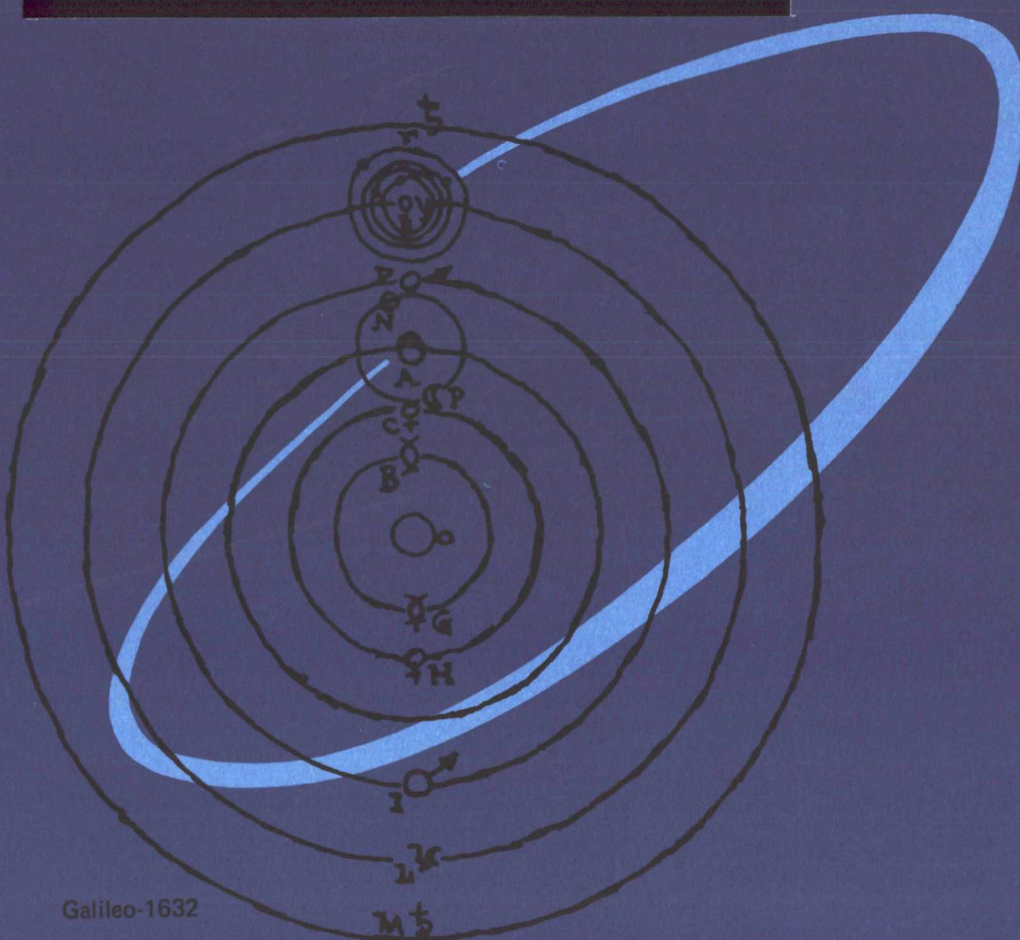
SELENIDE ISOTOPE GENERATOR

for the

GALILEO MISSION

MASTER



Galileo-1632

TELEDYNE ENERGY SYSTEMS

DISCLAIMER

Pictured on the cover is Galileo's drawing of the solar system, which includes the four satellites of Jupiter he discovered in the 1600's. A Renaissance professor, inventor and astronomer, Galileo perfected the telescope with which he made his Jupiter discoveries. The 1982 NASA mission to Jupiter is named in his honor. Like Galileo and his telescope, the NASA mission to the far reaches of outer space will be contributing to Mankind's never ending quest for knowledge.

SELENIDE ISOTOPE GENERATOR

for the

GALILEO MISSION

SIG HERMETIC BIMETAL WELD
TRANSITION JOINT

TES-33009-51

AUGUST 1979

Prepared for the U.S. Department of Energy
under Contract DE-AC01-78ET33009

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SIG/GALILEO

SIG HERMETIC BIMETAL WELD TRANSITION JOINT

FINAL REPORT

TES-33009-51

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This report was prepared for the United States
Department of Energy under Contract DE-AC01-78ET33009

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1.0 SUMMARY

The successful development of the commercial 6061-T651/Silver/304L explosive clad plate material as a bimetal weld transition joint material, as described herein, satisfies all SIG Galileo design requirements for hermetic weld attachment of stainless steel subassemblies to aluminum alloy generator housing or end cover structures. The application of this type weld transition joint to the hermetic attachment of stainless steel shell connectors is well-developed and tested. Based on on-going life tests of stainless steel receptacle/bimetal ring attachment assemblies and metallurgical characterization studies of this transition joint material, it appears evident that this transition joint material has more than adequate capability to meet the 250-300°F and 50,000 hour design life of the SIG/Galileo mission. Indeed, its extended life temperature capability may well approach 350 to 400°F.

Manufacturing and inspection procedures for receptacle type bimetal ring attachments have been developed and are well established. This technology is readily adaptable to several new SIG/Galileo design applications. Development of these new applications was in process at the time of "work termination."

Preliminary evaluation of a "back up" explosive clad plate material, 6061 Aluminum/Tantalum/304L stainless suggest that the use of the "tantalum" interlayer in place of silver yields a significant increase in the microstructural thermal stability of the clad bond. Approaches for the development of this technology for potential extended life use temperatures in the 500-600°F regime are discussed.

2.0 BACKGROUND & SCOPE

The SIG/Galileo RTG design is based on an hermetically sealed aluminum alloy (i.e., 6061-T6) generator housing which is vented to space during post shuttle launch deployment of the generator. During generator ambient operation, storage, and launch, the generator housing assembly must exhibit a leak rate of $\leq 1 \times 10^{-8}$ scc He/sec.-atm., a requirement dictated by the sensitivity of the selenide thermoelectrics to oxygen contamination. Dissimilar metal hermetic attachments, primarily of austenitic stainless steel components as described in Section 8.0, are inherent in this design.

The development of the bimetal joining technology to satisfy this design requirement was initiated in the ERTG study program with a technical review and assessment of bimetallic seal technology. This study (Ref. 1) recommended that dissimilar bimetal hermetic attachments should be accomplished via a bimetal "weld transition joint"-- a short length structural segment containing the dissimilar metal joint which can be integrated into the primary structure by conventional fusion welding techniques. Three manufacturing methods for the bimetal joint were recommended for continued engineering development, evaluation and design integration studies:[(1)]

a. Explosive Cladding

b. Friction Welding

c. Brazing

[(1)] Other techniques considered in this review included extrusion, roll bonding, diffusion bonding and electroplating.

The above candidate manufacturing processes are listed in accord with a decreasing order of merit or probablility of success.

The development, evaluation and application of the explosive clad plate weld transition joints was initiated and implemented in support of the design and build of the first selenide generator, GDS-1 (i.e., during the LCHPG/Selenide Phase II Program, approximately August 1976 thru March 1978). These activities included the following:

a. Metallurgical characterization of explosive clad 6061-T651/ 0.035" Silver/304L Stainless transition joint material

b. Screening of a "back-up" transition joint material, explosive clad 6061-T651/0.035" Tantalum/304L stainless

c. Clad plate procurement

d. Development of machining and inspection techniques for transition joint manufacture

e. Design and manufacture of the following GDS-1 weld transition joint component test and generator hardware:

   (1) Stainless steel receptacle (304 or 20 Cb-3 shell material) to 6061-T651 aluminum boss on end covers

   (2) 6061-T6 housing to 304L stainless which is fusion welded to the platinum alloy isolation hot frame (IHF).

f. Development of weld tooling and weld parameters for the weld attachment of the above transition joints

g. Development, design and manufacture of component test assemblies for simulated life testing of the respective weld transition joints

h. Manufacture of GDS-1 weld transition joint hardware

Initial emphasis was directed toward development of the IHF* bimetal ring (i.e., weld transition joint). The primary GDS design was based on the development of a hermetic aluminum alloy shell connector (c.f. Ref. 2). When it became evident in late 1977 that the development of this hermetic receptacle was unlikely, the stainless steel receptacle weld transition joint effort was accelerated and focused on utilization of the existing Viking Deutsch 20Cb-3 stainless shell receptacle.

Application of the GDS receptacle weld transition joint technology to the SIG/Galileo flight design was readily accomplished. A receptacle/bimetal ring functional and reliability test series was planned for implementation on procurement of the flight lot of Deutsch 20Cb-3 stainless shell receptacles.

Based on the success of ongoing receptacle/bimetal ring (weld transition joint) life tests and the GDS-1 applications, three additional applications of the weld transition joint were adopted in the SIG/Galileo RTG/ETG flight design. These included the following 6061 aluminum to 304 stainless steel attachments:

a. GVS (Generator Vent System) stainless steel diaphragm to 6061-T6 aluminum body

b. Stainless steel gas management tubing to 6061-T651 end cover

c. Stainless evacuation tube to 6061-T651 RTG temporary end cover

The above cited steps in the evolution and development of the explosive clad weld transition joint technology are reviewed and discussed in the following sections.

*The isolation hot frame (IHF).

3.0 BIMETAL WELD TRANSITION JOINT MATERIALS

The essential requirements of the two pending GDS hermetic weld transition joints are:

a. Stainless Steel (304 or 20 Cb-3) Shell Receptacle to 6061-T651 Aluminum Alloy Cover - Service Temperature 100 to 125°C

b. Platinum Alloy Isolation Hot Frame to 6061-T6 Aluminum Alloy Housing - Service Temperature 130 to 180°C

In both cases the nominal design life is ~50,000 hours. Screening tests conducted at ORNL demonstrated the feasibility of fusion welding a Pt-20 Rh alloy to 304L stainless. Hence a 304 stainless/6061 aluminum transition joint would satisfy both applications.

3.1 Explosive Clad Plate Weld Transition Joint Material Selection

Two commercially available clad plate materials were considered:

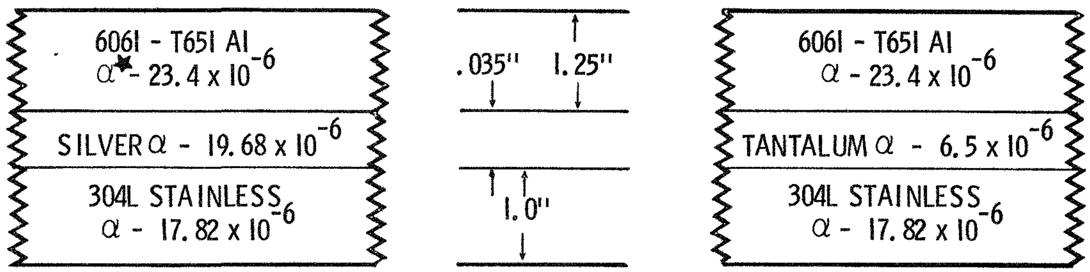
a. 6061-T651 Aluminum/0.035"Silver/304L Stainless

b. 6061-T651 Aluminum/0.035"Tantalum/304L Stainless

Several physical characteristics of these materials are compared in Figure 1.

The silver interlayer material, item A, was developed by E. I. duPont for hermetic tubular weld transition joints in cryogenic piping systems and vacuum systems. This material (4"nominal plate stock as described in section 3.2) was, and currently is, being used in the extensive ultra-high vacuum system of the Stanford Linear Accelerator (SLAC). The main concern regarding the GDS application of this material was the potential for degradation of the Ag/6061 bond during long time service at GDS operating temperatures.

• THERMAL EXPANSION MATCH



★ α - IN./IN./^{0}C
RT - ~200^{0}C

• BOND INTERFACE DIFFUSION INTERACTIONS

DIFFUSION COUPLE	INTERMETALLIC PHASE FORMATION	ESTIMATED REACTIVITY RATES 120 - 180^{0}C
304L Fe Cr Ni/Ag	NONE	VERY LOW
Al-6061/Ag	YES	MODERATE
304L Fe Cr Ni/Ta	YES	VERY LOW
Al-6061/Ta	YES	LOW

• QUALITATIVE CONCLUSIONS

- •• TANTALUM INTERLAYER OFFERS SUPERIOR THERMAL STABILITY.
- •• SILVER INTERLAYER OFFERS MINIMAL BOND INTERFACE RESIDUAL STRESS DUE TO DIFFERENTIAL EXPANSION EFFECTS.

Figure 1: A Comparison of Silver vs. Tantalum Interlayer 6061 Aluminum/304L Stainless Explosive Clad Weld Transition Joint Materials

The tantalum interlayer material, item B, offers the potential of superior thermal stability. However, as noted in Figure 1, there is a trade-off between bond line thermal stability and interfacial residual stresses due to differential expansion effects. Commercial production and use experience with the "tantalum interlayer" material, while not unfavorable, was limited in comparison with that of the "silver interlayer material."

In view of the above observations, the silver interlayer explosive clad plate material was selected as the primary weld transition joint material candidate for GDS application development. Also, it was concluded that the "tantalum interlayer" material would be carried as a "back-up material" and procurement and evaluation of this material would be pursued on a limited basis.

3.2 Explosive Clad Plate Procurement

Explosive clad plate was procured from E. I. duPont in accord with the following vendor specifications:

Material	Specification	
6061-T651 Aluminum/0.035" Silver/ 304L Stainless	DETA-605-M*	(Ref. 3)
6061-T651 Aluminum/0.035" Tantalum/ 304L Stainless	DETA-610-M*	(Ref. 4)

Materials were procured in two thicknesses as follows:

	Thickness, Typical - inches		
	6061-T651 Plate	304L Stainless	Total Clad Plate
Type I	1.9	2.0	3.9
Type II	1.25	1.0	2.2

Results from the initial procurement of "silver interlayer" explosive clad

---

* See text for added flatness requirement.

plate stock of both thickness types indicated that the standard "1/4" flatness requirement was unsatisfactory for machining large diameter "flat disc type" transition joints, due to difficulties in meeting dimensional requirements in relationship to the bond line (i.e. non-planar bond zone). This problem was alleviated by specifying a 1/16" flatness. This flatness requirement was accepted (premium price) and generally met.

The nominal clad plate size, 20" x 40", is restricted by available size of close tolerance pure silver sheet. The Type I thickness is the standard commercial product. The thinner Type II stock was procured for GDS hardware development in order to reduce machining time. Both stock sizes are required for SIG/Galileo flight generator applications.

The "tantalum interlayer" explosive clad plate stock was procured in the Type II thickness with the 1/16" flatness requirement.

With the exception of occasional minor deviations from the flatness requirement, product specifications were met and generally exceeded (i.e., leak rate of ram tensile specimen and bond strength).

4.0 EXPLOSIVE CLAD PLATE METALLURGICAL CHARACTERIZATION

Metallurgical characterization studies were aimed at elucidating the question of "adequate thermal stability" of the explosive clad bonds. These studies were focused on the 6061 Al/Ag/304L material. Examination of the "tantalum interlayer" product was limited to a preliminary assessment of its comparative thermal stability.

4.1 Metallurgical Characterization of Aluminum/Silver/304 Stainless Clad Plate

Characterization studies included (1) an assessment of bond zone diffusional growth (i.e., formation and growth of intermetallic compounds) due to thermally activated diffusion and (2) an evaluation of the influence of accelerated aging on bond strength.

4.1.1 Effect of Thermal Aging on Bond Zone Microstructure

Metallographic (100-1000X magnification) examination of as-received and thermally aged specimens of the 6061/Ag/304L explosive clad plate yielded the following observation (Ref. 5):

a. No intermetallic growth was observed at the Ag/stainless steel interface

b. No intermetallic growth was evident in either, as-bonded or specimens aged at 300°F for times up to 336 hours.

c. All specimens aged for one hour or more at temperature of 500°F and above exhibited obvious intermetallic(s) growth at the Ag/6061 aluminum interface. Two distinct phases were noted:

   - Ag_3Al or μ phase
   - Ag_2Al or ξ phase

   The growth of the Ag_2Al, ξ phase, predominated.

d. As shown in Fig. 2, the growth kinetics of the Ag_2Al phase follow a parabolic law, i.e.,

$$d_1 = \sqrt{\beta_1 (t_1)}$$

where d_1 and β_1 are the thickness of the Ag_2Al zone at time t_1 and the growth rate constant, respectively, for an aging temperature, T.

The growth rate dependence on temperature follows an Arrhenius type relationship, as shown in Figure 3, i.e.

$$\beta_1 = K e^{-Q/RT}$$

The activation energy for the process, Q, is 22.8 K cal/mole. Based on these kinetic equations, calculated growth rates at 300°F and 250°F are illustrated in Figure 2.

e. Extremely large intermetallic growth zones (i.e., extremely high interdiffusion, d_1 >100 microns) is generally associated with the formation of voids (i.e., Kirdendall porosity) in the aluminum rich region.

Typical microstructures of aged specimens are shown in Figures 4 and 5.

