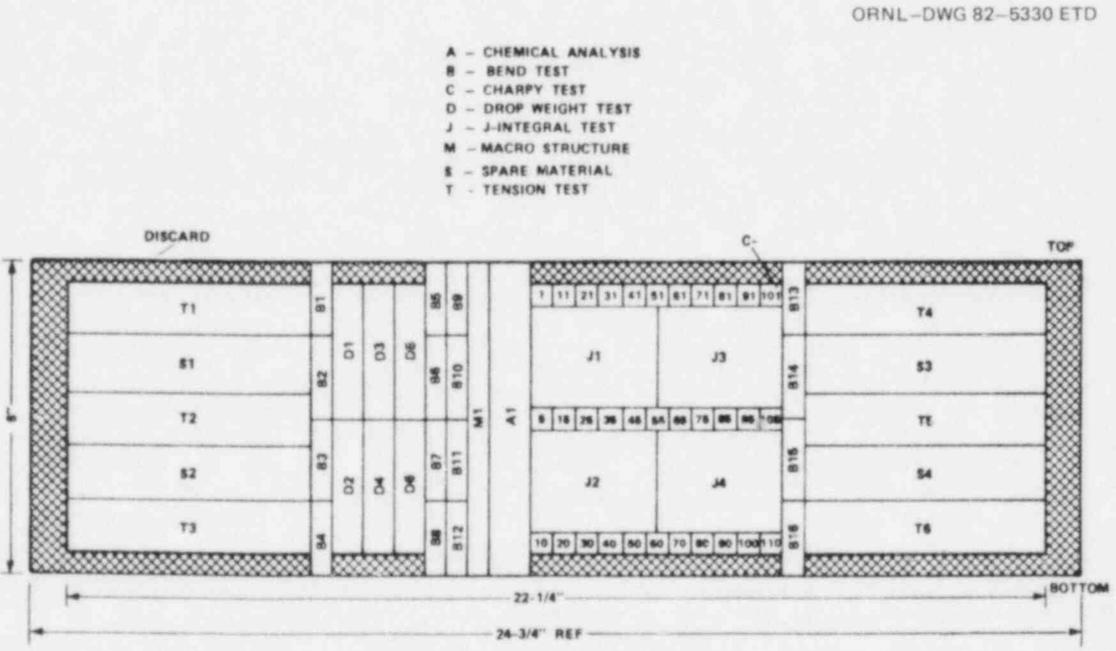


Figure C-1 Side-View Weld V842 Cutting Diagram

C.4.1 Macrostructure

Figure C-2 is a photomacrograph of the weld. The macrostructure appears normal for this type of weld.

C.4.2 Chemical Analyses

Spectrographic chemical analyses were performed in accordance with ASME BPVC, Section III, NB 2432, of the weld cross-section at the top, middle, and root locations. These results are given in Table C-1.

C.4.3 Transverse Weld Bend Tests

Sixteen transverse weld bend tests were made with specimens located at the positions shown previously in Figure C-1. All 16 specimens passed the acceptance criteria of QW 163, ASME BPVC.

C.4.4 Tensile Tests

The tensile test results for all weld metal specimens are given in Table C-2.

C.4.5 Charpy V-Notch Tests

A Charpy V-Notch impact transition curve and additional tests near the upper shelf start were obtained with specimens from locations near the top, middle, and bottom of the weld as previously indicated in Figure C-1. These results are given in Table C-3 and Figure C-3.

C.4.6 Drop Weight Tests

Eight drop weight tests were performed with the specimens (previously indicated in Figure C-1); these test results are given in Table C-4. Specimens 7 and 8 were machined from a discard piece at the end of the weld. From the results shown, it is estimated that the nil ductility temperature (NDT) is +10°F.

ORNL PHOTO 1255-82

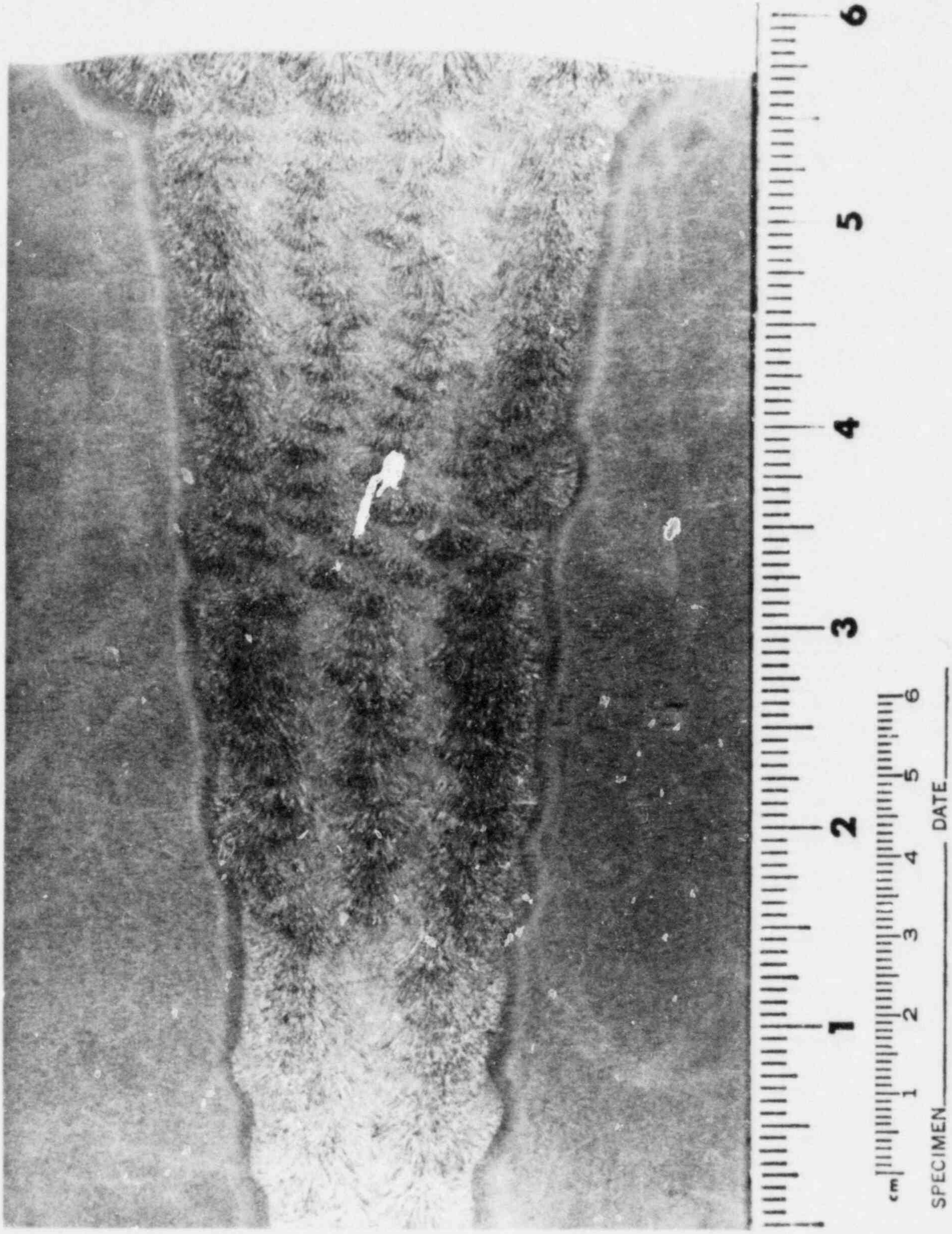


Figure C-2 Photomacrograph of Weld V842 Cross-Section

Table C-1

CHEMICAL ANALYSES, WEIGHT PERCENT (V842)

	C	Mn	P	S	Si	Cr	Ni	Mo	Cu	Sn	V	Al
Top	.049	1.51	.030	.017	.67	.05	.64	.46	.24	.026	.007	.006
Middle	.048	1.50	.028	.015	.67	.05	.63	.45	.30	.025	.007	.006
Bottom	.060	1.50	.025	.015	.65	.06	.60	.45	.26	.027	.006	.007

Table C-2

TENSILE TEST RESULTS - WELD V842

Specimen Identification	Yield Strength Ksi	Ultimate Strength Ksi	Elongation %	Reduction of Area, %
		Room Temperature		
V842T1	66.15	81.93	27.5	56.9
T2	67.61	82.64	26.5	54.7
T3	66.46	82.60	23.5	54.4
		250°F Test Temperature		
T4	59.15	73.87	24.5	55.8
T5	62.17	75.99	25.5	52.7
T6	61.33	75.88	23.0	51.9

Table C-3

CHARPY V-NOTCH IMPACT TEST RESULTS - WELD V842

Specimen Identification	Test Temp., °F	Absorbed Energy Ft Lbs	Lateral Expansion, Mils	Shear %
V842C5	-100	2.3	5	0
15	-100	2.2	3	0
Avg.	-100	2.3	4.0	0.0
25	0	13.5	15	10
35	0	15.4	18	10
Avg.	0	14.5	16.5	10.0
1	100	26.5	32	45
10	100	31.4	38	70
Avg.	100	29.0	35.0	57.5
11	150	40.[illegible]	50	85
20	150	37.6	48	90
Avg.	150	39.1	49.0	87.5
51	175	42.4	48	95
105	175	42.7	48	100
60*	175	41.3	49	98
Avg.	175	42.1	48.3	97.7
21	200	43.1	52	90
91	200	47.1	52	100
95	200	39.9	46	100
30	200	40.0	50	100
100	200	44.0	48	100
Avg.	200	42.8	49.6	98.0
61	210	43.9	48	100
81	210	47.0	51	100
65	210	38.5	42	100
85	210	40.1	48	100
70	210	42.6	46	100
90	210	42.5	49	100
Avg.	210	42.4	45.7	100.0
71	220	46.3	50	100
75	220	42.2	51	100
80	220	44.2	49	100
Avg.	220	44.2	50.0	100.0
31	250	44.0	54	100
40	250	41.0	53	100
Avg.	250	42.5	53.5	100.0
41	300	42.6	54	100
50	300	41.3	51	100
Avg.	300	42.0	52.5	100.0
45	400	37.5	51	100
55	400	38.0	50	100
Avg.	400	37.8	50.5	100.0
101	500	43.0	56	100
110	500	40.5	52	100
Avg.	500	41.8	54.0	100.0

*This specimen had a slag inclusion of 1/32" diameter on the back face of the specimen which apparently did not affect the test result.

ORNL-DWG 82-5331 ETD

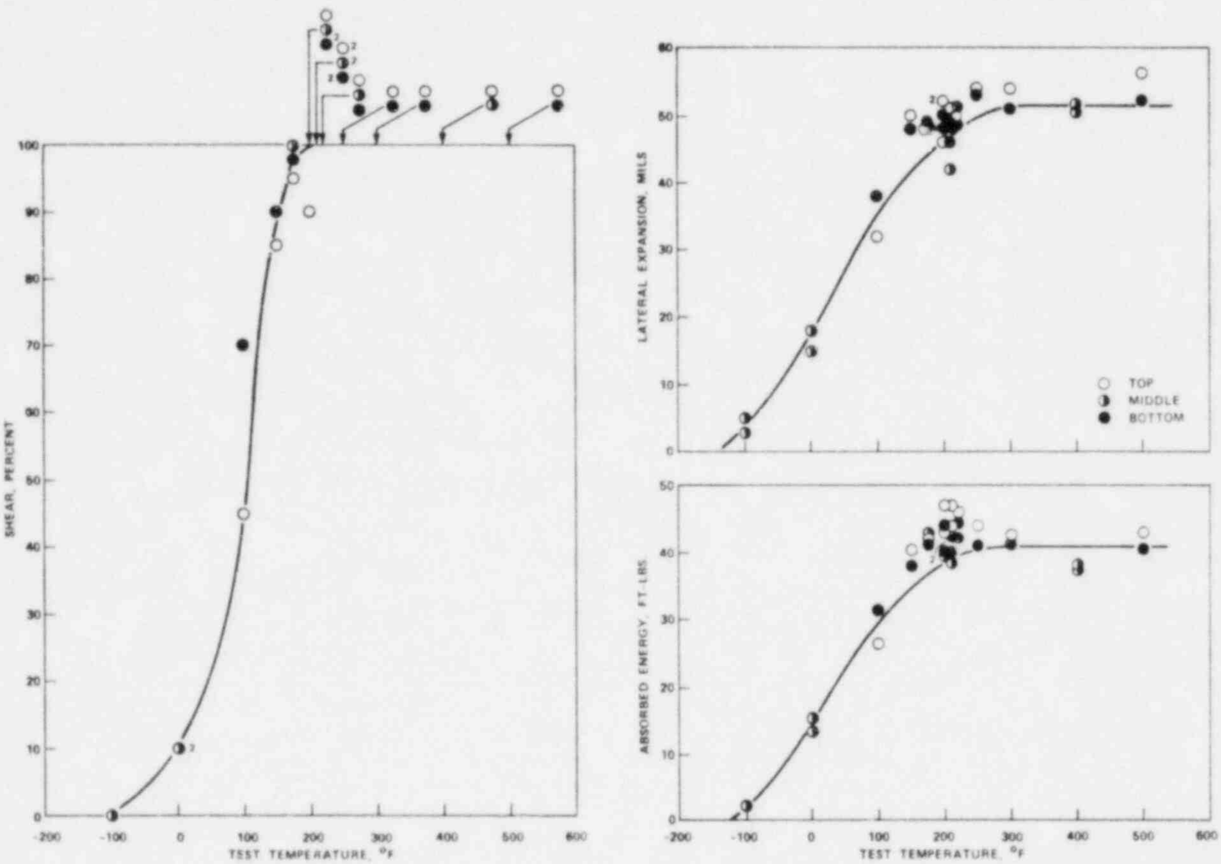


Figure C-3 Charpy V-Notch Test Results for Weld V842

Table C-4

DROP WEIGHT TEST RESULTS - WELD V842

Specimen Identification	Test Temp., °F	Result
V842D1	0	NF
2	-40	F
3	-20	F
4	-10	F
5	0	F
6	+10	F
7	+20	NF
8	+30	NF

C.4.7 Single Specimen J-Integral Tests

Four 1T compact tension specimens of WL orientation were prepared from blocks as previously indicated in Figure C-1. Long times (cycles) were encountered in fatigue precracking, particularly with Specimens V842J3 and V842J4. After fatigue cracking, side grooves of 0.10 in./side were machined and two specimens each were tested at 240° - 245°F and 250° - 255°F using B&W's computer-controlled single specimen J-test.

The fatigue crack of Specimen V842J4 was found to be irregular after the test. Specimen V842J3, which had an initial compliance equal to the machined notch in the same manner as the -J4 specimen, was fatigue cycled until crack extension was measured by compliance.

The fracture faces of all four specimens are shown in Figures C-4 through C-7.

The test results are given in Appendix D.

ORNL PHOTO 1256-82

Figure C-4 Fracture Faces of Specimen V842J1

ORNL PHOTO 1257-82

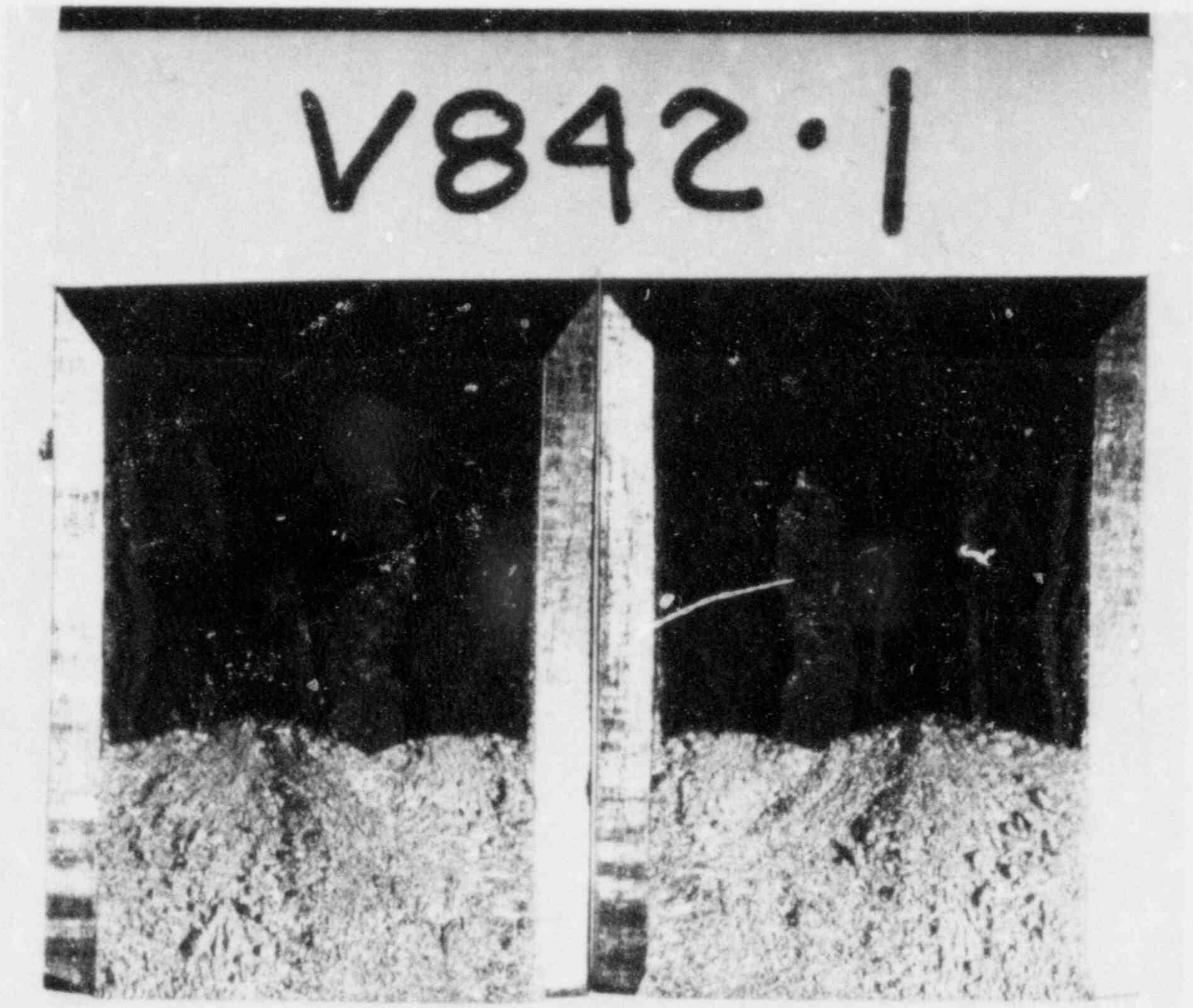


Figure C-5 Fracture Faces of Specimen V842J2

ORNL PHOTO 1258-82

Figure C-6 Fracture Faces of Specimen V842J3

ORNL PHOTO 1259-82

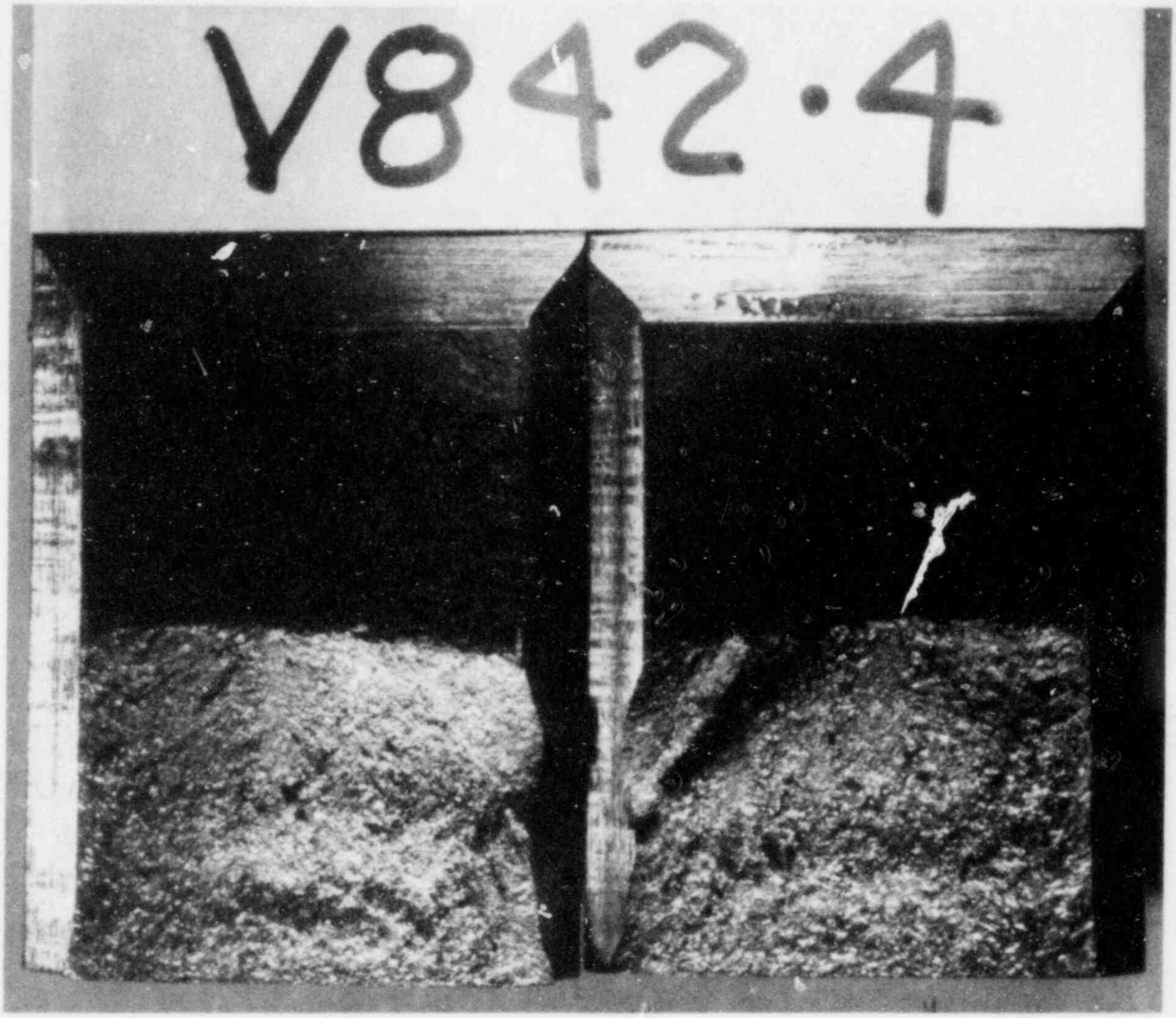


Figure C-7 Fracture Faces of Specimen V842J4

APPENDIX D

CHARACTERIZATION WELDS

APPENDIX D

CHARACTERIZATION WELDS

D.1 MAKING THE WELDS

Four welds were made in the V-10 prolongation and one in plate material. The same welding conditions as in the trial weld (see Appendix C) were used. Because one of the welds (designated V872) had extensive radiographic indications in the vicinity of the backing strap, a fifth characterization weld (V8102) was made from base material cut off of the trial weldment (V842). Weld V872 was used by UCC-ND as a second flawing practice weld. The four welds mechanically tested were V852, V862, V882, and V8102. They were all 6" deep by 23" to 25" long.

	Welds V852 - V882		Weld V8102
Base Metal, SA 533 B1	V-9 Prolongation		Heat C6200-4
Preheat	-------------------	300°F min.	---------------
Interpass Temperature	-------------------	500°F max.	---------------
Current	-------------------	450 - 500 A	---------------
Voltage	-------------------	30 - 34 VAC	---------------
Travel Speed	-------------------	11 - 13 IPM	---------------
Flux	----------- 7560 (0894) - 2580 (0592) ----------		
Flux Batch	First Batch		Second Batch*
Electrode	1/8" Diameter, SFA 5.23 Mn Mo Ni, Heat F60853		

* The second batch of flux was also used in the Vessel V-8A test weld.

The macrostructures of Welds V852 and V8102 are shown in Figures D-1 and D-2.

D.2 POST WELD HEAT TREATMENT

The post weld heat treatment of these test pieces was accomplished at different times. The thermal cycles achieved are given in Table D-1.

ORNL PHOTO 1260-82

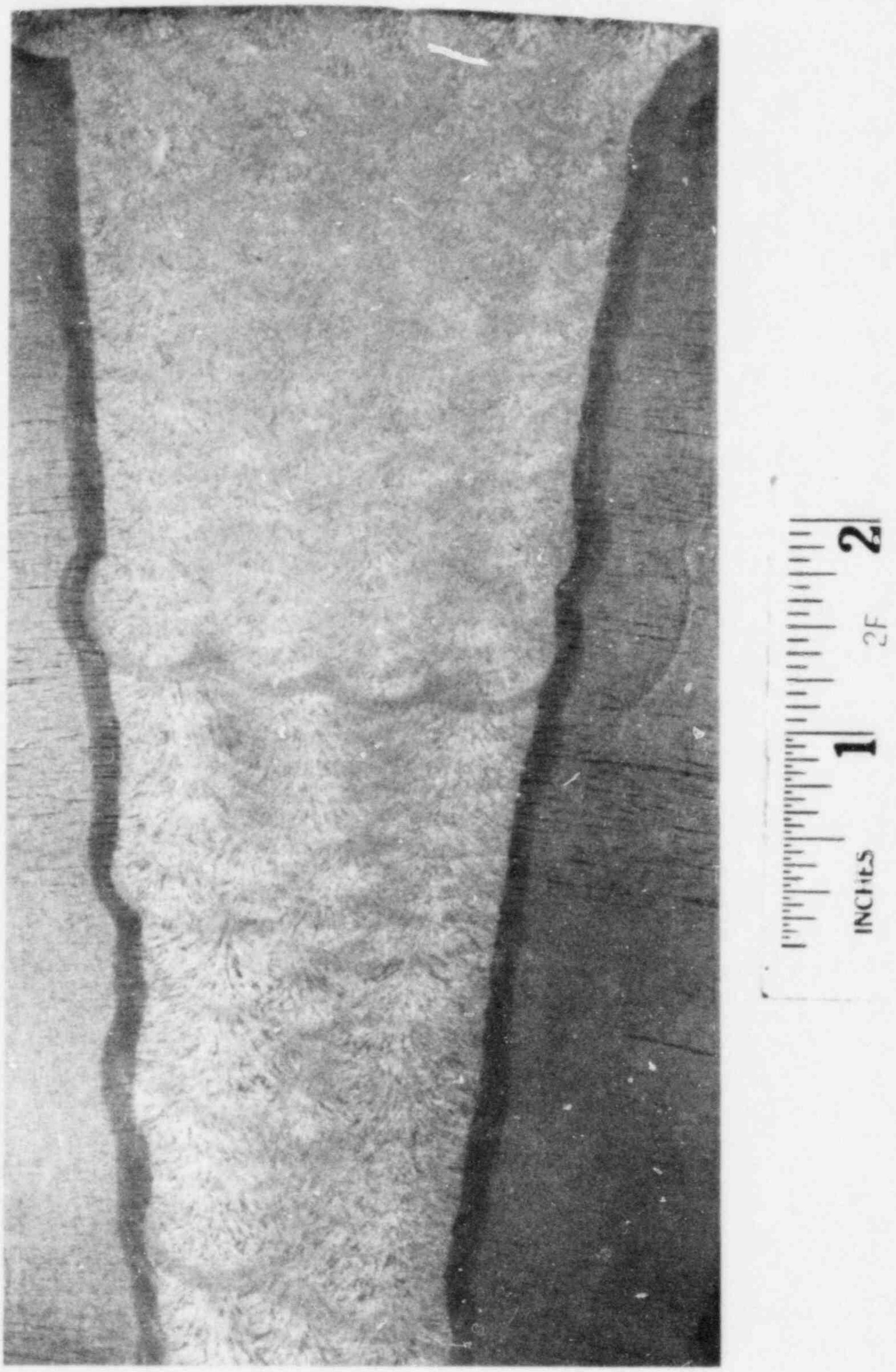


Figure D-1 Photomacrograph of Weld V852 Cross-Section

ORNL PHOTO 1261-82

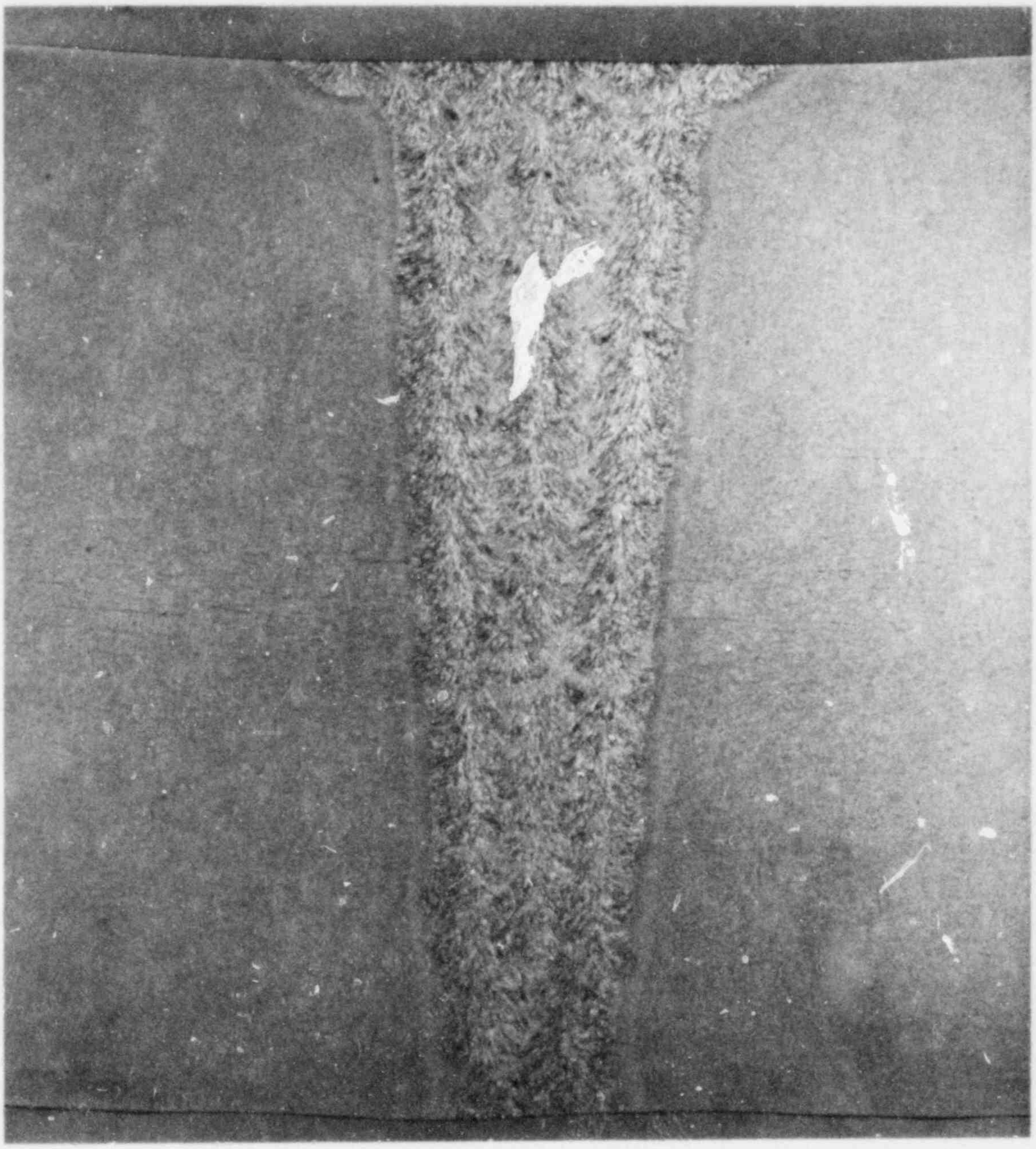


Figure D-2 Photomacrograph of Weld V8102 Cross-Section

Table D-1

PWHT CYCLES OF CHARACTERIZATION WELDS

	V-10 Prolongation	
	Welds V852, V862, V872, and V882	Weld V8102
Heating Rate - 600° to 1050°F, °F/hr	37.0	50.0
Hold Time at 1050° - 1100°F, hours	50.0	48.5
Average Hold Temperature, °F	1071	1068
Cooling Rate - 1050° to 600°F, °F/hr	15.5	12.4

D.3 WELD BEND TEST RESULTS

Transverse weld bend specimen test results for Welds V862 and V882 are given in Table D-2.

Table D-2

TRANSVERSE WELD BEND TEST RESULTS

Specimen Identification	Failed	Passed
V862 B1		X
B2		X
B3		X
B4		X
V882 B1		X
B2		X
B3		X
B4		X

D.4 DROP WEIGHT TEST RESULTS

The results of drop weight tests in Table D-3 indicate that the NDT of Weld V862 is 0 or -10°F and 0°F for Weld V882.

Table D-3

DROP WEIGHT TEST RESULTS

Specimen Identification	Test Temp., °F	Result
V862 D1	+10	NF
D2	+10	NF
D3	-10	NF
D4	-30	F
D5	-10	F
D6	-20	F
	NDT = 0 or -10°F	
V882 D1	+10	F
D2	+10	NF
D3	-10	F
D4	0	F
D5	0	NF
D6	Not Tested	
	NDT = 0°F	

D.5 CHEMICAL ANALYSES

Chemical analyses results for the top, middle, and bottom of Welds V852 and V8102 are given in Table D-4.

Table D-4

CHEMICAL ANALYSES, WEIGHT PERCENT

	C	Mn	P	S	Si	Cr	Ni	Mo	Cu	Sn	V	Al
						Weld V852						
Top	.06	1.53	.030	.016	.67	.04	.63	.46	.17	.018	.008	.004
Middle	.06	1.58	.036	.016	.77	.04	.64	.48	.28	.020	.009	.004
Bottom	.06	1.58	.028	.017	.70	.04	.62	.49	.29	.020	.008	.005
						Weld V8102						
Top	.05	1.52	.026	.015	.65	.04	.64	.47	.18	.030	.006	.007
Middle	.05	1.52	.025	.013	.62	.04	.64	.47	.17	.030	.006	.011
Bottom	.07	1.52	.022	.013	.58	.04	.61	.47	.17	.027	.005	.045

D.6 CHARPY V-NOTCH TEST RESULTS

Charpy V-Notch impact tests performed on the four characterization welds are reported in Table D-5 and plotted in Figures D-3, D-4, and D-5.

Table D-5

CHARPY V-NOTCH IMPACT TEST RESULTS

WL Orientation Except as Noted

Specimen Identification	Test Temp, °F	Absorbed Energy, ft-lbs	Lateral Expansion, Mils* 1	2	3	Avg	Shear, %* 1	2	3	Avg
			Weld V852							
C1	-100	1.9	1	0	1	0.7	1	0	0	0.3
C2	0	14.5	15	14	14	14.3	10	0	5	5.0
C3	100	38.7	47	42	43	45.7	65	65	50	60.0
C4	150	46.1	55	54	53	54.0	85	90	80	85.0
C5	175	46.9	55	54	49	52.7	95	100	100	98.3
C6	200	44.8	56	49	49	51.3	99	97	98	98.0
C11	220	51.5	57	57	56	56.7	100	100	100	100.0
C12	220	56.5	66	64	57	62.3	100	100	100	100.0
C18	220	48.8	57	57	56	56.7	100	100	100	100.0
C19	220	47.7	56	55	53	54.7	100	100	100	100.0
C20	220	46.1	54	53	53	53.3	95	96	95	95.3
C7	225	45.1	56	55	54	55.0	100	100	100	100.0
C13	240	49.9	59	59	58	58.7	100	100	100	100.0
C14	240	51.6	61	59	60	60.0	100	100	100	100.0
C15	240	49.5	63	62	51	58.7	100	100	100	100.0
C16	240	49.9	56	55	54	55.0	100	100	100	100.0
C17	240	50.4	57	55	55	55.7	100	100	100	100.0
C8	250	44.6	55	54	51	53.3	100	100	100	100.0
C9	400	45.0	60	56	54	56.7	100	100	100	100.0
C10	500	44.6	55	54	61	56.7	100	100	100	100.0

* Lateral expansion was measured and shear was estimated independently by three technicians. The absorbed energy was read by Technician No 1.

Table D-5

CHARPY V-NOTCH IMPACT TEST RESULTS (Cont'd)

WL Orientation Except as Noted

Specimen	Test	Absorbed	Lateral Expansion, Mils*				Shear, %*			
Identification	Temp, °F	Energy, ft-lbs	1	2	3	Avg	1	2	3	Avg
					Weld V862					
C1	-100	3.7	7	7	6	6.7	1	0	5	2.0
C2	0	14.2	16	16	16	16.0	10	5	10	8.3
C3	100	35.9	42	40	41	41.0	50	75	40	55.0
C4	150	41.8	49	49	48	48.7	85	80	70	78.3
C5	175	46.8	55	54	53	54.0	99	97	98	98.0
C6	200	46.0	50	55	54	53.0	99	99	100	99.3
C11	220	49.2	55	55	54	54.7	100	100	100	100.0
C12	220	47.1	54	53	55	54.0	100	100	100	100.0
C18	220	42.0	51	50	49	50.0	100	100	100	100.0
C19	220	46.9	54	50	49	51.0	100	100	100	100.0
C20	220	43.9	53	51	51	51.7	100	100	100	100.0
C7	225	46.2	54	53	49	51.5	99	100	100	99.7
C13	240	38.9	50	50	52	50.7	100	100	100	100.0
C14	240	45.6	59	58	59	58.7	100	100	100	100.0
C15	240	43.7	54	54	49	52.3	100	100	100	100.0
C16	240	44.0	55	53	55	54.3	100	100	100	100.0
C17	240	44.1	54	53	52	53.0	100	100	100	100.0
C8	250	45.0	54	54	53	53.7	100	100	100	100.0
C9	400	48.0	57	60	58	58.3	100	100	100	100.0
C10	500	41.2	56	55	55	55.3	100	100	100	100.0
					Weld V882					
C1	220	43.8	52	52	49	51.0	100	100	100	100.0
C2	220	50.0	59	59	58	58.7	100	100	100	100.0
C8	220	41.6	51	51	52	51.3	100	100	100	100.0
C9	220	41.0	51	49	47	49.0	100	100	100	100.0
C10	220	43.2	55	53	53	53.7	100	100	100	100.0
C3	240	44.0	56	55	53	54.7	100	100	100	100.0
C4	240	41.2	51	51	51	51.0	100	100	100	100.0
C5	240	44.9	53	52	53	52.7	100	100	100	100.0
C6	240	40.8	50	48	50	49.3	100	100	100	100.0
C7	240	44.0	53	51	46	50.0	100	100	100	100.0

* Lateral expansion was measured and shear was estimated independently by three technicians. The absorbed energy was read by Technician No 1.

