ADVANCED GAS COOLED NUCLEAR REACTOR MATERIALS EVALUATION AND DEVELOPMENT PROGRAM

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FORWARD

The Advanced Gas Cooled Nuclear Reactor Materials Evaluation and Development Program is being conducted for the Division of Nuclear Research and Applications, U.S. Energy Research and Development Administration by the Energy Systems Programs Department, General Electric Company, Schenectady, New York, 12345. The Program is under the direction of Mr. J.E. Fox, ERDA 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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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

2.0 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 progress report COO-2975-3.

During the second quarter of the program work was continued on Task 1 (Selection of Candidate Alloys), 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). Preliminary work was initiated on Task 2 (Materials Procurement and Characterization).

2.1 TASK 1 - SELECTION OF CANDIDATE ALLOYS

Work on this task culminated with a preliminary draft, COO-2975-7, of an alloy selection report entitled "Selection of Alloys for the Advanced Gas Cooled Nuclear Reactor Materials Evaluation and Development Program." This report was prepared by R.M. Goldhoff and R.V. Hillery.

The report was circulated for review by ERDA to the General Atomic Co., Battelle Memorial Institute, Westinghouse Electric Co., NASA Lewis Research Center, Cabot Corp., and the International Nickel Co. Resolution of comments received from these organizations is in progress: a list of alloys in which there was common agreement should be available by the end of April; disagreements in the inclusion of specific alloys will be resolved by the end of May and should allow the program to remain on schedule.

2.1.1 DIRECT CYCLE HELIUM TURBINE (DCHT) ALLOY SELECTION - R.V. HILLERY

Work in this Task has resulted in the selection of ten alloys for potential turbine blade or vane use and two ducting alloys to be recommended

for evaluation in the screening tests of this program (Task 5). The selection criteria and procedures used are briefly summarized here and will be more fully detailed in the Alloy Selection Topical Report to be issued at a later date.

2.1.1.1 GENERAL CONSIDERATIONS IN ALLOY SELECTION AND SELECTION APPROACH

Two types of materials are required for DCHT components of interest. Turbine blades and vanes must have high creep, rupture, and fatigue strengths at elevated temperatures. Material candidates for DCHT application are all alloys currently used for similar applications in aircraft, marine, and industrial applications. A discussion of the relative merits of alloys selected for and discarded from consideration is presented.

In contrast, alloys for ducts and casings must be fabricable and weldable into pressure vessels, whose integrity is crucial to the entire system. The logical alloy candidates here also are alloy candidates for Nuclear Process Heat (NPH) systems discussed in Section 2.1.2 of this report.

The selection of candidate alloys for use in the turbine blades and vanes of a DCHT is based upon many factors, some of which are common to those required for conventional (air breathing) turbines, but many of which are peculiar to the helium environment and the proximity of materials to a nuclear reactor. The selection criteria can be broadly classified in the following categories:

- (1) Availability and cost
- (2) Fabricability (casting, forming, machining, joining, etc.)
- (3) Mechanical properties (creep rupture, fatigue, yield strength)
- (4) Environmental resistance (oxidation, corrosion, surface stability).

Obviously these criteria cannot be isolated from each other and, particularly with respect to mechanical properties and environmental resistance, the interrelationship is such that primary consideration must be given to the problems peculiar to the specific application.

The current commercial availability of DCHT materials is not considered as important in selection for this test program as it is for the NPH materials. The primary reason for this apparent discrepancy is that, in the case of

turbine blades and vanes, the volume of material and the size of heats needed for fabrication of an engine set is relatively small. (This differs from many NPH components where large fabricated parts would be required, representing relatively high tonnages of material.) Although production availability is a criterion, and would weigh heavily in a choice between two similar materials, it is not considered a primary requirement for the initial phases of the program. Other industrial users, conventional industrial gas turbines and aircraft engines for example, will probably ultimately determine the availability, and cost, of DCHT materials. For this reason, the selection of materials considered availability, and probable availability in the mid 1980's, but did not necessarily exclude any material from recommendation.

There are basically three classes of alloys to be considered as potential blade and vane materials for DCHT application based on the requirements and constraints of the system. These alloy classes are as follows:

- (1) Cast Nickel-base γ' strengthened superalloys;
- (2) Oxide dispersion strengthened (ODS) alloys; and
- (3) Molybdenum-base alloys.

Although cobalt-base alloys such as X-40 and MM-509 have very wide usage as the first stage vane material for conventional aircraft and industrial gas turbines, it seems appropriate to dismiss these as viable candidates for DCHT selection. Although the "safe" level of cobalt in turbine materials to be used in a closed loop system with a nuclear reactor core has not been defined in absolute terms, the possibility of cobalt containing oxides spalling from the turbine component and being carried through the reactor core via the helium gas stream must be minimized and, if at all possible, eliminated. The surface reaction products formed on X-40 or MM-509 in a contaminated helium environment will obviously be significantly different than those formed in air -- and will undoubtedly vary with the concentrations of the several contaminants as well as the temperatures and pressures in the turbine -- but it is extremely likely that some cobalt-bearing "scale" would eventually be formed. In addition, it is generally recognized that surface films on cobalt-base alloys are less protective and more prone to spallation than corresponding films on nickel or iron base alloys. Taking into account all these factors,

it was concluded that from the standpoint of contamination problems caused by potential generation of the Co_{60} isotope that the cobalt-base alloys should not be considered further for the materials selection.

For turbine blade airfoils, the following mechanical property requirements were considered in the overall alloy selection process:

- (1) Creep and rupture strength;
- (2) Combined stress high cycle fatigue; and
- (3) Creep-fatigue interactions.

In addition, the dovetail (root) of the blade is designed in terms of yield and tensile strength and combined stress low cycle fatigue.

For turbine vanes, the following mechanical properties were considered:

- (1) Creep and rupture strength; and
- (2) Thermal/low cycle fatigue.

For most alloys under consideration, tensile and rupture properties are well documented for a wide range of temperatures, albeit in an air environment. Other properties, however, are not as readily available and in many cases are only available in user handbooks and then only for a very specific application range. Therefore, while it is reasonable to assume that an alloy which has found widespread use in, for example, a gas turbine engine has well understood and defined properties, these data may not be available in the open literature. In these cases, judgment on applicability was made based upon available property data, which may be very sparse. In addition, other than limited creep rupture data, essentially no information was available on the mechanical properties of all candidate alloys in an appropriate helium environment. The selection process therefore became somewhat arbitrary and was based to a large degree on extrapolated rupture data from air testing.

The selection of materials for DCHT blade and vane applications considered the propensity toward long time bulk instabilities such as sigma, or other TCP, phase formation and carbide precipitation. (These concerns affect primarily turbine blades and ducts, including the weldments in ducts.) Other types of instabilities -- including recrystallization, grain growth, changes in phase morphology -- may be encountered and were considered where data were available.

There are several key fabricability requirements for blades and vanes for a DCHT system. For cast alloys, the material must be castable to the required sizes to extremely high quality levels, particularly for rotating parts. In addition, since hot isostatic pressing (HIP) is being utilized more and more to improve casting integrity, the HIP thermal cycle (if used) must not degrade the microstructure or creep rupture strength of the alloy. For oxide dispersion strengthened (ODS) and wrought molybdenum-base alloys, the material must be available and producible in the required sizes for turbine vanes. In addition, brazing or other joining schemes must be made available for such materials; at least for ODS alloys, the aircraft gas turbine industry is gaining considerable experience in this field. Coating systems must also be adaptable to alloys selected for DCHT blade and vane applications.

The objective of this Task was to consider all the criteria discussed above and to arrive at a recommended list of no more than twelve alloys to be included in the screening phase of the DCHT test program. A master list of possible candidate materials, including cast nickel-base superalloys, ODS alloys and Mo-base alloys was prepared and is shown in Table 2-1. This list included alloys that have been considered for HTGR service in other programs and are in test or are to be tested. The wrought sheet alloys and some of the more recently released or development casting alloys have not been included, nor have the alloys that are used primarily for disc or large structural applications in conventional gas turbine technology. The list is, however, reasonably comprehensive and is a representative sampling of alloys that may be appropriate for consideration.

Next, the cast nickel-base superalloys were grouped in order of decreasing strength (high, intermediate, good, and weak) to allow immediate elimination of some, and side-by-side comparisons of others. Although the very weak alloys were immediately eliminated from further consideration, it was felt appropriate to include in the final selection at least one alloy from each strength group. Also, it was considered mandatory, for a screening program such as this, to include at least one alloy from the ODS and Mo-base alloy categories. Based on these criteria, the considerations discussed above, and available alloy data, the final alloy selection was made.

