NASA CONTRACTOR REPORT

NASA CR-806

NASA CR-8

STABILIZATION OF CARBON AND NITROGEN IN STAINLESS STEEL AND ITS EFFECT ON MASS TRANSFER IN A STAINLESS STEEL - Cb-1Zr - POTASSIUM SYSTEM

by R. W. Harrison

Prepared by
GENERAL ELECTRIC
Cincinnati, Ohio
for Lewis Research Center

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • JUNE 1967

NASA CR-806

STABILIZATION OF CARBON AND NITROGEN IN STAINLESS STEEL AND ITS EFFECT ON MASS TRANSFER IN A STAINLESS STEEL - Cb-1Zr - POTASSIUM SYSTEM

By R. W. Harrison

Prepared under Contract No. NAS 3-6012 by
GENERAL ELECTRIC
Missile and Space Division
Cincinnati, Ohio

for Lewis Research Center

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

For sale by the Clearinghouse for Federal Scientific and Technical Information
Springfield, Virginia 22151 – CFSTI price $3.00

FOREWORD

The work described herein was performed by the General Electric Company under the sponsorship of the National Aeronautics and Space Administration under Contract NAS 3-6012. Its purpose, as outlined in the contract, was to investigate the corrosion mass transfer of elements from stainless steel to a refractory alloy in a potassium environment thereby accruing knowledge on the possible use of these materials in space power conversion systems.

This work, originally issued as General Electric Report R66SD3009, was administered for the General Electric Company by Dr. J. W. Semmel, Jr., Manager, Materials and Processes. The experimental investigations were directed by R. W. Harrison with the assistance of K. P. Hake. R. G. Frank, Manager, Physical Metallurgy, also contributed to the program, particularly during the initial phase of the work.

Mr. R. L. Davies of the NASA-Lewis Research Center was the Technical Manager for this study. Recognition is also given to Mr. T. A. Moss of the NASA-Lewis Research Center for his assistance in monitoring the program.

ABSTRACT

Systems presently under investigation for space power generation in excess of 100 KW are of refractory alloy construction and employ alkali metals as working fluids. The use of stainless steel, rather than refractory alloys, for space power plant radiator construction and for the lower temperature portion of experimental facilities would constitute considerable material and fabrication cost savings. However, in such a bimetallic system the major uncertainty and limitation arises from the mass transfer of the interstitial elements, carbon and nitrogen, from the stainless steel to the refractory alloys through the alkali metal. It is, therefore, appropriate to consider the stabilization of carbon and nitrogen in the stainless steel by the addition of metallic elements which form carbides and nitrides of high thermodynamic stability. Commercially available, titanium stabilized Type 321SS is one such alloy. A comparative investigation of this alloy and Type 316SS (a non-stabilized alloy) was performed to determine whether the titanium addition would reduce or eliminate interstitial element mass transfer in a stainless steel--Cb-1Zr alloy--liquid potassium system.

Columbium-1% zirconium alloy specimens were exposed to liquid potassium in Type 321SS and Type 316SS capsules for 1000 hours at 1400°F under isothermal conditions. The capsules were filled with high purity, vacuum distilled and hot trapped potassium with an oxygen content less than 20 ppm, and sealed by electron beam welding in a high-vacuum chamber. The capsule exposures were conducted in an air environment. Post-test vacuum fusion and combustion-conductivimetric analyses, for nitrogen and carbon, respectively, showed evidence of extensive mass transfer in Cb-1Zr--Type 316SS capsules. No detectable interstitial increase was found in the Cb-1Zr specimens exposed in Type 321SS capsules. Changes in the room temperature and high temperature mechanical properties of the Cb-1Zr alloy specimens were consistent with the observed changes in chemical composition.

CONTENTS

INTRODUCTION

The use of a stainless steel, rather than a refractory alloy, as the alkali metal containment material for space power plant facilities constitutes material and fabrication cost savings. Two methods of employing this approach are: use of co-extruded, stainless steel shell-refractory alloy core, tubing in the radiator or use of an all stainless steel radiator joined to the refractory alloy system by a bimetallic joint. Although the latter approach is preferred considering cost and problems associated with fabrication and joining of co-extruded tubing, a major uncertainty and limitation arises from the mass transfer of interstitial elements from the stainless steel to the refractory alloys through the alkali metal.

It is well established that the carbon and nitrogen transfer from Type 316SS to Cb-1Zr alloy at temperatures near 1500°F (1). While some important aspects of this mass transfer behavior have been examined, several critical details require additional investigation. There is a need to define acceptable time and temperature conditions of operation interns of maintaining satisfactory performance of the refractory alloys, such as Cb-1Zr. Also, there are certain metallurgical aspects of this behavior which should be investigated in an effort to eliminate or reduce the extent of mass transfer. In the latter category, it is most appropriate to consider the stabilization of carbon and nitrogen in the stainless steel by the addition of metallic elements which form carbides and nitrides of high thermodynamic stability. Commercially available, titanium stabilized Type 321SS is one such alloy.

The structure of the 18-8 stainless steels consists of ferrite, austenite and chromium carbide under equilibrium conditions. Normal rapid cooling of such steels will insure the retention of austenite but if they are heated within the temperature range of approximately 800° and 1600°F for any appreciable length of time, carbide precipitation will occur in the grain boundaries. This behavior is referred to as sensitization. In some aqueous media, the sensitization of an austenitic stainless steel permits corrosive attack to start at areas adjacent to the grain boundaries where there is a deficiency of chromium. Sensitization may occur in the welding of 18-8 stainless steel. The precipitation usually occurs not in the weld itself, but in that portion of the structure which is heated within the sensitization range for a sufficient length of time. The addition of elements such as titanium to 18-8 stainless steels will tend to prevent sensitization by combining with the carbon and preventing chromium depletion from the matrix by carbide precipitation. In commercial applications in a corrosive aqueous media, Type 321SS is therefore preferred over Type 316SS where fabrication by welding may introduce sensitization. Whereas Type 316SS and Type 321SS have similar fabricability and weldability, Type 316SS has higher mechanical properties than Type 321SS. As an example, the 1% creep strength in 10,000 hours at 1400°F for Type 316SS is 4,000 psi as compared to 2,700 psi for Type 321SS.

A comparative investigation of Type 321SS and Type 316SS was performed to indicate the ability of the titanium addition to reduce or eliminate interstitial element mass transfer in a stainless steel--Cb-1Zr alloy bimetallic system. Columbium-1% zirconium alloy specimens were exposed to liquid potassium in Type 321SS and Type 316SS capsules for 1000 hours at 1400°F under isothermal conditions to evaluate this premise. Post-test evaluation showed that Type 321SS has a significant advantage over Type 316SS in refractory metal - stainless steel - potassium systems in inhibiting mass transfer of the interstitial elements, carbon and nitrogen, from the stainless steel to the refractory alloy.

MATERIALS PROCUREMENT

Type 316SS and Type 321SS 1-1/4-inch diameter Schedule 80 pipe, of the chemical analyses shown in Table I, were selected for capsule fabrication. This analysis indicated the titanium content of the Type 321SS to be approximately seven times the carbon content. Since the molar ratio to form TiC requires the titanium content to be only four times the carbon content, the excess should insure that all the carbon and nitrogen atoms were combined as a carbide, nitride, or carbonitride.

Cb-1Zr alloy sheet, 0.040-inch thick, of the chemical analysis shown in Table II was selected for insertion in the stainless steel capsules.

CAPSULE FABRICATION

Two Type 321SS and two Type 316SS corrosion capsules were fabricated to the design shown in Figure 1. A ballizing technique was employed to improve the finish of the inside diameter of the capsules. This technique consists of axially pressing a hardened (chrome-alloy tool steel), oversized ball (0.006-inch interference fit) through the pipe which has been well lubricated with a high-pressure wax. After removal of the wax with organic solvent and a light pickle in 20%HF, 20%HNO_3, 60%H_2O solution, the resulting finish was better than 16 rms. Metallographic examination of the internal diameter of the capsules indicated that no deleterious effects are produced by employing this technique to reduce surface irregularities, Figures 2 and 3. Bottom caps were tungsten-inert-gas welded to each capsule after ballizing; subsequent helium mass spectrometer leak tests indicated no leaks.

Cb-1Zr alloy sheet specimens for insertion in the stainless steel capsules were machined to the dimensions shown in Figure 4. The final surface finish was prepared by hand polishing through 640 grit paper, washing, light pickling in 20%HF, 20%HNO_3 and 60%H_2O solution, and cleaning in ethanol. A fixture to hold the Cb-1Zr alloy specimens vertical and equidistant from the internal walls of the capsules was constructed from 0.062-inch diameter Cb-1Zr alloy wire and is shown in Figure 5.

CAPSULE FILLING

The four stainless steel capsules were filled with potassium and sealed under vacuum in a 30KV electron beam welding chamber, Figure 6. The potassium was procured from the Mine Safety Appliances Research Corporation as their high-purity grade and was further purified at General Electric by vacuum distillation at approximately 600°F at a pressure in the 10^{-5} torr range and hot trapping for approximately 50 hours at 1400°F in a titanium lined, zirconium

TABLE I. CHEMICAL ANALYSES OF 1-1/4-INCH DIAMETER SCHEDULE 80 STAINLESS STEEL PIPE

Element	Type 316SS(1) ppm	Type 321SS(2) ppm
C	410	690
O	78	85
N	170	125
H	4	8
	w/o	w/o
Cr	17.39	17.44
Ni	12.33	11.90
Mn	1.86	1.62
Mo	2.24	--
Ti	--	0.46
Si	0.75	0.59
Cu	0.21	0.09

(1) Heat No. Carpenter 803776.

(2) Heat No. B & W 27634X.

TABLE II. CHEMICAL ANALYSIS OF Cb-1Zr ALLOY SHEET (MCN 454)

Element	Vendor's Analysis(1) ppm	GE Analysis ppm
C	35	10
O	90	75
H	5	6
N	42	14
Zr	0.89%	-
Ta	500	-
Fe	50	-
Si	60	-
Hf	<50	-
W	<100	-

(1) Kawecki Chemical Company.