Table D-5

CHARPY V-NOTCH IMPACT TEST RESULTS (Cont'd)

WL Orientation Except as Noted

Specimen Identification	Test Temp, °F	Absorbed Energy, ft-lbs	Lateral Expansion, Mils* 1	2	3	Avg	Shear, %* 1	2	3	Avg
			Weld V8102							
C1	300	38.4	50	49	48	49.0	100	100	100	100.0
C2 WT	300	40.5	52	52	52	52.0	100	100	100	100.0
C3	240	38.6	50	49	47	48.7	100	100	100	100.0
C4 WT	240	39.9	51	49	49	49.7	100	100	100	100.0
C5	300	37.0	47	47	46	46.7	100	100	100	100.0
C6 WT	300	40.0	50	50	49	49.7	100	100	100	100.0
C7	240	36.9	48	47	47	47.3	100	100	100	100.0
C8 WT	240	36.5	46	46	45	45.7	100	100	100	100.0
C9	300	36.1	45	45	43	44.3	100	100	100	100.0
C10 WT	300	37.5	49	48	48	48.3	100	100	100	100.0

* Lateral expansion was measured and shear was estimated independently by three technicians. The absorbed energy was read by Technician No 1.

ORNL-DWG 82-5332 ETD

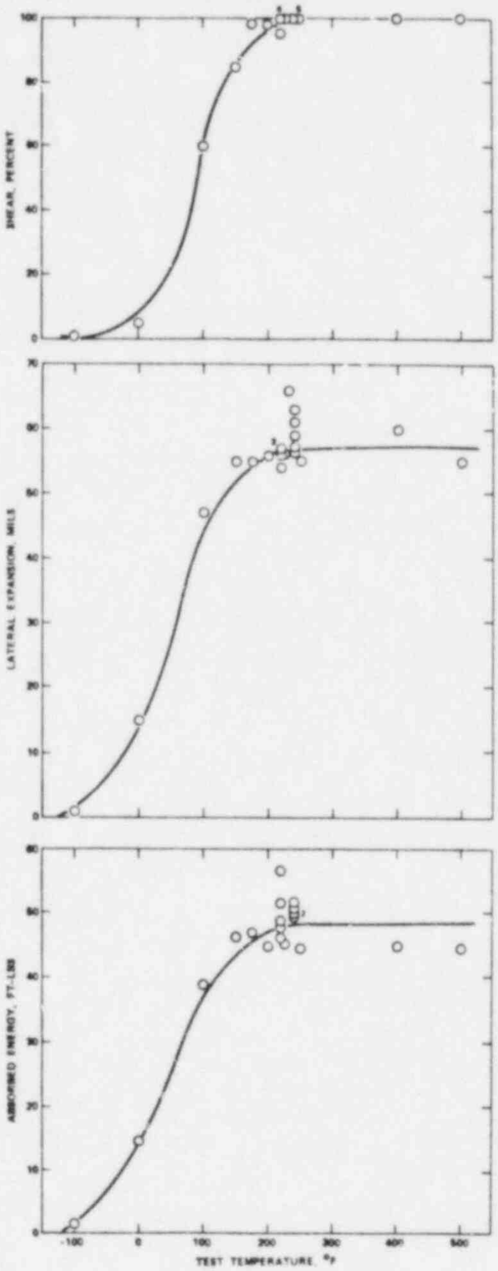


Figure D-3 Charpy V-Notch Impact Test Results for Weld V852

ORNL-DWG 82-5333 ETD

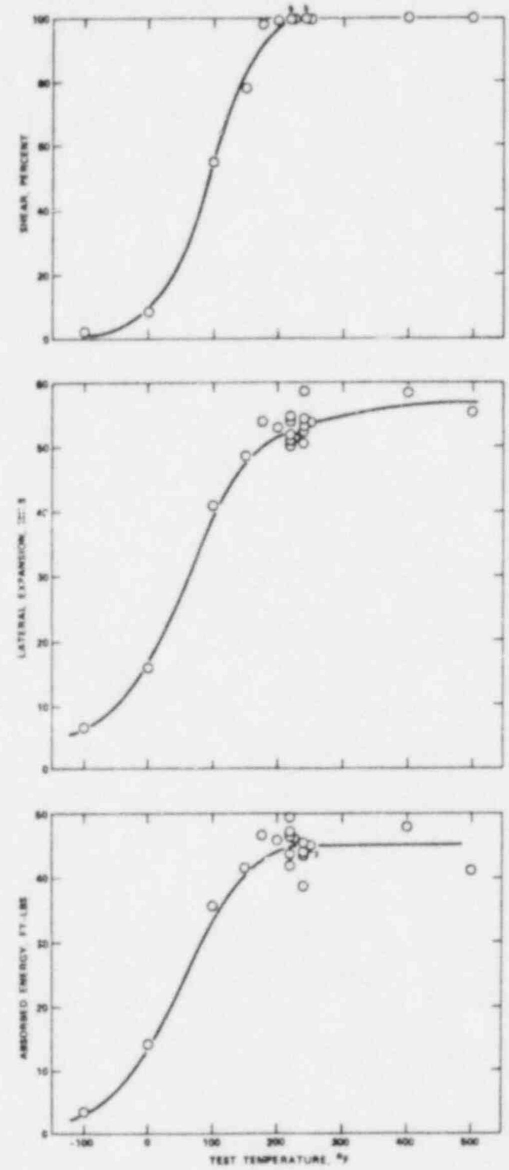


Figure D-4 Charpy V-Notch Impact Test Results for Weld V862

ORNL-DWG 82-5334 ETD

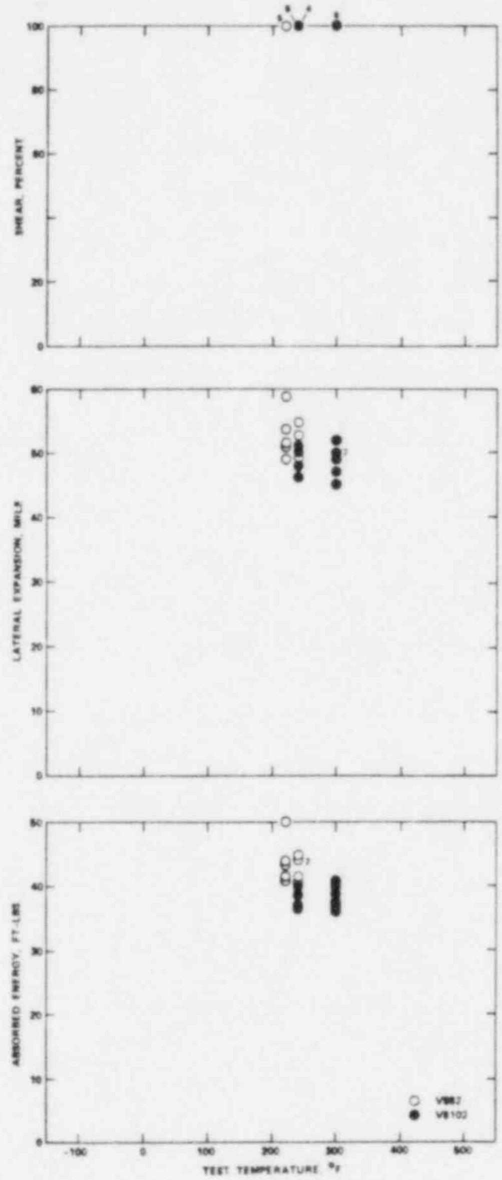


Figure D-5 Charpy V-Notch Impact Test Results for Welds V882 and V8102

D.7 J-TEST RESULTS

The following figures of load-displacement, J versus Δa, and tabulated J - Δa for each J-Integral test are arranged according to weld number and specimen number.

The following J-R curves were obtained with three corrections:

1) Unloading compliance was corrected by adjusting the elastic modulus to give agreement between the measured initial length and experimental derived values using a modulus expected for the material and its test temperature in the following expression:

$$E_{expected} = (E_{assumed}) \times \frac{C_{calculated}}{C_{measured}}$$

where:

$E_{assumed}$ = modulus value used during test

$C_{calculated}$ = specimen compliance calculated from measured initial crack length

$C_{measured}$ = specimen compliance measured at start of test

2) NRC J-Expression (Moving Crack Correction)

$$J_{i+1} = \left\{ Ji + \frac{\eta}{b}\Big|_i \frac{Ai,i+1}{Bn} \right\} \left\{ 1 - \frac{\gamma}{b}\Big|_i (a_{i+1} - a_i) \right\}$$

η = 2+.522 b/w
γ = 1+.76 b/w
b = w-a
Ai,i+1 = incremental area between lines of constant displacement at points i & i+1
Bn = net specimen thickness
a = crack length

3) Rotation Correction

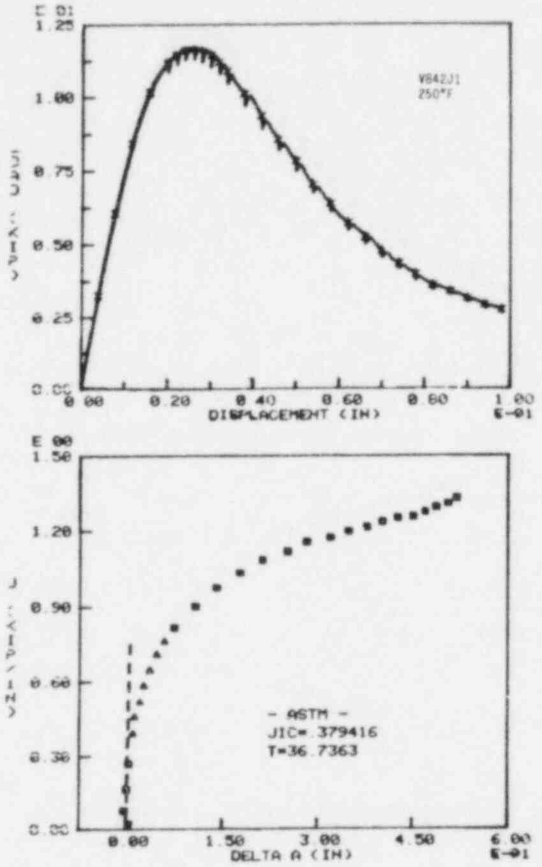
$$C\Big|_{corrected} = \frac{C\Big|_{measured}}{\left\{ \frac{H}{R} \sin(\theta) - \cos(\theta) \right\} \left\{ \frac{D}{R} \sin(\theta) - \cos(\theta) \right\}}$$

H = half span of loading points
R = $\frac{w+a}{2}$ = radius of rotation
D = distance from crack plane to knife edge at zero load

$$\theta = \sin^{-1} \left\{ \frac{\delta m + D}{(D^2 + R^2} \right\} - \tan^{-1} \left(\frac{D}{R}\right)$$

δm = measured load-line displacement

ORNL-DWG 82-5335 ETD

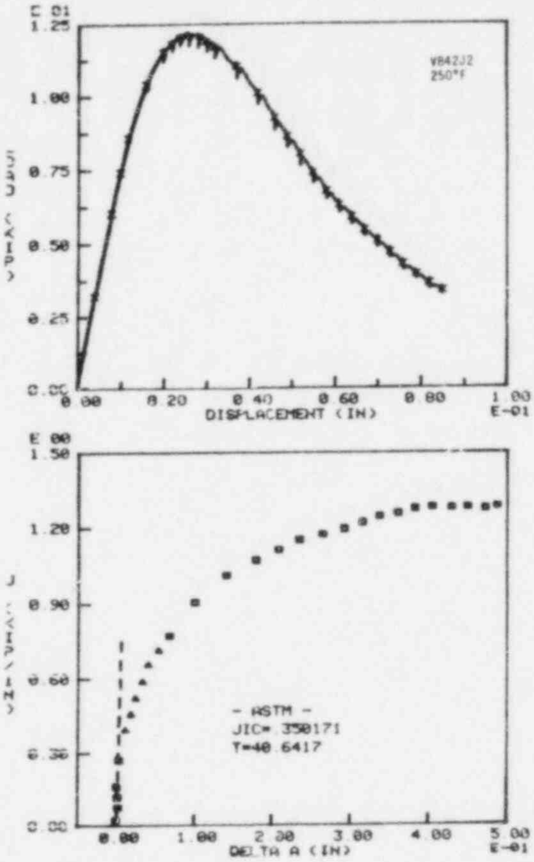


	J KIP/IN	CRACK EXTENSION IN
1 .	.0213272	3.37576E-03
2 .	.0768852	-2.98664E-03
3 .	.167999	2.90381E-04
4 .	.270637	3.80348E-03
5 .	.395076 *+	.0106127
6 .	.462331 *+	.0120982
7 .	.521297 *+	.0212201
8 .	.587514 *+	.0273313
9 .	.648462 *+	.0366416
10 .	.71117 *+	.0474265
11 .	.763476 *+	.0569292
12 .	.81532 +	.0749186
13 .	.90202	.107234
14 .	.97433	.141212
15 .	1.03426	.1762
16 .	1.08576	.213572
17 .	1.11976	.253043
18 .	1.15686	.28434
19 .	1.17449	.319394
20 .	1.19987	.347841
21 .	1.21766	.377255
22 .	1.23797	.402081
23 .	1.25234	.426541
24 .	1.25802	.451187
25 .	1.27715	.470035
26 .	1.29455	.487922
27 .	1.30868	.505375
28 .	1.33103	.518922

*-DENOTES POINTS USED FOR JIC DETERMINATION
+-DENOTES POINTS USED IN TEARING MODULUS CALCULATION

Figure D-6

ORNL-DWG 82-5336 ETD

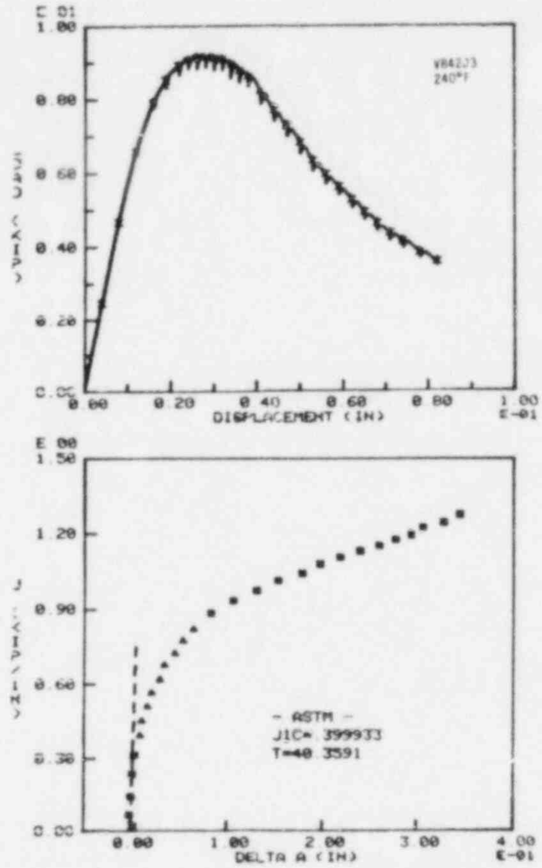


	J KIP/IN		CRACK EXTENSION IN
1 .	.0215366		-8.43484E-04
2 .	.0753323		2.09526E-03
3 .	.117331		9.86378E-04
4 .	.16247		-2.46007E-04
5 .	.271683		2.59332E-03
6 .	.397133	*+	.0110307
7 .	.459979	*+	.0178764
8 .	.524858	*+	.0237587
9 .	.590753	*+	.0329454
10 .	.657845	*+	.0405517
11 .	.71503	*+	.0539523
12 .	.770434	+	.0675555
13 .	.904039		.100281
14 .	1.01146		.139952
15 .	1.07251		.176303
16 .	1.11227		.20786
17 .	1.15191		.234545
18 .	1.17435		.264012
19 .	1.19602		.291628
20 .	1.22161		.315152
21 .	1.24703		.337134
22 .	1.2587		.360855
23 .	1.27576		.382662
24 .	1.28303		.404358
25 .	1.28018		.428533
26 .	1.28214		.449529
27 .	1.27593		.471984
28 .	1.26507		.487506

*-DENOTES POINTS USED FOR JIC DETERMINATION
+-DENOTES POINTS USED IN TEARING MODULUS CALCULATION

Figure D-7

ORNL-DWG 82-5337 ETD

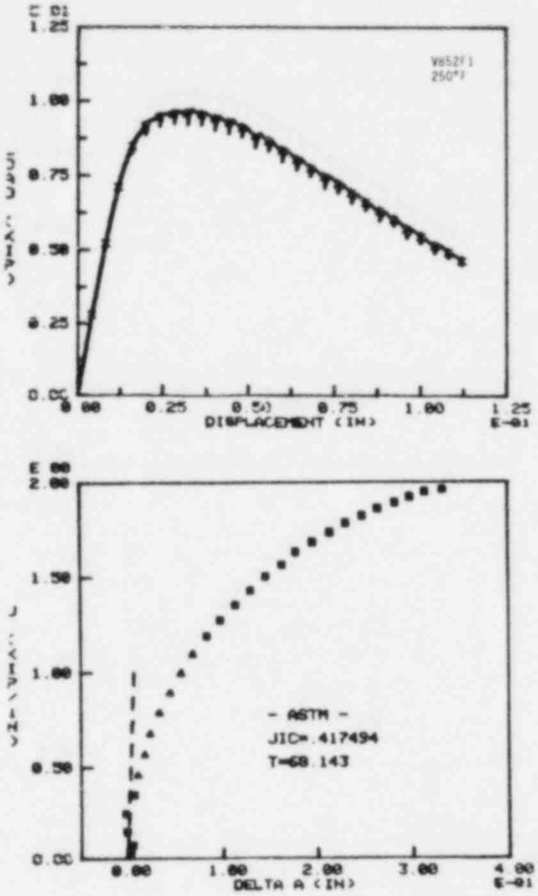


	J KIP/IN		CRACK EXTENSION IN
1 .	.0189994		2.62169E-03
2 .	.0677593		-1.00323E-03
3 .	.142563		-2.95293E-05
4 .	.23662		2.04292E-03
5 .	.315381		3.96282E-03
6 .	.396492	*+	9.76199E-03
7 .	.456589	*+	.0117267
8 .	.512707	*+	.0173977
9 .	.567266	*+	.0218782
10 .	.621167	*+	.030535
11 .	.678169	*+	.0349635
12 .	.725412	*+	.0458196
13 .	.775462	*+	.0540835
14 .	.821108	*+	.0647573
15 .	.883166	+	.0828991
16 .	.932997		.106714
17 .	.973679		.131699
18 .	1.01317		.154261
19 .	1.04371		.176477
20 .	1.07977		.197691
21 .	1.10691		.216442
22 .	1.13178		.239291
23 .	1.1538		.259439
24 .	1.17609		.276978
25 .	1.19592		.297878
26 .	1.22569		.306447
27 .	1.24573		.328142
28 .	1.27581		.344695

*-DENOTES POINTS USED FOR JIC DETERMINATION
+-DENOTES POINTS USED IN TEARING MODULUS CALCULATION

Figure D-8

ORNL–DWG 82–5338 ETD

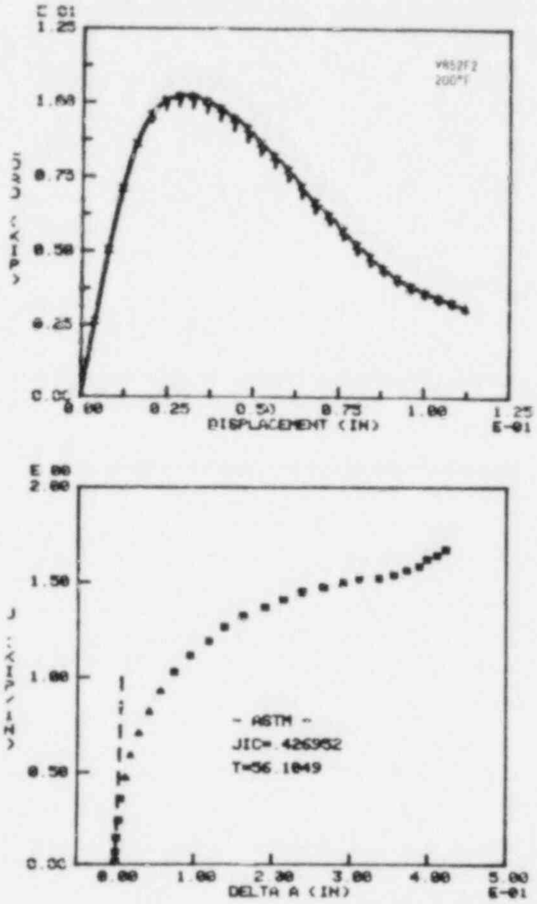


	J KIP/IN	CRACK EXTENSION IN
1 .	.0213453	3.20877E-03
2 .	.0727448	5.70812E-03
3 .	.147539	-3.11119E-04
4 .	.2469	-1.61527E-03
5 .	.34934	7.06653E-03
6 .	.462126 *+	.0113471
7 .	.572249 *+	.0185939
8 .	.682035 *+	.0242711
9 .	.793262 *+	.034078
10 .	.896484 *+	.0454134
11 .	1.00202 *+	.0565837
12 .	1.1015 *+	.0666758
13 .	1.19338 +	.0829955
14 .	1.27691	.097558
15 .	1.35628	.114148
16 .	1.43231	.130364
17 .	1.50199	.146978
18 .	1.56752	.164146
19 .	1.63408	.17841
20 .	1.68681	.195978
21 .	1.73775	.21377
22 .	1.78545	.230403
23 .	1.82482	.248217
24 .	1.8621	.264291
25 .	1.89224	.282027
26 .	1.92473	.297872
27 .	1.95087	.313937
28 .	1.96421	.332439

*-DENOTES POINTS USED FOR JIC DETERMINATION
+-DENOTES POINTS USED IN TEARING MODULUS CALCULATION

Figure D-9

ORNL-DWG 82-5339 ETD

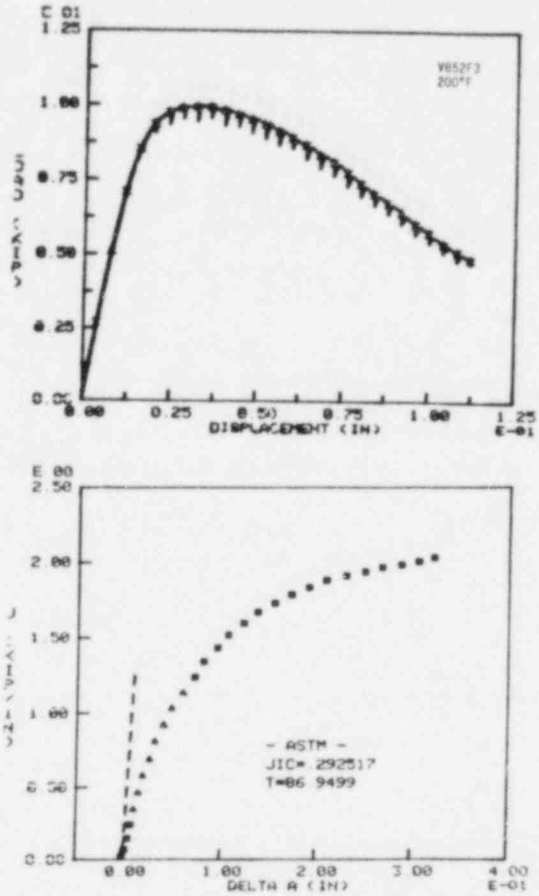


	J KIP/IN	CRACK EXTENSION IN
1 .	.01946	8.26672E-05
2 .	.0694237	1.53948E-05
3 .	.14629	9.45784E-04
4 .	.242367	4.20262E-03
5 .	.357788	5.57031E-03
6 .	.475711 *+	.0119584
7 .	.594664 *+	.0182878
8 .	.71197 *+	.0260494
9 .	.823913 *+	.0421369
10 .	.933352 *+	.0565369
11 .	1.0313 +	.0729901
12 .	1.11745	.0939824
13 .	1.19341	.116207
14 .	1.26717	.138175
15 .	1.32789	.162015
16 .	1.37282	.192019
17 .	1.4141	.214374
18 .	1.45257	.236202
19 .	1.47674	.264962
20 .	1.49936	.28693
21 .	1.52173	.31672
22 .	1.52474	.336401
23 .	1.54121	.356261
24 .	1.56624	.372499
25 .	1.58598	.386569
26 .	1.62354	.396406
27 .	1.64429	.411407
28 .	1.67421	.422232

*-DENOTES POINTS USED FOR JIC DETERMINATION
+-DENOTES POINTS USED IN TEARING MODULUS CALCULATION

Figure D-10

ORNL-DWG 82-5340 ETD

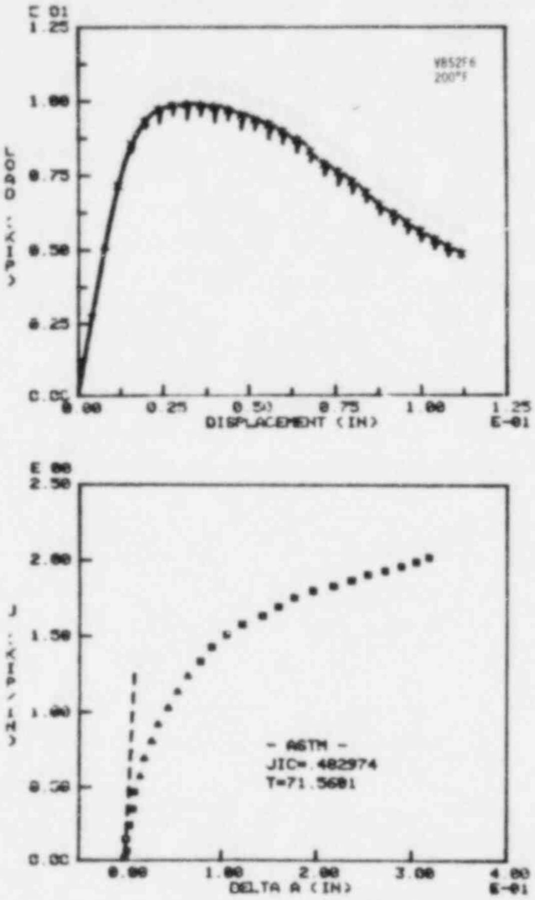


	J KIP/IN		CRACK EXTENSION IN
1 .	.0196502		-1.05412E-03
2 .	.0694396		1.61283E-03
3 .	.145399		4.30160E-03
4 .	.240844		7.55291E-03
5 .	.351437	*+	.0101457
6 .	.46674	*+	.014533
7 .	.58254	*+	.0152385
8 .	.697724	*+	.0262203
9 .	.816398	*+	.0314416
10 .	.926759	*+	.0407303
11 .	1.03794	*+	.0487913
12 .	1.14153	*+	.0601373
13 .	1.24185	+	.0718775
14 .	1.34519	+	.0810006
15 .	1.43447		.0949442
16 .	1.52336		.106422
17 .	1.59903		.12248
18 .	1.67137		.137547
19 .	1.73089		.155527
20 .	1.78745		.172717
21 .	1.83656		.191305
22 .	1.88283		.208903
23 .	1.91377		.225367
24 .	1.94101		.249697
25 .	1.97128		.267631
26 .	1.98777		.287731
27 .	2.00831		.305447
28 .	2.03527		.320697

*-DENOTES POINTS USED FOR JIC DETERMINATION
+-DENOTES POINTS USED IN TEARING MODULUS CALCULATION

Figure D-11

ORNL-DWG 82-5341 ETD

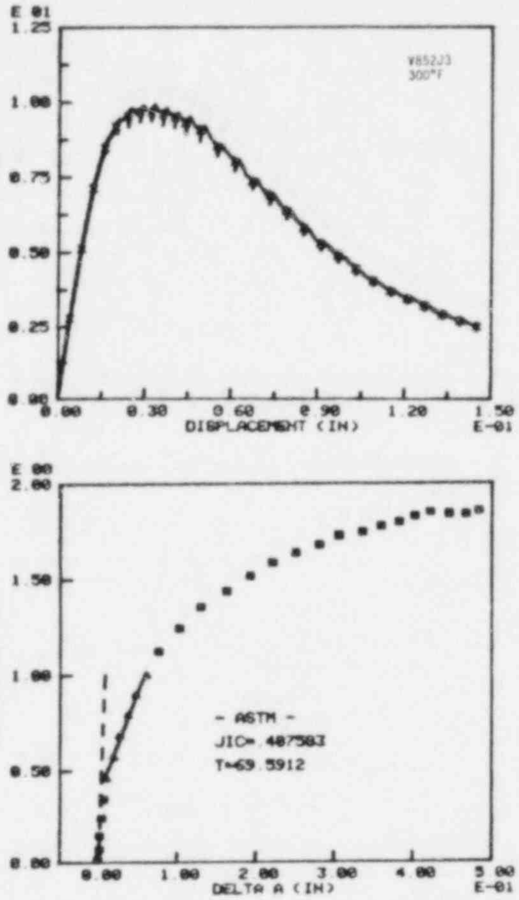


	J KIP/IN		CRACK EXTENSION IN
1 .	.01962		1.45765E-04
2 .	.0697974		2.30850E-03
3 .	.146733		1.05062E-03
4 .	.242482		3.96000E-03
5 .	.352358		7.64021E-03
6 .	.467838		9.36291E-03
7 .	.581057	*+	.0155896
8 .	.690781	*+	.0198381
9 .	.811695	*+	.0279567
10 .	.926247	*+	.0342849
11 .	1.0328	*+	.0449575
12 .	1.13874	*+	.054045
13 .	1.24219	*+	.0651121
14 .	1.33732	+	.0776000
15 .	1.43823	+	.0857397
16 .	1.51147		.10542
17 .	1.5828		.1224
18 .	1.63656		.144279
19 .	1.69829		.160842
20 .	1.75815		.176794
21 .	1.80395		.196344
22 .	1.8348		.217856
23 .	1.86993		.236555
24 .	1.90829		.253503
25 .	1.9373		.271239
26 .	1.96546		.288597
27 .	1.99384		.304141
28 .	2.02613		.31009

*-DENOTES POINTS USED FOR JIC DETERMINATION
+-DENOTES POINTS USED IN TEARING MODULUS CALCULATION

Figure D-12

ORNL-DWG 82-5342 ETD

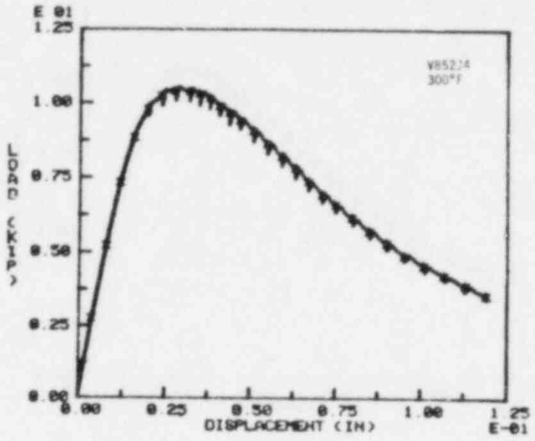


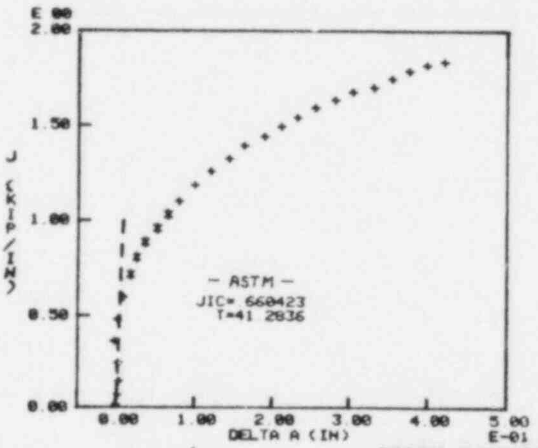
	J KIP/IN		CRACK EXTENSION IN
1 .	.0204443		-8.41517E-04
2 .	.0693392		6.19751E-04
3 .	.146653		1.36838E-03
4 .	.241836		3.28324E-03
5 .	.346067		6.76976E-03
6 .	.462828	*	.0102891
7 .	.575179	*	.0195345
8 .	.686159	*	.0261971
9 .	.796088	*	.0371103
10 .	.900802	*	.0470965
11 .	1.00404	*	.0604683
12 .	1.12433		.075927
13 .	1.2464		.10281 +
14 .	1.35836		.129725 +
15 .	1.4391		.163231 +
16 .	1.51951		.191982 +
17 .	1.58872		.220654 +
18 .	1.639		.251538 +
19 .	1.67957		.281355 +
20 .	1.72772		.305883 +
21 .	1.74727		.335378 +
22 .	1.77761		.359322 +
23 .	1.79896		.382488 +
24 .	1.82964	+	.402099 +
25 .	1.84952	+	.422219 +
26 .	1.84146	+	.446653 +
27 .	1.84096	+	.46785 +
28 .	1.85844	+	.483806 +

*-DENOTES POINTS USED FOR JIC DETERMINATION
+-DENOTES POINTS EXCEEDING ASTM SPECIFICATIONS

Figure D-13

ORNL-DWG 82-5343 ETD



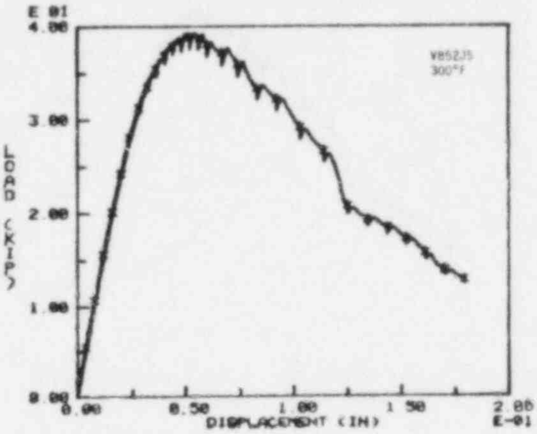


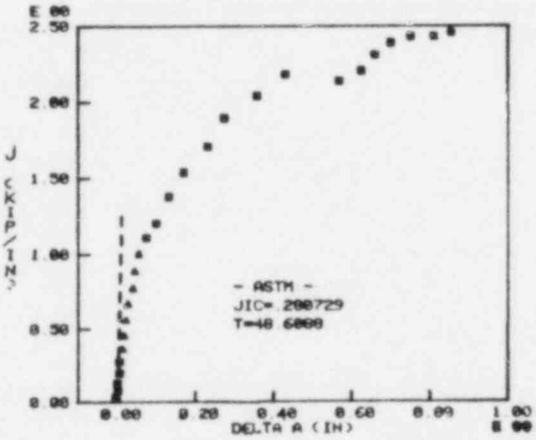
	J KIP/IN	CRACK EXTENSION IN
1 .	.0196594	-3.50374E-04
2 .	.0701954	1.40300E-03
3 .	.146816	3.76914E-03
4 .	.245747	2.90571E-03
5 .	.363022	-1.68500E-03
6 .	.481412	1.76035E-03
7 .	.601662	8.90419E-03
8 .	.718645 *	.0187344
9 .	.807874 *	.0258899
10 .	.887768 *	.0368087
11 .	.96013 *	.0521023
12 .	1.03261 *	.0655501
13 .	1.102	.0798368
14 .	1.18698	.0999294 +
15 .	1.26148	.121302 +
16 .	1.3273	.144601 +
17 .	1.39371	.164238 +
18 .	1.44216	.189252 +
19 .	1.49383	.210363 +
20 .	1.54203	.230503 +
21 .	1.59606	.254714 +
22 .	1.63679	.280642 +
23 .	1.67827	.30378 +
24 .	1.70143	.32977 +
25 .	1.74681	.352939 +
26 .	1.78772	.375228 +
27 .	1.81757 +	.397004 +
28 .	1.83665 +	.420297 +

