EPRI NP-179
ORNL/Sub/88242-76/1
Dist. Category NRC-5

WELD REPAIR OF HEAVY SECTION STEEL TECHNOLOGY PROGRAM VESSEL V-7

Final Report, Research Project 604-1, August 1976

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Program Sponsored by
U.S. Nuclear Regulatory Commission
Office of Nuclear Regulatory Research
Under Interagency Agreement ERDA 40-551-75

Prepared under Purchase Order 73Y-88242
with Electric Power Research Institute for the
OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37830
operated by
UNION CARBIDE CORPORATION
for the
ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION

NOTICE

OVERVIEW

The in situ repair of a flaw in a large nuclear pressure vessel is likely to be a complex undertaking. Normally, a thermal stress relief is required to reduce peak welding stresses; however, accomplishing this task under field conditions can result in difficulties related to warpage of the vessel. Consequently, Section XI of the ASME Boiler and Pressure Vessel Code has provided guidelines for making major repairs without a subsequent thermal stress relief. The repair weld procedure employs a technique known as the "half (or temper) bead" technique. In theory this procedure is structured such that each weld pass is applied in a manner which results in tempering the preceeding weld pass. Thus brittle transformation products created during welding will be rendered ductile. Although this technique currently is used in the repair of petrochemical pressure vessels, a demonstration of the practicality and effectiveness of this repair technique has yet to be accomplished for a nuclear pressure vessel.

The Heavy Section Steel Technology (HSST) Program conducted by the Oak Ridge National Laboratories (ORNL) and sponsored by the Nuclear Regulatory Commission (NRC) has been pressure-testing intermediate sized vessels roughly scaled to nuclear reactor pressure vessels. One such vessel - ITV-7, intentionally flawed in the axial direction, was hydraulically pressurized to failure-leakage occurred when the vessel was presurrized to 2½ times the design pressure. Arrangements were made with the HSST Program Office to use this vessel for the purpose of repairing the thru wall flaw according to Section XI procedures. The repair was performed to demonstrate the utility of such a weld repair. This report documents details of the procedures used with that repair.

The repaired test vessel was returned to ORNL along with accompanying test pieces for the purpose of retesting the vessel. Plans are to reflaw away from the weld, and pneumatically pressurize to failure. Since the applied flaw will be similar to the original, the effect of pneumatic loading will be evaluated. Subsequent to this test, plans are to repair the vessel, reflaw in the new weld repair heat-affected zone, and retest. Thus, the serviceability of the Section XI repair procedure will be demonstrated for both the unflawed and the flawed conditions. Details of the testing conditions and results will be reported through HSST reporting channels.

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R.E. Smith
EPRI

Program Scope

This report describes the weld repair and non-destructive testing of Heavy-Section Steel Technology (HSST) vessel number V-7. The weld repair and non-destructive testing were performed in accordance with the ASME Boiler and Pressure Vessel Code, Section XI, "Rules for Inservice Inspection of Nuclear Power Plant Components" by Combustion Engineering, Inc., under contract with the Electric Power Research Institute.

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INTRODUCTION

This report describes the weld repair and non-destructive testing of Heavy-Section Steel Technology (HSST) vessel number V-7 performed by Combustion Engineering, Inc., under contract with the Electric Power Research Institute (RP604-1). These operations were performed in accordance with weld repair procedures prepared by the Union Carbide Corporation-Nuclear Division[6] (UCC-ND) with technical support from the Pressure Vessel Research Council, Advisory Task Group on Weld Repairs, headed by Mr. E. Landerman.[1] The weld repair procedures were formulated in accordance with paragraph IWB-4420, "Procedure Number 4, Welding Low Alloy Steels," of Section XI ASME Boiler and Pressure Vessel Code.[2] In order to provide the required mechanical property samples, a similar weld was made in a HSST vessel prolongation test piece (Fig. 1b). The test vessel (Fig. 1a) and the prolongation test piece were instrumented with strain gages to provide weld induced residual stress measurements. These data are presented in Appendix D. Additional residual stress measurements will be made by UCC-ND when the weld procedure qualification samples are removed from the prolongation test weld.

HEAVY-SECTION STEEL TECHNOLOGY VESSEL NUMBER V-7

HSST vessel V-7 is one of several low alloy steel test vessels pressurized to failure at ORNL to evaluate the effect of large flaws on vessel performance. The tests have been described in HSST program reports.[3] The Vessel V-7 test was designed to demonstrate that a large flaw would not cause catastrophic vessel failure when pressurized at a temperature higher than the Charpy upper-shelf temperature.

This cylindrical vessel was 6 inches thick with a 39 inch outside diameter and weighs approximately 7-1/3 tons (Fig. 1a). The vessel shell was fabricated from ASME SA-533, Grade B, Class 1 low alloy steel plate. A large trapezoidal-shaped flaw (18' x 4" x 5" deep) was milled into center of the 54" long vessel shell (Fig. 2). The flaw was sharpened with an electron beam weld made around the periphery of the milled cavity. This weld was then charged with hydrogen to induce cracking. The vessel was pressurized with water at 196°F until leakage occurred by propagation of the flaw through the vessel wall. Leakage occurred at a pressure of approximately 2.2 times the unflawed vessel design pressure. Upon depressurization, the flaw closed and a pressure equal to 1.8 times the vessel design pressure could be maintained without leakage.

The flaw grew approximately an inch from the root of the embrittled electron beam weld to the vessel I.D. surface. There was negligible plastic deformation in the vessel. Yielding was limited to the area adjacent to the flaw. This report describes how the flaw and the adjacent strained material was removed and how the resulting cavity was repaired by welding. The repaired vessel will be then retested with the future artificial flaw located outside of the repair weld. A subsequent repair and retest cycle is planned. A flaw will be located in one or both of the repair welds to demonstrate the adequacy of Section XI Vessel Repair Procedure Number 4.

VESSEL V-7 AND VESSEL PROLONGATION WELD REPAIR AND EXAMINATION

Weld Cavity Excavation Using Air Carbon-Arc Cutting

The milled cavity in HSST vessel V-7 (Figure 1B) was enlarged with a conventional manual air-carbon arc process to provide access for manual shielded metal arc welding.[4] In this process, a D.C. arc is maintained between the work piece and a copper coated carbon electrode. The molten material is blown away by high velocity jets of compressed air. The vessel prolongation test piece cavity was also excavated using the air-carbon arc process and an oxygen lance[4] was used to pierce a starter hole through the prolongation. Preheat was maintained between 350°F and 400°F during lancing and air carbon-arc gouging. The final arc-air surfaces are shown in Figure 4.

Weld Cavity Preparation by Grinding

In order to assure complete removal of the air-arc surface and any heat affected zone resulting from the air-arc process, a minimum of 1/4 inch of metal was ground from the surface. Metal removal was gaged by grinding grooves into the cavity walls 1/4 inch deep. The cavity was then ground smooth after the grooves were completely eliminated. Figure 6 shows the grooves in the cavity surface. Some of the mechanical grinders are shown in Figure 7.

The ground cavities of the vessel and of the prolongation received a liquid penetrant and a magnetic particle examination. The liquid penetrant examination of the prolongation cavity is shown in Figure 9.

End Restraint for the Prolongation

Due to the short length of the prolongation (25 inches), it was necessary to weld restraints on each end to simulate the V-7 vessel restraint. Four inch square carbon steel bars were welded to the ends of the prolongation with shielded metal arc fillet welds. Installation of these bars is shown in Figures 10 and 11.

Strain Gages

After the end restraints were welded to the prolongation, strain gages were attached as shown in Figure 12. The gages located near the weld cavity were Ailtech Model 425 (900°F Max.) and the gages remote from the cavities were Ailtech Model 125 (600°F Max.). A total of six high temperature gages and eight intermediate temperature gages were used. The location of these gages is shown in Figure 12. The four high temperature gages on Vessel V-7 are shown in Figure 13 and five of the prolongation gages can be seen in Figure 14. In Figure 15A one can see gage Number 19 located 180° away from the cavity of the prolongation O.D. A thermocouple was installed adjacent to each set of gages (Figure 15A). Digital strain indicators for the strain gages are shown in Figure 15B.

(All strain gage material and strain gage instrumentation were provided by UCC-ND.) Strain readings were taken from the gages at various steps in the repair procedure. These readings are tabulated in Appendix D, and preliminary residual stress calculations are included.

Vessel and Prolongation Electrical Preheat

Two 11 kilowatt resistance heaters (Figure 16A) were placed inside the vessel. The heaters were tack welded to supports placed inside the vessel and'welded to the vessel weld cavity backing bar (Figure 16B). Two additional heats of 1-1/2 kilowatt each were placed in the flange opening (Figure 18A) to trim and balance the heat flow in the vessel. The prolongation was preheated by placing five 3-1/3 kilowatt heating elements across the end braces. Approximately five hours were required to bring both the vessel and prolongation from room temperature up to the required preheat temperature range of 350°F to 500°F.

Welding Procedure

Regions of base metal adjacent to a weld are known as weld heat affected zones (HAZ) because they are heated to a temperature above the lower critical temperature during welding and quenched very rapidly. Normally, an elevated temperature post weld heat treatment is performed after welding to temper any transformation products in the HAZ and to relax the weld induced residual stresses. When an elevated temperature post weld heat treatment can not be performed, as in the case of the V-7 vessel repair, tempering of the HAZ is performed by controlling the welding heat input from subsequent weld layers, and is called the half bead temper procedure. The entire cavity is first buttered (covered) with weld metal using a small diameter electrode to produce a shallow, uniform HAZ. Approximately one half of this first layer is removed by grinding, thus allowing heat from the second layer of butter to penetrate and temper any transformation products present in the weld HAZ. A larger electrode is used for the second weld layer to provide additional heat input for HAZ tempering. The third and remaining layers are deposited using a still larger electrode to provide additional tempering of the HAZ.

Both cavities were buttered using 3/32 inch diameter electrodes with the bead sequence indicated in Figure 17. The vessel and prolongation were rotated to facilitate the cavity buttering in the flat or horizontal welding position. One half of the cavity was buttered (Step 1, Figure 17) with the vessel in the position shown in Figure 18B. The vessel was then rotated 180° and the other half of the cavity was buttered (Step 2, Figure 17). The resulting weld appearance for the vessel and prolongation cavity buttering is shown in Figure 19A.

The two rectangular areas punch marked on the upper side of the Cavity (Figure 20B) are reference gage marks which were used for measuring the cavity dimensions before and after buttering. A gage was placed into the cavity and a measurement taken from each side wall to the cavity centerline. Approximately one half of the buttered layer was removed by grinding and measurements was taken after grinding to assure that the remaining weld thickness was appropriate. It proved rather difficult to take accurate, reproducible measurements in the cavity at 400°F.

After one half of the layer was ground off, the cavity was inspected by magnetic particle (MT) examination and then a second weld layer was deposited over the cavity surface using a 1/8 inch diameter electrode. The weld bead sequence used for the second layer was the same as for the first. After the second layer of buttering was completed and MT inspected, the cavity was rotated to the 12:00 o'clock position and the welding completed using 1/8 and 5/32 inch diameter electrodes. The first bead deposited in each vertical layer was placed next to the cavity side wall and the subsequent beads were sequenced inward toward the center of the cavity (see Figure 21). MT inspection was performed on alternate layers and on the final ground layer (Figure 21C). There were no MT indications detected in either cavity at any inspection point.

Electrode Moisture

Special precautions were taken to keep the electrode moisture level as low as practical to reduce the possibility of hydrogen delayed cracking. All coated electrodes were baked in accordance with the time-temperature parameters specified in paragraph IWB-4423(3)(d) of Section XI of the ASME Code and then the electrodes were placed in sealed vacuum packages. After removal from the vacuum packages, the electrodes were placed in portable heating ovens operating in the temperature range of 225°F to 300°F. Electrodes left in a portable oven for over one hour were discarded.

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.[5] The results of over-checks were compared with the moisture level in the electrode coatings prior to vacuum packaging. These results are given in Table 1. Note that the highest moisture determination was 0.14%, which is almost a factor of three less than the 0.4% maximum specified in the UCC-ND repair procedure.[6]

Post Weld Intermediate Temperature Heat Treatment

After the welding was completed, the weld surface was ground smooth while maintaining the temperature in the range of 350°F to 500°F.

The final ground surfaces were inspected by magnetic particle examination and the welds were then heated in the temperature range of 450°F to 550°F for four hours. The temperature of the vessel and prolongation repair welds were always controlled within ± 20°F the average vessel temperature. The heat up and cool down rates were approximately 25°F per hour. Figure 23 shows the prolongation after heat treatment and removal of the thermal insulation and electrical heaters. Similarly, the vessel weld surface after heat treatment is shown in Figure 24. On the right side of Figure 24 it can be seen that strain gage Number 7 has been damaged by grinding. This damage occurred during the final grinding of the weld surface.

The backing bar was ground from the vessel I D. with the pole grinder shown in Figure 25. The final ground surface was M. T. inspected using an A. C. yoke so as not to leave prod marks on the final I.D. weld surface.

Ultrasonic and Radiographic Examination

An ultrasonic examination was performed on the entire weld and 1/2T of adjacent base metal of both the vessel and prolongation in accordance with the requirements of paragraph IWA-2232 and Appendix I of ASME Code Section XI.[2] The calibration block, supplied by C-E, was identical to that shown in Figure I-3131 of Section XI. The volume was scanned in two directions 180° to each other using both straight beam, 45° and 60° angle beams. The required examination was performed three times: as soon as the vessel and prolongation surfaces reached room temperature, 48 hours later, and approximately four weeks later. There were no recordable indications detected during any of three inspections.

A radiographic examination of the weld repairs were performed with a 7-1/2 Mev Varian linear accelerator using Kodak type "M" film. This examination was performed in accordance with the requirements of paragraph IWA-2231 of Section XI. There were no defects in the vessel weld. Some porosity was detected near the I.D. of the prolongation weld. This porosity is probably related to the restricted access in the bottom of the cavity and was caused by arc starts. The prolongation cavity was only 7/8 inch wide and 2 inches long at the I.D., and is apparently not large enough for proper welder access in a 6-inch deep cavity.

Test Plates

Two test plates (Figure 26) were welded with the same procedure to provide weld qualification test material. For the test plates, preheat was provided by natural gas burners and temperature indicating crayons (Tempilsticks) were used to monitor preheat and interpass temperatures (Figure 27B). These test plates were buttered using 3/32 inch diameter electrodes. One half of the butter layer was removed by grinding and then a second layer of buttering was deposition using 1/8 inch diameter electrodes. The first layer, alternate layers, and the final layer were all inspected using magnetic particle examination. The plates were radiographed and there were no rejectable indications in either place. The plates were heat treated with the same time-temperature parameters used to heat treat the vessel and prolongation. Electrical heating elements (Figure 28) were placed under each plate and insulating blankets placed over the plate. A thermocouple was attached to the top side of the plate (Figure 28B). The qualification tests are to be conducted by ORNL.

OBSERVATIONS AND RECOMMENDATIONS

A. Weld cavity buttering should be done using a small diameter electrode to assure that the weld HAZ properties are not reduced significantly. It should not be necessary to actually measure the thickness of the ground butter layer, but care should be exercised not to grind off the entire layer. We found it difficult to obtain accurate reproducible measurements in a cavity at 400°F.

B. 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. The porosity clusters observed in the prolongation weld may be a result of the erratic arc starts due to chipped end coating. Therefore, the condition of each electrode end should be inspected 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.

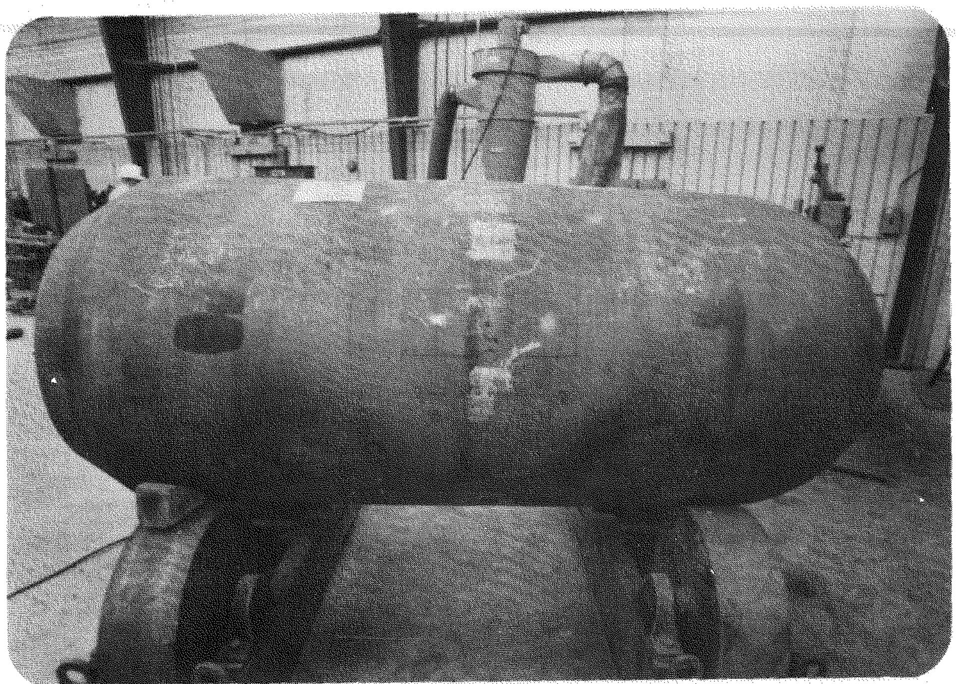
C. The electrode moisture level was maintained below 0.15% and no delayed cracking could be detected four weeks after the welds were completed. Experience has shown that higher moisture levels will produce welds free of delayed cracking and the additional effort required to keep the level below 0.15% may not be necessary. Special care should be taken with the 3/32 inch diameter electrodes used for the butter layer because the weld HAZ is an area especially susceptible to hydrogen delayed cracking.

