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TITLE

EFFECTS OF REACTOR ENVIRONMENT ON CANDIDATE PRTR GAS LOOP MATERIALS.

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EFFECTS OF REACTOR ENVIRONMENT ON CANDIDATE PRTR GAS-LOOP MATERIALS

OBJECTIVE

The purpose of this program is to determine the effects of neutron radiation and reactor gaseous atmospheres on the structural integrity of candidate materials for the PRTR gas-cooled loop.

BASIS AND JUSTIFICATION

An exploratory investigation is being conducted to select a high temperature resistant alloy for the fabrication of tubes and supporting appliances for the PRTR gas-cooled loop. In addition to a low neutron cross section, the material must be able to withstand the operating conditions outlined in Table 1.

TABLE 1

OPERATING CONDITIONS FOR PRTR GAS LOOP

Component	Atmosphere		Temperature		Pressure
	Stagnant	Flowing	°F	°C	psig
Ex-Reactor Tube Section		CO_2	1500	816	500
In-Reactor Tube Section		CO_2	600	316	500
Inner Sleeve	CO_2		1500	816	

Although Inconel X was originally selected, this alloy is difficult to fabricate and is susceptible to intergranular embrittlement in reactor environment. Consequently, several nickel-base alloys which have the necessary high-temperature strength, oxidation resistance, neutron economy, fabricability, and weldability for intended applications are being considered. The principal alloys are Inconel, Inconel 702, Hastelloy X, and Hastelloy R-235. Of these alloys Inconel 702 and Hastelloy R-235 are precipitation hardening, while Inconel and Hastelloy X are only moderately so.

One step in selecting the optimum alloy for PRTR special loop applications is to compare the effects of irradiation in gaseous reactor atmospheres. The irradiation of age hardening alloys usually causes embrittlement which drastically reduces ductility at elevated temperatures. Since the hardening mechanisms vary somewhat among the alloys listed, important differences in irradiation effects on strength and ductility may occur.

Exposure of nickel alloys to reducing atmospheres at elevated temperatures usually results in surface reactions and grain boundary attack causing rapid deterioration. These reactions are complex and favored by the presence of CO in combination with water vapor, hydrogen, or sulphur. Internal oxidation is also harmful; however, this reaction normally occurs at temperatures and pressures exceeding the intended applications. During operation of the PRTR gas-cooled loop, CO_2 containing water vapor will come in contact with hot graphite under neutron irradiation. Several products of the form C_xO_y are possible, therefore, it is necessary to determine whether this enviroment will seriously attack the candidate materials thereby shortening their design life.

Extent of Effort

Two types of irradiations are planned, both of which employ pre- and post-irradiation testing. These are described below under the headings Reactor Enviroment Evaluation and Mechanical Porperties Evaluation.

A. Reactor Enviroment Evaluation

This will be a short-time irradiation of several favorable high-temperature resistant alloys. The specimens will be exposed to pile atmosphere at graphite temperatures, and measurements of weight gain and hardness in addition to metallography will be made before and after irradiation.

1. Materials to be Irradiated

These are listed in Table 2 along with their chemical composition, annealing heat treatments, macroscopic cross sections, and specimen weights. In addition to four nickel-base superalloys previously mentioned, the list includes two additional nickel-base alloys (Hastelloy F and Inconel X), three low manganese steels, three iron-chromium-aluminum alloys, and type 406 stainless steel. Although these additional alloys are not included in the mechanical properties irradiation, a cursory evaluation of their stability in reactor environment will be useful in evaluating their usefulness for several application under study. Washer-shaped specimens of the dimensions shown in Figure 1 will be cut from strip, and numbered according to Table 3.

2. Testing Program

The studies to be made include changes due to irradiation in microstructural appearance, hardness, and weight. This work will be performed within lead shielding, now under construction in the Physical Metallurgy Operation's laboratories. One of these specimens to be irradiated (A) will be polished, pre-characterized, and examined metallographically. The remainign specimen(s) will be tested for Rockwell hardness. All specimens to be irradiated will then be accurately weighed on a gram balance. After irradiation, the specimens will be re-weighed, and examined for hardness and metallographic changes. All specimens will be irradiated in the annealed or, in the case of the age-hardening alloys, solution-treated condition. Since the irradiation temperature will approach the aging temperature for some of the alloys, it will be necessary to separate temperature and irradiation effects; to do this,