*-DENOTES POINTS USED FOR JIC DETERMINATION
+-DENOTES POINTS EXCEEDING ASTM SPECIFICATIONS

Figure D-14

ORNL-DWG 82-5344 ETD



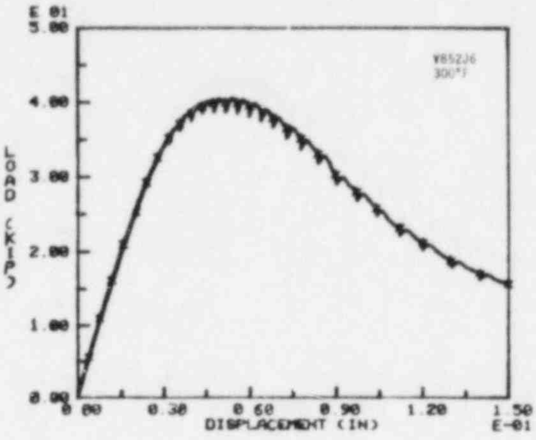


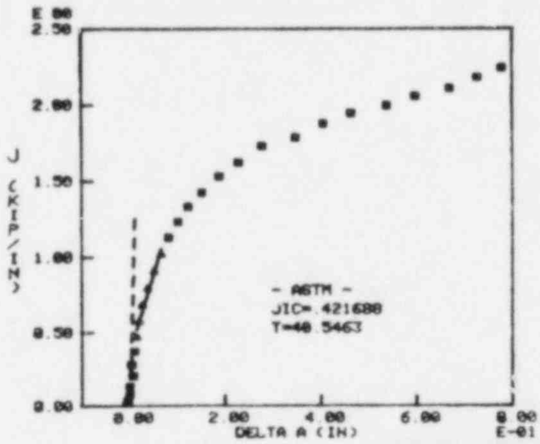
	J KIP/IN	CRACK EXTENSION IN
1 .	.0102627	-2.23654E-03
2 .	.036444	-5.21749E-03
3 .	.0761841	9.40064E-04
4 .	.131087	-5.82869E-04
5 .	.198757	5.09555E-03
6 .	.277954	4.92746E-03
7 .	.36727 *+	.0110989
8 .	.459859 *+	.014921
9 .	.565798 *+	.0158465
10 .	.674333 *+	.0253313
11 .	.777975 *+	.037981
12 .	.89338 *+	.0423563
13 .	1.00564 *+	.0530768
14 .	1.11076 +	.072388
15 .	1.20416 +	.098137
16 .	1.37879 +	.130459
17 .	1.53772 +	.169552
18 .	1.7088	.23227
19 .	1.89725	.273746
20 .	2.04331	.355614
21 .	2.1826	.429228
22 .	2.13999	.566743
23 .	2.2064	.624306
24 .	2.31304	.658765
25 .	2.39206	.695929
26 .	2.43062	.751082
27 .	2.43229	.806521
28 .	2.45301	.853136

*-DENOTES POINTS USED FOR JIC DETERMINATION
+-DENOTES POINTS USED IN TEARING MODULUS CALCULATION

Figure D-15

ORNL-DWG 82-5345 ETD



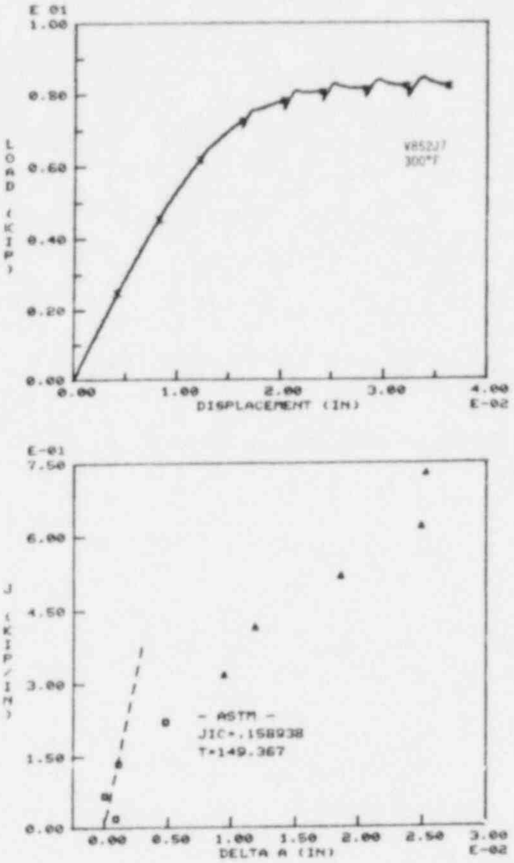


	J KIP/IN	CRACK EXTENSION IN
1 .	.0103429	-6.91982E-03
2 .	.0357043	-4.78708E-03
3 .	.0764214	-8.77342E-04
4 .	.133992	-1.11838E-03
5 .	.203382	5.74736E-03
6 .	.282291	3.17768E-03
7 .	.373893	8.87003E-03
8 .	.474986 *	.0128658
9 .	.581512 *	.0194362
10 .	.680706 *	.0257764
11 .	.80032 *	.037323
12 .	.912206 *	.0511387
13 .	1.02418 *	.0653417
14 .	1.13146	.0820165
15 .	1.23412	.102445
16 .	1.33537	.124579
17 .	1.42599	.152638
18 .	1.53224	.189833
19 .	1.62398	.225102 +
20 .	1.73856	.277305 +
21 .	1.78767	.347146 +
22 .	1.8773	.405352 +
23 .	1.94693	.462675 +
24 .	1.99714	.537578 +
25 .	2.05854	.596637 +
26 .	2.11108	.669585 +
27 .	2.18083	.727104 +
28 .	2.24434	.779532 +

*-DENOTES POINTS USED FOR JIC DETERMINATION
+-DENOTES POINTS EXCEEDING ASTM SPECIFICATIONS

Figure D-16

ORNL-DWG 82-5346 ETD

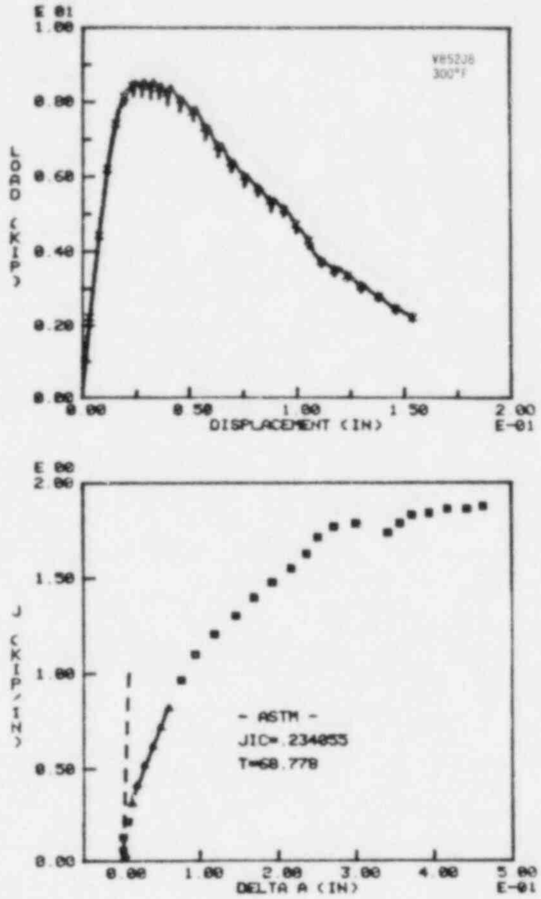


	J KIP/IN	CRACK EXTENSION IN
1 .	.0195025	9.27384E-04
2 .	.0672444	2.12746E-05
3 .	.135356	1.10501E-03
4 .	.222228	4.81993E-03
5 .	.318792 *+	9.42093E-03
6 .	.41589 *+	.011838
7 .	.519224 *+	.0186253
8 .	.619918 *+	.0248969
9 .	.729099 *+	.0252431

*-DENOTES POINTS USED FOR JIC DETERMINATION
+-DENOTES POINTS USED IN TEARING MODULUS CALCULATION

Figure D-17

ORNL-DWG 82-5347 ETD

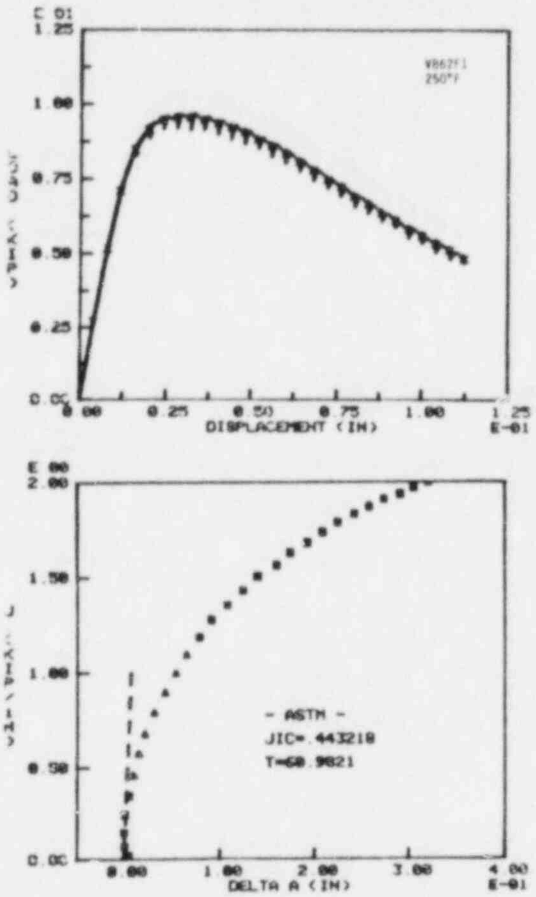


	J KIP/IN	CRACK EXTENSION IN
1 .	.014982	2.92037E-03
2 .	.0615096	4.76819E-04
3 .	.129654	5.36066E-04
4 .	.216231	6.18575E-03
5 .	.316531 *	.0121419
6 .	.418216 *	.0183022
7 .	.52283 *	.0277713
8 .	.625418 *	.0387477
9 .	.723873 *	.0488677
10 .	.824294 *	.0594052
11 .	.966921	.0763048
12 .	1.1004	.0941712 +
13 .	1.20978	.11987 +
14 .	1.30567	.146255 +
15 .	1.39985	.169159 +
16 .	1.48119	.19223 +
17 .	1.55437	.216918 +
18 .	1.62891	.236798 +
19 .	1.71639	.251741 +
20 .	1.77136	.272028 +
21 .	1.78662	.300539 +
22 .	1.74054	.340835 +
23 .	1.78935 +	.356769 +
24 .	1.83399 +	.372165 +
25 .	1.8415 +	.394414 +
26 .	1.8652 +	.418383 +
27 .	1.8649 +	.443782 +
28 .	1.8781 +	.464423 +

*-DENOTES POINTS USED FOR JIC DETERMINATION
+-DENOTES POINTS EXCEEDING ASTM SPECIFICATIONS

Figure D-18

ORNL-DWG 82-5348 ETD

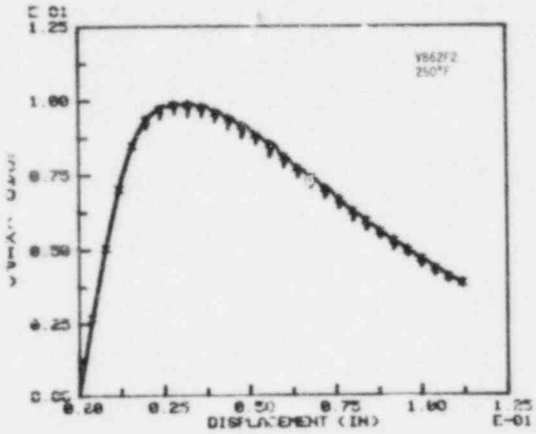


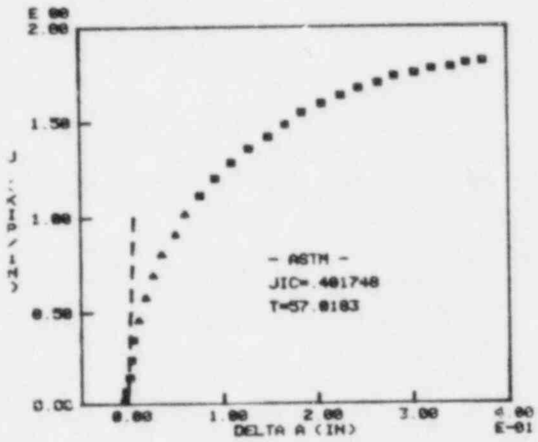
	J KIP/IN	CRACK EXTENSION IN
1 .	.0195634	4.99747E-03
2 .	.0708735	7.90936E-04
3 .	.143735	6.07790E-05
4 .	.244173	6.71611E-04
5 .	.347132	5.11072E-03
6 .	.459436 *+	9.96719E-03
7 .	.575482 *+	.0152048
8 .	.681695 *+	.0216807
9 .	.792329 *+	.0314154
10 .	.89735 *+	.0425077
11 .	.999922 *+	.0527704
12 .	1.09735 *+	.0652112
13 .	1.188 +	.0768102
14 .	1.27921 +	.09153
15 .	1.35739	.106669
16 .	1.43267	.122274
17 .	1.50665	.140586
18 .	1.56642	.16042
19 .	1.63075	.17478
20 .	1.68218	.192131
21 .	1.73832	.206387
22 .	1.78954	.224200
23 .	1.83318	.241551
24 .	1.87236	.257292
25 .	1.91181	.272956
26 .	1.93785	.290393
27 .	1.97266	.304657
28 .	2.0024	.319969

*-DENOTES POINTS USED FOR JIC DETERMINATION
+-DENOTES POINTS USED IN TEARING MODULUS CALCULATION

Figure D-19

ORNL-DWG 82-5349 ETD



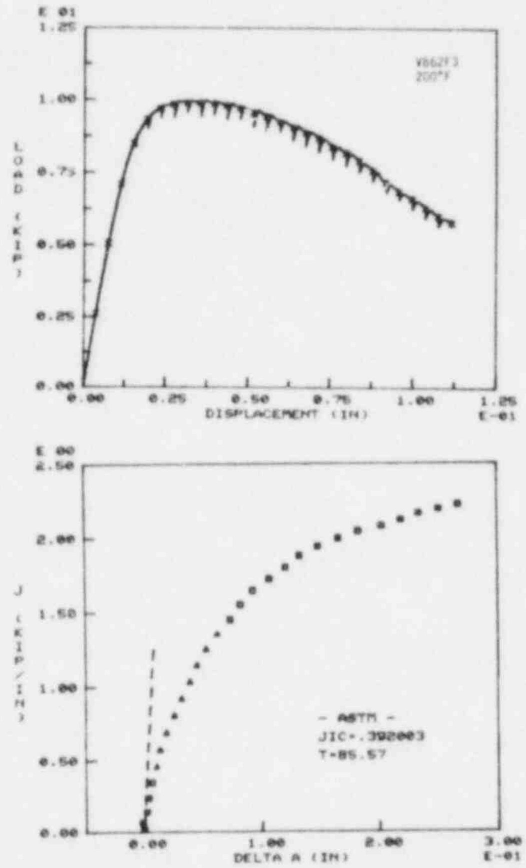


	J KIP/IN	CRACK EXTENSION IN
1 .	.0206011	-3.34796E-03
2 .	.0711751	-2.06765E-03
3 .	.145759	2.06369E-03
4 .	.243223	3.96291E-03
5 .	.351861	6.37892E-03
6 .	.462995 *+	.0119552
7 .	.581817 *+	.0154463
8 .	.69042 *+	.0270875
9 .	.810386 *+	.0359634
10 .	.915153 *+	.0504976
11 .	1.02104 *+	.0607995
12 .	1.11652 +	.0763446
13 .	1.20397 +	.0927477
14 .	1.28886	.110163
15 .	1.3612	.128857
16 .	1.42142	.149272
17 .	1.49919	.166689
18 .	1.54943	.184192
19 .	1.5972	.205192
20 .	1.6385	.225587
21 .	1.67846	.244559
[illegible]	1.70648	.264494
[illegible] .	1.74	.28177
[illegible]	1.75648	.303441
[illegible] .	1.7794	.321453
[illegible] .	1.78785	.341987
[illegible] .	1.80707	.357657
[illegible] .	1.61918	.374785

*-DENOTES POINTS USED FOR JIC DETERMINATION
+-DENOTES POINTS USED IN TEARING MODULUS CALCULATION

Figure D-20

ORNL-DWG 82-5350 ETD

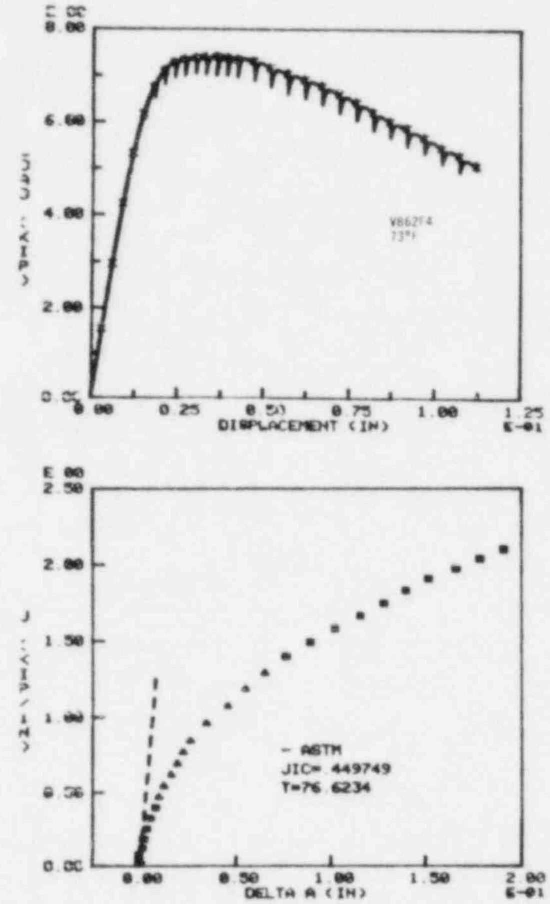


	J KIP/IN	CRACK EXTENSION IN
1 .	.0179889	2.08789E-04
2 .	.0671396	-1.01454E-03
3 .	.141676	2.29793E-03
4 .	.237899	4.48948E-03
5 .	.346446	7.35992E-03
6 .	.461849 *+	.0109848
7 .	.578906 *+	.0139331
8 .	.694888 *+	.0195555
9 .	.809494 *+	.0263827
10 .	.92524 *+	.0325435
11 .	1.03769 *+	.0397386
12 .	1.14964 *+	.0458706
13 .	1.25739 *+	.0537135
14 .	1.35935 *+	.063383
15 .	1.45565 +	.0744347
16 .	1.55489 +	.0832019
17 .	1.6476 +	.0937203
18 .	1.72714	.107677
19 .	1.80326	.121277
20 .	1.88079	.13373
21 .	1.94354	.149624
22 .	1.99684	.166719
23 .	2.0466	.183334
24 .	2.07853	.203194
25 .	2.12025	.219757
26 .	2.16385	.234722
27 .	2.19361	.251432
28 .	2.22324	.267703

*-DENOTES POINTS USED FOR JIC DETERMINATION
+-DENOTES POINTS USED IN TEARING MODULUS CALCULATION

Figure D-21

ORNL-DWG 82-5351 ETD

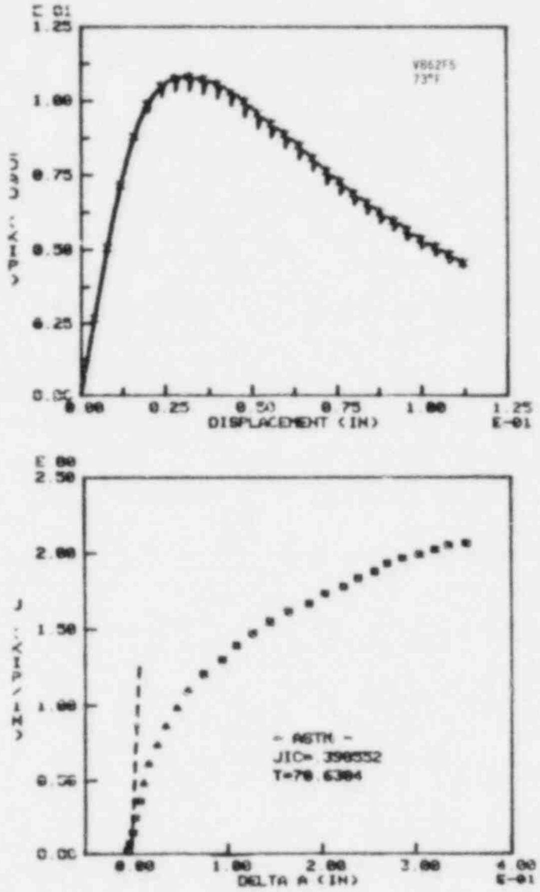


	J KIP/IN	CRACK EXTENSION IN
1 .	.0107606	6.0E140E-04
2 .	.0363356	-4.37630E-04
3 .	.0759671	-4.77499E-04
4 .	.126212	1.59305E-03
5 .	.186694	2.16561E-03
6 .	.254986	3.94207E-03
7 .	.327049	5.75994E-03
8 .	.401266	8.37803E-03
9 .	.475503 *+	.0108596
10 .	.551701 *+	.0125719
11 .	.625805 *+	.0165967
12 .	.702364 *+	.0197008
13 .	.777867 *+	.0228302
14 .	.851269 *+	.0266438
15 .	.969 *+	.0348589
16 .	1.06089 *+	.0458859
17 .	1.19219 *+	.0553043
18 .	1.29787 *+	.0656404
19 .	1.40046 +	.0767032
20 .	1.49405	.0893149
21 .	1.58469	.102137
22 .	1.6679	.115617
23 .	1.75056	.126097
24 .	1.83275	.139993
25 .	1.91085	.151565
26 .	1.97475	.165581
27 .	2.04047	.178179
28 .	2.10065	.190923

*-DENOTES POINTS USED FOR JIC DETERMINATION
+-DENOTES POINTS USED IN TEARING MODULUS CALCULATION

Figure D-22

ORNL–DWG 82–5352 ETD

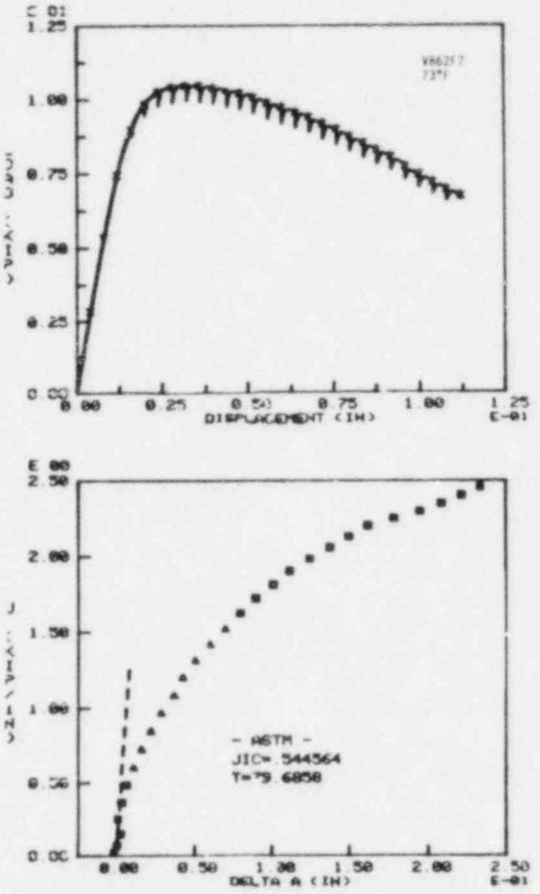


	J KIP/IN		CRACK EXTENSION IN
1 .	.0[illegible]9292		-3.06275E-03
2 .	.0694554		-1.72211E-03
3 .	.147392		1.02592E-03
4 .	.246485		3.70716E-03
5 .	.361465		8.95564E-03
6 .	.486828	*+	.0131782
7 .	.617058	*+	.0185947
8 .	.742776	*+	.0273746
9 .	.869179	*+	.0364847
10 .	.988773	*+	.0480561
11 .	1.10532	*+	.0595454
12 .	1.20943	+	.0752711
13 .	1.30098		.094723
14 .	1.3955		.109063
15 .	1.47707		.127467
16 .	1.55403		.145671
17 .	1.62047		.165393
18 .	1.67319		.186988
19 .	1.73618		.203503
20 .	1.78415		.223016
21 .	1.83894		.238485
22 .	1.88122		.25645
23 .	1.93405		.26598
24 .	1.97043		.286588
25 .	1.9948		.304759
26 .	2.02553		.320195
27 .	2.05408		.334906
28 .	2.06837		.352551

*-DENOTES POINTS USED FOR JIC DETERMINATION
+-DENOTES POINTS USED IN TEARING MODULUS CALCULATION

Figure D-23

ORNL-DWG 83-5353 ETD

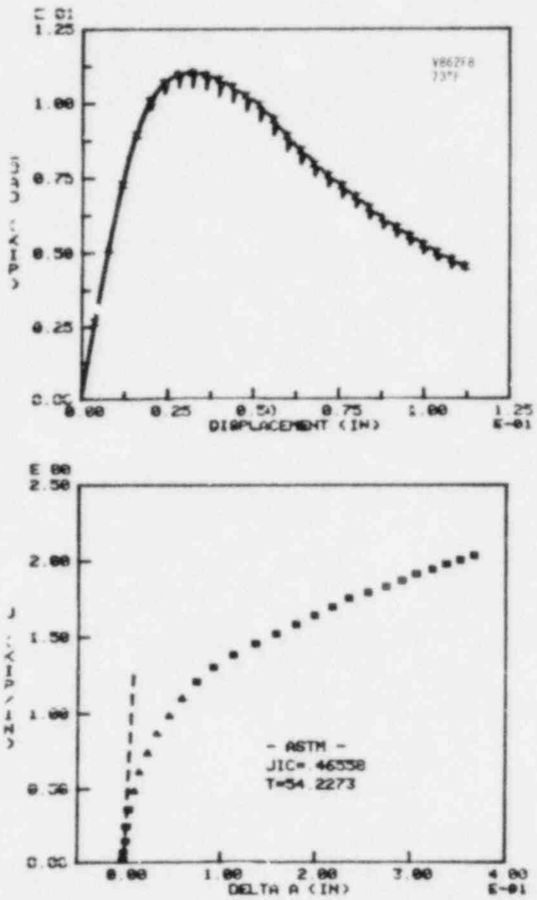


	J KIP/IN	CRACK EXTENSION IN
1 .	.0210027	-1.32535E-03
2 .	.0729871	7.32789E-04
3 .	.151467	2.85047E-03
4 .	.253462	1.16476E-03
5 .	.366225	3.62950E-03
6 .	.486363	6.94030E-03
7 .	.607436 *+	.0114366
8 .	.731159 *+	.0166802
9 .	.851429 *+	.0224004
10 .	.970444 *+	.0296573
11 .	1.08715 *+	.0378951
12 .	1.20485 *+	.0425923
13 .	1.31682 *+	.0505533
14 .	1.42265 *+	.0602229
15 .	1.5266 *+	.069902
16 .	1.62672 +	.0797673
17 .	1.72392 +	.0898119
18 .	1.8152	.100759
19 .	1.90539	.111073
20 .	1.98469	.124035
21 .	2.05941	.137058
22 .	2.13104	.149503
23 .	2.20273	.161699
24 .	2.25206	.178287
25 .	2.2987	.194677
26 .	2.35202	.208391
27 .	2.40581	.221284
28 .	2.45911	.23343

*-DENOTES POINTS USED FOR JIC DETERMINATION
+-DENOTES POINTS USED IN TEARING MODULUS CALCULATION

Figure D-24

ORNL-DWG 82-5354 ETD

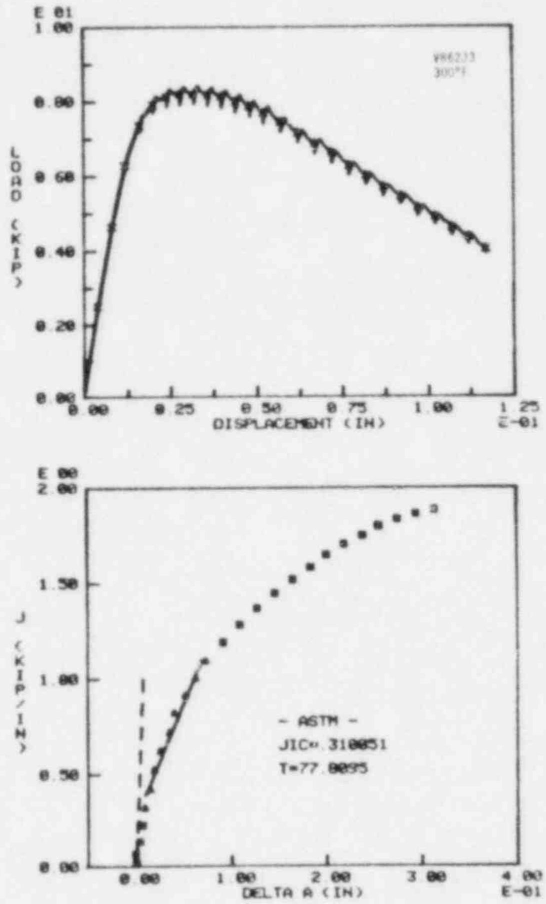


	J KIP/IN		CRACK EXTENSION IN
1 .	.0187872		-8.70612E-04
2 .	.0688716		-4.91526E-04
3 .	.146521		1.52550E-03
4 .	.247072		2.01127E-03
5 .	.364002		4.37591E-03
6 .	.489473	*+	.010014
7 .	.618227	*+	.015223
8 .	.745965	*+	.0235197
9 .	.872089	*+	.0331985
10 .	.99068	*+	.0457835
11 .	1.10345	*+	.0592315
12 .	1.20987	+	.07442
13 .	1.3061	+	.0927475
14 .	1.38932		.113643
15 .	1.45945		.137133
16 .	1.52592		.15872
17 .	1.58771		.179342
18 .	1.64725		.199136
19 .	1.70296		.21771
20 .	1.75734		.235069
21 .	1.79711		.255323
22 .	1.83539		.273835
23 .	1.87555		.29082
24 .	1.91766		.305997
25 .	1.94773		.322617
26 .	1.9812		.337396
27 .	2.01054		.352073
28 .	2.03739		.366442

*-DENOTES POINTS USED FOR JIC DETERMINATION
+-DENOTES POINTS USED IN TEARING MODULUS CALCULATION

Figure D-25

ORNL–DWG 82–5355 ETD

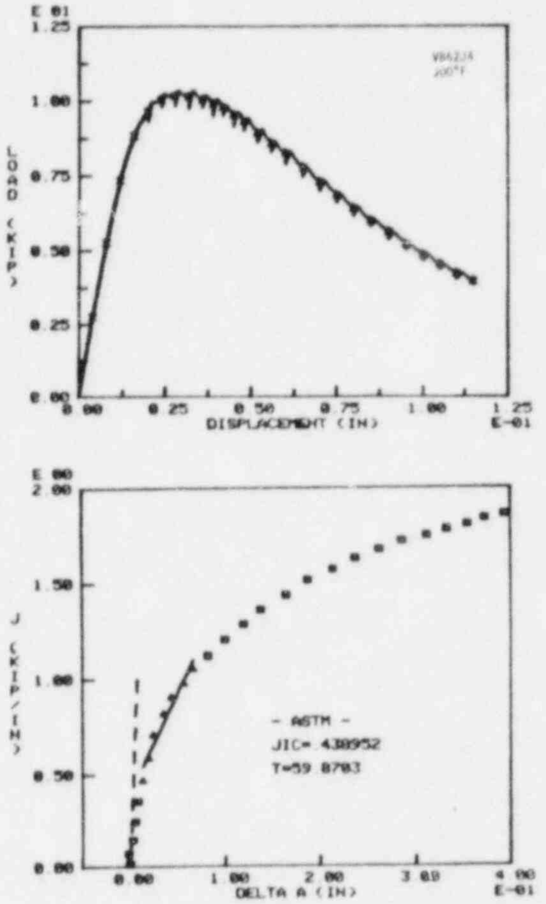


	J KIP/IN	CRACK EXTENSION IN
1 .	.020122	1.00732E-04
2 .	.0683823	-9.83595E-04
3 .	.137092	3.47734E-03
4 .	.22465	6.37925E-03
5 .	.322251 *	8.00790E-03
6 .	.422138 *	.0148437
7 .	.52599 *	.0188178
8 .	.625785 *	.0257311
9 .	.724054 *	.0351263
10 .	.825458 *	.040623
11 .	.917566 *	.052072
12 .	1.00747 *	.0625752
13 .	1.09644 *	.0731266
14 .	1.19335	.0915364 +
15 .	1.28511	.108665 +
16 .	1.37105	.126476 +
17 .	1.44955	.145508 +
18 .	1.52637	.163958 +
19 .	1.58511	.183316 +
20 .	1.65035	.200261 +
21 .	1.70624	.218751 +
22 .	1.75026	.238695 +
23 .	1.8003	.255273 +
24 .	1.83519	.274613 +
25 .	1.86365	.293636 +
26 .	1.88461	.31344 +

*-DENOTES POINTS USED FOR JIC DETERMINATION
+-DENOTES POINTS EXCEEDING ASTM SPECIFICATIONS

Figure D-26

ORNL-DWG 82-5366 ETD

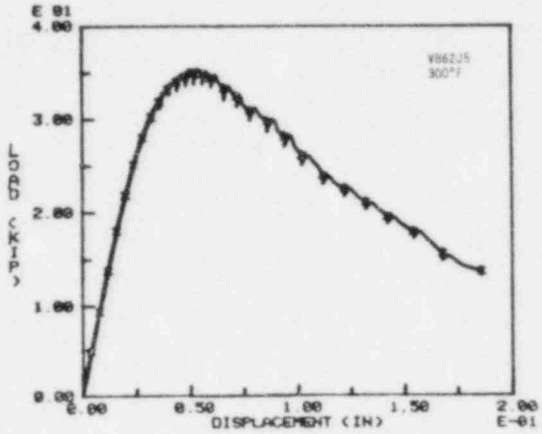


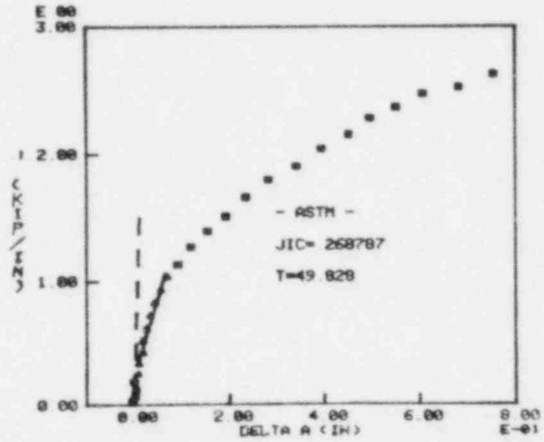
	J KIP/IN	CRACK EXTENSION IN
1 .	.0197557	-2.85394E-04
2 .	.0704225	-1.46019E-03
3 .	.14766	3.14318E-03
4 .	.245423	5.52284E-03
5 .	.357793	8.26132E-03
6 .	.473791 *	.0133006
7 .	.592177 *	.0196408
8 .	.713007 *	.0247127
9 .	.824678 *	.0357866
10 .	.909273 *	.0441261
11 .	.981736 *	.0569307
12 .	1.0601 *	.0669719
13 .	1.12419	.082296
14 .	1.20991	.100585 +
15 .	1.28754	.120076 +
16 .	1.36477	.137573 +
17 .	1.44073	.164181 +
18 .	1.51748	.187548 +
19 .	1.57417	.214003 +
20 .	1.63386	.237365 +
21 .	1.67087	.262507 +
22 .	1.72332	.285836 +
23 .	1.74867	.311785 +
24 .	1.78274	.333513 +
25 .	1.80731	.355984 +
26 .	1.83837	.374416 +
27 .	1.85902 +	.394459 +

*-DENOTES POINTS USED FOR JIC DETERMINATION
+-DENOTES POINTS EXCEEDING ASTM SPECIFICATIONS

Figure D-27

ORNL-DWG 82-5357 ETD



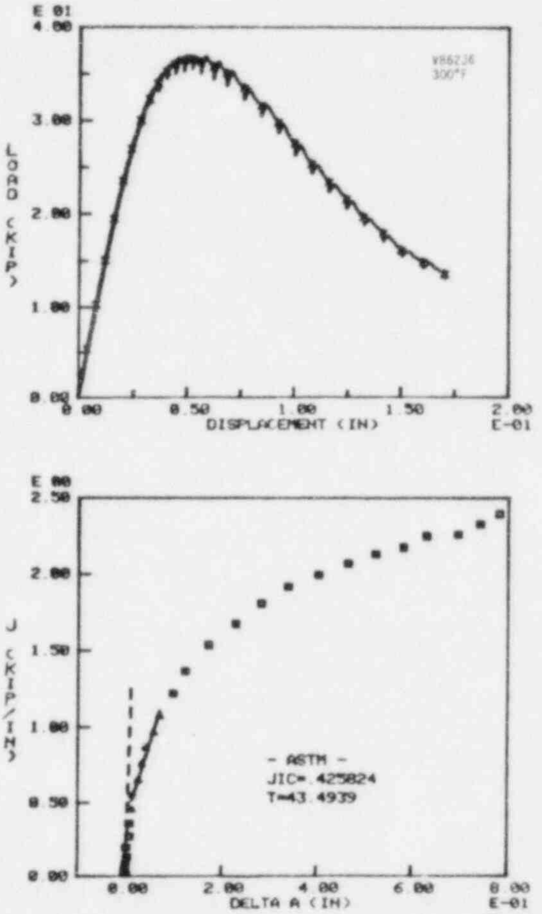


	J KIP/IN	CRACK EXTENSION IN
1 .	9.57002E-03	-3.92772E-03
2 .	.0331375	-2.90515E-03
3 .	.0700498	1.75999E-03
4 .	.12139	3.23318E-03
5 .	.186079	-2.37242E-04
6 .	.256691 *	8.14222E-03
7 .	.341586 *	9.57249E-03
8 .	.430016 *	.0107654
9 .	.52807 *	.018307
10 .	.626825 *	.0259142
11 .	.732004 *	.0335457
12 .	.835296 *	.0434191
13 .	.937219 *	.0557432
14 .	1.04004 *	.0694394
15 .	1.13275	.0909407
16 .	1.27215	.118942
17 .	1.39647	.154584
18 .	1.51358	.192843 +
19 .	1.66219	.235642 +
20 .	1.79919	.282634 +
21 .	1.90353	.34024 +
22 .	2.04215	.39431 +
23 .	2.15439	.451715 +
24 .	2.28023	.496636 +
25 .	2.36737	.550303 +
26 .	2.47225	.606835 +
27 .	2.52399	.684507 +
28 .	2.62462	.756241 +

