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CALANDRIA CORE
WELD JOINT DEVELOPMENT

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ATOMICS INTERNATIONAL
A DIVISION OF NORTH AMERICAN AVIATION, INC.

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CALANDRIA CORE
WELD JOINT DEVELOPMENT

By

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CONTENTS

TABLES

FIGURES

ABSTRACT

With the advent of the large SGR suspended reactor with a calandria core containing a lattice work of process channels, it has become necessary to study and design methods for the installation, maintenance or replacement of the process channels. Thus, with regard to welded joints and machine parting characteristics, a development program was initiated to determine joint configuration and replacement processes. The design and initial test of cutting and welding equipment developed to remotely cut and re-weld the bottom process tube joint are discussed in this report. The equipment to remotely cut and weld the upper process tube joint is in the process of manufacture and will be covered in a subsequent report.

I. INTRODUCTION

The current reactor structure design concept for large sodium graphite reactors (SGR) is considerably different from that of the canned moderator core design utilized in the Sodium Reactor Experiment (SRE) and the Hallam Nuclear Power Facility (HNPF). The concept for these large, high performance SGR reactors* embodies a top supported calandria type core structure in which the graphite is contained. Stainless steel process channels penetrate the calandria heads to provide coolant paths through the core. Within the process channels are located the fuel and control elements. The calandria core permits operation at high sodium temperatures (1150°F - 1200°F) and high core power density, improving neutron economy over the canned moderator designs of the SRE and HNPF. The reactor structure and a simplified process channel are shown in Figure 1 and 2.

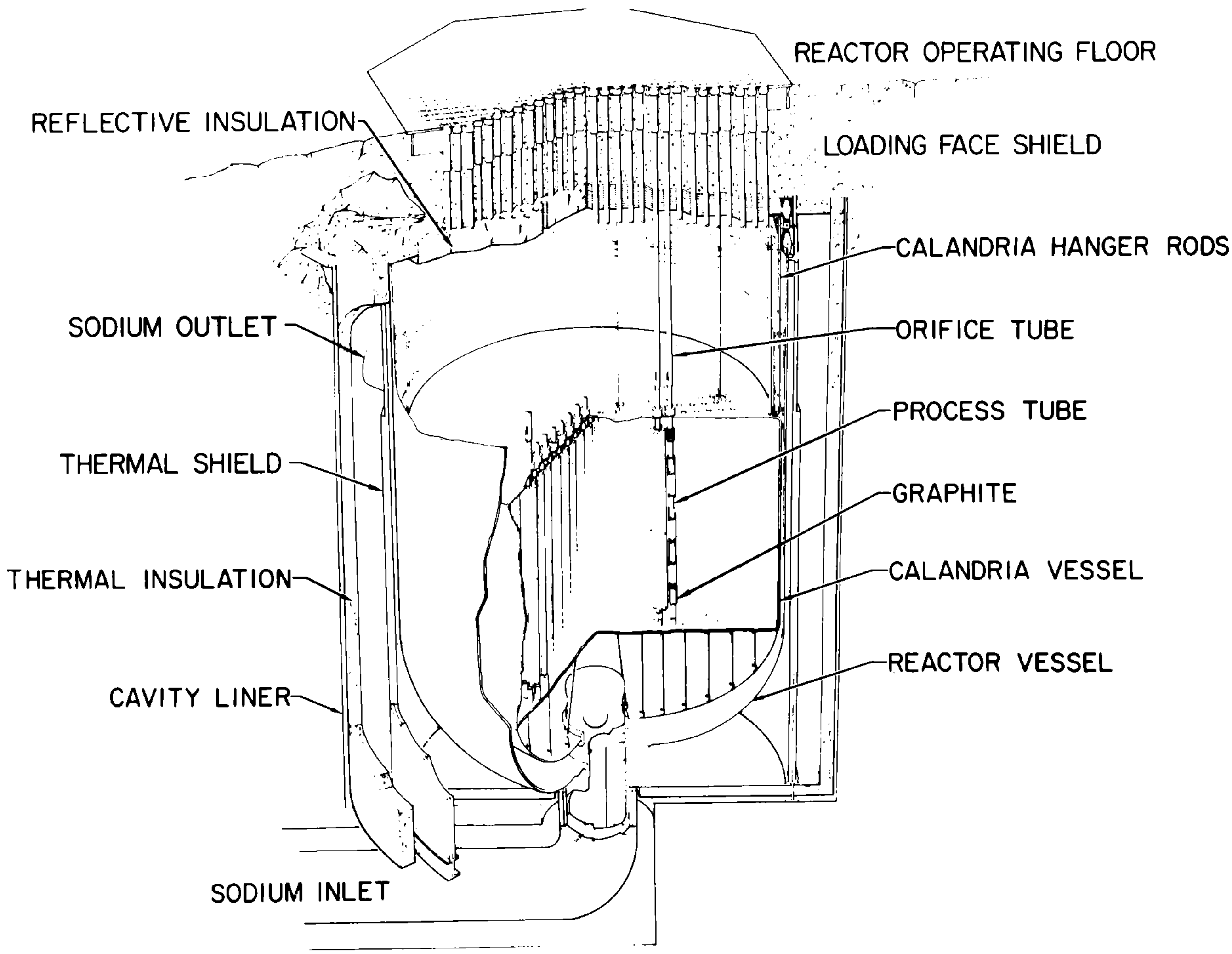

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Figure 1. Reactor Structure

*AI Staff, "1000 Mwe SGR and Prototype Evaluation Study," Vol I, and Vol II, NAA-SR-9213, (1963)

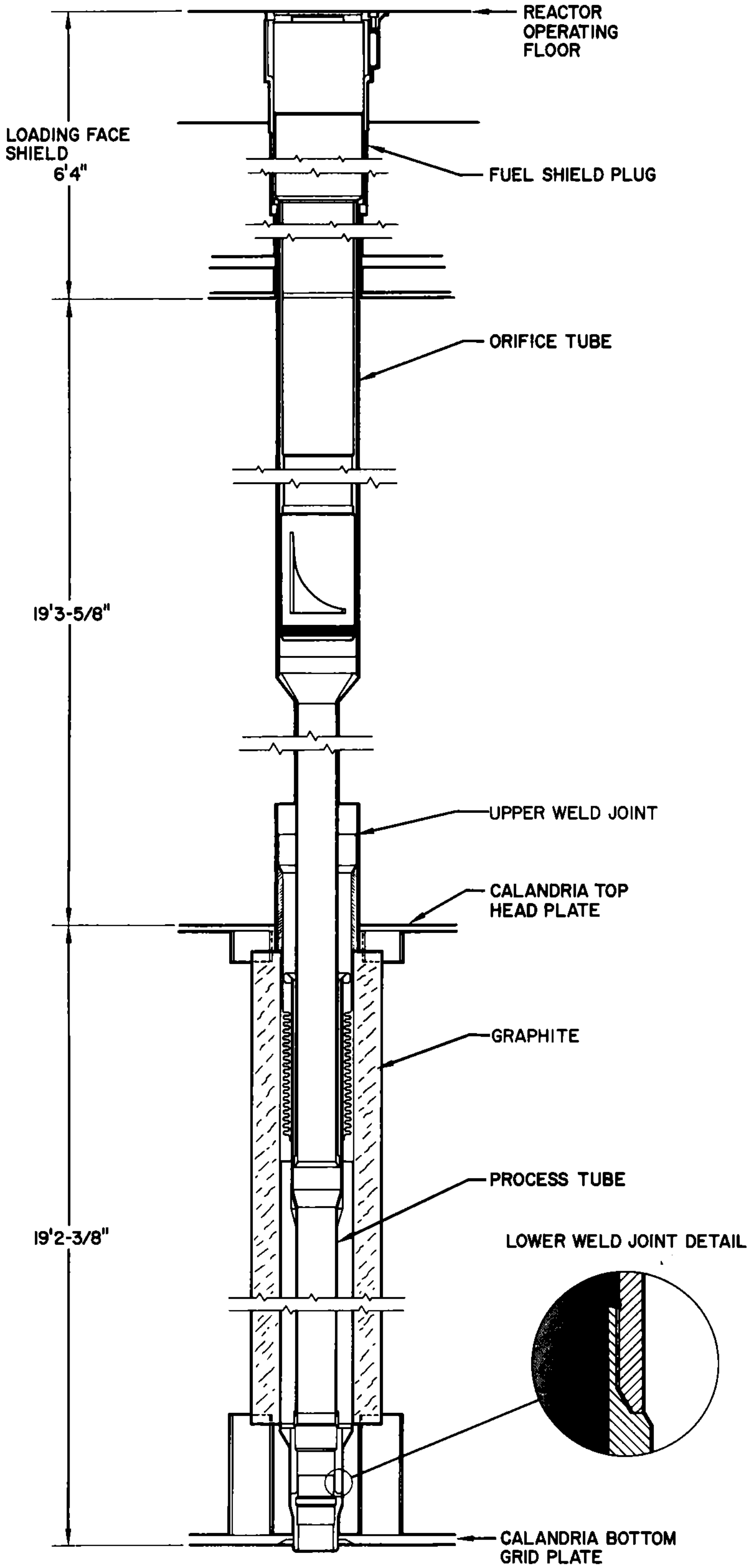

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Figure 2. Simplified Process Channel

Because the calandria is a large vessel (18.5 ft diameter by 24.5 ft high), removal and replacement of the entire vessel for maintenance is impractical. Therefore, design features must be incorporated in advance, to facilitate repair of the calandria in place. The calandria shell and grid plates are designed for 30-yr operation with no expectation of failure. Components comprising this section of the structure are designed on an ultra conservative basis, similar to other reactor structure components that are categorized as nonreplaceable after reactor operation. The large SGR concept can afford this conservative approach because of low operating pressures, resulting in reasonable metal thicknesses. Design of the process tube in the calandria is an economic compromise between the objective of minimizing neutron poison in the active core region and providing a reasonably safe design for 30-yr operation. Due to this compromise, there is a small but finite probability of process tube failure. The calandria design provides for remote removal and replacement of process tubes and associated graphite logs. In addition, special features for detecting and locating a leak and for minimizing the extent of damage to the graphite have been incorporated.

The objective of the work described herein is to develop equipment and techniques to maintain the thin wall process tube assemblies* by remote welding and machining operations. Process tube replacements must be made in a reactor which has been shut down following a period of extended operation. After shutdown, the fuel is removed from the core and the sodium coolant drained from the reactor vessel. The entire reactor structure is held at the preheat temperature of 350°F by means of electrical heaters. An inert helium atmosphere of 1/4 psig is maintained in the reactor and calandria vessels. The process channel and area of machining and rewelding will be exposed to gamma flux radiation in the range of 2,000 to 10,000 roentgens/hour, which corresponds to approximately 1 year to 30 year reactor operation, respectively. Welding and machining operations must be accomplished from the reactor operating floor, requiring a reach of over 45 ft to the lower process tube replacement joint. After the reactor is made ready for a process tube replacement, the process channel is parted at top and bottom and then removed. The new process channel is subsequently inserted, positioned, welded at the top and bottom, and helium leak checked.

