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ADVANCED GAS COOLED NUCLEAR REACTOR MATERIALS EVALUATION AND DEVELOPMENT PROGRAM

**PROGRESS REPORT
FOR PERIOD**

April 1, 1980 - June 30, 1980

**BY
PROJECT STAFF**

**GENERAL ELECTRIC COMPANY
ENERGY SYSTEMS PROGRAMS DEPARTMENT
SCHENECTADY, NEW YORK 12345**

GENERAL ELECTRIC

November 14, 1980

**Prepared for
THE U. S. DEPARTMENT OF ENERGY
Under Contract No. DE-AC-02-76ET34202**

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FOREWORD

The Advanced Gas Cooled Nuclear Reactor Materials Evaluation and Development Program is being conducted for the Nuclear Power Development Division, U.S. Department of Energy, by the Energy Systems Programs Department, General Electric Company, Schenectady, New York 12345 under Contract DE-AC02-76ET34202. The Program is under the direction of Mr. J.E. Fox, DOE Program Manager, and is being managed for the General Electric Company by Mr. R.G. Frank, Manager, Materials Technology. The Principal Investigator, with responsibility for overall technical coordination of the Program is Dr. O.F. Kimball, Manager, Gas Reactor Materials, assisted by Dr. J.F. Stubbins, Materials Engineer, Gas Reactor Materials. Major contributors to the Program are:

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ABSTRACT

This report presents the results of work performed from April 1, 1980 through June 30, 1980 on the Advanced Gas-Cooled Nuclear Reactor Materials Evaluation and Development Program. The objectives of this program are to evaluate candidate alloys for Very High Temperature Reactor (VHTR) Nuclear Process Heat (NPH) and Direct Cycle Helium Turbine (DCHT) applications, in terms of the effect of simulated reactor primary coolant (helium containing small amounts of various other gases), high temperatures, and long time exposures, on the mechanical properties and structural and surface stability of selected candidate alloys. A second objective is to select and recommend materials for future test facilities and more extensive qualification programs.

Work covered in this report includes the activities associated with the status of the simulated reactor helium supply system, testing equipment and gas chemistry analysis instrumentation and equipment. The progress in the screening test program is described; this includes: screening creep results and metallographic analysis for materials thermally exposed or tested at 750, 850 and 950°C (1382, 1562 and 1742°F). The initiation of air creep-rupture testing in the intensive screening test program is discussed. In addition, the status of the data management system is described.

OTHER REPORTS IN THIS SERIES

QUARTERLY PROGRESS REPORTS

September 23, 1976 to December 31, 1976	C00-2975-3
January 1, 1977 to March 31, 1977	C00-2975-10
April 1, 1977 to June 30, 1977	C00-2975-13
July 1, 1977 to September 30, 1977	C00-2975-17
October 1, 1977 to December 31, 1977	C00-2975-20
January 1, 1978 to March 31, 1978	C00-2975-21
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April 1, 1979 to June 30, 1979	C00-2975-34
July 1, 1979 to September 30, 1979	C00-2975-37
October 1, 1979 to December 31, 1979	C00-2975-40
January 1, 1980 to March 31, 1980	C00-2975-43

TOPICAL REPORTS

1. Selection of Candidate Alloys	C00-2975-16
Volume 1 - Advanced Gas Cooled Reactor Systems Definition by M. Marvin	October 31, 1978
Volume 2 - Selection of Alloys for Screen- ing Creep and Structural Stability Studies by R.M. Goldhoff, R.V. Hillery, and S. Yukawa	December 31, 1978
Volume 3 - Selection of Surface Coating/ Substrate Systems for Creep and Structural Stability Studies	June 20, 1980

Section 1.0
INTRODUCTION

ADVANCED GAS COOLED NUCLEAR REACTOR
MATERIALS EVALUATION AND DEVELOPMENT PROGRAM

1.0 INTRODUCTION

The Very High Temperature Reactor (VHTR) Nuclear Process Heat (NPH) and Direct Cycle Helium Turbine (DCHT) Systems are being developed to provide an expanded energy capability and to facilitate conservation of or substitution for scarce energy resources. In both cases, the use of high temperature helium-cooled reactors will require a knowledge of the long term properties of reactor primary coolant containment materials and of the materials used in constructing related hardware. Because of the very high temperatures required for NPH and DCHT applications, the need is evident for materials testing in the proper helium environment in the temperature range from 750° - 1050°C (1382° - 1922°F) on those alloys which might serve as materials of construction for heat exchangers, ducting, turbine blades and vanes and other high temperature structural components.

The objectives of the Advanced Gas Cooled Nuclear Reactor Materials Evaluation and Development Program are to:

1. Evaluate candidate alloys for Very High Temperature Reactor (VHTR) Nuclear Process Heat (NPH) and Direct Cycle Helium Turbine (DCHT) applications, in terms of the effect of the primary coolant and thermal exposure on:

- Surface stability ("corrosion" resistance) in 10,000 hours.
- Structural stability in 10,000 hours - changes in microstructure and tensile, impact and fatigue properties.
- Creep - rupture properties in 15,000 hours.
- Fatigue properties

Low Cycle 10^3 to 10^5 cycle

High Cycle 10^5 to 10^7 cycle

2. Select and recommend materials for future test facilities and more extensive qualification programs.

The data base will permit the selection of materials of construction and should provide a reliable level of design data for the construction of various items of development hardware leading to the successful development of NPH and DCHT systems. The present lack of an accurate measure of materials capabilities under these high temperature helium environments is a factor which is limiting the development of the NPH and DCHT systems. This program is intended to provide such initial information.

Section 2.0

PROGRAM STATUS

2.0 PROGRAM STATUS

The Advanced Gas Cooled Reactor Materials Evaluation and Development Program is organized into nine (9) tasks which are designed to accomplish the program objectives listed in Section 1.0 of this report. The task structure (Program Work Breakdown Structure) and a brief description of each task (Program Work Statement) have been included in the first Quarterly Report covering the period September 23, 1976 - December 31, 1976, report number C00-2975-3.

2.1 TASK 1 - SELECTION OF CANDIDATE ALLOYS

The selection of alloys for the screening phase of the program has been completed. A list of the alloys selected for the program was presented in topical report number C00-2975-16, Volume 2, dated December 31, 1978 and entitled: Selection of Alloys for Screening Creep and Structural Stability Studies. The selection of alloys for the Intensive Screening Phase of the program was completed in November 1979 and approved by DOE in January 1980. The alloys and their nominal compositions are listed in Table 1.

2.2 TASK 2 - MATERIALS PROCUREMENT AND CHARACTERIZATION

2.2.1 Direct Cycle Helium Turbine (DCHT) Alloys

2.2.1.1 Materials Procurement

The procurement of all DCHT material for the Phase 1 screening test program was completed by June 1978.

The alloys for the Phase 2 intensive screening test program were procured during the present quarter. All of these alloys have been received or were being shipped by end of the quarter. The material includes MA-754, Rene' 100 and Alloy 713LC.

Due to a misunderstanding by the vendor, cast-to-size specimens were poured from Alloy 713C rather than Alloy 713LC, as intended. The vendor was required to re-cast test specimens with Alloy 713LC. The main difference between Alloy 713C and Alloy 713LC is lower C in the LC version; 0.13 wt. % C nominal vs 0.06 wt. % C nominal. The heat of Alloy 713C shipped by the vendor has 0.10 wt. % C. Table 2 shows the chemical composition (vendor analyses) of the heats presently used in the

TABLE I

ALLOYS SELECTED FOR INTENSIVE SCREENING TESTS AND THEIR NOMINAL COMPOSITIONS

Alloy	Alloy Type	C	Ni	Fe	Cr	Co	Mo	W	Nb	Al	Ti	Si	Mu	Cu	Other
800H	Iron-Base Austenitic	.08	32.5	Bal	21	--	--	--	--	.4	.4	.5	.75	.4	
Hastelloy X	Nickel-Base Austenitic	.10	Bal	18.5	22	1.5	9	.6	--	--	--	.5	.5	--	
Inconel 617	Nickel-Base Austenitic	.07	Bal	--	22	12.5	9	--	--	1.0	<.6	<1.0	<1.0	<.5	
MA 956	ODS Alloy Iron-Base	--	--	Bal	20					5.0	.4				.5Y ₂ O ₃
MA 754	ODS Alloy Nickel-Base	.07	Bal	--	20					.3	.3				.6Y ₂ O ₃
Rene' 100	Precipitation Hardened Nickel-Base	.18	Bal	--	9.5	15	3	--	--	5.5	4.2	--	--	--	
713 LC	Precipitation Hardened Nickel-Base	.05	Bal	--	12	--	4.5	--	2	5.9	.6	--	--	--	
Coated 713 LC	Codep B Coating														Vapor Deposited (Pack Cementation) Aluminide Coating

TABLE 2

ALLOY COMPOSITION OF DIRECT CYCLE HELIUM TURBINE ALLOYS FOR INTENSIVE SCREENING TESTING

VENDOR CHEMISTRY CERTIFICATION (W/O):

Alloy	Heat No.	Cr	Ni	W	Fe	Co	Mo	Al	Ti	Cb + Ta	Zr	B	C	Other
Rene' 100 ⁽¹⁾	7-11047	9.85	Bal.	---	.20	15.18	3.03	5.46	4.19	---	.07	.015	.18	1.05V
Rene' 100 ⁽²⁾	UP047	9.17	Bal.	---	.20	14.90	3.10	5.45	4.15	---	.05	.015	.16	1.03V
IN-713LC ⁽¹⁾	66B6965	12.00	Bal.	---	.15	.10	4.10	5.85	.71	2.04	.06	.007	.06	---
IN-713LC ⁽²⁾	WA441	12.00	Bal.	---	.08	<.10	4.25	5.77	.68	2.25	.09	.005	.06	---
IN-713C ⁽²⁾	MH2038	13.49	Bal.	---	.14	<.10	4.50	5.82	.84	2.12	.06	.011	.10	---
MA 754 ⁽¹⁾	DT0110B	20.2	77.03	---	1.04	---	---	.29	.41	---	---	---	.07	.58Y ₂ O ₃ .38O ₂
MA 754 ⁽²⁾	DT06A1B	20.05	76.76	---	1.46	---	---	0.30	0.41	---	---	---	0.07	0.58Y ₂ O ₃ , .37O ₂

(1) Material for Screening Phase

(2) Material for Intensive Screening Phase

screening program and the compositions of the heats in the intensive screening program for Rene' 100, Alloy 713, MA754.

The lower carbon version, Alloy 713LC, was developed to solve casting problems encountered, with Alloy 713C. In small sections, the castability is very similar, but in larger sections some segregation problems occur with Alloy 713C, and it is less castable than Alloy 713LC. For test specimen sizes used in this program, castability is not a concern. Due to this, it was decided to use the Alloy 713C for coated specimens, and run some uncoated Alloy 713C in parallel for comparison purposes in addition to testing uncoated Alloy 713LC.

2.2.1.2 Materials Characterization

This subtask was completed for the Phase I screening test program and the final results reported in the Progress Report for July 1, 1978 to September 30, 1978, report number C00-2975-25.

Additional characterization air creep-rupture tests will be run on the heats of MA-754, Alloy 713LC, Alloy 713C and Rene' 100 procured for the intensive screening test program. Stress levels, selected for 300 hours to rupture, will be used for these tests. The results will allow proper selection of stress for longer term creep-rupture tests in both controlled purity He and in air.

2.2.2 Nuclear Process Heat (NPH) Alloys

2.2.2.1 Materials Procurement

The procurement of all NPH materials, sufficient for both testing phases, was completed by September 1978.

2.2.2.2 Materials Characterization

The materials acceptance and characterization testing was completed in the quarter ending in December 1978.

Three 300 hour creep-rupture tests on MA-956 are currently in progress. These tests are designed to characterize the creep-rupture properties of a second heat (Heat No. ZDCR) of MA-956. This material was used in the manufacture of the MA-956 intensive phase specimens. Creep-rupture results for Heat No. ZDCR are tabulated in Table 3, along with the results obtained from the heat of MA-956 used in the screening phase. Analysis of the data obtained to date suggests that the heats appear to be fairly comparable in terms of rupture strength. The two ZDCR specimens which have ruptured failed in or very near the radius between the gage length and

TABLE 3

MA-956 CREEP-RUPTURE CHARACTERIZATION TEST RESULTS

Heat No.	Specimen No.	Test Temp. (°C) (°F)	Test Stress MPa (ksi)	Time to 1% Total Strain (hours)	Rupture Life (hours)	El. (%)	RA (%)
LCWZ	1D00CR02	850 (1562)	79 (11.5)	~1000	1168.6	4.4	16.3
ZDCR	1D10CR18	850 (1562)	79 (11.5)		623.2*	0.13	
LCWZ	1D00CR03	950 (1742)	69 (10.0)	130	1254.6	4.5	1.8
LCWZ	1D00CR04	950 (1742)	69 (10.0)	---	20.0	2.3	3.2
ZDCR	1D10CR19	950 (1742)	69 (10.0)	---	183.3	---	---
LCWZ	1D00CR05	1050 (1922)	69 (10.0)	---	37.5	2.1	1.2
ZDCR	1D10CR20	1050 (1922)	69 (10.0)	---	448.2	-0.07	8.3

* In Test

the shoulder, This is consistent with the behavior of the original heat of material employed and implies a notch sensitivity.

An as-received MA-956 (Heat No. ZDCR) RT tensile test was run during the quarter. The results are compared in Table 4 with the tensile properties obtained from the original heat of MA-956 (Heat No. LCWZ), and vendor results from similarly heat treated sheet stock. Heat No. LCWZ is the heat being used for Phase 1 of the test program. Note that no tensile specification exists at the present time for MA-956.