*-DENOTES POINTS USED FOR JIC DETERMINATION
+-DENOTES POINTS EXCEEDING ASTM SPECIFICATIONS

Figure D-28

ORNL—DWG 82—5358 ETD

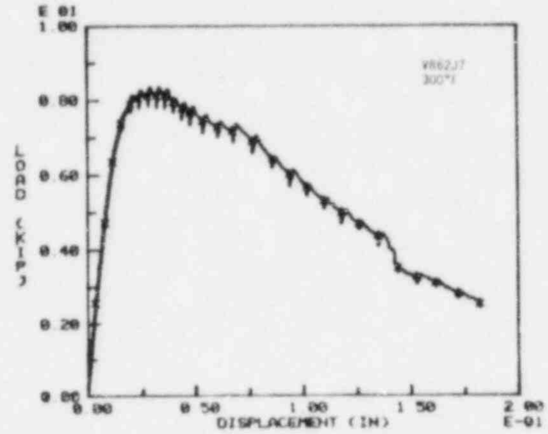


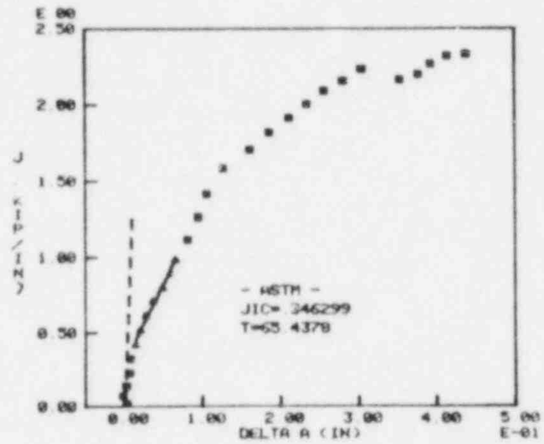
	J KIP/IN	CRACK EXTENSION IN
1 .	.0102189	1.74559E-03
2 .	.035364	-1.73294E-03
3 .	.0756576	-5.15813E-04
4 .	.128824	2.43032E-03
5 .	.196447	1.25707E-03
6 .	.271133	7.40517E-03
7 .	.358743	7.16699E-03
8 .	.456187 *	.0120524
9 .	.55492 *	.0150391
10 .	.656503 *	.024774
11 .	.763557 *	.0334309
12 .	.87211 *	.0421385
13 .	.971214 *	.0586213
14 .	1.07802 *	.070243
15 .	1.22286	.0951658
16 .	1.36717	.124778
17 .	1.53945	.171696
18 .	1.67621	.220617 +
19 .	1.81	.282187 +
20 .	1.91967	.339168 +
21 .	1.99778	.403489 +
22 .	2.07012	.464524 +
23 .	2.13247	.521408 +
24 .	2.17663	.581097 +
25 .	2.24999	.630004 +
26 .	2.26211	.695317 +
27 .	2.32844	.742425 +
28 .	2.39635	.783092 +

*-DENOTES POINTS USED FOR JIC DETERMINATION
+-DENOTES POINTS EXCEEDING ASTM SPECIFICATIONS

Figure D-29

ORNL-DWG 82-5359 ETD



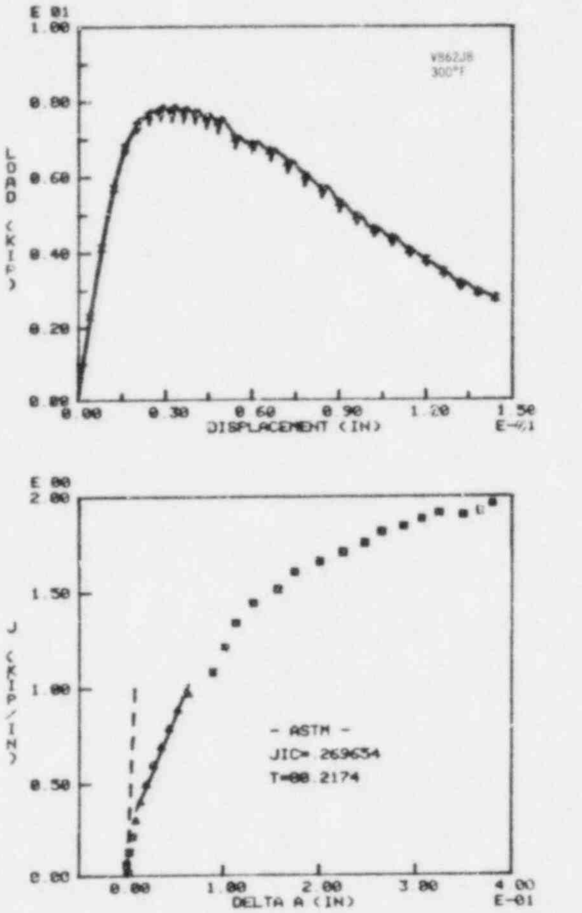


	J KIP/IN	CRACK EXTENSION IN
1 .	.0197534	2.50425E-03
2 .	.069315	-1.97647E-03
3 .	.138381	1.84025E-03
4 .	.22647	5.81517E-03
5 .	.325157	7.20610E-03
6 .	.421082 *	.0134814
7 .	.520332 *	.0192913
8 .	.62232 *	.0265232
9 .	.716341 *	.0353594
10 .	.806282 *	.0479032
11 .	.900262 *	.0581017
12 .	.989645 *	.0550139
13 .	1.11754	.0810869
14 .	1.26712	.0950085 +
15 .	1.41889	.105458 +
16 .	1.5899	.126746 +
17 .	1.70947	.160929 +
18 .	1.82245	.185782 +
19 .	1.91406	.21158 +
20 .	2.00742	.234374 +
21 .	2.09165	.256334 +
22 .	2.15856 +	.280523 +
23 .	2.23317 +	.304335 +
24 .	2.1649 +	.353376 +
25 .	2.20086 +	.376881 +
26 .	2.27061 +	.392823 +
27 .	2.32044 +	.413705 +
28 .	2.33299 +	.438064 +

*-DENOTES POINTS USED FOR JIC DETERMINATI)N
+-DENOTES POINTS EXCEEDING ASTM SPECIFICA/IONS

Figure D-30

ORNL–DWG 82–5360 ETD

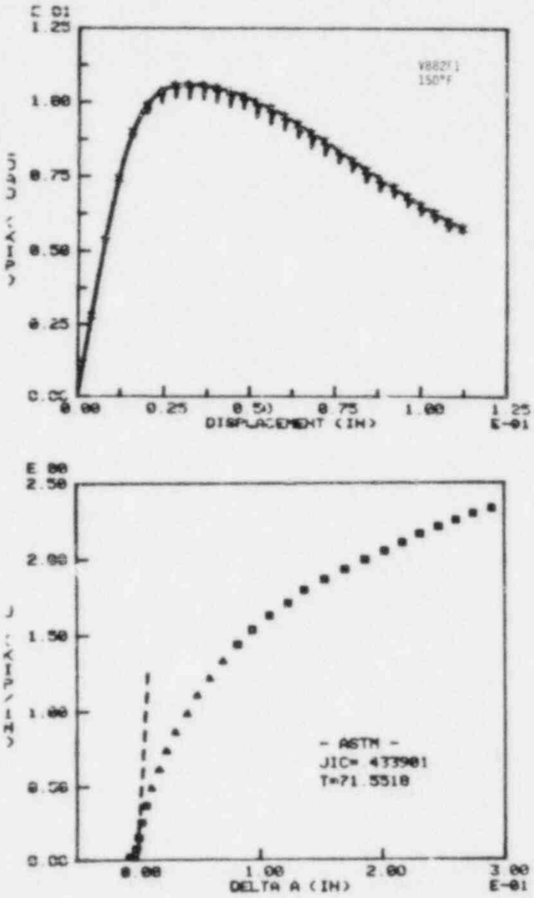


	J KIP/IN		CRACK EXTENSION IN
1 .	.0192151		8.61173E-04
2 .	.0641243		-4.15678E-04
3 .	.131643		2.38479E-03
4 .	.214665		5.28169E-03
5 .	.305662	*	9.10032E-03
6 .	.403543	*	.013667
7 .	.500405	*	.0194115
8 .	.602071	*	.0270125
9 .	.698831	*	.035097
10 .	.794519	*	.0431997
11 .	.889309	*	.0522485
12 .	.976591	*	.0636206
13 .	1.08613		.0894365 +
14 .	1.21484		.102268 +
15 .	1.34268		.113043 +
16 .	1.44629		.131162 +
17 .	1.51761		.156605 +
18 .	1.60812		.17423 +
19 .	1.66173		.200411 +
20 .	1.7098		.22466 +
21 .	1.75824		.247104 +
22 .	1.81636		.264632 +
23 .	1.84644		.287287 +
24 .	1.88391	+	.306198 +
25 .	1.91548	+	.324546 +
26 .	1.90554	+	.349989 +
27 .	1.92477	+	.367818 +
28 .	1.96352	+	.380356 +

*-DENOTES POINTS USED FOR JIC DETERMINATION
+-DENOTES POINTS EXCEEDING ASTM SPECIFICATIONS

Figure D-31

ORNL-DWG 82-5?`1 ETD

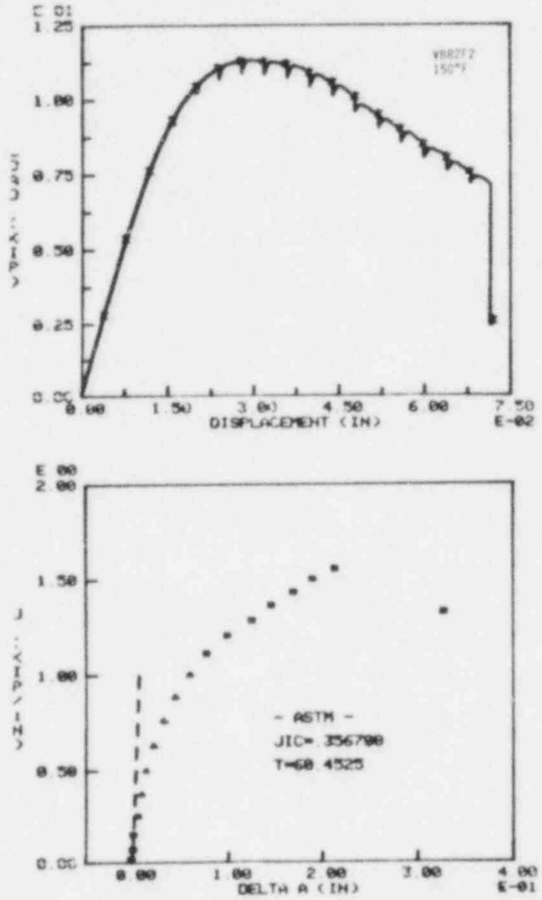


	J KIP/IN		CRACK EXTENSION IN
1 .	.0209077		-5.85364E-03
2 .	.0736991		-6.77090E-04
3 .	.153211		1.17351E-03
4 .	.255911		3.27934E-03
5 .	.371316		7.02978E-03
6 .	.495064	*+	.0112292
7 .	.621514	*+	.017395
8 .	.746121	*+	.0232421
9 .	.872464	*+	.0304616
10 .	.991435	*+	.0390965
11 .	1.1127	*+	.0460499
12 .	1.22567	*+	.058382
13 .	1.33494	*+	.0692017
14 .	1.44025	+	.0816201
15 .	1.53885	+	.0937309
16 .	1.63044		.106152
17 .	1.71375		.123288
18 .	1.79088		.136559
19 .	1.86896		.153255
20 .	1.93369		.170092
21 .	1.99657		.186545
22 .	2.05384		.20326
23 .	2.11168		.217185
24 .	2.16478		.231537
25 .	2.21156		.246678
26 .	2.25799		.260984
27 .	2.29997		.274021
26 .	2.33454		.290025

*-DENOTES POINTS USED FOR JIC DETERMINATION
+-DENOTES POINTS USED IN TEARING MODULUS CALCULATION

Figure D-32

ORNL–DWG 82–5362 ETD

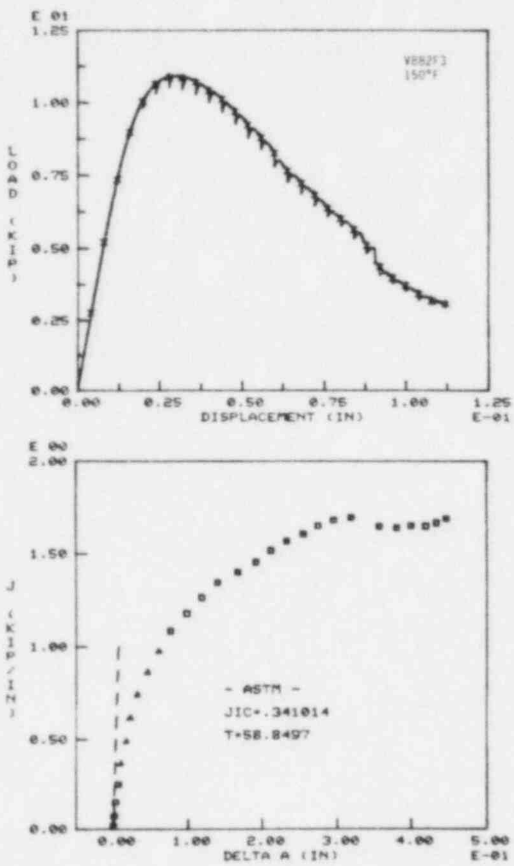


	J KIP/IN		CRACK EXTENSION IN
1 .	.0190027		-1.36191E-03
2 .	.0715223		1.96398E-04
3 .	.151004		4.98726E-04
4 .	.255111		5.08024E-03
5 .	.375796	*+	9.68821E-03
6 .	.504571	*+	.0140077
7 .	.635652	*+	.0219197
8 .	.764401	*+	.032451
9 .	.888503	*+	.0445508
10 .	1.00742	*+	.0595316
11 .	1.11559	+	.0772927
12 .	1.20931		.0969446
13 .	1.28712		.124871
14 .	1.36803		.145379
15 .	1.43513		.165082
16 .	1.50329		.185456
17 .	1.55693		.212742
18 .	1.32917		.327429

*–DENOTES POINTS USED FOR JIC DETERMINATION
+–DENOTES POINTS USED IN TEARING MODULUS CALCULATION

Figure D-33

ORNL-DWG 82-5363 ETD

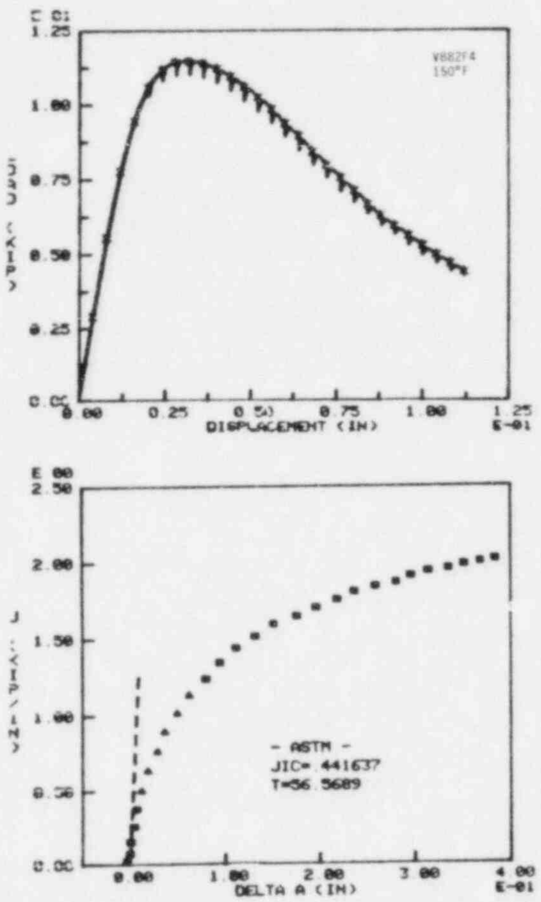


	J KIP/IN		CRACK EXTENSION IN
1 .	.0212686		-3.51684E-04
2 .	.0725544		9.35896E-04
3 .	.152586		2.70007E-03
4 .	.252361		6.51191E-03
5 .	.370123	*+	9.65618E-03
6 .	.494332	*+	.0170111
7 .	.623304	*+	.0227684
8 .	.748651	*+	.0324586
9 .	.868619	*+	.0464345
10 .	.981492	*+	.0613029
11 .	1.08833	+	.0777294
12 .	1.18063		.0988487
13 .	1.26761		.118917
14 .	1.34862		.139849
15 .	1.40274		.167527
16 .	1.45699		.192178
17 .	1.5191		.211945
18 .	1.56821		.233069
19 .	1.6061		.255165
20 .	1.65106		.274216
21 .	1.68295		.294995
22 .	1.69649		.318529
23 .	1.64864		.356927
24 .	1.64222		.381048
25 .	1.65077		.399836
26 .	1.65058		.419916
27 .	1.66772		.43404
28 .	1.68877		.446905

*-DENOTES POINTS USED FOR JIC DETERMINATION
+-DENOTES POINTS USED IN TEARING MODULUS CALCULATION

Figure D-34

ORNL-DWG 82-5364 ETD

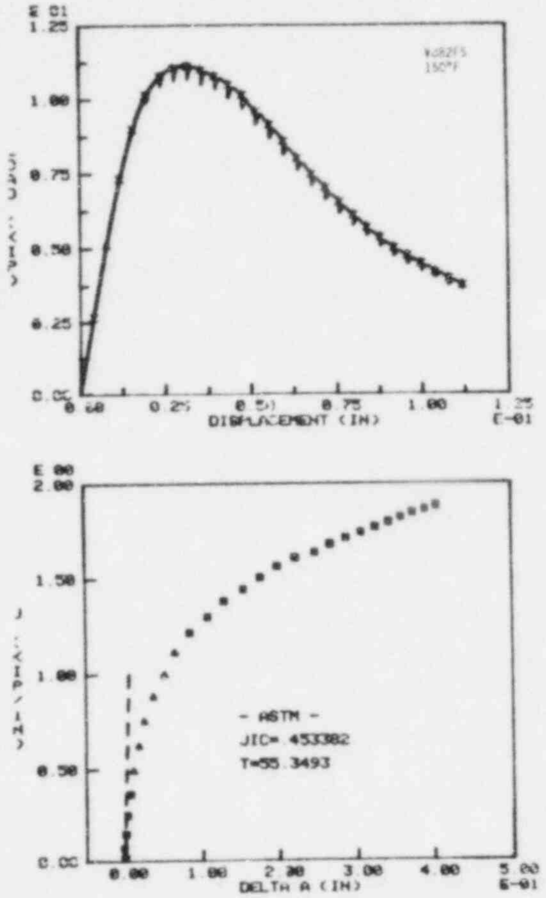


	J KIP/IN		CRACK EXTENSION IN
1 .	.0207228		-3.35549E-03
2 .	.0734191		-1.54958E-04
3 .	.151581		8.16862E-04
4 .	.25777		4.44330E-03
5 .	.379874		6.96651E-03
6 .	.507072	*+	.0118168
7 .	.640831	*+	.0167041
8 .	.767835	*+	.0268422
9 .	.899016	*+	.0367218
10 .	1.02036	*+	.0503198
11 .	1.13805	*+	.0627912
12 .	1.2423	+	.0799685
13 .	1.34852	+	.0947925
14 .	1.4431		.111749
15 .	1.52059		.131782
16 .	1.59726		.151747
17 .	1.6505		.175978
18 .	1.70808		.196375
19 .	1.7585		.216017
20 .	1.81111		.236326
21 .	1.84507		.256438
22 .	1.87034		.280683
23 .	1.91386		.296189
24 .	1.94553		.314212
25 .	1.96036		.334708
26 .	1.98599		.35084
27 .	2.00522		.367647
28 .	2.02093		.383969

*-DENOTES POINTS USED FOR JIC DETERMINATION
+-DENOTES POINTS USED IN TEARING MODULUS CALCULATION

Figure D-35

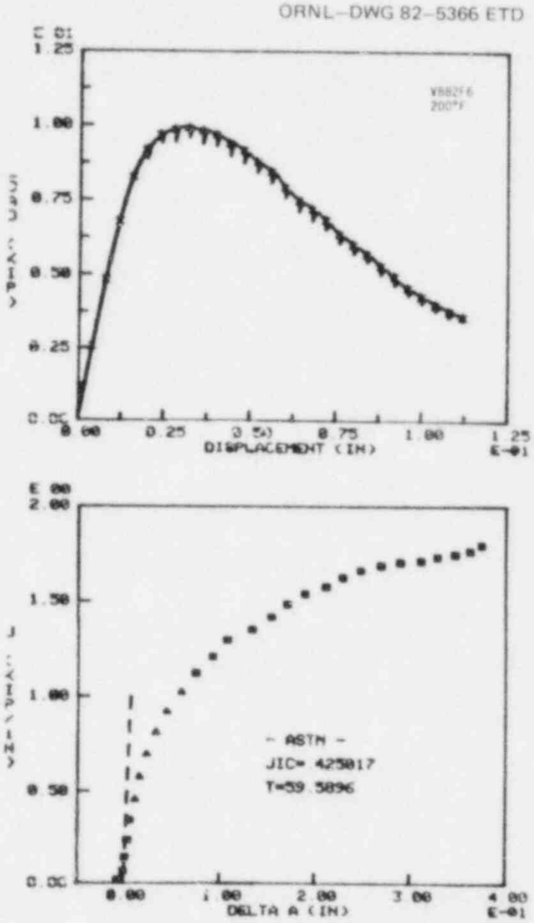
ORNL–DWG 82–5365 ETD



	J KIP/IN		CRACK EXTENSION IN
1 .	.0200959		4.42907E-04
2 .	.0704897		-1.02844E-03
3 .	.149901		1.35369E-03
4 .	.251478		3.70235E-03
5 .	.368117		7.55600E-03
6 .	.497272	*+	.0121597
7 .	.627353	*+	.01507
8 .	.758171	*+	.0264564
9 .	.88511	*+	.0364159
10 .	1.00109	*+	.052764
11 .	1.11600	*+	.0661886
12 .	1.21774	+	.0850625
13 .	1.30263		.107967
14 .	1.36441		.129567
15 .	1.44775		.154757
16 .	1.50879		.17716
17 .	1.56603		.195357
18 .	1.61246		.221979
19 .	1.64059		.247504
20 .	1.683		.267199
21 .	1.71638		.287342
22 .	1.74356		.307162
23 .	1.77028		.32588
24 .	1.79649		.34317
25 .	1.82127		.359309
26 .	1.84736		.37443
27 .	1.86448		.390447
26 .	1.88261		.40517

*-DENOTES POINTS USED FOR JIC DETERMINATION
+-DENOTES POINTS USED IN TEARING MODULUS CALCULATION

Figure D-36

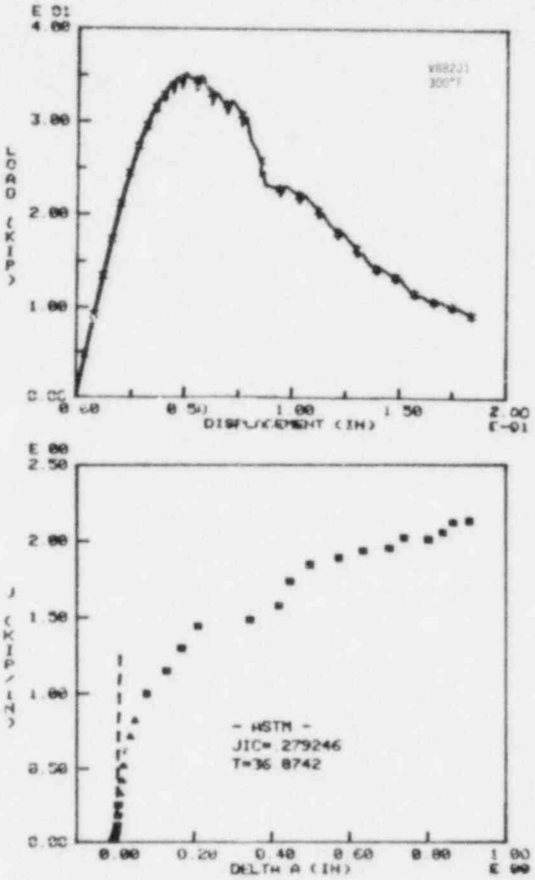


	J KIP/IN		CRACK EXTENSION IN
1 .	.0196485		-6.80045E-03
2 .	.0674781		-5.40468E-04
3 .	.142141		1.18963E-03
4 .	.23708		3.70614E-03
5 .	.347007		6.28068E-03
6 .	.46254	*+	.0120517
7 .	.583219	*+	.0166425
8 .	.701922	*+	.0238768
9 .	.817931	*+	.033511
10 .	.92612	*+	.0451395
11 .	1.02862	*+	.0601154
12 .	1.12678	+	.0746992
13 .	1.21386		.0923822
14 .	1.2996		.107834
15 .	1.3554		.134138
16 .	1.42859		.154134
17 .	1.49909		.17046
18 .	1.54312		.185093
19 .	1.58199		.21128
20 .	1.62951		.228851
21 .	1.66544		.247845
22 .	1.69006		.266944
23 .	1.70932		.285554
24 .	1.71675		.311622
25 .	1.73752		.328799
26 .	1.74991		.347024
27 .	1.7683		.362343
28 .	1.79704		.374366

*-DENOTES POINTS USED FOR JIC DETERMINATION
+-DENOTES POINTS USED IN TEARING MODULUS CALCULATION

Figure D-37

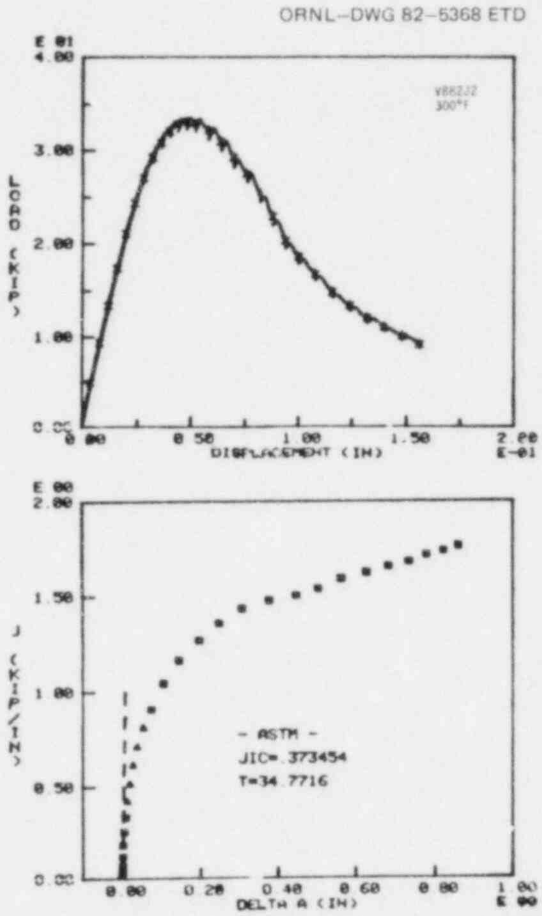
ORNL-DWG 82-5367 ETD



	J KIP/IN	CRACK EXTENSION IN
1 .	9.63074E-03	-.0104273
2 .	.032685	-3.52863E-03
3 .	.0699977	-2.76031E-04
4 .	.117305	2.15938E-03
5 .	.180988	4.05194E-03
6 .	.25341	5.42423E-03
7 .	.336143 *+	9.90507E-03
8 .	.425581 *+	.0142605
9 .	.523562 *+	.0178764
10 .	.622443 *+	.0262067
11 .	.722213 *+	.0356381
12 .	.827295 *+	.0468051
13 .	1.00137 +	.077765
14 .	1.15048 +	.130022
15 .	1.30002 +	.16625
16 .	1.44469	.210241
17 .	1.48621	.343131
18 .	1.57842	.416815
19 .	1.73828	.4457
20 .	1.84775	.497311
21 .	1.88979	.570985
22 .	1.93636	.633568
23 .	1.95211	.700041
24 .	2.02277	.73777
25 .	2.01151	.80139
26 .	2.05636	.836801
27 .	2.11953	.86631
28 .	2.13157	.900163

*-DENOTES POINTS USED FOR JIC DETERMINATION
+-DENOTES POINTS USED IN TEARING MODULUS CALCULATION

Figure D-38

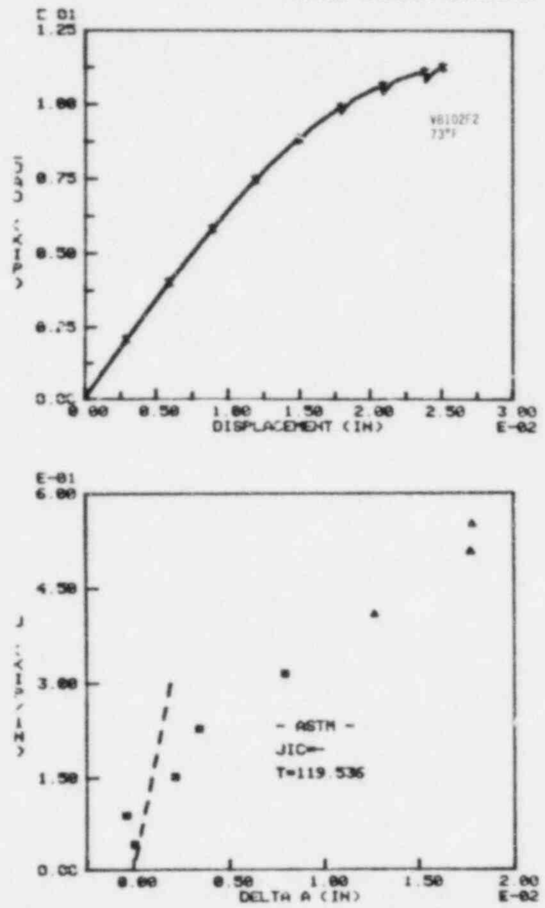


	J KIP/IN		CRACK EXTENSION IN
1 .	9.62589E-03		-9.27308E-04
2 .	.033615		1.96597E-04
3 .	.0699059		3.60629E-04
4 .	.120331		1.16556E-03
5 .	.183223		1.52125E-03
6 .	.256969		3.66752E-03
7 .	.336622		8.16828E-03
8 .	.427581	*+	.0111898
9 .	.520898	*+	.018984
10 .	.620446	*+	.0267822
11 .	.717076	*+	.0378608
12 .	.816156	*+	.0533291
13 .	.910873	+	.0745183
14 .	1.04748	+	.105778
15 .	1.1674	+	.146517
16 .	1.27255		.196321
17 .	1.36305		.248511
18 .	1.43935		.306342
19 .	1.48024		.376386
20 .	1.5067		.446392
21 .	1.54095		.503055
22 .	1.59469		.562768
23 .	1.62575		.627531
24 .	1.65821		.68305
25 .	1.68262		.73498
26 .	1.71727		.778601
27 .	1.73754		.822101
28 .	1.76404		.859972

*-DENOTES POINTS USED FOR JIC DETERMINATION
+-DENOTES POINTS USED IN TEARING MODULUS CALCULATION

Figure D-39

ORNL-DWG 82-5369 ETD

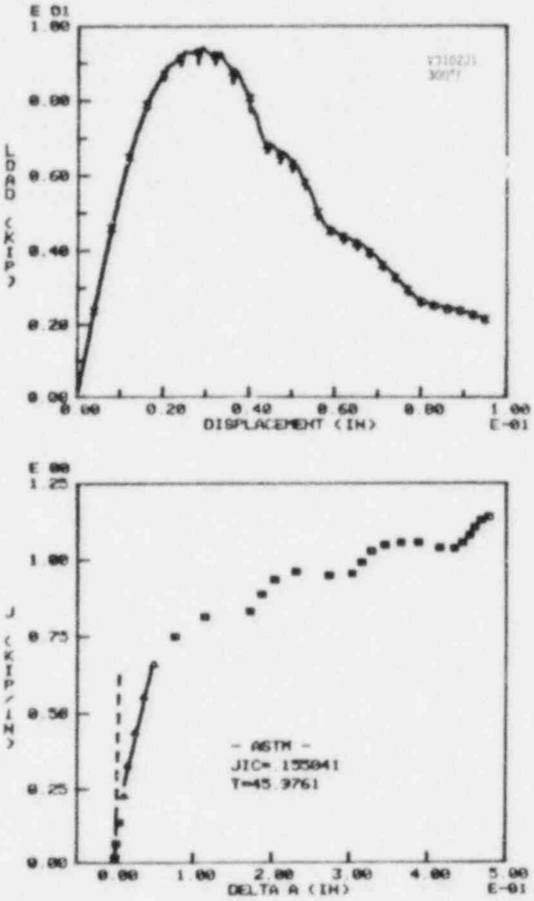


	J KIP/IN	CRACK EXTENSION IN
1 .	.0118775	-3.42267E-03
2 .	.0420827	4.41722E-05
3 .	.0994525	-3.83312E-04
4 .	.153076	2.19924E-03
5 .	.229551	3.42316E-03
6 .	.316345	7.93404E-03
7 .	.410875 *+	.0127028
8 .	.5093 *+	.0177695
9 .	.55274 *+	.0178575

*-DENOTES POINTS USED FOR JIC DETERMINATION
+-DENOTES POINTS USED IN TEARING MODULUS CALCULATION

Figure D-40

ORNL-DWG 82-5370 ETD

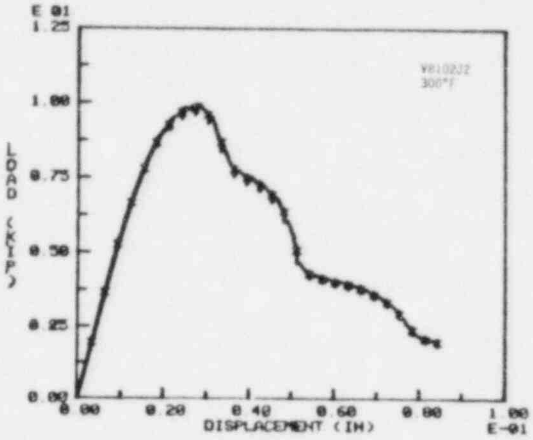


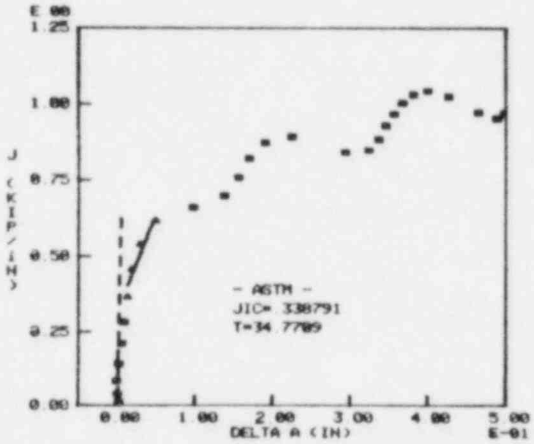
	J KIP/IN	CRACK EXTENSION IN
1 .	.0182838	-3.69402E-04
2 .	.0652566	9.69676E-04
3 .	.137471	4.64025E-03
4 .	.229352 *	.0107143
5 .	.331306 *	.01568
6 .	.440173 *	.0245672
7 .	.55492 *	.0354278
8 .	.662372 *	.0486896
9 .	.751399	.076082
10 .	.816451	.114368 +
11 .	.83398	.171082 +
12 .	.880063	.186926 +
13 .	.93633	.203535 +
14 .	.961366	.23127 +
15 .	.949787	.273922 +
16 .	.95582	.302044 +
17 .	.993189	.315173 +
18 .	1.02898	.327058 +
19 .	1.04815	.344943 +
20 .	1.05763	.365202 +
21 .	1.05648	.387737 +
22 .	1.03963	.414838 +
23 .	1.03815	.433923 +
24 .	1.05772	.44426 +
25 .	1.0813	.453398 +
26 .	1.10768	.460345 +
27 .	1.13003	.46812 +
28 .	1.14068	.478532 +