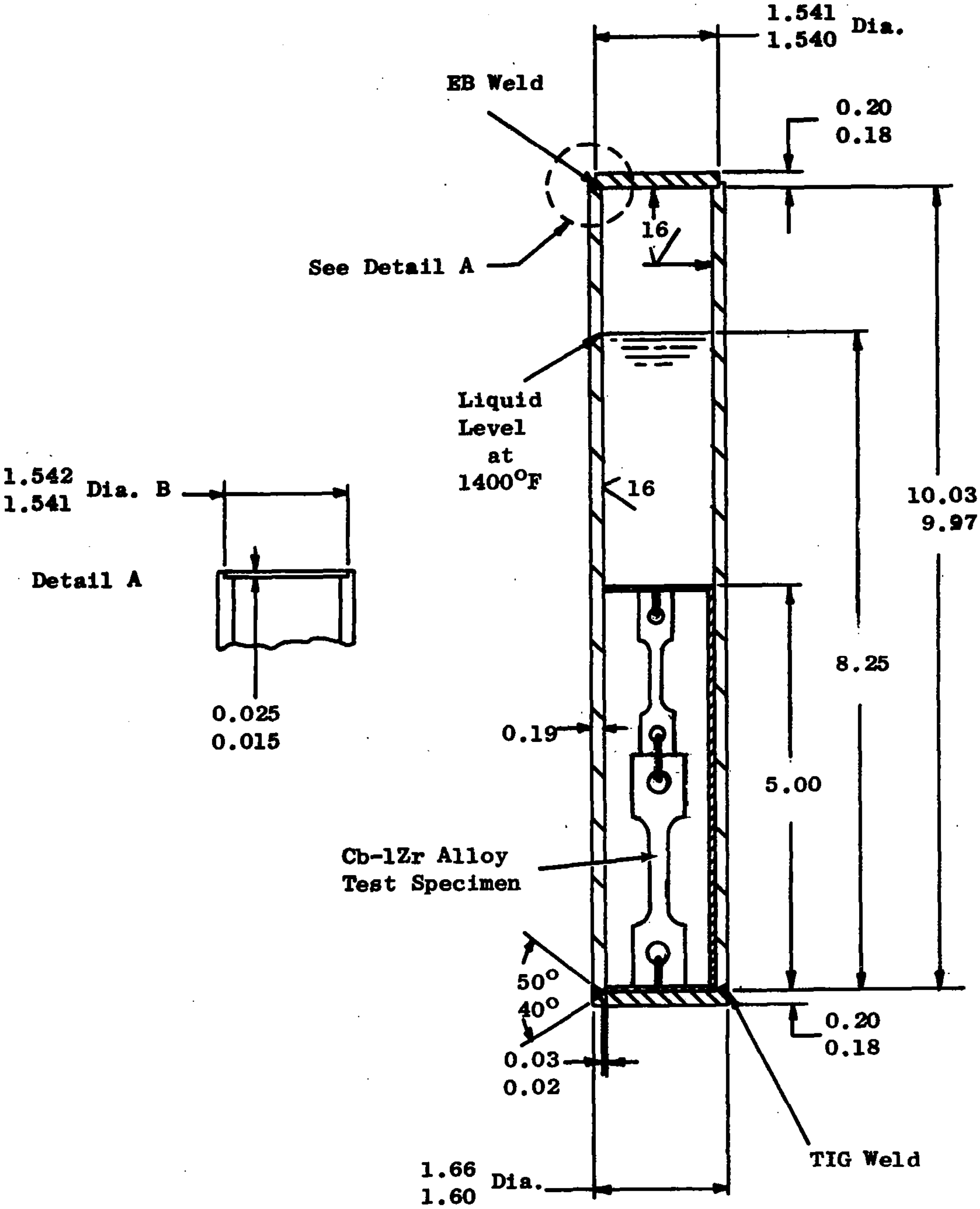


Figure 1. Stainless Steel Capsule Design.

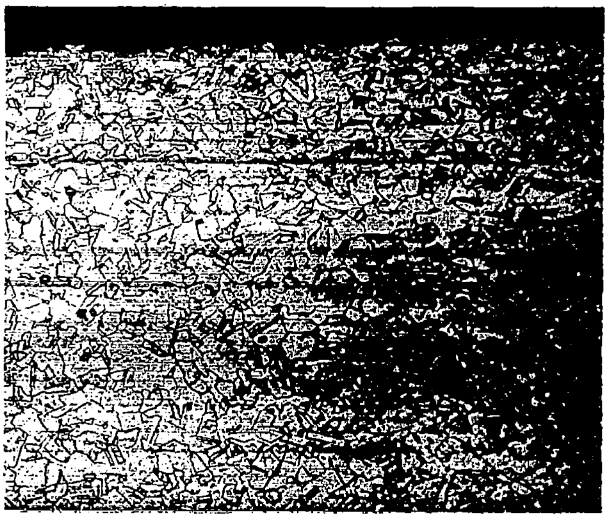


Figure 2. Transverse Section of As-Received Type 321SS Schedule 80 Pipe Showing Rough Internal Diameter Surface.

Etchant: Aqua Regia Mag: 250X

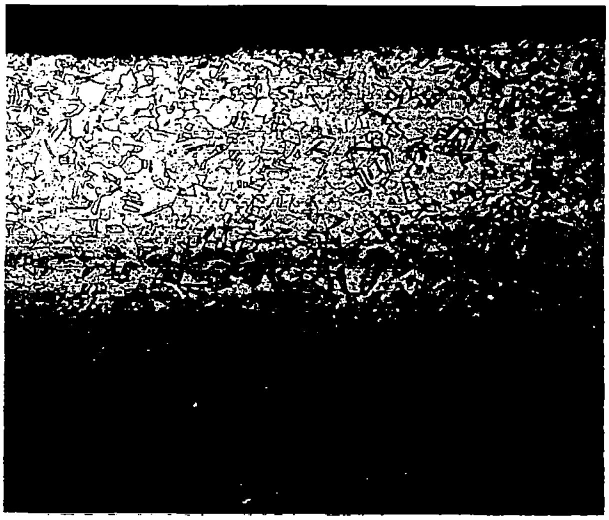
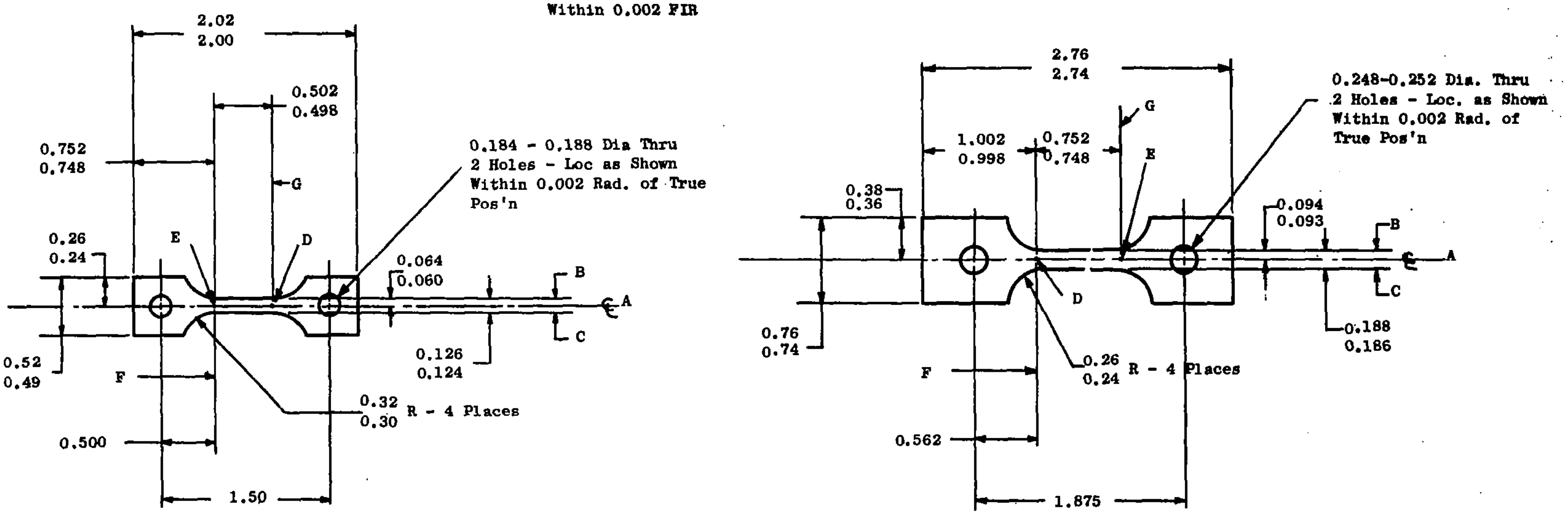


Figure 3. Transverse Section of Ballized Type 321SS Schedule 80 Pipe. Internal Diameter Surface Finished Better Than 16 rms with no Evidence of Flowed Metal.

Etchant: Aqua Regia Mag: 250X

Surfaces B and C are to be Parallel With Each Other and ℄ Axis A Within 0.002 FIR

Planes F and G Must be Established Thru Points D and E and Perpendicular to Surfaces B and C Within 0.002 FIR



Sheet Tensile Specimen

Sheet Rupture Specimen

Figure 4. Tensile and Stress-Rupture Test Specimens.