4.1.2 Effect of Accelerated Aging on Bond Zone Strength

The ram type tensile specimen, as shown in Figure 6, is suited for measurement of the explosive clad plate bond strength (note-tensile failure occurs in the weakest member of the bond) and integrity of the bond as evidenced by the measurement of helium leak rate thru the nominal 0.100" thick cylindrical bond zone wall. The explosively clad plate, exhibits an excellent quality high

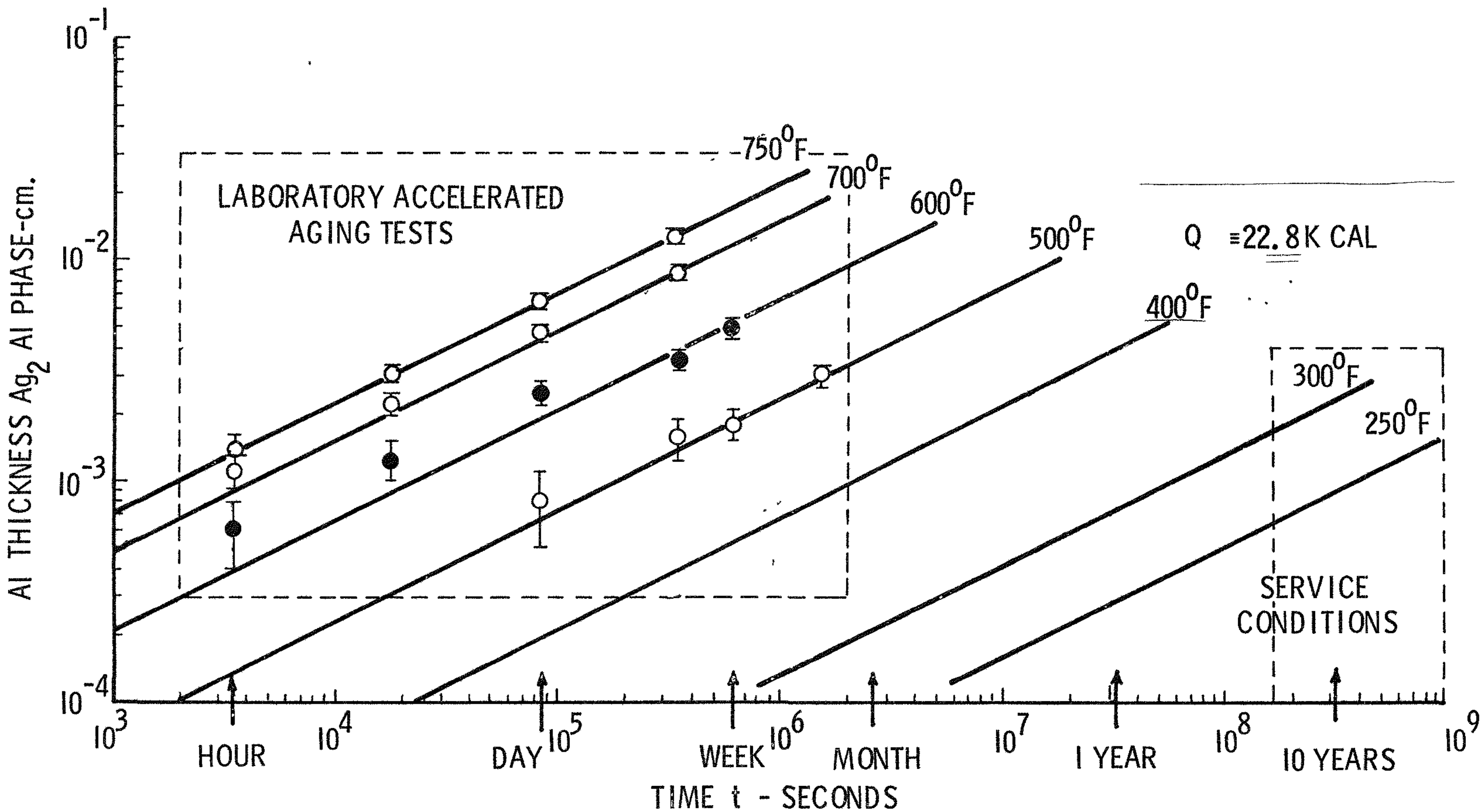


Figure 2. Ag_2Al Intermetallic Phase Growth Kinetics in Thermally Aged 6061-T651/ Ag/304L Explosive Clad Plate

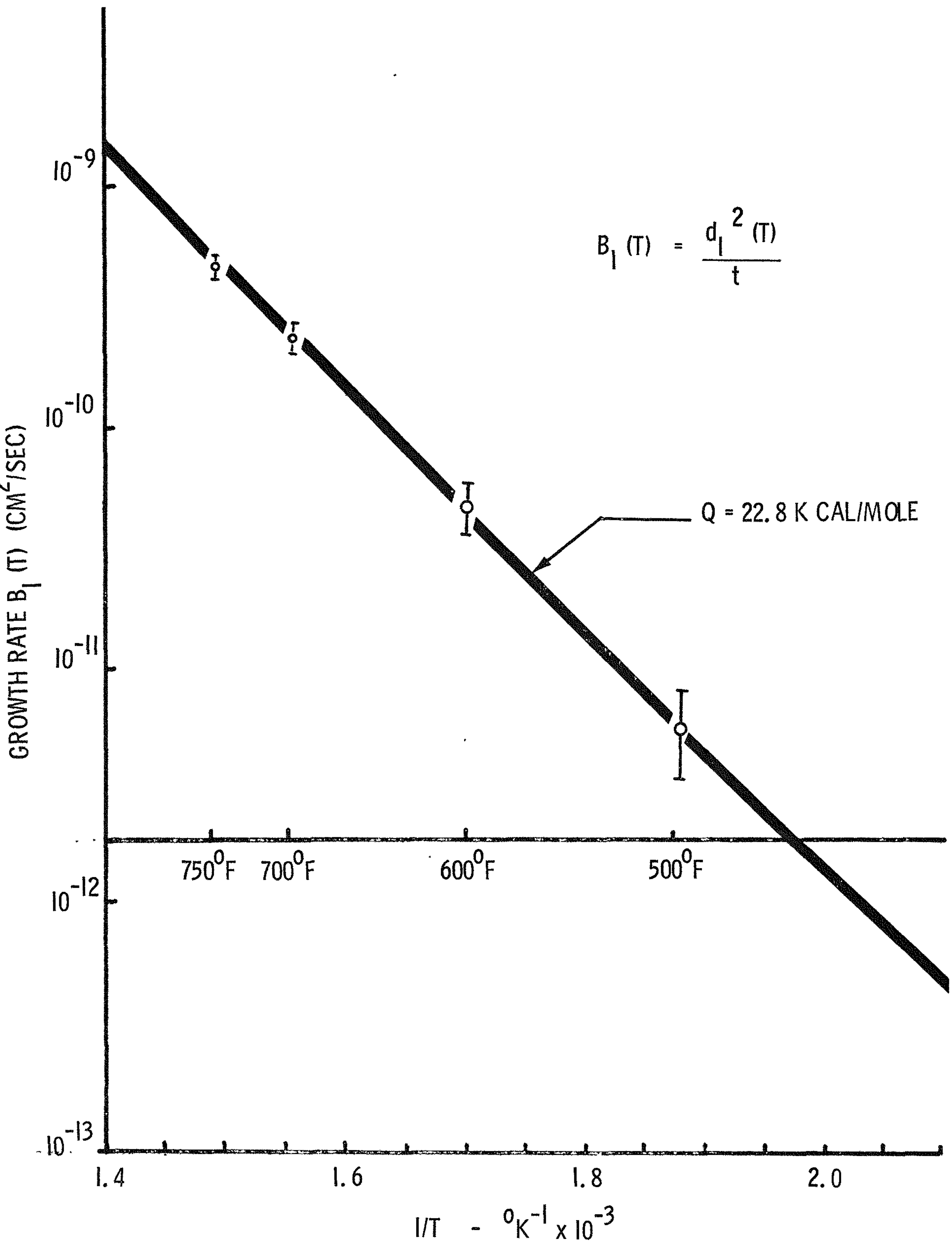


Figure 3: Arrhenius Plot of Growth Rate Constant for Ag_2Al Phase

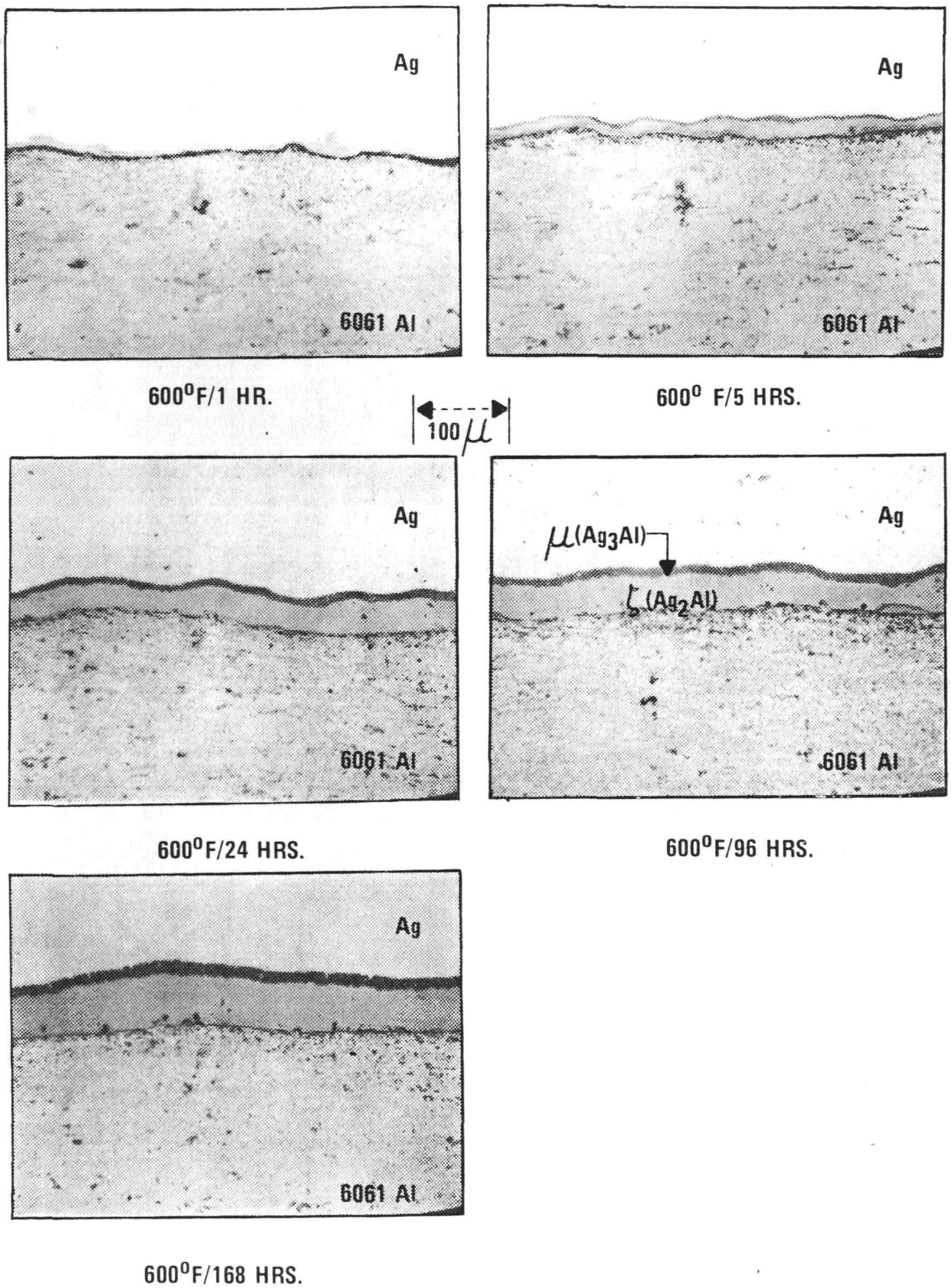


Figure 4: Typical Microstructures Depicting Intermetallic Phase Growth at Clad Plate Ag/6061 Aluminum Bond Zone Interface-Aging Temperature 600°F

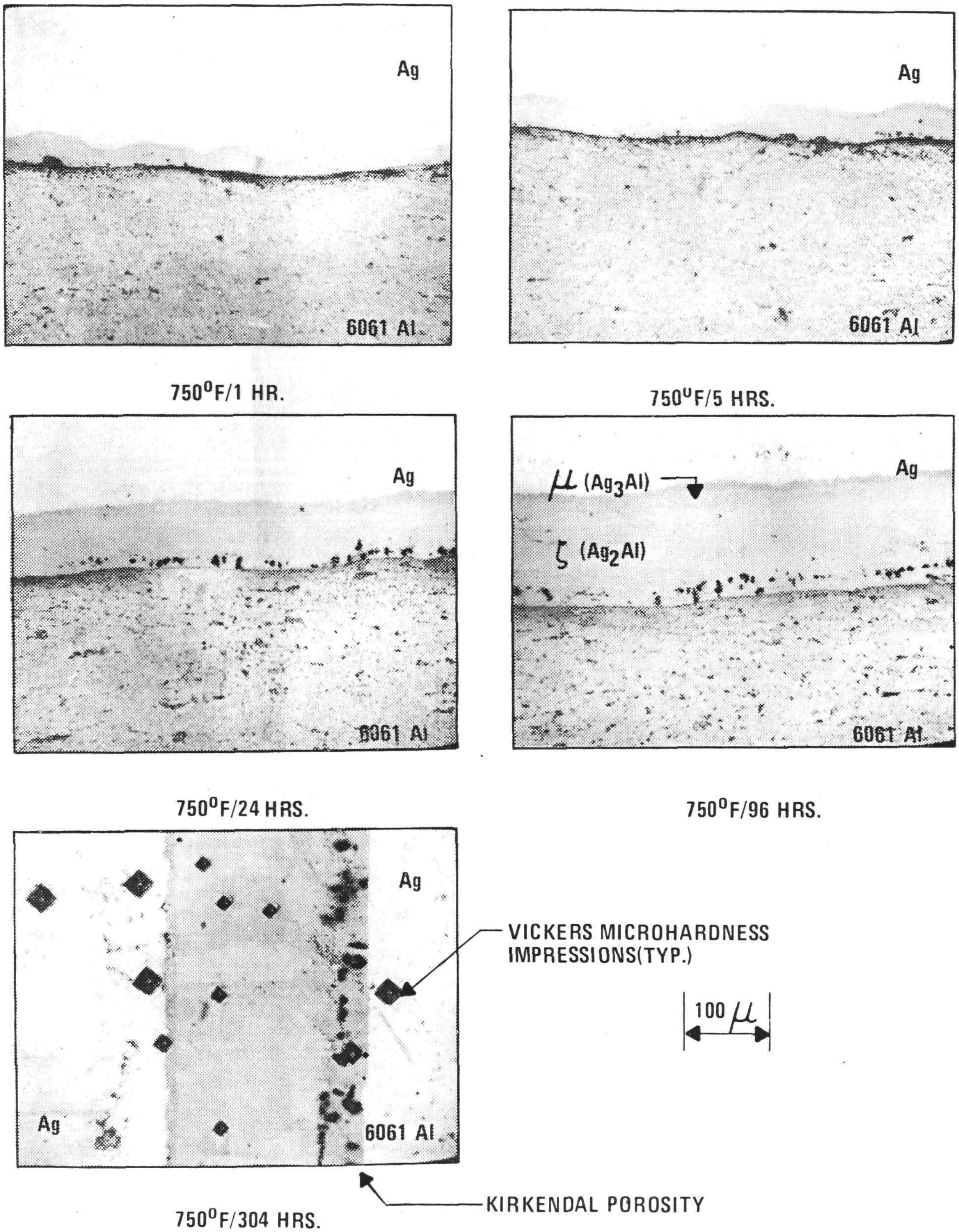


Figure 5: Typical Microstructures Depicting Intermetallic Phase Growth at Clad Plate Ag/6061 Aluminum Bond Zone Interface-Aging Temperature 750°F

strength bond, typical room temperature strengths being in excess of the tensile strength of the aluminum alloy plate. That is failure occurs in the base aluminum alloy and not at the Ag/stainless or Ag/6061 aluminum interfaces. The influence of thermally aging ram tensile specimens on the helium leak rate and bond strength is summarized in Table 1.

Inspection of these data, Table 1, yields the following observations:

a. Intermetallic zone (i.e., Ag_2Al phase) growth to thicknesses circa 25 microns does not influence the "leak tight" integrity of the bond zones as evidenced by helium leak rate measurements.

b. The apparent decrease in bond strength with increasing severity of thermal aging is primarily associated with the "overaging" of the 6061 aluminum alloy. Bond strength degradation arising from intermetallic bond zone growth is either less than or approximately the same as the strength decrement due to overaging of the aluminum alloy. Visual observations indicate that tensile failure generally occurred in the aluminum alloy segment, adjacent to the Ag/6061 aluminum bond zone.

c. A bond zone intermetallic (Ag_2Al) zone thickness of ~25 microns resulted in a minimum bond strength of ~17,000 psi.

4.2 Metallurgical Characterization of Aluminum/Tantalum/304L Stainless Clad Plate

Screening thermal aging tests conducted on the "tantalum interlayer" explosive clad plate confirmed the superior (i.e., relative to the silver interlayer clad plate) microstructural thermal stability of the bond zones in this material.

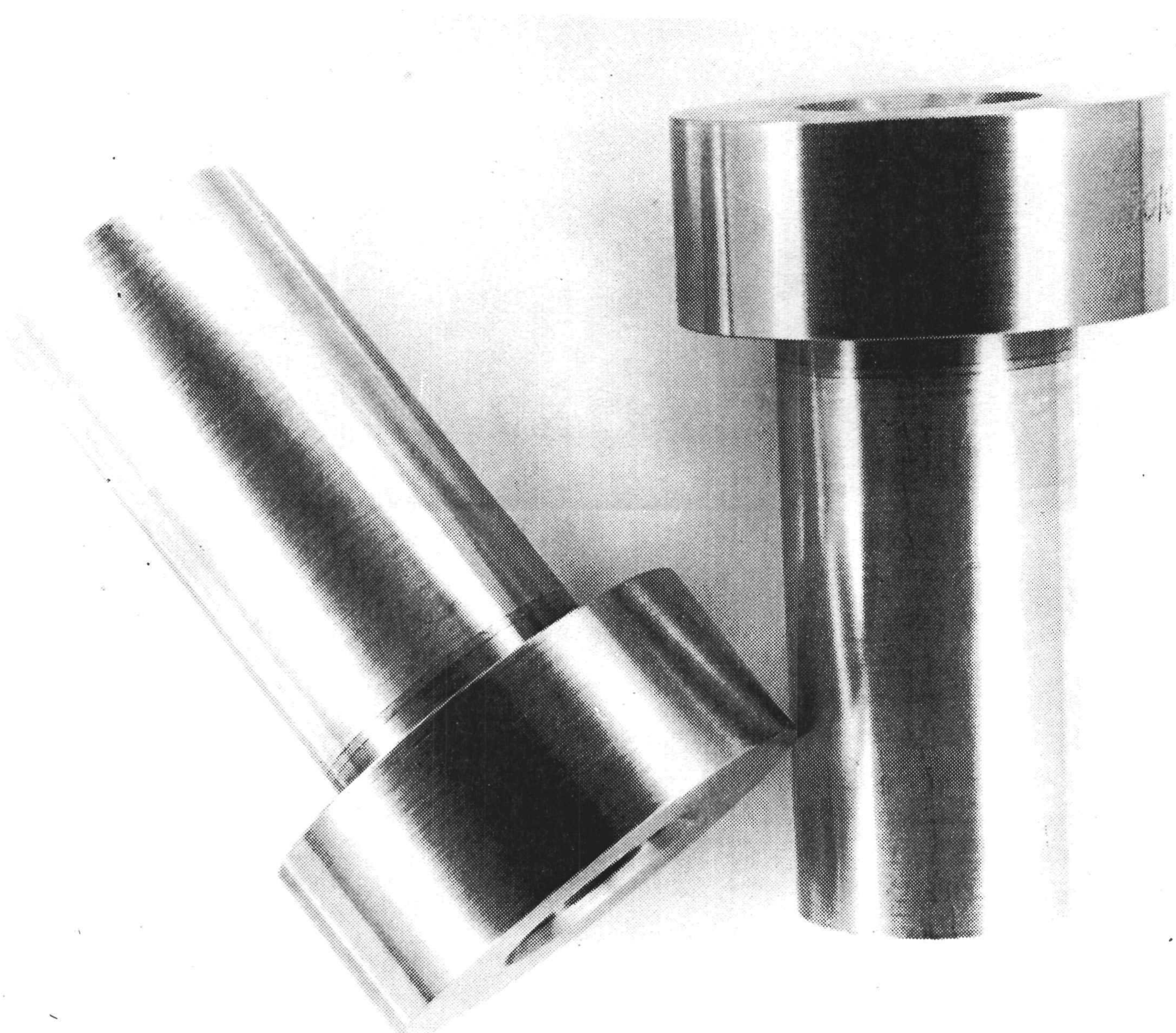


Figure 6: Ram Type Tensile Specimen Used for Evaluation of Clad Plate Bond Quality, Strength and Leak Rate

TABLE 1. EFFECT OF THERMAL AGING ON THE BOND STRENGTH OF EXPLOSIVE CLAD PLATE WELD TRANSITION JOINT MATERIAL

6061-T651 Aluminum - 0.035" Silver - 304L Stainless

Pretest Aging	Helium Leak Rate[a]-SCC/sec.	Test Temperature-°F	Ultimate Tensile Strength[b] - psi	Percent of Average 300°F/24 hr. Aged UTS - %	Predicted[c] Strength Due to Overaging of 6061 Alloy; percent of Ave. 300°F/24 hr. Aged UTS - %
None	$< 2 \times 10^{-10}$	R.T.	49,900	108.8	100+
None	$< 2 \times 10^{-10}$	R.T.	48,400	105.5	100+
300°F-24 Hrs.	$< 2 \times 10^{-10}$	R.T.	48,500	105.8	100
300°F-24 Hrs.	$< 2 \times 10^{-10}$	R.T.	43,200	94.2	100
500°F-1 Hr.	$< 2 \times 10^{-10}$	R.T.	36,000	78.5	72
500°F-1 Hr.	$< 2 \times 10^{-10}$	R.T.	36,100	78.7	72
500°F-24 Hrs.	$< 2 \times 10^{-10}$	R.T.	24,800	54.1	58
500°F-24 Hrs.	$< 2 \times 10^{-10}$	R.T.	24,700	53.9	58
500°F-24 Hrs.	$< 2 \times 10^{-10}$	250°F	24,400	(53.2)	(58)
500°F-24 Hrs.	$< 2 \times 10^{-10}$	250°F	25,000	(54.5)	(58)
600°F-24 Hrs.	$< 2 \times 10^{-10}$	R.T.	19,200	41.9	47
600°F-24 Hrs.	$< 2 \times 10^{-10}$	R.T.	17,700	38.6	47

a. Measured on ram type tensile specimen at 15 & 30 psi ΔP.

b. Measured using ran type tensile specimentested at a loading rate of 5,000 lbs./min.

c. Predicted values calculated on base of MIL-Handbook V (Ref. 6) data.