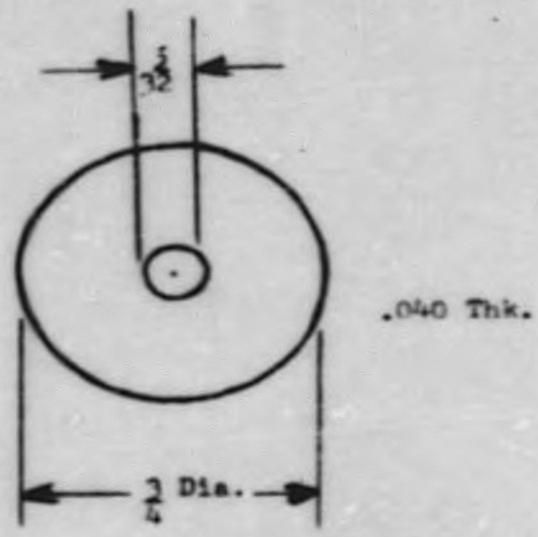

FIGURE I

Pile Atmosphere Effects Specimen

TABLE 3

NUMBERING ARRANGEMENT FOR REACTOR ENVIRONMENT TEST SPECIMENS

Material	Unirradiated Control Specimens		Irradiated Specimens	
	No.	Designation	No.	Designation
JoL 318472	3	5X-5Y-5Z	2	5A-5B
JoL RH-1031	3	6X-6Y-6Z	2	6A-6B
JoL RH-1053	3	7X-7Y-7Z	2	7A-7B
Ferral Modified	3	14X-14Y-14Z	3	14A-14B-14C
AISI 406 SS	3	15X-15Y-15Z	2	15A-15B
Fe-Cr-Al	3	19X-19Y-19Z	2	19A-19B
Fe-Cr-Y	3	20X-20Y-20Z	2	20A-20B
Hastelloy X	3	22X-22Y-22Z	3	22A-22B-22C
Hastelloy-R-235	3	24X-24Y-24Z	3	24A-24B-24C
Inconel	3	26X-26Y-26Z	3	26A-26B-26C
Inconel X	3	27X-27Y-27Z	3	27A-27B-27C
Inconel 702	3	28X-28Y-28Z	3	28A-28B-28C
Hastelloy F	3	30X-30Y-30Z	3	30A-30B-30C

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TABLE 2

CHEMICAL COMPOSITION - HEAT TREATMENTS - CROSS SECTION AND SPECIAL WEIGHT MATERIAL IRRADIATED TO EVALUATE EFFECTS OF REACTOR ENVIRONMENT

Alloy No.	Designation of Alloy	Chemical Composition w/o C	Si	Mn	P	S	Al	Cr	Cu	Mo	Nb	Ni	Ti	Zr	Y	Fe	W	Heat Treatments* Time-Temp-Quench	H** cm^{-1}	Specimen Weight gms
7	JoL RH-1053	.06	.09	.08	.008	.015	.30		.40					.31		Bal.		1550F Air	.213	2.2
14	Ferral Modified	.05	.05	.08	.004	.005	7.5	4.90			1.0			.50		Bal.		2 Hrs. 1600F Air	.176	.5
15	AISI 406 SS	.10	.38	.40	.016	.012	4.15	13.25	.04	.03		.16	.15			Bal.		1400F Air	.197	.4
19	Fe-Cr-Al	.03	.10	.10	.009	.014	5.6	24.00				.10				Bal.		2 Hrs. 1600F Air	.192	.48
20	Fe-Cr-Y	.01	.11		.005	.012	.12	30.00							1	Bal.		2 Hrs. 1600F Air	.218	.54
21	D-979	.05	.50	.50			1.00	15.00		3.75		45.00	3.0			Bal.	3.5	1850F Oil		1.50
22	Hastelloy X	.15	1.0					22.00		9.00		47.00				19	1.0	1 Hr. 2150F H_2O	.303	2.20
24	Hastelloy R-235	.16	1.0	1.0			2.00	14.00		5.50		65.00	2.5			8		1 Hr. 2150F Air	.329	2.23
26	Inconel	.15	.50	1.0				17.00	.50			73.00				8		15 M 1800F H_2O	.366	2.30
27	Inconel X	.08	.50	1.0			1.00	17.00	.50		1.0	70.00	2.5			7		30 M 2000F H_2O	.351	2.18
28	Inconel 702	.10	.70	1.0			3.75	17.00	.5			75.00	1.0			2		30 M 2000F H_2O	.335	2.10
30	Hastelloy F	.05						22.00		6.50		48.00				13	1.0	1 Hr. 2150F Air	.344	2.16
32	AISI 304L SS	.03	1.0	2.0			1.00	19.00		2.50		10.00						1850F Air		
33	AISI 316L SS	.03	1.0	2.0			1.00	18.00		2.50	10xC	11.00						1040F Air		