D. Electrical preheat proved to be very reliable and easy to control. We recommend that only experienced contractors be considered for preheat operations of this nature.

E. The residual stress data are preliminary. A value of 34.1 ksi tensile stress was calculated from the strain readings at a distance of two inches from the edge of the vessel repair cavity. Additional strain measurements are to be made by UCC-ND and the weld repair area will be fully instrumented during the next V-7 vessel pressure test.

F. The carbon air-arc process is a very effective method for excavating weld cavities, but the process requires skilled operators and should not be used in a confined area due to the spray of molten metal ejected from the air-arc torch. The choice of any cavity excavation method must be based on available personnel, equipment, and access.

FIGURES



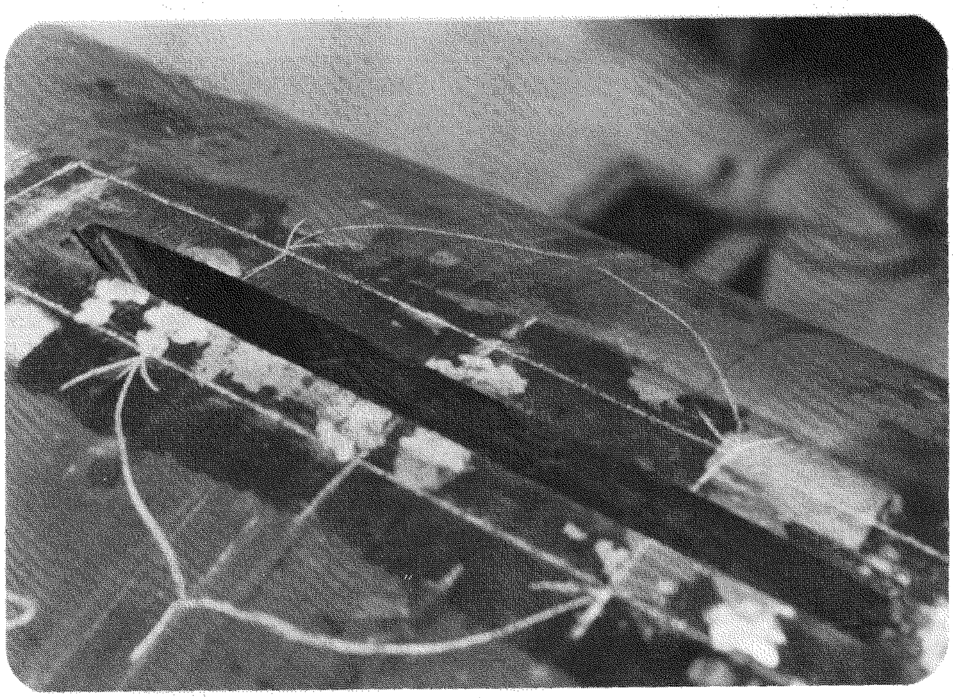


Figure 1 HSST Vessel V-7 As Received at C-E

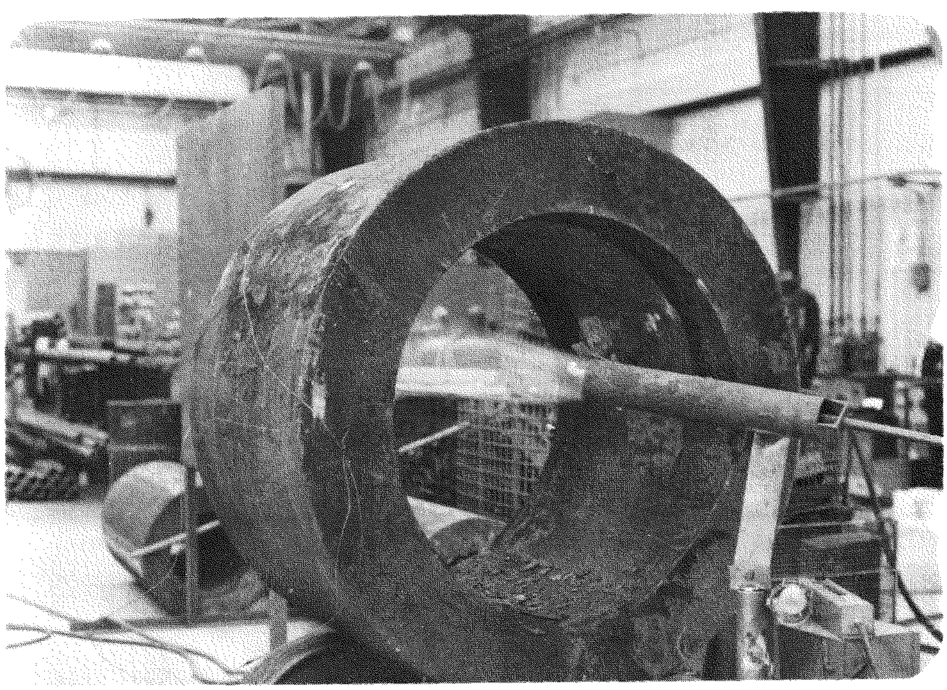


Figure 2 Vessel V-7 and Vessel Prolongation Prior to Weld Cavity Excavation

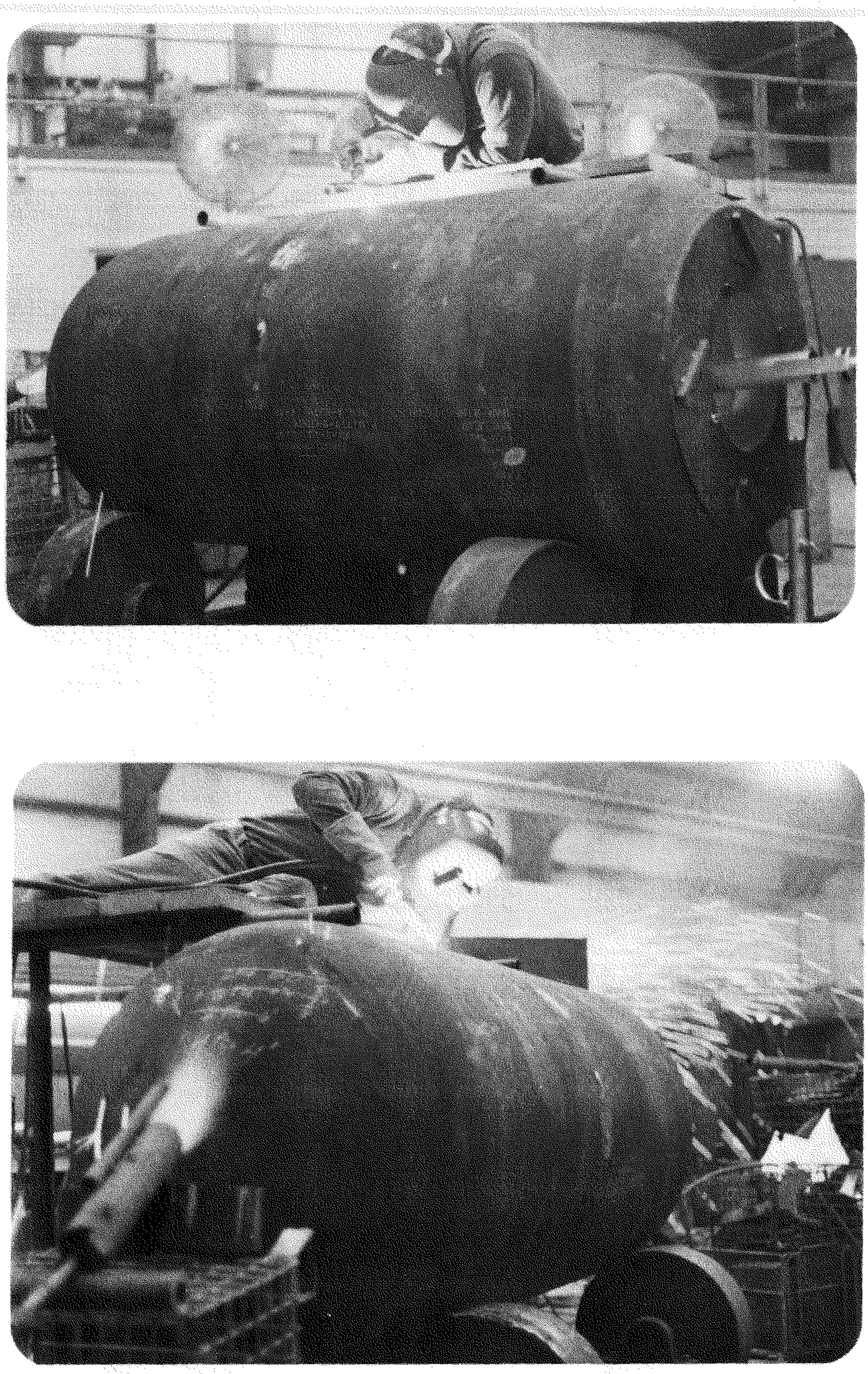


Figure 3 Arc-Air Gouging of the Vessel Weld Cavity

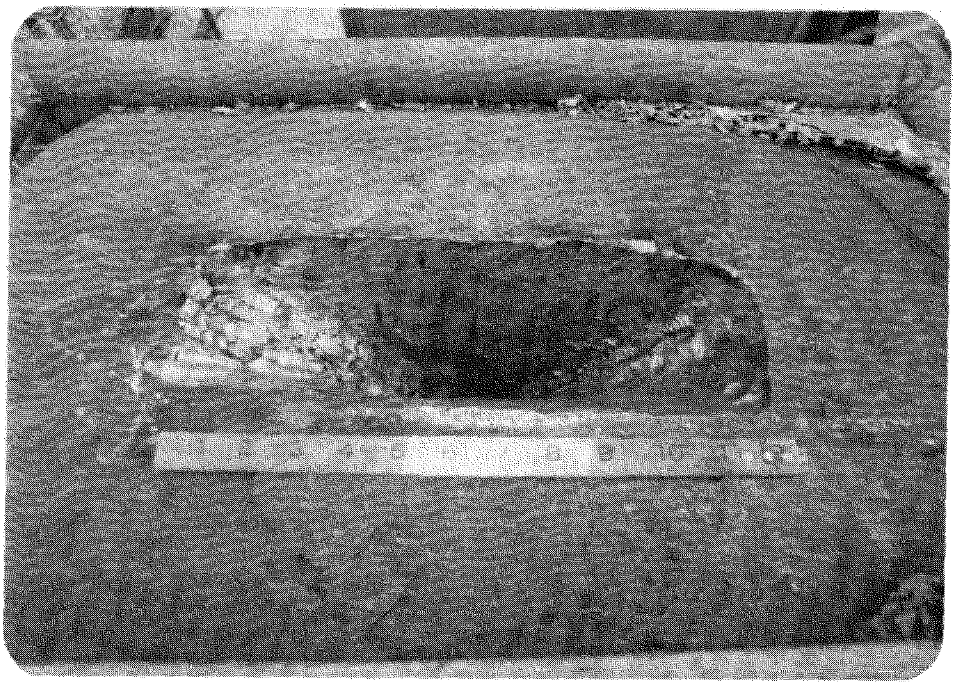
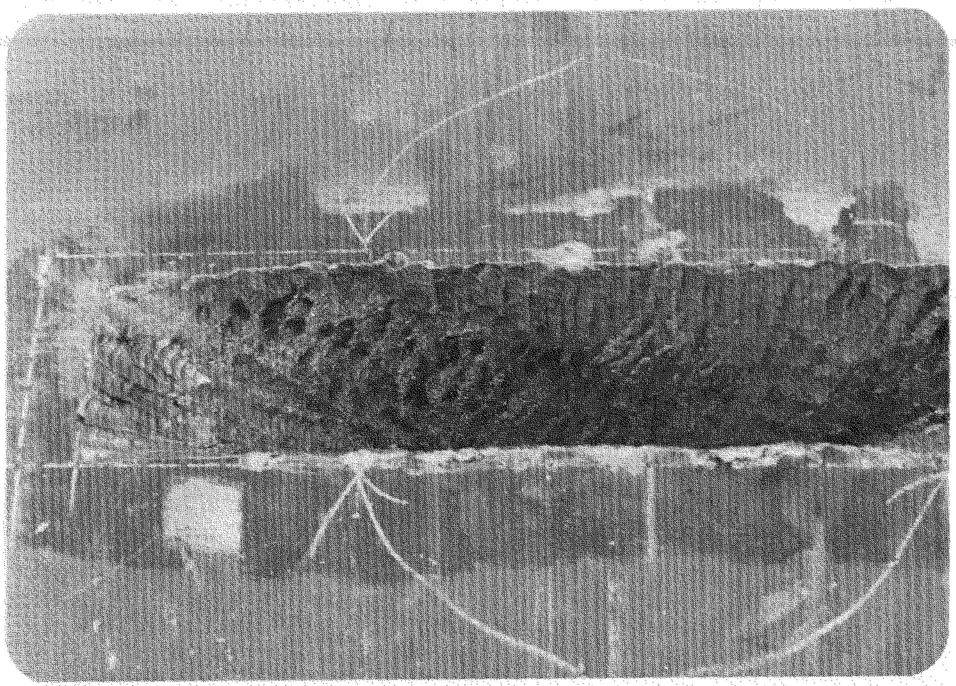


Figure 4   Prolongation Cavity After Arc-Air Gouging



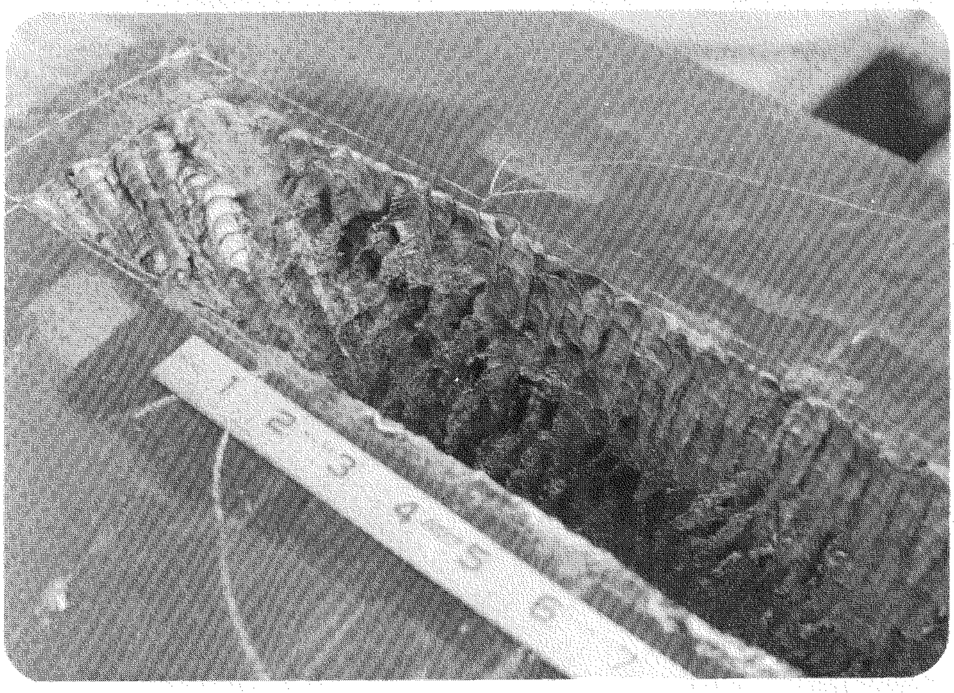
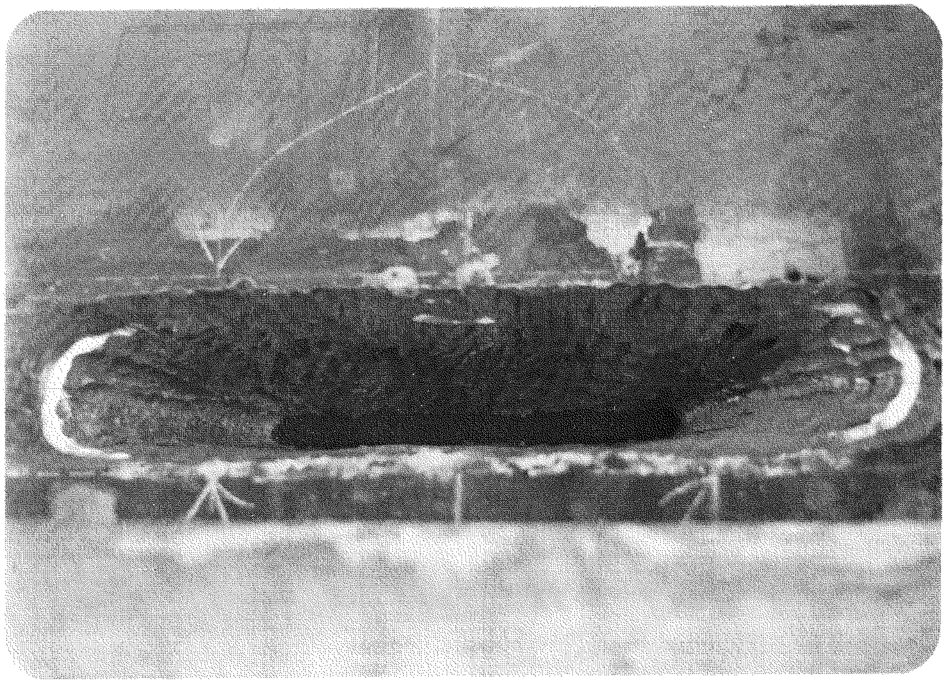