Inspection of the data reveal that the strengths of the two heats are fairly comparable; however, the ductility of Heat No. ZDCR appears reduced somewhat relative to Heat No. LCWZ. There are no obvious explanations for this ductility difference at the present time, and the dissimilarity may, in fact, be due to the inherent scatter between the various heats of material. An additional feature which is readily apparent upon inspection of the data is that the bar product has about a 10 to 15% increase in tensile strength relative to the sheet product, with comparable ductility.

2.2.2.3 Materials Joining Studies

The final results for Vareststraint tests were covered in the quarterly report for the period October 1, 1978 to December 31, 1978, report number C00-2975-28.

Three weldments will be included in the intensive screening phase: Alloy 800H - Alloy 800H, Inconel 617 - Inconel 617, and Hastelloy X - Hastelloy X. Welds will be evaluated by guided bend testing of transverse side bend specimens at room temperature after 1000-hour and 10,000-hour exposures at 750^o, 850^o, 950^o, and 1050^oC. This test is widely used to determine the ductility and soundness of welds in both ferrous and non-ferrous products (see ASTM E190-64, Standard Method for Guided Bend Test for Ductility of Welds).

The three weldments were prepared by using current commercial "best practice" techniques in order to simulate state-of-the-art industrially-employed procedures and standards in a laboratory environment. For each of the three alloys, gas tungsten arc (GTA) welding was employed. Filler metals included Inconel filler metal 82 for the Alloy 800H weldment, Inconel 617 filler metal for the Inconel 617 weldment, and Hastelloy X filler metal for the Hastelloy X weldment. Filler wires were 2.4mm (0.093 in.) diameter x 91.4 cm (36.0 in.) long in each case.

TABLE 4

MA-956 ROOM TEMPERATURE
TENSILE TEST RESULTS

<u>Heat No.</u>	<u>Ultimate Tensile Strength</u>		<u>0.2% Offset Yield Strength</u>		<u>Elong. (%)</u>	<u>RA (%)</u>
	<u>MPa</u>	<u>(ksi)</u>	<u>MPa</u>	<u>(ksi)</u>		
LCWZ (Bar)	796	(115.5)	786	(114.0)	13.0	41.6
	800	(116.0)	786	(114.0)	12.0	39.1
ZDCR (Bar)	792	(115.0)	757	(109.8)	10.0	27.9
Vendor Data (Sheet)	720	(104.4)	635	(92.1)	13.0	---

The geometry which was selected for the wrought plate butt weldments is shown in Figure 1. Prior to welding, the specimens were clamped to a full-restraint metallic backing plate. Commercial grade argon was used as the shielding gas for the GTA welding, with the flow rate maintained at 0.12-0.16 liters/sec (15-20 CFH). A 2% thorium tungsten electrode (2.4 mm (0.093 in.) dia) was employed with direct current, straight polarity. Welds were wire brush cleaned and visually inspected after every pass to insure a defect-free product. The specific welding parameters (number of passes, current, and voltage) employed in the fabrication of the butt welds are presented in Table 5. After welding, the Inconel 617 weldment was judged to exhibit excessive joint distortion. This plate was, therefore, sawed through the weld, the opposite edges of the plate were machined to the appropriate weld prep configuration, and the weld was redone with much improved results.

Ten side bend specimens were machined from each alloy; eight samples will be bend tested at room temperature after controlled-purity helium exposure, one specimen will be tested in the as-welded condition, and the tenth sample will be used as a spare.

Each of the completed side bend specimens were inspected radiographically for defects. It should be noted that two radiographs were produced for each sample, with specimens rotated 90° about their longitudinal axis after the first exposure. This technique is capable of detecting a discontinuity which is approximately 2% of the thickness of the material. A few detects (generally fine porosity) were noted by this technique. These samples will be tested in the as-welded condition or used as spares. As-welded side bend tests will be conducted during the next quarter.

2.3 TASK 3 - TESTING AND ANALYSIS FACILITIES AND EQUIPMENT

2.3.1 Multispecimen Creep (MSC) Equipment

Helium leakage detected during an attempt to restart the 950°C test in MS-6 led to the identification of cracks in the ceramic retort. The leak was detected before the specimens reached 200°C. The cracks were circumferential, as much as 10 cm (3.9 inches) in length, and were found over a 15 cm (5.9 inches) length of retort corresponding to the location of the bottom heating element of the furnace. The cracked tube was removed.

Figure 1. Geometry of Wrought Plate Butt Weldments.

TABLE 5

PARAMETERS EMPLOYED IN THE FABRICATION OF
WELDMENTS FOR PHASE 2 TESTING

<u>Base Metal/Filler Metal</u>	<u>Passes (#)</u>	<u>Current (Amps)</u>	<u>Voltage (volts)</u>
Alloy 800H/Inconel Filler Metal 82	18	1st: 145 - 150 Others: 150 - 160	16 - 18
Inconel 617/Inconel Filler Metal 617	17	140 - 160	16 - 18
Hastelloy X/Hastelloy X Filler Metal	14	140 - 150	16

The cracked alumina tube in MS-6 was replaced with an Inconel 601 retort supplied by Applied Test Systems (ATS). At the end of the report period this tube was in position, ready for conditioning (preoxidation). This retort tube change also necessitated another furnace change, back to the original hot-zone length design which has performed satisfactorily in the 750° and 850°C tests to date.

Three of the four multispecimen creep stands used for helium tests have been modified to accommodate two thermocouple probes for each of the five furnace zones. The original construction provided one T/C per zone with one additional T/C for an over-temperature trip circuit. The four added T/C's will allow all-zone over-temperature protection. Extra T/C's had been added to MS-2 (1050°C tests), MS-4 (750°C tests), and MS-6 (950°C tests) by the end of the report period. MS-1 (850°C tests) will be similarly modified during its scheduled shutdown in July for specimen measurements after 5000-hours of testing.

During a preliminary run to establish the temperature profile in MS-6, prior to resumption of the 950°C tests, the center heating element burned out. The furnace was removed, shipped to ATS for repair, and replaced by a reduced hot-zone length furnace. Slightly heavier wire will be used during rewinding to help increase furnace life. This is the first furnace burn-out for any of the MS stands.

2.3.2 Thermal Stability [Aging/Corrosion (A/C)] Test Equipment

All of the retorts have been equipped with additional thermocouples as described above for the multispecimen creep stands. The two T/C's for a given furnace zone are located at the same elevation in the vertical retort, but 180° apart azimuthally. The control T/C's are maintained at the desired test temperature, generally within $\pm 0.5^\circ\text{C}$. Checks of the second T/C have shown that the temperature at its location can differ from the first T/C by as much as 8°C. It is believed that such differences are due to the irregularity of the furnace loads, that is that the heat transfer to a given T/C is strongly influenced by its immediate surroundings at these temperatures where heat transfer is primarily by radiation.

The cause of the cracks in the ceramic retort used for 1050°C exposures, reported in the Progress Report for period January 1, 1980 - March 31, 1980 (C00-2975-43) remains unknown. Detailed calculations of the steady state temperature drop across the retort wall (based on known power inputs and temperatures) indicate that induced thermal stresses probably do not exceed 3.45 MPa (500 psi), which should be easily tolerated by the alumina. It seems, therefore, that cracking must be associated with transient stresses arising from the manner in which the furnaces are operated. It was recommended that specific temperature distributions be obtained experimentally before any further theoretical evaluation is attempted. It is possible that detailed finite element modelling may be required to accurately assess the magnitude of these stress transients.

2.3.3 Single Specimen Creep-Rupture (ST) Equipment

Test stands ST-11 through ST-20 were conditioned and stands ST-21 through ST-30 were cleaned, reassembled, leak checked and readied for conditioning during the report period.

Furnace burn-outs in the 1050°C ST stands continue to be a concern. Several burned out furnace elements have been returned to the vendor, ATS, for repair. In order to address this problem, heavier winding wire and temperature control during cool down may have to be implemented. It is felt that thermal cycling of the furnaces, an unavoidable part of furnace function for testing use, is the major contributor to furnace element failure.

A series of tests on metallic and ceramic rod and tube extensometers have been initiated. Due to concern about the dimensional stability of metallic extensometers in the test atmosphere, tests have been designed to elucidate the nature of any dimensional changes, their magnitudes and time and temperature dependences. Ceramic extensometers also have been included in testing since they may provide a dimensionally stable alternative to metallic systems. Preliminary results indicate that the highest test temperature, 1050°C, may be the most troublesome as far as dimensional changes are concerned.

Several revisions have been incorporated in the prototype ceramic rod and tube extensometer after preliminary checkouts. These include:

- 1) Addition of a brace near the bottom (cold) ends of the tubes. This device maintains the rods parallel to the lower load bar and prevents rod and tube swinging in response to vibration. This was needed because of the necessarily loose nature of the joints between ceramic components and metal crossheads and results in elimination of "flutter" from the LVDT outputs.
- 2) Replacement of the vendor's Inconel locking pin at these same ceramic/crosshead joints. The replacement pin is 3 mm (.125 inch) dia alumina. This change was made after estimation of the shear stresses on the locking pin indicated significant creep would occur at 1050°C.
- 3) Increased stiffness springs were installed in the LVDT's with the objective of keeping the slack out of the ceramic-to-metal joints during a test.
- 4) Shorter rods were procured after the first attempted test start was aborted due to insufficient remaining LVDT travel after attaining test temperature. By the last week of June, the new ceramic rods had been machined to their proper length and the system was being re-calibrated prior to start of the test.

2.3.4 Fatigue Test Equipment

During the report period, the assembly of the two closed-loop control electro-hydraulic test stands, environmental test chambers, load cells, hydraulic pumps, induction heaters, temperature control and readout connections, and liquid metal grip heating and cooling lines was completed. This completes the assembly of the test stands. Two check-out tests on dummy fatigue specimens have been successfully run.

2.4 TASK 4 - SIMULATED REACTOR HELIUM ENVIRONMENT

2.4.1 Loop No. 1 Operation

The average gas composition of the controlled-purity He for the report period is given in Table 6.

TABLE 6

Loop No. 1 Gas Chemistry History

April 1, 1980 to June 30, 1980

<u>Constituents</u>	<u>Target Chemistry & Normal Limits (μatm)</u>	<u>Actual Average Chemistry (μatm at 2 atm. abs.)</u>
H ₂	400 $\pm$ 75	402
H ₂ O	2.0 $\pm$ 1.0	2.2 (a)
CO	40 $\pm$ 10	40.2
CO ₂	0.2 $\pm$ 0.15	0.20
CH ₄	20 $\pm$ 5	18.9
N ₂	6 $\pm$ 4	9.0
He		Balance

(a) This number was determined by the EG&G dew point hygrometer.

Due to the criticality of maintaining invariant impurity gas levels in the helium supplied to the test specimens, retort inlet and outlet chemistry has continued to be monitored and compared over the life of the test program. It is difficult to use retort outlet chemistries averaged over a period of time as a basis of comparison since these readings are taken less often than loop readings and are sensitive to normal fluctuation in the loop helium gas impurity levels. For this reason, a comparison is made of inlet and outlet chemistries at specific points in time and the differences compared. The two readings, inlet versus outlet, are usually made within an hour of one another. Table 7 lists the averages of the outlet minus the inlet impurity gas levels for the report period.

2.4.2 Pumping, Purification and Analysis Station (PP&A) No. 1

There were no significant revisions or additions to this system during the report period.

2.4.3 Pumping, Purification and Analysis Station (PP&A) No. 2

Loop No. 2 construction and leak checking operations were completed during the report period. The system was filled with helium and subjected to a brief check-out test. The check-out test uncovered some equipment problems, which are now being rectified.

Loop No. 2, capable of operating at any gas composition, will be used in the present program as a backup to Loop No. 1. Gas supply lines are being plumbed to facilitate this, and the capability of supplying controlled-purity helium to all the stands in the laboratory using either loop (presently 15 ST stands cannot be supplied by Loop No. 1 and a different 15 ST stands cannot be supplied by Loop No. 2) will be done when the testing schedule and priorities permit.

2.4.4 Fatigue Testing Gas Supply System

The frame for the controlled-purity helium gas supply console was put in place. Connection of the gas purification train, impurity gas addition train, gauges, flowmeters and other auxiliary lines has been completed. The gas chromatograph and oxygen probe have also been installed, but the gas chromatograph was not operable by the end of the report period. The hygrometers and the gas supply and return lines to and from the retorts have yet to be installed.

TABLE 7

Average Gas Chemistry Change, By Retort,
April to June, 1980

Test Stand No.	Temp. °C.	Avg. Outlet-Inlet Difference, μ -atm				
		<u>H₂</u>	<u>CO</u>	<u>CO₂</u>	<u>CH₄</u>	<u>N₂</u>
ST-1	950	36	1.5	-.19	-5.3	0
ST-2	1050	25	5.3	-.19	-10.2	0
ST-3	1050	9.6	0.9	-.17	-5.5	0
ST-4	1050	20	-2.3	-.19	-10.5	1.4
ST-6	950	4	0	-.14	-6.2	0
ST-9	850	20	9.5	-.04	-2.0	1
ST-10	850	0	-1.3	-.08	-1.0	0
MS-1	850	14	-4.0	-.18	-1.3	.8

2.5 TASK 5 - MECHANICAL PROPERTIES EVALUATION

2.5.1 Test Specimen Machining

Machining of test specimens required for the screening test program was completed by September, 1978.

The nuclear process heat (NPH) alloy specimens for Phase 2 testing have all been machined. These are test specimens from Alloy 800H, Hastelloy X, Inconel 617 and MA-956.

The machining of the direct cycle helium turbine (DCHT) alloys for Phase 2 testing has begun. The alloys are Rene' 100, Alloy 713LC and MA-754. In addition, some specimens are being machined from Alloy 713C for coating with Codep B. These specimens should be received for testing during the next quarterly reporting period, July to September, 1980.