* Annealing or Solution Treatment

** Calculated Macroscopic Thermal Neutron Absorption Cross Section duplicate unirradiated control specimens will be annealed in vacuum at the irradiation temperature and for the period of irradiation. Any changes in hardness or microstructure resulting from these treatments will be accounted for in the examination of the irradiated specimens.

3. Irradiation Procedure and Capsule Description

The irradiation will be conducted in a side-to side-graphite channel at C reactor. The exposure period will be approximately one month at full power. Operating temperatures will not be monitored, but will be calculated on the basis of normal ambient temperatures. These can be adjusted from the monitored temperature data for the tensile capsules to be irradiated in the second phase of the program.

The irradiation capsule is illustrated in Figure 2. The capsule body is fabricated from graphite, and is open on either end for the passage of reactor gas. The specimens are supported on a stainless steel rod which is flame sprayed with Al_2O_3, and the specimens are separated from one another with ceramic spacers. The support rod is in turn attached to a 304L stainless rack which slides freely in the capsule. The rack is held in place with a graphite end plug which is secured to the capsule with a "truarc" retaining ring. The capsule is "nosed" in front to allow easy sliding over graphite irregularities in the channel.

After discharge, the capsule is easily disassembled by removing the retaining rings at the end plug and support rod. No hazards in the irradiation of the capsule are anticipated; however, care should be exercised during discharge to prevent inadvertent breakage of the.capsule.

B. Mechanical Porperties Evaluation

The effects of irradiation and reactor environment on the tensile properties of our nickel-base alloys will be determined during this phase of the program. Two levels of irradiation, three and six months, will be employed at reactor graphite temperature. The same irradiation facility and atmosphere used for the environment evaluation will be used for these irradiations.

1. Materials to be Irradiated

Four nickel-base alloys, namely, Inconel, Inconel 702, Hastelloy X, and Hastelloy R-235 will be irradiated. Inconel 702 and Hastelloy R-235 will be aged, and Inconel and Hastelloy X will be stabilized prior to irradiation. The heat treatments and specimen weights for these alloys are presented in Table 4. The dimensions of the tensile specimens are shown in Figure 3.

2. Testing Program

Duplicate tensile tests will be conducted on the irradiated and unirradiated specimens at both room temperature and 700°C (1292°F). Within the range of operating temperatures for the gas-cooled loop, the nickel-chromium alloys always exhibit a minimum in ductility at about 700°C. It is of interest to determine the added effects of neutron damage to embrittlement at this critical

