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OPEN- AND CLOSED-LOOP TOP CLOSURE
REMOTE CUTTING AND WELDING EVALUATION

R. F. Gilmore

May 1970

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By

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ABSTRACT

One of the prime objectives of the FFTF is to perform nuclear fuels testing. The facility must have the capability to install and remove test assemblies by remotely controlled equipment. The development and testing of equipment with which to weld and cut the open- and closed-loop reactor top closures for removal and reinstallation of experimental test assemblies is discussed in this report.

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OPEN- AND CLOSED-LOOP TOP CLOSURE
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INTRODUCTION

The question of how refueling operations are to be accomplished for removal and reinstallation of the open-position and closed-loop test assemblies in the FFTF must be established before firm detail design of the reactor cover hardware and handling apparatus can proceed.

This report covers the various design and development activities that have produced acceptable test hardware and the capability for realistic testing. Problems encountered, and their resolutions, are discussed. Design and test requirements are stated, and the results of significant tests are given.

The concepts chosen for development were, in general, based on proven principles, processes, and techniques long accepted by industrial applications. However, extensive experimentation and feature testing was necessary to satisfy the stringent functional requirements of high temperature, pressure, and cleanliness resulting from radioactive sodium environments.

The advantages afforded by employing remotely controlled welding and cutting equipment for maintenance and repair functions on highly radioactive components have long been recognized by Plant Designers. Similar development programs^(1,2) lend credibility to the remote welding and cutting philosophy, although, as yet, no known remote equipment has been adopted on a regularly scheduled basis.

Because of the need for a reliable method of remotely sealing and separating the reactor top closures, it was essential that aggressive development programs be implemented as early as possible.

WELDING

The assessment of operational requirements, commensurate with known welding technology, immediately directed welding development work towards a mechanically driven, tungsten-arc welding-head and filler-ring concept. The requirements for easy equipment handling and accessibility, along with weld joint characteristics, established the nozzle joint configuration (Figure 1). The three-phase welding development program consisted of:

- Phase I - Evaluate welding methods and techniques and study joint characteristics. Define supporting test apparatus and initiate procurement.
- Phase II - Verify selected designs compatible with expected sodium conditions.
- Phase III - Fabricate, procure, and test the selected concept for the remote welder.

Major problems encountered during the welding development concerned the filler ring, joint configurations, and also ring holddown devices to achieve the optimum weld profile for a good leak-tight, structurally sound, uniform closure.

CUTTING

The most significant problems to be solved for remote cutting were the development of tools conforming to the narrow face gland (0.125 in. wide $\times$ 0.230 in. deep) to match weld filler ring designs and the capability of producing small metal chips. All cut material must be completely removed through a vacuum system to avoid contamination of the sodium

FIGURE 1. FFTF Open/Closed Loop Top Closures

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coolant. Cutter tool concepts investigated includes: single-point trepanning tools, utilizing chip breaker features and vibration techniques; end- and side-mill cutters.

A cutter head assembly was constructed of the side-mill concept to demonstrate remote cutting capabilities, while a module assembly of the Trepan concept was developed as a ready back-up design.

SUMMARY AND CONCLUSIONS

Development programs have produced new equipment and the testing capabilities to prove that remote welding and cutting is a reliable method for sealing and separating the open-position and closed-loop top nozzles.

WELDING

The three phase welding development program accomplished:

- Determination of reactor nozzle joint configurations
- Development of prototypic model of the remotely controlled tungsten arc weld head
- Fabrication of environmental test chamber
- Procurement of weld programmer and power supply equipment
- Testing capabilities and technical skill development.

The design, development, and testing activities were performed by Development Engineer Operations Section. The environmental test chamber was originally excess CANEL (Connecticut Advanced Nuclear Engineering Laboratory) equipment; modifications provided the capability for welding tests over molten sodium in inert atmosphere.

The culmination of welding development resulted in quality seal welds being made on simulated reactor top closures previously separated by remote cutting. Welding completely by remote control, was performed inside the test chamber on nozzle specimens containing molten sodium (500 °F) and in an inert helium atmosphere.

CUTTING

Numerous single-tool experiments were tried, concepts evaluated, and two test modules fabricated and tested before an acceptable cutting concept was selected. Extensive testing was performed on the Multiple Tooth Trepanning, and Side Mill Cutter test assemblies. The advantage of excellent chip

control led to the fabrication of the side mill remote cutter for proof-of-principle testing. Although procurement lead time did not permit construction of the entire remote side-mill machine, the equipment assembled does demonstrate that all critical functions can be accomplished by remote control. A test stand was constructed to perform remote cutter testing.

Cutting tests were performed on nozzle samples previously seal-welded inside the environmental chamber by the remote welder. The samples were heated to 500 °F to simulate reactor temperature conditions. The weld joint was completely separated with no evidence of material fallout beneath the open gland. With the exception of manual alignment of the work piece with the cutter latch mechanism, the entire cutting process was performed by remote control from the control panel.

The trepanning concept was explored, with note-worthy success, as a backup design by the incorporation of a pulsed-feed mechanism closely simulating a natural vibration cutting condition. The final test configuration tested yielded small flaky chips compatible with the vacuum clean-up system.

RECOMMENDATIONS

The feasibility of the cut and weld concept for seal welding and separating the top closures on the FTR has been satisfactorily demonstrated. It is recommended that the tungsten-arc welding and side-mill cutting concepts described in this report be further developed for reactor operations. Although the programs were specifically directed to prove remote capabilities, the equipment, processes, and techniques developed are also applicable to contact maintenance. A rigorous qualification and reliability testing program, along with effective quality assurance will be required for the final prototype models. Continuation of present development programs is necessary to complete design inputs for vendor fabrication contracts and the reactor design.

CUTTING (SIDE MILL CONCEPT)

To construct a prototype model of a cutter machine (Figure 2) complying with LPM envelope requirements, the following modifications would be needed:

- Incorporation of a new, single-drive motor, transmission, reaction brake, and pneumatic and electrical connectors.
- Modification of existing cutter head assembly to add sodium vapor gas seals.
- Upgrading of the rotary cutters to increase cutter life.
- Modification of cutter geometry to provide initial break-through on the nozzle spool piece.

Compatibility and endurance testing performed over molten sodium in the environmental chamber and within a simulated LPM tooling tube would include the determination of failure modes and the study of surveillance and monitoring methods.

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FIGURE 2. FFTF Open and Closed Loop Top Closure Remote Cutter

WELDING (TUNGSTEN ARC CONCEPT)

Additional testing on simulated closures is needed to gather statistical data for:

- Determining the effect repeated welding will have on surface distortions, and diametrical shrinkage.

Deciding the durability of the equipment when subject to extreme operating conditions.

- Finding the allowable limits of sodium exposure and establish cleaning requirements.
- Confirming weld joint integrity by performing destruct burst tests, bending, and material property analysis.
- Investigating and demonstrating suitable nondestruct inspection testing, surveillance and monitoring methods.

Evaluate the quality of the weld joint by using selected material combinations.

DEFINITION OF TERMS

The following are the definition of terms as used in this report:

- Automatic Weld Sequence Control Unit A programmer and power supply that synchronizes the weld current to the travel of the welding arc and gas flow. Time and current are adjustable; the high accuracy timers assure repeatability of the weld.
- Crater Used to define the indentation that is formed by the abrupt termination of the weld current.
- "Dowanol EB" A commercial solvent that reacts slowly, but predictably, with sodium and is used to remove residual sodium from sodium contaminated equipment.
- Electron Beam Welding A welding process that applies heat by means of a concentrated beam of electrons. Magnetic field focus and accelerates electrons from an incandescent filament.
- Fillet Weld One of the two basic welds--the other being the "Groove Weld." The basic difference being in the preparation of the joint prior to welding. There is little preparation of the joint for the fillet weld; with the groove joint, the base metal is contoured to accept the welding metal.
- Metal Inert Gas (MIG) A welding method that employs an automatically-fed bare electrode. The arc is enveloped by a stream of inert gas. No flux is needed.
- Tungsten Inert Gas (TIG) A welding process using heat from an arc between the work and a nonconsumable tungsten electrode. The arc is enveloped by a stream of inert gas. No flux is needed.

Insert Filler Ring A ring specially designed to provide the exact amount of weld material to bridge the gland produced by the remote cutting process.

Metallic Soft Seal A "K" shaped ring located at the seating surface of the nozzle shield plug to the spool piece. The shrinkage of the weld is sufficient to mate the seal.

Nozzle Shield Plug The final closure of the closed loop tube.

Positioning Jib A fabricated plate that allows the suspension of the test nozzle shield plug into the test spool piece for accurate positioning prior to making the weld. (Used in early Phase 2 testing.)

Spool Section The "Nozzle" of the closed loop tube, containing the inlet and outlet connections and also serves as a support from which the fuel test specimen will be suspended.

- LPM Loop Preparation Machine.
- POP Proof-of-Principle.
- Weld Filler Material Added metal fed into the molten pool to provide "extra" metal.

Weld Head (As used in this report) The electrode, locking device, drive motor that is lowered onto the nozzle shield and makes the weld.

Weld Puddle The molten pool beneath the arc.

Trepanning Concept A machining concept which involves rotating one or more cutter teeth about a fixed clamp to generate a circular slot at a given radius. The concept involves two motions: rotation of the tooth holder about the clamp, and feed (travel of the tooth holder toward the workpiece).

- Cutter Cratering The formation of a cavity near the cutting edge of the tool face.
 - Side Milling Concept A machining concept which involves rotating multiple milling cutters about a fixed clamp to generate a circular slot at a given radius. The concept involves three motions: feed (rotation of the milling cutter holder about the clamp), plunge (travel of the milling cutter holder toward the workpiece), and cutter rotation (rotation of the milling cutters about their own axis within the holders).
 - Single Point Tool A cutting tool consisting of a single tooth placed in a tool holder and applied to the workpiece.
- Pulsed Feed An induced fluctuation (pulse) in the plunge of the tool toward the workpiece. The frequency and amplitude of the fluctuation are designed to approximate the frequency and amplitude of self induced tool chatter. Pulsed feed is an attempt to produce, predictably, the finely broken chips usually produced by self induced chatter.

FUNCTIONS AND DESIGN REQUIREMENTS

The function of the equipment developed is to provide a reliable means to remotely seal weld and separate the top closure nozzle joint for removal and reinstallation of the open and closed loop test assemblies. The design basis and criteria are in accordance with previous guidelines.⁽³⁾ BNWL-500,* Volume 61⁽⁴⁾ provides an outline for the Closed Loop Irradiation System. The Loop Preparation Machine (LPM) will house both pieces of equipment and provide the necessary systems; i.e., electrical, inert gases, and vacuum for their operation. [Appendix E, Page E-1⁽⁵⁾ shows a sequence of operations that may be suitable for test loop change out.]

CUTTER

Once the instrumentation connector has been removed and the LPM is properly aligned and secured in position with the reactor nozzle, remote cutting operations can begin. The test final equipment must demonstrate that the following functions can be accomplished by remote control:

- The cutting machine can be lowered into the tooling tube of the LPM until it is positioned on the nozzle shield plug. The cutter can be secured in place by the actuation of the collet nozzle latch mechanism and the torque reaction brake (Figure 2).
- The total process can be initiated, including cutter motions and vacuum systems.
- All systems can be programmed for staged termination by the automatic actuation of the cutter depth limit switch.
- The shield plug locking mechanism can be then de-energized, and the cutter returned to its original stowed position in the LPM.

* *It should be noted that CSDD, BNWL-500 series, is constantly being updated.*

The present configuration for the proof-of-principle (POP) cutter is not representative of the prototype model. A single-drive motor, gear box and reaction-brake mechanism must be adapted to the existing cutter assembly to meet the requirements outlined above.

