Figure VI-19. - Schematic representation of T-111 creep behavior in the 1600° to 2200° F (870° to 1204° C) range, showing unusual nature of transient first stage creep in this alloy.

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VII. FABRICATION OF T-111 TEST LOOP SYSTEMS*

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INTRODUCTION

The construction of the first large T-111 alloy loop, corrosion loop I, was begun during early 1967. Previously, the performance and reliability of the individual components had been proven with Cb-1Zr alloy during the 5000-hour testing of the Cb-1Zr Rankine system corrosion test loop. Fabrication procedures proven with Cb-1Zr were, therefore, applied directly to the T-111 corrosion loop.

As the welding of T-111 proceeded, it became evident that more stringent requirements for joint alignments were required to prevent external loads during welding. Such loads resulted in a few instances of weld cracking. In general, however, components were fabricated with no more difficulty than normally expected in the first application of an alloy to large systems.

The most serious instance of weld cracking occurred in the boiler component and resulted in cross-leakage between the lithium and potassium circuits. The boiler repair procedures included removal of the boiler and reinstallation in the loop assembly. Since removal of this defect, the corrosion loop has accumulated over 3500 hours of operation at test conditions, thus reaffirming the basic system reliability.

The construction of the boiler development test loop is currently nearing completion. The discussion herein is limited to three components, the lithium heater, boiler, and condenser, which are unique to this system. In each case, the fabrication sequence and related welding techniques are given primary emphasis.

T-111 CORROSION LOOP FABRICATION

The overall fabrication sequence for the T-111 Rankine system corrosion test loop is illustrated in figure VII-1. During loop fabrication, four major subassem-

*Based on work conducted under NASA contract NAS 3-6474.

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blies, the boiler, condenser, lithium heater, and potassium surge tank, were constructed. The condenser and boiler subassemblies were postweld annealed at 2400⁰ F for 1 hour in a vacuum furnace. In the other subassemblies, components were individually postweld annealed prior to assembly welding. These assembly welds were postweld annealed locally using a small refractory metal annealing furnace positioned over the weld joint.

The final loop assembly consisted of first joining the boiler and potassium surge tank major subassemblies. This unit together with the condenser and sodium heater was then positioned in the loop support structure. The welding fixture was then placed in position and attached to the various support positions on the loop. This fixture provided rotation of the loop within the welding chamber to facilitate welding of seven joints required during the final assembly. These welds were postweld annealed locally at 2400⁰ F for 1 hour using a small refractory metal annealing furnace positioned over the weld joint.

The T-111 Rankine system corrosion test loop components as delineated in figure VII-1 were the boiler, condenser, lithium heater, turbine simulators, potassium preheater, two electromagnetic (EM) pump ducts, two surge tanks, a stressed diaphragm pressure transducer, five slack diaphragm pressure transducers, and two bellows sealed valves. The location of these components in the loop assembly is depicted in figure VII-2.

GENERAL WELDING PROCEDURES

Prior to the welding of the T-111 Rankine system corrosion test loop, a preliminary qualification test of the welding equipment was conducted according to requirements defined in GE NSP specification 03-0025-00-A. This specification requires that the inert gas be purified to contain less than 1 ppm each of oxygen and water vapor by volume and that no contamination of the weld metal as determined by chemical analysis occurs during the welding cycle.

The mass spectrometer helium analysis system described in an earlier report (ref. 1) was used to monitor the welding chamber helium for oxygen and nitrogen. An electrolytic hygrometer was used to monitor the helium for moisture concentration. This analysis system was qualified according to specification 03-0025-00-A, which requires a measure of response time after introduction of oxygen (20 ppm), nitrogen (80 ppm), and water vapor (50 ppm) impurities. Response times recorded were 0.8, 2.3, and 4.0 minutes for oxygen, nitrogen, and water vapor, respectively. The full value of water vapor contamination required 14 minutes, because system response was limited by the rate of water evaporation into the helium envi-

ronment. The welding chamber shown in figures VII-3 and VII-4 was used for all tungsten inert gas welding performed on the loop. To accommodate long, straight tubing sections such as the boiler, an extension tube shown in figure VII-3 was attached to the basic chamber. During final loop assembly, the 8-foot-diameter extension tank illustrated in figure VII-4 was used.

The general welding procedure consisted of an overnight vacuum pumpdown with hot water bakeout (140° F) on the chamber. After the chamber was cooled, a pressure of less than 1×10^{-5} torr was attained. The pressure rise rate on the chamber was then taken prior to backfilling with purified helium gas. Welding operations were continued until completed or until gaseous contaminants reached the upper limits of GE NSP specification 03-0025-00-A, 5 ppm oxygen, 15 ppm nitrogen, and 20 ppm moisture (10 ppm moisture content in the case of components to contain lithium).