*Type 304 stainless steel tubing, 4.0 in. OD, 0.025 in. wall thickness, and approximately 19 ft long.

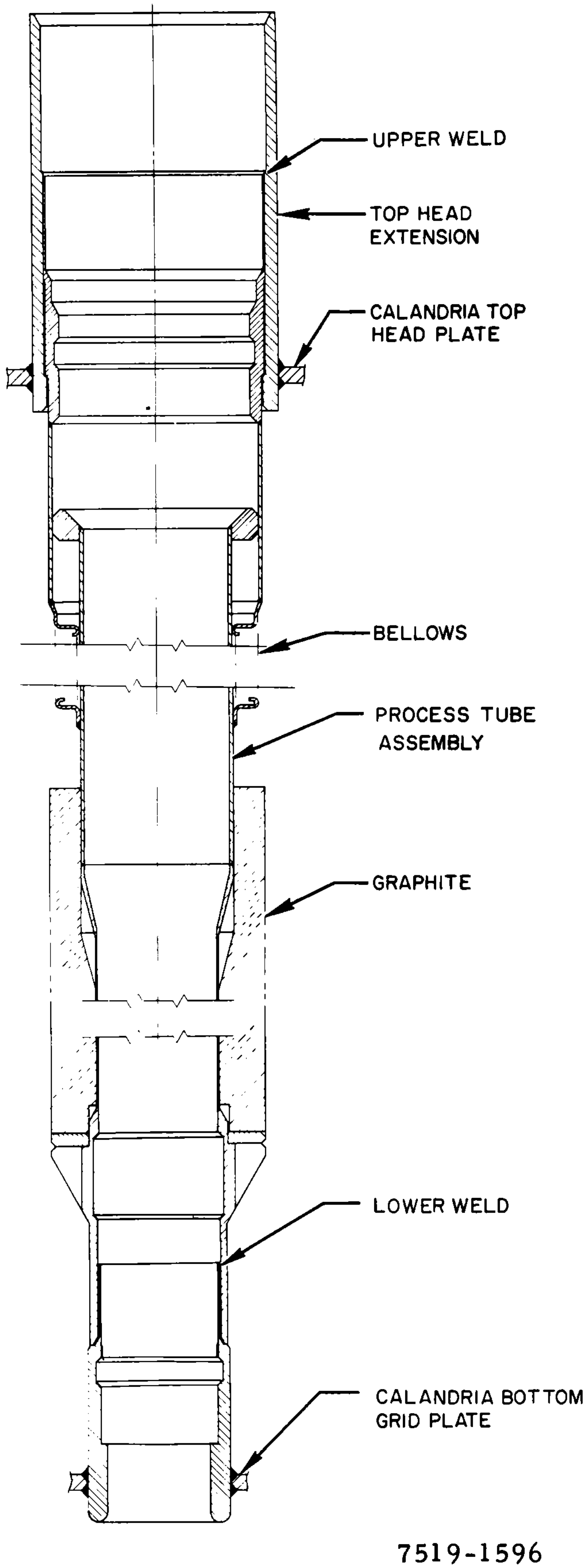

Figure 3. Typical Process Tube Assembly

The weld joint design selected for development is a slip type lap joint incorporating a burn down weld and is shown in Figure 3. Replacement parting and welding must be accomplished from the inside of the process tube. All foreign material, such as graphite and chips from machining, must be removed from the reactor, to keep the sodium system free of contamination. The reweld bead must be free of contamination by sodium, graphite, or other foreign matter and must conform with the requirements of Section VIII of the ASME boiler and Pressure Vessel Code.

Initial studies of welding processes indicated that the inert-gas-shielded-tungsten-arc welding process would be most adaptable. The tungsten-arc welding process can be made an automatic process since it is only necessary to maintain the arc, weld speed and the welding current.

A study of machining processes indicated that a saw type slitting process with self contained drive devices would be most adaptable. The slitting method reduces the amount of metal to be removed and the necessary power requirements. Further, the slitting operation would require only two motions, (1) feeding of the cutter into the work piece and (2) 360° minimum rotation of the cutter.

This report describes the lower slip type lap joint developed for the process tube,the machining device capable of making the parting cuts for process channel removal, the welding equipment capable of making burn down welds internally, and the welding process which has been developed.

II. PROCESS TUBE JOINT

Due to remote welding and machining requirements, the weld joint (Figure 3), was designed around a burn down lap-type weld, thus eliminating the use of filler wire and a wire feed mechanism. This also eliminates the necessity of preparing a beveled joint or the complete parting of a heavy wall tube.

Due to alignment and replacability of the process tube, it becomes advisable to use an overlap slip joint. The slip fit of the process tube to the upper and lower plate tube extension is held dimensionally within five mils. Thirty degree lead angles are provided to align the process tube during the positioning of a new process tube.

As designed, the upper and lower joint will allow five replacements of the process tube. Additional replacement cycles could be provided if deemed necessary. The lower joint is parted by cutting 3/8 in. below the weld; the weld nugget stays with the faulty process tube and is removed with the tube. The weld nugget in the upper joint must be removed completely by machining, to allow pulling of the process tube through the upper calandria top plate extension.

A locating groove for the lower weld joint is located approximately 1-1/2 in. above the weld nugget. This groove provides clamping surface for toggle paws on the welding and machining head. The groove is also used to accept handling tools for raising faulty process tubes, and in lowering new process tubes into position. Below the weld nugget is a fuel element holddown latch groove and a support ledge. The support ledge is also used to control the weld and parting dimensions in relation to the calandria bottom grid plate tube extension.

The upper weld joint is located on a bevel in the calandria top grid plate tube extension. The upper joint has a handling groove to facilitate removing and replacing the process tube.

III. APPARATUS AND EQUIPMENT

For the process tube replacement operation, nine pieces of equipment in two categories are required. These catagories are; (a) the machining equipment which includes machining head, positioner, test stand, electrical control station, and contaminate container, and (b) the welding equipment which includes welding head, positioner, test stand, weld programmer and power supply. The weld programmer and power supply are purchased to special order. All other items are peculiar to the application and are of special design.

A. MACHINING EQUIPMENT

1. Machining Head

The machining head and components (Figure 4) have been designed to meet the specifications outlined in Section II. The cutter motor is an air operated type with offset head, manufactured by Aro Corporation. The motor number is EP2623-64-L1A, "000" series with speed reduction (112.5:1 total) gear heads; output speed is 150 rpm. The motor is operated by helium, rather than air, at 120 psi for use in the helium atmosphere of the reactor. The cutter is 1-1/4in. diameter, 1/2 in. diameter hole, 1/16 in. wide and has 20 teeth with side chip clearance. The cutter is made of high speed steel with TT treatment for additional surface hardness. The motor is mounted and secured with 4 bolts to the dovetail slide assembly. High temperature flexible hose with stainless steel braid is used to conduct helium to the cutter motor. This hose must be capable of one rotation of wrap about drive shaft.

The male dovetail slide is actuated for plunge of cutter into the process channel wall by a cam roller and eccentric way in drive shaft. The cutter is rotated one revolution by the drive shaft, turning the complete assembly made up of internal sleeve, retaining coller, female dovetail assembly, cam roller, dovetail cutter motor mount, cutter motor and locating spacer.

The feed motor chosen was a Globe Model No. 102A328 and varies from a standard model in that it has a special output shaft and planetary gear reduction of 6452:1. The motor is reversible with an output speed of 0.95 to 1.05 rpm at 27 vdc and normal rated load. Normal rated load is 260 to 430 in. lb. Output speed is approximately 0.25 rpm at 6.8 vdc at 260 in. lb. torque. The feed

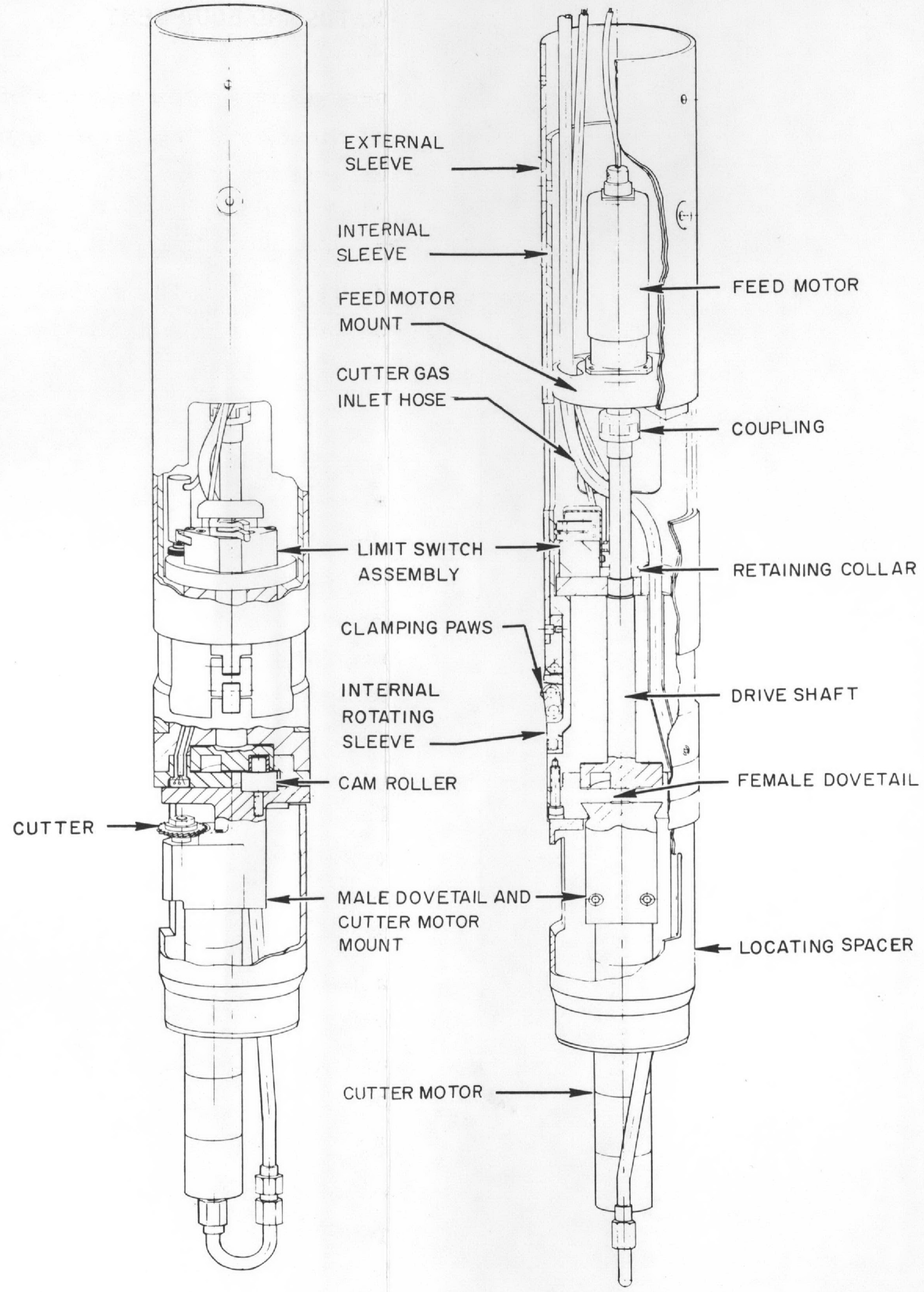

Figure 4. Machining Head Assembly

motor is supplied from a 24 vdc control station. The feed motor rotates the drive shaft by means of a coupling.