Figure 5 Vessel Cavity After Arc-Air Gouging



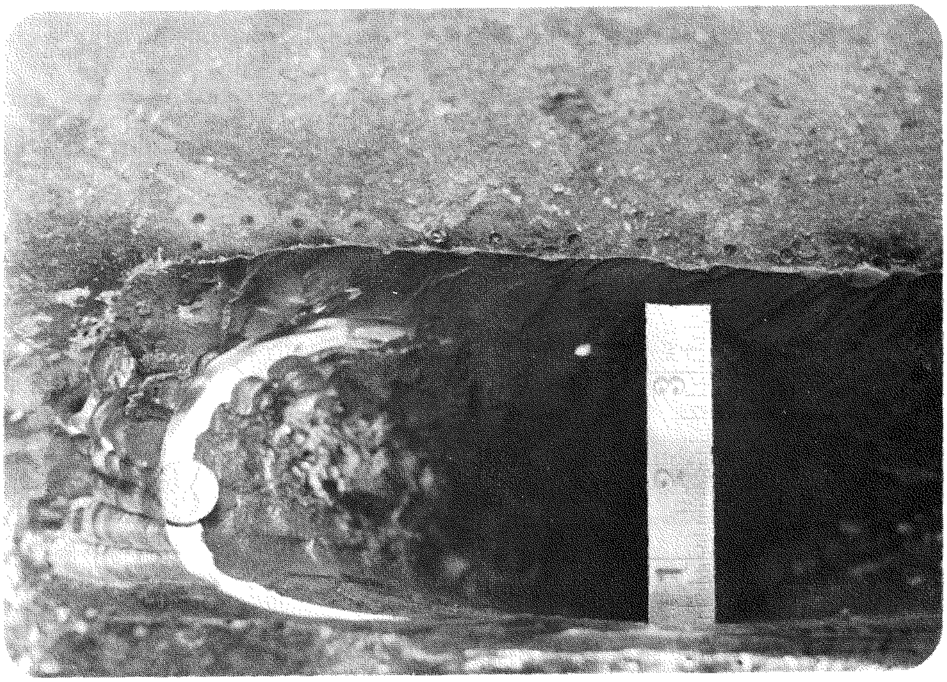


Figure 6   1/4 Inch Deep Grooves in the Vessel Cavity Walls

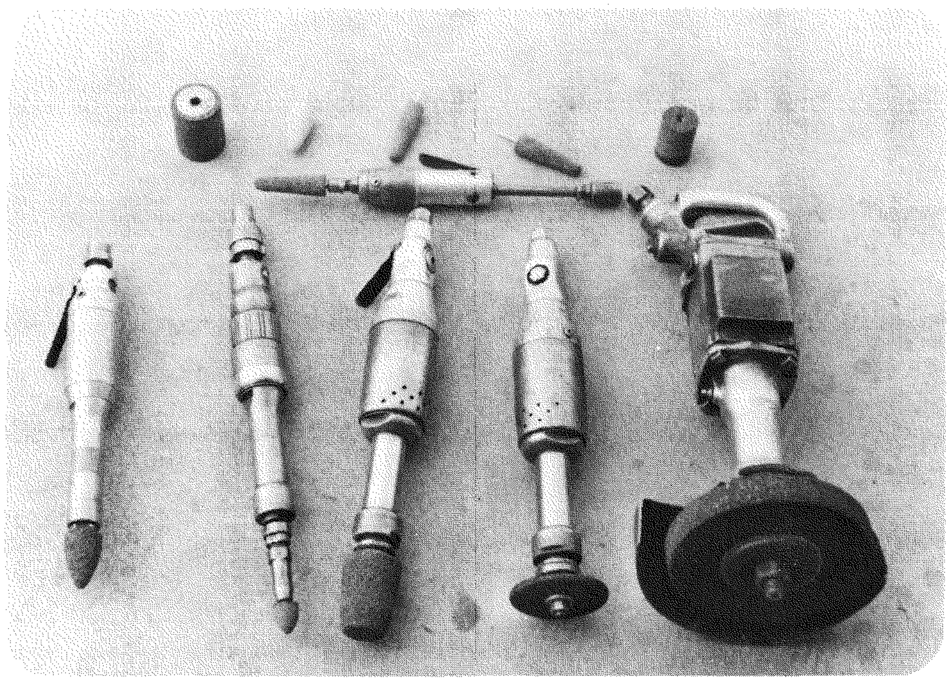


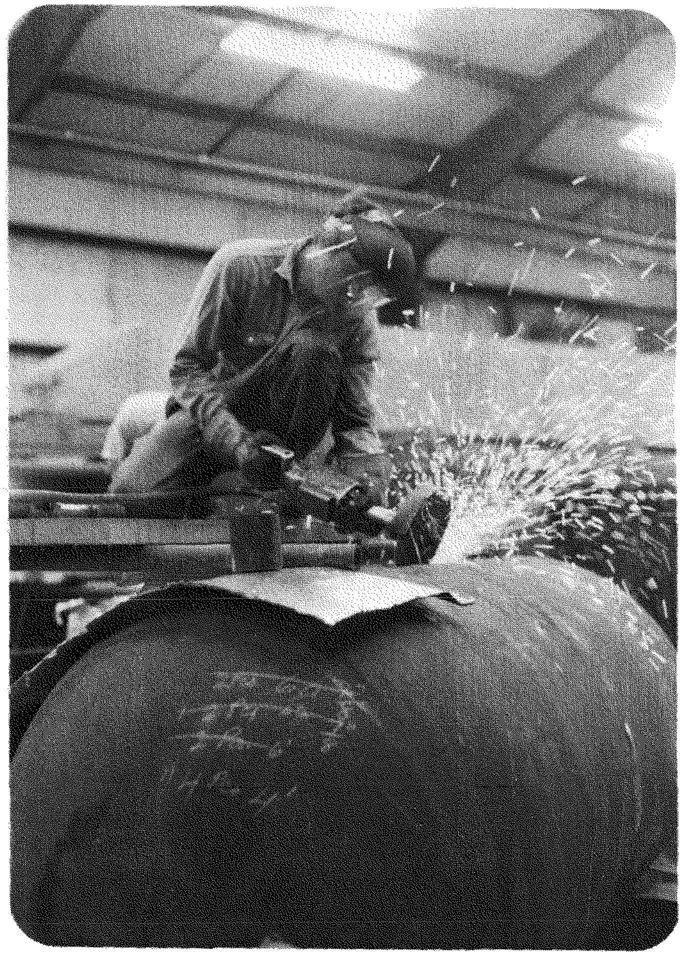
Figure 7 Grinders Used to Prepare Cavities for Welding

Grinders A and B are pencil grinders used near the cavity I.D.

Grinder C was used for grinding the cavity mid thickness.

Grinder D is a cutting wheel used to cut the 1/4" deep cavity side wall grooves.

Grinder E is a large grinder which was used where access was not restricted (near vessel O.D.).



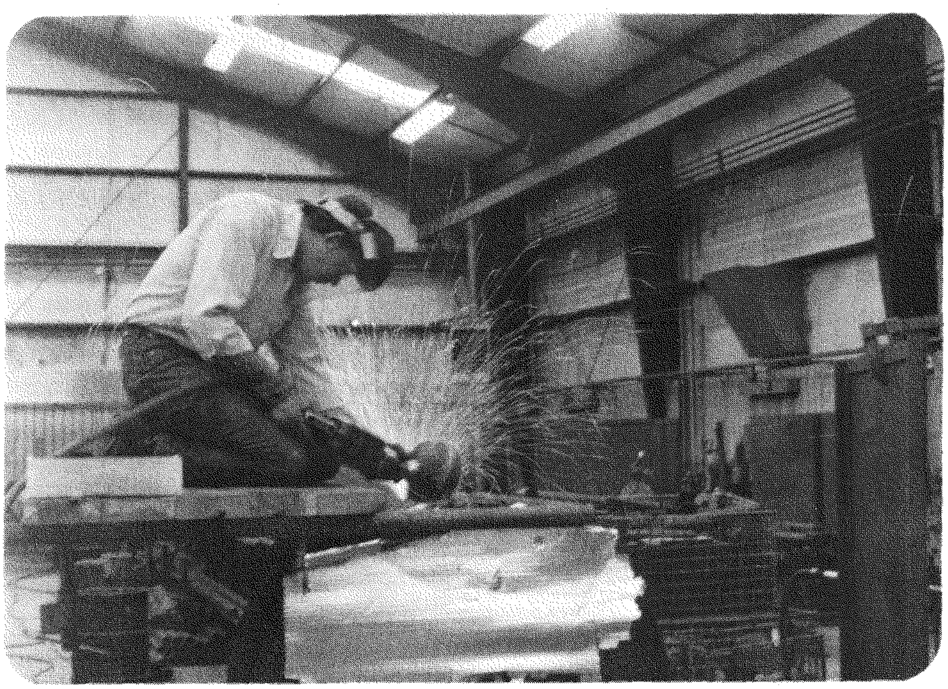
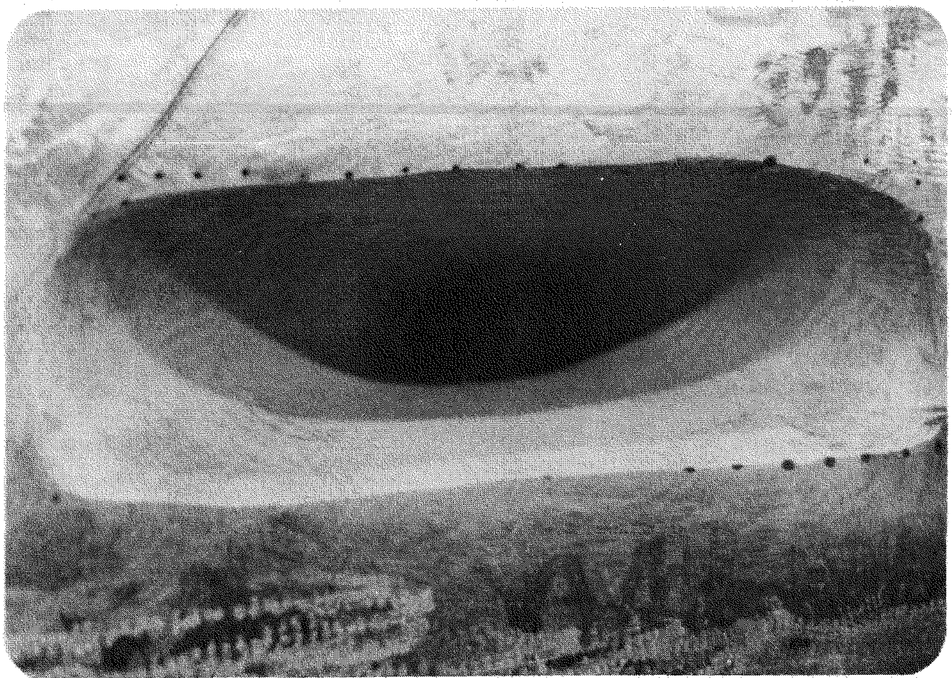


