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

**PROGRESS REPORT
FOR PERIOD**

JANUARY 1, 1979 - MARCH 31, 1979

**BY
PROJECT STAFF**

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

JULY 19, 1979

Prepared for
**THE U.S. DEPARTMENT OF ENERGY
Under Contract No. EY-76-C-02-2975**

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FOREWORD

The Advanced Gas Cooled Nuclear Reactor Materials Evaluation and Development Program is being conducted for the Nuclear Power Development Division, U.S. Department of Energy, by the Energy Systems Programs Department, General Electric Company, Schenectady, New York 12345 under Contract EY-76-C-02-2975. 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 Principle Investigator, with responsibility for overall technical coordination of the Program, is Dr. O. F. Kimball, Manager, Gas Reactor Materials, assisted by Dr. J. F. Stubbins, Materials Engineer, Gas Reactor Materials. Other major contributors to the Program are:

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Dr. A. W. Urquhart, Corporate Research and Development Center,
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Helium Gas Chemistry (Dr. H. S. Spacil) and
Corrosion (Dr. D. W. McKee)

ABSTRACT

This report presents the results of work performed from January 1, 1979 through March 31, 1979 on the Advanced Gas Cooled Nuclear Reactor Materials Evaluation and Development Program. The objectives of this program are to evaluate candidate alloys for Very High Temperature Reactor (VHTR) Nuclear Process Heat (NPH) and Direct Cycle Helium Turbine (DCHT) applications, in terms of the effect of simulated reactor primary coolant (helium containing small amounts of various other gases), high temperatures, and long time exposures, on the mechanical properties and structural and surface stability of selected candidate alloys. A second objective is to select and recommend materials for future test facilities and more extensive qualification programs.

Work covered in this report includes the activities associated with the creep-rupture testing of the test materials for the purpose of verifying the stresses selected for the screening creep test program, and the status of the simulated reactor helium supply system, testing equipment, and gas chemistry analysis instrumentation and equipment. The status of the data management system is presented. In addition, the initiation of the screening test program is described.

OTHER REPORTS IN THIS SERIES

QUARTERLY PROGRESS REPORTS

September 23, 1976 to December 31, 1976	C00-2975-3
January 1, 1977 to March 31, 1977	C00-2975-10
April 1, 1977 to June 30, 1977	C00-2975-13
July 1, 1977 to September 30, 1977	C00-2975-17
October 1, 1977 to December 31, 1977	C00-2975-20
January 1, 1978 to March 31, 1978	C00-2975-21
April 1, 1978 to June 30, 1978	C00-2975-22
July 1, 1978 to September 30, 1978	C00-2975-25
October 1, 1978 to December 31, 1978	C00-2975-28

TOPICAL REPORTS

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

Section 1.0

INTRODUCTION

ADVANCED GAS COOLED NUCLEAR REACTOR
MATERIALS EVALUATION AND DEVELOPMENT PROGRAM

1.0 INTRODUCTION

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

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

Low Cycle 10^3 to 10^5 cycle

High Cycle 10^5 to 10^7 cycle

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

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

Section 2.0

PROGRAM STATUS

2.0 PROGRAM STATUS

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

2.1 TASK 1 - SELECTION OF CANDIDATE ALLOYS

The selection of alloys for the screening phase of the program has been completed. A list of the alloys selected for the program was presented in topical report number C00-2975-16, Volume 2, dated December 31, 1978 and entitled: Selection of Alloys for Screening Creep and Structural Stability Studies.

2.2 TASK 2 - MATERIALS PROCUREMENT AND CHARACTERIZATION

2.2.1 Direct Cycle Helium Turbine (DCHT) Alloys - (E.W. Ross)

2.2.1.1 Materials Procurement

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

2.2.1.2 Materials Characterization

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

2.2.2 Nuclear Process Heat (NPH) Alloys - (S.Z. Hayden and R.A. Ellis)

2.2.2.1 Materials Procurement

The procurement of all NPH materials was completed by September 1978.

2.2.2.2 Materials Characterization

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

In addition to the scheduled testing, a few longer time air creep-rupture tests were run to improve the data base for selecting stresses for the screening creep tests. These tests have been completed and the data are reported in Table 2.1. New results for Incoloy DS, HK-40, Manaurite 36XS, IN-519, coated* Alloy 800H and coated** Inconel 617 are listed along with data previously available for these alloys as well as the other NPH alloys to be included in the screening creep program. This completes the materials characterization subtask.