2.5.2 Screening Creep Testing

Multispecimen creep results for the fourth 1000-hour test interval at 750° and 850°C were obtained during the report period. Since several specimens are removed after 3000 hours on test, their replacements have now accrued 1000 hours on test, and those results were also obtained. Tables 8 and 9 give the results of room temperature strain measurements for the stated test conditions for the NPH alloys and the DCHT alloys, respectively. These tables include screening creep data which were previously reported.

No excessive creep strains were noted in this set of data. Comparison can now be made in some cases of the desired versus actual creep strains in some of the tests slated for 6000 hours. Stresses were selected to give 1% total strain in 6000 hours, but the actual stress on many of these specimens is somewhat less than the desired stress due to the limitations of multi-specimen creep testing. (The actual versus desired stresses for all multi-specimen creep testing were reported in the quarterly report for April 1, 1979 to June 30, 1979, report number C00-2975-34.) At 750°C, five NPH alloys,

TABLE 8

SCREENING (MULTISPECIMEN) CREEP RESULTS FOR THE
NUCLEAR PROCESS HEAT ALLOYS

Alloy	Temp °C	Exposure Time-Hrs.	Specimen Number	Stress MPA ksi	% Strain			
					1000 Hrs	2000 Hrs	3000 Hrs	4000 Hrs
Alloy 800H	750	10,000	1000SC3	21 3	.00210	.0127	-.00847	.0116
		3,000	1000SC1	48 7	.386	.910	1.512 comp (a)	
		6,000	1000SC2	48 7	.440	1.100	1.700	2.764
		7,000	1000SC4	48 7	.268			
	850	3,000	1000SC6	7 1	-.00952	-.00318	-.0116 comp.	
		10,000	1000SC7	7 1	-.0275	-.00423	-.0159	.0275
		7,000	1000SC9	7 1	.0222			
		6,000	1000SC5	21 3	.396	.811	1.255	1.593
	950	10,000	1000SC11	.7 .1	-.0310			
		3,000	1000SC10	6 .9	-.0300			
Alloy 800H- Coated	750	3,000	1001SC1	21 3	.0160	.053	.0739 comp.	
		6,000	1001SC2	21 3	.0180	.0666	.0782	.101
		10,000	1001SC3	21 3	.0180	.0380	.0613	.0750
		7,000	1001SC4	21 3	.0422			
	850	3,000	1001SC6	7 1	.00950	.00422	.0264 comp.	
		6,000	1001SC7	7 1	.0105	.0190	.0370	.0444
		10,000	1001SC8	7 1	.00950	.00950	.0264	.0443
		7,000	1001SC9	7 1	.0159			
	950	6,000	1001SC12	.7 .1	-.0180			
		10,000	1001SC13	.7 .1	+.0042			
		3,000	1001SC11	6 .9	.0530			
Incoloy 802	750	10,000	1100SC3	48 7	-.0495	-.0296	-.0138	-.0138
		3,000	1100SC1	76 11	-.0260	.0106	.0233 comp.	
		6,000	1100SC2	76 11	.122			
	850	10,000	1100SC7	21 3	-.0420	-.0349	-.0154	-.0106
		3,000	1100SC5	34 5	-.0220	.0244	.0434 comp.	
		6,000	1100SC6	34 5	.00634			
	950	10,000	1100SC10	6 .9	-.0360			
		6,000	1100SC11	9 1.25	-.0150			
		3,000	1100SC9	14 2	-.0120			

(a) comp. - complete; these specimens have reached their planned exposure time and have been removed from test.

TABLE 8 (continued)

SCREENING (MULTISPECIMEN) CREEP RESULTS FOR THE
NUCLEAR PROCESS HEAT ALLOYS

Alloy	Temp °C	Exposure Time-Hrs.	Specimen Number	Stress MPA ksi	% Strain			
					1000 Hrs	2000 Hrs	3000 Hrs	4000 Hrs
Incoloy 807	750	10,000	1200SC3	21 3	-.0100	.00528	.00740	.0116
		3,000	1200SC1	62 9	.437	1.252	1.845 comp.	
		6,000	1200SC2	62 9	.0740	.174	.250	.365
		7,000	1200SC4	62 9	.134			
	850	10,000	1200SC8	7 1	-.00634	-.00740	.00630	.00316
		3,000	1200SC6	21 3	.0380	.0623	.0876 comp.	
		6,000	1200SC7	28 4	.0580	.0919	.114 comp.	
		7,000	1200SC10	28 4	.0730			
	950	10,000	1200SC13	.7 .1	-.0074			
		6,000	1200SC12	6 .9	.0300			
		3,000	1200SC11	14 2	.590			
Incolov DS	750	3,000	1300SC1	21 3	-.0630	.000	.000 comp.	
		10,000	1300SC2	21 3	.00739	.0159	.0222	.0275
		6,000	1300SC3	21 3	.541			
	850	6,000	1300SC4	7 1	.00212	-.0116	.00630	.0190
		3,000	1300SC5	7 1	-.00635	-.00424	.00740 comp.	
		10,000	1300SC6	7 1	.0106	-.00530	.00950	.0307
		7,000	1300SC8	7 1	.00529			
	950	6,000	1300SC10	.7 .1	.0110			
		10,000	1300SC11	.7 .1	.0150			
		3,000	1300SC9	6 .9	.0310			
HD-556	750	10,000	1400SC3	21 3	-.0240	-.00635	-.00635	.00105
		6,000	1400SC2	62 9	.1215	.159	.192	.206
		3,000	1400SC1	76 11	.200	.268	.293 comp.	
		7,000	1400SC4	76 11	.314			
	850	10,000	1400SC7	21 3	-.0130	-.0116	-.00420	.00845
		6,000	1400SC8	21 3	-.00850	-.0116	-.00420	.00317
		3,000	1400SC31	34 5	.0350	.0749	.113 comp.	
		7,000	1400SC9	34 5	.0929			
	950	10,000	1400SC11	6 .9	-.0510			
		3,000	1400SC12	17.5 2.5	.0700			
		6,000	1400SC13	17.5 2.5	-.0117			

TABLE 8 (continued)

SCREENING (MULTISPECIMEN) CREEP RESULTS FOR THE
NUCLEAR PROCESS HEAT ALLOYS

Alloy	Temp °C	Exposure Time-Hrs.	Specimen Number	Stress		% Strain			
						1000 Hrs	2000 Hrs	3000 Hrs	4000 Hrs
Manaurite 36XS750		10,000	1500SC3	21	3	.0265	.0454	.0676	.0792
		6,000	1500SC1	48	7	.297	.484	.585	.700
		3,000	1500SC2	48	7	.300	.495	.605 comp.	
		7,000	1500SC5	48	7	.536			
	850	10,000	1500SC7	21	3	.0180	.0338	.772	.0877
		6,000	1500SC8	28	4	.0620	.0920	.173	.209
		3,000	1500SC6	34	5	.174	.305	.520 comp.	
		7,000	1500SC9	34	5	.313			
	950	10,000	1500SC12	6	.9	-.0053			
		3,000	1500SC11	14	2	.0529			
HK-40	750	10,000	1700SC3	48	7	.0370	.0510	.0751	.117
		10,000	1700SC4	48	7	.0455	.0850	.0930	.135
		6,000	1700SC1	62	9	.095	.169	.245	Failed
		3,000	1700SC2	62	9	.0645	.144	.212 comp.	
		7,000	1700SC6	62	9	.182			
	850	10,000	1700SC8	21	3	-.0260	-.0095	.106	.243
		6,000	1700SC9	28	4	.0210	.0243	.0876	.113
		3,000	1700SC7	34	5	.0360	.0993	.197 comp.	
		7,000	1700SC10	34	5	.133			
	950	10,000	1700SC13	6	.9	-.0240			
		3,000	1700SC12	14	2	.0140			
IN-519	750	10,000	1800SC3	48	7	.138	.220	.261	.330
		3,000	1800SC2	62	9	.1825	.428	.586 comp.	
		7,000	1800SC5	62	9	.302			
		6,000	1800SC1	76	11	.680	1.490 (b)	---	
		(Replaced SC1 after 2000 hrs)	1800SC30	76	11	.520	.983		
	850	6,000	1800SC7	28	4	-.0180	.0160	.0425	.0468
		10,000	1800SC8	28	4	-.00320	.00212	.0499	.0563
		3,000	1800SC6	34	5	.0340	.0730	.147 comp.	
		7,000	1800SC9	34	5	.292			

(b) replaced do to ding found in gage section.

TABLE 8 (continued)

SCREENING (MULTISPECIMEN) CREEP RESULTS FOR THE
NUCLEAR PROCESS HEAT ALLOYS

Alloy	Temp °C	Exposure Time-Hrs.	Specimen Number	Stress MPa ksi	% Strain			
					1000 Hrs	2000 Hrs	3000 Hrs	4000 Hrs
IN-519	950	10,000	1800SC12	6 .9	-.0446			
		3,000	1800SC11	14 2	.0095			
		6,000	1800SC13	17.5 2.5	.0053			
Hastelloy X	750	10,000	1900SC2	21 3	.0318	.0498	.0413	.0477
		6,000	1900SC3	48 7	.228	.280	.288	.323
		3,000	1900SC1	62 9	.378	.471	.544 comp.	
		7,000	1900SC5	62 9	.476			
	850	10,000	1900SC8	7 1	-.00106	-.00742	.00210	.0180
		6,000	1900SC6	21 3	.126	.140	.192	.210
		3,000	1900SC7	28 4	.238	.340	.498 comp.	
		7,000	1900SC9	28 4	.259			
	950	10,000	1900SC12	.7 .1	-.0079			
		6,000	1900SC11	6 .9	.0550			
		3,000	1900SC10	14 2	1.270			
Inconel 617	750	10,000	1A00SC3	62 9	-.143	-.0148	.0159	.0254
		3,000	1A00SC1	76 11	-.0260	.0150	.0423 comp.	
		6,000	1A00SC2	76 11	-.00750	.0320	.0761	.111
		7,000	1A00SC4	76 11	.00949			
	850	10,000	1A00SC8	28 4	-.0286	-.00636	.00420	.0106
		3,000	1A00SC6	34 5	.000	.0201	.0401 comp.	
		6,000	1A00SC7	34 5	-.0110	.00105	.0200	.0295
		7,000	1A00SC9	34 5	.0138			
	950	10,000	1A00SC11	14 2	.0340			
		6,000	1A00SC12	17.5 2.5	.0700			
		3,000	1A00SC13	17.5 2.5	.0410			
Inconel 617- Coated	750	10,000	1A01SC3	21 3	-.0220	-.0117	.00529	.000
		6,000	1A01SC2	48 7	.0180	-.0110	-.00319	.00424
		3,000	1A01SC1	76 11	-.00530	.0230	.0602 comp.	
		7,000	1A01SC4	76 11	.00848			
	850	10,000	1A01SC8	7 1	-.0243	-.00952	.00210	.00317
		6,000	1A01SC7	21 3	.031	.0592	.121	.181
		3,000	1A01SC6	34 5	1.333	2.523	3.530 comp.	
		7,000	1A01SC9	34 5	1.633			

TABLE 8 (continued)

SCREENING (MULTISPECIMEN) CREEP RESULTS FOR THE
NUCLEAR PROCESS HEAT ALLOYS

<u>Alloy</u>	<u>Temp °C</u>	<u>Exposure Time-Hrs.</u>	<u>Specimen Number</u>	<u>Stress</u>		<u>% Strain</u>			
						<u>1000 Hrs</u>	<u>2000 Hrs</u>	<u>3000 Hrs</u>	<u>4000 Hrs</u>
Inconel 617 coated	950	10,000	1A01SC13	.7	.1	.0160			
		6,000	1A02SC12	9	1.25	.0500			
		3,000	1A01SC11	14	2	.160			
Mo-Re 2	750	10,000	1C00SC3	48	7	.304	.360	.375	.397
		3,000	1C00SC2	76	11	.680	.790	.836 comp.	
		6,000	1C00SC1	76	11	.703	.811	.870	.937
		7,000	1C00SC4	76	11	.844			
	850	10,000	1C00SC11	28	4	.166	.191	.224	.240
		6,000	1C00SC39	34	5	.166	.222	.290	.300
		3,000	1C00SC8	34	5	.198	.236	.299 comp.	
		7,000	1C00SC12	34	5	.398			
	950	10,000	1C00SC14	14	2	.146			
		3,000	1C00SC15	17.5	2.5	.176			
		6,000	1C00SC16	17.5	2.5	.143			
MA-956	850	6,000	1D00SC1	42	6	.0100	.0220	.0235	.00733
		10,000	1D00SC2	42	6	.0290	.0412	.0412	.0324
		3,000	1D00SC3	55	8	.00880	.0293	.0293 comp.	
		7,000	1D00SC5	55	8	.00589			
	950	6,000	1D00SC7	34	5	.0410			
		10,000	1D00SC8	34	5	.0180			

TABLE 9

SCREENING (MULTISPECIMEN) CREEP RESULTS FOR THE
DIRECT CYCLE HELIUM TURBINE ALLOYS

Alloy	Temp °C	Exposure Time-Hrs.	Specimen Number	Stress MPa ksi		% Strain				
						1000 Hrs	2000 Hrs	3000 Hrs	4000 Hrs	
TZM	750	10,000	C01SC16	345	50	.0439	.0548	.0495	.0538	
		6,000	C01SC17	345	50	.0580	.0713	.0799	.0856	
		3,000	C01SC19	345	50	.0410	.0524	.0609 comp. (a)		
		6,000	C01SC20	345	50	.0512				
	850	6,000	C00SC1	152	22	.0225	.0183	.0183	.0254	
		3,000	C00SC2	152	22	.00857	.00714	.00129 comp.		
		10,000	C00SC3	152	22	.00288	.00144	.0072	.0354	
		6,000	C00SC5	152	22	.0170				
	MA-754	850	6,000	B00SC1	110	16	.0660	.0663	.0945	.107
			10,000	B00SC2	110	16	.0660	.0692	.109	.105
3,000			B00SC3	110	16	.0636	.0537	.0876 comp.		
6,000			B00SC5	110	16	.0297				
950		6,000	B00SC6	48	7	.0180				
		10,000	B00SC7	48	7	.0226				
		3,000	B00SC8	48	7	.0085				
MM-0011	750	10,000	100SC1	262	38	.0130	.0356	.0541	.0626	
		10,000	100SC31	262	38	.0100	.0428	.0257	.0399	
		6,000	100SC7	345	50	.0584	.0869	.1367	.160	
		3,000	100SC19	345	50	.0385	.0898	.1012 comp.		
		6,000	100SC32	345	50	.0370	.0754	.0869	.137	
		6,000	100SC8	345	50	.0327				
		850	10,000	100SC5	110	16	.0290	.063	.0845	.107
			6,000	100SC2	152	22	.0650	.0896	.141	.189
	3,000		100SC3	152	22	.0560	.0915	.150 comp.		
	3,000		100SC4	152	22	.0830	.106	.154 comp.		
	6,000		100SC9	152	22	.0429				
	6,000		100SC24	152	22	.0200				
	950	10,000	100SC12	34	5	.0300				
		3,000	100SC11	48	7	.0440				

(a) comp. - complete; these specimens have reached their planned exposure time and have been removed from test.