Figure 8 Grinding of the Vessel and Prolongation Cavities



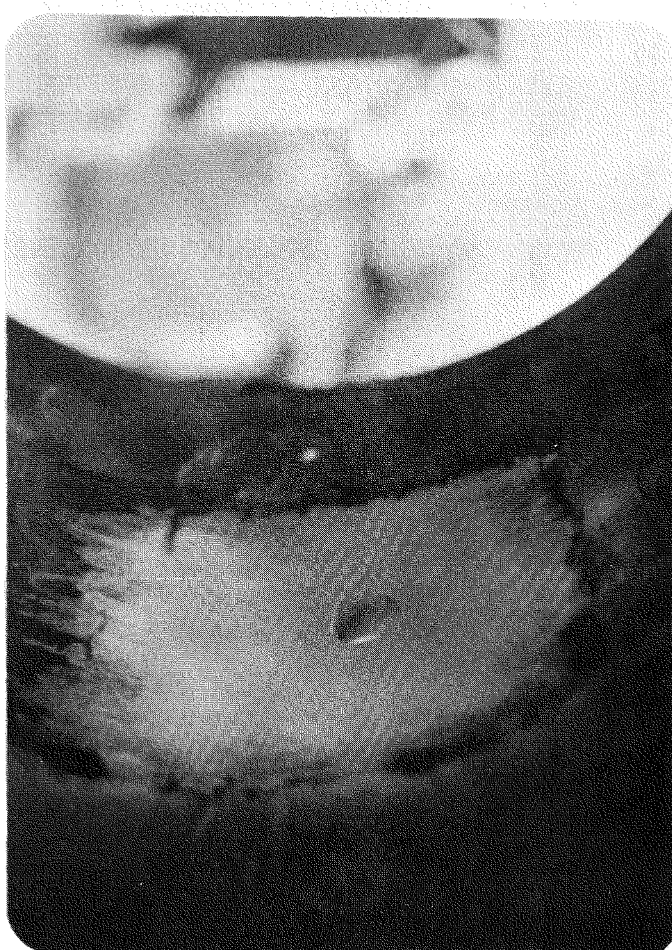


Figure 9 Liquid Penetrant Examination of the Prolongation Cavity After Grinding

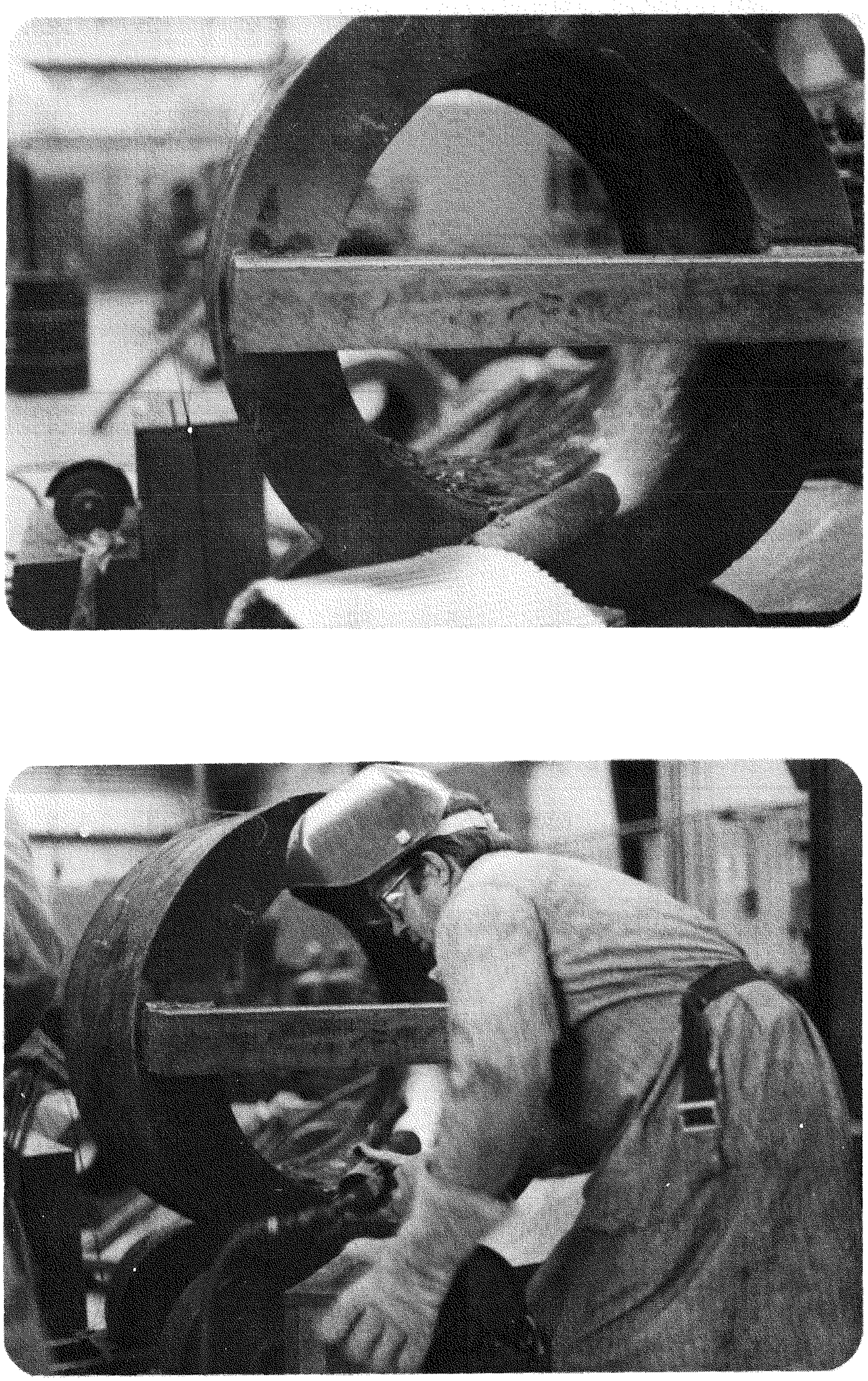


Figure 10 Installation of the Vertical End Restraint on the Prolongation

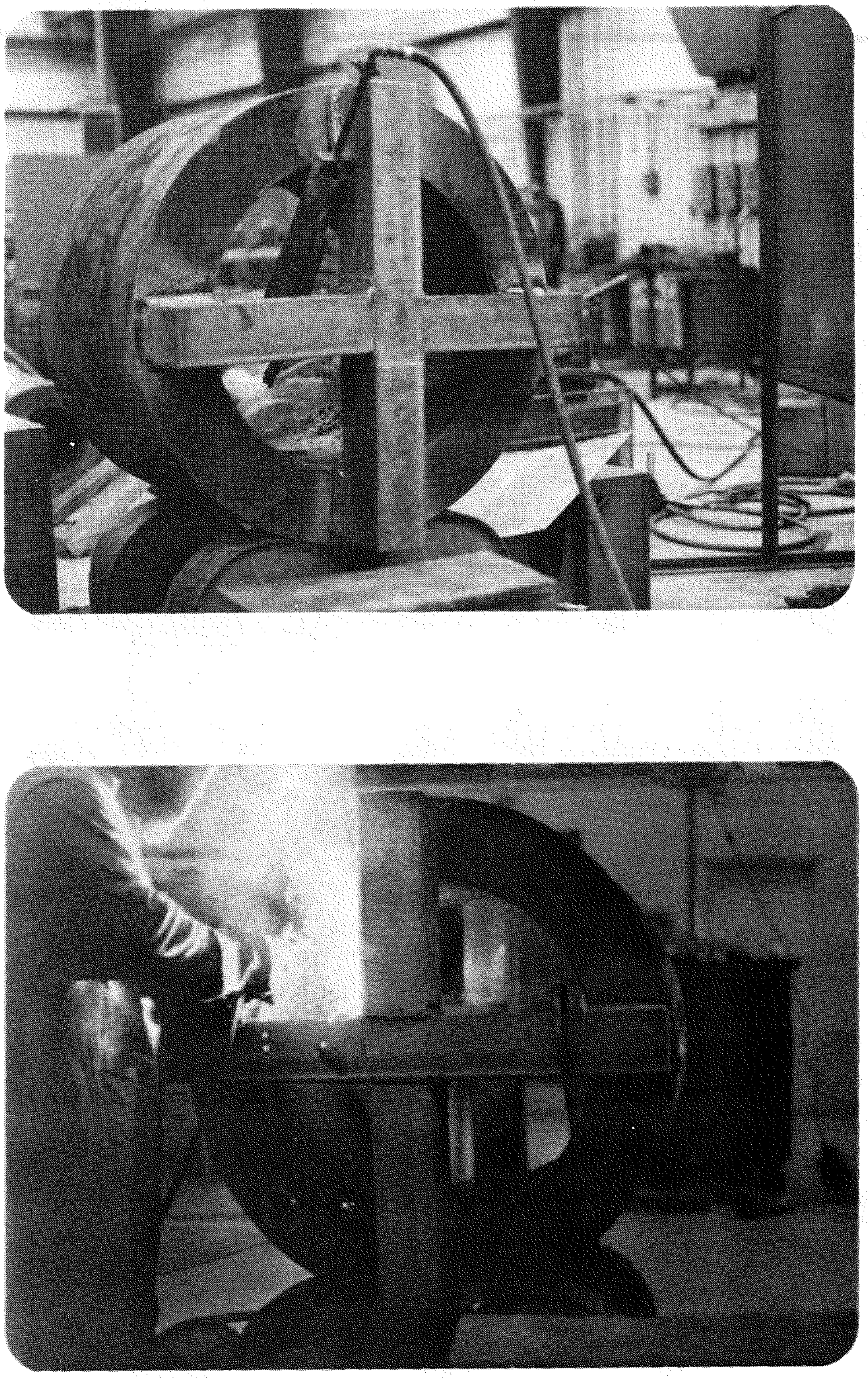
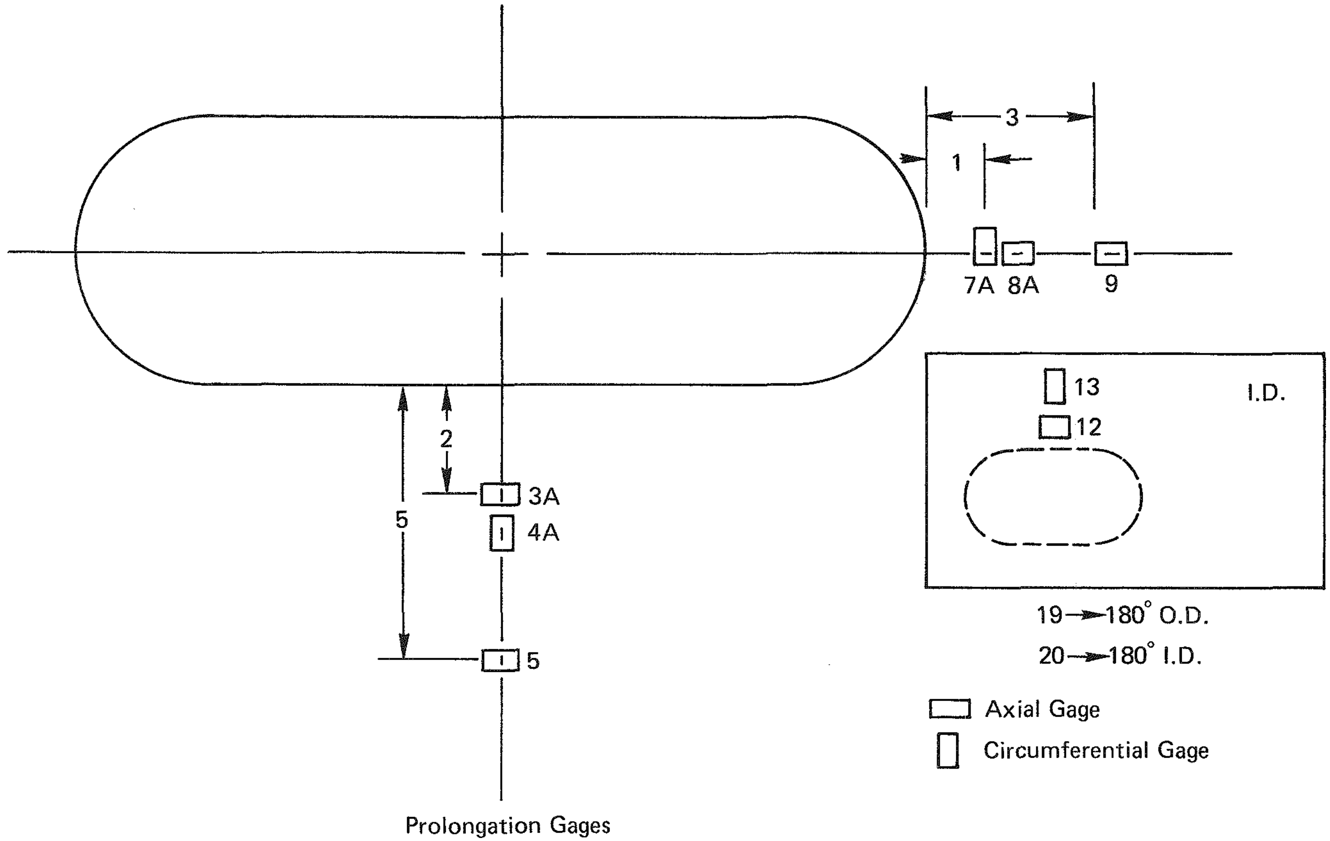


Figure 11 Installation of the Horizontal End Restraint on the Prolongation



Note: 1) The 4 vessel gages 3, 4, 7 and 8 have the same orientation and position as prolongation gages 3A, 4A, 7A and 8A respectively.

2) Gages 3, 4, 7, 8, 7A and 8A are Ailtech model 425 (900 °F max.).

3) Gages 3A, 4A, 5, 6, 9, 12, 13, 19 and 20 are Ailtech model 125 (600 °F max.).

Figure 12 Location and Identification of the Strain Gages

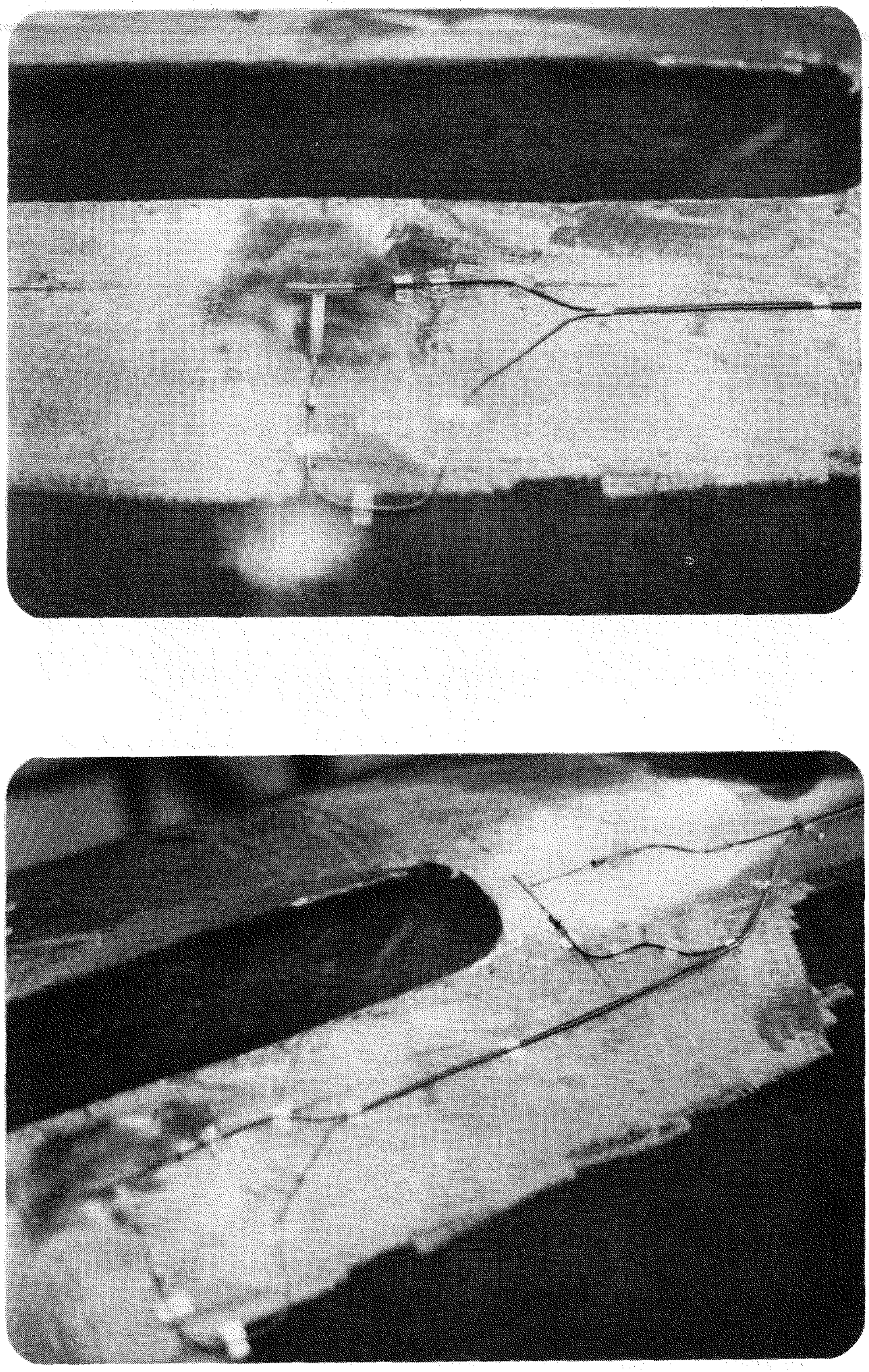


Figure 13 Strain Gauge Installation on the Vessel

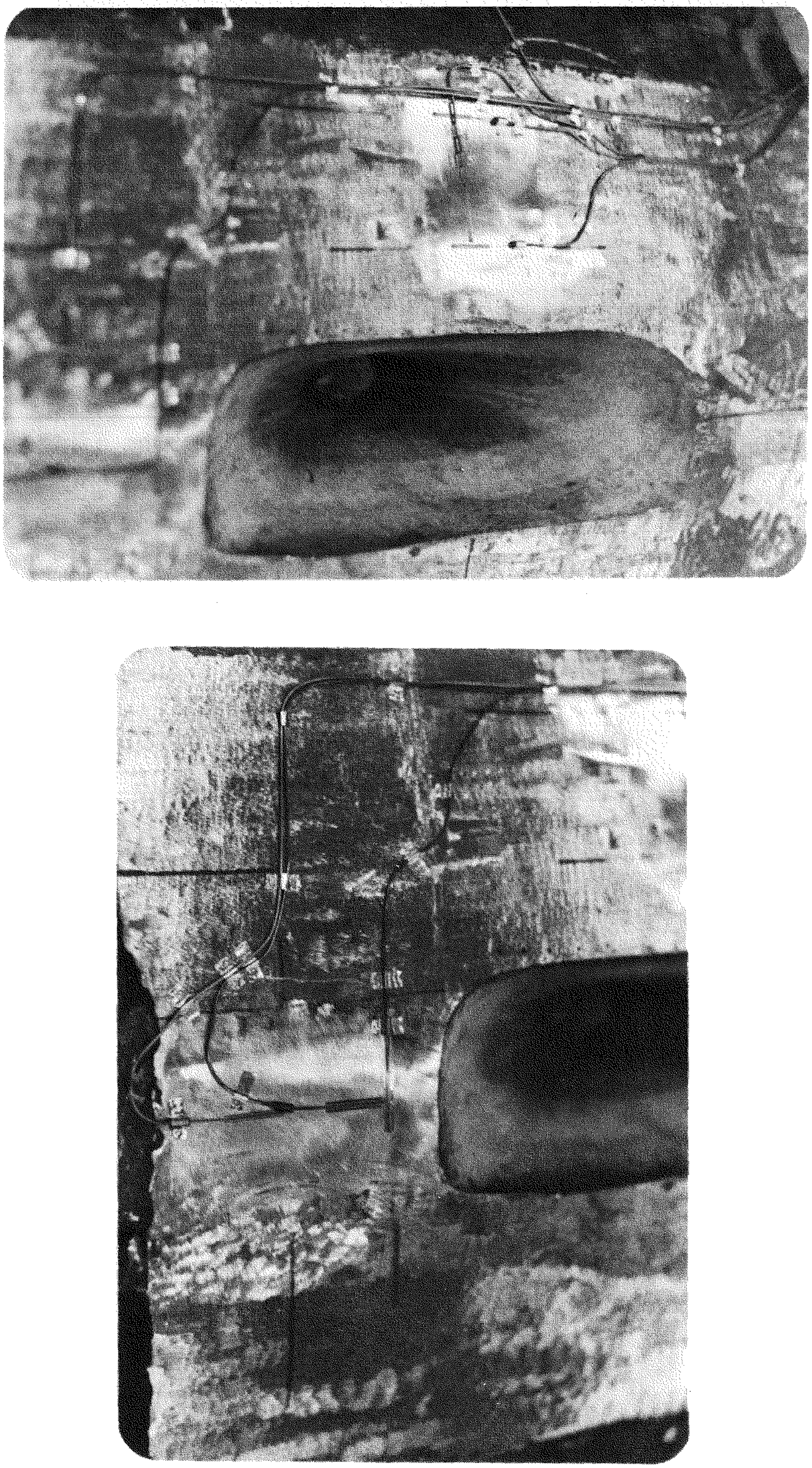
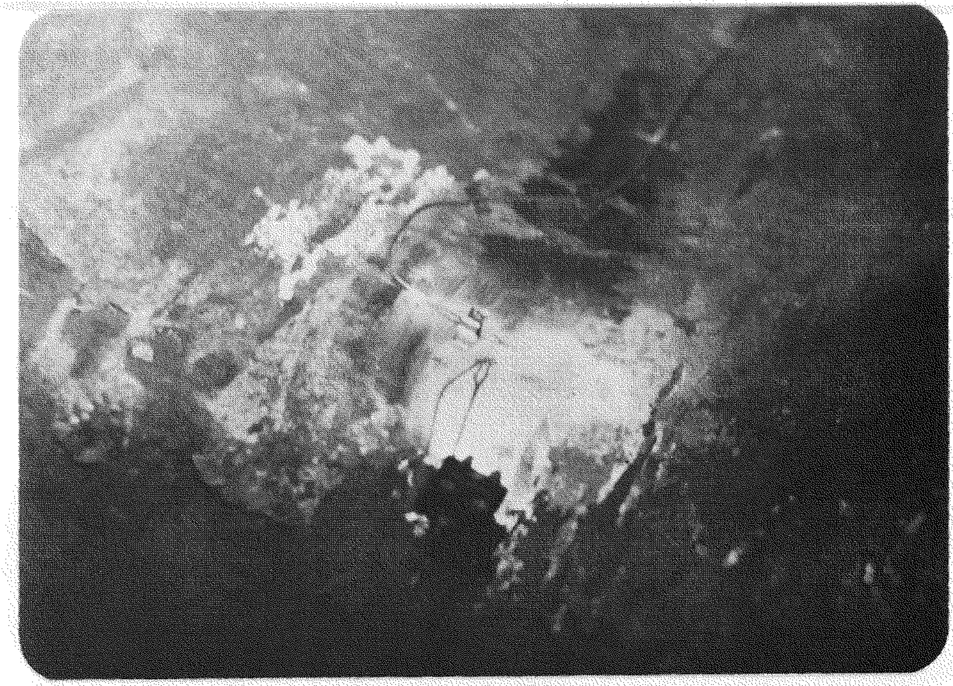


