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**ADVANCED GAS COOLED NUCLEAR REACTOR MATERIALS EVALUATION
AND DEVELOPMENT PROGRAM**

Progress Report, July 1—September 30, 1977

MASTER

November 14, 1977

Work Performed Under Contract No. EY-76-C-02-2975

General Electric
Energy Systems Programs Department
Schenectady, New York

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ADVANCED GAS COOLED NUCLEAR REACTOR MATERIALS EVALUATION AND DEVELOPMENT PROGRAM

PROGRESS REPORT FOR PERIOD

JULY 1, 1977 — SEPTEMBER 30, 1977

**BY
PROJECT STAFF**

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**ENERGY SYSTEMS PROGRAMS DEPARTMENT
SCHENECTADY, NEW YORK 12345**

NOVEMBER 14, 1977

MASTER

Prepared for
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FOREWORD

The Advanced Gas Cooled Nuclear Reactor Materials Evaluation and Development Program is being conducted for the Division of Nuclear Research and Applications, U.S. Department of Energy, by the Energy Systems Programs Department, General Electric Company, Schenectady, New York 12345. 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 for the Program is Dr. O. F. Kimball, Manager, Gas Reactor Materials, with responsibility for overall technical coordination. Other major contributors to the Program are:

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ABSTRACT

This report presents the results of work performed from July 1, 1977 through September 30, 1977 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) Process Heat and Direct Cycle Helium Turbine (DCHT) applications, in terms of the affect of simulated reactor primary coolant (impure Helium), 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 an updated listing of the alloys selected for the screening tests, plus complete test specimen matrices for the screening program. The present design and construction status of the simulated reactor helium loops and testing and analysis facilities and equipment are discussed. Also covered are the loading matrices for the screening creep tests.

Section 1.0

INTRODUCTION

ADVANCED GAS COOLED NUCLEAR REACTOR
MATERIALS EVALUATION AND DEVELOPMENT PROGRAM

1.0 INTRODUCTION

The Very High Temperature Reactor (VHTR) Process Heat and the Direct Cycle Helium Turbine (DCHT) Systems are being developed to provide an expanded nuclear power capability. In both cases the use of high temperature helium-cooled reactors will require a knowledge of the long term properties of reactor fluid containment materials and of the materials used in constructing related hardware. Because of the very high temperatures required for process heat and DCHT applications, the need is evident for materials testing in the proper helium environment in the temperature range from 960 - 1093°C (1400 - 2000°F) on those alloys which might serve as materials of construction for heat exchangers, ducting liners, turbine buckets 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) Process Heat and Direct Cycle Helium Turbine (DCHT) applications, in terms of the effect of the primary coolant exposure and thermal exposure on:
 - o Surface stability (corrosion resistance) in 10,000 hours.
 - o Structural stability in 10,000 hours - changes in micro-structure and tensile, impact and fatigue properties.
 - o Creep properties in 15,000 hours.
 - o Stress rupture properties in 10,000 hours.
 - o 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 VHTR and DCHT systems. The present lack of an accurate measure of materials capabilities under these high temperature helium environments is a factor which is currently limiting the development of the VHTR/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 structures (Program Work Breakdown Structure) and a brief description of each task (Program Work Statement) have been included in the first quarterly report: COO-2975-3.

During the fourth quarter of the program some minor changes were made in Task 1 (Selection of Candidate Alloys); a final Alloy Selection Report is now scheduled for release during the first quarter of FY 1978. Work has continued on Task 2 (Materials Procurement and Characterization), Task 3 (Testing and Analysis Facilities and Equipment), Task 4 (Simulated Reactor Helium Environment Facilities and Equipment), and Task 9 (Data Management and Program Management). During this quarter, work was initiated on Task 5 (Mechanical Property Evaluation), Task 6 (Thermal Stability Evaluations) and Task 7 (Corrosion Resistance Evaluation).

2.1 TASK 1 - SELECTION OF CANDIDATE ALLOYS

2.1.1 Candidate Alloys for Direct Cycle Helium Turbine (DCHT)

The list of direct cycle helium turbine materials selected for the screening tests is given in Table 2.1. Nine (9) alloys and two (2) processing methods will be tested in screening creep; the two processing methods, conventional investment casting and directional solidification, will be investigated in the evaluation of MM-0011 (previously designated MM-247). Eighteen (18) alloy/process combinations will be tested in unstressed exposure tests, to evaluate their structural stability (bulk and surface stability). Preoxidation of alloys (or coatings) with a high aluminum and titanium content and coatings are given emphasis because of possible improvements in carburization resistance expected from these surface treatments.

TABLE 2.1

DIRECT CYCLE HELIUM TURBINE MATERIALS
SELECTED FOR SCREENING STUDIES

Material		Alloy Type
Screening Creep Tests	Unstressed Exposure Tests	
	TZM	Molybdenum-Base Alloy
TZM-Coated	TZM-Coated	
	YD-Ni	Oxide Dispersion Strengthened Nickel-Base Alloy
MA-754	MA-754	"
	YD-NiCrAl	"
MM-0011	MM-0011	Cast Nickel-Base Superalloy, Precipitation Hardened
MM-0011DS (Directionally Solidified)	MM-0011DS	"
Rene' 80	Rene 80'	"
	Rene' 80 Preoxidized	"
Rene' 100	Rene' 100	"
	M-21	"
	M-21-Preoxidized	"
Alloy 713LC	Alloy 713LC	"
	Alloy 713LC-Coated	"
	Alloy 713LC-Coated plus Preoxidized	"
IN-738	IN-738	"
Udimet-720	Udimet-720	Wrought Nickel-Base Alloy, Precipitation Hardened
NX-188	NX-188	Cast Nickel-Base Alloy, Refractory Metal Strengthened

Some changes were made in the list of candidate DCHT materials as compared to that published in the last quarterly Progress Report, COO-2975-13. From the five (5) previously listed candidate refractory metal strengthened alloys, NX-188 was chosen for study because it was felt to have the most favorable combination of availability, desirable properties and prior (U.S.) experience.

The wrought nickel-base superalloy Nimonic 115 was replaced by Udimet 720 (also a wrought, nickel-base, precipitation strengthened superalloy) because of procurement delays expected for Nimonic 115 (no U.S. source), considerable U.S. commercial experience with Udimet 720, and the high Titanium/Aluminum ratio for Udimet 720, which may be of importance for carburization resistance.

Finally, because of inadequate furnace capacity, MM-004 and several of the preoxidized alloys listed in the previous quarterly report for evaluation in the unstressed condition, will not be tested in the initial screening tests. The advantages/disadvantages of preoxidation as a surface treatment method will be determined from the three preoxidized materials listed in Table 2.1. If additional tests are desired (within budgetary limitations), they could be run as furnace capacity becomes available. MM-004 contains 1.3% Hf; otherwise the composition of MM-004 is the same as INCO alloy IN-713LC. The effect of Hf additions will be determined from studies of MM-0011 which also contains Hf.

The nominal compositions of the alloys chosen for evaluation as candidate materials for the DCHT are given in Table 2.2. (It should be noted that candidate ducting alloys for helium turbine applications are included among the nuclear process heat candidate alloys.)

2.1.2 Candidate Alloys for Nuclear Process Heat (NPH)

The list of candidate nuclear process heat materials selected for screening studies is given in Table 2.3. Twelve (12) alloys and two (2) alloy/coating systems will be studied in the screening creep tests; fourteen (14) alloys and two (2) alloy/coating systems will be studied after unstressed exposure tests.

TABLE 2.2

NOMINAL COMPOSITIONS (W/O) OF ALLOYS

FOR DCHT SCREENING PROGRAM

Alloy	Composition, W/O										
	Ni	Cr	Al	Ti	Co	Ta	Mo	W	Cb	C	Other
TZM	--	--	--	0.45	--	--	Bal	--	--	0.015	0.09 Zr
YD-Ni	Bal	--	--	--	--	--	--	--	--	--	2Y ₂ O ₃
MA-754	Bal	20.5	.3	.5	--	--	--	--	--	0.05	0.6Y ₂ O ₃ , 1Fe
YD-NiCrAl	Bal	16	4.0	--	--	--	--	--	--	--	1.0Y ₂ O ₃
MM-0011	Bal	8.3	5.5	1.0	10.0	3.0	0.7	10.0	--	0.16	1.5 H _f
Rene' 80	Bal	14.0	3.0	5.0	9.5	--	4.0	4.0	--	0.17	
Rene' 100	Bal	9.5	5.5	4.2	15.0	--	3.0	--	--	0.18	
M-21	Bal	5.7	6.0	--	--	--	2.0	11.0	1.5	0.08	
IN-713LC	Bal	12.0	5.9	0.6	--	--	4.5	--	2.0	0.05	
IN-738	Bal	16.0	3.4	3.4	8.5	1.7	1.75	2.6	0.9	0.17	
Udimet 720	Bal	18.0	2.5	5.0	14.75	--	3.0	1.25	--	0.03	0.03 Zr
NX-188	Bal	--	8.0	--	--	--	18.0	--	--	0.04	

TABLE 2.3

SELECTED PROCESS HEAT MATERIALS FOR SCREENING STUDIES

Material		Alloy Type
Screening Creep Tests	Unstressed Exposure Tests	
Incoloy 800H	Incoloy 800H	Wrought Iron-Base (Austenitic)
Incoloy 800H-Coated	Incoloy 800H-Coated	"
Incoloy 802	Incoloy 802	"
Incoloy 807	Incoloy 807	"
Incoloy DS	Incoloy DS	"
HD-556	HD-556	"
Manaurite 36XS	Manaurite 36XS	Cast Iron-Base (Austenitic)
	Manaurite 900	"
HK-40	HK-40	"
IN-519	IN-519	"
Hastelloy X	Hastelloy X	Wrought Nickel-Base (Austenitic)
Inconel 617	Inconel 617	"
Inconel 617-Coated	Inconel 617-Coated	"
	Inconel 618E	"
Mo-Re 2	Mo-Re 2	Cast Nickel-Base Austenitic
MA-956E	MA-956E	Oxide Dispersion Strengthened Iron-Base Alloy

As discussed in the previous quarterly report (C00-2975-13), Inconel 625 and IN-643 were removed from the original list of alloys; and upon re-evaluation of the candidate alloys, no other alloy with outstanding potential was found. Also, because of the severe carburization observed in the General Atomic Co. (GAC)/High Temperature Materials Programme (HTMP) tests on wrought iron- and nickel-base solid solution strengthened alloys,⁽¹⁾ it was decided to evaluate coated Incoloy 800H in the screening creep program (as well as in unstressed exposure tests).

Because of furnace capacity, it was decided not to test coated Hastelloy X in the initial unstressed exposure tests. The advantages/disadvantages of coatings on wrought iron and nickel base alloys will be shown by the tests on coated Incoloy 800H and Inconel 617.

Nominal compositions of all nuclear process heat candidate alloys to be tested in the screening tests are given in Table 2.4.

2.2 TASK 2 - MATERIALS PROCUREMENT AND CHARACTERIZATION

2.1.1 Nuclear Process Heat Alloys (NPH) - (S. Z. Hayden)

The preparation of specifications has been completed and purchase orders have been placed for all the candidate alloys for NPH application.

Arrangements have been made with Huntington Alloys, Inc. (HAI) to ship the experimental wrought iron-base alloy Inconel 618E, with the Incoloy 800H, Incoloy 802 and Inconel 617. One plate 102cm (40 in.) x 30.5cm (12 in.) x 1.9cm (0.75 in.) (~ 45.5 kg/100 lbs.) will be provided by HAI at no cost to GE. Inconel 618E will be evaluated only in the unstressed condition and 45.5 kg will yield more than enough material to fulfill this requirement.

One centrifugally cast tube each of Manaurite 900 and Manaurite 36XS have already been received from General Atomic Company (GAC), San Diego, CA. The tubes were centrifugally cast by Acieries Manoir Pompey, Pitres, France. Tube dimensions are nominally 249cm (98 in.) length x 15.6cm (6.125 in.) O.D. x 1.82cm (0.72 in.) wall thickness. These tubes will provide sufficient material to meet program needs. The chemical composition of the centrifugally cast tubes are presented in Table 2.5. The values are the result of Acieries Manoir Pompey certificates and analyses conducted for General Atomic Co. (GAC) by the

Table 2.4

NOMINAL COMPOSITIONS (W/O) OF ALLOYS FOR VHTR/NPH SCREENING PROGRAM

Alloy	COMPOSITION, W/O										
	C	Ni	Co	Cr	Fe	Al	Ti	Mo	W	Cb	Other
Incoloy 800H	0.08	32.5	--	21.0	Bal	0.4	0.4	--	--	--	--
Incoloy 802	0.35	32.5	--	21.0	Bal	0.6	0.75	--	--	--	--
Incoloy 807	0.08	40.0	8.0	20.5	Bal	0.4	0.4	--	5.0	1.0	--
Incoloy DS	0.05	37.0	--	18.0	Bal	--	--	--	--	--	2.3 Si
HD-556	0.10	20.0	20.0	22.0	Bal	0.3	--	3.0	2.5	0.1	1.3 Mn, 0.9 Ta
Manaurite 36XS	0.40	34	--	26	Bal	--	--	--	2.0	1.5	2.0 Si
Manaurite 900	0.15	32.0	--	21.0	Bal	--	--	0.3	--	1.5	1.0 Si
HK-40	0.40	20.0	--	24.0	Bal	--	--	--	--	--	1.8 Si
IN-519	0.30	24.0	--	24.0	Bal	--	--	--	--	1.5	1.0 Si
Hastelloy X	0.10	Bal	1.5	22.0	18.0	--	--	9.0	0.6	--	1.0 Si
Inconel 617	0.07	Bal	12.5	22.0	--	1.0	--	9.0	--	--	--
Inconel 618E	0.05	54	≤0.1	23	Bal	--	--	--	6	--	--
Mo-Re 2	0.4	51	--	33	--	1.0	--	--	15	--	--
MA-956E	--	--	--	20	Bal	4.5	0.5	--	--	--	0.5Y ₂ O ₃

TABLE 2.5

CHEMICAL COMPOSITION OF ACIÉRIES MANOIR POMPEY ALLOYS

Chemical Composition, W/O											
Alloy	C	Mn	Si	P	S	Ni	Cr	Mo	Nb	W	Fe
Manaurite 900-Specification	0.10- 0.18	1.50 Max	1.25 Max	0.030 Max	0.030 Max	30.00- 35.00	19.00- 23.00	0.50 Max	+	--	Bal
Manaurite 900 - 1 (a)	0.105	1.11	0.62	0.024	0.017	32.60	21.35	0.01	1.06	--	43.1(c)
- 2 (a)	0.105	1.02	0.70	0.025	0.019	32.70	21.90	0.01	1.12	--	42.4(c)
Manaurite 900 - (b)	0.12	0.99	0.74	0.24(a)	0.018(a)	34.8	22.4	< 0.10	--	< 0.10	40.1(c)
OTHER (b)											
Co	<0.10		V	<0.1							
Al	<0.10		Zr	<0.1							
Ti	<0.10		Y	<0.1							
Cu	<0.50										
Manaurite 36XS-Specification	0.35- 0.45	2.00 Max	2.00 Max	0.030 Max	0.030 Max	32.00- 35.00	24.00- 27.00	--	+	+	Bal
Manaurite 36XS - (a)	0.38	1.28	1.68	0.026	0.018	34.05	25.56	--	1.12	1.50	34.4(c)
Manaurite 36XS - (b)	0.39	1.30	1.92	0.026(a)	0.018(a)	36.0	24.8	<.10	1.05	1.5	32.1(c)
OTHER (b)											
Co	0.18		Ti	<0.1		Zr	<0.10				
Ta	<0.10		Cu	<0.05		Y	<0.10				
Al	<0.1		V	<0.10							

(a) Values from Acieries Manoir Pompey Certifications

(b) Values determined by International Nickel Research Laboratories for General Atomic Co.