TABLE 9 (continued)

SCREENING (MULTISPECIMEN) CREEP RESULTS FOR THE
DIRECT CYCLE HELIUM TURBINE ALLOYS

Alloy	Temp °C	Exposure Time-Hrs.	Specimen Number	Stress MPa ksi		% Strain			
						1000 Hrs	2000 Hrs	3000 Hrs	4000 Hrs
2-24 MM-0011DS	750	10,000	120SC1	345	50	.0286	.0414	.0657	.0999
		6,000	120SC7	345	50	.0472	.0429	.0830	.0983
		3,000	120SC19	345	50	.0370	.0654	.0853	comp.
		6,000	120SC32	345	50	.0371			
	850	6,000	120SC3	152	22	.0390	.0859	.129	.163
		3,000	120SC4	152	22	.0370	.0840	.124	comp.
		10,000	120SC23	152	22	.0340	.0840	.116	.173
		6,000	120SC24	152	22	.0200			
	950	6,000	120SC9	48	7	.0540			
		3,000	120SC10	48	7	.0660			
		10,000	120SC11	48	7	.0600			
	750	10,000	200SC1	262	38	.0350	.0709	.123	.162
		10,000	200SC26	262	38	.0440	.0937	.140	.186
		6,000	200SC6	345	50	.275	.408	.479	.580
		3,000	200SC16	345	50	.269	.402	.477	comp.
		6,000	200SC17	345	50	.256			
	850	10,000	200SC4	110	16	.0397	.0694	.108	.147
		6,000	200SC2	152	22	.0426	.172	.240	.334
		3,000	200SC3	152	22	.0990	.168	.263	comp.
		6,000	200SC8	152	22	.0726			
	950	10,000	200SC11	17	2.5	.0240			
		3,000	200SC10	34	5	.0210			
		6,000	200SC9	48	7	.0380			
Rene' 100	750	10,000	300SC32	124	18	-.0140	.00285	.00568	.00568
		10,000	300SC1	262	38	-.00850	-.00143	.00426	.0185
		10,000	300SC31	262	38	-.00570	.00993	.00283	.0185
		6,000	300SC7	345	50	.0640	.114	.161	.209
		3,000	300SC19	345	50	.0497	.108	.128	comp.
		6,000	300SC20	345	50	.0583			

TABLE 9 (Continued)

SCREENING (MULTISPECIMEN) CREEP RESULTS FOR THE
DIRECT CYCLE HELIUM TURBINE ALLOYS

<u>Alloy</u>	<u>Temp °C</u>	<u>Exposure Time-Hrs.</u>	<u>Specimen Number</u>	<u>Stress MPa ksi</u>	<u>% Strain</u>			
					<u>1000 Hrs</u>	<u>2000 Hrs</u>	<u>3000 Hrs</u>	<u>4000 Hrs</u>
Rene' 100	850	10,000	300SC5	110 16	-.00850	-.00570	.0114	.0270
		6,000	300SC2	152 22	.00330	.0600	.0880	.107
		3,000	300SC3	152 22	.0260	.0583	.0853 comp.	
		3,000	300SC4	152 22	.0130	.0600	.104 comp.	
		6,000	300SC9	152 22	.0128			
		6,000	300SC10	152 22	.0327			
	950	10,000	300SC13	17 2.5	-.055			
		3,000	300SC12	34 5	-.0160			
		6,000	300SC11	48 7	.0398			
Alloy 713LC	750	10,000	400SC26	124 18	-.00995	.00284	.00852	.0114
		10,000	400SC27	124 18	-.0140	-.00995	.00853	-.00569
		10,000	400SC1	262 38	.0485	.102	.134	.166
		3,000	400SC16	262 38	.0327	.0668	.102 comp.	
		6,000	400SC17	262 38	.0710			
		6,000	400SC6	345 50	.240	.39	.570	.839
	850	10,000	400SC4	55 8	.0028	.00852	.0185	.0540
		3,000	400SC2	110 16	.0380	.1067	.135 comp.	
		6,000	400SC3	110 16	.0410	.0994	.133	.153
		6,000	400SC5	110 16	.0710			
	950	10,000	400SC11	1.4 .2	-.0340			
		3,000	400SC9	17 2.5	.0410			
		6,000	400SC10	17 2.5	.0130			
IN-738	750	10,000	500SC32	124 18	-.0185	-.0114	-.0128	-.0142
		10,000	500SC1	152 22	-.0130	-.00700	.0127	.0113
		6,000	500SC7	262 38	.0283	.0991	.130	.173
		3,000	500SC19	262 38	.0300	.109	.173 comp.	
		6,000	500SC20	262 38	.0284			

TABLE 9 (Continued)

SCREENING (MULTISPECIMEN) CREEP RESULTS FOR THE
DIRECT CYCLE HELIUM TURBINE ALLOYS

Alloy	Temp °C	Exposure Time-Hrs.	Specimen Number	Stress		% Strain			
						1000 Hrs	2000 Hrs	3000 Hrs	4000 Hrs
IN-738	850	10,000	500SC4	55	8	-.0028	.000	-.00280	-.0170
		3,000	500SC2	110	16	.0430	.0625	.102 comp.	
		6,000	500SC3	110	16	.0430	.0784	.135	
	950	10,000	500SC11	1.4	.2	-.0071			
		6,000	500SC9	17	2.5	.0071			
		3,000	500SC10	17	2.5	-.0300			
	750	10,000	A00SC1	152	22	.0270	.00570	.0327	.0356
		6,000	A00SC6	262	38	.0410	.0641	.114	.172
		3,000	A00SC16	262	38	.0540	.0811	.111 comp.	
		6,000	A00SC17	262	38	.0533			
NX-188	850	10,000	A00SC4	55	8	.0170	-.00285	.0100	.0185
		3,000	A00SC2	110	16	.0310	.0555	.0812 comp.	
		6,000	A00SC3	110	16	.0280	.0313	.0697	
	950	10,000	A00SC10	.7	.1	-.0240			
		3,000	A00SC9	17	2.5	.0014			
	750	10,000	600SC1	152	22	.0930	.1030	.130	.147
		10,000	600SC26	152	22	.102	.119	.126	.141
		6,000	600SC6	262	38	.224	.307	.341	.388
		3,000	600SC16	262	38	.242	.317	.383 comp.	
		6,000	600SC17	262	38	.226			
		10,000	600SC2	69	10	.140	.170	.209	.243
	850	6,000	600SC3	110	16	.184	.236	.236	
		3,000	600SC4	110	16	.200	.254	.315 comp.	
	950	3,000	600SC12	17	2.5	.0990			
		10,000	600SC13	17	2.5	.0980			
		6,000	600SC9	28	4	.117			

Alloy 800H, Incoloy 807, HD-556, IN-519, and Mo-Re2, and one DCHT alloy, Rene' 80 are tested at 100% of the stress to give 1% total creep in 6,000 hours. At 850°C, only Alloys 800H and Udimet 720 are tested at 100% of the desired stress for 1% total creep in 6,000 hours. For these alloys and temperatures, it is possible to review the 4,000 hour-test data with respect to the 6,000-hour target. Alloy 800H, for instance, had already passed the 1% total creep mark for the 6,000 hour specimens between 1,000 and 2,000 hours at 750°C and between 2,000 and 3,000 hours at 850°C. Of the other NPH alloys at 750°C, IN-519 is also creeping faster than expected; creep for Incoloy 807 and HD-556 is lower than expected; and Mo-Re 2 is right on target. Rene '80 at 750°C is also performing as expected, but Udimet 720 at 850°C has a lower creep rate than expected. In all cases, the creep levels fall within available scatter bands and cannot be viewed as excessively high for the high creep rates or low for low creep rates.

An HK-40 sample (1700SC01) in the 750°C multispecimen creep furnace failed at 3,424 hours on test. This sample was being tested at 62 MPa (9 ksi) and was scheduled for 6,000 hours of testing. Based upon original estimates, the (desired) stress of 69 MPa (10 ksi) should have produced 1% total strain in 6,000 hours. The actual stress level employed should have resulted in a rupture life of about 40,000 hours, based on air characterization tests of this heat. The strain measured on the specimen at 3,000 hours was 0.254%. The fracture strain was measured as 1.3%; however, the two pieces did not fit together well, so the actual strain would be lower. Reduction-in-area was approximately 1%.

Post-fracture examination revealed that the fracture was interdendritic. Nothing unusual (such as porosity or non-metallic inclusions) was observed in the appearance of the fracture surface which could have contributed to premature failure. The microstructure was quite similar to that observed for the unstressed specimen exposed for 3,000 hours at 750°C in the same environment, except for a couple of voids, probably creep-induced, along dendrite boundaries near the fracture surface, and perhaps slightly more secondary carbide precipitation.

An additional point of interest is the behavior of certain specimens put on test at the 3,000-hour interval to replace those taken off test. These specimens have now reached 1,000 hours on test and their creep strain can be compared with the 1,000-hour strains measured on the specimens they replaced.

For the DCHT alloys, the strains are similar. On the other hand, several of the replacement NPH specimens show significantly larger creep strains, up to an order of magnitude, when compared to their predecessors. The wrought iron-base alloys show the effect at 750°C, while the effect is prevalent for the cast iron-base alloys at both 750° and 850°C. The strains for the replacement and original wrought nickel-base alloy specimens are very similar, as is the case for the one ODS alloy. For the one nickel-base cast alloy, the strains are similar at 750°C but about a factor of two larger at 850°C. The outstanding feature is that generally the creep strains are as large or larger than the previously tested specimens. The reason for this is not understood and is currently being investigated. When all the results are reviewed, that is the 4,000-hour as well as the 1,000-hour results for both groups of alloys, there is no evidence that the stresses are too high for the replacement specimens. The test atmosphere may be affected to some extent, since roughly two-thirds of the specimens have been on test for over 3,000 hours and no longer react with the atmosphere the way they did when new (i.e. depletion conditions may not be the same for the replacement specimens as for the original specimens).

2.5.3 Phase 2 - Intensive Screening Creep-Rupture Testing

All of the 24 air creep-rupture tests for the NPH alloys have been initiated. The results and test status at the end of the report period are shown in Table 10. The results reveal no significant deviations from expected values, with the exception of the high creep rates shown by two Alloy 800H specimens (1000CR19 and 1000CR09). Five specimens have ruptured so far, all stressed for 1,000-hour rupture lives. All of the rupture lives are within the scatterband of available air test data on the alloys.

2.5.4 Impact Test Results

Figures 2 and 3 show the appearance of the fracture surfaces of the Inconel 617 Charpy V-notch impact specimens tested to date.

The uncoated, as-received specimens show significant plastic deformation before fracture and exhibited a fibrous fracture appearance; the uncoated samples exposed to HTR helium at 750° and 850°C had a completely intergranular fracture (Figure 2).

The coated samples exhibited intergranular fracture surfaces both as coated and after exposure to HTR helium (Figure 3). However, a ductile zone was evident around the rim of each specimen, below the coating. The ductile zone was thinner in the sample exposed at 750°C than in the as-received samples or in the sample exposed at 850°C.

- (a) 1A00IM09
As-Received
 $E_T > 325J$ (240 ft-lb)
- (b) 1A00-IM10
As-Received
 $E_T > 325J$ (240 ft-lb)
- (c) 1A00IM01
Exposed $750^{\circ}C/1279$ hr
 $E_T = 99J$ (73 ft-lb)
- (d) 1A00IM04
Exposed $850^{\circ}C/1104$ hr
 $E_T = 21J$ (15.5 ft-lb)

Figure 2. Fracture Surfaces of Uncoated Inconel 617 Charpy Impact Specimens.

(a) 1A01IM02

As-Coated

$E_T = 181J$ (134 ft-lb)

(b) 1A01IM03

As-Coated

$E_T = 187J$ (138 ft-lb)

(c) 1A01IM01

Exposed 750°C/1279 hr

$E_T = 61J$ (45 ft-lb)

(d) 1A01IM06

Exposed 850°C/1104 hr

$E_T = 111J$ (82 ft-lb)

Figure 3. Fracture Surfaces of Coated Inconel 617 Charpy Impact Specimens.