TABLE 2-1

NOMINAL COMPOSITIONS (W/O) OF POSSIBLE CANDIDATE DCHT MATERIALS

Alloy	Ni	Cr	Al	Ti	Co	Ta	Mo	W	Cb	C	Other
Unalloyed Mo (Rx)	--	--	--	--	--	--	Bal	--	--	0.02	
Mo TZM	--	--	--	.45	--	--	Bal	--	--	0.015	0.09 Zr
YDNI	Bal	--	--	--	--	--	--	--	--	--	2 Y ₂ O ₃
MA754	Bal	20	.3	.6	--	--	--	--	--	--	0.6 Y ₂ O ₃
HD8077	Bal	16	4.0	--	--	--	--	--	--	--	0.8 Y ₂ O ₃
MA757	Bal	16	4.0	--	--	--	--	--	--	--	0.6 Y ₂ O ₃
YDNIcrAl	Bal	16	4.0	--	--	--	--	--	--	--	1 Y ₂ O ₃
MA956	--	21	5.0	--	--	--	--	--	--	--	0.6 Y ₂ O ₃ , Bal Fe
Rene'125	Bal	8.9	4.75	2.5	10.0	3.8	2.0	7.0	--	0.11	1.5 Hf
TRW VIA	Bal	6.0	5.4	1.0	7.5	9.0	2.0	5.8	0.5	0.13	0.5 Re, 0.5 Hf
MM200	Bal	9.0	5.0	2.0	10.0	--	--	12.5	1.8	0.15	
MM246	Bal	9.0	5.5	1.5	10.0	1.5	2.5	10.0	--	0.15	
MM002	Bal	9.0	5.5	1.5	10.0	2.5	--	10.0	--	0.15	1.5 Hf
MM247	Bal	8.3	5.5	1.0	10.0	3.0	0.7	10.0	--	0.16	1.5 Hf
B1900	Bal	8.0	6.0	1.0	10.0	4.3	6.0	0.1	0.1	0.1	
Rene'100	Bal	9.5	5.5	4.2	15.0	--	3.0	--	--	0.18	
Rene'80	Bal	14.0	3.0	5.0	9.5	--	4.0	4.0	--	0.17	
IN792	Bal	12.7	3.2	4.2	9.0	3.9	2.0	3.9	--	0.21	
IN738	Bal	16.0	3.4	3.4	8.5	1.7	1.75	2.6	0.9	0.17	
IN713LC	Bal	12.0	5.9	0.6	--	--	4.5	--	2.0	0.05	
Rene'77	Bal	15.0	4.25	3.5	15.0	--	4.2	--	--	0.15	
MM004	Bal	12.0	5.9	0.6	--	--	4.5	--	--	0.05	1.3 Hf
M21	Bal	5.7	6.0	--	--	--	2.0	11.0	1.5	0.08	
MM421	Bal	15.5	4.25	1.75	10.0	--	1.75	3.5	1.75	0.15	
U700	Bal	15.0	4.4	3.5	18.5	--	5.0	--	--	0.07	
U500	Bal	19.0	3.0	3.0	18.0	--	4.0	--	--	0.08	
SEL 15	Bal	11.0	5.4	2.5	14.5	--	6.5	1.5	0.5	0.07	
IN731	Bal	9.5	5.5	4.7	10.0	--	2.5	--	--	0.18	

TABLE 2.2

RECOMMENDED DCHT ALLOYS

Alloy Type	Alloy	Application	Status
Molybdenum-Base Alloys	Mo-TZM	Buckets and Vanes	Commercial
ODS Alloys	YD-Ni	Vanes	Development
	MA-754	Vanes	Commercial
	YD-NiCrAl	Vanes	Development
Cast Nickel-Base Alloys	MM-247	Buckets and Vanes	Commercial
	Rene' 80	" "	"
	Rene' 100	" "	"
	M-21	" "	"
	MM-004	" "	"
	IN-713LC	" "	"
Wrought Nickel-Base Alloys	Inconel 617	Ducts and Casings	"
	Hastelloy X	" "	"

2.1.1.2 SELECTION RECOMMENDATIONS

2.1.1.2.1 THE SELECTED ALLOYS

The recommended list of alloys to be evaluated in the DCHT screening program is given in Table 2-2. As indicated above, this list includes at least one choice from each alloy category, and in the case of the γ' strengthened nickel-base superalloys, the various strength levels of alloys are represented. At this point in the program, Mo-TZM and all the γ' strengthened nickel-base alloys are considered candidates for either DCHT blades or vanes and only the ODS alloys are considered exclusively for vanes. Hastelloy X and IN617 are suggested for use in turbine casings and ducts.

2.1.1.2.2 COATINGS AND WELDMENTS

The screening program will evaluate two coating systems (selected for blade and vane alloys) and weldments on the two duct alloys. The weldments will be evaluated in the same manner as that to be used in the VHTR section of the program.

A simple aluminide, a preoxidation and an aluminide plus preoxidation system will be used on selected nickel-base γ' alloys in this program. The possibility of a chromide or silicide coating for the Mo-TZM alloy evaluation is being considered, but no firm recommendation has been made at this time.

2.1.1.3 DISCUSSION OF ALLOY RECOMMENDATIONS

Mo-TZM is the strongest alloy available for the temperatures and times being considered for the DCHT. The Ti and Zr additions provide dispersion hardening and retard recrystallization and grain growth. Mo-TZM has a span of tensile strength from 690-520 mPa (100-75 ksi) over the 760-1093°C (1400-2000°F) temperature range with an excellent high temperature modulus of elasticity. Its long time stress rupture properties are in the range 415-85 mPa (60-12 ksi) over the temperature range 870-1093°C (1600-2000°F). Rupture ductilities are fair over the same temperature range.

Despite the findings given in a recent report by General Atomic⁽¹⁾ which suggest that carburization of Mo-TZM can be significant and result in degradation of tensile strength and ductility, it is felt that Mo-TZM must be included in the proposed evaluation of DCHT materials. Unalloyed Mo does not have the stress bearing capabilities required in the DCHT blades and does not merit evaluation in this part of the program.

ODS alloys are used as turbine vanes and bands in advanced aircraft engines because of their high-temperature advantages over cast vane alloys. ODS alloys derive their properties from a combination of submicron particle dispersoid strengthening and microstructures which remain stable virtually to their melting points. Compositionally, the alloys have not been complex. Because of their phase simplicity and dependence on inert oxides, the thermal stability of their microstructures is excellent.

The selected ODS alloys for evaluation are YD-Ni, MA-754 and YD-NiCrAl for the following reasons. The Ni-base is chosen because it has found the most widespread use (and therefore has the broadest data base) and because it allows evaluation of the complete series in increasing degree of alloying (Ni → NiCr → NiCrAl). Also, although the Fe-base MA-956 may have some benefit in hot corrosion/oxidation environments (versus an ODS NiCrAl), the poorer thermal/low cycle fatigue resistance of this alloy suggests that it should not be selected for DCHT vane application evaluation. Despite the obvious similarity in composition of HD-8077, MA-757 and YD-NiCrAl, General Electric experience with each strongly indicates the superiority of YD-NiCrAl in transverse properties. For this reason, and the fact that because of it, the alloy will probably more readily be commercially available and have a broader data base, YD-NiCrAl is recommended for evaluation in this program.

The six alloys listed in the high strength Cast Ni-base alloy category (Rene'125, NASA TRW VI-A, MM-200, MM-246, MM-002 and MM-247) are all very strong, high temperature, γ' strengthened superalloys with 1000-hour rupture lives at a stress of 140mPa (20 ksi) and a temperature of 980°C (1800°F). Of the four MM alloys in this category, MM-247 is selected for the present

(1) S.N. Rosenwasser and W.R. Johnson, Ga-Al4122, "Gas Turbine HTGR Materials Screening Test Program", Quarterly Progress Report for the Period July 1, 1976 through September 30, 1976.

program, since increased usage of this alloy can be expected in the aircraft gas turbine industry, and therefore the data base and experience will improve markedly.

NASA TRW VI-A alloy has not found widespread commercial use in the aircraft engine industry, although a substantial amount of test data has been accumulated on the material. For the present program, however, a more disturbing feature of the alloy is the large amount of tantalum (9%) it contains. This, in addition to the 7.5% cobalt, makes the nuclear contamination risk higher than for any other alloy and, since there is no strength advantage compared to others in the class, this alloy is ruled out in the selection process.

In selecting one of the two alloys, MM-247 or Rene'125, compositional differences do not provide a significant separation. Industry-wide, it is felt that MM-247 will be more rapidly introduced into service and a broader operating experience will be gained with it than with Rene'125.

The four alloys selected as potential candidates in the intermediate strength category (B-1900, Rene'100, Rene'80, IN-792) are all γ' strengthened superalloys with 1000-hour rupture lives at a stress of approximately 100 mPa (15 ksi) and a temperature of 980°C (1800°F). All of the alloys have found very widespread use in aircraft and industrial gas turbine blade and vane applications and as such a substantial data base exists for each alloy.

All the alloys in this category contain significant amounts of cobalt, and two contain approximately four percent tantalum. From the standpoint of possible nuclear contamination, none of the alloys is particularly attractive, but at least one in this strength class should be evaluated. B-1900 and IN-792 were eliminated, somewhat arbitrarily, since they both contain tantalum, which can be avoided by considering Rene'80 and Rene'100.

Having eliminated B-1900 and IN-792, two alloys remain which together form an interesting series of comparisons for evaluation in a DCHT He environment. It is suggested that the screening program could be used to allow evaluation of these compositional differences. First, the Co and Cr

level in the two alloys (Rene'80 and Rene'100) are reversed and testing may provide some insight into the relative problems of Co and nuclear contamination and the reactivity of Cr and its effect on surface stability and bulk properties. Second, the Al/Ti ratios are essentially reversed in the two alloys and comparative testing might provide guidance for future alloy development relative to the amounts of these two reactive elements. Both Rene'80 and Rene'100 are therefore recommended for evaluation in the program.

The remaining group of alloys listed in Table 2-1, having eliminated the bottom group of five because they are too weak for the proposed applications, contains five alloys -- IN-738, IN-713LC, Rene'77, MM-004 and M-21. These are alloys that typically have 1000-hour rupture lives at a stress of 140 mPa (20 ksi) and a temperature of 925°C (1700°F); approximately 56°C (100°F) lower capability than the strongest cast γ' alloy to be tested in this program.

IN-713LC, IN-738 and Rene'77 have the advantage of wide General Electric and industry baseline experience in conventional gas turbines. Although M-21 is not known to be used in the U.S. gas turbine industry, it has had some application in European aircraft turbines (principally as vanes for the Concorde SST engine) and hence, a background of experience is available. MM-004 is a hafnium modified IN-713LC alloy and offers the promise of improved castability and enhanced ductility.

Three of these five alloys were very interesting for the current evaluation since they contain neither tantalum nor cobalt and are, therefore, free from possible nuclear contamination problems. This factor alone eliminates the other two alloys (Rene'77 and IN-738) since there is no advantage seen in pursuing a parallel investigation of these Co bearing materials. The selection is therefore between alloys IN-713C, MM-004 and M-21.