(c) Balance of alloy obtained by difference.

International Nickel Company (INCO) Research Laboratories.⁽¹⁾ It should be noted that the Ni value of the Manaurite 36XS alloy, as determined by INCO, is slightly in excess of the vendor specification. Acieries Manoir Pompey supplied room temperature tensile mechanical properties along with Heat No., form, and as-received treatment are presented in Table 2.6. Tensile properties appear to exceed the vendor specifications for each of the two materials.

Table 2.7 summarizes the applicable specification, material producer, form and quantity ordered or received and status for each of the NPH materials. As indicated in Table 2.7, two purchase orders have been placed for the Henry Wiggin & Co., Ltd. supplied ODS alloy, MA-956E. This is a result of the extremely long MA-956E production schedule (~ 18-22 weeks) quoted by Wiggin which may have resulted in program delays. The first purchase order was placed for 7.7 meters (25 ft.) of 2.5cm (1.0 in.) diameter bar (~ 30kg/61 lbs) which Wiggin currently has on hand. The chemical composition and mechanical properties of this material will be determined by Wiggin and reported to GE. Although there will be increased wastage [due to the 2.5cm (1.0 in.) diameter versus the 1.9cm (0.76 in.) diameter bar which was desired] this shipment will provide enough material to complete the screening portion of the program. A second purchase order was placed for 45.5 kg (100 lbs.) of 1.9cm (0.750 in.) diameter bar. In combination with the first order, this will result in the procurement of approximately 72 kg (160 lbs.) of material as compared with about 136.4 kg (300 lbs.) for wrought plate and cast tube alloys. However, because of the decreased wastage of the round bar product compared to the other forms, this quantity will be adequate for both phases of the program with sufficient margin for joining studies and archive samples.

2.2.2 Direct Cycle Helium Turbine (DCHT) Alloys

Materials specifications for most of the direct cycle helium turbine alloys have been prepared and associated process, property and quality assurance testing specifications have been completed. Vendor contacts for purchasing (cost and delivery) most of the alloys have been made.

2.3 TASK 3 - TESTING AND ANALYSIS FACILITIES AND EQUIPMENT - (D. BALDWIN)

TABLE 2.6

PROCESSING HISTORY AND MECHANICAL PROPERTY DATA FOR ACIERIES MANOIR POMPEY MATERIALS

<u>Alloy</u>	<u>Heat No.</u>	<u>As-Received Form</u>	<u>Heat Treatment</u>		<u>Tensile Properties</u>		
					<u>Y.S.</u> <u>Kg/mm²(ksi)</u>	<u>U.T.S.</u> <u>Kg/mm²(ksi)</u>	<u>Elongation</u> <u>%</u>
Manaurite 900	1268.0402	15.6 - Cm (6.12 in.) O.D. X 11.9 - Cm (4.68 in.) I.D. Centrifugally Cast Tube	As-Cast	Min.	19 (27.0)	45 (64.0)	25
				1	20.9 (27.7)	50.9 (72.4)	42.5
				Actual 2	19.8 (28.2)	48.4 (68.8)	44
Manaurite 36XS	1268.0726	15.6 - Cm (6.12 in.) O.D. X 11.9 - Cm (4.68 in.) I.D. Centrifugally Cast Tube	As-Cast	Min.	25 (35.6)	45 (64.0)	8
				Actual	31.6 (44.9)	54.5 (77.5)	15.5

Table 2.7

STATUS OF NPH MATERIAL PROCUREMENT

<u>Alloy</u>	<u>Applicable Specification</u>	<u>Material Vendor</u>	<u>Form and Quantity Ordered or Received</u>	<u>Expected Shipping Schedule</u>
Incoloy 800H	EPD 01-0001-00-0	Huntington Alloys, Inc.	1.59cm (5/8 in.) plate, 136kg (300 lbs.)	10-28-77
Incoloy 802	EPD 01-0002-00-0	Huntington Alloys, Inc.	1.59cm (5/8 in.) plate, 136kg (300 lbs.)	10-28-77
Incoloy 807	EPD-01-0005-00-0	Henry Wiggin & Co., LTD	1.59cm (5/8 in.) plate, 147kg (324 lbs.)	11-4-77
Incoloy DS	EPD-01-0004-00-0	Henry Wiggin & Co., LTD	1.59cm (5/8 in.) plate, 140kg (308 lbs.)	11-4-77
HD-556	EPD-01-0008-00-1	Stellite Div., Cabot Corp.	1.59cm (5/8 in.) plate, 146kg (321 lbs.)	12/77
Manaurite 900	--	Aciéries Manoir Pompey(a)	15.5cm (6.12 in.) O.D. x 11.9cm (4.68 in.) I.D. 249cm (98 in.) length tube	Received
Manaurite 36XS	--	Aciéries Manoir Pompey(a)	15.5cm (6.12 in.) O.D. x 11.9cm (4.68 in.) I.D. 249cm (98 in.) length tube	Received
HK-40	EPD-01-0009-00-1	Duraloy Blaw-Knox, Inc.	14.3cm (5.625 in.) O.D. x 10.5cm (4.125 in.) I.D. 244cm (96 in.)	12/77
IN-519	EPD-01-0011-00-0	Duraloy Blaw-Knox, Inc.	4.2cm (5.625 in.) O.D. x 10.5cm (4.125 in.) I.D. 249cm (96 in.)	
Hastelloy X	EPD-01-0007-00-1	Stellite Div., Cabot Corp.	1.59cm (5/8 in.) plate, 146kg (321 lbs.)	12/77
Inconel 617	EPD-01-0003-00-0	Huntington Alloys, Inc.	1.59cm (5/8 in.) plate, 272kg (600 lbs.)	10-28-77
Inconel 618E	--	Huntington Alloys, Inc.	1.9cm (3/4 in.) plate, 45.5kg (100 lbs.)	10-28-77
Mo-Re 2	EPD-01-0010-00-1	Duraloy Blaw-Knox, Inc.	14.3cm (5.625 in.) O.D. x 11.9cm (4.125 in.) I.D. 244cm (96 in.)	12/77
MA-956E	EPD-01-0006-00-1	Henry Wiggin & Co., LTD	27.7kg (61 lbs.) 2.54cm (1 in.) bar 45.5kg (100 lbs.) 1.9cm (0.75 in.) bar	11/77 2/78

(a) Received from General Atomic Co., San Diego, CA

2.3.1 High Temperature Reactor/Materials Testing Laboratory (HTR/MTL)

2.3.1.1 Utility Frames

Installation of helium distribution piping subassemblies on the utility frames has begun. These subassemblies consist of valve clusters, pressure regulators, and solenoid valves for each test station with inter-connecting stainless steel tubing. Four units servicing 20 creep stands have been fabricated and leak checked.

Some problems have been encountered with the welds necessary to join subassembly sections together on the utility frames. Primarily, these have to do with the restricted area in which the welder must work, coupled with the thin walled (0.9 mm) tubing which is highly susceptible to melt-through. Assembly sequences are being altered to allow as many of these welds as possible to be made on the bench.

2.3.1.2 Power Distribution

Electrical wiring inside the laboratory has been completed to the point of test stand connection. All wall-mounted distribution panels have been installed and connected and power leads have been run to each test station ready for connection. Installation of the 525 KVA transformer and main circuit breaker panel in the HTR/MTL utility room has been completed and all connections to distribution wiring made.

The remaining work to be done on the electrical power system is installation of feeder lines and the automatic tie-breaker. This work is underway and will be completed well in advance of the time power is needed in the laboratory.

2.3.1.3 Water Distribution System

Installation of overhead supply and return headers and shut-off valves and drops to all utility frames has been completed. Installation of connections to rotameters and shut-off valves to each test station has been scheduled after installation of helium subassemblies is complete, since it is much simpler to make minor adjustments and accommodations in the copper water lines than in the prefabricated stainless steel helium subassemblies.

The construction of the water pump/heat exchanger package is expected to be completed by November 1.

2.3.1.4 Air Conditioning

The 25-ton auxiliary air conditioning unit has been installed. Power transformers have been installed in the utility room and cooling water supply and drain lines have been installed excepting final tie-in to mains. All ductwork has been installed.

2.3.1.5 Helium Distribution Piping

Installation of helium distribution piping has begun. This is recognized as a critical item in laboratory construction and extensive planning and preparations have been made.

2.3.1.5.1 Cleaning

All the stainless steel tubing for use in fabrication of this system has been specially cleaned. This procedure is spelled out in G.E. Engineering Specification EPD 02-0002-00-0, "Cleaning Procedure for Stainless Steel Parts to be Used in the High Temperature Controlled Impurity Helium Test Facility". Essentially, it consists of soaking and internally scrubbing the tubes in trichloroethylene, rinsing with fresh trichloroethylene, rinsing twice with acetone and drying under hot helium.

In order to verify the cleanliness of the tubing, evaporated solvent extracts from the inner tube surfaces were examined by infrared photospectrometry. This is a sensitive test for the presence of oil and related compounds and the results indicated no traces of such contaminants. A second series of tests based on hydrochloric acid extracts ruled out the presence of soaps and greases. Finally, the tube walls passed the water film adherence test which is a good direct indicator of surface contamination by hydrocarbons. Thus the tubing has been shown to be clean except for observed loose oxide particles; they will be removed by blowing nitrogen at high pressure and high flow rate through each length of tubing prior to fabrication.

2.3.1.5.2 Laboratory Preparation

In order to insure no contamination of the tubing during helium loop construction, all other phases of construction have been stopped, and the room itself carefully cleaned to remove all dust, dirt, and oils or greases. The laboratory area has been closed to pedestrian traffic except by essential workers and Laboratory personnel. Workers have been provided with shoes which are worn only in the clean area and Laboratory personnel and occasional necessary visitors are instructed to wear plastic foot covers to avoid tracking dirt into the clean room.

All tools which come in contact with the piping have been solvent cleaned and are restricted for use only on this project. All workers or inspectors who must handle or touch the tubing wear clean white cotton gloves. Finally, only the tubing necessary for current work is removed from the shipping containers, and all open ends are capped.

2.3.1.5.3 Welder Qualifications

Each welder who is to work on fabrication of the helium system has been qualified by the Materials and Processes Laboratory. Qualification is based on all-position welding of sample joints in the largest and smallest tubing diameters involved [in this case 25.4 mm (1.0 inch) and 6.4 mm (0.250 inch)]. These joints must pass metallographic examination for penetration and porosity, bend tests for structural integrity and must also be helium leak tight to at least 2×10^{-8} stc.cc/sec of air.

2.3.2 Multi-Specimen Screening Creep Equipment

2.3.2.1 Test Machine Construction

A design review was held at the vendor's plant on July 25, 1977. Minor changes were incorporated and details of testing and checkout and delivery schedules were discussed.

Three of the six multi-specimen screening creep test stands have been completed. The retorts have been leak checked and are currently undergoing final temperature distribution checking at the plant. Delivery has been scheduled for the week of October 10-14, 1977. Construction of the second set

of three stands is underway and delivery of these units has been planned for the end of November. A portion of the final checkout of units 1-3 was witnessed by a GE representative. Figure 2.1 is a photograph of one of the first screening creep stands.

2.3.2.2 Specimen Design

There have been several changes made in the proposed test sample configurations contemplated for the screening phase of this program. The resultant designs and the considerations and concessions made in arriving at them are summarized below.

The original specimen design (0.452 cm/0.178 in.) gauge diameter was based on the samples already found successful by other laboratories doing similar testing. This design was given to prospective test machine vendors who dimensioned their equipment designs to accommodate the stipulated 15 specimens in each of 6 stringers. Later, when test matrices were laid out for the program, it was found that some of the desired test loads were very low as a consequence of the small specimen cross-section (0.452 cm or 0.178 inch diameter) and high test temperatures. For example, stresses on the order of 0.7 MPa (0.1 ksi) were required. This meant a load of 1.13 kg (2.5 lbs) on the specimen string or 113 gm (0.25 lb) at the weight pan of the test stands. The test machine manufacturer could not guarantee test load accuracy at such low levels, so it was decided to change to larger specimen cross sections.

