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Half-Bead (Temper) Repair Welding for Heavy-Section Steel Technology Program Vessels

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

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HALF-BEAD (TEMPER) REPAIR WELDING FOR HEAVY-SECTION STEEL TECHNOLOGY PROGRAM VESSELS

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CONTENTS

FOREWORD

This report is designated Heavy-Section Steel Technology Program Technical Report No. 49. Prior reports in this series are listed below.

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Copies of these reports may be obtained from Laboratory Records Department, Oak Ridge National Laboratory, P.O. Box X, Oak Ridge, TN 37830.

HALF-BEAD (TEMPER) REPAIR WELDING FOR HEAVY-SECTION STEEL TECHNOLOGY PROGRAM VESSELS*

S. W. Wismer† P. P. Holz

ABSTRACT

The "half-bead (temper) welding technique" performed to Section XI of the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code guidelines was used successfully on cavities placed in three thick-walled pressure vessel models to simulate repair welding of operational nuclear reactor vessels. One of the models served as a qualification-procedure test specimen, as required by the Code, and was subsequently utilized for detailed metallurgical examinations. The weld repair program was conducted by Westinghouse Tampa Division (WTD) in Tampa, Florida, under contract to Union Carbide Corp., Nuclear Division, Oak Ridge National Laboratory (ORNL). The temper-, or half-bead, technique, in theory, is structured such that each weld pass is applied in a manner which results in tempering the preceding weld pass. Thus, brittle transformation products created during welding will be rendered ductile. Conventional postweld thermal stress relief is not required.

The repair welding was performed on 152.4-mm-thick (6-in.) low-alloy steel vessel material (ASME SA-533, grade B, class 1) in the vertical position, using 2.4-mm-diam (3/32-in.) type 8018-C3 electrodes for the first layer and 3.2-mm-diam (1/8-in.) electrodes of the same type for subsequent passes and for completing the weld. After welding, a low-temperature [260°C (500°F)] temper treatment, or postweld heat treatment (PWHT), was performed for 4 hr. Routine magnetic-particle inspections were conducted for each of the first three weld passes and thereafter on alternate passes. Final nondestructive repair inspections were made a minimum of 48 hr after the vessels had cooled to ambient temperature. Magnetic-particle surface inspections and ultrasonic inspections of the repairs revealed no indications of any delayed cracking. A second ultrasonic inspection of one of the vessel repairs by ORNL approximately 12 weeks after postrepair welding also revealed no indications of delayed cracking. Final ultrasonic and radiographic test results were acceptable for all repair welds.

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*Performed by Westinghouse Electric Corporation, Westinghouse Tampa Division, under Union Carbide Corporation, Nuclear Division, Oak Ridge National Laboratory, Contract UCC-ND 75Y-13494V.

†Westinghouse Tampa Division.

GARD, Inc.* used acoustic-emission equipment to record sounds emitted during welding, and no significant or rejectable indications were identified. Strain gage instrumentation to record the residual stresses induced by welding was attached for repair operations and was monitored by ORNL personnel.

1. INTRODUCTION

Westinghouse Tampa Division (WTD), under contract to Union Carbide Corp., Nuclear Division (UCC-ND), Oak Ridge National Laboratory (ORNL) (Contract UCC-ND 75Y-13494V), used the "half-bead (temper) welding technique" to weld repair three Heavy-Section Steel Technology (HSST) Program simulated reactor "vessels," with the vessels placed in a fixed vertical position. These vessels (intermediate test vessels V-7B and V-8 and a qualification test cylinder, or prolongation V-8) had 152-mm-thick (6-in.) walls. The vessel V-7B work involved a through-the-wall cavity repair; the vessel V-8 work involved a half-wall thickness repair; and the prolongation V-8 involved replications of both intermediate test vessel repairs to qualify vessel repair procedures in accordance with ASME Code Section XI requirements. The WTD contract work also included preliminary practice and familiarization half-bead welding on test plate of similar wall thickness and called for the preparation of tensile test plate specimens to be furnished to ORNL for analysis.

The repairs made by WTD involved the previously used vessel V-7A, a new vessel V-8, and a new prolongation V-8. Their preparations for the V-7B test included removing the V-7A flaw zone and forming appropriate through-the-wall cavity boundaries for half-bead repair welding, as well as similar cavity preparations on prolongation V-8. The vessels and respective cavity details are shown in Fig. 1. The prolongation consisted of an open-ended test cylinder which was manufactured from the same heat, with heat treatment and stress relief identical to those for the vessels. The prolongation had two test areas located 180° apart, one with a through-the-wall cavity similar to the cavity in the V-7B vessel and the other with a cavity about halfway through the wall similar to the cavity in the V-8

*GARD, Inc., subsidiary of GATX Corp., 7449 North Natchez Ave., Niles, Ill. 60648.

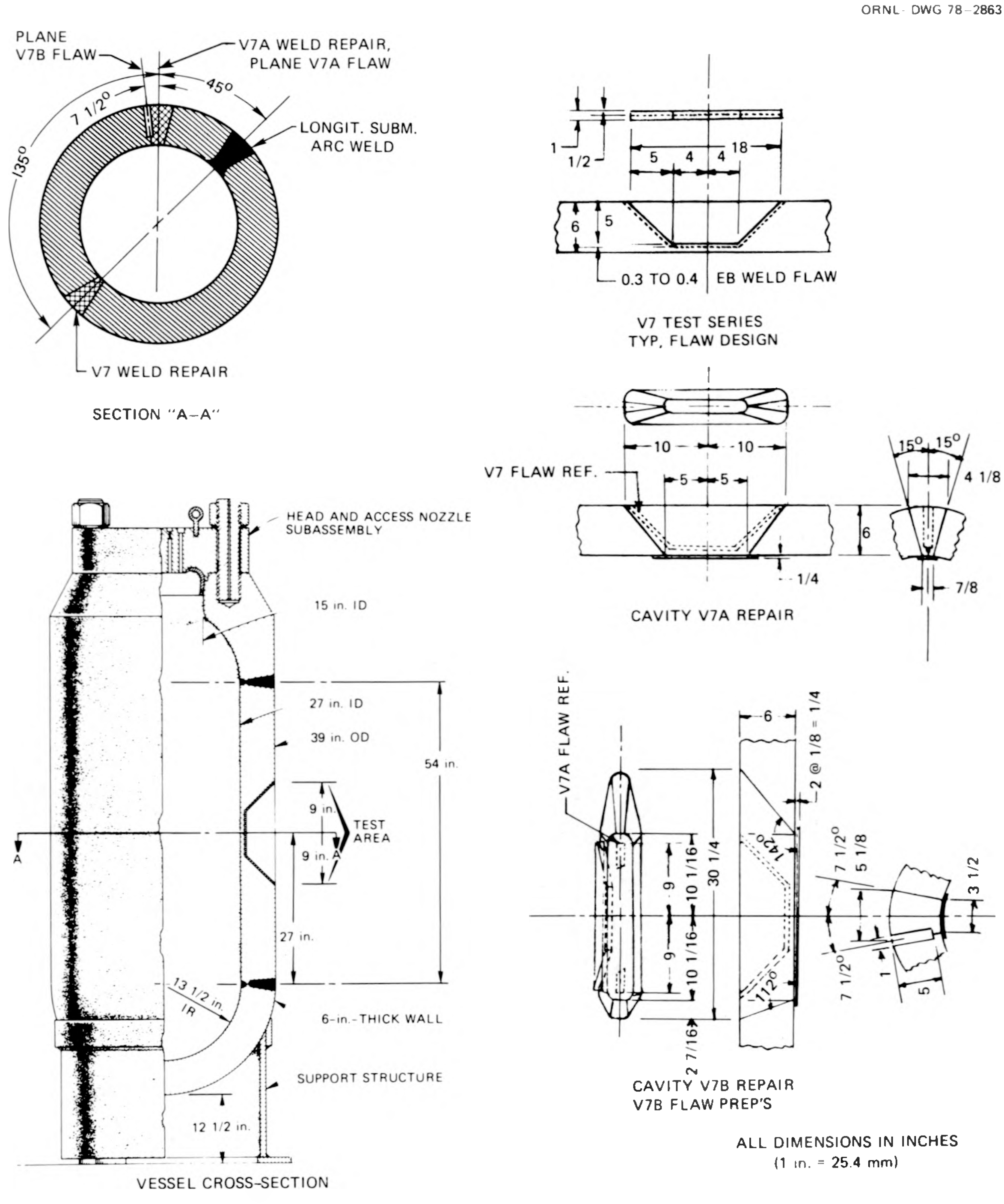


Fig. 1. Intermediate test vessel V-7A.

vessel. The half-wall-thickness cavities had been premachined into the longitudinal seam welds of both the V-8 vessel and the V-8 prolongation by ORNL. Heavy crossbraces were welded to both ends of the prolongation cylinder for restraints.

Detailed accounts of earlier tests and repairs of vessels V-7 and V-7A are documented in Refs. 1, 2, and 3. Post-repair-weld machining and flawing of vessel V-7B were centered in a longitudinal heat-affected zone of the weld repair, and the vessel was pressure tested at upper-shelf test temperature to approximately 2 1/4 times design pressure before leakage occurred. A report[4] is in preparation to cover findings from the V-7B test. Procedure qualification prolongation V-8 was destructively tested at ORNL to determine the mechanical, physical, and structural properties of the weld repair and to evaluate strain gage stress data taken in the areas of the repair welds and in the areas adjacent to them to determine repair-induced residual stress criteria.[4,5] The final details of vessel V-8 postrepair program activities are pending. The vessel is scheduled to be flawed in a high-residual-stress, low-toughness zone for pressure testing in the transition temperature regime. This report provides chronological listings and discussions for all half-bead weld repairs and related work performed by WTD during late January and early February 1977. UCC-ND Welding Specifications and WTD Process Specifications are included in the Appendix.

The "half-bead (temper) welding technique" is unique because of its use of a controlled heat-affected-zone tempering process. About half of the first, or "buttering," weld layer is ground off, and the heat from the second layer refines and tempers the remaining heat-affected zone between the first layer and the base metal. Thus, the properties of transformation products of the heat-affected zone of the prior weld layer are improved substantially. The second layer, another "buttering" layer, and subsequent filler layers are not ground, because tempering is necessary only for the first layer and for the base metal. Weld repairs using the half-bead (temper) method may be accomplished when it is impossible or impractical to perform a postweld heat treatment (PWHT) at conventional, considerably elevated temperatures. The requirements for half-bead weld repairs are listed in the ASME Code, Section XI, Paragraph IWB-4420, and in Section III, Paragraph NB-4640.

Similar half-bead weld repairs had previously been successfully performed by Combustion Engineering, Inc., Chattanooga, Tenn., in another section of HSST vessel V-7.[2] For Combustion Engineering's repairs, however, cavity preparation and half-bead and filler welding were all done with the vessel in a horizontal position. Flat-position welding was used. Equally successful completion of half-bead weld repairs by WTD in vertically placed vessels and welding in the vertical position proves that acceptable repairs can also be made to ASME Code guidelines for vessels in the vertical position without conventional PWHT stress relief.

2. GENERAL

2.1 Welding

All welding was done in the vertical position using stringer beads to WTD Process Specification NPT-77, except 4-mm-diam (5/32-in.) electrodes were not used because of excessive starting porosity. WTD Process Specification NPT-77, which is appended to this report, follows ASME Code, Section XI guidelines for half-bead repair welding.

All layers of weld were staggered whenever physically possible, but the starts and stops contained within a layer were in line with one another for most expeditious grindout. Corner deposits were in line, and most of the porosity was located in this area on the inside diameter, as visually observed after removing the backing bar. Some trouble was encountered with the fit of the two 3.2-mm-thick (1/8-in.) stacked and contoured backing bars: the inner bar became distorted and separated from the outer bar, thus leaving a gap which in some cases was easy to burn through. The backing bar arrangement is detailed in typical cross-sectional views in WTD drawing ETSK-379614-J, which is appended to this report.

2.2 Electrode Baking

The E8018-C3 electrodes supplied by ORNL were prebaked and sealed in vacuum packs of 45.4 g (10 lb) each. The electrodes were removed from their packs and placed into an oven at 121 ± 14°C (250 ± 25°F) prior to being transferred to the welding station where individual welders' ovens were used to maintain the rods at temperature. The electrode properties are given in Table 1.

The starting end and the coating of each electrode were inspected before placing the rods into the oven and again after the rods were removed from the oven. The welder also inspected each electrode end prior to striking the arc. In this way, obvious coating cracks were eliminated.

The moisture content of the electrodes was determined for multiple lot samples in each diameter of electrodes used and is recorded in Table 2. All moisture tests were in accordance with Specification SFA-5.5, AWS

Table 1. Mechanical properties of electrodes (as welded) — SFA 5.5, class E-8018-C3 (TO5318)[a]

Lot number	5237A	AE 74	TO5318[b]
Electrode diameter, in.	3/32	1/8	5/32
Yield strength (0.2% offset), psi	76,500	74,900	70,765
Tensile strength, psi	85,200	88,400	80,160
Elongation, %	27	29	29
Reduction of area, %	74	70.4	69
Charpy impact toughness @ —20°F, ft-lb	99 100 100	110 119 99	[c]
Charpy impact toughness @ +70°F, ft-lb			
80% lateral expansion			122
84% lateral expansion			112
86% lateral expansion			120

[a]1 in. = 25.4 mm; 1 psi = 6895 Pa; 1 ft-lb = 1.356 J.

[b]Stress relieved 24 hr at 1125°F.

[c]Drop weight tests at +20°F — no break. Based on Charpy V-notch results, RT_{NDT} is assumed to be ∿+10°F.

Classification E8018-C3 of Section II of the ASME Code. Tests of welding materials conformed to Subarticle NB-2400, Section III, of the ASME Code. All electrodes used were well within the 0.4% maximum moisture content allowance.

2.3 Heating Techniques

All preheating and postweld heating operations of the vessels were done under the direct control of the Cooperheat Company* in accordance with WTD Process Specification NPT-77. Cooperheat resistance heaters of the flexible ceramic pad type (with an imput voltage of 80 V) were supplied from a primary source of 440–480 V, 60 Hz, 3 phase, at 200 A per

*Cooperheat Company, Cooperheat Eastern Division, 955 E. Hazelwood Avenue, Rahway, N.J. 07065.

Table 2. Moisture content checks of E-8018-C3 welding electrodes[a]

Electrode lot No.	Electrode diam, size (in.)[b]	Moisture (%)	Test date	Westinghouse test No.
5237A	3/32	0.184	1/22/77	C-6129
AE 74	1/8	0.197	1/23/77	C-6130
5237A	3/32	0.190	1/24/77	C-6131
WTD-5318	5/32	0.141	1/24/77	C-6132
AE 74	1/8	0.209	1/24/77	C-6133
AE 74	1/8	0.268	1/25/77	C-6134
AE 74	1/8	0.290	1/26/77	C-6138
AE 74	1/8	0.202	1/27/77	C-6139
AE 74	1/8	0.218	1/28/77	C-6143
AE 74	1/8	0.268	1/29/77	C-6148
5237A	3/32	0.197	1/30/77	C-6149
AE 74	1/8	0.253	1/30/77	C-6150
AE 74	1/8	0.143	1/31/77	C-6151
AE 74	1/8	0.149	2/1/77	C-6158
AE 74	1/8	0.200	2/2/77	C-6159
AE 74	1/8	0.266	2/3/77	C-6162
AE 74	1/8	0.181	2/4/77	C-6163
AE 74	1/8	0.243	2/5/77	C-6164
5237A	3/32	0.207	2/5/77	C-6165
AE 74	1/8	0.201	2/6/77	C-6166
AE 74	1/8	0.202	2/7/77	C-6167
5237A	3/32	0.205	2/8/77	C-6173
AE 74	1/8	0.177	2/8/77	C-6174
AE 74	1/8	0.150	2/9/77	C-6179
AE 74	1/8	0.139	2/10/77	C-6186
5237A	3/32	0.200	2/14/77	C-6206
AE 74	1/8	0.240	2/10/77	C-6210
AE 74	1/8	0.254	2/15/77	C-6211
AE 74	1/8	0.172	2/16/77	C-6215
AE 74	1/8	0.156	2/17/77	C-6216
5237A	3/32	0.203	2/20/77	C-6217
AE 74	1/8	0.199	2/20/77	C-6218

[a]Electrode samples were periodically removed from the portable holding ovens and the moisture in the coating was measured using the moisture test specified in paragraph 25 of SFA-5.5, "Specification for Low Alloy Steel Covered Arc-Welding Electrodes," ASME Code, Section II.

[b]1 in. = 25.4 mm.

phase. All thermocouple circuitry was Chromel/Alumel Type K and registered on a 24-point Honeywell 112 Type K recorder using a 12-hr scroll-type chart. The thermocouples were spot-welded onto the vessel and insulated with ceramic high-temperature putty. Resistance heaters were used on the inside of the vessel; ceramic fiber insulation was used on the outside. The exception was the weld re-repair on the inside of vessel V-7B, for which resistance heaters were strapped onto the vessel's exterior with a fiber padding cover superimposed.

During preparations, the test plates were heated locally with gas torches and postweld heated in an electric furnace.

Auxiliary gas-fired radiant heaters were available as backup equipment, but they were not needed.

3. WELDING SEQUENCE

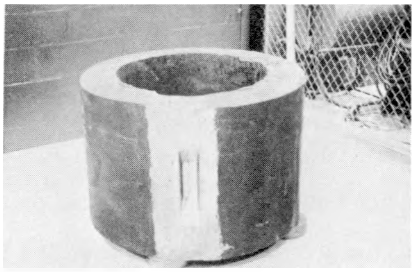
3.1 Prolongation

The prolongation was 648 mm tall (25.5 in.), with a 686-mm ID (27-in.), 991-mm OD (39-in.), and a 152-mm-thick (6-in.) wall, and is shown with qualification test cylinder details in WTD drawing EDSK 379614-J, which is appended to this report. Both ends of the cylinder were open. The prolongation was received with the V-8-type cavity machined from the exterior approximately halfway into the wall. The cavity was centered midway up the cylinder and was located approximately halfway into the longitudinal cylinder seam weld. The cavity measured 318 × 83 mm (12 1/2 × 3 1/4 in.) on the vessel's outer surface and was 89 mm deep (3 1/2 in.). Sidewalls were cut on radial planes; top and bottom ends were tapered on 45° slopes toward the cavity's center. The prolongation also included a through-the-wall cavity positioned on the opposite side. This through-the-wall V-7-type cavity [with the wall being 152 mm thick (6 in.)] was prepared by Westinghouse by drilling and air-arc gouging. Exterior surface measurements were ∿351 mm (∿13.8 in.) vertical by ∿127 mm (∿5 in.) across. Radial sides were on 97 1/2° angles — the top sloped on a 142° included angle and the bottom at 112°.

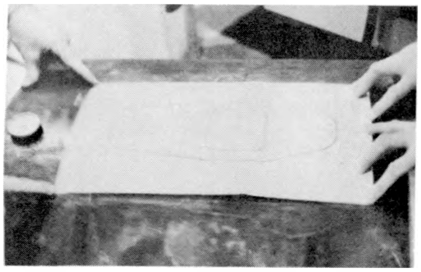
The selection of typical weld repair zones for the prolongation provided specific locations for materials for subsequent detailed comparison studies. Specimens were cut accordingly, and physical and material analyses were performed later at ORNL. The V-8 cavity was a direct replication for the vessel V-8 weld repair; the V-7-type prolongation cavity represented a reduced-size version for the vessel V-7B repair. The size of the root opening of the through-the-wall prolongation cavity was increased from 89 mm square (3 1/2 in.) to 92 mm square (3 5/8 in.) through a machining error. The thermal gouging and grinding operation resulted in a slight undercut at the bottom of the joint, which, however, was considered acceptable for the repair welding. See the photographs in Fig. 2.

The V-7B cavity backing bars consisted of two 3.2-mm-thick (1/8-in.) carbon steel sheets rolled to the prolongation's inside diameter. The first bar was welded all around and hammered in to ensure a good tight fit. The second bar was then welded all around on top of the first bar.

ORNL PHOTO 1669–78



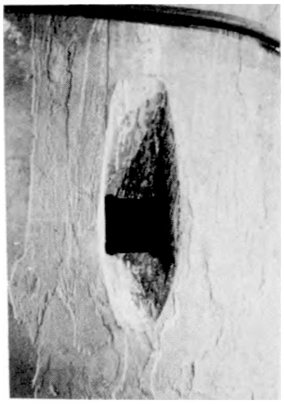
(*a*) MACHINED V-8 CAVITY



(*b*) LAYOUT TEMPLATE FOR V-7B THROUGH-THE-WALL CAVITY

(*c*) ROOT DRILL-OUT FOR V-7B CAVITY

(*d*) GRINDING V-7B CAVITY AFTER AIR-ARC GOUGING



(*e*) V-7B CAVITY PRIOR TO FINISH GRINDING

(*f*) V-7B CAVITY WITH BACKING STRIP IN PLACE

Fig. 2. V-8 prolongation — cavity details.

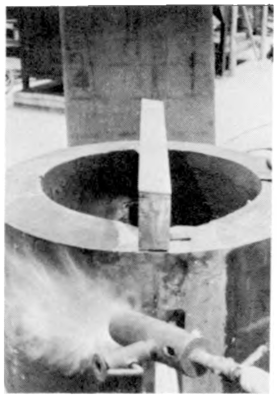
The prolongation was preheated locally by a gas-fired torch in order to weld the first, or lower, crossbrace restraint. Crosses made up of 102-mm-square (4-in.) bars were fillet-welded to each end of the prolongation cylinder. All the material used for these braces was ASME-SA533, grade A, class 2 plate stock. See the photographs in Fig. 3. After cooling to room temperature, ORNL personnel installed the strain gages. Fifteen weldable strain gages were placed on the prolongation's exterior surface and five gages on the interior surface. The gages provided residual stress measurements to give insight into the residual stress field that will exist around the weld repair zones and hence around the flaw test area.

The number and location of thermocouples attached by Cooperheat personnel are shown on drawing EDSK-379614-J appended to this report. The thermocouples were located circumferentially from the center of the weld cavity at a distance of 457 mm (18 in.), or 3 times the thickness of the repair. Because of the short overall length of the prolongation, distances to the upper and lower thermocouples were restricted to only ∿305 mm (∿12 in.). Additional thermocouples were also placed adjacent to the strain gages, and a protective stainless sheet was tacked in place to cover and protect the gages during repair welding. Cooperheat personnel then installed the resistance heaters to the inside surface of the prolongation. Thereafter, both inside and outside surfaces were insulated for heat control. See the photographs in Figs. 3 and 4.

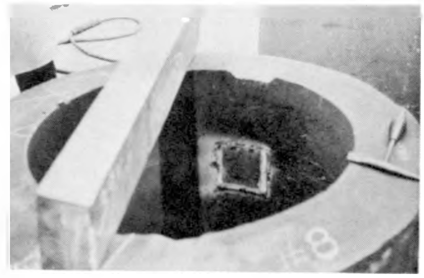
The prolongation was again preheated via the resistance heaters prior to welding the second, or top, crossbrace restraint. Thereafter, preheat was maintained for the required 4-hr strain gage stabilization hold time.

Next, half-bead repairs were started for the V-8 cavity of the prolongation. A period of ∿7 hr was required to deposit the "buttering" layer using 2.4-mm-diam (3/32-in.) electrodes. This first layer was then ground to approximately one-half of the original thickness of the deposit. "Before" and "after" grinding measurements are shown in Table 3. Thereafter, 3.2-mm-diam (1/8-in.) electrodes were used for the second layer, and 4-mm-diam (5/32-in.) electrodes were used for the third, fourth, and fifth layers. Difficulties were encountered with the weldability of the 4-mm-diam (5/32-in.) electrodes for vertical cavity position repairs; hence, it was decided to discontinue using these 4-mm-diam (5/32-in.) rods and to use

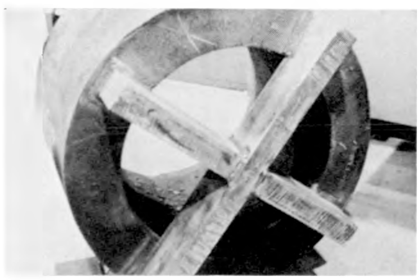
ORNL PHOTO 1670–78



(*a*) PREHEAT PRIOR TO BRACE INSTALLATION



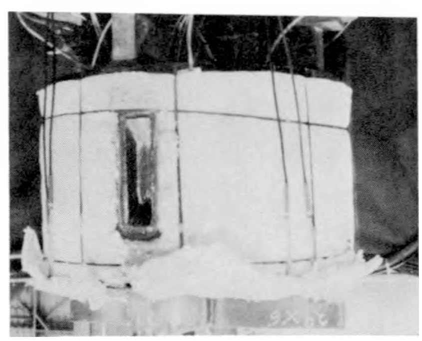
(*b*) LOWER BRACE END RESTRAINT



(*c*) COMPLETED LOWER BRACE RESTRAINT

(*d*) FITTING OF UPPER BRACE

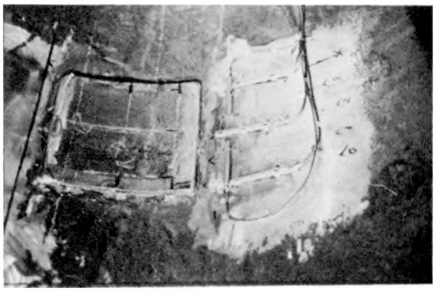
(*e*) BRACE RESTRAINT END WELDMENT



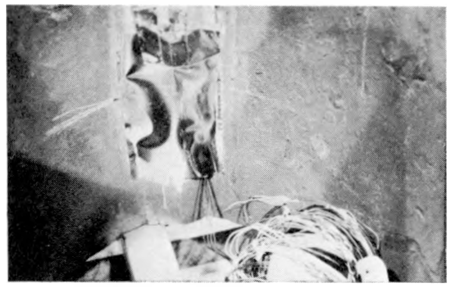
(*f*) RESTRAINTS AND INSULATION ATTACHED IN PREPARATION FOR V-8 CAVITY WELD REPAIR

Fig. 3. V-8 prolongation — preparations for cavity repair.

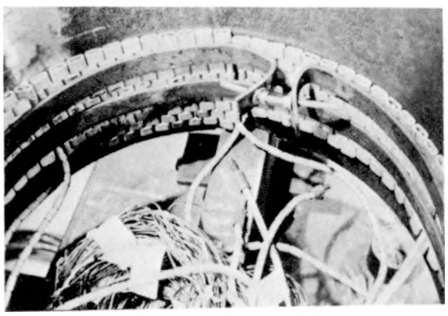
ORNL PHOTO 1671–78



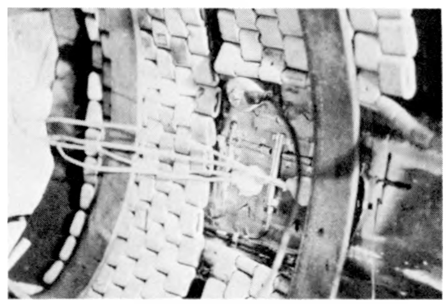
V-7B CAVITY – BACKING STRIP AND INSIDE SURFACE STRAIN GAGES



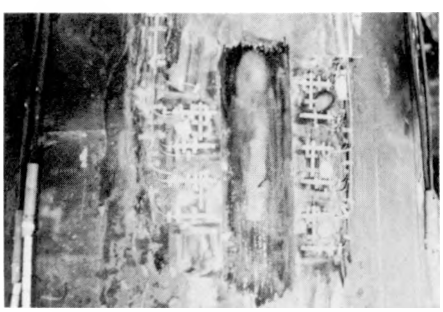
V-7B REPAIR – COVER FOR INSIDE STRAIN GAGES



RESISTANCE HEATERS ATTACHED TO CYLINDER INTERIOR



V-7B REPAIR – INTERIOR STRAIN GAGES AND MONITOR THERMOCOUPLES



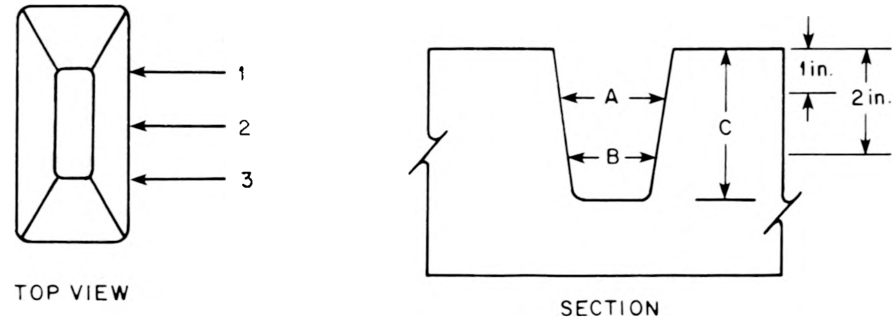
V-8 CAVITY – EXTERIOR STRAIN GAGES AND MONITOR THERMOCOUPLES

V–8 CAVITY – PROTECTIVE COVERS FOR EXTERIOR GAGES

Fig. 4. V-8 prolongation — miscellaneous details.

Table 3. Prolongation V-8 (V-8 cavity) and vessel V-8 half-bead weld repairs — locations for measuring and dimensional data for first layer grind-off (dimensions in inches)[a]

	Top view designation	A	B	C
Vessel V-8				
Prior to welding	1	3.055	2.815	3.485
	2	3.060	2.820	3.468
	3	3.080	2.835	3.478
After welding	1	2.828	2.699	3.375
	2	2.847	2.720	3.358
	3	2.823	2.711	3.338
After grinding	1	2.940	2.755	3.430
	2	2.945	2.770	3.413
	3	2.947	2.765	3.408
Prolongation V-8 (V-8 cavity)				
Prior to welding	1	3.090	2.926	3.446
	2	3.090	2.931	3.439
	3	3.078	2.916	3.444
After welding	1	2.982	2.734	3.250
	2	2.970	2.780	3.312
	3	2.977	2.697	3.250
After grinding	1	3.035	2.856	3.375
	2	3.038	2.851	3.375
	3	3.010	2.821	3.406



[a]1 in. = 25.4 mm.

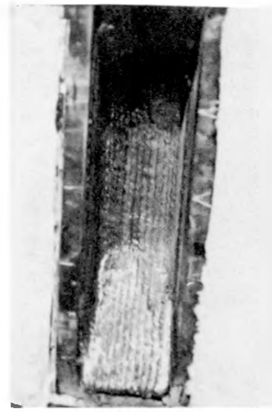
3.2-mm-diam (1/8-in.) electrodes for depositing all remaining layers. Thirty layers were required to totally fill the remaining cavity. Approximately 80 hr were spent in making the V-8 prolongation weld repair, and 88 2.4-mm-diam (3/32-in.), 728 3.2-mm-diam (1/8-in.), and a few 4-mm-diam (5/32-in.) electrodes were used to fill the cavity. Magnetic-particle inspections were performed on the ground "buttering" layer and on the next 3.2-mm (1/8-in.) rod layer, and thereafter on alternate layers and the final ground outer surface, with all results acceptable. Refer to the photographs in Fig. 5, which illustrate the V-8 cavity repair welding sequence.

Heat input to the inner surface resistance heaters was increased on completion of the repair welding. One and one-half hours were required to reach postweld tempering treatment temperatures. Prolongation temperatures were then held in this 260 ± 28°C (500 ± 50°F) range for 4 hr. Thereafter, the vessel was stripped of insulation and cooled to room temperature in about 24 hr at which time stabilized final strain gage recordings were taken. Another day was spent installing five internal and six external weldable strain gages for the prolongation's through-the-wall V-7B cavity repair. Welding commenced about 8 hr later, with 4 hr required to achieve preheat temperatures and another 4 hr at preheat for strain gage stabilization.

Sixteen hours were required to deposit the first, or "butter" pass, layer in the V-7B cavity of the prolongation, after which it was ground down. The before- and after-grinding measurements are shown in Table 4. It is important to note that the first weld layer deposit that covered the backing bar was not ground. Half-bead temper effects for this zone were eliminated by removing the backing bar from the interior surface by grinding, which followed the completion of all repair welding. The remaining cavity required 59 layers, all of which were deposited with 3.2-mm-diam (1/8-in.) electrodes. Magnetic-particle examinations were performed the same as before. The welders began to encounter porosity while welding in the lower quadrant of the cavity. After light grinding, a number of clusters of fine porosity could still be seen. Magnetic-particle inspections revealed still other small indications and one relatively large, ∿6.4-mm-long (∿1/4-in.) longitudinally oriented defect. It was

ORNL PHOTO 1672–78

(*a*) READY FOR REPAIR WELDING



(*b*) ROOT PASS WELD COMPLETED

(*c*) PARTIAL GRINDING STARTED ON FIRST LAYER ("BUTTER")

(*d*) GROUND LAYER READY FOR MAGNETIC-PARTICLE INSPECTION

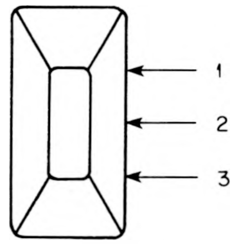
(*e*) MAGNETIC-PARTICLE INSPECTION BETWEEN LAYERS

(*f*) FILLED CAVITY WITH GAGE AND THERMOCOUPLE PROTECTOR COVERS REMOVED

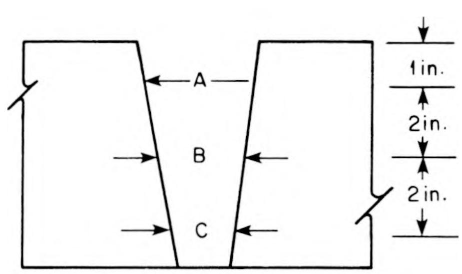
Fig. 5. V-8 prolongation — V-8 cavity repair welding sequence.