The welding machine used for both manual and automatic tungsten inert gas (TIG) welding is depicted in figure VII-5. This 400-ampere maximum constant current machine provides a complete weld sequence of upslope, weld, and downslope current control with time delay relays to provide for integration of motorized accessory equipment. During loop fabrication, a large percentage of the welding was done with the hand-held torch shown in figures VII-6 and VII-7. The molded silicon rubber and alumina insulator provide complete electrical insulation of the brass torch body and thus prevent inadvertent arcing to the workpiece. The single-piece chuck is easily accessible if the tungsten electrode requires replacement. Recently, as an added precaution, a T-111 chuck and a T-111 shield for the torch body have been incorporated into the torch design.

Full penetration butt joints were used wherever possible in loop design. Weld groove joint designs were in accordance with NSP specification 03-0015-00-A. This specification requires square grooves up to 0.06-inch thickness, a single 45° V between 0.06- and 0.19-inch thicknesses, and a single U for thicknesses greater than 0.19 inch. Special tantalum V blocks were used for tubular joint alinement. Full penetration tack welds on each side of the joint were then made to maintain alinement. After removal of the V blocks, the root and filler passes were made to complete the weld. Normally, approximately six weld starts and stops were required to complete each weld pass.

CORROSION LOOP FABRICATION

Loop Components

Lithium and potassium EM pump duct. - The typical EM pump fabrication is

illustrated in figure VII-8. Machining of the helical flow passage is the most critical fabrication step. The outer wrapper inside diameter is machined, honed, and inspected dimensionally. The helix is then ground to provide a 0.002-inch diametrical interference with the wrapper. The interference fit is produced by chilling the helix in liquid nitrogen and inserting it into the wrapper which is at room temperature. After completion of welding, the wrapper outside diameter is machined to the proper dimension for fitup with the bore of the EM pump stator. Postweld vacuum annealing at 2400° F for 1 hour is then performed to complete the fabrication cycle.

Slack diaphragm pressure transducers. - Six Taylor Instrument Companies pressure transducers were fabricated, five being required for the T-111 corrosion loop. Each transducer comprises upper and lower flanges, a slack convoluted diaphragm, a process tube, and a bimetallic joint between the Cb-1Zr and stainless steel. This joint, of the brazed tongue-in-groove design, provided for attachment of the stainless steel capillary tubing by Taylor Instrument Companies.

The weld between the diaphragm and upper flange was made by the electron beam process. Tungsten-inert-gas welding was used to join the process tube to the lower flange, the bimetallic joint assembly to the upper flange, and the final weld between the upper and lower flanges. The electron beam diaphragm weld is illustrated in figure VII-9. A trial electron beam weld is shown in figure VII-9(a) and the completed upper flange in figure VII-9(b). A metallographic cross section of this weld is shown in figure VII-9(c). The tungsten inert gas welding of the transducer housing is illustrated in figure VII-10. Radiographic inspection, heat treatment, and mass spectrometer leak tests were performed successfully. The six transducers were shipped to Taylor Instrument Companies for filling of the pressure transmitting capillary with NaK.

One of the six T-111 transducers was returned when a leak was detected across the diaphragm. This transducer was cut open and the defective diaphragm removed. Fluorescent penetrant inspection revealed two radial cracks in the diaphragm near the heat-affected zone of the weld. Subsequent metallographic examination revealed an intergranular crack in otherwise normal diaphragm material.

The transducer was repaired by welding a new diaphragm in place, and it was subsequently proof tested by applying 10 vacuum evacuation cycles on the NaK side of the diaphragm. Mass spectrometer leak testing indicated no failure, and welding and postweld annealing of the assembly was completed. A final mass spectrometer leak test indicated no diaphragm leakage.

The five acceptable transducers were each pulsated five times between vacuum and 0.5 psig by Taylor Instrument Companies. There was no evidence of leakage after testing.

The six transducers were then filled with NaK by Taylor Instrument Companies. A NaK sampler was also filled with NaK at the time of transducer filling. Chemical analysis indicated less than 3 ppm oxygen concentration in the NaK, an acceptable level.

Stressed diaphragm pressure transducer. - The components of the stressed diaphragm transducer are shown in figure VII-11. The 0.009-inch-thick T-111 alloy (Ta-8W-2Hf) diaphragm is welded to a T-111 alloy housing which is, in turn, welded to the T-111 body and process tube. A T-111 alloy probe mount is welded to the center of the diaphragm. The magnetic probe assembly is then brazed to the probe mount to complete the assembly.