TABLE 10

PHASE 2 INTENSIVE SCREENING NUCLEAR PROCESS HEAT ALLOY AIR CREEP-RUPTURE TESTS
(STATUS AS OF 6/24/80)

Alloy	Specimen Number	Test Temperature		Test Stress		Desired Rupture Time (hours)	Time To 1% Total Strain (hours)	Hours to Date	Elong. to Date (%)	RA (%)
		(°C)	(°F)	MPa	(ksi)					
Alloy 800H	1000CR08	750	1382	76	11.0	1,000	37.0	688.1 (a)	41.7	48.4
	1000CR19	750	1382	58	8.4	10,000	140.0	2710.6	13.11	
	1000CR09	850	1562	39	5.6	1,000	5.0	527.2	32.59	
	1000CR20	850	1562	27	3.9	10,000	370.0	1990.4	3.36	
	1000CR10	950	1742	18	2.6	1,000	410	1035.0	2.86	
	1000CR21	950	1742	11	1.65	10,000	- - -	2210.8	0.16	
Hastelloy X	1900CR14	850	1562	52	7.5	1,000	265.0	356.9	(1.51) (b)	55.5
	1900CR08	850	1562	36	5.2	10,000	1440.0	2159.1	1.77	
	1900CR15	950	1742	23	3.3	1,000	360.0	1682.5	26.4	
	1900CR09	950	1742	14	2.0	10,000	- - -	2163.9	0.43	
	1900CR16	1050	1922	9	1.3	1,000	57.5	803.3 (a)	50.4	
	1900CR10	1050	1922	4.1	0.6	10,000	1210.0	2786.1	3.03	
Inconel 617	1A00CR14	850	1562	79	1.5	1,000	18.5	596.1 (a)	56.72	64.08
	1A00CR08	850	1562	56	8.2	10,000	1125.0	2183.3	2.58	
	1A00CR15	950	1742	38	5.5	1,000	149.0	1609.3 (a)	34.4	
	1A00CR09	950	1742	25	3.7	10,000	- - -	2329.7	0.51	
	1A00CR16	1050	1922	14	2.1	1,000	900.0	1631.4	2.96	
	1A00CR10	1050	1922	11	1.55	10,000	- - -	2471.1	0.73	
MA-956	1D10CR07	850	1562	79	11.5	1,000	- - -	647.1	0.07	10.7
	1D10CR01	850	1562	76	11.0	10,000	- - -	2182.4	0.09	
	1D10CR08	950	1742	69	10.0	1,000	1300.0	1784.0 (a)	1.05	
	1D10CR02	950	1742	65	9.5	10,000	- - -	2642.4	- 0.01	
	1D10CR09	1050	1922	62	9.0	1,000	- - -	1681.1	-0.02	
	1D10CR03	1050	1922	56	8.2	10,000	- - -	2691.4	-0.08	

(a) Failed

(b) Sample had to be moved to new furnace. Test just restarted. Elongation listed is that at interruption of test.

As discussed in the last Quarterly Report, this ductile zone appears to be due to the presence of the carbide-denuded zone beneath the coating, which was thinner in the sample exposed at 750°C than in the other samples.

The intergranular appearance is apparently due to the precipitation of carbides at grain boundaries during exposure or during the coating cycle. These carbides cause the lower impact values seen for the exposed or coated samples compared to the as-received, uncoated material. The higher impact energy seen for the coated sample exposed at 850°C, as compared to the coated sample exposed at 750°C, may be due to a larger carbide-denuded (ductile) zone present.

2.6 TASK 6 & 7 - THERMAL STABILITY EVALUATION AND PRIMARY COOLANT CORROSION RESISTANCE EVALUATION

Reported is the weight change information and metallographic results obtained for six NPH alloys after 3,000 hours at 750°C. Due to an overtemperature problem at 2853 hours in Zones 1 and 2 (top two of five heating zones) of the furnace only Inconel 617, Inconel 618E, HK-40, Manaurite 36XS, Manaurite 900 and Mo-Re 2 specimens can be considered typical of 3,000 hours exposure at 750°C. Structural stability exposures for 3,000 hours at 750°C will be repeated for the test of the alloys.

2.6.1 Weight Change Results

The 750°C controlled-purity helium weight change results obtained from unstressed structural stability specimens exposed for 3,000 hours have been analyzed during the past quarter. In addition, helium weight change data for specimens exposed at 950°C for 2,000 hours also have been analyzed. The 950°C furnace (A/C-2), was stopped at 2,000 hours to allow the 1,000 hour samples to be loaded.

The weight change results obtained to date are presented in Table 11 with the test time and weight change per unit surface area shown, along with the alloy and specimen number.

Plots for weight change versus aging time at 750°C for wrought iron-base, wrought nickel-base, centrifugally cast, and oxide dispersion strengthened alloys are shown in Figures 4 to 9, respectively. Each curve represents the data from different samples aged for 1,000, 1,279, 1,579 (average of two samples) and 3,000 hours (for six alloys).

TABLE 11

WEIGHT CHANGE RESULTS OF SPECIMENS
AGED IN CONTROLLED-PURITY HELIUM

<u>Alloy</u>	<u>Time (hr)</u>	750°C		Test Temperature 850°C		950°C	
		<u>Specimen Number</u>	<u>Wt. Gain (mg/cm²)</u>	<u>Specimen Number</u>	<u>Wt. Gain (mg/cm²)</u>	<u>Specimen Number</u>	<u>Wt. Gain (mg/cm²)</u>
Alloy 800H	1000	1000CO01	0.618	1000CO05	0.892		
	1104			1000CO07	0.785		
	1104			1000CO08	0.703		
	1279	1000CO02	0.634				
	1575	1000CO03	0.662				
	1575	1000CO04	0.615				
	2000					1000CO18	0.802
Alloy 800H-coated	1000	1001CO01	0.379	1001CO05	0.158		
	1104			1001CO07	0.161		
	1104			1001CO08	0.110		
	1279	1001CO02	0.309				
	1575	1001CO03	0.302				
	1575	1001CO04	0.299				
	2000					1001CO17	0.141
Incoloy 802	1000	1100CO01	0.674	1100CO05	1.036		
	1104			1100CO07	1.065		
	1104			1100CO08	0.753		
	1279	1100CO02	0.713				
	1575	1100CO03	0.715				
	1575	1100CO04	0.683				
	2000					1100CO18	0.696
Incoloy 807	1000	1200CO01	0.489	1200CO05	-0.048		
	1104			1200CO07	1.050		
	1104			1200CO08	0.605		
	1279	1200CO02	0.523				
	1575	1200CO03	0.408				
	1575	1200CO04	0.533				
	2000					1200CO18	0.433

TABLE 11 (continued)

<u>Alloy</u>	<u>Time (hr)</u>	750°C		Test Temperature 850°C		950°C	
		<u>Specimen Number</u>	<u>Wt. Gain (mg/cm²)</u>	<u>Specimen Number</u>	<u>Wt. Gain (mg/cm²)</u>	<u>Specimen Number</u>	<u>Wt. Gain (mg/cm²)</u>
Incoloy DS	1000	1300CO01	0.340	1300CO05	-0.217		
	1104			1300CO07	-0.042		
	1104			1300CO08	0.102		
	1279	1300CO02	0.221				
	1575	1300CO03	0.251				
	1575	1300CO04	0.374				
	2000					1300CO18	0.110
HD-556	1000	1400CO01	0.491	1400CO05	0.591		
	1104			1400CO07	0.605		
	1104			1400CO08	0.460		
	1279	1400CO02	0.389				
	1575	1400CO03	0.476				
	1575	1400CO04	0.401				
	2000					1400CO18	0.377
HK-40	1000	1700CO01	0.284	1700CO05	-0.501		
	1104			1700CO07	-0.268		
	1104			1700CO08	-0.428		
	1279	1700CO02	0.299				
	1575	1700CO03	0.330				
	1575	1700CO04	0.296				
	2000					1700CO18	-0.211
	3000	1700CO17	-0.069				
IN-519	1000	1800CO01	0.341	1800CO05	0.127		
	1104			1800CO07	0.165		
	1104			1800CO08	0.333		
	1279	1800CO02	0.328				
	1575	1800CO03	0.285				
	1575	1800CO04	0.340				
	2000					1800CO18	0.634

TABLE 11 (continued)

Alloy	Time (hr)	750°C		Test Temperature 850°C		950°C	
		Specimen Number	Wt. Gain (mg/cm ²)	Specimen Number	Wt. Gain (mg/cm ²)	Specimen Number	Wt. Gain (mg/cm ²)
Manaurite 900	1000	1600CO01	0.362	1600CO05	0.296		
	1104			1600CO07	0.270		
	1104			1600CO08	0.233		
	1279	1600CO02	0.348				
	1575	1600CO03	0.355				
	1575	1600CO04	0.341				
	2000					1600CO18	0.844
	3000	1600CO17	0.168				
Manaurite 36XS	1000	1500CO01	0.370	1500CO05	-1.023		
	1104			1500CO07	-1.213		
	1104			1500CO08	-1.172		
	1279	1500CO25	0.377				
	1575	1500CO03	0.479				
	1575	1500CO04	0.290				
	2000					1500CO18	0.039
	3000	1500CO17	0.196				
Inconel 617	1000	1A00CO01	0.450	1A00CO05	0.564		
	1104			1A00CO07	0.579		
	1104			1A00CO08	0.737		
	1279	1A00CO02	0.467				
	1575	1A00CO03	0.549				
	1575	1A00CO04	0.510				
	2000					1A00CO18	1.128
	3000	1A00CO17	0.550				
Inconel 617-coated	1000	1A01CO17	0.268	1A00CO05	0.384		
	1104			1A00CO07	0.068		
	1104			1A00CO08	0.087		
	1279	1A00CO02	0.251				
	1575	1A00CO03	0.214				
	1575	1A00CO04	0.228				
	2000						

TABLE 11. (continued)

Alloy	Time (hr)	750°C		Test Temperature 850°C		950°C	
		Specimen Number	Wt. Gain (mg/cm ²)	Specimen Number	Wt. Gain (mg/cm ²)	Specimen Number	Wt. Gain (mg/cm ²)
Inconel 618E	1000	1B00CO01	0.389	1B00CO05	0.586		
	1104			1B00CO07	0.549		
	1104			1B00CO08	0.537		
	1279	1B00CO02	0.467				
	1575	1B00CO03	0.499				
	1575	1B00CO04	0.516				
	2000					1B00CO18	0.688
	3000	1B00CO17	0.413				
Hastelloy X	1000	1900CO01	0.501	1900CO05	0.664		
	1104			1900CO07	1.228		
	1104			1900CO08	0.414		
	1279	1900CO02	0.409				
	1575	1900CO03	0.601				
	1575	1900CO04	0.387				
	2000					1900CO18	0.899
Mo-Re 2	1000	1C00CO01	0.384	1C00CO05	0.700		
	1104			1C00CO07	0.948		
	1104			1C00CO08	0.819		
	1279	1C00CO02	0.408				
	1575	1C00CO03	0.469				
	1575	1C00CO04	0.471				
	2000					1C00CO18	1.542
	3000	1C00CO17	-0.330				
MA-956	1000	1D00CO01	0.212	1D00CO05	0.253		
	1104			1D00CO07	0.138		
	1104			1D00CO08	0.058		
	1279	1D00CO02	0.238				
	1575	1D00CO03	0.217				
	1575	1D00CO04	---				
	2000					1D00CO18	0.263

The 750°C data for the wrought iron-base alloys (Figure 4) indicate a sizeable weight gain for Incoloy alloy 807. The other four alloys and the single coated alloy generally fall in a band between 0.25-0.75 mg/cm² weight gain. The coating appears to have reduced weight gain; after about 1,600 hour exposure, Alloy 800H (uncoated) had gained about twice the weight of the coated modification.

Somewhat similar results are in evidence for the wrought nickel-base materials (Figure 5) where the weight gain is between 0.2-0.6 mg/cm². Again, the coated material gained weight at a slower rate than the uncoated alloy.

Distinct evidence of spallation was seen for at least two of the centrifugally cast alloys, HK-40 and Mo-Re 2, as indicated by the plot shown in Figure 6. Both of these alloys revealed a negative weight change after 3,000 hours of exposure.

Low weight gains (between 0.20-0.35 mg/cm²) are revealed by the oxide dispersion strengthened alloys, as shown by the plot in Figure 7.

Figure 8 and 9 compare the 3,000 hour results of weight change for Inconel 617 and three centrifugally cast alloys studied by both General Atomic Company (GA) (1) and GE. Inspection of these plots and the comparison plots of 1,000-hour results in Reference 2 reveal somewhat larger differences in the results after the longer time exposure. It is of interest to note, however, that the weight change of Inconel 617 as determined by GE is usually greater than that reported by GA. This may be due to the somewhat different environments employed by the two laboratories or to variations in the chemistry of the different heats of Inconel 617 used by the two laboratories.

2.6.2 Visual Examination of Aged Specimens

In order to characterize the undamaged texture and color of the surface scale that developed during controlled-purity helium exposure, the NPH corrosion pins removed from 750°C test were visually examined. These results are summarized in Table 12. Screening creep specimens tested at 750°C and 850°C were also visually characterized just prior to or just after strain measurements after 3,000 hours stressed exposure. Visual examination of the 950°C exposed specimens was also carried out after 1,000 hour stressed exposure. This information is tabulated for reference in Tables 13, 14 and 15.

Figure 4. Weight Change of Wrought Iron-Base Alloys Aged Unstressed at 750°C in Controlled Purity Helium.

Figure 5. Weight Change of Wrought Nickel-Base Alloys Aged Unstressed at 750°C in Controlled Purity Helium.

Figure 6. Weight Change of Centrifugally Cast Alloys Aged Unstressed at 750°C in Controlled Purity Helium.

Figure 7. Weight Change of Oxide Dispersion Strengthened Alloys Aged Unstressed at 750°C in Controlled Purity Helium.

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Figure 8. 3000 Hr. Weight Change Results for Inconel 617 Aged Unstressed in Controlled Purity Helium.

Figure 9. 3000 Hr. Weight Change Results for Selected Centrifugally Cast Alloys Aged Unstressed in Controlled Purity Helium.