Table 4. Prolongation V-8 (V-7B cavity) and vessel V-7B half-bead weld repairs — locations for measuring and dimensional data for first layer grind-off (dimensions in inches)[a]

	Top view designation	A	B	C
Vessel V-7B				
Prior to welding	1	4.813	4.750	4.750
	2	4.250	4.250	4.250
	3	3.750	3.750	3.750
After welding	1	4.650	4.625	4.625
	2	4.160	4.150	4.125
	3	3.560	3.620	3.650
After grinding	1	4.750	4.688	4.688
	2	4.218	4.218	4.218
	3	3.688	3.719	3.719
Prolongation V-8 (V-7B cavity)				
Prior to welding	1	4.285	3.943	3.928
	2	4.378	3.941	3.865
	3	4.216	3.815	3.720
After welding	1	4.133	3.806	3.773
	2	4.245	3.794	3.713
	3	4.102	3.702	3.596
After grinding	1	4.215	3.880	3.855
	2	4.315	3.872	3.812
	3	4.162	3.770	3.642



TOP VIEW



CROSS SECTION

[a]1 in. = 25.4 mm.

necessary to grind at least 5 mm (3/16 in.) deep for the full width of the cavity to remove this affected area, which was located ∿76 mm (∿3 in.) vertically from the bottom of the cavity. Total time for completion of the welding was ∿187 hr. One hundred ninety-six 2.4-mm-diam (3/32-in.) electrodes and 1624 3.2-mm-diam (1/8-in.) electrodes were used to fill the V-7B cavity. See the photographs in Fig. 6, which illustrate the prolongation V-7B cavity repair welding sequence.

One event possibly worth noting during V-7B prototype cavity repairs was an interpass temperature excursion between 260 and 343°C (500 and 650°F) for 5 hr. A control thermocouple malfunctioned during the welding of layers 51 and 52. These layers were located ∿13 mm (∿1/2 in.) down from the vessel's outer surface. The welder continued welding for 2 hr with the vessel temperature above 260°C (500°F). After shutting off the heat, 3 hr were required to bring the temperature below 260°C (500°F), at which time preheat was reapplied and repair welding continued.

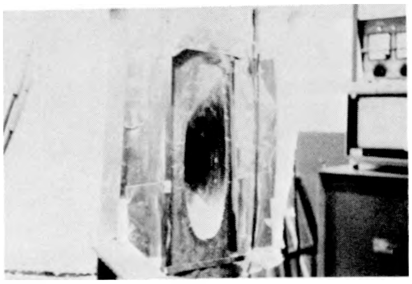
The top cover pass was ground smooth and found to be acceptable by magnetic-particle inspection during the 2 hr required to achieve PWHT temperature. After holding the temperature at 260 ± 28°C (500 ± 50°F) for 4 hr, the prolongation was stripped of insulation and cooled to room temperature in 16 hr.

Strain gage readings were recorded after gages stabilized. Recordings for evaluation by ORNL were also taken before, during, and after the removal of the cross-braces.

The backing bars were ground out next. All visual porosity was eliminated by grinding. Slightly recessed areas, or dimples, were formed by grinding on the prolongation interior; however, minimum allowable vessel wall thickness dimensions were held within Code Standard tolerance limits. See the photographs in Fig. 7, which illustrate details of the V-7B repair weld.

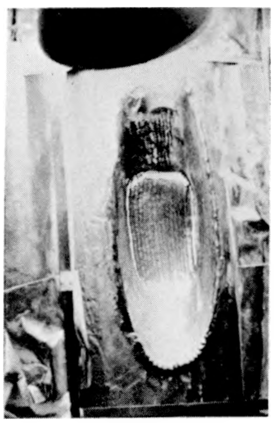
All the required final magnetic-particle, ultrasonic, and radiographic inspections were completed on both the prolongation weldments 48 hr later. Results were acceptable to Code Standards.

ORNL PHOTO 1673–78



(*a*) READY FOR REPAIR WELDING

(*b*) FIRST LAYER ("BUTTER") PASS COMPLETED, HALF-BEAD GRINDING



(*c*) INTERMEDIATE LAYER NEAR BOTTOM OF CAVITY

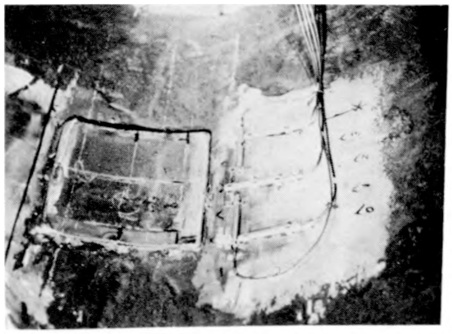
(*d*) INTERMEDIATE LAYER NEAR TOP OF CAVITY

(*e*) FINAL WELD CROWN PASS COMPLETED

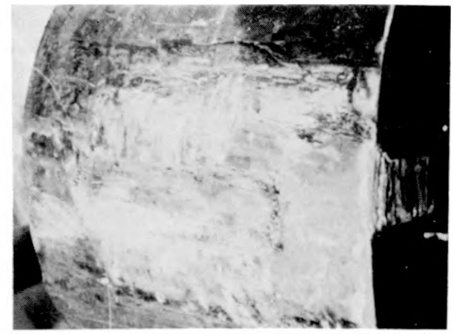
(*f*) FINAL WELD CROWN PASS AFTER GRINDING; GAGE AND THERMOCOUPLE COVERS IN PLACE

Fig. 6. V-8 prolongation — V-7B cavity repair welding sequence.

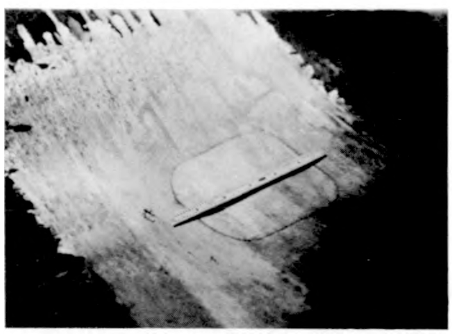
ORNL PHOTO 1674–78



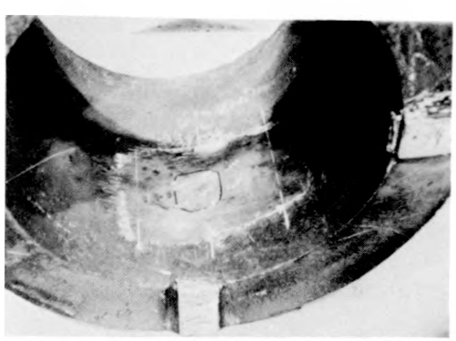
BACKING STRIP AND INTERIOR
GAGES IN PLACE

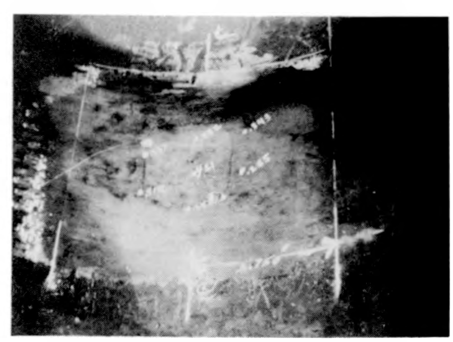


EXTERIOR SURFACE AFTER
FINAL GRINDING



ETCHED ID AREA SHOWING HEAT-AFFECTED ZONE





DIMENSIONS OF GROUND AREA

Fig. 7. V-8 prolongation — V-7B repair, miscellaneous details.

3.2 Vessel V-7B

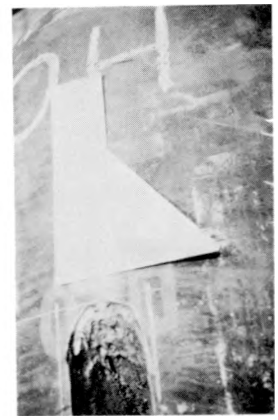
Vessel V-7B was ∿2.13 m tall (∿7 ft), with a 686-mm ID (27-in.), 991-mm OD (39-in.), and a 152-mm-thick (6-in.) wall and, less flanged head, weighed about 7222 kg (8 tons). Vessel details are shown in WTD drawing EDSK-379614J appended to this report. A through-the-wall cavity with outside surface dimensions of ∿768 mm (∿30 1/4 in.) vertically (or longitudinally) by 127 mm (5 in.) wide (circumferentially) was located about midway up the vessel. Sidewalls were cut radially and formed 97 1/2° included angles. The cavity's top end (toward the vessel's dome end) sloped on a 142° included angle plane; the bottom end (toward the head flange end) sloped on a 112° plane. The opening dimensions of the cavity on the vessel's inner surface measured ∿514 mm long (∿20 1/4 in.) by ∿90 mm wide (∿3 1/2 in.). ORNL had furnished the vessel with the cavity's 508-mm-long (20-in.) center portion sidewalls premachined in order to attain accurate reference surfaces for their later use to index flaw planes in the heat-affected zones of the weld repair. These zones are estimated to be ∿2.0 to ∿2.3 mm (∿80 to 90 mils) wide and are formed in the adjacent parent metal of the cavity sides. WTD prepared both connecting cavity ends by thermal gouging to WDT Process Specification NPT-78, which appears in the Appendix. All but the final 6.3-mm (1/4-in.) thickness was removed by air-arc gouging. Thereafter, manual grinding was used for final metal removal to eliminate any flame-induced heat-affected zones and/or carbon contamination within adjoining cavity boundary materials. Refer to the photographs in Figs. 8 and 9, which illustrate the preparations for repairing the cavity in vessel V-7B.

Backing bars were used to seal the cavity bottom; they consisted of 3.2-mm-thick (1/8-in.) carbon steel sheets rolled to the vessel's inside diameter. Two bars were used to expedite postweld bar removal by manual grinding. The first bar was welded all around and hammered in to ensure a good, tight fit, and then the second bar was welded all around on top of the first bar. Installation of the strain gages by ORNL personnel followed.

ORNL personnel installed nine external and six internal strain gages, and Cooperheat personnel installed eight thermocouples and banded internal

ORNL PHOTO 1675–78

(*a*) ARC-AIR GOUGING UPPER (SHELL END) SLOPE



(*b*) UPPER END TEMPLATE

(*c*) GRINDING TO REMOVE FLAME EFFECTS

(*d*) LOWER (FLANGE) END – GROUND; UPPER (SHELL) END – READY FOR GRINDING

(*e*)

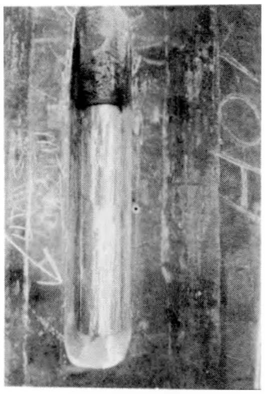
(*f*)

VIEWS OF AS-GROUND LOWER END

Fig. 8. Vessel V-7B — preparations for cavity repair.

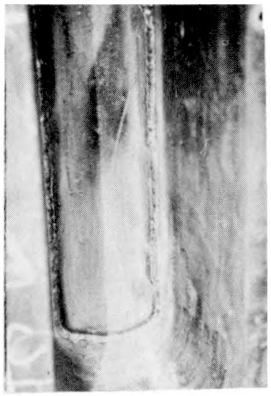
ORNL PHOTO 1676–78

(*a*) UPPER (SHELL) END — AS-GROUND

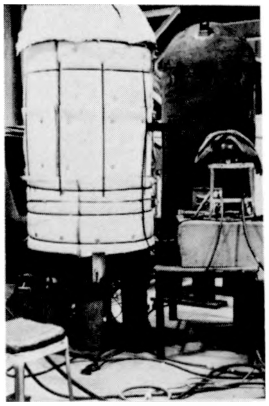


(*b*) CAVITY WITH BACKING BAR ATTACHED

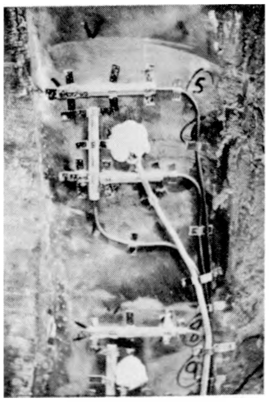
(*c*) EXTERIOR STRAIN GAGES ATTACHED



(*d*) ROOT PASS OVER BACKING STRIP



(*e*) DURING PREHEAT



(*f*) INTERNAL THERMOCOUPLES AND STRAIN GAGES

Fig. 9. Vessel V-7B — miscellaneous preweld preparations.

resistance heaters. Control thermocouples were placed at a 3t (thickness of repair) distance, or 457 mm (18 in.) from the center of the cavity. Stainless steel sheet covers were applied to protect the gages and thermocouples, and sheet blanket insulation was placed around the inner and outer surfaces of the vessel, as shown in Fig. 9.

Approximately 9 hr were required to preheat vessel V-7B up to 177°C (350°F), and this was followed by a 4-hr hold at preheat temperature for gage stabilization.

Twenty hours were spent in welding the first "butter," or temper-bead layer; and 354 electrodes, 2.4 mm in diameter (3/32 in.) were used. Manual grinding to remove half of the temper bead followed. It was extremely difficult to obtain accurate reproducible measurements in the cavity at about 204°C (400°F) to determine when half of the bead had been ground off. Measurements made before and after grinding are shown in Table 4. No attempt was made to grind the bead deposit from atop the backing bars. Final postrepair removal of the bars will effect similar tempering cures. The first layer ("butter") vertical-deposit sequence is shown in the photographs of Fig. 10. The second layer was deposited with 3.2-mm-diam (1/8-in.) electrodes and covered the first layer in the same vertical-pass-sequence buildup from the inside outwards for both bottom and sides. The rod-buildup sequence for cavity bottom and sides was continued for a third layer, using 3.2-mm-diam (1/8-in.) electrodes. The procedure stipulated that cavity welding hereafter could be made as "fill" from the interior up only, using 3.2-mm-diam (1/8-in.) or 4-mm-diam (5/32-in.) electrodes.* Three such fill passes were deposited with 4-mm-diam (5/32-in.) electrodes; however, difficulties with severe porosity formation were encountered. The welding technicians reported that after burning a 4-mm-diam (5/32-in.) electrode for ∿76 mm (∿3 in.), the remainder of the electrode overheated and hence could not be used. It was also noted that the area being welded overheated, resulting in excessive undercut occurences. Attempts were made to reduce the heat input to the electrode, but lowering the welding amperage made it extremely difficult to maintain an arc.

*Similar difficulties were also encountered on test plate and prolongation welding.

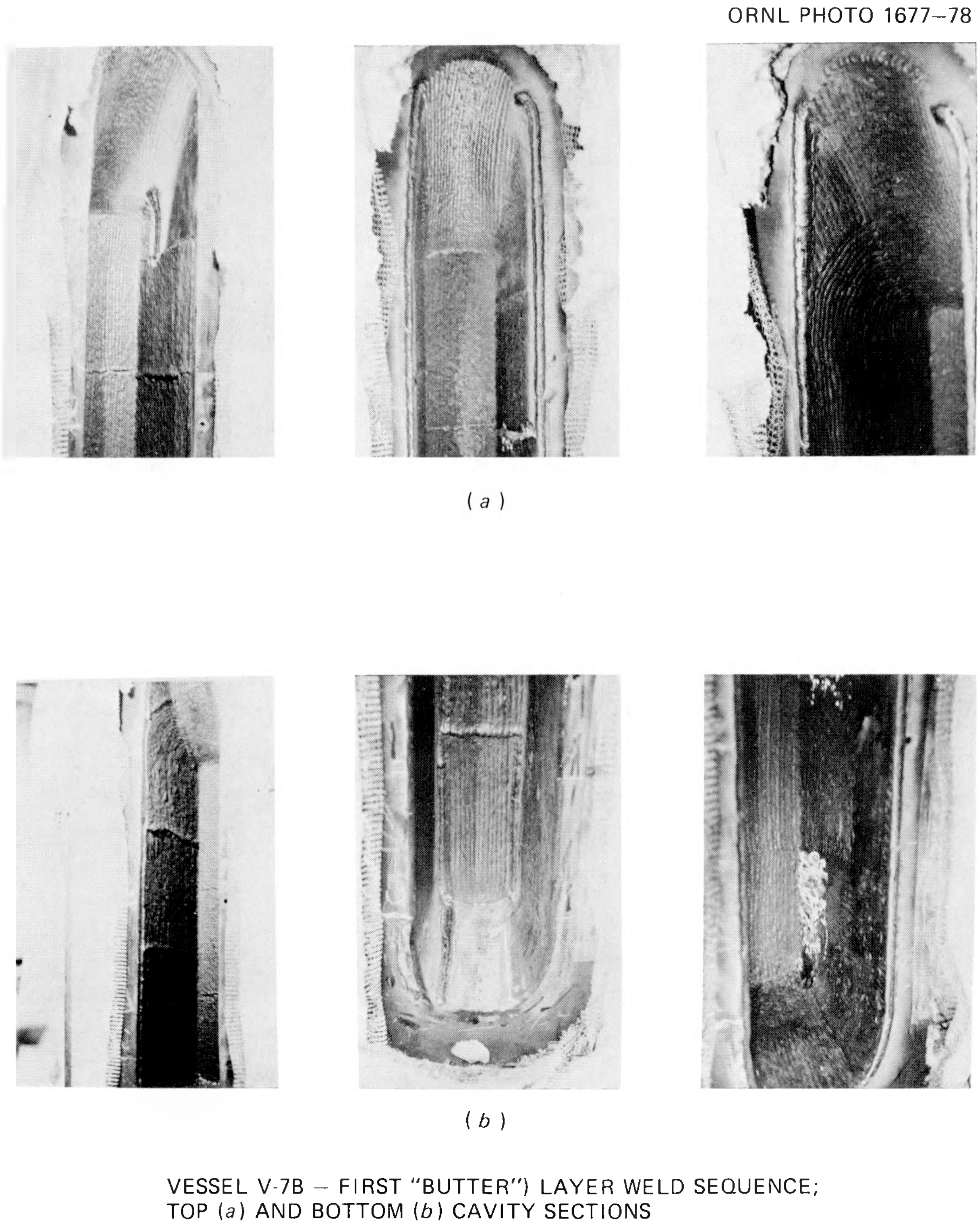


Fig. 10. Vessel V-7B — first ("butter") layer weld sequence; top (a) and bottom (b) cavity sections.

Therefore, it was decided to complete filling operations using 3.2-mm-diam (1/8-in.) electrodes.

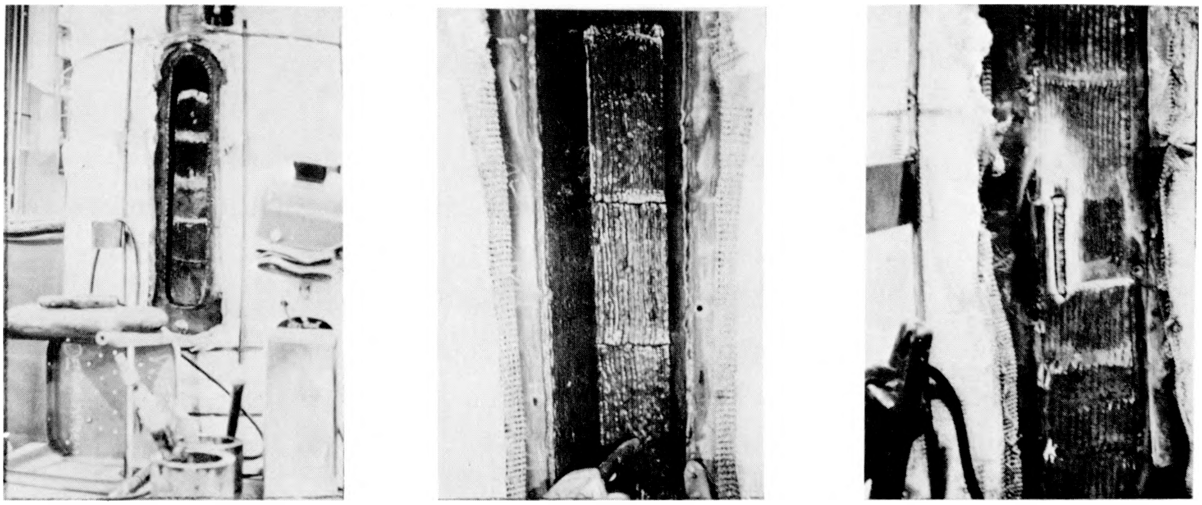
Some seemingly minor porosity was also encountered while using the 3.2-mm-diam (1/8-in.) rod electrodes to fill the cavity. For the most part, such porosity appeared to be located in the start and stop zones. All porosity indications were generally visible to the naked eye and were eliminated by grinding, as confirmed by the routine magnetic-particle inspections that were conducted on alternate layers.

Interpass temperature control was based on a thermocouple installed on the vessel's outer surface 76 mm (3 in.) in from the edge of the cavity. This thermocouple registered every 20 sec on a separate temperature recorder. Temperatures did not exceed the 177°C (350°F) limit, even during the welding of final cover passes.

Sixty-two layers were required to fill the cavity, and the work was accomplished in 408 hr (17 days) of continuous welding. Many electrodes were used in the welding: 371 2.4-mm-diam (3/32-in.) electrodes; 4876 3.2-mm-diam (1/8-in.) electrodes; and several boxes (estimated at $\sim$200 ea) of 4-mm-diam (5/32-in.) electrodes. Typical welding and grinding sequences are shown in the photographs in Fig. 11, and typical pass and layer sequences are listed in Figs. 12 and 13.

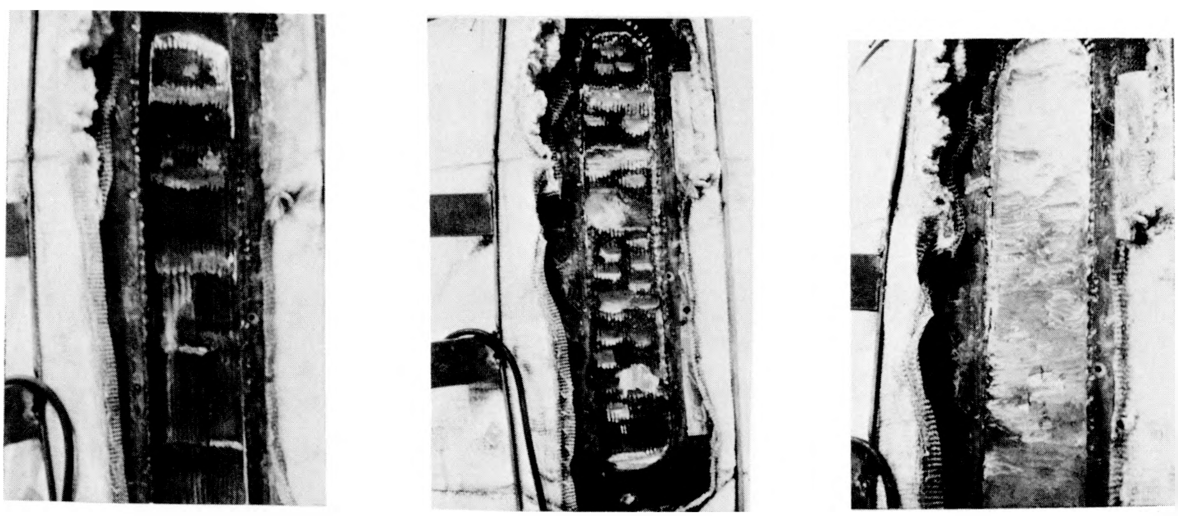
An attempt was made to save time by grinding the final cover pass to blend with the vessel's outer surface contour while increasing heater input to elevate vessel temperature to the PWHT temperature plateau of 260 $\pm$ 28°C (500 $\pm$ 50°F). Air-grinding operations, however, had an effect on the uniformity of heatup: thermocouple recordings registered considerable temperature spread between various vessel locations, and thermocouples uncovered for the grinding were influenced by the constant stream of air flow associated with the air-grinding process and hence indicated low readings. Accordingly, heat input had to be reduced to preheat settings until grinding was completed and the final magnetic-particle examination was made. Thereafter, it required 3 hr to attain vessel PWHT temperature. The vessel was then held at $\sim$260°C (500°F) for 4 hr before removal of insulation for cooldown. The vessel cooled down to ambient temperature in about 2 days, at which time final strain gage readings were taken prior to gage and thermocouple removal from the vessel.

ORNL PHOTO 1678–78



(a)

INTERMEDIATE LAYERS, REPAIR WELDING WITH STAGGERED WELDING SEQUENCE



(b)

TYPICAL GRINDING SEQUENCE BETWEEN LAYERS

Fig. 11. Vessel V-7B — repair details.

ORNL–DWG 78–8249

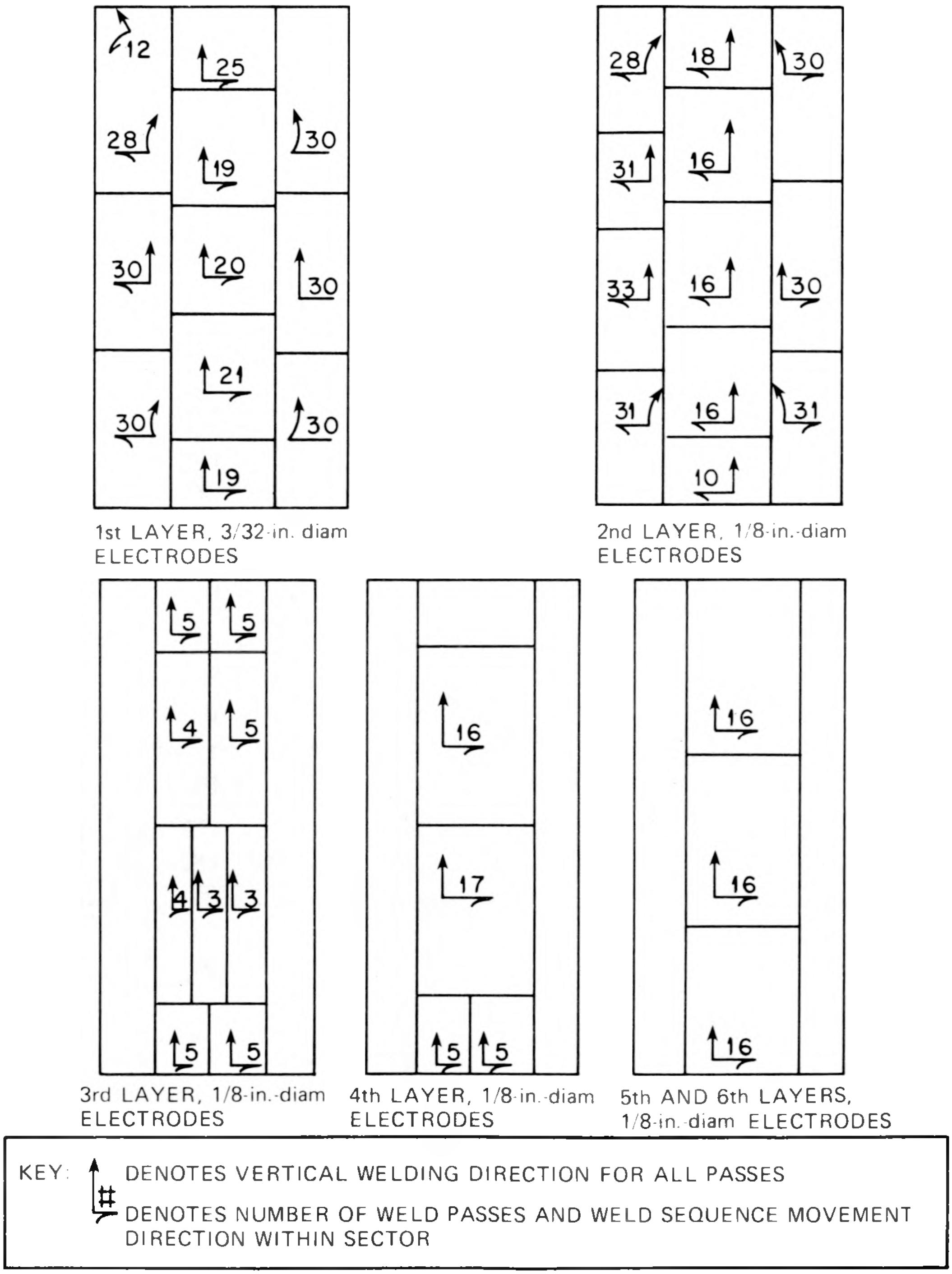


Fig. 12. Vessel V-7B — weld pass and layer sequences for layers 1–6 (1 in. = 25.4 mm).

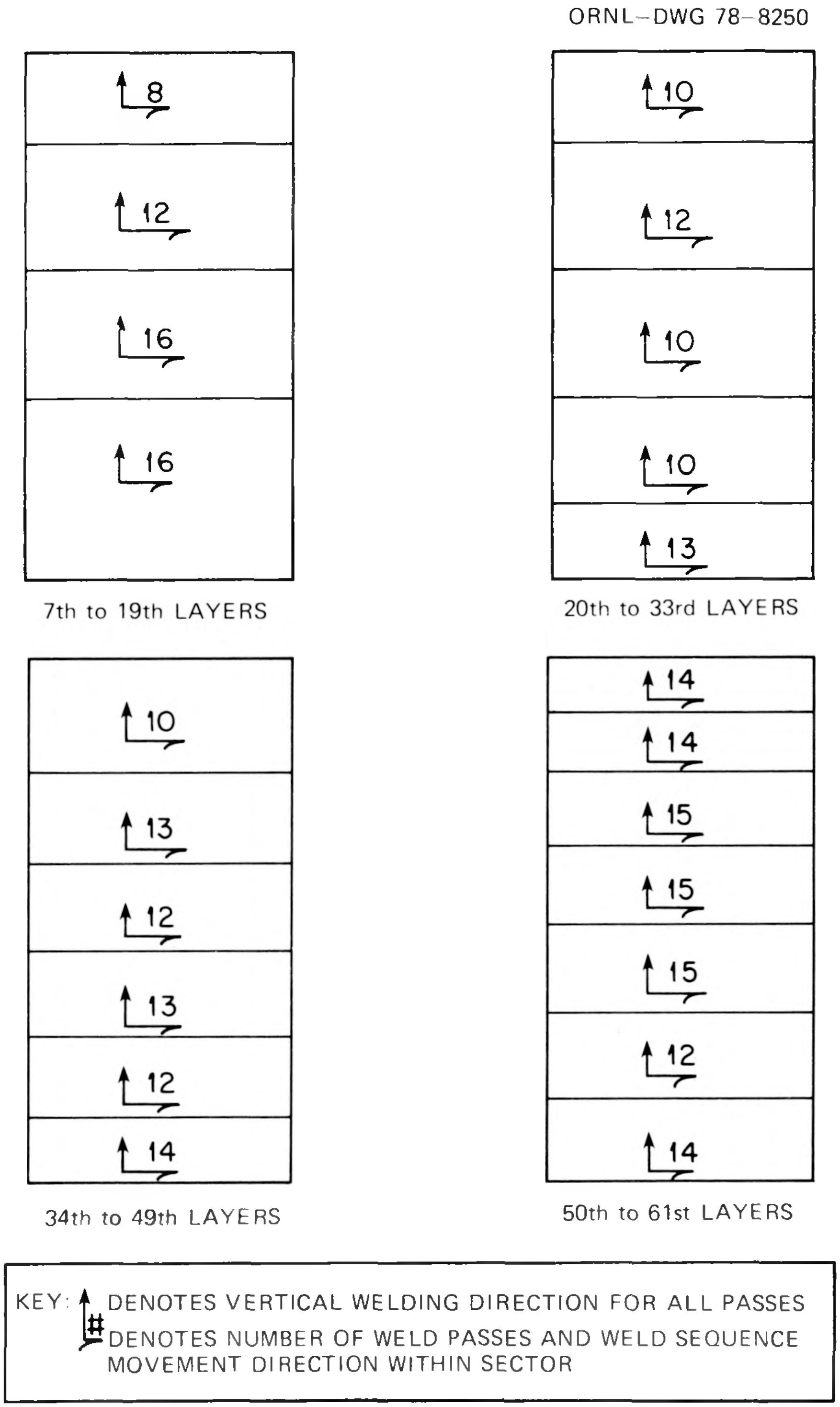


Fig. 13. Vessel V-7B — weld pass and layer sequences for layers 7–61 [all 3.2-mm-diam (1/8-in.) electrodes].