The diaphragm assembly shown in figure VII-11(b) was produced by first electron beam welding the 0.020-inch-diameter W-25Re wire to the T-111 alloy probe mount. A second electron beam weld attached the probe mount to the T-222 alloy diaphragm. The diaphragm was then positioned between the T-111 housing and housing cap and electron beam welded. As an added precaution, an electron beam weld was made between the T-111 alloy housing and retainer body on the outside diameter, which, in combination with the internal tungsten inert gas weld, effected a double seal between these components.

The final fabrication step was the brazing of the magnetic probe to the 0.020-inch-diameter W-25Re wire. Brazing was accomplished using localized heating with a graphite-tipped heater probe under high-purity argon in the welding chamber shown in figure VII-4. The brazing alloy (72Ag-28Cu) was applied to the joint manually in wire form. The completed assembly, shown in figure VII-11(c), was mass spectrometer leak tested successfully and submitted to instrumentation for room temperature calibration prior to installation in the loop.

Boiler. - Fabrication of the T-111 boiler was initiated by butt welding straight lengths of the inner tube using the welding chamber tube extension (fig. VII-3) to provide sufficient lateral travel. Triform spacers, illustrated in figure VII-12, were tungsten inert gas welded at 10-inch intervals along the boiler tube. The boiler tube was inserted in the shell, and the assembly was formed by the Philadelphia Pipe Bending Company. Prior to forming, the inner tube and the annulus were packed with sugar to aid in maintaining concentricity. This technique had to be used previously during forming of a similar Cb-1Zr boiler.

Upon receipt of the formed boiler from the vendor, the sugar was removed by mechanical vibration. When no additional sugar could be removed, a deionized water flush was initiated. The water was heated to 150° F and was allowed to flush through the boiler for 15 hours. An additional cold water flush for 30 minutes was used for the final rinse. At this time water samples were equilibrated for 2 hours in the boiler and tested for sugar using the Molisch test (ref. 2). Duplicate test

determinations indicated less than 50 ppm sugar, which is the limit of detection of the method used.

Welding of the boiler shown in figure VII-13 was then initiated. The inner and outer tubes were cut to the proper length, and the tube plug was welded to the inner tube. After inspection of this weld, the end connectors for the outer tube were positioned and welded to the boiler shell and inlet plug. The inlet plug configuration shown in figure VII-13 was made by forming 0.060-inch-diameter T-111 wire into a 1.0-inch-pitch helix on the 0.125-inch-diameter T-111 center rod. One TIG weld tack per revolution of the plug wire was made to hold the wire in place. The plug was then positioned within the straight section of the boiler inlet pipe and welded to the inlet fitting. The welded assembly was radiographed and leak tested prior to its inclusion in the boiler subassembly.

Turbine simulator. - Each turbine simulator stage consisted of a nozzle, turbine blade, and two specimen support pads, as shown in figure VII-14 for the second stage. The fabrication and assembly procedures used to construct the turbine simulators were dictated by the requirement to obtain very precise weight change data on these components following the 10 000-hour test. The Mo-TZC and Cb-132M alloy blades were polished to a 16-rms surface finish by the vendor utilizing a 240-grit alumina cloth followed by a final polish with 5-micron alumina before final cleaning and assembly. The Mo-TZC and Cb-132M alloy nozzles were prepared by electro-polishing, a refinement of electric spark discharge machining, to produce a 32-rms surface finish in the nozzle throat. The machining sequence is shown in figure VII-15. The surface was further polished with 400-grit alumina paper to remove approximately 0.001 inch from the surface. A polish with 5-micron alumina produced an 8-rms finish. Final hand polishing using 30- and 15-micron diamond paste was used to further improve the surface finish of the nozzles. Fluorescent penetrant inspection revealed three cracked Mo-TZC alloy blade support pads in the initial group. These pads were replaced with new Cb-132M alloy pads which passed inspection. After final weighing and cleaning operations, the nozzle assemblies were ready for positioning in the turbine simulator casing.

The first nozzle-blade assembly was positioned in a separate T-111 outer casing. The end caps, thermocouple wells, and 1-inch-diameter potassium flow tube were then welded to complete the single-stage turbine simulator. Postweld annealing of this subassembly was conducted after it was joined to the boiler to form a major subassembly.

