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RESEARCH PROGRAM FOR THE LONG TERM TESTING OF CYLINDRICAL DIODES AND THE IRRADIATION OF FUEL AND INSULATOR

prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

CONTRACT NAS 3-2544

GENERAL ELECTRIC COMPANY
Special Purpose Nuclear Systems Operation

General Electric Company
SPECIAL PURPOSE NUCLEAR SYSTEMS OPERATION
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P. O. Box 846
Pleasanton, California

February 17, 1965

Gentlemen:

In accordance with arrangements with the National Aeronautics and Space Administration, please find enclosed NASA CR-54267, (GEST-2039), entitled "Research Program for the Long Term Testing of Cylindrical Diodes and the Irradiation of Fuel and Insulator," September 17, 1964.

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FIFTH QUARTERLY SUMMARY REPORT

RESEARCH PROGRAM FOR THE LONG TERM TESTING OF CYLINDRICAL DIODES AND THE IRRADIATION OF FUEL AND INSULATOR

prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

September 17, 1964

CONTRACT NAS 3-2544

Technical Management
Nuclear Power Technology Branch
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RESEARCH PROGRAM FOR THE LONG TERM TESTING OF CYLINDRICAL DIODES AND THE IRRADIATION OF FUEL AND INSULATOR

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ABSTRACT

The experimental and analytical work in nuclear thermionics being performed by the Special Purpose Nuclear Systems Operation of the General Electric Company for the National Aeronautics and Space Administration under Contract NAS 3-2544, "Research Program for the Long Term Testing of Cylindrical Diodes and the Irradiation of Fuel and Insulator," is presented. Information from the literature, information generated under the contract, and information generated by the contractor in other studies, some of which were conducted under other contracts with the government, are included. The work is administered under the direction of the Nuclear Power Technology Branch, Lewis Research Center, Cleveland, Ohio.

author

RESEARCH PROGRAM FOR THE LONG TERM TESTING OF CYLINDRICAL DIODES AND THE IRRADIATION OF FUEL AND INSULATOR

SECTION I

SUMMARY

This is the Fifth Quarterly Summary Report describing progress on the research program for the long term testing of cylindrical diodes and the irradiation of fuel and insulator under Contract NAS 3-2544. The program consists of three work areas;(1) development of basic converter life,(2) thermal and irradiation testing of fuel/clad emitter, and(3) irradiation of high purity alumina at temperature.

The objectives and scope of each of these work areas are as follows:

1) Development of basic converter life - design and build thirteen single cell, cylindrical thermionic converters and place them on life test. Following life tests the converters are to be examined and on the basis of this examination a thermal, mechanical, and electrical analyses will be performed to relate test results and to improve design details of converters.

2) Thermal and irradiation testing of fuel/clad emitters - perform furnace and irradiation tests on fuel emitter

samples of several configurations; a) eight samples consisting of UO_2 clad with W-26% Re in a cesium environment at 2000°C, b) four samples consisting of dispersions of UO_2 in tungsten clad with W-26% Re in a vacuum at temperatures to 2000°C, and c) two capsule irradiations of both configurations (a and b) in the Plum Brook Reactor. Perform a reactor design analysis of the results.

3) Irradiation of high purity alumina at temperature - expose eight alumina capsule specimens to irradiation in the Plum Brook Reactor. Record electrical resistivity and breakdown voltage during irradiation and perform a post-irradiation examination.

A summary of the work performed during the fifth quarter and contained in Section III of this report follows.

1) The out-of-pile testing of converter 301 was terminated because of a filament failure after operating for 3754 hours at 7.2 W/cm^2.

2) The post-test examinations of converters 302 and 303 were completed. Results indicated converter failures in both cases were due to a leak in the tantalum thimble; however, localized distortion in the tungsten emitter due to impurities in the material were found in converter 303.

3) Out-of-pile converters 311 and 312 were operated for 2298 and 1676 hours, respectively, and are continuing. Converter 313 has been assembled and its processing was nearing completion at the end of the fifth quarter.

4) Thermal and stress analysis were initiated to determine cell temperature distributions for representative cells of a thermionic fuel element.

5) Assembly and detail drawings have been partially completed and submitted to NASA for the out-of-pile converters, fueled with UO_2 and clad with W-26% Re.

6) Procurement of the material for UO_2/W-26% Re compatibility studies was initiated.

7) The fuel/clad irradiation materials analysis was completed, the fabrication of the four W-26% Re clad UO_2 specimens was initiated and the VAFT testing facility was fabricated and assembled.

8) The alumina irradiation specimens and capsule were assembled and processed. Testing was initiated at the PBR with 270 hours of irradiation completed at the end of the 5th quarter.

SECTION II

INTRODUCTION

To meet future space power requirements over the range of kilowatts to megawatts with a light-weight, reliable and long life system, the Special Purpose Nuclear Systems Operation of General Electric has proposed the STAR-C (Space Thermionic Auxiliary Reactor).

A significant feature of the STAR-C is the integral thermionic fuel element which consists of a number (20 to 40) of nuclear-fueled series-connected, power converting diodes. Emphasis has been placed on this development.

The attainment of the high reliability levels which are required for a space power system will require each individual, series-connected thermionic cell to be fabricated and perform to exacting reliability standards. Development work on materials and converters to achieve the goals of reliability and life in configurations acceptable to the thermionic reactor system is supported as part of the present program as well as under other nuclear thermionic programs at General Electric.

This is the Fifth Quarterly Report describing progress on the research program for the long term testing of cylindrical diodes and the radiation of fuel and insulators under Contract NAS 3-2544. The program consists of three work areas:

A. Development of Basic Converter Life

B. Thermal and Irradiation Testing of Fuel/Clad Emitter

C. Irradiation of High Purity Alumina at Temperature

Objectives of each of these and technical progress during the quarter are summarized in Section III.

SECTION III

TECHNICAL PROGRAM STATUS

A. DEVELOPMENT OF BASIC CONVERTER LIFE

1. General

The objective of this task is to develop thermionic converters of high reliability under simulated out-of-pile thermionic fuel element conditions and obtain information on their possible failure modes. The converter design, fabrication, test equipment, and test initiation were described in the third quarterly report.[1] The converters are single cell, cesium filled, cylindrical devices employing a tungsten emitter and a columbium collector with an inter-electrode gap of 0.01-inch. The emitter is heated by a filament and electron bombardment. The filament is suspended within a tantalum emitter support sleeve.

During the fifth quarter, the testing of the converters was continued and is described in this report. Table 1 summarizes the results of these tests through the fifth quarter. The thermionic design values for power output and efficiency were calculated using the same methods as described in the second quarterly report.[2]

TABLE 1

COMPARISON OF CONVERTER CHARACTERISTICS

Conv. No.	Te °C	Tc °C	Tcs °C	P in watts	Electrode Spacing inches	P meas. watts/cm^2	V meas. volts	I meas. amps	P design watts/cm^2	η meas. %	η design %	Time on test (hours)
301	1830	680	402	675	0.010	7.4	0.695	91	9.1	9.4	12.9	3754 (continuing)
302	1830	700	386	841	0.010	7.9	0.555	122	11.3	8.1	12.6	100
303	1830	735	413	718	0.010	6.9	0.575	103	9.4	8.2	12.4	916
311	1830	700	380	662	0.010	7.1	0.71	86	8.8	9.2	12.7	2298 (continuing)
312	1830	700	370	665	0.010	6.5	0.61	91	8.4	8.4	12.2	1676 (continuing)

Te = emitter temperature
Tc = collector temperature
Tcs = cesium reservoir temperature
P in. = total emitter power input
P meas. = measured power output
V meas. = measured output voltage, at terminals on tube envelope
I meas. = measured output current
P design = design power output (with no lead losses)
η meas. = measured efficiency
η design = design efficiency

2. Converter Testing - Phase I

a. Converter 301

The initial testing and filament replacement of this converter was described in previous quarterly reports.[1,3] At the close of the fourth quarter, converter 301 had operated for 2288 hours and was continuing.

During the fifth quarter, the converter operation continued to 3754 hours, at which time the filament failed. Output power from 2288 hours to 3754 hours remained essentially constant. The measured output power density just prior to filament failure was 7.2 W/cm^2. This compares with 7.4 W/cm^2 at the start of the test.

Observations of the bomber characteristics just prior to filament failure indicate that there was no cesium leak into the bomber chamber. Prior experience indicates that the converter will be able to continue on test if the filament is replaced using standard procedures.

b. Converter 302

The life testing of converter 302 was terminated because of filament failure and the post-text examination was initiated during the third quarter.[1] This post-test examination was completed during the fifth quarter.

The bombardment filament was removed and the filament assembly found to have an appearance indicating positive ion bombardment. Further examination of the emitter assembly with a helium leak detector confirmed the presence of a leak in the tantalum thimble. This leak would provide a means for cesium to get into the bombardment chamber. All other converter parts were examined and appeared to be in as-built condition. There was no evidence of failure of any component except the tantalum thimble.

c. Converter 303

The life testing of converter 303 to 916 hours and initiation of its post-test examination was reported previously.[1,3] During the fifth quarter, the post-test examination and analysis was completed.

The post-test examination that was performed during the fourth quarter revealed blistering of the inner wall of the tungsten emitter. During the fifth quarter, metallographic examination of the blistered tungsten showed that the blisters originated between layers of the multi-layer vapor deposited tungsten. It also revealed contaminants between the layers in this tungsten. The multi-layer vapor deposited tungsten is made in a series of depositions. Between depositions the sample is allowed to cool. After cooling it is taken out of the vacuum region for inspection. The sample is then cleaned and the system evacuated and another layer of

tungsten is applied. The contaminant was qualitatively identified as a metal oxide or an organic which was not properly cleaned after inspection. The contaminant was found in the outer boundary layer.

Prior to the sectioning of the tantalum thimble and tungsten emitter assembly, a leak in the tantalum thimble was revealed using a helium leak detector. Subsequent examinination of the internal walls of the tantalum thimble with a Boroscope disclosed internal circumferential cracks as being the location of the leak path. The tantalum was then sectioned and metallographically examined. This examination showed that the cracks penetrated the tantalum wall and were intergranular. The location of the cracks was in the vicinity of the observed distortion or blistering of the tungsten emitter cylinder. The cracks are believed to have been associated with the tungsten distortion.