WELDER

The welding equipment has been designed to demonstrate that the following functions can be accomplished by remote control.

- The remote welder is lowered into the LPM tooling tube. Position and locked into place with the nozzle shield plug.
- The total programmed welding process is initiated and terminated by the actuation of a master signal control.
- Once the pneumatic latch mechanism is de-energized, the welder can then be returned to its original stowed position in the LPM.

INSPECTION

Methods and techniques for monitoring and remotely inspecting the quality of the welded joint during reactor operation have not been established at this stage of development. Stringent weld process control, confirmed by a thorough reliability assurance program is expected to assure good joint integrity. Radiography inspection techniques are not adaptable to the joint configuration because of the high radiation background and charged particle beams or magnetic fields are not suitable due to materials selected; nor do ultrasonic inspection techniques appear acceptable for remote applications. Direct viewing and acoustic emission techniques show promise, but would require extensive development.

SODIUM SERVICE

Materials used in the construction of the remote equipment and weldments must be compatible with sodium liquid or vapor. Mechanisms requiring special fits and surface treatments must be properly isolated by reliable gas seals. Any fallout of cut weld material or foreign particles that would contaminate the sodium cooling system must be avoided. The cutting operations prepare the metal surfaces for subsequent rewelding. Cleaning of the nozzle spool piece prior to welding will be necessary, however, to remove any deposits that may result from sodium spillage or vapor formations.

DESIGN CRITERIA

The actual operational and environmental conditions of the FFTF have not been confirmed. The requirements imposed on the top closure joint and the remote cutting and welding equipment are based on current Conceptual data, or on conservative parameters of expected conditions where reliable data are lacking. The final prototype cutting and welding equipment and top closure joint are expected to meet the following criteria:

Cutting and Welding Equipment

- Operational mode -- remote
- Operational time -- 10 min maximum for welding and 40 min maximum for cutting, between the time the equipment is positioned on the shield plug.
- Frequency of Removal -- 9 times maximum in 3 years.
- Space Envelope
 - a. Operate inside (LPM tooling tube) -- 7.50 in. minimum ID, 56 in. maximum height.
 - b. Weld joint -- 6.72 in. mean diameter.

- Reliability and Confidence Level

- a. Remote machines -- 100 consecutive operations without a failure.
- b. Cutter tool -- 6 consecutive separations before replacement.
- c. Nozzle replacement -- 9 weld applications.

Seal Parameters

- Temperature

- a. Design, nozzle and shield plug -- 500 °F.
- b. Normal operation nozzle and shield plug -- 300 to 450 °F.
- c. Refueling
- d. Thermal cycle -- normal 200 to 400 °F, 50 times maximum in 3 years.
- e. Transient -- 1000 °F maximum
Rate of change -- 30°/sec
- f. External gas -- 70 to 200 °F.

- Pressure

- a. Design (joint) -- 250 psia.
- b. Normal operation -- atmospheric to 200 psia.
- c. Burst -- 1100 psi
- d. Transient -- 800 ± 300 psi maximum
- e. Equipment operation -- atmospheric.

- Radiation Level

- a. Neutrons -- 10^3 N/cm²/sec
- b. Gamma -- 10^5 R/hr

- a Containment Media -- sodium and/or inert gas

- Leakage -- design conditions

- a. Sodium -- zero
- b. Cover gas -- $<10^{-7}$ atm cm³/sec helium

- Material -- nozzle, plug, and weld filler ring (304/316 SS)*
- External Media -- Air, nitrogen, argon, or helium
- Joint Life -- 3 years

HANDLING PROVISIONS

The remote welder and head assembly of the remote cutter have been designed to operate within the envelope of a 7 1/2 in. ID tooling tube. The latching mechanisms for the cutter has the capability of lifting the nozzle shield plug. The present concept requires a machine clean up operation on the pulled shield plug to remove residual weld material. Also, the new filler ring will be tack-welded in place on the shield plug prior to reinstallation with the nozzle spool piece.

The following parameters should be followed to assure that the present developed equipment will properly function with the LPM.

- LPM tooling tube -- 7.500 ± 0.005 ID
- Length of tooling tube -- 56 in. minimum.
- The tooling tube shall be positioned 0.030 in. maximum concentricity with the nozzle spool piece.
- The tooling tube shall create a gas seal when mated with the reactor nozzle.
- LPM tooling tube must be capable of transmitting 200 ft-lb torque induced by the cutter reaction brake, (Figure 2).
- LPM shall provide the handling provisions to store and transport the remote equipment.
- Electrical, pneumatic and vacuum sources shall be provided by the LPM.
- Instrumentation, surveillance, and monitoring apparatus shall be supplied by the LPM.

* Or material compatible with nozzle and plug.

REMOTE WELDING PROOF-OF-PRINCIPLE

The remote welding equipment developed, the support apparatus procured, and the configuration of the nozzle weld joint are discussed in this section.

A three-phase development program was initiated to prove the feasibility of remotely seal-welding the nozzle top closures and to assure that the optimum equipment will be available for dependable service on the FFTF. The primary objectives of the three phases were:

- Phase 1 To establish weld joint configurations and welding processes; evaluate techniques and procedures; and define problem areas. To specify equipment and support apparatus needed to carry out the development program.

Phase 2 To develop verification that the selected designs, processes, and techniques were feasible. To subject weld test specimens to the predicted reactor shutdown conditions while maintaining molten sodium inside the test specimen for extended periods of time and at various distances from the weld joint prior to and during welding.

- Phase 3 To include the activities of covered design, fabrication, procurement, and testing of the remote POP welding equipment, welding apparatus, and test support equipment.

REMOTE WELD HEAD

Figures 3 and 4 show the prototype remote welder that was fabricated for demonstration testing. The equipment, with minor modification, is expected to meet the stringent requirements specified previously (Design Criteria Section).

The remote weld head was designed by using information gathered during Phase 1 and 2 testing with a "bread board"

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FIGURE 3. FFTF Prototype Remote Weld Head

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FIGURE 4. FFTF Remote Welder Top Closure

weld head. The machine is composed of three main units: (a) the positioning and locking mechanism, (b) the gas and current distributor and torch unit, and (c) the drive train (Figure 3).

The positioning and locking mechanism consists of a mandrel shaft and locking collet device actuated by two gas cylinders. The mandrel shaft is designed to locate and lock on center over the instrument connector nozzle. The mandrel shaft contains three equally spaced holes which permit the three ball bearings to protrude inward. The collet housing has a cam which engages the ball bearings as the housing is moved upward by the gas cylinders, forcing them into the "v" shaped groove on the instrument connector nozzle. The collet housing is made of 430 Series SS, and hardened to 56-58 Rockwell-C, to reduce distortion caused by contact with the ball bearings. The collet housing shaft is connected directly to two pneumatic cylinders used to actuate the housing in both directions. The cylinders are designed for 300 psi gas pressure; positive locking is accomplished with 150 psi pressure. Two sintered bronze bearings in the collet housing shaft provide a close fit between the mandrel shaft and housing while permitting the necessary relative movement needed for the locking operation.

The current path through the weld head is by copper bus in the stationary upper portion of the head to a fixed copper current ring. The contact between the moving and stationary rings is accomplished with a carbon brush to permit slippage with minimum wear. Contact pressure is maintained by three equally spaced compression springs. A solid copper bus completes the circuit from the rotating ring to the torch assembly. Since the arc is initiated by a high frequency voltage super-imposed on the direct current, carefully designed

insulation is a very important part of current train. All insulation is designed with an offset at each joint in order to prevent a line of sight path to the ground.

The inert gas flow from the stationary portion of the head to the welding torch is accomplished through the gas distributor (Page 22). The gas manifold to the distributor is copper tubing connected by mechanical fittings to permit disassembly. O-rings are used to prevent leakage from the distributor. Since the gas is fed to the torch by copper tubing, an insulating section is necessary to prevent grounding the torch.

Power from the drive mechanism is supplied by a standard Linde DC variable speed motor through an 800 to 1 gear reduction to a ring gear. Motor speed is controlled between 0 to 25 in./min by a Linde Type "E" electronic governor. The motor is attached to the stationary portion of the head which is keyed to the locking mechanism, thereby fixing it in place prior to starting the welding sequence.

WELD PROGRAMMER AND POWER SUPPLY

Figure 5 shows the weld programmer, power supply, and accessory equipment used for POP testing.

A Weld Programmer and constant current power supply was purchased from Auto Arc, Inc. to remotely operate and control the weld head. This equipment provides automatic sequencing and weld programming functions. For automatic tungsten arc welding, five portions of the welding sequence must be carefully controlled:

- Weld starting current and high frequency voltage and time for this portion
- Time to slope current from starting current to full welding current

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FIGURE 5. Weld Programmer and Power Supply

- Main welding current and time duration
- Time to "crater fill" current
- The "crater fill" current and time duration

The power supply obtained is capable of accurately controlling all of these functions over a wide variation of input line voltage. The power supply and programmer also controls the starting and stopping of the drive motor, and cover gas flow to the weld torch.

Mode of Automatic Operation

All the functions necessary to perform the welding process are accomplished by depressing the "start weld - reset" control. The following sequence takes place:

- (1) The automatic sequence timers, "Preflow" of the inert torch gas is initiated.
- (2) After a selected time interval, "High Frequency Arc" is initiated and automatically cuts off after the arc is established.
- (3) "Initial Weld Current" is maintained for a preselected time. Simultaneously, with the initial weld current, the drive motor delay timer is energized and is set to provide "instant start" or "delayed start" as required.
- (4) Weld head travel initiates following this selected sequence.
- (5) After a predetermined time, the weld current leaves the preset initial current level and transfers to an adjustable timed current slope, either "Up" or "Down" as selected from the initial weld current to "Main Weld."
- (6) The main weld current level will be maintained for a predetermined time.
- (7) After completing the weld (one complete revolution of the weld head around the weld joint and approximately one-half inch beyond the initial weld start area), the main weld

current will gradually decrease* on an adjustable timed current slope to a preset "Finishing" current.

- (8) At the completion of the crater fill sequence, the programmer will shut off the weld current and stop the weld head rotation.
- (9) "Postflow" of the torch will continue for a selected time.

ENVIRONMENTAL TEST CHAMBER

Phase 3 welding was performed in a vacuum chamber obtained from excess CANEL equipment. The chamber was modified to permit remote handling of the mechanically driven, tungsten-arc weld head and weld cutter and to simulate the predicted reactor "shutdown" conditions regarding: temperature, inert cover gas, and sodium environment for the closed loops. The modifications required are shown in Figures 6, 7, and 8, and include:

- The overhead tower housing a remote operated traveling hoist that "picks up" the remote weld head from its "stored" position, traverses to and lowers the weld head into position over the simulated closed loop test specimen.
- Sodium supply system consists of a lower "well" housing the simulated closed-loop test specimen; reservoir; heater facilities and temperature monitoring thermocouples.
- An air lock is provided to permit removal and replacement of test specimens and other required apparatus without the necessity of opening the main portion of the chamber to the atmosphere (thus, substantially reducing the amount of wasted inert cover gas).

* *This gradual reduction of weld current prevents "Cratering" of the weld and forms a smooth finished weld.*

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FIGURE 6. Environmental Test Chamber

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FIGURE 7. Interior Environmental Test Chamber

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FIGURE 8. Top Closure Hardware Weld Test Specimen

- A 20 cfm vacuum pump is used to evacuate the chamber to approximately 1000 μ prior to back-filling with inert (helium) gas.
- A recirculating gas purification system is provided to maintain the required inert gas purity regarding O_2 and moisture level.