The remaining nine nozzle-blade assemblies were positioned as shown in figure VII-16. These assemblies are rabbeted together and aligned in their T-111 casing with a 0.062-inch-diameter wire which extends through a keyway in the nozzles and casing. This wire insert prevents rotation of the individual nozzle in the

casing during test operation, but its primary purpose is to facilitate disassembly of the turbine simulator without damaging the individual nozzles and blades as this would make it impossible to obtain accurate weight change data on these components. The assembly of the nozzle-blade stack in the casing required careful handling since both unit straightness and axial alignment had to be maintained.

Condenser. - The 60-inch-long condenser was originally to be fabricated from a 1- by 2-inch cross section T-111 bar with a 0.406-inch-diameter hole gun-drilled the length of the bar. Twenty 0.25-inch-thick tantalum fins would then be welded along the length of the bar to provide radiant cooling.

Initial gun-drilling trials, however, resulted in failure due to a breakage of carbide drills or excessive wear of high-speed steel drills. A sample of T-111 alloy was then supplied to Standard Tool Company, a producer of gun drills for evaluation. Their report indicated the most success using a high-speed gun drill head to which they applied a positive rake chip break along with a 10° stack point. Additional material would be required to further define gun-drilling parameters.

Concurrent with the above investigation, one 32-inch-long condenser bar was committed for conventional drilling. A 0.406-inch-diameter hole was drilled successfully using a long fluted twist drill with an extension brazed to the shank. The drill was ground with an included angle of 135° . A hand feed of approximately 0.003 inch per revolution and a drill speed of 6 surface feet per minute produced the best cutting action. After the success of conventional drilling was demonstrated, the 63-inch-long condenser bar was cut in half and one additional section was drilled successfully to produce the two sections required for the 60-inch-long condenser. These two drilled bars were then finally machined and honed on the inside diameter.

The welding of the condenser was then completed with the joining of the two condenser bars and tantalum fins as shown in figure VII-17. During welding, alignment of the fins was maintained by the welding fixture shown in figure VII-18. Molybdenum blocks were incorporated in the fixture at each clamp location to provide refractory metal contact with the condenser.

Major Subassemblies

During loop fabrication, four major subassemblies, the condenser, boiler, potassium surge tank, and lithium heater, were sequentially assembled as described in figure VII-1.

Condenser assembly. - The condenser assembly consists of the condenser, nine-stage turbine simulator, subcooler reservoir, and associated piping, as shown

in figure VII-19. A more detailed view of the turbine simulator and potassium vapor line is shown in figure VII-20. Radiographic inspection of this assembly revealed a 0.060-inch-diameter spherical defect in the weld between the subcooler reservoir and the condenser. Because of scheduling difficulties with the large vacuum furnace required to postweld anneal this assembly, this weld repair was postponed until the assembly anneal was completed as described below. Subsequently, the defect was removed and the weld repair completed. This weld was then locally annealed at 2400° F for 1 hour in accordance with GE NSP specification 03-0037-00-A.

The high-emittance coating of iron titanate (Fe_2TiO_5) was then applied to the unalloyed tantalum condenser fins by Pratt and Whitney Aircraft using the procedures established previously (ref. 3).

Boiler assembly. - The boiler assembly consists of the boiler, single-stage turbine simulator, and potassium preheater, as shown in figure VII-21. Conventional tube joint welds join these components.

Potassium surge tank assembly. - The potassium surge tank subassembly (fig. VII-22) illustrates the intermediate fixturing required to maintain component orientation. During this fabrication the pressure transducer T welds and the weld between the surge tank and EM pump duct were made and postweld annealed locally. Each component had been postweld annealed previously.

Lithium heater subassembly. - The lithium heater subassembly, which consists of the lithium heater, EM pump duct, and surge tank, is shown in figure VII-23. Three welds were required to join these components, but extensive fixturing was again required to maintain component orientation.

Postweld Annealing of Major Loop Subassemblies

The boiler and condenser major subassemblies and the lithium heater, all wrapped with one overlapping layer of Cb-1Zr foil, were postweld annealed at 2400° F for 1 hour in Stellite's Brew furnace Model 966 at Kokomo, Indiana. This anneal was conducted in accordance with GE NSP specification 03-0037-00-A. This furnace had previously been qualified at 3000° F using 0.040-inch-thick T-111 alloy test coupons both wrapped with Cb-1Zr alloy foil and unwrapped. The results of this qualification run are shown in table VII-1 and indicate no significant increase in interstitial element concentration occurred during annealing.

During the annealing, the various loop assemblies, which weighed approximately 250 pounds, were suspended from Ta-10W alloy hanger bars that were mounted on the top flanged dome of the chamber.