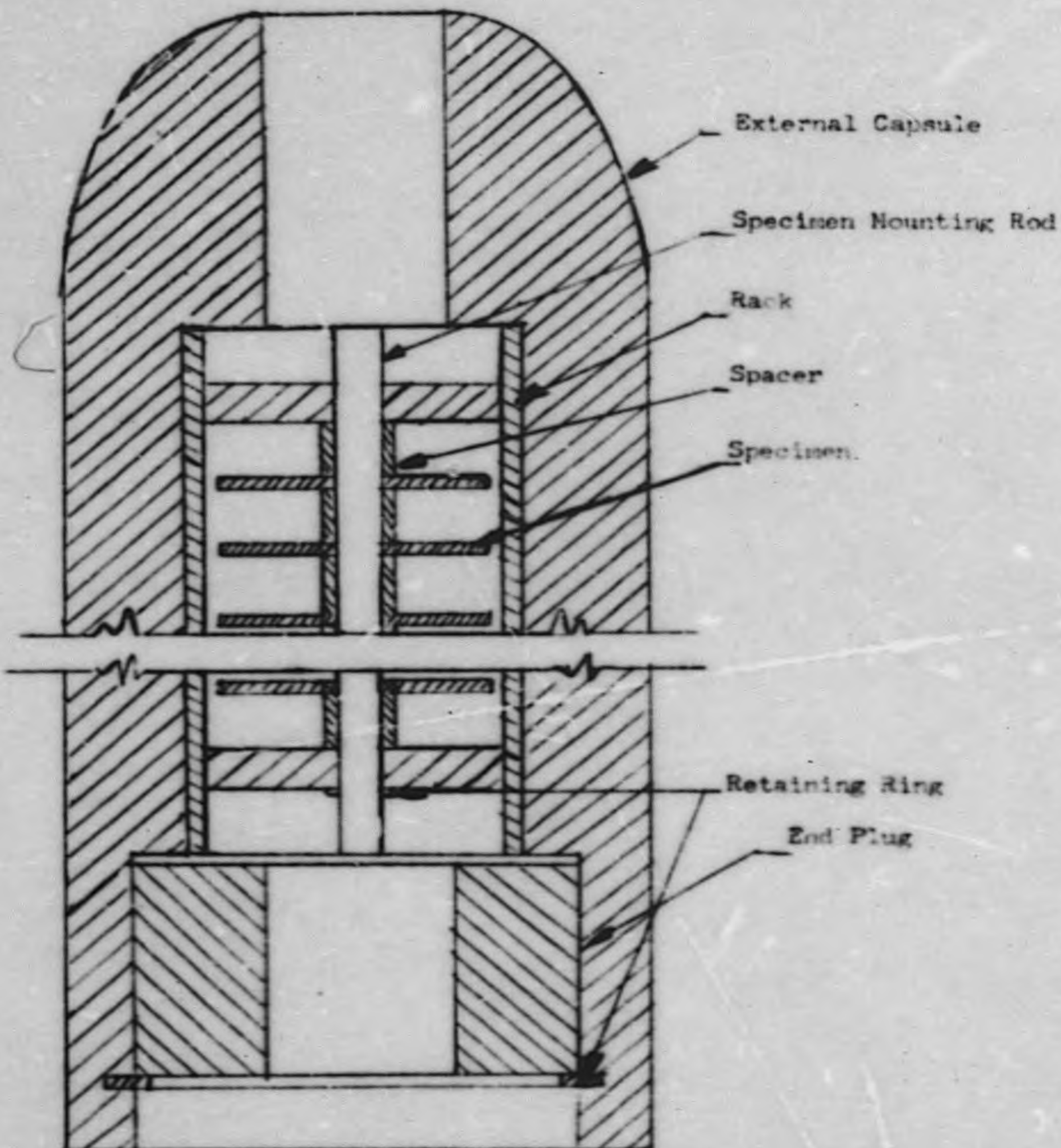


FIGURE 2

Pile Atmosphere Test Capsule

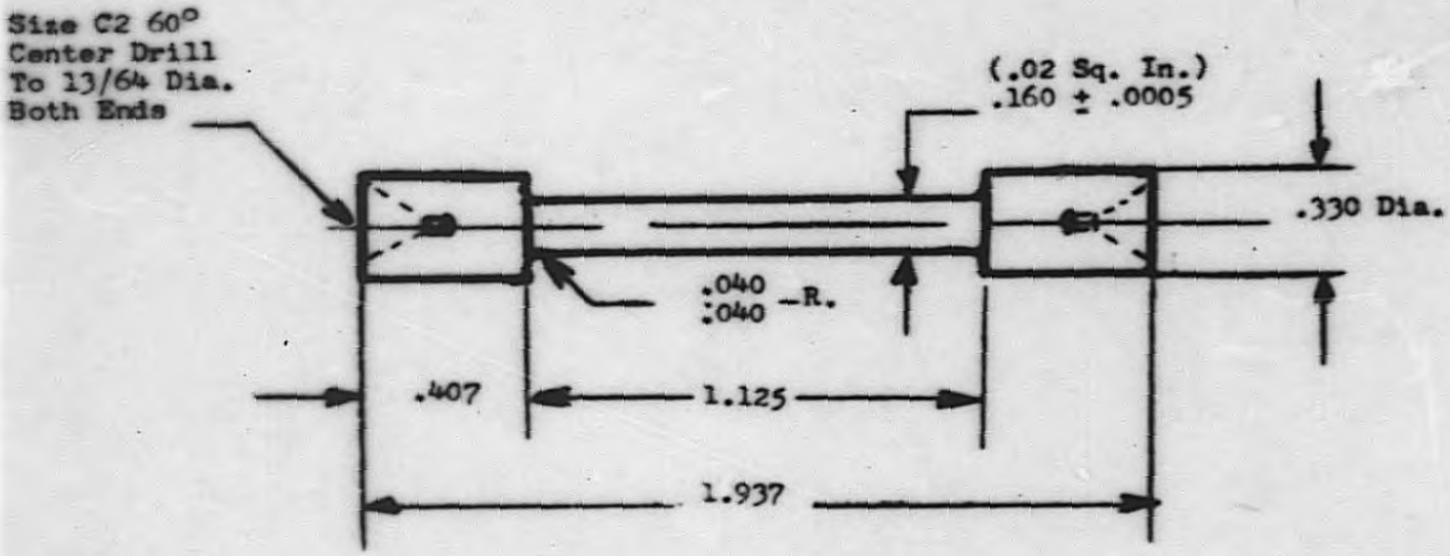


FIGURE 3

Tensile Test Specimen

TABLE 4

HEAT TREATMENTS AND SPECIMEN WEIGHTS OF NICKEL-BASE ALLOYS IRRADIATED TO DETERMINE EFFECTS OF NEUTRON RADIATION AND REACTOR ENVIRONMENT ON TENSILE PROPERTIES

Material	Solution Annealing			Aging or Stabilizing		Specimen
	Temp. (F)	Time	Cooling Media	Temp. (F)	Time	Weight (gms)
Inconel	1900	5 min.	Air	1400	8 hrs.	12.62
Inconel 702	1925	30 min.	Air	1400	5 hrs.	11.60
Hastelloy X	2150	20 min.	Air	1400	8 hrs.	12.4
Hastelloy R-235	2150	30 min.	Furnace Cool	---	---	12.30

TABLE 5

TESTING CONDITIONS AND SPECIMEN MARKINGS FOR TENSILE PROPERTY INVESTIGATION

Condition	Specimen Markings			
	Inconel	Inconel 702	Hastelloy X	Hastelloy R-235
Unirradiated				
Room Temp.	26R1-26R2	28R1-28R2	22R1-22R2	24R1-24R2
700°C	2671-2672	2871-2872	2271-2272	2471-2472
Irrudiated 3 months				
Room Temp.	26R5-26R6	28R5-26R6	22R5-22R6	24R5-24R6
700°C	2675-2676	2875-2876	2275-2276	2475-2476
Irradiated 6 months				
Room Temp.	26R9-26R0	28R9-28R0	22R9-22R0	24R9-24R0
700°C	2679-2670	2879-2870	2279-2270	2479-2470

FIGURE 4

High Temperature Tensile Testing Equipment

temperature. The testing conditions and specimen markings are listed in Table 5.

The testing equipment to be used on the program is illustrated in Figure 4. This equipment consists of a vacuum capsule containing the specimen mounts and pull rods, a high-temperature furnace and controller, an Instron tensile testing instrument, and a vacuum system. The strength of the unit exceeds 1500 pounds of tensile force at 2200°F, and a vacuum pressure of better than 10 microns is easily obtained. Provisions are made for backfilling with helium or argon to overcome the small force exerted at the friction seals. All tests will be performed at a constant strain rate of .002 in/in/min.