Vertical positioning of the machining head is accomplished by positioning equipment and locating spacer, as shown in Figure 5. Positioning of machining head concentrically and rigid clamping to the process channel uses 3 clamping paws which, when actuated, exert force on the inside wall of the channel thus centering the machining device. The clamping paws are actuated by sliding the external sleeve linearly along the stationary internal sleeve. The machining head assembly is adapted and mounted to long reach positioning tubes and positioning equipment (Figure 5).

2. Positioner

The positioning device illustrated in Figure 5 locates radially to a simulated mockup and is attached to the machine head assembly; the long reach tubes are adjusted vertically with screws and lock nuts. With the machining unit and positioner in the process channel, the vertical adjustment is accomplished by rotating a hand wheel thus positioning the locating spacer on the contaminate bucket and support ledge of the process channel. The machining unit is then raised 0.125 in. and clamping paws are actuated by a hand operated lever. Excess hose and cable are coiled in the reservoir, with electrical fittings and hose connections for external hook up to the electrical control station and helium source mounted in the wall of the reservoir. The complete unit with machine head, long reach tubes and positioner is raised and lowered by means of an overhead crane hooked to an eye bolt mounted to the reservoir.

3. Shop Test Stand

The tripod pipe pedestal was designed to accommodate the simulated lower process channel joint, and to match upper mounting conditions on a four channel mockup test. The simulated process channel joint is located and clamped to the lower shelf, with upper mounting surface locating and retaining both positioner and machine head. The stand is capable of being secured to the floor, as it was designed to provide a short reach test of approximately 36 inches.

4. Electrical Control Station

An electrical control station (Figure 6) was designed to sequence the machine head through the process channel cutoff operation. This control station

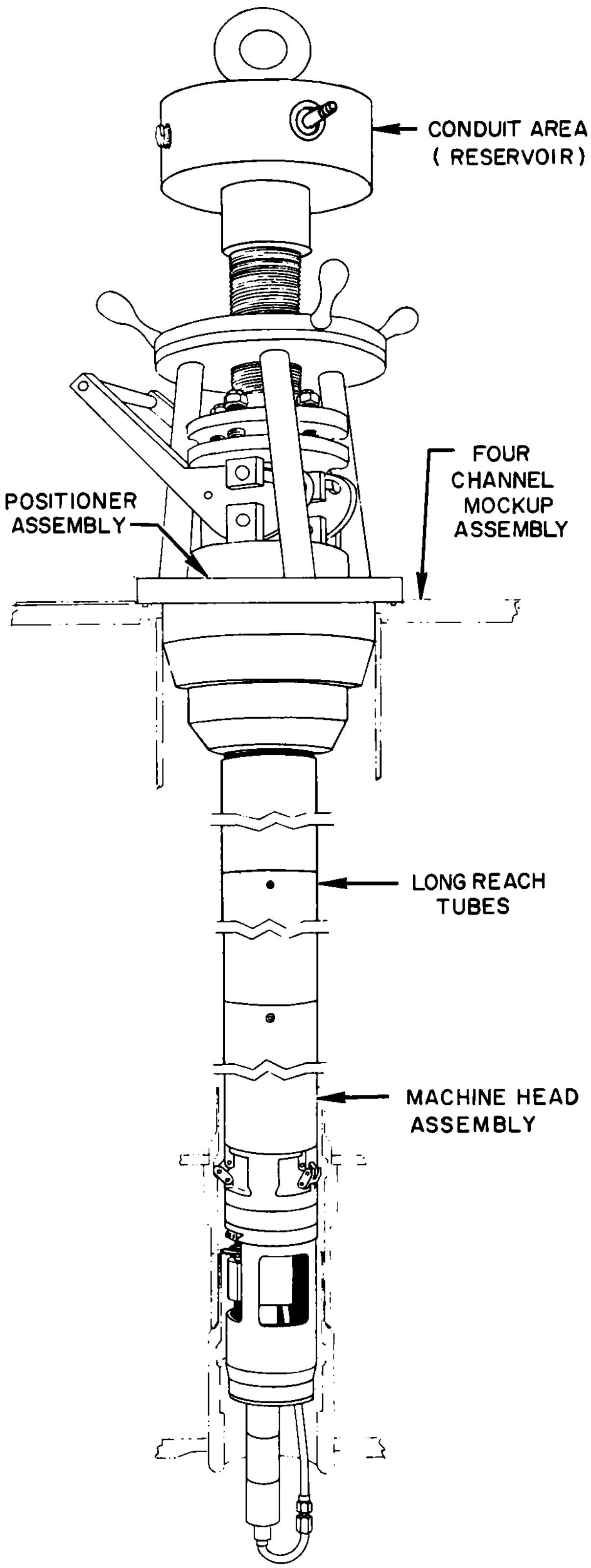

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Figure 5. Machine Head Positioner Assembly

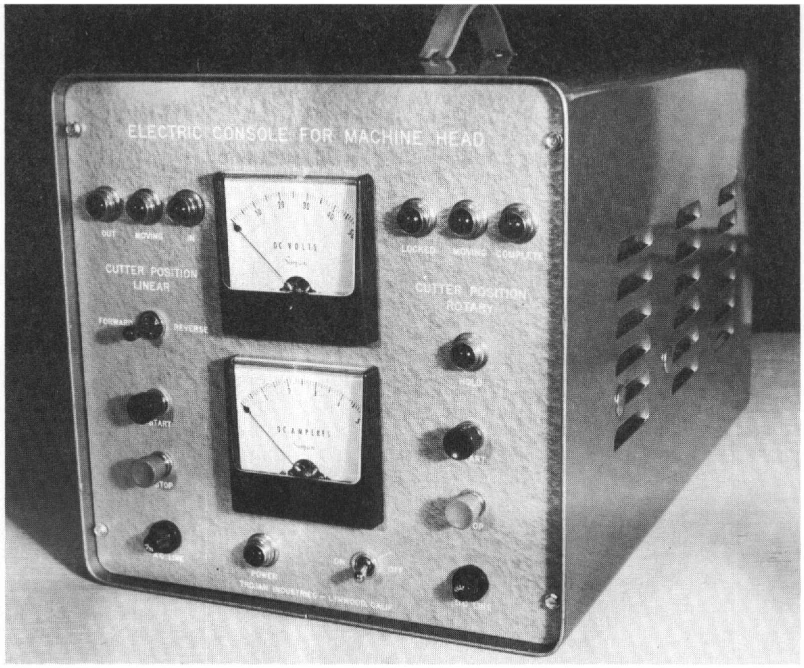

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Figure 6. Machining Head Control Station

is equipped with suitable transformer-rectifier circuitry to provide conversion from 115 v, 60 cycle, single phase to approximately 6.8 and 27 v direct current. Both voltages are individually adjustable by variable transformers, through access plugs in the side of the cabinet. One variable transformer will cause the feed motor to produce approximately 4 in./min, for moving the cutter into the work piece, and the other will cause the machine head to rotate for parting at approximately 1-7/8 in./min. Four limit switch assemblies are used in the machine head to guide the drive motor sequence. Control relay coils and pilot lights are driven from a basic control circuit transformer with an output of 12 v ac 60 cycle single phase. Fuses are provided to prevent overload of the circuitry. An ON-OFF switch and pilot light are provided for an on-off system. Forward and reverse switches allows reversing to a start position. Start buttons are pushed to plunge and rotate the cutter through the cutoff sequence. Stop buttons are pushed to stop rotation of the machine head, or for emergency stops. A dc voltmeter is mounted on the control station face to serve as a constant check of voltage output. A dc ammeter is used to show motor current load thus indicating parting conditions.

The control station is a portable cabinet with a 6 ft cable and plug for 110 v ac power source, and has 12 ft of cable with connector for hookup to the positioner.

5. Contaminate Bucket

For chip and foreign material removal, a contaminate bucket was designed to rest on the fuel element support ledge located in the grid plate tube extension. Above this step, an additional step is provided in the bucket for locating the machine head spacer. This bucket has a handling groove for insertion into and removal from the process tube. A thin wall upper sleeve with 0.010 in. slots is used to hug the inside diameter of the bottom extension. This contaminate bucket remains in the reactor through the complete channel replacement process.

B. WELDING EQUIPMENT

1. Welding Head

The welding head shown in Figure 7 has been designed to meet the specifications outlined (Section II). The electrode holder is a LINDE "gas lens", LINDE electrode collet and LINDE ceramic gas cup adapted to a insulating sleeve assembly. This assembly is held in a retaining sleeve mounted inside an internal drive housing retained with a clamping collar. Bolted to the drive housing is a locating spacer used to position the weld head in the process channel and bottom tube extension. Therefore, during a welding operation the rotating members are the electrode holder, retaining sleeve, clamping collar, drive housing and locating spacer. This rotating assembly is precision fit. The rotating assembly is contained in a stationery housing and retaining collar.

The internal drive housing has an internal gear driven by a drive shaft with integral pinion gear retained in a stationary housing. The drive shaft is connected to the drive motor by a coupling.

The welding head drive must provide a variable and closely regulated means for uniform arc travel speed. The arc travel speed is determined by the type and the thickness of the material welded. The drive motor chosen is a Globe planetary gear reduced, dc motor, Model No. 5A523-1, 3 rpm output, 3382:1 gear ratio. The speed control is incorporated in the weld programmer and power supply. The speed control unit is coordinated to the weld programmer,