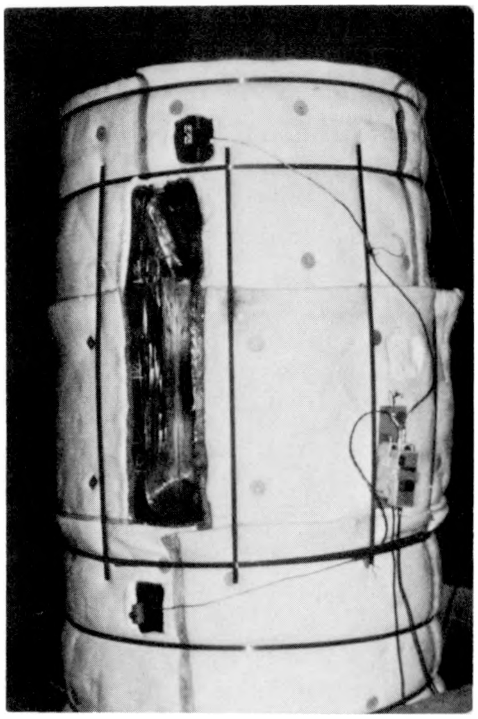
Acoustic-emission (AE) monitoring of the vessel was performed on a continuous basis by personnel of GARD, Inc., under the direction of D. W. Prine, Project Engineer. Preheat, repair welding, PWHT, and the cooldown operation were monitored using the GARD AE-monitoring equipment shown in Fig. 14. AE sensors were attached to the vessel's outer surface just beyond each end of the repair cavity. The sensors were coupled to an adjacent mounted preamplifier, and cables connected to the preamplifier transmitted boosted signals to a console located near the work station where the signals were processed, displayed, and stored.

The GARD AE weld monitor is built around commercial Dunegan Endevco acoustic-emission equipment with a GARD-designed flaw alarm and signal-processing system added to permit location of the AE sources that satisfy the flaw alarm criteria. These criteria vary for material and welding process and include AE burst energy, frequency, and burst rate. The flaw location information is read out on a storage oscilloscope, and permanent records are made by photographing the scope display. Raw AE data are stored on magnetic tape for later playback using a GARD-modified Sony video tape recorder. Data recording band width is 0.1–1 MHz. AE data are also stored on paper strip chart recordings, which include burst energy (signal ring down count) and AE alarms. Records are also made of weld current vs time to help keep track of weld passes.

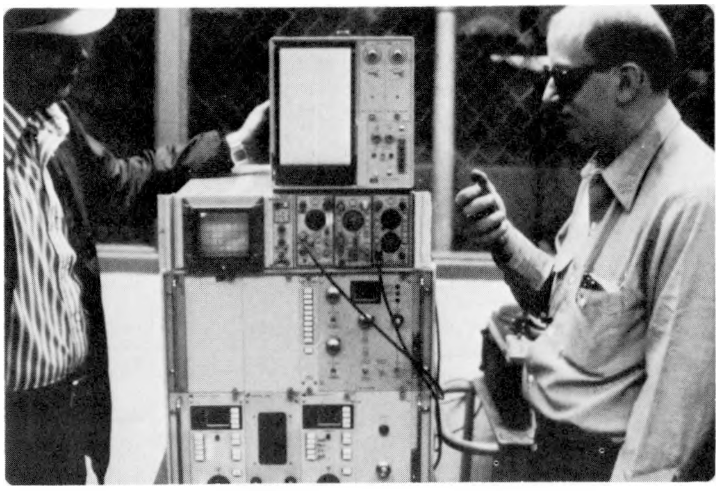
Weld repair backing bars were removed by grinding inside the vessel with the grinder standing on the floor and inside the vessel's flanged head opening. In removing the backing plates, the grinder encountered visible porosity ∿254 mm (∿10 in.) below the repair cavity centerline, or near the junction of the vessel's inner surface and the 112° included corner angle slope toward the vessel's flanged head end. Porous areas were then ground out as verified by magnetic-particle inspection. The resultant newly ground inner cavity measured approximately 127 mm (5 in.) wide circumferentially by 25.5 mm (1 in.) high vertically by 22 mm (7/8 in.) deep.

The entire weld repair zone of the vessel was next subjected to both straight and 45° shear-wave ultrasonic and radiographic inspections to ensure that no additional repairs were needed before commencing to reweld

ORNL PHOTO 1679–78



(a)



(b)

the newly formed "corner cavity." Generally acceptable ultrasonic indications were noted throughout. Questionable ultrasonic indications, however, were observed in an area near the intersection of the vessel wall and the 142° slope. Ultrasonic shear-wave inspection recheck indications produced signals equivalent to 20 to 30% of the distance amplitude correction (DAC) curve, and radiographic inspection confirmed these findings. Radiography also revealed minor porosity indications adjacent to a predrilled 1.6-mm-diam (1/16-in.) passage previously placed in the vessel to establish test pressure equalization on both sides of a patch liner. (For the final vessel pressurization test, a patch is used on the inside surface of the vessel below the flaw to deter or stop the pressurization media from leaking through the cracked vessel wall.) Repeat radiography via triangulation methods indicated that these porosity effects were located in various staggered thickness planes respectively separated by about 25.5 mm (1 in.) of solid metal. Hence, porosity was unstacked and not continuous. Another area of minor porosity [∿6.3 mm (∿1/4 in.) in diameter] was noted ∿114 mm (∿4 1/2 in.) from the 1.6-mm (1/16-in.) passage toward the vessel's head flange end adjacent to the cavity wall on the side of the hole. Radiography indicated that the porosity was located in two planes, 9.5 mm (3/8 in.) and 36.5 mm (1 7/16 in.), respectively, below the vessel's outside surface. No other defects were revealed by radiography. The surfaces and all areas adjacent to the newly ground-out inner surface cavity appeared to be sound.

Wherever there were questionable implications of minor porosity and/or isolated slag inclusion based on the ultrasonic and radiographic findings, these minute areas were separated by solid metal. It was therefore decided to limit repairs to rewelding the ground-out cavity area at the vessel's inside diameter to the 112° slope. ORNL and WTD agreed to accept all the minor imperfections noted on the radiographic films. The fine porosity indications were all passable within the Code, except possibly for the single marginal [∿3.2 mm (∿1/8 in.) × 16 mm (5/8 in.)] very thin horizontal defect noted near the dome end of the repair. It was also considered acceptable, however, based on repeat triangulation x rays and the intended end use of the vessel for test purposes.

The half-bead (temper) technique (WTD Process Specification NPT-77) was also used for the weld re-repairs on the vessel's inner surface with additional Cooperheat resistance heaters (63-kW total capacity) this time placed on the vessel's exterior surface only. Exterior thermocouples and blanket insulation were installed. It required ∿1 day for the vessel to reach the 177°C (350°F) preheat temperature, and then a welder wearing protective clothing and mask entered the vessel to start repairs. "Butter" layer welding with 2.4-mm-diam (3/32-in.) electrodes, grinding down half of that layer, and subsequent depositing of 3.2-mm (1/8-in.) layers were all accomplished with the welder standing upright on the floor, working through the vessel's flanged head opening in a 177°C (350°F) highly confined oven-like environment. Re-repairs were identical to earlier work, with the following exceptions:

1. the weld repair position was horizontal;
2. magnetic-particle test inspections were conducted at similar frequency, but using the yoke technique;
3. strain gaging was not used;
4. AE monitoring was omitted;
5. preheat was maintained at the 177°C (350°F) minimum condition for the immediate cavity area.

About 9 hr were required to complete all re-repair welding, grinding, and inspections. Refer to Fig. 15 for pass and layer sequences. The ∿100-cm^3 (∿6-$in.^3$) cavity was filled with 13 2.4-mm-diam (3/32-in.) and 38 3.2-mm-diam (1/8-in.) electrodes. Additional heat input then brought the vessel up to postweld heat temperature in about 30 min. After the temperature was held at 260 ± 28°C (500 ± 50°F) for 4 hr, the vessel was stripped of all insulation and cooled to ∿52°C (∿125°F) in 1 day. Forty-eight hours later final magnetic-particle testing and ultrasonic testing inspections were held on both the re-repair and the entire cavity repair. Re-repairs were acceptable; other findings were as previously noted.

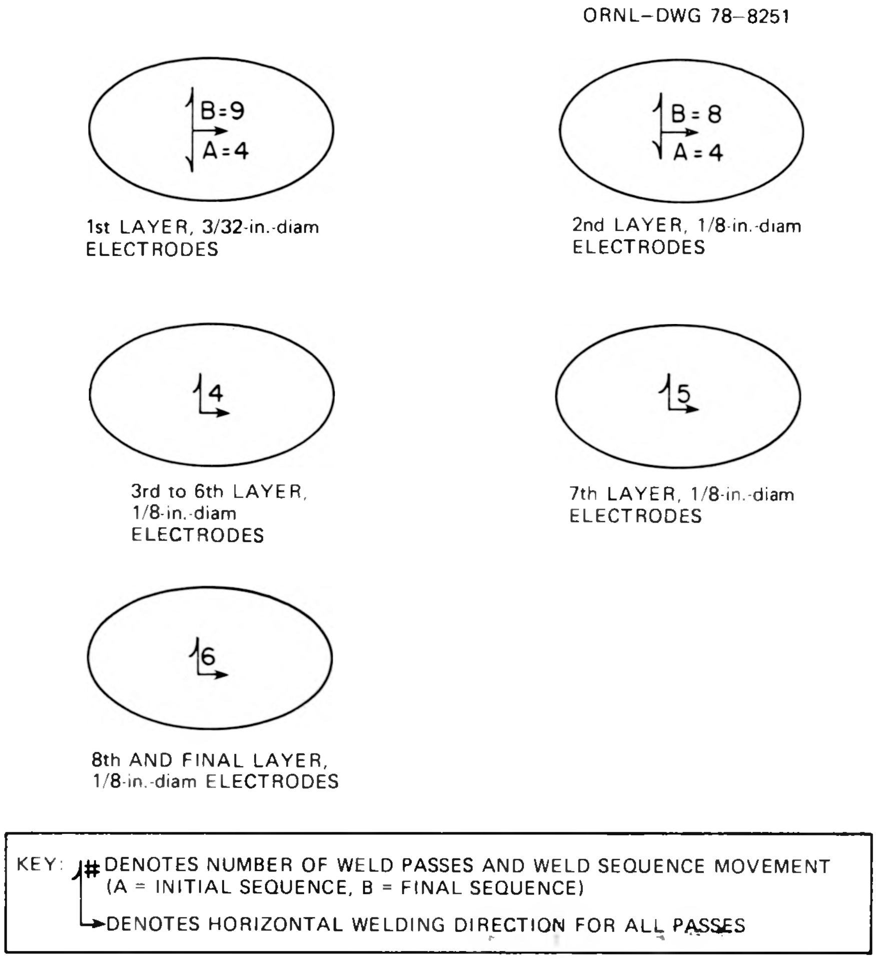


Fig. 15. Vessel V-7B re-repair (half-bead repair to vessel interior); weld pass and layer sequences (1 in. = 25.4 mm).

3.3 Vessel V-8

The basic test vessels V-7B and V-8 are identical. Vessel V-7B had previously been used in two tests; V-8 was an unused vessel. Only the repair cavity and flaw sizes and the azimuth locations differed for the two vessels. Vessel V-8 was furnished to Westinghouse with an approximately half-wall-thickness premachined cavity midway up the vessel's cylindrical portion extending halfway into the vessel's seam weld. This cavity, identical to the prolongation V-8 cavity, measured 318 mm (12 1/2 in.) × 82.5 mm (3 1/4 in.) on the vessel's outer surface and was 90 mm (3 1/2 in.) deep.

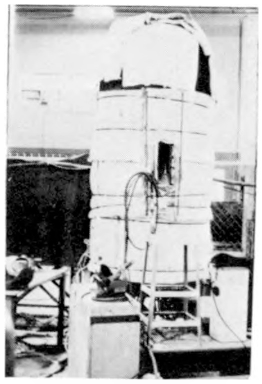
Sidewalls were cut on radial planes; top and bottom ends were tapered on 45° slopes toward the cavity's center, as shown on the appended drawing EDSK-379614J. The V-8 repair selections were made to simulate field repairs to vessel weldments.

Actual vessel V-8 weld repairs were held up pending the completion of the prolongation V-8 cavity repair to evaluate strain gage data and to possibly alter strain gage locations. Preliminary data analysis, however, indicated that the gage number and placement selections were adequate, and the vessel was instrumented the same as the prolongation. Thermocouples were also placed on the vessel in accordance with the Code requirements; the outermost thermocouples were located at 3T (thickness of work), or 457 mm (18 in.), from the cavity center.

The vessel was preheated to 177°C (350°F) in ~14 hr; an additional 4 hr were allowed for strain gage stabilization hold time. Thereafter, ~6 1/2 hr were required to deposit the "butter" layer with 2.4-mm-diam (3/32-in.) electrodes, which was followed by grinding off half of the deposit. The before- and after-grinding measurements are recorded in Table 3. A period of 91 hr was required to complete the weldment, including time for all prescribed magnetic-particle inspections. The final 18 layers were staggered to minimize and hopefully eliminate porosity trends based on earlier experience with vessel V-7B repairs and ultrasonic and radiographic inspections of those repairs. Photographs of the welding sequence are shown in Fig. 16. Figure 17 illustrates the typical pass and layer sequences used. One hundred twenty-four 2.4-mm-diam (3/32-in.) and 771 3.2-mm-diam (1/8-in.) electrodes were used to fill the ~1557-cm^3 (~95-$in.^3$) cavity in vessel V-8.

One 8-hr shift was spent in contour-grinding the cover pass and in making the final magnetic-particle inspection, followed by a 2-hr heatup to postweld temper temperature — 260 ± 28°C (500 ± 50°F). After this temperature was held for 4 hr, the vessel was stripped of insulation and cooled to room temperature in ~2 days. Forty-eight hours later, the required final magnetic-particle, ultrasonic, and radiographic inspections were completed. These inspections indicated that the welding was acceptable according to ASME Code requirements.

ORNL PHOTO 1680–78



(*a*) DURING PREHEAT

(*b*) FIRST LAYER AFTER GRINDING

(*c*) WELDING SEQUENCE

(*d*) CONTINUED WELDING

(*e*) FINAL GRINDING

(*f*) EXTERIOR SURFACE THERMOCOUPLE AND STRAIN GAGE LOCATION

Fig. 16. Vessel V-8 repair details.

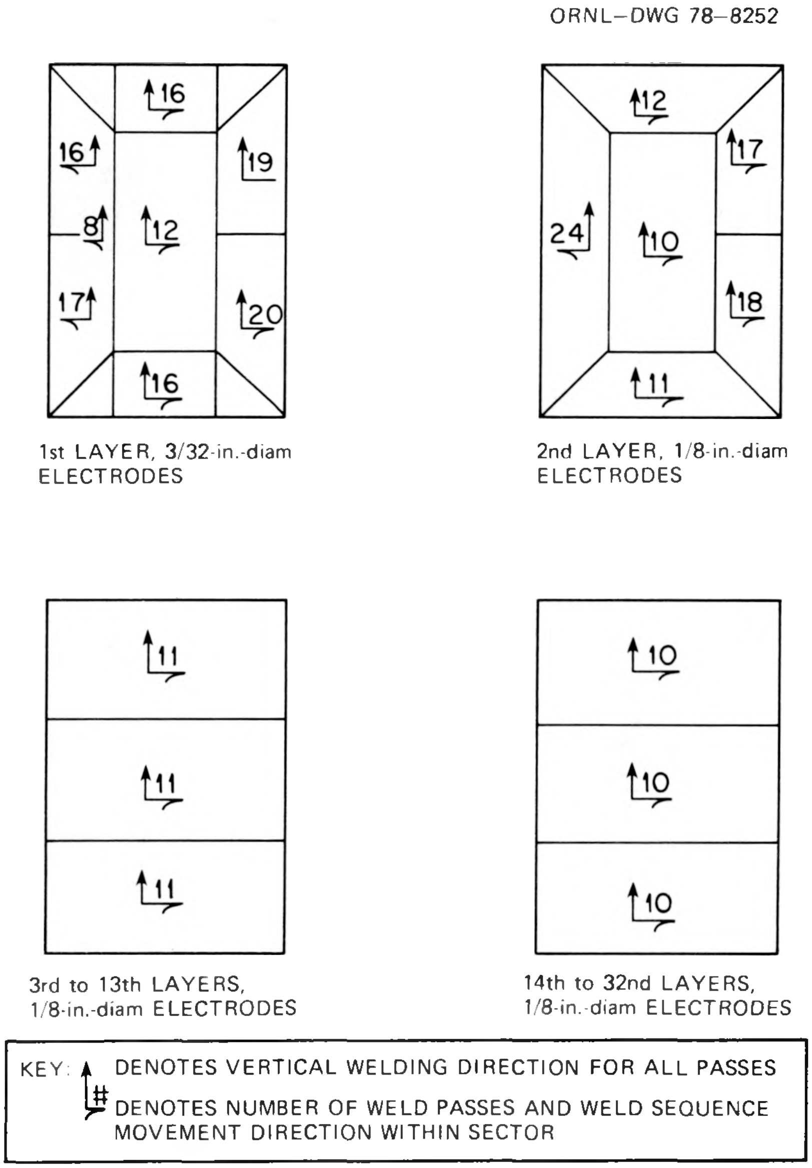


Fig. 17. Vessel V-8 — weld pass and layer sequences (1 in. = 25.4 mm).

3.4 Plate 57 and Weld Coupons

ORNL had provided WTD with A-533, grade B, class 1 plate stock for use in familiarizing their welders with the upcoming weld repair work on the prolongation and the two vessels. An alternate purpose for this practice plate stock was to provide ORNL with typical weldments for use in their work on electron-beam flawing development. Job specifications also called for all practice work to be performed to ASME Code half-bead repair weld guidelines, except for substituting visual examinations for otherwise timely magnetic-particle inspections of alternate layers.

Figure 18 illustrates repair work sequences for plate 57, a 152-mm-thick (6-in.) plate, 902 mm (35 1/2 in.) × 432 mm (17 in.), provided with two V-8-size cavities premachined into the stock. This plate was mounted in the vertical position and preheated to 177°C (350°F) using gas torches. "Buttering," grinding, "rebuttering," and fill-welding required 53 and 48 hr, respectively, for the two cavity welds. The 260°C (500°F) PWHT was also accomplished with gas torches and magnetic temperature indicators.

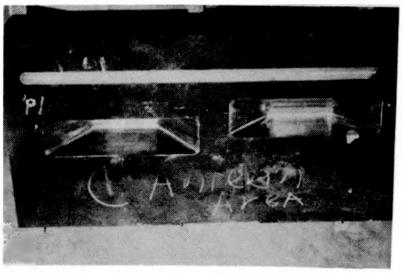
Four pregrooved weld coupons, as shown in Fig. 16, were also provided for additional practice block material. The SA-533B plate stock [50-mm-thick (2-in.) and 132 mm (5.2 in.) × 335 mm (13.2 in.)] included continuous grooves 44 mm deep (1 3/4 in.) × 38 mm wide (1 1/2 in.) and 44 mm deep (1 3/4 in.) × 64 mm wide (2 1/2 in.), respectively, with 7 1/2° side slopes to simulate the vessel cavity configurations. Gas torches were used for preheat and a furnace for the PWHT.

3.5 Tensile Test Plates

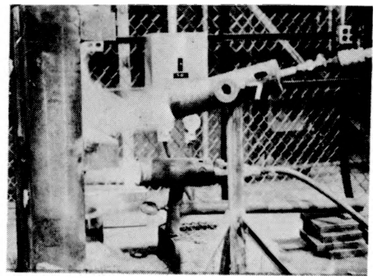
WTD fabricated special support braces for welding pairs of flat bars from SA-533B plate stock in vertical position for the manufacture of tensile test plates. One set of 46-mm-thick (1.8-in.) × 89-mm-wide (3 1/2-in.) flats and two sets of 43-mm-thick (1.7-in.) × 89-mm-wide (3 1/2-in.) flats, all of which were ∿508 mm long (20 in.), were restrained into and tack-welded to these fixture braces. The bars were tapered the same as the vessel cavity sides; bar spacings simulated the cavity layout. Plate backing bars, sequential heating, welding, and inspection operations were to Process Specification NPT-77 (the WTD shop specification issued to meet ASME Code Section XI half-bead welding guidelines). The plates were preheated with gas burners and preheat and interpass temperatures were determined by magnetically attached thermometers, as shown in Fig. 19.

The tensile specimens were ultrasonically and radiographically examined following the completion of welding and the prescribed postweld temper treatment at 260°C (500°F) in an electric furnace. Two of the

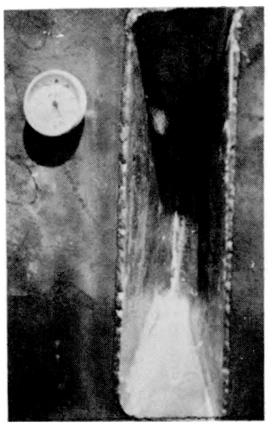
ORNL PHOTO 1681–78



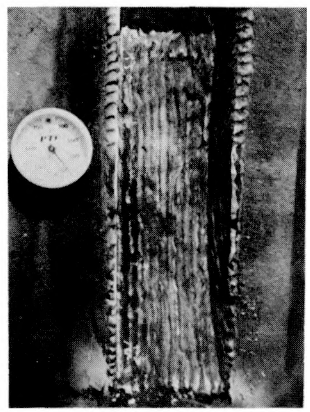
(*a*) TEST PLATE AS RECEIVED



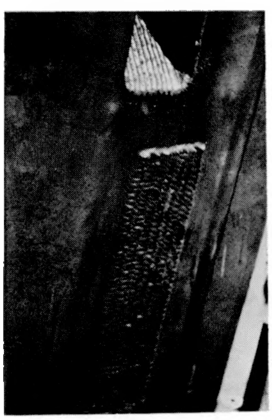
(*b*) PREHEAT FOR VERTICAL WELDING



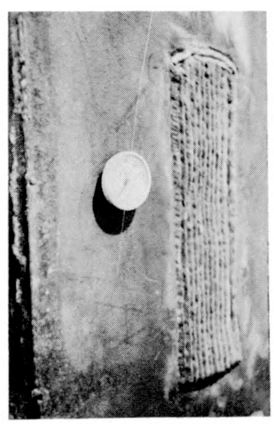
(*c*) FIRST LAYER AFTER GRINDING



(*d*) CONTINUED WELDING



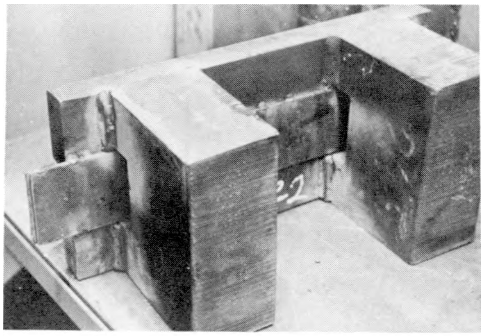
(*e*) COMPLETED FIRST CAVITY



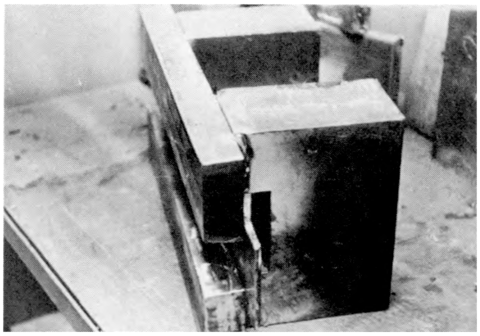
(*f*) COMPLETED SECOND CAVITY

Fig. 18. Weld practice test plate.

ORNL PHOTO 1682–78

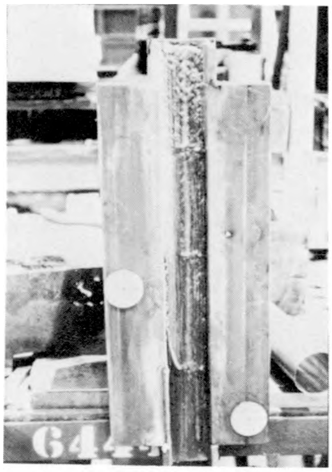


(*a*)

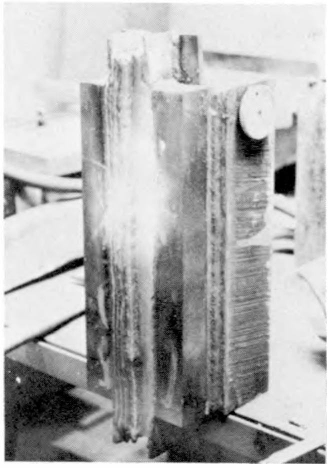


(*b*)

TEST PLATES WITH BACKING BARS IN SUPPORT BRACES

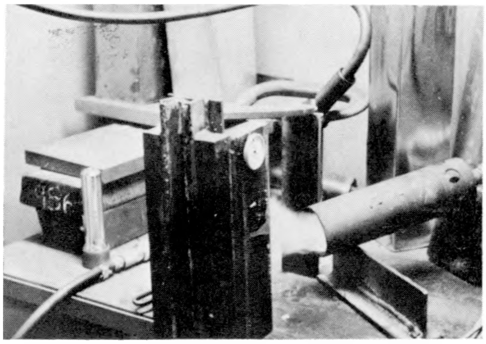


(*c*)



(*d*)

TYPICAL WELDING SEQUENCE VIEWS



(*e*) TYPICAL PREHEAT

(*f*) TYPICAL COMPLETE WELD

Fig. 19. Tensile test plates.

three specimens prepared met inspection acceptance standards, but the third specimen was rejected based on porosity indications in excess of that permissible by the ASME Code. The tensile specimens were forwarded to ORNL for analysis.

4. RECOMMENDATIONS

For deep vertical repair welds which are to be done manually, greater access for welders must be provided by substantially increasing the wall angle. Limited access hampers manual repair welding efforts, especially for vertical-position welding. Welding the half-wall-thickness cavity in the prolongation and in vessel V-8 did not present unusual welding problems because, for these repairs, the maximum welding depth was limited to 89 mm (3 1/2 in.). The welders had sufficient working room, which afforded easy access to the entire bottom of the repair area. The through-the-wall 155-mm (6-in.) repair cavities in both the prolongation and in vessel V-7B, however, presented considerable problems for the welders. The primary difficulties were the limited access for welding, the 152-mm (6-in.) repair depth, the narrowness of the area to be repaired, and the 7 1/2° angles on each of the cavity's sidewalls.

Additional development work is suggested to test alternate techniques for achieving proper tempering of the "butter" layer. The determination of when the first, or "butter," layer has been ground off ends up as a decision based on judgment. It is extremely difficult to establish accurate reproducible depth measurements in a repair cavity at 177 to 204°C (350 to 400°F). The literal interpretation of "grinding off half of the first layer" resulted in many hours of discussion and measurements before agreement was reached as to when the surface approximating the half-layer was reached. Care can be exercised to not grind off the entire layer, but actual ground layer measurements should not be required. The use of small electrodes for the "buttering" layer followed by a second "buttering" layer applied with larger-diameter electrodes may achieve adequate tempering of the initial layer and the adjacent base metal. It may even be possible to omit grinding of the first layer altogether.

The suggested development efforts should also test repairs employing staggered electrode sizes for early layers only — omitting grinding. Considerable savings could result if it were possible to eliminate grinding operations without sacrificing tempering effects. If these suggested tests prove to establish repair welds of a quality equivalent to the present half-bead repairs, then combined efforts should be solicited from the developer and industry to revise the present Section III and Section XI ASME Code requirements for half-bead welding.

Semiautomated or automated process welding repairs or such repairs in conjunction with and following manual half-bead process welding of early layers would help to greatly reduce the time required for repairs. For in-service repairs at a nuclear facility, this might mean vastly reduced welder exposure time. Research and development efforts should also be extended in this direction. The man-hour-to-cavity-fill deposit rate for WTD half-bead repairs averaged only $\sim$8.2 cm^3 ($\sim$0.5 $in.^3$) of deposit for each man-hour spent. The number of man-hours includes the hours worked by all personnel assigned to a shift — generally two welders and a part-time inspector. Equivalent clock-time-to-cavity-fill rates averaged 19 cm^3 (1.16 $in.^3$) of deposit for each clock-hour of operation.

The maximum extent of repair limitations (ASME Code, Section III, Paragraph NB 4642.2) and extensive welding procedure and welder prequalification requirements (ASME Code, Section XI, Paragraph IWB 4423.3) should now be reviewed by Code committee personnel. Favorable Code changes to establish increased depth of weld repair allowances and less extensive prequalification requirements seem to be in order based on the success of WTD and Combustion Engineering on HSST vessel half-bead weld repairs.

ACKNOWLEDGMENTS

The authors wish to express their deep appreciation for efforts far beyond the normal requirements by personnel of Cooperheat Company and GARD, Inc., by M. L. Carpenter of Westinghouse Tampa Division, by the Westinghouse welding technicians, and by C. E. Childress and T. A. King of Oak Ridge National Laboratory.

We also wish to thank Combustion Engineering, Inc., for giving us a copy of Report EPRI-NP-179 covering their work on a similar assignment, which provided helpful background and direction.

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1. J. G. Merkle et al., *Test of 6-in.-Thick Pressure Vessels. Series 3: Intermediate Test Vessel V-7*, ORNL/NUREG-1 (August 1976).

2. W. D. Goins and D. L. Butler, *Weld Repair of Heavy Section Steel Technology Program Vessel V-7*, EPRI NP-179 (ORNL/Sub/88242-76/1), Combustion Engineering, Inc. (August 1976).

3. R. H. Bryan et al., *Test of 6-in.-Thick Pressure Vessels, Series 3: Intermediate Test Vessel V-7A*, ORNL/NUREG-9 (February 1978).

4. R. H. Bryan et al., *Test of 6-in.-Thick Pressure Vessels, Series 3: Intermediate Test Vessel V-7B*, ORNL/NUREG-38 (in preparation).

5. G. C. Smith and P. P. Holz, *Repair Weld Induced Residual Stresses in Thick-Walled Steel Pressure Vessels*, ORNL/NUREG/TM-153 (in preparation).

APPENDIX

Union Carbide Corporation, Nuclear Division
(Oak Ridge National Laboratory)

WELDING SPECIFICATION W-HB-105

10/8/76 Issue Date

WELDING SPECIFICATION NO. W-HB-105*†

LOW HYDROGEN ELECTRODE MANUAL SHIELDED METAL-ARC WELDING FOR "HALF-BEAD" REPAIR WELDING (Vessel positioned vertically)

Scope

This specification covers the Welding Procedure (Part I) and Welder Performance Qualification and Procedure Qualification Tests (Part II) for manual shielded metal-arc repair welding on 6-in.-thick low-alloy steel materials using low-alloy, low-hydrogen steel electrodes comparable to Section XI requirements. This weld procedure is specifically applicable for vessel weld repairs from the exterior for vertically positioned vessels using the "half-bead" technique, whereby the entire cavity of the preheated vessel is "buttered" using 3/32-in.-diam electrodes. The "buttered" deposit thickness is then half removed by grinding. Subsequently, the remainder of the cavity is then filled using 1/8-in.- and/or 5/32-in.-diam electrodes. Removal of half of the initial weld layer (buttering) permits the heat from the next weld pass to refine the grain size of the base metal heat-affected zone, as well as for tempering purposes. Preheat is to be maintained throughout the entire welding operations.

The machined notch and the adjacent cracked and yielded zone of the vessel shown in Fig. 1 will be repaired by this welding procedure. This procedure

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*Reference: ASME Boiler and Pressure Vessel Code, Section XI (In-Service Inspection), Subsubarticle IWB-4420 (Repair Procedure No. 4).

References to portions of the Code are to the 1974 edition with the Summer 1974, 1975, and Winter 1975 addenda and are to Section XI unless stated otherwise.

†In this Welding Specification "fabricator" is used to mean the subcontractor in whose shop the welding is performed, and the "UCC-ND" is used to mean the Union Carbide Corporation, Nuclear Division.

2

also requires the preparation and welding of a qualification test piece as follows:

> Qualification Test Piece: A UCC-ND furnished 6-in.-thick wall ASTM A533, grade B, class 1 prolongation from a vessel, as shown in Fig. 4, along with a bracing arrangement for the backing plates and end restraints for the cylinder ends to be furnished by the fabricator.
>
> The same qualification test piece shall be used also to qualify this procedure for an apporximately half-wall thickness "half-bead weld repair" to a submerged-arc longitudinal vessel seam weld as shown in Fig. 8. The two cavities shall be spaced at approximately 180° per Fig. 8 layout.
>
> The weld repairs to the prolongation must be done sequentially. The prolongation shall be allowed to cool to room temperature and then to remain at room temperature for a minimum of 24 hours in between sequential weld repairs.
>
> Test coupons shall also be furnished (refer to Fig. 3).