3. Converter Testing Phase II

The design, fabrication, and the initiation of testing of Phase II converters was reported in the fourth quarter.[3]

These converters incorporate a modified collector emitter spacing method, back emission shielding, and intercell electrical connecting techniques on the lower end of the converter while retaining as much of the Phase I design as possible. The primary objective of this converter test series is to subject the collector-to-emitter spacing

components to realistic temperature and operating conditions. This design was described in detail in the fourth quarter report.[3]

a. Converter 311

Converter 311 was placed on life test and had accumulated 116 hours during the fourth quarter.[3] The converter has continued to operate satisfactorily and at the end of the fifth quarter had operated for 2298 hours.

The converter power output decreased to 90% of its initial value during the first 760 hours of operation. The input power remained constant during the period. The emitter temperature had increased due to the decreasing emission cooling value. Since the primary purpose of the converter test is to operate the emitter and intercell structure at realistic temperatures, the external load resistance was adjusted to return the emitter temperature to 1830°C by increasing the output current and thus increasing the electron cooling of the emitter. The input power was kept constant. This resulted in a non-optimum load condition and the output power decreased to 78% of the initial value. Since the load was changed, the converter power output has remained constant during the test. Data given in Table I was taken at the initial test time.

b. Converter 312

The design, fabrication, and processing of converter 312 was completed during the fourth quarter. In the fifth quarter, converter 312 was placed on life test. By the close of the quarter it had achieved 1676 hours on test and was continuing.

The life test of converter 312 was initiated at an emitter temperature of 1830°C with operating conditions selected to maximize the converter output power. The maximum power output, obtained by sweep voltage measurements, was achieved at a cesium reservoir temperature of 370°C and a collector temperature of 700°C. While operating at these conditions, converter 312 produced a design power output of 8.4 W/cm^2.

The filament emission characteristics of this converter were observed to be different from those of other converters. It was found that the filament temperature could not be reduced below 2400°C without causing excessive variation in bombardment current, voltage, and power. Even at a filament temperature of 2400°C, noticeable variation in bombardment power was observed. During the first 300 hours of operation, the power output of converter 312 varied in correspondence with the power input as described above. After 300 hours of operation, however, adjustments were made to stabilize the input power at the value of

the initial life test conditions. When this was done, the output power was 95% of the initial life test value. The output power remained at approximately this value from 300 to 1676 hours of testing at the end of the quarter.

c. Converter 313

The design of converter 313 is identical to converters 311 and 312. Fabrication of converter 313 was initiated in the fourth quarter. During the fifth quarter, the fabrication of converter 313 was completed, the emitter was calibrated, it was assembled, and the processing completed.

The emitter was calibrated in a vacuum belljar with a mockup collector clamped to the emitter and seal assembly. The mockup collector has suitable view holes for optical pyrometry and provided a thermal mockup for measurements of emitter temperature distribution as a function of emitter power input. Figure 1 presents the emitter calibration for converter 313.

4. Design and Life Testing of Thermionic Converter Components

The objective of this task is the design, fabrication, and testing of two thermionic converters to investigate the integrity of collector-emitter spacer and insulator assemblies, intercell electrical connections, and related internal components required in the thermionic reactor

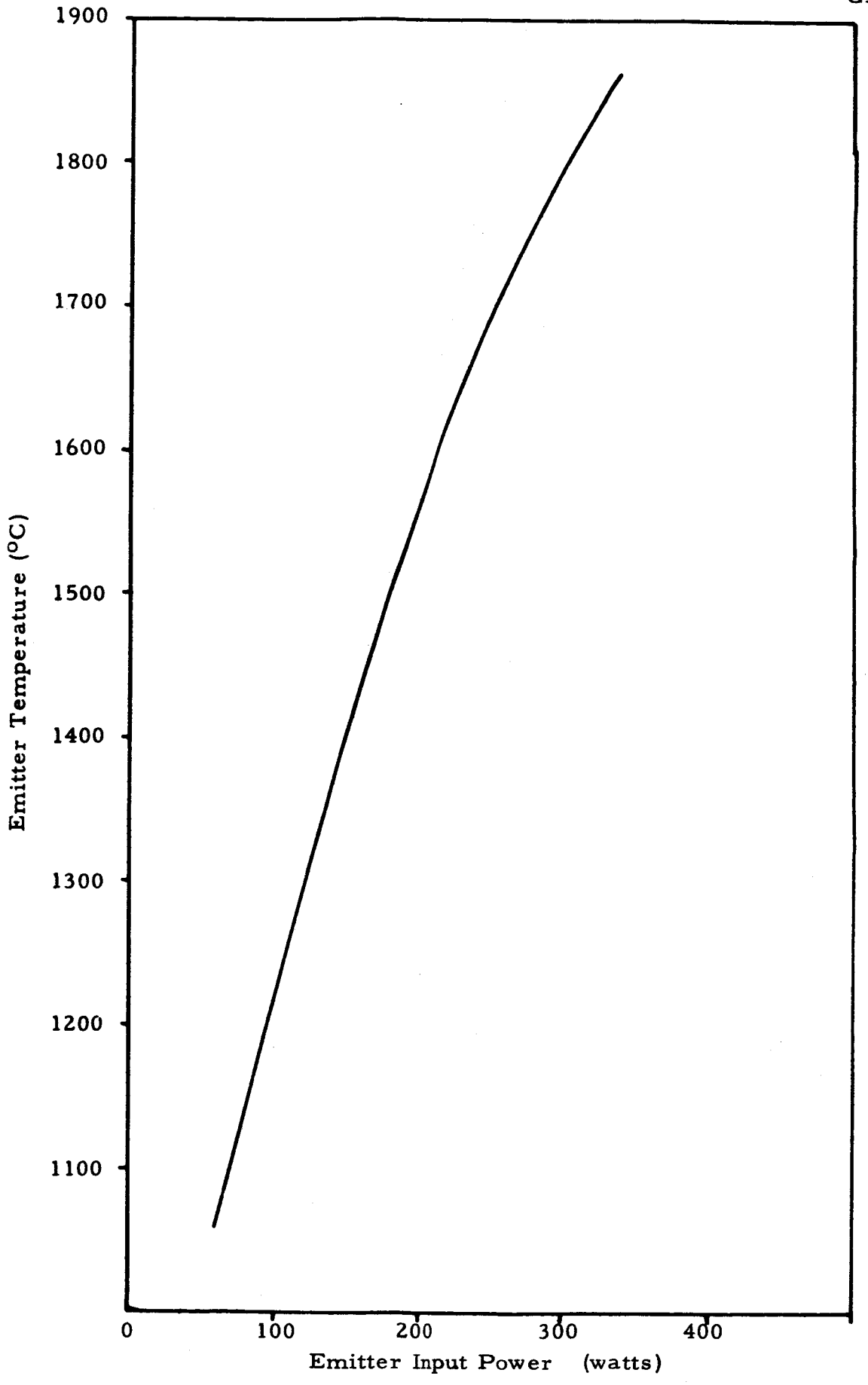


Figure 1 Emitter Calibration for Converter 313 in Vacuum

application. The intercell electrical connection in the converters will be the current carrying lead for the emitter. This converter design is to be based on a thermionic fuel element design and a thermal and stress analysis thereof.

The work on these tasks has been confined to the thermal and stress analysis of three adjacent representative cells of a thermionic fuel element.

Analysis was initiated to determine the cell temperature distribution. Five calculational models were developed to obtain preliminary temperature distributions. The results obtained from these preliminary runs were used to identify which portions of the cell warranted further analysis, and to provide a base for refinement of models.

Using the thermionic modification of TIGER V computer code, one R-Θ, and four R-Z models were analysed. The R-Θ model was a 120° sector of a transversal plane passing through the cell at mid-length of the emitter. The R-Z models consisted of representative longitudinal sections required to describe the temperature distribution in the regions of the emitter-collector spacers, intercell electrical connections, and other required components. The configuration analyzed is similar to the assembly used in the Phase II converter tests with modifications made in the method of emitter to collector spacing. The results from these models indicated those sections with sufficient temperature gradients to warrant further analysis. Continued effort was devoted to

examination of the R-Z planes with models improved by better representation of the geometry and by more applicable thermionic characteristics.

5. Life Testing of Fueled Out-of-Pile Thermionic Converters

The primary objective of this converter program is to investigate the possible influence of UO_2 on the performance of nuclear thermionic converters which employ UO_2 as fuel and tungsten-26% rhenium as the emitter cladding. This will be investigated through the life testing of three fueled out-of-pile (electrically heated) thermionic converters. The test converter will be basically the same as the 301-303 series with the added provision for longitudinal slots to contain the UO_2 within the emitter. The design of the collector will be modified to allow operation at 1000°C with 4500 hours as the life objective.

During the report period, with the exception of weld details on the emitter and braze details on the collector, assembly and detail drawings were prepared for submission to NASA for review. Work was started on the development of a design for achieving 1000°C collector temperature. This included investigation of copper and nickel braze integrity as a function of temperature and time.

Procurement of the tungsten-26% rhenium emitter material was initiated using the same specification as that for the compatibility tests described in section B-1. All other required material procurement was initiated. Development

was initiated for fabricating a thermocouple to measure emitter temperature.

B. THERMAL AND IRRADIATION TESTING OF FUEL/CLAD EMITTERS

1. Long Term Compatibility Tests of UO_2 Clad with W-26% Re

During prior contract work, stoichiometric UO_2 was found to be compatible with W-25% Re when tested isothermally in a gaseous cesium environment (1-5 torr), at 1800 and 2000°C and for times up to 2000 hours. An extension of these compatibility studies to 5000 hours is required in the continuing test program for the second contract year. The testing conditions will be the same as those employed during the first contract year with the addition of compatibility evaluation at 2200°C. The second year program is presented in Table 2. All test samples will be vented.

Preparations for initiating the second year compatibility studies are underway. Specifications for the procurement of W-25% Re have been written and approved by NASA and procurement of the material initiated. All other necessary materials have been received. UO_2 pellet fabrication and cesium chamber construction are in progress.

2. Fuel/Clad Irradiation

a. General

The objective of this task is to obtain data on chemical compatibility, dimensional stability, venting

TABLE 2

PROGRAM FOR LONG TERM COMPATIBILITY TESTING OF UO_2 CLAD WITH W-26% Re

Specimen No.	Test Temperature	Environment for Specimen	Test Duration
1	1800°C	Vented to Cs vapor (approx. 4 torr)	2000 hours
2	1800°C	"	2000 hours
3	1800°C	"	500 hours
4	1800°C	"	1000 hours
5	1800°C	"	3000 hours
6	1800°C	"	3000 hours
7	1800°C	"	5000 hours
8	1800°C	"	5000 hours
9	2000°C	"	2000 hours
10	2000°C	"	3000 hours
11	2200°C	"	500 hours
12	2200°C	"	1000 hours

characteristics, weld microstructure, and fission product release on UO_2 fueled W-26% Re clad emitters at temperature in a nuclear environment. The test consists of irradiating a capsule assembly containing four W-26% Re clad UO_2 specimens in the Plum Brook Reactor (PBR). Two irradiations are planned.