Four Pt/Pt-10Rh thermocouples were used to monitor the temperature of the loop components. These thermocouples were wrapped with two layers of Cb-1Zr foil wrap which surrounded the components. A W-5Re/W-26Re thermocouple was used to monitor the furnace temperature.

The furnace heating rate, which was programmed at 25° F per minute, was interrupted, and the temperature held constant at 1000°, 1500°, 2040°, and 2200° F for time periods of 10 to 15 minutes to allow time for thermal equilibration, outgassing, and pressure reduction. The chamber pressure was 7×10^{-6} torr at the start of the 1-hour anneal and decreased to 3×10^{-6} torr after 1 hour. The temperatures of the various components equilibrated with the furnace temperature in less than 10 minutes at 2400° F. The maximum temperature difference for the three components of 25° F indicated excellent temperature uniformity within the furnace.

Final Loop Assembly

The completed lithium heater, condenser, boiler, and potassium surge tank subassemblies were positioned in the stainless steel support structure attached to the vacuum chamber spool section for reference alignment. The tubing which joins the boiler and potassium surge tank subassemblies was match marked for alignment, and the two subassemblies were removed from the spool section for welding in the 8-foot-diameter extension to the welding chamber. This assembly step was required because this particular weld could not be reached with the entire loop positioned in the welding chamber. After radiographic inspection of this weld, this unit was repositioned in the permanent support structure.

The lithium heater and condenser subassemblies were also positioned in the support structure. The final assembly weld fixture was attached to the loop (fig. VII-24) holding the subassemblies and three slack diaphragm pressure transducers (not shown) in alignment. The permanent support structure was disassembled and the loop, now supported by the welding fixture, was removed from the vacuum chamber spool section and placed in the welding chamber as shown in figure VII-25.

The seven welds required to join the subassemblies and attach the three pressure transducers were inspected radiographically and subsequently annealed in the welding chamber at 2400° F for 1 hour in accordance with NSP specification 03-0037-00-A.

The loop was removed from the welding chamber, and the electrode area of the lithium heater and the potassium preheater were grit blasted to increase emittance according to specification NSP 03-0011-00-A, "Grit Blasting of Columbium and Columbium Alloy Products." The loop was then positioned in the vacuum chamber

spool section, and the permanent support structure was affixed. After the loop was supported properly, the final welding fixture was removed. An overall view of the loop and spool piece is shown in figure VII-26. A closeup photograph of the components in the lower portion of the loop is given in figure VII-27.

The stainless steel tube attachments to the drain and gas pressurization lines were welded to the loop connections and vacuum chamber feed-throughs. A final mass spectrometer helium leak test was then performed on the entire loop with no leak indication. The vacuum connections for the NaK-filled tubes from the slack diaphragm pressure transducer and the EM pump duct stainless steel outer cans were welded to the appropriate vacuum spool section feed-throughs. The completed loop was then removed to the test site.

Boiler Repair

After a short period of loop operation, a leak between the potassium and lithium circuits was discovered at a weld in the potassium boiler tube. The evaluation of this weld is discussed in paper VIII in this volume. Only the repair and reinstallation of the boiler are discussed in this paper. To effect the repair, a number of modifications to the boiler design were required, as shown schematically in figure VII-28. Since one coil was removed from the boiler, an additional length of T-111 1-inch-diameter tubing was added to the top of the boiler to achieve a total boiler height equal to the original boiler for correct fitting during installation into the loop. New fittings were required for attachment to the lithium inlet and outlet lines. During installation of the boiler the lithium lines originally on the loop were inserted into socket fittings to ensure correct alignment during welding. Butt welding is normally the technique utilized for joining tubing; however, because of the location of these welds and limited access during installation of the boiler into the loop, the socket weld approach was selected. The main concern with this type of weld joint was the possibility of an open gap between the socket fitting inside diameter and the outside diameter of the inserted tubing. A trial fitting was machined with a double socket, and weld experiments were performed to develop a technique to prevent this gap. The welded specimen is shown in figure VII-29. Subsequent radiographic and metallographic examination of this specimen indicated full penetration welds with no gaps were achieved when the tubing was inserted in the socket and pulled back slightly so the bottom of the tube did not contact the bottom of the socket. The joint between the 0.375-inch-outside diameter inner boiler tube and the 1-inch-outside diameter outer boiler tube at the top of the boiler was also modified with a new fitting similar to that used at the bottom of the boiler. This butt joint design was pre-

ferred over the previously employed tube-to-header joint. These design modifications are compared with the original design in figure VII-30.