Individual welders must be qualified under Section IX of the Code for a procedure having the same essential variables for welding performance qualification as the procedure of Part I, or they must weld the 3 in. qualification plate shown in Fig. 2 of this specification to demonstrate qualification under this procedure. The Weld Procedure Qualification Test Piece (Fig. 4) is used to demonstrate the qualification of the procedures used by the welders for repair of the vessel.

Participation of UCC-ND and GARD*

The UCC-ND shall be permitted access to the fabricator's facilities to witness all work on this project and to make strain measurements as required.

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*General American Research Division, Inc. (Subsidiary of GATX Corporation).

GARD personnel shall be permitted access as required to acoustic emission monitor vessel repair welding.

UCC-ND and GARD shall furnish material, labor, and equipment for this work; the fabricator shall provide utilities to support the work. UCC-ND work may consist of the application of weldable strain gages that have been stabilized to both the vessel and the prolong after the backing plate and suitable internal brace restraints have been installed but prior to preheating. Strain gage measurements will be recorded as follows:

1. prior to the application of preheat;
2. four hours after the vessel reaches the specified preheat range but before welding commences;
3. after all welding is completed but prior to the post-weld heat treatment;
4. after the post-weld heat treatment is completed but before cooling;
5. after the temperature has been at ambient temperature for a minimum of 2 hours but before removal of bracing and restraints;
6. after removal of bracing and restraints.

GARD personnel will attach sensors to the vessel and connect these sensors to their console equipment for AE monitoring.

The fabricator shall notify UCC-ND and GARD of the testing schedule at least 24 hours prior to each measuring hold point. Should test or monitoring personnel be unavailable for testing during these hold points, on a reasonable basis, the fabricator shall have the authority to bypass the required strain or acoustic measurements.

Efforts should be made to electrically ground the test vessel symmetrically for repair welding and MT examinations and thereby minimize the formation of asymmetric magnetic fields which tend to cause problems if electron-beam welding means are used to subsequently artificially flaw the vessel.

4

Acceptance of Work

The fabricator shall use UCC-ND supplied bar stock and furnish test coupons made in accordance with NB-2430 of Section III of the Code for each lot of electrodes. The coupon for each lot shall be of sufficient width and thickness such that tensile and impact specimens can be removed and shall be no less than 48 in. in total length. Coupons shall also be welded, vertically placed, and shall be adequately restrained to avoid warpage. A typical coupon is shown in Fig. 3.

All test pieces, the prolong, and the repaired vessel shall be accepted by the UCC-ND upon acceptance of the vessel in accordance with Section 13 of Part I of this specification.

The fabricator shall furnish an ultrasonic calibration block appropriate for use with inspections under Section XI, Fig. 1-3131, Appendix 1 of the Code.

Records and Documentation

Appropriate records as follows shall be kept by the fabricator for inclusion in the final report. Information should also be transmitted informally to UCC-ND as requested and prior to issuing the final report in order to expedite testing requirements of UCC-ND.

1. Copies of documentation qualifying welding electrode lots and methods of handling.
2. Statements on welder certification.
3. Procedure for air-arc gouging and grinding for cavity preparation.
4. Sketches showing as-fabricated cavity preparations in the vessel and the qualification test piece.

5. Procedures for grinding to insure thickness control of the "buttering layer."
6. A detailed welding procedure.
7. A summary report of the evaluation made pursuant to Section 13 of Part I of this specification.
8. Charts, or copies thereof, from temperature recording instruments and sketches showing locations of thermocouples related to the charts for the vessel.
9. Sketches showing size, location, and orientation of both repaired and allowable flaw indications found during post-weld nondestructive inspections.

PART I — WELDING PROCEDURE

1. Welding Qualification

All welding in accordance with this procedure shall be done by welders qualified and currently certified under Part II (pages 13-15), or under Section IX. Paragraph NB 4300, of the Code for a procedure having the same essential variables for welding performance qualification as this procedure. Welder certification papers shall be available at the job site at all times.

2. Base Metal

The base metal will be low-alloy, high-strength carbon steel plate (ASTM A533, grade B, class 1, or equal), P Number 3, Group 3 (Table QW 422, Section IX of the Code).

3. Filler Metal

The filler metal shall be covered low-alloy steel electrodes and shall conform to the requirements of Specification SFA-5.5, AWS Classification E8018-C3 of Section II of the Code or, if the fabricator so elects, shall conform to such other specifications as may be previously approved in writing by UCC-ND. Electrodes shall be clean and dry, and the flux shall not be cracked or spalled. (See Care of Welding Electrodes, Section 8 of Part I of this specification.) Tests of welding materials shall conform to Subarticle NB-2400 of Section III. Evaluation of each lot of weld metal shall be based upon the manufacturer's certification test report (supplied by the fabricator) and approved in writing by UCC-ND.

4. Electrical Characteristics

The fabricator shall determine appropriate welding voltage and amperages.

2

As a guide the following conditions are suggested. Direct current at 20 to 26 volts connected for reverse polarity (DCRP), with the base metal on the negative side of the line. Amperages, based upon electrode diameter, are suggested as follows:

Electrode Diam-In.	Amperages
3/32	85-100
1/8	110-140
5/32	130-185

5. Repair Zone

For preheating purposes, each repair zone of the vessel shall consist of the cavity plus a region around the cavity lying beneath the area circumscribed by a line on the outside surface a minimum distance of 3T* from the boundary of the cavity. For inspection purposes the repair zone of the vessel shall consist of the regions specified above for the vessel, except the distance there specified shall be 1T.**

6. Instrumentation

Thermocouples and recording instruments shall be used to monitor the preheat, gouging, grinding, welding, and final post-weld heat treatment operations. Thermocouples may be attached by welding where practicable.

7. Cavity Preparation and Cleaning

The cavity for the vessel repair, except for the longitudinal boundary for the heat-affected zone flaw may be partially formed by flame cutting and/or air-arc gouging to rough dimensions and grinding to finished dimensions.

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*nT means n times the wall thickness.

**This is a deviation from the Code, which requires an examination of a 3T band.

Finished dimensions are shown in Fig. 5 for the vessel. The repair zone shall be preheated and maintained at temperature in the range of 350°F to 400°F until flame or arc cutting and grinding are finished.* After such cutting is completed, a layer of metal under the cut area a minimum of 1/4-in. in depth shall be removed by grinding.

Note: The vessel's longitudinal cavity surfaces have been premilled by UCC-ND to establish final and optimum planes for subsequent post-weld repair heat-affected zone flaw preparations. These longitudinal surfaces shall not be ground. The layout for gouging the top and bottom cavity boundaries must allow for 1/4-in. post gouge grinding and the blending of ground ends to the premachined middle section. Care should be exercised in cavity corners to retain minimum radii as shown in Figs. 4 and 5. Care must also be taken to preserve the preground longitudinal sides.

The V-7B cavity for the procedure qualification prolongation shall be formed by the fabricator entirely by air-arc gouging and grinding. The cavity shall be centered about the center lines now scribed to the vessel's outer surface. Cavity end angles must match the angles of the vessel repair cavity ends. Dimensions shown in Fig. 4 are finished (final ground) dimensions.

The V-8 repair cavity for the same prolongation and shown in Fig. 8 will be furnished to the fabricator premachined and ready for half bead technique weldup.

Detailed procedures for cavity preparation and cleaning as prepared previously shall be kept and adhered to at the job site.

In final preparation for welding, the cavity shall be ground smooth and clean, except as noted above, with beveled sides and edges slightly rounded

*This is a deviation from the Code which does not allow flame (thermal) cutting. (With agreement of the Advisory Task Group on Weld Repair for Pressure Vessels; PVRC, Atlanta Meeting 6/6/76).

4

to provide suitable accessibility for welding. The surfaces within 1T distances of the joint shall be cleaned of all dirt, oil, grease, paint and excessive amounts of scale and rust. The cavities of the vessel and test pieces shall be examined by magnetic particle inspection in accordance with the requirements of IWA-2221 prior to welding. Additional grinding shall be performed with preheat as necessary to remove indications of flaws. Actual dimensions and location of the cavity shall be documented.

8. Care of Welding Electrodes

The moisture content in the protective coating of the low hydrogen electrodes shall not exceed 0.4% by weight. The following steps shall be taken to prevent moisture pickup; provided that, with prior written approval of UCC-ND, minor deviations may be allowed.

All coated electrodes shall have been baked before use at temperatures of 800°F ±25°F for 30 minutes to one hour. The temperature of the oven shall be at 300°F or lower when the electrodes are placed in the oven for baking. During the baking cycle, the temperature shall not be raised more than 300°F per hour when oven temperatures are above 500°F, and the total time above 500°F shall not exceed five hours. After baking, and before the electrodes are allowed to cool below 150°F, they shall be repackaged in sealed containers. The fabricator shall record and report moisture levels of each batch of electrodes. Electrodes shall not be rebaked more than once.

During the repair, the electrodes shall be removed from their sealed containers and thereafter kept in portable heated ovens which shall be at the work station. These ovens shall be at 225°F to 300°F. Electrodes shall not be out of an oven more than 20 minutes prior to use. Electrodes not used within 20 minutes after removal from the oven shall be returned to the holding oven and held at 225°F to 300°F for at least 8 hours before reissue. Random moisture contents rechecks should be conducted at least once a day on electrodes of each size in use and taken from the portable heater ovens at the welder work stations. The fabricator shall initiate and maintain records to indicate conformance to the above electrode bakeout and rod issuance regulations.

All electrode end conditions should be inspected carefully before use. The small diameter electrodes are likely to have the flux coating chipped off at the start end. Electrode ends should be examined three times:

(1) when the electrode is rebaked,

(2) when the vacuum package is opened, and

(3) when the electrode is taken from the electrode holding oven by the welder. Electrodes must be rejected whenever there are any signs of cracks in the flux coating.

Detailed fabricator procedures for the care of electrodes must be forwarded to UCC-ND for written approval within one week after contract award. Upon approval, these procedures shall be kept and adhered to at the job site.

9. <u>Conditions for Welding</u>

The prolongation, vessel and test coupons shall all be adequately braced to prevent warpage. Test pieces shall be restrained to avoid warpage and to simulate the restraint of the vessel. Backing plates shall be installed before anchoring or bracing. Backing plates shall consist of two layers of precontoured standard fabricator steel backing material. Flat test pieces shall be anchored to heavy support plates or welding tables. All work must be vertically positioned for all welding.

6

All subsequent repair work shall be performed with preheat applied to the base material. The preheat temperature in the repair zone shall be within the temperature range of 350 to 500°F. The temperature shall not be allowed to fall below 350°F until the completion of either an intermediate post-weld heat treatment (PWHT)* of 450 to 550°F for 1/2 hour or after a final PWHT at the same temperatures for four hours. If electrical heat is used, standby torches shall be provided to maintain vessel temperature or perform an intermediate PWHT in case of prolonged power outages or unanticipated equipment malfunctions. A magnetic particle test of the weld cavity would be required following any intermediate PWHT.

10. Position of Welding

All welding shall be done with the longitudinal axis of the vessel and/or prolong or test piece in the vertical position. For the half-bead pass and at least the first pass thereafter, welding shall be in the vertical position for the cavity sides.

11. Weld Metal Deposition

Welding shall be done in general accordance with the illustrations of Fig. 6.

The cavity shall be buttered using 3/32-in. maximum diameter electrodes as shown in Step 1, Fig. 6. Approximately one-half the thickness of this buttering layer shall be removed by grinding before depositing a second layer. Special procedures shall be established as needed to control the grinding of the buttering layer. Such procedures may employ the use of workmanship specimens, dimensional measurements, or other means to demonstrate compliance. The maximum interpass temperature shall be held to 500°F. See Step 2. The second layer

*PWHT actually infers a post-weld tempering treatment only.

shall be deposited with either 1/8-in.- or 5/32-in.-diameter electrodes. The maximum bead width shall not exceed four times the electrode core diameter. Bead position shall be performed in a manner to temper the prior beads and their heat-affected zones as shown in Step 3 of Fig. 6. The completed weld shall have at least one layer of weld reinforcement (crown pass) deposited. This final layer should overlap, but shall not extend beyond the "buttering" deposit of the first pass. This reinforcement shall thereafter be removed by grinding, making the finished surface of the repair substantially flush with the surface of the vessel surrounding the repair. Likewise following all welding and the post-heat and cooldown, the backing plate shall be removed, and the interior repair surface shall be contoured evenly to conform to vessel inside diameter dimensions plus or minus 1/8 in. Back welding may be required to satisfy this requirement. UCC-ND will be notified prior to and shall approve any back welding operations. Temper-bead techniques may again be required. Peening shall not be employed for this weld repair.

Possible benefits of controlled peening, as permitted by Section XI, shall not be evaluated in this weld repair.

Detailed procedures for grinding and controlling the thickness of the buttering layer and, if elected, controlled peening shall be kept at the job site during this part of the work. Utmost care should be exercised to grind off approximately half of the buttering layer as dimensional verification by measurement is extremely difficult in a cavity at approximately 400°F.

8

12. Inspection During Welding (Vessel and both prolongation welds)

A magnetic particle examination (MT) shall be performed on the ground "buttered" layer, the next 1/8-in. layer, and thereafter on alternate layers and the final ground outside surface.* The final MT shall be completed prior to the start of the four-hour post-weld heat treatment. Layers not inspected by MT shall be visually inspected. Where necessary, weld defects shall be removed and the repaired zone reinspected. If defects occur within 3/16 in. of the base metal, such repairs shall be made using the "buttering" and half-bead grinding technique. An MT examination shall be performed on the vessel ID after grinding and backwelding (if required). MT indications shall be removed by grinding and blending and a subsequent MT exam shall be made to insure removal of defects.

13. Post-Weld Nondestructive Inspection (Vessel and both prolongation welds)

The repair zone as defined above under Repair Zone shall be nondestructively examined after the completed weld has been at ambient temperature for a period of not less than 48 hours. A volumetric examination of the repair zone shall be made by radiography in accordance with IWA-2231 and ultrasonic examination in accordance with IWA-2232, except that calibration block material of the same specification as the base material shall be deemed to meet the requirement of paragraph I-3121. A magnetic particle examination in accordance with IWA-2221 shall be made of the surfaces of the repair zone and of areas representing locations of weld attachments. A visual examination shall be made in accordance with IWA-2210.

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*This deviation from the Code, which calls for examining every layer (with agreement of the Advisory Task Group on Weld Repair for Pressure Vessels, PVRC, Atlanta Meeting, 6/6/75).

9

Acceptance of the repaired vessel shall be determined in accordance with IWB-3500 and Examination Category B-A. If necessary, repairs of the repair zone of the vessel shall be made in accordance with the half-bead weld technique as described in the foregoing sections of Part I.

PART II — WELDER PERFORMANCE QUALIFICATION AND PROCEDURE QUALIFICATION TESTS (IF APPLICABLE)*

1. General

All welding shall be in accordance with the requirements of Part I. The welder performance and procedure qualification requirements will be satisfied upon the successful completion of the tests described below.

2. Test Welds

Test A. Each welder to be qualified under this procedure shall be tested by completing the welding of a plate as specified for the 3 in. qualification plate, Fig. 2, which shall be tested in accordance with QW-302 and QW-304 of Section IX of the Code. Each test piece of this type shall be stenciled with the welder's stencil number on the upper surface where he originates the weld. Figure 2 illustrates a typical setup for 3-in.-thick qualification plate weld preparations. The fabricator will supply plate stock for this optional practice work.

Test. B. Test B is a procedure qualification. Test piece B, previously referred to as the vessel prolongation furnished by UCC-ND and shown in Fig. 4,

*Refer to final paragraph under SCOPE, pg. 2 of this procedure. "Individual welders must be qualified under Section IX of the Code for a procedure having the same essential variables for welding performance qualification as the procedure of Part I, or they must qualify as outlined in this Part II."

10

shall be prepared and welded in accordance with the procedure of Part I. Only welders who have qualified under Test A or are qualified under Section IX of the Code for a procedure having the same essential variables for welding performance qualification as the procedure of Part I shall be permitted to weld in Test B.

3. Welder Certification

A prequalified welder and or a welder passing Test A and thereafter participating in the procedure qualification, Test B, shall be certified to weld in accordance with W-HB-105.

4. Retests

A welder who fails to meet the requirements as set forth in Test A may be retested after he has had further training or practice. A complete repetition of Test A shall be made. Retest specimens shall be tested and evaluated by the same procedure used for the first test.

5. Period of Effectiveness

The qualification of a welder for this procedure shall be considered as indefinite but shall expire upon termination of a 90-day period in which the welder has not used this process. This qualification period may be extended to six months if the welder is continuously employed in shielded metal-arc welding. A welder's qualification may be withdrawn if the quality of his work is substandard to the requirements of this procedure. When a welder leaves the employment of that particular manufacturer or contractor for whom he worked at the time of his qualification, his qualification is automatically canceled.

Renewal of Qualification:

Renewal of qualification may be obtained by Code Section IX provisions, or by passing Test A.

Records:

Certified records of the welder qualification tests shall be originated by the fabricator at the plant where the test was conducted. When a welder from an outside agency is qualified, a record of the test shall be submitted to and become the responsibility of that agency. A suggested form for the record is provided in Fig. 7.

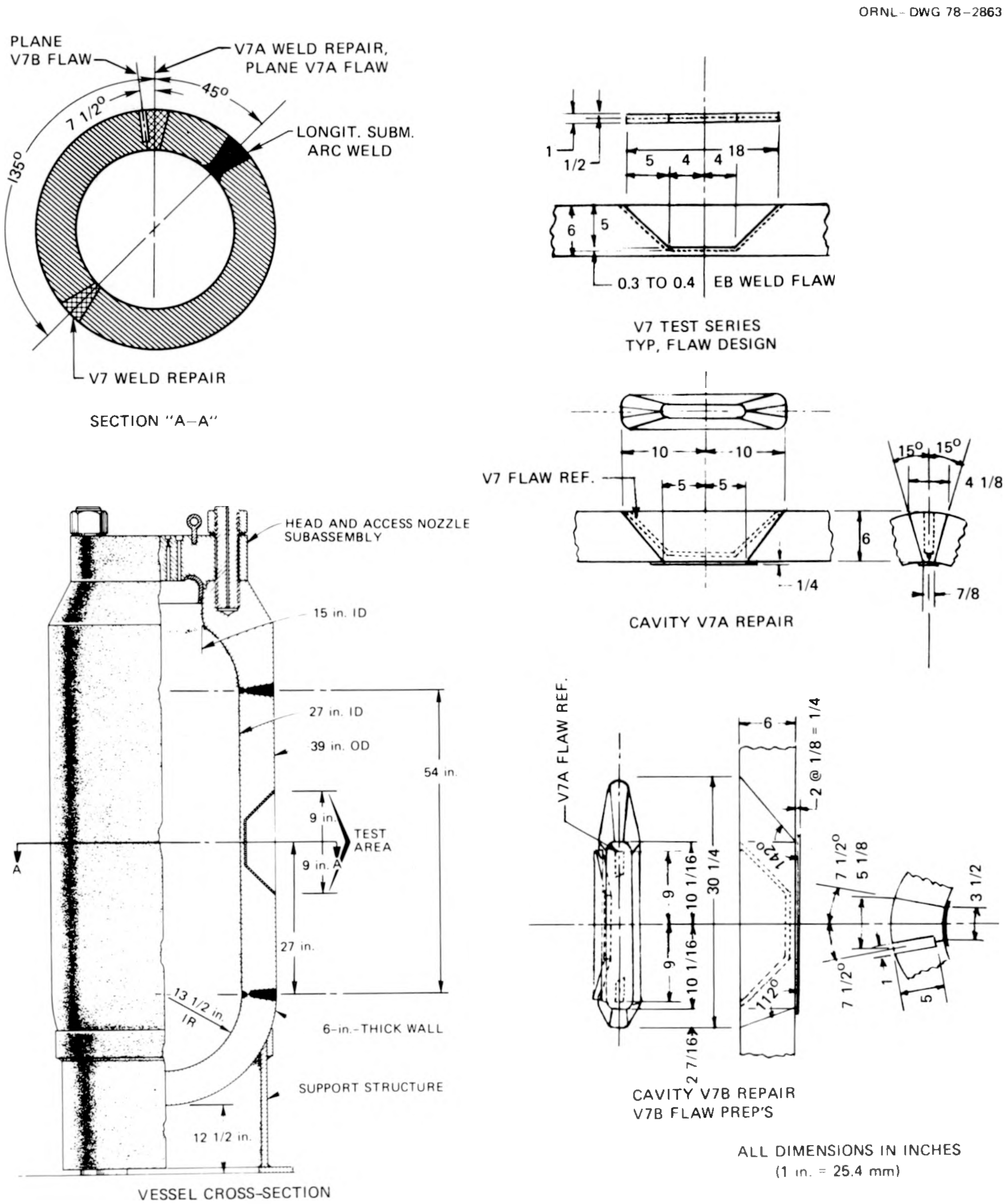
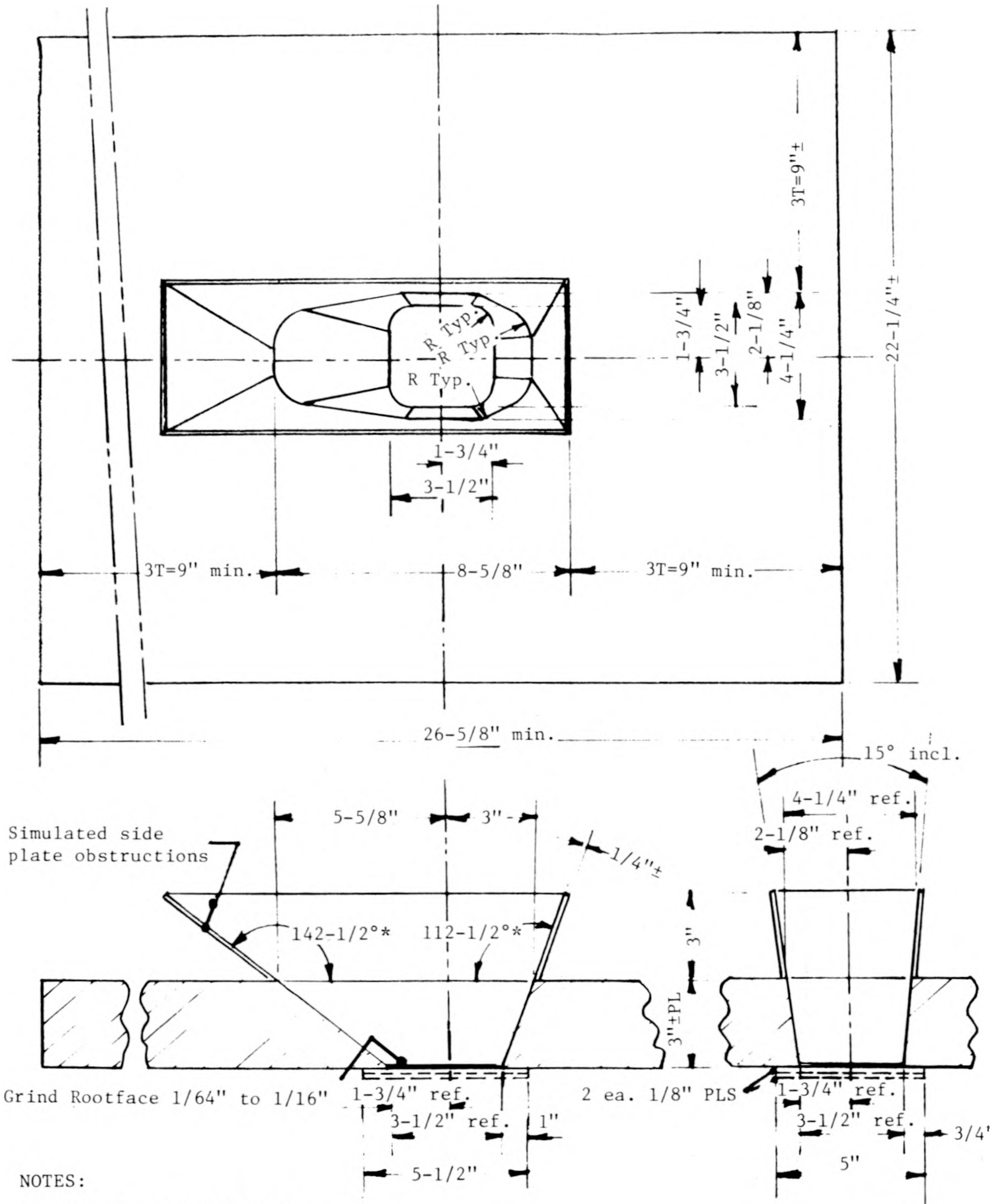


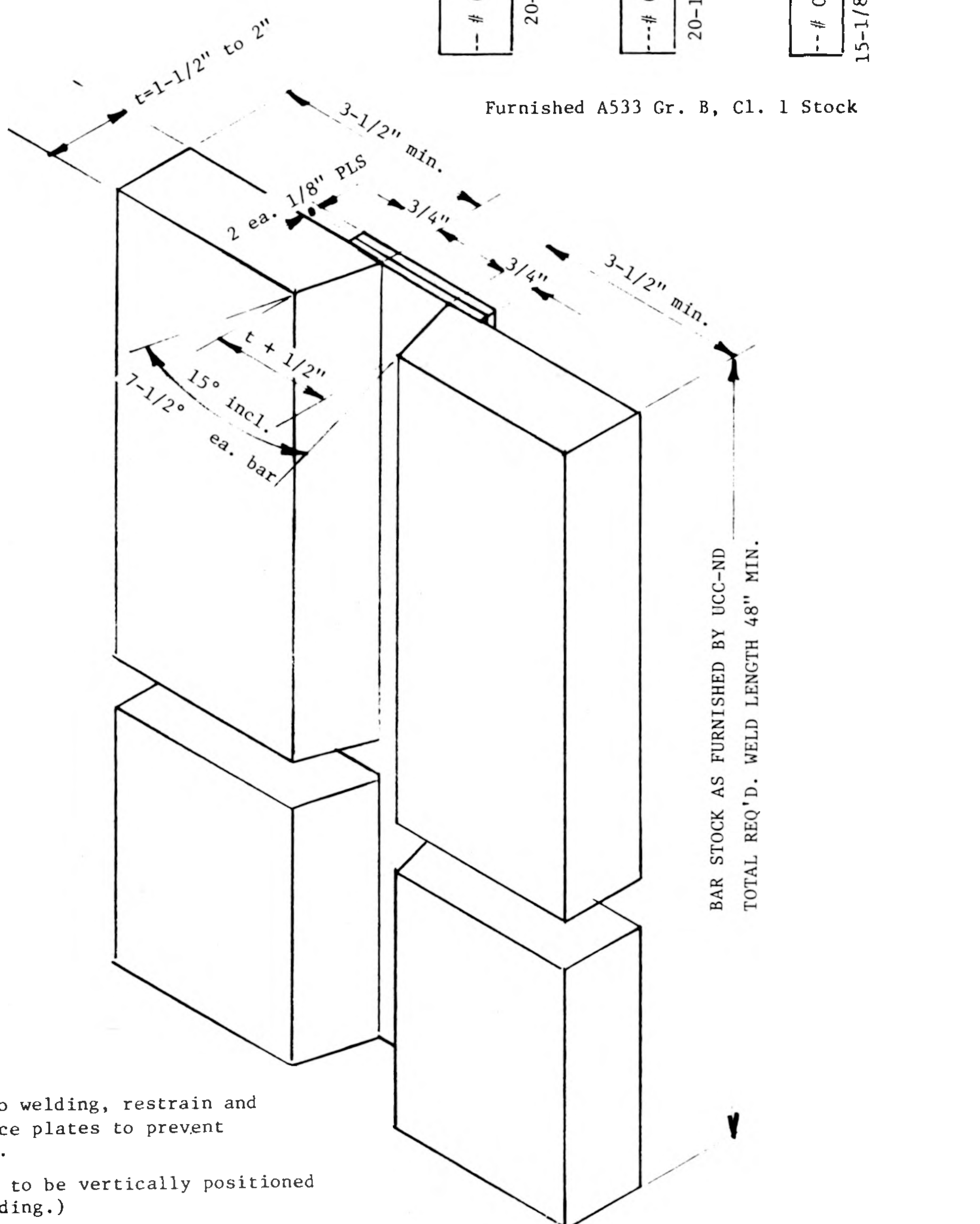
Fig. 1. Intermediate test vessel 7.



NOTES:

1. * Same as for vessel.
2. Position plate vertically for welding; restrain and reinforce to prevent warpage.
3. ** Qualification plate is optional — refer to specifications.

Fig. 2. Suggested 3" qualification rate (optional — see specs).



NOTES:

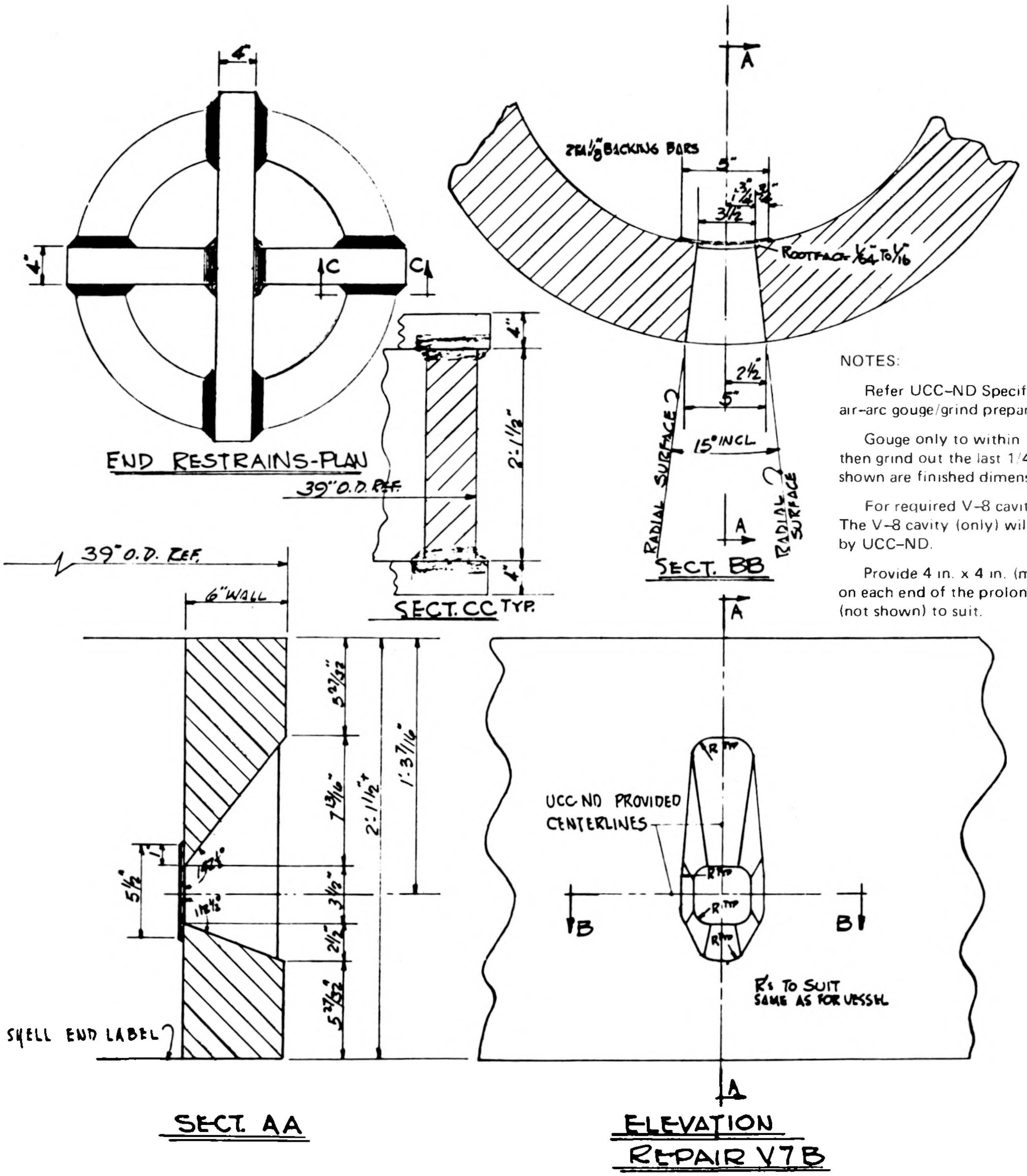
Prior to welding, restrain and reinforce plates to prevent warpage.

(Plates to be vertically positioned for welding.)

Grind root face 1/64" to 1/16".

Fig. 3. Typical weld metal test plate.

ORNL–DWG 78–6375



NOTES:

Refer UCC–ND Specification W–HB–105 for fabricator required air–arc gouge/grind preparations, etc.