2.2.2.3 Materials Joining Studies

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

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

2.3.1 Multi-Specimen Creep (MSC) Equipment

At the beginning of this report period, an on-line MSC ceramic retort failed just after being brought to temperature at 1050°C (1922°F). No test specimens were contained in the retort for the test run which was an experiment to determine the depletion effects in the controlled purity He for a retort at temperature with the design He flow rate of 10 l/min. The fracture was located near the lower end of the retort, between the bottom end of the furnace and the lower retort support clamp. Subsequent stress analysis and temperature distribution measurements have related the failure to a high thermal gradient between the bottom furnace element and the water-cooled support clamp. This situation was aggravated by a machining step in the retort located near the thermal gradient.

In order to address this problem, which is a potential concern for other similar ceramic retorts, several corrective actions are being taken. The machining steps in other similar retorts have been blended smooth by the retort

*Alloy 800H is coated with a platinum-chromium-aluminide type coating similar to RT-22.

**Inconel 617 is coated with an aluminide coating similar to Codep B.

TABLE 2.1

**CREEP-RUPTURE TEST RESULTS FOR LONG TIME
STRESS VERIFICATION FOR NPH ALLOYS**

Alloy	Condition For Tests (a)	Temp (°C)	Test Stress (MPa) (Ksi)		Time to 1% Total Strain (Hours)	Rupture Life (Hours)	Elongation (%)	Reduction In-Area (%)
Alloy 800H	S.A. 1232°C	750	97	14.0	7.8	286.9 ^(d)	35.6	41.0
		850	45	6.5	3.6	306.8	62.9	64.1
		950	21	3.1	155	464.5	39.6	36.0
		1050	10	1.5	380	1005.4 Disc. (b)	7.7	5.5
		1050	14	2.1	4.6	141.3	26.5	22.9
Incoloy 802	S.A. 1271-1282°C	750	152	22.0	480	480.6	2.7	8.5
		850	86	12.5	350	433.7	3.7	5.6
		950	38	5.5	--	767.6	3.7	11.0
		1050	21	3.0	215	1493.2	13.5	15.8
		1100	12	1.8	145	820.8	11.9	40.7
Incoloy 807	S.T. 1230°C/5 min., W.Q.	750	145	21.0	2.7	100.2	85.8	73.0
		850	55	8.0	115	2257.4	34.4	43.5
		950	19	2.7	210	1002.7 Disc.	2.5	--
		1050	7	1.0	145	1103.3 Disc.	7.1	5.5
		1100	6	0.9	--	769.5 Disc.	--	--
Incoloy DS	S.T. 1150°C/5 min., A.C.	750	12	1.8	77	409.9	10.1	9.6
		750	62	9.0	11.5	299.4	34.2	37.0
		850	32	4.7	97	495.1	28.9	30.6
		950	17	2.5	91	445.1	24.2	34.0
		1050	10	1.4	10.5	377.4	65.0	39.8
HD-556	S.T. 1177°C/30 min., W.Q.	850	38	5.5	9.7	194.3	36.2	34.4
		1050	6	0.9	41	1884.8 Disc.	(19.8)	--
		750	165	24.0	19	535 Disc.	51.0	57.1
		850	103	15.0	4.0	104 Disc.	67.4	75.8
		950	35	5.1	220	1535.0	34.9	48.2
HK-40	As-Cast	1050	17	2.5	128	543.1	28.4	39.2
		1100	10	1.5	20.5	469.5	36.3	40.0
		850	62	9.0	2.8	38.6	80.6	89.3
		750	103	15.0	815	1014.0	8.2	3.5
		850	62	9.0	250	296.1	2.9	4.3
Mahaureite 36XS	As-Cast	950	28	4.0	240	530.1	2.0	3.3
		1050	17	2.5	225	346.9	2.5	4.3
		1100	15	2.2	73	94.8	8.5	5.3
		1100	7	1.0	177	558.5	14.3	19.1
		750	110	16.0	4.8	127	32.8	34.0
Inconel 617	S.A. 1204°C	850	97	9.0	11.7	369.7	29.6	32.3
		950	36	5.2	42.5	346.1	28.9	41.1
		1050	21	3.0	38	171.9	37.3	48.4
		1100	14	2.0	38.5	258.8	35.1	48.5
		1100	9	1.3	81	2018.8 Disc.	(13.8)	--
Hastelloy X	S.T. 1177°C/31 min., W.Q.	750	200	29.0	97	625.4	19.6	24.8
		850	72	10.5	20.5	1126.0	58.3	60.9
		950	48	7.0	6.7	333.6	46.9	46.9
		1050	21	3.0	135	1146.2	23.2	35.4
		1100	15	2.2	70	722.3	34.9	33.9
MA-956E	S.T. 1330°C/1 hr., A.C.	750	138	20.0	9.1	279.1	93.4	87.0
		850	69	10.0	22.5	417.3	84.8	91.0
		950	29	4.2	71	547.6	65.8	67.0
		1050	12	1.8	20	287.4	59.0	56.0
		1100	6	0.9	--	1088.7	65.4	63.1
IN-519	As-Cast	750	90	13.0	0.07% @ Disc	2733.2 Disc.	--	--
		850	79	11.5	~1000	1168.6	4.4	16.3
		950	69	10.0	130	1254.6	4.5	1.8
		950	69	10.0	0.04 @ 10.0 hrs.	20.0	2.3	3.2
		1050	69	10.0	0.36 @ 35.3 hrs.	37.5 ^(c)	2.1	1.2
Mo-Re 2	As-Cast	1050	63	9.2	1350	2040.5 Disc.	--	--
		1100	57	8.3	~900	1034.0	2.1	3.5
		750	117	17.0	125	313.0	6.7	6.9
		850	68	9.8	90	311.6	5.4	11.2
		950	37	5.3	530	717.9	4.9	8.8
Alloy 800H* Coated	S.A. 1232°C	1050	18	2.6	170	744.3	11.4	27.6
		1100	11	1.6	140	666.3	19.5	29.7
		1100	7	1.0	105	2017.1 Disc.	(5.7)	--
		750	248	36.0	<0.1	7.2	22.9	29.4
		850	114	16.5	1.9	35.5	32.6	45.9
Inconel 617** Coated	S.A. 1204°C	950	51	7.4	17	159.3	17.0	24.0
		1050	23	3.4	95	285.1	6.7	6.5
		1100	17	2.5	125	200.0	4.6	7.6
		1100	10	1.5	--	2208.6	(3.6)	--
		750	97	14.0	0.7	203.4	50.2	59.1
Inconel 617** Coated	S.A. 1204°C	850	45	6.5	1.7	167.9	76.6	73.6
		950	21	3.1	3.8	387.8	46.8	37.9
		1050	14	2.1	4.3	101.6	24.5	23.6
		1050	10	1.5	--	581.4	22.8	23.9
		750	200	29.0	5.5	452.4	64.6	62.3
		850	72	10.5	7.0	436.8	102.7	76.5
		950	48	7.0	1.5	66.3	60.6	66.5
		1050	21	3.0	--	138.2	75.0	72.4
		1100	15	2.2	2.9	117.9	73.2	79.2