Phase 2 experience with the above recirculating system has demonstrated a savings of consumed inert gas by a factor of 5 to 1.

WELD JOINT

The final weld joint developed for demonstration testing is shown in Figure 8. The shape and dimensional configurations of the insert filler ring must mate with the groove previously prepared by the remote cutting process. The shape of nozzle and spool pieces is very important in producing a successful weld. Contact areas between the pieces must be kept at a minimum while assuring dimensional tolerances are not exceeded. Additionally, the mass of metal in the weld joint areas of the nozzle and spool pieces must also be kept at a minimum to reduce the "Heat Sink" which results in a weld notch on the under portion of the bead or a condition where the insert ring may not be totally consumed.

To minimize contact areas, the insert filler ring body has been tapered 5 degrees, and the upper section angled outward 50 degrees to create a shoulder that will contact the nozzle shield plug and spool piece (Page C-3). Machined on the inner lower portion of the body of the insert filler ring is a small angle retaining ledge. This retaining ledge prevents an upward movement of the ring during welding, as was experienced during early development testing. At the present time the filler ring is spot welded, at three locations, to the nozzle piece for positive positioning.

For better weld bead control, both the shield plug weld joint and the spool piece weld joint have been undercut to reduce the amount of metal in these areas.

PROOF-OF-PRINCIPLE (POP) TEST

The purpose of the POP test is to prove that the weld equipment developed is capable of remotely performing quality seal welds on reactor top closures during reactor operations.

The simulated top nozzle hardware, test weld head assembly, welding apparatus and testing chamber are as described in this section. Testing was conducted in accordance with "Top Closure Remote Weld Test Procedure" (Page A-1).

Test Summary and Conclusions

Testing has confirmed that the mechanically driven, tungsten-arc welding process and filler-ring concept is a feasible means of remotely sealing the top closures.

X-rays and visual inspection of the nozzle weld indicate uniform bead shape and weld penetration. Proof pressure test performed on the heated sample with helium gas confirmed the joint to be structurally sound and leak tight. Sodium vapor exposure to the weld joint apparently had no effect on weld quality. However, previous testing revealed that sodium wetting on the weld melt area would necessitate a cleanup operation prior to welding.

Presently only six remote welds have been performed inside the environmental chamber; of these, only one sample had been separated by the remote cutting process. Testing is being continued to further optimize welding operations and gather statistical data for final design inputs.

REMOTE CUTTING, POP

This section covers development and testing of the POP remote cutter, fabricated to prove the feasibility of separating the open- and closed-loop seal top welded closures.

Two distinct test subassemblies were fabricated and tested to evaluate cutting concepts. Of these, the side mill technique was chosen for the proof-of-principle machine, while the multiple tooth test module was further developed as a ready backup. These programs are discussed under "Cutter Development" (p. 65).

The cutter machine constructed for testing is not entirely representative of the reactor prototype model required to operate within the LPM envelope. The next development phase will produce the final prototype. It will adapt a single electric motor, transmission train, and reaction brake to the existing cutter head assembly (Figure 2).

The environmental test chamber used to perform welding studies has been designed to accommodate the prototype cutting equipment for sodium environmental testing.

The functions considered most important for remote control cutting can be demonstrated in the cutter test stand (Figure 9). The stand provides separate motor drives for each of the three cutter motions. Motor outputs can be varied during testing and a permanent record made. This selective control is beneficial for determining the optimum cutter feed, speed and plunge to match the particular cutter configuration being tested. The nozzle samples used for cutter testing were remotely welded inside the environmental test chamber.

CUTTER HEAD ASSEMBLY

Figure 10 shows the cutter head assembly that was fabricated for proof of principle testing. This assembly, with the

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FIGURE 9. Test Stand Remote Cutter

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FIGURE 10. Remote Cutter Head Assembly

addition of sodium vapor seals and unitization of the cutter drive, is expected to fulfill all design requirements. Important feature development problems such as; cutter tool characteristics, dynamic stability, vacuum chip control, and others were resolved on the test module assembly.

The POP cutter is composed of three main units, (a) the positioning and locking mechanism, (b) the vacuum chip removal and gas makeup system, and (c) the cutter motion drive train. The components that comprise the cutter head assembly can be seen on Page D-9, while a breakdown of the cutter ring mounting is shown on Page D-10.

The positioning and locking mechanism consists of a collet and collet-chuck device actuated by a gas cylinder. The collet shaft is designed to locate and lock on center over the instrument connector nozzle. The collet shaft is connected directly to a pneumatic cylinder which is used to actuate the check in both directions. The cylinder is designed for 3000 psi gas pressure, positive locking is accomplished with 1500 psi pressure. Bearings in the collet housing provide a close fit between the mandrel shaft and housing while permitting the necessary relative movement needed for the locking operation.

The vacuum chip removal passage, through the assembly, begins with a channel above each of the four cutters. The chips pass through the rotating head assembly into a slip ring in the stationary plenum, then through four tubes to a collector manifold. The vacuum source connects directly to the collector manifold. Exhaust from the vacuum source is channeled down around the cutter machine by a glass cylinder. The cylinder simulates the inside of the IPM tube. This channeling produces a closed circuit of air which is the chip removal medium. Because of pressure drop within the system, additional plant air is added to attain a differential pressure between top and

bottom surfaces of the sample. This is to prevent loss of chips at the time the cutters break through. The additional plant air is dispersed through the collet to prevent chips from gathering towards the center of the shield plug.

TEST STAND

The test stand consists of a rigid tubular steel framework upon which are mounted the control panel, feed and cutter rotation drive motors, sample workpiece, glass cutter shroud, and two guide pins to establish a track for vertical cutter travel. The cutter mounting plate is raised on the guide pins with a lifting bolt to allow removal of the sample workpiece from the test stand, and insertion of a new specimen. When the uncut workpiece is in place, the cutter mounting plate is lowered and locked in place with a collar so it can withstand the cutting forces.

Drive to the cutters are provided by three variable speed motors, each providing one of the three cutter motions; feed, plunge, and cutter rotation. The feed rate can be adjusted from 0.75 in./min to 18.9 in./min, the plunge from 0.003 in./min to 0.079 in./min, and the cutter rotation from 3 to 155 rpm. Each drive shaft is protected from overloading by torque limiting clutches. All gear and shaft bearing surfaces are treated with hard-coat dry-film lubricant to assure long maintenance-free operation.

Mode of Operation

Three functions are required before the actual cutting operation can proceed:

- (1) The collet clamp cylinder must be actuated (locking the cutter to the workpiece).
- (2) The chip vacuum exhaustor must be turned on.

- (3) The cutter cavity pressure must be brought to atmospheric by adjusting the makeup air.

When the cutting process is initiated by pressing the "on" button, the following sequence of events take place:

- (1) The three drive motors start simultaneously and rotate the four milling cutters, feed the cutters around the workpiece and lower the cutters into the weld metal.
- (2) The chips produced by the cutting operation are totally removed by the vacuum chip removal system.
- (3) When the cutters have cut to a predetermined depth through the weld, the down limit switch is actuated to terminate cutter motions.
- (4) Placing the plunge motor selector switch in reverse withdraws the cutter head from the workpiece.

Equipment Shakedown

The cutter assembly was positioned in the test stand and aligned with the work sample. Drive units were attached and speed calibrated. The limit switches were set and slip clutches installed and adjusted to prevent overloads. Preliminary cutting was made under the following conditions:

- Dummy shaft was used to replace the collet chuck and latch mechanism.
- Vacuum-return and make-up shop air was not installed.
- Test-module cutter ring was used in place of the new ring which called for hard chrome bushings and structural improvements.
- Automatic plunge control was operated manually.

Initial testing soon revealed excessive cutter wear and that modifications were needed to stabilize the cutter drives. This was accomplished by beefing up the motor mounts, increasing

the size of the drive shafts, eliminating backlash in the drive line connectors and applying a torsional slip brake to the cutter housing. While these improvements were being made the collet, collet chuck and new cutter ring were received and installed. The SCR control unit for the automatic plunge was repaired and the vacuum return and shop air connections were also added.

Adjustments and modification during subsequent testing further improved the stability problems, minor changes were again made to the cutter geometry. All systems have been debugged and are now operating satisfactorily.

PROOF-OF-PRINCIPLE TEST

Testing was performed to prove that the side mill cutting concept is a reliable method for remotely separating the welded open and closed loop top closures during reactor operation.

Testing was conducted in accordance with Development Test Procedure Side Mill Remote Cutter (Appendix B).

Test Summary and Conclusions

Testing has confirmed that the side cutting concept is feasible.

The vacuum chip-removal technique proved successful in attaining good chip removal when separating nozzle samples heated to 500 °F. There was no cut material evident beneath the gland. Surface finishes were very good and the size of the gland well within the prescribed limits. The data gathered is not sufficient to predict cutter life. The present cutters required regrinding after 56 min of cutting time through the workpiece. A harder tool steel is needed to assure repeatable separations and reduce maintenance replacement.

Testing is continuing to gather statistical data for design inputs and fabrication of the complete remote cutter to be tested in the environmental chamber.

WELDING DEVELOPMENT*PHASE I - WELD JOINT DESIGN

The welds performed during Phase 1 were conducted primarily to establish a preliminary weld joint shape that would provide the reliability required to insure zero sodium leakage and permit the repeated removal and remote rewelding of the closed loops. Welding equipment utilized for this phase of the weld studies consisted of:

- (1) A 200 amp three phase DC weld power supply.
- (2) Automatic weld sequence control unit.
- (3) Two-channel weld current and weld voltage recorder.
- (4) A water-cooled mechanically driven, remote-controlled tungsten arc weld head (Figure 11, depicts this weld head after modification for gas cooling).

Weld test pieces were fabricated from 304 SS with 1 in. thick plate used to simulate the nozzle shield plugs. A 3 1/16 in. hole was machined into the center of the nozzle plugs and used to locate the weld-head locking mandrel. To simulate the spool section, 3/8 in. plate was rolled, seam welded, and machined to the required diameter. To provide weld filler material, a 1/8 × 1/8 in. lip was machined into the top OD of the nozzle plug of test specimen No. 1. The top of the nozzle plug was then positioned 3/8 in. down from the top of the spool piece and automatically welded. Although surface appearance and weld bead shape was acceptable, further inspection revealed that the extended lip of the spool section had shrunk toward the ID approximately 0.045 in. It was apparent that the shrinkage would interfere with mechanical cutting of the weld and would result in loss of spool material. Therefore, this type of weld joint was discarded.

* Written by L. J. Rousseau

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FIGURE 11. Experimental Remote Controlled Weld Head

The weld joint of Test Weld No. 2 was set up with the top of the nozzle plug extended $3/16$ in. above the top of the spool piece. A "melt-down" weld was made, using the outer edge of the nozzle plug for weld filler metal. Appearance of the finished weld was acceptable. Etched sections of the specimen revealed satisfactory weld bead shape. After the first weld cut-out was performed, the area used for weld filler metal would be destroyed. Consequently, only one weld could be made with the original weld joint shape. To resolve the problem, it was decided to evaluate weld joints which would permit the use of a weld insert filler ring.

A weld joint and 304 SS insert filler ring were prepared for Test Specimen No. 3. The test section was assembled for welding with the top of the nozzle plug extending $3/16$ in. above the top of the spool piece. The filler ring was positioned in the weld joint and tack welded into place with four equally spaced small tack welds. Welding was performed by using parameters shown on Page A.12). Weld puddle shape observed during welding appeared to be very good a satisfactory fillet was formed. However, it appeared that the filler ring was not being totally consumed as desired. This was later substantiated at the time the weld was cut out. After the cut was completed, the bottom section of the unfused filler ring was removed from the weld joint groove. Average thickness of the remaining unfused section of ring was 0.085 in. This indicated that approximately 0.175 in. of the parent ring had been consumed in the weld, which produced a satisfactory cross section for the seal weld.