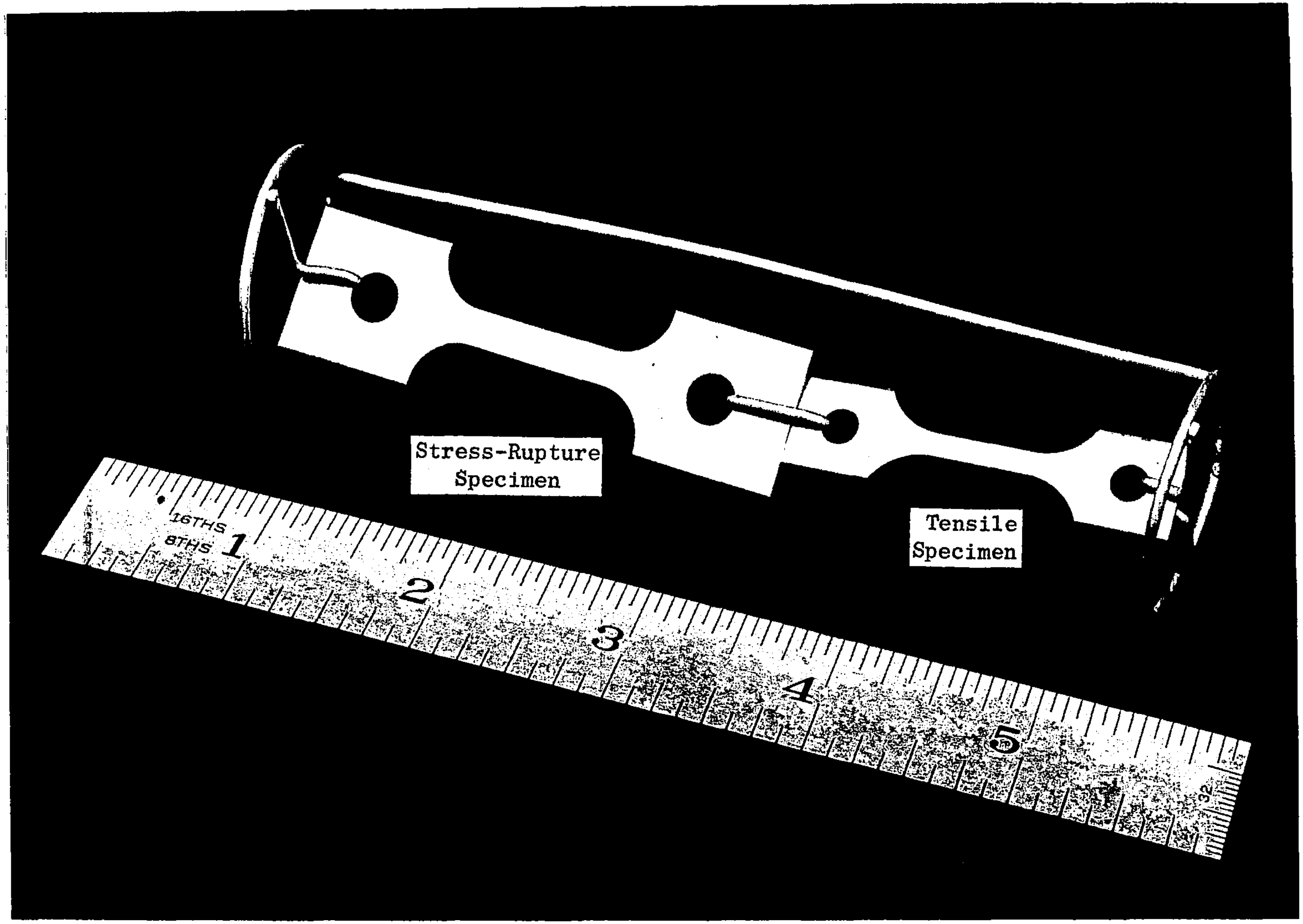


Figure 5. Cb-1Zr Alloy Holding Fixture for Positioning Cb-1Zr Alloy Test Specimens Within Stainless Steel Corrosion Capsules.

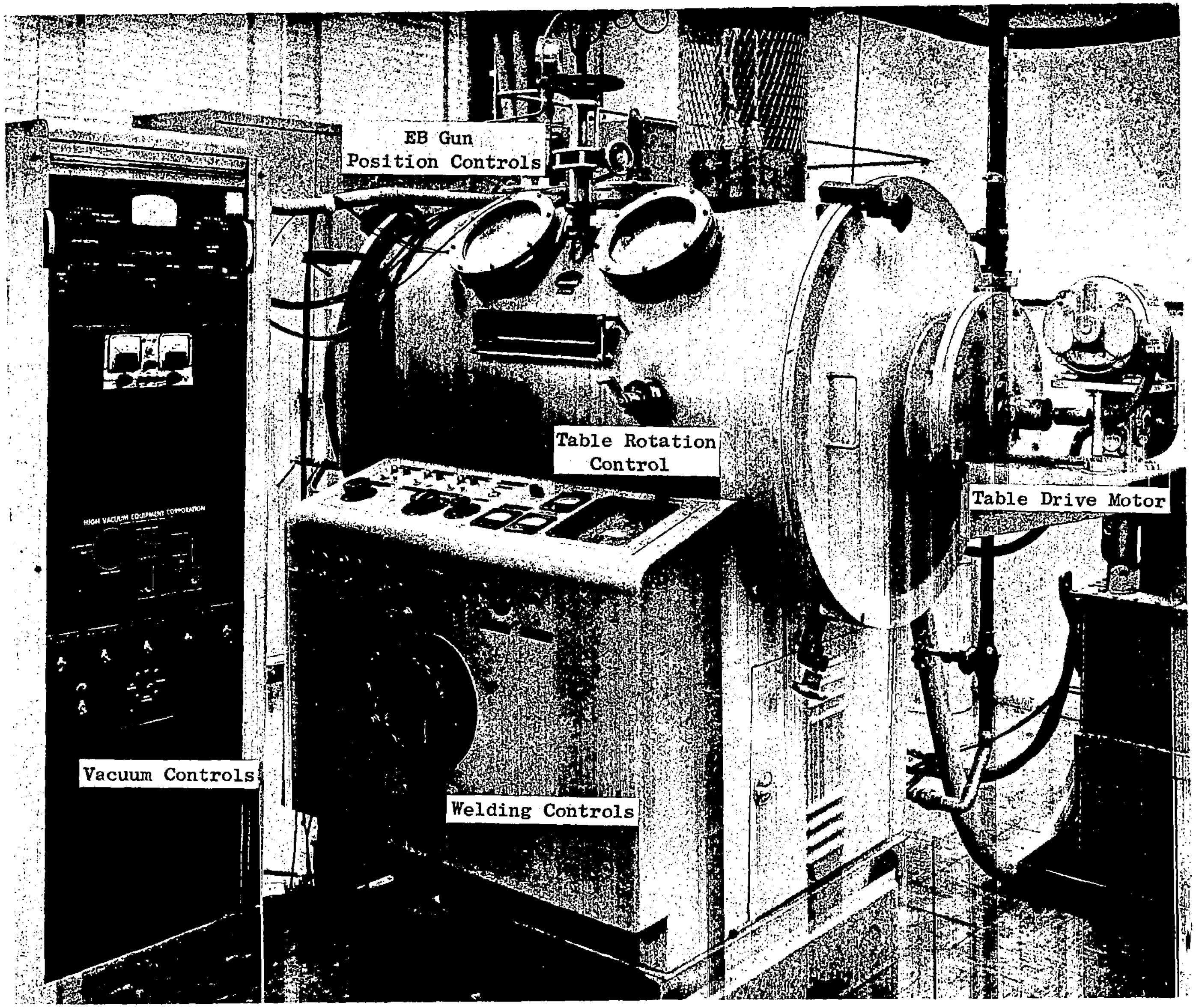


Figure 6. 30KV Electron Beam Welding Chamber and Controls Used to Fill Corrosion Capsules with Potassium.

gettered hot trap. The integral purification system is shown in Figure 7. The potassium was transferred under argon pressure directly from the final hot trapping container, Figure 8, into the evacuated chamber (3 x 10^{-5} torr) through a heated fill tube and into a calibrated stainless steel cup, Figure 9. The temperature of the cup was maintained at 200°F. Using the data depicted in Figure 10, calculations show that 135 cc of potassium at 200°F would result in a 8.25-inch fill height in the capsules at the test temperature of 1400°F. This height also is based on consideration of the volume displacement of the Cb-1Zr alloy specimens and fixture. The surface area ratio between the stainless steel and the Cb-1Zr alloy in contact with liquid potassium has been shown to be critical (1). The relationships described in this study constitute a 4:1 ratio which is more than sufficient to observe mass transfer of nitrogen and carbon in Type 316SS at temperatures near 1500°F (1).

The measured potassium was poured from the cup through a heated stainless steel funnel into the capsule. Each capsule was positioned under the funnel by means of a flexible cable which attached on one end to a gear train on the table and on the other end to a crank outside the chamber, Figures 6 and 11. A can was placed on the rotating table to provide means of dumping any excess potassium during filling. The first cup of potassium was discarded in this manner as a result of possible contamination from pickup along the walls of the empty fill line. When filled, each capsule was rotated under a manipulator which was used to position the capsule cap in the machined, slotted well on the capsule top. The manipulator is sealed on the outside of the chamber by a bellows. The capsule was positioned under the EB gun by means of a flexible cable in conjunction with the table drive. The gear on each capsule was thus adjusted to mesh with the welding drive gear such that the capsules rotated around their axes during welding. This gear is controlled by a variable speed motor which can be adjusted to obtain the optimum welding speed. Copper chill blocks were fitted on each capsule to reduce the heat conduction along the capsule during welding and the resulting possible vaporization of the potassium which would cause unsound welds.

Analytical samples of the potassium used to fill the capsules were taken in two locations. One sample was obtained by filling a stainless steel tube in the same manner as the capsules are filled, Figure 11. The other sample was taken by removing a section of the fill line between the chamber and the hot trap. The resulting oxygen analyses by the mercury amalgamation method showed 2.5 ppm oxygen in the potassium taken from the chamber sample and 3.0 ppm oxygen in the potassium taken from the fill tube. Metallic impurities were determined by spectrographic analysis and the results are shown in Table III.

The four filled and sealed capsules were examined radiographically to assure sound electron beam welds and subsequently put on test.