- (a) S.A. - Solution Annealed
 S.T. - Solution Treated
 (b) Discontinued.
 (c) Step loaded.
 (d) Incorrectly reported as 333.8 in the last quarterly, C00-2975-25.
- *Alloy 800H is coated with a platinum-chromium-aluminide type coating similar to RT-22.
 **Inconel 617 is coated with an aluminide coating similar to Codep B.

vendor. An analysis of the thermally-induced stresses has shown that the thermal gradient, initially spread primarily over the 5-cm (2-inch) gap between the furnace bottom and the retort clamp, can be reduced to acceptable levels by removing the furnace's bottom heating element and by replacing the water-cooled clamp with a flexible metal collar and band clamp not requiring cooling. In addition, an increase in the insulation around the lower end of the retort and bottom end of the furnace should help to further reduce the thermal gradient. Finally, retorts susceptible to similar failures will undergo proof testing prior to on-line use in the materials testing program. These tests are described in other sections of this report on the thermal stability and single specimen creep test equipment (Section 2.3.2 and 2.3.3).

These changes will not affect the MSC stands for He testing at 750°C and 850°C (1382°F and 1562°F) since metallic retorts are being used with those units. The change in the bottom furnace element for the 950°C and 1050°C (1742°F and 1922°F) units will result in a reduction in the useable hot-zone length from 99.1 to 91.5 cm (39 to 36 inches). This means that the number of multi-specimen creep specimens must be reduced by at least 1 per stringer for each of the 6 stringers per retort. This reduction can be accommodated by deleting dummy or filler specimens, and will result in no loss of test data.