A second test assembly was welded using similar conditions as described for Test Weld No. 3. Figure 12 shows a section of an unwelded filler ring and a portion of the weld produced from the "melt down" of the ring of that test specimen.

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FIGURE 12. Partially Completed Weld

It was felt that this type of weld joint and insert ring would be acceptable for the closed loop seal welds and would be compatible with the remote cutter, although further refinement was necessary. On that basis, it was decided to proceed into the next step of the weld studies.

PHASE 2 - REMOTE CLOSURE WELDS

Prior to the start of Phase 2 weld studies, concept dimensions of the closed loop were changed. This change reduced the outside diameter of the nozzle shield plug from 11.000 to 9.500 in. Outside diameter of the spool section remained at 11.500 in. It was felt that the dimensional changes of the closed loop sections would not affect the basic weld joint design which was established during Phase 1. Four simulated nozzle shield plugs, four spool sections, and nine insert filler rings were fabricated from the basic dimensions established in SK-3-13669 (page C-1). These test assemblies were used throughout Phase 2 weld studies. The spool sections were modified to function as a sodium container which permitted maintaining sodium in the spool sections at the desired levels and temperatures.

The weld joint in the nozzle plug and spool section, is designed to provide a downward movement of the nozzle plug through normal weld shrinkage. This downward movement is to apply an additional load to a "metallic soft seal," which is located at the bottom of the actual nozzle shield plug where it intersects the spool seal area.

The basic weld equipment used throughout Phase 1 was also utilized for Phase 2 studies. However, since these welds would be performed over a sodium environment, the weld head was converted from water cooled to gas cooled.

Other test apparatus used during early Phase 2 consisted of:

- Pressure type welding chamber
- 14.2 lb sodium storage reservoir
- Temperature controllers and a six-point temperature recorder
- O_2 indicator
- Sodium level monitoring system, i.e., storage reservoir "high level" indicator light, and test specimen "low" and "high" level indicator lights (Figure 13).

Generally, the "Weld Test Procedure" (page A-12) was used throughout Phase 2 testing program. The Equipment Operation Procedure was as follows:

- (1) Install test specimen in weld chamber and purge system, monitor O_2 content of inert gas.
- (2) Recheck atmosphere in weld chamber by firing a test arc on titanium, zircalloy and/or copper. (Test weld must be completely free of oxide formation before molten sodium is brought up into spool piece.)
- (3) Establish temperature in the sodium system and test specimen at the desired level for the specific test.
- (4) With the nozzle plug removed from the spool piece, bring sodium up into the spool, check and set sodium level to indicate on the level lights at the desired level.
- (5) Drain sodium back to storage reservoir, install nozzle plug into spool piece and tack weld in place.
- (6) Return sodium to test piece to "pre-set" level; maintain level for desired period of time, prior to initiating test weld.

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FIGURE 13. Phase 2 Weld Test Apparatus

- (7) After completion of test weld, drain sodium back to storage reservoir, turn off heaters, permit specimen to cool down and remove from test chamber.
- (8) Clean residual sodium from test specimen with "Dowanol EB" and perform required weld inspections.
- (9) Cut out nozzle plug from spool section and recondition pieces for a reweld.

During this initial checkout procedure, temperature of the test specimen, AT-1 (Figure 14) and the sodium system was maintained at 450 °F. Inert gas (helium) was purged through the welding chamber for approximately 1 1/2 hr. The purge reduced the O₂ content in the chamber to an indicated level of slightly less than 1%. After the indicated O₂ level was achieved, a test arc and weld bead was run on a piece of titanium and also on a piece of copper. No oxide formation was seen on either piece and the test welds remained bright and shining. Therefore, it was felt that the weld chamber atmosphere would be sufficient to support the molten sodium and prevent its oxidation.

The riser valve to the storage reservoir was opened slightly and sodium was permitted to flow up into the spool piece. A slight oxide formation was noted as the sodium first entered the bottom of the spool. However, the oxide formation appeared to diminish after repeated filling and draining of the test piece, Figure 15. It was felt that the oxide condition was caused by contamination trapped in the riser between the spool and storage reservoir, since the sodium remained bright during the remainder of this test.

Following the initial system checkout, test specimen AT-1 was prepared for a test weld. The nozzle plug and weld insert filler ring were installed in the spool piece, using the "positioning jig" (Figure 16). The jig is adjustable for

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FIGURE 14. Sodium Test Specimen

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FIGURE 15. Sodium Oxide Formation on Weld Test Specimen

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FIGURE 16. Shield Plug Positioning Jig

locating the desired height of the nozzle plug. The nozzle plug and filler ring are then tack welded into place, using eleven equally spaced small tack welds.

It should be noted at this point that the tack welds are required on these preliminary test sections since the simulated nozzle plugs are not designed to be self-supporting and self-centering in the simulated spool piece. In addition, the remote weld head used through Phase 1 and 2 does not have the capability of holding down the weld insert filler ring. These features were designed into the test equipment used during Phase 3 testing.

Following tack welding of the nozzle plugs and prior to removal of the positioning jig, reference measurements are taken to establish the amount of "pull down" of the nozzle plug into the spool section.

The closure test weld was performed on specimen AT-1 under the following conditions: temperature of the test specimen was maintained at 250 °F, sodium was held at a level of 1 in. below the bottom of the nozzle plug for a period of 2 hr, and then drained back to the storage reservoir, prior to initiating the weld.

After initiating the weld, the welding arc and weld puddle were closely observed throughout the entire weld sequence. No irregular arc action was noted, indicating that the sodium and/or sodium vapors which may have been present in the test piece, had no ill effect on the weld bead. Surface appearance and weld bead shape were very good. Welding parameters for this test specimen are shown on page A-12 ("Welding Procedure Form").

A dimensional check of the nozzle plug "pull down" revealed an average pull-down of 0.025 in. It was felt that this amount of pull down would be adequate to insure contact of the nozzle shield plug and the spool "soft metallic seal."

Several radiographs were taken of the test specimen from a variety of angles. Due to the general shape of the weld joint and test specimen, radiography was unable to reveal anything significant regarding defects or inner weld bead shape. On that basis, no further radiography was performed on the simulated closed loop weld test specimens.

The weld was cut out of Specimen AT-1. Inspection of that area revealed that the weld filler ring was not uniformly consumed. However, evidence of complete melt through was noted in some areas of the last quadrant of the weld.

Test Specimen AT-2 was set up in the weld chamber and prepared for welding. The weld was performed using the same welding parameters; regarding weld current, voltage, and rotational travel, as reported for Specimen AT-1. Temperature level of this test specimen was increased to 300 °F and sodium was maintained at a level of 2 in. below the weld joint for a period of 3 hr, prior to and during welding. The welding arc and weld puddle observed during welding indicated no adverse affect from sodium being present at that level inside the test piece. However, the filler ring was not being totally consumed as desired. This was substantiated after the weld was cut and the bottom side of the weld area inspected. Slightly more melt-through was noted in the last quadrant of this weld than indicated on the preceeding test. This was attributed to the increased test temperature used during this weld.

The problem of inconsistent melt of the filler ring appeared to be caused by the nozzle plug shifting in the spool piece due to weld shrinkage. It was evident that the nozzle plug was tightly wedging the ring into the spool. This created a good heat path for the ring, preventing it from being totally consumed. This condition was occurring in the first half quadrant of the weld, while in the last half quadrant, the ring fit

loosely in the weld joint, thus permitting a more rapid melt of the ring. To assist in controlling the shifting of the nozzle plug, slightly larger tack welds were used in the last half quadrant of the test weld. In addition, to insure a more uniform "melt down" of the filler ring, the ring was modified to provide minimum surface contact with the adjacent parts. This was accomplished by reshaping the lower section of the ring.

Sodium Contaminated Welding

During preparations to establish conditions for a weld over sodium, the spool-piece level monitor failed and the surface of the weld area was flooded with sodium. The sodium was drained back to the storage tank, all heaters were turned off, and the system was shut down. After cooldown, the test chamber was opened up to permit removal of the nozzle plug and weld filler ring for cleaning. The weld test pieces, including the spool section, which was not removed from the test chamber, was cleaned with Dowanol EB, followed with an acetone rinse. After cleaning, the nozzle plug and weld filler ring were reinstalled in the spool piece and tack welded into position, and the system was again reactivated in preparation for another test run. It was intended to establish a similar test condition as previously described, except, sodium was brought up to an indicated level of 2 in. below the weld joint and held for a period of 3 hr. After a period of 2-1/2 hr, it was noted that a sodium frost was forming on the surface of the test specimen at various locations around the weld joint. Temperature of the test specimen was maintained at 500 °F for an additional 1/2 hr. During that time the frost, crystals appeared to grow and spread over a larger area. The system was again shut down and the test specimen removed and cleaned by the previously described procedure. It is not known at this time what caused the sodium frost formation; however, the condition has not reoccurred.

The cleaned test specimen was reinstalled in the welding chamber and the system reactivated. A temperature of 450 °F was established, and sodium was brought up into the test specimen. Because of a failure of a high level indicator light, the weld joint was again flooded. Sodium inside the spool piece was drained back to the storage tank. The remaining molten sodium on the surface of the weld area was wiped off with an asbestos glove and cloth. At that temperature (450 °F), it was not possible to clean off the sodium trapped between the nozzle plug, weld filler ring, and spool piece.

It was decided to initiate an arc on the sodium contaminated weld joint and to observe the results. The weld head was placed in position and a 200-A arc was initiated and maintained for approximately 20 sec. As the arc fired, a dense black smoke formed, and molten sodium appeared to be drawn into the weld area, which further contaminated the weld joint. The arc temperature caused some of the sodium to wet out into a larger area and to tin onto the stainless steel in the heat-affected area adjacent to the weld joint. Prior to extinguishing the arc, molten metal from the weld puddle was splattered upward, contaminating the electrode.

The conditions observed during the time that the arc was on, substantiates an earlier prediction that welding on a sodium contaminated weld joint will not produce an acceptable weld without proper cleaning.

Figure 17 is a top view of the simulated closed loop weld test specimen showing extent of sodium contamination. Figure 18 is a view of the area where the welding arc was fired and maintained for a short period. The large ball-shaped area at the end of the torch electrode is caused by the intense arc heat vaporizing the sodium. Some of the vapors are trapped under the weld puddle until, finally, sufficient pressure is

FIGURE 17. Top View of Simulated Weld Test Specimen Showing Sodium Contamination

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FIGURE 18. View of Area Where Welding Arc Was Fired

created which "blows" molten metal out of the puddle and onto the electrode. Figure 19 shows the extent of sodium vapor accumulated on the upper edge of the spool section. Weld joint inspection and cleaning methods are definitely required and must be established to prevent such an occurrence on the reactor.

Two additional test specimens (AT-3 and AT-4) were welded by using the modified filler ring. The welding procedure used was the same as reported for Test Specimen AT-2. Environmental test conditions were as follows: Specimen AT-3 - test temperature 400 °F, sodium level was maintained 1 in. below the weld joint for a period of 3 hr prior to and during welding; Specimen AT-4 - test temperature 450 °F, sodium level same as AT-3 except maintained for a period of 4 hr. The weld puddle was closely observed during welding, and it appeared from the depth of melt that the filler ring was being totally consumed. After cutting, inspection of the bottom side of the remaining portion of the welds revealed that a much more uniform melt of the filler ring was achieved on both test specimens. Figure 20 shows a weld cross section of Specimen AT-3.