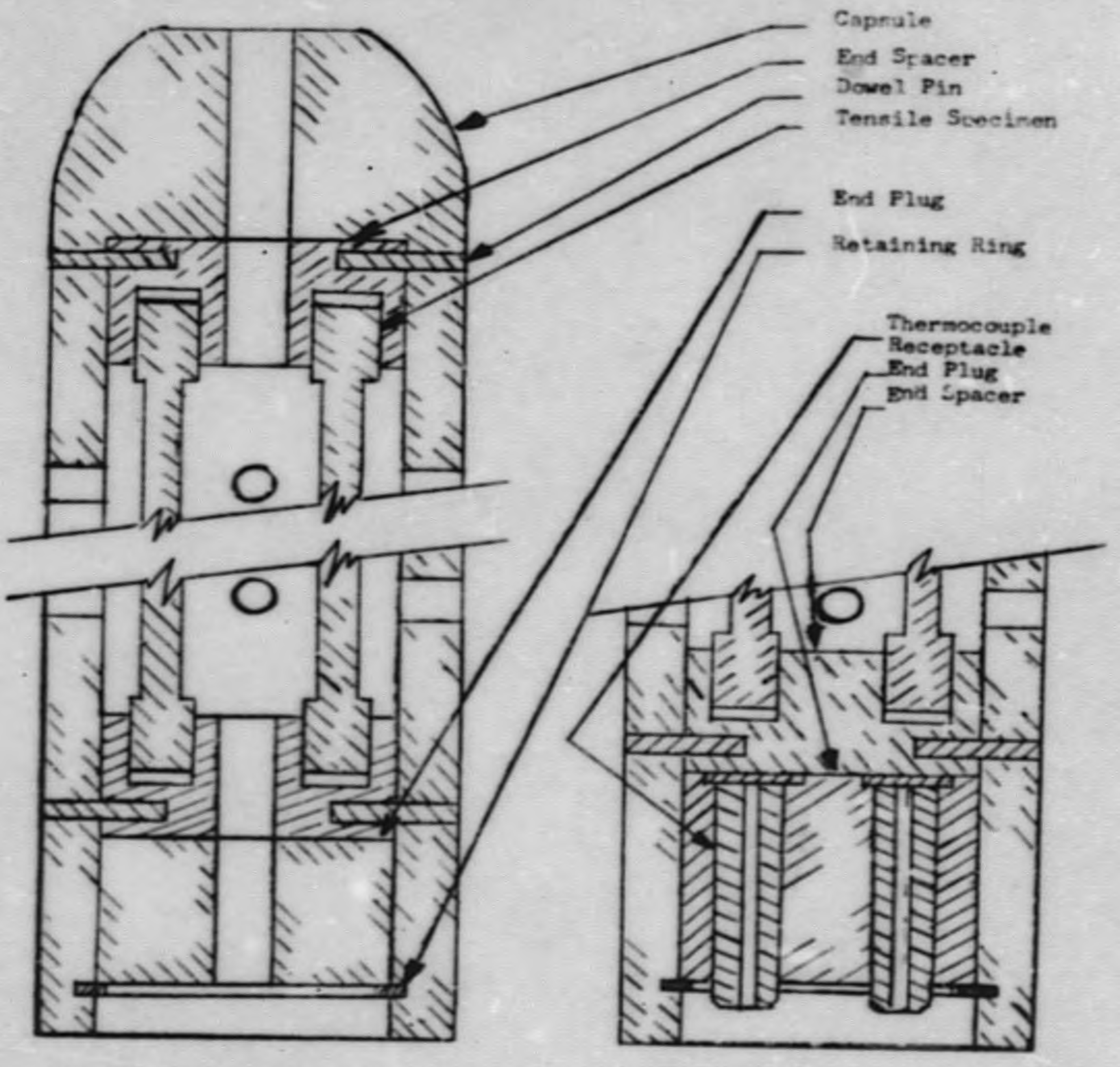
3. Irradiation Procedure and Capsule Description

As pointed out above, the tensile capsules will be irradiated under the same conditions, except for total exposure, and in the same facility as used for the first phase of the program. Changes in irradiation may occur after the effects of invironment on nickel-base alloys are evaluated.

The capsules to be irradiated three and six months will be charged simultaneously, the six months capsules in front. By means of a special tool, the three months capsules will be retracted and discharged upon exposure, leaving the six months capsules to accumulate their respective exposure. The temperature of alternate capsules will be monitored with thermocouples.

The irradiation capsule is illustrated in Figure 5. The main body of the capsule is graphite, and is open in the center both to accommodate thermocouples from the leading capsules and for the passage of reactor gases. Sixteen specimens are held in place with graphite and spacers which are doweled to the capsule body to maintain specimen spacing and alignment. Additional holes are drilled through the capsule to improve gas circulation. The last end spacer is secured with an end plug which is held in place with a "truarc" ring. The capsule is "nosed" in front to allow easy sliding over graphite irregularities in the channel.

After discharge, the capsule is disassembled by either shearing the dowel pin at each end spacer or by breaking the capsule at the vent holes. No hazards in the irradiation are anticipated; however, care should be exercised during discharge to prevent inadvertent breakage of the capsule.



Tensile Specimen Capsule

End Modification for Thermocouple

FIGURE 5