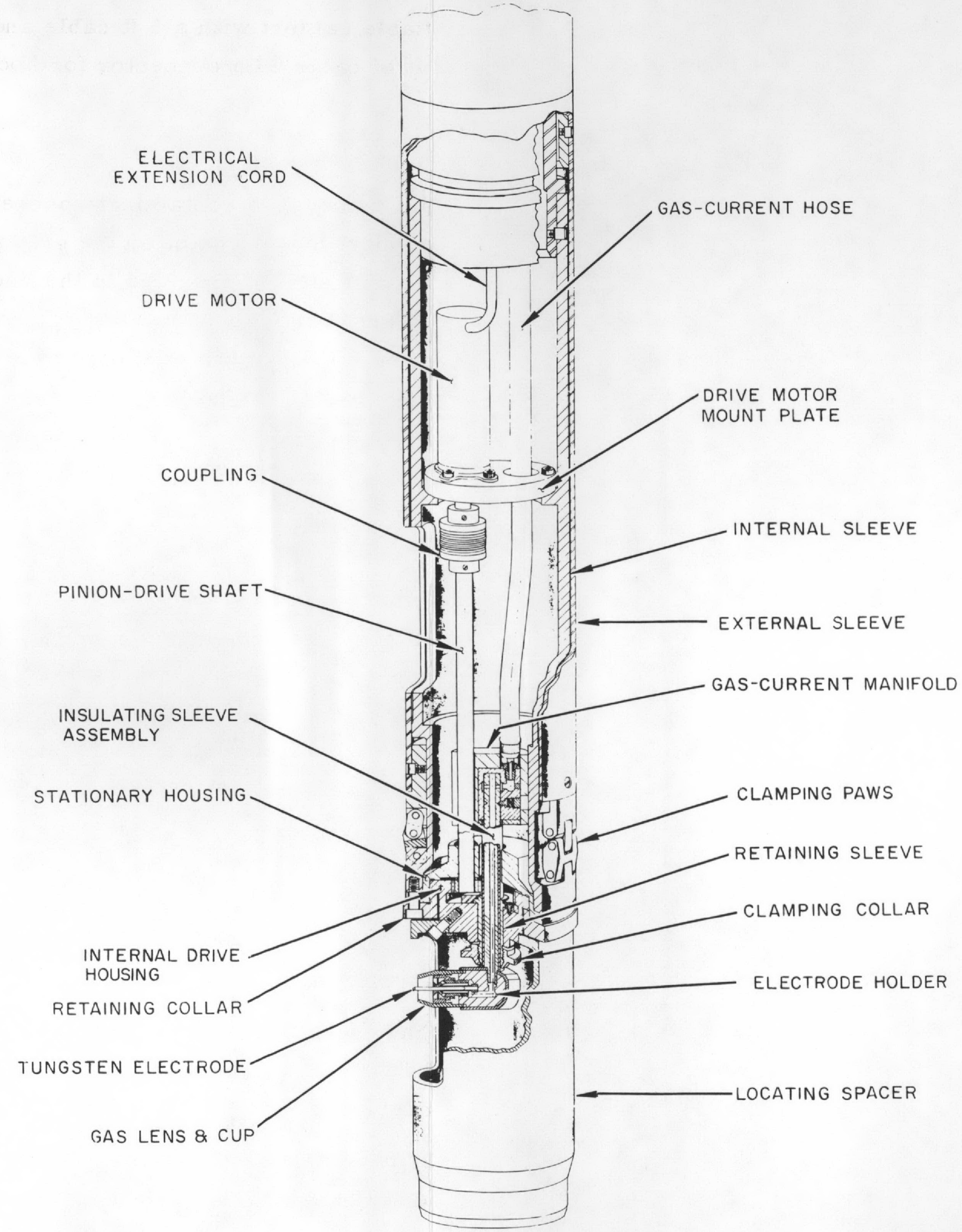

Figure 7. Welding Head Assembly

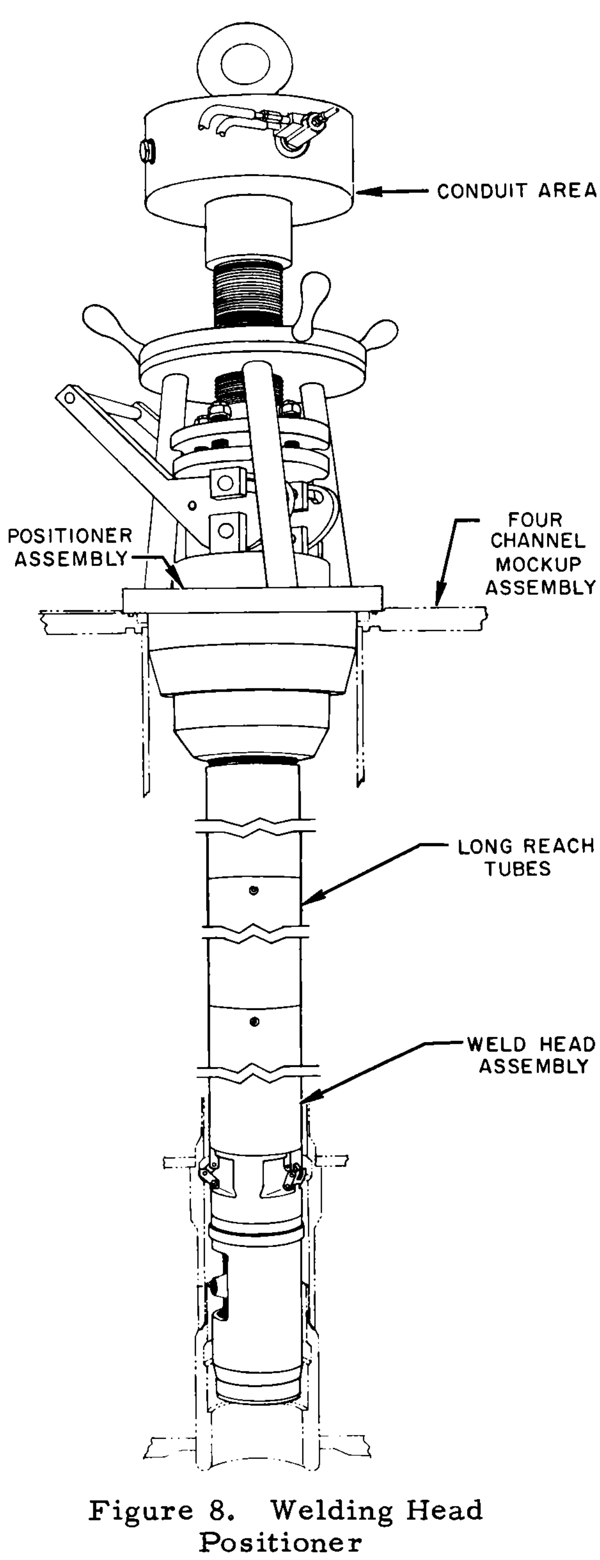

Figure 8. Welding Head Positioner

to control the weld head travel portion of the weld cycle. The drive motor is energized by the sequence controls and rotates the weld electrode at the predetermined regulated speed.

The equipment discussed thus far is necessary to position and rotate the weld head for internal welding requirements. In addition, tube clamping paws, identical to the clamping paws used in the machine head equipment, are pinned to the movable external sleeve, the stationary internal sleeve and the motor mounting plate. The clamping paws are actuated by the positioner assembly (Figure 8) and accurately align the weld head concentrically within the process channel.

The tungsten electrode holder is designed to carry current and internal purge gas, as well as holding the tungsten electrode. The holder consists of an adapter for gas lens, cup and collet, and includes internal gas purge hole, plus a round hard copper rod having an axially drilled hole. Approximately 1-3/4 in. of the upper end of the copper rod is a round polished surface to accept the gas-current manifold. The electrode holding collet accepts a 1/16 in. diameter tungsten electrode which is replaceable by loosening and tightening of the gas lens as required. Thus, the electrode holder is a copper assembly, insulated for current and high temperature resistance, providing inert gas and welding current to the preset electrode.

The manifold conducts the current and the inert gas from a current cable and gas supply to the electrode holder, and is made from hard copper. The gas-current manifold is a slip-fit on the polished, noninsulated end of the electrode holder. It is easily removed or replaced on the electrode holder and remains semi-stationary as the electrode holder rotates during the weld cycle.

The weld head is a totally contained unit which accepts any length extension tubes and is retained to these tubes by shoulder screws; it requires only a three conductor electrical extension cable and gas-current conducting hose extension. The unit is 3-3/4 in. in diameter and approximately 28 in. long.

2. Positioner

The positioning equipment (Figure 8), is identical to the device as defined for the machining operation, with the exception of a 3-pin hermetically sealed electrical connector and through connection for current-gas manifold, as required for the weld function. The current-gas manifold is attached and sealed to the reservoir teflon seals and lock nut; it also accepts and returns coolant from the weld power supply.

3. Test Stand

A test stand of the same type as defined previously in machining apparatus, is required for the weld test.

4. Weld Programmer and Power Supply

The weld power package chosen for this welding process was a PAKCO welding system WP400 SC consisting of a Vickers solid state weld programmer, a PAKCO sequencer with a remote control station, and a Hydromount recirculating coolant system. This unit was also designed to meet Atomics International specifications.

This power package features direct reading instrument dials, has no interaction between controls, and provides repeatability of the weld cycle and continuous control of the welding current over the full current range. Power package components are placed in cabinets and mounted on one common base (a Hydromount on wheels), thus, the complete unit is readily transportable.

The weld programmer permits presetting a programming of three sequence levels of welding currents; i.e., upslope current, weld current (which can be controlled remotely), and downslope current, together with the presetting of time periods required to gradually change at a linear rate from one current level to another. The programmer has a high frequency start circuit, including separate time and current controls for arc starting, with critical control of the amplitude and duration of current over-shoot. Depressing the programmer START button initiates the weld cycle. After the cycle is completed, the programmer resets automatically to a ready-start position.

The PAKCO-built sequencer provides preset automatic timing for the complete weld cycle. This includes settings in seconds for gas prepurge, initial weld current, preheat, upslope, weld current, delay for weld head travel, downslope, sequence delay, postheat current, and postpurge. This sequence timing resets for exact repetition.

IV. EXPERIMENTAL PROCEDURES

Areas of experimental activity covered the simulated test joint, the techniques of using the deep hole machining head and deep hole welding head, and methods used to determine quality of the welds. Each item is discussed in detail in the following sections.

A. THE SIMULATED TEST JOINT

Due to the smaller diameter and the longer reach requirements of the lower weld joint, it was determined that first considerations should be given to the lower weld and cutoff area. The lower test joint was simulated using a calandria bottom grid plate tube extension and simulated process tube (Figure 9). The

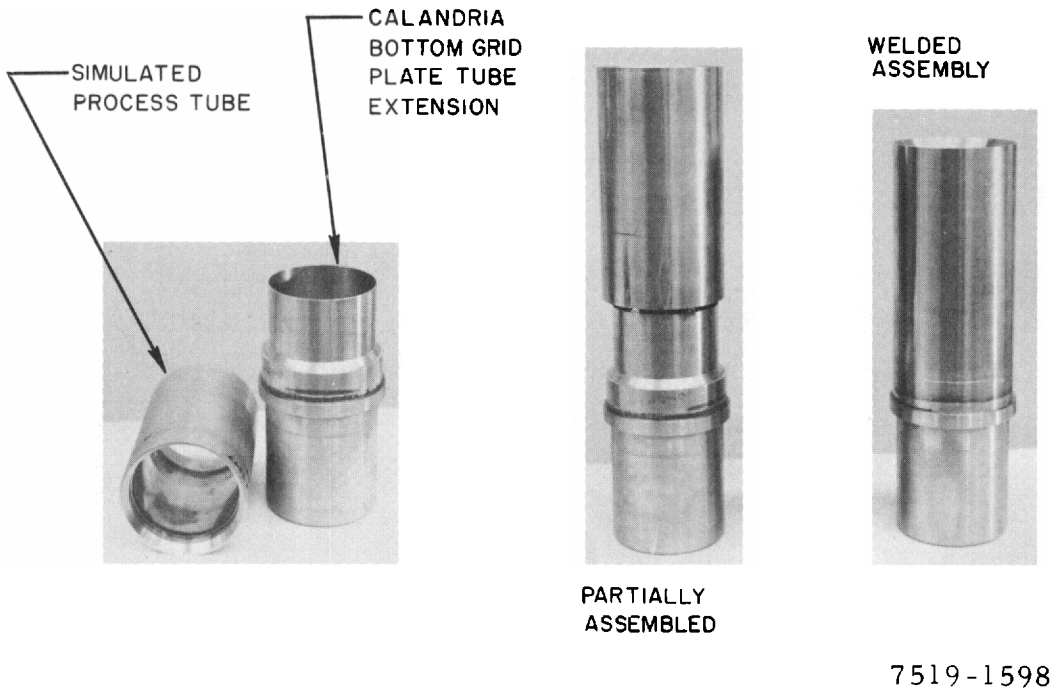

Figure 9. Typical Specimens Used for Welding Tests

bottom grid plate tube extension has a thin wall (0.040 in.) extending up 3-1/2 in. This length allows for five replacements with the cutting and welding equipment moving 3/8 in. down in the process channel for each replacement. For test purposes, the bottom grid plate tube extension will be used with five simulated process tubes. The simulated tube used is approximately 8 in. long.