Specimens were aged for one and eight hours at 850°F (inert atmosphere). Subsequent microstructural examination of the bond zones showed no apparent diffusional intermetallic phase growth (i.e., typically < 3 microns or 3×10^{-4} cm). This degree of thermal stability is markedly superior to that exhibited by the silver interlayer material, Figure 2.

5.0 GENERAL FEATURES OF TRANSITION JOINT DESIGN, MANUFACTURE, INSPECTION AND WELD ATTACHMENT

The essential steps in the manufacture, inspection and weld integration of a bimetal explosive clad weld transition joint are shown in Figure 7. Specific developments and pertinent restrictions associated with each of these steps are discussed below:

5.1 Transition Joint Design Restrictions and Requirements

The following restrictions and requirements, evolved during the GDS development effort, must be followed in the design stage:

A. Joint envelope must be compatible with either Type I or Type II plate thicknesses and a "blank thickness" for which an ultrasonic inspection procedure and appropriate ultrasonic test block is available.

B. Configuration must be amenable to weld joint access, not only for the welding operation but for the installation and removal of required weld tooling.

C. Typical minimum thicknesses for both the 6061 and 304 segments of the transition joint is 0.10". Heavier sections are required in the vicinity of the weld joints in order to meet thermal restriction during welding (c.f. para 5.5).

5.2 Machining of Clad Plate

Machining of clad plate blanks and transition joints is accomplished by conventional machining techniques. The preferred coolant is a non-sulfurized type, such as Buttercut, in order to minimize "tarnishing" of the silver interlayer.

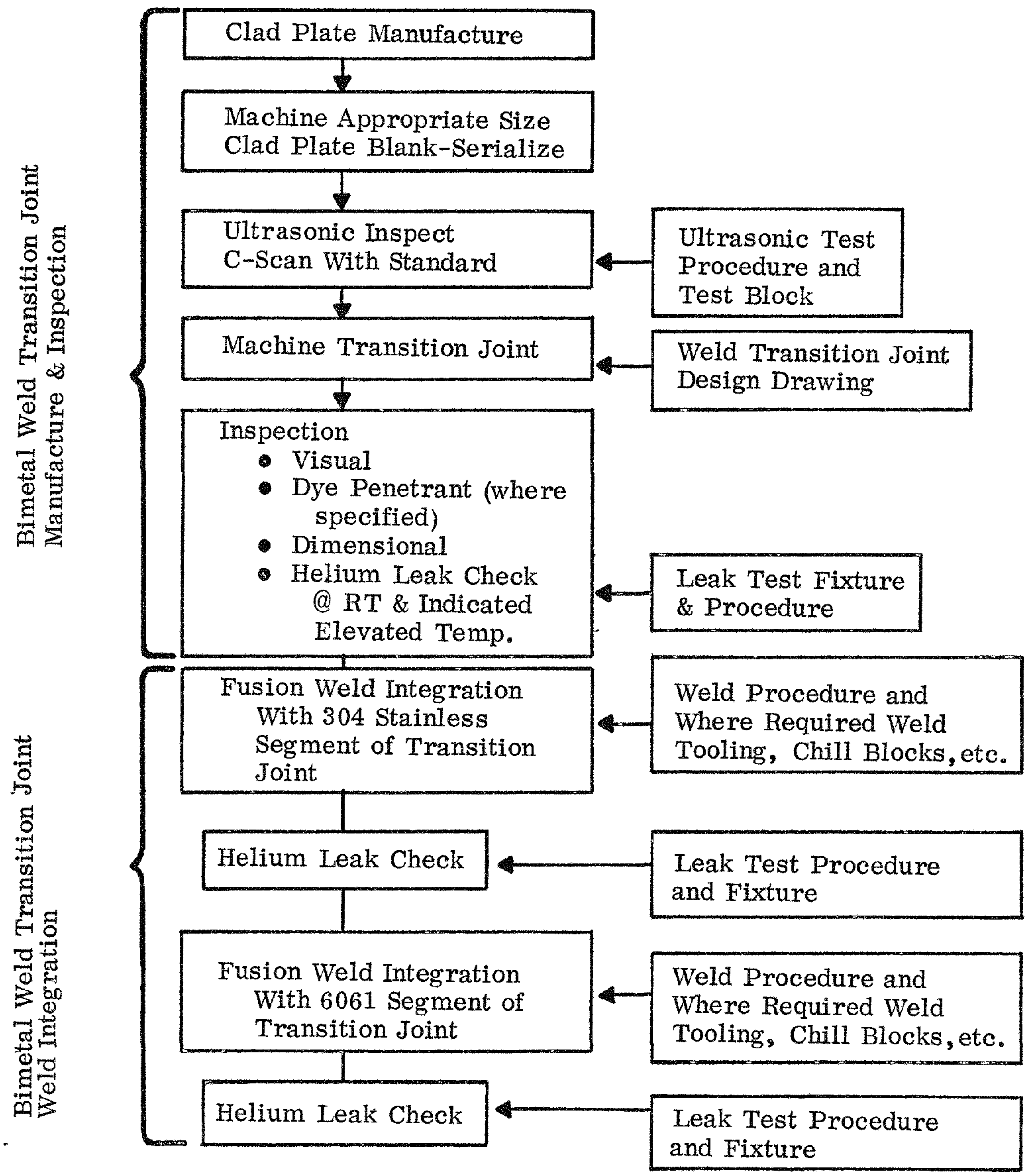


Figure 7: Typical Flow Chart for the Manufacture and Installation of a Bimetal Explosive Clad Weld Transition Joint

Dimensional control relative to the clad plate bond line required the adaption of an ultrasonic contact thickness measurement technique. Modification by Panametrics*, Waltham, Massachusetts of their standard ultrasonic thickness gage Model 5221 permitted reproducible measurement of aluminum alloy or 304L stainless thickness with respect to the respective silver interlayer interface. Reproducibility and accuracy of this technique was checked using machined stepped thickness test blocks which were calibrated by visual measurements on the exposed surfaces.

Control of external blank or joint surfaces with respect to the bond interface can be readily achieved within an accuracy of ± 0.015"

5.3 Ultrasonic Inspection of Machined Blanks

Ultrasonic immersion "C"-scan inspection techniques were evaluated (Ref. 7) and an inspection procedure was developed (Ref. 8 and 9) for the following thickness blank:

6061 Al	0.750"± .015"
Silver	0.035" (typical)
304L Stainless	0.560"± .015"

The standard reference block employed a 3/64" diameter flat bottom hole at the nominal center line of the silver interlayer. Inspection was conducted from the aluminum alloy surface. Blank inspections were conducted at NDT International, West Chester, PA.

*Modifications accomplished with the assistance of Mr. H. F. Coll, Testech, Inc. Downington, PA.

Development of inspection standards and procedures for a thicker blank configuration as required for SIG/Galileo application was in process at the time of "work termination."

5.4 Leak Checking

The development and design of suitable helium leak check tooling was a continuing problem throughout this development. Hot leak checks presented the most severe problem due to the high permeability of "O" rings to helium. Complete isolation of the helium source from leak detector sensor or minimization of "foreign leak paths" was essential for successful tool design. The use of Viton type "O" rings or seals is essential. Double "O" ring seals with an evacuated or appropriately purged inter-cavity are preferred.

5.5 Weld Integration

Weld procedures and tooling (chill blocks, etc.) shall be compatible with a peak bond zone interface temperature of 600°F maximum, preferably 500°F. Temperature measurements, using high speed (Brush Oscillocorder) recorder and suitably instrumented piece parts, during the weld development phase, were a key input in the establishment of weld attachment procedures. This thermal restriction was based on conversative engineering judgement with the intent of minimizing bond zone thermal stresses and bond zone thermal (diffusion) degradation.

6.0 GDS BIMETAL WELD TRANSITION JOINT APPLICATIONS

6.1 IHF Bimetal Ring Transition Joint

A machined IHF bimetal ring, LCP10013, is illustrated in Figure 8. Ten bimetal rings were produced and shipped to ORNL. Three rings were assigned to Isolation Hot Frame manufacture for GDS-1, three for manufacturing process development, and four for the fabrication of IHF bimetal ring component life test assemblies. Fabrication of the life test assemblies subsequently was cancelled, since the isolation hot frame design concept was eliminated in the SIG Galileo flight generator design.

Operational steps for the manufacture, inspection and weld integration of the IHF bimetal ring into the GDS-1 Housing Assembly are illustrated in Figure 9. Integration of the IHF bimetal ring with the platinum alloy IHF subassembly, as illustrated in Fig. 10, was successfully accomplished at ORNL by a manual TIG weld. The final weld integration of the IHF assembly into the GDS-1 aluminum housing, as shown in Figures 11, 12 and 13, was accomplished at TES using a DC manual TIG process with a water cooled hold down chill block.

While the functional performance of the IHF in the GDS-1 generator was marred by the occurrence of a small leak in the platinum alloy can bottom closure weld (leak initiated during GDS assembly process, possibly due to an inadvertent ΔP across the can bottom during a leak check sequence), all leak checks showed no deficiencies in the IHF bimetal ring weld transition joint.

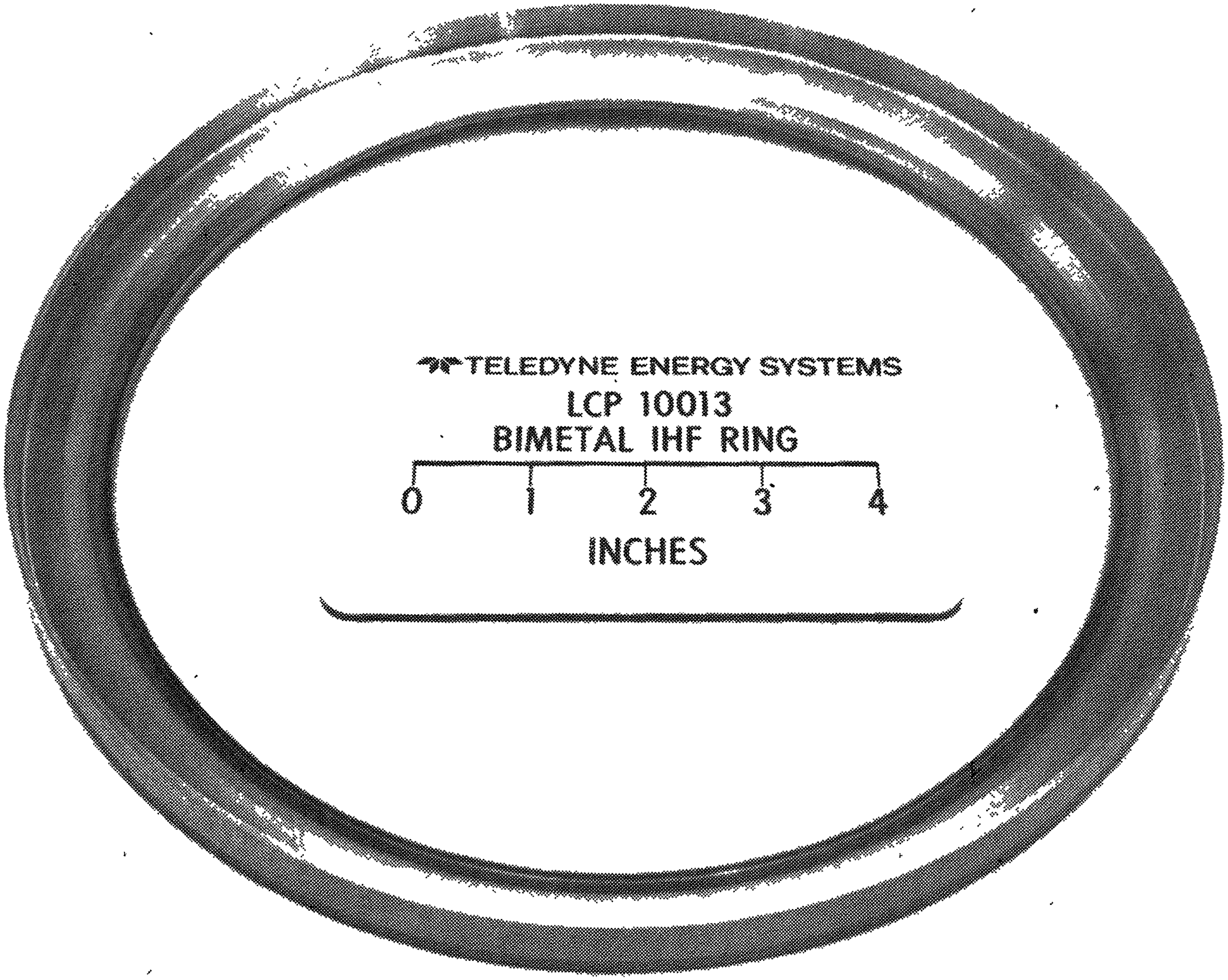


FIGURE 8. BIMETAL IHF RING

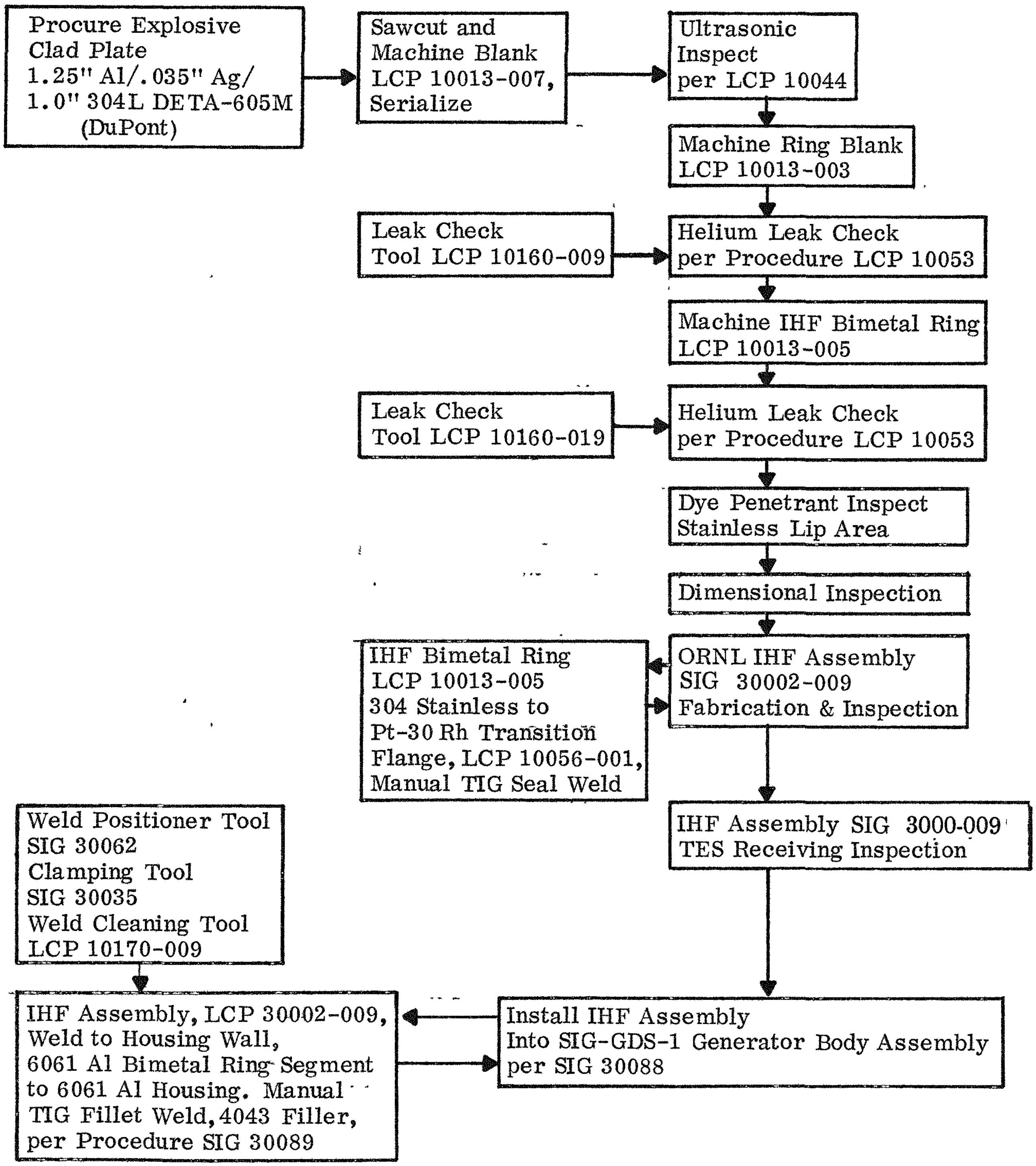


Figure 9: Flow Chart of Operational Steps for the Manufacture, Inspection and Weld Integration of the IHF Bimetal Ring into the GDS-1 Housing Assembly