Two larger samples were designed, having two and four times the cross-sectional areas of the original design. The first step was to scale-up the original design, maintaining geometric similarity. When the test matrices were expressed in terms of these geometries, it was observed that nearly half of the strings were several inches longer than the design hot zones of the already-in-manufacture test furnaces and retorts. This situation forced reconsideration of both matrices, with respect to reduction in number of samples tested, and specimens, with regard to possible means of shortening each sample.

FIGURE 2.1 Multi-Specimen Screening Creep Test Stand.
Photo Courtesy of Applied Test Systems, Inc.

To the latter end, it was found possible to shorten the length of the threaded portions of samples. The lengths finally decided upon are based on the same safety factors in the threads as calculated for the smaller original sample. A second reduction in length was achieved by using the same fillet radius of 5 mm (0.197 inch) as in the original design, rather than the larger values required for geometric similarity. It was determined that this would not seriously increase the stress concentration factors for the particular sizes of specimens involved.

Since the shorter thread lengths on the specimens also results in shorter couplings, the vendor's coupling design was revised. This necessitated calculations of the stress-rupture parameters of the coupling material (MAR-M246) and verification that the shortened couplings will possess sufficiently long rupture life for the program.

The dimensions of the two sample sizes agreed upon are shown in Table 2.8 and its accompanying sketch.

2.3.3 Thermal Stability Equipment

A design review was held at the vendor's plant on August 11, 1977. Several minor changes in retort design were made.

Eight complete systems are being built. A prototype furnace has been constructed and successfully tested at the low end of the proposed test temperature spectrum, 750°C (1382°F). Testing is continuing at the upper limit, 1050°C (1922°F).

Orders have been placed for ceramic retort tubes and for the internal specimen support. The ceramic's vendor has indicated a delivery date of early December. Thus final system delivery to GE may not be made until late December 1977 or January 1978. The furnaces and test stands are being purchased for the program by G.E.

Table 2.8

SCREENING CREEP SPECIMEN DESIGN
Dimensions in mm (inches)

Specimen Designation

	<u>B</u>	<u>C</u>
Gauge Diameter	6.4 (0.252)	9.1 (0.357)
Parallel Length L _p	36 (1.417)	50 (1.964)
Shoulder Length L _s	42.5(1.673)	57.8(2.276)
Threaded Length L _T	9.4 (0.372)	12.8(0.503)
Overall Length L	66.5(2.617)	88.4(3.482)
Thread Size	7/16-14	5/8-11

Note: Groove in shoulders is for strain measurements. Groove is 1.07 (0.042) wide by 0.41 (0.016) deep with a radius of 0.30 (0.012) Flanks are at 45° to specimen axis.

2.3.4 Single Specimen Precision Creep Equipment

Forty-five (45) test stands are under construction by the vendor. The present schedule agreement between G.E. and the vendor is for delivery of the first 10 stands with retorts to Schenectady by November 20, 1977, and 20 additional test stands (without retorts) by December 31, 1977.

The furnaces and test stands are being purchased for the program by G.E.

2.3.5 Temperature Control System

A design review was held with the vendor on July 25, 1977. Software design, hardware construction, and delivery were discussed.

The digital temperature control system is being designed and constructed by the vendor. They have scheduled delivery of the first portion of their equipment for the end of October 1977.

There have been two modifications to the system during the past quarter. First was the decision that the eight thermal stability test stands would be converted to five zone control instead of three as originally planned.

The second was the decision to proceed with the extension of system capabilities to cover the full complement of 45 single specimen test stands, 8 thermal stability stands, and 6 multi-specimen stands. This additional equipment will be delivered and installed by December 31, 1977. The temperature control system is being purchased for the program by G.E.

2.4 TASK 4 - SIMULATED REACTOR HELIUM ENVIRONMENT FACILITIES AND EQUIPMENT

2.4.1 Simulated Reactor Helium "Loop" System Design and Construction

2.4.1.1 Design (C.L. Ehde, R.K. Elton)

Figure 2.2 is an updated schematic presentation of the controlled purity helium system. While several revisions have been made to the gas addition systems, as discussed below, the overall system remains basically as presented in detail in the April 1977 Quarterly Report (C00-2975-10).

The latest changes in the gas addition system include changing the fill gas system from mixed gas of required loop composition to helium purified by liquid nitrogen cooled activated charcoal. This change was made because of the impossibility of buying mixed bottled gas with the extremely low level of oxygen required; it also would be difficult to obtain the required water and carbon dioxide levels in pre-mixed bottled gas. Further, it would be very difficult to selectively remove oxygen from the fill gas (especially important if the fill gas is used to maintain the required volume of gas when retorts are brought "on-line") to required levels. Because of these problems with premixed gas, it was decided to fill the loop initially with high purity helium, purified by passing the gas over liquid nitrogen cooled activated charcoal. This change also allows the use of one fill gas system for both loops, instead of the two fill gas systems originally planned.

High purity helium will be used only during the initial filling of the loops; this will allow determination of oxygen levels present in the loop when the loop purification system is not used. After loop start-up, the fill (maintenance) gas can be welding grade helium, which will be considerably less expensive (see Table 2.9 for estimated differences in costs). This helium also would be passed through liquid nitrogen cooled activated charcoal.

The purge gas system also was modified to include a liquid nitrogen activated charcoal trap. The trap is designed to remove oxygen and other impurities to levels well below those obtained by considerably more expensive commercially prepared high purity helium. After the initial fillup, most of the gas would be added to the system when a retort is opened to the loop, by pressurizing the retort with purified purge helium until the pressure corresponds roughly to that of the loop itself. Other minor adjustments to the loop gas volume would be taken up by the fill gas system. Small adjustments in the loop chemistry will be necessary after each retort is added, to bring the levels of H_2 , CO, CO_2 and CH_4 to the test specification.

During the bakeout of a retort containing new specimens, it is possible that the specimens may be exposed to a high oxygen level even before the retorts are opened to the loop. This could result from physical desorption

of oxygen from the retort surfaces. To minimize specimen oxidation, the purge gas, in addition to being purified over activated charcoal, will contain a fraction of hydrogen roughly corresponding to that found in the loop gas. The hydrogen will tend to shift the equilibrium oxygen level to a satisfactorily low value and will not be removed by the charcoal trap.

In the backup gas system, an attempt to getter as much oxygen as possible at the high flow rates anticipated will include two heated cannisters of copper catalyst in parallel followed by a container of 4 A molecular sieve. The copper reagent was chosen to replace the much more expensive Pt-Pd catalyst previously selected for this function. The 4 A sieves were selected for drying in place of the more potent magnesium perchlorate desiccant since the latter material could form a fine dust which could be carried into the system at high helium flow rates required for the back-up gas. While the equilibrium oxygen level of this system may exceed that found in the operating loop, the backup gas should help minimize any damage which might occur to the specimens during the event of a loop shut-down. Further protection will be afforded by specifying that the backup gas consist of ultrapure helium (total impurities <1ppm V), with ~ 500ppm V hydrogen to buffer against oxidation.

The suggested gas compositions to be used in routine loop operation are given in Table 2.9.

2.4.1.2 Construction - (C.L. Ehde)

Major effort during this past quarter has been in the area of hardware procurement and fabrication. The subassemblies of helium piping (utility frame helium distribution subassemblies) required to distribute helium to the screening creep test stands, aging/corrosion test stands, and 10 of the precision creep/rupture stands were completed (at AEP/Evendale) and shipped to the HTR/MTL in early September, 1977.

Figure 2.3 indicates the general fabrication status of the first controlled purity helium pumping, purification and analysis package. Shown is the back side of the control console. Shown are: (1) one of the two

Table 2.9

HELIUM GAS COMPOSITIONS TO BE USED IN
THE SIMULATED HTR HELIUM SUPPLY SYSTEM

<u>Purpose</u>	<u>Gas Composition</u>	<u>Subsequent Purification</u>	<u>Approximate Cost Per Cylinder (a)</u>
Initial Fill Gas	High Purity He	Activated Charcoal at 77°K	\$180
Fill (Maintenance) Gas	Welding Grade He	Activated Charcoal at 77°K	30
Purge Gas	Welding Grade He, ~500 ppm V H ₂	Activated Charcoal at 77°K	49
Backup Gas	High Purity He, ~500 ppm V H ₂	Cu catalyst at 500°K	200
Impurity Gas	99.99% CO, CO ₂ CH ₄ , or H ₂	None	50-250

(a) Price does not include cylinder demurrage charge.

FIGURE 2.3 Pumping, Purification and Analysis Subsystem for the HTR Helium Supply System

buffer tanks, (2) the four helium pumps (three are required for operational pumping, one on standby to be used in event of failure of any of the three operating pumps), (3) several of the purification systems cannisters, (4) four purification system furnaces, and (5) much of the stainless steel piping, valves, etc.

This sub-assembly and the associated consoles which house the gas analysis instrumentation, power supplies, GC annunciator and some of the system controls are about 75% complete. The first pumping and purification system, with its associated instruments and controls is now scheduled for shipment to the HTR/MTL by the end of November, 1977. All subassemblies required for the "helium" distribution system are scheduled for completion in early December, 1977. This represents a slippage of about three months in the original schedule; this slippage is due to procurement delays for many items (due to vendor's inability to meet promised schedules), and longer fabrication time requirements, partly due to changes in the design of the system (made for technical reasons -- i.e., to improve system performance).

2.4.2 Simulated Reactor Helium Instrumentation and Control System - (R.K. Elton)

2.4.2.1 Instrumentation

Four pieces of instruments ordered during the last quarter, the Carle AGC 111 gas chromatograph, the Veeco MS-9 helium leak detector, (Purchased by GE), the Shaw dew point meter, and the CSI integrator have arrived. The Shaw SADP portable dew point meter and the Antek 320 helium ionization gas chromatograph are scheduled to arrive in early October 1977. The helium leak detector has been checked out, and demonstrates excellent sensitivity in finding leaks when used either in the sniffing or evacuation modes. The other pieces of equipment are awaiting inspection, and will be calibrated and examined systematically during October.

2.4.2.2 Calibration of Instrumentation

The design of the analytical instrumentation calibration and support system, to accompany the loop console, has been completed, and the appropriate equipment is on order. The system is designed to permit routine calibration of the console gas chromatograph, and to supply it with purified helium to be

used as a carrier gas during normal operation. This helium is to be purified by means of an activated charcoal trap at 77°K which is shared by lines serving both the DCHT and the VHTR/NPH gas chromatographs.

By opening the appropriate valves, any one of the three gas streams may be directed to the gas chromatograph for sampling. Thus one may analyze loop gas, premixed calibration gas, or gas emanating from an exponential dilution flask. This latter piece of equipment, which continuously dilutes aliquots of known gas concentration at a predetermined rate, can generate very low concentration standards, and has the advantage of gas samples over a large range of concentrations so that a calibration curve may be constructed. However, since this is a time consuming procedure, requiring two to four hours to obtain a curve, it is not planned to be utilized routinely. The exponential dilution flask would be used primarily to calibrate the cylinders of commercially obtained premixed calibration gas. Once the cylinder has been accurately assayed it would be sampled routinely by the chromatograph as a means for providing a rapid calibration.

The calibration of the helium leak detector will be conducted using standard helium leaks which have already been purchased. The Shaw dew point meter has been supplied with a 10 point calibration curve for each probe, covering the concentration range from 0.2 to 10 ppm V H₂O. Since field studies by the manufacturer suggest that these probes retain their calibration after one year of service, no immediate calibration appears necessary. However, several ideas for future calibration are currently being entertained, including a vapor permeation tube, a catalytic water vapor generator (quantitative reaction of H₂ and O₂ over a catalyst), commercially available calibration standards of water vapor in compressed gas, and exponential vapor dilution. All of the equipment necessary to carry out these techniques is currently available on the market.

2.4.2.3 Startup Procedure

A preliminary draft of the loop startup procedure has been completed and is currently under review. The proposed startup would involve the basic elements listed in the following tabulation:

Basic Elements of Proposed Loop Startup

1. Instrumentation calibration and checkout
2. Functional/mechanical/electrical checkout
3. Regeneration of getters
4. Systematic evacuation, purging, and filling of loop components
5. Helium leak detection of console, main loop, distribution piping system, gas manifolds, etc.
6. Oxygen inleakage measurements in loop
7. Retort addition
8. Retort oxygen inleakage, desorption and bakeout effects measurements
9. Response time and characterization of loop for gas addition
10. Response time and characterization of loop for gas purification
11. Retort conditioning experiments
12. Attain and maintain test chemistry
13. Begin tests

Some of these tasks can be performed independently, and therefore some overlap of the tasks is possible.

The functional/mechanical/electrical checkout will require some preliminary work prior to installation and will be continued when the console and pumping purification package have been installed. After the welding is completed and the final connections are made between the loop and the console, the loop must be evacuated and the volatile impurities lining the walls of the tubing desorbed. This task should be performed systematically to characterize related sections of the loop simultaneously. These sections are subsequently to be filled with purified helium. Once this gas is circulating, sensitive measurements of changes in the ambient oxygen concentration will be made, and should lead to conclusions about oxygen inleakage and desorption in the system. The presence of H_2 or CO in the initial fill gas would not allow these effects to be readily observed, and therefore a premixed gas will not be used in this phase of the startup. Similarly, several measurements of the retort gas chemistry will be made to establish the extent to which inleakage, desorption and pyrolysis reactions affect the gas chemistry as the retort is coming up to temperature. From this information, a temperature-time program to allow for a safe thermal bakeout will be constructed, insuring that adsorbed contaminants are sufficiently removed before the specimens reach a temperature where extensive reaction could occur.

Measurements of various loop parameters (concentration change, equilibrium rates, etc.) for both gas addition and purification are also planned as part of the startup procedure. These data will serve to characterize the loop and facilitate adjustments in the gas chemistry once the system becomes operational.