The target test conditions were established and a chemical and metallographic analysis was partially completed on the specimen material during the fourth quarter.[3] A detailed description of the test design and procedures also were reported in the fourth quarter.[3]

During the fifth quarter, the materials analysis was completed, fabrication of the specimens was initiated, and the vertical adjustable facility tube (VAFT) for testing in the PBR was fabricated and assembled. This work is described in detail below.

b. Materials Analysis

The chemical and metallographic analysis of the W-26% Re tubing and lower end caps and of the natural and enriched UO_2 powders was described in the fourth quarterly report.[3]

During the fourth quarter, analysis revealed an excess sigma phase in a bar of W-26% Re to be used for making the upper stem end caps. A new bar of this material was supplied by the Hoskins Company. The new bar met the

sigma phase specifications and was accepted for use in this application. The Hoskins Company certified that Zyglo inspection revealed no cracks, that no sigma phase was found at 100X magnification in both longitudinal and traverse sections, and provided a certified chemical analysis as presented in Table 3. The Zyglo and sigma phase inspections were repeated by the General Electric Company upon receipt of the material at the Vallecitos Atomic Laboratory. The material was sectioned and examined at 150X magnification. This material shown in the photomicrographs is sigma phase free (Figures 2 and 3). These inspections confirmed the information supplied by the Hoskins Company.

Following acceptance of the W-26% Re material, one upper end cap with a stem was machined from the material and TIG welded to a W-26% Re tube (Figure 4). This specimen will be used for the thermocouple calibration test.

Irradiation Test Capsule and Specimen Fabrication - UO_2 Fuel Pellet

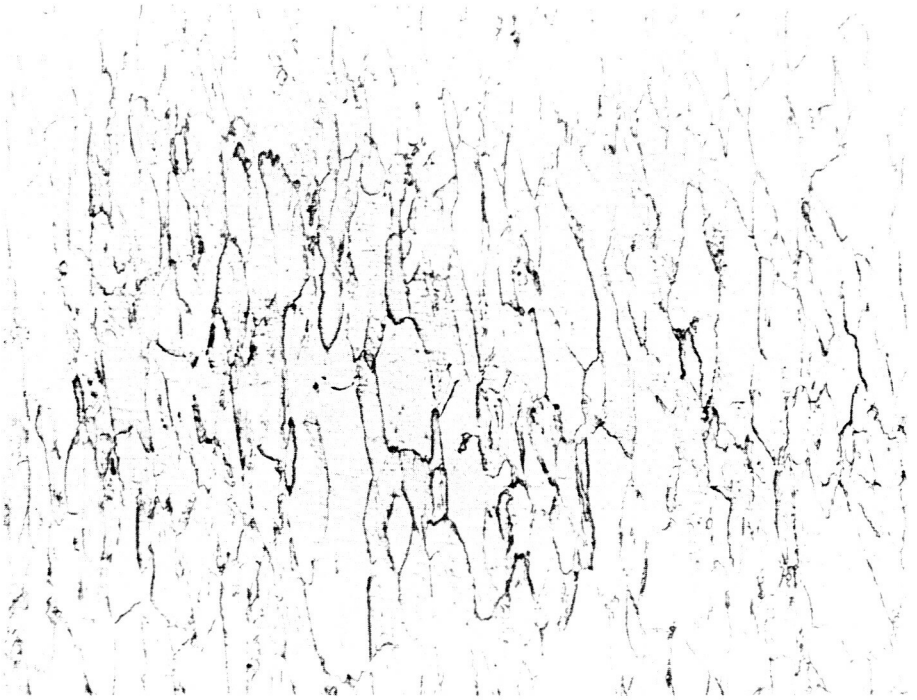
UO_2 fuel pellets were fabricated during the fifth quarter. A wet blending technique was used to blend the natural and nominally 20% enriched UO_2 powders. The wet blending technique was used to assure the best possible homogeneity. The UO_2 powders of natural and 19.9% enrichment were weighed to give batches of 200 grams each of the desired 1.50% and 2.40% enrichments. The batches were blended in a ball mill rack

TABLE 3

CHEMICAL ANALYSIS OF W-26% Re

(Bar for Stem End Caps)

Element		Element	
W	74.62%	Ti	< 1 ppm
Re	25.32	Ni	15 ppm
C	81 ppm	Mo	50 ppm
O_2	120 ppm	Cu	4 ppm
N_2	25 ppm	V	< 10 ppm
Al	< 10 ppm	Mn	< 10 ppm
Fe	35 ppm	Ca	< 1 ppm
Si	< 20 ppm	Bi	< 10 ppm
Mg	< 1 ppm	Zr	< 1 ppm
B	< 2 ppm	Pb	< 20 ppm
Sn	< 10 ppm	Na	< 10 ppm
Ag	< 10 ppm	K	< 50 ppm
Co	< 5 ppm	Cb	< 50 ppm
Sb	< 100 ppm	Li	< 10 ppm
Zn	ND	Cd	ND
Ba	< 10 ppm	As	ND
Sr	< 10 ppm		



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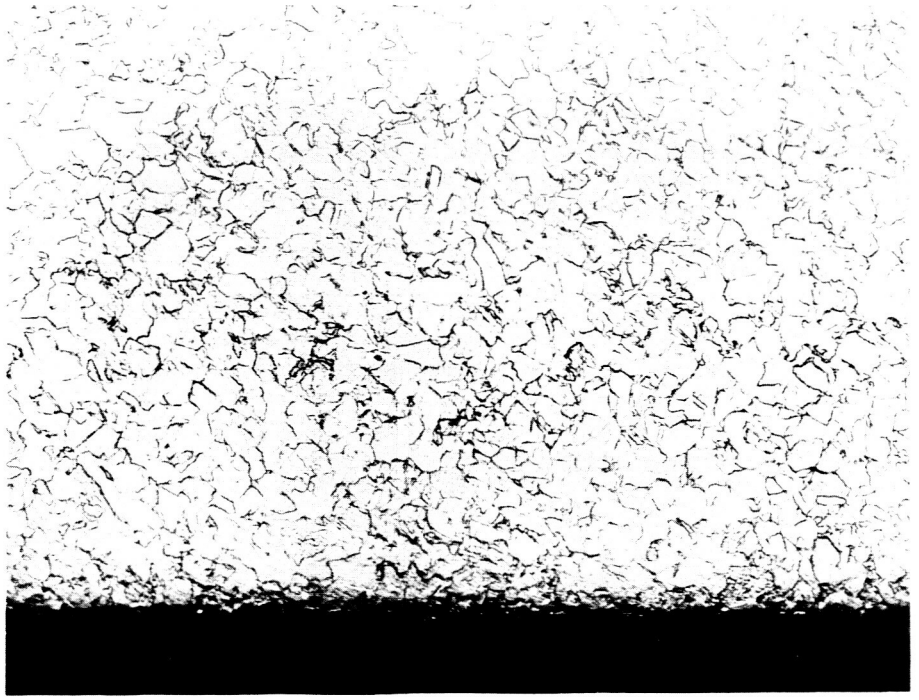

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Figure 3 Transverse Section of W-26% Re Bar that is Sigma Phase Free

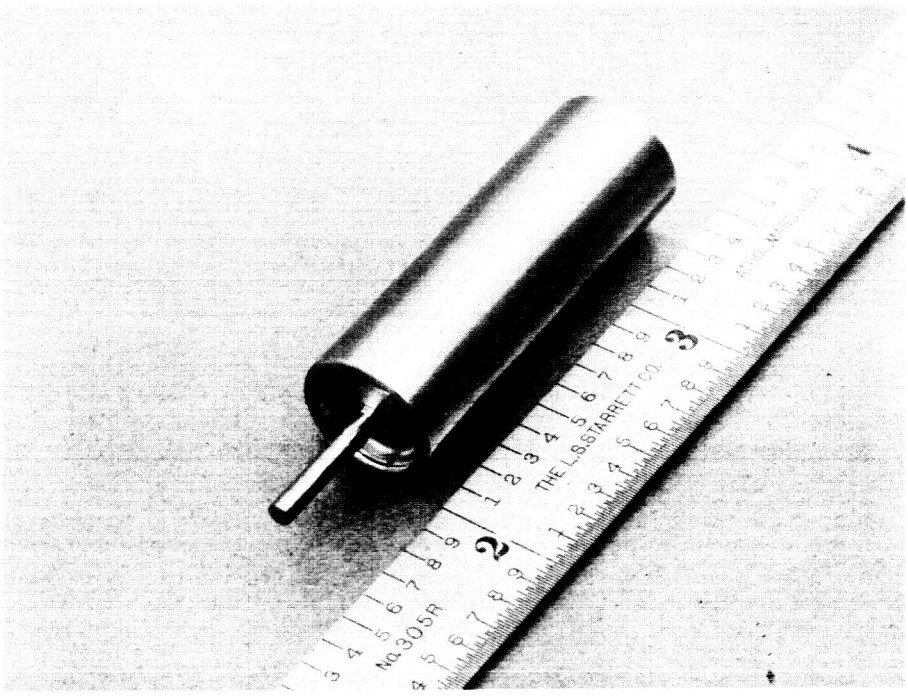


Figure 4 W-26% Re Fuel/Clad
Calibration Specimen

for six hours.

The pellets were then formed by cold pressing at 20,000 psi. The water content had been adjusted to 3 w/o before pressing. This water served as a binder; no organic binders or lubricants were employed. The pellets were then sintered for 6 hours at 1700-1750°C in H_2. The outside diameter was adjusted by centerless grinding, the core was formed by ultrasonic drilling. Finally, the pellets were cleaned and outgassed by heating at 1200°C for four hours. The dimensions of the cored UO_2 pellets are 0.402-inch O.D., 0.450-inch length, and a 0.119-inch diameter core. Two pellets make up the 0.900-inch long fuel pellet for each of the four specimens. Listed in Table 4 is an isotopic analysis of one pellet from each batch. Listed in Table 5 is a chemical analysis of one pellet from each batch.