M-21, although placed in this "good strength" category in the compilation of Table 2-1, is the strongest in the group and, in the temperature range 760-927°C (1400-1700°F), is essentially equivalent to Rene'80. Selection of M-21 would therefore allow evaluation of a Co free alloy for comparison with

an intermediate strength alloy containing almost 10% Co, at least over a specific temperature range.

IN-713LC is very widely used in conventional turbine applications and the alloy is fully characterized and has broad service experience. This abundance of data in addition to the fact that the alloy contains neither Co nor Ta makes it a natural selection for inclusion in the DCHT evaluation program. The hafnium-modified version of the alloy, MM-004, is also suggested as a candidate to allow comparison of the two alloys through at least the initial screening program to provide valuable information for future materials selection. A direct comparison of the two alloys would provide valuable information on the fabricability, mechanical properties and environmental resistance attributable to the hafnium.

M-21, IN-713LC and MM-004 are therefore recommended for evaluation in the DCHT program. These same alloys have been included in other HTGR materials screening programs and this data base can be drawn upon to add to that generated in the current program.

2.1.2 NUCLEAR PROCESS HEAT (NPH) ALLOY SELECTION

Fifteen alloys were recommended for evaluation in screening tests, according to selection criteria and procedures briefly summarized here. As for the DCHT alloys, more detailed discussions will be presented in the Alloy Selection Topical Report, to be issued at a later date.

2.1.2.1 GENERAL ALLOY SELECTION CRITERIA

The criteria used for alloy selection can be categorized as:

1. Availability: commercial alloy or in advanced stages of development.
2. Alloy Types: initial consideration was confined to the following basic alloy types:
 - a. Wrought iron-base austenitic alloys (Incolloys typical)
 - b. Cast iron-base austenitic alloys (HK-40 typical)
 - c. Wrought nickel-base alloys (Inconels typical)
 - d. Cast nickel-base alloys (Supertherm typical)
 - e. Oxide dispersion strengthened (ODS) alloys (Inco MA Series typical)

f. Molybdenum-base alloys (Mo-TZM typical)

3. Environmental behavior and prior He test data
4. High temperature strength characteristics
5. Metallurgical stability and resistance to embrittlement
6. Fabricability and product form availability
7. Cost

2.1.2.2 ALLOY SELECTION APPROACH

Using the selection criteria given above, a list of 35 possible alloys that met these criteria was established. The alloys and their nominal compositions are given in Table 2.3.

Data for the 35 alloys was obtained from the open literature, vendor publications, and personal contacts. Based on the data compilations for the 35 alloys, the alloys were ranked, within the six alloy categories, according to their rupture strength 870-1090°C (1600-2000°F), impact strength (elevated temperature, where available, or room temperature), corrosion resistance (oxidation resistance, carburization resistance, and/or sulfidation resistance), behavior in helium, structural stability, fabricability, availability, adequacy of air data base, and industrial use experience.

Based on the rankings within each category, and other more subjective considerations, the list of 35 potential alloys was reduced to a recommended candidate alloy list of fifteen (15) alloy/process combinations, as listed in Table 2.4. The list includes at least one choice from each alloy category (except for Mo-base alloys, as discussed below) and suggests possible component applications.

2.1.2.3 DISCUSSION OF ALLOY RECOMMENDATIONS

2.1.2.3.1 WROUGHT IRON-BASE (AUSTENITIC) ALLOYS

In any VHTR/NPH development program, this category of alloys is likely to play a major role. Perhaps the most important feature is the ability to produce sheet and tube products and concomitant weldability. While on the lower side, the creep and rupture strength of this group should be adequate

TABLE 2.3

NOMINAL COMPOSITIONS (W/O) OF POSSIBLE CANDIDATE NPH MATERIALS

<u>Alloy</u>	<u>C</u>	<u>Ni</u>	<u>Co</u>	<u>Cr</u>	<u>Fe</u>	<u>Al</u>	<u>Ti</u>	<u>Mo</u>	<u>W</u>	<u>Cb</u>	<u>Other</u>
<u>Wrought Iron-Base Alloys</u>											
Alloy 800	0.04	32.5	---	21.0	Bal	0.4	0.4	---	---	---	---
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 DS	0.05	37.0	---	18.0	Bal	---	---	---	---	---	2.3 Si
Sanicro 32X	0.07	31.0	---	21.0	Bal	0.35	0.35	---	3.0	---	---
HD 556	0.10	20.0	20.0	22.0	Bal	0.3	---	3.0	2.5	0.1	1.3 Mn
Incoloy 807	0.08	40.0	8.0	20.3	Bal	0.4	0.4	---	5.0	1.0	0.9 Ta
<u>Cast Iron-Base Alloys</u>											
IN-519	0.30	24.0	---	24.0	Bal	---	---	---	---	1.5	1.0 Si
HK 40	0.40	20.0	---	24.0	Bal	---	---	---	---	---	1.8 Si
Manaurite 36X	0.40	34.0	---	25.0	Bal	---	---	---	---	1.5	1.5 Si
Manaurite 900	0.15	32.0	---	21.0	Bal	---	---	0.3	---	1.5	1.0 Si
Manaurite 36XS	0.35-.45	32-35	---	24-27	Bal	---	---	---	2.0	1.5	2.0 Si
Mo-Re 1	0.45	35-38	---	25-28	Bal	---	---	---	1.40	---	0.75 Si
<u>Wrought Nickel-Base Alloys</u>											
Hastelloy X	0.10	Bal	1.5	22.0	18.0	---	---	9.0	0.6	---	1.0 Si
Hastelloy X-280	0.10	Bal	---	22.0	18.0	---	---	9.0	0.6	---	1.0 Si
Hastelloy S	0.02	Bal	---	15.5	1.0	0.2	---	15.0	---	---	0.1 La
Nimonic 75	0.15	Bal	---	19.5	2.0	---	0.4	---	---	---	---
Nimonic 80A	0.06	Bal	1.0	20.5	---	1.4	0.05	---	---	---	---
Nimonic 90	0.09	Bal	16.5	19.5	---	1.4	2.35	---	---	---	---
IN-586	0.05	Bal	---	25.0	---	---	---	10.0	---	---	0.3 Ce
Inconel 600	0.04	Bal	---	15.8	7.2	---	---	---	---	---	---
Inconel 601	0.05	Bal	---	23.0	14.0	1.4	---	---	---	---	---
Inconel 617	0.07	Bal	12.5	22.0	---	1.0	---	9.0	---	---	---
Inconel 625	0.05	Bal	---	22.0	3.0	0.2	0.2	9.0	---	4.0	---
<u>Cast Nickel-Base Alloys</u>											
IN-638	0.5	53	15.0	26.0	---	---	---	---	5.0	1.0	---
IN-643	0.5	49	12.0	25.0	3.0	---	---	0.5	9.0	2.0	---
Supratherm	0.5	35	15.0	26.0	17.0	---	---	---	5.0	---	1.6 Si

TABLE 2.3 (continued)

	<u>C</u>	<u>Ni</u>	<u>Co</u>	<u>Cr</u>	<u>Fe</u>	<u>Al</u>	<u>Ti</u>	<u>Mo</u>	<u>W</u>	<u>Cb</u>	<u>Other</u>
<u>Cast Nickel-Base Alloys</u>											
Mo-Re 2	0.15-.25	51	---	33	Bal	1.0	---	---	15-17	---	---
NA22H	0.5	48	---	27	Bal	---	---	---	6	---	1.0 Si 1.3 Mn
<u>ODS Alloys</u>											
HD 8077	---	Bal	---	16.0	---	4.0	---	---	---	---	1.5 Y ₂ O ₃
MA 956	---	---	---	21.0	Bal	5.0	---	---	---	---	1.5 Y ₂ O ₃
MA 754	0.06	Bal	---	20.0	1.5	0.4	0.4	---	---	---	1.0 Y ₂ O ₃
MA 755	0.07	Bal	---	15.0	---	4.5	3.0	3.0	5.5	---	2.5 Ta 1.0 Y ₂ O ₃
<u>Molybdenum-Base Alloys</u>											
Mo	---	---	---	---	---	---	---	100	---	---	---
Mo-TZM	0.015	---	---	---	---	---	0.45	Bal	---	---	0.09Zr

TABLE 2.4

RECOMMENDED NPH ALLOYS

Alloy Type	Alloy	Application*	Status
Wrought Iron-Base Austenitics	Incoloy 800H	D, L, V, I	Commercial
	Incoloy 802	D, R, I	Commercial
	Incoloy 807	D, R, I	Commercial
	Sanicro 32X	D, L, I, R	Commercial
	HD 556	D, L, I, V	Development
Cast Iron-Base Austenitics	Manaurite 36X	D, R	Commercial
	HK-40	D, R	Commercial
Wrought Nickel-Base Alloys	Hastelloy X (W)	D, L, V	Commercial
	Hastelloy X (C)	D, L, V	Commercial
	Hastelloy S	D, L, V	Commercial
	Inconel 586	D, I, R, V	Developmental
	Inconel 617	D, L, I	Commercial
Cast Nickel-Base Alloys	Mo-Re 2	D, R	Commercial
	Supertherm	D, R	Commercial
ODS Alloys	MA-956	L, I	Commercial

Selected Priority of Back-up Alloy Recommendations:

1. IN-643
2. Manaurite 36XS
3. IN-519
4. MA-754
5. Unalloyed Mo (Rx)

* D = Duct
 L = Liner
 I = IHX
 R = Reformer
 V = Valve

for most ducting and IHX tubing application. Structural stability appears adequate in air studies in that adequate ductility generally is retained after exposure. The alloys are known for good oxidation and carburization resistance up to at least 980°C (1800°F). Strength is basically attained by solid solution additions, usually of the refractory metals, to the Fe-30Ni-20Cr base. This accounts for the good structural stability. Many of the alloys listed in this category have many years of experience in aircraft engine application or in petro-chemical reforming operations. Thus, considerable data is available as well as service experience in air or process gas environment.