2.5 TASK 5 - MECHANICAL PROPERTY EVALUATION - (S.Z. Hayden)

2.5.1 Test Matrices

2.5.1.1 Screening Creep Tests

Details of the proposed tests for the materials chosen for the screening studies (See Tables 2.1 and 2.3) are given in Tables 2.10 to 2.16.

Tables 2.10 to 2.12 cover the proposed screening creep tests. Table 2.10 shows that each material will be tested, nominally, at three different stress levels, with different total test durations to times $\geq 10,000$ hours. Strain will be measured approximately every 1000 hours until termination of the test. Table 2.11 gives the test temperatures for each material for tests in controlled purity helium. Each material will be tested at a minimum of three temperatures; certain lower strength alloys will be tested only at 750° , 850° , and 950°C ; some stronger alloys at 850° , 950° , and 1050°C ; and the rest of the materials will be tested at all four temperatures. Screening creep tests that will be run in air, at 850° and 950°C , for comparison purposes, are listed in Table 2.12.

2.5.1.2 Screening Structural Stability Tests (Bulk and Surface)

Specimens to be exposed in the unstressed condition in controlled purity helium are listed in Table 2.13. The specimen size is a 6.35 mm (0.25 in.) diameter x 25.4mm (1 in.) long pins. Although part of Task 6 and Task 7, this test matrix is presented here for comparison purposes. These specimens will be studied by weight change and surface structure characterization methods (Task 7) and hardness and bulk microstructure characterization methods (Task 6). Exposure times will be identical to those for the screening creep specimens, plus an exposure of 1000 hours, at all four test temperatures (750° , 850° , 950° , 1050°C). Note that the pre-oxidized samples will be exposed only for 10,000 hours, and the welded samples for 1000 and 10,000 hours.

Again, for purposes of providing a "standard reference", the samples indicated in Table 2.14 will be exposed in air for 3000 and 10,000 hours.

Tensile and impact specimens will be tested at room temperature after being exposed in controlled purity helium. The materials and exposure conditions are shown in Tables 2.15 and 2.16 respectively. Note that tensile specimens will be exposed for 3000, 6000 and $\geq 10,000$ hours and impact specimens for 3000 and $\geq 10,000$ hours. Also only NPH alloys are to be tested in impact.

Table 2.10

STRESS LEVEL AND TEST DURATION CONDITIONS FOR SCREENING CREEP TESTS

Stress Level	Test Duration
80% Stress for Rupture in 10,000 Hours	3000 Hours
100% Stress for 1% Total Strain in 6000 Hours	6000 Hours
100% Stress for 1% Total Strain in 100,000 Hours	≥10,000 Hours

Table 2.11
SCREENING CREEP TEST MATRIX
(Controlled Purity Helium)

Material	Test Temperature (°C) (a)			
	750	850	950	1050
TZM-Coated		X	X	X
MA-754		X	X	X
MM-0011	X	X	X	X
MM-0011 DS	X	X	X	X
Rene 80	X	X	X	
Rene 100	X	X	X	X
Alloy 713 LC	X	X	X	
IN-738	X	X	X	X
Udimet 720	X	X	X	
NX 188	X	X	X	
Incoloy 800H	X	X	X	
Incoloy 800H-Coated	X	X	X	
Incoloy 802	X	X	X	
Incoloy 807	X	X	X	X
Incoloy DS	X	X	X	
HD-556	X	X	X	X
Manaurite 36XS	X	X	X	X
HK-40	X	X	X	X
IN-519	X	X	X	X
Hastelloy X	X	X	X	X
Inconel 617	X	X	X	X
Inconel 617-Coated	X	X	X	X
Mo-Re2	X	X	X	X
MA-956E		X	X	X

(a) Three tests (3 stress levels) at each temperature.

Table 2.12

SCREENING CREEP TEST MATRIX (AIR)

Material	Test Temperature (^o C) (a)	
	850	950
TZM-Coated	X	X
MA-754	X	X
MM-0011	X	X
MM-0011 DS	X	X
Rene' 80	X	X
Rene' 100	X	X
Alloy 713 LC	X	X
IN-738	X	X
Udimet 720	X	X
NX-188	X	X
Incoloy 800H	X	X
Incoloy 800H-Coated	X	X
Incoloy 802	X	X
Incoloy 807	X	X
Incoloy DS	X	X
HD-556	X	X
Manaurite 36XS	X	X
HK-40	X	X
IN-519	X	X
Hastelloy X	X	X
Inconel 617	X	X
Inconel 617-Coated	X	X
Mo-Re 2	X	X
MA-956E	X	X

(a) Three tests (3 stress levels) at each temperature

Table 2.13

SCREENING STRUCTURAL STABILITY TEST MATRIX

(Controlled Purity Helium)

Material	Exposure Time (Hours) (a)			
	1000	3000	6000	≥10,000
TZM	X	X	X	X
TZM-Coated	X	X	X	X
YD-Ni	X	X	X	X
MA-754	X	X	X	X
YD-NiCrAl	X	X	X	X
MM-0011	X	X	X	X
MM-0011 DS	X	X	X	X
Rene' 80	X	X	X	X
Rene' 80-Preoxidized				X
Rene' 100	X	X	X	X
M-21	X	X	X	X
M-21-Preoxidized				X
Alloy 713 LC	X	X	X	X
Alloy 713 LC-Coated	X	X	X	X
Alloy 713 LC-Coated & Preoxidized				X
IN-738	X	X	X	X
Udimet 720	X	X	X	X
NX-188	X	X	X	X
Incoloy 800H	X	X	X	X
Incoloy 800H-Coated	X	X	X	X
Incoloy 802	X	X	X	X
Incoloy 807	X	X	X	X
Incoloy DS	X	X	X	X
HD-556	X	X	X	X
Manaurite 36XS	X	X	X	X
Manaurite 900	X	X	X	X
HK-40	X	X	X	X
IN-519	X	X	X	X
Hastelloy X	X	X	X	X
Inconel 617	X	X	X	X
Inconel 617-Coated	X	X	X	X
Inconel 618E	X	X	X	X
Mo-Re 2	X	X	X	X
MA-956E	X	X	X	X

Cont'd.

Table 2.13 (Cont'd.)

SCREENING STRUCTURAL STABILITY TEST MATRIX
(Controlled Purity Helium)

Material	Exposure Time (Hours) (a)			
	1000	3000	6000	10000
Incoloy 800H-Welded	X			X
Incoloy 802-Welded	X			X
Incoloy 807-Welded	X			X
Incoloy DS-Welded	X			X
HD-556-Welded	X			X
Manaurite 36XS-Welded	X			X
HK-40-Welded	X			X
IN-519-Welded	X			X
Hastelloy X-Welded	X			X
Inconel 617-Welded	X			X
MO-Re 2-Welded	X			X

(a) Exposure temperatures: 750°, 850°, 950°, and 1050°C for each exposure time indicated in the table. Also, one as-received sample of each material will be examined.

Table 2.14

SCREENING STRUCTURAL STABILITY TEST MATRIX (AIR)

Material	Exposure Time (Hours) ^a	
	3000	>10,000
TZM	X	X
YD-Ni	X	X
MA-754	X	X
YD-NiCrAl	X	X
MM-0011	X	X
MM-0011DS	X	X
Rene' 80	X	X
Rene' 100	X	X
M-21	X	X
Alloy 713LC	X	X
IN-738	X	X
Udimet 720	X	X
NX-188	X	X
Incoloy 800H	X	X
Incoloy 802	X	X
Incoloy 807	X	X
Incoloy DS	X	X
HD-556	X	X
Manaurite 36XS	X	X
Manaurite 900	X	X
HK-40	X	X
IN-519	X	X
Hastelloy-X	X	X
Inconel 617	X	X
Inconel 618E	X	X
Mo-Re 2	X	X
MA-956E	X	X
Incoloy 800H-Welded		X
Incoloy 802-Welded		X
Incoloy 807-Welded		X
Incoloy DS-Welded		X
HD-556-Welded		X

Table 2.14 (Cont.)

SCREENING STRUCTURAL STABILITY TEST MATRIX (AIR)

Material	Exposure Time (Hours) ^a	
	3000	>10,000
Manaurite 36XS-Welded		X
HK-40 - "		X
IN-519 - "		X
Hastelloy X - "		X
Inconel 617 - "		X
Mo-Re 2 - "		X

(a) Exposure Temperatures: 750°, 850°, 950°, and 1050°C for each exposure time indicated in the table.

Table 2.15

SCREENING PROGRAM - TENSILE TESTS^(a)
(Exposed in Controlled Purity Helium)

Material	Test Temperature (°C) ^(b)			
	750	850	950	1050
TZM - Coated		X	X	X
MA-754		X	X	X
MM-0011	X	X	X	X
MM-0011 DS	X	X	X	X
Rene' 80	X	X	X	
Rene' 100	X	X	X	X
Alloy 713 LC	X	X	X	
Alloy 713 LC - Coated	X	X	X	
IN-738	X	X	X	X
Udimet 720	X	X	X	
NX-188	X	X	X	
Incoloy 800H	X	X	X	
Incoloy 800H - Coated	X	X	X	
Incoloy 802	X	X	X	
Incoloy 807	X	X	X	X
Incoloy DS	X	X	X	
HD-556	X	X	X	X
Manaurite 36XS	X	X	X	X
HK-40	X	X	X	X
IN-519	X	X	X	X
Hastelloy X	X	X	X	X
Inconel 617	X	X	X	X
Inconel 617 - Coated	X	X	X	X
Mo-Re 2	X	X	X	X
MA-956E		X	X	X

(a) Post exposure tensile tests to be conducted at room temperature.

(b) Exposure Times: 3000, 6000, and ≥ 10,000 hours at each exposure temperature. Also, two as-received tensile specimens for each material.

Table 2.16

SCREENING PROGRAM-IMPACT TESTS^(a)
(Exposed in Controlled Purity Helium)

Material	Exposure Temperature (°C) ^(b)			
	750	850	950	1050
Incoloy 800H	X	X	X	
Incoloy 800H - Coated	X	X	X	
Incoloy 802	X	X	X	
Incoloy 807	X	X	X	X
Incoloy DS	X	X	X	
HD-556	X	X	X	X
Manaurite 36XS	X	X	X	X
HK-40	X	X	X	X
IN-519	X	X	X	X
Hastelloy X	X	X	X	X
Inconel 617	X	X	X	X
Inconel 617 - Coated	X	X	X	X
Mo-Re 2	X	X	X	X
MA-956E		X	X	X

(a) Post exposure impact tests to be conducted at room temperature.

(b) Exposure Times: 300 and $\geq 10,000$ hours at each exposure temperature. Also two as-received impact specimens for each material.

2.5.1.3 Intensive Test Program

The intensive test program planned for the materials selected from the screening studies is presented in summary form in Table 2.17. Less detail is available for these tests since it is not possible to know at this time which alloys, coatings, etc. will be selected or what the critical exposure temperatures and times will be for the intensive program.

2.5.2 Screening Creep Loading Schedule

The screening test stresses have been determined for 1% total strain in 100,000 hours (to be tested for at least 10,000 hours), 1% total strain in 6,000 hours (to be tested for 6,000 hours), and 80% of the stress for rupture in 10,000 hours (to be tested for 3,000 hours). The first condition (1% ϵ_T in 100,000 hrs.) was selected to most nearly represent component hardware stresses encountered during actual service conditions. The three (3) stress values for each DCHT and NPH alloy were determined for each of the four (4) screening test temperatures [750°C (1385°F), 850°C (1562°F), 950°C (1742°F) and 1050°C (1922°F)]. Test stresses for the DCHT and NPH materials are presented in Table 2.18 and 2.19, respectively. Test values for the DCHT alloys were established in the main from GE Aircraft Engine experience. Considering the NPH alloys, stresses are usually interpolated or extrapolated directly from vendor supplied creep and rupture data. However, for a limited number of alloys (Incoloy DS, Incoloy 807, MA-956E, HD-556 and Manaurite 36XS) creep data was simply not available in vendor brochures or the open literature. When data was not available, the material vendors were contacted and requested to supply the appropriate creep values. To date, creep data has not been received for the above five alloys and for the purposes of designing a "controlled-purity" helium screening creep loading matrix the Gill-Goldhoff Relationship⁽²⁾ was employed to obtain the required creep lives. Test stress values range from 66 ksi (1% ϵ_T in 6,000 hours) for MM-0011 and MM-0011DS at 750°C (1382°F) to 0.1 ksi (1% ϵ_T in 100,000 hours) for Hastelloy X at 1050°C (1922°F).

Table 2.17

SUMMARY OF INTENSIVE TEST PROGRAM

Type of Test	Test Conditions	Number of Test Specimens	
		NPH	DCHT
Creep	"He" : 750°, 850°, 950°, 1050°C at stress levels to produce 1% total strain in 100, 1000, & 10,000 hours.	96	72
	Air : 750°, 850°, 950°, 1050°C at stress level to produce 1% total strain in ~ 1000 hours.	24	16
Stress-Rupture	"He" : 750°, 850°, 950°, 1050°C, at stress levels to cause rupture in ~ 300, 1000, & 10,000 hours.	95	72
	Air : 750°, 850°, 950°, 1050°C at stress levels to produce rupture in ~ 300, 1000, 3000 hours (includes one stress level from screening tests).	43	36
Fatigue (in "He")	<p>High Cycle: On as-received material: 3 stress ranges, 2 A (aspect) ratios, at 750 & 850°C (duplicate samples)</p> <p>On material exposed for worst case temp./time, as determined from screening program; 3 stress ranges, 1 A ratio, at 750° & 850°C.</p> <p>Low Cycle: On as-received material: 3 strain ranges, duplicate samples, at 750°C & 850°C.</p> <p>On material exposed for worst case temp./time, as determined from screening program; 3 strain ranges, at 750° & 850°C.</p>	180	120

Table 2.17 (Continued)
SUMMARY OF INTENSIVE TEST PROGRAM

Type of Test	Test Conditions	Number of Test Specimens	
		NPH	DCHT
Structural (Bulk/Surface) Stability	Environment #2: 750°, 850°, 950°, 1050°C 1000-Hr. (M,W,T), 3000 Hr. (M), 6000 Hr. (M), ≥ 10,000 Hr. (M,W,T)	M 128 W 32 T 64 I 24	M 96 W 8 T 48 --
Elevated Temperature Tensile	Test Temp.: Same as exposure and/or creep temperatures Exposure Temp.: 750°, 850°, 950°, 1050°C Exposure Time: Critical time as established in screening program	32	24
	Test Temp.: 400°C, 650°C Exposure Temp.: 750°, 850°, 950°, 1050°C Exposure Time: Critical time as established in screening program	64	48
Elevated Temperature Impact	Test Temp.: 550°C Exposure Temp.: 2 temperatures, selected from screening studies Exposure Time: critical exposure time as established in screening program.	24	
Weld Tests	Room temperature bend tests after 1000- and 10,000- Hr. exposures at 750°, 850°, 950°, 1050°C	32	8

Code: M = Metallography
W = Weld
T = Tensile
I = Impact

Materials Selection: Materials selection will be based on results from the screening program

- o For Nuclear Process Heat Materials, up to 6 alloys, 2 coating systems, and 4 welded alloys will be tested.
- o For Direct Cycle Helium Turbine applications, up to 4 alloys, 2 coating systems and 1 welded alloy will be tested.