TABLE 4

ISOTOPIC ANALYSIS OF ENRICHED UO_2 FUEL PELLETS

Sample	Isotope	
1.5% enrichment	234	0.005 ± 0.0001
	235	1.55 ± 0.01
	236	0.010 ± 0.001
	238	98.44 ± 0.10
2.4% enrichment	234	0.160 ± 0.001
	235	2.47 ± 0.02
	236	0.010 ± 0.001
	238	97.36 ± 0.10

TABLE 5

SPECTROGRAPHIC CHEMICAL ANALYSIS OF ENRICHED UO_2 FUEL PELLETS

1.5% enrichment

N	<	10 ppm	Cu	<	1
C		15.7	Mg		1
F		2.3	Mn		0.5
Ag	<	0.1	Mo		3
Al		54	Ni		24
B	<	0.2	Pb	<	1
Cd	<	1	Si		34
Cr		8	Sn	<	1
Co	<	2	V	<	15
			Fe		60

2.4% enrichment

N		50 ppm	Cu	<	1
C		17.3	Mg		1
F		1.8	Mn	<	0.5
Ag	<	0.1	Mo		3
Al		54	Ni		24
B	<	0.2	Pb	<	1
Cd	<	1	Si		34
Cr		10	Sn	<	1
Co	<	2	V	<	15
			Fe		80

Pellet Density

1.5% enriched - average % theoretical density - 95.48%

2.4% enriched - average % theoretical density - 95.24%

Capsule Fabrication

All of the parts for the stainless steel capsule shell have been fabricated and are ready for assembly. Shown in Figure 5 are the capsule parts in order of assembly. Shown in Figure 6 is a closeup view of the upper and lower end of the capsule.

d. Irradiation Test Support Equipment

The vertical adjustable facility tube (VAFT) for PBR position LD-11 will be used for testing both capsules in this program. The fabrication and assembly of the VAFT was completed during this quarter and is ready for out-of-pile testing.

This facility is an electromechanical device for positioning a capsule in the upper half of the fueled portion of the PBR core. It allows a total capsule movement from top to bottom of 10 inches. However, only 9 inches are used for control. The capsule bottom is located at core midplane (O) when the facility is full in. The facility protrudes approximately 42 inches above the top grid plate of the reactor core. A carriage rod is mounted on one side of the facility with two stainless steel ball bushings. The carriage rod has a mounting plate and anchor bolt so the capsule can be remotely attached to the top. The rod is moved up and down by a ball bearing remote control push-pull cable which is fastened to the rod. All materials of construction for the facility are either stainless steel or aluminum alloys.

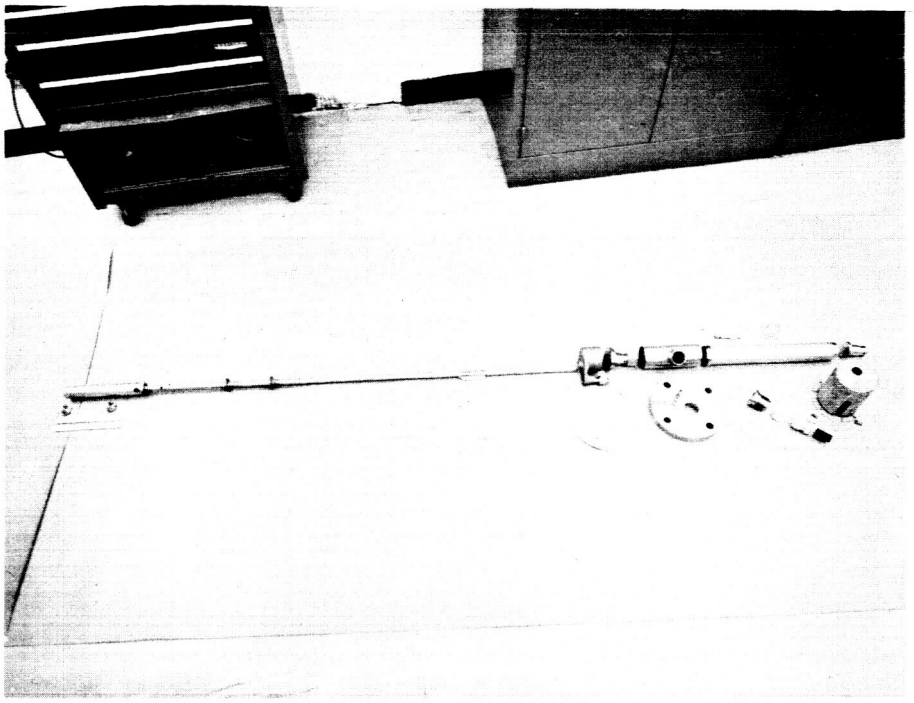


Figure 5 Fuel/Clad Irradiation Capsule and Test Apparatus in Order of Assembly

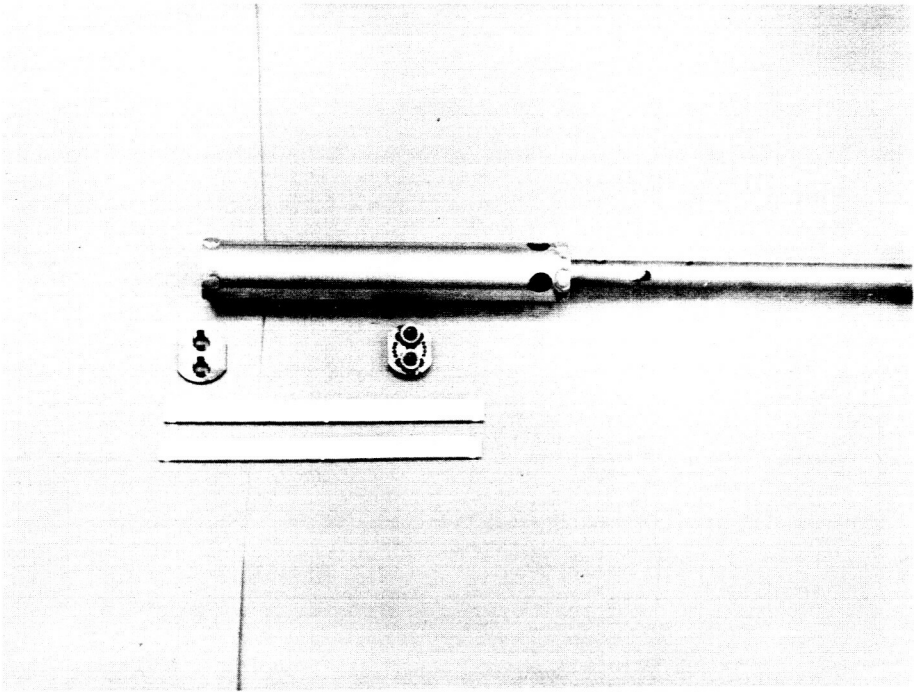


Figure 6 View of Capsule Assembly

The in-core portion of the VAFT (Figure 7) consists of a 2-inch O.D. aluminum tube that fits into the LD-11 position. The tube fits into the lattice piece in the reactor core grid. The facility seats in the lower grid portion of the lattice piece and will be held in place by a bracket or support rod.

Cooling water flows between the lattice piece and the outside of the aluminum facility tube from top to bottom through a 0.075-inch annular gap. This provides cooling for the gamma heat generated in the tube. Water also flows in the top of the tube and in slots in the side and down through the 1-1/2 inch inside diameter to cool the experiment capsule. Baffles are provided on the capsule connecting rod to control coolant flow to the capsule. The control flex cable is routed to the NW 4-inch gooseneck penetration and would be secured in two in-vessel instrumentation mounting rings using clamps at the vessel wall. The assembly of the penetration flange and facility mechanism is similar to that used for the alumina irradiation experiment. The moving seal for the pressure vessel is made with a double V-ring packing similar to that used on reactor control rod drives for the Vallecitos Boiling Water Reactor. The whole mechanism projects approximately 54-3/8 inches above the gooseneck flange. Shown in Figure 8 is the drive mechanism mounted on its out-of-pile test stand. Shown in Figure 9 are drive parts prior to assembly. A special out-of-pile test stand and