Among these alloys, Incoloy-807 was assessed as being available only in Europe and has the disadvantage of containing up to 10% Co. However, this alloy is relatively strong in this class and has been designed for reformer application. It should be included. The Haynes development alloy 556 (HD-556) is classed as experimental and contains some 20% Co as well as 1% Ta, but is quite strong and considered a possibility worth further exploration. Among the remaining alloys there appears to be little to choose from. Sanicro 32X has somewhat better strength at the lower temperatures but on the whole the group probably ranges from 80-35 mPa (12-5 KSI) over the range of temperature 760-1090°C (1400-2000°F) in short term tensile strength and about 20-1 mPa (3-0.2 KSI) 10-hour rupture strength within the same temperature range. All these alloys should be useable in some of the less stringent applications of VHTR/NPH's as sheet and tubing. Incoloy 800 has been replaced by the solution annealed, higher carbon Incoloy 800H which results in higher creep strength while maintaining all the useful characteristics of Incoloy 800. It is code approved for nuclear use to 760°C (1400°F). The inclusion of Incoloy 800H also provides comparison with several other existing programs. Since Incoloy 800, in this country, is only used for low temperature applications, Alloy 800 is deleted from the list. It should be noted that some mixed experience with Incoloy 800 in HTR He tests was found. Incoloy 802 is a higher carbon version of this group with higher Al+Ti content and has excellent strength and improved carburization resistance. Incoloy DS achieves good environmental characteristics through Si additions although strength is sacrificed. It appears too weak to be considered. Of the seven alloys shown in Table 2-3, five were retained with the final list of 15 chosen.

2.1.2.3.2 CAST IRON-BASE (AUSTENITIC) ALLOYS

Basically, the types of alloys listed in this category have been extremely important in reformer vessels, as centrifugal castings. Most of their current usage is in the petro-chemical industry. The practicality of the centrifugal casting process is the development of thick walled tubular products that are inherently sound, i.e. free from process defects normally found in static cast parts. Since these alloys are by and large quite weldable and competitive cost-wise, they need to be considered for VHTR/NPH development. The strength in this class is achieved mainly by carbide strengthening due to the high carbon contents ($\cong 0.40\%$) and the inherently large as-cast grain size. The first two alloys in this category are representatives of the ACI designated HK type, i.e. IN-519 and HK-40 having $\cong 20\%$ Ni and 25% Cr contents. IN-519 has Cb added for additional strengthening. Such castings are widely used in stressed applications up to 1150°C (2100°F). Carbide agglomeration and precipitation occur over long times in service and frequently the austenite is unstable leading to some sigma phase precipitation. Thus, loss of ductility and toughness can be expected. The remaining four alloys fall into the ACI HN or HT categories having $\cong 30\%$ Ni and $\cong 20\%$ Cr with C levels around 0.40% . The high Ni content makes the alloy more useful in thermal shock applications and basically more resistant to oxidation and particularly carburization at very high temperatures. In general, these alloys also rely on the addition of refractory elements (W and Cb) for added strength and increased thermal shock resistance. The short term strengths for this group over the $760\text{--}1090^{\circ}\text{C}$ ($1400\text{--}2000^{\circ}\text{F}$) temperature range are similar to the former category, but with a slightly higher range of $4.8\text{--}2.8\text{ mPa}$ ($7\text{--}0.4\text{ KSI}$) 10^5 -hour rupture strength in the same temperature range.

For this group of alloys as shown in Table 2.3, alloy HK-40 has the most extensive service use and air data base. It is known to be susceptible to structural instabilities after lengthy exposures at very high temperatures particularly in process gas environments. None the less it is a highly useful alloy, commercially available and the least costly in the group. No reactor He test results are available currently. It is a reasonable choice for this test program.

In an effort to improve on the HK types higher Ni contents have been adopted as noted above and the Manaurite alloys as well as Mo-Re 1 fall into this category. This grade of alloy appears to have excellent oxidation and carburization resistance and higher strength is achieved by the addition of refractory elements. IN-519 on the other hand is a lower Ni alloy like HK-40 but with Cb additions for strengthening. Its behavior has been likened to that of Manaurite 900. Some reactor He experience is available for both IN-519 and Manaurite 900 but it is insufficient to be conclusive. Among the group under discussion, the Manaurite 36X is commercially available and has had moderate industrial usage. Its properties suggest that it should also be recommended for inclusion in the test list. Both Manaurite 36XS and IN-519 are suggested as back-up candidates while Manaurite 900 is excluded.

2.1.2.3.3 WROUGHT NICKEL-BASE ALLOYS

As a class, these alloys are much the same as the class described as Wrought Iron-Base Austenitics. From Table 2.3, however, it can be seen that the Ni content in this category is approximately 50%, with much greater variations in refractory metal content and in some instances Al & Ti content. Again, there has been much service experience with many of these alloys in the aircraft engine field as well as for petro-chemical use. In general, their compositions demonstrate improvements in both short-time and long-time (10^5 hour) elevated temperature strength, 110-35 mPa (16-5 KSI) for the former and 35-35 mPa (5-0.5 KSI) for the latter over the 760-1090°C (1400-2000°F) temperature range as well as better thermal fatigue resistance. Their corrosion resistance is an outstanding feature and in some cases structural stability is reported to be good (Hastelloy S, Inconel 600 and 601) while in others degradation is reported (particularly IN-625).

Among the alloys suggested, Hastelloy X is commercially available and much studied. In air, this alloy retains good high temperature strength and environmental resistance but is subject to some structural instability after long exposure in the temperature range of interest here. It can also be used as cast or in readily wrought forms. There is considerable experience with this alloy in reactor He environments although the data is conflicting. In one series of tests between 600°C (1110°F) and 850°C (1560°F) very little

comparative strength difference was noted but at 900°C (1650°F) there was decided decarburization and loss of tensile ductility in post exposure tests. In other tests, however, there was a decided loss in strength for Hastelloy X in He when exposed between 650°C (1200°F) and 900°C (1650°F), but this result does not appear to have been reproduced. This alloy is recommended for this program in a cast/wrought combination which should provide some fruitful comparisons with other work in progress.

The alloy Hastelloy S is an extremely interesting composition for which outstanding structural stability and environmental resistance have been claimed. It appears to be somewhat less strong than other Hastelloys, but He experience in corrosion testing shows it to be somewhat better than Hastelloy X. Therefore, its inclusion in this program is recommended. Note that Hastelloy X-280, which is exactly like the Hastelloy X composition except for the removal of the 1.5% Co, is simply not available from the vendor.

Obviously alloy Inconel-617 is a very strong candidate and in fact it has already been chosen for possible use in IHX tubing by the Japanese. As might be expected, it is somewhat difficult to fabricate and has some reported structural instabilities but excellent environmental resistance. Note also that it contains 12.5% Co. Helium test results are again mixed for this alloy with one series of tests at 900°C (1650°F) showing an order of magnitude enhancement of creep rate over air tests and severe carburization. Yet in another test of 7000 hours at 850°C (1560°F), it was slightly superior in creep compared to air. The inclusion of Inconel-617 is recommended in this program and for comparative purposes the alloy In-586 as well. The latter alloy has been equated to Inconel-617 and though an experimental alloy it appears to be quite strong in preliminary tests and to have other desirable properties.

Among the remaining alloys it is apparent that the Nimonic series have had wide service usage and good experience in use. They are basically solid solution but are given an aging treatment to bring out some γ' strength improvement. They are among the weakest alloys in this class and will probably suffer some structural instability, particularly at the higher temperatures. It was therefore decided that this group of alloys would not be a good choice for this program.

In a similar manner the Inconel 600 and 601 alloys appear to be limited in strength relative to the other alloys in this group. There is a reasonable amount of experience with these types at lower temperatures and they have been included in other test programs similar to this one. The need to restrict choices here, however, mandates against their inclusion. The only remaining alloy is Inconel 625 and the data shows it to be only slightly less strong than Inconel 617 at temperatures up to 980°C (1800°F) and with excellent environmental resistance. Previous work, however, indicates the alloy to be quite unstable and for this reason it is not recommended for this program.

2.1.2.3.4 CAST NICKEL-BASE ALLOYS

These alloys bear the same relationship to the Cast Iron-Base Austenitic alloy group as the wrought Ni alloys bear to the wrought Iron-Base austenitic alloy group, i.e. the Ni content is about 50%, the Cr content about 25%, while the refractory metals are used as strengtheners. One feature of this group is their high short time strength capability (about 150-70 mPa (22-10 KSI) in the range 760-1090°C (1400°-2000°F) and their excellent long time strength capability 12-4 mPa (1.8-0.6 KSI) in the same temperature range. These alloys are akin to the ACI-HU type and are centrifugally cast. They have extremely good resistance to thermal fatigue and carburization in the presence of relatively high stress. They have been used mainly for hydro-carbon reforming and as furnace parts. Among the five alloys listed in this category in Table 2.3, the three Co containing alloys Inconel 638, Inconel 643 and Supertherm have the best very high temperature strength. However, both Inconel 638 and Inconel 643 are classed as experimental alloys, not fully commercial, and very little data are available. Additionally, Supertherm has been reported to have poor ductility and weldability after service exposure but it has a good air data base and much service experience. Viewing the two remaining alloys, it is seen that NA22H has the poorest strength of the group while Mo-Re 2 is the best of all the candidates after 10⁴ hours at 980°C (1800°F), falling off only at 1090°C (2000°F) to about 5.9 mPa (0.85 KSI) after 10⁵ hours. The alloy is free of Co and has the flexibility of being either cast at 0.45%C or wrought when the C is reduced to 0.05% Not too much data are actually available but reports from users suggest, for example, that Mo-Re 2 is a superior alloy if costs are not a main objective. Thus, Mo-Re 2 is chosen as an experimental candidate in this group while Supertherm is chosen

as a commercially available alloy with Inconel 643 as a good primary back-up choice.