Figure 14 Strain Gauge Installation on the Prolongation



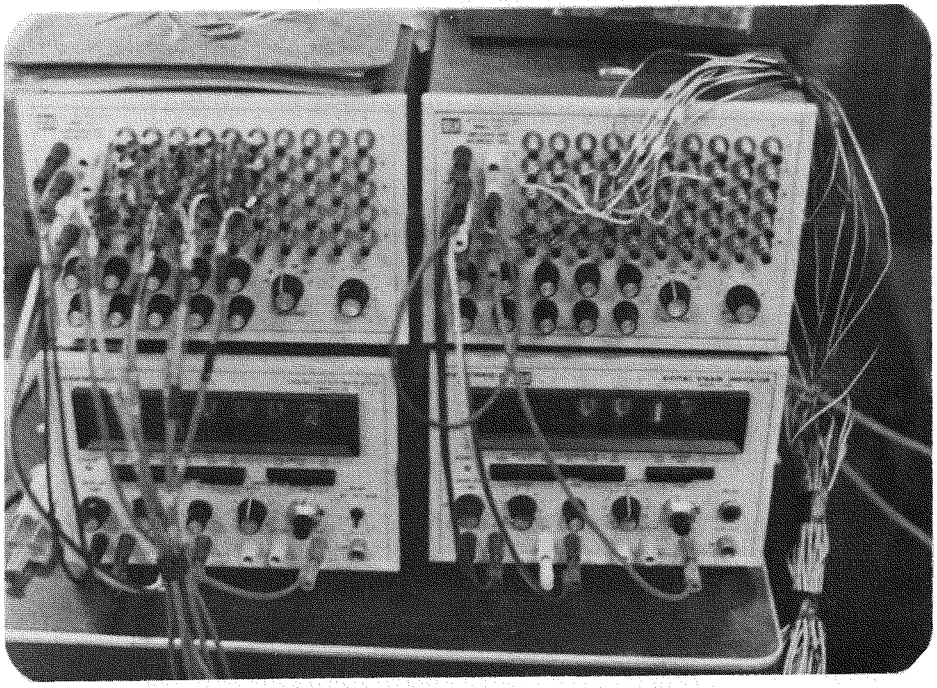


Figure 15   Strain Gauge Direct Readout Box and Strain Gauge Number 19

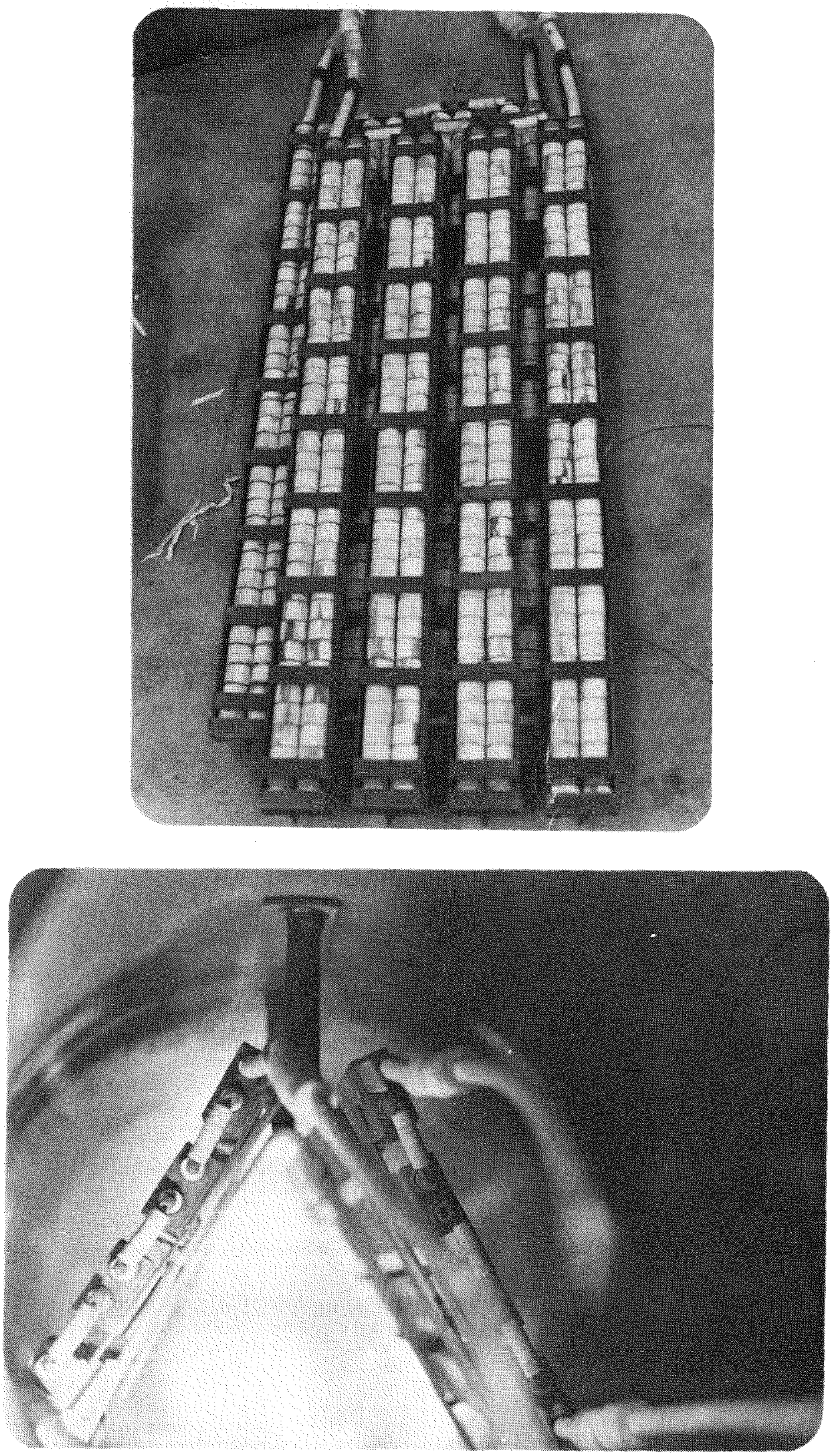


Figure 16 11 KW Electrical Heating Elements Used to Preheat Vessel V-7

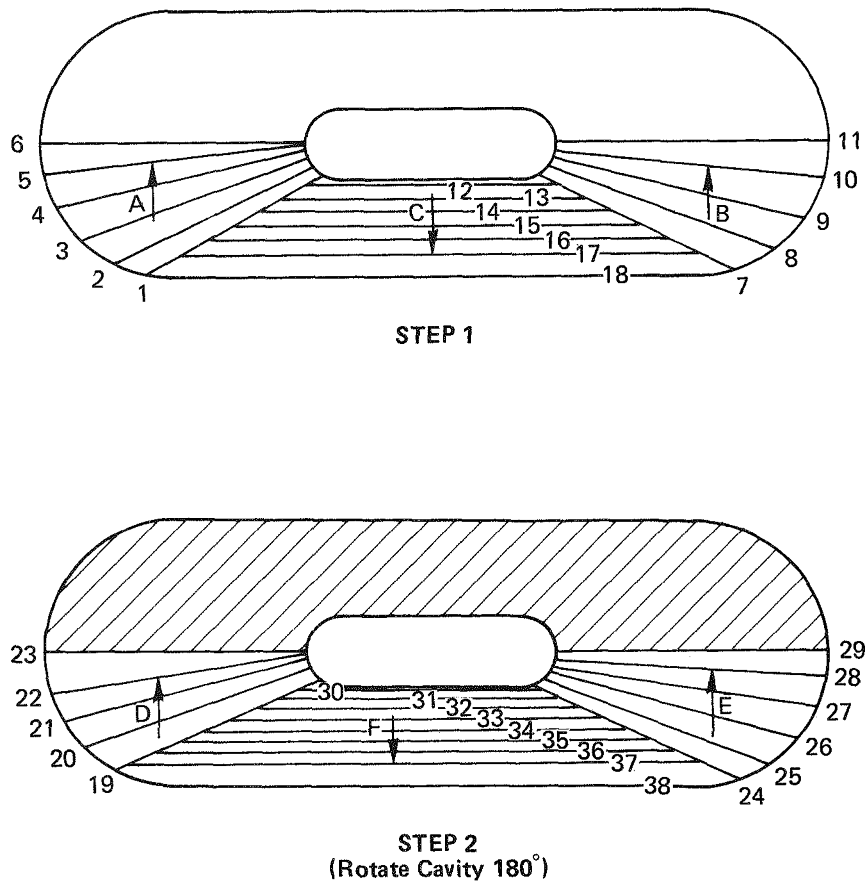
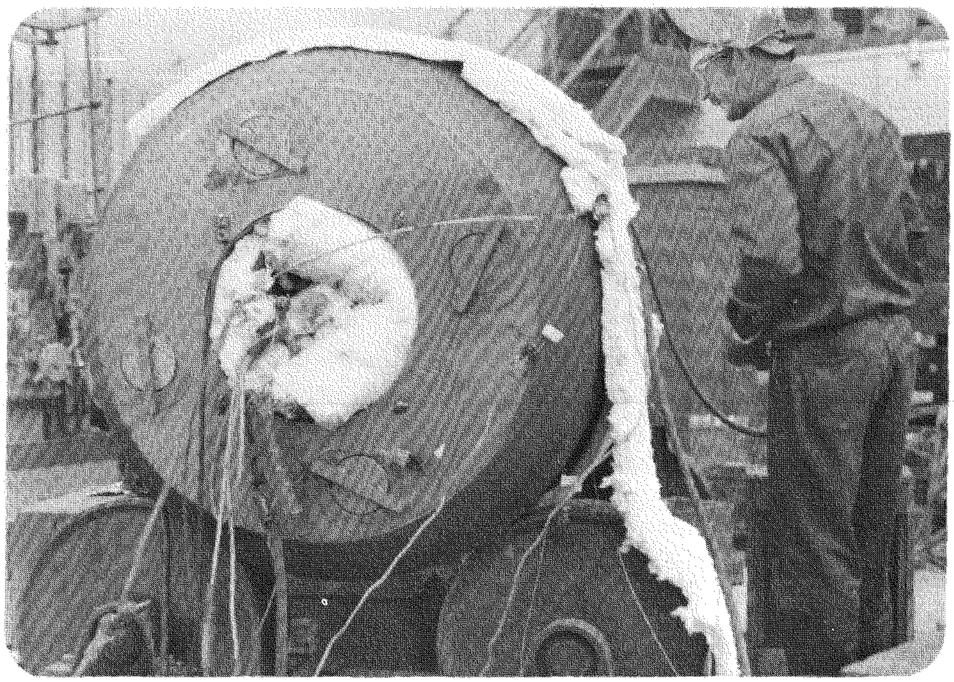