The material for the test joint is stainless steel, ASTM A-269-61 Type 304.

B. TECHNIQUES OF USING THE DEEP HOLE MACHINING HEAD

The semi-self contained machining unit was selected because of the long reach application, thus eliminating the need for long precision drive shafting for linear, plus rotating, motions and cutter power requirements. The helium operated air motor was used to deliver the necessary cutter torque requirements in the limited available space; selection of the electric drive motor was based on the need for low rpm with constant output speed. The cutter was selected for the least amount of metal removal and necessary cutter life.

Problem areas derived in proofing of the machining head and equipment were the determination of correct feeds and speeds, cutter configuration, transition of plunge of cutter into the work piece to rotation feed of the cutter, and exhaust flow of the helium from the cutter motor. With cutter motor output speed at 150 rpm, and using a 1-1/4 in. diameter cutter, the cutter surface speed is 50 in. /min. A feed rate of 1-7/8 in. /min was determined by test. Thus the average tooth load is 0.0006 in. per tooth, but due to the cutter spindle and cutter not rotating with absolute concentricity, the tooth load does vary slightly from tooth to tooth.

Cutter types tested were of 1/32, 0.040, and 1/16 in. thickness, in 20 and 28 tooth types. The 1/32 and 0.040 in. wide cutters did not have necessary chip clearance or stability to withstand side load characteristics. The 20 tooth cutter allowed for larger chip clearing area and sturdier tooth. Flat saw type cutters versus side tooth clearance cutters were also tested, resulting in a cleaner cut with little burr from the cutter with side chip clearance. The cutter chosen was 1-1/4 in. diameter, 1/16 in. thick, 1/2 in. hole, and 20 teeth with side chip clearance.

During test, difficulties were encountered in the transition of linear plunge of the cutter to feed rotation. This was resolved by adding an adjustable brake or drag, using brass plugs backed by adjustable set screws. This holds the cutter steady yet is easily overcome by the torque of the drive motor.

The exhaust gas of the cutter motor exhausts from a 1/4 in. port located in the motor shell. With exhaust flow directed to the inside wall of the contaminate bucket, additional vibration is encountered throughout the machining head, resulting in poor cutter life. By adding an exhaust deflector and directing the flow of gas up the process tube, on the side opposite of the cutter, the vibration is minimized and results in good cutter life.

In the event of cutter failure and the possibility of a broken tooth being left in the cutter groove, a new cut must be initiated, feeding the new cutter in 5/8 in. in advance of the location at which the cutter failed. When the parting cut is complete, the process channel can be pulled, with the possibility of a small projection remaining on the top edge of the bottom tube extension. By test, this extra material has not affected the weld bead.

C. TECHNIQUES OF USING THE INTERNAL WELDING HEAD AND EQUIPMENT

The tungsten-inert-gas (TIG) fusion welding process was selected because of its adaptibility to automatic equipment (Figure 10), thus reducing the possibility of human error. Furthermore, the only solution available for welding under such circumstances was by remote internal methods.

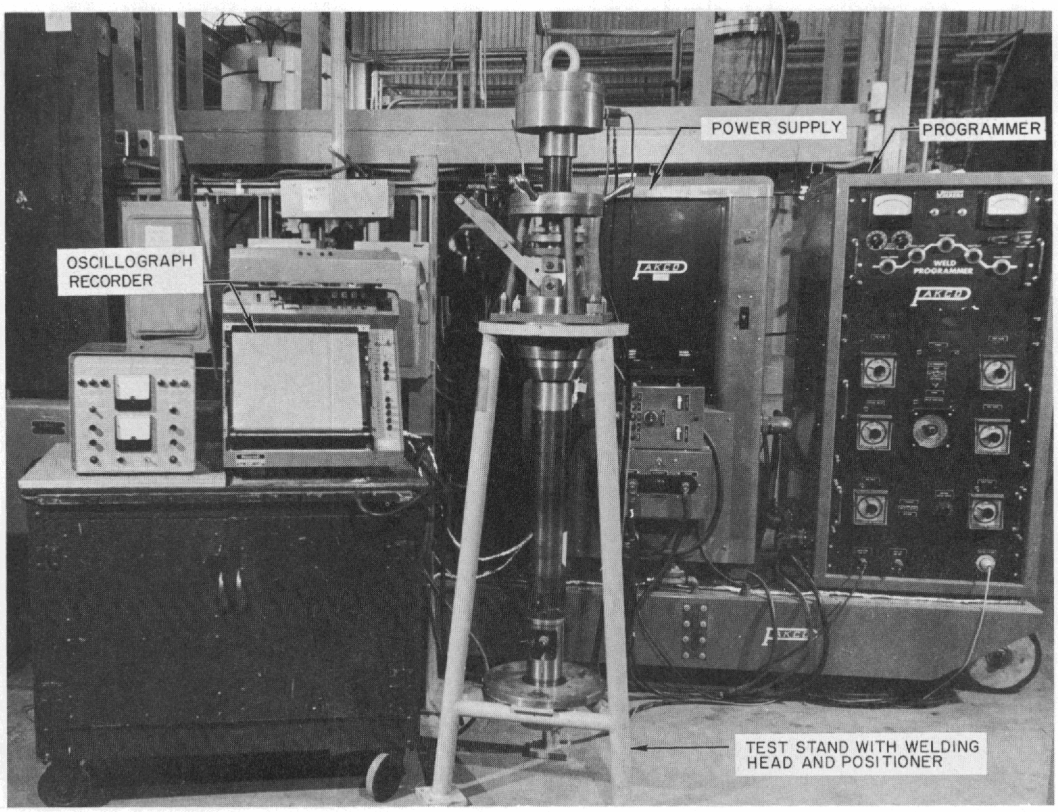

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Figure 10. Welding Test Setup with Automatic Programming Equipment

As previously mentioned, the burn down welding method, using no filler material, was required. A cutaway view of the electrode in position is shown in Figure 11. Normally, a helium-argon atmosphere is used in a TIG welding process. However, due to the existing atmosphere, a 100% helium purge was used. To set the tungsten electrode for necessary arc length, a gauge was designed to position the tungsten electrode tip a fixed distance from the collet retainer. The electrode is ground at angle of approximately 70°, to approximately 0.020 in. diameter at the tip. Composition of electrode used is 2% thoriated tungsten.

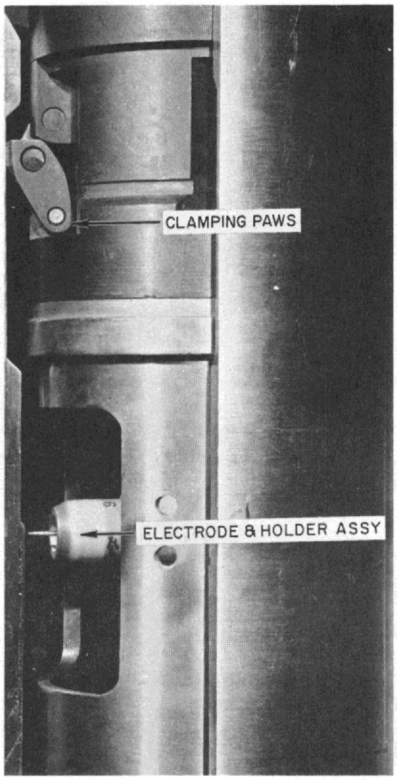

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Figure 11. Cutaway View of Welding Head in Process Tube

To establish an accurate method of determining consistent repeatability and a permanent record of each weld joint completed, a Honeywell Model 1012 Direct Recording Visicorder Oscillograph, (Figure 12) is electrically connected to the welder power supply and programmer. This recorder provides monitoring of the weld amperage, weld voltage at the electrode, and voltage at the drive motor, plus a permanent readout on paper tape. The paper tape has grid lines correlated to time, with each line indicating one second of the weld cycle. The readout tape would indicate variables that might occur during the weld cycle, thus problem areas can be related and located on the weld head in the process tube.

With the recorder reading directly with the weld programmer, the current (amperes) is followed through the weld cycle starting with a high frequency spike followed by established arc, up slope, weld current and down slope to current off. The arc voltage is recorded through open circuit, established arc, up slope, weld, down slope and open circuit. The drive motor voltage is recorded through time delayed start, motor start, weld head rotation, time delayed stop and motor off.

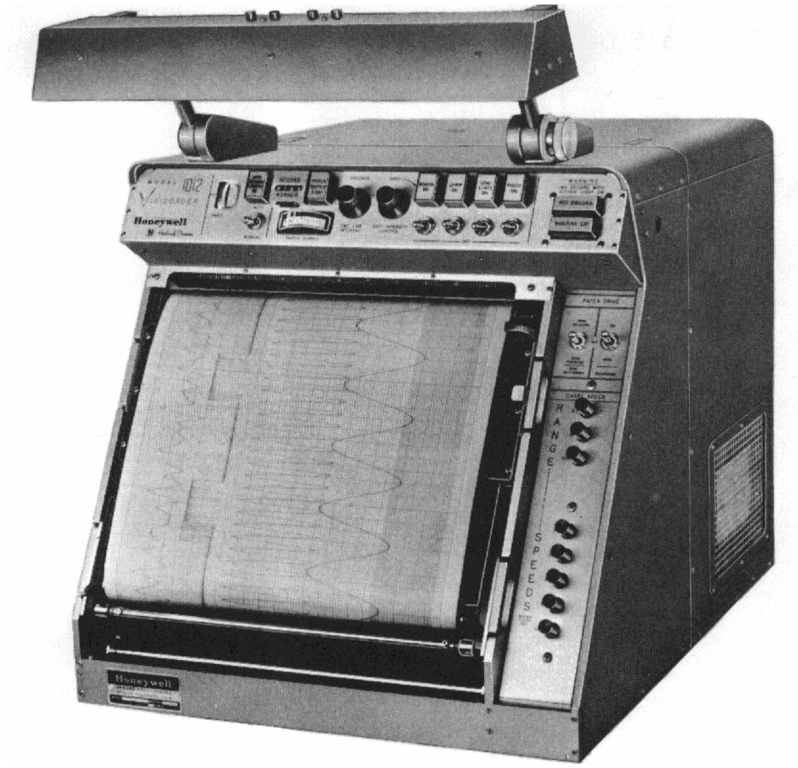

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Figure 12. Direct Recording Visicorder Oscillograph

D. METHODS USED TO DETERMINE QUALITY OF THE WELDS

The following outline illustrates the manner in which the weld samples were tested. Each procedure is discussed in greater detail in the section entitled "Test Results and Discussion".