2.3.2 Thermal Stability Test Equipment

Radial temperature profiles have been established for the eight (8) thermal stability test stands. (Axial profiles were characterized last quarter.) The radial temperature distribution was profiled with a partial load of dummy specimens in place in the retort, closely approximating actual test conditions. That is, specimens were placed in the positions that they would normally occupy in the section of the retort being profiled; other retort sections contained no specimens during profiling. A He flow rate of 10 l/min was used during these measurements since that flow rate will be used for testing. A maximum thermal gradient of 5.8°C/cm (26.4°F/inch), decreasing from the outside toward the retort center, was found. Due to the size of the retort, the large number of specimens involved in each test, and the effects of flowing He, this gradient is not unreasonable, and will be taken into account when analyzing the test results.

To verify that the thermal stability retorts would stand up under extreme operating conditions, they were given a proof test. This test consisted of running the retort 4 hours at 1093°C (2000°F) (43°C above maximum intended operating temper-

ature), 103.4 KPa (15 psig) He pressure and 10 l/min He flow rate, then cooling rapidly to simulate a total loss of electrical power. To date, seven (7) of the eight (8) thermal stability stands have been subjected to and passed this proof test.

2.3.3 Single Specimen Creep/Rupture Equipment

The last of the single specimen (ST) retorts which will be used in the screening portion of the program were conditioned. The method employed was described in the last quarterly report (C00-2975-28). In essence, it consists of heating the retort, its load bars, couplings and extensometer components to the test temperature under a flow of H_2 with H_2O at H_2 to H_2O ratios between 160:1 and 80:1. This range is consistent with the oxidation potential to be used for the screening tests.

To verify the integrity of ceramic ST retorts, proof tests were performed on two (2) retorts. This consisted of ramping to $1093^{\circ}C$ ($2000^{\circ}F$) at maximum pressure and flow rates, then cooling rapidly. The retorts withstood the tests with no evidence of any problems.

A system for rapid loading at the ST stands has been devised. It is now possible to apply the full required weight on the lower arm in approximately 10 seconds, and generate a record of the load and elongation in the process. An electrically driven weight pan elevator with a pancake-type load cell between the weight pan and load elevator is employed. With an X-Y-Y recorder, the loading versus the two (2) LVDT outputs can be recorded.

2.4 TASK 4 - SIMULATED REACTOR HELIUM ENVIRONMENT

2.4.1 Helium Distribution Systems - (D.H. Baldwin)

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

Further revisions, beyond those reported in the last quarterly report, were made to the impurity gas addition system. The eight (8) valves, two (2) each for the four (4) impurity gasses, were divided into isolatable banks of four (4) to facilitate servicing without interruption of loop operation. In addition, the helium flow for positive flushing of the valves has been plumbed so that it can either flow through or by-pass the oxygen sensor cell, adding to the ease of servicability of that component.

The plumbing connections to the 16-port sense line scan valve have also been revised. These revisions allow the scan valve to be isolated from the system and the scan and sense lines to be evacuated after servicing while a by-pass line permits continuous sampling of loop He during such servicing operations.

Gas sampling lines to the Antek gas chromatographs (GC) in PP&A Nos. 1 and 2 have been interconnected so that samples from either loop can be routed to either GC. This allows for greater flexibility during servicing operations.

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

Installation activities on PP&A No. 2 have proceeded during this quarter. The electrical installation of PP&A No. 2 was completed. The loop plumbing connections and up-dating of the original console plumbing are nearing completion.

Installation of all of the utility frame subassemblies for the single specimen creep/rupture stands has been completed. The cooling water connections to the remaining test stands has been complete, as has the installation of 21 of 35 furnace control panels for those stands.

2.4.3 Loop No. 1 Operation

2.4.3.1 Attainment of Dynamic Gas Equilibrium

Following initial characterization of the gas addition and purification systems, Loop No. 1 was brought to stable operation with a dynamically controlled loop gas chemistry. Impurity gases are added through the gas addition system and removed as needed through the purification system. To reach equilibrium, the flow rates through specific getters and their effects on individual impurity species were calculated from working curves and set for loop operation. Once He flow was established, the gas addition valves were adjusted to bring the impurity gas levels to their desired levels consistent with the gettering rates. The flow through both the addition and purification systems could then be adjusted in concert to maintain efficient impurity gas control at desired levels. After the desired chemistry was reached, the flow through the purification system was set and further impurity gas level control was maintained by adjusting the impurity gas addition rates.