TABLE 12

RESULTS FROM VISUAL EXAMINATION OF STRUCTURAL STABILITY SPECIMENS
AFTER EXPOSURE TO 750C CONTROLLED-PURITY HELIUM

<u>Alloy</u>	<u>Specimen Number</u>	<u>1000-Hr Exposure Surface Appearance</u>	<u>Specimen Number</u>	<u>3000 Hr-Exposure Surface Appearance</u>
Alloy 800H	1000CO10	Uniform gray-purple	1000CO17	Uniform dark gray
Alloy 800H	1001CO01	Uniform, matte gray-purple	-----	-----
Incoloy 802	1100CO01	Uniform dark gray-purple	1100CO17	Uniform dark gray
Incoloy 807	1200CO01	Medium gray-purple with area of light gray (possible spalling)	1200CO17	Uniform dark gray
Incoloy DS	1300CO01	Gray-purple with specks of light gray (spalling)	1300CO17	Gray with specks of light gray (possible spalling)
HD-556	1400CO01	Uniform dark gray	1400CO17	Uniform dark gray
HK-40	1700CO01	Gray with specks of light gray (spalling)	1700CO17	Gray-green with specks of light gray (spalling)
IN-519	1800CO01	Gray-green with lustrous specks or streaks (spalling)	-----	-----
Manaurite 900	1600CO01	Gray with random light gray specks (possible spalling)	1600CO17	Purple-gray with random areas of green (possible spalling)

TABLE 12 (Con't)

<u>Alloy</u>	<u>Specimen Number</u>	<u>1000 Hr Exposure Surface Appearance</u>	<u>Specimen Number</u>	<u>3000 Hr Exposure Surface Appearance</u>
Manaurite 36XS	1500CO01	Gray with random specks of light gray (spalling)	1500CO17	Purple-gray with random areas of green (spalling)
Inconel 617	1A00CO01	Uniform gray-purple	1A00CO17	Very dark gray
Inconel 617 Coated	1A01CO17	Gray with areas of purple and areas of green	-----	-----
Inconel 618E	1B00CO01	Uniform semi-lustrous gray-purple	1B00CO17	Uniform semi-lustrous dark gray
Hastelloy X	1900CO01	Uniform medium gray	1900CO17	Uniform dark gray
Mo-Re 2	1C00CO01	Semi-lustrous gray with purple green tint	1C00CO17	Gray with areas of purple and green (spalling)
MA-956	1D00CO01	Lustrous, areas of purple and areas of green	1D00CO17	Lustrous, purple-green

TABLE 13

RESULTS FROM VISUAL EXAMINATION OF SCREENING CREEP SPECIMENS
AFTER EXPOSURE TO 750C CONTROLLED-PURITY HELIUM

<u>Alloy</u>	<u>Specimen Number</u>	<u>String.</u>	<u>Pos.</u>	<u>Stress (MPa)</u>	<u>1000-Hr</u>	<u>Time Exposed 2000-Hr</u>	<u>3000-Hr</u>
Incoloy 802	1100SC01	2	5	75.8	dark gray	dark gray	dark gray
HD-556	1400SC01	2	6	75.8	gray	dark gray	dark gray
Inconel 617	1A00SC01	2	7	75.8	gray	dark gray	dark gray
Inconel 617 coated	1A01SC01	2	8	75.8	light gray with purple & green undertones	light gray with purple & green undertones	light gray with purple & green undertones
Inconel 617	1A00SC02	2	9	75.8	gray	dark gray	dark gray
2-46 IN-519	1800SC 30	2	10	75.8	black with areas of light gray (spalling)		
Mo-Re 2	1C00SC07	2	11	75.8	gray with green undertones	gray green	dark green gray
Mo-Re 2	1C00SC01	2	12	75.8	dark gray with green undertones	gray green	dark green gray
Alloy 800H	1000SC01	3	1	48.3	dark gray	dark gray	dark gray
Alloy 800H	1000SC02	3	2	48.3	dark gray	dark gray	dark gray
Incoloy 802	1100SC03	3	3	48.3	gray purple	gray purple	dark gray
Hastelloy X	1900SC03	3	4	48.3	dark gray	dark gray	dark gray
Inconel 617 coated	1A01SC02	3	5	48.3	light gray with under- tones of blue, gold & purple	gray with purple, green blue undertones	gray with purple and blue tint

TABLE 13 (Cont)

<u>Alloy</u>	<u>Specimen Number</u>	<u>String.</u>	<u>Pos.</u>	<u>Stress (MPa)</u>	<u>1000-Hr</u>	<u>Time Exposed 2000-Hr</u>	<u>3000-Hr</u>
Manaurite 36XS	1500SC01	3	6	48.3	gray with light gray specks (possible spalling)	dark gray	dark gray
Manaurite 36XS	1500SC02	3	7	48.3	gray with undertones of purple	medium gray	dark gray
HK-40	1700SC03	3	8	48.3	med. gray with specks of light gray (possible spalling)	gray with area of green (possible spalling)	dark gray with areas of gray (possible spalling)
HK-40	1700SC04	3	9	48.3	gray with areas of light gray	dark gray with areas of gray green	dark gray with areas of gray green
IN-519	1800SC03	3	10	48.3	gray green (possible areas of spalling)	gray green (possible areas of spalling)	green with areas of light gray (spalling)
Mo-Re 2	1C00SC03	3	11	48.3	dark gray with green undertones	dark gray	dark gray with green undertones
Incoloy 807	1200SC01	5	5	62.0	dark gray	dark gray	dark gray
Incoloy 807	1200SC02	5	6	62.0	medium gray	dark gray	dark gray
HD-556	1400SC02	5	7	62.0	medium gray	medium gray	dark gray
Hastelloy X	1900SC01	5	8	62.0	dark gray	dark gray	dark gray
Inconel 617	1A00SC03	5	9	62.0	dark gray	dark gray	dark gray
HK-40	1700SC01	5	10	62.0	gray-green with areas of light gray-green	gray-green with areas of light gray-green	gray-green with areas of light gray-green

TABLE 13 (Con't)

<u>Alloy</u>	<u>Specimen Number</u>	<u>String.</u>	<u>Pos.</u>	<u>Stress (MPa)</u>	<u>1000-Hr</u>	<u>Time Exposed 2000-Hr</u>	<u>3000-Hr</u>
HK-40	1700SC02	5	11	62.0	light gray-green	light gray-green	light gray-green with areas of green
IN-519	1800SC02	5	12	62.0	gray-green with large area light gray	gray-green with areas or specks of light gray	green with areas or specks of light gray (possible spall)
Alloy 800H coated	1001SC01	6	1	20.7	dark gray - purple	dark gray	dark gray
Alloy 800H coated	1001SC02	6	2	20.7	dark gray - green	dark gray	dark gray
Alloy 800H	1000SC03	6	3	20.7	dark gray	dark gray	dark gray
Alloy 800H coated	1001SC03	6	4	20.7	dark gray - purple	dark gray	dark gray
Incoloy 807	1200SC03	6	5	20.7	dark gray - purple	dark gray	dark gray
Incoloy DS	1300SC01	6	6	20.7	gray	gray	gray
Incoloy DS	1300SC02	6	7	20.7	gray	gray	gray
HD-556	1400SC03	6	8	20.7	dark gray	dark gray	dark gray
Hastelloy X	1900SC02	6	9	20.7	dark gray	dark gray	dark gray
Inconel 617 coated	1A01SC03	6	10	20.7	light gray with purple undertones	light gray	light gray with purple areas at shoulder
Manaurite 36XS	1500SC03	6	11	20.7	light gray - green	light gray	light gray-green

TABLE 14

RESULTS FROM VISUAL EXAMINATION OF SCREENING CREEP SPECIMENS
AFTER REMOVAL FROM 850C CONTROLLED-PURITY HELIUM EXPOSURE

<u>Alloy</u>	<u>Specimen Number</u>	<u>String.</u>	<u>Pos.</u>	<u>Stress (MPa)</u>	<u>1000-Hr</u>	<u>Time Exposed 2000-Hr</u>	<u>3000-Hr</u>
Incoloy 802	1100SC05	2	2	34.5	medium gray	medium gray	medium gray
HD-556	1400SC31	2	3	34.5	light gray with green & purple undertones	light gray with purple undertones	light gray
Inconel 617	1A00SC06	2	4	34.5	medium gray	light gray	silver
Inconel 617 coated	1A01SC06	2	5	34.5	gray with undertones of purple	dark gray	dark gray
Inconel 617	1A00SC07	2	6	34.5	medium gray	light gray	silver
Manaurite 36XS	1500SC06	2	7	34.5	medium gray	gray with specks of light gray (possible spalling)	gray with specks of light gray (possible spalling)
HK-40	1700SC07	2	8	34.5	light gray	gray with purple undertones	light gray
IN-519	1800SC06	2	9	34.5	light gray	medium gray	light gray
Mo-Re 2	1C00SC08	2	10	34.5	gray with green undertones	gray with green undertones	green
Mo-Re 2	1C00SC39	2	11	34.5	dark gray	dark gray with green undertones	dark gray green
MA-956	1D00SC01	3	1	41.4	gray with blue purple undertones	dark gray	dark gray
MA-956	1D00SC02	3	2	41.4	gray with blue purple undertones	dark gray	dark gray

TABLE 14 (Con't)

<u>Alloy</u>	<u>Specimen Number</u>	<u>String.</u>	<u>Pos.</u>	<u>Stress (MPa)</u>	<u>1000-Hr</u>	<u>Time Exposed 2000-Hr</u>	<u>3000-Hr</u>
Alloy 800H	1000SC05	3	3	20.7	medium gray	medium gray	medium gray
Incoloy 802	1100SC07	3	4	20.7	medium gray	gray with areas of light gray	gray with areas of light gray
Incoloy 807	1200SC06	3	5	20.7	medium gray	medium gray	medium gray
HD-556	1400SC07	3	6	20.7	light gray-metallic	light gray-metallic	light gray-metallic
HD-556	1400SC08	3	7	20.7	light gray-metallic	light gray-metallic	light gray-metallic
Hastelloy X	1900SC06	3	8	20.7	light gray	light gray	light gray
2-50 Inconel 617 coated	1A01SC07	3	9	20.7	light gray with blue & purple undertones	gray with purple undertones	dark gray
Manaurite 36XS	1500SC07	3	10	20.7	medium gray	medium gray	gray green
HK-40	1700SC08	3	11	20.7	light gray	light gray	light gray-green
MA-956	1D00SC03	5	1	55.2	medium gray with purple green undertones	dark gray	dark gray
Incoloy 807	1200SC07	5	5	27.6	medium gray	medium gray	medium gray
Hastelloy X	1900SC07	5	6	27.6	light gray	light gray	light gray
Inconel 617	1A00SC08	5	7	27.6	light gray	light gray	silver

TABLE 14 (Con't)

<u>Alloy</u>	<u>Specimen Number</u>	<u>String.</u>	<u>Pos.</u>	<u>Stress (MPa)</u>	<u>1000-Hr</u>	<u>Time Exposed 2000-Hr</u>	<u>3000-Hr</u>
Manaurite 36XS	1500SC08	5	8	27.6	medium gray	gray with specks of light gray (possible spalling)	gray with specks of light gray (possible spalling)
HK-40	1700SC09	5	9	27.6	light gray	light gray	light gray
IN-519	1800SC07	5	10	27.6	medium gray	medium gray	light gray
IN-519	1800SC08	5	11	27.6	medium gray	medium gray	light gray
Mo-Re 2	1C00SC11	5	12	27.6	dark gray with green undertones	dark gray with green undertones	dark gray with green undertones
2-51	Alloy 800H	1000SC06	6	1	6.9	medium gray	medium gray
	Alloy 800H coated	1001SC06	6	2	6.9	dark gray	dark gray
	Alloy 800H coated	1001SC07	6	3	6.9	dark gray	dark gray
	Alloy 800H	1000SC07	6	4	6.9	medium gray	medium gray
	Alloy 800H coated	1001SC08	6	5	6.9	dark gray	dark gray
	Incoloy 807	1200SC08	6	6	6.9	medium gray	medium gray
Incoloy DS	1300SC04	6	7	6.9	light gray	light gray	light gray

TABLE 14 (Con't)

<u>Alloy</u>	<u>Specimen Number</u>	<u>String.</u>	<u>Pos.</u>	<u>Stress (MPa)</u>	<u>1000-Hr</u>	<u>Time Exposed 2000-Hr</u>	<u>3000-Hr</u>
Incoloy DS	1300SC05	6	8	6.9	light gray	light gray	light gray
Incoloy DS	1300SC06	6	9	6.9	light gray	light gray	light gray
Hastelloy X	1900SC08	6	10	6.9	medium gray	light gray	light gray green
Inconel 617 coated	1A01SC08	6	11	6.9	medium gray with areas of dark gray	gray with areas of dark gray	dark gray

TABLE 15

RESULTS FROM VISUAL EXAMINATION OF SCREENING CREEP SPECIMENS
AFTER REMOVAL FROM 950C CONTROLLED-PURITY HELIUM EXPOSURE

<u>Alloy</u>	<u>Specimen Number</u>	<u>String.</u>	<u>Pos.</u>	<u>Stress (MPa)</u>	<u>1000-Hr</u>	<u>Time Exposed 2000-Hr</u>	<u>3000-Hr</u>
MA-956	ID00SC06	1	7	48.3	dark gray with gold undertones		
Incoloy 802	1100SC09	2	2	13.8	gray with fine uniform speckling		
Incoloy 807	1200SC11	2	3	13.8	uniform gray		
Hastelloy X	1900SC10	2	4	13.8	light gray with areas of gold and blue		
2-53 Inconel 617 coated	1A01SC11	2	5	13.8	dark gray with gold tint at shoulders		
	1A00SC11	2	6	13.8	uniform gray		
Manaurite 36XS	1500SC11	2	7	13.8	light gray		
HK-40	1700SC12	2	8	13.8	light gray		
IN-519	1800SC11	2	9	13.8	light gray		
Mo-Re 2	1C00SC14	2	10	13.8	light gray green		
Alloy 800H coated	1001SC11	3	1	6.2	black		
Alloy 800H	1000SC10	3	2	6.2	gray		
Incoloy 802	1100SC10	3	3	6.2	gray		
Incoloy 807	1200SC12	3	4	6.2	gray		
Incoloy DS	1300SC09	3	5	6.2	light gray		