PHASE 3 - PROTOTYPICAL WELD HEAD TEST

The weld test apparatus was given a complete checkout prior to the Phase 3 test weld studies. The test weld equipment consists of a small sodium storage reservoir, an environmental test chamber, a prototypical automatic remote weld head, and the simulated spool-piece and nozzle plug weld samples. The test apparatus provides control and/or indication of the following parameters:

- Helium gas flow and pressure
- Oxygen and moisture content in the environmental test chamber
- Temperatures of the sodium reservoir

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FIGURE 19. Extent of Sodium Vapor Accumulated in Upper Edge of the Spool Section

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FIGURE 20. Remote Weld Cross-Section

- Nozzle plug and spool piece
- The environmental test chamber.

The welding current, voltage, weld head, rotational travel speed, and weld joint temperature are recorded. Control of these four welding parameters is essential to permit accurate welding reproducibility.

By use of a remotely controlled hoist, the prototype weld head was lowered onto the nozzle shield plug instrument connector and locked.

The first closure test weld in this phase was performed on specimens using all 304 stainless steel material. The following conditions were established:

Initial Weld Current	160 A
Main Weld Current	147 A
ARC Voltage	18 VDC
Rotational Travel	5 in./min
Overall Weld Time	4 min, 36 sec
Specimen Temperature	500 °F

After initiating the weld, the welding arc and weld puddle were closely observed throughout the weld sequence. No irregular arc action was noted, indicating that sodium and/or sodium vapors which may have been present in the test specimen, had no adverse effect upon the weld bead. Surface appearance and weld bead shape were very good.

After welding and cooldown, the weld specimen was removed for examination. A dimensional check of the nozzle "pull down" was performed.

During Phase 3 testing closure welds were made with material combinations of 304 and 316 stainless steel. Filler rings of 304 material in combination with 304 or 316 base

material produce good quality welds where 316 filler rings used with 316 base material showed evidence of weld cracking.

The performance and tests indicate the automatic remote weld head is capable of producing reliable repeatable closures of the closed loop top face nozzle. Further, testing should be conducted for statistical reliability, and to improve operating techniques.

CUTTER DEVELOPMENT

There are many methods that can be applied for separating the stainless steel welded nozzle closures. Because of economics and scheduling, and FFTF design constraints, it was not possible to pursue methods, processes, or techniques that could not be substantiated by actual or related applications long accepted by industrial practices. A survey of metal removing processes was made and it was soon evident that conventional methanical cutting methods should be pursued if FFTF goals were to be realized.

Experimental tool bit tests were performed with conventional machine shop setups cutting on stainless steel plates. Methods that showed promise were the trepanning tool and side milling.

This section covers the experimental phase of the cutting program. The discussion concerns survey evaluation, conceptual studies, preliminary cutter designs, fabrication and feature testing of cutter tools, test modules, and the remote POP machine.

SURVEY OF MACHINING PROCESSES

In the early concept stage of the Remote Cutter Machine, many cutting processes and methods were considered for use in this program.

A list of machining processes reviewed follows:

Laser Beam Machining; (LBM)

Laser Beam Machining is a method of cutting where the work material is melted and vaporized by a narrow beam of intense monochromatic light (a lasser beam). When the beam strikes the workpiece, the heat that is produced melts and vaporizes even the most refractory work materials.

Disadvantages:

- High capital and operating cost
- Limited applicability (thin workpieces and removal of small amounts of material)
- Slow material removal rate
- Nonuniformity of holes and cuts
- Heat damage effects on workpiece.

Electron Beam Machining (EBM)

Electron Beam Machining is a method of cutting material in a vacuum by using a focused beam of high velocity electrons. As the electrons impact with the workpiece, the kinetic energy of the electrons changes into heat that vaporizes a small amount of the workpiece. The vacuum is necessary to prevent scattering of the electrons by collision with gas molecules. By controlling beam energy at a lower level, the process is used for welding instead of machining.

Disadvantages:

- High cost of equipment
- Limited applicability (only small amount of metal can be removed)
- Slow material removal rate
- Nonuniformity of holes and slots.

Abrasive Jet Machining (AJM)

Abrasive Jet Machining is no more than a controlled, concentrated sand-blasting operation.

Disadvantages:

- Slow material removal rate
- Embedding of abrasive in workpiece
- Limited amount of metal removal.

Ultrasonic Machining (USM)

Ultrasonic Machining is a process where material can be removed from a workpiece through vibration of an abrasive slurry between the workpiece and the tool.

The tool oscillates at approximately 20,000 cycles/sec.

Disadvantages:

- The use of abrasive slurry
- Particles left imbedded in the workpiece
- Very low metal removal rate

Chemical Machining (CHEM)

This process is a further refinement of metal etching.

Disadvantages:

- Too much time is needed to complete the process.
- Required ambient temperature of the area to be machined, relative to the material to be machined, is far from ideal (The material to be machined is approximately 500 °F).

Electro Chemical Machining (ECM)

Electro Chemical Machining is the controlled removal of metal by anodic dissolution in an electrolytic cell where the workpiece is the anode and the tool is the cathode. An electrolyte is pumped through the gap between the tool and workpiece while DC current is passed through the cell at a low voltage, thus dissolving the metal of the workpiece at a very high efficiency.

Disadvantages:

- Very high cost of operating equipment
- Electrolytic cell requirement
- The use of liquid sodium in the immediate area is not allowable in this program.

Electrical Discharge Machining (EDM)

Electrical Discharge Machining is a method of cutting material by means of controlled removal of material through melting or vaporization by high frequency electrical spark. The spark is produced by controlled pulsing of direct current between the workpiece (positively charged) and the tool (negative electrode).

This process requires that the workpiece and the electrode be immersed in a dielectric fluid. The gap between the workpiece and electrode is approximately 0.0005 to 0.020 in. The fluid is partially ionized under the pulsed application of high voltage and thus enables the spark to pass between electrode and workpiece with enough heat to melt or vaporize the material being machined (leaving a tiny pit or crater).

Disadvantages :

- A fluid is used
- In this program, the requirement of a positively charged workpiece is impractical.
- Electrode wear rate is very high
- Operation is lengthy

Grinding

Metal removal by grinding normally is accomplished by subjecting the workpiece to abrasive grits constrained in a suitable matrix, with the removed particles being carried away through the use of suitable coolant.

Disadvantages :

- Removed particles are left imbedded in the wheel
- Abrasive particles are left imbedded in the cut material
- Slow material removal rate
- Size control - wheel wear would tend to contribute to a size variation.
- Use of coolant is required

Milling (End Mill Test)

One end mill (flute spiral) was held in a spindle of a Bridgeport Milling Machine and was operated at 1000 ~~RM~~ (32.7 FPM) and plunged-cut 0.010 in. deep into 304L SS weld material with no coolant used. The diameter of the cutter was 1/8 in.

The workpiece was clamped to a rotary table rotated by hand power.

Results:

- Cutter made four revolutions at a total depth of 0.040 in. and then failed.
- Cutting chips appeared almost granular; excellent for vacuum removal.
- Tool failure was attributed to loss of cutting edge. This resulted in excessive cutting pressure causing beam failure at neck of tool. This in turn caused the cutter to break at the neck near the shank.

DESIGN STUDIES

Several concepts have been considered for separation of the top closure weld joint. Some of the methods investigated appeared feasible, but could not be pursued beyond drawing layout studies because of economic and schedule constraints. The most significant uncertainty common to all concepts reviewed was the stringent requirement for 100% removal of the cut material. Also, the absence of lubricants during the cutting process further aggravates chip recovery problems. Excessive heat promotes tool degradation shortening tool life and causes erratic chip formations.

Concepts that were considered appropriate candidates for separation of the top closure welds, or related application are:

- a Vibration Cutting: The controlled vibration method of cutting investigated was based on the excellent broken chips produced as a result of natural vibration (chatter) that was inherent in the multiple tooth test module ("Multiple Tooth Trepanning Tool," page 75). Experimental testing would be necessary to derive the optimum chip formations compatible with axial amplitudes and frequency rate induced to the rotating cutters. Suitable low cost hydraulic oscillators are currently available that, with minor modifications, could be adapted to the existing cutter head trepan test assembly.
- Nutator Cutting Concept: A layout was prepared (page to evaluate a unique scheme of nutating a rotating cutter head (grinding or hole saw type) by air motors. The angle of nutation is only 1° , which relieves normal full contact tool pressures and also aids in cut material dispersion. The scallop cutting action derived from the tilt cutting axis is expected to produce short stringers if a cutter type tool were used.
- Diamond Cutting: Diamond abrasive grinding wheels are rarely used to remove stainless steel material; particularly, where proper liquid coolants-lubricants are not permitted. However, new bonding resins are being developed and gas coolants considered in place of liquid lubricants. Extensive review and experimentation would be required to develop this technique of joint separation.

TREPPANNING CUTTING CONCEPT

Single Point Trepanning Tool

The major objective of this development phase was to obtain a cutting tool shape that would consistently produce chips that are capable of being 100% removed by vacuum. Tool manufacturers were consulted for technical support to establish

tool configurations. Modifications of three basic chip breaking techniques were tried. Figure 21 shows the designs and test results of the configurations that appeared to hold promise. These are:

- Compounding bending fracture technique
Chip flow circle
- Stepped tool cutter

Compounding Bending Fracture Technique

This cutting method is based on breaking the cut stringer into short segments by inducing bending in two directions. The fracture is caused by forming a lateral fold in the chip from cutting action along with a subsequent tight curl as the material is pushed off the front rake of the tool face. Experimental setups were made in a conventional engine lathe utilizing special built tool holders. The optimum chip produced was approximately 3/4 in. long during short time testing periods. Extended running time, or new setups made, produced either a combination of intermittent short and long chips or the conventional long stringer. Many design modifications based on compound bending principles were tested with spasmodic success. It was concluded that due to the variance of tool wear, cratering and chipping, this method would not consistently produce chips of a size that could be easily extracted through a vacuum system.

Chip Flow Circle

This technique is based on bending the cut material in an extremely tight circle. It was found that when the chip flow circle approached the breaking range, the material buildup on the tool would either break the tool cutting face or change the chip formation. (This condition would normally be combated

COYPOUND BENDING					
Tool Geometry	Material		Feed in/RPM	Speed S.F.P.M	Remarks
	Tool	Sample			
1.	SS-T8	304 SST	.001		Design parameters required vacuumable chips. Subsequent testing succeeded only with tool chatter and manual feed of .0001 in/REV, otherwise, chip consisted of continuous helical stringer.
2.	HSS-T8	304 SST	.0076	30	Produced continuous stringer. Also experienced heat build-up at tool edge.
3. Tool Ground same as #2, except 5/8 Dim. changed to 1"	HSS-T8	304 SST	.0076	30	Produced continuous stringer. Heat build-up at tool edge.
4. Tool ground same as #3, except 3° changed to 1° and 1" changed to 1/4"	HSS-T8	304 SST	.0076	30	Stringer curled tighter than #3 test. Also experienced less heat build-un.
5. Tool ground same as #4	HSS-T8	304 SST	.0038	30	Stringer curled tighter than #4.
6.	HSS-T8	304 SST	.0014	30	Produced small vacuumable chins. However, chip configuration inconsistent (not uniform in section).
7.	HSS-T8	304 SST	.0014	30	Tight Helical chips. Uniform in section. Varied in length from 1/8" to 4".
8. Tool ground same as #7, except .080R changed to .070R	HSS-T8	304 SST	.0014	30	Same general chip appearance, except more 1/8 long than test #7.
9.	HSS-T8	304 SST	.001	30	Produced irregular chips of many shapes.
			.005	30	Produced chips of more constant shape with more 3/8 long than continuous Helical coils.
10.	HSS-T8	304 SST	.001	30	Continuous coiled chin.
			.005	30	Continuous coiled chin heavier section.
CHIP FLOW CIRCLE					
11.	HSS-T8	304 SST	.001	30	Light feed rate - continuous stringer
			.003	30	Heavy feed rate - material build-up on tool face. Chip essentially the same.
			.005	30	
	Tungsten Carbide (K-6)	304 SST	.001	70	Chip configuration essentially the same (better flow characteristics).
			.003	70	
			.005	70	
12.	Tungsten Carbide (K-6)	304 SST	.001	70	Continuous stringer.
			.002	70	Continuous stringer (tighter helix).
			.005	70	Tool loaded (due to non-lubricated cutting).
13.	Tungsten Carbide (K-6)	304 SST	.001 through .010	70	Stringers at low feed rates with increasing chip breaking action occurring at higher feed rate. (.010 feed rate approaching maximum Dower capabilities of application.)
14.	Tungsten Carbide (K-6)	304 SST	.001 through .010	70	Same action as Test 13, however, chip breaking occurred in medium feed range.
STEPPED CONFIGURATION
HSS-T4	304 SST	.001 through .010	70	Chip breakage by directed collision occurred, but not with uniform results.