The following paragraphs describe the initial loop operating experience and the philosophy and practicalities of impurity gas control for He testing.

2.4.3.2 Gas Chemistry Limits

The helium system is currently in operation, controlling impurity levels to the following limits, depending on circumstances:

Gas	Normal Retort Supply	Max. Limits, Retorts Supply	Max. Limits Retort Exhaust
µat. at 2 atm. abs.			
H ₂	400 $\begin{smallmatrix} + 100 \\ - 50 \end{smallmatrix}$	300 - 500	300 - 500
H ₂ O	2.0 $\pm$ 1.0	1.5 - 4.0	1.5 - 5.0
CO	40 $\pm$ 10	30 - 50	20 - 60
CO ₂	0.2 $\pm$ 0.15	0.05 - 0.40	0.03 - 0.50
CH ₄	20 $\pm$ 5	10 - 30	5 - 50
N ₂	6 $\pm$ 4	1 - 20	1 - 20
O ₂	None Detectable by Gas Chromatograph		

The significance of the impurity gas levels on oxidation and carburization potential was discussed in the quarterly report for January 1, 1978 - March 31, 1978, report number C00-2975-21. The overriding factor controlling these effects is the partial pressure ratios of the various impurity gasses. The ranges are set so that the following partial pressure ratios are not exceeded:

<u>Pressure Ratio</u>	<u>Maximum Allowable Pressure Ratio Range</u>
P_{H_2}/P_{H_2O}	10 - 1000
P_{CO}/P_{CO_2}	10 - 5000
$P_{CO}P_{H_2}/P_{H_2O}$	Not Determined

<u>Pressure Ratio</u>	<u>Maximum Allowable Pressure Ratio Range</u>
P_{CO}^2 / P_{CO_2}	0.002 - 0.10
$P_{CH_4} / P_{H_2}^2$	10 - 1000
$\frac{P_{CO} P_{CH_4}}{P_{H_2} P_{H_2O}}$	Not Determined

The significance of the gas chemistry limits in terms of system operation are as follows:

Target levels are always those in the first column. The chemistry will be reported as out of limits whenever the indicated bounds are exceeded.

During transition periods as when test retorts are being tied-in to the helium system, the limits shown in the second column define certain procedures the operator must follow, primarily to protect other specimens already in test.

Maximum limits on retort exhaust defines certain actions the operator must take in order to minimize the effects of depletion within a test retort.

When a new retort is being added to the helium system, for example, the present operational procedure requires that the gas chemistry analysis system be ready to analyze that retort's effluent. In addition, the initial flow rate through the retort is limited to 1 l/min. Comparison of retort exhaust analysis against known loop chemistry prior to tie-in immediately alerts the operator as to whether impurity addition rate adjustments may be required. If so, he is then required to monitor loop chemistry and make necessary adjustments to keep it within the "Max. Limits, Retort Supply" limits above. If, on the other hand, the composition of the retort effluent is only slightly out of the limits shown in the "Max. Limits, Retort Exhaust" column, the operator is required to increase the flow of helium through that retort in an effort to bring the overall retort composition within limits. Flow rates are increased gradually, generally in 2 l/min. increments, with intermittent checks on loop chemistry. The 2 l/min. increment limitation also avoids thermal shocks to ceramic retort tubes. This strategy of increased flow rate to overcome depletion effects is limited to

maximum flow rates of 150% of design levels:

<u>Retort Type</u>	<u>Design Flow</u>	<u>Max. Flow</u>
Single Spec. Creep	2 l/min.	3 l/min.
Thermal Stability	10	15
Multi-spec. creep	10	15

Finally, when the flow rate through the new retort has been increased either to its design level or the maximum described above, the operator's principal concern is to restore the loop to normal operating condition. In addition, if retort depletion decreases with time, retort flow rates are gradually reduced to design levels.

2.4.3.3 Loop Chemistry Control

Loop chemistry is controlled primarily by operator adjustments made to the impurity gas addition valves while impurity removal rates remain constant. Basically, there are two reasons for this strategy:

The impurity addition valves represent the most sensitive control element in the gas system. Impurity removal rates are determined to a large extent by flow rates through various canisters of gettering agents, and the flow rate control valves for these elements are at least an order of magnitude coarser than the micro-metering valves used to control impurity addition rates.