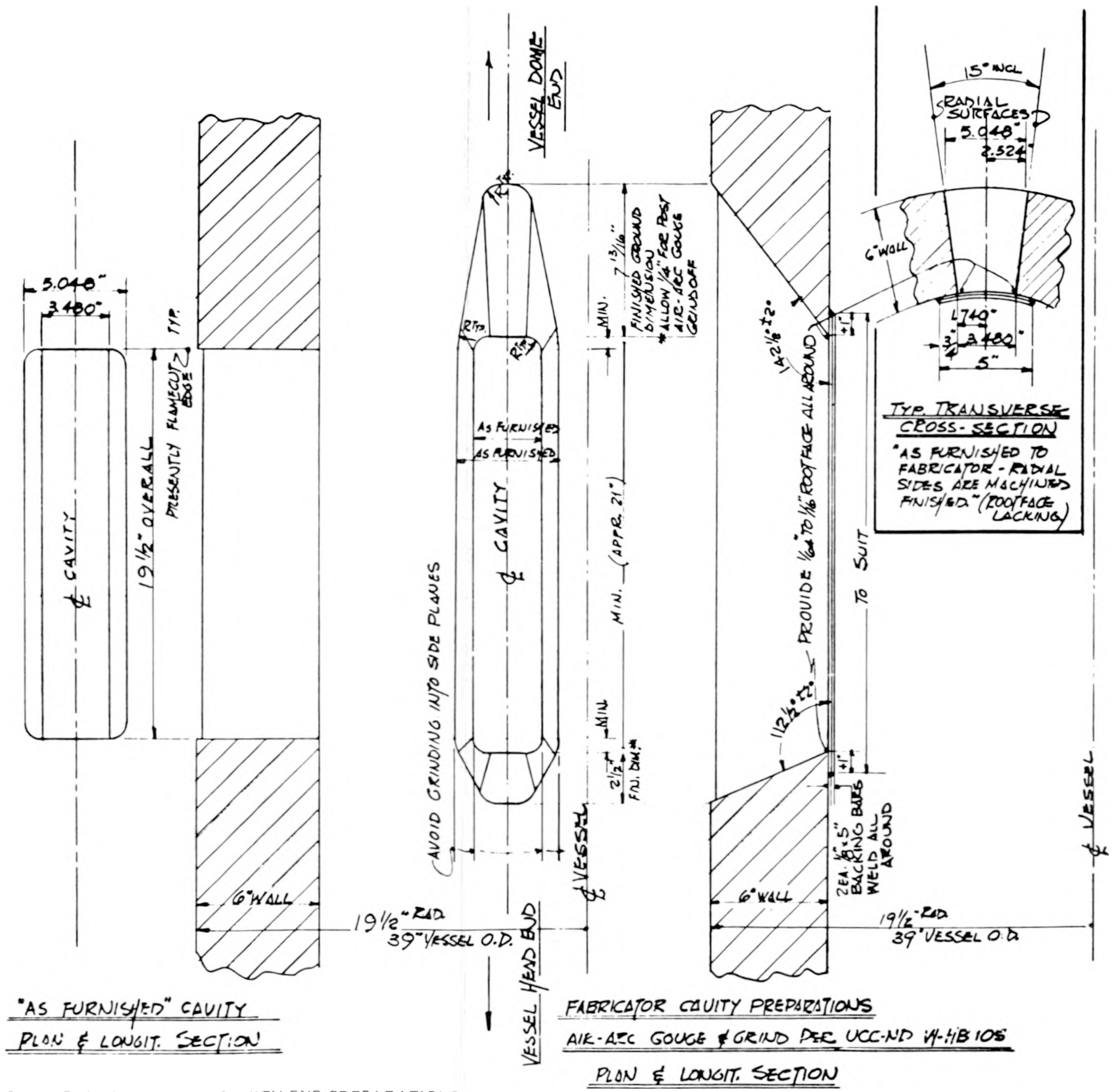
Gouge only to within 1/4 in. of the surface dimensions shown; then grind out the last 1/4 in. of material. Drawing dimensions shown are finished dimensions.

For required V–8 cavity work on same prolong refer to Fig. A.4. The V–8 cavity (only) will be premachined to final cavity dimensions by UCC–ND.

Provide 4 in. x 4 in. (minimum) cross–brace bars for end restrains on each end of the prolongation. Provide backing plate supports (not shown) to suit.

Fig. 4. Weld procedure prolong V8 details for V7B repair weld.

ORNL–DWG 78–6374

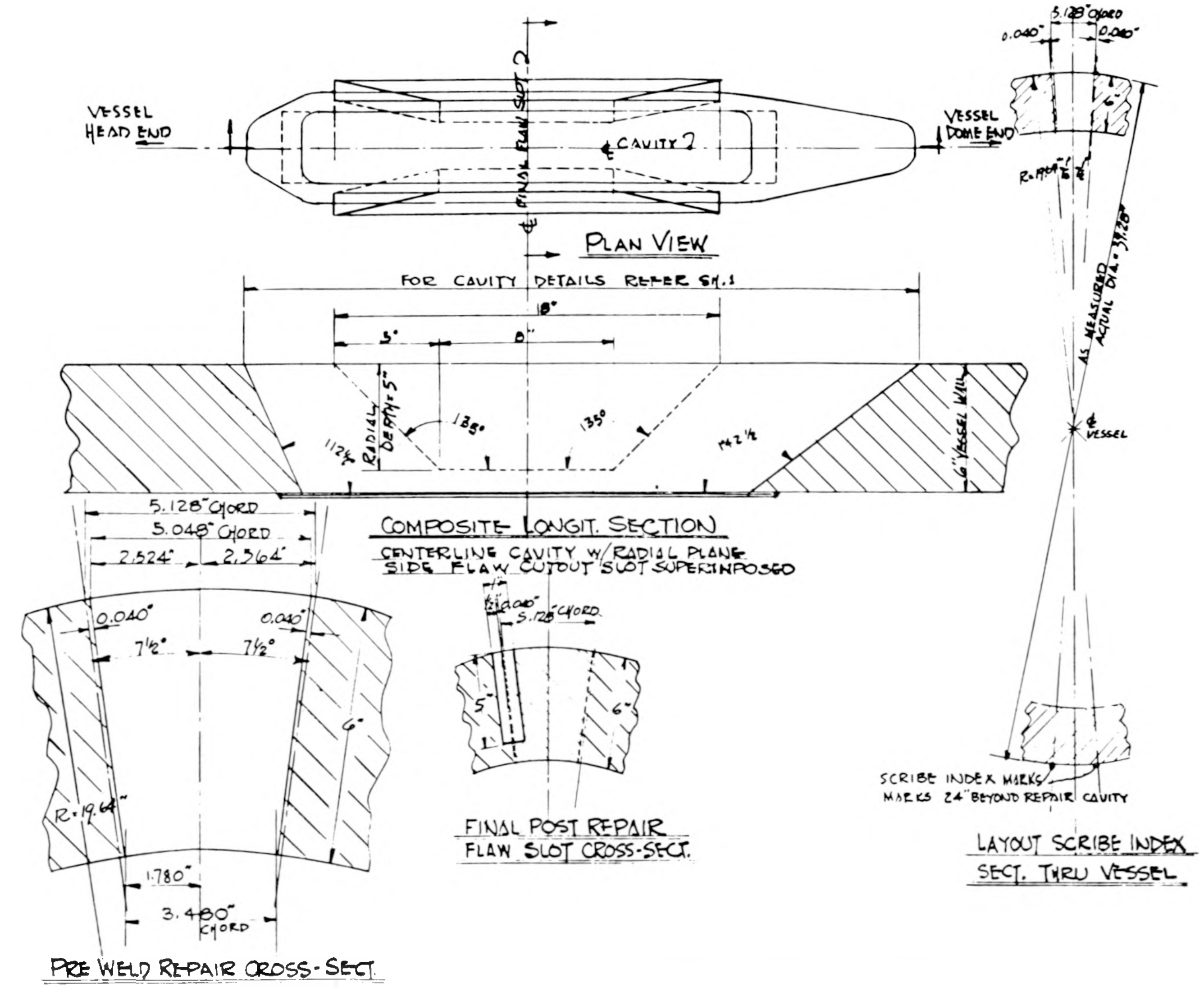


FINAL PREWELD REPAIR CAVITY END PREPARATIONS.

Air-arc gouge top and bottom ends of cavity to within 1/4 in. of limits shown. Grind the final 1/4 in. to final dimensions shown. Blend to contour ends with center portion of cavity. Radius corners as indicated.

Attach backing plates.

Provide backing plate bracing supports. (Not shown)



NOTES:

The vessel is furnished to the fabricator with premachined radial sides for the center portion of the cavity. The fabricator shall air-arc gouge cavity ends to a distance of 1/4 in. of final prerepair weld surfaces; the final 1/4 in. material to be removed by grinding. Care must be taken not to nick into the premachined radial sides of the cavity center portion. (For preheat, etc. refer to UCC-ND Specification W-HB-105.)

The premachined transverse (sectional) weld repair cavity layout was made to have final 5.128 in. chord width for a cavity with radial sides and an included 15° angle. The 5.128 in. reference locates the centerline for the post weld repair flaw slot. The heat-affected zone (from the weld repair) was assumed to be 0.080 in. wide, or 0.040 in. to the center of the heat-affected zone. Accordingly, the machined prerepair weld cavity was offset by 0.040 in. with the cavity sides parallel to the final radial plane sloped surfaces; the resultant prerepair weld cavity chord dimensions, therefore, are 5.058 in. at the vessel exterior and 3.480 in. at the vessel interior. Scribe bench marks have been placed on two flats at 180° from the future flaw slot centers to the 5.128 in. reference dimension. A tape measure should be used to reestablish the 5.128 in. chord reference at the completion of weld repairs. It is intended to use but one flaw slot on either side of the cavity's weld repair. Selection of what side to place slot will be made after weld repair and may depend on fabricator's weld inspection results.

Fig. 5. IVT 7B repair sequence.

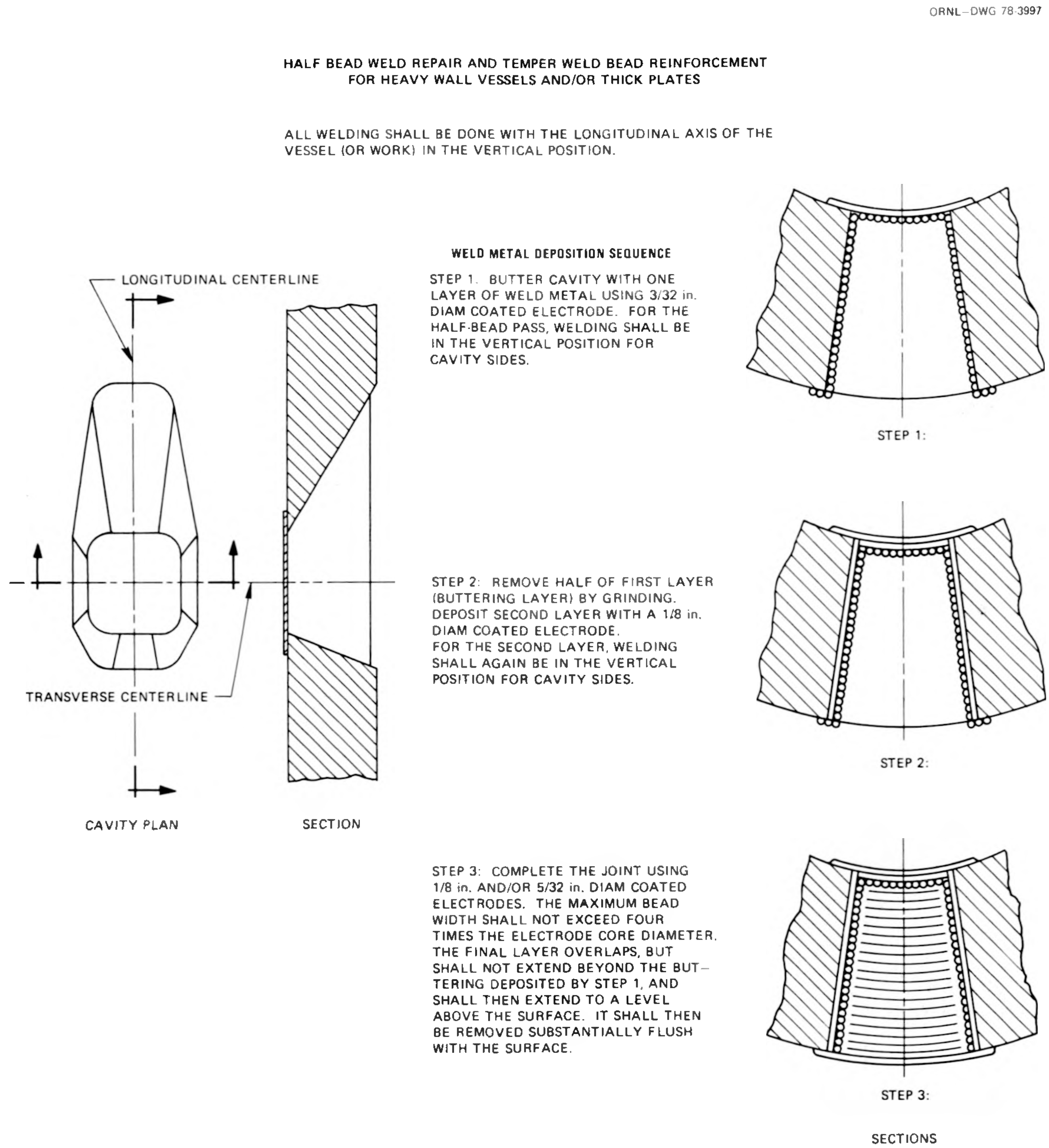


Fig. 6. Half bead weld repair sequence.

RECORD OF WELDER QUALIFICATION TEST

WELDER'S NAME	STENCIL NO.	BADGE NO.	DEPT. NO.
EMPLOYER	PROCEDURE NO.	DATE STARTED	DATE COMPLETED

MATERIAL (PLATE OR PIPE & SPEC. NO.)	THICKNESS AND DIAMETER	ROD OR ELECTRODE & SPEC. NO.
WELD PROCESS (ARC, GAS, HELIARC, ETC.)	WELD TEST POSITION	FIRST TEST, DOUBLE, RETEST

RECORD TEST RESULTS BELOW GIVING A BRIEF DESCRIPTION OF DEFECTS.
RECORD SILVER BRAZING TESTS ON BACK SIDE.

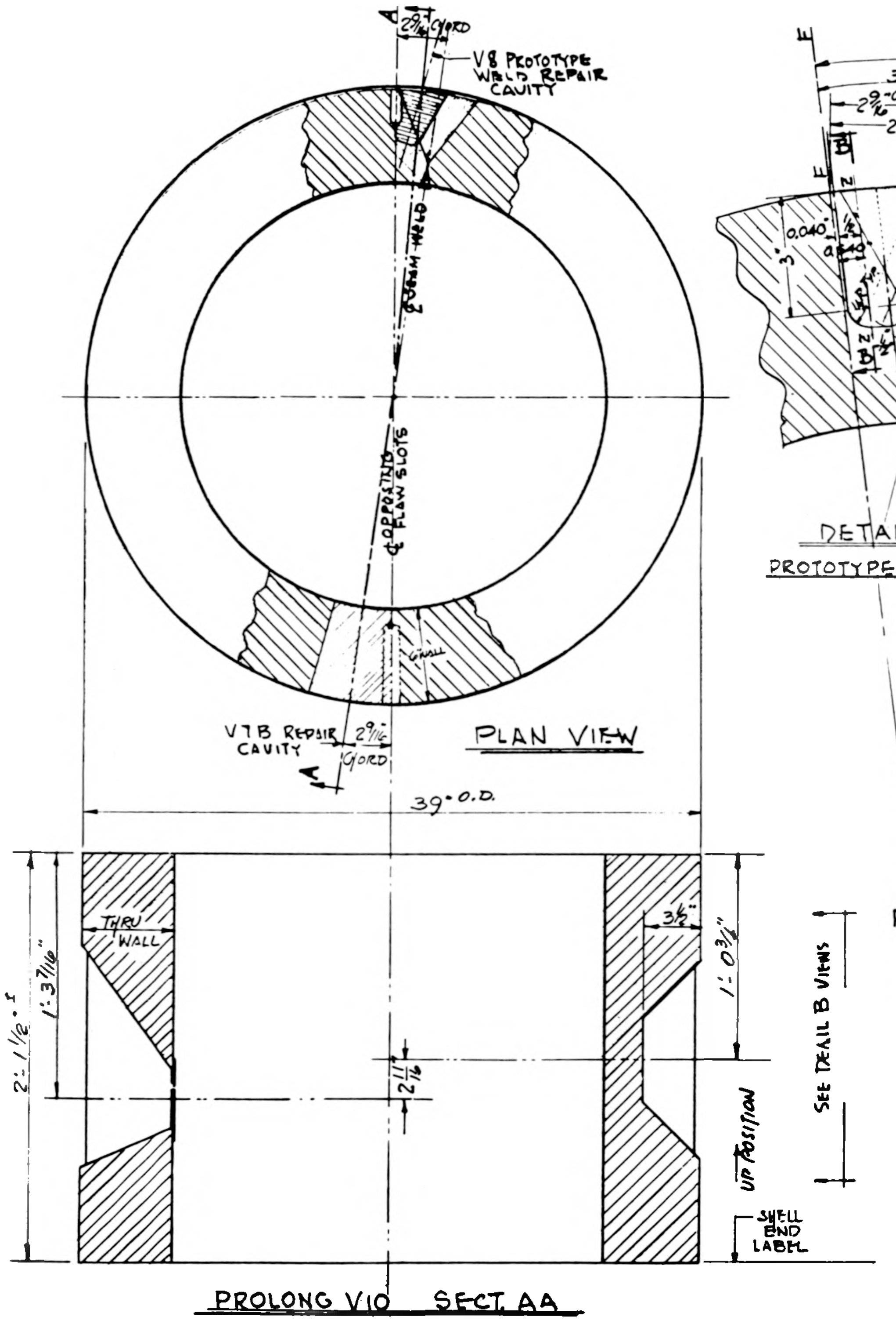
TEST METHOD	SPECIMEN NO.	PASSED	FAILED	NATURE, SIZE, AND LOCATION OF DEFECTS
X-RAY	1			
	2			
	3			
	4			
FACE BEND	1			
	2			
	3			
	4			
ROOT BEND	1			
	2			
	3			
	4			
OTHER (EXPLAIN)	1			
	2			
	3			
	4			

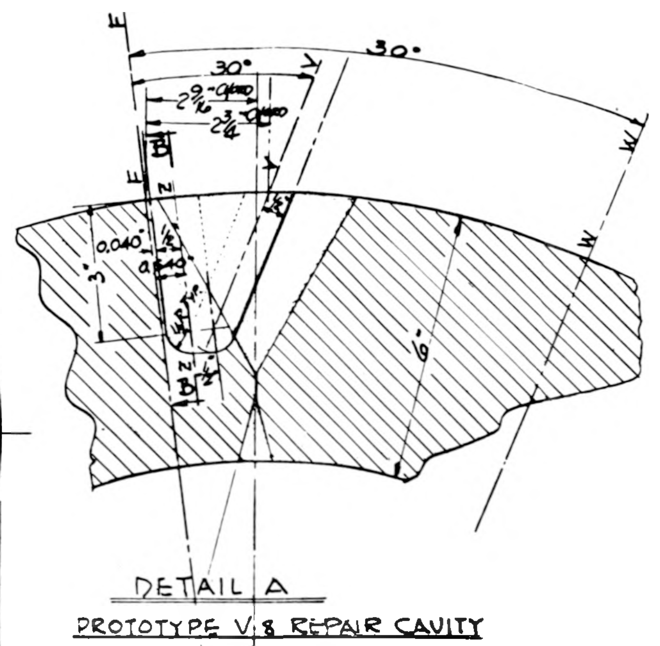
I CERTIFY THAT THE STATEMENTS IN THIS RECORD ARE CORRECT AND THAT THE TEST WELDS WERE PREPARED, WELDED, AND TESTED IN ACCORDANCE WITH THE REQUIREMENTS OF SECTION IX OF THE ASME CODE.

INSPECTOR	DATE
APPROVED	DATE

Fig. 7. Record of welder qualification test.

ORNL–DWG 78–6376





Notes for Layout and Machining V-8 Repair Cavity:

Refer Detail A, PLAN VIEW, Looking Down. Labelled shell end to be at bottom. Locate the corners of the cylinder's seam weld; verify an approximate 5 in. outer surface weld width. Measure 2 9/16 in. cc from the seam weld's centerline to locate the radial centerline, line FF, for the postweld repair flaw. Scribe index line FF over the entire cylinder surface distance.

Measure clockwise from line FF to locate centers for a 1-in.-diam ball mill cutout, line ZZ, which is to be parallel to line FF and 0.040 in. (one half width heat-affected zone of weld repair) plus 1/2 in. (ball mill radius), or 0.540 in. away. Scribe index line ZZ.

Again measure clockwise, 30° from line FF, along the cylinder's perimeter. (Measure the entire perimeter and divide distance by 12); scribe line WW onto the cylinder's surface. Also measure clockwise from line FF, a distance of 2 3/4 in. to locate line VV, centers for a 1-in.-diam ball mill cut for the opposite side of the cavity. Scribe line VV.

Set vessel with line FF aligned horizontally and with the horizontal boring mill tool axis.

Lower the tool axis a distance of 0.540 in. and make the trapezoidal cut shown in SECTION BB. Maximum 1-in.-diam ball mill cutting depth – 3 1/2 in.

Rotate the vessel to align the tool axis to center the 1-in.-diam ball mill on line VV. Machine trapezoidal cutout.

Reset cylinder to remove cylinder surface material for the center portion of the cavity. Hand grind as necessary to blend contours and/or corners.

Note: Postrepair flaw slotting to center about line FF.

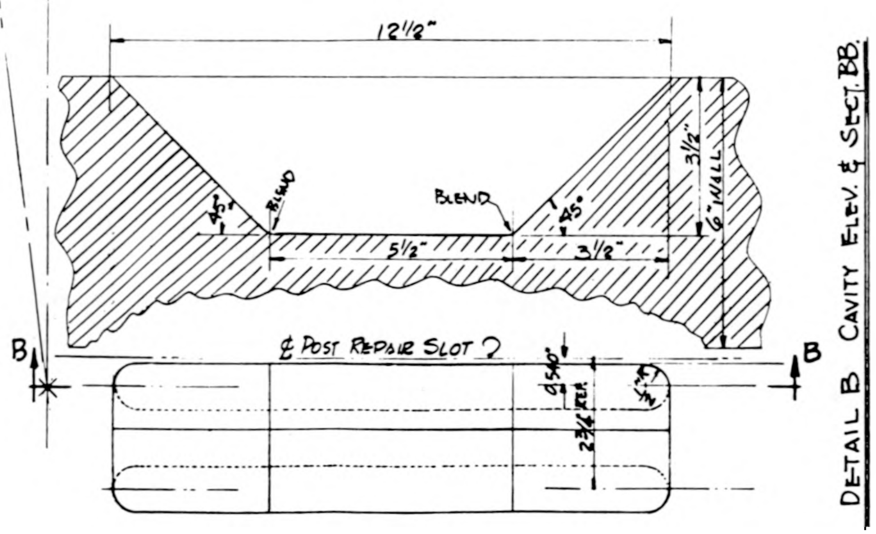


Fig. 8. Weld procedure prolongation V10 cavity layout for IVT 8 prototype repair weld.

10/8/76 Issue Date

WELDING PROCEDURE W-HB 105

STATEMENT OF WORK

"Field Demonstration of Section XI Weld Repair and Flaw Propagation in the Heat-Affected Zone of the Weld Repair"
(Vessel positioned vertically)

1. Introduction

A major activity in the Heavy-Section Steel Technology Program is the testing of pressure vessels of a size intermediate between laboratory models and full size nuclear components. Although the specific test vessel geometries have not been designed to be scale models of typical nuclear components, they have been designed to provide realistic demonstrations of fracture mechanics principles. To date, eight vessels have been tested, and all tests demonstrated a margin of safety in excess of design rules. This project concerns one of these vessels which has already been tested twice, ITV-7.

2. Objective

It is planned to reuse intermediate test vessel 7 for a third overpressure test, a hydrostatic test, at a test temperature of 91°C (196°F). The objective of the test will be to demonstrate the toughness of the heat-affected zone of a half bead repair weld region utilizing a defect comparable in size to the previous tests. The heat-affected zone of such a temper bead technique weld repair performed to procedures listed in the ASME Boiler and Pressure Vessel Code, and without conventional post welding heat treatment, represents a zone of high residual stress in the vessel. The zone

2

also exhibits metal hardness with peak values up to 31 Rockwell "C" immediately adjacent to the fusion line. The fracture toughness will be determined from specimens obtained from the typical vessel prolongation repair weld (Fig. 4) which is furnished for use in weld procedure qualifications.

Post repair machined slot and flaw indexing (relative to the heat-affected zone) are shown in Fig. B.

3. Background

ITV-7 was flawed artificially on the outside surface to a configuration approximately 45-cm long x 13-cm deep (18 in. x 5.3 in.). For both the original June 1974 hydrostatic test and the subsequent June 1976 pneumatic test, uniform stable crack extension occurred around the flaw periphery to result in leak without break. At testing pressures of 147 and 144 MPa (21,350 and 20,920 psi) the crack front penetrated the inside surface of the vessel and leakage occurred. Subsequently, the crack closed upon relief of the pressure. A residual pressure of about 124.2 MPa (18,000 psi) could be maintained in the hydraulic test; an inside 1 1/2-mm- thick (1/16-in.) patch liner served to retain total vessel pressure when leaking occurred in the pneumatic test.

Following the initial test, Combustion Engineering, Inc., Chattanooga, Tennessee, repaired the vessel under Contract RP604-1 from the Electric Power Research Institute, Palo Alto, California (CE Contract 10875). Repair operations were performed in accordance with weld repair procedure W-HB-100 prepared by Union Carbide Corporation, Nuclear Division, with technical support from the Pressure Vessel Research Committee Advisory Task Group on Weld

Repairs. Weld Repair Procedure W-HB-100 was formulated in accordance with Section XI of the ASME Boiler and Pressure Vessel Code, in particular, Paragraph IWB 4420, "Procedure No. 4, Welding Low Alloy Steels," Weld procedure qualifications and mechanical properties samples were also made. The repaired vessel was next reflawed remote from the weld repair and reinstrumented for the June 1976 pneumatically pressure sustained load retest. No abnormalities were noted during the test in the area repaired.

No tests have been conducted to date that endeavor to study vessel behavior with flaws located in the heat-affected zone at the periphery of a weld. Test data from a vessel pressurization test with a flaw artificially placed into this zone of a repair weld would provide realistic evaluation and decision guides for possible future field repair needs in actual nuclear systems. The recent V-7A pneumatic pressurization test proved that temper bead technique repair welding performed under typical shop conditions and meeting all Code provisions and inspection criteria will produce effective, acceptable repairs. The proposed ITV-7B hydrostatic pressurization test with a known flaw placed into the vessel repair weld in the vessel wall will demonstrate the margin of safety against failure in the presence of residual stress when defects are present. The ITV-7B repairs will be welded with the vessel positioned vertically to simulate field repair positioning.

The proposal to artificially place a flaw into a repair weld heat-affected zone for a follow-up hydraulic vessel pressurization test in CY 1977 presupposes that it will be possible to sharpen such flaws via combination electron beam welding and electrochemical hydrogen charging. We have already conducted a limited feasibility development test on a small portion of a tensile specimen bar section prepared to Procedure W-HB-100 by Combustion Engineering, Inc. during the V-7A repairs. A piece was cut from one end of the specimen and both ends were ground and etched to display the heat-affected zone of the specimen's center weld. Slots were milled, centered about and perpendicular to the straight portion of the zones on each side of the weld; these slots were about 9 mm (3/8 in.) down from the top of the specimen to eliminate outbound zone curvature caused by final weld crowning passes. The bar was next mounted below the electron beam gun and attempts were made to place two flawing welds centered to and in line with the heat-affected zones of the specimen weld. A third flaw weld was also placed into the center portion of the tensile bar's weld metal deposit. The electron beam welds were but 10-cm long (4 in.) to retain 12.5 mm (1/2 in.) end boundaries on the 12.5 cm (5 in.) specimen for restraints during the subsequent hydrogen charging. Figure A represents a slice from the specimen and indicates the cracks that formed in the heat-affected zone welds during the charging. The electron beam weld placed into the electrode weld deposit metal did not crack during charging. Figure A also illustrates the wavyness of the heat-affected zone and its narrow 2 mm (5/64 in.) width.

4. Status of Vessel 7B and Repair Requirements

The segment of the V-7A vessel wall that included the cracked flaw has been removed from the vessel by flame cutting. A UCC-ND machine shop thereafter removed an approximately 8-mm-thick (5/16-in.) layer from each flame cut longitudinal surface and to index align and shape the longitudinal cavity boundaries to form radial surfaces with a 15 degree included angle. It was decided to accurately final machine mill-cut to prepare the cavity sides for the repair welding to assure adequate alignment reference for post weld flaw indexing along the weld heat-affected zones of the longitudinal weld to base metal boundaries.

The future V-7B flaw will be identical to the V-7 and V-7A trapezoidal flaw and will also locate within the typical 24-mm-wide (1-in.) slot (Fig. 1).

Cavity ends remain "as flame cut." No further machining needs are contemplated since the "as-machined" cavity end boundaries will locate beyond the future V-7B flaw terminations. Air-arc gouge preparations as outlined in Welding Procedure W-HB-105, Section 7, shall be followed by the fabricator to taper cavity ends appropriately and to blend longitudinal and transverse cavity contours. Refer to Fig. 5, Sheet 1.

All repair welding shall be done in strict accordance with the appended Welding Specification W-HB-105. UCC-ND's Weld Repair Procedure W-HB-105 for Half Bead Technique Repair Welding in the horizontal and/or vertical position is based upon previously used Repair Procedure W-HB-100 for Half Bead Repair Welding to Code, Section XI requirements and for welding in the flat position which was employed successfully during the initial weld repairs to vessel ITV-7A at Combustion Engineering, Inc., Chattanooga, Tennessee, in September 1975.

As before, UCC-ND will permit the Procedure Qualification and Vessel Repair to be done concurrently for scheduling and economical reasons.

The Procedure Qualification is to be performed on the Vessel Prolongation labeled V-10, furnished by UCC-ND. This prolongation is from a like vessel from the same plate. The fabricator will be required to prepare the entire cavity (as illustrated in Fig. 4) by air-arc gouging and grinding

6

and thereafter provide and attach end restraints, backing bars, and make the weld repairs to comply with the attached Procedure W-HB-105, Part I. The prolongation must also be positioned vertically for repair welding.

Different slope contours have been selected for the upper (142 1/2° included angle) and the lower (112 1/2° included angle) ends of the cavity as shown in Fig. 4. These selections were made to simplify the manual welding operation and to retain approximately 1T, or 6 in. minimum restraint distance based on the cylinder's upper surface beyond the repair. It is imperative that like slopes be used for cavity ends of vessel V-7B.

Prolong V-10 shall also be used to qualify the W-HB-105 procedure for vessel V-8, for an approximately half wall thickness half-bead weld repair to a submerged-arc longitudinal vessel seam weld with a vessel also positioned vertically. Figure C is included to provide schematic information on how UCC-ND plans to later machine into the fabricator's weld repair (after the vessel is shipped back) to attain a slot for flawing the heat-affected zone of a typical cylinder seam weld region half-bead technique weld repair.

The cavity for the partial thickness weld repair for prolongation V-10 will be furnished to the fabricator premachined by UCC-ND as shown in Fig. 8.

The two cavities for prolong V-10 shall be spaced at approximately 180° per Fig. 8 layout. The vertical and horizontal center lines for the V-7B qualification repair will be prescribed onto the V-10's outside cylinder surface by UCC-ND. The fabricator shall place similar center lines to the inner surface following his final cavity preparations. These lines are to extend 18 in. beyond repair end to preserve the lines during the grindoff of the backing bars. The lines will be used for gauge layout for UCC-ND's vessel pressurization test.

Vessel 8, a new vessel identical to vessel V-7A, will also be furnished with a premachined partial wall thickness cavity at the edge of a cylindrical seam weld as shown in Fig. 9. The fabricator is to weld repair the cavity in the same manner as the half-thickness repairs to prolongation V-10.

UCC-ND will install from 20 to 25 strain gages to prolongation V-10 for residual stress determinations during the fabrication process. The fabricator shall notify UCC-ND as soon as the prolongation starts its post air-arc gouge cooldown to schedule UCC-ND personnel to be on hand to install strain gages. In addition, UCC-ND will also install from 10 to 15 strain gages to monitor vessel V-7B repairs and from 15 to 20 gauges for vessel 8 repairs.

UCC-ND has no preference regarding the order of weld repairs to prolong V-10, except that the repairs must be done sequentially and that the prolong be allowed to cool to room temperature and then remain at room temperature for a minimum of 24 hours in between the sequential weld repairs during which time gage readings will be taken by UCC-ND.