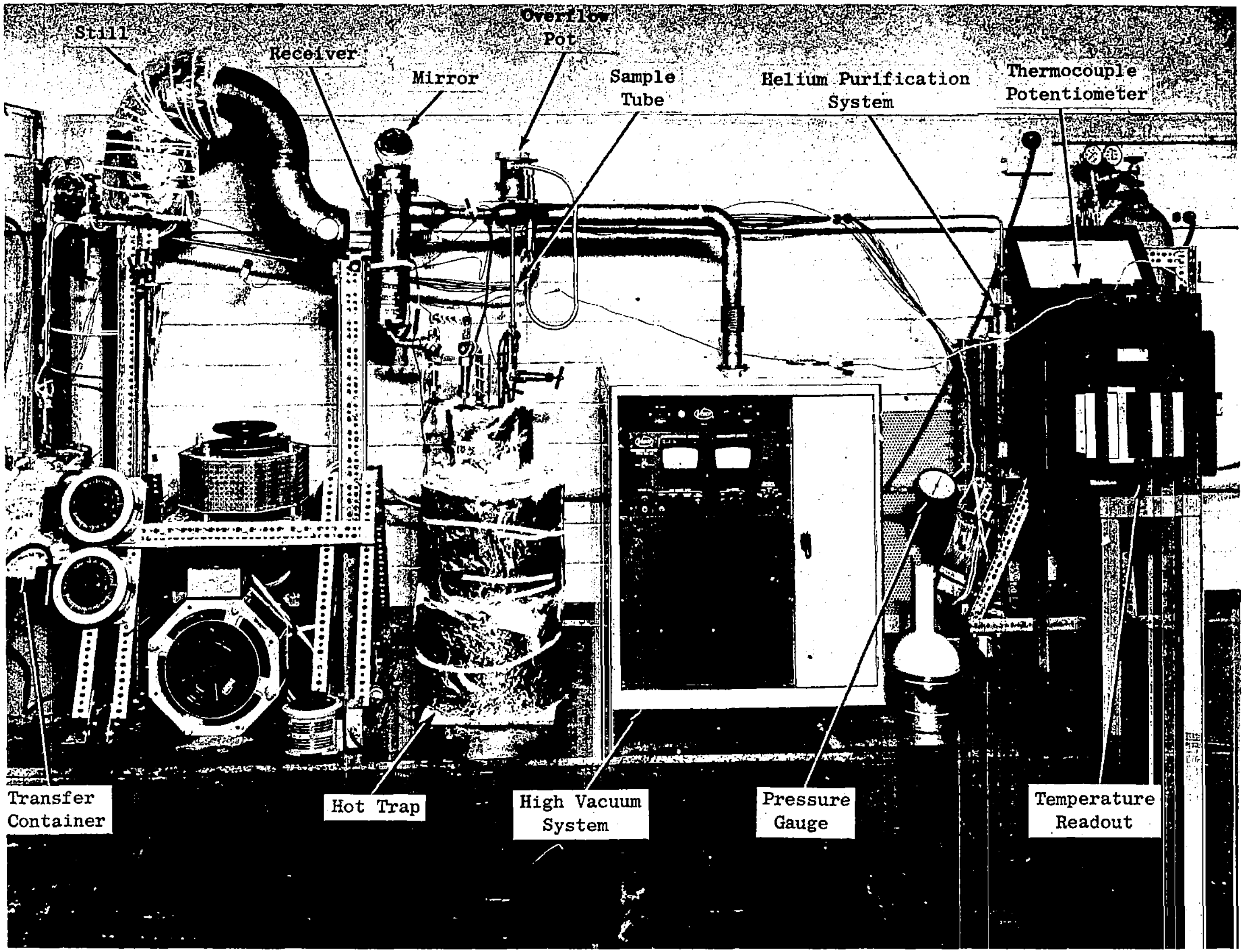


Figure 7. Potassium Purification System.

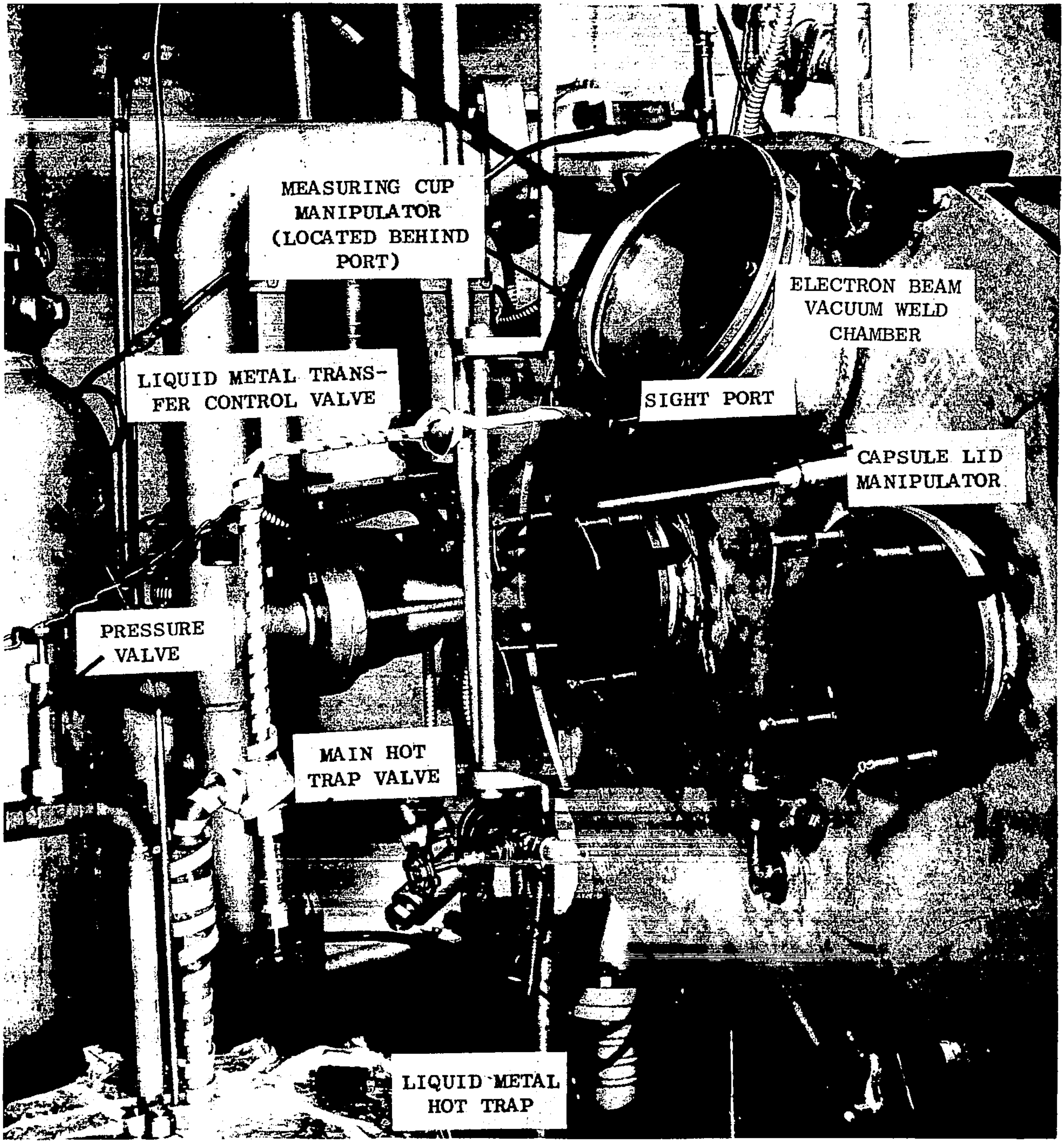


Figure 8. External View of the Facility for Potassium Transfer; the Hot Trap is Shown Attached to the Vacuum Tank Closure.

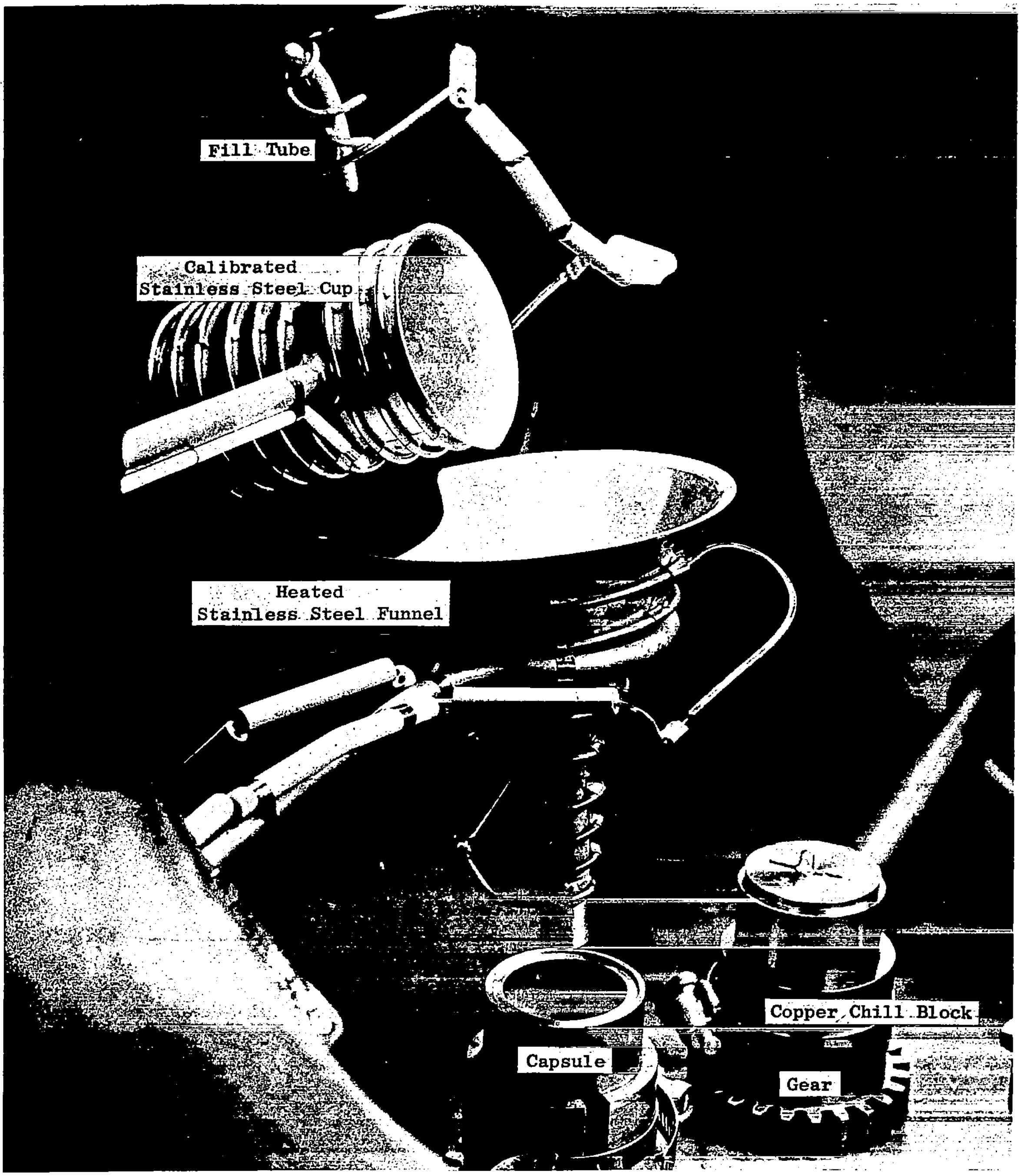


Figure 9. Internal Arrangement of Facility for Filling Corrosion Capsules with Potassium as Viewed Through Sight Port of Electron Beam Welding Chamber.