Figure 17   Weld Cavity Buttering Bead Sequence



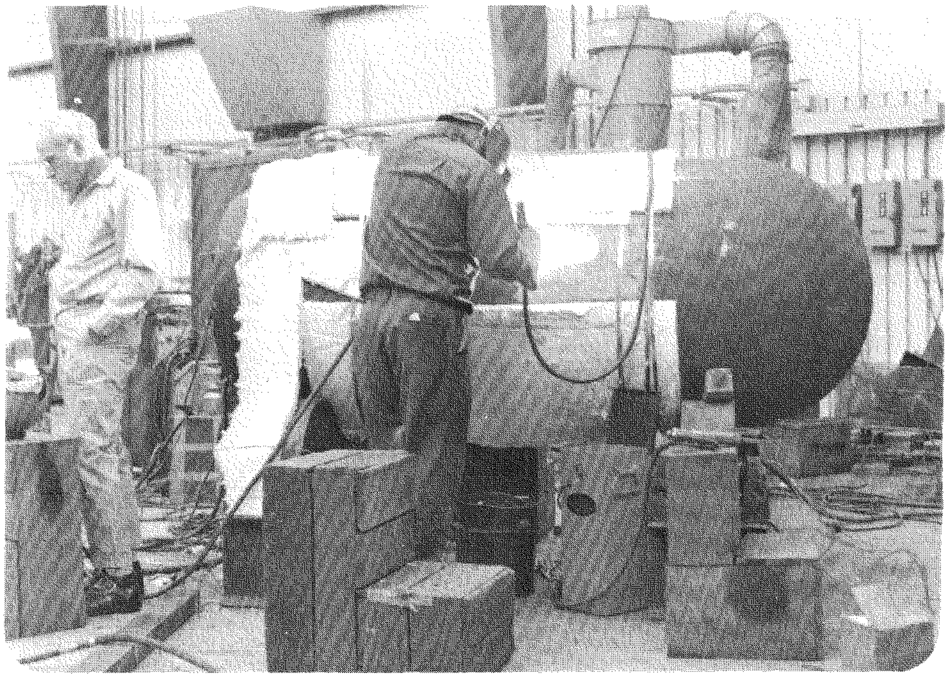


Figure 18 Vessel Cavity Buttering

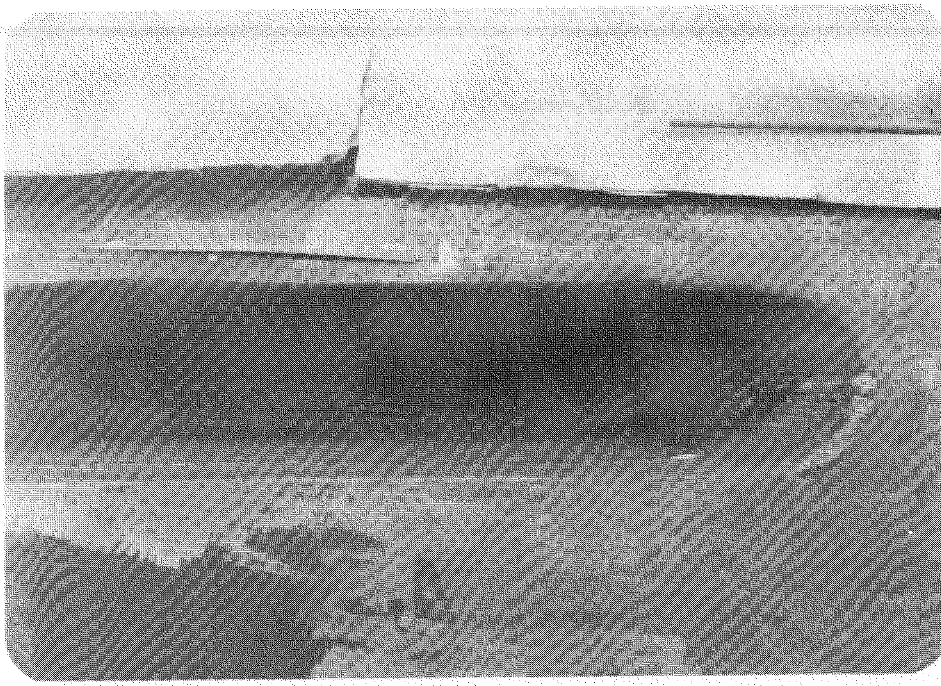


Figure 19 Prolongation and Vessel Cavity Buttering

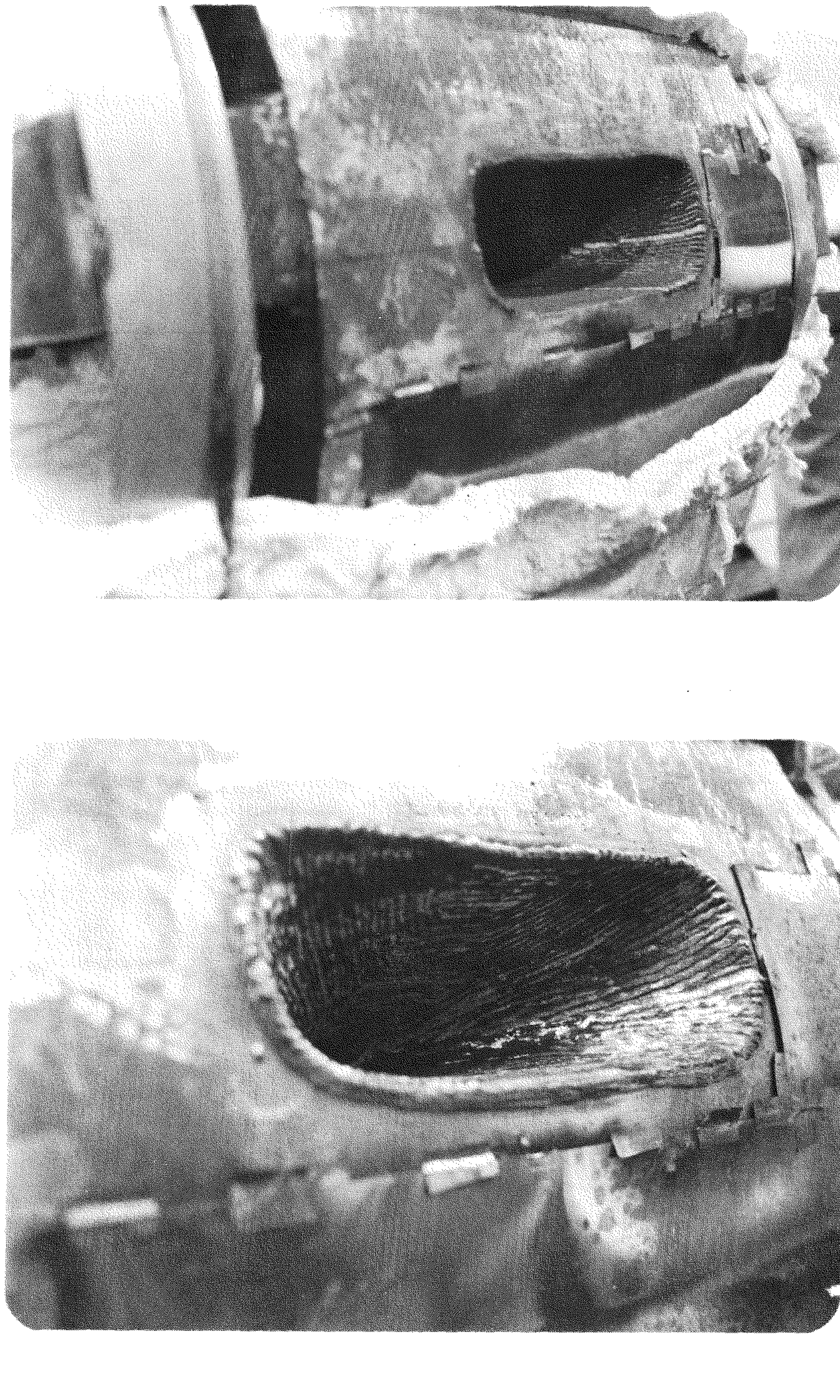


Figure 20   Prolongation Buttering

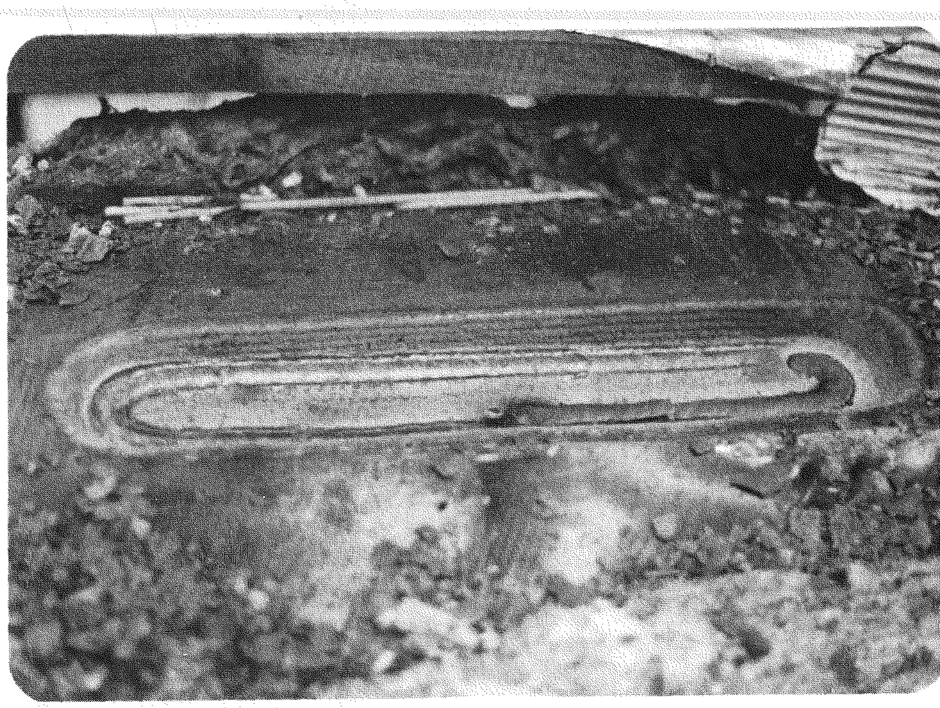


Figure 21 Vessel Weld Surfaces

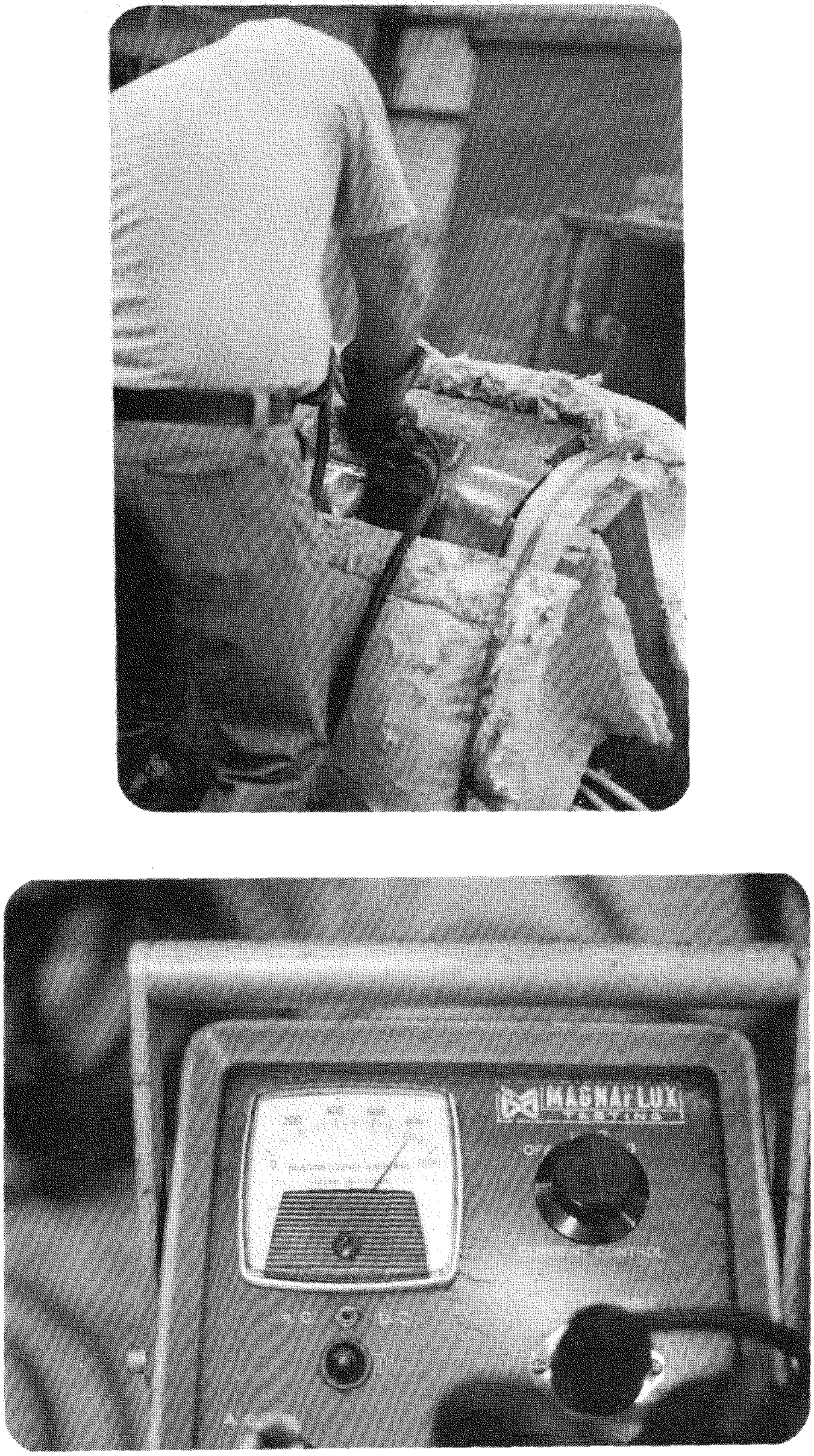


Figure 22 Magnetic Particle Examination

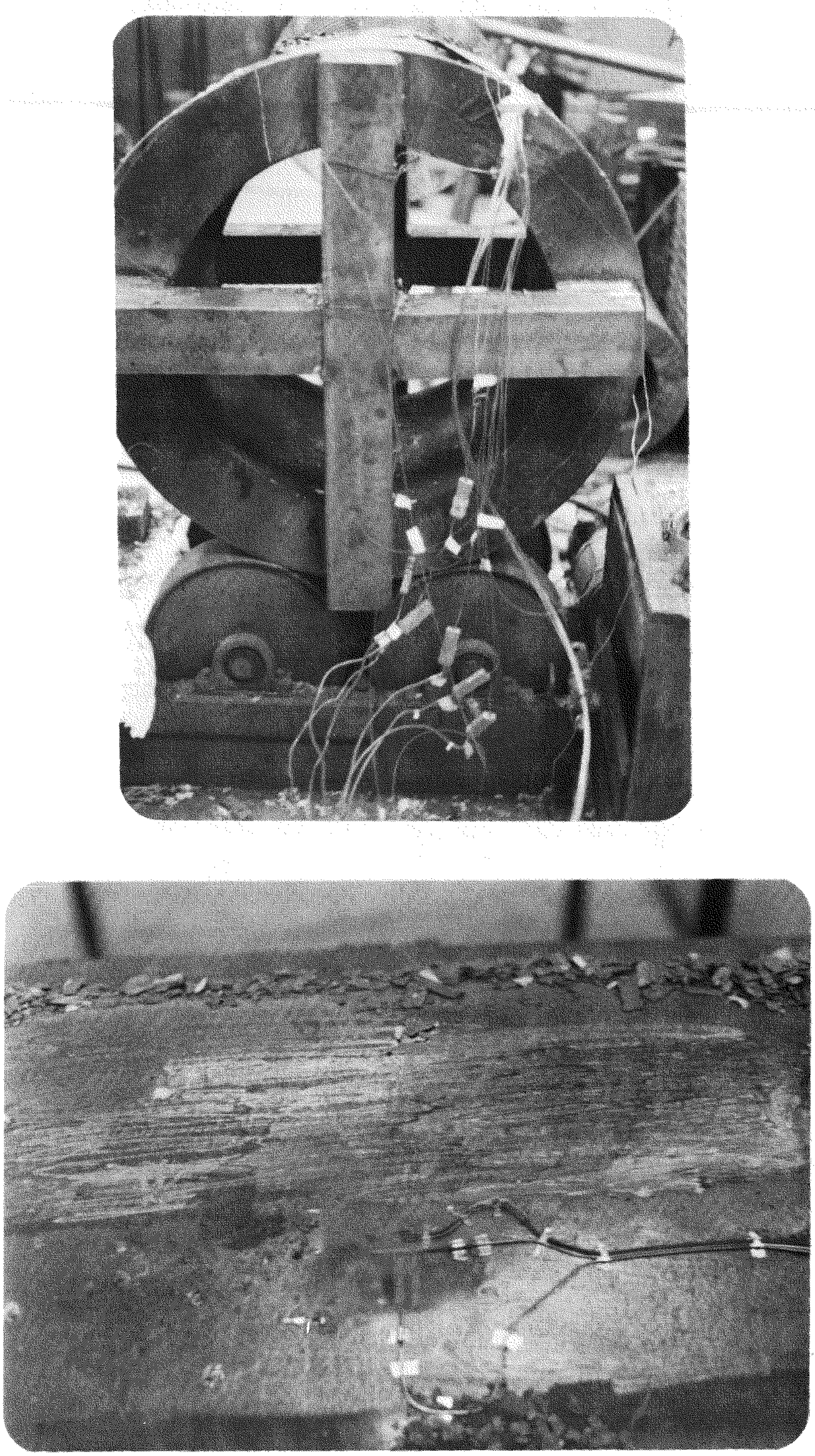


Figure 23 Prolongation After Heat Treatment

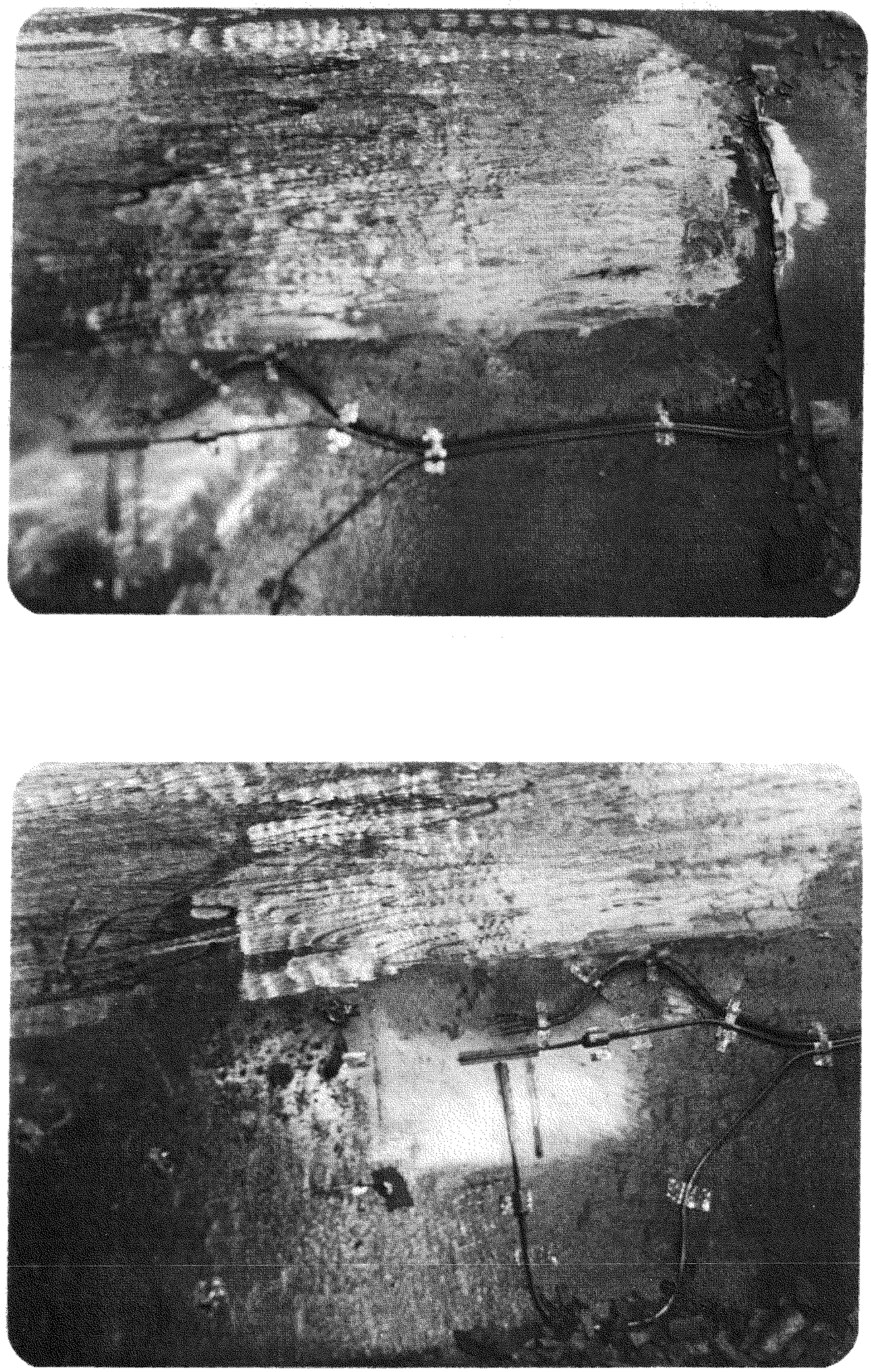


Figure 24 Vessel Strain Gauges and Thermocouples After Heat Treatment

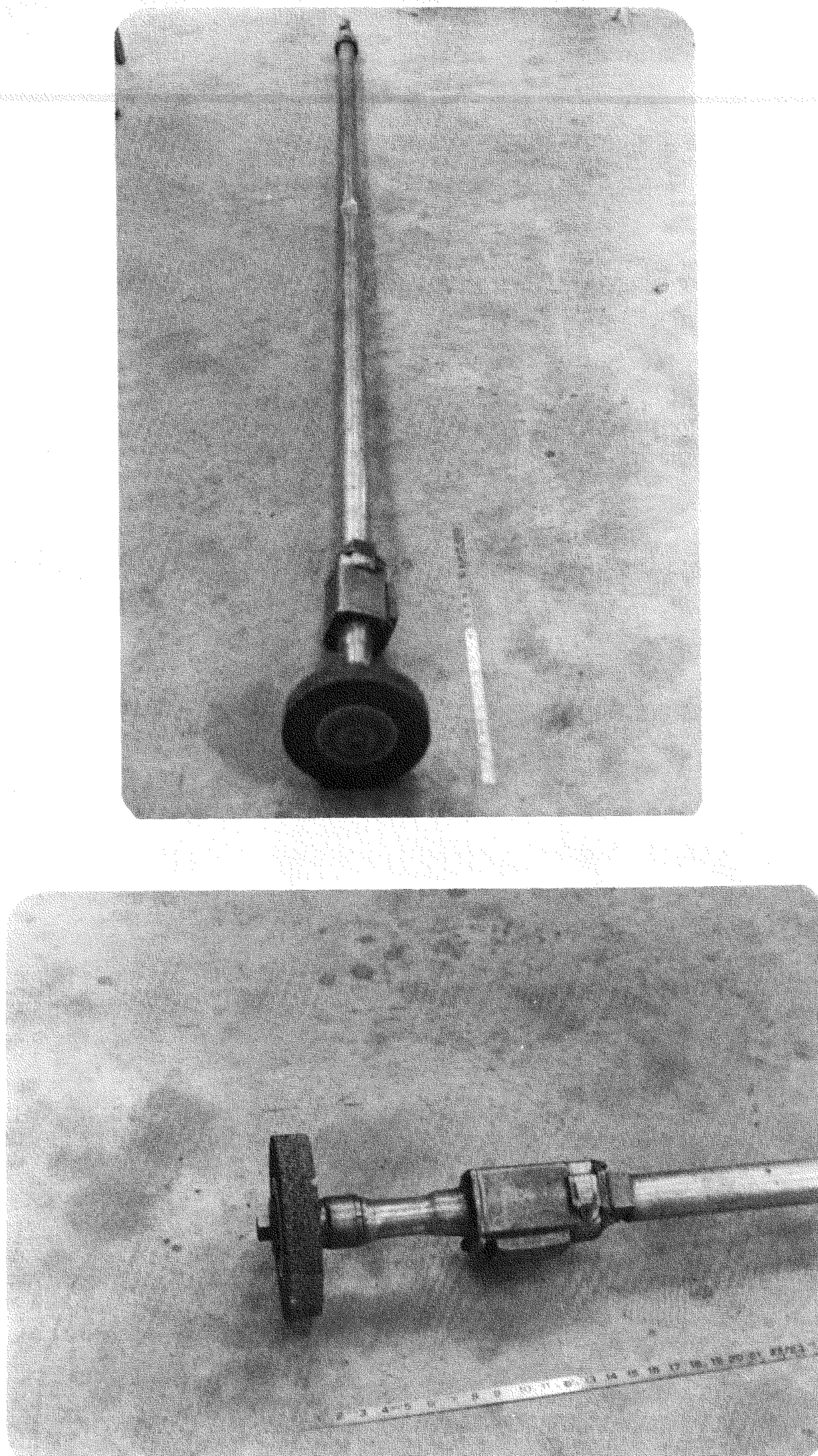


Figure 25 Pole Grinder Used to Remove the Backing Bar From the Vessel Inside Diameter