1) Visual inspection

2) Leak check

3) Radiographic inspection

4) Cross sectioned and etched samples

5) Stress analysis

6) Chemical analysis

All weld specimens were given visual and helium leak check inspection. Spot checks were made on radiographic and cross sectioned specimens. For test purposes, contamination (graphite and sodium) was added to the weld area on specific specimens. These contaminates were added to simulate possible reactor conditions.

In the event of a weld failure, reweld passes were conducted to determine the feasibility of a repair weld. Two types of reweld passes were used, one type using the electrode at the same position as the previous pass, and another with the electrode lowered to weld-in parent metal.

V. TEST RESULTS

A. MACHINING RESULTS OF FLOOR STAND TEST

Cutoff data of the floor stand test with simulated process channel and bottom head extension was recorded (Table 1). Of the last twenty-two cutoff passes attempted, twenty were successful. The two failures were passes conducted with experimental adaptations. These failures were overcome by deflecting the flow of exhaust gas as previously mentioned in "The Techniques of Using the Machining Head."

TABLE 1

TABULATION OF RESULTS FOR MACHINE CUTOFF

Specimen No.	Cutoff	Remarks
1 thru 7	-	Preliminary proofing
8	1 pass	Cutter travel 1-1/2 in./min.
9	pass	Cutter mislocated, cut in weld
10		carbide cutter used. Insufficient output torque on cutter motor at increased speed
11	1 pass	Heavy cutter reinforcing side plates added
12	1 pass	(same cutter used on no's. 12,
13	1 pass	13, and 14)
14	1 pass	
15	2 cutters	Cutter mislocated
16	2 cutters *(11 & 1)	Cutter failure
17	2 cutters *(9 & 3)	Cutter failure
19	1 pass	Cut completed (1 tooth broken)
20	2 cutters (8 & 4)	Cutter failure
21	2 cutters (11 & 1)	Cutter failure
22	1 pass	New cutter used on each joint,
24 thru 32	1 pass	contaminate bucket not used
33	2 cutters (5-1/2 & 6-1/2)	Contaminate bucket used
34	1 pass	No contaminate bucket
35	2 cutters (10-1/2 & 1-1/2)	Contaminate bucket used
36 thru 44	1 pass	Exhaust gas deflector added

No adverse conditions arose in machining within 1/8 in. of the weld nugget. No apparent change in metal cutting characteristics were noted. A visual check of the machine cutoff area (Figures 13 and 14) showed a clean surface with a

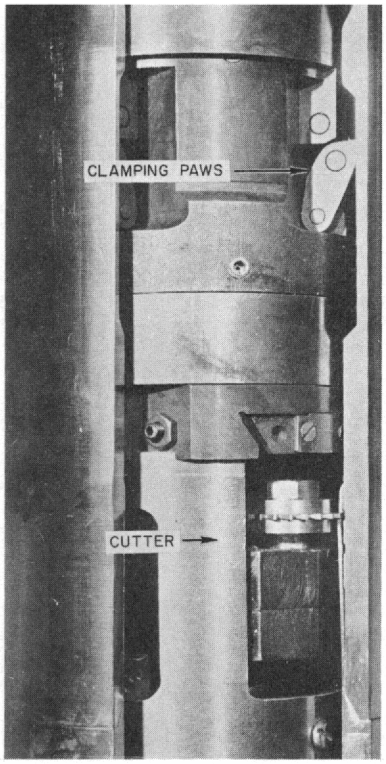

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Figure 13. Cutaway View of Cutter in Position for Parting Operation

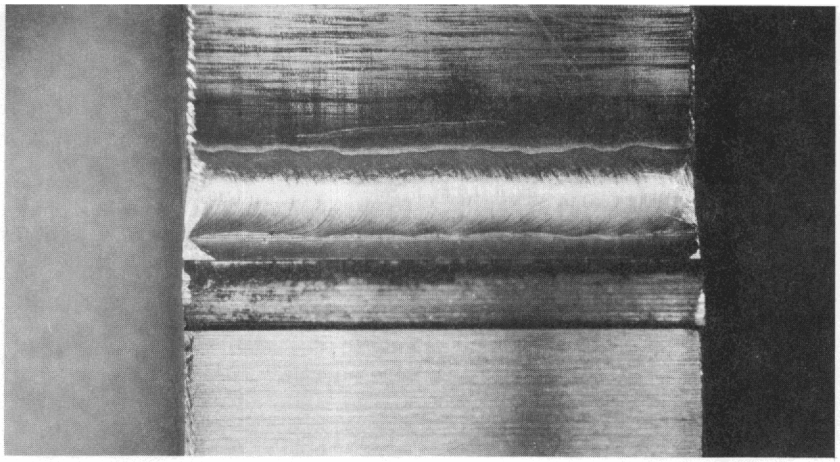
7519-47184B

Figure 14. Section Showing Typical Cut Made in Simulated Process Tube

minimum burr on the cutting edge. Of prime importance is the precise following of the machine sequence through set up and machine cycle. All required settings should be checked thoroughly prior to the start of cutoff operation. No special preparation on the cutoff edge of the bottom grid plate tube extension is required for the weld follow-up, i.e., deburring, polishing, etc.

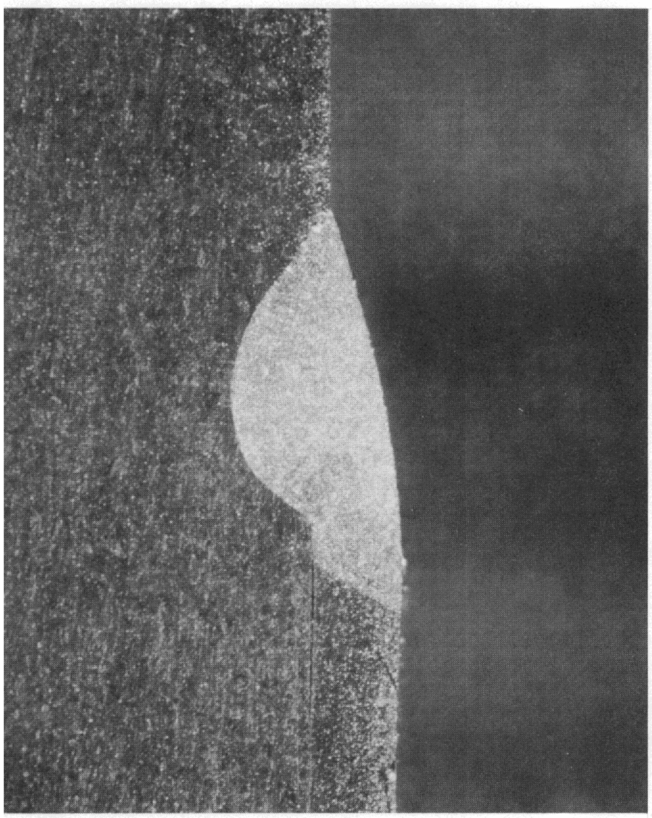
B. WELD TEST AND INSPECTION RESULTS

Visual inspection disclosed that the weld surfaces were free of harmful discontinuities, and were uniformly smooth (Figure 15). Cross-sectioning of the weld revealed good penetration and good blending of the weld bead to parent metal as shown in Figure 16. The welds were of excellent quality and met the quality requirement of Section VIII of the ASME Boiler and Pressure Vessel Code. The weld surface shows a blackened, soot type area which is typical of a 100% helium gas purged weld. This is not detrimental to the weld and does not affect the metallurgical properties of the material.



Mag: 3X 7519-15101

Figure 15. Photograph of Weld Bead

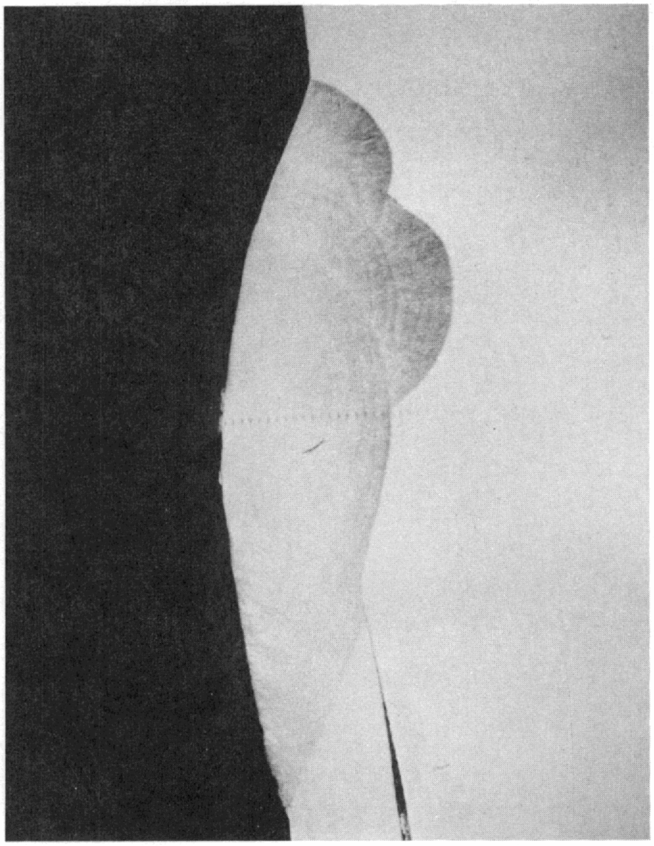


Mag: 10X 7519-15102

Figure 16. Cross-section of Typical Weld Joint

In test, the bottom grid plate tube extension was reduced approximately 0.010 in. in diameter due to weld shrinkage. During welding of the simulated replacement process tube, the weld would not hold the molten puddle due to the excess clearance. A preheat pass was used with some success, but after two rewelds the weld puddle could not be retained. A sizing operation was added to expand the tube extension thus providing a good fit for welding. The sizing provides a circumferential clearance of 0.002 to 0.005 in. between details.

In the event a helium leak tight weld joint is not accomplished with the initial pass, reweld passes may be made without adversely effecting the joint. Reweld passes which were conducted have shown no ill effects to the weld bead or its metallurgical structure. The weld surface continues to be free of irregularities or stress cracks and a cross section (Figure 17) exhibits a sound, acceptable weld.



Mag: 10X 7519-15103

Figure 17. Cross-section of Weld Joint with One Initial and Three Reweld Passes

Oscillograph recordings (Figure 18) demonstrate the repeatability of the weld cycle. These recordings provide a permanent record of each individual weld joint.

Welded joints have continually met helium leak tight requirements. The welded joints were helium leak checked by VEECO Leak Detector Model AMS 9-AB with a machine leak rate sensitivity of 1×10^{-10}; the standard leak rate is 2.5×10^{-8} cc/sec of helium.

Radiographic inspection was conducted under standard x-ray techniques. The x-ray tube was set at 90° to the weld and the film placed inside the simulated process channel, or close to the weld as possible as shown in Figure 19. Results show acceptable welds free of cracks and with no porosity or inclusions.