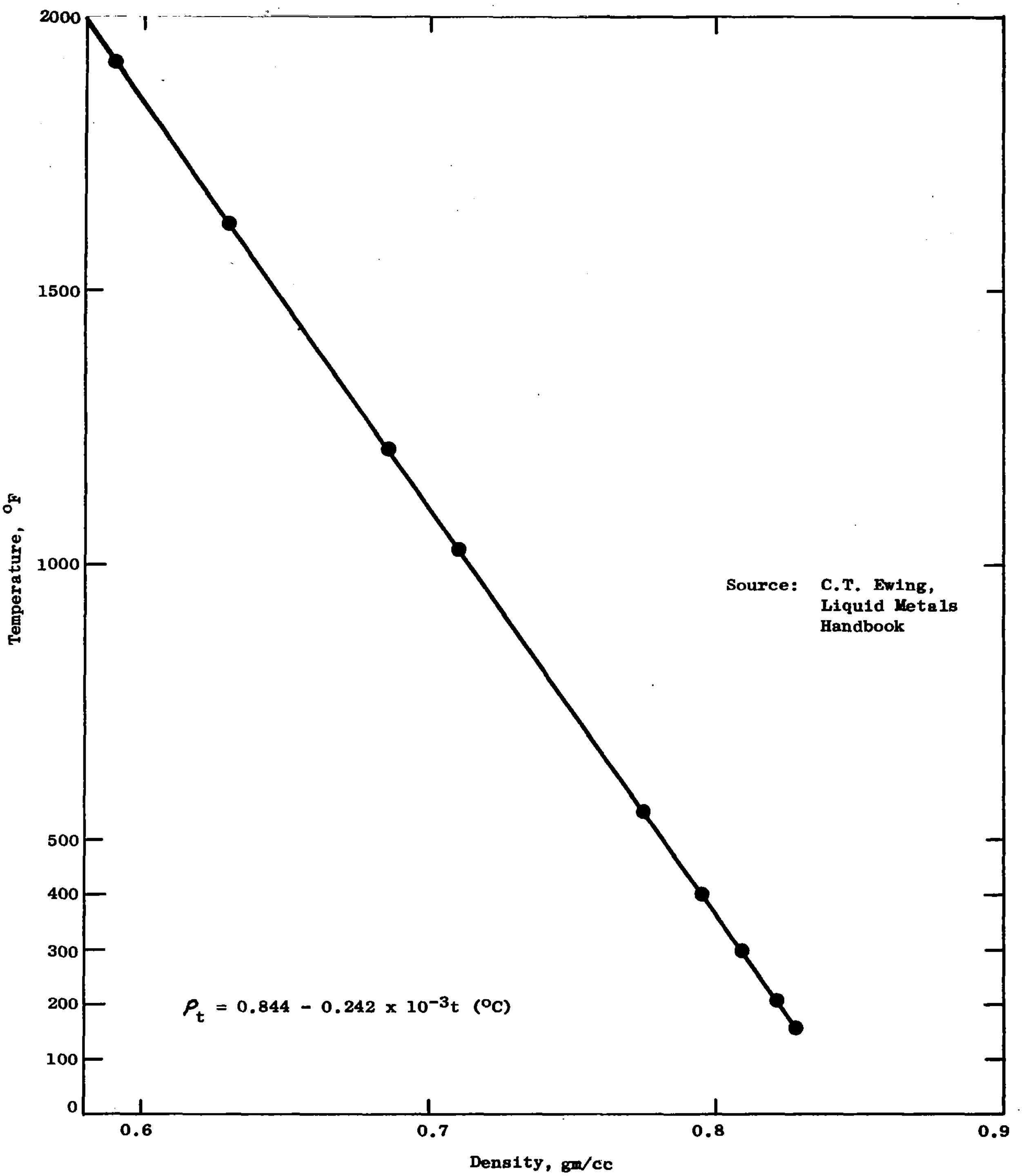


Figure 10. Density of Liquid Potassium as a Function of Temperature.

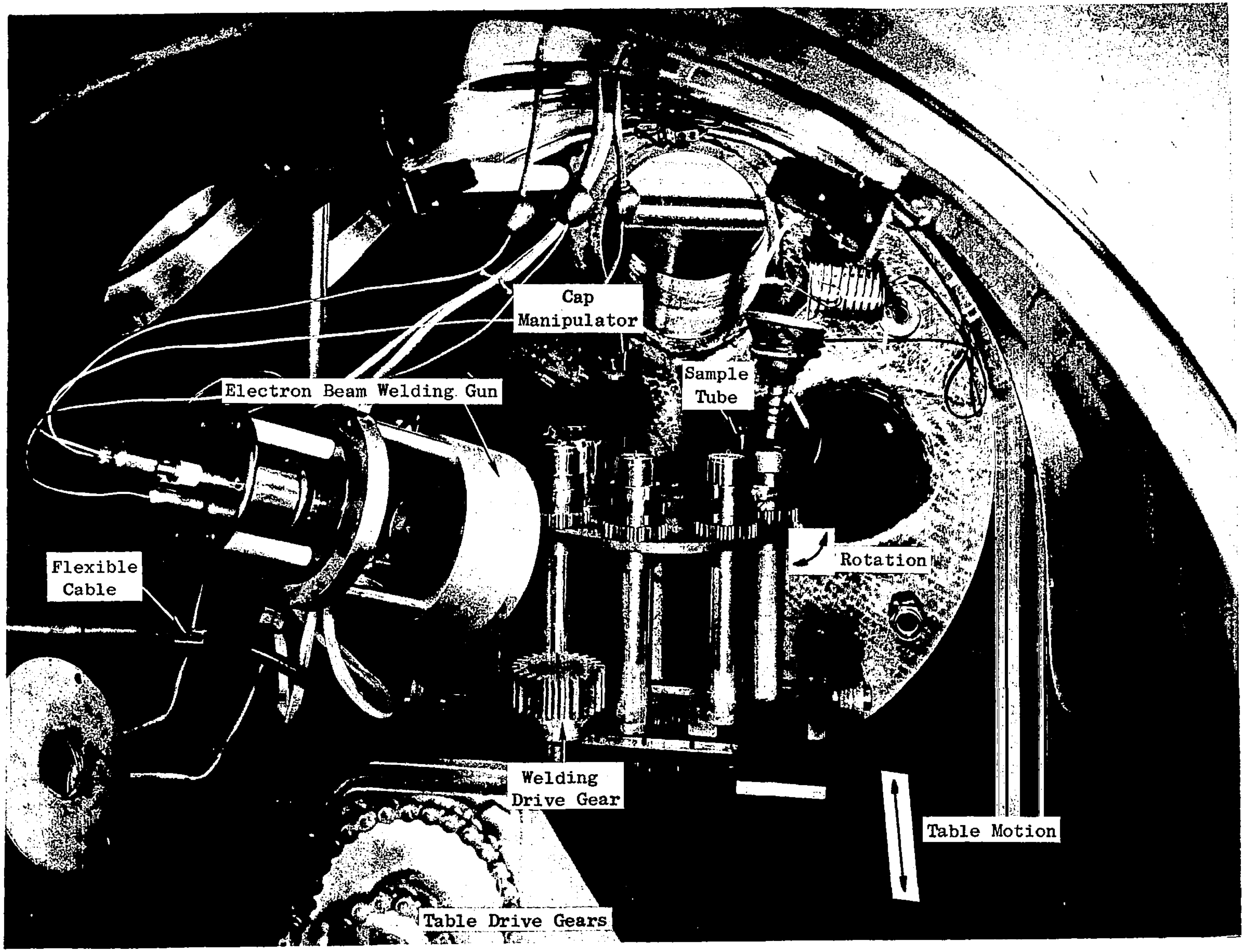


Figure 11. Internal View of Facility Showing the Components Required to Fill Capsules with Potassium.

TABLE III. SPECTROGRAPHIC ANALYSIS OF THE POTASSIUM USED IN FILLING THE STAINLESS STEEL CAPSULES

Element	Chamber Sample ppm	Fill Line Sample ppm
Ag	<1	<1
Al	1	1
Ca	25	15
Cb	<5	<5
Co	<1	<1
Cr	<1	<1
Cu	<1	<1
Fe	1	1
Mg	1	<1
Mn	<1	<1
Mo	1	1
Na	25	15
Ni	1	5
K	Bal.	Bal.
Si	5	5
Sn	<5	<5
Ti	<1	<1
Zr	<5	<5

TEST FACILITY

The air environment furnace used for testing the stainless steel isothermal corrosion capsules, Figure 12, consists of four 1340-watt, nichrome-wound resistance elements, individually controlled with General Electric Volt-Pac 9H60 variable transformers. Each capsule was held in place with an adjustable tie bolt attached to a stainless steel retaining plate. The 8-point recorder allowed dual temperature monitoring of each capsule with chromel-alumel thermocouples.

CAPSULE TESTING

The two Type 321SS and two Type 316SS capsules, each containing one stress-rupture and one tensile specimen of Cb-1Zr alloy sheet in potassium, were exposed for 1000 hours at 1400°F in an air environment. A maximum temperature variance of 20°F from the mean temperature 1405°F was measured for this time period. The mean temperature was calculated on the basis of temperature readings from seven beaded, chromel-alumel thermocouples spot welded to the sides of the capsules. A temperature differential of 20°F also was measured between the top and bottom of one capsule. The capsules were removed from the test facility and examined. As anticipated no leaking was evident and oxidation was minor, Figure 13.

TEST EVALUATION

The stainless steel capsules were opened in an argon atmosphere and drained of potassium. After removal of the Cb-1Zr alloy sheet specimens, the capsules and specimens were cleaned and examined. No appreciable differences in appearance of the internal surfaces of any of the capsules were noted from visual observation, Figure 14. However, a definite discoloration was noted on the Cb-1Zr alloy specimens which were exposed in the Type 316SS capsules, Figure 15. This discoloration was not evident on the Cb-1Zr alloy specimens exposed in the Type 321SS capsules. Also, a 300 ppm weight increase was measured for a specimen exposed in a Type 316SS capsule; no increase could be detected in a similar specimen exposed in a Type 321SS capsule.