2.1.2.3.5 ODS ALLOYS

Characteristically, these alloys have tensile strengths of about 103 mPa (15 KSI) at 1093°C (2000°F) and maintain 10^5 hour strengths in the range of 138-48 mPa (20-7 KSI) over the temperature range of 760-1093°C (1400-2000°F). While commercially available, quantities of these alloys for typical use in VHTR/NPH applications would require highly increased production capability. If this occurred, then the extremely high current cost might be expected to decrease. Obviously, in addition to fabricability problems, none of these compositions can be fusion welded. Such problems remain to be solved. Despite these factors, it is apparent that some of the proposed VHTR/NPH conditions might well be amenable to satisfaction only through the use of such an alloy. Hence it seems reasonable to test among this group. From Table 2.3, it is noted that MA-754, MA-755 and HD-8077 are Ni base while MA-956 is Fe base. The former alloys must be canned and hot rolled while MA-956 can be cold rolled, a factor which could considerably reduce its cost. Studying the composition of these alloys, one notes that MA-755 is essentially a γ' -strengthened alloy which has been formed from powder with yttria additions. As such, it is extremely difficult to process and is extremely brittle. Little real data are available on its structural stability but it may well be quite poor. This alloy would seem a poor choice. Both MA-754 and HD-8077 are reasonable choices but even so, both alloys are not extensively tested and there is some indication of very poor structural stability in MA-754. Also, no fusion welding or joining methods are available. On the other hand, MA-956 appears to be stronger than HD-8077 and is an order of magnitude better in oxidation in air than Hastelloy X with further claim of excellent resistance to process gas environment corrosion. The alloy has a very stable and flat rupture curve and it can be produced in rod, bar, sheet and plate form. Further, there is experience in the brazing of this particular alloy. All told, this ODS alloys seems the best recommendation for the VHTR/NPH program with MA-754 as a back-up. This complements the nickel-base ODS alloys recommended for testing as DCHT candidate alloys.

2.1.2.3.6 Mo AND Mo ALLOYS

The only viable candidates in the refractory metals now commercially available are unalloyed Mo or Mo-TZM in the warm worked and stress relieved condition. There is no question that in this condition Mo-TZM is by far the strongest of the two materials available for the temperatures and times of VHTR/NPH considerations. The Ti and Zr additions provide dispersion hardening and retard recrystallization and grain growth. TZM has a span of tensile strength from 690-517 mPa (100-75 KSI) over the 760-1093°C (1400-2000°F) temperature range with an excellent high temperature modulus of elasticity. Its long time stress-rupture properties are in the range 414-82 mPa (60-12 KSI) over the temperature range 871-1093°C (1600-2000°F) with fair ductilities. It is well known that molybdenum alloys suffer catastrophic oxidation at higher temperatures in air. In inert but slightly impure gases its behavior is excellent with some reports of nitrification and carburization about 1093°C (2000°F). Structural stability is fair but not much data are available. The major drawback to this alloy is the onset of recrystallization during exposure. If the material is worked heavily, this can occur rapidly but for moderate working the stability is said to be good. However, stress reduces the recrystallization temperature and its onset during a creep-rupture test drastically reduces the slope of stress-rupture time curves. Fabrication is quite difficult as with all group VI A refractory metals and while weldable, heat affected zones will have recrystallized properties. Some He exposure tests are reported in the range 955-1000°C (1750-1832°F) in which the material was found to become extremely brittle with zero post exposure ductility at room temperature. More recent tests at 800°C (1472°F) in He produced extreme carburization, degraded tensile strength and zero ductility. This was evident to a lesser degree at 650°C (1202°F) but in each case severe carburization appears responsible for the loss.

Unalloyed Mo can be used in either the stress-relieved or recrystallized condition and its strength properties up to about 982°C (1800°F) are twice as great (both short and long term) in the stress relieved condition. In the recrystallized condition, the tensile strength ranges from 206-124 mPa (30-18 KSI) over the 760-982°C (1400-1800°F) temperature range and its 10⁵ hour stress rupture properties range from 124-21 mPa (18-3 KSI) in the range 760-1093°C

(1400-2000°F). There is a wide range in the ductile-to-brittle transition temperature in Mo alloys but they all appear to lose ductility and toughness at low temperatures, i.e. DBTT's are around 371°C (700°F) as measured in Charpy notch tests. Unalloyed Mo has about the same environmental resistance as Mo-TZM alloy, but in the recrystallized condition there are apparently no structural instabilities encountered other than grain growth, i.e. good strength and ductility are maintained. As has been noted, C plays an important role in strengthening with a change from 0.015 to 0.05% increasing strength some 30%. Fabricability is again difficult, but the material appears readily weldable. It is available in all mill forms but is brittle as cast. Also, it can be processed as powder. In any event, Mo and its alloys would be quite expensive, not immediately available in high production quantities and would pose significant development problems in fabrication for large components.

Given the difficulties attendant upon the procurement and fabrication of Mo and its alloys and the drastic reductions in properties reported in reactor He exposure, this class of alloy is not recommended, but unalloyed Mo is included as a back-up.

2.1.2.3.7 COATINGS AND WELDMENTS

Two coating systems will be evaluated; one would be a simple aluminide or chrome-aluminide coating produced by a pack diffusion process. The other coating would be a more sophisticated system consisting of an electroplated Pt layer followed by a chromizing cycle and finally an aluminizing cycle.

The initial test plan calls for the thermal aging of about 12 weldments. In the characterization stage of Task 2 (Procurement and Characterization), all alloys will be subjected to weld "patch" tests using vendor recommended weld practice. The 12 weldments for the program will be chosen based on the success in the characterization phase.

2.1.3 SUMMARY

The lists of alloys recommended for the screening studies by GE are given in Table 2.4 for NPH alloys; Table 2.3 for DCHT alloys. If, as has been proposed by G.E., all screening studies are initially done in one

environment representing a possible DCHT gas chemistry and a possible gas chemistry for NPH with an intermediate heat exchanger (see Section 2.4), then the NPH and DCHT lists would be combined, as indicated in Table 2.5, for a total of 26 alloys (24 alloys plus 2 processing variations) and 5 coatings.

This list, of course, is subject to change by the ERDA Alloy Selection Committee.

2.2 TASK 2 - MATERIALS PROCUREMENT AND CHARACTERIZATION

Preliminary work has been initiated to produce specifications for procurement of materials for testing in HTR He. Included in this preliminary work was a meeting with a major vendor to begin the specification and procurement process.

2.3 TASK 3 - TESTING AND ANALYSIS FACILITIES AND EQUIPMENT - R. STEPIEN

2.3.1 HELIUM ENVIRONMENT MATERIALS TESTING LABORATORY DEVELOPMENT

The laboratory layout with construction drawings and equipment parts lists is essentially complete. Detail drawings on the He distribution plumbing are in progress. Initiation of the construction of the laboratory facilities will begin in April

2.3.2 MULTI SPECIMEN CREEP EQUIPMENT

The specifications for this equipment has been issued. Bids have been received, evaluated, and a vendor recommendation made. Applied Test Systems (ATS) has been awarded a letter contract to begin detailed design.

The load frame will be designed to support the furnace and retort independently and provide force to six load strings. The load strings will be supported at the top on a plate which is inside the retort. They will exit at the bottom of the retort through triple o-ring seals. Force will be applied through the action of a double lever arm precision weight system with load accuracy within $\pm 1\%$ of the 1360 Kg (3000 lb.) per string capacity.

TABLE 2.5

CANDIDATE ALLOYS AND COATINGS FOR TESTING IN A COMBINED SCREENING PROGRAM

<u>Alloy or Coating</u>	<u>Alloy Type</u>
<u>Alloys</u>	
Mo-TZM	Mo-Base
YD-Ni	ODS Ni
MA-754	ODS NiCr
YD-NiCrAl	ODS NiCrAl
MA-956	ODS FeCrAl
MM-247	Age Hardenable Nickel-Base Directionally Solidified
MM-247	Age Hardenable Nickel-Base Conventionally Cast
Rene' 80	" "
Rene' 100	" "
M-21	" "
IN-713LC	" "
MM-004	" "
Hastelloy X (Cast)	Cast Nickel-Base Alloy
Hastelloy X (Wrought)	Wrought Nickel-Base Alloy
Hastelloy S	"
Inconel-586	"
Inconel-617	"
Mo-Re 2	Cast Nickel-Base Alloy
Supertherm	"
Incoloy 800H	Wrought Iron-Base Austenitic
Incoloy 802	"
Incoloy 807	"
Sanicro 32X	"
HD-556	"
Manaurite 36X	Cast Iron-Base Austenitic
HK-40	"
<u>Coatings</u>	
	Pre-oxidized high Al and/or Ti Alloy
	Aluminide Coating
	Pre-oxidized Aluminide Coating
	Electroplated Pt + Chromizing + Aluminiding
	Chromide or Silicide/Mo-TZM

The furnace will be cylindrical with 127 mm (5 in.) I.D. x 356 mm (14 in.) O.D. x 1245 mm (49 in.) long enclosed in a solid AISI 304 stainless steel jacket. It will have 127-229 mm (5-9") long heating zones with embedded Kanthal Al windings for 1204°C (2200°F) operation. One thermocouple port will be located in the middle of each zone for temperature monitoring during normal operating conditions.