Control of impurity concentration by rate of addition adjustments rather than rate of removal adjustments avoids synergetic effects. For example, both H_2 and CO are reducing agents for CuO. Therefore, when it is necessary to lower the concentration of H_2 in the loop, and this is accomplished by increasing the rate of loop helium flow over the CuO, the rate of CO removal also will be increased and its loop concentration decreased. If, on the other hand, the H_2 level is reduced by dropping the addition rate and not changing the gettering rate, the CO level will not be disrupted. In operations to date this control strategy has proven quite effective.

2.4.3.4 Retort Tie-in Procedure

All metal surfaces in a test retort, including test specimens, are cleaned in xylenes first, then acetone*. Ultrasonic agitation is employed whenever possible (i.e., limited to small parts such as specimens, couplings, load bars, *Analytical reagent grade, less than 0.001% residue after evaporation

etc.). All subsequent handling is carried out with clean white cotton gloves. Other components too large for ultrasonic cleaning are wiped with clean cotton cloth wetted with reagent grade acetone. Cleaning of ceramic components is by heating to a temperature above that planned for the test.

Assembled test retorts are leak checked under vacuum with a helium mass spectrometer leak detector. Leaks larger than 5×10^{-8} scc/sec are repaired before a retort is committed to test.

The leak checked retort is back-filled with purge gas (He with 500 ppm H_2) and a flow of 250 cc to 1 l per minute is established, depending on the size of the retort. The retort effluent is passed through a portable gas analysis station containing, in series, a Carle AGC-111 chromatograph and a Shaw hygrometer. Analyses are made periodically as the retort is heated to the test temperature. The heat-up is linear with time at a maximum rate of 110°C/hr . If any unusual amounts of impurities are evolved, the temperature ramp is interrupted until they have been effectively baked out. This procedure means the loop operator need only be concerned with depletion effects once the retort is tied-in to the loop.

If the test stand involved is a creep test unit, load is applied to the hot specimen(s) before loop tie-in is attempted. Thus, if a major leak develops in the seal as a result of test load application, only the specimen(s) in the new retort will be jeopardized. Approximately 15 minutes are allowed after loading to verify leak tightness integrity before loop tie-in begins.

2.4.4 Controlled Purity Helium Testing

2.4.4.1 Preliminary Exposures

In order to verify the oxidation potential of the controlled purity He, two (2) coupons each of high purity Fe and Cr were exposed to loop He at 850°C (1562°F) for periods of 117 and 149 hours. The loop He, as described in the preceding section, should be oxidizing to Cr but not to Fe. A record of the loop and retort exhaust chemistries over the first test period is shown in Figure 2.1. This was typical of both runs. {Operation in purge gas (440 ppm H_2 in He) for approximately 20 hours was necessary during the second, longer test.}

Figure 2.1 Loop and Retort Exhaust Chemistries for 117 Hour Fe and Cr Exposures.

Post exposure visual examination of the coupons revealed that while the Fe specimens had remained bright, except for possibly some thermal etching, the Cr specimens had a dark gray surface film with a slight greenish tint. These specimens, along with control (unexposed) specimens were subjected to micro-structural examination. Optical microscopy of the specimen cross-sections showed that only the exposed Cr specimen had any noticeable scale. Auger analysis of the specimen surfaces showed that the scale on the exposed Cr specimen was indeed an oxide layer.

All specimens, Fe and Cr, both exposed and control, showed similar low but real levels of adsorbed oxygen and carbon at the specimens' surface [depths up to $5.0\text{ }\mu\text{m}$ (2.0×10^{-7} inches)]. Except for the exposed Cr specimen, only background levels of those elements were found beyond that depth. The Cr showed high levels of oxygen beyond that depth, but no carbon. These data indicate that carburization is not a significant effect for either Fe or Cr for these exposure times and conditions.

The formation of a surface oxide on Cr and not on Fe under these exposure conditions (i.e., normal operating gaseous impurity levels) is consistent with the gas chemistry requirements for materials testing.

2.4.4.2 Initiation of the Screening Test Program

During this quarter, two single specimen creep stands were brought on line at 850°C (1562°F) with TZM specimens for the screening creep tests. The loop gas chemistry record and the retort exhaust gas chemistry records for the initial few days of testing are given in Table 2.2. The metallic retort, ST-5, outlet chemistry shows that CO_2 is depleted during initial exposure to loop He. A similar depletion effect was not found for ST-9 which is a ceramic retort.