Subsequently, the Cb-1Zr alloy specimens were analyzed for carbon, oxygen, nitrogen, and hydrogen and the data are presented in Table IV. The chemical analyses further clarify the preliminary observation. Negligible changes in nitrogen and carbon contents were noted in the Cb-1Zr alloy specimens exposed in Type 321SS capsules as compared to the significant transfer of carbon and nitrogen that occurred in the Type 316SS capsules. There is no pronounced difference in the oxygen content of the Cb-1Zr alloy specimens exposed in either

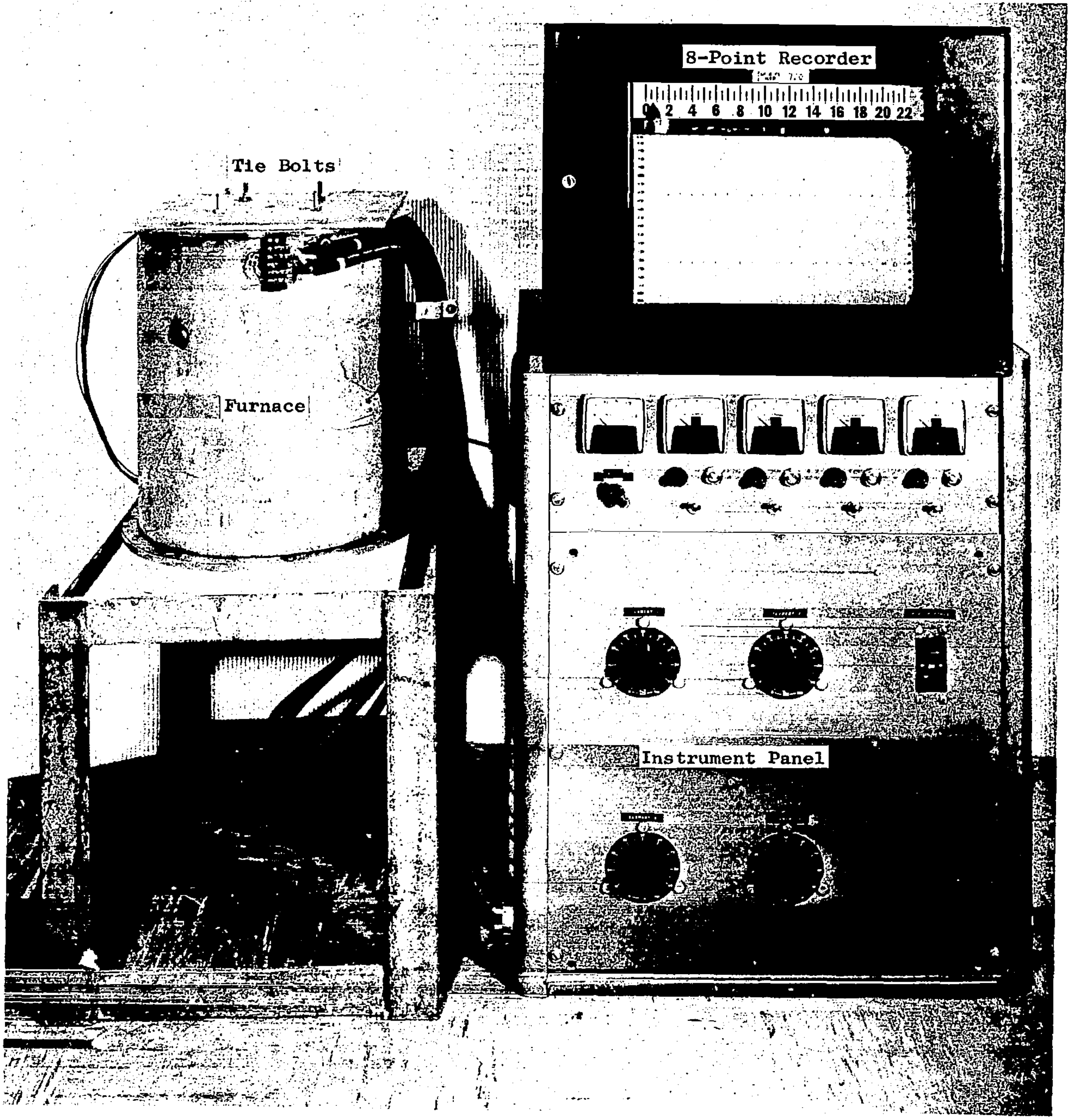


Figure 12. Test Facility for Isothermal Corrosion Capsule Tests.

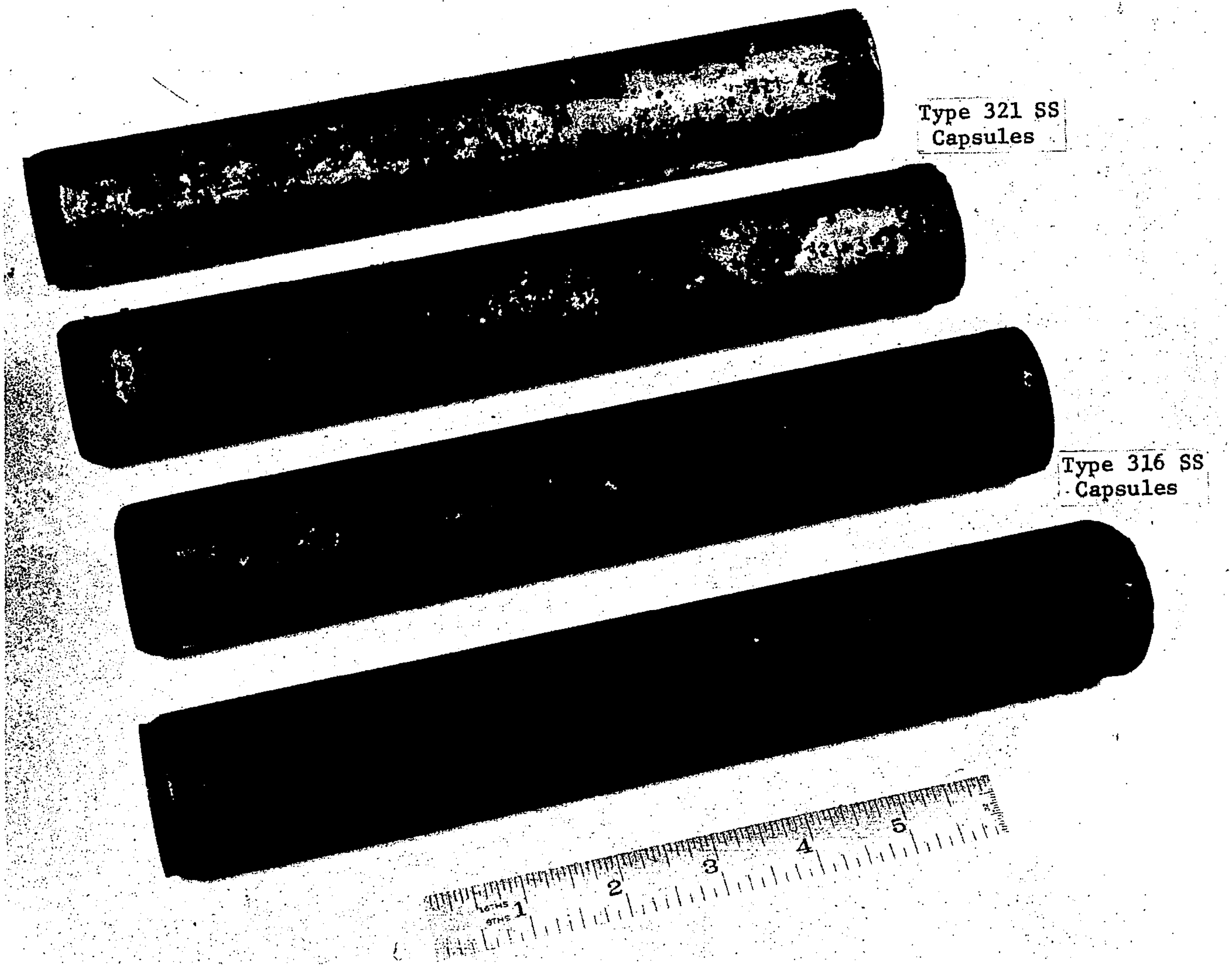


Figure 13. Type 316SS and Type 321SS Isothermal Corrosion Capsules, Containing Potassium and Cb-1Zr Alloy Test Specimens, After Being Exposed for 1000 Hours at 1400°F in Air.

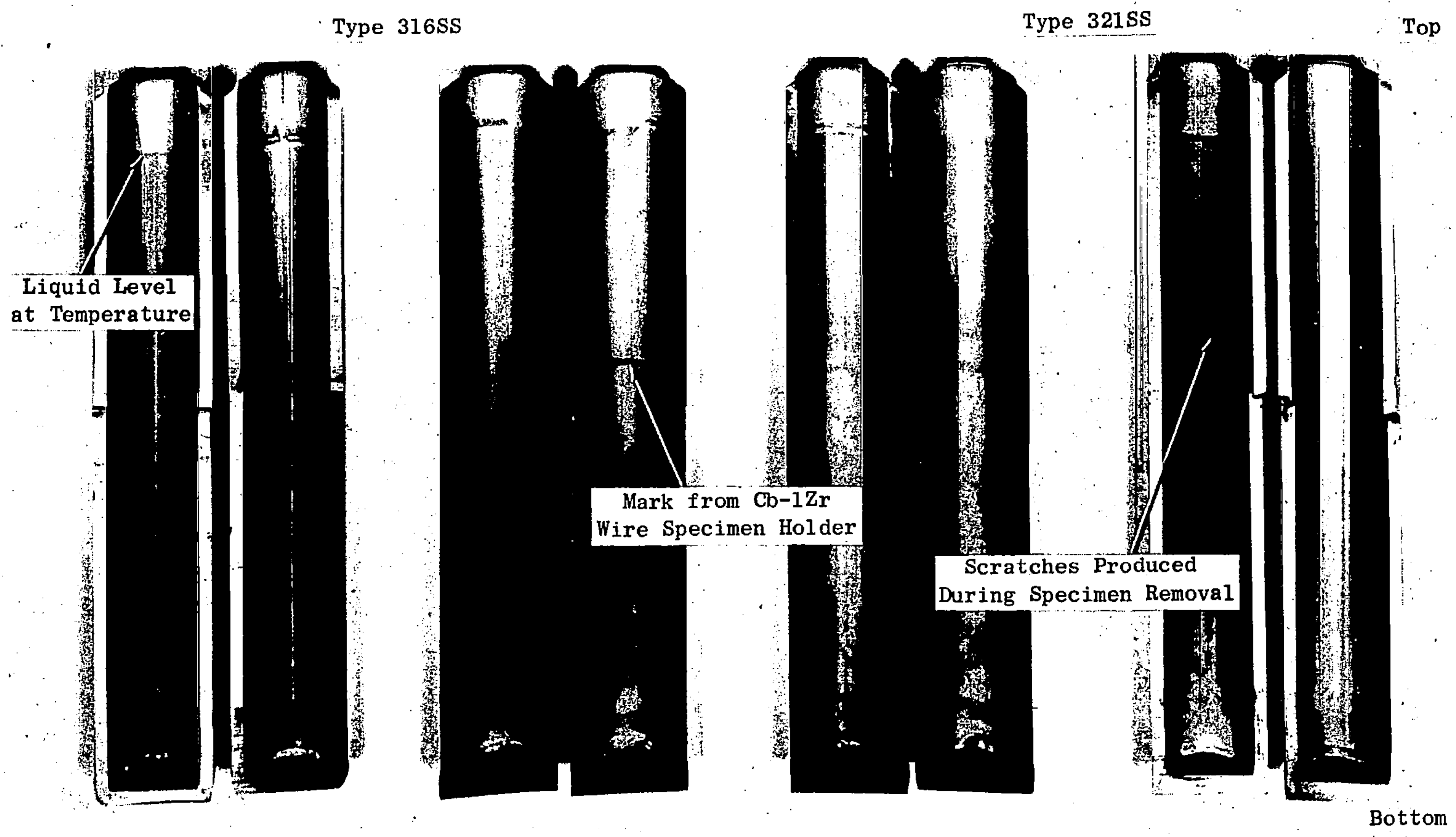


Figure 14. Sectioned Type 316SS and Type 321SS Isothermal Corrosion Capsules After Being Exposed to Potassium for 1000 Hours at 1400°F.