Table 2.18

DESIRED (CALCULATED) STRESSES FOR DCHT MATERIALS
CONTROLLED-PURITY HELIUM SCREENING CREEP TEST

Alloy	Temperature °C	Stress for 1% ϵ_T in 100,000 hours (ksi)	Stress for 1% ϵ_T in 6,000 hours (ksi)	Stress for 80% σ_R in 10,000 hours ^R (ksi)
Rene' 80	750	30	50	44
	850	13	27	21
	950	3	12	4
	1050	4	2	2.5
Rene' 100	750	40	55	46
	850	14	28	20
	950	2	8	4
	1050	0.2	0.5	1.5
MM-0011	750	50	66	54
MM-0011DS	850	23	35	27
NX-188	950	7	12	10
	1050	2	3	3
IN-738	750	30	50	41
	850	13	22	17
	950	4	12	8
	1050	1	2	1.5
IN-713LC	750	27	45	36
Udimet-720	850	11	21	16
	950	1	5	3
	--	--	--	--
MA-754	750	15	24	21
	850	12	18	17
	950	8	14	12
	1050	5	11	8
TZM	750	60	68	67
(To be	850	50	58	52
Evaluated	950	40	46	36
Coated)	1050	30	38	21
Range of	750	15-50 (60)	24-66 (68)	21-54 (67)
Desired	850	11-23 (50)	18-35 (58)	16-27 (52)
Stresses	950	1-8 (40)	5-14 (46)	3-12 (36)
(TZM)	1050	0.2-5 (30)	0.5-11 (38)	1.5-8 (21)

Table 2.19

DESIRED (CALCULATED) STRESSES FOR VHTR/NPH MATERIALS
CONTROLLED PURITY HELIUM SCREENING CREEP TEST

Alloy	Temperature °C	Stress for 1% ϵ_T in 10,000 hours ^T (ksi)	Stress in 1% ϵ_T in 6,000 hours ^T (ksi)	Stress for 80% σ_R in 10,000 hours ^R (ksi)
Incoloy 800H	750	5	7	7
Incoloy 800H	850	3	4	3
Coated	950	0.4	1	1
	1050	0.2	0.2	0.5
Incoloy 802	750	8	12	10
	850	3	7	4
	950	1	2	2
	1050	0.2	0.5	0.6
Incoloy 807	750	6	10	10
	850	2	4	4
	950	0.7	1	2
	1050	0.2	0.4	0.4
Incoloy DS	750	2	4	4
	850	1	2	2
	950	0.4	0.7	1
	1050	0.2	0.3	0.5
HD-556	750	7	12	11
	850	2	5	5
	950	0.7	2	2
	1050	0.2	0.4	0.6
Manaurite 36XS	750	6	9	9
	850	3	4	5
	950	1	2	2
	1050	0.3	0.8	1
HK-40	750	8	13	7
	850	3	5	4
	950	1	2	2
	1050	0.4	0.7	1
IN-519	750	7	10	9
	850	3	6	5
	950	1	3	2
	1050	0.4	1	1
Hastelloy X	750	5	8	9
	850	2	3	4
	950	0.6	1	2
	1050	0.1	0.3	0.4
Inconel 617	750	8	12	14
Inconel 617	850	3	5	6
Coated	950	1	2	3
	1050	0.6	1	1

Table 2.19 (Continued)

DESIRED (CALCULATED) STRESSES FOR VHTR/NPH MATERIALS
CONTROLLED PURITY HELIUM SCREENING CREEP TEST

<u>Alloy</u>	<u>Temperature °C</u>	<u>Stress for 1% ϵ_T in 10,000 hours (ksi)</u>	<u>Stress in 1% ϵ_T in 6,000 hours (ksi)</u>	<u>Stress for 80% σ_R in 10,000 hours (ksi)</u>
Mo-Re 2	750	5	7	19
	850	3	4	8
	950	2	3	3
	1050	1	2	1
MA-956E	750	10	11	12
	850	8	9	10
	950	7	8	8
	1050	5	6	7
Range of Desired Stresses	750	2-10	4-13	4-19
	850	1-8	2-9	2-10
	950	0.4-7	0.7-8	1-8
	1050	0.1-5	0.2-6	0.4-7

The screening program currently includes 24 alloy/processes that are candidate materials for key components of NPH or DCHT systems which will be evaluated in the "controlled-purity" helium screening creep study. Since test furnace space is limited and because 1050°C (1922°F) is above the design operating temperature for many of the alloys in the program, eleven (11) of the alloy/processes will be evaluated at three of the four test temperatures, while the remainder will be evaluated at each of the four test temperatures. Table 2.11 presented the alloy/test temperature combinations to be employed in the screening creep portion of the program. It should be noted that although 1050°C (1922°F) is anticipated to be above the design operating temperature for Rene' 100 and IN-738, for helium turbine applications, these materials are also candidates for ducting components (e.g. attachment fixtures) and therefore should be tested at the highest temperature.

"Controlled-purity" helium screening creep loading matrices have been compiled and are presented in Tables 2.20, 2.21, 2.22 and 2.23 for test temperatures 750°C (1382°F), 850°C (1562°F), 950°C (1742°F) and 1050°C (1922°F), respectively. Two (2) different specimens have been employed; however, to maintain as much consistency as possible, a particular specimen gauge diameter has been maintained within a generic alloy class: 6.4mm (0.252 in.) diameter for helium turbine candidate alloys (for vane, bucket, etc. applications), 9.53mm (0.357 in.) diameter for nuclear process heat candidate alloys as presented in Table 2.24. The two screening creep specimens were illustrated in Table 2.8. The rationale behind the selection of two (2) different size screening creep specimen gauge diameters is presented below:

1. Each of the six GE multi-specimen screening creep furnaces contain six strings, allowing the application of six different load levels for a given temperature. However, as can be seen from inspection of Tables 2.20 - 2.23, a broad spectrum of stress levels are required to fulfill the test requirements at any particular screening temperature. For example, 26 different stress levels are specified for the 750°C (1382°F) test temperature, with a greater than an order-of-magnitude stress level difference between the

Table 2.20

LOADING PLAN FOR 750°C (1382°F) SCREENING CREEP FURNACE

Desired Stress (ksi)	Alloy	Condition	Specimen Type/ Stringer No.	Test Stress (ksi)	Desired Stress (ksi)	Alloy	Condition	Specimen Type/ Stringer No.	Test Stress (ksi)
66	MM-0011	1% 6x10 ³	B/6	54.0	11	HD-556	0.8R10 ⁴	C/2(D-3)	9.0
66	MM-0011 DS	1% 6x10 ³	B/6	54.0	10	Incoloy 802	0.8R10 ⁴	C/2(D-2)	9.0
66	NX-188	1% 6x10 ³	B/6	54.0	10	Incoloy 807	0.8R10 ⁴	C/3	13.5
55	Rene' 100	1% 6x10 ³	B/6	54.0	10	Incoloy 807	1% 6x10 ³	C/2(R-2)	9.0
54	MM-0011	0.8R10 ⁴	B/6	54.0	10	IN-519	1% 6x10 ³	C/3	13.5
54	MM-0011 DS	0.8R10 ⁴	B/6	54.0	9	Manaurite 36XS	0.8R10 ⁴	C/3	13.5
54	NX-188	0.8R10 ⁴	B/6	54.0	9	Manaurite 36XS	1% 6x10 ³	C/2(R-3)	9.0
50	Rene' 80	1% 6x10 ³	B/6	54.0	9	IN-519	0.8R10 ⁴	C/2(D-8)	9.0
50	IN-738	1% 6x10 ³	B/6	54.0	9	Hastelloy X	0.8R10 ⁴	C/2(D-4)	9.0
50	MM-0011	1% 10 ⁵	B/5	44.0	8	Inconel 617	1% 10 ⁵	C/2	9.0
50	MM-0011 DS	1% 10 ⁵	B/5	44.0	8	Inconel 617*	1% 10 ⁵	C/2	9.0
50	NX-188	1% 10 ⁵	B/5	44.0	8	Hastelloy X	1% 6x10 ³	C/2(R-4)	9.0
46	Rene' 100	0.8R10 ⁴	B/5	44.0	7	Incoloy 802	1% 10 ⁵	C/1	5.0
45	Udimet 720	1% 6x10 ³	B/5	44.0	7	Incoloy 800H	0.8R10 ⁴	C/2(D-6)	9.0
45	IN-713LC	1% 6x10 ³	B/5	44.0	7	HD-556	1% 10 ⁵	C/2	9.0
44	Rene' 80	0.8R10 ⁴	B/5	44.0	7	HK-40	0.8R10 ⁴	C/2(D-5)	9.0
41	IN-738	0.8R10 ⁴	B/5	44.0	7	Mo-Re 2	1% 6x10 ³	C/2(R-5)	9.0
40	Rene' 100	1% 10 ⁵	B/4	36.0	6	IN-519	1% 10 ⁵	C/1	5.0
36	Udimet 720	0.8R10 ⁴	B/4	36.0	6	HK-40	1% 10 ⁵	C/1	5.0
36	IN-713LC	0.8R10 ⁴	B/4	36.0	7	Incoloy 800H	1% 6x10 ³	C/2(R-6)	9.0
30	Rene' 80	1% 10 ⁵	B/3	27.0	6	Manaurite 36XS	1% 10 ⁵	C/1	5.0
30	IN-738	1% 10 ⁵	B/3	27.0	6	Incoloy 807	1% 10 ⁵	C/1	5.0
27	Udimet 720	1% 10 ⁵	B/3	27.0	5	Hastelloy X	1% 10 ⁵	C/1	5.0
27	IN-713LC	1% 10 ⁵	B/3	27.0	5	Mo-Re 2	1% 10 ⁵	C/1	5.0
19	Mo-Re 2	0.8R10 ⁴	C/4	18.0	5	Incoloy 800H	1% 10 ⁵	C/1	5.0
14	Inconel 617	0.8R10 ⁴	C/3	13.5	4	Incoloy DS	0.8R10 ⁴	C/1(D-7)	5.0
14	Inconel 617*	0.8R10 ⁴	C/3	13.5	4	Incoloy DS	1% 6x10 ³	C/1(R-7)	5.0
13	HK-40	1% 6x10 ³	C/3	13.5	2	Incoloy DS	1% 10 ⁵	C/1	5.0
12	Incoloy 802	1% 6x10 ³	C/3	13.5	7	Incoloy 800H*	0.8x10 ⁴	C/2(D-1)	9.0
12	HD-556	1% 6x10 ³	C/3	13.5	7	Incoloy 800H*	1% 6x10 ³	C/2(R-8)	9.0
12	Inconel 617	1% 6x10 ³	C/2	9.0	5	Incoloy 800H*	1% 10 ⁵	C/1	5.0
12	Inconel 617*	1% 6x10 ³	C/2(R-1)	9.0					

* - Coated

R - Replacement at 3,000 hrs.

D - Discontinue at 3,000 hrs.

e.g. spec.(R-1) replaces spec. (D-1) at 3,000 hrs.

Key: 1% 6x10³ : 100% Stress for 1% Total Strain in 6,000 hrs.
 1% 10⁵ : 100% Stress for 1% Total Strain in 100,000 hrs.
 0.8R10⁴ : 80% Stress for Rupture in 10,000 hrs.