The retort tubes will be fabricated from 99.8 Al₂O₃ on approximately 50% of the screening test stands -- the balance being Inconel 601. In either case the tubes connect to AISI 304 stainless steel end flanges. The top end flange will provide for 6 thermocouple feed throughs, a multi-purpose tube connection and gas outlet port. The bottom end flange will provide for vacuum and gas inlet ports. The Inconel 601 tube will be GTA welded to the end flange. This connection provides a leak free joint with sufficient strength to support the retort weight plus the force of internal pressure acting on the end flange surface. These retorts will be pressure tested in accordance with the ASME Unfired Pressure Vessel Code and helium leak tested at 204°C (400°F) bake out temperature on the retort tube heat zone. Retorts having 99.8 Al₂O₃ work tubes will be sealed with two viton o-ring seals at the tube-end flange interface. Since this connection provides little structural strength and in addition may leak from repeated sliding of mating surfaces (such as thermal expansion) a method has been devised for rigidly connecting the end flange to cemented extensions on the exterior of the work tube. This approach will accommodate thermal expansion of the tube and end flange pressure loads without sliding of the o-ring seals.

The load string assembly will consist of an upper pull rod with spherical nut and washer seal with 150.8 mm (2 inch) take up, lower pull rods with o-ring seals and 16 specimen couplings. Load string material will be MM 246. In the event of a specimen failure the load string will be restrained from hitting the retort or other strings by spacer plates at the ends of the load bars nearest the specimens.

Applied Test Systems has quoted twenty-five week delivery after receipt of order; shipment is expected the first week in October, 1977.

2.3.3 AGING CORROSION STABILITY STANDS

The specification for eight stands, incorporating Inconel 601 retorts, was issued and preliminary engineering proposals received. Retort material has since been changed to 99.8% Al_2O_3 and new engineering proposals have incorporated this material. Vendor selection is anticipated by May 1, 1977.

Current proposals incorporate retort and furnace designs very similar to the screening creep stations. The test furnace will be 1321 mm (52 inches) long with a 1016 mm (40 inch) uniform heat zone $\pm 2.8^\circ\text{C}$ ($\pm 5^\circ\text{F}$). Each furnace will have three zones of Kanthal A1 embedded windings and be contained in a solid stainless steel case.

The retort will have a 79.4 mm (3 1/8 inch) I.D. and 89.9 mm (3 1/2 inch) O.D. End flanges will be AISI 304 stainless steel with the lower section of the retort having a vacuum valve and gas inlet port and the upper section having a gas outlet port, five thermocouple feedthroughs and the specimen suspension plate. Retort end flange attachment will incorporate double o-ring seals and end flange restraints.

The test specimen support frame will be made of 99.8% Al_2O_3 and consists of a central tube with 19.1 mm (3/4 inch) O.D. X 12.7 mm (1/2 inch) I.D. provided with through holes to accept 6.35 mm (1/4 inch) diameter pins. Seven point locations, each holding six specimens will be provided at approximately 139.7 mm (5 1/2 inch) spacing.

Delivery is expected six months from the date of order.

2.3.4 SINGLE SPECIMEN CREEP RUPTURE STATIONS

The specification covering design and construction of these stands has been issued, quotations received, and vendor recommendation made. Ordering of stands has been delayed due to the higher priority of the multi-specimen and aging corrosion stands. A prototype of the proposed stand was examined at the vendors site and found to be acceptable with minor revision.

The load frame will have a dual lever arm ratio of 10:1 and 3:1 with a maximum load capacity of 10,000 lbs. Adjustable alignment at the bottom

of the load string will minimize specimen bending. The load frame will support the retort and furnace independently to ease test setup.

The test furnace will have the dimensions 76.2 mm (3 in.) I.D. X 254 mm (10 in.) O.D. by 406.4 mm (16 in.) long and have split construction with three heat zones of embedded Kanthal Al elements. One thermocouple port will be located in the middle of each zone for temperature monitoring during normal operating conditions.

The retort tube will be 99.8% Al_2O_3 in approximately 50% of the machines (test temperatures of 982°C (1800°F) and 1093°C (2000°F) and Inconel 601 in the others (test temperatures of 760°C (1400°F) and 871°C (1600°F)). Upper and lower pull rods will be of MM-246 (water-cooled) and equipped with radiation shields. The upper end flange will be furnished with three thermocouple ports and one gas outlet port. The lower pull rod will have a welded metal bellows seal for load train alignment. The retort assembly will be helium leak tested at 204°C (400°F) and 310 KPa (45 psig) prior to acceptance.

All creep retorts will be equipped with extensometers for strain measurement. Each extensometer will have two rods, four tubes, one 2.5 mm (0.100 in.) range LVDT, and one 6.35 mm (0.250 in.) range LVDT. The two spare tubes are included to provide a means for gas entry and discharge at the specimen gauge section if necessary. Precision power supplies will provide voltage to the LVDT's while the output will be monitored with a computer based data acquisition and reporting system. This acquisition system provides signal processing, storage, printed reports and automatic curve plotting.

Delivery of the first group of ten single specimen test stands is expected late in 1977.

2.3.5 TEST TEMPERATURE CONTROL SYSTEM

An integrated temperature control system has been developed for the various temperature setpoints on all test stands except fatigue and tensile. This system consists of a centralized digital control package and remote located analog overtemperature controllers. The digital package will

control the furnace heat up from room temperature to the operating setpoint and will automatically balance the specimen temperature. The various test temperatures will be monitored for alarm conditions and a printed report provided. This package is operational from the thermocouples on the specimen on those in the furnace. It is designed as a stand-alone control system with manual backup capability and expansion space for control of other parameters.

The analog overtemperature controllers will be located at the test stand and set to control when the digital system is in error or is down for maintenance.

The digital system has been ordered with delivery promised for September, 1977. The analog devices will be supplied with the test stands.

2.4 TASK 4 - SIMULATED REACTOR HELIUM ENVIRONMENT FACILITIES AND EQUIPMENT

2.4.1 SIMULATED REACTOR HELIUM "LOOP" SYSTEM DESIGN - C.L EHDE

The general arrangement of the HTR Materials Laboratory which will be located in the Large Steam Turbine and Generator Operation's Material and Process Laboratory is shown in Figure 2.1. The laboratory will contain 45 test stands where precision creep and stress rupture materials testing can be performed with the specimen subjected to a controlled atmosphere. The laboratory will also contain eight structural stability and six multi-string creep screening test stands. Two fatigue type test machines will be located in an adjacent room as shown in the general layout.

Two complete and independent closed loop He systems with pumping and purification trains, impurity injection system, gas analysis system plus controls and instrumentation will be housed in consoles as indicated in Figure 2.1. System pre-mixed, fill gas, backup (standby He gas) and He purge manifolds are indicated behind the packaged dual He loop systems. Additional space for gas bottle storage is also indicated adjacent to the manifolds. An overhead He distribution system for supplying He gas to the various test stands along with utilities frames which contain the He gas supply, return, sense, purge gas supply and dump plus provision for valving in conditioning gas to each test stand retort is also a part of the gas

distribution system. The utilities frames also contain water supply and return systems and provisions for supplying electrical power and instrumentation wiring to and from each test stand.

An office and an assembly area where multi-string and structural stability specimens will be assembled into retorts are also depicted in Figure 2.1. An adjacent room at the south end of the main laboratory area (utility room) will contain a closed loop water pumping and cooling package 204.8 liter, 344.5 KPa (45 gpm, 50 psi), will provide demineralized cooling water to the entire lab area through a distribution system. This system contains dual pumps (operating and standby) plus automatic switchover to domestic water supply in the event of a failure of both pumps. The utility room also contains the electrical power supply (225 KVA transformer) automatic tie-breaker for emergency switchover to standby plant generated power and main circuit breaker panel which feeds power to the entire lab area. Power and control wiring distribution will be accomplished via a network of overhead wire trays with drops to utility frames adjacent to test stands. A second network of overhead wire trays will be utilized to carry instrumentation wiring from utility frames to the automatic data logging system. This overhead network will also support the He piping distribution system and water piping to and from utility frames.

Shielded isolation transformers provide 120 volt, 1 $\emptyset$, 60 Hz instrument power to gas analysis instrumentation, data scanners and loggers, computer and other instrumentation.

Figure 2.2 indicates, in simplified schematic form, one of the He loops. Both loops are basically identical so that a discussion of one system only is presented. One overall system breaks down into three major systems; within each system are several subsystems. The major systems are the packaged system, the distribution system, and the manifolds.

The package system consists of a pumping subsystem, purification and impurity gas injection subsystem and a gas analysis subsystem. The pumping subsystem consists of three metal bellows type, two cylinder pumps, each driven by a 1/2 hp electric motor and capable of supplying 75 liter/min. of He gas with a suction pressure of 34.5 KPa (5 psig) and discharge pressure of 172.3 KPa (25 psig). The three pumps are connected in a parallel arrange-

FIG. 2.1 ADVANCED GAS REACTOR MATERIALS TESTING LABORATORY LAYOUT

a) 45 single specimen creep/rupture stands
b) 8 thermal stability retorts

c) 6 multi-string creep screening stands
d) 2 closed loop He supply system

e) 2 fatigue machines

FIG. 2.2 SIMULATED REACTOR HELIUM SUPPLY SYSTEM SCHEMATIC

ment to provide a flow of 225 liters/min. to the loop. A fourth pump in a standby mode will be automatically energized should the pressure from any of the other three pumps fall below a pre-set level (i.e., pressure switch sensor on the discharge side of each pump). Check valves on the discharge of each pump prevent back flow through a shutdown pump. Isolation valves allow removal of a pump for maintenance while the remaining units are in operation. Inlet and discharge buffer tanks each approximately 6 in. in diameter by 5 feet long and containing a volume of approximately 1 ft.³ (15.3 cm diameter, 152.5 cm long, 0.0283 m³) are provided. A bypass valve which will allow manual control of the main loop flow completes the pumping system.