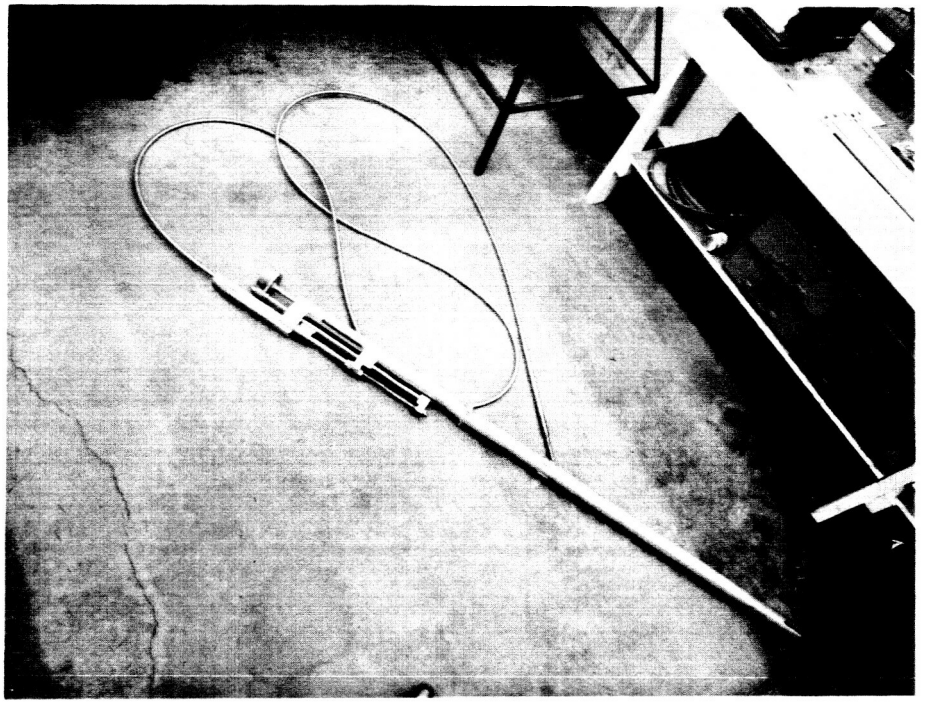


Figure 7 In-core Portion of VAFT

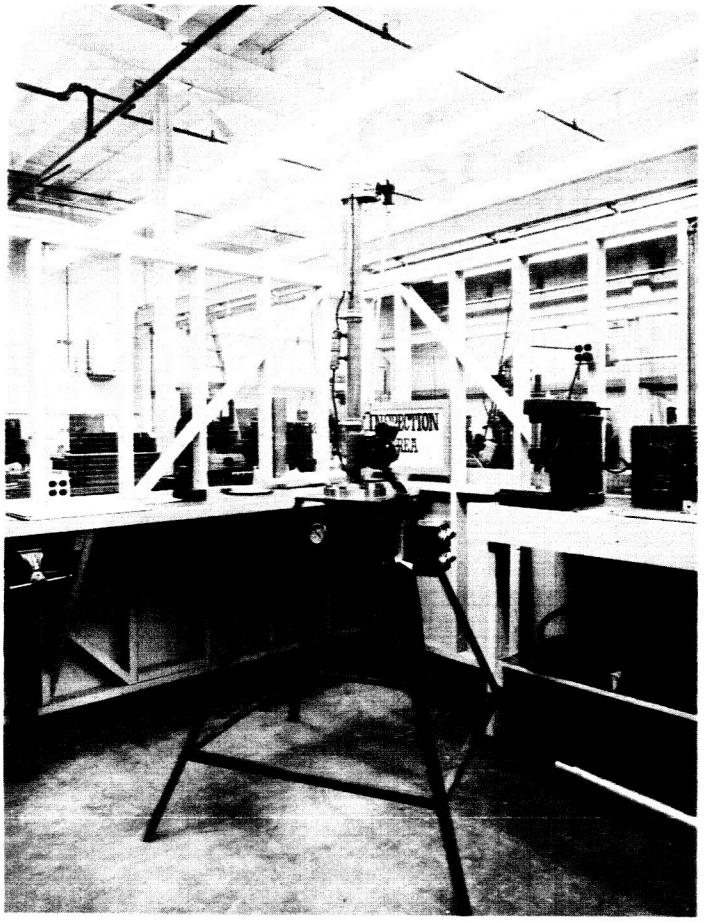


Figure 8 VAFT Drive Mechanism Mounted on its Out-of-Pile Test Stand

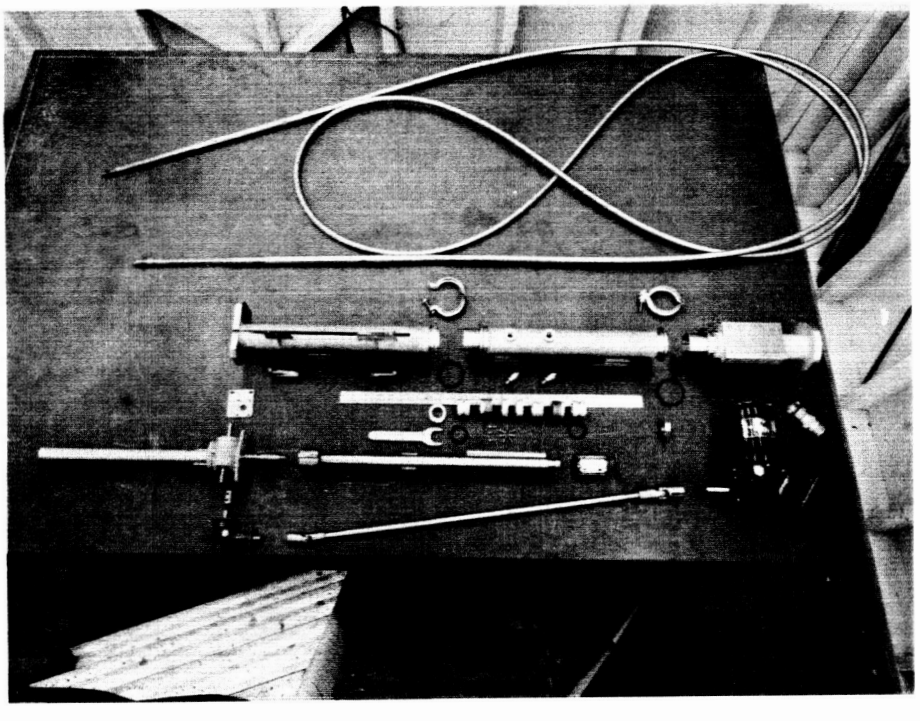


Figure 9 VAFT Drive Mechanism Parts
Prior to Assembly

mockup goosenecks were fabricated for testing the VAFT out-of-pile. The total movement of the push-pull cable is 10 inches. One end of the push-pull control cable is attached to a worm gear actuator drive through an angle-gear and gear reduction train to an AC, phase shift, reversible motor controlled from the console. The control consists of a spring-loading, three-position switch with indicator lights mounted on the console. Lugs mounted on the shaft actuate limit switches that stop the movement at full-in and full-out position independently of the operating control.

C. IRRADIATION OF ALUMINA

1. General

Detailed descriptions of the test specimen design and fabrication, the test equipment, test procedures, and the thermal mock-up test were presented in previous quarterly reports.[1,2,3] At the close of the last quarter, the fabrication of the specimen parts was completed and the assembly of the parts initiated. The supporting experiment apparatus (cut-off shear, consoles, lead harness, vessel penetration, etc.) was fabricated, tested, and shipped to the PBR site. During the fifth quarter, the specimens and capsule were assembled, shipped to the PBR, processed, and the irradiation testing initiated.

2. Test Apparatus Assembly and Installation

a. Capsule Assembly

The alumina irradiation capsule assembly was completed during the fifth quarter and shipped to the NASA Plum Brook Reactor Facility on August 5, 1964.

The vacuum seal, specimens, and leads are shown in Figure 10 prior to installation in the vacuum can. All leads are insulated with high purity alumina sleeving. Shown in Figure 11 are the vacuum seal and the thermocouples brazed into place. Shown in Figure 12 is the final alumina specimen assembly with electrode and thermocouple leads in place. The alumina specimens and vacuum seal were then installed in the vacuum can and pumped down on a vacuum station. The vacuum can was heated to 675°F before pinch off. The vacuum can was pinched off at 8×10^{-6} torr after cooling to room temperature. All parts inside the vacuum can were cleaned and prefired in accordance with the procedures stated in the Quality Control Document QCSI-6.

The assembled capsule is shown in Figure 13 prior to installation in the outer shell. The completely assembled capsule is shown in Figure 14. Shown in Figure 15 is the pressure vessel penetration end of the capsule. The coaxial connectors were removed and repotted at PBR prior to installation.

b. Capsule Check-out

The capsule assembly was tested at the PBR prior to

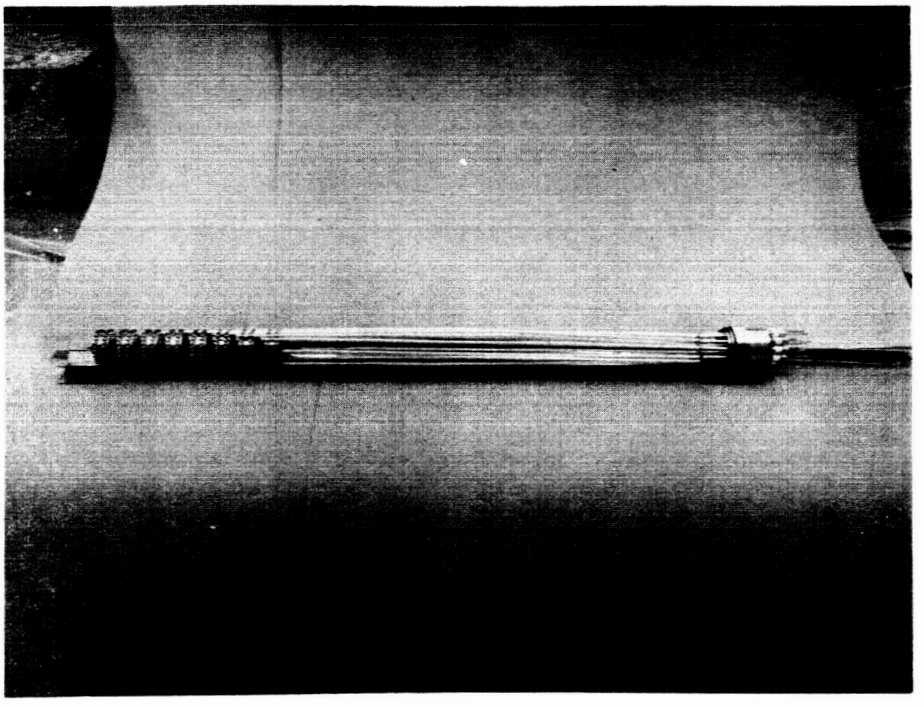


Figure 10 Alumina Specimens, Leads, and Vacuum Seal Prior to Installation in Vacuum Can