Table 2.21

LOADING PLAN FOR 850°C (1562°F) SCREENING CREEP FURNACE

Desired Stress (ksi)	Alloy	Condition	Specimen Type/ Stringer No.	Test Stress (ksi)	Desired Stress (ksi)	Alloy	Condition	Specimen Type/ Stringer No.	Test Stress (ksi)
58	TZM	1% 6x10 ³	B/6 (a)	27.0	6	Inconel 617	0.8R10 ⁴	C/4	7.0
52	TZM	0.8R10 ⁴	B/6 (a)	27.0	6	Inconel 617*	0.8R10 ⁴	C/4	7.0
50	TZM	1% 10 ⁵	B/6 (a)	27.0	5	HD-556	0.8R10 ⁴	C/3	5.5
35	MM-0011	1% 6x10 ³	B/6	27.0	5	HD-556	1% 6x10 ³	C/2	4.0
35	MM-0011DS	1% 6x10 ³	B/6	27.0	5	Manaurite 36XS	0.8R10 ⁴	C/3	5.5
35	NX-188	1% 6x10 ³	B/6	27.0	5	HK-40	1% 6x10 ³	C/3	5.5
28	Rene' 100	1% 6x10 ³	B/6	27.0	5	IN-519	0.8R10 ⁴	C/3	5.5
27	Rene' 80	1% 6x10 ³	B/6	27.0	5	Inconel 617	1% 6x10 ³	C/3	5.5
27	MM-0011	0.8R10 ⁴	B/6	27.0	5	Inconel 617*	1% 6x10 ³	C/3	5.5
27	MM-0011DS	0.8R10 ⁴	B/6	27.0	4	Mo-Re 2	1% 6x10 ³	C/2	4.0
27	NX-188	0.8R10 ⁴	B/6	27.0	4	Hastelloy X	0.8R10 ⁴	C/2(D-3)	4.0
23	MM-0011	1% 10 ⁵	B/5	21.0	4	HK-40	0.8R10 ⁴	C/2(D-4)	4.0
23	MM-0011DS	1% 10 ⁵	B/5	21.0	4	Incoloy 807	0.8R10 ⁴	C/3	5.5
23	NX-188	1% 10 ⁵	B/5	21.0	4	Incoloy 807	1% 6x10 ³	C/2(R-2)	4.0
22	IN-738	1% 6x10 ³	B/5	21.0	4	Incoloy 802	0.8R10 ⁴	C/2(D-7)	4.0
21	Rene' 80	0.8R10 ⁴	B/5	21.0	4	Manaurite 36XS	1% 6x10 ³	C/2(R-3)	4.0
21	Udimet 720	1% 6x10 ³	B/5	21.0	4	Incoloy 800H	1% 6x10 ³	C/2(R-4)	4.0
21	IN-713LC	1% 6x10 ³	B/5	21.0	3	Incoloy 800H	0.8R10 ⁴	C/2(D-2)	4.0
20	Rene' 100	0.8R10 ⁴	B/5	21.0	3	Manaurite 36XS	1% 10 ⁵	C/2	4.0
18	MA-754	1% 6x10 ³	B/5	21.0	3	IN-519	1% 10 ⁵	C/1	2.0
17	MA-754	0.8R10 ⁴	B/4	14.0	3	Hastelloy X	1% 6x10 ³	C/2(R-5)	4.0
17	IN-738	0.8R10 ⁴	B/4	14.0	3	Inconel 617	1% 10 ⁵	C/2	4.0
16	Udimet 720	0.8R10 ⁴	B/4	14.0	3	Inconel 617*	1% 10 ⁵	C/2	4.0
16	IN-713LC	0.8R10 ⁴	B/4	14.0	3	Mo-Re 2	1% 10 ⁵	C/1	2.0
14	Rene' 100	1% 10 ⁵	B/4	14.0	2	Incoloy 802	1% 10 ⁵	C/1	2.0
13	Rene' 80	1% 10 ⁵	B/4	14.0	2	HK-40	1% 10 ⁵	C/1	2.0
13	IN-738	1% 10 ⁵	B/3	11.0	3	Incoloy 800H	1% 10 ⁵	C/1	2.0
12	MA-754	1% 10 ⁵	B/3	11.0	2	Incoloy 807	1% 10 ⁵	C/1	2.0
11	Udimet 720	1% 10 ⁵	B/3	11.0	2	Incoloy DS	0.8R10 ⁴	C/1(D-6)	2.0
11	IN-713LC	1% 10 ⁵	B/3	11.0	2	Incoloy DS	1% 6x10 ³	C/1(R-6)	2.0
10	MA-956E	0.8R10 ⁴	B/3(D-1)	11.0	2	HD-556	1% 10 ⁵	C/1	2.0
9	MA-956E	1% 6x10 ³	B/3(R-1)	11.0	2	Hastelloy X	1% 10 ⁵	C/1	2.0
8	Mo-Re 2	0.8R10 ⁴	C/4	7.0	1	Incoloy DS	1% 10 ⁵	C/1	2.0
7	MA-956E	1% 10 ⁵	B/2	8.0	4	Incoloy 800H*	1% 6x10 ³	C/2(R-7)	4.0
7	Incoloy 802	1% 6x10 ³	C/4	7.0	3	Incoloy 800H*	0.8R10 ⁴	C/2(D-5)	4.0
6	IN-519	1% 6x10 ³	C/4	7.0	3	Incoloy 800H*	1% 10 ⁵	C/1	2.0

(a) Note - 3 TZM spec. also to be tested in single spec. stands at desired stress levels in addition to tests in table.

* - Coated

R - Replacement at 3,000 hrs.

D - Discontinue at 3,000 hrs.

e.g. spec. (R-1) replaces spec. (D-1) at 3,000 hrs.

Key: 1% 6x10³ : 100% Stress for 1% Total Strain in 6,000 hrs.
 1% 10⁵ : 100% Stress for 1% Total Strain in 100,000 hrs.
 0.8R10⁴ : 80% Stress for Rupture in 10,000 hrs.

Table 2.22

LOADING PLAN FOR 950°C (1742°F) SCREENING CREEP FURNACE

Desired Stress (ksi)	Alloy	Condition	Specimen Type/ Stringer No.	Test Stress (ksi)	Desired Stress (ksi)	Alloy	Condition	Specimen Type/ Stringer No.	Test Stress (ksi)
46	TZM	1% 6x10 ³	B/6(a)	12.0	2	Incoloy 802	0.8R10 ⁴	C/4(D-3)	3.0
40	TZM	1% 10 ⁵	B/6(a)	12.0	2	Incoloy 802	1% 6x10 ³	C/4(R-3)	3.0
36	TZM	0.8R10 ⁴	B/6(a)	12.0	2	Incoloy 807	0.8R10 ⁴	C/3	2.0
14	MA-754	1% 6x10 ³	B/6	12.0	2	HD-556	0.8R10 ⁴	C/4	3.0
12	MM-0011	1% 6x10 ³	B/6	12.0	2	HD-556	1% 6x10 ³	C/3	2.0
12	MM-0011DS	1% 6x10 ³	B/6	12.0	2	Manaurite 36XS	0.8R10 ⁴	C/4	3.0
12	NX-188	1% 6x10 ³	B/6	12.0	2	Manaurite 36XS	1% 6x10 ³	C/3	2.0
12	IN-738	1% 6x10 ³	B/6	12.0	2	HK-40	0.8R10 ⁴	C/4	3.0
12	Rene' 80	1% 6x10 ³	B/6	12.0	2	HK-40	1% 6x10 ³	C/3	2.0
12	MA-754	0.8R10 ⁴	B/5	9.0	2	IN-519	0.8R10 ⁴	C/3(D-4)	2.0
10	MM-0011	0.8R10 ⁴	B/5	9.0	2	Hastelloy X	0.8R10 ⁴	C/3(D-5)	2.0
10	MM-0011DS	0.8R10 ⁴	B/5	9.0	2	Inconel 617	1% 6x10 ³	C/3(R-4)	2.0
10	NX-188	0.8R10 ⁴	B/5	9.0	2	Inconel 617*	1% 6x10 ³	C/3(R-5)	2.0
8	MA-754	1% 10 ⁵	B/4	6.0	2	Mo-Re 2	1% 10 ⁵	C/2	1.0
8	IN-738	0.8R10 ⁴	B/5	9.0	1	Udimet 710	1% 10 ⁵	B/1	1.0
8	Rene' 100	1% 6x10 ³	B/5	9.0	1	IN-713LC	1% 10 ⁵	B/1	1.0
8	MA-956E	1% 6x10 ³	B/5	9.0	1	Incoloy 800H	0.8R10 ⁴	C/3	2.0
8	MA-956E	0.8R10 ⁴	B/5	9.0	1	Incoloy 800H	1% 6x10 ³	C/2	1.0
7	NX-188	1% 10 ⁵	B/4	6.0	1	Incoloy 802	1% 10 ⁵	C/2	1.0
7	MM-0011	1% 10 ⁵	B/4	6.0	1	Incoloy 807	1% 6x10 ³	C/2	1.0
7	MM-0011DS	1% 10 ⁵	B/4	6.0	1	Incoloy DS	0.8R10 ⁴	C/2(D-7)	1.0
6	MA-956E	1% 10 ⁵	B/4	6.0	1	Manaurite 36XS	1% 10 ⁵	C/2	1.0
5	Udimet 720	1% 6x10 ³	B/3	4.0	1	HK-40	1% 10 ⁵	C/2	1.0
5	IN-713LC	1% 6x10 ³	B/3	4.0	1	IN-519	1% 10 ⁵	C/2	1.0
4	Rene' 80	0.8R10 ⁴	B/3	4.0	1	Hastelloy X	1% 6x10 ³	C/2(R-5)	1.0
4	Rene' 100	0.8R10 ⁴	B/3	4.0	1	Inconel 617	1% 10 ⁵	C/1	0.5
4	IN-738	1% 10 ⁵	B/3	4.0	1	Inconel 617*	1% 10 ⁵	C/1	0.5
3	Udimet 720	0.8R10 ⁴	B/2(D-1)	2.0	0.7	Incoloy 807	1% 10 ⁵	C/1	0.5
3	IN-713LC	0.8R10 ⁴	B/2(R-1)	2.0	0.7	HD-556	1% 10 ⁵	C/1	0.5
3	Rene' 80	1% 10 ⁵	B/2	2.0	0.7	Incoloy DS	1% 6x10 ³	C/1	0.5
3	IN-519	1% 6x10 ³	C/4(R-2)	3.0	0.6	Hastelloy X	1% 10 ⁵	C/1	0.5
3	Inconel 617	0.8R10 ⁴	C/4(D-2)	3.0	0.4	Incoloy 800H	1% 10 ⁵	C/1	0.5
3	Inconel 617*	0.8R10 ⁴	C/4	3.0	0.4	Incoloy DS	1% 10 ⁵	C/1	0.5
3	Mo-Re 2	0.8R10 ⁴	C/5	4.5	1	Incoloy 800H*	1% 6x10 ³	C/2(R-7)	1.0
3	Mo-Re 2	1% 6x10 ³	C/4	3.0	1	Incoloy 800H*	0.8R10 ⁴	C/2(D-6)	1.0
2	Rene' 100	1% 10 ⁵	B/2	2.0	0.4	Incoloy 800H*	1% 10 ⁵	C/1	0.5

(a) Note - 3 TZM spec. also to be tested in single spec. stands at desired stress levels in addition to tests in table.

Key: 1% 6x10³ : 100% Stress for 1% Total Strain in 6,000 hrs.
 1% 10⁵ : 100% Stress for 1% Total Strain in 100,000 hrs.
 0.8R10⁴ : 80% Stress for Rupture in 10,000 hrs.

* - Coated

R - Replacement at 3,000 hrs.

D - Discontinue at 3,000 hrs.

e.g. spec. (R-1) replaces spec. (D-1) at 3,000 hrs.

Table 2.23

LOADING PLAN FOR 1050°C (1922°F) SCREENING CREEP FURNACE

Desired Stress (ksi)	Alloy	Condition	Specimen Type/ Stringer No.	Test Stress (ksi)
38	TZM	1% 6x10 ³	B/6(a)	8.0
30	TZM	1% 10 ⁵	B/6(a)	8.0
21	TZM	0.8R10 ⁴	B/6(a)	8.0
11	MA-754	1% 6x10 ³	B/6	8.0
8	MA-754	0.8R10 ⁴	B/6	8.0
7	MA-956E	0.8R10 ⁴	B/6	8.0
6	MA-956E	1% 6x10 ³	B/5	4.4
5	MA-956E	1% 10 ⁵	B/4	3.2
5	MA-754	1% 10 ⁵	B/5	4.4
3	MM-0011	0.8R10 ⁴	B/5	4.4
3	MM-0011DS	0.8R10 ⁴	B/5	4.4
3	MM-0011	1% 6x10 ³	B/4	3.2
3	MM-0011DS	1% 6x10 ³	B/4	3.2
2	MM-0011	1% 10 ⁵	B/3	2.0
2	MM-0011DS	1% 10 ⁵	B/3	2.0
2	Mo-Re 2	1% 6x10 ³	C/5	2.2
2	IN-738	1% 6x10 ³	B/3	2.0
1.5	IN-738	0.8R10 ⁴	B/2	0.8
1.5	Rene' 100	0.8R10 ⁴	B/3	2.0
1	IN-738	1% 10 ⁵	B/1	0.4
1	Mo-Re 2	0.8R10 ⁴	C/4	1.6
1	HK-40	0.8R10 ⁴	C/3	1.0
1	Inconel 617	1% 6x10 ³	C/4	1.6
1	Inconel 617*	1% 6x10 ³	C/4	1.6
1	Inconel 617	0.8R10 ⁴	C/3	1.0
1	Inconel 617*	0.8R10 ⁴	C/3	1.0
1	IN-519	1% 6x10 ³	C/4	1.6
1	Manaurite 36XS	0.8R10 ⁴	C/4	1.6
1	IN-519	0.8R10 ⁴	C/3	1.0
0.8	Mo-Re 2	1% 10 ⁵	C/3	1.0
0.8	Manaurite 36XS	1% 6x10 ³	C/2	0.4
0.7	HK-40	1% 6x10 ³	C/2	0.4
0.6	HD-556	0.8R10 ⁴	C/3	1.0
0.5	Inconel 617	1% 10 ⁵	C/2	0.4
0.5	Inconel 617*	1% 10 ⁵	C/2	0.4
0.5	Rene' 100	1% 6x10 ³	B/2	0.8
0.4	Incoloy 807	1% 6x10 ³	C/3	1.0
0.4	Incoloy 807	0.8R10 ⁴	C/2	0.4
0.4	HD-556	1% 6x10 ³	C/2	0.4
0.4	HK-40	1% 10 ⁵	C/1	0.2
0.4	IN-519	1% 10 ⁵	C/2	0.4
0.4	Hastelloy X	0.8R10 ⁴	C/2	0.4
0.3	Hastelloy X	1% 6x10 ³	C/2	0.4
0.3	Manaurite 36XS	1% 10 ⁵	C/1	0.2
0.2	Rene' 100	1% 10 ⁵	B/1	0.4
0.2	Incoloy 807	1% 10 ⁵	C/1	0.2
0.2	HD-556	1% 10 ⁵	C/1	0.2
0.1	Hastelloy X	1% 10 ⁵	C/1	0.2

(a) Note - 3 TZM spec. also to be tested in single spec. stands at desired stress levels in addition to tests in table.