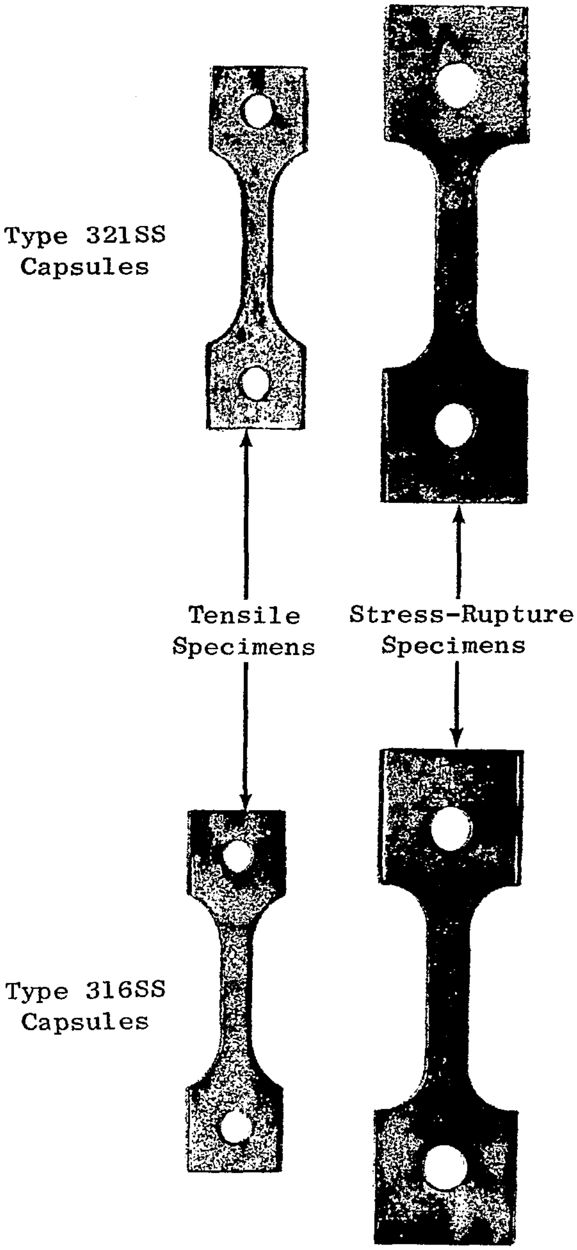


Figure 15. Cb-1Zr Alloy Tensile and Stress-Rupture Sheet Specimens Exposed for 1000 Hours at 1400°F in Potassium Contained in Type 316SS and Type 321SS Capsules. Definite Discoloration Can be Noted on Specimens Exposed in a Type 316SS Capsule.

TABLE IV. POST-TEST CHEMICAL ANALYSES OF 0.040-INCH THICK Cb-1Zr ALLOY SPECIMENS EXPOSED FOR 1000 HOURS AT 1400°F IN POTASSIUM CONTAINED IN TYPE 321SS AND TYPE 316SS CAPSULES

Capsule Material and Specimen No.	Chemical Analyses of Cb-1Zr Alloy Specimens(1), ppm			
	C(2)	N(3)	O(3)	H(3)
Type 316SS-1	210	206	258	23
Type 316SS-2	280	336	156	7
Type 321SS-3	50	21	147	13
Type 321SS-4	35	16	114	14
Pre-Test-1(4)	10	14	75	6
Pre-Test-2(5)	50	50	200	24

(1) MCN 454.

(2) By Combustion Conductometric Techniques.

(3) By Vacuum Fusion Techniques.

(4) Conducted for Incoming Material Quality Control Purposes on 9-8-64.

(5) Conducted as Companion Analysis at the Same Time the Analyses were Performed on the Specimens Exposed to Potassium (2-15-65).

the Type 316SS or the Type 321SS capsules. The increased nitrogen and carbon contents of the Cb-1Zr alloy specimens tested in Type 316SS capsules significantly affected the room temperature tensile properties as evidenced by the higher yield strength and the lower tensile elongation, Table V.

Whereas no observable change in metallographic structure was observed in Cb-1Zr alloy specimens tested in Type 321SS capsules, Figure 16, two distinct layers, believed to be CbC and Cb_2N as reported in similar investigations (1), were observed on the Cb-1Zr alloy specimens tested in Type 316SS capsules, Figure 17. No change in metallographic morphology was observed in the Type 321SS capsule material, Figure 18. However, gross sensitization and sigma phase formation occurred in the Type 316SS capsule material, Figure 19. The reduced amount of chromium carbide precipitation and the increased amount of iron-chromium sigma phase formation at the capsule ID results from the depletion of carbon due to the mass transfer reaction. Although the majority of the sigma phase has been pulled out during metallographic preparation of this specimen, some selective removal of this phase at the surface by liquid potassium is possible. Similar microstructural effects were observed in an investigation of Type 316SS boiling potassium test loops at ORNL as described by D. H. Jansen and E. E. Hoffman (2).

Electron microprobe analysis of a Cb-1Zr alloy specimen exposed in a Type 316SS capsule is presented in Table VI. Nickel was not detected although the results indicate chromium and iron mass transfer from the stainless steel to the Cb-1Zr alloy specimen has occurred. No variance was observed in the zirconium content across the entire 0.040-inch specimen. The carbon concentration gradient indicated by these results suggests most of the carbon found in chemical analyses of Cb-1Zr alloy specimen exposed in Type 316SS capsules was in the outer 0.005 inches of the specimen cross section. This could be anticipated from the presence of the carbide layer found on the Cb-1Zr specimen, Figure 17, and the low diffusion rate of carbon in Cb-1Zr alloy at 1400°F. Spectrographic analyses of the Cb-1Zr alloy specimens tested in both Type 316SS and Type 321SS capsules indicated similar traces of the metallic elements found in the microprobe analysis.

Stress-rupture results, Table VII, also indicate the effects of carbon and nitrogen mass transfer on the properties of Cb-1Zr alloy specimens tested in Type 316SS capsules. Again, little change was noted in the properties of the Cb-1Zr alloy specimens tested in the Type 321SS capsules. The first stress-rupture tests were conducted at 2000°F. At this temperature, diffusion of carbon and nitrogen from the carbide-nitride layer produced during the 1400°F test exposure of the Cb-1Zr alloy in Type 316SS capsules would accentuate the increased strength. Rupture tests at 1400°F would, therefore, be more meaningful as they would more closely indicate the strength differences resulting from capsule exposure alone. The measured 1400°F-25,000 psi creep rate of the Cb-1Zr alloy specimen which was exposed to potassium in a Type 321SS capsule indicated an inconveniently long rupture life. Therefore, the specimen was loaded to 30,000 psi after 259 hours; the specimen ruptured on reloading. An identical test was performed on a Cb-1Zr alloy specimen exposed to potassium in a Type 321SS capsule. However, this specimen ran an additional 100 hours after reloading to 30,000 psi and the test was terminated without rupture.

TABLE V. ROOM TEMPERATURE TENSILE PROPERTIES OF 0.040-INCH THICK Cb-1Zr ALLOY SPECIMENS(1) EXPOSED FOR 1000 HOURS AT 1400°F IN POTASSIUM CONTAINED IN TYPE 321SS AND TYPE 316SS CAPSULES

Capsule Material and Specimen No.	0.2% Yield Strength(2), psi	Ultimate Tensile Strength, psi	Elongation In/In, %
Type 316SS-1	46,700	56,000	20
Type 316SS-2	40,300	57,000	15
Type 321SS-3	29,600	49,300	30
Type 321SS-4	25,300	42,800	36
Pre-Test	23,300	40,000	37

(1) MCN 454.

(2) Strain Rate 0.005 Inch Per Inch Through 0.2% Yield Point.

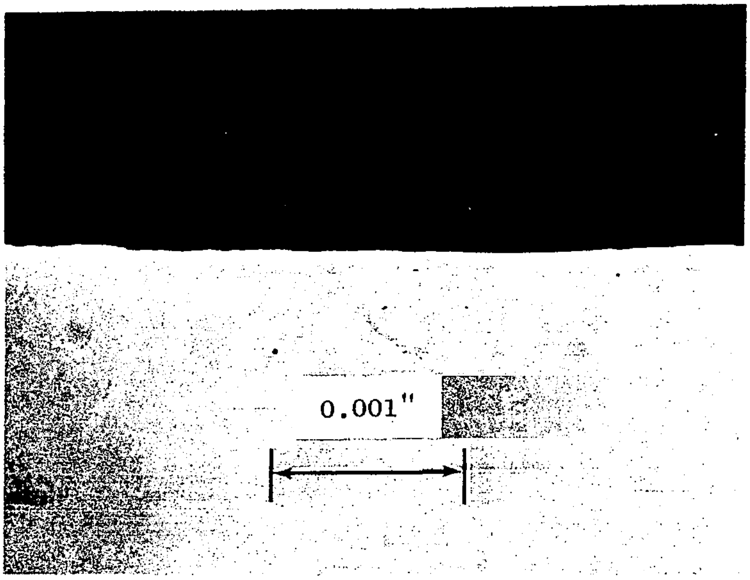


Figure 16. Cb-1Zr Alloy Exposed for 1000 Hours in Potassium Contained in a Type 321SS Capsule Heated Isothermally at 1400°F.