In the initial welding step a new section of 0.375-inch-diameter tubing was butt welded to the inner boiler tube. Subsequent helium mass spectrometer leak checking and radiographic inspection indicated this weld to be sound. Two sections of 1-inch-diameter boiler tube were then welded in place as shown in figure VII-31. These pieces were obtained from the boiler coil which was removed during sectioning of the boiler. Following the joining of the new end fitting to the 0.375-inch-diameter tubing, the three welds were inspected by radiography and helium mass spectrometer leak checking and found to be sound. The boiler was completed with the addition of the lithium inlet fitting and boiler extension piece at the top of the boiler as shown in figure VII-32 and the addition of the lithium outlet fitting at the bottom of the boiler as shown in figure VII-33. The boiler plug was reattached at this time by tack welding to the bottom boiler fitting. The repaired boiler is compared with the original boiler in figure VII-34. The removal of one coil from the boiler reduced its total length by approximately 27 inches.

After appropriate postweld annealing and leak testing, the boiler was ready for reinstallation into the loop. The requirements of NSP specification 03-0025-00-A necessitated the purchase of a special welding chamber to be installed around the loop for the welding operations. The chamber, shown after installation on the T-111 corrosion loop test facility in figure VII-35, comprises two flanged spool sections 4 feet in diameter and 4 feet high such that each can be rotated independently for improved access to weld locations. Sight ports and glove ports were appropriately positioned in the areas where welding was performed at the top and bottom of the boiler location. An independently pumped tool port was also provided such that necessary tools could be brought into the chamber without contaminating the chamber environment.

Rough pumping was accomplished with the 260-liter-per-second turbomolecular pump, and the loop facility ion pumps were used to achieve the high vacuum ($<1 \times 10^{-5}$ torr) called for in the welding specification. The chamber was backfilled with ultrahigh purity helium which was passed through a molecular sieve dryer before entering the chamber. The inert gas analysis equipment included C. E. C. (model 26-303) and Planametrics (model 1000) moisture monitors and the gas chromatograph shown in figure VII-36. Gas lines attached to the gas chromatograph made analysis of oxygen and nitrogen in the inlet gas as well as outlet gas from the chamber possible.

After weld chamber qualification, the boiler was welded into the loop as shown in figure VII-37. Four welds were required to reinstall the boiler; two at the top of the boiler and two at the bottom, as shown in figures VII-38 and VII-39, respec-

tively. Subsequent radiographs of the welds indicated a very small area in the upper lithium line weld of incomplete penetration, which was subsequently repaired. Mass spectrometer helium leak checking radiography of the welds showed no indications of leaks or weld defects. The four installation welds were postweld annealed in position using the annealing furnace shown in figure VII-40. The furnace comprises tantalum shields and shell, alumina insulations, and tungsten wire (0.050-in.-diam) elements. The power for heating the elements was supplied from a standard welding machine, one electrode being the welding torch and the other electrode grounded. The welds were annealed for 1 hour at 2400° F.

POTASSIUM BOILER DEVELOPMENT LOOP FABRICATION

The overall fabrication sequence for this large T-111 alloy system followed the general guidelines established during corrosion loop fabrication. Preplanning of fabrication steps was incorporated into the design phase to assure trouble-free assembly within the limits of the welding chambers and to provide suitable locations for final assembly welds. The size of furnaces required for postweld annealing of components was also given careful consideration, and in certain instances this was the limiting factor in component design. General welding procedures were equivalent to those employed during T-111 corrosion loop fabrication. Many components, such as pressure transducers, valves, and EM pump ducts were also similar to those fabricated previously. However, the large lithium heater, boiler, and condenser presented unique fabrication problems which are discussed individually in this section. The location of these components is shown in the schematic of the potassium boiler development test rig, figure VII-41.

LITHIUM HEATER

The lithium heater includes six heater coils. Each 11-inch-diameter coil is formed from 0.875-inch-outside diameter by 0.100-inch-wall T-111 tubing and has a developed length of 124 inches. Appropriate manifolds and electrodes were required to split the lithium flow uniformly and to provide attachment of high current electrical buses.

A fixture was designed to hold the lithium heater as shown in figure VII-42. A more detailed view of the three-tube manifold joints is shown in figure VII-43. The size and weight of this component made it difficult to handle manually within the welding chamber. To alleviate this problem, the multipurpose weld positioner

shown in figure VII-44 was utilized. This unit provides motor driven rotation and manual translation of the workpiece within the 8-foot-diameter welding chamber.