*-DENOTES POINTS USED FOR JIC DETERMINATION
+-DENOTES POINTS EXCEEDING ASTM SPECIFICATIONS

Figure D-41

ORNL-DWG 82-5371 ETD



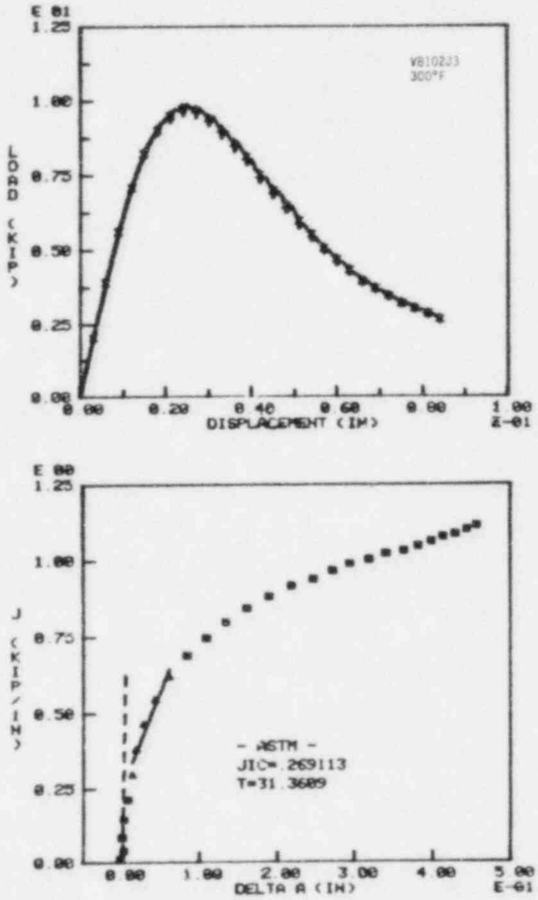


	J KIP/IN	CRACK EXTENSION IN
1 .	.0123015	1.55533E-03
2 .	.0401039	-2.74889E-04
3 .	.0826926	-6.72810E-04
4 .	.142019	2.12718E-03
5 .	.210553	5.11778E-03
6 .	.28441	7.71154E-03
7 .	.369783 *	.0126669
8 .	.43935 *	.018338
9 .	.542301 *	.0291814
10 .	.62032 *	.0495428
11 .	.662373	.0983747 +
12 .	.701128	.137447 +
13 .	.761435	.155729 +
14 .	.823125	.16959 +
15 .	.874246	.190518 +
16 .	.89462	.22519 +
17 .	.943556	.293942 +
18 .	.850006	.324693 +
19 .	.885690	.337628 +
20 .	.930354	.346653 +
21 .	.968966	.356993 +
22 .	1.00554	.368054 +
23 .	1.03223	.382168 +
24 .	1.04425	.400277 +
25 .	1.02573	.428384 +
26 .	.9738[illegible]4	.466314 +
27 .	.955372	.489976 +
28 .	.971799	.499324 +

*-DENOTES POINTS USED FOR JIC DETERMINATION
+-DENOTES POINTS EXCEEDING ASTM SPECIFICATIONS

Figure D-42

ORNL-DWG 82-5372 ETD

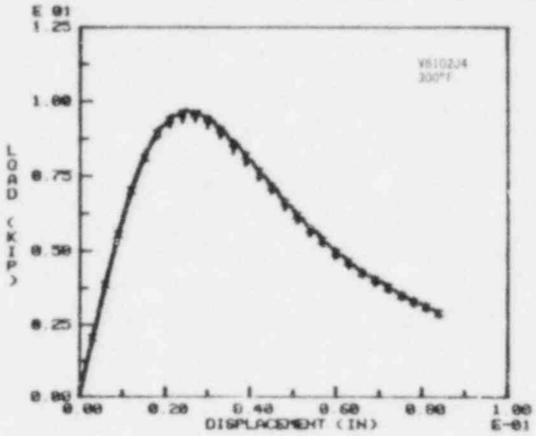


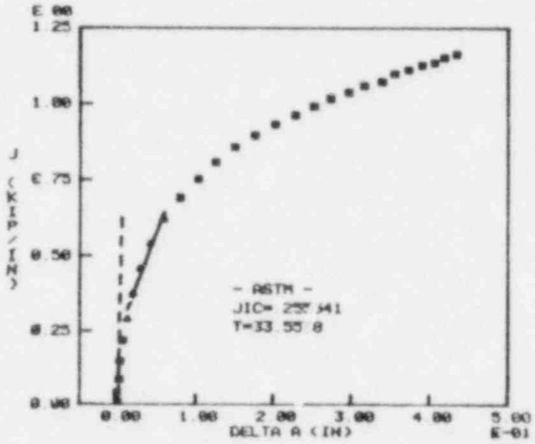
	J KIP/IN	CRACK EXTENSION IN
1 .	.0116946	-1.66526E-03
2 .	.0400062	2.29654E-03
3 .	.0843656	1.35638E-04
4 .	.146715	2.04787E-03
5 .	.21500	7.37713E-03
6 .	.299652 *	.0138589
7 .	.384112 *	.018334
8 .	.468193 *	.0263689
9 .	.546662 *	.042953
10 .	.62166 *	.0614562
11 .	.698394	.0843678
12 .	.749739	.100886 +
13 .	.800585	.134458 +
14 .	.845743	.161246 +
15 .	.884496	.18948 +
16 .	.919202	.217737 +
17 .	.941496	.246519 +
18 .	.968539	.272119 +
19 .	.991493	.294269 +
20 .	1.00576	.319042 +
21 .	1.02402	.339045 +
22 .	1.03386	.362586 +
23 .	1.04905	.380619 +
24 .	1.06368	.398258 +
25 .	1.078	.413579 +
26 .	1.08796	.429066 +
27 .	1.10194	.444921 +
28 .	1.11468	.457636 +

*-DENOTES POINTS USED FOR JIC DETERMINATION
+-DENOTES POINTS EXCEEDING ASTM SPECIFICATIONS

Figure D-43

ORNL—DWG 82-5373 ETD



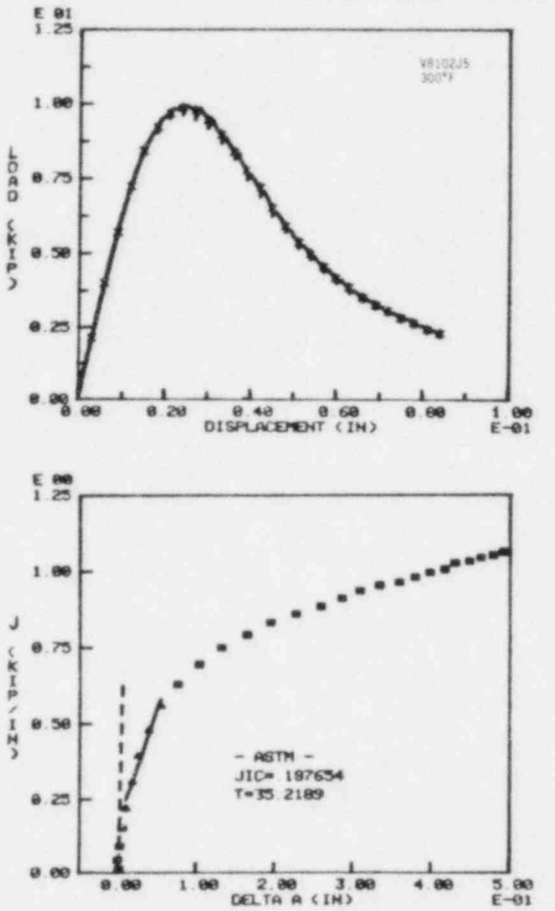


	J KIP/IN	CRACK EXTENSION IN
1 .	.0122077	-6.32127E-04
2 .	.0410291	-1.45694E-03
3 .	.0858755	1.46667E-03
4 .	.146887	2.68393E-03
5 .	.219468	5.92140E-03
6 .	.293789 *	.0117053
7 .	.378826 *	.0187796
8 .	.460753 *	.0279812
9 .	.542283 *	.0411383
10 .	.622083 *	.0584994
11 .	.691703	.0793103
12 .	.752567	.102838 +
13 .	.80892	.126033 +
14 .	.858815	.151123 +
15 .	.897438	.176025 +
16 .	.933778	.202408 +
17 .	.964241	.227823 +
18 .	.994929	.25206 +
19 .	1.01949	.273467 +
20 .	1.04048	.296537 +
21 .	1.0622	.315739 +
22 .	1.07503	.338186 +
23 .	1.09963	.354717 +
24 .	1.11343	.372883 +
25 .	1.12844	.389655 +
26 .	1.13697	.406539 +
27 .	1.15482	.419544 +
28 .	1.16465	.434635 +

*—DENOTES POINTS USED FOR JIC DETERMINATION
+—DENOTES POINTS EXCEEDING ASTM SPECIFICATIONS

Figure D-44

ORNL-DWG 82-5374 ETD

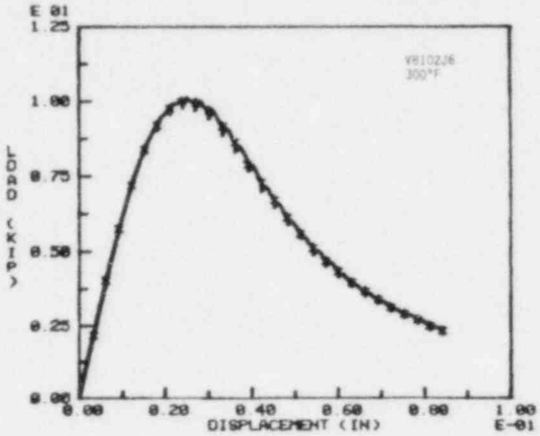


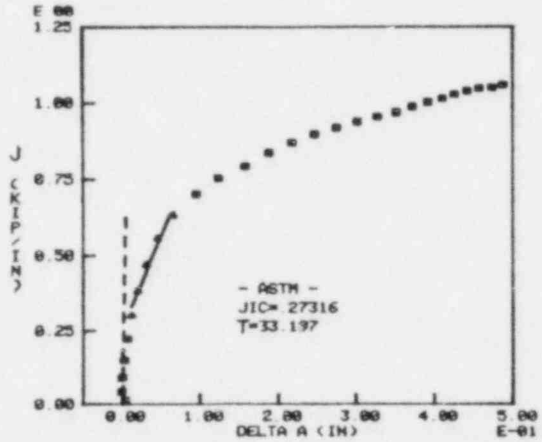
	J KIP/IN	CRACK EXTENSION IN
1 .	.0130273	6.06381E-04
2 .	.043247	-6.91093E-04
3 .	.0900838	1.58700E-03
4 .	.153265	4.23940E-03
5 .	.222417 *	9.34514E-03
6 .	.310821 *	.0177439
7 .	.397254 *	.0249325
8 .	.481481 *	.0384407
9 .	.561576 *	.0537545
10 .	.632076	.0764665
11 .	.69742	.103469 +
12 .	.752141	.132125 +
13 .	.793809	.16391 +
14 .	.8341	.194612 +
15 .	.861811	.227584 +
16 .	.886444	.256977 +
17 .	.913827	.286008 +
18 .	.93761	.305066 +
19 .	.955736	.333873 +
20 .	.965412	.358025 +
21 .	.981664	.376512 +
22 .	.9975	.397704 +
23 .	1.00739	.417146 +
24 .	1.02796	.430355 +
25 .	1.03419	.448719 +
26 .	1.0452	.463669 +
27 .	1.05242	.479583 +
28 .	1.06352	.492254 +

*-DENOTES POINTS USED FOR JIC DETERMINATION
+-DENOTES POINTS EXCEEDING ASTM SPECIFICATIONS

Figure D-45

ORNL-DWG 82-5375 ETD



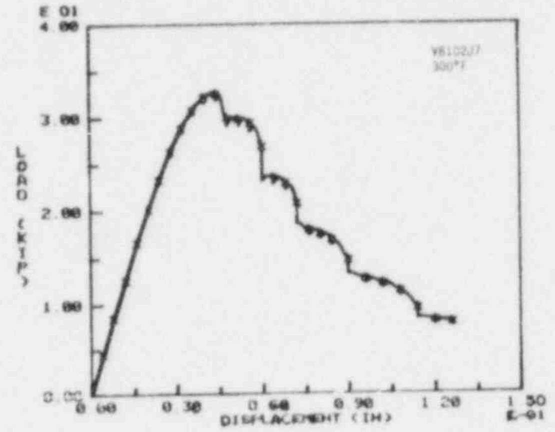


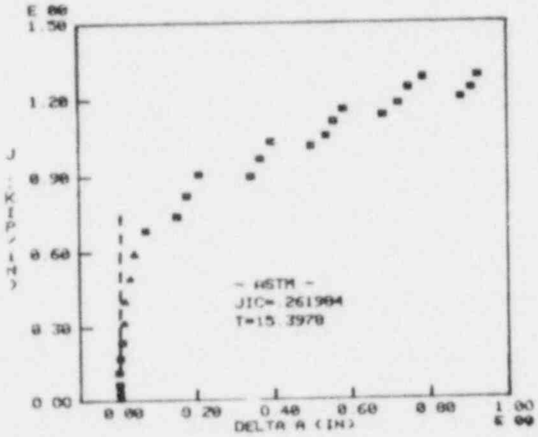
	J KIP/IN	CRACK EXTENSION IN
1 .	.0136211	3.95709E-03
2 .	.0433737	-9.50871E-04
3 .	.0912673	1.46800E-04
4 .	.150601	2.32548E-03
5 .	.224554	6.64503E-03
6 .	.305274 *	.0118187
7 .	.38808 *	.0158337
8 .	.47384 *	.0313388
9 .	.560182 *	.0455383
10 .	.636064 *	.0656603
11 .	.703982	.0949406 +
12 .	.756814	.123993 +
13 .	.794904	.157549 +
14 .	.839109	.187664 +
15 .	.872561	.217141 +
16 .	.899756	.246491 +
17 .	.921226	.275263 +
18 .	.940611	.301981 +
19 .	.956979	.32732 +
20 .	.971215	.350625 +
21 .	.990663	.371188 +
22 .	1.0054	.391569 +
23 .	1.01682	.410376 +
24 .	1.03032	.426348 +
25 .	1.04067	.443069 +
26 .	1.04939	.458701 +
27 .	1.05129	.475223 +
28 .	1.06034	.488935 +

*-DENOTES POINTS USED FOR JIC DETERMINATION
+-DENOTES POINTS EXCEEDING ASTM SPECIFICATIONS

Figure D-46

ORNL-DWG 82-5376 ETD



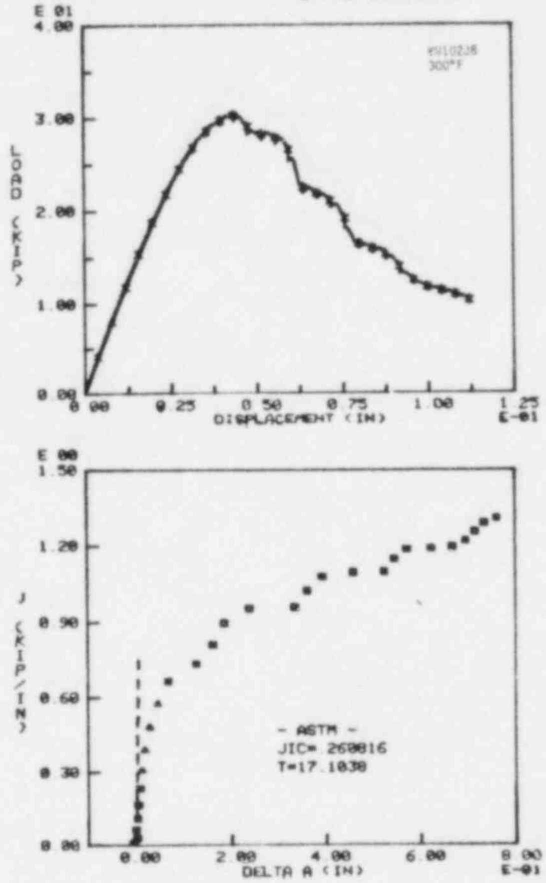


	J KIP/IN		CRACK EXTENSION IN
1 .	8.76569E-03		2.32360E-03
2 .	.0297141		4.94435E-04
3 .	.0656592		1.62330E-06
4 .	.114079		-2.16515E-03
5 .	.173744		1.06963E-03
6 .	.239742		7.62555E-03
7 .	.319637	*+	.0122916
8 .	.407475	*+	.0142602
9 .	.497233	*+	.0266037
10 .	.595396	*+	.0400026
11 .	.685641	+	.0700054
12 .	.740425	+	.152379
13 .	.821601		.178107
14 .	.905835		.206816
15 .	.896441		.340953
16 .	.965106		.364907
17 .	1.03203		.392750
18 .	1.01529		.495665
19 .	1.05474		.535475
20 .	1.11037		.555203
21 .	1.159		.581078
22 .	1.13602		.69219
23 .	1.18207		.721084
24 .	1.24295		.747097
25 .	1.28129		.792053
26 .	1.20325		.882727
27 .	1.23817		.905723
28 .	1.28842		.925065

*-DENOTES POINTS USED FOR JIC DETERMINATION
+-DENOTES POINTS USED IN TEARING MODULUS CALCULATION

Figure D-47

ORNL--DWG 82--5377 ETD

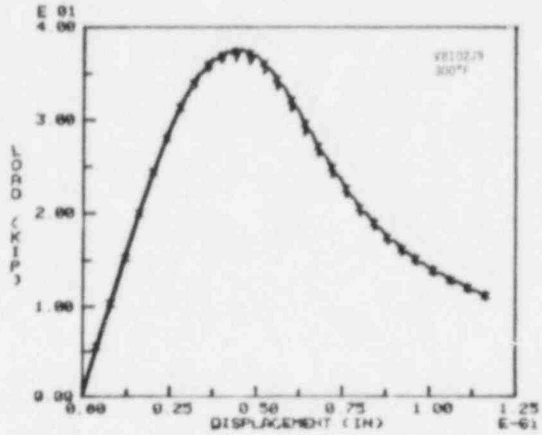


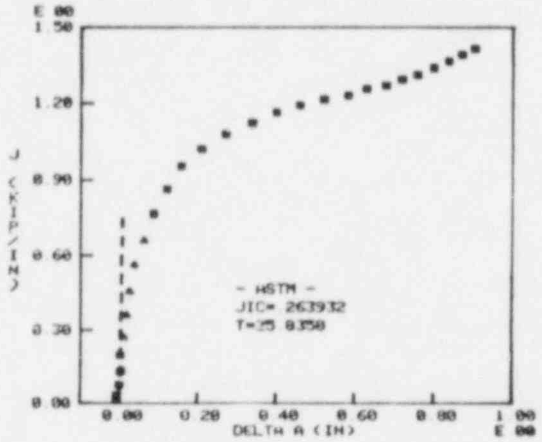
	J KIP/IN	CRACK EXTENSION IN
1 .	8.29328E-03	-5.94076E-03
2 .	.0300177	8.22219E-04
3 .	.0644617	-1.74793E-03
4 .	.109389	1.04289E-03
5 .	.166557	3.95862E-03
6 .	.235282	7.37158E-03
7 .	.312022 *+	.0116924
8 .	.39448 *+	.0180511
9 .	.485533 *+	.0277845
10 .	.579181 *+	.0457815
11 .	.665517 +	.067886
12 .	.734326 +	.127737
13 .	.810954 +	.162039
14 .	.896823	.186902
15 .	.952402	.240094
16 .	.958394	.33536
17 .	1.02315	.361959
18 .	1.07893	.394045
19 .	1.09457	.459172
20 .	1.09806	.52388
21 .	1.14782	.545802
22 .	1.18689	.572717
23 .	1.18985	.624213
24 .	1.19572	.669108
25 .	1.2205	.69654
26 .	1.2553	.71656
27 .	1.28692	.735844
28 .	1.30824	.76244

*-DENOTES POINTS USED FOR JIC DETERMINATION
+-DENOTES POINTS USED IN TEARING MODULUS CALCULATION

Figure D-48

ORNL-DWG 82-5378 ETD



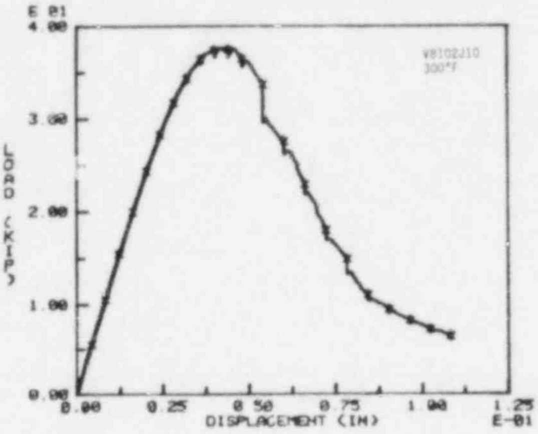


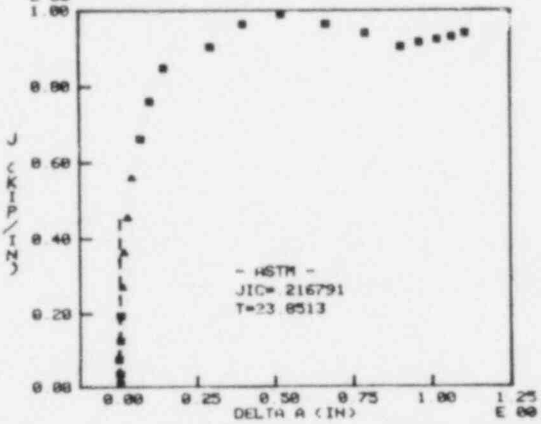
	J KIP/IN		CRACK EXTENSION IN
1 .	.0103279		-8.42596E-03
2 .	.0347957		-7.99490E-03
3 .	.0754095		-6.02212E-04
4 .	.130431		1.59262E-03
5 .	.19824		3.40687E-04
6 .	.274201	*+	8.86868E-03
7 .	.364007	*+	.0166081
8 .	.460953	*+	.0235073
9 .	.565898	*+	.0361912
10 .	.661071	*+	.0602903
11 .	.765604	+	.0856373
12 .	.862053	+	.119532
13 .	.953278	+	.156405
14 .	1.02026		.206637
15 .	1.07959		.272789
16 .	1.12351		.337514
17 .	1.16153		.398204
18 .	1.19442		.459379
19 .	1.21773		.520343
20 .	1.23214		.581699
21 .	1.25764		.626897
22 .	1.27076		.676126
23 .	1.29428		.71689
24 .	1.31316		.75705
25 .	1.33954		.798717
26 .	1.36592		.836355
27 .	1.3917		.870873
28 .	1.4159		.903673

*-DENOTES POINTS USED FOR JIC DETERMINATION
+-DENOTES POINTS USED IN TEARING MODULUS CALCULATION

Figure D-49

ORNL–DWG 82–5379 ETD

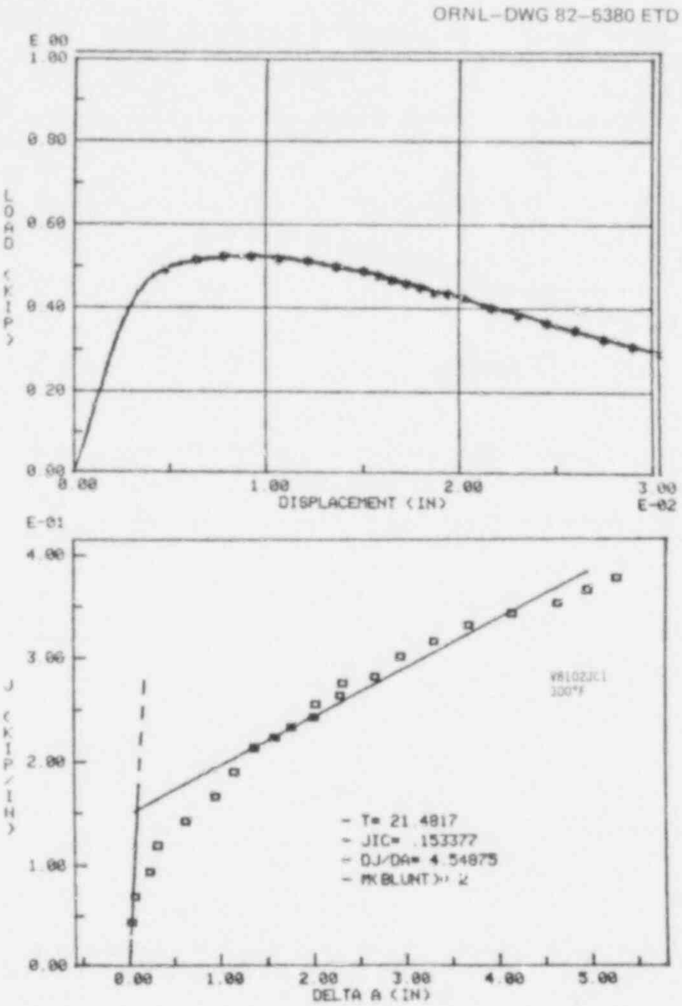




	J KIP/IN		CRACK EXTENSION IN
1 .	.0101763		2.55373E-03
2 .	.0353271		2.10812E-03
3 .	.0769116		-4.55114E-04
4 .	.127278		2.91303E-03
5 .	.195157		4.32065E-03
6 .	.274761	*+	.0102279
7 .	.365434	*+	.0161014
8 .	.457533	*+	.0276263
9 .	.561421	*+	.0412069
10 .	.662842	+	.0684784
11 .	.76676	+	.0992472
12 .	.848508	+	.146078
13 .	.90386		.295301
14 .	.964323		.400014
15 .	.990721		.520955
16 .	.96395		.66477
17 .	.941401		.780631
18 .	.903676		.901519
19 .	.916296		.961602
20 .	.922825		1.01803
21 .	.93005		1.06746
22 .	.940098		1.10948

*-DENOTES POINTS USED FOR JIC DETERMINATION
+-DENOTES POINTS USED IN TEARING MODULUS CALCULATION

Figure D-50

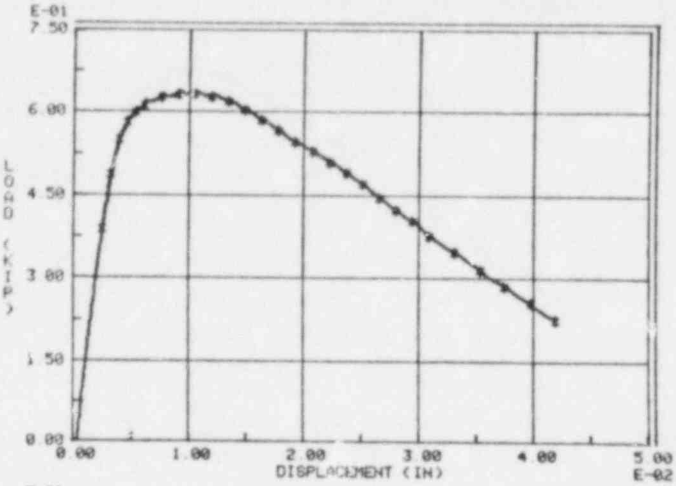


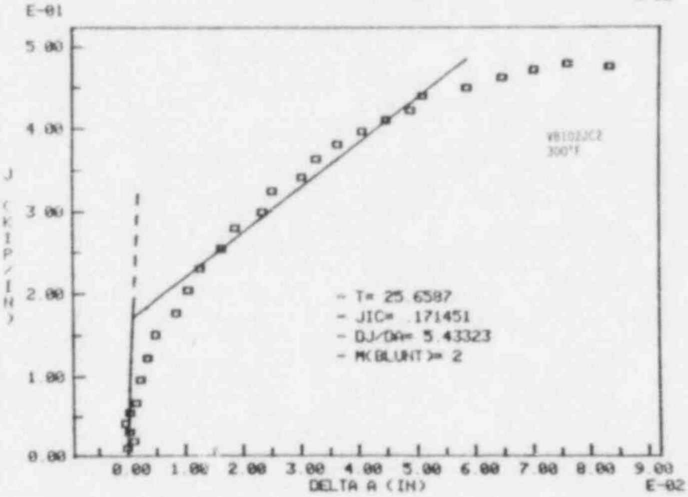
	J KIP/IN	CRACK EXTENSION IN	DISTANCE FROM STRETCH LINE
1	.0437651	2.84189E-04	-8.77115E-11
2	.0695587	6.95684E-04	2.44004E-04
3	.0939811	2.30522E-03	1.69495E-03
4	.11929	3.20562E-03	2.43201E-03
5	.142428	6.26542E-03	5.34157E-03
6	.166155	9.54775E-03	8.46982E-03
7	.190192	.0116248	.0103298
8	.213398	.0139007	.012415
9	.223499	.0159334	.0145291
10	.233388	.0177506	.0162351
11	.243251	.0200973	.0185177
12	.255466	.0203431	.0186842
13	.263766	.0229714	.0212587
14	.276078	.0232348	.0214421
15	.282158	.0267367	.0249045
16	.301902	.029528	.0275676
17	.316339	.033121	.0310669
18	.331694	.0369043	.0347505
19	.343164	.0415475	.0393192
20	.352583	.0463997	.0441102
21	.365508	.0496421	.0472686
22	.377264	.0527344	.0502846

*-DENOTES POINTS USED FOR JIC DETERMINATION
+-DENOTES POINTS EXCEEDING ASTM SPECIFICATIONS

Figure D-51

ORNL-DWG 82-5381 ETD



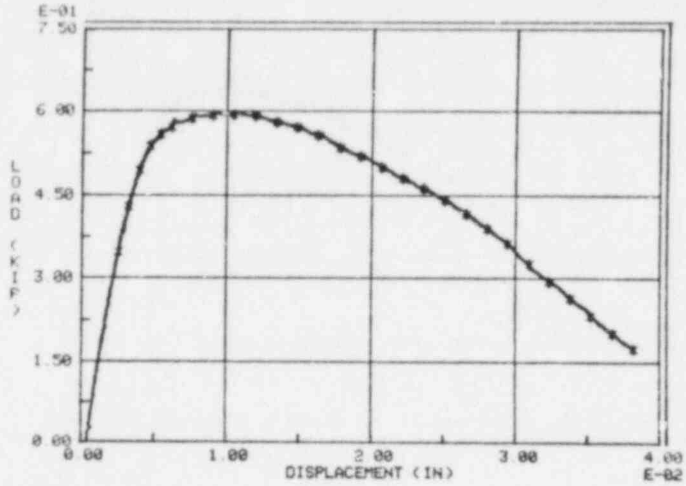


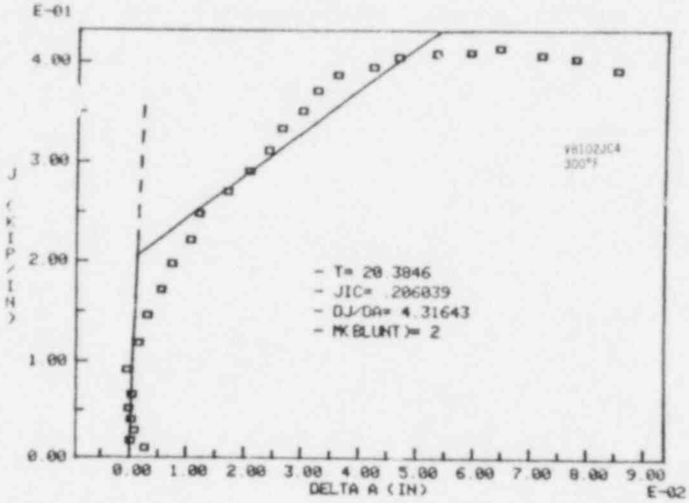
	J KIP/IN	CRACK EXTENSION IN	DISTANCE FROM STRETCH LINE
1 .	.010496	-5.09069E-05	-1.19063E-04
2 .	.0188412	1.02715E-03	9.04802E-04
3 .	.0301763	3.27016E-04	1.31067E-04
4 .	.0413887	-3.31242E-04	-6.00803E-04
5 .	.0552145	4.28911E-04	7.03751E-05
6 .	.0676507	1.50249E-03	1.06320E-03
7 .	.0561353	2.32681E-03	1.70255E-03
8 .	.123077	3.56726E-03	2.76805E-03
9 .	.151385	5.03759E-03	4.05457E-03
10 .	.177194	8.57210E-03	7.42149E-03
11 .	.204267	.0105869	9.36051E-03
12 .	.231036	.0127264	.0112263
13 .	.255247	.0165014	.014844
14 .	.28006	.0188928	.0170743
15 .	.299956	.0236358	.021688
16 .	.325123	.0252662	.023155
17 .	.342017	.030356	.0281351
18 .	.364217	.0327346	.0303696
19 .	.381641	.0364736	.0339954
20 .	.3971	.0407754	.0381968
21 .	.410935	.0449615	.0422931
22 .	.42323	.0493525	.0463043
23 .	.440786	.0511144	.0482521
24 .	.450295	.0587577	.0558337
25 .	.462612	.064863	.0610591
26 .	.47169	.0702731	.0672101
27 .	.479548	.0761079	.072994
28 .	.476001	.0834764	.0803855

*-DENOTES POINTS USED FOR JIC DETERMINATION
+-DENOTES POINTS EXCEEDING ASTM SPECIFICATIONS

Figure D-52

ORNL-DWG 82-5382 ETD



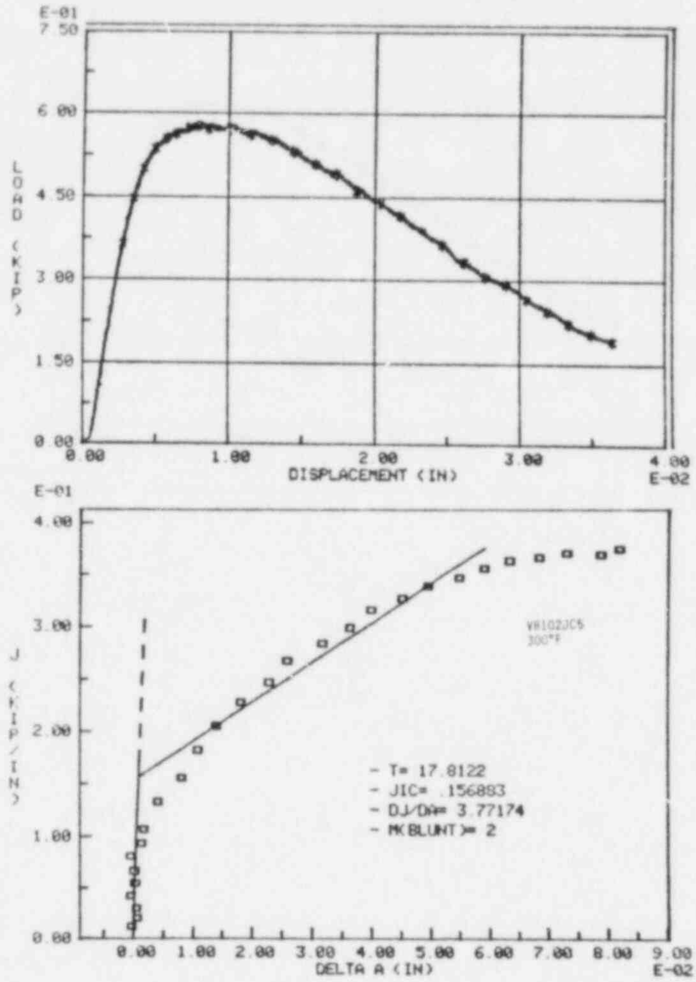


	J KIP/IN	CRACK EXTENSION IN	DISTANCE FROM STRETCH LINE
1	.0102777	2.67709E-03	2.61036E-03
2	.0181608	2.12501E-04	9.45741E-05
3	.0288015	8.79060E-04	6.92037E-04
4	.0402998	3.12563E-04	5.08755E-05
5	.0522673	-7.92486E-05	-4.18647E-04
6	.0661631	4.23859E-04	-5.77146E-06
7	.0922033	-4.01278E-04	-1.00800E-03
8	.118808	1.65420E-03	3.82726E-04
9	.146196	3.09829E-03	2.14897E-03
10	.172047	5.59847E-03	4.48128E-03
11	.198394	7.44679E-03	6.15852E-03
12	.221925	.0107245	9.28342E-03
13	.248524	.0122493	.0106355
14	.270545	.0170918	.015335
15	.29102	.0207735	.0188837
16	.311891	.0241395	.0221053
17	.333874	.026371	.024203
18	.35178	.0303397	.0277554
19	.371796	.032559	.0301447
20	.387722	.0360419	.0335243
21	.39572	.0422361	.0396665
22	.405222	.0465779	.0439401
23	.410333	.0532315	.0505699
24	.411198	.0591493	.0564792
25	.415162	.0642601	.0615642
26	.408	.0716586	.0690093
27	.404576	.0776814	.0750543
28	.393235	.0850953	.0825418

*-DENOTES POINTS USED FOR JIC DETERMINATION
+-DENOTES POINTS EXCEEDING ASTM SPECIFICATIONS

Figure D-53

ORNL-DWG 82-5383 ETD

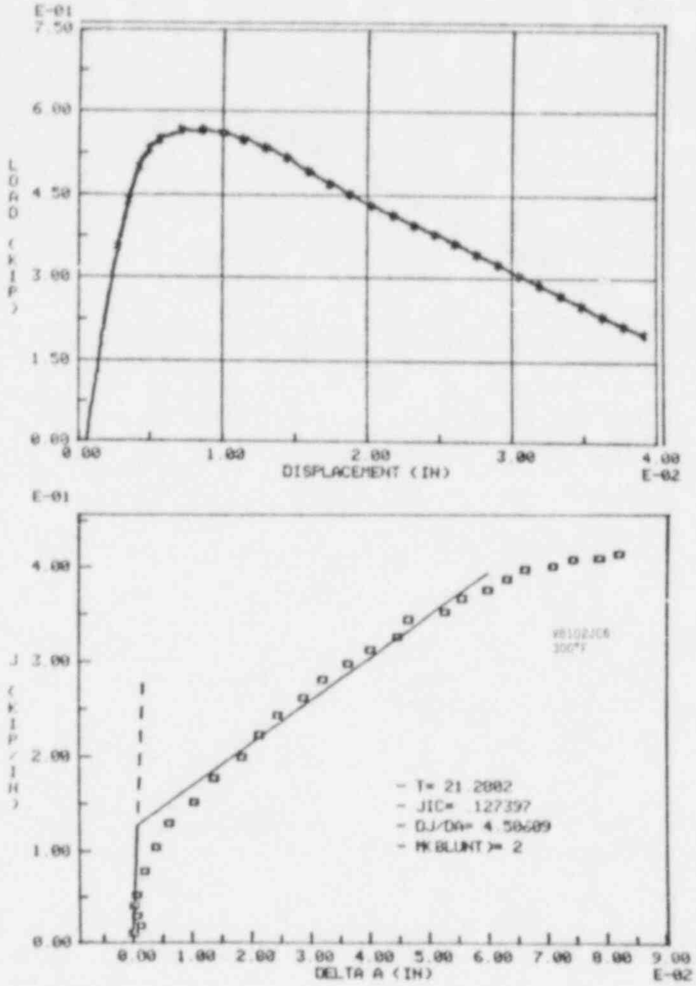


	J KIP/IN	CRACK EXTENSION IN	DISTANCE FROM STRETCH LINE
1 .	.01184	-2.14483E-04	-2.91366E-04
2 .	.0201981	7.12235E-04	5.81078E-04
3 .	.0301279	5.90001E-04	3.94365E-04
4 .	.0425144	-3.23932E-04	-6.00[illegible]E-04
5 .	.0553376	4.62343E-04	1.032[illegible]E-04
6 .	.0672923	3.04778E-04	-1.32185E-04
7 .	.0818618	-2.89806E-04	-8.21379E-04
8 .	.0938123	1.53952E-03	9.30347E-04
9 .	.107386	1.89494E-03	1.19763E-03
10 .	.133486	4.21799E-03	3.35115E-03
11 .	.156521	8.17611E-03	7.15974E-03
12 .	.182678	.0109199	9.73370E-03
13 .	.206509	.0140524	.0127114
14 .	.228472	.0182197	.0167361
15 .	.247825	.0229689	.0213596
16 .	.26842	.0260002	.0242572
17 .	.284764	.031797	.0299479
18 .	.299866	.0364382	.034491
19 .	.316855	.0399749	.0379174
20 .	.327975	.0452379	.0431092
21 .	.339911	.0496109	.0474036
22 .	.34719	.0548357	.0525812
23 .	.356421	.0593512	.05673[illegible]8
24 .	.363663	.0632992	.0609377
25 .	.366744	.0684062	.0660248
26 .	.370795	.0730753	.0706676
27 .	.369544	.0788215	.0764219
28 .	.375435	.0819239	.079486