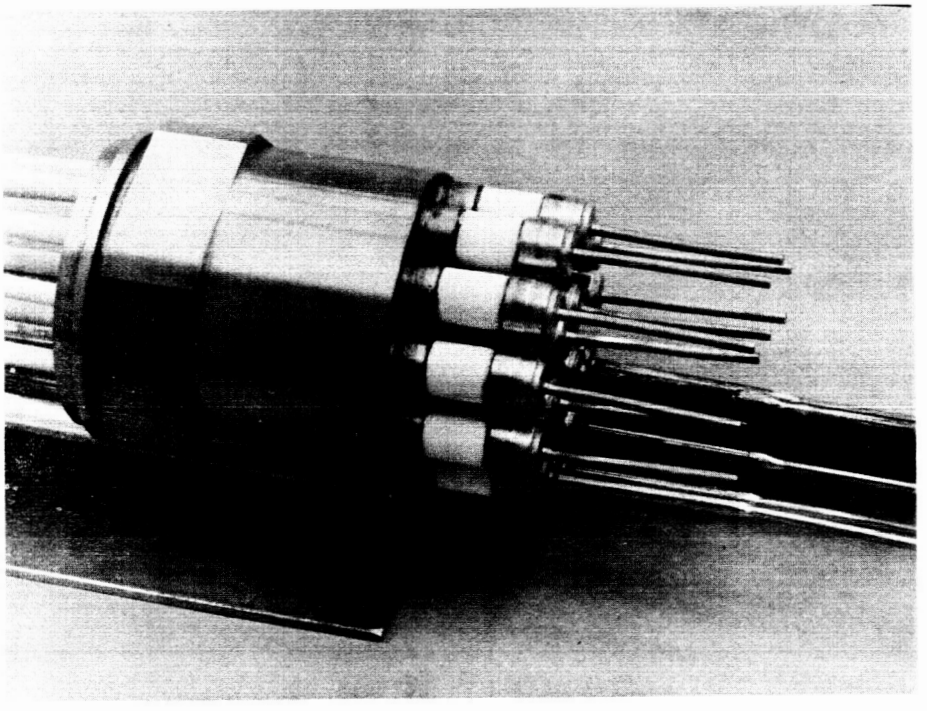


Figure 11 The Vacuum Seal with Thermocouples Attached

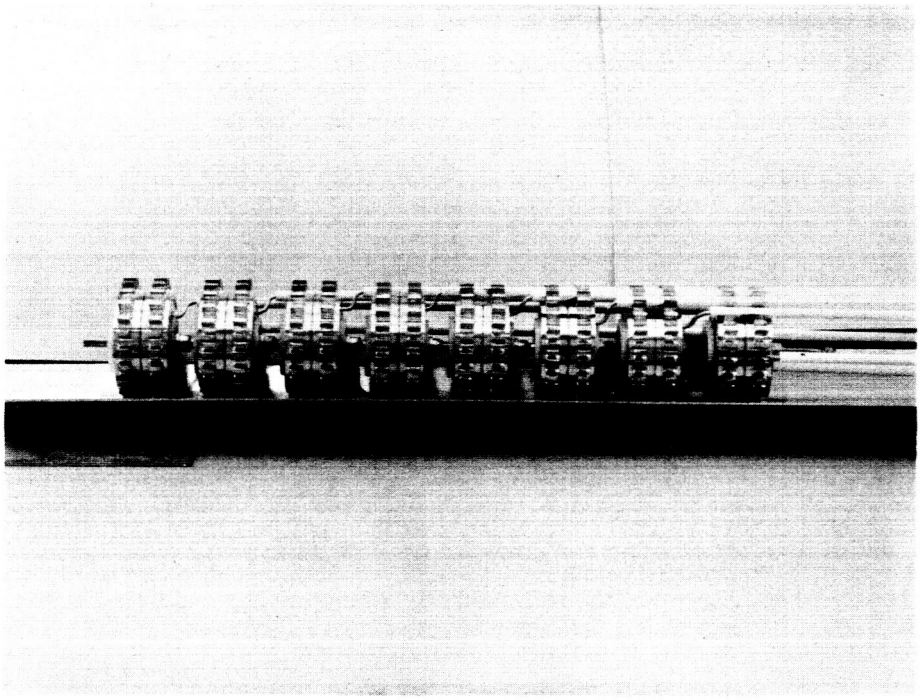


Figure 12 Final Alumina Specimen Assembly with Leads in Place

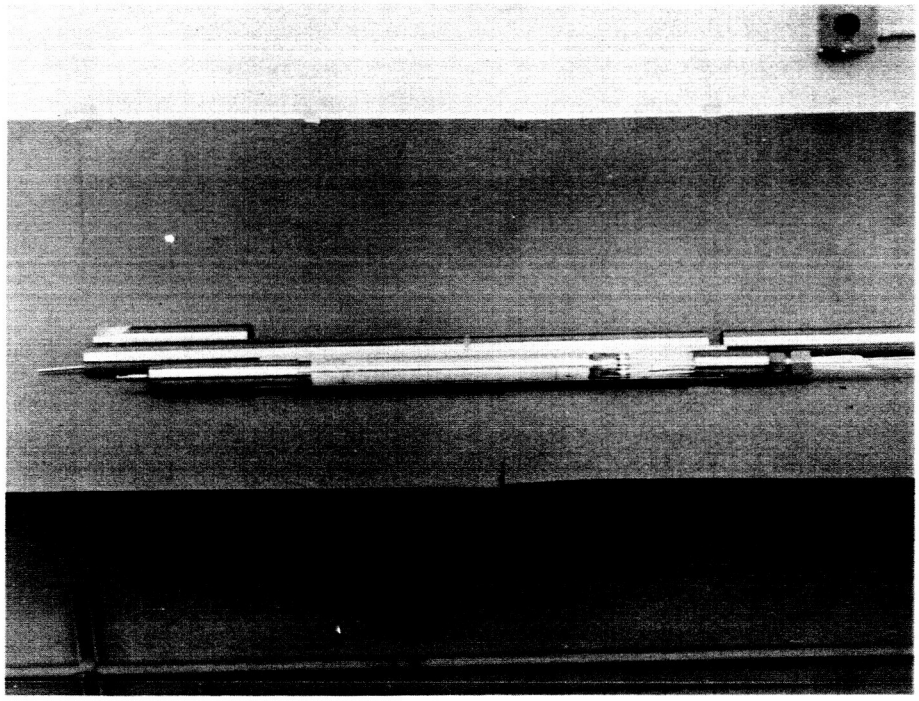


Figure 13 Assembled Capsule Prior to Installation in Outer Shell

Figure 14 Completely Assembled Capsule

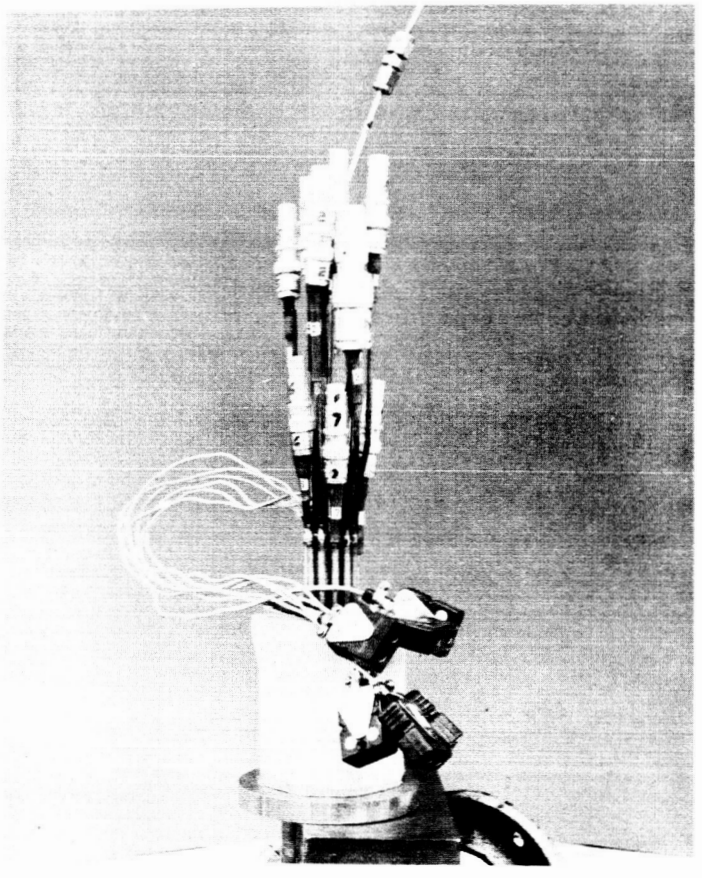


Figure 15 Pressure Vessel Penetration
End of Capsule

installation in the reactor pressure vessel. The leads and thermocouples were checked and agreed with pre-shipping data recorded in the Quality Control Document. The capsule was then checked for core fit in the PBR Mockup Reactor. The capsule, lead hose, and pressure vessel penetration were helium leak tested at 190 psig helium pressure. Two leaks were found in the penetration that had not been detected in final check at the Vallecitos Atomic Laboratory. These were repaired and the capsule was found to pass requirements with a helium leak rate of 10^{-6} cc/sec as measured with a mass spectrometer type leak tester.

The capsule then was subjected to a hydro test. A pressure of 8 psig of helium was applied in the lead system with an outside water pressure of 65 psig. The water pressure was raised to 225 psig for 2 hours. The penetration flange, nut, and gasket performed satisfactorily. All leads were checked several times during the hydro test. The pressures were adjusted to 182 psig helium and 149 psig water and held for 20 hours. The helium pressure held to within 2 psig correcting for temperature change. This test was considered satisfactory.

The capsule was removed from the hydro test and re-helium leak checked to 190 psig. The leak rate was 10^{-3} to 10^{-4} cc/sec. Primarily this leak was traced to the MgO insulation on the leads at the pressure vessel penetration. Since this would indicate a helium loss of

approximately 1 ft^3 per cycle, the test was considered satisfactory.

During these tests, the lead to the common resistances dropped below the megohm range on several leads. This was apparently due to moisture pick up in the MgO insulation of the leads at the pressure vessel penetration. The leads were baked out and the resistances restored to the 10 megohm and up level. The MgO was sealed with Glyptal and RTV silicone sealant. It was also found that the lead resistance was a function of whether the helium pressure was applied to the system or not. When the lead system was depressurized, the lead to common resistance tended to go down. This is believed to be due to moisture pick up in the MgO insulation from the humid atmosphere near the pressure vessel penetration. When the lead system was repressurized, the resistances returned to values in the range before depressurization.

Due to the use of metal sheath electrode leads and metal thermocouple connectors in accordance with PBR requirements, it was impractical to prevent common lead grounding. As a result, a wiring modification was made at the console to use ground as a common lead and float the power supply. Satisfactory use of the electrometer was made during cycle 24 with this arrangement. During cycle 23 a Simpson microammeter was used because several range resistors burned out in the

electrometer. This occurred during early attempts to measure resistance directly with the megohmmeter circuit in the electrometer.

3. Irradiation Testing

Upon completion of the capsule assembly check out, it was installed in the PBR. After installation, the lead resistances were again checked using the electrometer ohmmeter and resistance measurements were made for the thermocouples and heater wire. The results of these checks are given in Tables 6 and 7 and were in agreement with measurements made at Vallecitos prior to shipping.

The reactor was taken to power on August 13 (cycle 23P). When the power level reached 2 mw, temperatures at the specimens started to increase. The lead system was viewed inside the vessel by remote TV. No excessive vibration or problems were noted. At a power level of 40 MW, the specimens reached the temperature design limit, as follows:

TC-1	980°C
TC-2	1065°C
TC-3	1102°C
TC-4	1090°C

The actual specimen temperature is approximately 30°C lower than the above recorded values.

The temperatures followed the predicted distribution very

TABLE 6

LEAD RESISTANCE PRIOR TO REACTOR STARTUP

Lead #1	30 megohms	#6	10 to 12 megohms
#2	38 to 40 megohms	#7	34 to 36 megohms
#3	6.6 to 7.4 megohms	#8	28 megohms
#4	26 to 34 megohms	#9	Common ground
#5	13 to 14 megohms	#10	12 megohms

TABLE 7

THERMOCOUPLE AND HEATER WIRE RESISTANCE MEASUREMENTS PRIOR TO REACTOR STARTUP

	Between Leads	Leads to Ground
TC-1	18.1 ohms	Infinite
TC-2	18.6 ohms	Infinite
TC-3	19.6 ohms	Infinite
TC-4	19.8 ohms	Infinite
TC-5	13.4 ohms	Infinite
TC-6	17.5 ohms	Infinite
Heater	36.0 ohms	360,000 ohms

well at startup and as the cycle progressed the temperature distribution shifted as expected. When the reactor power reached 40 MW, the maximum operating temperatures of 1000°C was exceeded on thermocouple 2, 3, and 4 by approximately 35°C to 72°C. In order to hold the capsule temperature within the design operating limits, the reactor ran at 40 MW for cycle 23 instead of the 60 MW test design power and used shim rod control to hold the specimen temperatures below 1000°C. The specimen temperatures varied between 856 and 1005°C. The average temperature for the specimens was approximately 990°C.