Appropriate 1 1/2 in. to 2 in. thick A533, grade B, class 1 bar stock will also be furnished to the fabricator for his groove preparation, backing bar attachment, and weldup of no less than 48 in. (total length) of test plates to be sent to UCC-ND for Purchasers' use and processing as test coupons in accordance with NB 2431-1 of Section III of the Code. All test plate welding must be performed to typical Procedure outlines, including the vertical positioning, and the use of restraints to avoid warpage.

UCC-ND will furnish the fabricator with 200 pounds of 3/32-in.-diam, 1070 pounds of 1/8-in.-diam, and 650 pounds of 5/32-in.-diam electrodes; each size in individual sealed 10-pound containers.* These packaged electrodes comply to the acceptance requirements listed in Part I, Section 3 of this procedure. Electrode mechanical properties are listed in Table I.

Additional electrodes may be required to complete all work. The fabricator's proposal shall include a listing of anticipated total electrode

*The available welding electrodes in the sealed vacuum pack containers have already been baked (refer Part I, Sect. 8, Para. 2), hence are ready for use.

requirements along with available sources for electrodes, if necessary. Prior to the start of welding, the fabricator shall furnish UCC-ND a report of the welding material properties for all supplemental welding electrodes. The tensile and impact properties of the material must conform to the Specifications of SFA 5.5, AWS Classification E 8108-C3 of Section II of the Code.

Table I.
MIL-E8018C3 Electrode Mechanical Properties

Lot Number	5237A	AE 74	AE 77	AE 90
Electrode Size	3/32	1/8	5/32	5/32
Yield Strength (0.2% offset)	76,500	74,900	76,900	70,100
Tensile Strength	85,200	88,400	83,400	82,000
Elongation (%)	27	29	30	30
Reduction of Area (%)	74	70.4	70.6	73.5
Charpy Impacts at −20°F	99 100 100	110 119 99	87 91 82	93 97 91

5. Schedules

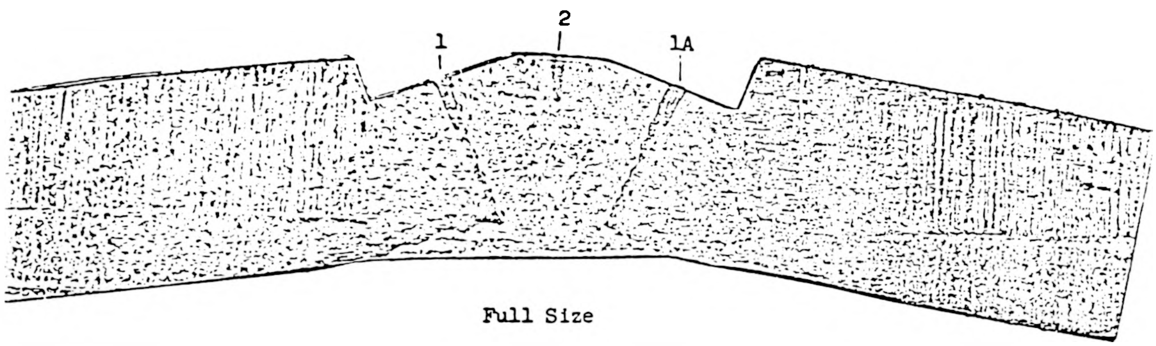
UCC-ND personnel shall be allowed access to the fabrication facilities, as reasonable, to follow the repair operations and to monitor strain gage and temperature measurements on the vessel. UCC-ND's sponsors, the Division of Reactor Safety Research, Metallurgy and Materials Research Branch, Nuclear Regulatory Commission, Washington, D.C. is also sponsoring inspection of welding by acoustic emission with the General American Research Division, Inc. (GARD), a subsidiary of GATX Corporation, and requests permission for GARD personnel to AE monitor vessel repair welding. GARD personnel shall also be allowed access to the fabrication facilities, as reasonable.

UCC-ND will pay for test coupon, prolong, and vessel shipping costs to and from fabricator's plant.

Vessel ITV-7A, the prolongation and stock for weld metal test pieces are all available for immediate shipment to the fabricator. Vessel repairs and inspections should preferably be completed within a six (6) week period for vessel return to UCC-ND, Oak Ridge, Tennessee, as soon as possible.

6. Reports

A final report shall be supplied to UCC-ND upon the completion of all work. The report is to include the results of all testing, inspections, and a detailed chronology of the welding operations. Information considered essential to this report is detailed in the welding specification, W-HB-105. The report shall also include a discussion and evaluation of the applied technique and recommendations for changes in procedures. The report shall be supplied in draft form for approval within 30 days after delivery of the vessel. Following review and approval, six (6) copies and one camera-ready master shall be supplied to UCC-ND for reproduction.



Full Size

Welds 1 and 1A	Generally within the heat affected zone of the weld repair. Cracked on hydrogen-charging.
Weld 2	In weld metal deposit. Did not crack with charging.

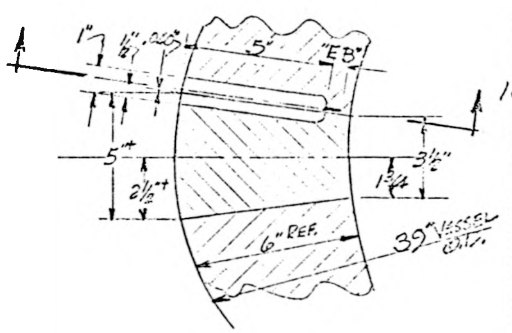
CROSS-SECTION OF HYDROGEN-CHARGED ELECTRON BEAM WELDS IN TENSILE BAR SPECIMEN PREPARED BY COMBUSTION ENGINEERING, INC. CHATTANOOGA, TN. AS PART OF V-7A VESSEL HALF-BEAD TECHNIQUE WELD REPAIRS TO UCC-ND WELDING SPECIFICATION W-HB 100.

FIGURE A

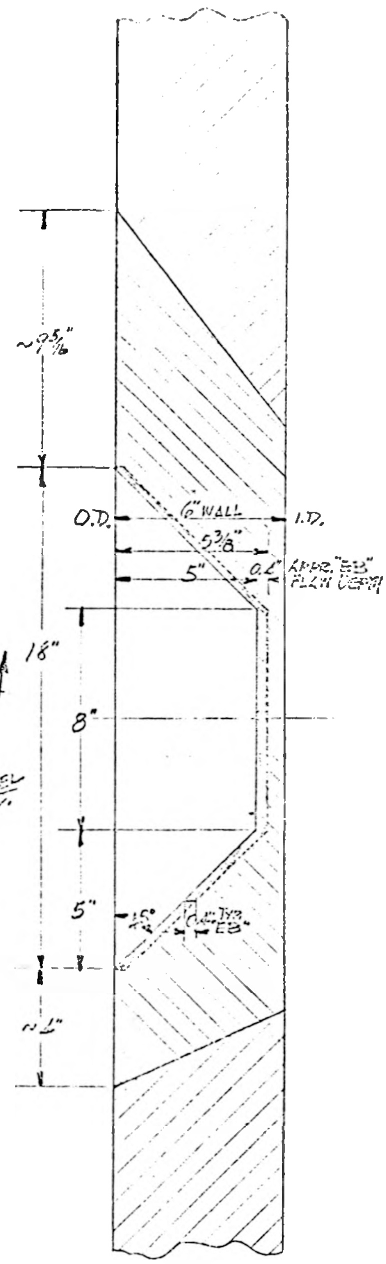
Notes:

Post weld repair slot to be machined radially, centered about an assumed centerline of an 0.030" wide heat affected zone, or 0.040" beyond the edge of the pre-repair cavity side. Slot to locate on one side of the weld repair only. Side slection to be made post weld repair.

Fabricator to provide "buttering" layer information for initial bead's profile at depth 5" for the trapezoid bottom, and along the 45° sides. Adapt a template for these determinations. Profile info to assist UCC-ND to properly place the post weld repair slot centered about the HAZ of the repair.



PLAN

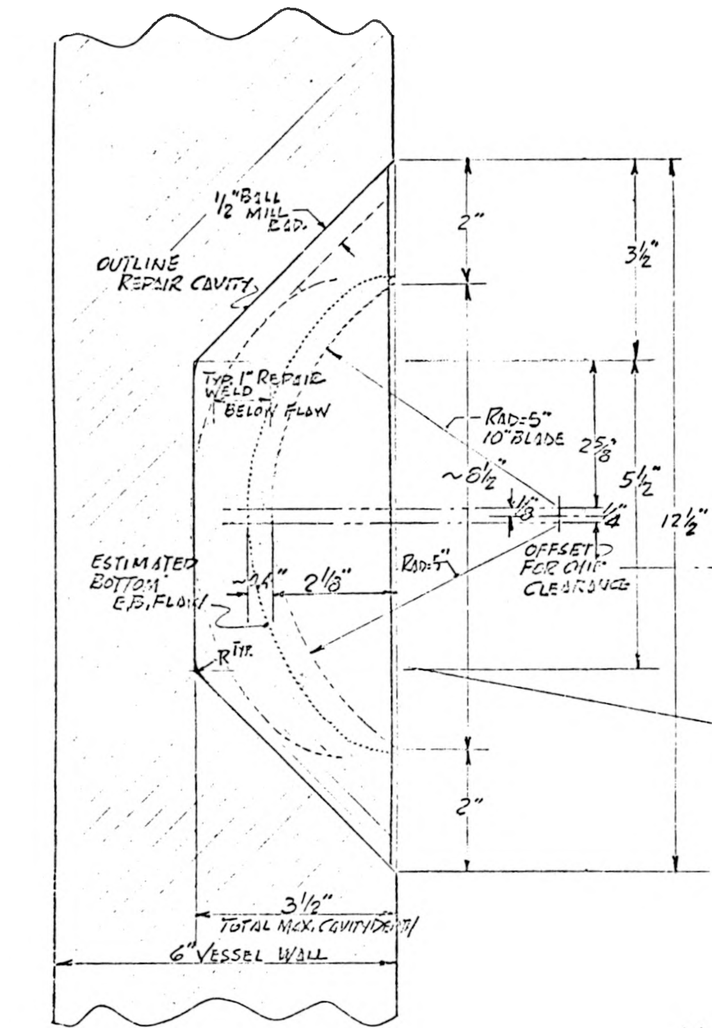


ELEVATION

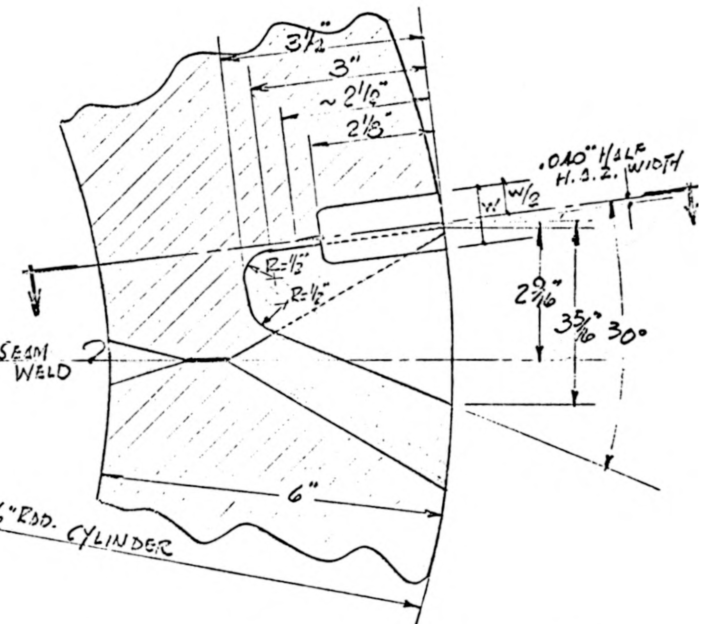
FLAW SECTIONS

IVT 7 B POST WELD REPAIR FLAW PREPARATIONS

FIG. B.



FLAW SECTION - ELEV.



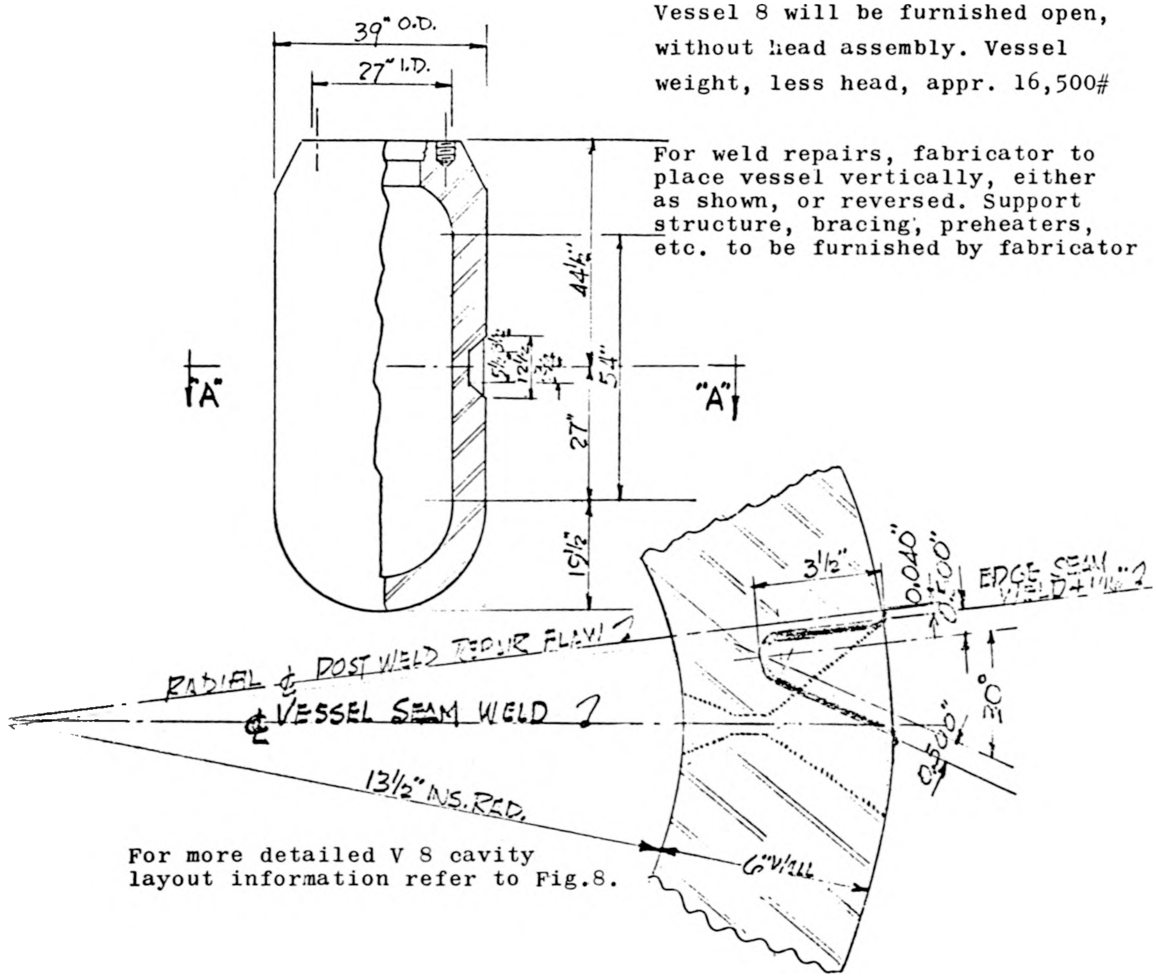
"W" TO SUIT - 3/8" MIN. WIDTH ; 3/4" MAX. WIDTH

FLAW SECTION - PLAN

V8 PROTOTYPE POST WELD REPAIR FLAW PREPARATIONS

Vessel 8 will be furnished open, without head assembly. Vessel weight, less head, appr. 16,500#

For weld repairs, fabricator to place vessel vertically, either as shown, or reversed. Support structure, bracing, preheaters, etc. to be furnished by fabricator



For more detailed V 8 cavity layout information refer to Fig.8.

FIG. 9

HSST INTERMEDIATE VESSEL V 8.

ELEVATION & PARTIAL CENTER SECTION "AA"

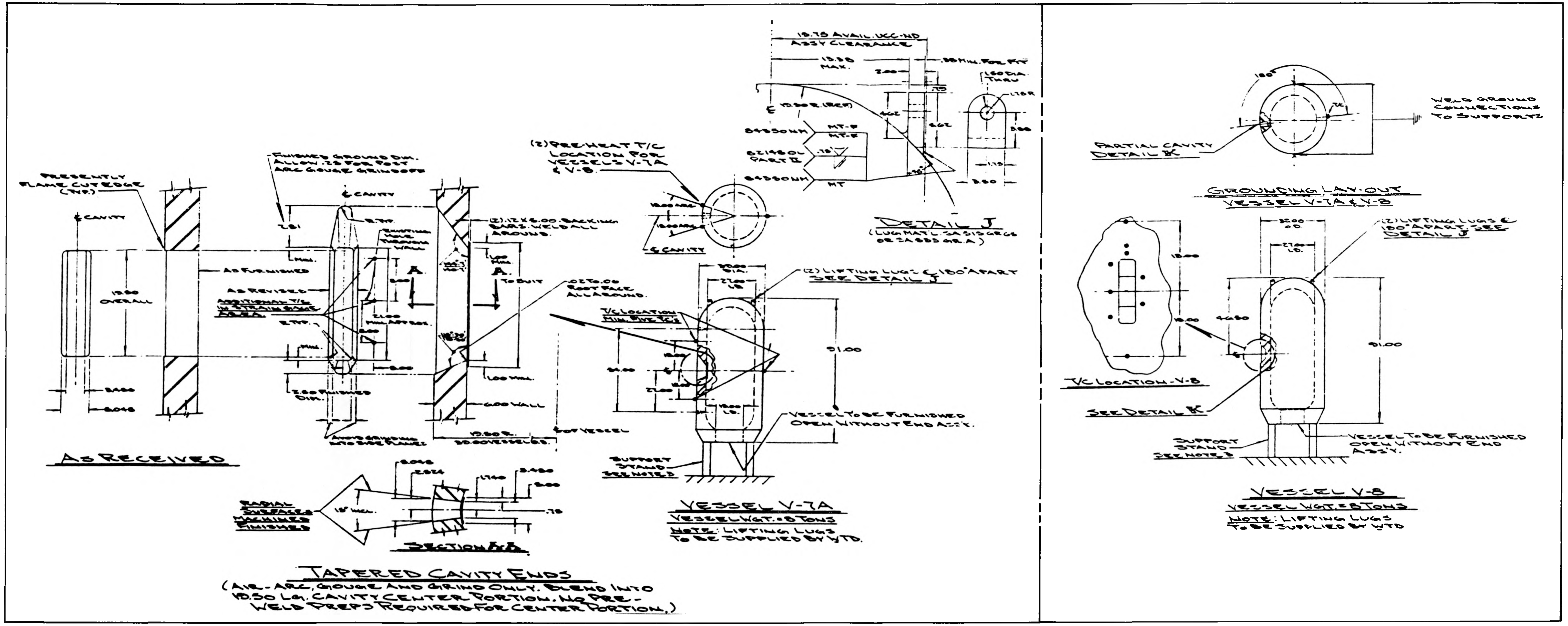
(Section "AA" shown with half-bead layer weld deposit installed.)

Westinghouse Electric Corporation
Westinghouse Tampa Division

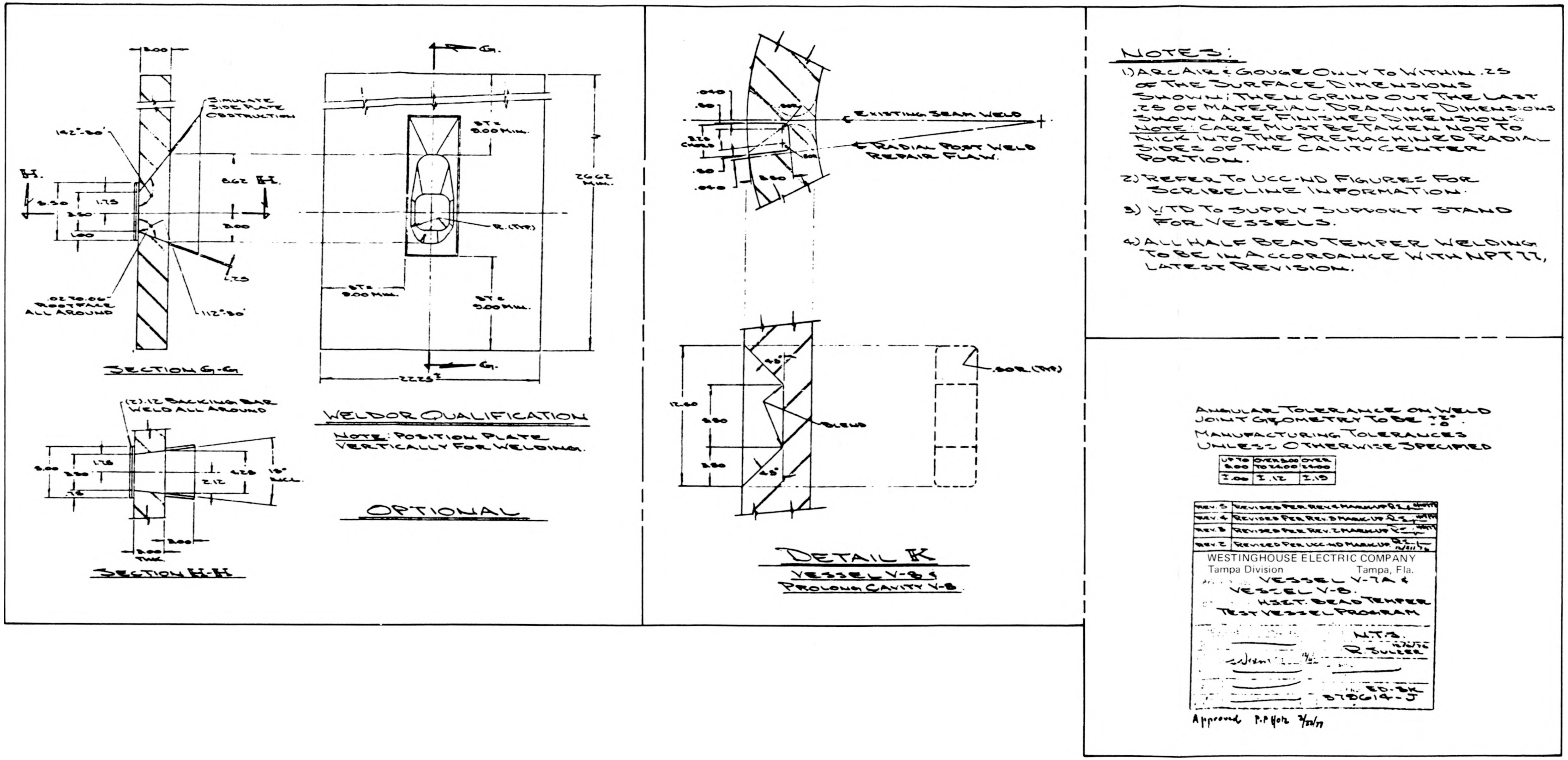
Drawing ED-SK-379614-J

PROCESS SPECIFICATIONS NPT-77, NPT-78,
84350 LL, 84350 NM, and 84350 RT

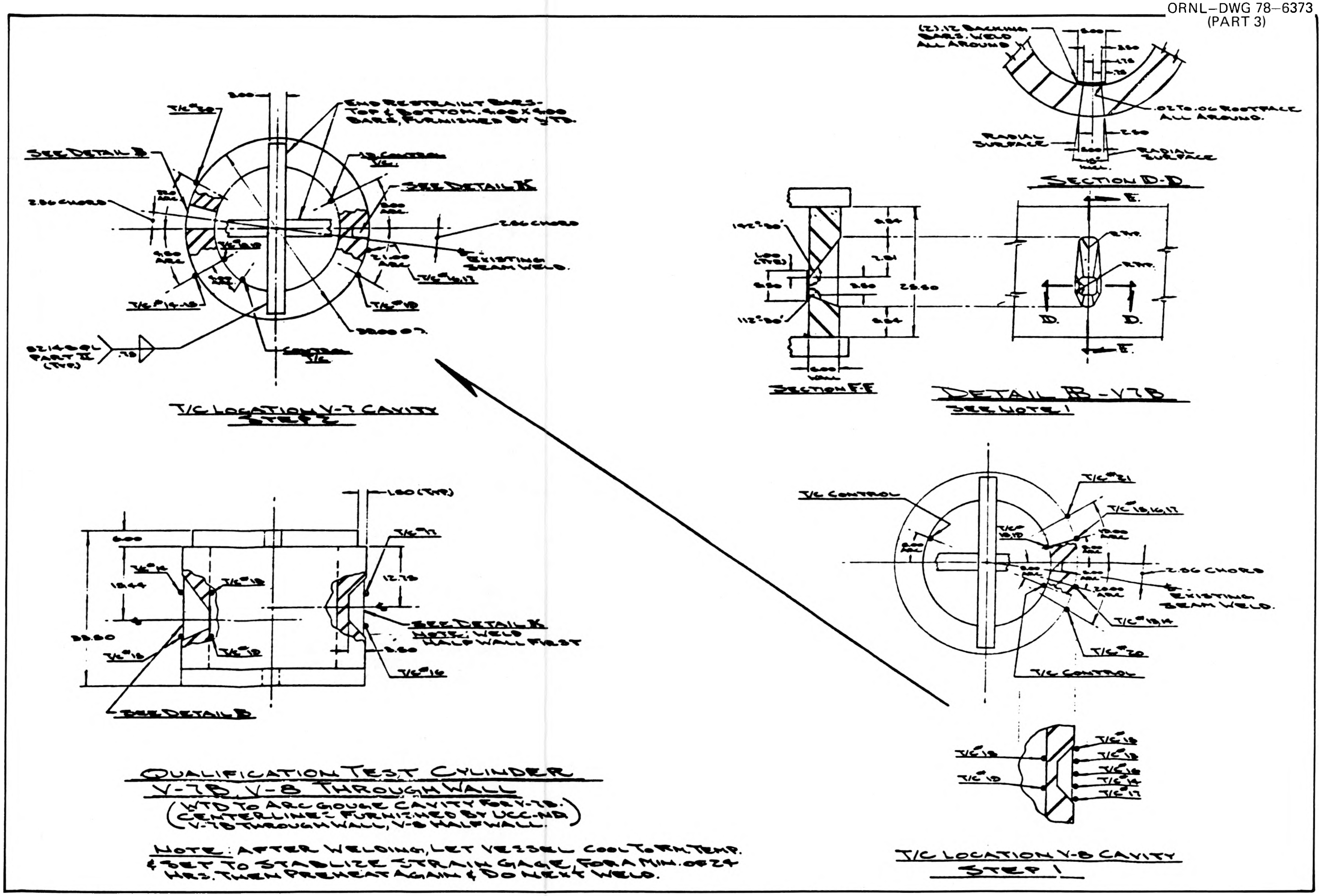
ORNL–DWG 78–6373
(PART 1)



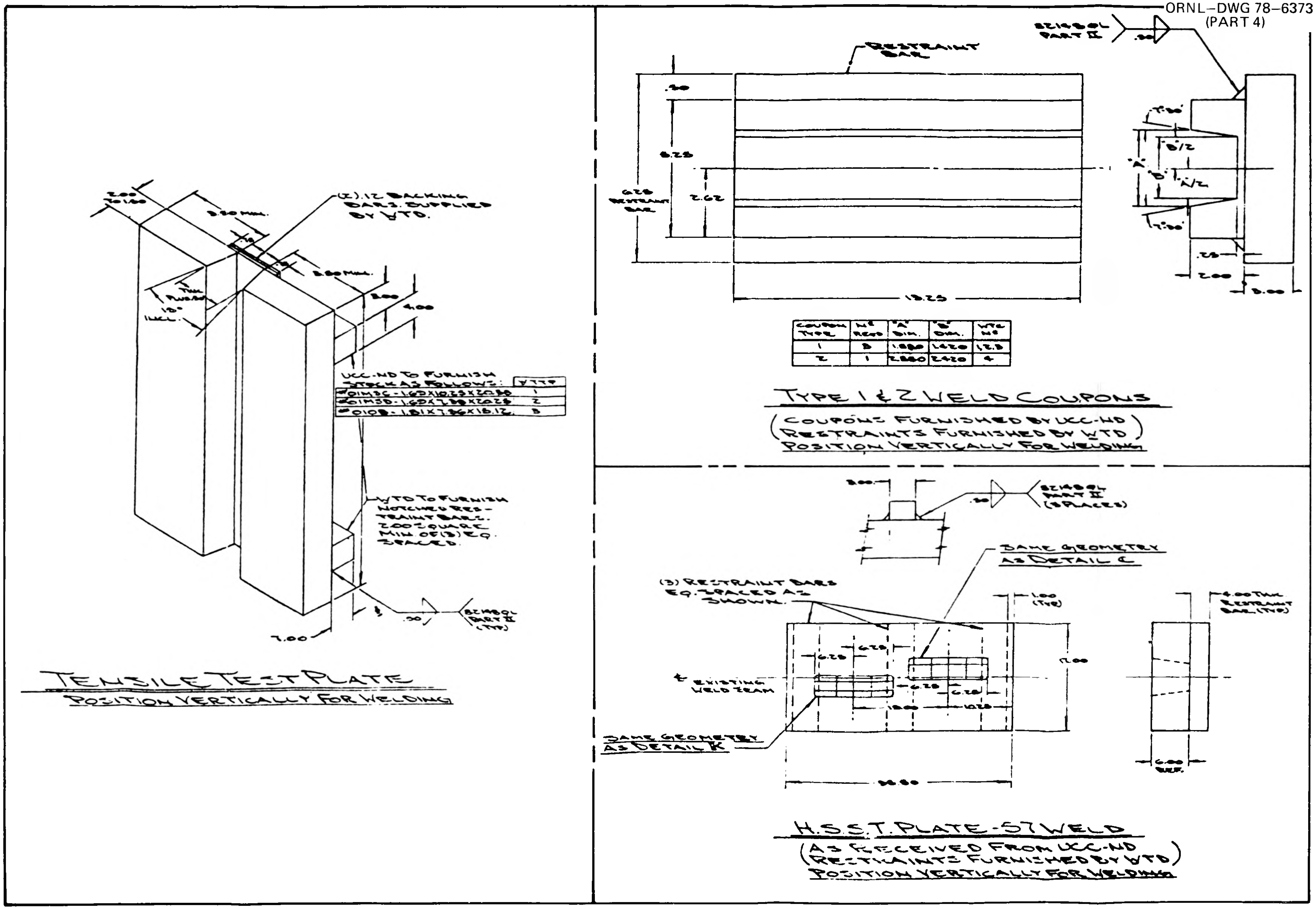
ORNL–DWG 78–6373
(PART 2)



ORNL–DWG 78–6373
(PART 3)



ORNL–DWG 78–6373
(PART 4)



APPENDIX A

Process Specification

Effective Date: 1/5/77

Issue 1

1/5/77

S. W. Wismer

Changed

HALF BEAD TEMPER WELDING REPAIR OF LOW ALLOY STEEL (P3)

A. Scope:

(1) This specification covers the manual shielded metal arc welding (SMAW) with Type E-8018-C3 electrodes on low alloy steel material classified in ASME Section IX as P3 Group 3.

(2) The "Half Bead Temper" technique is described as depositing the first layer with a 3/32" dia. electrode, then grinding half of the deposit off before welding the next layer. Removal of half of the initial layer permits the heat from the next weld pass to refine or temper the grain size of the base metal heat affected zone.

B. Process Qualification:

(1) This process has been qualified to meet the intent of the following ASME Boiler and Pressure Vessel Codes:

a. Sections III Nuclear Vessels
b. Sections IX Welding and Brazing Qualifications
c. Section XI Inservice Inspection

C. Materials:

(1) Base materials shall be P3 Group 3 low alloy steel (SA-533 Grade B Class 1).

(2) Welding electrodes shall be SFA 5.5 E-8018 C3, 3/32" dia., 1/8" dia., 5/32" dia., equivalent to W-PDS 10365 BA.

(3) Electrode Baking:

a. All electrodes shall be removed from their containers and be baked, before using, at a temperature of $800^{\circ} \pm 25^{\circ}$F for thirty (30) minutes to one (1) hour.

b. The temperature of the oven shall not exceed 300°F when the electrodes are placed in the oven.

c. During the baking cycle, the temperature shall not be raised more than 300°F per hour when the oven temperature is above 500°F.

d. The total time above 500°F, including the holding time, shall not exceed five (5) hours.

e. After baking and before the electrodes are allowed to cool below 250°F, they shall be transferred to holding ovens operating at 250°F $\pm$ 25°F.

f. Electrodes shall not be out of an oven more than 20 minutes prior to use.

g. Electrodes not used within 20 minutes, after removal from the oven, shall be returned to the holding oven and held at 250°F ± 25°F for 8 hours before reissue.

(4) Electrode moisture test

a. All moisture tests shall be in accordance with ASME SFA 5.5.