TABLE 15 (Con't)

<u>Alloy</u>	<u>Specimen Number</u>	<u>String.</u>	<u>Pos.</u>	<u>Stress (MPa)</u>	<u>1000-Hr</u>	<u>Time Exposed 2000-Hr</u>	<u>3000-Hr</u>
HD-556	1400SC11	3	6	6.2	light gray with blue tint		
Hastelloy X	1900SC11	3	7	6.2	light gray with gold tint		
Manaurite 36XS	1500SC12	3	8	6.2	light gray with gray area (possible spall)		
HK-40	1700SC13	3	9	6.2	light gray		
IN-519	1800SC12	3	10	6.2	light gray		
MA-956	1D00SC07	4	1	34.5	dark gray with gold undertones		
2-54 MA-956	1D00SC08	4	2	34.5	dark gray with gold undertones		
HD-556	1400SC12	4	6	17.2	light gray with blue/gold tint		
Inconel 617	1A00SC12	4	7	17.2	gray		
Inconel 617	1A00SC13	4	8	17.2	gray		
IN-519	1800SC13	4	9	17.2	light gray		
Mo-Re 2	1C00SC15	4	10	17.2	light gray		
Mo-Re 2	1C00SC16	4	11	17.2	light green gray		
Incoloy 802	1100SC11	5	10	8.6	gray with fine uniform speckling		
HD-556	1400SC13	5	11	8.6	gray		

TABLE 15 (Con't)

<u>Alloy</u>	<u>Specimen Number</u>	<u>String.</u>	<u>Pos.</u>	<u>Stress (MPa)</u>	<u>1000-Hr</u>	<u>Time Exposed 2000-Hr</u>	<u>3000-Hr</u>
Inconel 617 coated	1A01SC12	5	12	8.6	dark gray with gold tint at shoulders		
Alloy 800H coated	1001SC12	6	4	0.69	black		
Alloy 800H	1000SC11	6	5	0.69	light gray		
Alloy 800H coated	1001SC13	6	6	0.69	black		
Incoloy 807	1200SC13	6	7	0.69	gray		
Incoloy DS	1300SC10	6	8	0.69	light gray		
Incoloy DS	1300SC11	6	9	0.69	light gray		
Hastelloy X	1900SC12	6	10	0.69	light gray with blue/ gold tint		
Incoloy 617 coated	1A01SC13	6	11	0.69	black with gold undertones		

Generally, the wrought alloys revealed medium to dark gray scales with blue or purple undertones similar to the wrought alloys exposed in controlled-purity helium at 750°C for 1,000 hours. None of the wrought alloys showed evidence of spallation except Incoloy DS.

In contrast, the entire group of centrifugally cast alloys showed some evidence of scale spallation. This is somewhat similar to the 750°C/1,000 hour results, where each of the centrifugally cast alloys, except Mo-Re 2, exhibited evidence of spallation. In a few cases, large areas appeared to have spalled, especially for the two Manaurite alloys and Mo-Re 2. These observations are in agreement with the weight change results in that Mo-Re 2 and HK-40 revealed negative weight changes indicating scale spallation.

The appearance of the iron-base ODS alloy was little changed from the 1,000 hour exposure and again looked rather lustrous.

2.6.3 Metallographic Results

Metallography has been completed on the six structural stability pins exposed for 3,000 hours at 750°C. Specimens were prepared and examined as discussed in Reference 2. The results of the metallographic analysis, including comparative evaluations of the internal structure of as-received samples are presented in the following subsections. Reference is often made to the structure aged for 1,000 hours at 750°C; these results can be found in Reference 2.

The results of surface corrosion measurements and microstructural analysis for each of the six alloys are summarized in Table 16. The table includes measurements of scale thickness, oxide penetration, alloy depletion, and heavy carbide precipitation. In reviewing the photomicrographs showing the surface features of exposed samples, note that the white layer above the scale is electroplated nickel in all cases.

2.6.3.1 Wrought Nickel-Base Austenitic Alloys

2.6.3.1.1 Inconel 617

Representative optical photomicrographs of the internal microstructure of Inconel 617 after 3,000 hours exposure to controlled-purity helium at 750°C are shown in Figure 10. The microstructure was somewhat similar to that observed

TABLE 16
SUMMARY OF SURFACE CORROSION MEASUREMENTS AND INTERNAL MICROSTRUCTURAL ANALYSIS FOR
ALLOYS AGED UNSTRESSED IN CONTROLLED-PURITY HELIUM FOR 3000 HOURS

Alloy/ Specimen No.	Condition (Exposure Temperature)	Typical Corrosion Depth (μm (in))				Summary of Internal Structure
		Scale Thickness	Internal Oxidation	Alloy Depletion	Heavy Carbide Precipitation (Carburization)	
Inconel 617	As-Received	--	--	--	--	Ni-rich γ -matrix (austenite) containing a mixture of coarse and fine carbides. The carbides were dispersed both intra- and intergranularly within the structure.
Inconel 617 1A00CO17	750°C (1382°F)	$2-3$ (8×10^{-5} - 1×10^{-4})	$9-11$ ($3.5-4.3 \times 10^{-4}$)	$20-24$ ($7.9-9.4 \times 10^{-4}$)	$48-60$ ($1.9-2.4 \times 10^{-3}$)	Ni-rich γ -matrix (austenite) containing a mixture of primary carbides and intermediate-to-fine precipitated carbides dispersed both intra- and intergranularly on twin boundaries. Preferential precipitation of carbides along certain crystallographic directions was evident.
Inconel 618E	As-Received	--	--	--	--	Ni-rich γ -matrix (austenite) containing a mixture of coarse and fine carbides dispersed both intra- and intergranularly.
Inconel 618E 1800CO17	750°C (1382°F)	$2-3$ (8×10^{-5} - 1×10^{-4})	1 (4×10^{-5})	$12-16$ ($4.7-6.3 \times 10^{-4}$)	$36-44$ ($1.4-1.7 \times 10^{-3}$)	Ni-rich γ -matrix (austenite) containing a mixture of coarse and fine carbides dispersed both intra- and intergranularly.
HK-40	As-Cast	--	--	--	--	Fe-rich γ -matrix (austenite) containing an austenite-carbide eutectic. The eutectic was dispersed at the dendrite boundaries or inter-dendritically as a lace-like or script-like network or as a grouping of blocky particles.
HK-40 1700CO17	750°C (1382°F)	$2-3$ (8×10^{-5} - 1×10^{-5})	--	8 (3×10^{-4})	--	Constituents same as for as-cast condition except microstructure contains large amounts of fine secondary (precipitated) carbides in intradendritic regions.

TABLE 16

Typical Corrosion Depth
(μm (in))

Alloy/ Specimen No.	Condition (Exposure Temperature)	Scale Thickness	Internal Oxidation	Alloy Depletion	Heavy Carbide Precipitation (Carburization)	Summary of Internal Structure
Manaurite 36XS	As-Cast	--	--	--	--	Fe-rich γ -matrix (austenite) containing an almost continuous austenite-carbide eutectic at the dendrite boundaries and in interdendritic regions. The eutectic carbides generally appear as a lace-like network or as groupings of blocky carbide particles.
Manaurite 36XS 1500CO17	750°C (1382°F)	$2-3$ (8×10^{-5} - 1×10^{-4})	1 (4×10^{-5})	$6-10$ ($2.4-3.9 \times 10^{-4}$)	$10-14$ ($3.9 \times 5.5 \times 10^{-5}$)	Constituents same as for as-cast condition except microstructure contains copious amounts of carbides precipitated mainly in the intra-dendritic regions near eutectic carbides. More abundant and somewhat larger acicular particles relative to 750°C/1000 hrs structure.
2-58 Manaurite 900	As-Cast	--	--	--	--	Fe-rich γ -matrix (austenite) containing an austenite carbide eutectic. The eutectic carbides, present at dendrite boundaries and interdendritically, generally appear as a lace-like network.
Manaurite 900 1600SC16	750°C (1382°F)	2 (8×10^{-5})	--	$8-10$ ($3.1-3.9 \times 10^{-4}$)	$14-28$ (5.5×10^{-4} - 1.1×10^{-3})	Constituents same as for as-cast condition except microstructure contains fine secondary (precipitated) carbides in inter and intradendritic regions.
Mo-Re 2	As-Cast	--	--	--	--	Ni-rich γ -matrix (austenite) containing an austenite carbide eutectic at the dendrite boundaries and in interdendritic regions. Eutectic carbides generally appeared as lace-like or script-type carbides.
Mo-Re 2 1700CO17	750°C (1382°F)	$5-7$ ($2-3 \times 10^{-4}$)	$5-7$ ($2-3 \times 10^{-4}$)	$5-7$ ($2-3 \times 10^{-4}$)	$15-18$ ($5.9-7.1 \times 10^{-4}$)	Constituents same as for as-cast condition except microstructure contains a large amount of secondary carbides. Coalescence of eutectic carbide to a grouping of globular carbide particles.

after 1,000 hours aging at 750°C and consisted of a mixture of primary carbides like those observed in the as-received alloy, and intermediate-to-fine precipitated carbides appearing both intra- and intergranularly and on twin boundaries. Again, precipitation along certain crystallographic directions was evident; however, the grain boundaries revealed an almost continuous film of intermediate-sized globular particles rather than the finer carbides observed after 1,000-hour exposure at 750°C.

The surface microstructure of Inconel 617 after 3,000 hours at 750°C is shown in Figure 11 and was characterized by a 2-3 µm thick, continuous gray scale containing widely scattered, small white particles. Beneath the scale, gray finger-like particles characterized a 9-11 µm deep internally oxidized zone. An alloy depleted zone was observed to a depth of 20-24 µm. The most significant near-surface microstructural difference between the 750°C 1,000-hour and 3,000-hour aged samples was the increase in twin boundary, intra- and intergranular carbide precipitation (as a result of carburization) observed in the latter specimen (Figure 10b) to a depth of 48-60 µm.

2.6.3.1.2 Inconel 618E

Typical optical photomicrographs showing the internal microstructure of Inconel 618E after 3,000-hour/exposure to controlled-purity helium at 750°C are presented in Figure 12. As with Inconel 617, the internal microstructure of the 3,000 hour aged Inconel 618E sample was essentially equivalent to the 1,000-hour aged sample, but with perhaps somewhat finer carbide precipitation. Constituents are essentially the same as for the Inconel 617 alloy.

The surface condition of Inconel 618E (shown in Figure 13) was rather similar to that observed for Inconel 617, except the extent of internal oxidation was minimal (approximately 1 µm deep), due to the alloy's extremely low aluminum content. Scale thickness was 2-3 µm, and an alloy depleted zone extended to a depth of 12-16 µm. Below the depleted zone, a high density of precipitated carbides was evident to a depth of 36-44 µm. Additionally, although not readily apparent in Figure 13, the alloy depleted zone appeared to be composed of fine (roughly 10 µm diameter) recrystallized grains. This effect was also observed after 1,000-hour aging at both 750°C and 850°C. After prolonged etching and microscopic examination, a similar situation is believed to exist for the Inconel 617 alloy depleted (denuded) zone. Unfortunately evidence of recrystallization is partially masked by the presence of a significant amount of internal oxidation.

2.6.3.2 Centrifugally Cast Alloys

2.6.3.2.1 HK-40

The photomicrographs shown in Figure 14 are typical of the microstructure of HK-40 after 3,000 hours aging in controlled-purity helium at 750°C. This exposure resulted in an abundant degree of carbide precipitation. For the most part, the carbides were evident as fine-to-intermediate, roughly spherical particles; however, precipitates with a Widmanstätten structure (presumably carbides) were also observed throughout the sample (Figure 14). This type of precipitate has been previously observed (3) (at least in the near surface region) in samples of HK-40 which had been thermally exposed in controlled-purity helium. Additionally, in contrast to the 750°C/1,000-hour exposed specimen, evidence of coring was no longer apparent after 3,000-hour aging.

The surface features of HK-40, shown in Figure 15, were fairly similar to those observed after aging for 1,000 hours at 750°C. As before, the scale (approximately 2-3 μm thick), appeared to be noncontinuous or spalled. Evidence of internal oxidation was not apparent; however, the scale occasionally appeared to intrude into the base metal. Below the surface scale, an alloy depleted region extended to a depth of 8 μm . Surprisingly, evidence of increased near-surface carbide precipitation was not apparent.

2.6.3.2.2. Manaurite 36XS

The internal microstructure of Manaurite 36XS after 3,000-hour aging in controlled-purity helium at 750°C is typified by the optical photomicrographs shown in Figure 16 and 17. The microstructure revealed an abundant degree of secondary carbide precipitation, mainly in the intradendritic regions near the eutectic carbides. Some coarsening of the globular eutectic carbide structure was also evident when compared with the alloy aged at 750°C for 1,000 hours. Additionally, the acicular particles first observed after 1,000-hour aging were now abundant and somewhat larger. These needle-like particles, preferentially precipitated along certain crystallographic directions, are typical of the Sigma phase.

The surface of Manaurite 36XS was characterized by a partially spalled, 23 μm thick scale which contained fine white particulates (probably carbides). Little evidence of internal oxidation was observed; however, a light etching alloy depleted zone was observed to a depth of 6-10 μm . In this alloy, evidence

of carburization was manifested by increased fine-to-coarse intradendritic carbide penetration to a depth of between 10-14 μm .