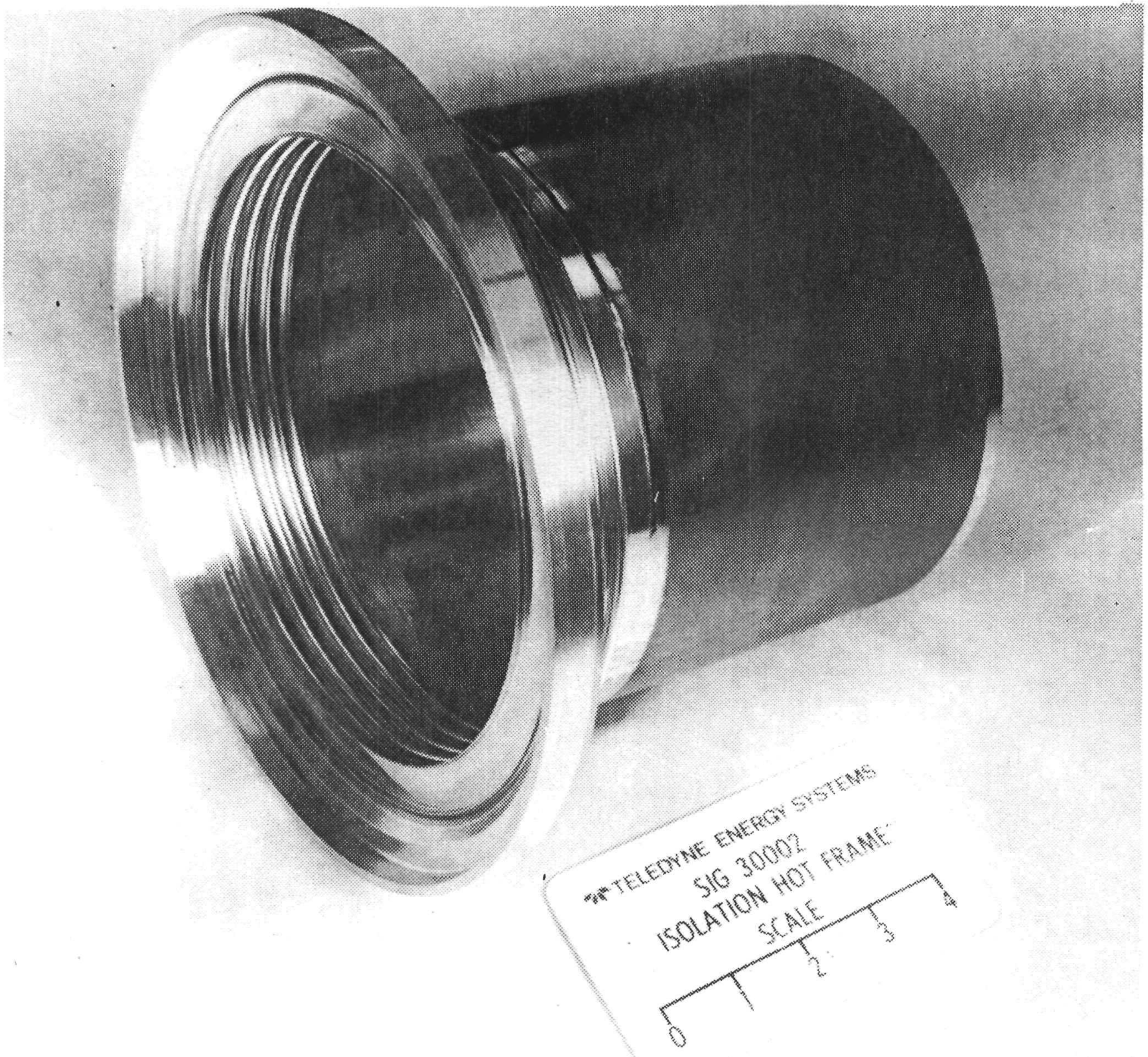


Figure 10: Isolation Hot Frame Assembly-SIG 30002

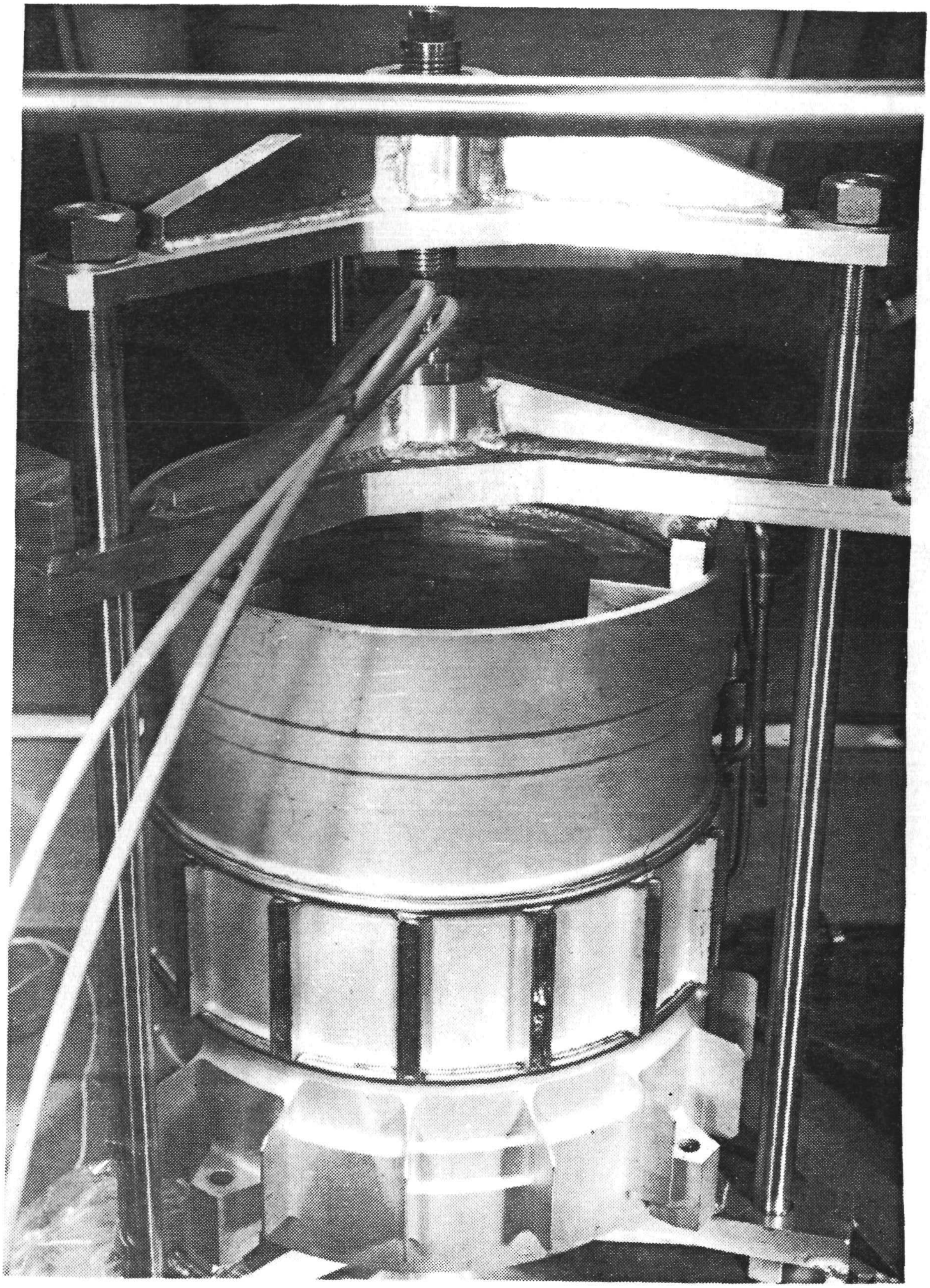


Figure 11: Weld Tooling and Associated Fixtures-IHF to GDS-1 Housing Weld

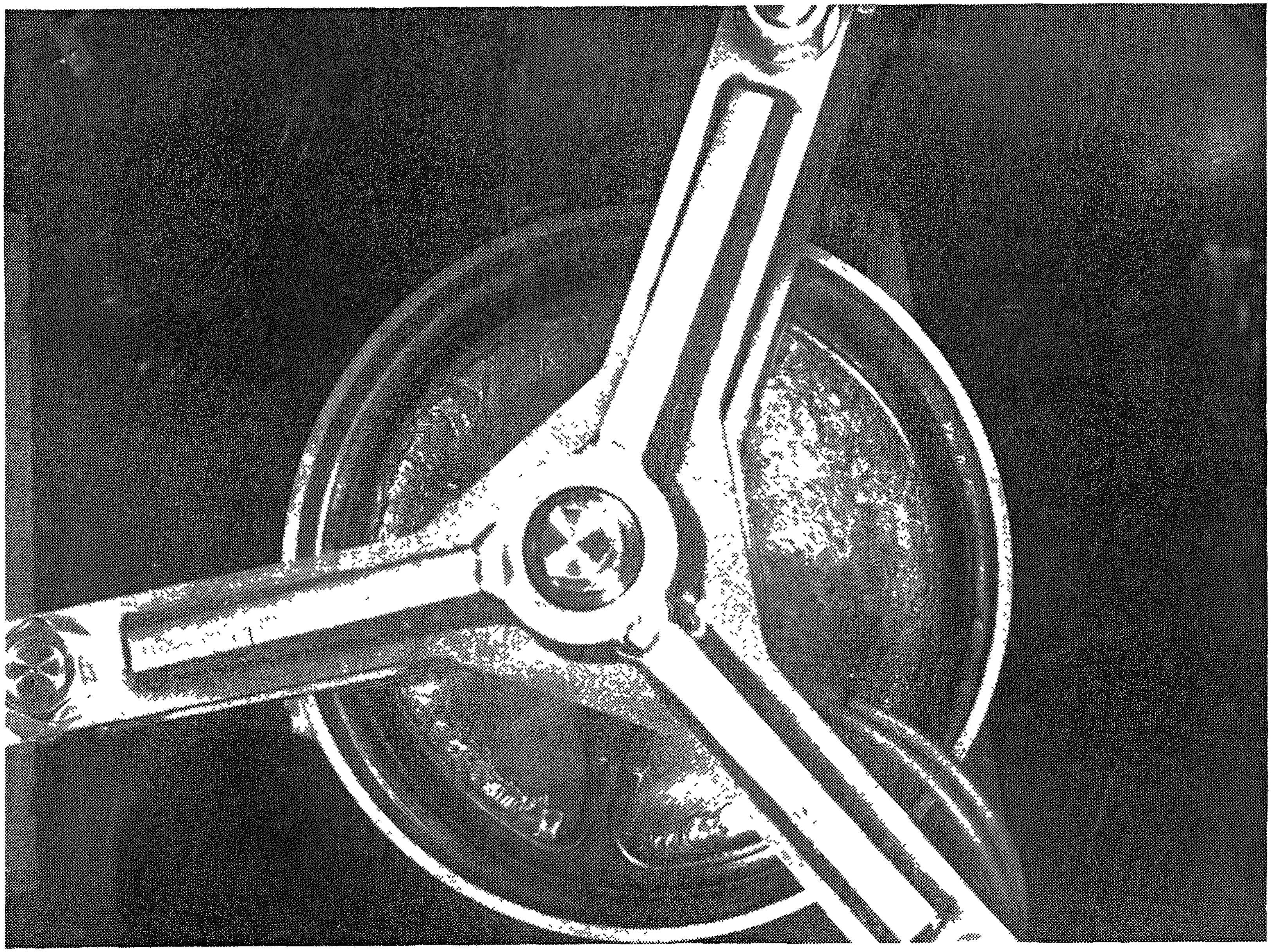


Figure 12: Weld Tooling and Associated Fixtures-IHF to GDS-1 Housing Weld (Top View)

Figure 13: Isolation Hot Frame Installed in GDS-1 Housing

6.2 Receptacle Bimetal Ring Attachment

The typical configuration of a bimetal weld transition joint for an electrical receptacle attachment is shown in Figure 14. A machined bimetal receptacle weld transition ring is shown in Figure 15. The operational steps for the manufacture, inspection and weld integration of a receptacle bimetal ring weld transition joint into the GDS-1 cover assembly are shown in Figure 16. A typical GDS-1 cover illustrating the bimetal ring/receptacle installation is shown in Figure 17. The performance of the bimetal ring/receptacle installations in GDS-1 was excellent. All assemblies remained leak-tight throughout the life of GDS-1.

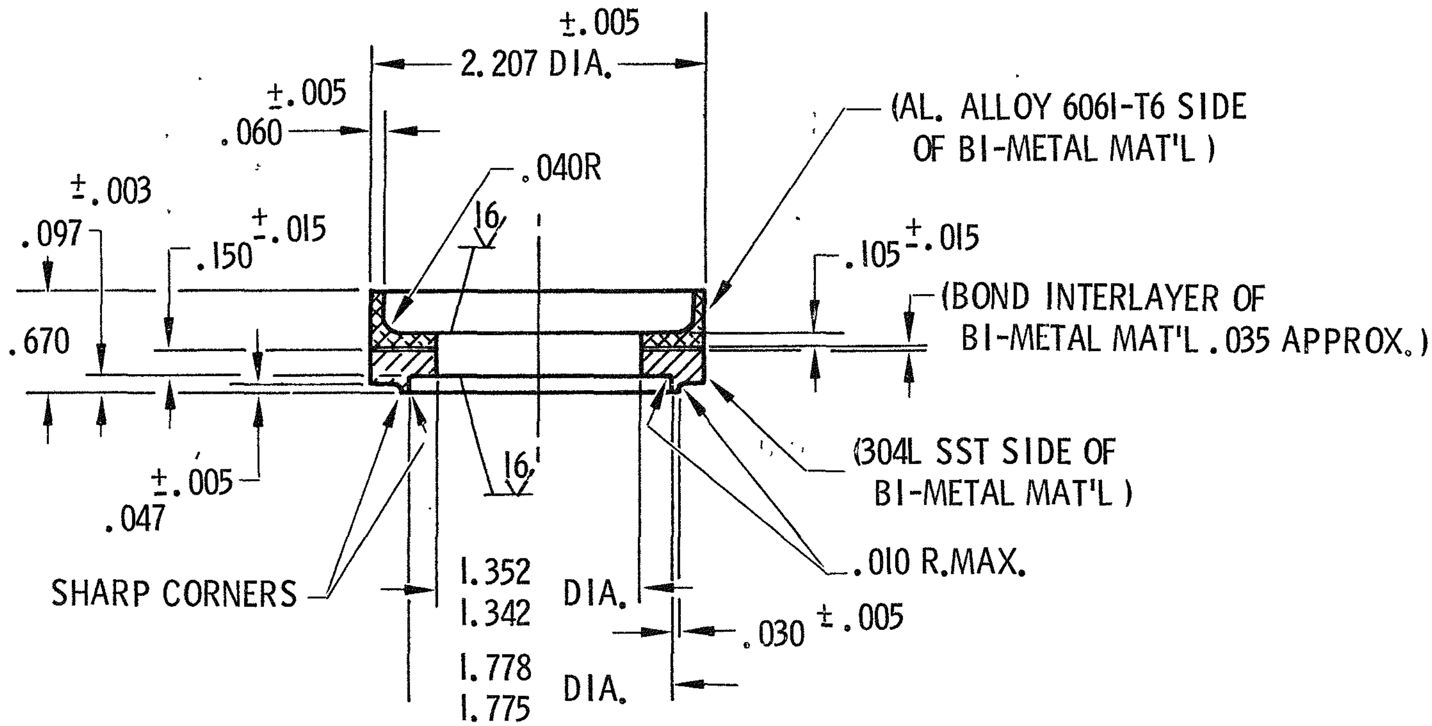


Figure 14: Typical Configuration of Bimetal Weld Transition Joint for Electrical Receptacle Attachment

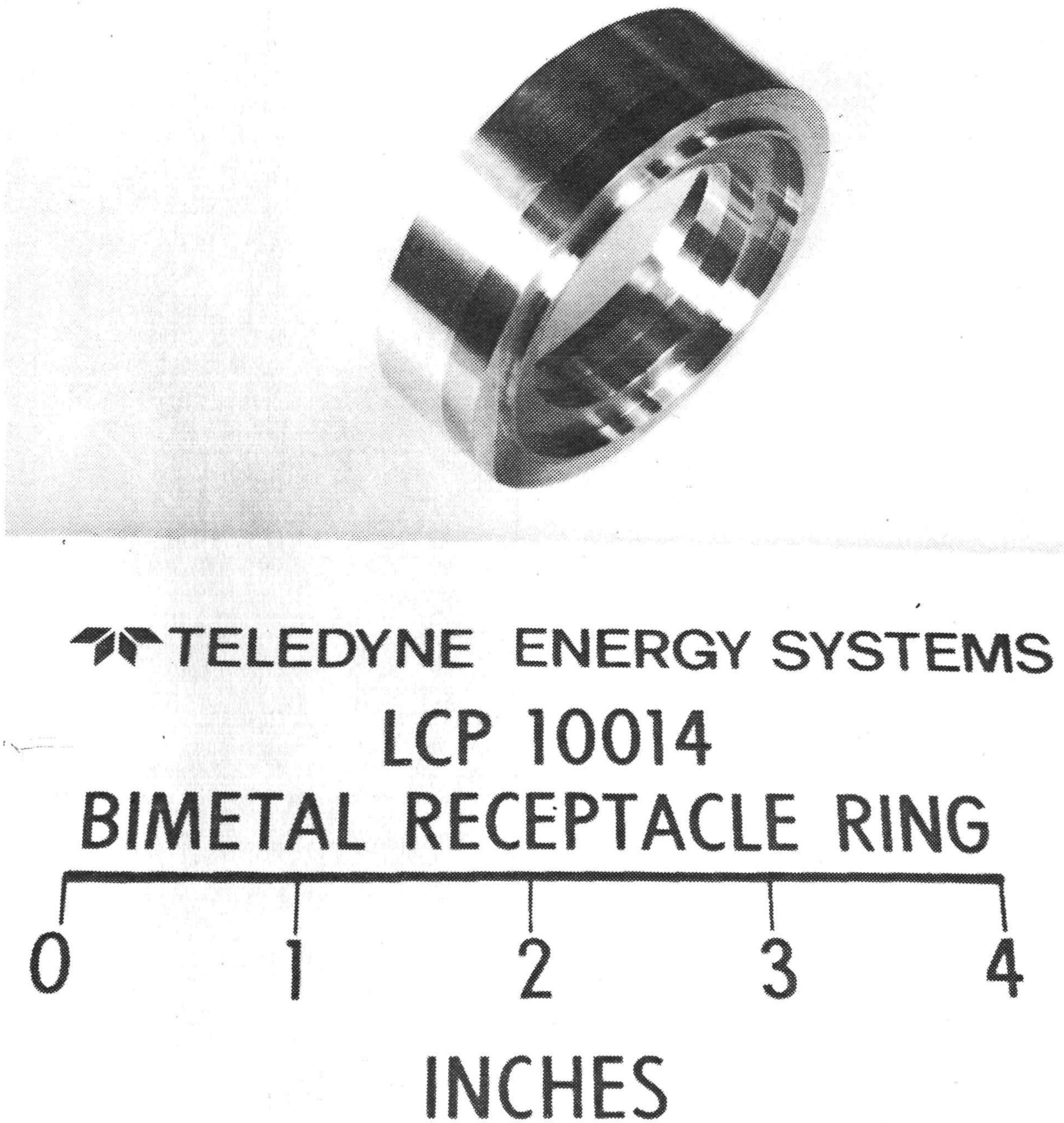


Figure 15: Bimetal Weld Transition Joint for Electrical Receptacle Attachment

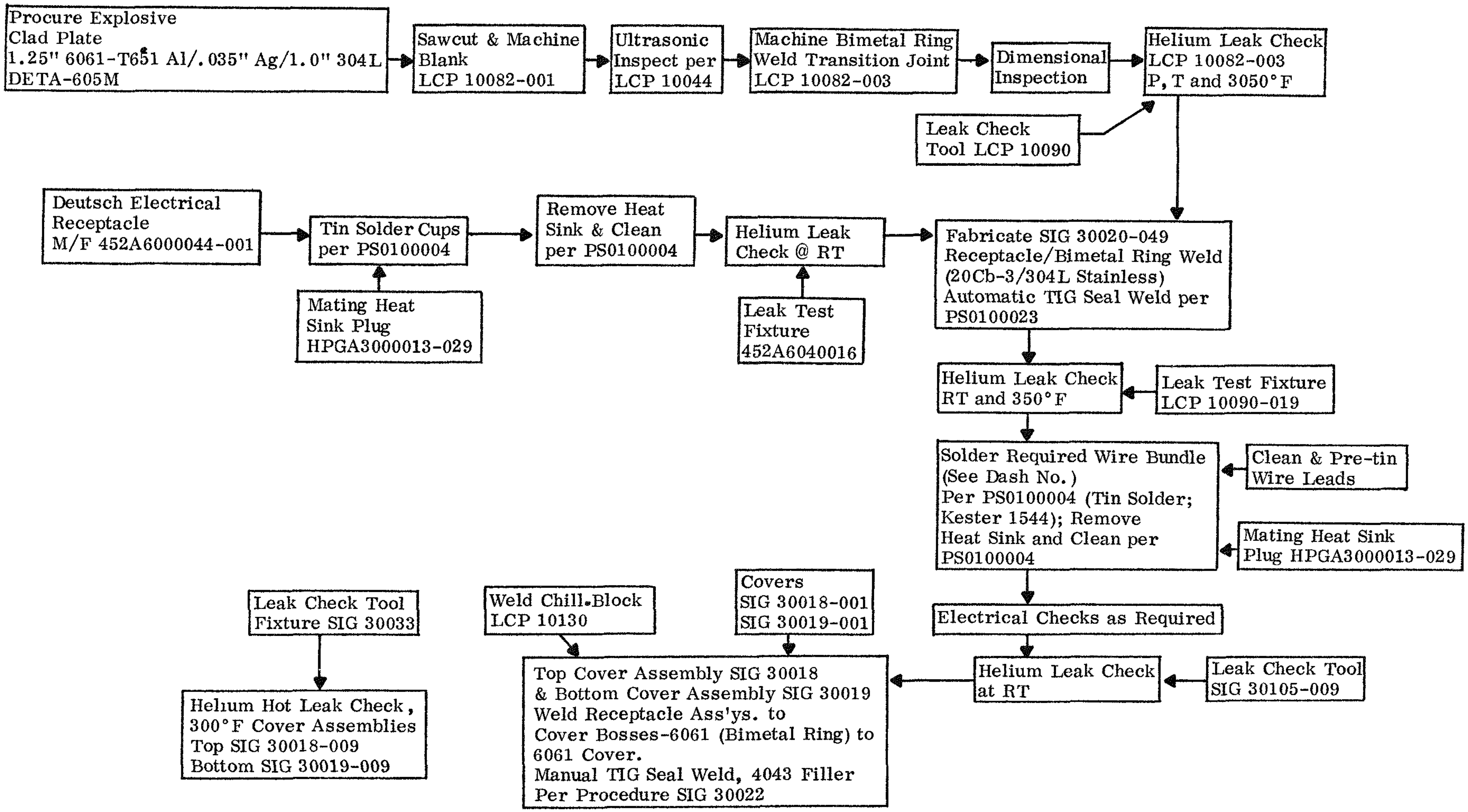


Figure 16: Flow Chart of Operational Steps for the Manufacture, Inspection and Weld Integration of Receptacle Bimetal Weld Transition Joints into GDS-1 End Cover Assembly