(5) Electrode Inspections

a. All electrode starting end conditions should be inspected for chipped flux coating as follows:

1. When the electrode is removed from the container, prior to baking.
2. After baking and before transfer to the holding oven.
3. When the electrode is taken from the holding oven by the welder.
4. Immediately before welding.

b. Electrodes shall be rejected whenever there are any signs of cracks in the flux coating.

c. Rejected electrodes shall be stored in specially marked containers for future salvage.

D. Welders Qualification:

Manual welders performance qualifications shall be to W WQ-103 and WQ-106, which are in accordance with ASME Boiler and Pressure Vessel Section IX.

E. Heating Parameters:

(1) Preheat: 350°F to 500°F.

(2) Interpass Temperature: 350°F to 500°F.

(3) Post Weld Heat Treatment: Hold at 500°F ± 50°F for four (4) hours after final welding.

(4) Note: Under special conditions an intermediate post weld heat treatment of 500°F ± 50°F held at 1/2 hour may be used.

(5) The preheat temperature shall not be allowed to fall below 350°F until completion of either an intermediate or final post weld heat treatment.

F. Welding Parameters:

Electrode Dia. and Layers		Amperage DCRP	Voltage
3/32" Ø	1st Layer	85 - 100	22 - 25
1/8" Ø	2nd Layer	110 - 140	22 - 25
5/32" Ø	Remaining Layers	130 - 185	22 - 25

NOTE: 1/8" Ø electrode may be used, as needed, for the remaining layers.

G. Welding Technique:

(1) See Sketch 1.

H. Inspection:

(1) Magnetic particle (MT) inspect to WPS 84350 NM as follows:

a. Surface prior to welding.
b. Ground off buttered layer.
c. Second 1/8" Ø layer.
d. Alternate layers.
e. Final ground surface prior to post weld heat treatment.

(2) Visually inspect all layers.

(3) After post weld heat treatment, the weldment shall remain at ambient temperature for at least 48 hours prior to the following:

a. Magnetic particle (MT) inspect to WPS 84350 NM, both final surfaces (OD and ID).

b. Radiographic (RT) inspect to WPS 84350 RT.

c. Ultrasonic (UT) inspect to WPS 84350 LL.

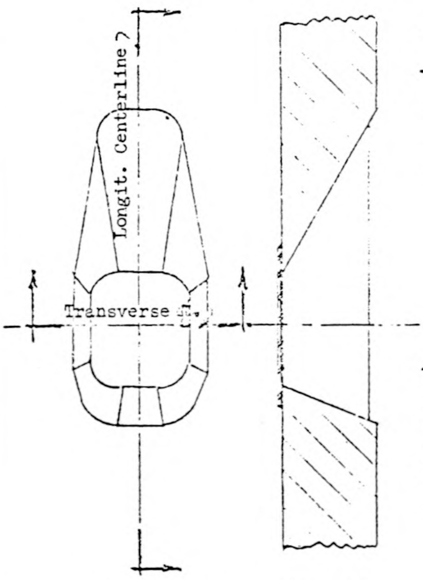
I. Repair Welding:

(1) When necessary, weld defects shall be removed and the repaired zone reinspected.

(2) If defects occur within 3/16" of the base metal, the "half bead temper" technique shall be used.

(3) An MT inspection shall be performed on the vessel ID after grinding and back welding (if required).

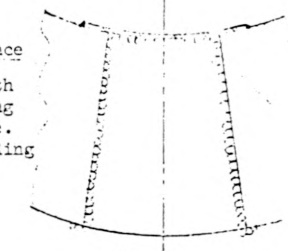
All welding shall be done with the longitudinal axis of the vessel (or work) in the vertical position.



Cavity Plan Section

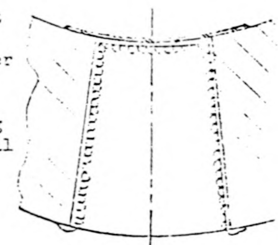
Weld Metal Deposition Sequence

Step 1: " Butter" cavity with one layer of weld metal using 3/32" diam. coated electrode. For the half bead pass, welding shall be in the vertical position for cavity sides.



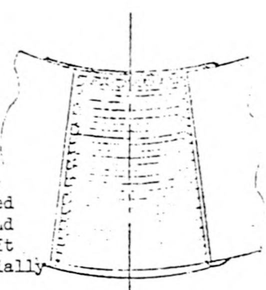
Step 1:

Step 2: Remove half of first layer ("buttering layer") by grinding. Deposit second layer with a 1/8" diam. coated electrode.
For the second layer, welding shall again be in the vertical position for cavity sides.



Step 2:

Step 3: Complete the joint using 1/8" and/or 5/32" diam. coated electrodes. The maximum bead width shall not exceed four times the electrode core diameter. The final layer overlaps, but shall not extend beyond the "buttering" deposited by Step 1, and shall then extend to a level above the surface. It shall then be removed substantially flush with the surface.



Step 3:

Sections

HALF BEAD WELD REPAIR SEQUENCE

SKETCH 1

1. Scope: This specification covers the "arc-air" gouging of steel in casting forgings, plates or bars. Specific applications for which this process is approved are:

   a. The removal of the unfused root of a double sided weld prior to depositing the second side.

   b. Exploration and removal of defects.

   c. Scarfing grooved weld joints.

2. Operator Instruction and Qualification: Prospective arc-air operators shall be properly instructed in the technique of arc-air gouging. Formal operator qualification is not necessary other than the instructor's evaluation and confidence in the individual's ability to perform the arc-air operation satisfactorily.

3. Equipment:

   3.1 Power Source: A D.C. motor generator set with a minimum output of 600 amps with high current surge protection. An alternate power source is a 600 amp. minimum, silicon diode rectifier provided with suitable protection for arc-air gouging.

   3.2 Manual Torch: Arc-air general purpose torch for electrodes up to 1/2" diameter.

   3.3 Electrodes: Copperclad electrodes 1/4", 3/8", or 1/2" diameter.

   3.4 Compressed Air Source: Capable of supplying a continuous pressure of 80 to 100 psi.

4. Manual Arc-Air Gouging:

   4.1 Preheat

   Preheat prior to gouging varies with the type of steel and the welding process specification preheat requirements shall be used.

   4.2 Gouging

   The arc-air copperclad electrode produces a gouge that is approximately 1/8" wider than the diameter of the electrode used. Select an electrode size appropriate with the joint geometry or the size of the defective casting area to be explored. Current requirements vary with the electrode diameter used as shown below:

CURRENT REQUIREMENTS

Electrode Size	1/4"	3/8"	1/2"
Minimum Amperage	200	400	500
Maximum Amperage	400	600	600

4.2 Gouging (Continued)

The depth of cut varies with the angle between the electrode and the work surface. The steeper the angle, that is, the nearer the electrode becomes normal to the work surface, the deeper the cut and the greater the amperage requirement. Generally, this angle is varied between 20° to 60° with the work.

Power and compressed air are brought to the torch through concentric cables. As the angle of the electrode is adjusted, the compressed air nozzle automatically compensates so as to always direct the air stream toward the electrode. The torch is held such that the air stream is always under the electrode.

4.3 Cleaning

4.3.1 Arc-air gouged areas are clean except for a heat discoloration in the general area. Such areas are cleaned by wire brushing and chipping hammer to remove any pimples, scale, debris, etc.

4.3.2 Other areas in which the electrode is permitted to contact the work are clearly evident. They are covered with the black sooty remains of the electrode. These areas are to be ground smooth to remove a layer of metal .005" minimum, thus removing any area of possible carbon pick-up.

4.3.3 Special clean-up dimensions shall be shown on the drawing.

4.4 Inspection

All gouges and adjacent areas shall be magnetic particle inspected and cleared of all indications if required by drawing or process specification.

Process Specification
NUCLEAR POWER COMPONENTS
ULTRASONIC EXAMINATION OF WELDS

Issue 1
7/9/69
C.A Galyen
T.D.Rorrer
Changed
6/20/75 2

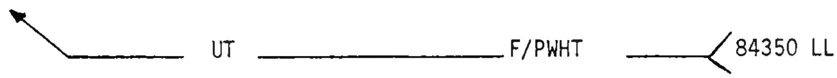
A.C.Garrison 6/10/75
R. P. Wedler 6/11/75
W. Beers 6/10/75
E.P.Longphre 6/13/75
R.H.Anderson 6/9/75
E. P. Loch 6/17/75

Purpose: This specification covers the ultrasonic examination of materials for use on nuclear power components. This covers the examination of welds and meets the requirements of A.S.M.E. Boiler and Pressure Vessel Code, Section III, Nuclear Vessels and is in accordance with A.S.M.E. Section V, Nondestructive Examination.

PROCESS QUALIFICATIONS: This Process Specification specifies examination procedures and acceptance standards when referenced on the applicable drawing.

GENERAL: Use of this Process Specification will be indicated by:

Drawings, with symbols in accordance with AWS A 2.2-69.
A typical symbol is:



The principal objective of the methods given herein is the detection, location and evaluation of defects within the weld and heat affected zone. The welds shall be examined by the angle beam method where practical. In the examination of weldments where geometry does not allow angle beam examination from both sides of the weld from a single surface or a combination of surfaces, either a combination of angle beam and straight beam or straight beam in two (2) directions at 90 degrees to each other shall be used.

QUALIFICATION OF PERSONNEL: Personnel performing tests under this Process shall be qualified in accordance with SNT-TC-1A.

EQUIPMENT: The ultrasonic instrument shall be of the pulsed reflection type and shall be capable of carrying out all provisions of this Specification.

The nominal test frequency shall be 2.25 megahertz with a transducer of one square inch in area. Immersion or contact transducers may be used. Smaller size transducers and other frequencies may be used to explore or better define the size or location of flaws.

SURFACE PREPARATION:

A. Surface finish: All surfaces to be examined shall be flat and have a 250 microinch finish or better.

NOTE: A "flat" surface is considered sufficiently level or smooth when it provides good transducer contact. The surface shall be cleaned of paint or dirt prior to using the liquid couplants.

B. Ultrasonic couplants: A suitable liquid couplant such as clean S.A.E. 30 oil shall be used to couple the search units to the surface. The residual total halogen content shall not exceed one percent by weight. Solid couplants such as greases, "seal peel", putty, etc., shall not be used.

C. Contact surfaces: The finished contact surfaces shall be free from weld spatter and any roughness that would interfere with free movement of the search unit or impair the transmission of ultrasonic vibrations.

D. Welded surfaces: The finished weld surfaces where accessible, shall be of adequate smoothness to prevent interference with the interpretation of the examination. The weld surface shall merge smoothly into the surfaces of the adjacent base materials.

E. Base material: After the weld is completed but before the angle beam examination, the area of the base material through which the sound will travel in angle beam examination shall be completely scanned with a straight beam search unit to detect reflectors which might affect the interpretation of angle beam results. Consideration must be given to these reflectors during interpretation of weld examination results, but their detection is not a basis for rejection of the base material.

EXAMINATION PROCEDURE:

Basic calibration reflectors: Drilled holes shall be used as basic calibration reflectors to establish a primary reference response of the equipment and to construct a distance-amplitude corrective curve. These holes shall be located either in production material or in a basic calibration block.

A. Basic calibration block: If a basic calibration block is used, it shall have a thickness relative to the production material thickness as shown by Figure No. "A". Where two or more thicknesses are involved, the calibration thickness shall be determined by the thickness of the production material to which the search unit is applied. If the contact surface of the production material has a radius of curvature of 10 inches or less, the curvature of the basic calibration block shall correspond to the radius of the production material within ± 10 per cent.

B. Basic calibration hole: The basic calibration hole shall be drilled parallel to the contact surface of the basic calibration block or the production material. The location, depth, and diameter of this hole shall be as given in the table in Figure No. "A".

C. Other calibration reflectors: In lieu of the above, other calibration reflectors are permitted, provided equivalent response is demonstrated.

ANGLE BEAM METHOD:

A. Beam angle: The beam angle in the production material shall be in the range of 40 degrees to 75 degrees inclusive with respect to the perpendicular to the contact surface.

B. Distance-amplitude correction: Compensation for the distance traversed by the ultrasonic beam as it passes through the material shall be provided by the use of curves, as shown by Figure No. "B" or electronically.

C. Determination of curves: Distance-amplitude correction curves shall be constructed by utilizing the responses from the basic calibration hole described in Basic Calibration Reflectors. The first point on the curve is obtained by placing the search unit as near as possible but not less than 3/8 vee-path, (vee-path same as node) or 2 inches, whichever is less, from the calibration hole and positioning for maximum response. The gain control then is set so that this response is 75 percent of full screen. This is the primary reference response. Without changing the gain, the search unit shall be placed similarly at other nodal positions, or additional calibration holes may be drilled, covering the contemplated examination distance range and the corresponding responses marked on the screen. These points shall be joined by a smooth line, the length of which shall be such as to cover the examination range. See Figure No. "B".

D. Examination procedure: Coverage: Where possible, welds shall be examined from both sides of the weld (Usually from one surface only). Each pass of the search unit shall overlap a minimum of 10 percent transducer width and the scanning rate shall not exceed 6 inches per second.

Sensitivity level: The reference level sensitivity for monitoring discontinuities is the primary reference response corrected for distance by the distance-amplitude curve or electronically, modified by the transfer mechanism if used.

When possible, scanning shall be performed at a minimum gain setting of two times the reference level sensitivity.

Reference level: The reference level for monitoring discontinuities is the primary reference response corrected for distance by the distance-amplitude curve or electronically, modified by the transfer mechanism.

Detection of defects parallel to the weld: The search unit shall be placed on the contact surface with the beam aimed about 90 degrees to the weld and manipulated laterally and longitudinally so that the ultrasonic beam passes through all of the weld metal in two different approaches of the beam.

Techniques employing two search units may be used to detect lack of penetration in double welded butt joints.

Detection of defects transverse to the weld: Two search units shall be placed on the contact surfaces adjacent to the weld, one on each side, making an angle of 45 degrees or less with the axis of the weld as shown by Figure No. "A". Alternatively, if the weld surface is suitable, one search unit may be placed on the centerline of the weld with the beam directed along the weld in such a manner that the entire depth and width of the weld is scanned.

STRAIGHT BEAM METHOD:

A. Distance-amplitude correction: A distance-amplitude correction curve need not be constructed when the thickness of material is one inch or less. For greater thicknesses, using the proper basic calibration block (See Figure No. "A"), position the search unit for maximum response for the basic calibration hole at 1/4 T (See Figure No. "D"). Adjust the signal amplitude to 50 percent of full screen. This is the primary reference response. Without changing the gain control, position the search unit for maximum response for the basic calibration maximum response from the basic calibration hole at 3/4 T and mark its amplitude on the screen. Join the two points with a straight line and extend its length to cover the test range.

B. Examination procedure: Scanning motion: The weld shall be examined by moving the search unit progressively along and across a sufficient contact area so as to scan the entire weld.

Sensitivity level: When possible, scanning shall be performed at a minimum gain setting of two (2) times the primary reference level. Evaluation of discontinuities shall be carried out with the gain control set at the reference level.

Verification of penetration: Penetration shall be verified by (a) obtaining a reflection from an opposite parallel surface, or (b) obtaining the back reflection on similar material while using approximately the same length of sound travel.

C. Evaluation of indication: All indications which produce a response greater than 20 percent of the reference level shall be investigated to the extent that the operator can determine the shape, identity and location of all such reflectors and evaluate them in terms of the acceptance standards.

ACCEPTANCE STANDARDS: Portions of welds that are shown by ultrasonic examination to have any of the following types of discontinuities are unacceptable unless the discontinuities are removed and the weld is repaired.

A. Cracks, lack of fusion, and incomplete penetration.

B. Other linear type discontinuities if the signal amplitude exceeds the reference level and discontinuities have lengths which exceed the following:

1/4 inch for t up to 3/4 inch inclusive.
1/3 t for t from 3/4 inch to 2 1/4 inch inclusive.
3/4 inch for t over 2 1/4 inch.

where t is the thickness of the thinner portion of the weld. If a weld joins two members having different thicknesses at the weld, t is the thinner of these two thicknesses.
Repairs: Repairs shall be re-examined by the same procedures used for detection of the discontinuities. Acceptability of repairs shall be determined by the same acceptance standards.

RECORDING EXAMINATION RESULTS: For each ultrasonic examination, fill out in detail Form TA-00175, "Report of Ultrasonic Examination."

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Issue 1
7/9/69
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T.D.Rorrer
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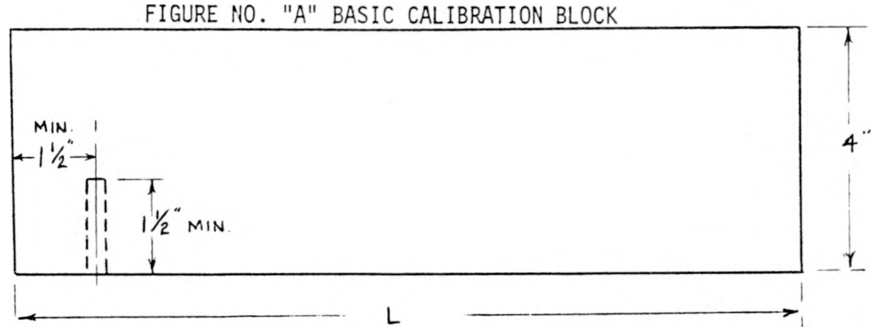
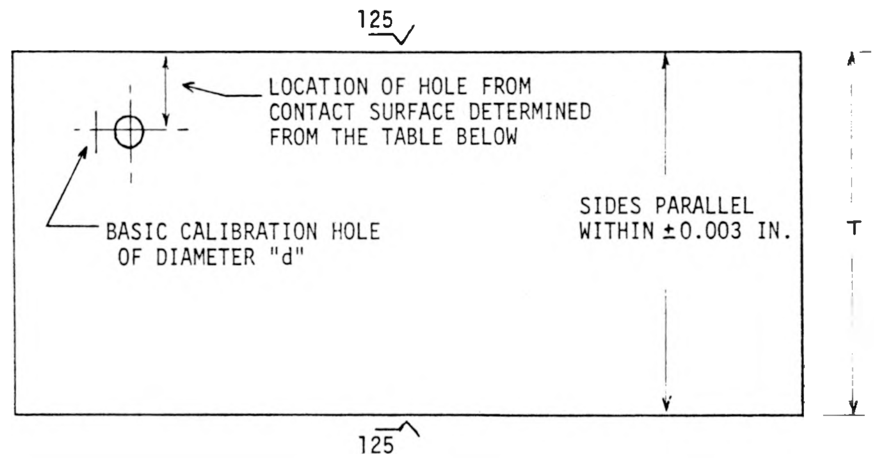
6/20/75 2

FIGURE NO. "A" BASIC CALIBRATION BLOCK

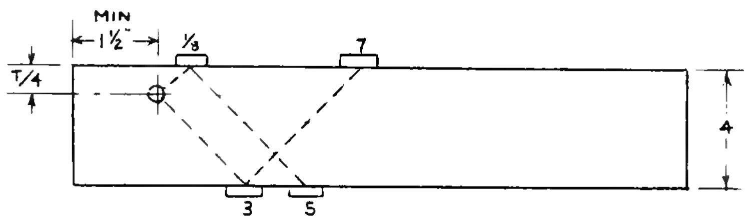




L = Length of block determined by the angle of search unit and the node used for examination of Production Materials.
T = Thickness of basic calibration block (see Table below).
D = Depth of Basic Calibration hole (See Figure).
d = Diameter of Basic Calibration hole (See Table below)
t = Nominal production material thickness.

PRODUCTION Material Thickness (t)	BASIC CALIBRATION Block Thickness (T)	HOLE Location	HOLE Diameter (d)
Up to 1" Incl.	3/4" to t	1/2 T	3/32"
Over 1" thru 2"	1-1/2" or t	1/4 T	1/8"
Over 2" thru 4"	3" or t	1/4 T	3/16"
Over 4" thru 6"	5" or t	1/4 T	1/4"
Over 6" thru 8"	7" or t	1/4 T	5/16"
Over 8" thru 10"	9" or t	1/4 T	3/8"
Over 10"	t	1/4 T	See Page 6*

* For each increase in thickness of 2 inches or fraction thereof the hole diameter shall increase 1/16 inch.



FOR THICKNESS OVER 1 INCH

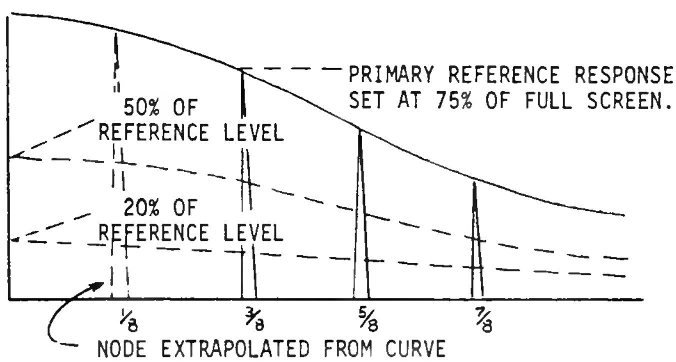


FIG. NO. "B-1" TYPICAL DISTANCE AMPLITUDE CORRECTION CURVE
(ANGLE BEAM METHOD)

(DISTANCE IN EIGHTS OF A NODE. FOR EXAMPLE 7 is 7/8 NODE)

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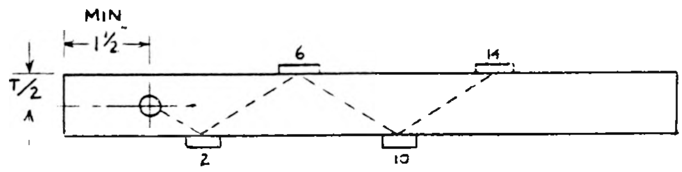
Tampa, Florida U. S. A.

Issue 1
7/9/69
C.A.Galyen
T.D.Rorrer
Changed
6/20/75 2



FOR THICKNESS 1 INCH OR LESS

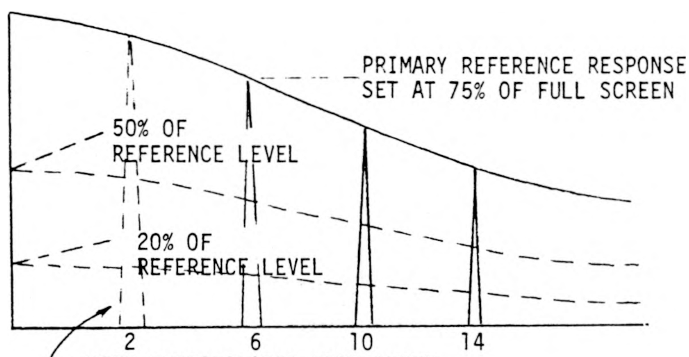


FIG. NO. "B-2": TYPICAL DISTANCE AMPLITUDE CORRECTION CURVE (ANGLE BEAM METHOD)

(Distance in eights of a node, For example, 14 is 14/8 node.)

Process Specification
NUCLEAR POWER COMPONENTS
ULTRASONIC INSPECTION OF WELDS

Issue 1	
7/9/69	
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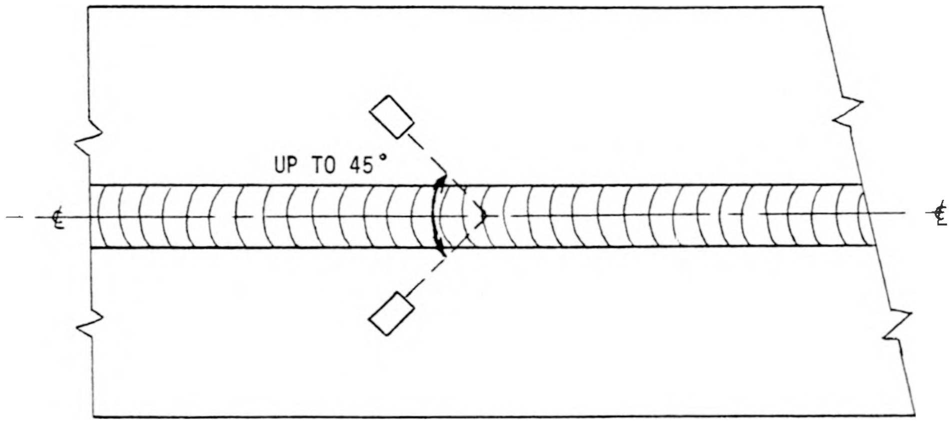

FIGURE NO. "C": TYPICAL TWO SEARCH UNIT TECHNIOUE FOR DETECTING TRANSVERSE DISCONTUNITIES

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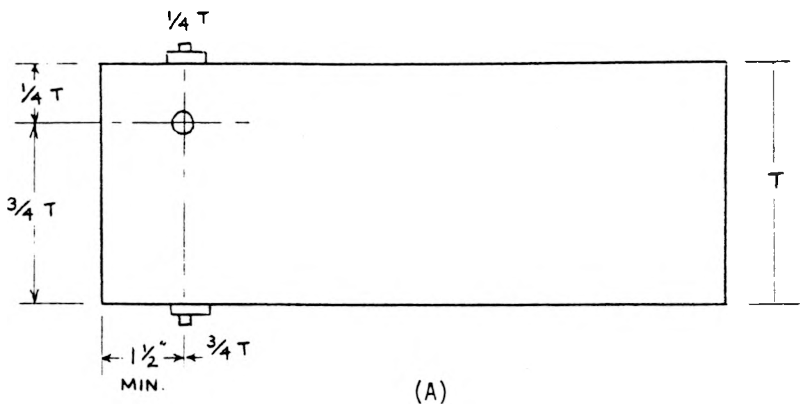
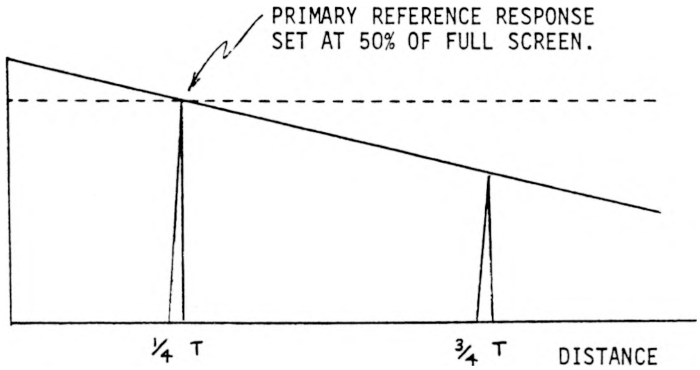


(A)



(B)

FIG. NO. "D" TYPICAL DISTANCE AMPLITUDE CORRECTION CURVE
(STRAIGHT BEAM METHOD)

Issue 1
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Changed	
8/17/70	2
5/29/73	3
4/16/74	4
4/16/75	5
10/25/75	6
6/23/76	7

A.C. Garrison 6/9/76
R. P. Wedler 6/21/76
W. Beers 6/8/76
S. J. Longphre 6/9/76
R.H. Anderson 6/8/76
E. P. Loch 6/11/76

NUCLEAR POWER COMPONENTS MAGNETIC PARTICLE EXAMINATION

I. Purpose: This Process Specification covers the magnetic particle examination of materials and weldments for use in nuclear power components.

Part I: Magnetic particle examination by D.C., dry powder, continuous method; other than for fine-finish machined surfaces or after final heat treatment, final machining or hydrotest; and joints and repairs such as closures that are normally inaccessible or impractical for prod application.

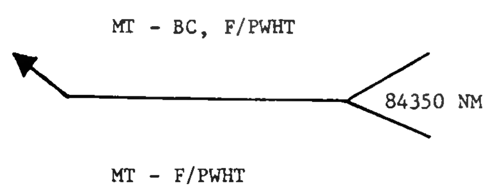
Part II: Magnetic particle examination by yoke method; for fine-finish machine surfaces and after final heat treatment, final machining or hydrotest; and joints and repairs such as closures which are normally inaccessible or impractical for prod application; A.C. or D.C., dry powder, continuous method.

II. A. Process Qualification: This Process Specification meets the intent and requirements of ASME, Sections III, V and VIII.

B. Personnel Qualifications: Personnel shall be qualified and certified in accordance with SNT-TC-1A.

III. General: Use of this Process Specification will be indicated by:

A. Drawings with symbols in accordance with AWS 2.2-69. Typical symbol



The following typical abbreviations are to be used with above symbol:

- MT - Magnetic Particle Examination
- R - Examination of root pass
- BC - Examination of back chipped weld
- F - Examination of final surface as welded, machined or ground before or after post weld heat treatment.
- F/PWHT - Examination of final surface after post weld heat treatment.
- EA 3/8 - Examination of each 3/8 inch of deposited weld. (typical)
- F/HYD - Examination of final weld after hydrotest.

B. Welding specifications called for on the drawing.

C. Shop work tickets, or other special instructions.

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3	5/29/73
4	4/16/74
5	4/16/75
6	10/25/75
7	6/23/76

IV. Precautions: The following safe practice data sheets are applicable to this specification:

Material	Safe Practice Data Sheet	W No.
Petroleum Distillate	S-6	55812-CJ
Alcohol	A-9	51100-BM
Alcohol (Methyl)	A-14	51100-AD

V. Equipment:

A. Source of Magnetic Field: See applicable Part.

B. Field Indicator: A field indicator may be used to demonstrate the adequacy of the magnetic field strength. Field indicator is described in ASME Section V.

C. Magnetic Particle Application and Removal Equipment: Particles may be applied by means of mechanical shakers, bulb blowers, or mechanical blowers. Excess particles may be removed satisfactorily using an air line held obliquely about 1-1/2 inches to 2 inches from the tested area. Nozzle size and air pressure shall be such that, when operating in free air, a pressure of 1.5 maximum of water will be produced when measured with a manometer tube located at an axial distance of 1 inch from the nozzle. A commercial powder blower manufactured by the Magnaflux Corporation, or equivalent, which has been calibrated to the above, is considered an acceptable means for removing excess powder.

D. Lighting: The test areas shall be adequately illuminated for proper evaluation of the indications revealed on the test surface.

VI. Materials: The following materials shall be used with this specification:

A. Magnetic Particles: Dry finely divided ferromagnetic particles of high permeability and low retentivity, free from deleterious rust, grease, paint, dirt, or other material which might interfere with their proper functioning; and of such size, shape and color contrast as to provide adequate sensitivity and contrast shall be used. Manufactured by Parker Institute or Magnaflux Corporation. Red, black or gray may be used as needed to provide contrast; however, red is universal and acceptable for use on most surfaces.

VII. Surface Preparation:

A. Surface Finish: The surface to be inspected shall be finished to drawing requirements. Where the drawing does not specify otherwise, "As Welded" surfaces shall be considered suitable for inspection without any grinding, provided the following conditions are met. There shall be no rollover or undercutting valleys or grooves along the axis of or within the weld that will interfere with the conduct and evaluation of the test. The deposited metal must be fused smoothly and uniformly into the base metal surfaces. The finished weld shall be reasonably smooth and free from irregularities, grooves or depressions.

3/13/70	
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8/17/70	2
5/29/73	3
4/16/74	4
4/16/75	5
10/25/75	6
6/23/76	7

VII. Surface Preparation (continued)

A. (continued)

Back-chipping of welds shall be sufficiently ground to prevent non-relevant indications. Root passes or subsequent layers of welds may be inspected in the "As Welded" condition provided there is no interfering rollover or undercutting.

With the exception of incomplete welds, all surfaces being tested shall be the finished surfaces. If any metal is removed by grinding, machining, or any other method subsequent to the magnetic particle inspection, the surfaces or areas so affected shall be reinspected.

B. Surface Conditioning: Rust, scale, slag, weld pimples, and other hard tenacious materials shall be removed by shot blasting, wire brushing, grinding or machining. A thin, adherent coating of aluminum or other non-insulating paint will not interfere with the formation of indications and is considered a suitable surface condition, if the coating material is firmly affixed and there is no evidence of peeling or other separation. When peeling or separation is evident, it is necessary to remove the paint or coating from the area of inspection to insure meaningful examination.

C. Magnetic Particle examination shall not be performed on surfaces which exceed 600^{o}F.

D. The Westinghouse Quality Control personnel conducting the examination shall determine the acceptability of the surface for magnetic particle examination.

VIII. Acceptance Standard: Any indication which is believed to be nonrelevant shall be regarded as a defect and shall be reexamined to verify whether or not actual defects are present. Surface conditioning may precede the reexamination. Nonrelevant indications which would mask indications of defects are unacceptable .

Defects shall be evaluated to the acceptance standards below.

Note: For the purpose of this specification, a rounded indication may be either circular or elliptical in shape with the longer axis less than (3) times as long as the smaller axis and with no sharp corners. Thus a linear indication has the major axis three (3) times or greater than the minor axis and/or exhibits sharp corners.

A. Examination Extent: Examination of welds or surfaces by the magnetic particle method shall be made over an area extending at least 1/2 inch beyond the area of interest.

Changed	
2	8/17/70
3	5/29/73
4	4/16/74
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6	10/25/75
7	6/23/76

B. Unless otherwise specified below, the following relevant indications are unacceptable. All surfaces shall be free of:

1. All cracks, laps, fissures and other linear defects.

2. All rounded indications with dimensions greater than 3/16 inch.

3. Four or more rounded indications in a line separated by 1/16" or less edge-to-edge; other in-line porosity which appears as a linear accumulation of test medium power shall also be removed.