The apparent reason for the temperature problem is a much higher gamma heat than the design values provided by PBR for LD-11. This was due in part to the recent change to 200 gm elements at PBR. The gamma heat was predicted for this experiment from a PBR-MUR run using 168 gm elements and extrapolating to 200 gm elements. The extrapolation indicated a 15% reduction in gamma heat when in reality a 30% increase occurred.

The capsule was later moved to position LA-11 for operation in cycle 24. PBR predicted this position would have 50% less gamma heat than position LD-11. Subsequent operation indicated a 30% reduction in gamma heating in this position. At the close of the fifth quarter, the capsule had been exposed to 270 hours of irradiation and was operating in cycle 24 with the reactor power at 60 MW. The temperatures were being controlled in the same range as during cycle 23P by the use of control rods.

a. Discussion of Data from PBR Cycle 23

For this cycle it is estimated that the specimens received an integrated fast neutron dose of 5.6×10^{19} nvt. In evaluating the results to date on the basis of resistivity as a function of temperature, it is necessary to consider the accuracy of the temperature measurements as well as that of the electrical measurements. The variation in specimen temperature with time is shown in Figure 16. The specimen temperature values used throughout this report were calculated from thermocouple measurements as follows: thermocouples 1, 2, 3, and 4 are attached to specimens 1, 3, 6, and 8 respectively. Each thermocouple is located within a hole in the end of the Kovar inner electrode (see D&H Manual, Exp. 63-10, G.E. Dwg. No. 148F355, Part 7). For the data reduction reported in this memorandum, the specimen temperature was calculated by subtracting 30°C from the indicated Kovar temperature. (For specimens 2, 4, and 7, temperatures were interpolated on a straight-line basis from values for specimens 1, 3, 6, and 8.) The 30°C correction term includes 5°C for the drop in the Kovar and 25°C to account for the drop at the contact between the Kovar and alumina and for the average temperature of the alumina specimen, itself. These corrections are consistent with the heat transfer analysis presented in the D&H Manual for Exp. 63-10 and the temperature measurements made during the pre-irradiation thermal mockup test, as reported in Appendix D in the D&H Manual. The question

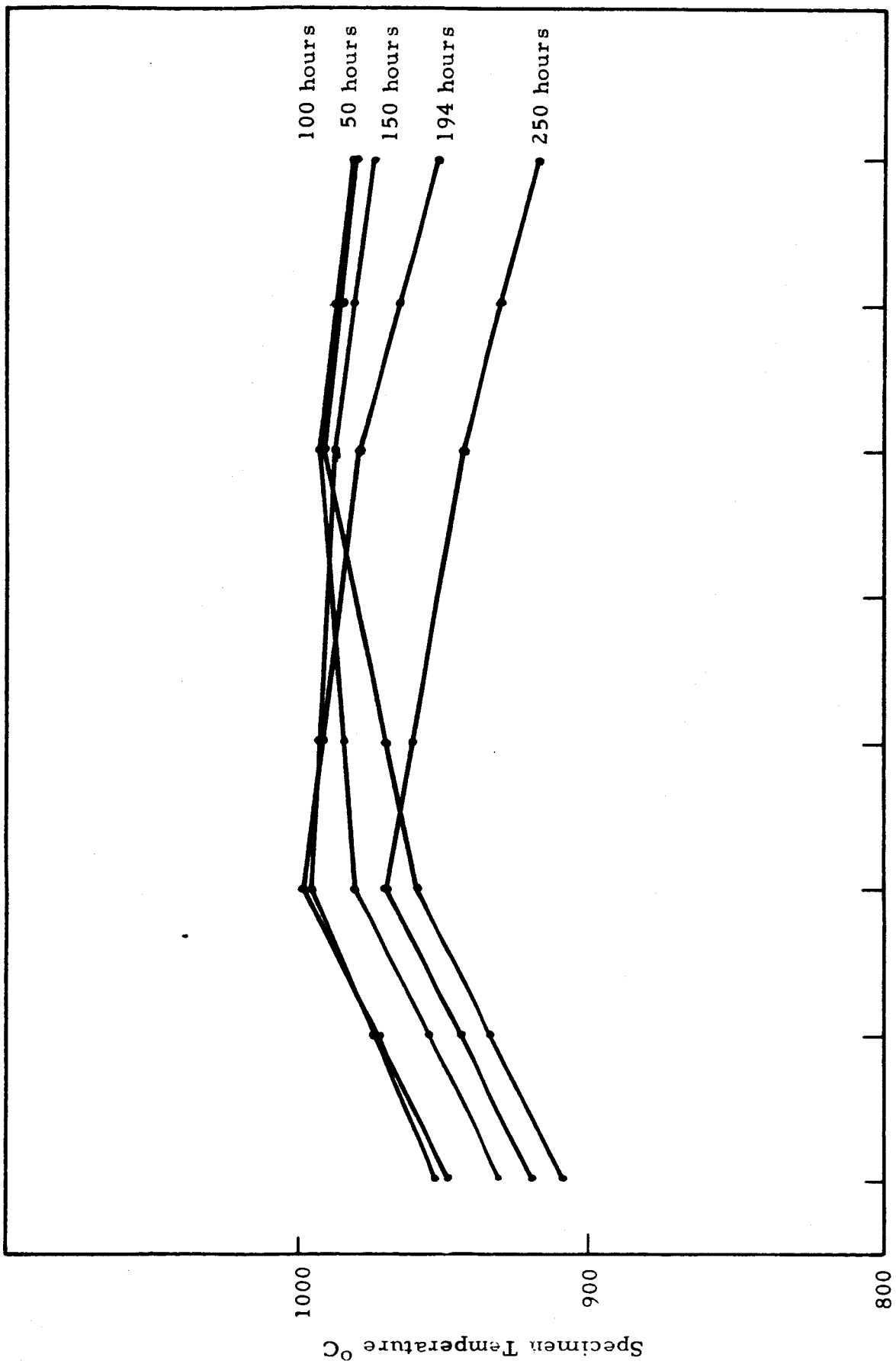
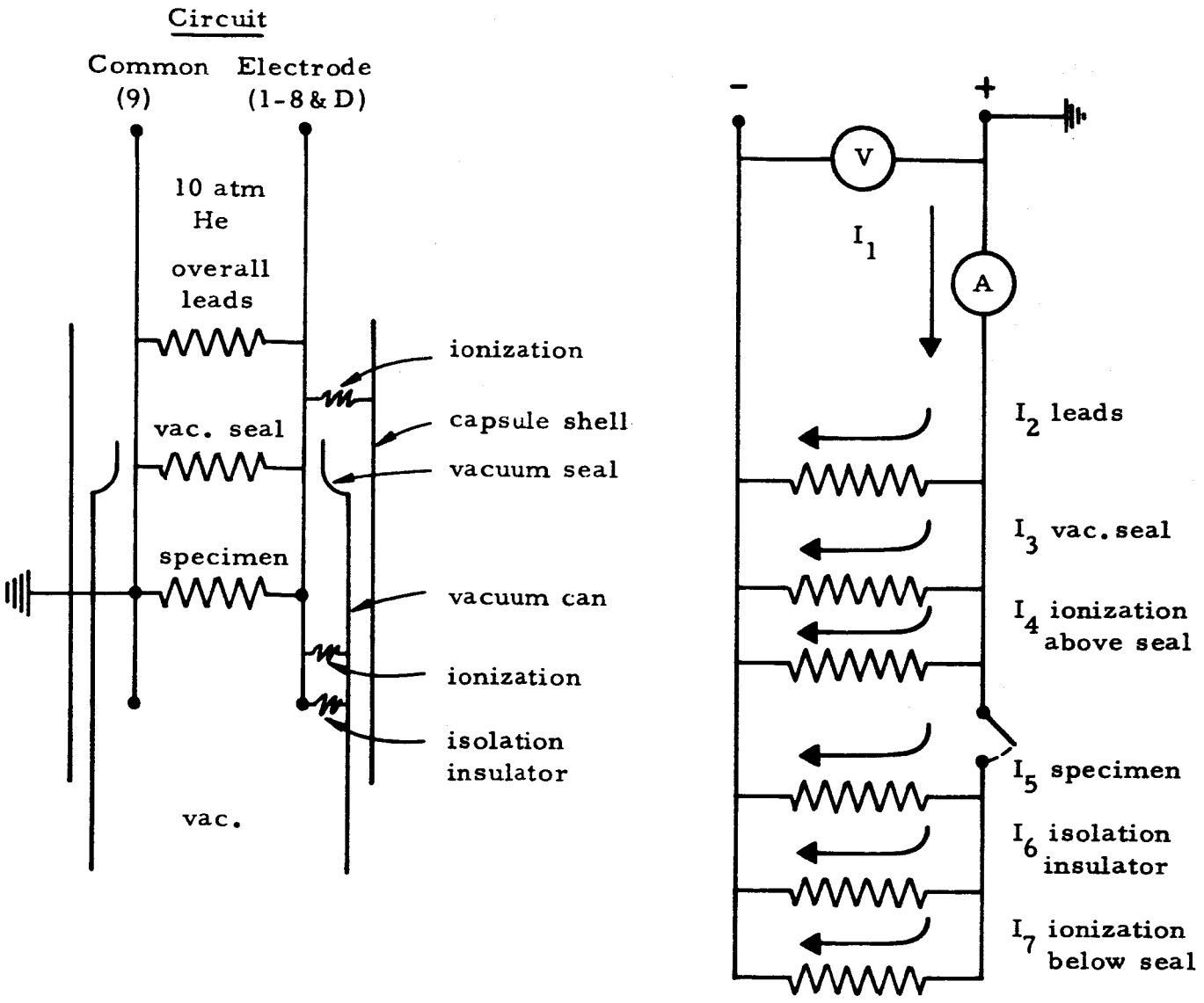


Figure 16 Alumina Irradiation Specimen Temperature Profiles During PBR Cycle No. 23

of the true temperature of the specimens and particularly of the temperature drop at the contact will receive careful continuing study in view of the strong temperature dependence of resistivity.