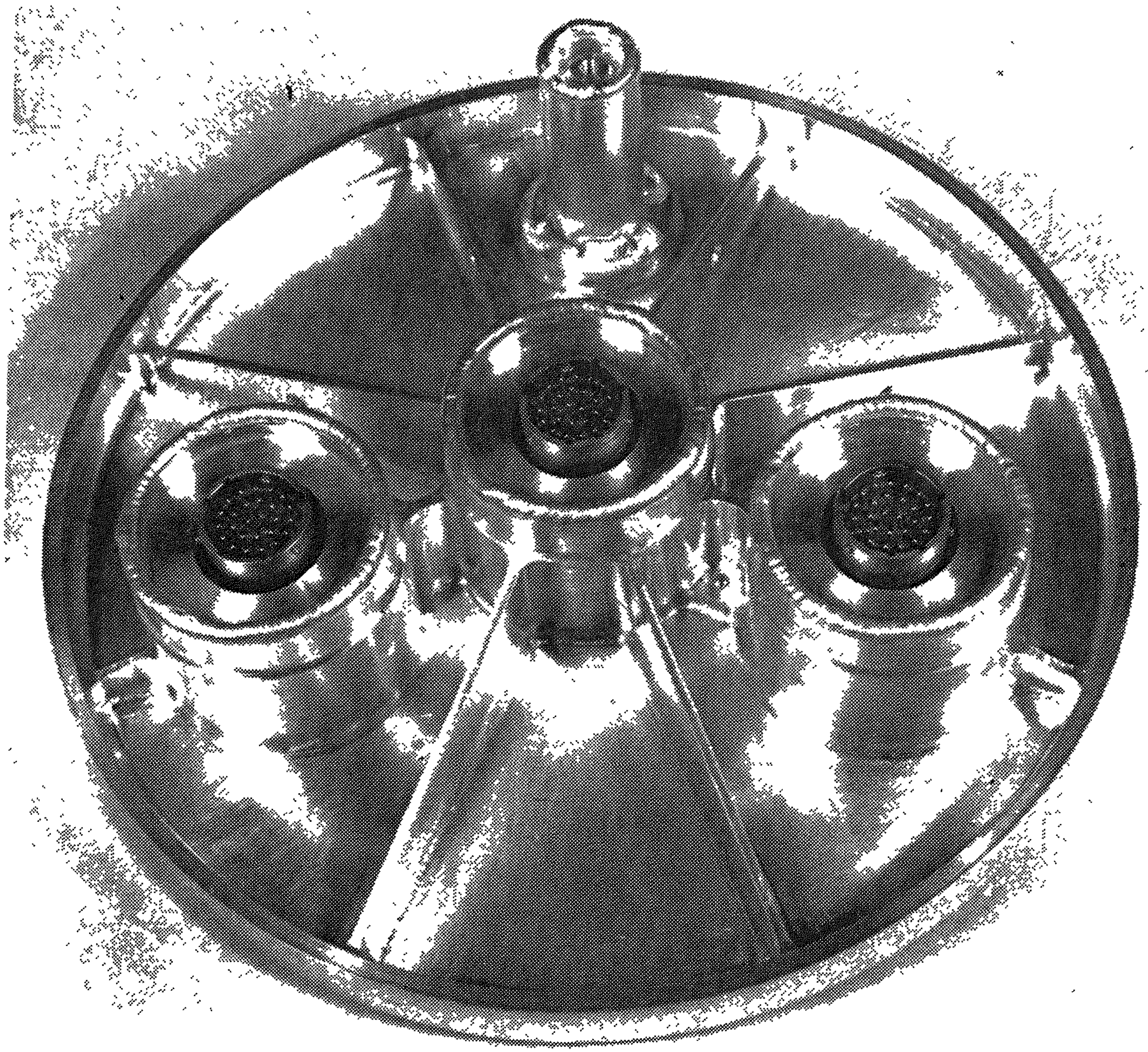


Figure 17: Receptacle/Bimetal Ring Assemblies
Installed in GDS-1 Cover

7.0 BIMETAL RING/RECEPTACLE ATTACHMENT LIFE TESTING

A service capability exceeding 8,000 hours at operating temperatures of up to 400°F has been demonstrated by simulated service life tests conducted on bimetal ring/receptacle assemblies (both dummy stainless steel and Deutsch stainless steel shell, 20 Cb-3, receptacles). This performance capability easily meets SIG/Galileo design requirements.

7.1 Bimetal Ring/Receptacle and Attachments Life Demonstration Test Plan

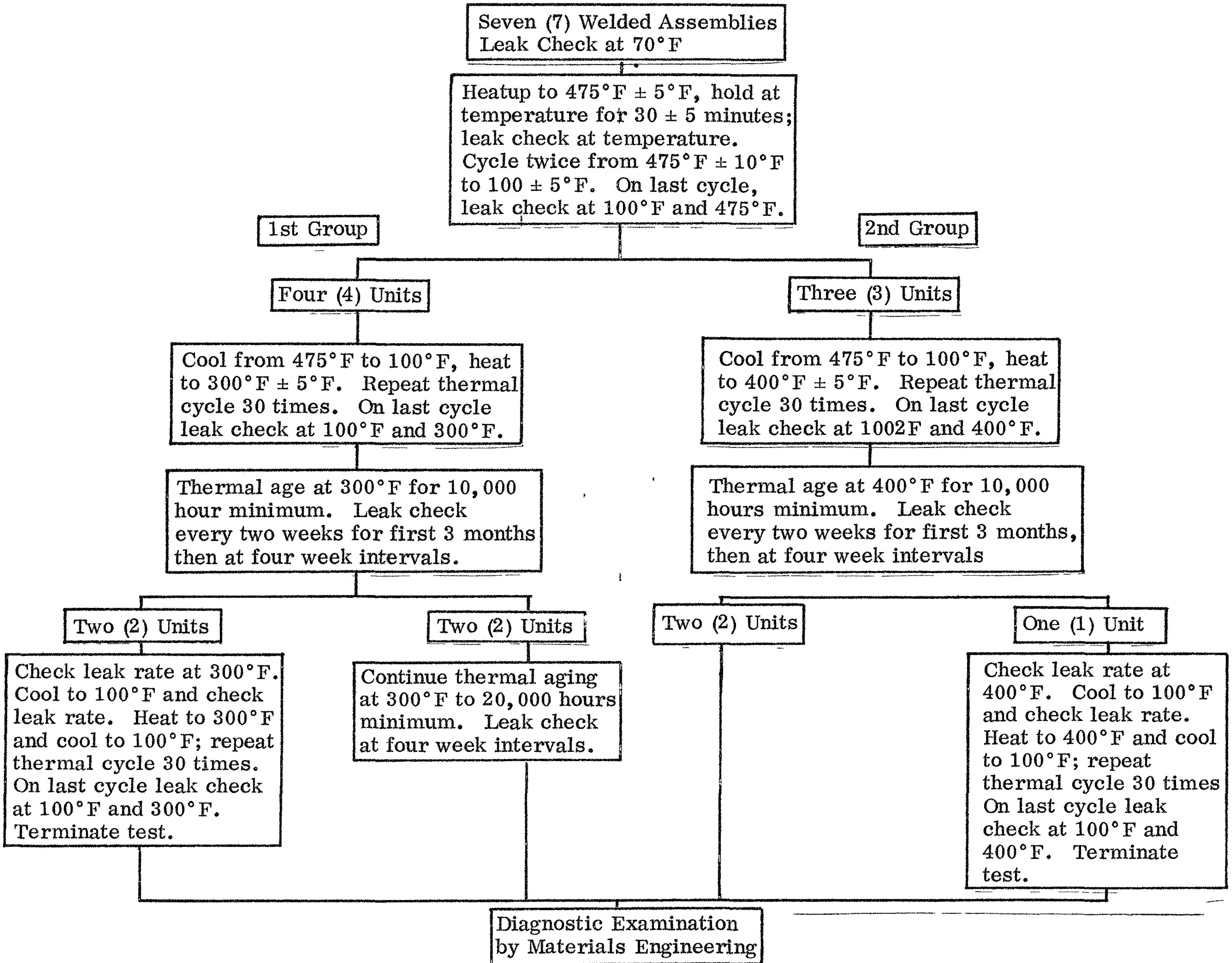
These simulated service (i.e. cyclic plus isothermal long term thermal aging) tests of bimetal ring/receptacle/boss assemblies were designed to demonstrate the suitability of this hermetic attachment technique for the SIG/Galileo flight generator design. Both "dummy" 20 Cb-3 stainless steel receptacles (Deutsch configuration) and Viking vintage Deutsch stainless steel electrical receptacles were employed in this test series. Test thermal profiles for each of these life demonstration component test series are summarized in Figures 18 and 19. The rationale and evolution of these test plans are reviewed in detail in References 2, 10, and 11.

A more extensive Deutsch electrical receptacle/bimetal ring attachment test program, as described in Ref. 2, was initiated to provide the desired SIG/Galileo reliability data base. However, this program has not progressed to the testing phase.

7.2 Bimetal Ring/Receptacle Attachment Test Fixture and Facility

7.2.1 Test Fixture Configuration

The bimetal ring/receptacle attachment test fixture configuration is shown in Figure 20. The LCP 10150 test fixture is comprised of: (1) an "O"-ring sealed 6061 aluminum alloy cover-flange -079 assembly which mates with test facility vacuum manifold and (2) the 6061 aluminum alloy base welded assembly, -059, which contains the



*These tests are a continuation of Phase II activities.

Figure 18: Test Plan Parameters for Dummy Stainless Steel Receptacle/Bimetal Ring Attachment Life Demonstration Tests*

1st Group — 2 Units (Unit S/N-323, Unit S/N-370)

Previous Test History: 2 thermal cycles 300°F to 150°F to 300°F. 36 thermal cycles 400°F to 150°F to 400°F. Aging at 400°F for 3694 hours up to date.

Thermal Aging (2 Units): Age at 400°F for 8000 hours. Leak check biweekly for first 3 months, then one monthly.

Post-Life Cycling (2 Units): Leak check at 400°F. Cycle from 400°F to 150°F to 400°F at stated rate 30 times. Leak check at 150°F and 400°F on last cycle. Remain at 400°F.

Post-Life Thermal Margin (2 Units): Stabilize for 2 hours at 400°F. Leak check at 400°F. Increase temperature at stated rate in increments of 20°F until leak rate increases to 1×10^{-7}. Leak check after each temperature increase. Cooldown at stated rate to 70°F and leak check at 70°F. If unit reseals during cooldown, repeat thermal margin test as described above and leak test after 2nd cooldown at 70°F.

Repeat thermal margin test per direction of test engineer.

2nd Group — 1 Unit (Unit S/N 3-68)

2 thermal cycles 300°F to 150°F to 300°F. Aging at 400°F for 1000 hours. 36 thermal cycles 400°F to 150°F to 400°F. Thermal margin tests.

3 Units (both groups combined): Probe with surgical needle probe for locations where unit leaked. Record all locations. Remove test fixture assembly for this operation from the receptacle test loop and place directly on leak detector.

Post-Test Analysis: Receptacle batch data evaluation, data correlation. Failure analysis, if required. Reliability analysis. Batch characteristic comparison.

*These tests are a continuation of Phase II activities.

Figure 19: Test Plan Parameters for Deutsch Electrical Receptacle/Bimetal Ring Attachment Life Demonstration Tests*

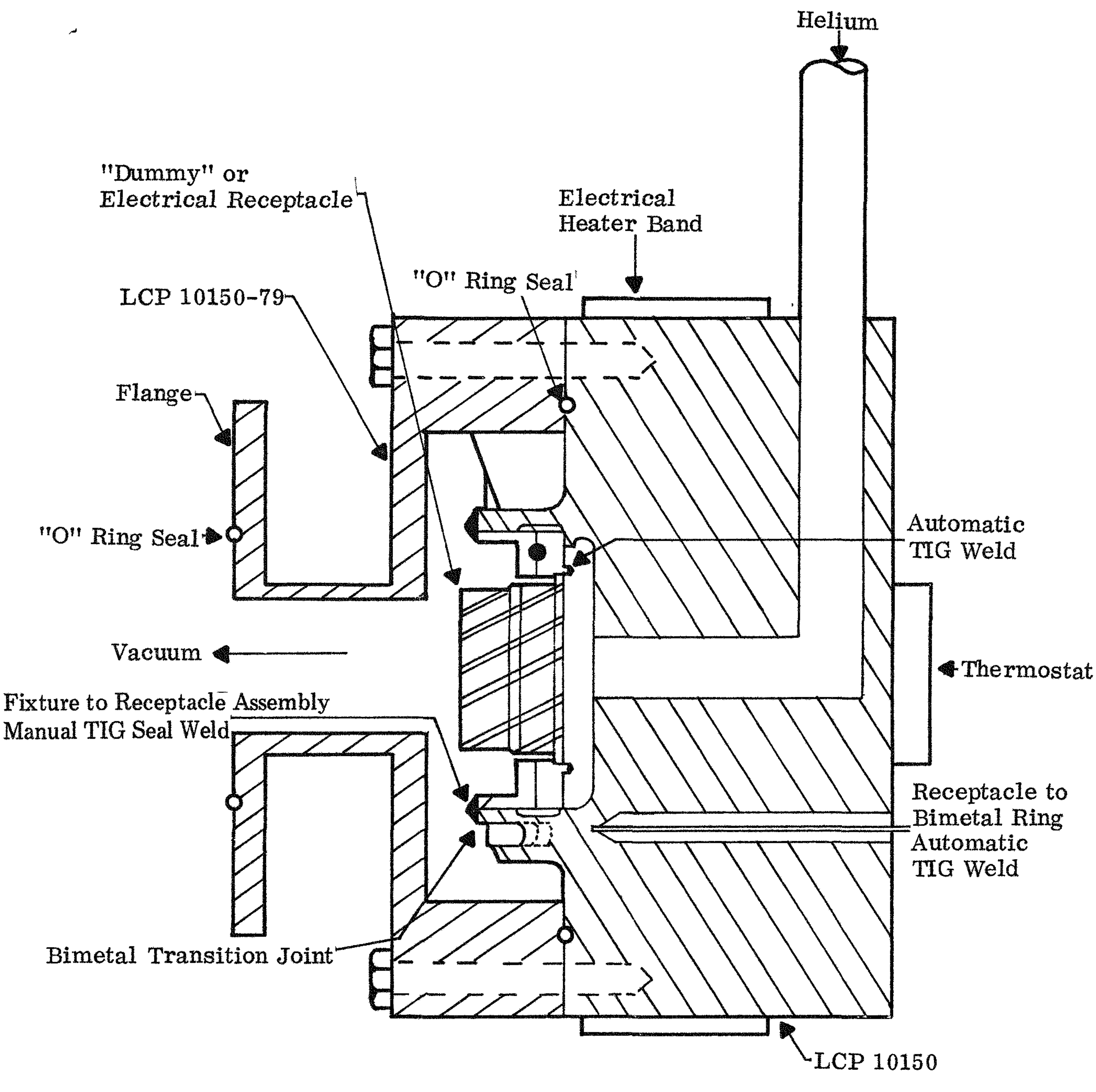


Figure 20: Bimetal Ring/Receptacle Leak Rate Test Fixture LCP 10150

bimetal ring weld transition joint/receptacle assembly which is welded into an aluminum alloy boss.

The boss/bimetal ring/receptacle configureation is essentially the same as the receptacle attachments employed in the GDS and SIG/Galileo generator cover designs. The bimetal ring weld transition joint will accept either a "dummy" stainless steel or actual Deutsch electrical receptacle.

Provision for heating the test assembly is provided by the external electrical band heater. Two thermocouples are mounted in the base in close juxtaposition to the test assembly, one for control and one for monitoring. The cavity below the receptacle boss terminates in a tubular connection which is attached to the test facility helium/vacuum supply line. External Fiberfrax thermal insulation is added as required.

7.2.2 Bimetal Ring/Receptacle Attachment Test Facility

The bimetal ring/receptacle attachment test facility, Figure 21, is comprised of two manifolds (vacuum and helium) with thirty-six independent test stations. The primary vacuum manifold utilizes a Welch Model 3115-D turbo-molecular pumping station. Manifold pressure is monitored using thermocouple type vacuum gauges. As noted in Fig. 20, the connector side of the receptacle is subjected to the high vacuum test environment. The gas manifold provides high purity helium (Federal Spec. BB-H-1168 Grade A) at one atmosphere pressure.

Leak rate of helium through the welded bimetal ring/receptacle test assembly is measured using a Veeco helium leak detector, Model MS-18 or equivalent. Leak rate measurements are made individually on each assembly. The vacuum manifold valve system permits periodic introduction of the leak detector at each of the thirty-six test stations.