FIGURE 21. Single Point Tool Designs

with the use of a proper lubricant and cooling.) Further investigation of this cutting method utilizing harder materials was planned for in the multiple tool head assembly.

Stepped Tool Cutter

This approach incorporated two separate cutting surfaces staggered in depth in the same tool bit. The two surfaces were ground so as to direct their respective shavings into a collision course with each other, thus, promoting chip breakage. Various designs were tested and all yielded similar negative results. In addition to producing separate curled thin stringers, the material had a tendency to pile up in the gland ahead of the cutter creating a tool breakage hazard.

Multiple-Tooth Trepanning Tool

Chip formations obtained during the single point Chip Flow Circles tests appeared suitable for **adaption** into the multiple-tooth head assembly. A basic trepan cutter was designed and constructed, utilizing four equally-spaced tungsten carbide inserts to combat wear and cratering of the cutting edges (Figures 22 and 23), thus providing not only quality cutting edges but less obstructions for chips to cling to. The initial design employed basic tool geometry, using positive rake angles with minimum clearances. No chip breaker was used so that cutting characteristics and chip formations could be studied as tool modifications were made. The cutter head was tested in a radial-arm drill press while the work piece was mounted to the drill press table. An interesting phenomenon occurred from this arrangement.

Because of the cantilevered mounting of the rotating head assembly in the press, coupled with reaction loads from cutting pressure, a definite axial vibration (chatter) was set up that produced excellent small broken chips throughout the entire

FIGURE 22. Trepanning Cutter Test Assembly

FIGURE 23. Trepanning Test Assembly

Neg 50518-1

cutting process (Figure 24). Natural frequency was 59 cycles per cutter revolution at precisely 14 rpm feed and 0.004 in. plunge per revolution. It is interesting to note that the frequency cycles per revolution is uneven and not a multiple of number of cutters (4). Natural chatter cutting cannot be predicted for a remote cutting machine; however, duplication of vibration motions by mechanical means to obtain segmented chips does appear feasible.

The trepanning test assembly was then modified to impart a pulsed-feed motion to the cutters similar to the natural frequency cut profile experienced in the unsupported drill-press setup. The mechanism consists of two hardened steel cam surfaces designed to trace 7/16 in. scallops 0.007 in. deep into the weld material (see drawing, Appendix D-1).

Testing of the pulsed-feed concept in a rigid power head produced segmented chips too long to be vacuumed through the test assembly. It appeared that short sections had been separated, but subsequently welded together, apparently because of heat generated from cutting, and pressure and resulting from metal flow restrictions. The four cutter tool bits were equally spaced in the test head assembly and, therefore, traced identical cutting paths. The final design tested, located two of the four cutters 180° apart but 1/2 pulse out of phase with the other cutters also 180° apart. Preliminary testing of this scheme produced excellent chip formations. Continued testing is needed to further evaluate the merits of this concept. Figure 25 shows the pulsed-feed trepan test model and chip formations.

SIDE-KILL CUTTER CONCEPT

Rotary mill cutting is a conventional machine shop method for cutting parallel side slots. Small tooth penetrations in the cut material yield only small granular chips. The

Neg 50518-6

FIGURE 24 Multiple Tooth Cutter

Neg 51582-3

FIGURE 25. Pulsed-Feed Trepan Test Module

important benefit of small chip formations, easily vacuumed, led to an investigation of the side-mill cutting technique. Multiple cutters, rotated in a circular path to make a face-cut gland, conform ideally with the annular shape of the nozzle weld joint developed by the welding program. Two basic uncertainties had to be resolved to verify this cutting concept: (a) development of specially ground, side-cutting surfaces on the cutter to shape the inside face* of the gland; and (b) development of structurally sound cutters capable of penetrating through the weld bead (0.220 in.) with only a 0.128 in. gland width. Experimental testing was initiated on standard shop cutters modified for side cutting to resolve these questions. Favorable results led to construction of the multiple cutter test module and then the POP remote cutting machine.

Single Cutter Evaluation

A standard 14-tooth Woodruff key cutter was modified (page D-2). The modification consisted of grinding cutting teeth on one side of the cutter as well as the normal cutting surfaces. This cutter was placed in a standard milling machine and tested on acrylic plastic. A granular cutting chip was produced which was excellent for vacuum removal. The modified cutter was then tested on aluminum plate, and again a successful chip configuration was obtained, with the chip granular and excellent for vacuum removal. A third test was performed on welded stainless steel plate, and once again a successful chip was produced.

* *The cutting edges must be capable of withstanding extended dry cutting on stainless steel.*

Multiple Cutter Test Module

Design features that obtained excellent test results for the modified Woodruff key cutter were applied to the design of the Multiple Cutter Test Module. The module had to be designed within the limitations of the machine shop equipment. Figure 26 illustrates the improved module while Figure 27 shows the test module initially tested.

The module consists of four rotary cutters equally spaced in a cylindrical housing. Rotary motion is provided by a bevel ring gear that turns a small bevel pinion gear fixed to each cutter. The circular feed control is provided by manual control of the work table which mounts the cut specimen.

A shroud coupled to a vacuum source is positioned around the head assembly for chip removal. The first module assembly was equipped with four 14-tooth side-milling cutters as shown in Figure 28.

Initial testing in aluminum plates produced good results; the component parts functioned satisfactorily, and the gland size was well within the limits required for the weld filler ring. The cutters produced small granular chips that were all removed through the shop vacuum system.

The next development step was to test the cutters on a welded stainless steel work sample. After five minutes of cutting, a failure occurred in the cutter shaft assembly bolt. The test module was disassembled and inspected, and the following design changes were incorporated:

- A third bearing surface was provided inboard of the pinion gear to prevent shaft bending

FIGURE 26. Side-Mill Test Module

Neg 50518-3

FIGURE 27. Original Side Mill Test Module

Neg 50518-5

FIGURE 28. 14 Tooth Side-Mill Cutter

- The radial ball bearing was replaced with a close tolerance tapered roller bearing to provide dynamic stability
- Machining tolerances were reduced, in general, to provide a better running fit
- Uniform torque was applied to all assembly bolts
- Cleanliness of assembly procedures was improved
- A new set of high quality cutters was procured and several design and material changes were incorporated to improve wear, cutting stability, and structural integrity (The revised 40-tooth cutter assembly is shown in Figure 29.)
- The bevel gears were resurfaced and dry-film lubricated to minimize backlash; to improve wear and tooth bearing loads
- The sintered iron cutter shaft bushings were replaced with precision-ground chrome-plated surfaces.

The module was again assembled for testing with the incorporation of the design changes mentioned (see Figure 26) with the exception of the chrome-plated bushings. Static-load deflection tests proved the new cutter shaft mounting rigid. Testing was limited, however, to cutting on soft materials only until the new, 40-tooth cutter could be reground to remove soft skin material from the cutter face surfaces. Although extensive testing has not been performed on welded steel samples, the cutter module assembly provided sufficient data to proceed onto construction of the POP test stand and remote cutting machine [discussed under "Remote Cutting," POP].

Neg 51241-4

FIGURE 29. 40 Tooth Side Mill Cutter Assembly

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APPENDIX A
WELD PROCEDURE

APPENDIX A*

WELD PROCEDURETOP CLOSURE REMOTE WELD TEST PROCEDUREGeneral

The purpose of this procedure is to describe the functions necessary to perform a test weld under controlled prototypical conditions in the FFTF Environmental Weld Test Chamber. The procedure is divided into four parts: Environmental Chamber Operation, Test Specimen Installation, Weld Procedure, and Test Specimen Removal.

Environmental Chamber Operation Start Up

1. Energize the gas purification system for at least 16 hr to regenerate the oxygen removal system in accordance with instruction manual for Model RTL-700-5-7 purification system.
2. Energize the moisture and oxygen monitors. Allow to "warm-up" at least 30 min prior to placing in operation.
3. Switch moisture monitor attenuator switch to the X100 position. Make sure the slide switch in the rear is in the "AC" position.
4. Valve the O₂ and moisture monitors to the gas bottle and adjust the flow through the O₂ monitor to $\approx 100 \text{ cm}^3/\text{min}$. Adjust the gas pressure to the moisture monitor to 20 to 40 psig. Check and verify flow.
5. Seal off the environmental test chamber. By using the vacuum "roughing" pump, pump the environmental test chamber down to $\sim 1000 \mu$.

* *Procedures, L. J. Rosseau*

6. Close isolation valve between the test chamber and the "roughing" pump. Take a leak rate check; the test chamber must maintain a minimum of -28 in. for 15 min. Locate and correct leakage(s) before continuing if necessary.
7. Pump down the test chamber with the "roughing" pump to -30 in. Hg. Hold this vacuum with the "roughing" pump.
8. Calibrate the O_2 monitor by the following method:
Zero Adjustment. With the sample gas from the helium bottle set at $\approx 100 \text{ cm}^3/\text{min}$, set the helipot Duodial at zero. Turn the lamp "on". Rotate the zero knob until the light beam is centered on the vertical black line engraved in the middle of the translucent scale. Turn lamp "off" to conserve the lamp life.
9. At the gas purification panel, turn on the vacuum pump switch, the selector switch, and the pressure safety control switch. All other switches except the main power switch should be "off".
10. Close valve from the test chamber to the "roughing" pump.
11. Open the valve from the helium gas storage bottles to the test chamber. Thoroughly purge the entire system including the test chamber, the air lock, piping, and the gas purification system. Open the main inlet valve and the main outlet valve to the dryer-purifier tank, plus the main stream recirculation control valves.
12. After purging, turn "on" the recirculation pump. All main flow valves are fully open and vent valves closed.
13. Slowly close the inlet/outlet cross-over valve. Do not allow the pump pressure to become excessive (greater than 6 psig delta). Allow the system to dry down.

14. Valve the O₂ and moisture monitors from the helium gas storage to the environmental test chamber recirculating system.
15. At the O₂ monitor adjust the flow to $\approx 100 \text{ cm}^3/\text{min}$. Turn "on" the lamp. Rotate the Duodial until the light beam is brought back to the vertical line.
16. Read the Duodial, and calculate the O₂ concentration with the following formula:

$$\frac{\text{Duodial Reading}}{1000} \times \text{Range Switch Reading} = \text{O}_2$$

17. Turn "off" O₂ monitor lamp.
18. If the O₂ concentration is greater than 1% turn "on" the oxygen furnace on-stream valves. Turn "on" the oxygen furnace heater. Continue recirculation of the test chamber atmosphere. Periodically check the oxygen concentration with the oxygen monitor. Turn lamp "off" after each analysis to conserve lamp life.
19. Continue oxygen removal until analysis shows "0" indicated oxygen in the test chamber atmosphere.
20. Valve the moisture monitor from the gas bottle storage to the test chamber atmosphere. Moisture content must be less than 4 ppm before test weld. Continue gas purification recirculation until this parameter is reached.