The purification subsystem (see Figure 2.3) consists of a series parallel train of impurity gas getters piped as a bypass around the pumps. Water injection equipment is also contained in this subsystem. Dual copper furnaces operating at 510°C (950°F) for the removal of O₂, a molecular sieve primarily for removal of CH₄; an ascarite bed for the removal of CO₂, a magnesium perchlorate bed for the removal of H₂O and an activated charcoal bed held at liquid nitrogen temperature (primarily for removal of N₂) are arranged in one of the series trains. A maximum flow of 50 liter/min. of He can be passed through this train and valving and flow meters allow selection of individual or series getters.

The second series train consists of a copper oxide furnace operating at 150°C for removal of H₂ & CO; a molecular sieve primarily for removal of CH₄, an ascarite bed for removal of CO₂, and a magnesium perchlorate unit for removal of H₂O. This train is also capable of handling flows up to 50 liters/min. with valving and flow meters for selection of specific getters. A third parallel branch contains a magnesium perchlorate getter for the removal of large amounts of H₂O. A flow rate of 50 liters/min. is possible. The fourth parallel branch contains hydrated oxalic acid bed maintained at 1.6°C (35°F) and flows up to 500 cc/min. can be passed through this unit to add H₂O to the He. Each of the four parallel branches contains a micro-meter type valve so that very small amounts of He can flow through each branch at all times keeping the system in a dynamic state. Solenoid type valves

FIG. 2.3 HELIUM LOOP PURIFICATION & ADDITION SYSTEM SCHEMATIC

in parallel with the micrometer valves can be opened to allow a large flow through any of the trains. Solenoid valves are also utilized to select which particular getter or series of getters will be utilized in a particular train. The pressure drop available across the series parallel purification system is approximately 137.8 KPa (20 psig). Each getter unit is approximately 7.6 cm dia x 61.0 cm long (3 in. dia. x 24 in. long) and contains approximately 2788 cm³ (170 in.³) of getter material. Valving allows a removal and replacement of a particular getter during operation.

The impurity gas injection system consists of four individual bottles of pure H₂, CO, CH₄ and CO₂ gases. Pressure regulators on each bottle will be set at a pressure slightly higher than the main loop header pressure. Micrometer type valves capable of controlling gas flow rates down to 10⁻¹⁰ cc/sec. are located in each of the lines from the regulators. A solenoid valve with a second micrometer valve as a bypass is located in each line close to the main stream line (i.e., downstream of the purification train). The solenoid valves are for future possible automatic control of the injection system utilizing signal levels from the gas chromatograph. To insure a dynamic system the micrometer bypass valves will be cracked at all times allowing minute amounts of impurity gases to enter the system. Larger amounts of a particular impurity gas would be injected when the solenoid valves are opened. The flow rate through these valves would be determined by experience from settings of the first micrometer valve (not the bypass units). Gas analysis signal levels indicating a low level of a particular impurity would activate the solenoid valves for a predetermined adjustable time period. This system of automatic control is not contemplated initially; however, the addition of controls will make it possible in the future without modifications to the plumbing system.

The gas analyzer system consists of a manifold to which a Gas Chromatograph, Dew Point Indicator, and Solid Electrolyte O₂ Cell are piped. A second O₂ cell is available and continuously monitors the O₂ content of the main loop supply header. A 16-port gas scanning valve allows spot monitoring of various exhaust gas manifolds to which test stands are attached. Via manual valving the exhaust of any of the 59 test stands can be monitored. The multipoint valve controller allows manual selection of any one channel or an automatic scan of all 16 channels on an adjustable time basis. A digital readout on

the controller indicates which particular channel (i.e., retort or bank of retorts) is being monitored.

The Gas Chromatograph contains appropriate separating columns (2) for the intended species of gas to be monitored. The sampling valve is time sequenced with the multipoint scanning valve. The recorder will contain event markers triggered by sample valve operation. A future tie-in of the GC output signal to the central laboratory computer is contemplated so that an integrated printout of impurity gas composition can be obtained. High and low signal levels will result in annunciation of these conditions and allow future automatic control of purification and injection systems.

The Dew Point Indicator will provide both a voltage output and a reading of dew point temperature. The dew point temperature will be indicated on a panel meter in analog form. A voltage output linear signal will feed a 10.2 cm (4 in.) strip chart recorder for continuous monitoring. Chart paper event markers will indicate when an automatic scan is in operation. The recorder will also contain adjustable high and low relays which will activate an alarm system. Future tie-ins of these high and low levels to activate H_2O injection system solenoid valves and magnesium perchlorate H_2O removal getters through variable time relays is contemplated.

The dual O_2 cell and 2-channel readout/control comprise a system capable of measuring the partial pressure of oxygen in He. The cell is a solid ceramic electrochemical unit which operates at temperatures from $600^{\circ}C$ to $750^{\circ}C$. The cell contains a cylinder of calcia stabilized zirconia with porous platinum electrodes. The cell utilizes air as a reference gas and is calibrated on this gas.

The readout/control unit selects the output from either of the two cells (via manual switch) and displays these in digital form. A 0-100 MVDC signal from each cell is fed continuously to a two pen recorder. Adjustable high level relays for each cell are contained in the readout/controller. Activation of the high level relay by cell #1 (i.e., cell sensing main loop header O_2 level) will result in the loop going to an emergency condition whereby bottled He gas is fed directly to the retorts and dumped overboard.

Activation of a high level relay by cell #2 (located in the gas analysis manifold) will result in the automatic closing of isolation valves on a particular manifold or test stand which is being scanned at the time a high level is obtained. The panel annunciation system will be activated in an audible and visual manner at the same time. During future unattended night operation of the lab, alarm signals will also be sent to the plant guard station for call-in of laboratory personnel. All gas analysis will be done at a pressure between (34.5 and 69 KPa (5 and 19 psig)). Pressure gauges and flow meters at the inlet of all instruments are provided.

The analysis scanner valve (16 point) has the capability of bypassing 15 channels back to the low pressure side of the system while porting one channel to the gas analysis manifold. This system allows all sense lines, some of which are 9.1 to 12 m (30 to 40 ft.) long to be flowing (dynamic) at all times thus improving the response time of gas analysis.

The distribution system consists of a main loop header 2.54 cm (1.0 in.) ID whose pressure is maintained at approximately 172 KPa (25 psig) by a back pressure regulator (BPR) located in the return line. The supply header feeds various branch manifolds which in turn feed gas to particular test stands. Each branch manifold is equipped with an inlet solenoid valve. Valving at the inlet to each test stand for purge gas and conditioning gas is also provided. A flow meter (rotameter) and pressure gauge are provided at each stand. Retort discharge valving allows dumping of gas to atmosphere (purge and conditioning gas) or to a portable GC/Dew Point analysis package cart mounted, and hence to atmosphere. Normal operating valving allows gas to enter the return manifold which contains an isolation solenoid valve and back pressure regulator. Additional manual valving allows selection of a manifold or individual retort discharge for gas analysis via sense tubing to the main console scanning valve. With the exception of the overhead loop 2.54 cm (1 in. dia.) piping and vertical drops, all of the above piping and valving is located on utility frames which are positioned adjacent to test stands and floor mounted. This allows installation of the complete He distribution without the need of test stands being in place. The selection of which particular test stand shall be on which of the two available gas compositions contains some flexibility in that overhead valving will

allow the structural stability and all creep screening test stands to be placed on either gas system. Approximately 30 of the 45 Precision Creep Stands can be placed on either gas system. This selection is by groups of five stands, however, since one manifold feeds five units.

All retorts will be operated at approximately two atmospheres 103 KPa (15 psig) and the design flow rates are indicated below.

Precision Creep Stands	0.2 to 2.0 liters/min.
MS Creep Screening Stands	1.0 to 10 liters/min.
Structural Stability Stands	1.0 to 10 liters/min.

Stand flow meter maximum ranges are double the above figures so that it is possible to go above the design maximum depending on the number of test stands in operation vs. the output capability of the loop pumps.

A distribution system for purge gas which is a once-through and dump system fabricated from copper tubing is provided. Spent gas is collected via copper tubing and discharged outside the building. One purge system provides gas to all laboratory test stands.

The manifold system consists of fill and backup gas manifolds for each loop, impurity gas bottles and regulators, plus a single purge gas bottle manifold. The system fill gas will be pre-mixed to specifications covering the impurity content and purchased from a gas supply company. Certificates of analysis will be obtained for each bottle of gas and further tests will be conducted by GE after receipt of the gas. To insure a low O₂ level, a copper furnace will be installed between the manifold regulator and the inlet solenoid valve. Normal operation will be with the solenoid valve open and the pressure regulator set at 34 KPa (5 psig). This will allow gas to enter the system as additional retorts are placed on the line. A flow meter in the fill line will be equipped with an electrical follower which will be used as an alarm if the fill system flow rate exceeds a predetermined rate. An abnormally high flow rate into the system without a rise in pressure is an indication of a system loss of He to the atmosphere and a system leak would cause such a condition.

The backup gas system will consist of sufficient He gas to operate

the system at design conditions (i.e., maximum rate 200 liters/min.) for a period of 8 hours (i.e., 96,000 liters). This requires approximately 12, A size bottles of He at 8000 liters (286 Ft.³) per bottle. It is expected that the test operator would reduce flow rates to approximately 1/2 of the design value in the event a complete shutdown were necessary. This would extend the time period to approximately 16 hours. The backup gas system will actually contain 20 A size bottles of high purity He (containing ~ 100 ppm H₂) and be utilized for both the VHTR and DCHT He loops. A Pt-Pd catalyst furnace will be maintained at ~ 150°C and the backup gas will be passed through this unit before entering either of the loops. As previously discussed, the backup gas system will be automatically activated by a high O₂ level in the system or a lack of adequate pressure in the main loop.

