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REPORT NO. RN-S-0325
TO
AEC-NASA SPACE NUCLEAR PROPULSION OFFICE

FINAL DATA REPORT:
LVDT PRESSURE TRANSDUCER
EXPERIMENT NO. 23/R510

MASTER

NERVA PROGRAM

CONTRACT SNP-1

FEBRUARY 1967

AEROJET-GENERAL CORPORATION

SACRAMENTO, CALIFORNIA

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**AEROJET
GENERAL**

REPORT NO. RN-S-0325

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LVDT PRESSURE TRANSDUCER
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NERVA PROGRAM

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ROCKET ENGINE OPERATIONS - NUCLEAR

FEBRUARY 1967

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W. J. Kelly
CLASSIFYING OFFICER

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REPORT NO. RN-S-0325

FINAL DATA REPORT LVDT PRESSURE TRANSDUCER EXPERIMENT
NO. 23/R510

J. P. Oggerino

A handwritten signature in black ink, appearing to read 'C. M. Rice', with a stylized, cursive script.

C. M. Rice
Program Manager
Rocket Engine Operations - Nuclear

ABSTRACT

Four Consolidated Controls Corporation pressure transducers (Model No. 412M117-250) were irradiated in the Plum Brook Reactor Facility at Sandusky, Ohio. The integrated fast neutron flux (fluence) was $3.0 \times 10^{16} \frac{n}{cm^2}$ ($E_n > 1.0$ Mw). The integrated gamma dose was 8.5×10^8 Rads (C). Transducer signal failure occurred at a heat deposition rate of 0.75 watts/gm (15 Mw), but pretest moisture damage of cable/connector assemblies was instrumental in the failure. Posttest operations indicated that the transducers physically withstood radiation exposure satisfactorily.

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I. INTRODUCTION

Four pressure transducers for prospective use as NERVA and XE engine instrumentation were tested in the Plum Brook Reactor Facility (PBRF), Sandusky, Ohio, during CY 66 to determine their performance in a radiation environment. These transducers were the linear variable differential transformer type manufactured by Consolidated Controls Corporation (Model No. 412M117-250). Stainless-steel sheathed, magnesium-oxide insulated, copper conductor cables were used for transmission lines between the transducers and the instrumentation console. Three extra cable/connector assemblies were included in the capsule for additional study.

Pretest operations included nonnuclear testing of the test fixture at the REON Research Laboratory and nonnuclear testing of the integrated test fixture/Westinghouse test capsule in the WANL mockup test loop at Large, Pennsylvania. REON Research Laboratory operations consisted of pressure calibrations at various temperatures, insulation resistance measurements, and coil resistance measurements. WANL water-loop operations simulated nonnuclear test conditions relative to water flow rate, pressure, and temperature. After these tests were completed, the capsule was shipped to PBRF. On 26 and 27 May 1966, the irradiation portion of the test was performed in two parts: Part I determined the maximum radiation level to which the transducers could be subjected without exceeding their rated operational temperatures; the objective of Part II was to determine operational or damage thresholds by allowing internal temperatures to exceed the maximum operational values. However, this effort was curtailed when "off-gas" venting problems required capsule withdrawal and test termination. Part I was not expected to affect the results of Part II. On 9 June posttest operations were performed in the PBRF hot cell.

II. SUMMARY

Four prospective pressure transducers for NERVA and XE engine instrumentation were irradiated in the Plum Brook Reactor Facility at Sandusky, Ohio. The transducers were exposed to integrated gamma doses of 8.3×10^8 Rads (C) and 0.4×10^8 Rads (C) for Parts I and II of the test, respectively. The total neutron fluence (nvt) was $3.00 \times 10^{16} \frac{n}{cm^2}$ ($E_n > 1.0$ Mev).

The test items (Consolidated Controls Corporation, Model 412M117-250) were differential transformer-type pressure transducers. The components of the transducer include a diaphragm that is axially connected to a moveable slug (the slug is surrounded by a secondary coil with a center tap), a primary coil that surrounds the secondary coil, and a temperature-compensation coil. The housing for these components is 410 stainless steel. Figure 1 shows a cross section of the transducer. Pressure on the diaphragm causes the slug to move, resulting in a magnetic coupling change between the primary and two secondary coils and causes a linear change in output signal.

To determine the effect of the instrumentation cable on performance, three sets of identical dummy cable/connector assemblies were included in the test fixture. The cables were of the stainless-steel sheathed, magnesium-oxide insulated, four copper conductor type made by AeroResearch Corp. The cable assemblies included Physical Science right-angle connectors.

The transducers and dummy cable/connector assemblies were mounted in an aluminum test fixture fabricated by Aerojet-General, Sacramento, Calif. The test fixture was sent to Westinghouse Astronuclear Laboratories in Large, Pa., where it was integrated with a test capsule designed for use with tests performed at PBRF (Reference 1). The capsule was operationally checked at WANL, Large, Pa., in the WANL mockup test loop.

After the successful completion of system checks, the test capsule was shipped to PBRF. On-site equipment checks and acceptance tests were performed, and the system was prepared for insertion into Horizontal Throughtube-1 (HT-1). Just prior to insertion in HT-1, preirradiation reference data were obtained, but the data were erratic because of water leakage into the test fixture. The test capsule was removed, sent to WANL/Large, and reopened. Approximately 200 cubic centimeters of water were found in the transducer cavity. Examination of the test fixture at WANL indicated that leaks at the corners of the mounting plate welds had allowed water to enter the transducer cavity. The fixture was dried, purged, rewelded, and returned to PBRF. On 25 May 1966 the radiation portion of the test was initiated.