*-DENOTES POINTS USED FOR JIC DETERMINATION
+-DENOTES POINTS EXCEEDING ASTM SPECIFICATIONS

Figure D-54

ORNL-DWG 82-5384 ETD

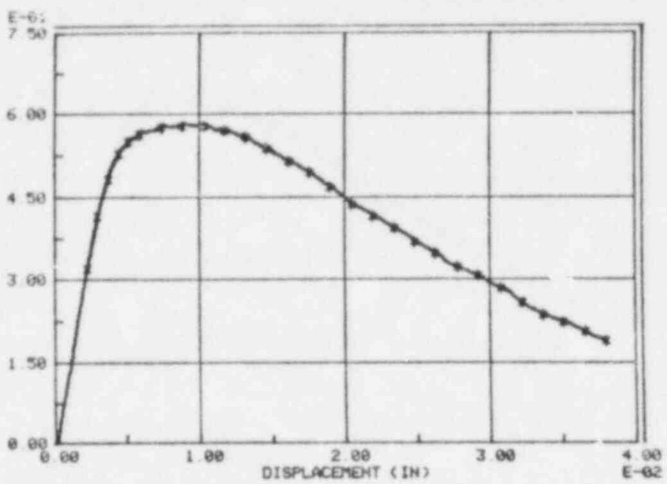


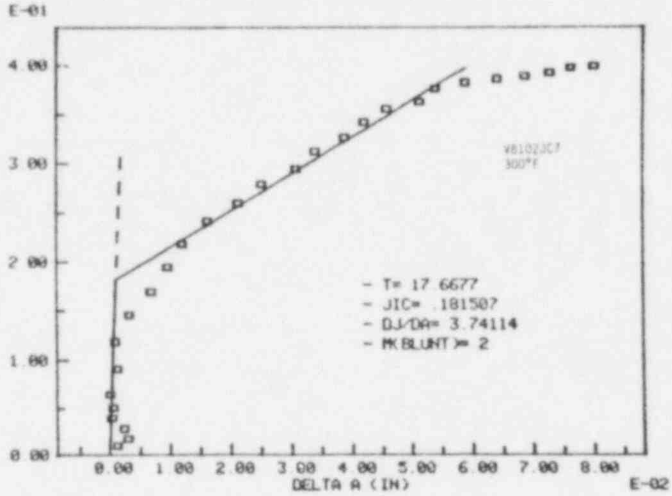
	J KIP/IN	CRACK EXTENSION IN	DISTANCE FROM STRETCH LINE
1 .	.0101581	6.59614E-05	-7.27596E-12
2 .	.0169948	1.32091E-03	1.19756E-03
3 .	.0293013	6.06178E-04	4.95909E-04
4 .	.0418596	2.49359E-04	-1.72121E-05
5 .	.0521972	6.82393E-04	3.43368E-04
6 .	.0786257	2.08721E-03	1.49665E-03
7 .	.104815	4.09715E-03	3.32654E-03
8 .	.129735	6.20472E-03	5.36228E-03
9 .	.152171	.0104169	9.42877E-03
10 .	.177219	.0137159	.0125651
11 .	.199794	.0184858	.0171885
12 .	.223072	.0214329	.0199844
13 .	.244401	.0245048	.0229178
14 .	.262518	.0288979	.0271932
15 .	.281412	.032193	.0303656
16 .	.298392	.0364662	.0345286
17 .	.313305	.0402395	.0382846
18 .	.326783	.0447463	.0426243
19 .	.344979	.0465594	.0443193
20 .	.353277	.0526517	.0503977
21 .	.367224	.0556517	.0532672
22 .	.37635	.0599209	.0574771
23 .	.387254	.0631461	.0606315
24 .	.397862	.0662850	.0636223
25 .	.401229	.0709767	.0683714
26 .	.40799	.074352	.0717027
27 .	.409538	.0787318	.0760724
28 .	.414606	.0819734	.0792006

*-DENOTES POINTS USED FOR JIC DETERMINATION
+-DENOTES POINTS EXCEEDING ASTM SPECIFICATIONS

Figure D-55

ORNL-DWG 82-5385 ETD



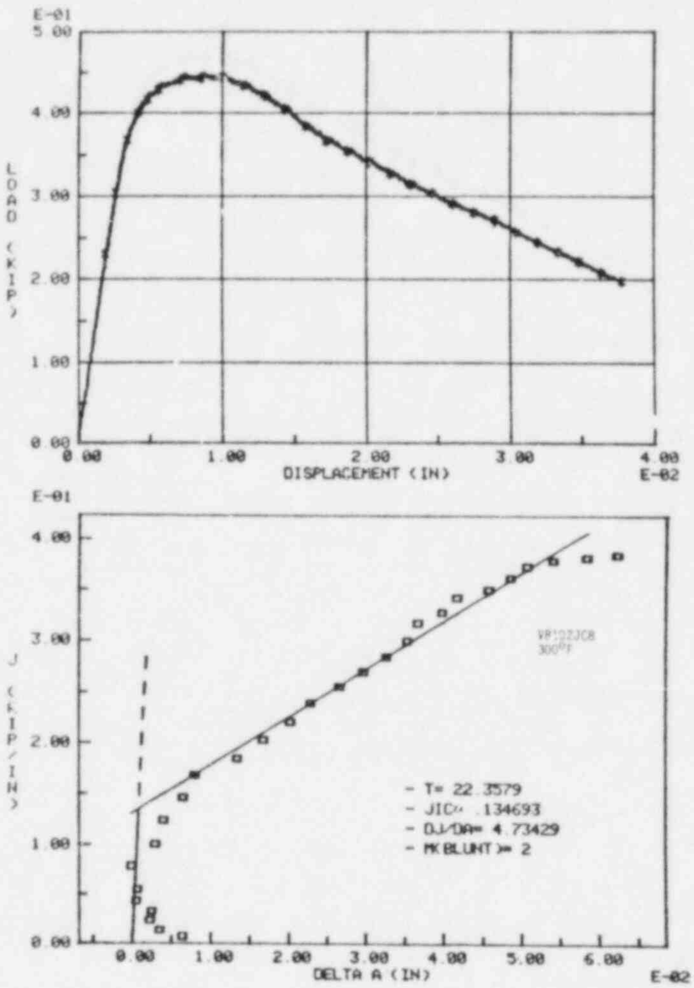


	J KIP/IN	CRACK EXTENSION IN	DISTANCE FROM STRETCH LINE
1	9.77657E-03	1.29348E-03	1.23082E-03
2 .	.0171617	3.03060E-03	2.91916E-03
3 .	.0260944	2.42302E-03	2.24059E-03
4 .	.0394601	4.07979E-04	1.51745E-04
5 .	.0597187	6.72657E-04	3.43311E-04
6 .	.0644633	1.18703E-04	-3.00301E-04
7 .	.091212	1.37867E-03	7.86385E-04
8 .	.118939	1.04856E-03	2.76236E-04
9 .	.145955	3.31692E-03	2.36826E-03
10 .	.16924	6.94035E-03	5.84144E-03
11 .	.194303	9.63975E-03	8.37805E-03
12 .	.218449	.0121011	.0106826
13 .	.241604	.0162115	.0146426
14 .	.260375	.0212771	.0195863
15 .	.279455	.0251779	.0233632
16 .	.294866	.0308685	.0289537
17 .	.313034	.0340783	.0320458
18 .	.327053	.0388301	.0367063
19 .	.342373	.0420128	.0398196
20 .	.355296	.0458153	.0435082
21 .	.36332	.0512474	.0488852
22 .	.376976	.0539501	.0515281
23 .	.382569	.0588642	.0563799
24 .	.385307	.0640659	.0615575
25 .	.389116	.0687272	.0662035
26 .	.392541	.0727954	.0702464
27 .	.397689	.0762648	.0736824
28 .	.399497	.0800769	.0774828

*-DENOTES POINTS USED FOR JIC DETERMINATION
+-DENOTES POINTS EXCEEDING ASTM SPECIFICATIONS

Figure D-56

ORNL-DWG 82-5386 ETD

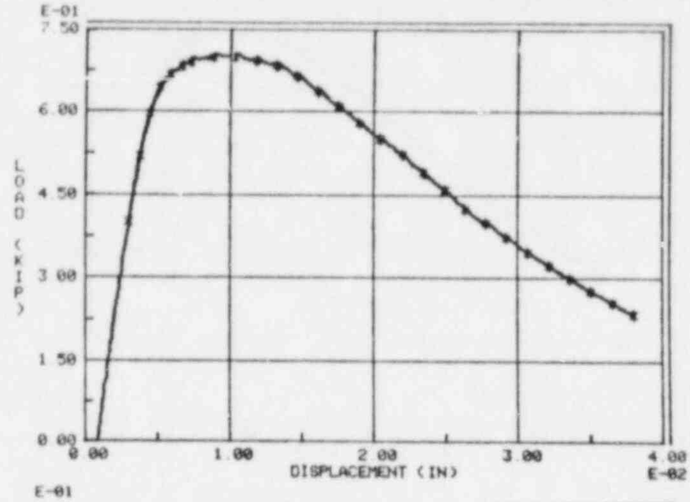


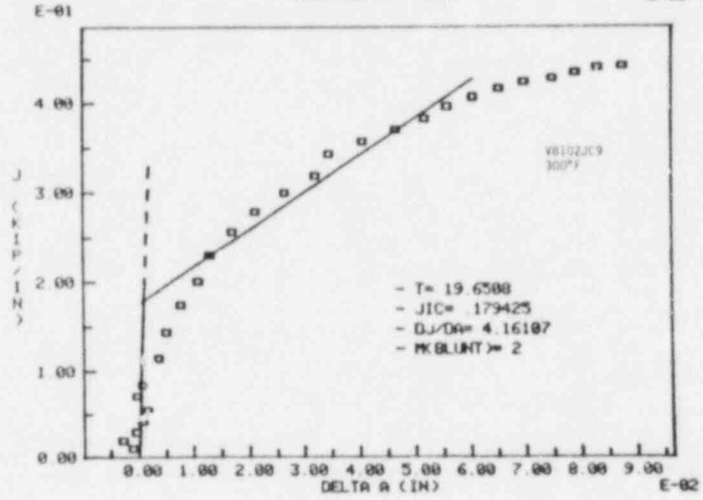
	J KIP/IN	CRACK EXTENSION IN	DISTANCE FROM STRETCH LINE
1 .	7.43279E-03	6.34384E-03	6.29552E-03
2 .	.0139635	3.48130E-03	3.39263E-03
3 .	.0235738	2.29037E-03	2.13729E-03
4 .	.0334046	2.48205E-03	2.26518E-03
5 .	.0437055	5.67304E-04	2.83502E-04
6 .	.0552177	7.16956E-04	3.58400E-04
7 .	.0790522	-6.67385E-06	-5.20000E-04
8 .	.100694	2.98703E-03	2.33320E-03
9 .	.124206	4.05821E-03	3.26116E-03
10 .	.146128	6.54033E-03	5.59145E-03
11 .	.168378	8.01829E-03	6.92492E-03
12 .	.184778	.0134847	.0122848
13 .	.20358	.0167924	.0154705
14 .	.221049	.0202511	.0188157
15 .	.239748	.0228822	.0213254
16 .	.256032	.0266551	.0249926
17 .	.270761	.0296362	.027878
18 .	.285508	.0326354	.0307815
19 .	.301089	.0352611	.033226
20 .	.317839	.0366422	.0345779
21 .	.329119	.0397935	.0376563
22 .	.343278	.0417125	.0394834
23 .	.350614	.0457033	.0434236
24 .	.362472	.0484575	.0461038
25 .	.373664	.0505258	.0481994
26 .	.37954	.0543701	.0516956
27 .	.382387	.0583582	.0558751
28 .	.385385	.062227	.0597245

*-DENOTES POINTS USED FOR JIC DETERMINATION
+-DENOTES POINTS EXCEEDING ASTM SPECIFICATIONS

Figure D-57

ORNL-DWG 82-5387 ETD



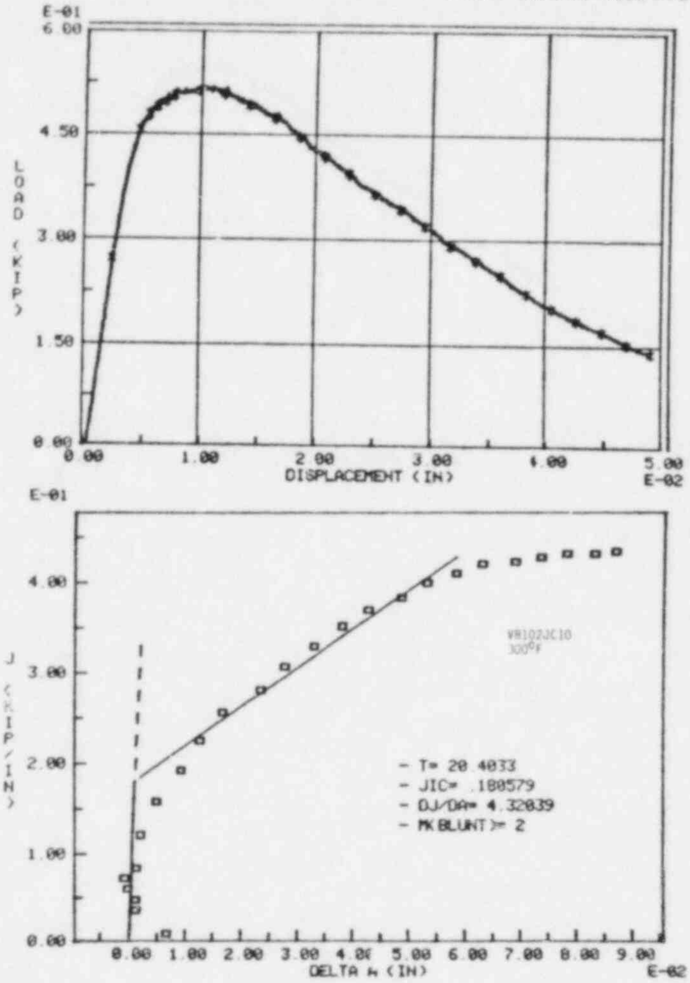


	J KIP/IN	CRACK EXTENSION IN	DISTANCE FROM STRETCH LINE
1 .	.0105168	-1.00623E-03	-1.07452E-03
2 .	.0194428	-2.77375E-03	-2.98[illegible]E-03
3 .	.0293777	-4.13181E-04	-6.03945E-04
4 .	.041763	7.12692E-04	4.41583E-04
5 .	.0553747	1.62394E-03	1.26437E-03
6 .	.0717555	-2.35901E-04	-7.01846E-04
7 .	.0847542	8.10326E-04	2.59674E-04
8 .	.114576	3.75000E-03	3.00608E-03
9 .	.14445	5.22597E-03	4.28798E-03
10 .	.174555	7.90416E-03	6.77068E-03
11 .	.200529	.0110677	9.76552E-03
12 .	.229993	.013168	.0116746
13 .	.256098	.017097	.015434
14 .	.279315	.0212281	.0194144
15 .	.300435	.0266096	.0246587
16 .	.319012	.0321836	.0301121
17 .	.343332	.0347062	.0324768
18 .	.357387	.0407776	.0394569
19 .	.370407	.0467704	.0443652
20 .	.382776	.0518092	.0493946
21 .	.396353	.0559763	.0534326
22 .	.406987	.0605386	.0579958
23 .	.41618	.0654058	.0627043
24 .	.42392	.0699265	.06[illegible]738
25 .	.428078	.074962	.072182[illegible]
26 .	.434398	.0791373	.0763165
27 .	.44022	.0831316	.080273
28 .	.442015	.0875912	.084721

*-DENOTES POINTS USED FOR JIC DETERMINATION
+-DENOTES POINTS EXCEEDING ASTM SPECIFICATIONS

Figure D-58

ORNL-DWG 82-5388 ETD



	J KIP/IN	CRACK EXTENSION IN	DISTANCE FROM STRETCH LINE
1 .	8.09887E-03	6.61771E-03	6.56512E-03
2 .	.0360378	1.21230E-03	9.78484E-04
3 .	.0477908	1.20443E-03	8.94103E-04
4 .	.0606721	-1.22099E-04	-5.15984E-04
5 .	.0724574	-6.29498E-04	-1.10[illegible]E-03
6 .	.084245	1.40976E-03	8.62710E-04
7 .	.121302	2.13048E-03	1.34281E-03
8 .	.157974	4.99894E-03	3.96513E-03
9 .	.192205	9.42649E-03	8.17841E-03
10 .	.225341	.0128383	.0113751
11 .	.256981	.0169341	.0152654
12 .	.281546	.0236049	.0217767
13 .	.307594	.0279178	.0259205
14 .	.329841	.0331319	.03099
15 .	.351875	.0382313	.0359464
16 .	.370038	.0428297	.0404269
17 .	.383436	.0487292	.0462393
18 .	.399657	.0532565	.0506613
19 .	.410101	.0583382	.0556752
20 .	.420288	.0629756	.0602465
21 .	.423234	.0689434	.0661952
22 .	.427681	.0736204	.0708432
23 .	.431756	.0782097	.0754061
24 .	.431456	.0831335	.0803319
25 .	.434509	.0868167	.0839952

*-DENOTES POINTS USED FOR JIC DETERMINATION
+-DENOTES POINTS EXCEEDING ASTM SPECIFICATIONS

Figure D-59

D.8 TEARING MODULUS CALCULATION RESULTS

The fit of the J-R curves with a power law was often found to be inaccurate and the following 5-coefficient expression was used:

$$J = C_1 \; (C_2 + \Delta a)^{C_3} + C_4 \Delta a + C_5$$

The results for the two types of fit are illustrated in Figures D-60 and D-61 for two typical cases.

The J versus T (tearing modulus) curves which follow were obtained with the above 5-coefficient expression. Since tensile tests were not available for Welds V862 and V882, the yield and ultimate tensile strengths for the T calculations were estimated by using their Charpy upper-shelf energies in relation to those of Welds V852 and V8102 and linearly interpolating between them.

ORNL-DWG 82-5389 ETD

... J-TEST ...

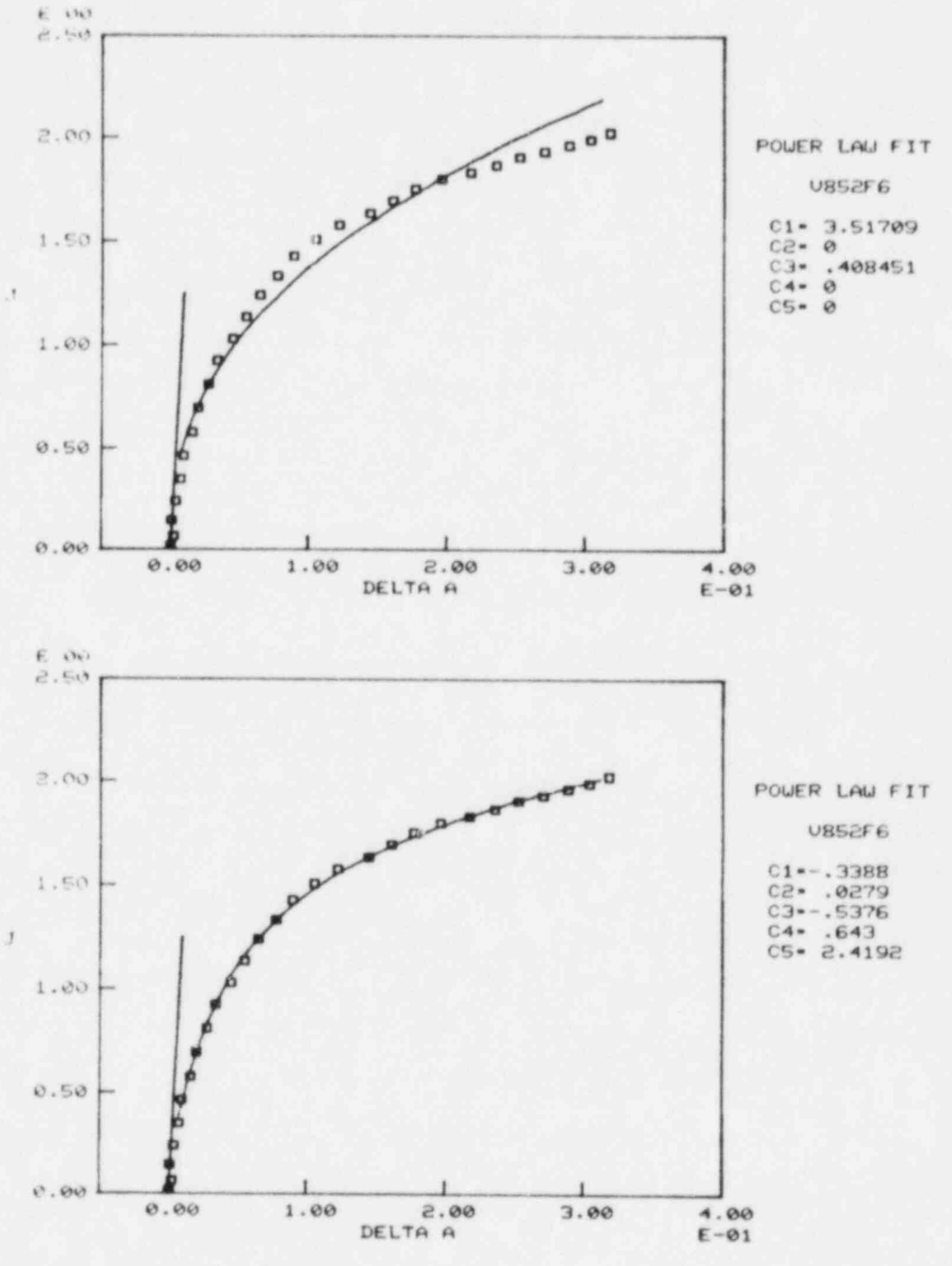


Figure D-60 J Versus Δa Fit for 2- and 5-Coefficient Power Law Fits for Specimen V852F6

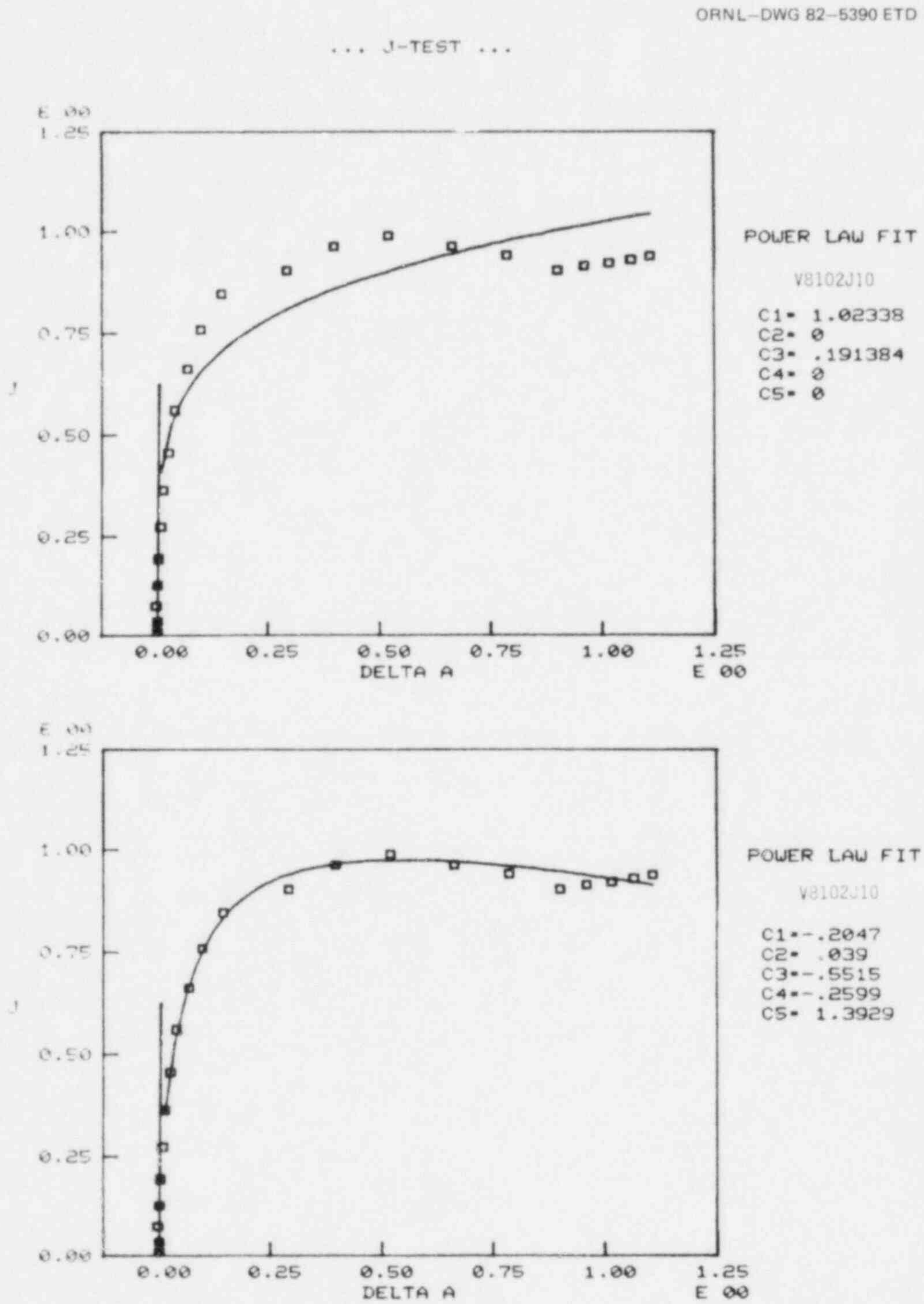


Figure D-61 J Versus Δa Fit for 2- and 5-Coefficient Power Law Fits for Specimen V8102J10