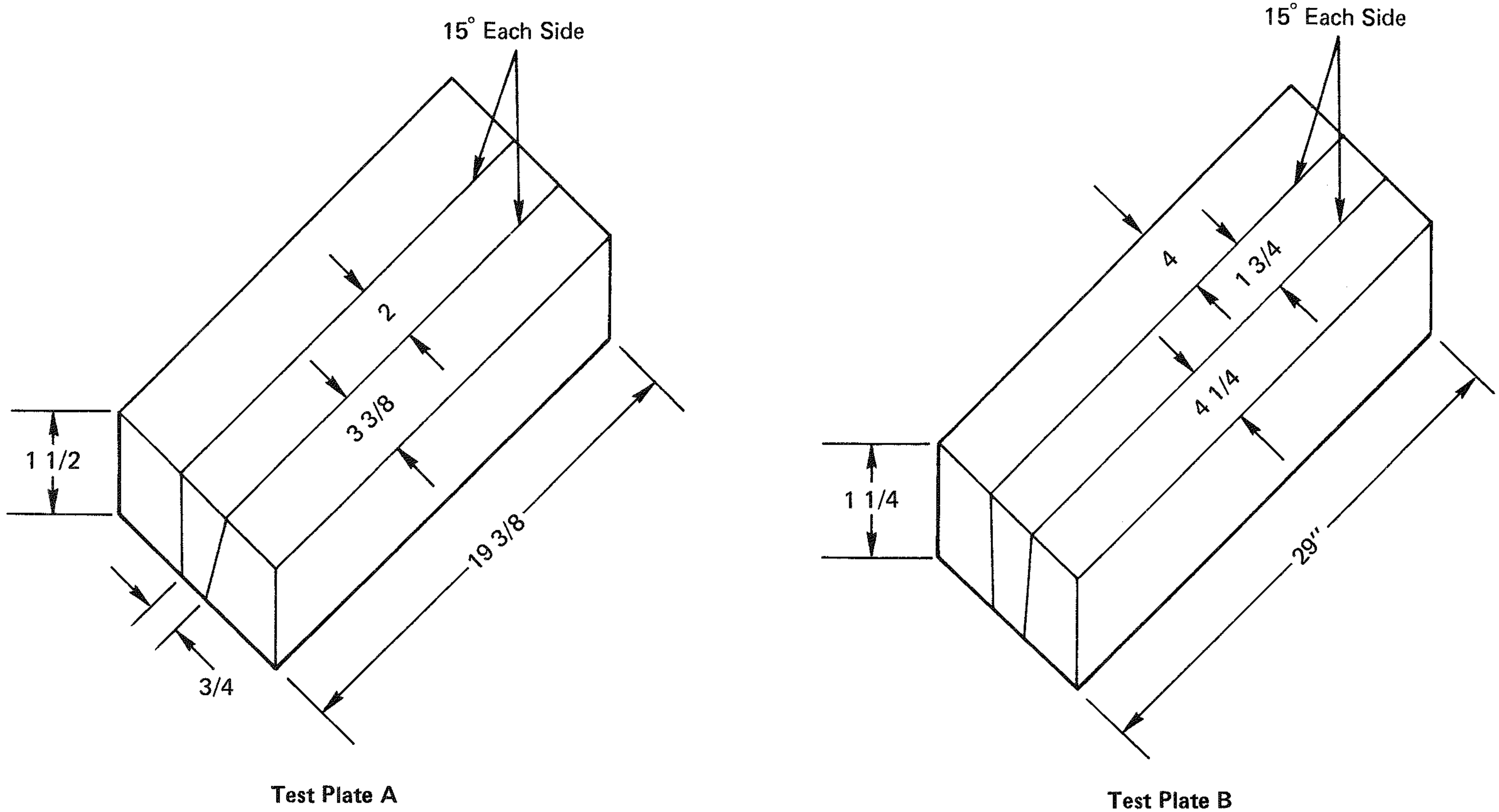
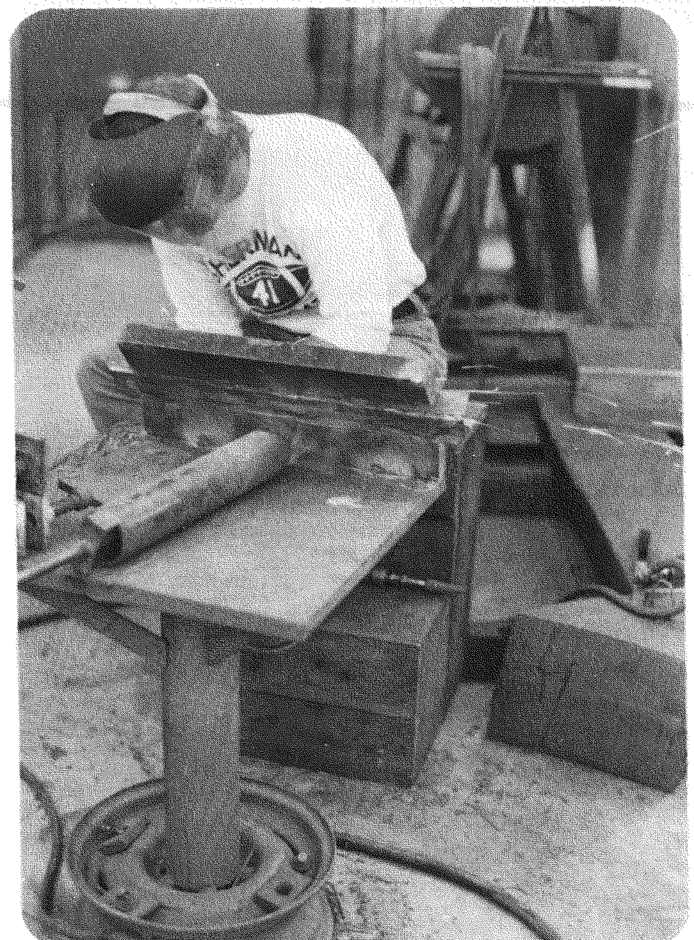


Figure 26 Weld Metal Test Plates A and B (all dimensions are in inches)



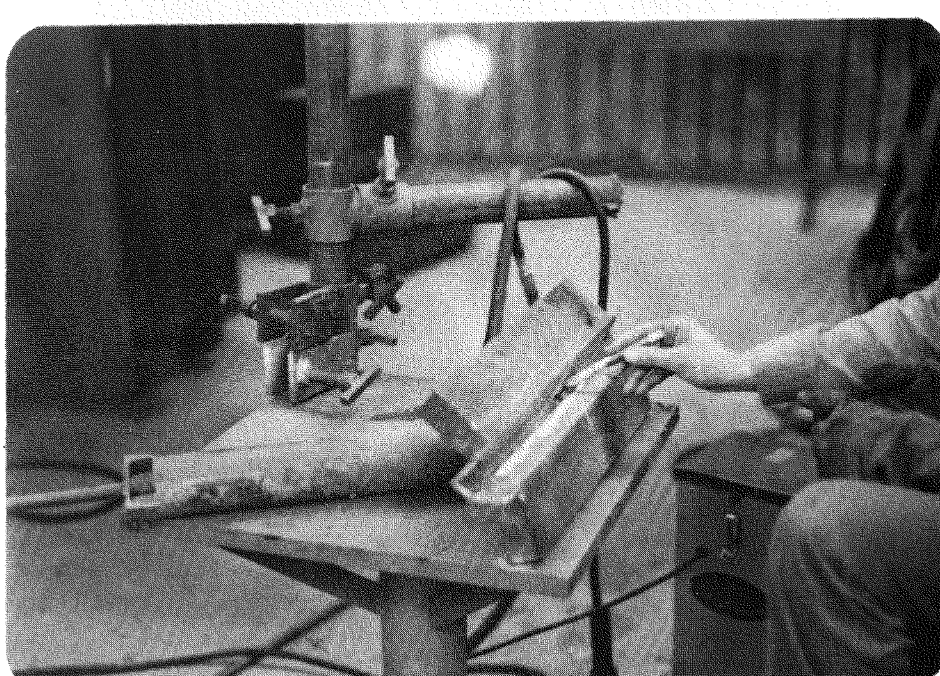


Figure 27 Weld Test Plate A

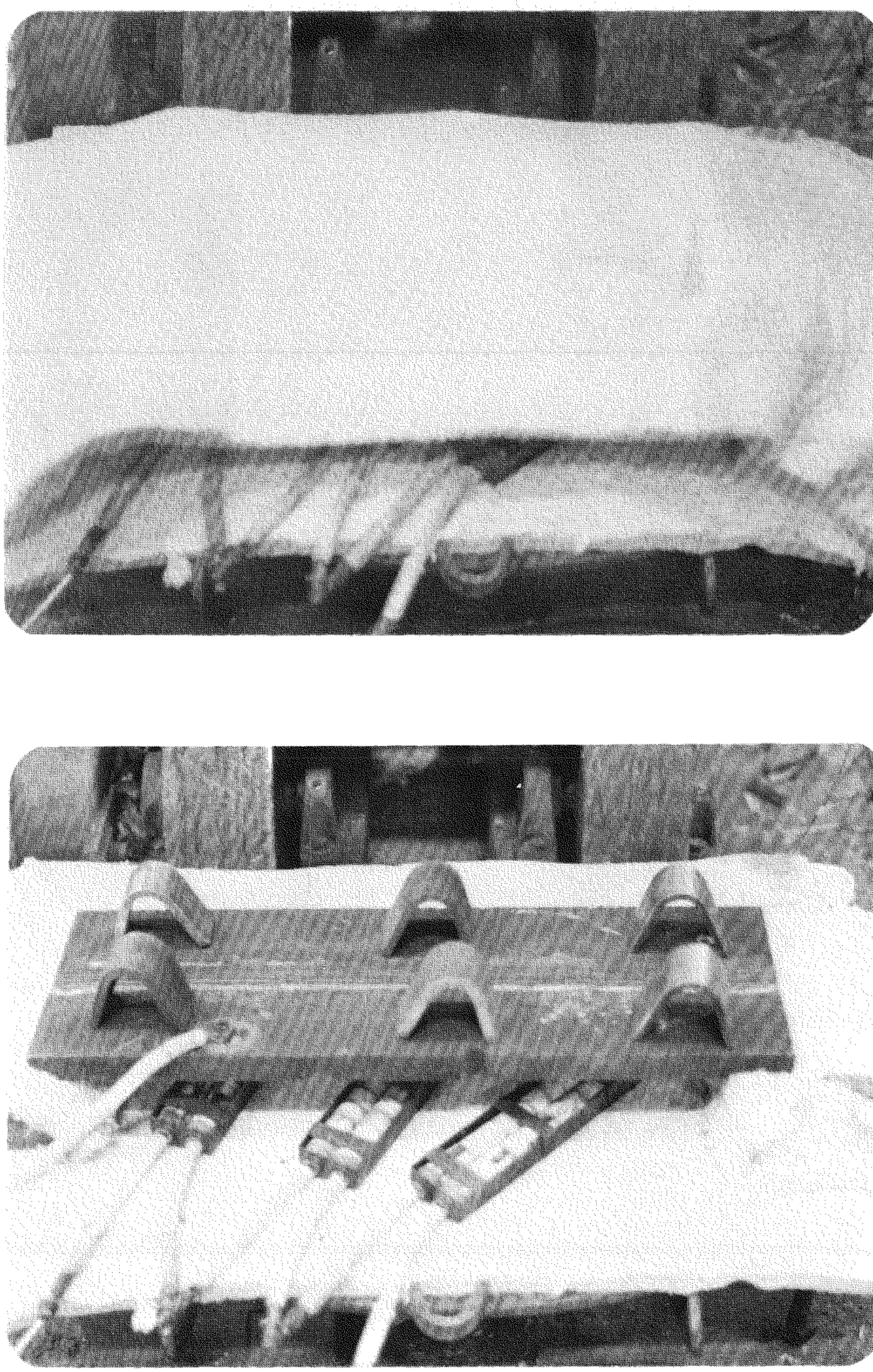


Figure 28 Heat Treatment of Weld Test Plate B

APPENDIX A

SECTION XI WELD REPAIR PROCEDURE

COMBUSTION ENGINEERING, INC.
NUCLEAR COMPONENTS DEPARTMENT
CHATTANOOGA, TENNESSEE

Contract 10875

Date: September 25, 1975

References: SMA-3.3-113
QMA-11A(1)F4

Qualifications:

DETAIL WELDING PROCEDURE
No. MA-574-0
FOR WELDING P 3 TO P 3
TYPE OF WELD Repair
Permissible Welding
Positions Flat, Horizontal, Vertical
Qualified on 8 1/2 " thickness.