* - Coated

Key: Same as Table 2.22

Table 2.24

TEST SPECIMEN PLAN

SPECIMEN "B"
GAUGE DIAMETER
6.4mm (0.252 inch)

SPECIMEN "C"
GAUGE DIAMETER
9.53mm (0.357 inch)

Cast Nickel-Base Superalloy,
(γ' Strengthened)

Rene' 80
Rene' 100
IN-713LC
IN-738
MM-0011
MM-0011DS

Wrought Iron Base Austenitic

Incoloy 800H
Incoloy 800H Coated
Incoloy 802
Incoloy 807
Incoloy DS
HD-556

Cast Nickel-Base Alloy,
(Refractory Metal Strengthened)

NX-188

Wrought Nickel-Base Austenitic

Hastelloy X
Inconel 617
Inconel 617 Coated

Wrought Nickel-Base Superalloy,
(γ' Strengthened)

Udimet 720

Cast Iron-Base Austenitic

Manaurite 36XS
HK-40
IN-519

Oxide Dispersion Strengthened

MA-754
MA-956E

Cast Nickel-Base Austenitic

Mo-Re 2

Mo-Base Alloy

TZM-Coated

highest (66 ksi) and lowest (2 ksi) stress. By employing 2 different size screening creep specimens (while maintaining specimen consistency within an alloy class) the number of allowable stress levels per furnace is doubled, hence, the assignment of stress levels can be made more effectively and accurately. Use of the two remaining multi-specimen creep furnaces for uninstrumented helium testing, in lieu of the 2 different specimen configurations, would not improve the situation markedly since there would be two temperatures at which only one furnace could be employed (only 6 furnaces are available). Additionally, no furnaces would be available for parallel air screening creep tests. This situation could lead to significant problems concerning the evaluation of "impure" helium screening creep data during the course of the program.

2. The uppermost test temperature, 1050°C (1922°F), proposed for the GE/DOE program is 50°C (90°F) above the testing regime currently employed in the GAC/HTMP collaborative effort. Consequently, screening creep test stress levels for 1% total strain in 100,000 hours, in particular, are extremely low. Considering NPH alloys, the designated stress levels at 950°C (1742°F) range between 6.0 and 0.5 ksi, while at 1050°C (1922°F) the required stress values are between 4.0 and 0.2 ksi. For the 6.4mm (0.252 in.) diameter specimen, a 4.5 kg (10-lb.) load is required to produce a 0.2 ksi stress level. The uncertainty in stringer loads due to friction in the seals may be as high as 0.9 kg (2 lbs.). With a 4.5 kg (10 lb.) applied load, the uncertainty in error could, therefore, be as high as 20 percent. However, by employing the larger 9.5cm (0.357 in.) diameter specimen for NPH alloys (which would require a higher load for a given stress level) possible experimental errors due to uncertainty in the applied load would significantly be reduced. Finally, the assignment of the 6.4cm (0.252 in.) diameter specimen to DCHT candidate alloys is convenient since these alloys have, in general, greater creep capability compared with NPH materials.

A number of general items are discussed below with reference to the formulation of the "controlled-purity" helium screening creep loading matrices.

1. Each screening creep furnace loading plan (Tables 2.20-2.23) tabulates the desired or actual stress, alloy, test condition, specimen designation plus string, and test stress. Specimens are designated "B" or "C", by alloy class, and refer to the specimen configurations illustrated in Table 2.8. For a given load or string, the stress level imposed on the "B" specimen will be twice that placed on the "C" specimen. Stress levels, number and types of specimen per string, and overall stringer lengths for each of the 4 test temperatures are summarized in Table 2.25.

2. Compromises had to be made in the assignment of stress levels at all four temperatures since a greater number of different stress levels are required than the available six levels per alloy class per temperature.

3. One of the original design aims for the furnace loading matrix was to load all creep specimens at the initiation of test. However, since stringer space is limited, a number of samples to be tested at stress levels to yield 1% total strain in 6,000 hours (to be tested for 6,000 hours) will be substituted for discontinued specimens tested at 80% of the stress for rupture in 10,000 hours. Samples tested at 80% of the stress for rupture in 10,000 hours will be creep tested for 3,000 hours. Discontinued samples are denoted with a "D" while replacement samples are denoted with an "R" in the specimen designation/stringer column of Tables 2.20, 2.21., 2.22 and 2.23. For example, at 750°C (1382°F) specimen C2(D-1) (Incoloy 800H) will be discontinued and replaced by specimen C2(R-1) (Inconel 617 coated) subsequent to 3,000 hours of test.

4. Since the creep strength capability of TZM is significantly in excess of other DCHT and NPH materials, the alloy will be screened at 850°C (1562°F), 950°C (1742°F) and 1050°C (1922°F) in both the uninstrumented creep frames as well as single specimen creep stands. Creep tests in the single specimen stands will be conducted at the desired stress level in each case while the TZM specimens run in the multi-specimen furnaces will be evaluated at the highest planned test stress for comparative purposes.

Table 2.25

LOADING MATRIX SUMMARY FOR CONTROLLED-PURITY HELIUM SCREENING CREEP TESTS

Stringer No.		<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>	<u>6</u>
Temp.	Specimen	σ (No.) L	σ (No.) L	σ (No.) L	σ (No.) L	σ (No.) L	σ (No.) L
750°C	B	10.0 (-)	18.0 (-)	27.0 (4) 10.468	36.0 (3) 7.851	44.0 (8) 20.936	54.0 (9) 23.553
	C	5.0 (11) 38.302	9.0 (11) 38.302	13.5 (8) 27.856	18.0 (1) 3.482	22.0 (-)	27.0 (-)
	Length, Total (in.)	38.302*	38.302*	38.328*	11.333	20.936	23.553
850°C	B	4.0 (-)	8.0 (1) 2.617	11.0 (5) 13.085	14.0 (6) 15.702	21.0 (9) 23.553	27.0 (11) 28.787
	C	2.0 (11) 38.302	4.0 (10) 34.820	5.5 (7) 24.374	7.0 (5) 17.410	10.5 (-)	13.5 (-)
	Length, Total (in.)	38.302*	37.437*	37.459*	33.112	23.553	28.787
950°C	B	1.0 (2) 5.234	2.0 (3) 7.851	4.0 (5) 13.085	6.0 (5) 13.085	9.0 (8) 20.936	12.0 (9) 23.553
	C	0.5 (9) 31.338	1.0 (9) 31.338	2.0 (7) 24.374	3.0 (7) 24.374	4.5 (1) 3.982	6.0 (-)
	Length, Total (in.)	36.572*	39.189*	37.459*	37.459*	24.418	23.553
1050°C	B	0.4 (2) 5.234	0.8 (2) 5.234	2.0 (4) 10.468	3.2 (3) 7.851	4.4 (4) 10.468	8.0 (6) 15.702
	C	0.2 (5) 17.410	0.4 (9) 31.338	1.0 (7) 24.374	1.6 (5) 17.410	2.2 (1) 3.482	4.0 (-)
	Length, Total (in.)	22.644	36.572*	34.842	25.261	13.950	15.702

Code

σ = Stress, ksi
 (No.) = Number of specimens
 L = Total length of specimens
 * = Denotes filled string

B Specimen = 2.617 inches
 C Specimen = 3.482 inches

5. Subsequent to the assignment of all stress levels it became apparent that a number of strings in each of the four furnaces were not completely filled. In an effort to utilize furnace space most efficiently a series of "duplicate" samples are suggested for creep test. The duplicate screening creep samples are presented in Tables 2.26, 2.27, 2.28, 2.29 and 2.30 for temperatures of 750°C (1382°F), 850°C (1562°F), 950°C (1742°F) and 1050°C (1922°F), respectively. Table 2.31 summarizes the furnace loading matrices including duplicates. Included in this table are stress levels, number and types of specimen per string and overall string lengths for each of the four test temperatures. It can be seen that the number of specimens per string ranges between a minimum of 11 and a maximum of 14 while the maximum stringer length is 99.54cm (39.189 in.).

2.6 TASK 6 - THERMAL STABILITY EVALUATION

A description of the planned thermal stability tests was included in the discussion under Task 5, page 31.

2.7 TASK 7 - PRIMARY COOLANT CORROSION RESISTANCE EVALUATION - (D.W. MC KEE)

In addition to corrosion studies of the commercially available alloys and coatings summarized under Task 5, page 31, corrosion studies of some simple binary and tertiary alloys will be begun under Task 7 with the objection of achieving a more basic understanding of the corrosion mechanisms in HTR helium.

Although the results of a number of environmental stability tests with commercial alloys in impure helium are available in the literature, there is still no generally accepted theory or explanation of the role of individual alloying elements which has proven predictive value and which can be utilized in the development of new and improved corrosion resistant alloys for the hot components in the primary circuit of VHTR systems. The problem of rationalizing the reported data is complicated by the fact that widely different helium impurity levels have been used by different groups of investigators and at different times, as shown in Table 2.31.

Table 2.26

DUPLICATE SPECIMEN LOADING PLAN FOR
750°C (1382°F) SCREENING CREEP FURNACE

Desired Stress (ksi)	Alloy	Condition	Specimen Type/ Stringer No.	Test Stress (ksi)	Desired Stress (ksi)	Alloy	Condition	Specimen Type/ Stringer No.	Test Stress (ksi)
68	TZM +	1% 6×10^3	B/6	54.0	40	Rene' 100	1% 10^5	B/4	36.0
67	TZM +	0.8R10 ⁴	B/6	54.0	36	Udimet 710	0.8R10 ⁴	B/4	36.0
60	TZM +	1% 10^5	B/6	54.0	36	IN-713LC	0.8R10 ⁴	B/4	36.0
55	Rene' 100	1% 6×10^3	B/6	54.0	40	Rene' 100	1% 10^5	B/4	36.0
50	IN-738	1% 6×10^3	B/6	54.0	36	Udimet 720	0.8R10 ⁴	B/4	36.0
50	MM-0011	1% 10^5	B/5	44.0	36	IN-713LC	0.8R10 ⁴	B/4	36.0
50	NX-188	1% 10^5	B/5	44.0	36	IN-713LC	0.8R10 ⁴	B/4	36.0
46	Rene' 100	0.8R10 ⁴	B/5	44.0	19	Mo-Re2	0.8R10 ⁴	C/4	18.0
45	Udimet 720	1% 6×10^3	B/5	44.0	19	Mo-Re2	0.8R10 ⁴	C/4	18.0
45	IN-713LC	1% 6×10^3	B/5	44.0					
45	Rene' 80	0.8R10 ⁴	B/5	44.0					

+ Uncoated

Key:

1% 6×10^3 : 100% Stress for 1% Total Strain in 6000 hrs.
 1% 10^5 : 100% Stress for 1% Total Strain in 100,000 hrs.
 0.8R10⁴: 80% Stress for Rupture in 10,000 hrs.

Table 2.27

DUPLICATE SPECIMEN LOADING PLAN FOR
850°C (1562°F) SCREENING CREEP FURNACE

<u>Desired Stress (ksi)</u>	<u>Alloy</u>	<u>Condition</u>	<u>Specimen Type/ Stringer No.</u>	<u>Test Stress (ksi)</u>
28	Rene' 100	1% 6×10^3	B/6	27.0
27	Rene' 80	1% 6×10^3	B/6	27.0
27	NX-188	0.8R10 ⁴	B/6	27.0
22	IN-738	1% 6×10^3	B/5	21.0
21	Rene' 80	0.8R10 ⁴	B/5	21.0
21	Udimet 720	1% 6×10^3	B/5	21.0
21	IN-713LC	1% 6×10^3	B/5	21.0
20	Rene' 100	0.8R10 ⁴	B/5	21.0
17	MA-754	0.8R10 ⁴	B/4	14.0

Key:

1% 6×10^3 : 100% Stress for 1% Total Strain in 6000 hrs.
 1% 10^5 : 100% Stress for 1% Total Strain in 100,000 hrs.
 0.8R10⁴: 80% Stress for Rupture in 10,000 hrs.

Table 2.28

DUPLICATE SPECIMEN LOADING PLAN FOR
950°C (1742°F) SCREENING CREEP FURNACE

<u>Desired Stress (ksi)</u>	<u>Alloy</u>	<u>Condition</u>	<u>Specimen Type/ Stringer No.</u>	<u>Test Stress (ksi)</u>
14	MA-754	1% 6x10 ³	B/6	12.0
12	MM-0011	1% 6x10 ³	B/6	12.0
12	MM-0011DS	1% 6x10 ³	B/6	12.0
12	NX-188	1% 6x10 ³	B/6	12.0
12	IN-738	1% 6x10 ³	B/6	12.0
12	MA-754	0.8R10 ⁴	B/5	9.0
10	MM-0011	0.8R10 ⁴	B/5	9.0
10	MM-0011DS	0.8R10 ⁴	B/5	9.0
8	IN-738	0.8R10 ⁴	B/5	9.0
8	Rene ¹ 100	1% 6x10 ³	B/5	9.0

Key:

1% 6x10³ : 100% Stress for 1% Total Strain in 6,000 hrs.
 1% 10⁵ : 100% Stress for 1% Total Strain in 100,000 hrs.
 0.8R10⁴ : 80% Stress for Rupture in 10,000 hrs.