4. Ten or more rounded indications in any six square inches of surface, with the major dimension of this area not to exceed 6 inches and with the area taken in the most unfavorable location relative to the indications being evaluated.

C. <u>Weld Edge Preparation</u>:

1. All weld edge preparation surfaces in material 2 inches or more in thickness shall be examined for cracks, laminations, or other discontinuities.

2. Laminar type indications:

   a. Laminar type indications are acceptable if they do not exceed 1 inch in length.

   b. Laminar type indications which exceed 1 inch in length require Ultrasonic Testing examination of the area for evaluation of acceptance as to the UT requirements of the product form. If UT inspection permits acceptance of the involved area, then the indications will be removed to a depth to accomplish elimination or a maximum of 3/4 inch, whichever is lesser; and then be repair welded to the applicable welding procedure. In event of material basis UT rejection, the effective repair must be to an extent to permit acceptance to the product form; in which situation repairs may be more extensive than the 3/4 inch provision.

   Note: Dependent on anticipated discontinuity removal or ability to meet the one inch minimum length at a depth of removal being less than the 3/4 inch maximum grinding, the U.T. examination for product form acceptance may be deferred until the initial grinding is performed.

3. Only indications with major dimensions greater than 1/16" shall be considered relevant. Further, separated, nonlaminar, relevant, linear indications not exceeding 3/16" are acceptable.

4. Indications in weld preparations other than those specified in this paragraph will be evaluated to the requirements of Paragraph B, 1, 2 and 3 above.

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D. Forging, Casting and Plate Material.

In the conduct of examination of forging, casting and plate material indications are unacceptable on the following basis in respect to material thickness:

"t"	Maximum Rounded	Maximum Major Dimension of Linear Consideration
Up to 5/8"	greater than 1/8"	greater than 1/16"
5/8" - under 2"	" " 3/16"	" " 1/8"
2" and greater	" " 3/16"	" " 3/16"

For linearly disposed or cluster count acceptance, same as B. 3 and B. 4 above, with basis that indications with major dimensions greater than 1/16" are considered relevant.

E. Plate material repairs; at supplier or in-house.
Unacceptable surface defects shall be removed by grinding and/or machining, provided the remaining section thickness is not reduced below drawing minimum; the depression, after defect removal, blends uniformly, 4:1 minimum taper, into the surrounding surface, and is examined by the magnetic particle method to the acceptance criteria of Paragraph D above.

F. Only such defects need be removed as to render the surface acceptable to the requirements of this specification. Areas containing unacceptable defects shall be gound to remove the necessary defects. The ground-out areas shall be reinspected to insure the defect(s) being completely eliminated. Minor cavities resulting from the removal of small discontinuities, that do not reduce the wall or weld deposited overlay below drawing requirements, or that do not affect machined surfaces or gasket fits, need not be repair welded. They shall, however, be blended to a 4:1 minimum taper into the surrounding area. Other defects may be repair welded by means of the original or other approved repair welding process. Completed repairs shall be, at a minimum, magnetic particle examined for final acceptance.

IX. Repair Welding: Specific approval for repair welding must be obtained in the following cases:

A. Repair of base metal defects in pressure boundary application, excluding Weld Edge Preparation discontinuities in accordance with Paragraph VIII C.2.b., above, which meet material product form requirements, and repairs accomplished in accordance with TQAI 1.5.3. Non-pressure boundary materials (internals) will require approval only in event of abnormal or multi-cycle conditions for which welding or Manufacturing Engineering personnel request assistance.

B. Repair of weld defects, except those repairs defined as permissible in the appropriate weld process.

C. Repair of weld or base metal cracks or fissures which persist after the first cycle of repair.

D. Repairs necessary following any one or combination of final heat treatment, final radiographic examination or hydrostatic test.

Changed	
2	8/17/70
3	5/29/73
4	4/16/74
5	4/16/75
6	10/25/75
7	6/23/76

X. Demagnetization: Demagnetization following examination is required where residual magnetism will interfere with subsequent processes or usage. In respect to magnetic particle examination sequence, demagnetization of the specimen or section is recommended when a higher field has been imposed for the first direction than that to be used for a subsequent examination.

Complete demagnetization is practically impossible to attain, the process is thus limited to reducing the residual fields, as appropriate, to an acceptable level. Essentially, residual magnetism will result from D.C. magnetic particle examination, a result of penetration effect; A.C. test application residual effects are less severe.

When direct current magnetization has been employed, demagnetization may be accomplished by repeatedly reversing and progressively decreasing the D.C. magnetizing current. The initial field strength used during demagnetization shall be greater than the original magnetizing force. When the current has been reduced to the vanishing point, the part should be demagnetized.

When alternating current magnetization has been employed, A.C. demagnetization can be accomplished by decreasing the magnetizing current in small steps or continuously to a very low amperage. For small components, demagnetization may be effected by passing the part through a coil with AC flowing, and removing the part at least 18 inches from the coil. The initial demagnetizing current shall be greater than that of the original magnetizing force.

PART I

Procedure for magnetic particle examination by D.C. dry powder, continuous method; other than for fine finish machine surfaces or after final heat treatment, final machining or hydrotest; and joints and repairs such as closures that are normally inaccessible or impractical for prod application.

I. Equipment: The magnetizing equipment, as a source of magnetic field, shall be capable of inducing in the item under test a magnetic flux of suitable intensity in the desired direction by either the circular or longitudinal method. Direct current (D.C.) obtained from D.C. generators, storage batteries or rectifiers shall be used to induce the magnetic flux. Alternating current (A.C.), as a magnetic flux inducing field source may be used only when permitted by this process specification.

Half-Wave Direct Current (H.W.D.C.) is similarly suitable - even preferred as a magnetic field source as a function of pulsation and powder mobility response.

For D.C. prod application, the open circuit voltage of the magnetizing source shall not exceed 25V.

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II. Procedure:

A. Pre-inspection

B. Pre-cleaning

C. Application of magnetic field

D. Application of magnetic particles

E. Removal of excess particles

F. Examination and evaluation

G. Certification of Examination

H. Demagnetization

A. Pre-Inspection: Prior to magnetic particle examination, the surface shall be examined to determine its compliance to Paragraph VII and a dimensional examination including, but not necessariliy limited to machined sizes, fillet sizes, wall thickness, and weld suitability. All unacceptable conditions must be corrected prior to magnetic particle examination. Lighting (Paragraph V.D) and materials (Paragraph VI) shall be checked for compliance to this specification.

B. Pre-Cleaning: The materials or parts to be examined shall be suitably cleaned to remove all foreign matter which could interfere with the formation or evaluation of magnetic particle powder patterns or indications. Oil and grease shall be removed using petroleum distillate (spirits) and/or alcohol or methyl-alcohol. Cleaning shall extend at least one inch on each side beyond the area to be examined. The use of alcohol shall always follow the use of petroleum distillate.

C. Application of Magnetic Field:

1. Direction: The magnetic field shall be induced in more than one direction to insure detection of discontinuities in any direction. The second direction shall be at approximately 90° to the initial direction.

2. Magnetizing Time: For application in either direct or indirect magnetization, the current shall be passed through the part or through the auxiliary conductor for a minimum of 1/5 second.

3. Precaution: Care shall be taken to prevent local overheating, arcing or burning the surface being inspected. The magnetizing current shall not be turned on until the prods have been properly positioned in contact with the surface, and the current shall be turned off before the prods are removed. Prod tips shall be kept cleaned and dressed.

Changed	
2	8/17/70
3	5/29/73
4	4/16/74
5	4/16/75
6	10/25/75
7	6/23/76

II. (continued)

C. Application of Magnetic Field (continued)

4. Exception: When the surface being examined is a weld root pass, it is permissible to use alternating current.

5. Direct Magnetization:

a. Field Strength: When prods are employed to produce direct, circular magnetization, the current shall be at least 100 to 125 amperes per inch of prod spacing, for normal application.

b. Prod Spacing: Prods will be spaced not less then three (3) inches nor more than eight (8) inches apart for normal operations. Any requirements for exception as a result of component configuration or other basis shall be reviewed by the Quality Assurance Engineer or Quality Control Supervisor.

c. Cable Length: Cable leads in excess of 30 feet, each, shall not be employed under standard practice. For any requirement of exception, follow that of b. above.

d. Shot Sequence:

1. Welds, plate edges and joint geometry.

a. Longitudinal: Prods will be placed in line or not more than approximately 10° off the centerline at selected spacing. Overlap or back step of 1-1/2 to 2 inches will be made to permit evaluation of area of previous prod placement.

b. Transverse: Progressive prod intervals of four (4) to five (5) inches will be made at an approximate 90° relationship to the "prod centerlines" employed in a. above. As applicable, if an edge, prods will be set back 1/2" to 1"; however, for joint seams or spot areas, set back will be 1" to 1-1/2" beyond weld joint edge.

c. All transverse shots may follow completion of longitudinal shots, or shots may be alternated, whichever is convenient.

d. For magnetic particle examination of plate edges or root pass or intermediate weld deposits where section thickness is less than 3/4 inch, amperage of 90 to 110 per inch of prod spacing shall be employed.

2. Magnetic particle examination of surfaces.

a. Surface pattern: Mark off surface in approximate 4 inch squares.

b. Performance: Apply prods at 7-1/2 inch to 8 inch spacing across diagonal of square. This will permit prod spacing to extend beyond corners of the square by about one inch. Apply prods to opposite corners in the same manner. Proceed from one square to the next until the surface is completed.

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Changed	
8/17/70	2
5/29/73	3
4/16/74	4
4/16/75	5
10/25/75	6
6/23/76	7

2. Magnetic particle examination of surfaces (continued).

   c. "Head Shot": To impart circular magnetization to a component by current flow from end to the other, the magnetizing current shall be based on the external dimension, exclusive of length, as follows:

      1. Up to 5 inch dimension of diameter or cross section: 700 to 900 amperes per inch for HWDC.

      2. From 5 inch to 10 inch diameter; 500 to 700 amperes per inch.

      3. In excess of 10 inch dimension: 300 to 500 amperes per inch, HWDC.

6. Indirect Magnetization:

   a. Central conductor: Same as 5,d,2,c. above.

   b. Through Coils: Same as 5,d,2,c. above divided by the number of coils.

   c. Coil or wrapped cable: Provides longitudinal magnetization.

      1. Field Strength: For reliable test performance, L/D ratio must not be less than 2 nor greater than 15. Amperage is established by formulas:

         L/D ratio at least 2 but less than 4 AMPS $= \frac{45{,}000D}{LT}$ L/D ratio equal to 4 or greater AMPS $= \frac{35{,}000}{T(2+L/D)}$

         L: Length of specimen or testing segments
         D: Diameter of specimen
         T: Number of turns in coil or cable

      2. When the magnetizing coil is made of cable wound around the test part, the coils turns shall be closely spaced. The effective field extends for about six (6) inches on either side of the coil; longer parts shall be magnetized in sections.

   d. For use of central conductor or coil, the magnetizing element shall be in surface contact with the test specimen.

7. A different means than that of the first examination may be used for the second or necessary subsequent tests.

D. Application of Magnetic Particles: Dry magnetic particles shall be applied in such a manner that a light, dust-like coating settles upon the metal surface under test. The magnetic field shall be on while the particles are applied, see Paragraph V, C.

E. Removal of Excess Particles: While magnetic field is on, excess particles shall be removed by means of a dry air current of sufficient force to remove excess particles without disturbing those particles which are indicative of discontinuities. This removal may be accomplished by bulb blowers. If a commercial powder blower is employed for this purpose, refer to Paragraph V, C for use of equipment and procedures.

F. Examination and Evaluation: Each area shall be examined immediately upon removal of excess particles and prior to application of the magnetic field in another direction or location. Indications will appear as collections of powder which cannot be removed by a properly directed air current.

Evaluation and acceptance shall be made in accordance with Paragraph VIII. Note: In that magnetic particle build-up and retention, during the application and removal cycle, is a function of the discontinuity to field orientation, it is necessary to observe the area of examination during the course of the entire procedure cycle. Additional MT shots may thus be necessary in a repositioned direction with the field at approximately 90° to the suspect discontinuity alignment to obtain maximum sensitivity.

G. Certification of Examination: A certification of examination completion shall be made immediately on final acceptance.

ALTERNATE

G. Certification of Examination: Immediately upon final acceptance, the party responsible for conduct of the test shall certify completion by signing the Inspection Point Program, Operational Line-Up, or applicable forms designated by IPP, Line-Up, or other appropriate instructions.

H. Demagnetization: Refer to Paragraph X.

PART II

Procedure for magnetic particle examination by yoke method, for fine finish machine surface and after final heat treatment, final machining or hydrotest; and joints and repairs such as closures that are normally inaccessible or impractical for prod application; A.C. or D.C., dry powder, continuous method.

I. Equipment: A hand-held electro-magnetic yoke capable of producing a highly magnetized field in a uni-directional manner between the poles when placed upon ferrous material. Equipment supplying either A.C. or D.C., or both, may be used; with acknowledgement that D.C. is preferred.

II. Procedure:

A. Pre-inspection
B. Pre-cleaning
C. Application of magnetic field
D. Application of magnetic particles
E. Removal of excess particles
F. Examination and evaluation
G. Certification of inspection
H. Demagnetization

A. Pre-inspection: Same as Part I, Section II., A.

B. Pre-cleaning: Same as Part I, Section II., A.

Issue 1	
3/13/70 Kerch	
F. W. Dury	
Changed	
8/17/70	2
5/29/73	3
4/16/74	4
4/16/75	5
10/25/75	6
6/23/76	7

II. Procedure (continued)

C. Application of Magnetic Field:

1. Same as Part I, Section II, C.1.
2. Same as Part I, Section II, C.2.
3. Precaution: Care shall be taken to prevent local overheating of the equipment. The magnetizing current shall not be turned on until the poles have been properly positioned in contact with the surface. Similarly, the current shall be turned off before the poles are removed.
4. Indirect magnetization:

a. Field strength: Detection sensitivity is to be at least equivalent to that of the prod method when a direct or rectified magnetizing current of 25 to 30 amperes per inch of prod spacing is used. A field indicator, see Paragraph V, B., may be used to demonstrate the adequacy. Further, the lifting power of the yoke is to be, at a minimum, as follows:

Current	Pole Spacing	Weight Lift
AC	3 to 6 inches	10 pounds
DC	3 to 6 inches	40 pounds

b. Pole spacing: Being a fixed current device, pole spacing will be such as to comply with prerequisites of a. above.

c. Shot sequence:

1. Weld seams:

a. Surface pattern: Layout as necessary.

b. Longitudinal: Poles will be placed in line or not more than approximately 10° off the centerline at predetermined pole spacing. Overlap or back step of 1 to 1-1/2 inches will be employed to permit evaluation of area of prior pole placement.

c. Transverse: Progressive pole intervals of 4 to 5 inches will be used at an approximate 90° relationship to the initial pole placement centerlines. Set back should be approximately 1 inch beyond weld joint edge.

d. All transverse shots may follow completion of all longitudinal shots, or shots may be alternated, whichever is convenient.

Note: Reference to longitudinal or transverse is in reference to direction of yoke - not magnetic field.

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2	8/17/70
3	5/29/73
4	4/16/74
5	4/16/75
6	10/25/75
7	6/23/76

II. Procedure (continued)

C. 4. c. Shot sequence (continued):

2. Magnetic particle examination of surfaces:

a. Surface pattern: Mark off surface in approximate 5 inch squares.

b. Performance: Apply poles at approximate 6 inch spacing across centers of square. This should permit approximate 1/2 inch extension beyond sides of square. Examine each square in at least two directions and proceed from one square to the next until the surface is completed.

D. Application of Magnetic Particles: Same as Part I, Section II, D.

E. Removal of Excess Particles: Same as Part I, Section II, E.

F. Examination and Evaluation: Same as Part I, Section II, F. Specific attention should be given to Paragraph IX.

G. Certification of Examination: Same as Part I, Section II, G.

H. Demagnetization: Refer to Paragraph X.

Process Specification
NUCLEAR POWER COMPONENTS
RADIOGRAPHIC EXAMINATION

Effective 11/3/76
84350 RT

Issue 1
7/9/69
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Changed	
10/18/72	2
5/3/73	3
6/19/74	4
2/10/75	5
10/18/76	6

A.C. Garrison 10/5/76
R.P. Wedler 10/4/76
W. R. Beers 10/6/76
S.J. Longphre 10/7/76
R.H. Anderson 10/5/76
E. P. Loch 10/5/76

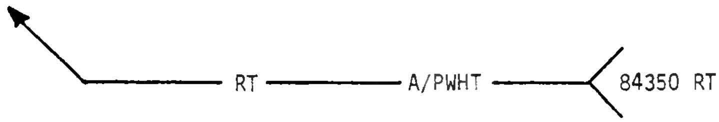
PURPOSE: This Process Specification covers the radiographic examination of low alloy carbon and austinetic steel materials and weldments for use in nuclear vessels.

PROCESS QUALIFICATIONS: This Process Specification meets the requirements of A.S.M.E. Boiler and Pressure Vessel Code, Section III, Nuclear Vessels.

PERSONNEL QUALIFICATIONS: Nondestructive Examination personnel shall be certified in accordance with the latest issue of ASNT, Recommended Practice No. SNT-TC-1A, and V, except that for visual examination the Jaeger Number 1 letters shall be used or equivalent.

GENERAL: Use of this Process Specification will be indicated by:

(A) Drawings with symbols shall be in accordance with AWS. A typical symbol is:



The following abbreviations are to be used with the above symbol:

RT	-	Radiographic Examination
R	-	Examination of root pass
BC	-	Examination of back chipped weld
F	-	Examination of final surface as welded, machined, or ground before post weld heat treatment.
A/PWHT	-	Examination of surface after post weld heat treatment
EA.3/8	-	Examination of each 3/8 inch of deposited weld.
F/HYD	-	Examination of final weld after hydrostatic test

(B) Welding specifications called for on the drawing.

(C) Shop work tickets, or other special instructions.

EQUIPMENT: X-ray equipment and Gamma emitters such as Iridium-192, Cobalt-60 and various radio-isotopes may be used, except that the Gamma-ray method shall not be used on aluminum alloys. Minimum thickness ranges shall be as specified in Tables C & D attached.

OPERATIONS:

(A) Surface Preparation
(B) Film
(C) Sensitivity
(D) Penetrameters
(E) Penetrameter Placement
(F) Acceptance Standard Welds
(G) Identification and Storage
(H) Castings
(I) Film Maintenance

(A) Surface Preparation: The weld ripples or weld surface irregularities, on both the outside and inside, shall be removed by any suitable mechanical process to such a degree that the resulting radiographic contrast due to any irregularities cannot mask or be confused with the image of any unacceptable discontinuity. Also, the weld surface shall merge smoothly into plate (base metal) surface.

The finished surface of the reinforcement of all butt welded joints may be flush with the plate or have a reasonably uniform crown not to exceed the thickness listed below:

Nominal Thickness Inch	Maximum Reinforcement Inch
Up to 1, incl.	3/32
Over 1 to 2, incl.	1/8
Over 2 to 3, incl.	5/32
Over 3 to 4, incl.	7/32
Over 4 to 5, incl.	1/4
Over 5	5/16

Note: All surfaces requiring radiographic examination shall be approved by a Quality Control Technician before the item is sent to the X-ray Laboratory.

(B) Film: Radiographs shall be made on non-flammable safety-base film.

Generally, the higher-contrast fine-grain films produce images of better quality, therefore, Class 1 and 2 films shall be used for radiography; i.e., film such as Kodak AA, T and M, and GAF 100, 200, 400, 800 and 1600 or equivalent.

All radiographs shall be free from mechanical, chemical or other processing defects that could interfere with proper interpretation of the radiographs.

The film during exposure shall be as close to the surface of the weld as possible.

The double film technique in which two films are sandwiched between lead intensifying screens or equivalent shall be used. For high intensity radiography, .040 or .010 inch front and .040 inch back screens shall be used. The fluorescent type screens shall not be used.

(C) Sensitivity: Radiographs shall have a quality level equal to 2-2T when required. The images of the identifying numbers, the penetrameter outline and the 2T hole are all essential indexes of image quality on the radiograph, and they shall appear on the radiograph. Geometrical unsharpness shall not exceed the following where Ug = FT/D:

Material Thickness Inch	Ug Maximum, Inch
Under 2	0.020
2 thru 3	0.030
Over 3 thru 4	0.040
Greater than 4	0.070

Ug = Geometric unsharpness
F = Source size or focal spot in inches
D = Distance in inches from source or radiation to object being radiographed.

T = Thickness of section being radiographed.

Objectional scatter radiation shall be reduced by suitable filters.

As a check on back-scattered radiation, a lead symbol "B" shall be attached to the back of the film holder. If the lighter density image of the "B" appears on the radiograph, protection from back-scatter is insufficient and the radiograph shall be considered unacceptable.

(D) Penetrameters:

(1) Material: Penetrameters for radiography of welds shall be fabricated from material that is either radiographically similar to or radiographically less dense than the base material and/or the weld metal on which they are used.

(2) Design: Penetrameters shall be in accordance with SE-142 and of thickness and dimensions as required in A.S.M.E. Section III, Tables "A" and "B" contained herein.

(3) Identification: The penetrameter shall be identified by permanently attached lead numbers at least 3/32 inch high. The numbers shall indicate the penetrameter thickness in accordance with A.S.M.E. Section V, SE-142. (See Tables "A" and "B" attached)

(E) Penetrameter Placement: A standard source side penetrameter of the proper thickness shall be placed on the side nearest the radiation source. Where it is physically impossible to do this, a film side penetrameter shall be placed on the film side of the joint and its thickness shall conform to Table A and a lead letter "F" at least 1/2" high shall be placed adjacent to the penetrameter.

(1) At least one penetrameter shall be used for each exposure, to be placed so that the plane of the penetrameter is normal to the radiation beam; except when the source is placed on the axis of the joint and the complete circumference is radiographed with a single exposure, at least three uniformly spaced penetrameters shall be employed.

(2) In the case of small diameter butt welds, such as nozzle attachments, piping and appurtenances, where the source is on the outside and the film is on the opposite outside surface, only that portion of the weld adjacent to the film and readable on the film shall be considered to have been examined and the penetrameter thickness shall be based on the single wall weld thickness. Single wall radiography shall be used when practical.

(3) Each penetrameter shall represent an area of essentially uniform radiographic density as judged by density comparison strips or a densitometer. If the film density through the weld varies by more than minus 15 or plus 30 per cent from the density through the penetrameter, then an additional penetrameter is required for the exceptional area(s). If the requirements are met by two penetrameters, one penetrameter appearing in the lightest area of a film, and the other in the darkest, the intervening densities on the film shall be considered acceptable.

(4) The film density through the section being radiographed shall be 2.0 minimum for single viewing, and 2.6 minimum for composite viewing of double film exposures, each film of the composite set to have a minimum density of 1.3. The maximum density allowable for either single or double film viewing is 4.0.

(5) For radiography of weldments, the penetrameter(s) shall be placed adjacent to the weld seam approximately 1/4" from weld edge, on the opposite side from the location markers. If the weld reinforcement and/or backing strip is not removed, a shim of a radiographically similar material to the weld metal shall be placed under the penetrameter. The shim thickness shall be selected so that the total thickness being radiographed under the penetrameter is the same as the total weld thickness.

(6) For all other radiography, the penetrameter(s) shall be placed adjacent to the area of interest (markers) in a manner that will meet the requirements of paragraph (3) and (4) above. Alternatively, the placement of the penetrameter on a block is acceptable provided the block is of radiographically similar material, the same thickness as the part being radiographed, and is placed as close as possible to the material (weld) being inspected.

(F) Acceptance Standards: Welds that are shown by radiography to have any of the following types of discontinuities are unacceptable:

(1) Any type of crack or zone of incomplete fusion or penetration.

(2) Any other elongated indication which has a length greater than:

a. 1/4 inch for t up to 3/4 inch inclusive
b. 1/3t for t from 3/4 inch to 2-1/4 inch inclusive
c. 3/4 inch for t over 2-1/4 inch

Where t is the thickness of the thinner portion of the weld.

(3) Any group of indications in line that have an aggregate length greater than t in a length of 12t except where the distance between the successive indication exceeds 6L, where L is the longest indication in the group.

(4) Porosity in excess of that shown as acceptable in Appendix VI.

(G) Film Identification and Storage:

(1) Location markers, the images of which will appear on the film shall be placed adjacent to the weld (approximately 1/4" from weld edge) on the part, not on the film or film holder, and their location shall be marked on the surface near the weld in such a manner that a defect appearing on a radiograph may be accurately located and in such a manner that it is evident on the film that complete coverage of the weld has been obtained.

(2) The date, job number, the vessel, the seam, or part and the manufacturer's identification symbol or name shall be plainly and permanently traceable for each film in the following manner.

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6/19/74	4
2/10/75	5
10/18/76	6

(a) Positive film identification shall be made by assigned sequential X-ray numbers which shall be perforated on each film. This perforated X-ray number shall include positive seam identification, X-ray cycle and the letters "T" and "W" identifying Tampa Division of Westinghouse. The date shall be perforated on the film out of the area of interest. Alternatively the above may be indicated by lead numbers on the film.

(b) In addition to the penetrameters as required by A.S.M.E. Section III or V, location markers, the images of which will appear on the film shall be placed adjacent to the weld on the part (not on the film or film holder) in such a manner that a defect appearing on a radiograph may be accurately located and in such a manner that it is evident on the film that complete coverage of the weld has been obtained.

(c) The Radiographic Examination Record shall accompany the film at all times and shall contain the following additional information:

Component, shop order, description of area or weld, test number, date, shooting sketch (including location markers or numbers plus penetrameters and placement), technician and ASNT Level, source of radiation, strength, focal distance, exposure time, film type and size, thickness of material and the disposition.

(3) The X-ray seam identification number, test number and the starting position (0-1) shall be stenciled adjacent to the weld seam using low stressed or blunt-nosed-interrupted-dot die stamps.

(4) All vendors shall comply with the intent of this specification. The vendor's RT procedure outlining compliance with above requirements shall be approved by WTD prior to implementation.

(H) Castings: Where specified, radiography of castings shall be performed to the requirements of this specification. Additionally:

(1) Acceptance standard shall be Severity Level II of ASTM E-71, ASTM E-446, ASTM E-186 or ASTM E-280 as applicable for the thickness being radiographed for categories A, B and C defects. No category D, E, F or G defects are acceptable.

(2) Penetrameters, film densities, radiography, etc. shall be as specified in the applicable sections of this Process Specification.

(3) Additionally, repair radiographs shall be identified as R_1, R_2, etc. as applicable.

(4) Castings radiographed prior to finished machining shall observe the following stipulations:

(a) For thicknesses less than 6 inches, castings shall be radiographed within 20% of the finished thickness with the penetrameter based on final thickness.

(b) For thicknesses 6 inches and greater, castings shall be radiographed within 10% of the finished thickness with penetrameter based on final thickness.

(I) A complete set of accepted radiographs on each job shall be maintained for the life of the plant, at the power plant site, the manufacturer's plant or other locations determined by mutual agreement.

TABLE "A"

THICKNESS AND IDENTIFICATION OF PENETRAMETERS REQUIRED FOR GIVEN THICKNE.S

THICKNESS RANGE SINGLE WALL (IN.)	SOURCE SIDE PENETRAMETER THICKNESS (IN.)	SOURCE SIDE PENETRAMETER DESIGNATION	FILM SIDE PENETRAMETER THICKNESS (IN.)	FILM SIDE PENETRAMETER DESIGNATION
Up to 1/4 incl.	0.005	5	0.005	5
Over 1/4 thru 3/8	0.0075	7	0.007	7
Over 3/8 thru 1/2	0.010	10	0.010	10
Over 1/2 thru 5/8	0.0125	12	0.012	12
Over 5/8 thru 3/4	0.015	15	0.012	12
Over 3/4 thru 7/8	0.0175	17	0.015	15
Over 7/8 thru 1	0.020	20	0.015	15
Over 1 thru 1-1/4	0.025	25	0.017	17
Over 1-1/4 thru 1-1/2	0.030	30	0.020	20
Over 1-1/2 thru 2	0.035	35	0.025	25
Over 2 thru 2-1/2	0.040	40	0.030	30
Over 2-1/2 thru 3	0.045	45	0.035	35
Over 3 thru 4	0.050	50	0.040	40
Over 4 thru 6	0.060	60	0.045	45
Over 6 thru 8	0.080	80	0.050	50
Over 8 thru 10	0.100	100	0.060	60
Over 10 thru 12	0.120	120	0.080	80
Over 12 thru 16	0.160	160	0.100	100
Over 16 thru 20	0.200	200	0.120	120

NOTE: For any material thickness range, the use of a penetrameter designation or thickness less than listed in Table "A" for that range will also be acceptable, provided all the other requirements for radiography are met. For welds, the thickness is the single wall thickness including reinforcement.

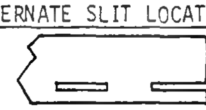
TABLE "B"

SLIT LOCATIONS IN PENETRAMETERS, IF USED

DIMENSIONAL TOLERANCES

DIMENSION	TOLERANCES
Length and Width	1/64 inch
Nominal Thickness	10%
Hole Nominal Diameter	10%
Hole Location	1/64 inch

ALTERNATE SLIT LOCATIONS



Issue 1
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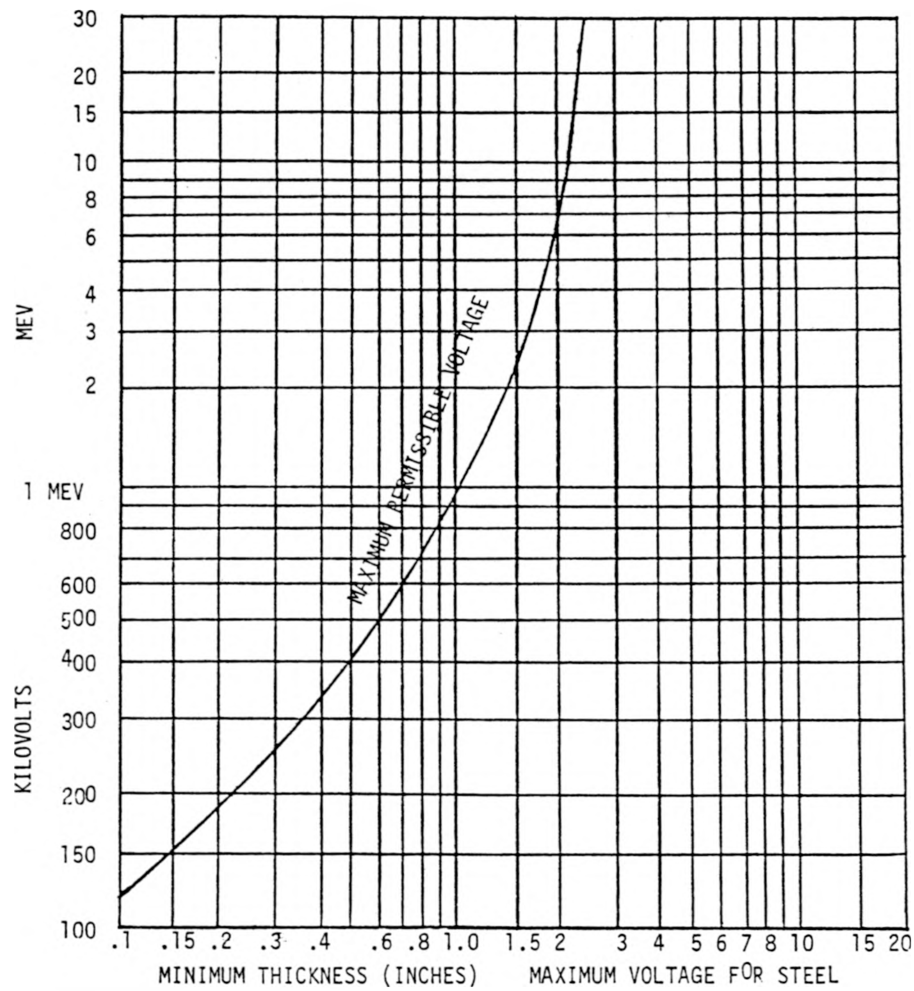
10/18/72	2
5/03/73	3
6/19/74	4
2/10/75	5
10/18/76	6

TABLE "C"

RADIOACTIVE ISOTOPES, MINIMUM THICKNESS RANGE

MATERIAL	IRIDIUM-192	COBALT 60
Steel	0.75 in.	1.50 in.
Copper/high nickel	0.65 in.	1.30 in.
Aluminum	2.5 in.	

TABLE "D"



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75. F. R. Mynatt
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77. H. Postma
78. G. C. Robinson
79. C. D. St. Onge (Y-12)
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81. G. M. Slaughter
82. C. B. Smith
83-85. G. C. Smith
86. J. E. Smith
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