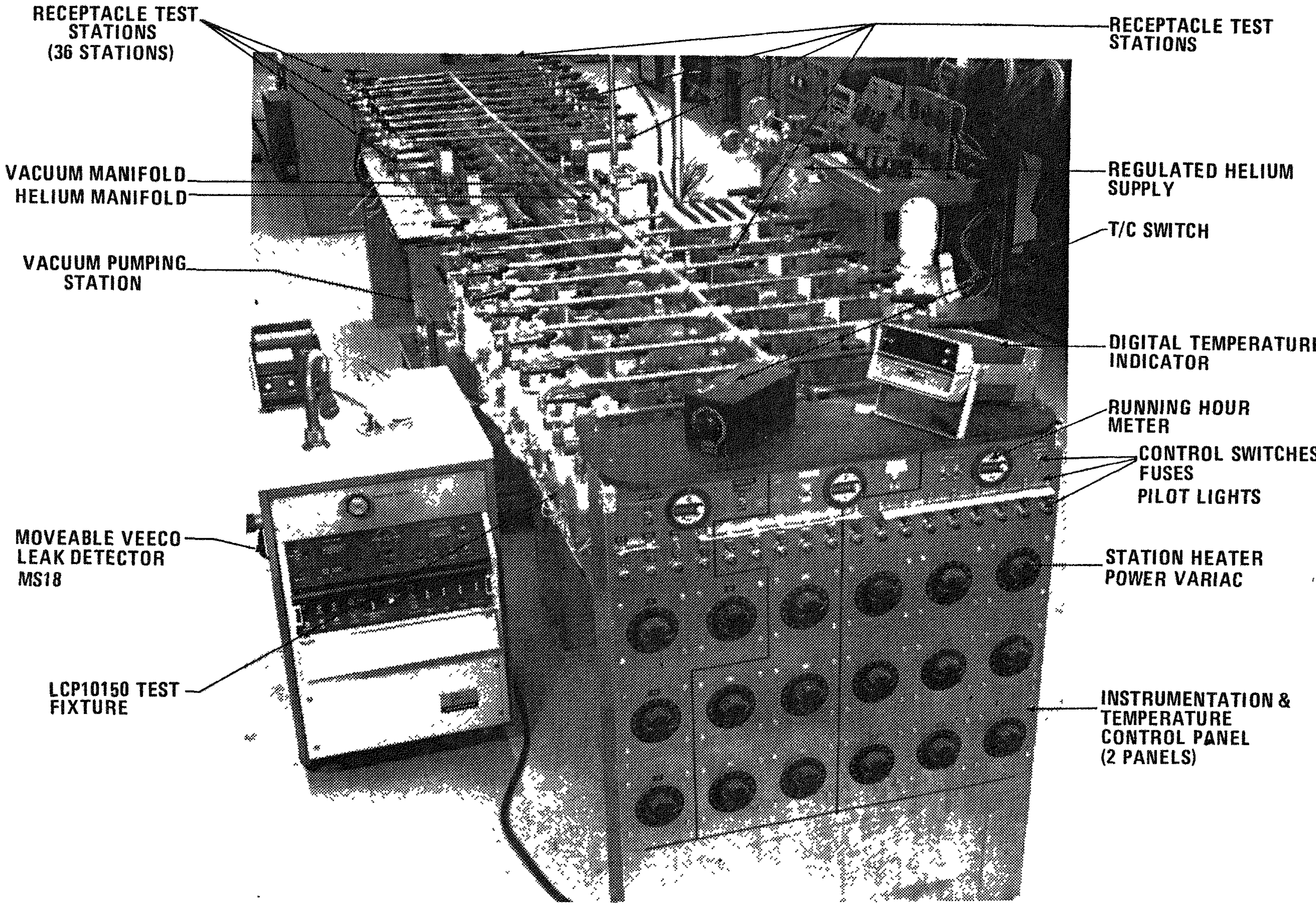


Figure 21: View of Bimetal Ring/Receptacle Attachment Test Facility

7.3 Test Specimen Fabrication and Weld Integration

The sequence of manufacturing and inspection steps involved in the manufacture of the bimetal ring/receptacle attachment test specimen is outlined in Figure 22. Each critical fabrication or inspection step is controlled by an appropriate process or procedure. The hermetic integrity of the fabricated test specimen is assured by ultrasonic inspection of the bimetal blank and by inprocess leak checks of piece parts and welded subassemblies. For example, leak test fixture LCP 10090, as shown in Figure 23 is employed for leak testing both the bimetal ring piece part and the bimetal ring/receptacle welded subassembly.

Weld integration of the receptacle (either dummy or electrical) is accomplished in two steps. First, the receptacle is joined to the bimetal ring by an automatic TIG weld process (seal weld; no filler metal addition). Thermal control of both the bimetal ring (bond interface) and electrical receptacle (glass seal) is achieved by the combined effects of the copper support fixture (i. e. heat sink) and the speed of the automatic welding process. Weld attachment of the receptacle/bimetal ring subassembly to the aluminum alloy boss of the test fixture is made by a manual TIG process with filler metal addition. The high heat input associated with this slow speed manual welding process necessitated the use of a water cooled chill block, Figure 24, in order to achieve the desired thermal control of the bimetal ring/receptacle assembly. This seal weld configuration is readily amenable to rework (i.e., receptacle assembly removal by machining and reinstallation by rewelding).

7.4 Bimetal Ring/Receptacle Attachment Life Demonstration Test Results

7.4.1 Bimetal Ring/Receptacle Attachment Life Demonstration Tests

Life demonstration tests were performed in accordance with the previously cited test plans, Section 7.1, and their respective test procedures (Refs. 12 and 13). Seven "dummy" receptacle and three Deutsch electrical receptacle bimetal ring attachment

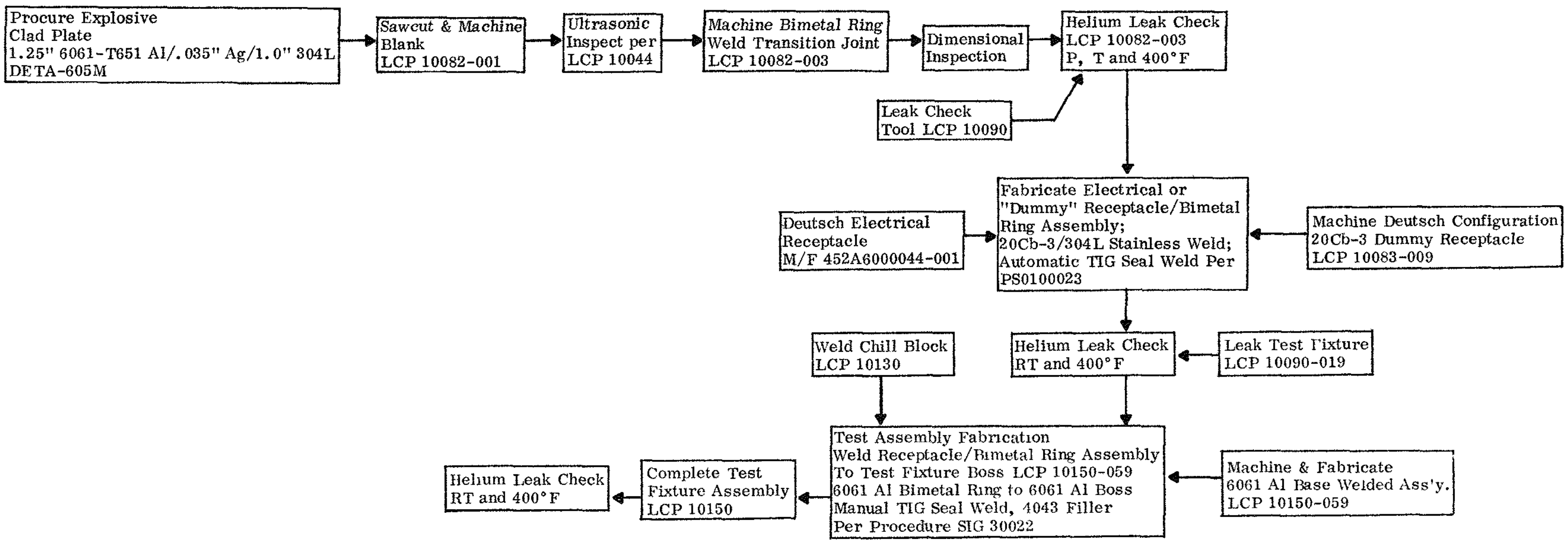


Figure 22: Manufacturing and Inspection Flow Chart for Receptacle/Bimetal Ring Attachments Test Specimen

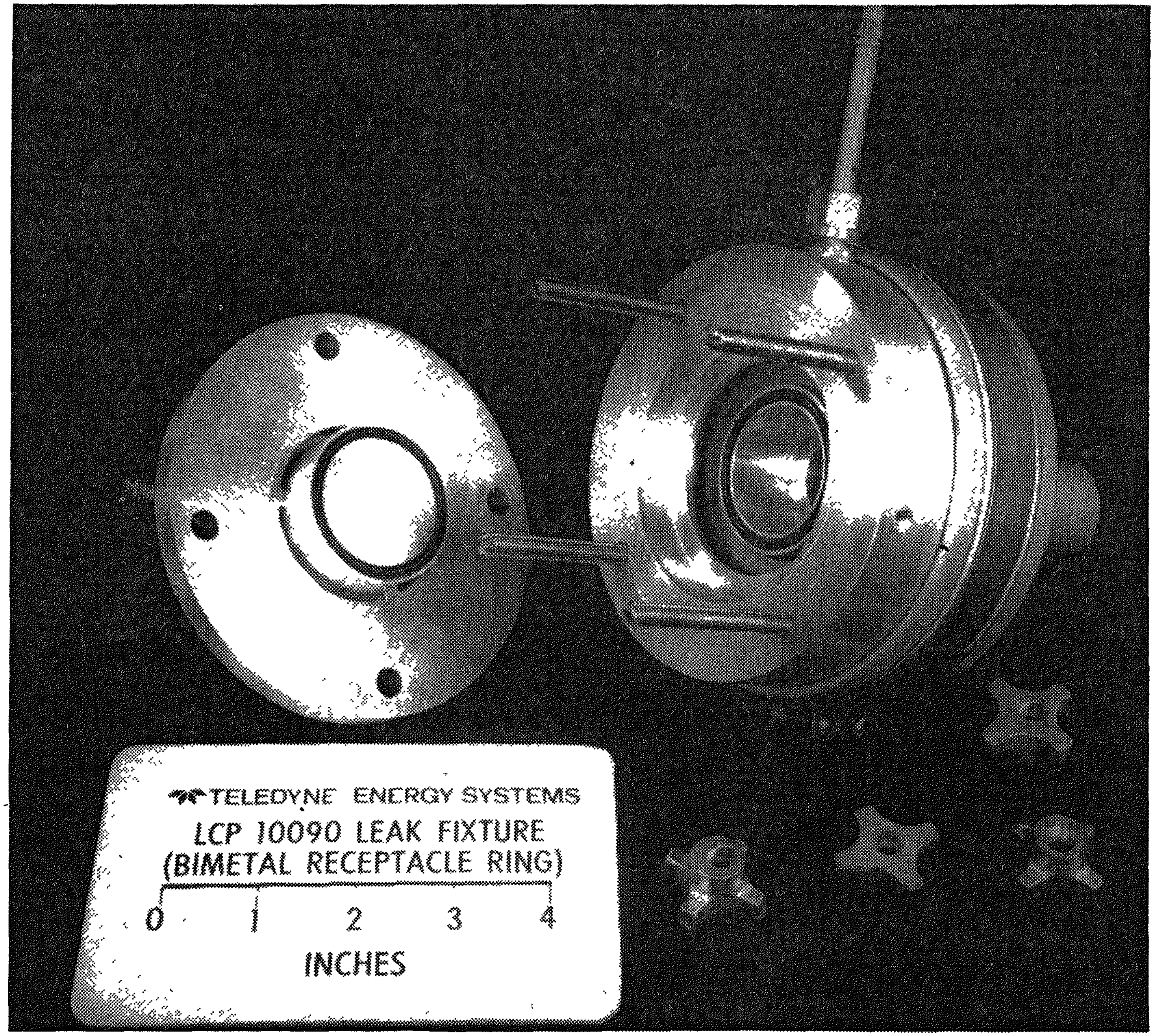


Figure 23: Leak Rate Test Fixture LCP 10090

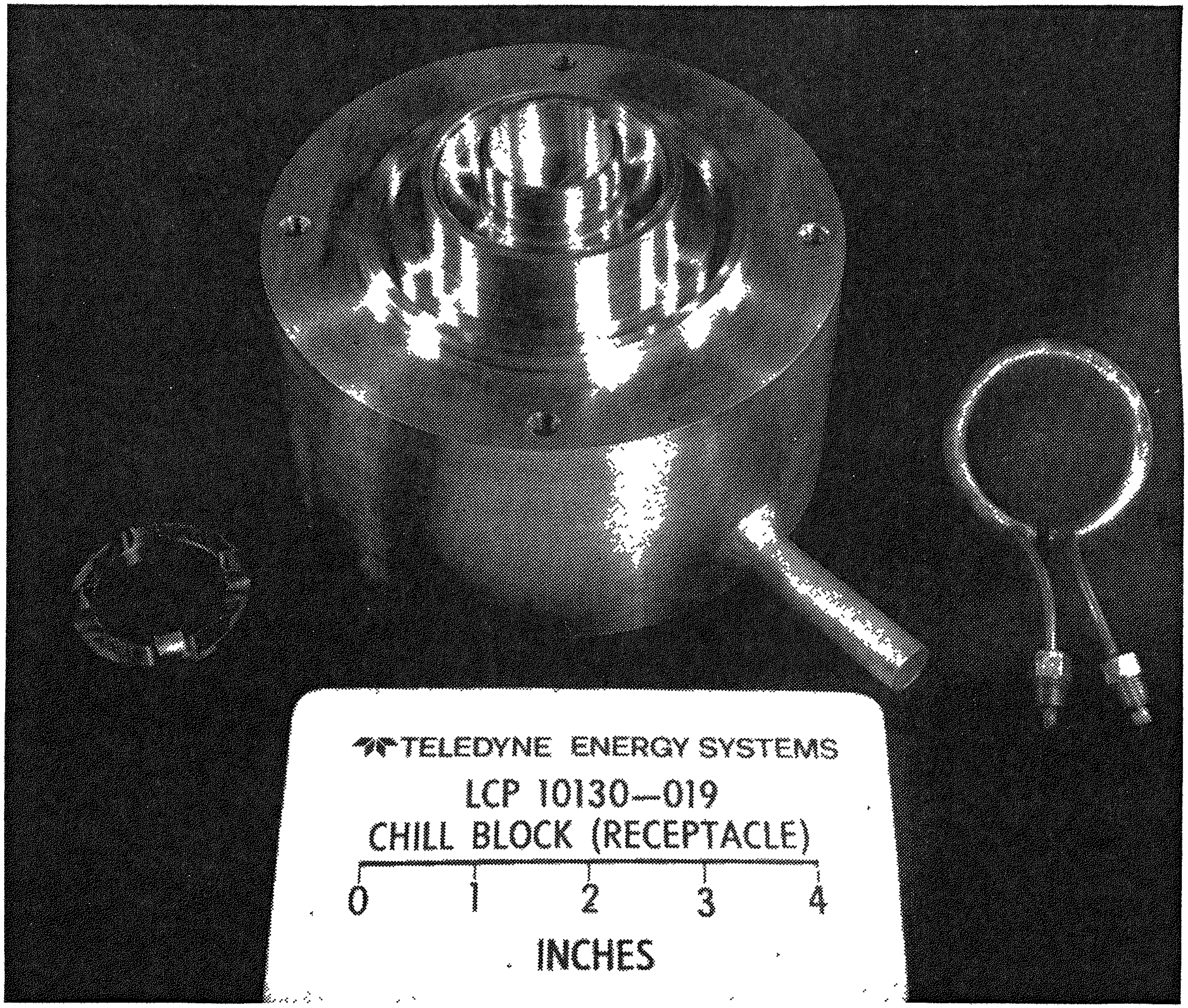


Figure 24: Chill Block Weld Fixture LCP 10130 and Bimetal Ring/Receptacle Test Fixture Assembly

assemblies (c.f. Figure 20) were subjected to "accelerated" simulated service life tests. Test results are summarized in Table 2. Detailed test data are presented in Appendix A, Tables 4 thru 13. Inspection of these data yield the following observations:

a. Both the "dummy" and Deutsch electrical receptacle bimetal weld transition joint assemblies remained "leak tight" (i.e. stable helium leak rate in low 10^{-9} or 10^{-10} range) during thermal aging at 300°F or 400°F for times in excess of 8,000 hours.

b. Thermal cycling, either prior to or after extended thermal aging, did not influence the excellent hermetic characteristic of these assemblies.

If one assumes that the ultimate failure mode for the bimetal ring will be related to the diffusion degradation of the Ag/6061 aluminum bond (c.f. Section 4.0), the following acceleration factors for the above life demonstration tests may be calculated from the cited diffusion kinetics:

Test Temperature °F	Nominal Acceleration Factors*
400	160X
300	6.7X

*Relative to a SIG/Galileo housing/receptacle steady state operating temperature of 250°F.

Thus, the projected performance capability of the bimetal ring receptacle attachment system far exceeds the 250°F/5.5 year design life required for the SIG/Galileo mission.

7.4.2 Bimetal Ring/Receptacle Attachment Thermal Margin Test

The thermal margin test (c.f. Ref. 2) is a destructive type of test which is utilized for the measurement of the thermal safety margin of the hermetic receptacle/bimetal ring

TABLE 2

SUMMARY OF BIMETAL RING/RECEPTACLE ATTACHMENT LIFE DEMONSTRATION TESTS

Type Receptacle	Test Specimen S/N-	Leak Rate - Std. cc He/sec.-atm. Pre-Test 70°F	At Thermal Aging Temperature: Initial	At Thermal Aging Temperature: After Indicated Aging Time	Cumulative Hours of Thermal Aging at 300°F	Cumulative Hours of Thermal Aging at 400°F
Deutsch	323	3.9×10^{-10}	9.0×10^{-10}	1.75×10^{-9}		8424
Deutsch	370	4.4×10^{-10}	1.20×10^{-9}	1.6×10^{-9}		8424
Deutsch	368	4.5×10^{-10}	1.90×10^{-9}	3.2×10^{-9}		1635*
Dummy	B0701	3.6×10^{-10}	9.0×10^{-10}	1.3×10^{-9}		8256
Dummy	B0702	4.4×10^{-10}	7.6×10^{-10}	1.2×10^{-9}		8256
Dummy	B0703	3.8×10^{-10}	4.8×10^{-10}	5.0×10^{-10}		8256
Dummy	B0704	3.4×10^{-10}	1.4×10^{-9}	8.6×10^{-10}	8256	
Dummy	B0706	2.7×10^{-10}	1.8×10^{-9}	8.1×10^{-10}	8256	
Dummy	B0801	2.7×10^{-10}	1.4×10^{-9}	1.2×10^{-9}	8256	
Dummy	A1205	2.0×10^{-10}	1.2×10^{-9}	9.1×10^{-10}	8256	

*Includes two thermal cycles from 400°F/150°F/400°F, plus thermal aging at 400°F for 1152 hours, plus thirty cycles from 400°F/150°F/400°F over following 480 hour period; test culminated in thermal margin test.

attachment assembly. The helium leak rate of the assembly is continuously monitored as its temperature is increased at a nominal rate of 2-3 °F/minute. The failure temperature is denoted by a sharp increase in assembly leak rate, typically >>1 x 10^{-8} scc He/sec-atm. Thus, the temperature difference between the nominal peak design operating temperature for the receptacle attachment assembly (i.e. 250 °F for the SIG/Galileo mission) and the observed thermal margin test failure temperature, provides a measure of the thermal margin of safety for the receptacle/attachment assembly.

Results of the thermal margin test conducted on the thermal and cyclic aged (c.f. Table 2) Deutsch electrical receptacle/bimetal ring assembly S/N-368 are presented in Table 3. Pertinent observations from this test and the post-test diagnostic inspection are as follows:

a. The indicated receptacle thermal limit, 698 °F, yields a thermal safety margin of 448 °F.

b. Despite the diffusional degradation associated with the prior thermal aging at 400 °F (i.e. 1152^{+} hours at 400 °F is equivalent to ~ 21 years at 250 °F), the hermetic integrity of the bimetal ring was maintained thru the 698 °F thermal cycle.