2.6.3.2.3 Manaurite 900

The photomicrographs shown in Figure 18 are representative of the microstructures of Manaurite 900 after 3,000-hour aging in controlled-purity helium at 750°C. As with the other centrifugally cast alloys, exposure at 750°C resulted in the precipitation of fine carbide particles both inter- and intradendritically. In this case, however, microstructures were essentially equivalent after both the 1,000-hour and 3,000-hour exposures. It is of interest to note (Figure 18) that the degree of secondary carbide precipitation is significantly reduced in Manaurite 900 relative to the other centrifugally cast alloys since the carbon level is 1/2 to 1/4 that of the other alloys in this class.

The surface of Manaurite 900 exhibited a 2 μm thick gray scale (Figure 19) above an 8-10 μm deep denuded zone. The near surface region also revealed evidence of carburization in the form of fine-to-intermediate sized precipitated carbides. Some preferentially oriented carbide precipitation was also evident, as shown in Figure 19.

2.6.3.2.4 Mo-Re 2

Typical optical photomicrographs showing the internal microstructure of Mo-Re 2 after 3,000-hour exposure to controlled purity helium at 750°C are shown in Figure 20.

Copious amounts of secondary carbide precipitation were revealed mainly within the intradendritic regions. This feature is quite similar to that observed in the 750°C/1,000-hour exposed specimen. However, the lace-like or script-type austenite-carbide eutectic which was evident after 1,000 hour aging at 750°C (as well as in the as-cast material) has coalesced after an additional 2,000-hour exposure and transformed to a grouping of discrete, intermediate-sized globular carbide particles.

After 3,000-hour exposure at 750°C, the surface of the alloy was covered by a discontinuous or partially spalled triple-layered scale about 5-7 μm thick, as shown in Figure 21. The layered scale consisted of a gray outer surface

layer, a secondary white layer, and a fairly continuous tertiary gray layer that contained fine white particles in some areas. As illustrated by the photomicrographs in Figure 21, significant portions of the outer two layers were discontinuous or spalled. Beneath the scale, a 5-7 μm deep, sparsely populated oxidized zone was evident in an alloy depleted region of similar depth. Additionally, a high density region of carbide precipitation was evident to a depth of 15-18 μm .

2.6.3.3 Summary of Metallographic Results

In reviewing the bulk microstructural features of the six alloys discussed above, it has become clear that, although similarities exist, thermal aging effects appear somewhat more pronounced after the 750°C/3,000 hour-exposure relative to that observed in comparable samples aged for 1,000 hours. Generally, the degree of both intragranular and intradendritic (secondary) carbide precipitation was greater after the longer aging time. Grain boundary carbides were also somewhat larger, globular and semi-continuous. Additionally, the acicular particles (typical of the Sigma phase) observed in the centrifugally cast alloy, Manaurite 36XS, were more abundant and somewhat larger.

Interestingly, the 850°C/1,000-hour/metallographic findings (reported in the last Quarterly Report) were slightly less akin to the results discussed in the preceding paragraphs. The most obvious difference was the notable absence of the acicular precipitate in the 850°C/1,000-hour aged sample of Manaurite 36XS. Other less obvious disparities were manifest in the degree of coalescence of the carbides (both intergranular and eutectic) which had taken place in the centrifugally cast alloys, with coalescence being greater at the higher aging temperature. Also, grain boundary carbide growth was somewhat more advanced after 850°C exposure.

A summary of the corrosion measurements for the six alloys discussed above is given in Table 17. Gas/metal interactions were quite evident and usually in excess of that observed after 750°C/1,000-hour aging. Aside from increased thickness, surface scales were generally more complex and, in one case (Mo-Re 2), a triple-layered, partially spalled scale was evident. Surface oxidation was also sporadically noted, but was present to a greater extent in the high aluminum content Inconel 617. An alloy depleted (or light-etching)

TABLE 17

SUMMARY OF CORROSION MEASUREMENTS FOR SELECTED ALLOYS
AGED UNSTRESSED IN CONTROLLED-PURITY HELIUM

Alloy	Exposure Temp (°C)	Exposure Time (hours)	Scale Thickness	Typical Corrosion Depths (μ m)			Avg. Wt. Change (mg/cm ²)
				Internal Oxidation	Alloy Depletion	Carbur- ization	
Inconel 617	750	1,000	1	4	6-12	--	+0.450
	750	3,000	2-3	9-11	20-24	48-60	+0.550
	850	1,000	2-5	5-14	~10	--	+0.658
Inconel 618E	750	1,000	2	--	6-14	~18	+0.389
	750	3,000	2-3	~1	12-16	36-44	+0.413
	850	1,000	2-7	--	6-26	--	+0.543
HK-40	750	1,000	2	--	8	--	+0.284
	750	3,000	2-3	--	8	--	-0.069
	850	1,000	2-7	--	8-10	--	-0.348
Manaurite 36XS	750	1,000	2	--	7	12	+0.370
	750	3,000	2-3	< 1	6-10	10-14	+0.196
	850	1,000	3-5	~20	6-7	--	-1.192
Manaurite 900	750	1,000	1	--	--	18	+0.362
	750	3,000	2	--	8-10	14-28	+0.168
	850	1,000	2-3	--	--	--	+0.252
Mo-Re 2	750	1,000	1	1	5-6	7-9	0.384
	750	3,000	5-7	5-7	5-7	15-18	-0.330
	850	1,000	4-5	10-20	8-10	~60	0.884

Oxalic Acid

250X

- (a) Microstructure shows mixture of coarse heterogeneously dispersed precipitates and fine precipitated carbides dispersed intergranularly on grain boundaries and on twin boundaries. Note fine carbide precipitation along preferred crystallographic directions.

Oxalic Acid

1000X

- (b) Microstructure shows typical phases present: fine-to-intermediate precipitated carbides (probably $M_{23}C_6$) and coarse roughly cubic or globular precipitates (presumably TiN or TiCN).

Figure 10. Optical Photomicrographs Showing Etched Internal Microstructure of Inconel 617 after 3,000 hr Exposure in Controlled Purity Helium at 750°C.

Oxalic Acid

1000X

- (a) Microstructure shows single layered scale containing white particles and region of internal oxidation.

Oxalic Acid

500X

- (b) Microstructure shows surface scale, internal oxidation, zone of alloy depletion, and increased carbide precipitation.

Figure 11. Optical Photomicrographs Showing Surface Condition (a) Unetched and (b) Etched for Inconel 617 after 3,000 hr Exposure in Controlled Purity Helium at 750°C.

Oxalic Acid

250X

- (a) Microstructure shows mixture of coarse heterogeneously dispersed precipitates and fine-to-intermediate precipitated carbides dispersed intra- and intergranularly and on twin boundaries.

Oxalic Acid

1000X

- (b) Microstructure shows typical phases present: coarse cubic or angular precipitates, (gray phase, presumably TiN or TiCN) and intermediate-to-fine precipitated carbides (probably $M_{23}C_6$).

Figure 12. Optical Photomicrographs Showing Etched Internal Microstructure of Inconel 618E after 3,000 hr Exposure in Controlled Purity Helium at 750°C.

Oxalic Acid

500X

Microstructure shows surface scale, zone of alloy depletion, and increased carbide precipitation.

Figure 13. Optical Photomicrograph Showing Surface Condition and Etched Subsurface Microstructure of Inconel 618E after 3,000 hr Exposure in Controlled Purity Helium at 750°C.

Murakami's Etch

250X

- (a) Microstructure shows austenite-carbide eutectic dispersed at dendrite boundaries or interdendritically and precipitated carbides dispersed intradendritically.

Murakami's Etch

1000X

- (b) Microstructure shows script-type austenitic-carbide eutectic, fine secondary carbides and fine Widmanstatten precipitate.

Figure 14. Optical Photomicrographs Showing Etched Internal Microstructure of HK-40 after 3,000 hr Exposure in Controlled Purity Helium at 750°C.

Murakami's Etch

500X

Microstructure shows spalled surface scale and alloy depleted zone.

Figure 15. Optical Photomicrograph Showing Surface Condition and Etched Subsurface Microstructure of HK-40 after 3,000 hr Exposure in Controlled Purity Helium at 750°C.

Murakami's Etch

250X

- (a) Microstructure shows austenite-carbide eutectic dispersed at dendrite boundaries or interdendritically, precipitated carbides and acicular precipitate typical of the Sigma phase.

Murakami's Etch

1000X

- (b) Microstructure shows globular eutectic carbide, fine secondary carbides and acicular precipitate typical of the Sigma phase.

Figure 16. Optical Photomicrographs Showing Etched Internal Microstructure of Manaurite 36XS after 3,000 hr Exposure in Controlled Purity Helium at 750°C.

Murakami's Etch

500X

Microstructure shows surface scale, alloy depleted region, and increased fine-to-coarse carbide precipitation in zone near surface.

Figure 17. Optical Photomicrograph Showing Surface Condition and Etched Subsurface Microstructure of Manaurite 36XS after 3,000 hr Exposure in Controlled Purity Helium at 750°C.

Murakami's Etch

250X

- (a) Microstructure shows austenite-carbide eutectic dispersed at dendrite boundaries or interdendritically and precipitated carbides dispersed intradendritically.

Murakami's Etch

1000X

- (b) Microstructure shows typical phases present: lace-like austenite-carbide eutectic and fine secondary (precipitated) carbides.

Figure 18. Optical Photomicrographs Showing Etched Internal Microstructure of Manaurite 900 after 3,000 hr Exposure in Controlled Purity Helium at 750°C.

Murakali's Etch

500X

Microstructure shows surface scale, alloy depleted zone, and increased fine-to-intermediate carbide precipitation in near surface region.

Figure 19. Optical Photomicrograph Showing Surface Condition of Manaurite 900 after 3,000 hr Exposure in Controlled Purity Helium at 750°C.

Murakami's Etch

250X

- (a) Microstructure shows austenite-carbide eutectic dispersed at dendrite boundaries or interdendritically and precipitated intradendritic carbides.

Murakami's Etch

1000X

- (b) Microstructure shows typical phases present: coarsened globular austenitic-carbide eutectic and fine secondary carbides.

Figure 20. Optical Photomicrographs Showing Etched Internal Microstructure of Mo-Re 2 after 3,000 hr Exposure in Controlled Purity Helium at 750°C.

Unetched

1000X

- (a) Microstructure shows partially spalled or missing triple layered surface scale.

Unetched
(Differential Interference Contrast)

1000X

- (b) Microstructure shows surface scale, zone of alloy depletion, and high density region of carbide precipitation.

Figure 21. Optical Photomicrographs Showing Unetched Surface Condition of Mo-Re 2 after 3,000 hr Exposure in Controlled Purity Helium at 750°C.

region was present in each of the six materials examined, with distinct signs of carburization seen in five of the six alloys studied. Perhaps the lack of increased subsurface carbide precipitation in the HK-40 specimen may be attributable to the inherently high carbon content of the material or may indicate that the incubation period for this phenomena has not been exceeded. At any rate, the premature rupture of an HK-40 screening creep specimen is not encouraging, since thermal effects alone (aside from carburization) may severely limit the usefulness of this alloy.

Although the results are limited, it appears that carburization was more prevalent after 750°C/3,000-hour exposure relative to that observed after 1,000-hour at 850°C, suggesting that, at least in this temperature regime, the 2,000-hour exposure increment is the more important variable in terms of carburization.

REFERENCES

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2. Advanced Gas Cooled Nuclear Reactor Materials Evaluation and Development Program, Progress Report for Period January 1, 1980 - March 31, 1980, C00-2975-43.
3. W.R. Johnson and L.D. Thompson, "Effects of Methane Concentration On The Controlled-Impurity Helium Behavior of Selected HTGR Structural Materials," General Atomic Company, GA-A15565, December 1979.

2.7 TASK 9 - DATA MANAGEMENT AND PROGRAM MANAGEMENT

2.7.1 Data Management

Work on encoding of the Planning and Management - Materials Evaluation and Development (PAMMED) forms continued during the quarter. The following forms were completed for all the NPH Alloys: Chemical Analysis, Material Description, Creep Rupture, Impact, Vareststraint Weld, Process Description, Tensile and Specimen Description.

2.7.2 Program Management

The following program meetings or related meetings were attended or conducted by program staff during the report period.

- An HTGR materials program coordination meeting was held at Oak Ridge, Tennessee on May 14, 15, 1980. The meeting was attended by program participants representing General Atomic Company (GAC), Oak Ridge National Laboratory (ORNL), Gas Cooled Reactor Associates (GCRA) and General Electric Co. (GE).
- General Electric personnel attended a meeting at the General Atomic Company on June 3, with materials engineers from GAC, ORNL and GCRA. The purpose of the meeting was to estimate materials evaluation and development costs for each of the four lead plant options being assessed for the U.S. HTGR Program.
- Weekly meetings were held with the General Electric program personnel in Schenectady, N.Y. to review technical results and program status.

The program master schedule is presented in Figure 22.

Section 3.0

WORK TO BE COMPLETED DURING THE NEXT QUARTER

3.0 WORK TO BE COMPLETED DURING THE NEXT QUARTER

- The multispecimen creep tests at 750°C and 850°C will reach 5,000 hours on test and the fifth 1,000-hour interval creep strain measurements will be completed on these specimens.
- The multispecimen creep tests at 950°C and 1050°C will reach 1,000 hours on test and the first 1,000-hour interval creep strain measurements will be completed on these specimens.
- The intensive screening single specimen creep rupture tests will continue.
- The intensive screening phase air creep rupture tests will continue.
- The room temperature tensile tests of specimens exposed in controlled purity helium for 1,000 hours at 950°C will be completed.
- Bend tests of as-welded NPH alloys for the intensive screening phase will be completed.
- Evaluation of corrosion pins and weldments exposed for 1,000 and 3,000 hours at 950°C in controlled purity helium will continue.