ORNL–DWG 82–5391 ETD

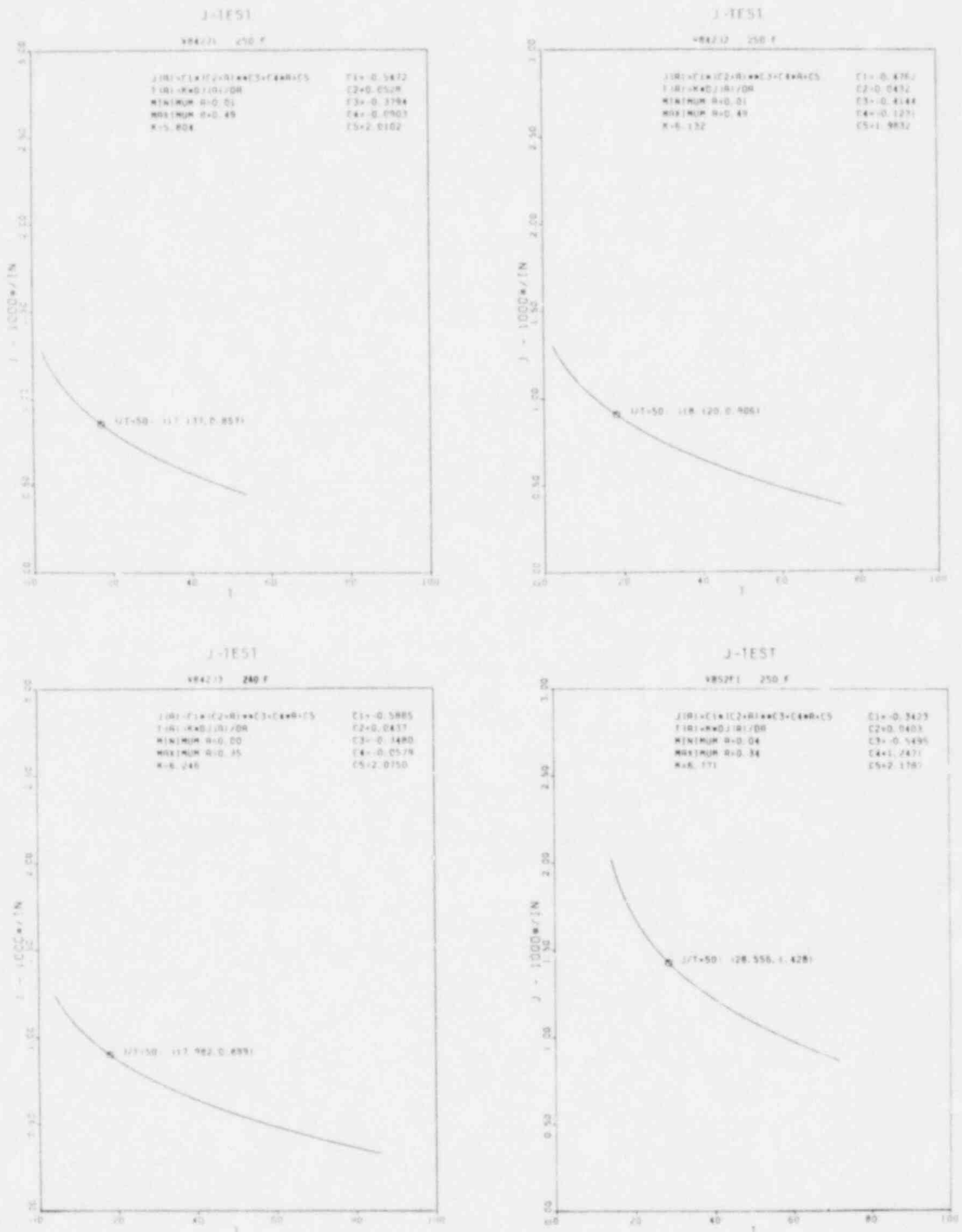


Figure D-62

ORNL–DWG 82–5392 ETD

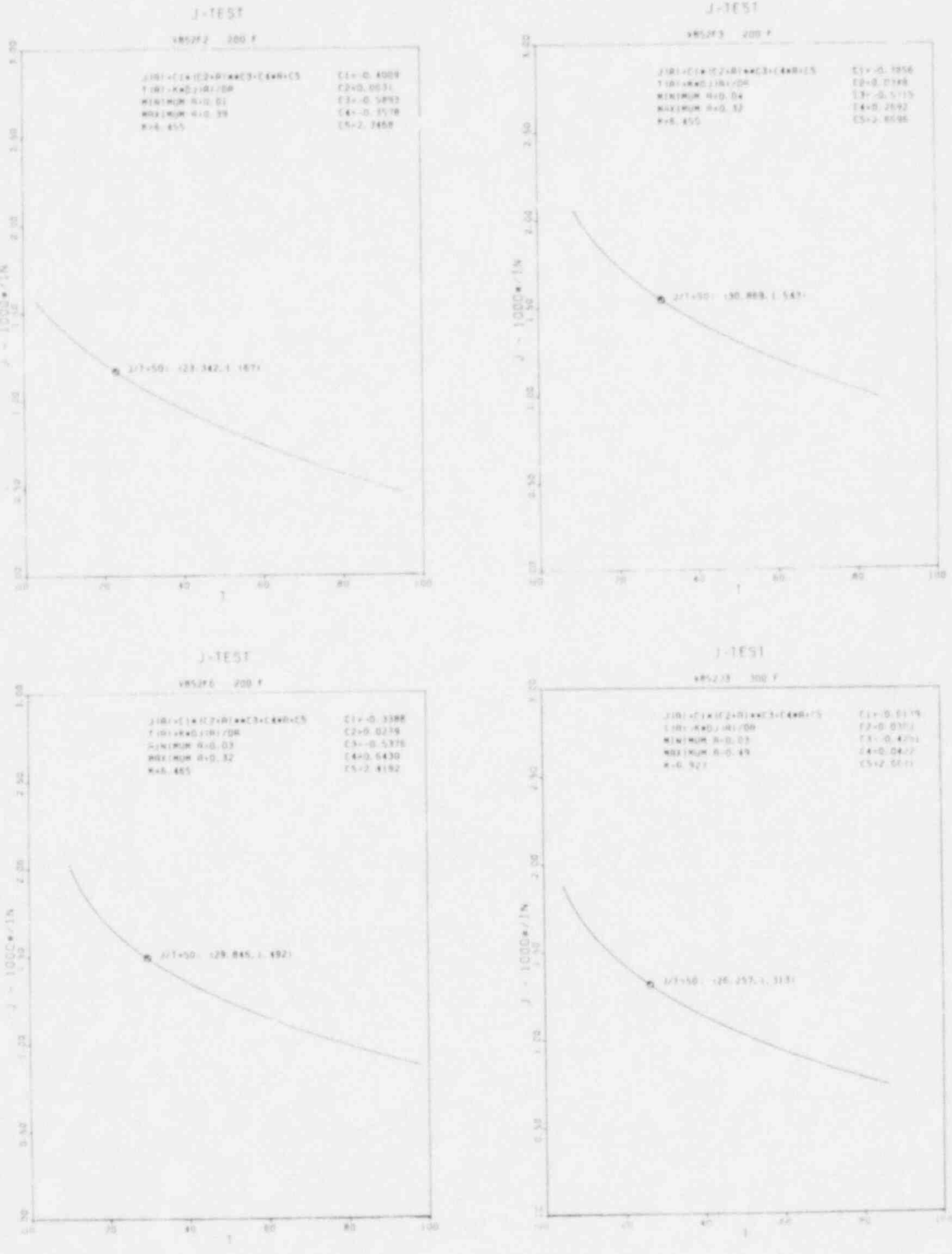


Figure D-63

ORNL-DWG 82-5393 ETD

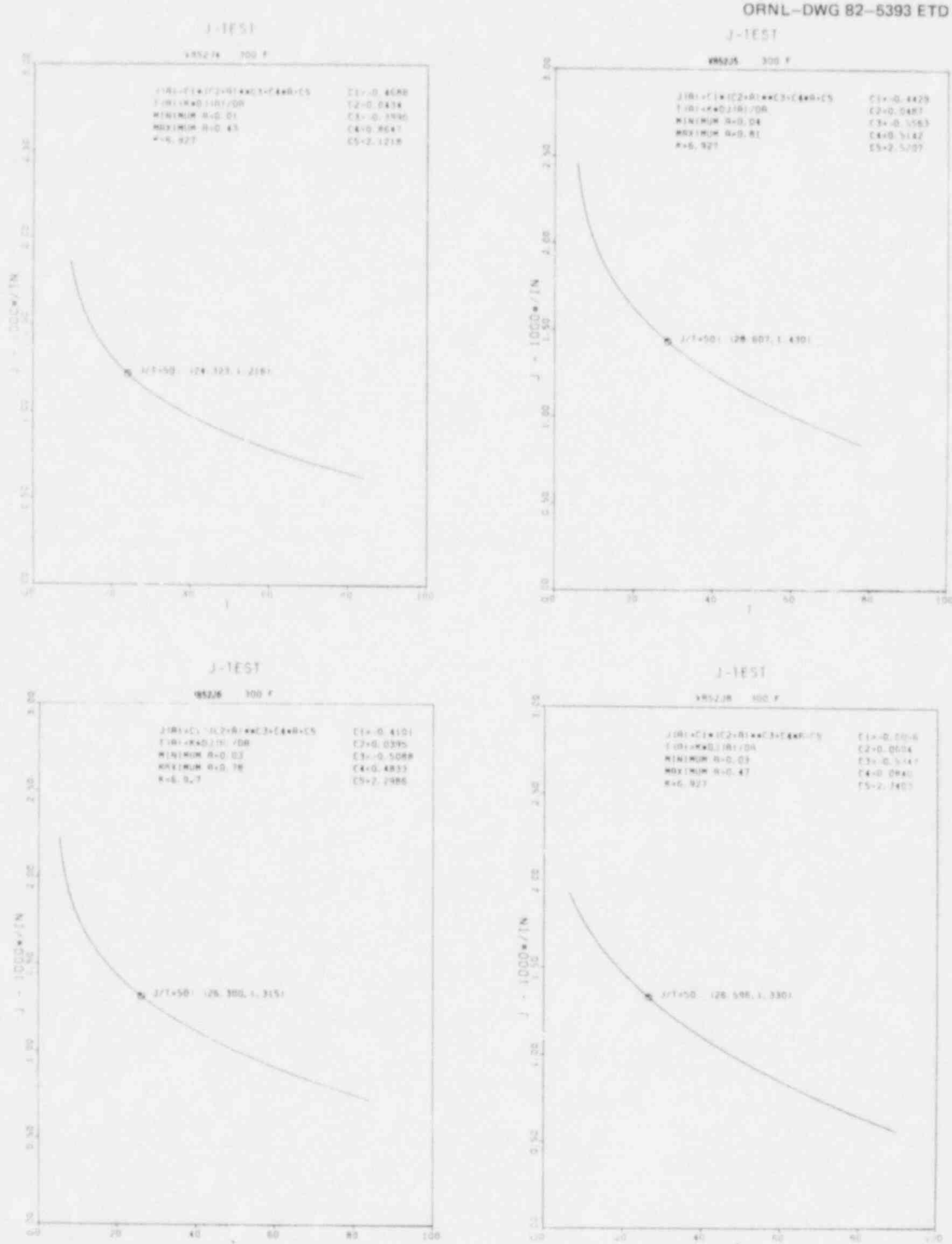


Figure D-64

ORNL-DWG 82-5394 ETD

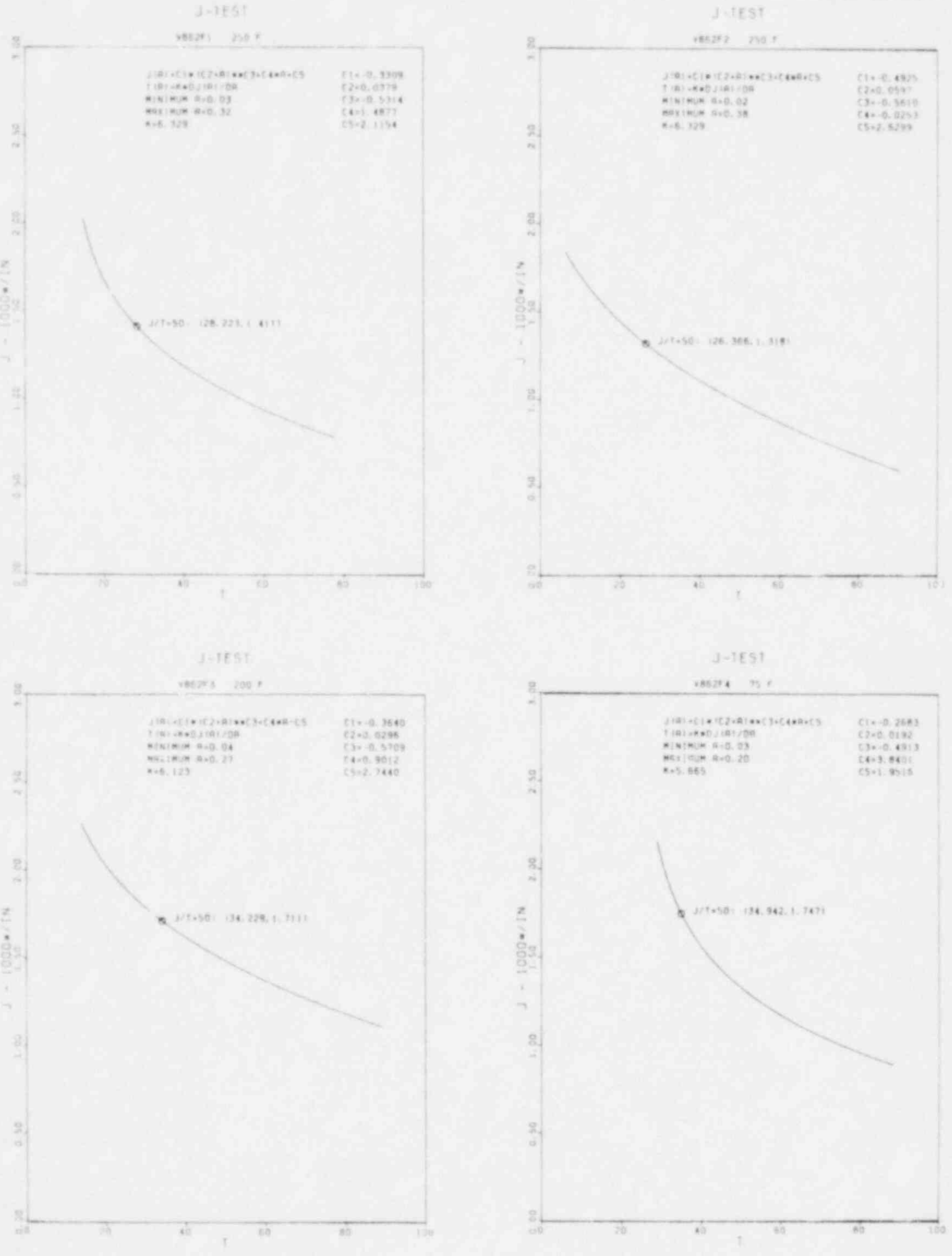


Figure D-65

ORNL-DWG 82-5395 ETD

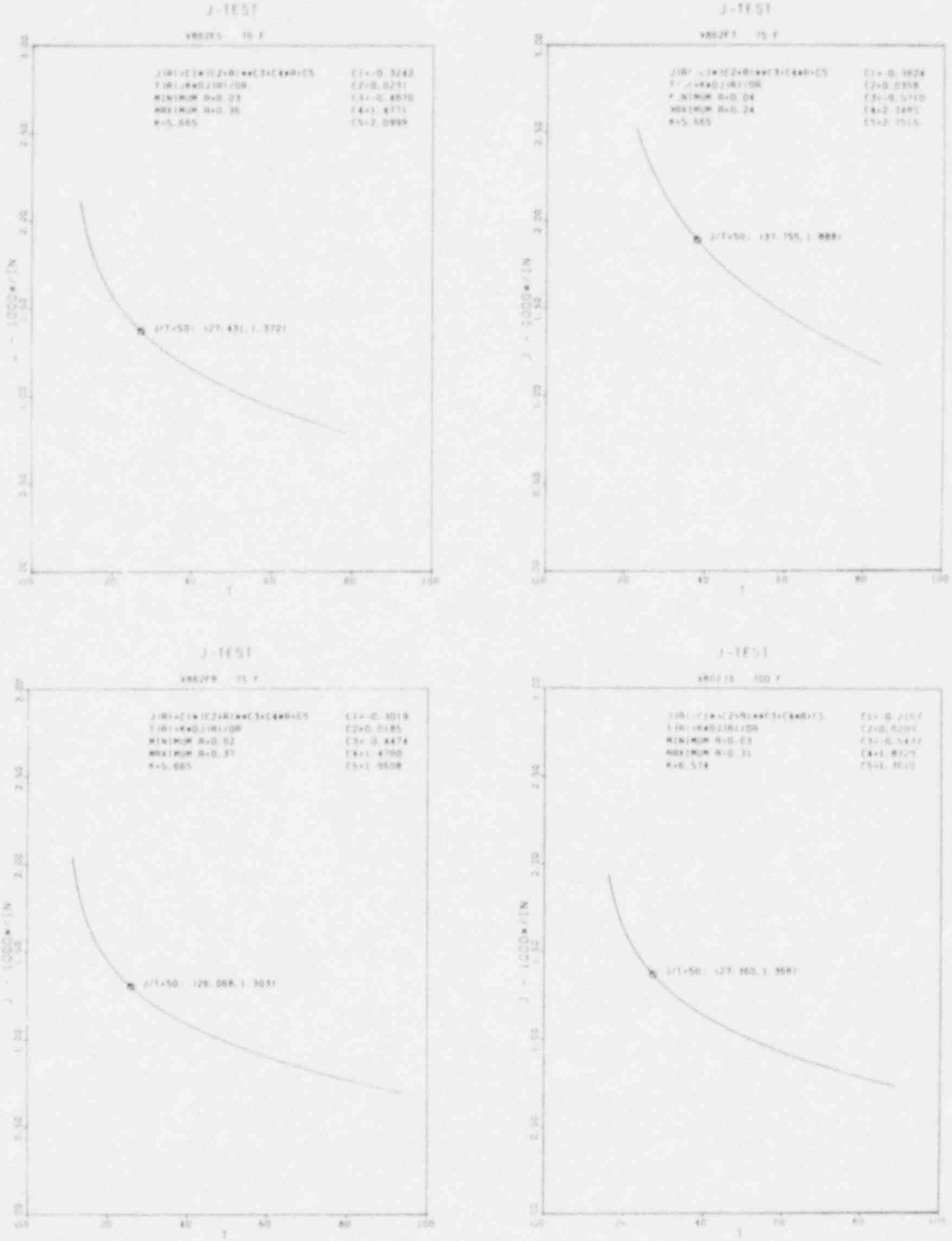


Figure D-66

ORNL–DWG 82–5396 ETD

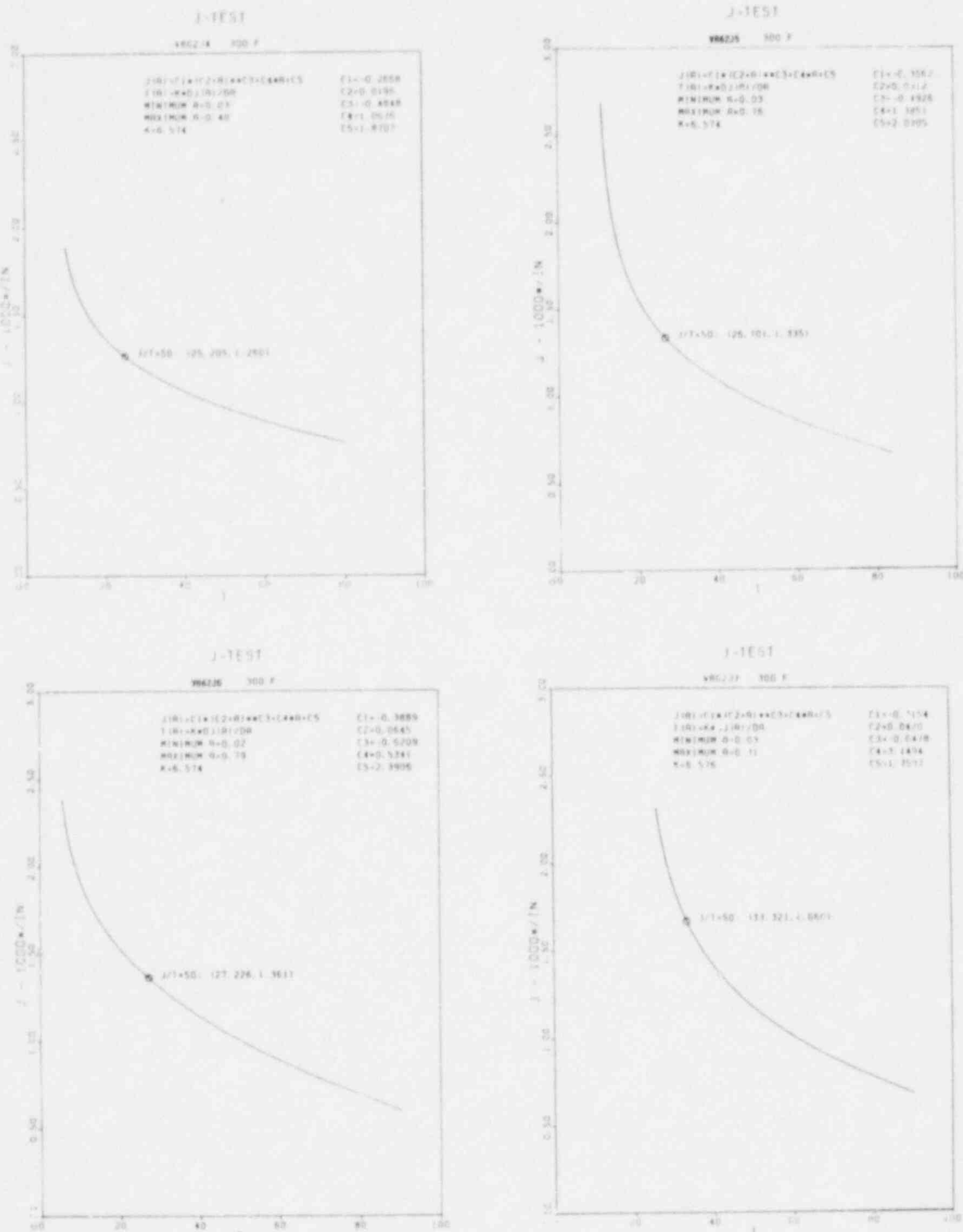


Figure D-67

ORNL–DWG 82–5397 ETD

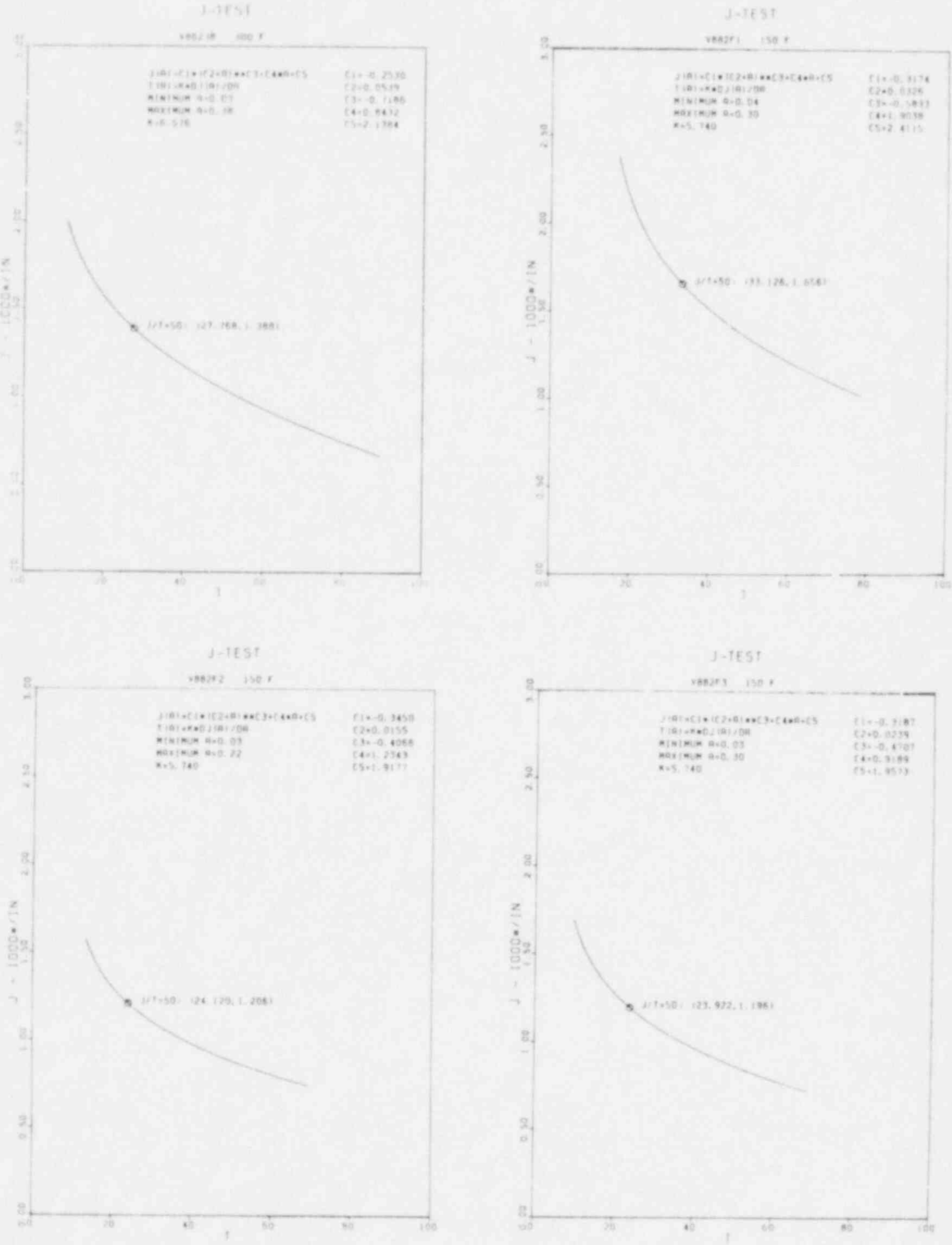


Figure D-68

ORNL-DWG 82-5398 ETD

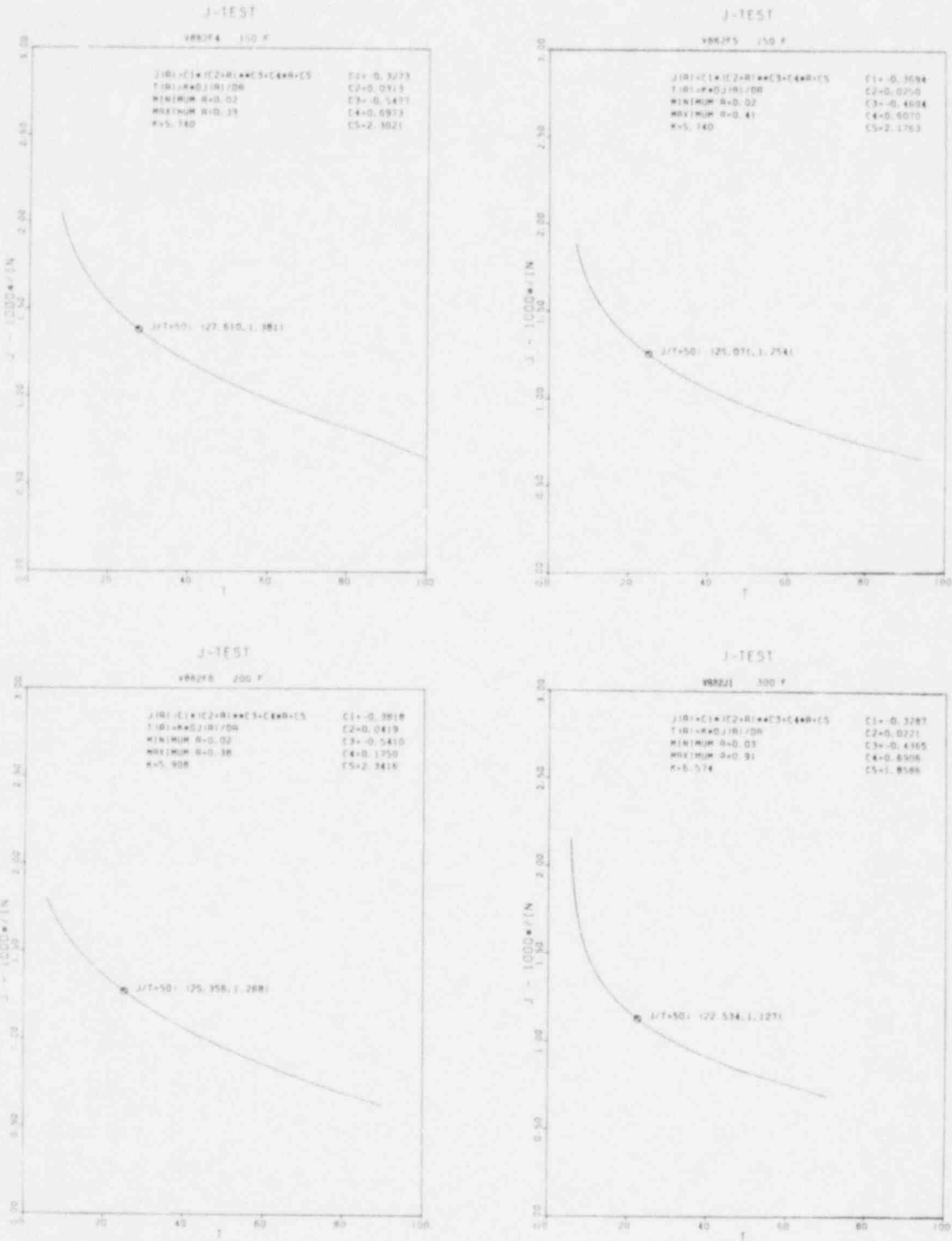


Figure D-69

ORNL-DWG 82-5399 ETD

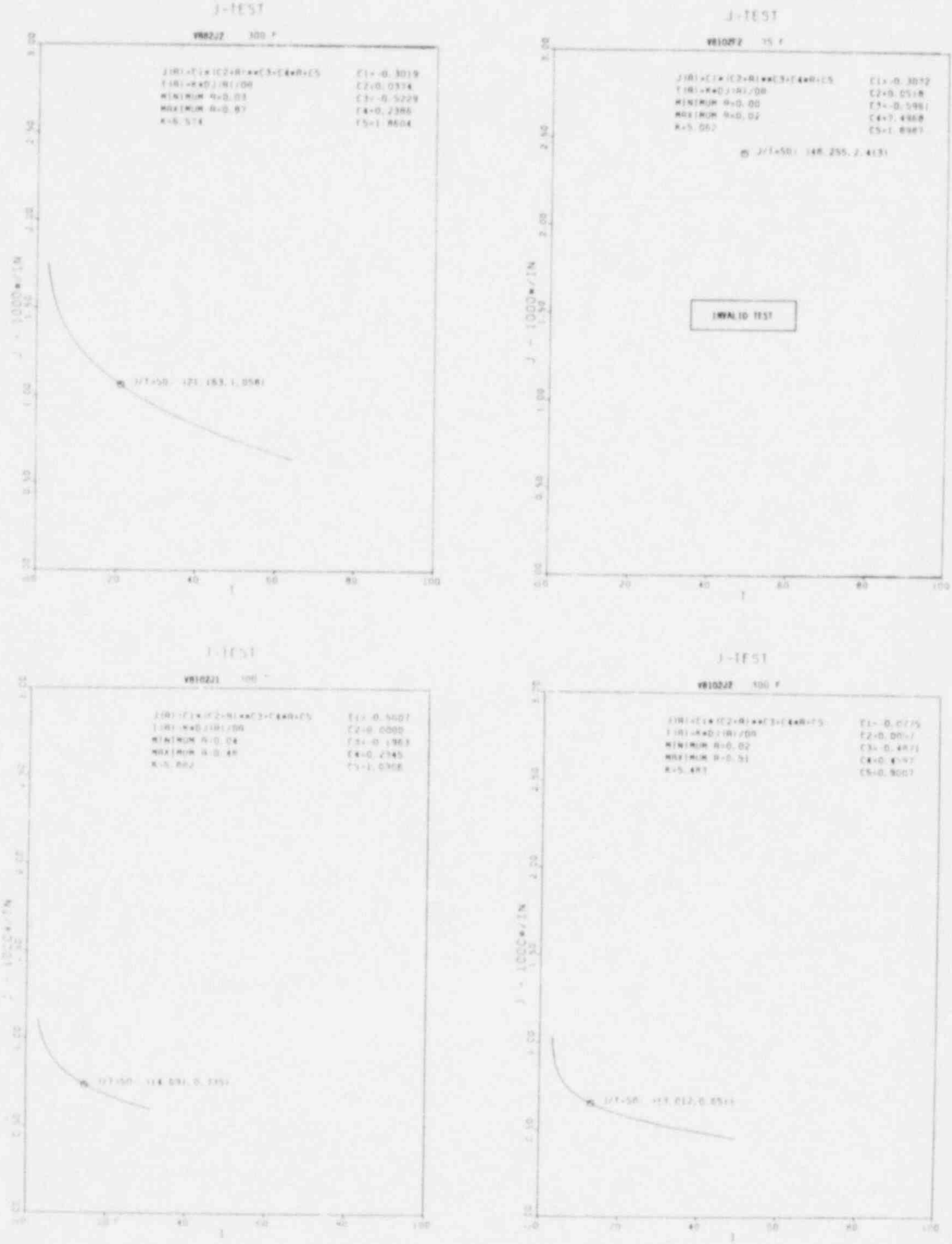


Figure D-70

ORNL-DWG 82-5400 ETD

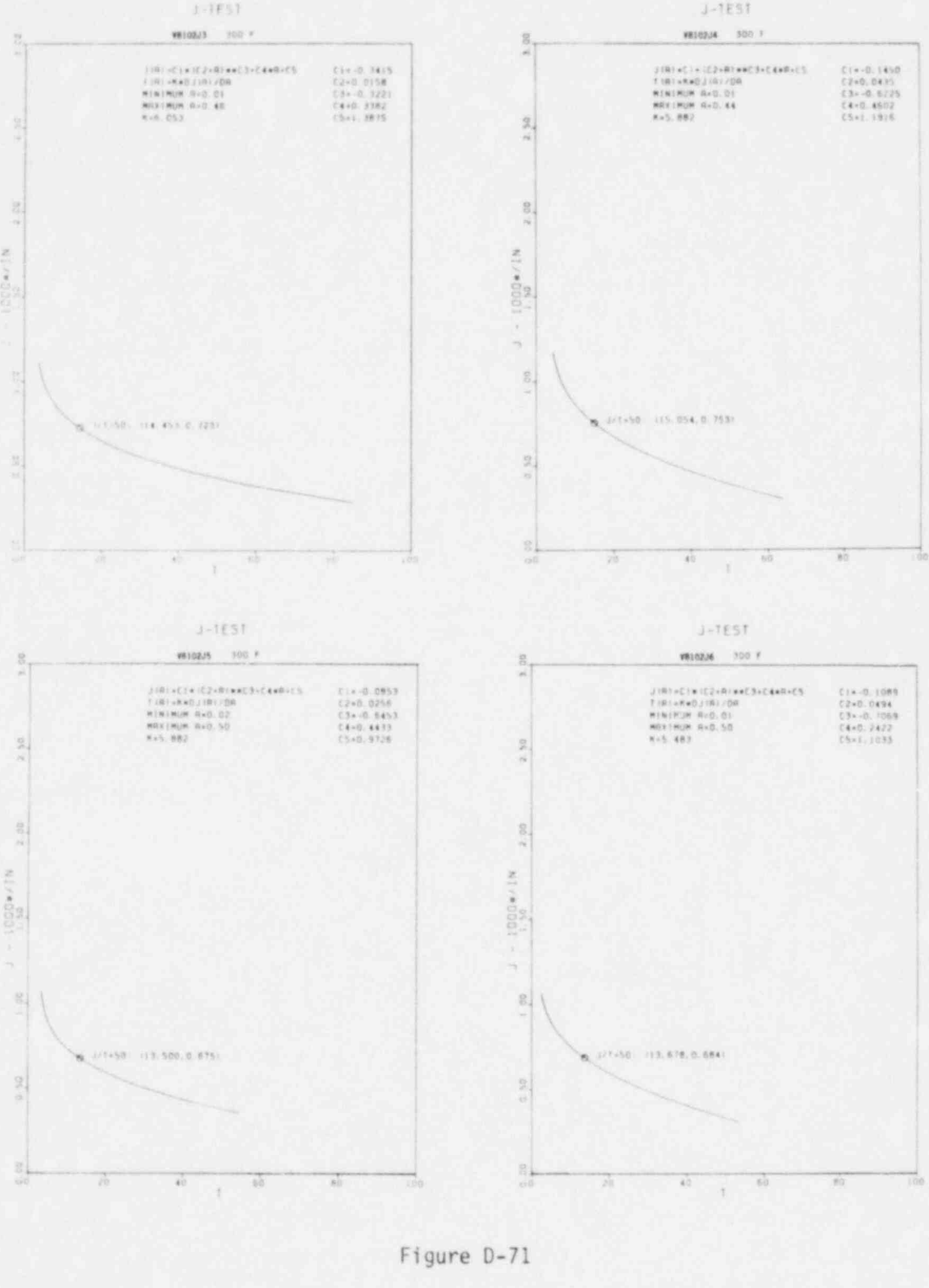


Figure D-71

ORNL–DWG 82–b401 ETD

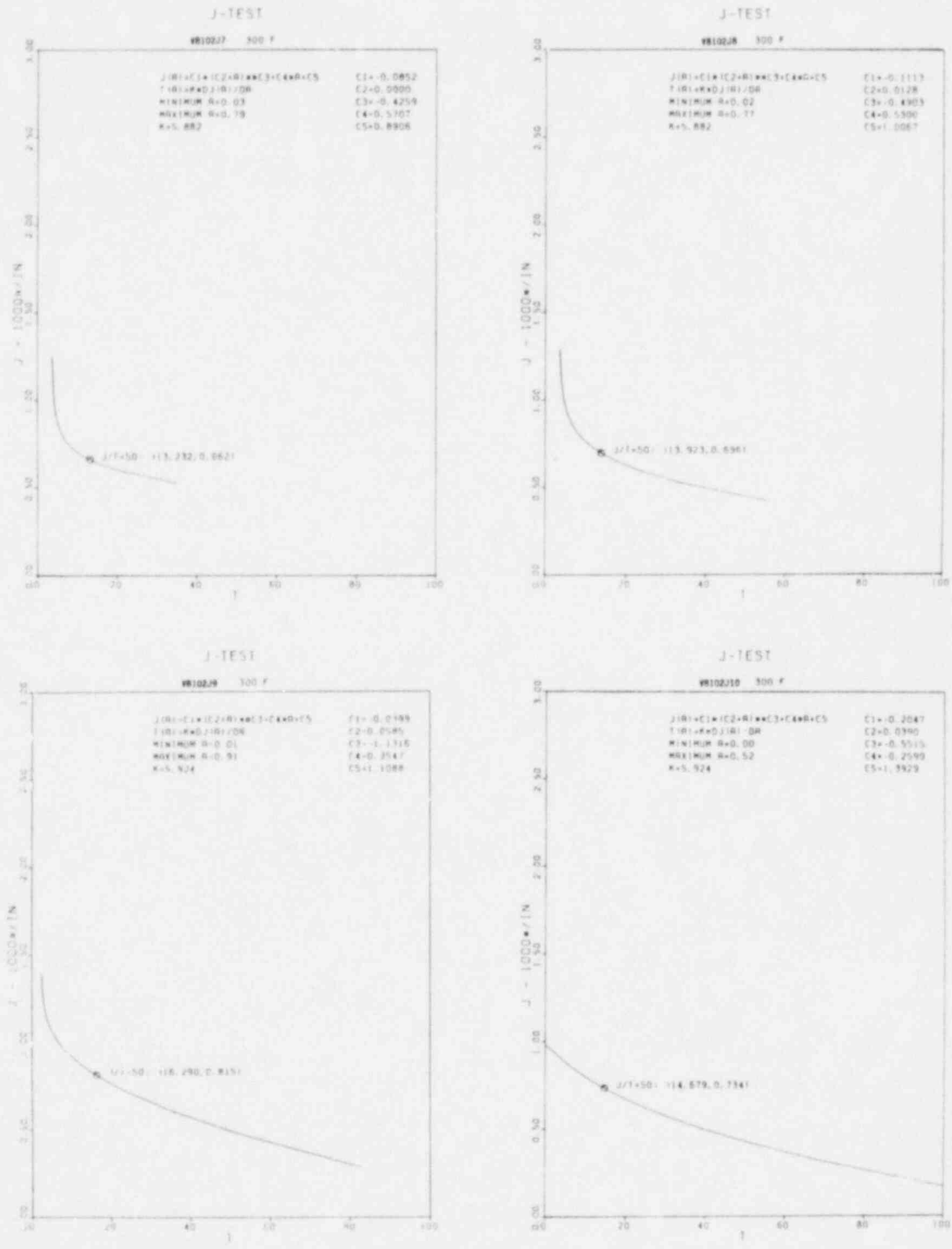
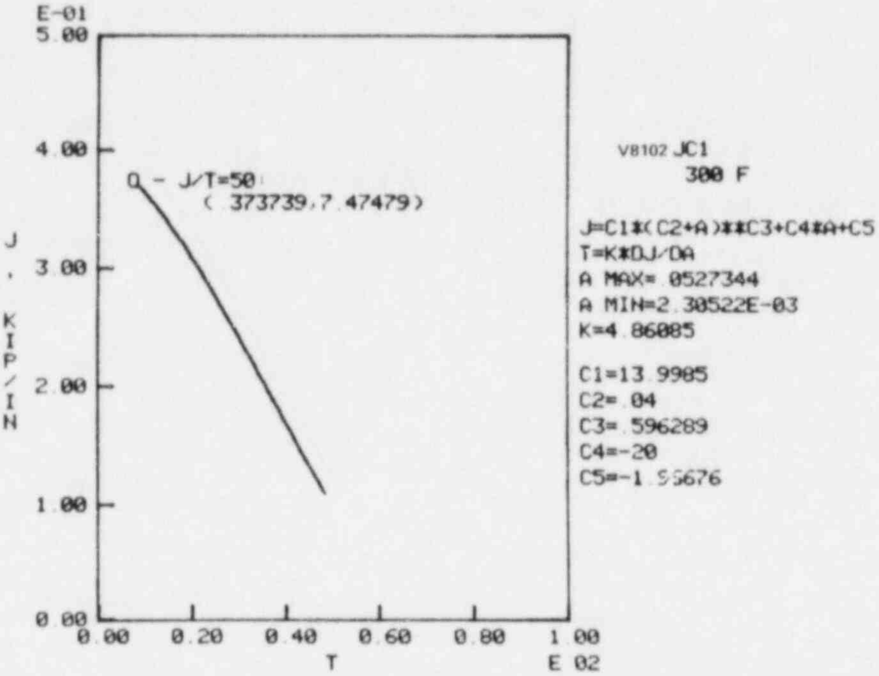


Figure D-72

ORNL-DWG 82-5402 ETD



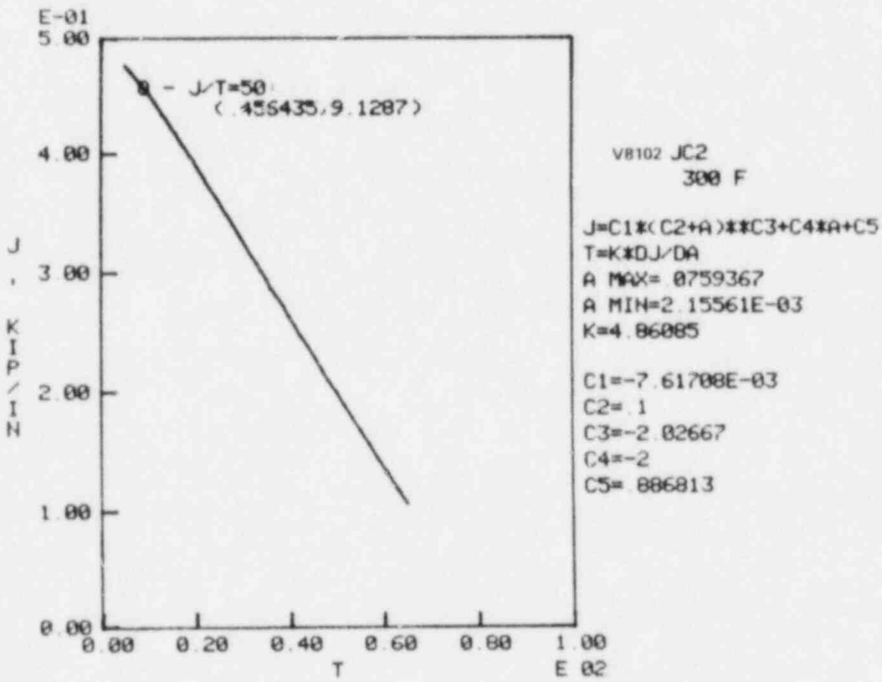
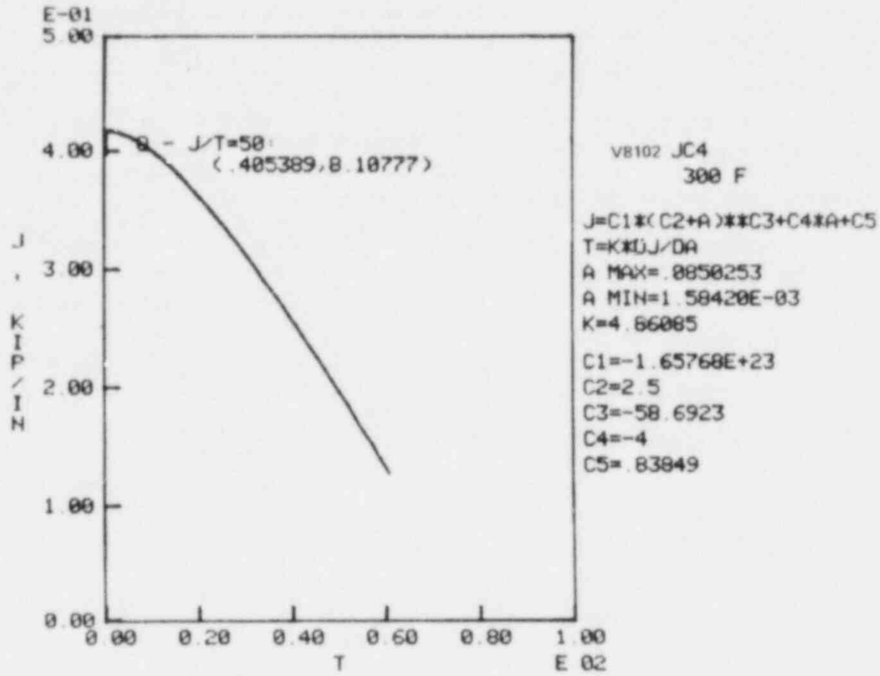