TABLE 3

TEST RESULTS FROM THERMAL MARGIN TEST ON
DEUTSCH ELECTRICAL RECEPTACLE/BIMETAL RING ASSEMBLY S/N 368

Temperature °F	Leak Rate scc He/sec.-atm.
400	3.20×10^{-9}
420	3.00×10^{-9}
440	2.95×10^{-9}
460	2.80×10^{-9}
480	2.60×10^{-9}
500	2.40×10^{-9}
520	2.00×10^{-9}
540	2.20×10^{-9}
560	2.00×10^{-9}
580	2.00×10^{-9}
600	2.10×10^{-9}
620	2.30×10^{-9}
640	2.20×10^{-9}
660	2.10×10^{-9}
675	2.30×10^{-9} to 1.8×10^{-8}
680	3.8×10^{-9}
690	2.6×10^{-9}
698	Open $> 3 \times 10^{-6}$
150	Open $> 3 \times 10^{-6}$
75*	Open $> 3 \times 10^{-6}$

*Probe of failed assembly indicated gross leak at, at least two, or more, pins in center of receptacle and no indication of a leak either in the bimetal ring or weld attachments.

8.0 SIG/GALILEO APPLICATIONS OF BIMETAL WELD TRANSITION JOINTS

8.1 Design Applications

In addition to the well developed bimetal ring/receptacle attachment, as shown in Figure 25, three additional applications of the 6061 Al/Ag/304L stainless weld transition joint were incorporated in the SIG/Galileo flight RTG design. These new design applications include the following:

a. Generator Vent System (GVS) - attachment of the stainless steel puncture diaphragm to the aluminum alloy base, Figure 26.

b. Gas Maintenance Plumbing System - attachment of stainless steel plumbing to aluminum alloy end cover as shown in Figure 27.

c. Outgassing Tube Assembly - attachment of stainless steel tube/conflat seal flange to aluminum alloy temporary end cover as illustrated in Figure 28.

8.2 SIG/Galileo Process and Hardware Development Status

The status of the supporting development activities for the above described SIG/Galileo bimetal weld transition joint applications at the time of "work termination" is as follows:

a. Receptacle Attachment - Thirty bimetal ring blanks were completed and were awaiting ultrasonic inspection.

b. GVS (Generator Vent System and Gas Maintenance System - Blanks were cut for preliminary manufacturing and weld development. An RFQ for electron beam weld process development for the stainless steel diaphragm/GVS bimetal transition joint attachment was prepared and released for bid.

c. Outgassing Tube Assembly - Manufacture of the required ultrasonic standard test block and development of the testing parameters was in process.

d. Clad Plate Procurement - Two Type II 6061 Al/Ag/304L nominal 20" x 44" explosive clad plates were received. This material satisfies all development and hardware requirements for the receptacle attachment, generator vent system and gas maintenance system requirement. Procurement of one Type I 6061 Al/Ag/304L (i.e. heavier gage; ~3.9" overall thickness) for the outgassing tube assembly application was delayed due to vendor manufacturing problems.

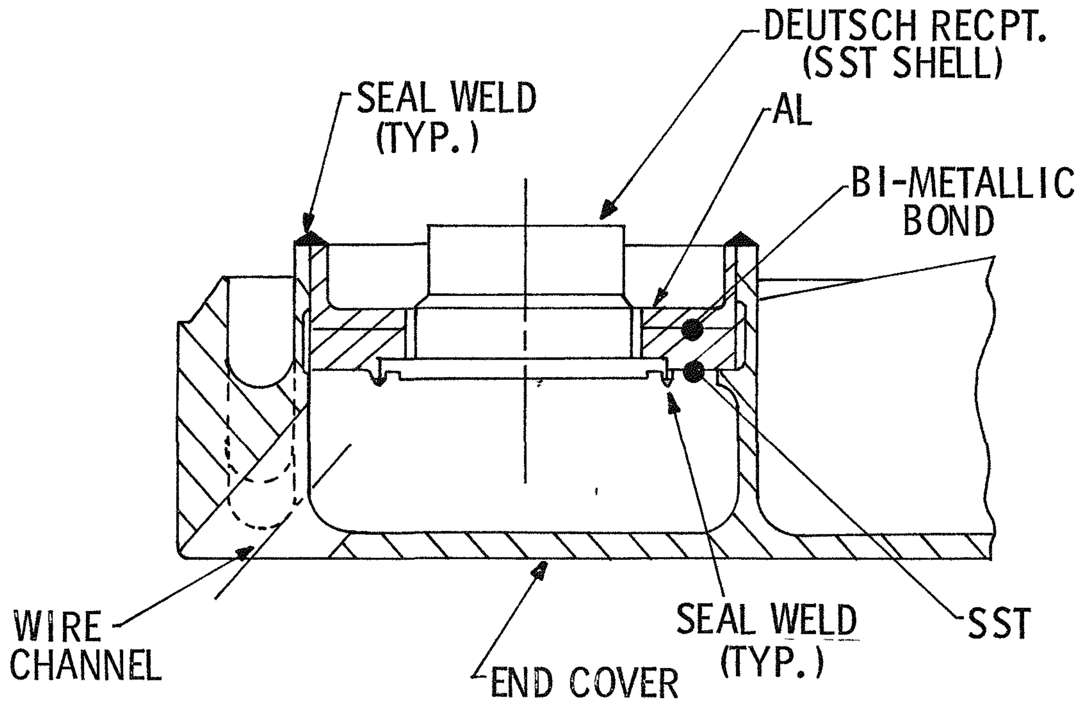


Figure 25: Electrical Receptacle Assembly Application of Bimetal Weld Transition Joint to the SIG/Galileo Design

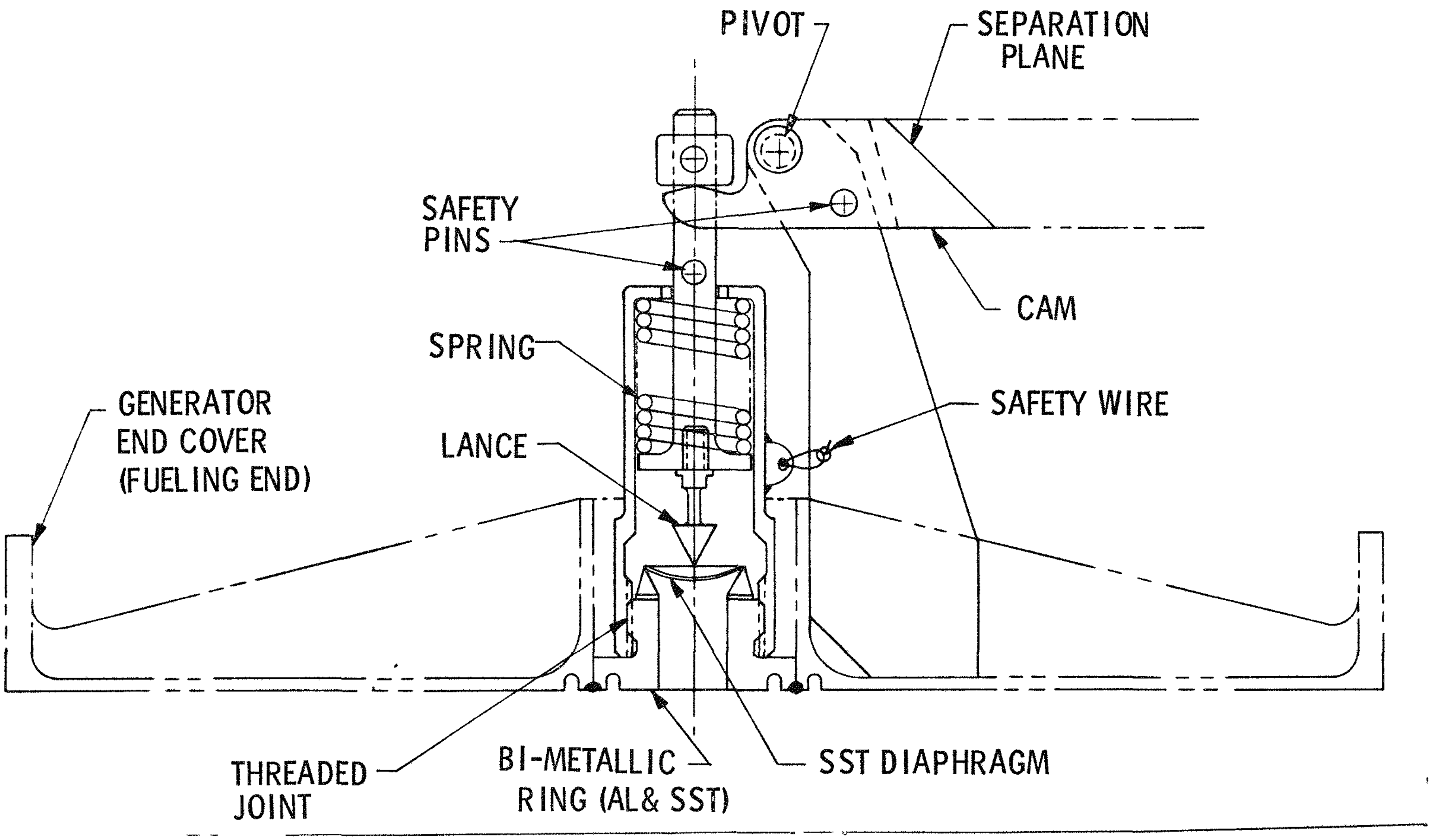


Figure 26: GVS Application of Bimetal Weld Transition Joint to SIG Galileo Design

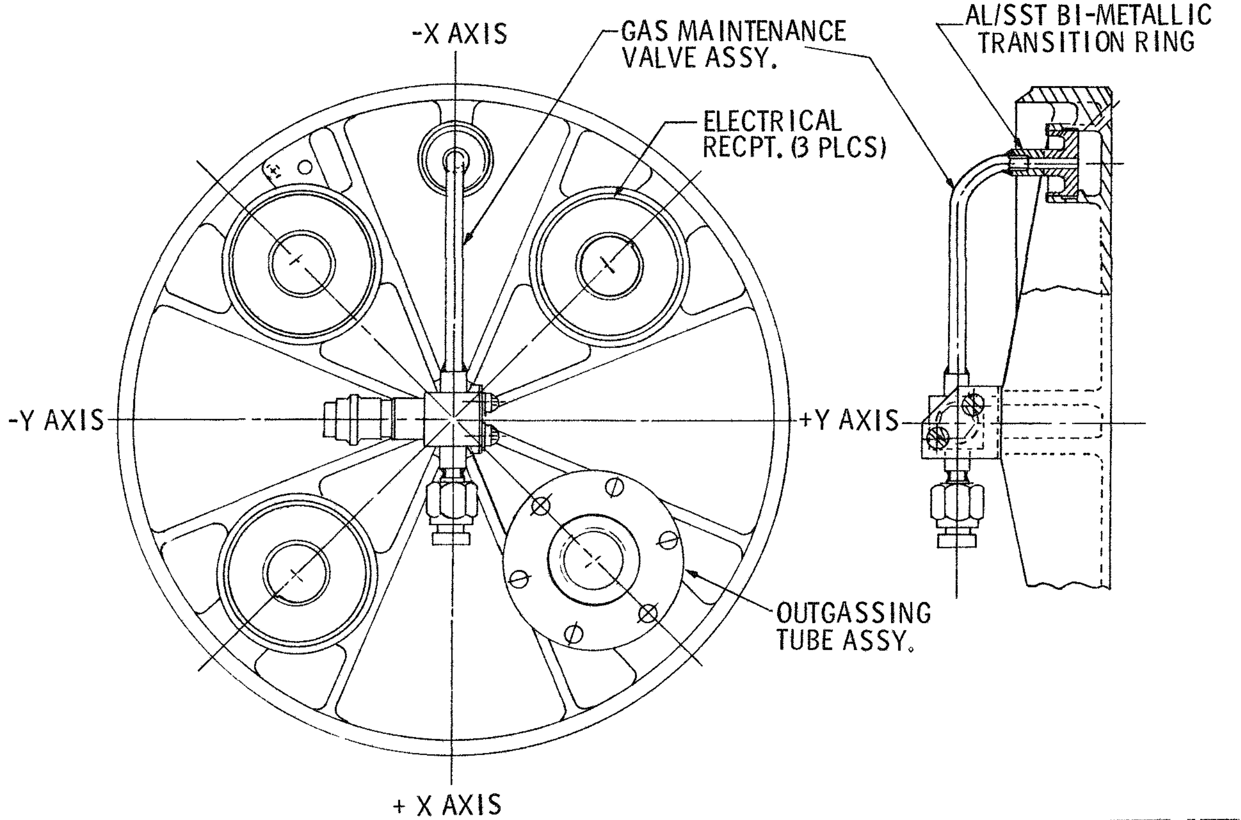


Figure 27: Gas Maintainence System Application of Bimetal Weld Transition Joint to the SIG/Galileo Design

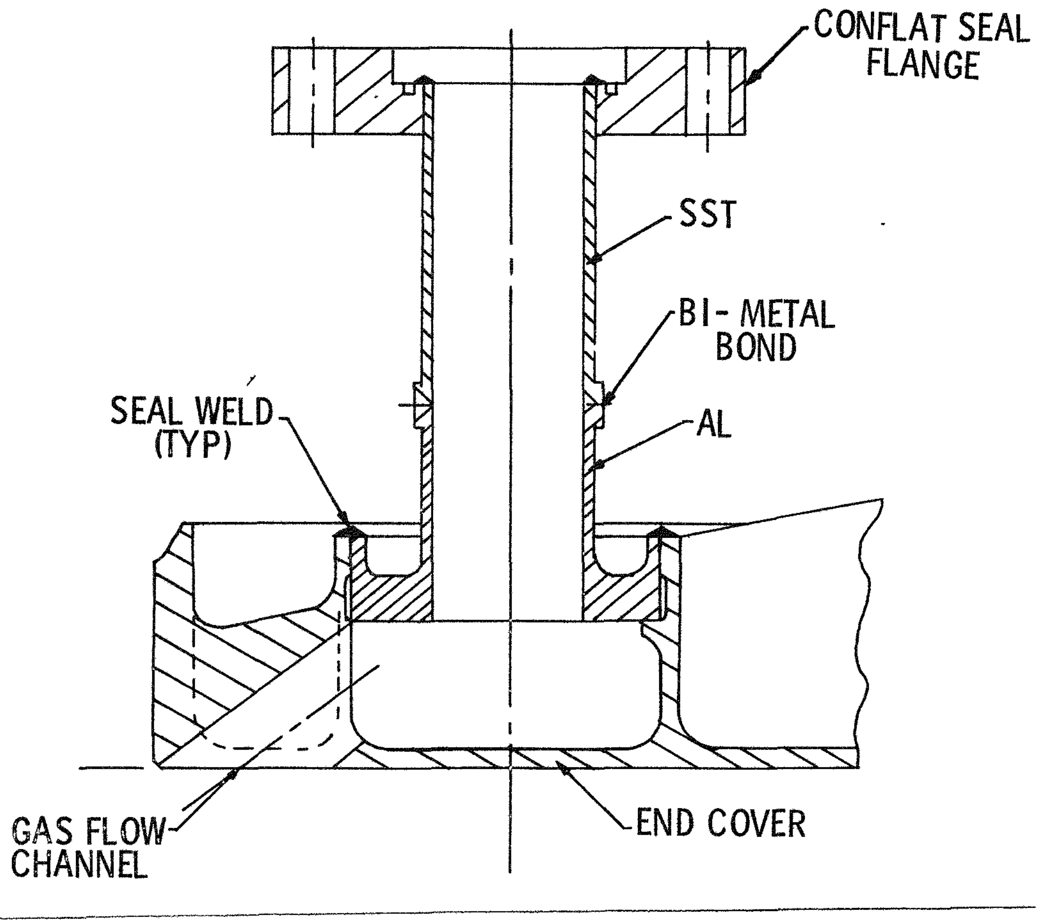


Figure 28: Outgassing Tube Assembly Application of Bimetal Weld Transition Joint to the SIG/Galileo Design

9.0 BIMETAL WELD TRANSITION JOINT - CURRENT AND GROWTH POTENTIAL

Two inherent metallurgical factors dictate the temperature/useful life application limit for an explosive clad aluminum alloy/stainless steel bimetal weld transition joint system. These are:

a. Bond zone diffusional degradation.

b. Aluminum alloy overaging (pertinent primarily to structural hermetic transition joints).

An estimated design application envelope (operating temperature/service life) for three weld transition joint materials is depicted in Figure 29.

The capabilities of the 6061 Al/Ag/304L weld transition joint material has been successfully demonstrated, as described in this report. This material is suited for current applications.

The latter two weld transition joint materials range from developmental (i. e. 6061 Al/Ta/304L) to technically feasible (i. e. 2219 Al/Ta/304L) but requiring reduction to practice. The 6061 Al/Ta/304L explosive clad weld transition joint material, as described herein, has been procured commercially and has exhibited excellent bond zone diffusional stability. Further material characterization and component hardware development and testing is required to qualify this material.

The substitution of 2219, a "high temperature" aluminum alloy, for the 6061 alloy, offers structural stability of the aluminum alloy circa 550-600°F. Thus coupling the high temperature strength capability of 2219 with the bond zone diffusional stability associated with the tantalum interlayer yields an attractive 2219/Ta/304L explosive clad weld transition joint material. It should be noted that the anticipated degradation mode which will limit the long term use temperature in an air atmosphere may be associated with the oxygen contamination of the tantalum interlayer - estimated limit 580-600°F. Development of this material is technically feasible and its pursuit is recommended.

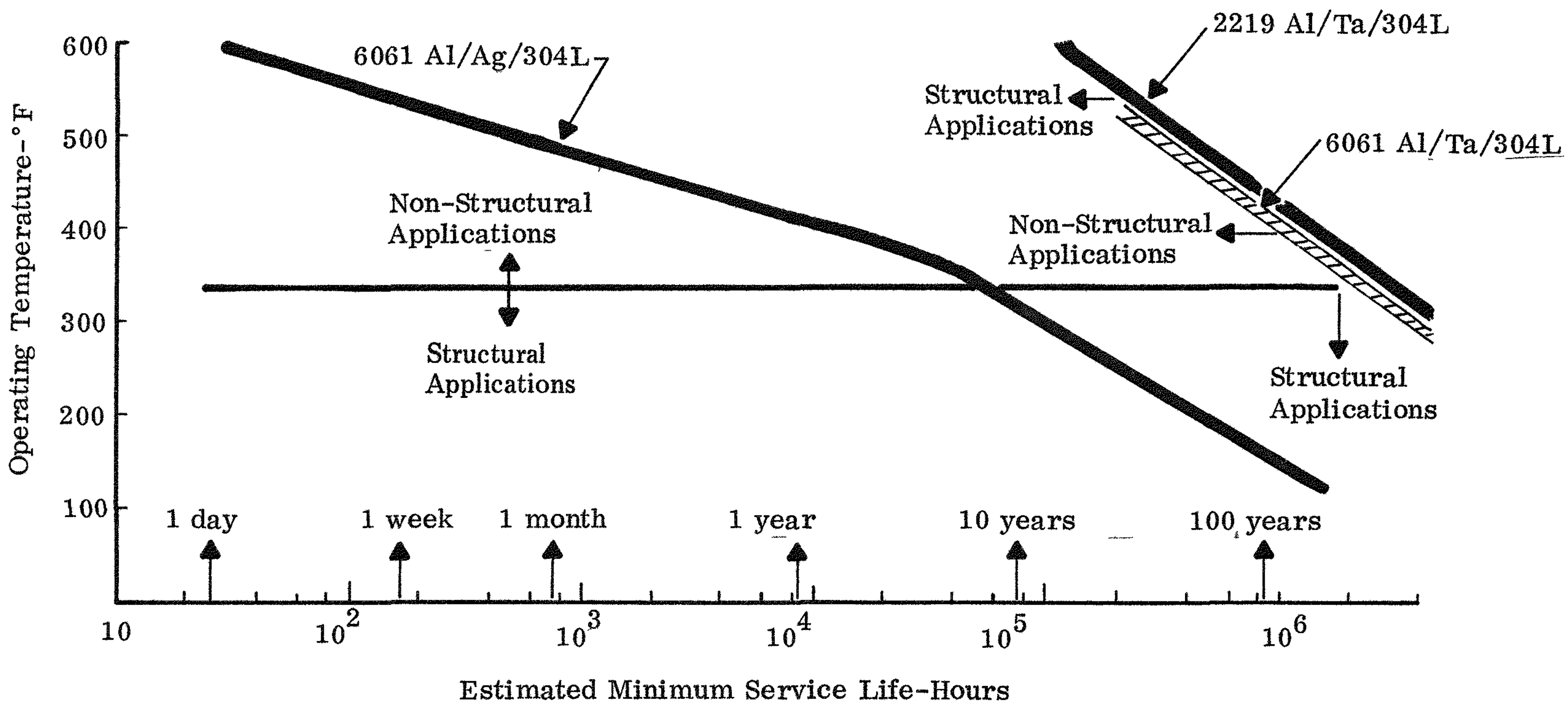


Figure 29: Estimated Design Application Envelope for Several Explosive Clad Hermetic Weld Transition Joint Materials

10.0 REFERENCES

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2. S. Roedel, "Receptacle Test Program Final Report," TES-33009-47, June, 1979.