CONDENSER

The three-tube potassium condenser is NaK-cooled on the shell side and is a basic hockey stick design. From the welding viewpoint, this component, being of multitube design, required the qualification and production of representative tube-to-header joints. In order to provide a fully inspectable butt joint, internal automatic welding was selected. In this process, a welding torch is positioned inside the joint as shown in figure VII-45 and is rotated by a motor drive which is controlled by the sequence control on the previously described automatic welder. The three tube-to-header joints shown in figure VII-46 were welded using this technique. After inspection of these welds, the tube bundle and support cage shown in figure VII-47 was slipped into the shell. The potassium outlet tubes were then bent and trimmed to proper length, and a reducer was welded to each tube, as shown in figure VII-48. These reducers were welded to the exit header, providing the same joint design as that of the inlet header. The completed condenser shown in figure VII-49 has connections of pressure transducers in addition to the NaK and potassium lines.

BOILER

The potassium test boiler is C-shaped in design and has a 0.75-inch-outside-diameter by 0.040-inch-wall T-111 potassium boiler tube maintained concentric within a 1.325-inch-outside-diameter by 0.100-inch-wall shell. A helical fin insert shown in figure VII-50 extended approximately half the boiler length. At the end of the fin a helical wire coil was attached and continued throughout the remainder of the boiler tube. Because the boiler tube required forming after the inserts were in position and each insert had a different rigidity in bending, it was necessary to proceed cautiously during tube forming. It was therefore decided to bend the shell and boiler tube separately to provide the best assurance of proper tube concentricity in the formed boiler. Several trials with stainless steel mockup boilers preceded the T-111 boiler tube bending. Initial bending was performed manually using a 360° machined steel mandrel for the inside diameter contour and a steel roll on the outside diameter. Final sizing to the shell diameter was done on a conventional three-roll tube bender. Four tube spacers were then TIG tack welded to the formed boiler

tube as shown in figure VII-51. The boiler shell shown in figure VII-52 was then slipped over the boiler tube. Mechanical vibration was necessary during this operation to reduce the considerable drag between the sliding T-111 components.

The completed boiler assembly shown in figure VII-53 indicates the complexity of a fully instrumented test boiler. Provision for pressure transducers, insert thermocouples, and bulk fluid thermocouple wells necessitates many sequential welding and inspection steps to provide high reliability in the component.

SUMMARY OF RESULTS

During the past 2 years, GE Nuclear Systems Programs Department has been committed to the fabrication of large T-111 components and alkali metal systems. As each project has progressed, understanding of the welding characteristics and metallurgy of T-111 alloy has been broadened. Particular instances of weld-associated cracking have been documented and are reported in paper VIII of this volume. However, the corrosion loop fabrication was accomplished without undo difficulties, as evidenced by the welding of rather complex components.

The boiler fracture, although a technical setback, necessitates the first repair of a T-111 component which had been previously exposed to alkali metals. The fact that many test hours have been accumulated since this repair is an important milestone in T-111 alloy utilization.

The boiler development test loop program provided the challenge of building components of a large T-111 alloy system. Concurrently, unique processes such as internal tube-to-header welding were applied to T-111 alloy. Each component provided a better understanding of the machining, forming, and welding processes required to fabricate large space power systems.

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TABLE VII-1. - RESULTS OF QUALIFICATION TEST OF
STELLITE'S BREW FURNACE MODEL 966

[Test time, 1 hr; temperature, 3000° F; maximum pressure at
temperature, 4.4×10^{-5} torr.]

Element ^a	Concentration, ppm ^b		
	Before anneal	Wrapped specimen ^c after anneal	Unwrapped specimen after anneal
O	26	27	51
N	14	12	14
H	1	1	2
C	<10	11	27

^aTest specimens: T-111 sheet, 0.040-inch-thick MCN 02A-078.

^bAnalytical methods: O, N, and H, vacuum fusion; C, combustion
conductometric.

^cSpecimen was wrapped with layer of 0.002-inch-thick Cb-1Zr foil
during heat treatment.

Figure VII-1. - Fabrication sequence for T-111 Rankine system corrosion test loop. All components other than boiler and condenser are furnace annealed prior to welding into major subassemblies. Assembly welds are annealed locally in welding chamber.

Figure VII-2. - Corrosion loop 1 (T-111).

Figure VII-3. - Vacuum-purge inert gas welding chamber (3-ft diam by 6-ft long) with helium supply and purity control system showing pipe welding extension tube attached to chamber door.

Figure VII-4. - Vacuum-purge inert gas welding chamber and helium purity control system with welding chamber extension tank attached to 3-foot-diameter by 6-foot-long welding chamber.

Figure VII-5. - Automatic tungsten inert gas welding machine controlled welding sequence.

Figure VII-6. - Component parts of water-cooled TIG torch head.