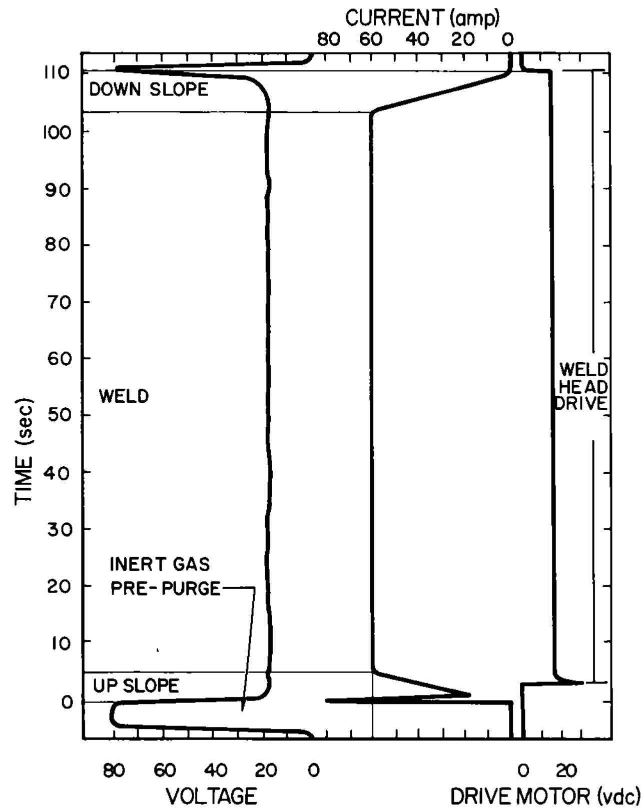
A particular lower weld joint, Serial No. 051, was evaluated for inspection and laboratory tests. One-half of this weld specimen was contaminated with graphite powder. The welding techniques used were recorded and, therefore, were correlated to the test results obtained.

The following inspection and laboratory tests were performed on the specimen,* Serial No. 051:

1) Visual

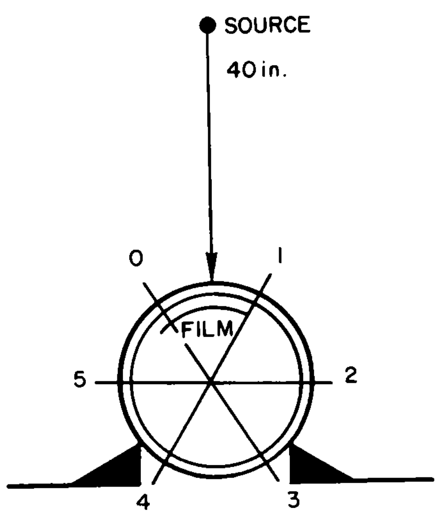
2) Leak Check

*ME 051 dated 4/23/64 by J. G. Roberts.



7519-15104

Figure 18. Typical Oscillograph Recording



7519-15105

Figure 19. Method Used in Radiographic Inspection

3) Radiographic

4) Hardness

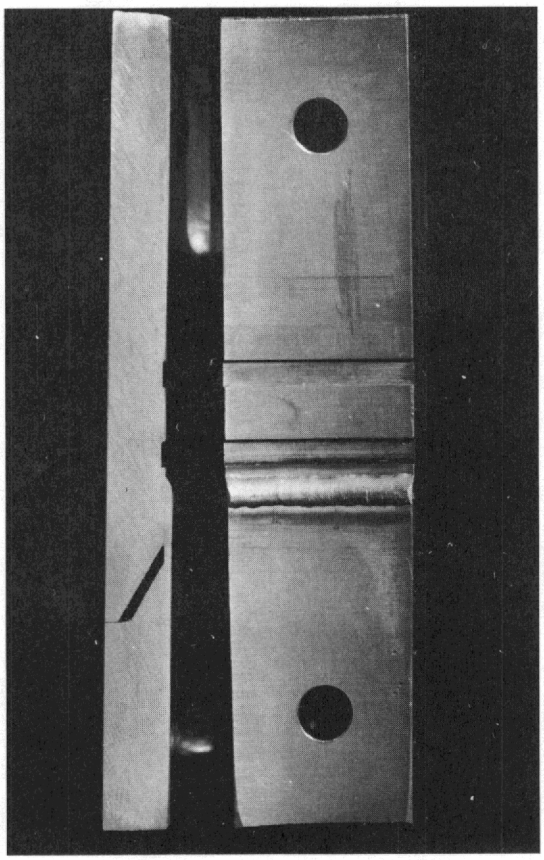
5) Tensile

6) Metallographic

7) Chemical analysis

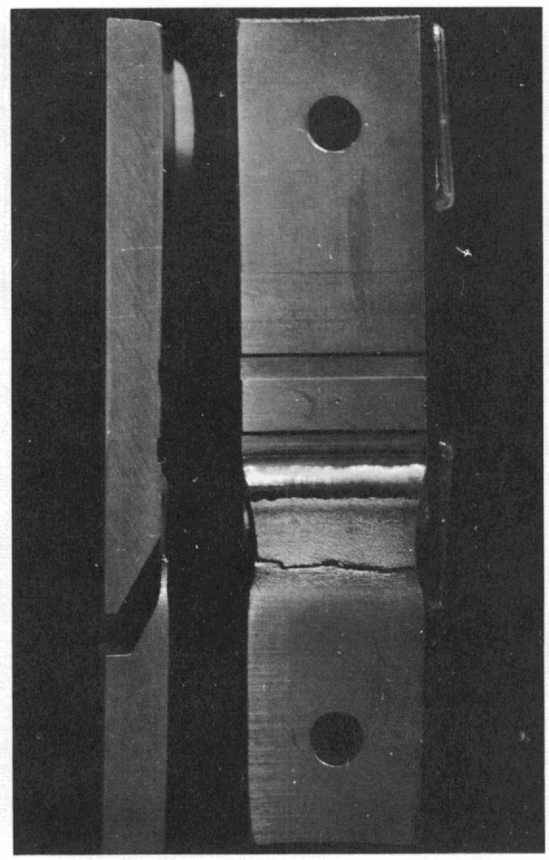
The test specimen was visually inspected and nondestructively tested (radiographic and helium leak check) prior to sectioning for metallographic hardness and tensile tests.

Visual inspection revealed the inside diameter weld surface to be uniformly smooth and free from harmful discontinuities or any concave condition. A standard helium leak check revealed no leaks. Again, a radiographic inspection was conducted under standard x-ray techniques. Results showed an acceptable weld with no porosity or inclusions and free of cracks. Figures 20 and 21 show the tensile specimens before and after testing. The samples failed in the parent metal and exhibited distinct "necking down" under tension, indicating a state of flow in the material prior to fracture. Results of room temperature tensile tests are given in Table 2.



7519-15106

Figure 20. Two Specimens Prior to Tensile Test



7519-15107

Figure 21. Same Specimens After Tensile Test

TABLE 2

TENSILE TEST RESULTS, SPECIMEN NO. 051

Spec. No.	Width (in.)	Thick (in.)	Area (in.^{2})	Yield (psi)	Ultimate Tensile (psi)	Elongation %
0	0.945	0.040	0.0378	52,910	89,815	67
1	0.913	0.040	0.0365	46,550	97,480	67

Microhardness tests were taken on two samples numbered 3 and 6. These tests were taken through the weld metal, heat affected zone and parent metal. Figure 22 is a photo of the samples; test results are given in Table 3.

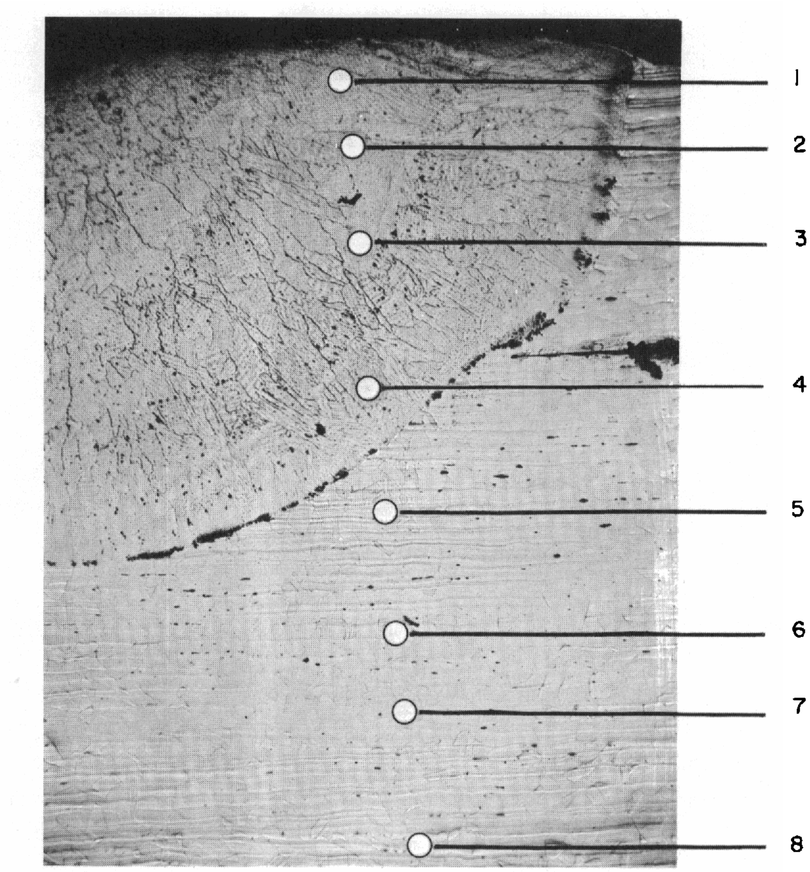


Figure 22. Enlargement of Cross Section Through Weld Indicating Indents from Microhardness Test

Cross-sectioning and metallographic examination revealed typical weld penetration with no evidence of harmful discontinuities, concave conditions, or cracks. Qualitative chemical analysis was conducted on three specimens, identified as parent metal, number 3 and number 6, with no significant difference between these specimens. Sample No. 6 was taken in graphite contaminated area and indicates no increase in carbon content. The results of a quantitative analysis conducted to determine carbon content of the samples are given in Table 4.

TABLE 3

MICROHARDNESS TEST RESULTS, SAMPLES NUMBER 3 AND 6

Sample Number	Area	Knoop Hardness Number	Rockwell "A" Scale Conversion
3	1	308	65.5
	2	382	69.5
	3	423	72.0
	4	337	67.5
	5	282	65.5
	6	222	57.5
	7	234	59.5
	8	234	59.5
6	1	337	67.0
	2	246	61.0
	3	253	61.5
	4	240	60.0
	5	188	53.5
	6	228	58.0
	7	217	57.0
	8	207	56.0

TABLE 4

CARBON CONTENT OF SAMPLE SPECIMENS

Sample Number	Weight % Carbon	
	Test (1)	Test (2)
Parent Metal	0.06	0.07
Number 3	0.06	0.06
Number 6	0.05	0.06

The inspection and laboratory tests indicated the welds to be of good quality. The graphite contamination did not affect the quality of the weld or induce adverse conditions for this joint.