3. E.I. duPont, Metal Cladding Section, Specification DETA-605M, "Aluminum-Silver-Stainless Steel Transition Joints for Structural Applications."

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5. J. Kim, "Bond Zone Intermediate Phase Growth for Explosively Clad 6061 Al/Ag/304L Plate," TES Memorandum SIG-JK-935, June 28, 1977.

6. Military Standardization Handbook, "Metallic Materials and Elements for Aerospace Vehicle Structures," MIL-HDBK-5B, September, 1971.

7. H.F. Coll, "Task II - Evaluation of Indication Response of Standard Test Blocks to Immersion Ultrasonic Test Variables," Report from Testech, Inc. Downington, PA, December 1976.

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10. W. Barnett, "Development and Test Plan for the GDS/ETG Electrical Feedthrough Receptacle Attachment, Subtask 2.1.4," TES Memorandum LCHPG-WJB-437, April 21, 1976.

11. W. Barnett, "Update of Development and Test Plan for the GDS/ETG Electrical Feedthrough Attachment, Subtask 2.1.4," TES Memorandum LCHPG-WJB-802, March 11, 1977.

12. "Life Test Procedure, Bimetal Attachment for Stainless Steel Electrical Receptacle Installation," LCP 10065, May 18, 1977.

13. "Electrical Receptacle Life Test Procedure," LCP 10032, May 3, 1977.

APPENDIX A

BIMETAL RING/RECEPTACLE ATTACHMENT LIFE DEMONSTRATION TEST DATA

Notes for Test Results of Tables 4 thru 13

1. Initial leak rate value of test sample prior to start of functional tests.
2. Leak rate data taken after 2 temperature cycles from 400°F to 150° to 400°F.
3. Test sample in burn-in at 400°F for 450 hours.
4. Leak rate data taken at start of 36 temperature cycle tests from 400°F to 150°F to 400°F.
5. Leak rate data taken after 36 temperature cycles from 400°F ro 150°F to 400°F.
6. Leak rate data taken during life performance test (thermal aging at 400°F).
7. Leak rate data taken at start of 30 temperature cycle tests from 400°F to 150°F to 400°F.
8. Leak rate data taken after 30 temperature cycles from 400°F to 150°F to 400°F.
9. Leak rate data taken after 2 temperature cycles from 475°F to 100°F to 475°F.
10. Leak rate data taken after 30 temperature cycle tests from 400°F to 100°F to 400°F.
11. Leak rate data taken after 30 temperature cycle tests from 300°F to 100°F to 300°F.
12. Leak rate data taken during life performance test (thermal aging at 300°F).

TABLE 4

Test results of Deutsch Receptacle/Bimetal Ring Assembly S/N-323 (Test Station 19)

Test Sample S/N 323 Notes*	Cumulative Hours of Aging at 400°F	Test Date	Test Result	Temperature (°F)		Leak Rate Std. cc He/sec - atm	
1		5/10/78	Good	81		3.9×10^{-10}	
1		5/11/78			302		2.6×10^{-9}
2		5/11/78		152		6.6×10^{-10}	
2	48	5/11/78			297		1.15×10^{-9}
3	498						
4	498	5/31/78		146		7.4×10^{-10}	
4	498	5/31/78			400		1.1×10^{-9}
5	936	6/19/78		152		9.5×10^{-10}	
5	936	6/19/78			400		9.0×10^{-10}
6	1272	7/3/78			397		1.1×10^{-9}
6	1608	7/17/78			400		1.2×10^{-9}
6	1944	7/31/78			400		2.0×10^{-9}
6	2208	8/11/78			400		1.7×10^{-9}
6	2616	8/28/78			400		7.9×10^{-10}
6	2952	9/11/78			400		1.1×10^{-9}
6	3648	10/10/78			400		1.45×10^{-9}
6	4320	11/7/78			400		1.2×10^{-9}
6	4968	12/4/78			400		1.45×10^{-9}
6	6192	1/24/79			400		2.0×10^{-9}
6	6480	2/7/79			400		1.8×10^{-9}
6	6176	3/8/79			400		1.5×10^{-9}
6	7800	4/2/79			400		1.3×10^{-9}
6	8664	5/9/79			400		1.6×10^{-9}
6	9360	6/7/79	Good		400		1.75×10^{-9}

*See Notes on Page A. 1.

TABLE 5

Test Results of Deutsch Receptacle/Bimetal Ring Assembly S/N-370 (Test Station 20)

Test Sample S/N 370 Notes*	Cumulative Hours of Aging at 400°F	Test Date	Test Result	Temperature (°F)		Leak Rate Std. cc He/sec - atm	
1		5/10/78	Good	81		4.4×10^{-10}	
1		5/11/78			305		3.5×10^{-9}
2		5/11/78		150		7.4×10^{-10}	
2	48	5/11/78			302		1.1×10^{-9}
3	498	---					
4	498	5/31/78		147		8.2×10^{-10}	
4	498	5/31/78			396		1.7×10^{-9}
5	936	6/19/78		153		1.1×10^{-9}	
5	936	6/19/78			397		1.25×10^{-9}
6	1272	7/3/78			398		1.3×10^{-9}
6	1608	7/17/78			400		1.4×10^{-9}
6	1944	7/31/78			400		1.8×10^{-9}
6	2208	8/11/78			400		1.1×10^{-9}
6	2616	8/28/78			400		9.7×10^{-10}
6	2952	8/11/78			400		1.4×10^{-9}
6	3648	10/10/78			400		1.48×10^{-9}
6	4320	11/7/78			400		1.2×10^{-9}
6	4968	12/4/78			400		1.2×10^{-9}
6	6192	1/24/79			400		2.2×10^{-9}
6	6480	2/7/79			400		1.9×10^{-9}
6	7176	3/8/79			400		1.6×10^{-9}
6	7800	4/3/79			400		1.4×10^{-9}
6	8664	5/9/79			400		1.4×10^{-9}
6	9360	6/7/79	Good		400		1.6×10^{-9}

*See Notes on Page A. 1.

TABLE 6

Test Results of Deutsch Receptacle/Bimetal Ring Assembly S/N-368 (Test Station 21)

Test Sample S/N 368 Notes **	Cumulative Hours of Aging at 400°F	Test Date	Test Result	Temperature (°F)		Leak Rate Std. cc He/sec - atm	
1		5/10/78	Good	81		4.5×10^{-10}	
1		5/11/78			303		1.9×10^{-9}
2		5/11/78		148		6.7×10^{-10}	
2	48	5/11/78			302		1.1×10^{-9}
6	474	5/30/78			399		1.9×10^{-9}
6	714	6/9/78			396		1.4×10^{-9}
6	1170	6/28/78			399		1.45×10^{-9}
7	1170	6/28/78			399		1.45×10^{-9}
7	1170	6/28/78		148		7.8×10^{-10}	
8	1635	7/18/78		112		4.2×10^{-10}	
8	1635	7/18/78			400		9.0×10^{-10}
*	1635	7/19/78	Good		400		3.2×10^{-9}

*Followed by a thermal margin test (c.f. Section 7.4.2).
**See Notes on Page A.1.

TABLE 7

Test Results of Dummy Receptacle/Bimetal Ring Assembly S/N-B070 (Test Station 22)

Test Sample S/N B0701 Notes *	Cumulative Hours of Aging at 400° F	Test Date	Test Result	Temperature (° F)	Leak Rate Std. cc He/sec - atm	
1		5/25/78	Good	83	3.6×10^{-10}	
1	120	5/30/78	↑	478		1.7×10^{-9}
9		6/1/78		91	7.9×10^{-10}	
9	124	6/1/78		473		1.3×10^{-9}
10	694	6/26/78		84	4.8×10^{-10}	
10	694	6/28/78		401		9.0×10^{-10}
6	1054	7/13/78		398		7.3×10^{-10}
6	1366	7/26/78		400		1.6×10^{-9}
6	1678	8/9/78		400		6.6×10^{-10}
6	2134	8/28/78		400		6.2×10^{-10}
6	2422	9/6/78		400		8.0×10^{-10}
6	2758	9/20/78		400		6.2×10^{-10}
6	3430	10/18/78		400		1.1×10^{-9}
6	3958	11/8/78		400		8.0×10^{-10}
6	4990	12/21/78		400		1.3×10^{-9}
6	5734	1/25/79		400		1.7×10^{-9}
6	6070	2/8/79		400		1.6×10^{-9}
6	6742	3/8/79		400		1.2×10^{-9}
6	7366	4/3/79		400		9.0×10^{-10}
6	8230	5/9/79	↓	400		9.6×10^{-10}
6	8926	6/7/79	Good	400		1.3×10^{-9}

*See Notes on Page A.1.

TABLE 8

Test Results of Dummy Receptacle/Bimetal Ring Assembly S/N-B0702 (Test Station 23)

Test Sample S/N B0702 Notes *	Cumulative Hours of Aging at 400°F	Test Date	Test Result	Temperature (°F)		Leak Rate Std. cc He/sec - atm	
1		5/25/78	Good	80		4.4×10^{-10}	
1	120	5/30/78			478		1.45×10^{-9}
9		6/1/78		79		8.4×10^{-10}	
9	124	6/2/78			473		9.0×10^{-10}
10	694	6/26/78		82		4.1×10^{-10}	
10	694	6/28/78			400		7.6×10^{-10}
6	1054	7/13/78			400		1.0×10^{-9}
6	1366	7/26/78			400		1.3×10^{-9}
6	1678	8/9/78			400		7.8×10^{-10}
6	2134	8/28/78			400		7.2×10^{-10}
6	2422	9/6/78			400		6.4×10^{-10}
6	2758	9/20/78			400		4.5×10^{-10}
6	3430	10/18/78			400		9.2×10^{-10}
6	3958	11/8/78			400		9.0×10^{-10}
6	4990	12/21/78			400		1.5×10^{-9}
6	5734	1/24/79			400		1.75×10^{-9}
6	6070	2/9/79			400		1.40×10^{-9}
6	6742	3/7/79			400		1.1×10^{-9}
6	7366	4/3/79			400		1.3×10^{-9}
6	8230	5/9/79			400		9.9×10^{-10}
6	8926	6/7/79	Good		400		1.2×10^{-9}

*See Notes on Page A. 1.

TABLE 9

Test Results of Deutsch Receptacle/Bimetal Ring Assembly S/N-B0703 (Test Station 24)

Test Sample S/N B0703 Notes *	Cumulative Hours of Aging at 400°F	Test Date	Test Result	Temperature (°F)		Leak Rate Std. cc He/sec - atm	
1		5/25/78	Good	81		3.8×10^{-10}	
1	120	5/30/78	↑		476		5.0×10^{-10}
9		6/1/78		78		7.8×10^{-10}	
9	124	6/2/78			471		8.2×10^{-10}
10	694	6/26/78		81		3.0×10^{-10}	
10	694	6/28/78			400		4.8×10^{-10}
6	1054	7/13/78			400		4.4×10^{-10}
6	1366	7/26/78			400		6.9×10^{-10}
6	1678	8/9/78			400		4.9×10^{-10}
6	2134	8/28/78			400		5.3×10^{-10}
6	2422	9/6/78			400		5.0×10^{-10}
6	2758	9/20/78			400		4.0×10^{-10}
6	3430	10/18/78			400		7.4×10^{-10}
6	3958	11/8/78			400		4.9×10^{-10}
6	4990	12/21/78			400		8.0×10^{-10}
6	5734	1/24/79			400		8.2×10^{-10}
6	6070	2/9/79			400		6.8×10^{-10}
6	6742	3/7/79			400		6.5×10^{-10}
6	7366	4/4/79			400		5.2×10^{-10}
6	8254	5/10/79	↓		400		5.8×10^{-10}
6	8950	6/8/79	Good		400		5.0×10^{-10}

*See Notes on Page A.1.

TABLE 10

Test Results of Dummy Receptacle/Bimetal Ring Assembly S/N-B0704 (Test Station 25)

Test Sample S/N B0704 Notes *	Cumulative Hours of Aging at 300° F	Test Date	Test Result	Temperature (° F)	Leak Rate Std. cc He/sec - atm	
1		5/25/78	Good	80	3.4×10^{-10}	
1	120	5/30/78	↑	476		9.4×10^{-10}
9		6/1/78		79	4.8×10^{-10}	
9	124	6/2/78		470		1.0×10^{-9}
11	694	6/26/78		82	4.4×10^{-10}	
11	694	6/28/78		301		1.4×10^{-9}
12	1054	7/13/78		300		1.0×10^{-9}
12	1366	7/26/78		300		1.7×10^{-9}
12	1678	8/9/78		300		9.2×10^{-10}
12	2134	8/28/78		300		8.6×10^{-10}
12	2422	9/6/78		300		5.9×10^{-10}
12	2758	9/20/78		300		4.0×10^{-10}
12	3430	10/18/78		300		9.0×10^{-10}
12	3958	11/9/78		300		8.7×10^{-10}
12	4990	12/21/78		300		1.7×10^{-9}
12	5734	1/25/79		300		1.9×10^{-9}
12	6070	2/4/79		300		1.4×10^{-9}
12	6742	3/7/79		300		1.1×10^{-9}
12	7366	4/4/79		300		1.3×10^{-9}
12	8254	5/10/79	↓	300		1.2×10^{-9}
12	8950	6/8/79	Good	300		8.6×10^{-10}

*See Notes on Page A. 1.

TABLE 11

Test Results of Dummy Receptacle/Bimetal Ring Assembly S/N-B0706 (Test Station 26)

Test Sample S/N B0706 Notes *	Cumulative Hours of Aging at 300°F	Test Date	Test Result	Temperature (°F)		Leak Rate Std. cc He/sec - atm	
1		5/25/78		81		2.7×10^{-10}	
1	120	5/30/78	↑		473		1.7×10^{-9}
9		6/1/78		79		8.8×10^{-10}	
9	124	6/2/78			479		1.5×10^{-9}
11	694	6/26/78		82		5.1×10^{-10}	
11	694	6/28/78			301		1.8×10^{-9}
12	1150	7/17/78			300		2.7×10^{-10}
12	1366	7/26/78			300		1.8×10^{-9}
12	1678	8/9/78			300		7.0×10^{-10}
12	2134	8/28/78			300		1.3×10^{-9}
12	2422	9/6/78			300		4.0×10^{-10}
12	2758	9/20/78			300		6.4×10^{-10}
12	3430	10/18/78			300		8.9×10^{-10}
12	3958	11/9/78			300		7.1×10^{-10}
12	4990	12/22/78			300		1.3×10^{-9}
12	5734	1/25/79			300		1.6×10^{-9}
12	6070	2/9/79			300		9.4×10^{-10}
12	6742	3/7/79			300		1.0×10^{-9}
12	7366	4/4/79			300		1.3×10^{-9}
12	8254	5/10/79	↓		300		1.1×10^{-9}
12	8950	6/8/79	Good		300		8.1×10^{-10}

*See Notes on Page A. 1.

TABLE 12

Test Results of Dummy Receptacle/Bimetal Ring Assembly S/N-B0801 (Test Station 27)

Test Sample S/N B0801 Notes *	Cumulative Hours of Aging at 300°F	Test Date	Test Result	Temperature (°F)		Leak Rate Std. cc He/sec - atm	
1		5/25/78	Good	81		2.7×10^{-10}	
1	120	5/30/78			473		1.6×10^{-9}
9		6/1/78		82		5.1×10^{-10}	
9	124	6/2/78			469		1.5×10^{-9}
11	694	6/26/78		84		4.8×10^{-10}	
11	694	6/28/78			300		1.4×10^{-9}
12	1150	7/17/78			300		3.44×10^{-10}
12	1366	7/26/78			300		1.9×10^{-9}
12	1678	8/9/78			300		1.0×10^{-9}
12	2134	8/29/78			300		9.6×10^{-10}
12	2422	9/6/78			300		5.2×10^{-10}
12	2758	9/20/78			300		5.0×10^{-10}
12	3430	10/18/78			300		9.5×10^{-10}
12	3958	11/9/78			300		8.3×10^{-10}
12	4990	12/22/78			300		1.2×10^{-9}
12	5734	1/25/79			300		1.6×10^{-9}
12	6070	2/9/79			300		1.12×10^{-9}
12	6742	3/6/79			300		1.1×10^{-9}
12	7366	4/4/79			300		1.1×10^{-9}
12	8254	5/10/79			300		1.2×10^{-9}
12	8950	6/8/79	Good		300		1.2×10^{-9}

*See Notes on Page A.1.

TABLE 13

Test Results of Dummy Receptacle/Bimetal Ring Assembly S/N-A1205 (Test Station 28)

Test Sample S/N A1205 Notes *	Cumulative Hours of Aging at 300°F	Test Date	Test Result	Temperature (°F)		Leak Rate Std. cc He/sec - atm	
1		5/25/78	Good	80		2.0×10^{-10}	
1	120	5/30/78			469		2.6×10^{-9}
9		6/1/78		81		9.2×10^{-10}	
9	124	6/2/78			469		7.8×10^{-10}
11	694	6/26/78		83		4.0×10^{-10}	
11	694	6/28/78			298		1.2×10^{-9}
12	1150	7/17/78			300		3.6×10^{-10}
12	1366	7/26/78			300		1.5×10^{-9}
12	1678	8/9/78			300		4.4×10^{-10}
12	2134	8/29/78			300		4.8×10^{-10}
12	2422	9/6/78			300		6.5×10^{-10}
12	2758	9/20/78			300		3.8×10^{-10}
12	3430	10/18/78			300		7.9×10^{-10}
12	3958	11/9/78			300		8.6×10^{-10}
12	4990	12/22/78			300		1.22×10^{-10}
12	5734	1/25/79			300		9.9×10^{-10}
12	6070	2/9/79			300		1.4×10^{-10}
12	6742	3/6/79			300		8.6×10^{-10}
12	7366	4/4/79			300		9.9×10^{-10}
12	8254	5/10/79			300		8.6×10^{-10}
12	8950	6/8/79	Good		300		9.1×10^{-10}

*See Notes on Page A. 1.