Figure VII-7. - Internal construction of water-cooled TIG welding torch.

Figure VII-8. - Components of T-111 EM pump duct before and following final welding and machining.

(a) Cutaway showing diaphragm and housing construction.

(b) Completed upper flange.

(c) Cross section of weld.

Figure VII-9. - Slack diaphragm pressure transducer diaphragm and housing following EB welding.

Figure VII-10. - Welding of Cb-1Zr alloy slack diaphragm pressure transducer housing.

Figure VII-11. - Refractory alloy pressure transducer (stressed diaphragm).

Figure VII-12. - Cb-1Zr boiler tube spacer before and following attachment to 0.375-inch Cb-1Zr potassium containment tube by welding.

Figure VII-13. - Tube-in-tube boiler of corrosion loop 1 (T-111) prior to insertion of boiler plug.

Figure VII-14. - Entrance and exit side of nozzle and blade assembly of second stage (Mo-TZC) of turbine simulator.

Figure VII-15. - Machining sequence required to produce Mo-TZM alloy nozzle for Cb-1Zr corrosion test loop turbine simulator. Two additional polishing operations are required to produce 8-rms surface finish.

Figure VII-16. - Turbine simulator (stages 2 to 10) of T-111 corrosion loop 1 prior to assembly.

Figure VII-17. - Corrosion loop 1 (T-111) condenser prior to coating of tantalum fins with iron titanate.

Figure VII-18. - Cb-1Zr corrosion test loop condenser and fixture during welding of fin to condenser pipe.

Figure VII-19. - Condenser-turbine-simulator assembly following application of iron titanate coating on tantalum fins.

Figure VII-20. - Nine stage turbine simulator and top of condenser.

Figure VII-21. - Potassium preheater-boiler-first-stage-turbine-simulator assembly following postweld anneal.

Figure VII-22. - Potassium surge tank and EM pump subassembly of T-111 corrosion test loop mounted on welding fixture.

Figure VII-23. - Lithium heater pump subassembly of T-111 corrosion test loop mounted on welding fixture.

Figure VII-24. - T-111 corrosion test loop and chamber spool piece during transfer of loop from support structure to welding fixture.

Figure VII-25. - T-111 corrosion test loop mounted on welding fixture prior to final welding and weld heat treatment operation.

Figure VII-26. - T-111 corrosion test loop and vacuum chamber spool piece following completion of loop fabrication.

Figure VII-27. - Lower portion of T-111 corrosion test loop following completion of fabrication.

Figure VII-28. - Schematic of T-111 corrosion loop boiler repair.

Schematic Cross Section of Tube-to-Socket Weld Joint

Figure VII-29. - Socket weld fitting specimen to qualify this joint design for T-111 corrosion loop boiler repair and reinstallation.

Figure VII-30. - Joint design at ends of T-111 corrosion loop boiler.

Figure VII-31. - Top of T-111 boiler following initial repair welds.

Figure VII-32. - Top of T-111 corrosion loop boiler following final repair welding.

Figure VII-33. - Bottom of T-111 boiler following repair welding.

Following Initial
Fabrication

Following Repair

Figure VII-34. - T-111 corrosion loop boiler.

Figure VII-35. - Welding chamber and ancillary instrumentation installed on T-111 Rankine system corrosion test loop facility.

Figure VII-36. - Gas chromatograph used to analyze helium atmosphere in welding chamber for repair of T-111 corrosion loop.

Figure VII-37. - Repaired boiler installed in T-111 corrosion loop.

Figure VII-38. - Top of repaired boiler after installation in T-111 corrosion loop.

Figure VII-39. - Bottom of repaired boiler after installation in T-111 corrosion loop.

Figure VII-40. - Refractory metal furnace for annealing of corrosion loop weldments.

Figure VII-41. - Potassium boiler development test rig.

Figure VII-42. - T-111 lithium heater positioned in support structure.

Figure VII-43. - T-111 lithium heater manifold joints.

Figure VII-44. - T-111 lithium heater in multipurpose weld positioner.

Figure VII-45. - View of seven tube header with internal rotating tungsten electrode shown in center tube boss.

Figure VII-46. - T-111 three-tube condenser potassium inlet header.

Figure VII-47. - T-111 three-tube condenser tube bundle and support cage.

Figure VII-48. - T-111 three-tube condenser during fabrication.

Figure VII-49. - Three-tube condenser for boiler development program.

Figure VII-50. - Helical fin boiler tube insert for boiler 1.

Figure VII-51. - Potassium boiler tube.

Figure VII-52. - Potassium boiler shell.

Figure VII-53. - T-111 single tube test boiler 1.