Test Specimen Transfer

Attach the insert filler ring to the nozzle plug by three equally spaced spot welds prior to installation into the test chamber.

1. Close inner air lock door.
2. Check and insure air lock valves to the gas purification system are closed.

3. Open outer air lock door and insert the spool piece, nozzle shield plug with insert filler ring attached, and the soft metallic "K" seal.
4. Close and lock outer air lock door.
5. With the vacuum "roughing" pump, evacuate the air lock to a -30 in. Hg.
6. Take a leak rate check. Hold at -28 in. for at least 15 minutes. Repair leaks if necessary.
7. Evacuate the air lock to -30 in. Hg. Close valves.
8. Back fill the air lock chamber to "0" psig with helium.
9. Repeat Item 7 and 8 twice before proceeding with next step.
10. Valve the gas purification system, oxygen monitor and moisture monitor from the test chamber to the aid lock chamber.
11. Recirculate until the air lock atmosphere is less than 4 ppm moisture and "0" ppm oxygen.
12. Valve the gas purification system from the air lock to the test chamber.
13. Equalize the test chamber and air lock by opening the by-pass equalizing valve.
14. Open inner air lock door.
15. Transfer test specimens into the weld test chamber.
16. Close and lock inner air lock door. Pump down air lock to at least -30 in. Hg vacuum and hold.
17. Pick up the test specimen spool piece with the remote hoist and transfer it to the test specimen well. Remove the hoist and install transfer spool section into test well.

18. At the control side of the environmental chamber, make up the 3/4 in. Swagelok sodium fill line fitting to the spool piece, using the remote 1/2 in. drive coupler.
19. At the opposite side, clamp the spool piece heater bands with the remote 3/8 in. drive.
20. Energize the spool piece heaters and heat until the TC's indicate desired test temperature.

Bring temperature of sodium system up to desired test temperature.

21. Pressurize the sodium storage tank with helium to -1 to 2 psig.
22. Slowly open the sodium fill valve until the sodium reaches the desired level in the spool piece.
23. Set sodium level in test spool piece by balancing pressure in sodium reservoir with pressure of test chamber.
24. Close helium supply to the sodium storage tank and using the vacuum pump, evacuate the gas from the storage tank.
25. Clean all residual sodium from "K" seal area at bottom of spool piece.
26. Install the soft metallic "K" seal into the spool piece.
27. Using the chamber hoist, pick up the nozzle shield plug test specimen grapple and place it on the nozzle plug.
28. Grapple will automatically lock to nozzle plug as the grapple is lifted by the hoist.
29. Transfer nozzle plug and lower into position in spool piece.
30. Remove the grapple and return it to its stored position.

31. At permanently identified 90 degree intervals, take reference measurement from the top of the nozzle plug to the top of the spool piece. Record this dimension as "Before Weld" for comparison to "After Weld" dimensional check.

Test Weld Procedure

1. Heat the nozzle and spool to the desired temperature.
2. At the Weld Programmer Control Panel, check and set the following:
 - a. Selective start switch at 6.
 - b. Initial current at 170.
 - c. Initial slope rate at 7.10 sec.
 - d. Weld current at 160.
 - e. Finish slope rate at 4.50 sec.
 - f. Finish current at 25.
 - g. Panel/remote switch on "Remote".
3. At the Sequence Timer Panel:
 - a. Sequence Timer I turned "on" and set at 110 sec.
 - b. Sequence Timer II turned "on" and set at 122 sec.
 - c. Sequence Timer III turned "on" and set at 5 sec.
4. At the Gas, Water and H.F. Panel, check and set:
 - a. High frequency in the start position.
 - b. Gas (and water) switch "off".
 - c. Preflow switch "off".
 - d. Postflow switch "off".
 - e. Polarity switch set in "straight" position.
5. Recheck test chamber atmosphere for O_2 and moisture. O_2 must be "0" ppm and moisture less than 4 ppm. Clean up if necessary.

6. If gas monitors indicate atmosphere is acceptable, fire test arc on titanium, tantalum, or Zircaloy using manual weld torch. Test weld must remain silvery and bright. If test weld shows discoloration, turn on all heaters in chamber and maintain temperature on test specimen at 500 °F while purification system is recirculating gas in the chamber. This will hasten chamber atmosphere cleaning.
7. Using the arc gap "feeler" gage, check the clearance between the electrode and the insert filler ring set arc gap at 0.025 in.
8. Place weld head lock-unlock selector switch in "Unlock" position. Make certain that locking cylinder gas pressure is at least 200 psi.
9. Pick up the weld head with the hoist and install it on the nozzle plug. Lock the collet by placing the lock selector switch in the lock position, energizing the locking gas cylinders.
10. Disconnect the hoist and return it to its stored position.
11. Set the weld head drive speed control to 3.74 and power switch "on" and the directional switch in the "R" position.
12. Set the weld current on the remote control unit to 160 amp.
13. Start the remote weld by depressing the "Start Weld Reset" button on the remote control unit. Observe that:
 - a. The weld arc is initiated and gradually increases for the programmed time to the main weld current.
 - b. The weld head starts and continues to rotate.

- c. Check the quality of the arc frequently for the duration of the weld.
 - d. At the finish of the weld head rotation, the weld current gradually decreases over the programmed time and is extinguished on schedule.
14. If any evidence of an "off-standard" condition occurs, terminate the test by depressing the "Stop Weld" button on the remote control unit.
15. Remove the weld head from the nozzle plug with the chamber hoist.

Test Specimen Discharge

1. Close the helium cover gas supply to the sodium storage tank.
2. Using the vacuum "roughing" pump, evacuate the gas from the sodium storage tank.
3. Open the spool "Drain-Fill" valve and allow the sodium to drain to the storage tank to its previous "filled" level.
4. De-energize the spool piece band heaters.
5. When cool, disconnect the nozzle and spool piece TC's.
6. Using the 3/8 in. drive opposite the control panel, loosen and free the spool piece band heaters.

At the control panel side of the panel, loosen and remove the sodium fill line from the test specimen with the 1/2 in. remote drive coupling.

8. Using the chamber hoist, position the grapple on the nozzle plug, remove welded test specimen, and transfer to the air lock door for removal from the chamber.
9. Install cap in spool piece 3/4 in. Swagelok prior to removing the specimen from the main test chamber.

10. Remove the test specimen grapple and return to the "Store" position.
11. Sample the air lock atmosphere for O_2 and moisture by valving the purification system from the test chamber to the air lock.
12. If O_2 is "0" and moisture less than 4 ppm, open the equalizing valve and open inner air lock door. If not, recirculate the air lock atmosphere before opening the inner door.
13. After inner door is opened, position the test specimen into the air lock, close the inner air lock door and close the equalizing valve.
14. Open the outer air lock door and remove the specimen.
15. Close and lock outer air lock door. Pump air lock down to 1000 μ .

Postinspection

1. Inspect the welded test samples as follows:
 - a. Visually inspect for welded bead uniformity, melt-down and defects.
 - b. Dimensionally inspect for distortions and shrinkage.
 - c. Pressure check with helium gas at 250 psig and 500 °F for 2-1/2 hr.
 - d. Check leakage rate. Leakage is not to exceed 10^{-7} atm m^3 /sec helium.
 - e. Repeat (b).
 - f. Radiograph entire test specimen to determine condition of "K" seal joint and weld bead profile.
 - g. Section selected sample to confirm weld bead characteristics.

PHASE I

WELD TEST PROCEDURE

Date: 2-22-68

Procedure: AUTOMATIC REMOTE CONTROLLED TUNGSTEN ARC CLOSURE WELDS.

SIMULATED CLOSED LOOP TOP FACE HARDWARE (FFTF)

Material Type: 304L STAINLESS STEEL

Weld Joint Design:

Weld Position: FLAT

Welding Process: AUTOMATIC TUNGSTEN ARC

Welding Power Supply VICERS - 200 "D"

Weld Sequence Time Controller Type: ROTOMATIC

Welding Current	Polarity	Pre-Weld	Time	Main-Weld	Time	Post-Weld	Time
Amps:	DC/SP	260	10.S	200	3M. 10S	60	7S.
Volts:		22	10.S	22	5M. 10S	20	7S.
O.C.V.: 84							

Arc Gap Setting: 0.065 In.

Inert Gas Flow @ C.F.H.	Pre-Flow	Time	Post-Flow	Time	Continuous
Torch:	- A. 30 He.	10S.	-- A. 30 He.	20S.	-- A. -- He.
Purge	" "	" "	" "	" "	" "
	" "	" "	" "	" "	" "
	" "	" "	" "	" "	" "

Drive Motor Speed Setting: 28 = 11-3/4" I.P.M.

Weld Joint Temp.	@ Weld Start	@ Weld Finish
Degree F:	-----	-----
Monometer Reading,		
@ Inch. Water Press:		
10th In. Water Press:		

Test Results:	X-ray	Section Etch	Bend Angle	Appearance
Sample Id: 3	-----	GOOD	-----	GOOD

PHASE II WELD TEST PROCEDURE

Date: 01-03-69

P o : AUTOMATIC REMOTE CONTROLLED TUNGSTEN ARC WELD, SIMULATED CLOSED LOOP
TOP FACE HARDWARE (FFTF), PHASE 2.

Material Type: 304 STAINLESS STEEL.

Weld Joint Design:

Weld Position: FLAT

Welding Process: AUTOMATIC TUNGSTEN ARC

Welding Power Supply VICKERS-200-D

Weld Sequence Time Controller Type: ROTOMATIC

Welding Current	Polarity	Pre-Weld	Time	Main-Weld	Time	Post-Weld	Time
Amps:	DC/S	220	10 sec	210	3m.10s	60	7 sec
Volts:		21		21		18	
O.C.V.:	80						

Arc Gap Setting: 0.065 In.

Inert Gas Flow @ C.F.H.	Pre-Flow	Time	Post-Flow	Time	Continuous
Torch:	- A.	15 He.	3m.27s.	- A.	- He.
Purge Recirculating	- "	"	- "	- "	" "
Helium Atmosphere In	- "	"	- "	- "	" "
Weld Chamber	- "	"	- "	- "	" "

Drive Motor Speed Setting: = I.P.M.

Weld Joint Temp.	@ Weld Start	@ Weld Finish
Degree F:	250°F	250°F
Monometer Reading,		
@ Inch. Water Press:	Chamber-0.500 in.	
10th In. Water Press:		

Test Results:-	X-ray	Section Etch	Bend Angle	Appearance
Sample No: <u>AT-1</u>	<u>No definition</u>			<u>Good</u>

APPENDIX B

SIDE - MILL CUTTER TEST PROCEDURE

APPENDIX B

SIDE-MILL CUTTER TEST PROCEDUREDEVELOPMENT TEST PROCEDURE REMOTE CUTTER

The purpose of this test is to prove that the Side-Mill Cutter Concept Design will satisfactorily cut a simulated closed loop top closure sample in a controlled environment with 100% chip removal.

Secondary benefits of the test include:

- Finalization of cutter drive speeds
- Tool life data
- System debugging before final design release.

DEVELOPMENT TEST PROCEDUREStatic Test

With the cutter head in the "up" position:

1. Disconnect electric power from the drive motors.
2. Turn on vacuum exhaustor (approximately 38 in. H₂O vacuum source).
 - a. Check for vacuum at cutter openings.
3. Turn on shop make-up air supply and check for air out of the tool outlet.