2.5 TASK 5 - MECHANICAL PROPERTIES EVALUATION

2.5.1 Test Specimen Machining

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

TABLE 2.2

LOOP AND RETORT EXHAUST CHEMISTRIES FOR
INITIAL SCREENING CREEP TESTING

Date	Time	Source of Gas Sample	Gaseous Impurity Levels, μ -atm						Comments
			H ₂	H ₂ O	CO	CO ₂	CH ₄	N ₂	
3/28	12.30	Loop	435	2.2	33.9	.23	17.7	3.4	ST-5 Tied-In 13.35 ^(a)
	13.50	ST-5	535	2.4	9.2	0.0	15.7	4.5	
3/29	00.30	Loop	490	2.0	40.7	.27	18.8	4.7	
	01.30	ST-5	502	1.4	26.4	0.0	17.1	4.8	
	12.00	ST-5	383	1.2	33.1	Hint	16.0	1.7	
	13.30	Loop	375	2.2	42.9	.25	17.4	3.0	
3/30	00.00	ST-5	362	1.3	34.7	Hint	17.4	3.8	
	01.30	Loop	358	2.4	41.9	.28	18.5	4.6	
	12.30	Loop	365	2.6	45.4	.27	18.5	2.7	
	14.00	ST-5	375	1.4	37.9	Hint	18.5	4.3	
3/31	15.00	ST-9	385	2.2	36.4	.25	20.8	11.5	ST-9 Tied-In 14.30 ^(a)
	00.30	Loop	350	2.4	47.4	.26	20.8	3.2	
	01.30	ST-5	360	1.3	36.4	Hint	20.3	4.1	
	02.30	ST-9	355	1.4	38.5	.15	20.8	4.4	
	12.30	Loop	320	2.4	43.4	.24	18.1	3.4	
	13.30	ST-5	342	1.4	34.3	Hint	17.3	2.7	
	14.30	ST-9	360	1.3	39.6	.14	18.5	2.4	

(a) ST-5 and ST-9 are single specimen creep retorts both run at 850°C (1562°F),
ST-5 is a metallic retort and ST-9 is ceramic.

2.5.2 Selection of Stresses for Screening Creep Tests

Based on the 300-hour creep and rupture test results, stresses were selected for the following three types of screening creep tests:

1. Stress for 1% total strain in 100,000 hours; to be tested for 10,000 hours.
2. Stress for 1% total strain in 6,000 hours; to be tested for 6,000 hours.
3. 80% of the stress for rupture in 10,000 hours; to be tested for 3,000 hours.

During the screening tests, the amount of creep on each sample will be measured at 1,000-hour intervals, following which the samples will be rehung at the same load unless excessive creep is occurring. In this case, the specimen will be removed from test and replaced in the stringer by a new specimen.

2.5.2.1 Direct Cycle Helium Turbine (DCHT) Alloys - (E.W. Ross)

The selection of desired stresses for all DCHT alloys for screening creep testing was completed and reported in the Quarterly Report for July 1, 1978 - September 30, 1978, report number C00-2975-25.

2.5.2.2 Nuclear Process Heat (NPH) Alloys - (S.Z. Hayden and R.A. Ellis)

The final desired stresses selected for the NPH alloys are listed in Table 2.3. These values take into account the additional data available this quarter from the longer term air creep-rupture tests.

Based on the desired stress levels for each alloy, loading schedules for screening (multispecimen) creep testing will be prepared. The actual testing stress will be set as near as possible to the desired stress levels for all specimens in any specimen stringer. Since there will be up to 15 specimens per stringer, all at the same load, specimens will be grouped accordingly. The loading schemes will be completed during the next quarter.

2.5.3 Screening Creep Testing

Two screening creep tests were initiated during this quarter. These are two (2) TZM specimens being tested at 352 MPa (51 ksi) for 3000 hours and 386 MPa (56 ksi) for 6000 hours, both at 850°C (1562°F). These stresses are chosen as 80% of the stress to rupture in 10,000 hours and the stress for 1%