The He purge system manifold will consist of 20 A size cylinders of pure He gas. No getters will be installed in this system.

The loops will be fabricated using AISI 304 tubing. All manual valves will be stainless steel with packless stems (i.e., bellows sealed). Where elastomers are used, they will be Viton. Solenoid valves will have stainless steel bodies with Viton inserts in the plunger. Viton O rings under the top works (solenoid assembly) seal the unit to atmosphere. Flow meters will have stainless steel bodies, borosilicate flow tubes and Viton seals under each end of the glass tube. Socket weld fittings will be used wherever possible, however, there will be some threaded joints and mechanical connectors used (i.e., swagelok connector) to make connections to components.

All tubing and components will be thoroughly cleaned before installation in a subassembly. After assembly a He mass spectrometer leak test will be conducted on subassemblies and, finally, on the complete system. A sniffer type He leak detector will be used outside of the piping with 206 KPa (30 psig) He pressure inside of the line.

2.4.2 SIMULATED REACTOR HELIUM CHEMISTRY

Early in the program it was decided that it would be desirable to test both NPH and DCHT alloys in He gas of the same composition during the

screening program. The gas composition would be within the expected range for typical DCHT and NPH systems; specifically, a chemistry common to a Nuclear Process Heat system with an intermediate heat exchanger (IHX) and to the Direct Cycle Helium Turbine system.

Such a common gas composition during the screening phase of the test program offers the following advantages:

1. Different types of materials can be compared in the same environment, eliminating different gas composition as a variable when comparing the performance of DCHT and NPH alloys.
2. The gas compositions for DCHT reactor systems and NPH reactor systems with an IHX are likely to be similar.
3. The six screening creep units and eight structural stability (thermal stability) units can be utilized more efficiently if the gas composition in all is the same.
4. Both loops need not be brought on line simultaneously, which is an advantage with respect to schedule and allows improvements to be made on the second loop based on experience with the first loop.

Two HTR helium compositions will be used in the intensive test phase of the program: one identical to that used for the screening studies, the other representative of an important off-design condition or representative of a process heat system without an IHX.

Based on the work of Graham, Everett, et. al.⁽²⁾ plus consideration of possible DCHT and NPH with IHX systems we feel that helium chemistries of typical DCHT and NPH/IHX systems should be quite similar. As Graham and Everett propose, the major differences will probably be in hydrogen levels (higher in the DCHT system because of the large amount of heat transfer surfaces in the pre-cooler; corrosion inside the pre-cooler tubes can liberate large quantities of H_2 , which can diffuse through the tubes into the helium) and in methane (higher in the DCHT system because of higher H_2 ,

(2) L.W. Graham, M.R. Everett, et. al., "Environmental Conditions in HTRS and the Selection and Development of Primary Circuit Materials," IAEA-SM-200/82.

which can react with the graphite of the core to form CH_4 , and due to breakdown of oil leakage from oil lubricated turbine bearings).

It is felt that the He chemistry levels proposed by Everett and Graham, as reported in Table 2.6, are valid for H_2 , H_2O , CO , and N_2 . For H_2 a compromise level of 150 microatmospheres ($\mu\text{atm.}$) has been selected. Also it is felt that the ratio of CO_2 to H_2O should be about 1:5. Finally, the CH_4 to H_2 ratio has been shown⁽³⁾ to vary between 1:10 to 1:100 as temperature is increased from about 815°C (1500°F) to about 980°C (1800°F). The "predicted" helium chemistry is thus:

H_2	150 $\mu\text{atm.}$
H_2O	0.5
CH_4	10
CO	20
CO_2	0.1
N_2	5-10

The "predicted" water level is so low that it probably cannot be obtained and certainly cannot be measured with any known practical, reasonable cost equipment. Therefore the "predicted" chemistry is adjusted to a reasonable H_2O level by multiplying by a factor of 3 (realizing that multiplication by a factor of N decreases the carburization potential from methane cracking by N, increases the carburization potential from CO and $\text{CO} + \text{H}_2$ by a factor of N).

The final helium chemistry tentatively recommended for the screening tests is:

H_2	450 $\mu\text{atm.}$
H_2O	1.5 "
CH_4	30 "
CO	60 "
CO_2	0.3 "
N_2	< 20 "

(3) J. Engelhard & K. Kruger, "Investigation of the Impurities and Fission Products in the AVR Coolant Gas at an Average Hot-Gas Temperature of 950°C :", Nuclear Eng. & Design, V. 34 (1975), No. 11, p. 85.

TABLE 2.6

PROPOSED HELIUM IMPURITY LEVELS

IMPURITY (μ atm.)	ERDA RFP		EVERETT/GRAHAM			G.E. (Proposed)
	DCHT	VHTR	NPH without IHX	NPH with IHX	DCHT	
H ₂	200-700	600-1200	200-1000	100	200	450
H ₂ O	.5-3	.5-50	1-5	0.5	0.5	1.5
CO	40-120	20-100	20-100	20	20	60
CO ₂	< 5	< 5	1-2	1	1	.3
CH ₄	40-80	30-70	20-30	15	20	30
N ₂	< 20	< 20	5-10	5-10	5-10	< 20
O ₂	< 10 ⁻¹⁴	< 10 ⁻¹⁴	--	--	--	< 10 ⁻¹⁴

Using the thermodynamics of the water shift reaction ($\text{CO} + \text{H}_2\text{O} \rightleftharpoons \text{CO}_2 + \text{H}_2$) and the above levels of CO , H_2O , and H_2 , the calculated equilibrium value for CO_2 is $0.2 \mu\text{atm}$. Further calculations on CO_2 level should be made. It is felt that it's necessary to predict CO_2 as accurately as possible and to measure and control CO_2 levels in the loop.

It may still be necessary to increase the water level to about $2 \mu\text{atm}$. due to difficulties in measuring water levels as low as $1.5 \mu\text{atm}$.

2.5 TASK 9 - DATA MANGEMENT AND PROGRAM MANAGEMENT

2.5.1 DATA MANAGEMENT

2.5.1.1 DATA ACQUISITION

2.5.1.1.1 TEST MATRICES COORDINATION

The detailed test matrices have not been established.

2.5.1.1.2 DATA ENCODING COORDINATION

Work on the mechanics of data acquisition is progressing. The current acquisition procedures have been reviewed. Modifications, revisions, and additions to the encoding forms are being made to add additional properties and to add the specimen test status information required for management control of the test program.

2.5.1.2 DATA STORAGE AND RETRIEVAL

2.5.1.2.1 SYSTEM REVIEW AND MODIFICATION

The current system is being reviewed for compatibility with the present program. This has led to a proposed structure for the Material Data Set which will have three tiers of information, as follows:

Tier 1: Material Description; e.g., material name, specification, vendor codes, processing and heat treating codes, material form, part description or drawing number, part serial number, and dimensions such as ingot and billet sizes, etc.

Tier 2: Specimen and Test Definitions.

A. Specimen Definition; e.g., specimen number, specimen drawing number, specimen location and orientation, grain size, hardness, surface finish codes and anticipated disposition such as environment and test parameters as indicated by the planned test matrices. The specimen number will uniquely identify the specimen with the material and with the material property to be tested.

B. Test Definition; e.g., test equipment, test parameters, environment, etc.

Tier 3: Test Results; e.g., material strength, life and other data obtained from the test.

In addition peripheral computer data sets may be accessed, by the use of common data fields having code numbers and specimen numbers, to provide detailed information on vendor name and location, etc.; processing and heat treating parameters, specimen dimensions; welding, surface finish and coating parameters, etc.

A Data Accumulation Set is also envisioned which will contain all the periodic measurements for screening creep, corrosion, helium composition, etc., until the data is used to update the Material Data Set.

2.5.2 PROGRAM MANAGEMENT

The Program Management Plan (C00-2975-5) and Program Work Plan (C00-2975-4) were completed during this quarterly period and submitted to ERDA.

A design review meeting was held with the ERDA Program Manager on the design of the "helium loops" and the design of the single specimen creep/rupture units, multispecimen creep units and structural stability (aging) units. Approval was given to proceed into fabrication of the helium loops and for purchase of the single specimen creep/rupture units. Additional information is required on the design of the multispecimen creep and structural stability units with ceramic retorts.

The first meeting of the GE Materials Program Advisory Review Board was held Feb. 22 and 23, 1977. Present were L. Jahnke (Review Board Chairman), Dr. L. Coffin (GE), J. DiStefano (ORNL), Dr. L. Graham (HTMP), Prof. Per Kofstad (U. of Oslo), Prof. H. Nickel (KFA), C. T. Sims (GE) and G. Slaughter (ORNL).

Generally the program, program plans, and presentations were well received. The alloy selections for the screening program were supported, in a broad sense, although the board recommended that a detailed review of the more recent HTMP/GAC results be conducted and fostered into the final alloy selections and alloy chemistry specification.

The helium loop design was supported, as was the recommendation to use one environment in the screening tests. The selected environment would be one applicable both to DCHT and to NPH designs using an IHX.

Recommendations were made for some program changes that were beyond the scope of the present program, or would cause scope modifications or additions. These will be incorporated into the program, where possible, or into proposals for add-on to the program. Recommendations within the scope of the present program were generally supportive of decisions already made by the Program Team.

Program review meetings with the ERDA Program Manager were held on Jan. 13 and Mar. 11, 1977.

3.0 WORK TO BE COMPLETED DURING THE
NEXT QUARTER

1. Task 1 - Selection of candidate alloys -- resolution of final candidate alloys for inclusion in the test program to be completed.
2. Task 2 - Alloy specifications will be completed and purchase orders for all test materials will be placed.
3. Task 3 - Detailed design of screening creep equipment and detailed design of thermal stability/helium corrosion equipment will be completed.
4. Task 4 - Design of the helium distribution subsystem will be completed and purchase orders placed.