Table 2.29

DUPLICATE SPECIMEN LOADING PLAN FOR
1050°C (1922°F) SCREENING CREEP FURNACE

Desired Stress (ksi)	Alloy	Condition	Specimen Type/ Stringer No.	Test Stress (ksi)	Desired Stress (ksi)	Alloy	Condition	Specimen Type/ Stringer No.	Test Stress (ksi)
38	TZM +	1% 6x10 ³	B/6	8.0	5	MA-956	1%10 ⁵	B/4	3.2
30	TZM +	1% 10 ⁵	B/6	8.0	3	MM-0011	1% 6x10 ³	B/4	3.2
21	TZM +	0.8R10 ⁴	B/6	8.0	3	MM-0011DS	1% 6x10 ³	B/4	3.2
11	MA-754	1% 6x10 ³	B/6	8.0	1	Mo-Re 2	0.8R10 ⁴	C/4	1.6
8	MA-754	0.8R10 ⁴	B/6	8.0	2	IN-738	1% 6x10 ³	B/3	2.0
7	MA-956	0.8R10 ⁴	B/6	8.0	0.4	HK-40	1% 10 ⁵	C/1	0.2
7	MA-956	0.8R10 ⁴	B/6	8.0	0.3	Manaurite 36XS	1% 10 ⁵	C/1	0.2
8	MA-754	0.8R10 ⁴	B/6	8.0	1	IN-738	1% 10 ⁵	B/1	0.4
					0.2	Rene' 100	1% 10 ⁵	B/1	0.4
					0.2	HD-556	1% 10 ⁵	C/1	0.2
6	MA-956	1% 6x10 ³	B/5	4.4					
5	MA-754	1% 10 ⁵	B/5	4.4					
3	MM-0011	0.8R10 ⁴	B/5	4.4					
3	MM-0011DS	0.8R10 ⁴	B/5	4.4					
6	MA-956	1% 6x10 ³	B/5	4.4					
5	MA-754	1% 10 ⁵	B/5	4.4					
2	Mo-Re 2	1% 6x10 ³	C/5	2.2					
2	Mo-Re 2	1% 6x10 ³	C/5	2.2					

+ Uncoated

Key:

1% 6x10³ : 100% Stress for 1% Total Strain in 6,000 hrs.
 1% 10⁵ : 100% Stress for 1% Total Strain in 100,000 hrs.
 0.8R10⁴ : 80% Stress for Rupture in 10,000 hrs.

Table 2.30

LOADING MATRIX SUMMARY, INCLUDING DUPLICATES FOR CONTROLLED-
PURITY HELIUM SCREENING CREEP TESTS

Stringer No. Temp.	Specimen	σ ($\frac{1}{\text{No.}}$) L	σ ($\frac{2}{\text{No.}}$) L	σ ($\frac{3}{\text{No.}}$) L	σ ($\frac{4}{\text{No.}}$) L	σ ($\frac{5}{\text{No.}}$) L	σ ($\frac{6}{\text{No.}}$) L
750°C	B	10.0 (-)	18.0 (-)	27.0 (4) 10.468	36.0 (10) 26.170	44.0 (14) 36.638	54.0 (14) 36.638
	C	5.0 (11) 38.302	9.0 (11) 38.302	13.5 (8) 27.856	18.0 (3) 10.446	22.0 (-)	27.0 (-)
	Length, Total (in.)	38.302*	38.302*	38.328*	36.616*	36.638*	36.638*
850°C	B	4.0 (-)	8.0 (1) 2.617	11.0 (5) 13.085	14.0 (7) 18.319	21.0 (14) 36.638	27.0 (14) 36.638
	C	2.0 (11) 38.302	4.0 (10) 34.820	5.5 (7) 24.374	7.0 (5) 17.410	10.5 (-)	13.5 (-)
	Length, Total (in.)	38.302*	37.437*	37.459*	35.729*	36.638*	36.638*
950°C	B	1.0 (2) 5.234	2.0 (3) 7.851	4.0 (5) 13.085	6.0 (5) 13.085	9.0 (13) 34.021	12.0 (14) 36.638
	C	0.5 (9) 31.338	1.0 (9) 31.338	2.0 (7) 24.374	3.0 (7) 24.374	4.5 (1) 3.482	6.0 (-)
	Length, Total (in.)	36.572*	39.189*	37.459*	37.459*	37.503*	36.638*
1050°C	B	0.4 (4) 10.468	0.8 (2) 5.234	2.0 (5) 13.085	3.2 (6) 15.702	4.4 (10) 26.170	8.0 (14) 36.638
	C	0.2 (8) 27.856	0.4 (9) 31.338	1.0 (7) 24.374	1.6 (6) 20.892	2.2 (3) 10.446	4.0 (-)
	Length, Total (in.)	38.324*	36.572*	37.459*	36.594*	36.616*	36.638*

Code

σ - = Stress, ksi
 (No.) = Number of specimens
 L = Total length of specimens including duplicates, inches
 * = Denotes filled string

B Specimen, L_B = 2.617 inches
 C Specimen, L_C = 3.482 inches

TABLE 2.31

VARIATION IN TEST ENVIRONMENTS USED BY OTHER INVESTIGATORS

Investigator	Organization	HTR Helium Impurity Levels (microatmospheres)				Remarks
		H ₂	CO	H ₂ O	CH ₄	
Huddle, 1974	CIIR (Oslo)	400	400	90	--	Wet
		100	100	20	--	Dry
		50-100	25-50	0.5-3	3	Ultra-Dry
	Dragon	10	3	1	1	Normal
		200	40	4	10	During Water Injection Experiment
Bates, 1977	HTMP	500	30	1.5	50	
Nickel, 1976	KFA	2400	2400	800	80	Simulate HHT Start-Up

Also, it is not clear to what extent the results of previous studies have been influenced by the occurrence of depletion effects and chemical compositional gradients in the test loops during the experiments. In real reactor systems, because of the very high gas flow rates, reactions of impurities with alloy surfaces probably occur only from very thin boundary layers. Most of the gaseous impurities in the primary helium are relatively unaffected and slow reactions do not have time to attain thermodynamic equilibrium. However, in test loops with low gas flow rates, reactions of impurity species with alloys may have sufficient time to closely approach equilibrium. Local depletion of oxidizing species (H_2O , CO_2 , CO) and carburizing species (CO , CH_4) may therefore occur. Such depletion can have many important effects, for example:

(1) Depletion of oxidizing species (particularly H_2O and CO_2) at the lower portion of retorts could change the nature of the oxide on alloy specimens at higher positions (i.e. downstream), thereby affecting the resistance of the materials to carbon penetration.

(2) Carburizing reactions involving CO ($2CO = C + CO_2$ and $CO + H_2 = C + H_2O$) are rapid but become less important as the temperature is increased, whereas carburizing reactions involving methane ($CH_4 = C + 2H_2$, $CO + CH_4 = 2C + H_2 + H_2O$) are generally slow at the lower temperatures and may not contribute significantly to carburization at reactor flow rates. However in test systems at low flow rates where significant depletion of CH_4 is occurring, these reactions may induce appreciable carburization at the lower positions in the retorts. In the forthcoming series of tests in this program, it is hoped that the effects of local depletion of gaseous species can be minimized.

In spite of these complexities, a few attempts have been made to rationalize the observed corrosion of commercial alloys in impure helium in terms of the behavior of individual alloying elements. The generalizations of Huddle, Kofstad and Pearce⁽³⁾ in 1973, Huddle⁽⁴⁾ in 1974 and Bates et. al.⁽⁵⁾ in 1977 were based on the Dragon Project data or HTMP/GAC data obtained since 1965 with a wide range of Fe, Mo and Ni-based alloys and stainless steels. Because of the complex nature and widely different

compositions of these commercial alloys and the interdependence and interactions of the alloying constituents, generalizations based on the effects of individual elements must be of somewhat limited validity. Nevertheless, the conclusions and patterns of behavior listed by Huddle have been widely quoted.⁽⁴⁾

A comparison of the conclusions made by Huddle in 1974 and by Bates in 1977 shows some significant differences. Thus Ti was listed by Huddle as a detrimental element, forming non-protective oxides and carbide precipitates, whereas Bates claimed Ti to be beneficial, with increasing Ti/Al ratios conferring enhanced resistance to carburization. Also Si is an undesirable element, according to Huddle, as it promoted internal oxidation, whereas Bates concludes that Si additions reduced carburization. Both authors agree, however, that Cr and Al caused internal oxidation, whereas Mn promoted both oxidation and carburization. The elements W, Mo and Nb appeared to be generally beneficial but this is far from clear. Also in the recent results from KFA, reported by Nickel,⁽⁶⁾ IN-586 (Nimonic 86) was only slightly carburized whereas Hastelloy S was markedly affected. This finding is opposite to that recently given by Graham from the HTMP series of tests.⁽⁷⁾

As shown in Table 2.31, the helium loop chemistry used for the recent HTMP corrosion tests was significantly different from that of the earlier Dragon work and also from recent Kerforschungsanlage (KFA) tests. Over a period of time, the gas composition in the CIIR (Oslo) loop has been changed from wet to dry and simultaneously became more carburizing. The chemistry described by Bates is dry and much more reducing than any previously described. Nickel describes the KFA atmosphere as relatively impure, chosen to simulate the start-up of an HHT (high temperature helium turbine system). This environment would be considerably more oxidizing than that used by Bates and Graham. It is therefore probable that the variations in nominal helium chemistry are responsible for the conflicting conclusions drawn by different authors. In general, recent work has identified carburization as a more deleterious mode of attack than internal oxidation which was emphasized in earlier studies.

In order to provide a better understanding of the behavior of individual elements in complex alloys and to form a basis for a more general interpretation of corrosion mechanisms in impure helium, it has been decided to include a number of simple binary and tertiary alloys in the current VHTR test program. A listing of experimental alloys to be included in the first phase for corrosion evaluation is given in Table 2.32. Essentially the main purpose will be to study the effect of the addition of low concentrations of a third element (e.g. Al, Ti, Si, Y, Nb) on the environmental stability of a basic Ni-20Cr binary alloy. Possible synergistic effects between Al and Ti will also be studied. These alloys have been fabricated as cast ingots from which cylindrical pins, 2.54 cm (1 in.) x 0.64 cm (0.25 in.) diameter, will be machined for mounting in the retorts later in the program. It is to be understood that the study of these experimental alloys is intended only to elucidate the role of specific elements in the corrosive process. It is not suggested that any of these materials will have practical utility as structural materials in VHTR systems but the conclusions concerning the effects of individual elements are expected to provide useful guidelines for the future development of new corrosion-resistant alloy compositions.

2.8 TASK 9 - DATA MANAGEMENT AND PROGRAM MANAGEMENT

2.8.1 Data Management

2.8.1.1 Data Acquisition

The test matrices for each material and property are being reviewed to assure a coordinated approach by the VHTR/NPH and DCHT test programs and to assure that the planned testing is compatible with evaluation and analysis requirements. Also, coincident with the material procurement phase and prior to the testing phase, the appropriate encoding forms are being selected.

2.8.1.1.1 Test Matrices Coordination

The test matrices, in rough form, have been examined. The VHTR/NPH and DCHT matrices are consistent with one another and are compatible with evaluation and analysis requirements.

TABLE 2.32

EXPERIMENTAL ALLOYS FOR VHTR CORROSION TESTING

IN IMPURE HE

Ni-20Cr

Ni-50Cr

Ni-20Cr-8Al

Ni-20Cr-5Ti

Ni-20Cr-8Al-2Ti

Ni-20Cr-2Al-8Ti

Ni-20Cr-2Si

Ni-20Cr-5Si

Ni-20Cr-1Y

Ni-20Cr-2Nb

2.8.1.1.2 Data Encoding Coordination

Modified, revised and additional encoding forms have been developed and are now being critiqued. These forms will permit suitable computer input to provide for management control of the test program.

2.8.1.1.3 Encoding Instructions

The Introduction and Encoding Instructions for Data Management Program "PAMMED" are being critiqued and finalized. PAMMED is a acronym for "Planning and Management -- Materials Evaluation and Development." Rough copies of representative encoding forms and instructions were provided to program personnel in mid-July, 1977.

2.8.1.2 Data Storage and Retrieval

The definition of the material, material condition, test environment and the test data will be stored in a centralized computer data bank with the capability of selective retrieval. This data bank will be a revised or modified version of the current GE/Aircraft Engine Business Group (AEBG) data bank computer program.

2.8.1.2.1 System Review and Modification

The new data management system "PAMMED" has been patterned after the AEBG system, but has greater capability. PAMMED is a logically and conceptually improved version of the AEBG system. In addition, instead of one data tape, PAMMED will use several tapes and disks in order to facilitate the retrieval of various kinds of data for a given material. The instruction manual on encoding, soon to be published, will also describe the overall operation of the program.

2.8.2 Program Management

General program review meetings for two international visitors were held during the past quarter. On July 21, 1977, Dr. Buresch from the

Institute Reactor Materials, Kernforschungsanlage, Jülich, Federal Republic of Germany visited GE Schenectady, NY under the auspices of the US/FRG umbrella agreement for international cooperation to discuss ceramics programs underway at GE. On September 7, 1977, a visit was made by Dr. Kazuo Tsuruoka (ERANS) to discuss programs in Nuclear Process Heat underway in Japan and the U.S.

A general program review meeting with the DOE Program Manager on August 18, 1977.

A Program Master Schedule is shown in Figure 2.4.

Task 1 (Alloy Selection) is complete. A topical report in two volumes covering the selection of alloys for the screening tests for both Nuclear Process Heat and Direct Cycle Helium Turbine Programs will be issued in January 1978. The report number and titles of the two volumes are:

COO-2975-16: Vol. 1 Advanced Gas Cooled Reactor Systems Definition
Vol. 2 Selection of Candidate Alloys for the Advanced
Gas Cooled Reactor Materials Screening Test Program.

Task 2 (Materials Procurement and Characterization) is in the procurement cycle. All the materials for the NPH Program will be received by December 31, 1977. The alloys for the DCHT Program will be on order by the end of December 1977, and the last delivery is expected by the end of March, 1978.

Task 3 (Testing and Analysis Facilities and Equipment) and Task 4 (Simulated Reactor Helium Environment Facilities and Equipment) are four months behind schedule and will result in a four month slip in the initiation of the screening tests. It now is expected the screening creep and structural stability (bulk and surface) tests will begin in May 1978.

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Section 3.0

WORK TO BE COMPLETED DURING THE NEXT QUARTER

3.0 WORK TO BE COMPLETED DURING THE
NEXT QUARTER

1. Task 2 - Purchase Direct Cycle Helium Turbine alloys for the screening program.

- Continue characterization of as-received materials.
2. Task 3 - Receive and install screening creep units.
3. Task 4 - The helium loop distribution systems will be completed.

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