Data taken at 50 v and 100 v were reduced in accordance with the data reduction plan shown in Figure 17. It should be noted that the correction term for leakage currents external to the vacuum can (I_g) in general was less than 5 microamperes, i.e., was less than 10% of the measured current.

Inspection of the measured resistivity values determined over the course of PBR cycle 23 as shown in Figures 18 and 19 reveal that in general the values lie parallel with and above the curves from the measurements made out-of-pile for identical specimens. It is observed that the temperature dependence follows that which would be expected for alumina, particularly if values determined at 50 and 100 hours are excluded. Although the accuracy of the data may not so warrant, it is observed that resistivity values from measurements up to 100 hours are generally lower than from later data. Possible explanations are: (i) improvements in data taking techniques with time, or (ii) an increase in some resistance in series with the specimens, e.g. poorer contact between the specimens and their electrodes, or (iii) an effect due to the irradiation.



$I_1 = I_2 + I_3 + I_4 + I_5 + I_6 + I_7$

I_1 = measured current for specimen

$I_2 + I_3 + I_4 = I_8$ or total lead system plus leakages

I_8 = measured current for dummy

$R_{spec} \times 11 \leqq R_{isolation\ rest}$

$\frac{E}{I_{spec}} \times 11 \leqq \frac{E}{I_{isolation\ current}}$

$I_{spec} \leqq 11\ I_{isolation}$ or $I_5 \leqq 11\ I_6$

$I_4 >>> I_7$

$I_1 - I_8 \approx I_5 + I_6$ or $I_5 + \frac{I_5}{11} \approx I_5 + 0.091\ I_5$

$I_1 - I_8 = 1.091\ I_5$

$I_5 \approx \frac{I_1 - I_8}{1.091}$

$$R = \frac{\rho \ln \frac{r_2}{(r_1)}}{2 \pi L}$$

whence:

$$\rho = \frac{2 \pi L}{\ln \frac{(r2)}{(r_1)}} \qquad R = 91.9\ R$$

$$\rho = 91.9 \frac{V\ measured}{(I_1 - I_8)/1.091}$$

$$= 100.2 \frac{V\ measured}{I_1 - I_8}$$

Figure 17. Data Reduction Plan

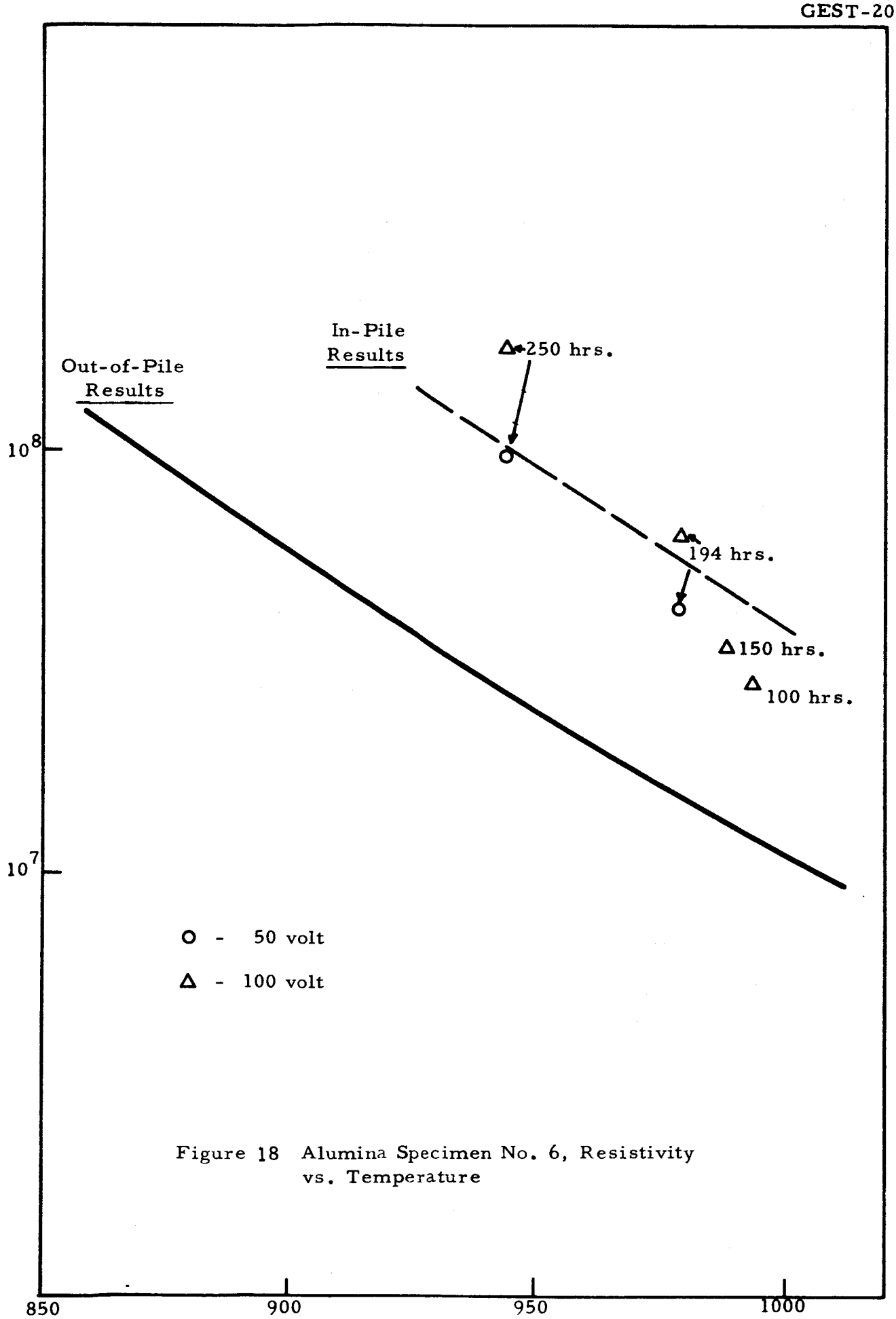


Figure 18 Alumina Specimen No. 6, Resistivity vs. Temperature

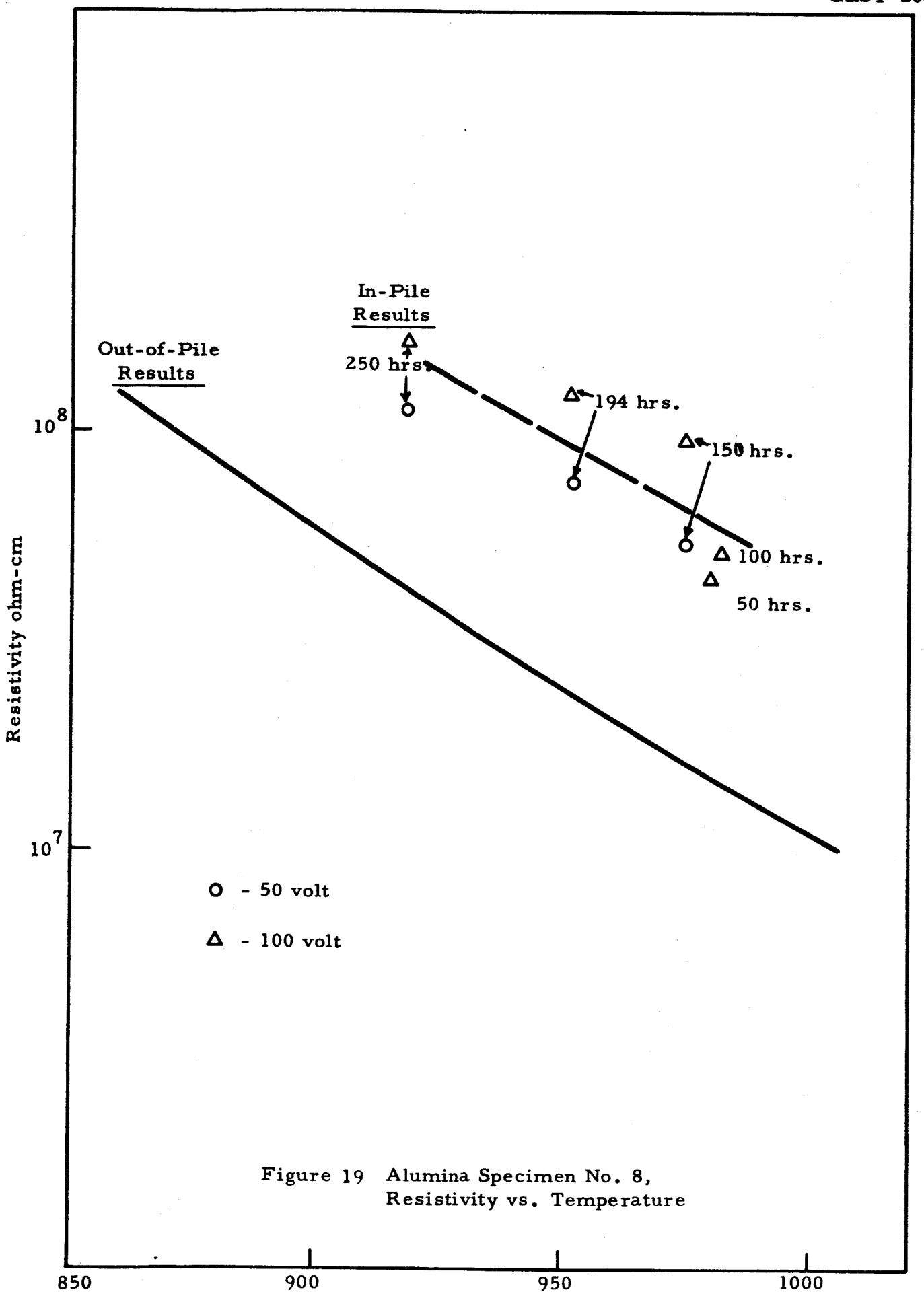


Figure 19 Alumina Specimen No. 8,
Resistivity vs. Temperature

Also shown in Figures 18 and 19 are determinations of resistivity which were made subsequent to PBR Cycle 23 as part of an evaluation of the resistivity data results from Experiment 63-10 during Cycle 23. These values were determined using a Lucalox alumina specimen from the same lot used in the Experiment 63-10 capsule and using an electrode assembly identical to those used in the capsule and in the pre-irradiation thermal mock-up test. The specimen in its electrode assembly was held at temperature (essentially isothermally) within a tube furnace in an atmosphere of argon. Temperatures were measured using thermocouples, and electrical resistance was determined using a Wheatstone Bridge. (Checks were made by the DC two-probe method using voltages between zero and ± 6.7 v, and found to agree with bridge measurements.)

SECTION IV

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