Running Test

With the cutter head in the "up" position (raise with jack screw) :

1. Energize electrical power to the drive motors.
2. Check plunge drive limit switches for operation.
 - a. Run plunge drive "down".
 - Check that down limit switch operates.
 - Adjust limit switch as required to provide full down travel.

- b. Run plunge drive "up".
 - Check that "up" limit switch operates.
 - Adjust limit switch as required to provide full up travel without jamming machine.
 - c. Check for unusual plunge drive operation--noise, vibration, binding, etc.
 - d. Set previously calibrated plunge control dial to 0.004 in./min.
3. Operate cutter drive
 - a. Check for eccentricity.
 - b. Check for unusual operation--noise, vibration, binding, etc.
 - c. Set previously calibrated drive control dial to 3/4 in./min (0.46 rpm on gearbox output shaft).
 4. Operate cutter rotation drive.
 - a. Check for cutter wobble.
 - b. Check for unusual operation--noise, vibration, binding, etc.
 - c. Set previously calibrated rotation dial to 90 rpm.
 - d. Mark controller so setting can be repeated.
 5. Stop drive motors with plunge drive in the "up" position.

Cut Preparation

1. Place "Cold Test" piece into fixture and secure.
2. Lower cutter head to work piece.
3. Activate collet clamp.
 - a. Check for security.
 - b. Check that cutter teeth clear work piece by approximately 1/8 in. (if teeth do not have clearance, readjust plunge drive limit switches.)
4. Actuate chip vacuum.

5. With regulator closed, open valve to shop make-up air.
6. Gradually open air regulator until 0 psi differential pressure is achieved between the test chamber and atmosphere.
7. Operate cutter rotation drive at speed determined in Running Test, Step 4.
8. Lower plunge until cutter teeth just engage the work piece.
 - a. Check for contact of all four cutters.
 - b. Check for looseness, or rocking of the cutter assembly.
9. Operate cutter feed at speed determined in Running Test, Step 4 for 1/3 revolution and check as in Step 8 above.

Cutting Test (Step Plunge)

1. With cutter rotation drive and cutter feed drive operating, lower plunge 0.030 in. (approximately 2-1/2 revolutions of the gearbox output shaft).
2. Allow tool to complete cut (approximately 1/4 revolution). While the tool is running, check for:
 - a. Proper chip removal.
 - b. Cutter chatter.
 - c. Hunting of cutter feed drive.
 - d. Hunting of cutter rotation drive.
 - e. Evidence of excessive cutting temperatures.
 - f. Evidence of excessive gear or bearing forces.
 - g. Evidence of collet clamp slippage or shaft bending.
3. Repeat Steps 1 and 2 until work piece is cut through.
 - a. Check for sudden rise or drop of the cutter mechanism at breakthrough.
 - b. Check for wobble of the cutter mechanism at breakthrough.

4. Raise cutter head with jack bolt.
5. Stop cutter drive motors.
6. Remove work piece outer ring from fixture.
7. Release collet clamp and remove work piece center section from the tool.
8. Inspect the cut for quality.
9. Check for chip residue as a result of breakthrough.
10. Run cutter plunge back to top position.

Test Recording

Repeat operation several times gradually increasing feed, rotation and plunge speeds.

1. Record any unusual operation.
2. Record rpm combinations run.
3. Record chip configuration and removal at each rpm combination.
4. Record time run between cutter sharpening grinds and depth of grind required to sharpen.
5. After each grind, check cutter teeth for configuration and record tooth hardness.
6. At end of test sequence, check cutter teeth for estimated life. (If cutters are replaced before test completion, record hours of cutting time, number of regrinds, and reason for replacement.)

Cutting Test (Continuous Plunge)

1. Perform cut preparation, Steps 1 through 7 (p. B-3).
2. With cutter rotation drive and cutter feed drive operating, operate cutter plunge drive at rpm determined in Running Test, Step 2.

3. When cutters contact work piece, check for even contact, wobble, or chattering.
4. Check cutters while operating as in Cutting Test (Step Plunge), Step 2.
5. Continue cutting until cutters break through bottom of work piece or plunge drive stops against down limit switch. (If drive stops before breakthrough, readjust limit switch.)
6. Perform Cutting Test (Step Plunge), Steps 4 through 10.
7. Perform Test Recording.

"Hot Test" Cutting

1. Place "hot test" piece into fixture and secure.
2. Turn heater "on" and let temperature of the work piece rise to 500 °F.
3. Perform steps as in Cutting Test (continuous plunge).
4. After each cut is complete, check cutter mechanism for evidence of heat damage.

BNWL-1303

APPENDIX C
WELD DESIGNS

SK-3-13669

APPROVED
FOR CONFORMANCE
WITH DESIGN CRITERIA
BATTELLE-NORTHWEST
DATE 4-2-69
BY [Signature]

U. S. ATOMIC ENERGY COMMISSION RICHLAND OPERATION OFFICE	
SCALE FULL	
DESIGNED BY B.P. MOYERS	DATE 3-25-68
ENGINEERED BY [Signature]	DATE 3-25-68
RESPONSIBLE ENG. [Signature]	DATE 3-25-68
APPROVED BY [Signature]	DATE 3-25-68
PROJECT NO. BE-0327 PROJECT TITLE FAST FLUX TEST FACILITY	
DRAWING NO. 300 GFE TUBES NO. 1500 02	
SHEET NO. 1 OF 1	

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
TOLERANCES ON
FRACTIONS DECIMALS ANGLES
± 1/64 ± .005 ± 2°
SURFACE ROUGHNESS IN ACCORDANCE
WITH ASA B46.1-1962

2	AD	3-25-68	(1) ADDED WELD FILLER RING DETAIL	3-25-68
1	12	4-10-68	1. DIM WAS 9.750-9.748	
			2. DIM WAS .765	
			3. DIM ADDED	
			4. DIM ADDED	
			5. REMOVED .750	
			6. DIM WAS 3/4	
			7. DIM ADDED	
			8. DIM WAS 3.750	
			9. DIM ADDED	
			10. DIM ADDED	
			11. DIM ADDED	
			12. DIM ADDED	
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			100. DIM ADDED

GENERAL NOTES
(UNLESS OTHERWISE SPECIFIED)

1. TOLERANCES: FRACTIONAL = $\frac{1}{64}$, DECIMAL = .005, ANGULAR = $0^{\circ}-30'$
2. ALL MACHINED SURFACES $\frac{63}{125}$ SURFACE TEXTURE SHALL BE IN ACCORDANCE WITH: (LATEST) B46.1 (LATEST REV).
3. BREAK ALL SHARP EDGES AND REMOVE ALL BURRS
4. ALL MATL SHALL BE AS SPECIFIED OR APPROVED EQUAL QUALITY.

5. ELECTRICAL ETCH MATL IDENTIFICATION

APPR FOR PERFORMANCE WITH DEDUCTION CONTINUED		DATE	
FOR BY <i>A. Roussau</i> <i>5/26</i>		U. S. ATOMIC ENERGY COMMISSION RICHLAND DISTRICT OFFICE PACIFIC NORTHWEST LABORATORY OPERATED BY BATTELLE MEMORIAL INSTITUTE	
WORK NAME <i>J. ROUSSEAU</i>		SIMULATED CLOSED LOOP WELD TEST SPECIMEN ASSY & DETAILS	
APPROV <i>Bill Jackson</i> <i>5/26</i> <i>HA PLASTING</i> <i>1/26/60</i>		F F F F	
REV NAME <i>NON E</i>		BLDG. NO. <i>300 GFF</i> INDEX NO. <i>1500.02</i>	
CLOSURE BY <i>1/26/60</i> DECLASSIFICATION		DATE <i>4-3-29653</i>	
LAST NAME <i>NON E</i>		PRINT NO. <i>1</i>

										WELD TEST SPECIMEN																					
										ASSY & DETAILS																					
										F T F F																					
<table><tr><td>DATE</td><td>BY</td><td>FOR</td><td>DATE</td><td>FOR</td><td>REV</td><td>DESCRIPTION</td><td>REV</td><td>NO</td></tr><tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr></table>										DATE	BY	FOR	DATE	FOR	REV	DESCRIPTION	REV	NO										CLASSIFIED BY W. S. Souter DATE 11-3-68 REV 1		RLD. NO. 300 GFF	INDEX NO. 1500.02
DATE	BY	FOR	DATE	FOR	REV	DESCRIPTION	REV	NO																							
REFERENCE DRAWINGS										OWB. NO.		H-3-29653																			
NEXT USED ON										DRAWING STATUS		CLASSIFICATION NONE																			

APPENDIX D
CUTTER DESIGN

FOR REMOTE CUTTER
 LOCATION FFTF
 SUBJECT DO-ALL MODIFIED WOODRUFF
KEY SEAT CUTTER

PAGE 1 OF 1
 JOB NO. BD 0490
 DATE JUNE 17 69
 BY L.E.L.

APPROVED. *A. J. [Signature]*

FIGURE D-1.

② CUTTER

CUTTER DATA	
NUMBER OF TEETH	40
MATERIAL	TI TOOL STEEL
PRE-HEAT TEMPERATURE	1500° F TO 1600° F
HARDEN TEMPERATURE	2350° F IN REDUCING ATMOSPHERE
QUENCH	OIL
DRAW TEMPERATURE	900° F FOR 8 HRS. Rc 60-62
SURFACE FINISH	16 RMS EXCEPT AS NOTED
	ALL CUTTING SURFACES 8 RMS

(CONCEPTUAL)

APPROPRIATE CRITERIA		DATE	
FOR <u>CONF</u>		U. S. ATOMIC ENERGY COMMISSION	
BY <u>CONF</u>		RICHLAND OPERATIONS OFFICE	
DATE <u>10/11/64</u>		HANFORD ENGINEERING SERVICES DIVISION OF VITRO CORP. OF AMERICA	
DATE <u>10/11/64</u>		CLOSED LOOP TOP	
DATE <u>10/11/64</u>		NOZZLE REMOTE CUTTER	
DATE <u>10/11/64</u>		DETAILS	
1	CHANGED	NO. NO.	PROJ. TITLE
REV NO.	101	80-2534	FFFF
1	101	100-FF	INDEX NO. 7202
DATE	10/11/64	DATE	10/11/64
NONE		30-K-15370	SHEET NO. 7

D-5

CONCEPTUAL		3RD ISSUE 2-17-70
		2ND ISSUE 5-28-69
		1ST ISSUE 5-9-69
U. S. ATOMIC ENERGY COMMISSION		
RICHLAND OPERATIONS OFFICE		
PACIFIC NORTHWEST LABORATORY		
OPERATED BY BATTTELLE MEMORIAL INSTITUTE		
DRAWN BY J. W. KOLB		5-8-69
CHECKED BY B. G. SMITH		5-8-69
SCALE FULL		
CLASSIFICATION		J.E.M.
NONE		
FAST FLUX TEST FACILITY		
300 GEN		
INDEX NO. 1500.01		
SK-3-14609		
DRAWN BY		
CHECKED BY		
SCALE		
CLASSIFICATION		
NONE		
FAST FLUX TEST FACILITY		
300 GEN		
INDEX NO. 1500.01		
SK-3-14609

Neg 51241-2

FIGURE: D-2. Side Mill Cutter Head Assembly

Neg 51241-2

FIGURE D-3. Side Mill Cutter Ring Assembly

APPENDIX E
FFTF CONCEPTS

(MODIFICATION OF WARD DWG. SK-20029)

FFTF TEST ASSEMBLY CHANGE-OUT SEQUENCE

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