Figure D-73

ORNL—DWG 82-5403 ETD



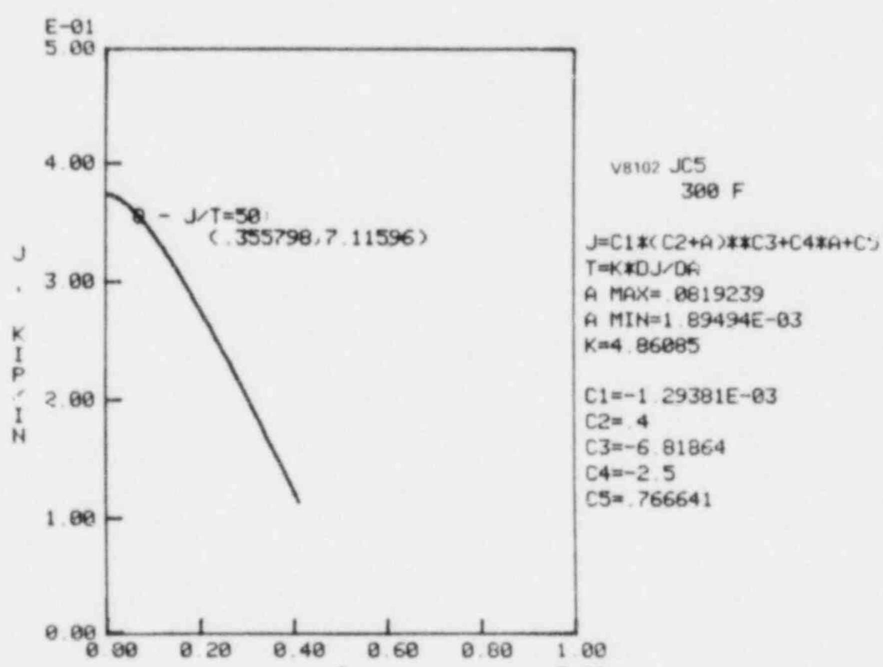
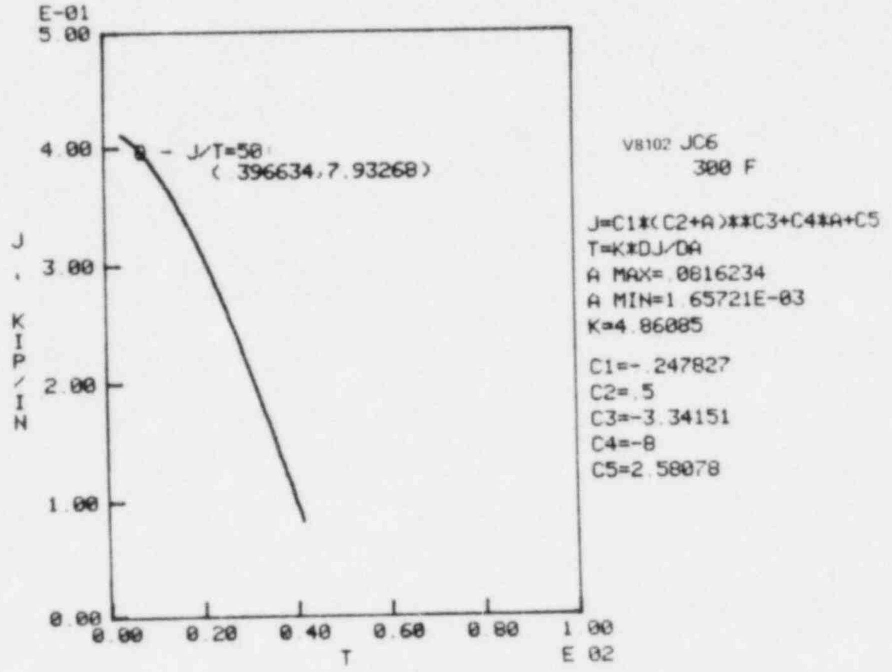


Figure D-74

ORNL-DWG 82-5404 ETD



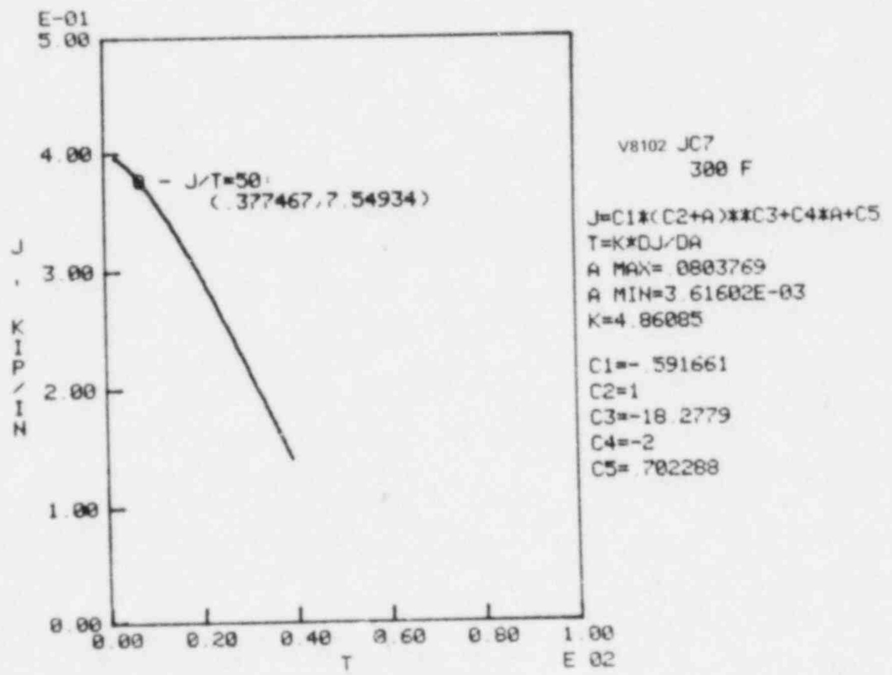
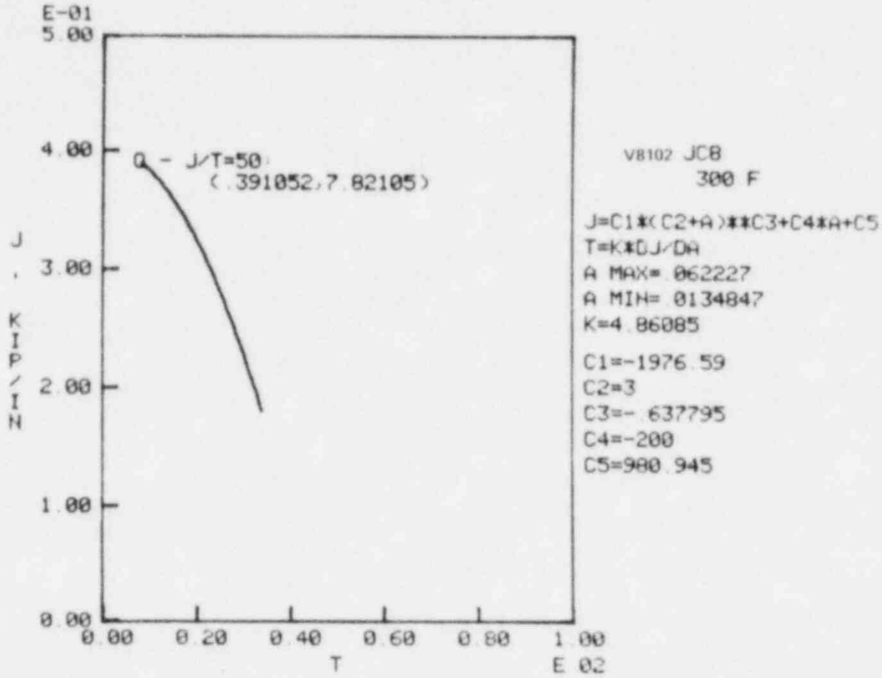


Figure D-75

ORNL-DWG 82-5405 ETD



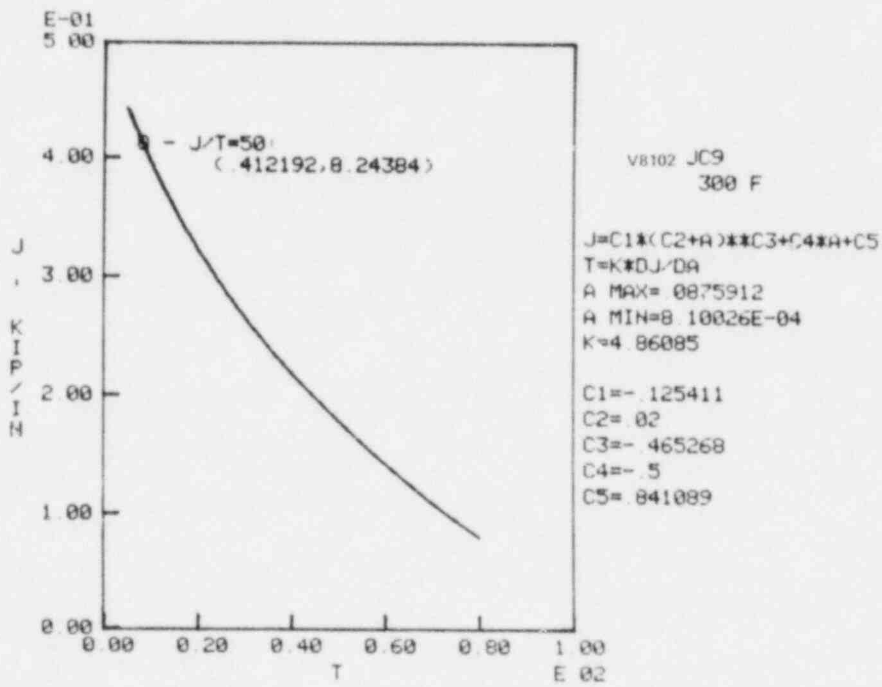


Figure D-76

ORNL-DWG 82-5406 ETD

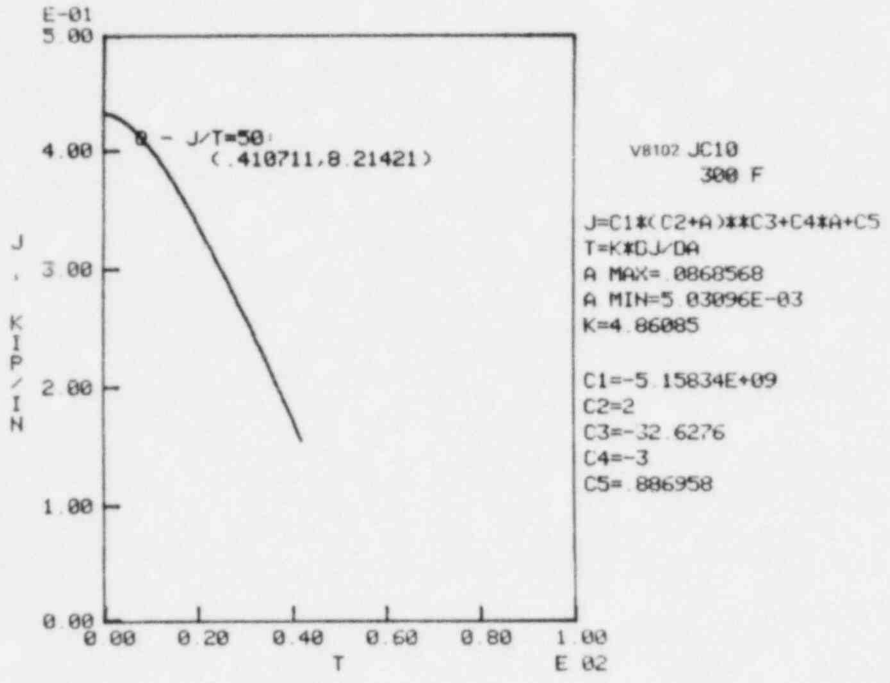


Figure D-77

APPENDIX E

J-INTEGRAL TESTS OF CHARPY V-NOTCH SPECIMENS WITH 5% AND 10% SIDE GROOVES

APPENDIX E

J-INTEGRAL TESTS OF CHARPY V-NOTCH SPECIMENS WITH 5% AND 10% SIDE GROOVES

E.1 SPECIMENS

Additional specimens were prepared from a slice (V8102A1) previously taken from Weld V8102 for chemical analysis. Charpy V-Notch (C_v) specimens were machined and numbered in the same sequence as before. In these cases however, the side grooves (SG) were either about 5% or 10% as compared to the 20% previously used. These tests were performed in accordance with E 813-81.

E.2 RESULTS

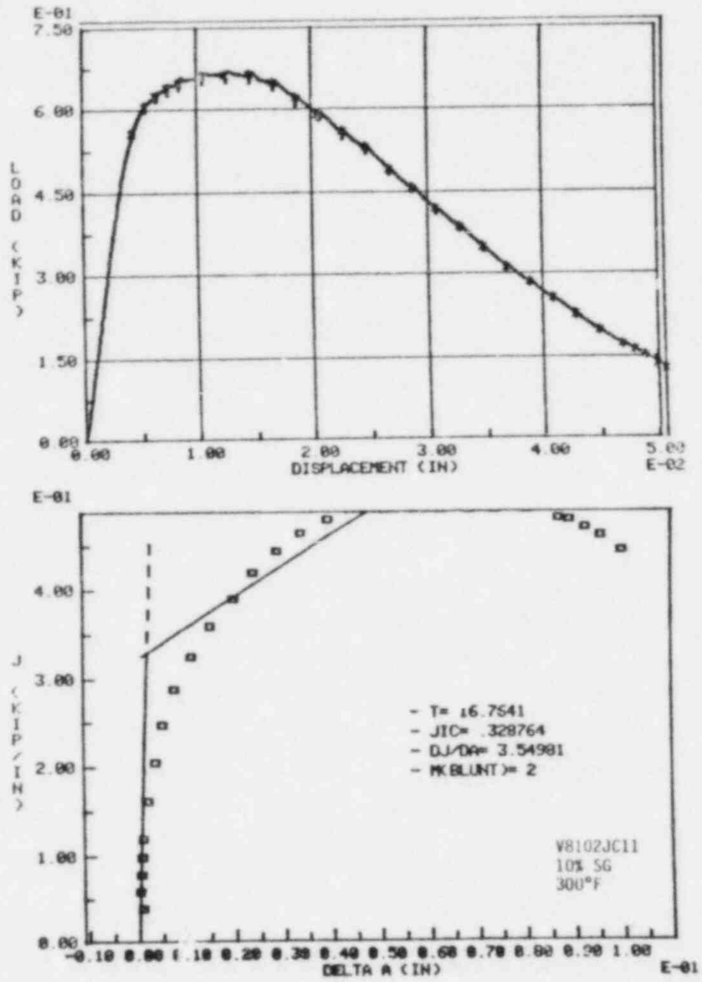
The results are given in Table E-1 and Figures E-1 through E-5.

Table E-1

J-INTEGRAL TESTS OF CHARPY-TYPE SPECIMENS
(All Specimens - WL Orientation - Weld V8102)

Specimen Identification	Side Grooves %-Approx.	Approx. Depth in Weld, in.	Net Thickness in.	Crack Length, in. Initial	Crack Length, in. Final	Corrected Modulus 10^6 psi	Test Temperature °F	J_{Ic} Kip/in.
V8102 JC11	10	.5 - 1.0	.359	.232	.325	28.0	300	.329
JC13	5	1.5 - 2.0	.378	.259	.311	28.0	300	.404
JC15	10	2.5 - 3.0	.357	.264	.334	28.0	300	.190
JC17	5	3.5 - 4.0	.378	.239	.311	28.0	300	.268
JC19	10	4.5 - 5.0	.356	.244	.322	28.0	300	.311

ORNL-DWG 82-5407 ETD

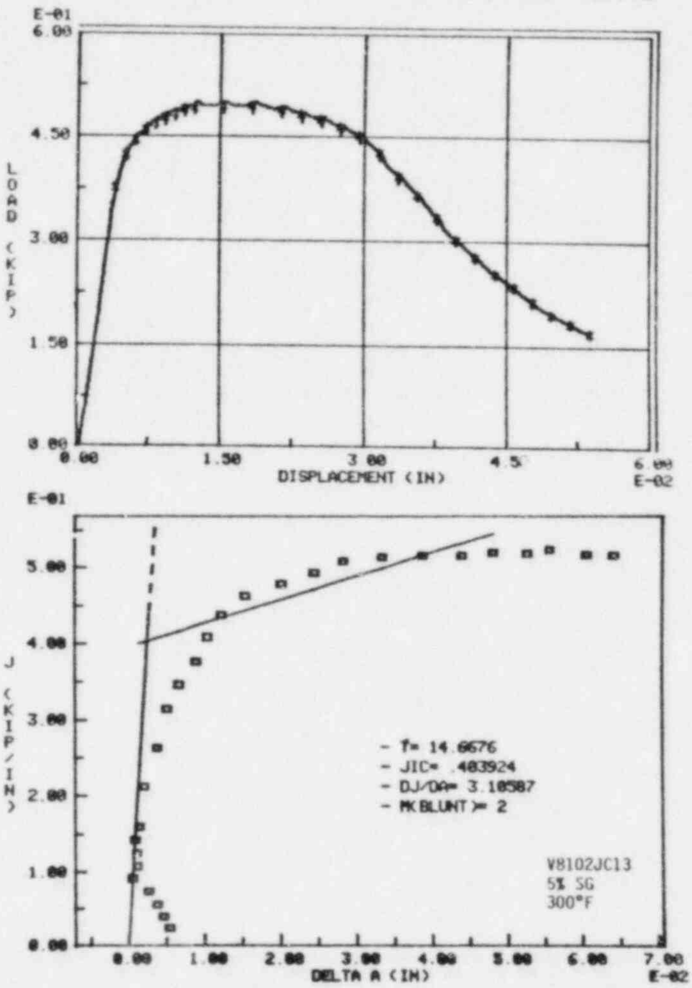


	J KIP/IN	CRACK EXTENSION IN	DISTANCE FROM STRETCH LINE
1 .	.0393757	4.06883E-04	1.51196E-04
2 .	.058449	-7.04611E-05	-4.56908E-04
3 .	.0781044	2.54831E-04	-2.52859E-04
4 .	.0986973	3.55921E-04	-2.84971E-04
5 .	.119629	5.81040E-04	-1.95767E-04
6 .	.161575	1.73969E-03	6.90501E-04
7 .	.205281	3.21846E-03	1.80547E-03
8 .	.240185	4.79116E-03	3.17959E-03
9 .	.288445	7.32984E-03	5.45683E-03
10 .	.325311	.0109091	8.79539E-03
11 .	.359331	.0147657	.0124324
12 .	.390441	.0195278	.0169925
13 .	.419052	.0235725	.0200462
14 .	.444526	.0284158	.0255292
15 .	.464934	.0334297	.0304108
16 .	.480942	.0390168	.0358938
17 .	.498151	.0435746	.0403379
18 .	.502604	.0505603	.0472367
19 .	.509389	.0560839	.0527762
20 .	.510739	.0621575	.058341
21 .	.509721	.062338	.0647281
22 .	.507707	.0734514	.0701546
23 .	.496083	.0799579	.0767314
24 .	.482163	.086442	.083311
25 .	.480633	.0886892	.0855682
26 .	.471271	.0919179	.0888577
27 .	.462092	.0951522	.0921516
28 .	.444729	.0994375	.0965436

*-DENOTES POINTS USED FOR JIC DETERMINATION
+-DENOTES POINTS EXCEEDING ASTM SPECIFICATIONS

Figure E-1 J-Test Results

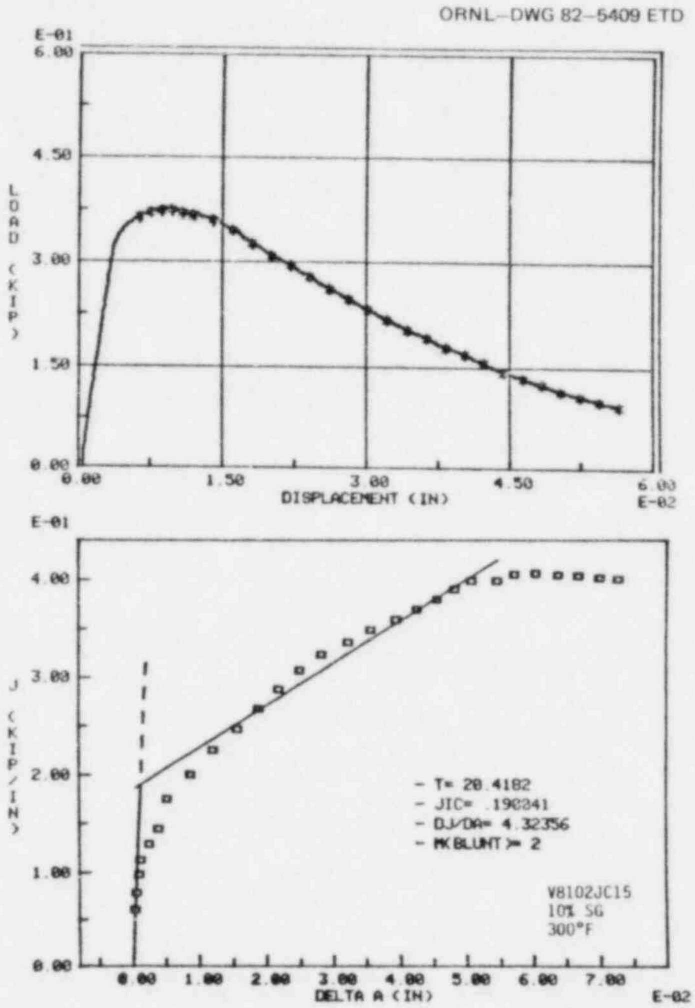
ORNL–DWG 82–5408 ETD



	J KIP/IN	CRACK EXTENSION IN	DISTANCE FROM STRETCH LINE
1 .	.0243088	5.34569E-03	5.10654E-03
2 .	.0396571	4.65702E-03	4.40031E-03
3 .	.0561767	3.00103E-03	3.43625E-03
4 .	.0741737	2.69663E-03	2.21498E-03
5 .	.0917268	5.95628E-04	-1.74623E-10
6 .	.108067	1.29031E-03	5.88570E-04
7 .	.125339	1.22741E-03	4.13516E-04
8 .	.142982	9.78424E-04	4.99665E-05
9 .	.159953	1.56574E-03	5.27083E-04
10 .	.212685	2.10938E-03	7.28304E-04
11 .	.263283	3.85810E-03	2.14047E-03
12 .	.31465	5.20177E-03	3.15859E-03
13 .	.347035	6.75420E-03	4.50073E-03
14 .	.3775	8.99906E-03	6.54777E-03
15 .	.40919	.0104695	7.81237E-03
16 .	.43862	.0123679	9.51976E-03
17 .	.463458	.0155275	.012518
18 .	.479373	.0202793	.0171665
19 .	.493457	.0245444	.0213[illegible]1
20 .	.508968	.0283393	.0259343
21 .	.514918	.0334627	.0301191
22 .	.516427	.038799	.0354455
23 .	.51632	.0440652	.0407125
24 .	.520396	.0481142	.044735
25 .	.519521	.0526716	.0492981
26 .	.524689	.0557341	.052327
27 .	.517462	.060642	.0572019
28 .	.517096	.0641016	.0608239

*-DENOTES POINTS USED FOR JIC DETERMINATION
+-DENOTES POINTS EXCEEDING ASTM SPECIFICATIONS

Figure E-2 J-Test Results

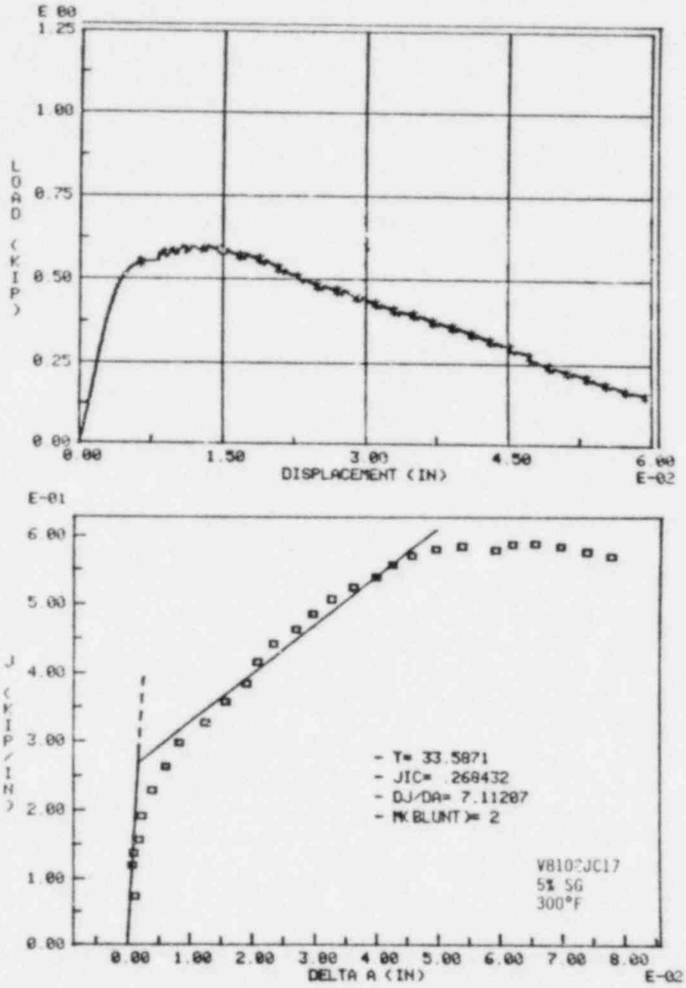


	J KIP/IN	CRACK EXTENSION IN	DISTANCE FROM STRETCH LINE
1 .	.0614730	3.99181E-04	4.65661E-10
2 .	.079034	6.01419E-04	8.82112E-05
3 .	.0982501	9.97075E-04	3.59035E-04
4 .	.11333	1.21095E-03	4.83041E-04
5 .	.129312	2.52841E-03	1.68072E-03
6 .	.145033	3.88100E-03	2.94011E-03
7 .	.175211	5.19637E-03	4.05064E-03
8 .	.200585	8.68977E-03	7.38727E-03
9 .	.225640	.0120755	.0106103
10 .	.247132	.0156940	.01409
11 .	.260415	.0189193	.0171763
12 .	.280012	.0219104	.0200402
13 .	.307209	.0250595	.0230646
14 .	.24004	.0262066	.0261822
15 .	.33623	.0323154	.0301321
16 .	.340744	.0356923	.0334277
17 .	.359111	.0394974	.0371655
18 .	.369967	.0425234	.040121
19 .	.380142	.0455306	.0430621
20 .	.390245	.0481553	.0456212
21 .	.399313	.0507552	.0481623
22 .	.399734	.0545901	.0519944
23 .	.406137	.0570856	.0544483
24 .	.407194	.0602993	.0576552
25 .	.405424	.0637109	.0610783
26 .	.404[illegible]52	.0667049	.0641596
27 .	.402175	.0699203	.0673008
28 .	.401227	.0726362	.0700300

*-DENOTES POINTS USED FOR JIC DETERMINATION
+-DENOTES POINTS EXCEEDING ASTM SPECIFICATIONS

Figure E-3 J-Test Results

ORNL-DWG 82-5410 ETD

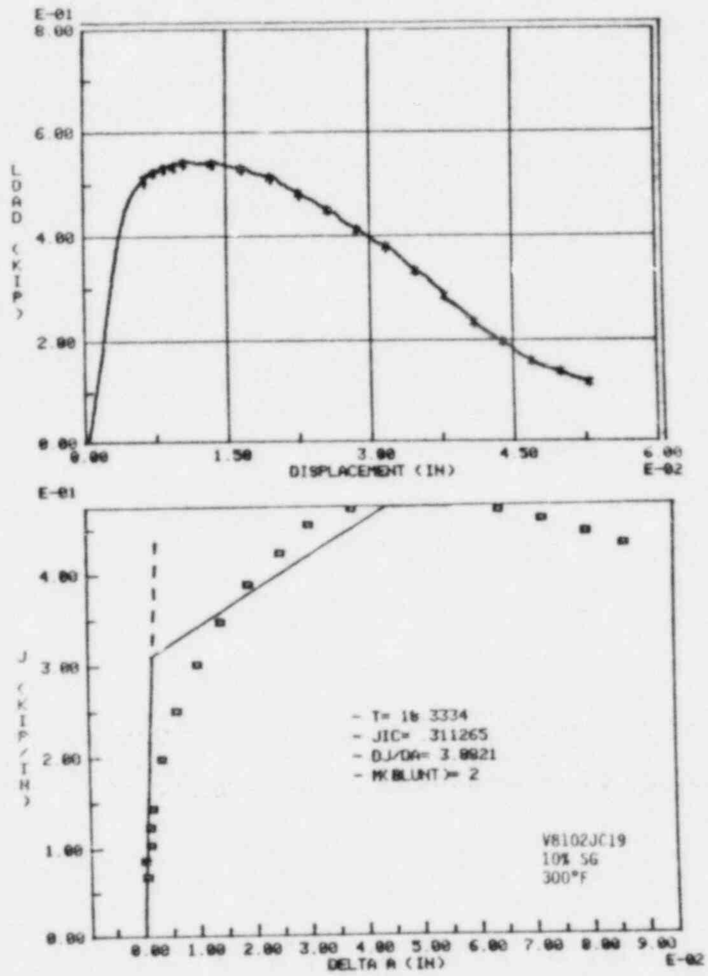


	J KIP/IN	CRACK EXTENSION IN	DISTANCE FROM STRETCH LINE
1 .	.0729102	1.24371E-03	7.70263E-04
2 .	.120339	7.79231E-04	5.82077E-11
3 .	.138157	1.04498E-03	1.47039E-04
4 .	.157119	1.87859E-03	8.58346E-04
5 .	.191465	2.29035E-03	1.04707E-03
6 .	.228229	3.98420E-03	2.59227E-03
7 .	.263336	6.23515E-03	4.52507E-03
8 .	.298554	8.38613E-03	6.44753E-03
9 .	.32807	.0125847	.0104544
10 .	.357904	.0158248	.0135007
11 .	.38501	.0191691	.0166691
12 .	.416367	.02089	.0181863
13 .	.442336	.0234869	.0206113
14 .	.463961	.0271452	.0241325
15 .	.486205	.0298246	.0266674
16 .	.50772	.0328112	.0295143
17 .	.524973	.0363141	.0329352
18 .	.539503	.0400414	.0365382
19 .	.557998	.0426508	.0390274
20 .	.572062	.0457957	.042081
21 .	.58082	.0496668	.0458953
22 .	.585833	.0537834	.0498845
23 .	.583164	.0592552	.0554879
24 .	.582036	.0619336	.0581152
25 .	.58927	.0655398	.0617134
26 .	.584921	.0697114	.0659132
27 .	.57738	.074	.0702508
28 .	.570976	.0778213	.0741137

*-DENOTES POINTS USED FOR JIC DETERMINATION
√-DENOTES POINTS EXCEEDING ASTM SPECIFICATIONS

Figure E-4 J-Test Results

ORNL–DWG 82–5411 ETD



	J KIP/IN	CRACK EXTENSION IN	DISTANCE FROM STRETCH LINE
1 .	.0678128	5.95796E-04	1.55453E-04
2 .	.0865312	2.61891E-04	-3.03020E-04
3 .	.103577	1.23559E-03	5.62368E-04
4 .	.123603	1.27363E-03	4.71016E-04
5 .	.147051	1.77393E-03	8.38856E-04
6 .	.190161	3.47954E-03	2.19175E-03
7 .	.250919	6.24895E-03	4.61951E-03
8 .	.301792	.0101041	8.14442E-03
9 .	.347062	.0142387	.0119798
10 .	.39049	.0192162	.0166936
11 .	.422940	.0250215	.0222751
12 .	.455125	.0301595	.0272042
13 .	.47238	.037815	.0347476
14 .	.48126	.0460292	.0429041
15 .	.47943	.0549	.0517060
16 .	.469044	.063949	.0600901
17 .	.459841	.0717596	.0687737
18 .	.444831	.0794368	.0766083
19 .	.431187	.0862144	.0834145

*-DENOTES POINTS USED FOR JIC DETERMINATION
+-DENOTES POINTS EXCEEDING ASTM SPECIFICATIONS

Figure E-5 J-Test Results

E.3 DISCUSSION OF RESULTS

The J_{1c} results obtained for the 5%, 10%, and 20% side-grooved 3-point C_v bend specimens are compared to each other and the compact tension specimen tests in Table E-2.

Table E-2

WELD V8102 J_{1c} RESULTS
(WL Orientation - 300°F)

Kip/in.

1TCT - 20% SG			2TCT - 20% SG			C_v - 20% SG			C_v - 10% SG			C_v - 5% SG		
No. Tested	Mean	S.D.	No. Tested	Mean	S.D.	No. Tested	Mean	S.D.	No. Tested	Mean	S.D.	No. Tested	Mean	S.D.
4	.244	.035	2	.246	.023	4	.168	.015	3	.277	.076	2	.336	.096

It appears that reducing the side grooves of C_v specimens produces closer agreement to the compact tension specimen results with 20% side grooves.

This is also illustrated in Figure E-6 which compares the J versus Δa results for various specimens taken from Weld V8102. It is seen that up to about 0.04 inch crack extension, the 5% and 10% SG C_v specimens give comparable results to the 1TCT - 20% SG specimens.

Figure E-7 shows that with the exception of Weld V8102JC11 (10% SG), the specimens with 5% or 10% SG give higher J-R curves as compared to the 20% SG specimens.

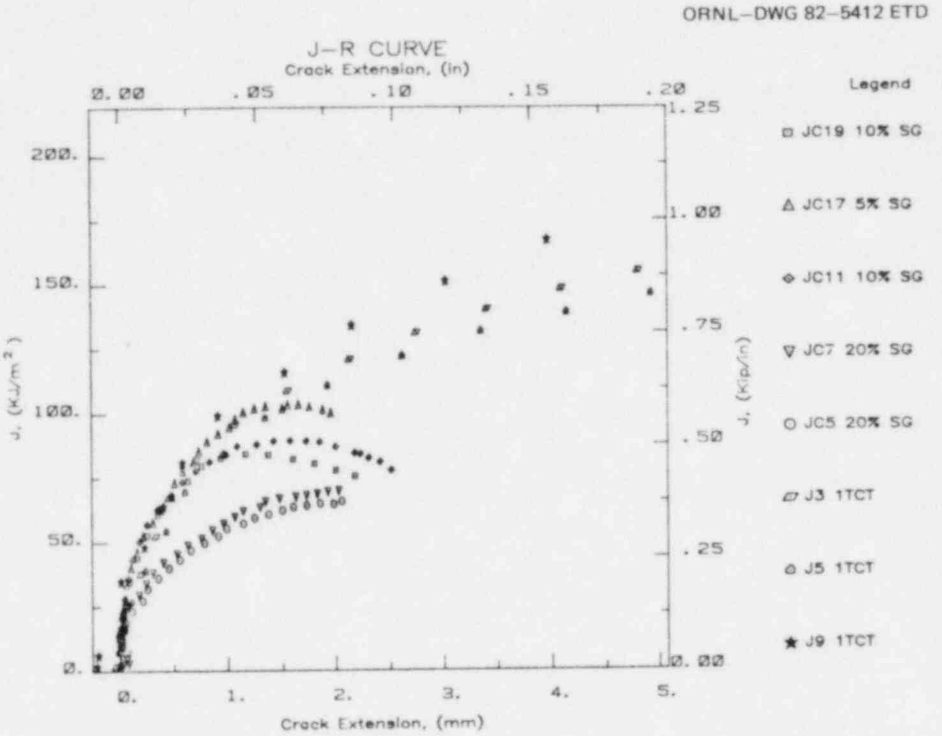


Figure E-6 J Versus Δa Plots for Some C_V and 1TCT (20% SG) WL-Orientated Specimens from Weld V8102 Tested at 300°F

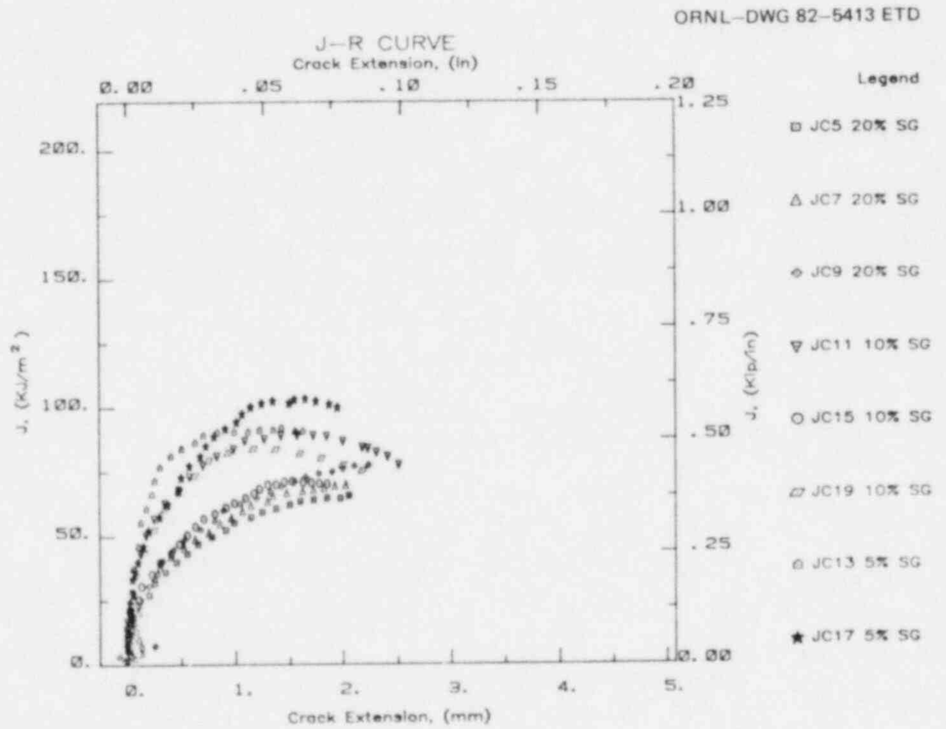


Figure E-7 Plots of J Versus Δa for C_V Specimens from Weld V8102 Tested at 300°F Having 5%, 10%, or 20% Side Grooves

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