TABLE 2.3

CALCULATED STRESSES FOR NPH SCREENING CREEP TESTS

Alloy	Temperature °C	Stress for 1% ϵ_T in			Stress for 1% ϵ_T in			Stress for 80% ϵ_T in		
		100,000 Hours			6,000 Hours			10,000 Hours		
		Original	Final	MPa	Original	Final	MPa	Original	Final	MPa
Alloy 800H	750	34	5	48	7	48	7	48	7	48
	850	21	3	28	4	21	3	21	3	14
	950	3	0.4	2	0.3	7	1	7	1	7
Incoloy 802	750	55	8	83	12	83	12	69	10	90
	850	21	3	48	7	41	6	28	4	41
	950	7	1	14	2	14	2	14	2	14
Incoloy 807	750	41	6	69	10	62	9	69	10	69
	850	14	2	28	4	28	4	28	4	28
	950	5	0.7	14	1	14	1	14	1	14
Incoloy DS	750	14	2	28	4	34	5	28	4	34
	850	7	1	14	2	14	2	14	2	14
	950	3	0.4	7	0.7	5	0.4	7	1	7
HD-556	750	48	7	62	12	62	9	76	11	96
	850	14	2	28	4	28	4	34	5	48
	950	5	0.7	14	1	14	1	14	1	14
Manaurite 36XS	750	41	6	62	9	55	8	62	9	55
	850	21	3	34	5	34	5	34	5	34
	950	7	1	14	2	14	2	14	2	14
HK-40	750	55	8	90	13	69	10	62	9	62
	850	21	3	34	5	34	5	34	5	34
	950	7	1	14	2	14	2	14	2	14
IN-519	750	48	7	69	10	76	11	62	9	69
	850	21	3	34	5	34	5	34	5	34
	950	7	1	14	2	14	2	14	2	14
Hastelloy X	750	34	5	55	8	55	8	62	9	69
	850	14	2	21	3	28	4	28	4	28
	950	4	0.6	7	1	7	1	14	1	14
Inconel 617	750	55	8	83	12	90	13	96	14	96
	850	21	3	34	5	41	6	41	6	48
	950	7	1	14	2	21	3	21	3	21
Mo-Re2	750	34	5	48	7	76	11	131	19	90
	850	21	3	28	4	41	6	55	8	48
	950	14	2	21	3	21	3	21	3	21
MA-956E	750	34	5	48	7	55	8	69	10	55
	850	21	3	34	5	48	7	55	8	48
	950	7	1	14	2	21	3	21	3	21
Alloy 800H*	750	34	5	48	7	28	4	48	7	41
	850	21	3	28	4	28	4	28	4	28
	950	3	0.4	7	1	7	1	7	1	7
Inconel 617**	750	55	8	83	12	55	8	96	14	76
	850	21	3	34	5	28	4	41	6	34
	950	7	1	14	2	21	3	21	3	21
Test Time		10,000 Hrs.			6,000 Hrs.			3,000 Hrs.		

*Alloy 800H is coated with a platinum-chromium-aluminate type coating similar to RT-22.
 **Inconel 617 is coated with an aluminate coating similar to Codep B.

total strain in 6000 hours, respectively. Because of the inordinately high strength of TZM, these specimens are being tested in single specimen creep (ST) stands. In line with normal procedure for screening creep, the specimens will be cooled down and unloaded at 1000-hour intervals for measurement of creep strain. The remainder of the screening creep tests will be initiated during the next quarter.

2.6 TASK 9 - DATA MANAGEMENT AND PROGRAM MANAGEMENT

2.6.1 Data Management - (R.B. Hand)

2.6.1.1 Data Storage and Retrieval

Work has continued on the Database Definition File which will define the database structure within the Mark III computer system. A preprocessor program is also required to structure the input.

2.6.2 Program Management

Weekly program coordination meetings were held with the High Temperature Reactor Materials Testing Laboratory personnel and with General Electric management continued to be held in order to maximize efforts toward the start-up of the controlled purity helium test facilities and the initiation of the screening test program which occurred on February 19, 1979. In addition, a general program review meeting was held with the program team on March 12, 1979 and with the General Manager of the General Electric Energy Systems Programs Department on March 26, 1979. Finally, a meeting was held with the DOE Program Manager in Washington, DC on March 22, 1979.

A revision to the DOE schedule 189a was prepared and forwarded to the DOE Program Manager on January 12, 1979.

The Program Master Schedule is presented in Figure 2.2. A major revision to the Program Master Schedule is being prepared to reflect the actual initiation of the screening test program this past quarter and other programmatic changes that will be submitted to the DOE Program Manager for approval in the next quarter.

Section 3.0

WORK TO BE COMPLETED DURING THE NEXT QUARTER

3.0 WORK TO BE COMPLETED NEXT QUARTER

- Multi-specimen screening creep furnace loading plans will be finalized.
- The remaining screening creep and structural stability tests will be started.
- Installation of Loop No. 2 will be continued.
- Alloy selection for the intensive testing phase of the program will be started.