VI. CONCLUSION

Equipment has been designed, built and tested to assure the maintainability and permit replacement of the thin-wall process tubes of the SGR calandria vessel. The tests to date have utilized shop floor stand equipment. Progress to date includes the following:

a) A weld joint for attaching the lower end of the process tube to the bottom head tube extension has been designed and approved for use in the calandria vessel assembly.

b) For the lower weld joint, an integrated machining head has been developed which is capable of parting an internal sleeve from an external tube, in a manner simulating the removal of a process tube from the bottom grid plate tube extension. The process involves the necessary mechanisms to provide motions for a parting operation within the 3.851 in. minimum diameter of the bottom head tube extension.

c) For the lower weld joint, an automatic device has been developed which is capable of internally completing a burn-down weld on an overlap sleeve type joint. The process involves a tungsten-inert gas-shielded arc (TIG) process. Inspection methods employed have proven the quality of weld joints to be acceptable.

Development effort is being continued to determine if the equipment is capable of meeting even more exacting conditions. Future tests will include use of the equipment in a sodium reservoir. For this test the simulated process tube joint will be welded and parted after exposure to sodium, thus investigating a sodium contaminated weld. The equipment will then be subjected to a long reach (30 ft) tower test to prove extended length and weld arc starting characteristics. Further tests will be conducted in a calandria four-channel mockup to ascertain whether the equipment operates functionally (with long reach extension) at an elevated temperature (350° F) inert atmosphere and with sodium contaminated joints.

APPENDIX A

I. PROCESS TUBE REPLACEMENT PROCEDURE

Major steps followed in replacing a process tube in a calandria vessel are outlined below. Detailed outlines of the machining and welding procedures follow.

1. Position simulated bottom head extension in test stand.
2. Add clamping collar and secure with bolts.
3. Position simulated process channel on bottom head extension.
4. Position contaminate bucket in bottom head extension.
5. Position and clamp deep hole weld head in test joint and on test stand.
6. Proceed with burn down weld at upper edge of bottom head extension and fuse to process channel per weld process No. 1057.
7. Remove weld equipment.
8. Check weld visually.
9. Helium leak check.
10. If weld is not leak tight, determine repair procedure.
11. If weld is leak tight, proceed.
12. Position and secure machining head in process tube at a point 0.375 in. below previous weld, and on test stand.
13. Initiate cutoff pass.
14. Upon completion of cutoff, raise positioning equipment, withdrawing process tube simultaneously.
15. Position new process tube and follow steps 5 through 14 for new sequence.

II. CUTOFF PROCEDURE

1. Position contaminate bucket in bottom head extension.
2. Install cutter in cutter motor.
3. Visually check machine for start position.
4. Install correct locating spacer, either A, B, C, D, or E as identified.
5. Retract clamping paws.
6. With overhead crane, lift assembly into process tube, bottoming on contaminate bucket.
7. By means of positioner hand wheel, raise machining head 0.125 in. (one rotation of hand wheel.)
8. Actuate cam lever, thus extending clamping paws.
9. Bolt positioner to test stand (4 places).
10. Set helium regulator for 120 psi.
11. Attach helium line to positioner gas fitting.
12. Plug electrical control station into 110 v ac socket.
13. Connect 12-pin connector from electrical control station to positioner head.
14. Place electrical control station toggle switch to ON position.
    a. Check control station for the following:
        (1) "Power" light on (red)
        (2) "Out" light on (green)
        (3) "Locked" light on (red)
        (4) "Complete" light on (blue)
        (5) "Hold" light on (red)
        (6) D. C. voltmeter reads 24 volts.
        (7) D. C. ammeter reads "O".

DATE	5/12
DETAIL	104 C
SERIAL	104 C
WELD JOINT	428
PLUNGE VOLTAGE	21
PLUNGE CURRENT	1.5
ROTATE VOLTAGE	8
ROTATE CURRENT	.4
CUTTER USED	20T 060
MOLYKOTE	✓
CUTTER RAISED	125
PSI (NITROGEN)	120
INCHES/MIN. TRAVEL	
NITROGEN START	2350
NITROGEN FINISH	1950
NITROGEN USED	400
CUTTER START POS.	✓
JOINT BOLTED	✓
CHIP BUCKET IN	✓
POSITIONER BOLTED	✓
POSITIONER CLAMPED	✓
ELECTRICAL HOOK UP	✓
GAS LINE CONNECTED	✓
SPACER CUP	B
COMPLETE REV. TIME	5:50
CONDITION OF CUTTER AFTER CUT	GOOD
OPERATER M.M.F.	

7519-15109

Figure 23. Setup Check List for Lower Weld Joint Cutoff

(8) Toggle switch on FORWARD position.

NOTE: The equipment is now ready for the cutoff operation; the check list (Figure 23) should be used to verify the operation. The following is the electrical control station sequence.

15. Turn helium gas on.

16. Hold linear START button on.

17. When OUT light goes off and MOVING light is on, release START button; dc ammeter should read 200 milliamperes.

18. When cutter IN light is on and MOVING light is off, the machine cutter is now into work piece full depth. Depress START button under HOLD. HOLD light goes out and LOCKED and COMPLETE light will go out momentarily, with MOVING light going on. Cutter will now rotate for 1 revolution; dc voltmeter should read 7 volts, and dc ammeter should read 400 milliamperes.

19. When cutter has completed one pass, COMPLETE light comes on and momentarily LOCKED light comes on. At this instant, actuate STOP button.

20. Move toggle switch to REVERSE.

21. Turn helium gas off.

22. Go through cycle, returning to start position.

    NOTE: Cutoff is now complete and process channel is ready for pulling.

23. Disconnect electrical control station extension cord.

24. Remove bolts from positioner (4 places).

25. With overhead crane, lift equipment and process channel out of test stand.

26. Actuate cam lever, retracting clamping paws.

27. Remove simulated process channel.

28. Inspect machine cut.

III. WELDING PROCEDURE

1. Place contaminate bucket in bottom head extension.
2. Check electrode for proper configuration.
3. Set electrode with spacer gauge.
4. Install correct locating spacer, either A, B, C, D, E, or F, as identified.
5. Clamping paws to be retracted.
6. Check the driving weld head by pushing the jog button on the remote control pendant. Adjust to complete one revolution in 78 seconds.
7. With overhead crane, lift welding assembly into process channel, bottoming on contaminate bucket.
8. By means of positioner hand wheel, raise weld head 0.125 in. (one rotation of hand wheel).
9. Actuate cam lever, thus actuating clamping paws.
10. Bolt positioner to test stand (4 places).
11. Check that gas hoses are attached to the gas sources.
12. Connect electric drive cable to weld head positioner.
13. Check current and ground cable fastenings. Upon completion of these steps, the next step is to set up the welding program to complete the automatic weld cycle. (Figure 24 illustrates programmer setup sheet.) With setup complete, initiation of weld is made by pushing START button on programmer. With weld cycle complete, positioning equipment and welder head are removed from the process tube.

POWER SUPPLY SETTINGS FOR WELD JOINTS										
DATE	1-31-4	1-31-4	1-31-4	2-4-4	2-4-4	2-4-4	2-5-4	2-5-4	2-5-4	
DETAIL	101	101	101	101	101	101	101	101	101	
SERIAL	004	005	006	004	005	006	004	005	006	
WELD JOINT	036	037	038	039	040	041	042	043	044	
START ARC CURRENT	/	/	/	/	/	/	/	/	/	
START ARC TIME	\	\	\	\	\	\	\	\	\	
INITIAL CURRENT	.12 .26	.12 .26	.12 .26	.12	.12	.12	.12 .58	.12	.12	
INITIAL SLOPE	4	4	4	4	4	4	4	4	4	
WELD CURRENT	58	58	58	58	58	58	60	60	60	
FINISH SLOPE	6	6	6	6	6	6	6	6	6	
FINISH CURRENT	.06	.06	.06	.06	.06	.06	.06	06	06	
LOCAL OR REMOTE	L	L	L	L	L	L	L	L	L	
AUTOMATIC, MAN. START, MAN. WELD, MAN. FINISH	A	A	A	A	A	A	A	A	A	
PREFLOW TIME	5	5	5	5	5	5	5	5	5	
FIXTURE DELAY	3	3	3	3	3	3	3	3	3	
WELD DURATION	102	102	102	102	102	102	102	102	102	
1 REVOLUTION TIME STOP WATCH	91 sec	91 sec	91 sec	91 sec	91 sec	91 sec	91 sec	91 sec	91 sec	
HIGH FREQUENCY START CONTINUOS	S	S	S	S	S	S	S	S	S	
POST FLOW TIME PUSH BUTTON	120	120	120	120	120	120	120	120	120	
SEQUENCE STOP TIME	8	8	8	8	8	8	8	8	8	
PREHEAT TIME	102	102	NONE	NONE	NONE	NONE	102	NONE	NONE	
FORWARD OR REVERSE	F	R	F	F	F	F	F	F	F	
MOTOR SPEED DIAL	56	56	56	56	56	56	56	56	56	
POSTHEAT TIME	NO	No	No.	NO	NO	NO	NO	NO	NO	
GAS INSIDE	12	12	12	12	12	12	12	12	12	
GAS OUTSIDE	18	18	18	18	18	18	18	18	18	
WATER PUMP	ON	ON	ON	ON	ON	ON	ON	ON	ON	
TYPE TUNGSTEN	2%	2%	2%	2%	2%	2%	2%	2%	2%	
TORCH CONNECTIONS	OK	OK	OK	OK	OK	OK	OK	OK	OK	
GROUND	OK	OK	OK	OK	OK	OK	OK	OK	OK	
WELDHEAD CLAMP & BOLTED	OK	OK	OK	OK	OK	OK	OK	OK	OK	
HELIUM LEAK CHECK	OK	OK	OK	OK	OK	OK	OK	OK	OK	
REWELD PASS										
Graphite powder on joint		✓	✓		✓					
SPACER CUP				£.218	C	C				
Sodium on joint					'	✓				
RAISE STINGER							.101	124	117	

7519-15110

Figure 24. Welding Setup Sheet

APPENDIX B

The upper and lower weld joints were analyzed for thermal stresses, thermal fatigue life, mechanical stresses and from the standpoint* of creep of the material during its 30 year life. The life of the lower joint is many times the anticipated five thermal cycles. The life of the upper weld joint is infinite for the normal scram cycle. The weld joint was found to be structurally adequate and it is predicated that it will remain so for it's design life.

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*1. IL, dated 2/1/64, to K. W. Foster from N. Dusanek, "Thermal Stress Analysis Welded Process Tube Joints."

2. IL, dated 2/20/64, to K. W. Foster from N. Dusanek, "Thermal Stress Analysis of Welded Process of Tube Joints."

3. IL, dated 3/11/64, to J. Roberts from J. M. Nishizaka, "Upper Weld Joint of Process Channel."

4. IL, dated 3/19/64, to J. Roberts from J. M. Nishizaka, "Upper Weld Joint of Process Channel."

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