THIS WELD SHALL BE EXAMINED BY NON-DESTRUCTIVE METHODS AT FREQUENCIES AS ASSIGNED ON THE WELDING PROCEDURE ASSIGNMENT SHEET (WPAS).

Heat Treatment:

Minimum Preheat & Interpass 350 °F and maintain until welding is completed.
Maximum Preheat and Interpass 500 °F
Hold Preheat Until a P.W.H.T.
Intermediate P.W.H.T. 500 °F ($\pm$50°F), hold 30 minutes minimum.
Final P.W.H.T. 500 °F ($\pm$25°F), hold one hour per inch weld thickness.

Welding Parameters:

Type of Electrodes Mil E-8018 C3

Use only 3/32 inch diameter electrodes to butter the entire cavity in accordance with the figure on the back. Approximately 1/2 of the thickness of this buttered layer shall then be removed by grinding. The second layer shall be deposited using 1/8 inch diameter electrodes.

CURRENT RANGE FOR MA ELECTRODES

Size	Amperage	Voltage
3/32	85-100	20-26
1/8	110-140	20-26
5/32	130-185	20-26

REPAIR OF BASE METAL AFTER

WELDING PROCEDURE QUALIFICATION RECORD PWHT

E-563 (1/72)

COMBUSTION ENGINEERING, INC.

DATE January 30, 1975

PROCEDURE QUALIFICATION NO. SMA-3.3-113

QUALIFIED TO CODE SECTION(S) ASME Code, Sec.III NB-4642

MATERIAL SPEC. & GRADE SA-533 Gr. B Cl. 1 TO SFA-5.5, E-8018/C3

FOR WELDING P No 3 TO ~~HNU~~ A2

THICKNESS (& DIA. IF PIPE) 8 1/2"

WELDING PROCESS Shielded Metal Arc (SMA)

TYPE WELD JOINT Groove

FILLER METAL F No 4 A No 2

POSITION TEST WELD Vertical (3G)

SPEC. or ANALYSIS SFA-5.5 E-8018/C3

SINGLE or MULTIPLE PASS Mutliple

ELECTRODE SIZE 1/8"Ø 1st Layer, 5/32"Ø Subsequent Layers

NO. OF LAYERS (IF CLAD)

FLUX

NO. OF ARCS One

SHIELDING GAS(ES) & COMPOSITION

PREHEAT 350°F Minimum

FLOW RATE

MAX. INTER-PASS 450°F Maximum

TYPE CURRENT DC-RP

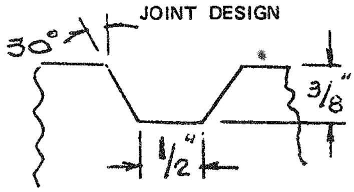
MAINTAIN PREHEAT UNTIL PWHT Yes

BACKING REQUIREMENTS

POSTHEAT TREATMENT 400°F-500°F For 2 Hrs. Min. Air Cool to Ambient

OTHER: Electrodes Baked at 800°F+ 25°F For 30 Min. to 1 Hr. and in accordance with NB-4642.

JOINT DESIGN



BEAD NO.	PROCESS	WIRE DIA.	AMPERES	ARC VOLTS	INCHES/MIN.
1	SMA	1/8"Ø	100-130	23	5-6
(Remove	Approx.	1/2 thickness of 1st Layer)			
Subsequent	SMA	5/32"Ø	120-160	24	6-7
(Deposited in a manner to provide tempering of prior beads)					

% FERRITE IN AUSTENITIC CLAD DEPOSIT

DEPOSIT ANALYSIS C ___ Mn ___ P ___ S ___ Si ___

Cr ___ Ni ___ Mo ___ Co ___ N2 ___ Other ___

GUIDED BEND TESTS

FACE:

ROOT:

SIDE: 4 Bends Acceptable

MACRO:

CHARPY V-NOTCH IMPACT TESTS

LOCATION	TEMP	FT/LBS	MILS LAT EXP
HAZ	+10°F	108	67
HAZ	+10°F	112	64
HAZ	+10°F	66	39

DROP-WEIGHT TESTS

TEMP	RESULTS

NDT °F

NON-DESTRUCTIVE TESTS

LIQUID PENETRANT	C. Linz #47 1/13/75
RADIOGRAPHIC	
ULTRASONIC	R. Wille II 1/13/75
MAG. PARTICLE	
VISUAL	

TENSILE TESTS

TYPE SPECIMEN	ULTIMATE STRESS—PSI	CHARACTER & LOCATION OF FAILURE
Reduced Sec.	94,200	Base Material
Reduced Sec.	95,200	Base Material
Reduced Sec.	91,000	Base Material
Reduced Sec.	91,400	Base Material

WELDER W. C. Jones SYMBOL BBE

DEPT Chattanooga, Tennessee

TEST NO 960001

TEST LAB. Bay 28 Lab

We certify that the statements in this record are correct, and that the test welds were prepared, welded and tested in accordance with requirements of the ASME Code.

COMBUSTION ENGINEERING, INC.

BY: Michael P Ryan

BY OTHER S/ R. Dinwiddie TITLE Eng. Sup.

APPENDIX B

Combustion Engineering

Fabrication Procedures

CE POWER SYSTEMS
Chattanooga, Tennessee
WELDING ENGINEERING DEPARTMENT

Procedure No.	SC-101-0
Issue Date	9-17-75
Revision Date	
Revision Letter	
Page	of
Prepared By	W.D. Goins
Approved By	D. G. Brooks

PROCEDURE FOR CARE OF WELDING ELECTRODES FOR REPAIR OF THE OAK RIDGE TEST VESSEL AND VESSEL PROLONGATION

1.0 All welding electrodes for the ORNL vessel repair shall be packaged by CE in hermetically sealed vacuum packages.

2.0 Each welder shall use the attached form SC-101-1 to document that each package of electrodes that he opened had an adequate vacuum. Packages which do not contain an adequate vacuum will be thrown away and this action noted on form SC-101-1.

3.0 Immediately after the package is opened the electrodes shall be placed in portable heated ovens operating in the temperature range 225°F to 300°F. Electrodes not used within 20 minutes after removal from a portable oven shall be thrown away.

4.0 Electrodes that remain in a portable oven for more than 4 hours shall be thrown away by the cognizant welding engineer assigned to the specific shift. This action shall be noted on form SC-101-1.

5.0 Each electrode shall be inspected by the welder for proper end condition when the package is opened. Electrodes shall be thrown away that have a coating end condition which could cause an improper arc start. The welder shall note on form SC-101-1 the number of electrodes in each package with bad end conditions.

CE POWER SYSTEMS
Chattanooga, Tennessee
WELDING ENGINEERING DEPARTMENT

Procedure No.	SC-100-0
Issue Date	9-17-75
Revision Date	
Revision Letter	
Page	1 of 3
Prepared By	W. D. Goins
Approved By	D. G. Brooks

PROCEDURE FOR WELD GROOVE PREPARATION FOR WELD REPAIR OF THE OAK RIDGE TEST VESSEL AND VESSEL PROLONGATION

1.0 Layout weld cavity in accordance with figures 4 and 5 of ORNL document W-HB 100.

2.0 Pierce the burning starter hole using a oxygen burning bar with the vessel rotated such that the starter hole is in a horizontal plane.

3.0 Burn the cavity using the following parameters and a Linde number 12 torch.

Cutting oxygen	50 psi
Preheat oxygen	20 psi
Preheat gas	10 psi
Travel speed	6 in/min

4.0 Remove the burned plug from the vessel cavity and shape the cavity ends using arc air gouging using 500 to 600 amps DCRP.

5.0 After air-arc gouging is completed, a layer of base metal under the gouged area a minimum of 1/4 inch in depth shall be removed by grinding.

6.0 Final dimensions of the cavity shall be recorded.

7.0 Preheat shall be 350°F minimum when arc air gouging is started.

POWER SYSTEMS
Chattanooga, Tennessee
WELDING ENGINEERING DEPARTMENT

PROCEDURE FOR WELD CAVITY INSPECTION TO INSURE THICKNESS CONTROL OF THE FIRST WELD LAYER IN THE OAK RIDGE VESSEL REPAIR CAVITY.

Procedure No.	SC-102-0
Issue Date	9-17-75
Revision Date	
Revision Letter	
Page	of
Prepared By	W. D. Goins
Approved By	D. G. Brooks

1.0 Prior to welding, cavity dimensions shall be recorded as required by figure SC-102-1.

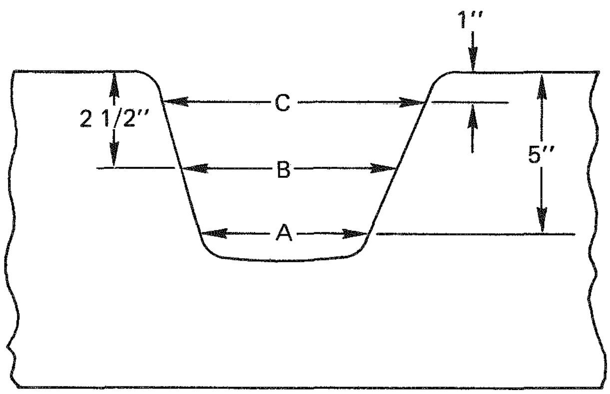
2.0 The first weld layer shall be deposited using 3/32 inch diameter electrodes and the bead sequence shown in figure SC-102-2.

3.0 Cavity dimensions shall be recorded on the as welded cavity as required by figure SC-102-3.

4.0 Approximately one half of the first weld layer shall be removed by grinding and the cavity dimensions recorded after grinding as required by figure SC-102-4.

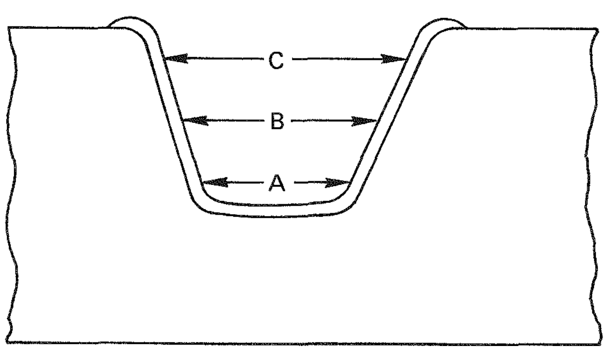
5.0 The cognizant welding engineer review the data from figures SC-102-1,2, and 3 to assure that approximately one half of the first weld layer has been removed.

6.0 All cavity dimensions shall be measured with the same micrometer caliper and measurements taken by the same individual where possible.



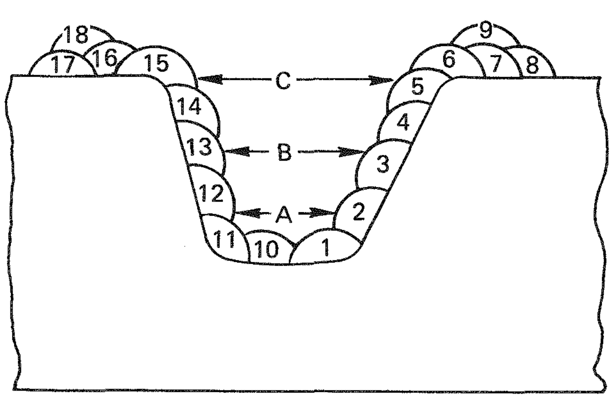
	2"	4"	6"
A			
B			
C			

FIGURE SC-102-1



	2"	4"	6"
A			
B			
C			

FIGURE SC-102-3



	2"	4"	6"
A			
B			
C			

FIGURE SC-102-2

APPENDIX C

Mil - E-8018 C3

Coated Electrode Mechanical Properties

TABLE I MIL-E8018C3 ELECTRODE MOISTURE

Electrode Lot No.	Electrode Size	Rack or Heater No.	Moisture (%)	Date	Time
AE90	5/32	36	.05	9/24	(1)
AE90	5/32	36A	.07	9/24	(1)
AE90	5/32	43	.07	9/24	(1)
AE77	5/32	26	.08	9/24	(1)
AE74	1/8	46	.06	9/24	(1)
AE74	1/8	46A	.07	9/24	(1)
AE74	1/8	19	.06	9/24	(1)
AE74	1/8	19A	.05	9/24	(1)
AE74	1/8	13	.06	9/24	(1)
5237A	3/32	38	.06	9/24	(1)
5237A	3/32	1	.10	9/26	16:00
5237A	3/32	2	.11	9/26	19:58
5237A	3/32	1	.10	9/26	23:00
5237A	3/32	1	.10	9/27	2:40
AE74	1/8	2	.10	9/27	6:20
AE74	1/8	1	.14	9/27	11:00
AE90	5/32	2	.14	9/27	15:15
AE90	5/32	1	.11	9/27	22:00
AE90	5/32	1	.13	9/28	4:00
AE90	5/32	2	.10	9/28	5:30

NOTE: (1) Moisture determined after electrodes were rebaked but prior to vacuum packaging.

TABLE 2

MIL-E8018C3 Electrode Mechanical Properties

Lot Number	5237A	AE 74	AE77	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 $-20^{\circ}F$	99 100 100	110 119 99	87 91 82	93 97 91

APPENDIX D

Strain Gage Data

TABLE 3 Strain Gage Data (in/in)
(Number in Parentheses is the Temperature (^{o}F) of the Gage)

	Gage Number	1	2	3	4	5	6
Vessel	3	0	-651(450)	-1456(475)	-1498(525)	-604(87)	
Vessel	4	0	-1134(450)	-106(475)	+25(525)	+1216(87)	
Vessel	7	0	-898(400)	-	-	-	
Vessel	8	0	-596(400)	+259(465)	213(515)	+838(85)	
Prolongation	7A	0	-872(365)	-2141(383)	-2338(500)	-1044(78)	-1206(90)
Prolongation	8A	0	-902(365)	+90(383)	-185(500)	+787(78)	+822(90)
Prolongation	3A	-7	+267(360)	-914(383)	-832(502)	-1110(78)	-1083(86)
Prolongation	4A	-3	+97(360)	+1507(383)	+1443(502)	+1327(78)	1291(86)
Prolongation	5	+4	+239(365)	-580(392)	-505(478)	-760(78)	-753(85)
Prolongation	9	+3	+243(370)	+637(385)	+564(495)	+172(78)	+286(92)
Prolongation	12	-3	+37(380)	-25(398)	-57(502)	+29(78)	+15(85)
Prolongation	13	-3	-85(380)	-66(398)	-40(503)	+48(78)	+156(85)
Prolongation	19	-3	-53(190)	-46(232)	-55(285)	+11(78)	-51(90)
Prolongation	20	-8	+239(180)	+294(230)	+365(282)	+63(78)	+231(90)

1. Prior to the application of preheat (reading taken at room temperature)
2. After the vessel reaches the specified preheat range but before any welding started
3. After all welding was completed but prior to the post weld heat treatment
4. After the post-weld heat treatment but before cooling to room temperature
5. After the weld repair temperature was at ambient temperature for a minimum of two hours but before removal of bracing and restraints
6. After removal of all bracing and restraints

TABLE 4

RESIDUAL STRESS MEASUREMENTS

(Preliminary)

Gage Number	Orientation of Stress	Vessel (ksi	Prolongation (ksi)
3 *	Axial	-22.9	-7.8
4 *	Circum	-31.8	+34.1
5 #	Axial		-22.6
7 *	Axial	-31.6	NA
8 *	Circum	15.1	25.1
9 #	Axial		8.6
12 *	Axial		1.0
13 *	Circum		5.0
19 #	Axial		-1.5
20 #	Axial		6.9

* $\sigma_A = \frac{E}{1-\mu^2} (\varepsilon_A + \mu\varepsilon_c)$ # $\sigma A = \varepsilon AE$

$\sigma_c = \frac{E}{1-\mu^2} (\varepsilon_c + \mu\varepsilon_A)$

See Figure 12 for Location and Orientation of Strain Gages

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4. American Welding Society Welding Handbook, Sixth Edition, Section 3A, Edited by Stanley T. Walter, pages 43.10 and 42.56, 1970.

5. The American Society of Mechanical Engineers, Section II - Material Specifications, Part C - Welding Rods, Electrodes and Filler Metals, ASME Boiler and Pressure Vessel Code, (New York: American Society of Mechanical Engineers, July 1974).

6. Welding Specification Number W-HB 100, Low Hydrogen Electrode Manual Shielded Metal - Arc Welding for "Half-Bead" Repair Welding, Union Carbide Corporation-Nuclear Division, Oak Ridge, Tennessee 1975 (unpublished).