Etchant: 20%HNO_3-20%HF-60% Glycerol Mag: 250X

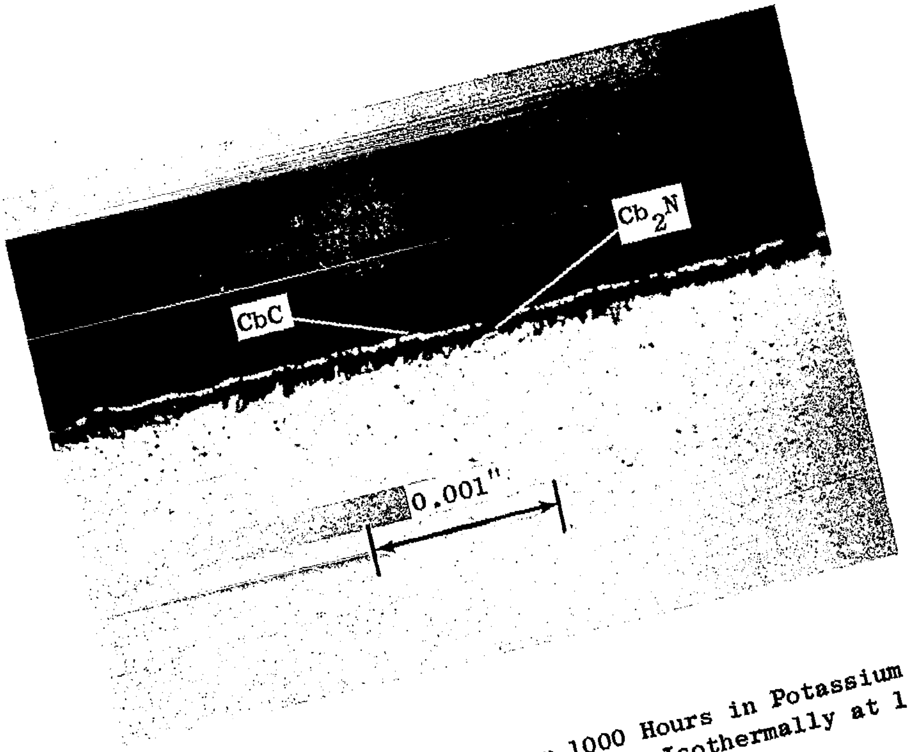


Figure 17. Cb-1Zr Alloy Exposed for 1000 Hours in Potassium Contained in a Type 316SS Capsule Heated Isothermally at 1400°F. Layers Believed to be CbC and Cb_2N. Mag: 1000X

Etchant: As Polished

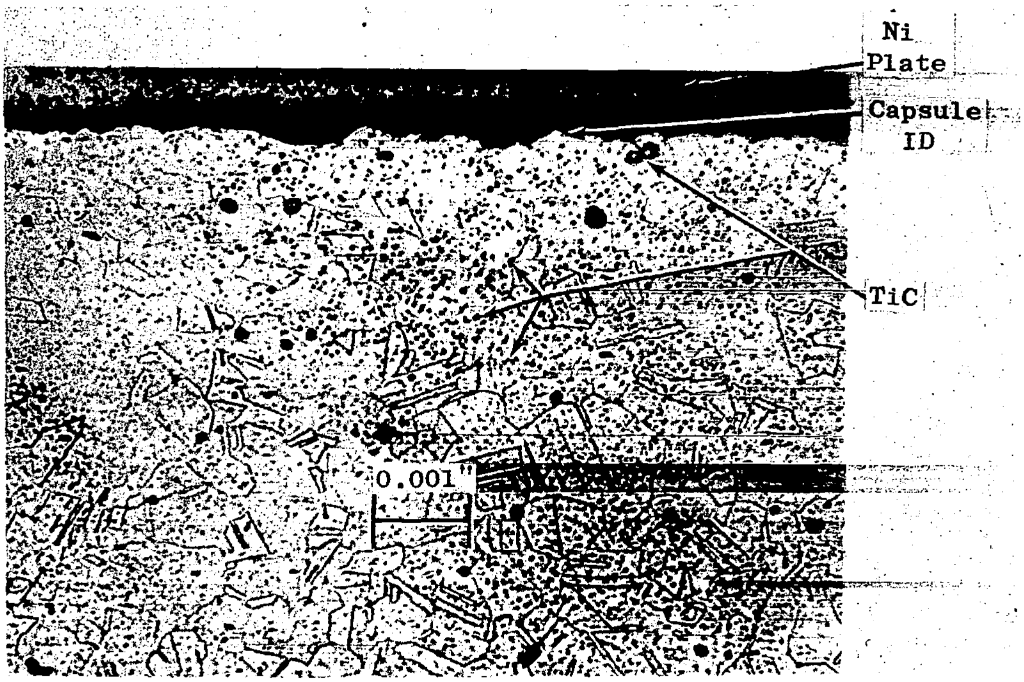


Figure 18. Microstructure of a Type 316SS Capsule After Being Heated Isothermally for 1000 Hours at 1400°F. The Inner Surface of the Capsule Wall Was Exposed to Liquid Potassium.

Etchant: Electrolytic, Oxalic Acid Mag: 500X

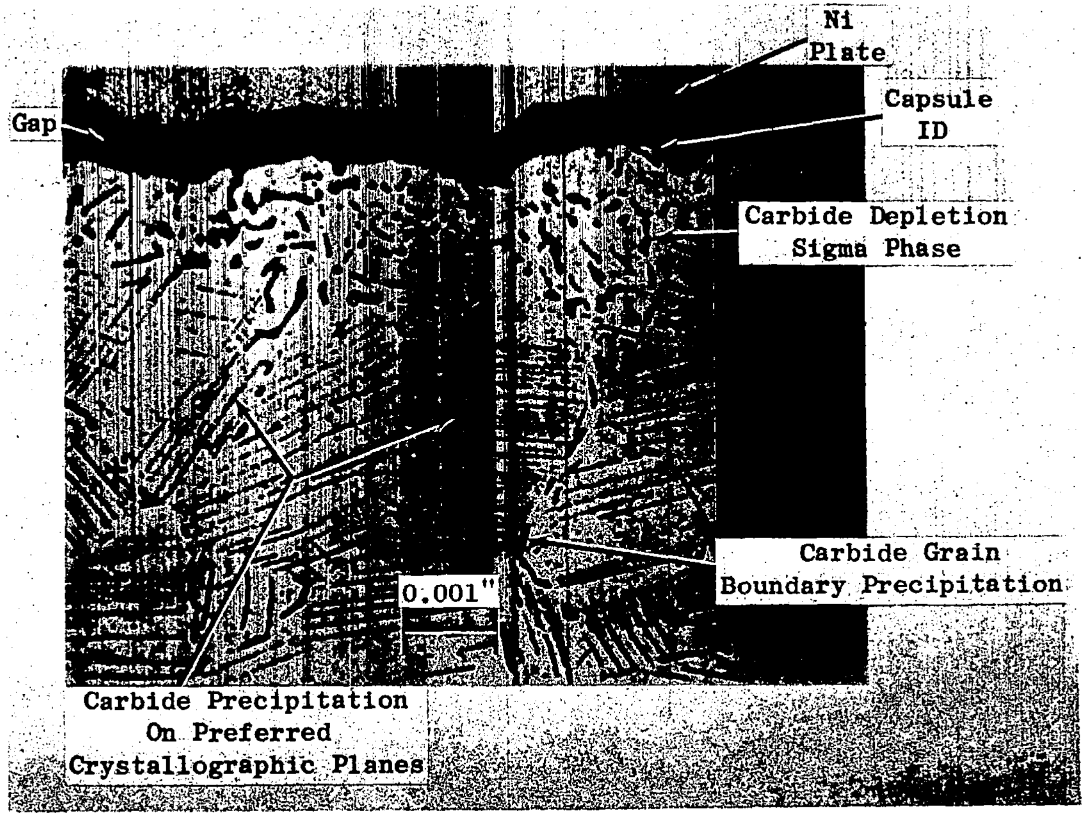


Figure 19. Microstructure of a Type 316SS Capsule After Being Heated Isothermally for 1000 Hours at 1400°F. The Inner Surface of the Capsule Wall was Exposed to Liquid Potassium.

Etchant: Electrolytic, Oxalic Acid Mag: 500X.

TABLE VI. ELECTRON MICROPROBE ANALYSIS OF A 0.040-INCH THICK
Cb-1Zr ALLOY SPECIMEN EXPOSED TO POTASSIUM FOR 1000 HOURS
AT 1400°F IN A TYPE 316SS CAPSULE

Distance From the Surface, Inches	Analysis, ppm(1)				
	Cr	Fe	Ni	C	Zr
0.001	2000	500	N.D.(2)	1000	1 $^{w}/_{o}$
0.002	1100	<100	N.D.	500	1 $^{w}/_{o}$
0.004	<100	N.D.	N.D.	<100	1 $^{w}/_{o}$
0.006	N.D.	N.D.	N.D.	N.D.	1 $^{w}/_{o}$

(1) Calculated From the Average of 5 Counts Taken at Each Area.

(2) Not Detected.

TABLE VII. STRESS-RUPTURE PROPERTIES OF 0.040-INCH THICK Cb-1Zr ALLOY SPECIMENS(1) CONTAINED IN TYPE 321SS AND TYPE 316SS CAPSULES AND EXPOSED TO POTASSIUM FOR 1000 HOURS AT 1400°F

Capsule Material and Specimen No.	Stress psi	Test Temp., °F	Rupture Life, Hours	Environment Torr
As-Received	10,000	2000	11	7×10^{-8}
Type 316SS-1	10,000	2000	95	5×10^{-8}
Type 321SS-3	10,000	2000	5	7×10^{-8}
Type 321SS-4	25,000	1400	259(2)	6×10^{-9}
	30,000	1400	--(3)	
Type 316SS-2	25,000	1400	260(4)	4×10^{-9}
	30,000	1400	100(5)	

(1) MCN 454.

(2) Specimen Did Not Rupture.

(3) Specimen Failed on Reloading, Total Elongation 22%.

(4) Specimen Did Not Rupture.

(5) Test Terminated Without Rupture, Total Elongation 2.6%.

In summary, it is very clear that, compared with the behavior of Type 316SS, the titanium addition to Type 321SS substantially reduced the transfer of carbon and nitrogen to the Cb-1Zr alloy. Expectations are that the results reported here have implications beyond the scope of this investigation. By appropriate employment of carbide-nitride forming alloying additions, such as titanium in Type 321SS, the transfer of nitrogen and carbon may be substantially reduced in a variety of systems and applications. A few examples of areas where this technique may be employed effectively are: 1) to reduce the outgassing of carbon and nitrogen from alloys exposed to high temperatures in high-vacuum systems, 2) to reduce the diffusion of carbon and nitrogen from the stainless steel to the refractory metal in co-extruded tubing, and 3) to reduce the mass transfer of carbon and nitrogen that is induced by a thermal gradient in certain monometallic systems which contain alkali metals. The latter case is of particular interest, inasmuch as carbon and nitrogen transfer have been observed in alloy steel, stainless steel and superalloy containment systems. Presumably, the extent of this transfer could be reduced by alloying the containment material with stabilizing elements such as titanium.

REFERENCES

(1) DiStefano, J. R. and Hoffman, E. E., "Corrosion Mechanisms in Refractory Metal-Alkali Metal Systems," *Atomic Energy Review*, (1964), Vol. 2, No. 1, p 20.

(2) Hoffman, E. E. and Jansen, D. H., "Type 316 Stainless Steel, Inconel, and Haynes Alloy No. 25 Natural-Circulation Boiling-Potassium Corrosion Test Loops," ORNL-3790, June 1965.

NASA-Langley, 1967 —— 17 E-3868