The following is a summary of the results of the pretest, test, and posttest operations.

A. CONSOLIDATED CONTROLS CORPORATION TRANSDUCERS

The Consolidated Controls Corporation transducers used in this test had serial numbers S/N 1186, 1188, 1195, and 1240.

All four transducers demonstrated output signal stability while being pressurized from 0 to 400 psig and heated from ambient to 650°F and to 400°F, respectively, in two separate tests in the REON Laboratory oven. Some degradation of insulation resistance occurred during heating, but this condition was not significant, and normal values were recorded after the units were cooled. Before shipment to WANL/Large, minimum insulation resistance was 4K megohms.

Coil resistance values during testing in the REON Laboratory were normal.

Subsequent to the water leak, but prior to the irradiation portion of the test, S/N 1186 and S/N 1240 were unacceptable relative to insulation resistance. S/N 1188 was acceptable and S/N 1195 was marginal. Despite this condition, the test was performed, because the two transducers with decreased insulation resistance continued to operate satisfactorily, and a test delay at this time would have delayed installation of the PBRF cryogenic test loop.

During Part I of the test unacceptable zero-shift levels were attained for all transducers at 10 Mw of power and above. Sensitivity values were stable through the test for S/N 1195 and S/N 1240. Transducer 1188 had a sensitivity decrease of 11 millivolts (approximately 15%) at the 10- and 20-Mw power levels.

Insulation resistance was very low for all transducers for reactor powers above 100 kw.

Coil resistance values were stable through the 20 Mw power hold.

An unscheduled 15 Mw power hold was performed after the 1 Mw hold. At this power, the transducers approached their failure threshold of 25% signal degradation, but data from 10 and 20 Mw were subsequently obtained. The 10 Mw data were obtained for interim information between 1 and 15 Mw. The 20-Mw data were obtained to determine the effect of the premature 15 Mw exposure. Output signal values at 15 Mw fell between those values obtained at 10 and 20 Mw indicating that no apparent damage had resulted from going to 15 Mw first.

After completion of Part I, the test fixture was withdrawn to the seal position and test data were recorded; only S/N 1188 recovered its normal zero unbalance value. S/N 1186 had failed completely and was totally inoperable. S/N 1195 and 1240 had normal sensitivity values, but a change of at least 25% in zero unbalance values categorized them as unacceptable. Coil resistances were normal but insulation resistance values showed further degradation from baseline values.

Part II of the test was started approximately 1 hour after the conclusion of Part I. After only 12 minutes of test operations, Part II of the test was concluded due to "off-gas" venting problems. The irradiated purge and transducer pressurization gas known as "off-gas" was filling the "off-gas" accumulator at a rate greater than it could be vented. As a result the capsule had to be withdrawn and the test halted. It was decided at this time to terminate the test.

Posttest checks of the transducers consisted of insulation-resistance measurements. These were inconsistent in that infinite insulation-resistance values were obtained for pin-to-ground on the three transducers that were measured after being removed from the test fixture. High activation dose-rates from the test items precluded an intensive study to determine the reason for these anomalous results. Measurements obtained 90 days after the test yielded values of 40K megohms to 60K megohms from pin-to-ground for all four transducers in an unmounted condition.

Analysis of temperature data during the test indicated that in an isotropic heat environment the temperature compensation coils in the transducers functioned satisfactorily, but in an environment of large axial temperature gradients the compensation coils were not useful.

B. CABLES AND CONNECTORS

Two groups of cables and connectors were used in this test: those connected to the transducers and those used as dummy cables.

The dummy cables had normal insulation-resistance values until water leaked into the test fixture. After the water leak, dummy cable insulation resistance was extremely low and no useful data were obtained.

The cables used with the transducers were used as a system and could not be treated as separate components until posttest operations. During posttest operations the cables were disconnected from the transducers. A 2-ft section with the connector (the irradiated end) was removed from the 75-ft-long cable. Insulation resistance measurements of the remaining 73-ft-long piece indicated that insulation capabilities were severely degraded. Absolute values were low, and there was no increase in resistance due to separation from the low-resistance transducer as was expected. The mechanism responsible for the degradation was not determined, but all insulation-resistance values obtained after water leaked into the test fixture were degraded.

III. TECHNICAL DISCUSSION

A. DESCRIPTION OF TEST FIXTURE

Figure 2 shows the test fixture with the top portion of the cover removed. Transducers, cables with connectors, thermocouples, and dosimeters used in this experiment were attached to the mounting plate. Figure 3 shows the specific positions of the test hardware.

1. Transducers

The Consolidated Controls Corporation (CCC) pressure transducers used in this test were of the linear variable differential transformer type. The transducers consist of a diaphragm that is axially connected to a moveable slug, which is surrounded by transformer coils. The components of the transducer are contained in a 410 stainless-steel housing.

Pressure applied to the diaphragm causes the slug to move, and movement results in a change in the magnetic coupling between the primary and two secondary windings. The voltage difference between the two secondary windings is the output voltage of the transducer.

A signal symmetry sensing module is used with the transducer. The module is an epoxy-resin-coated, printed circuit board containing all circuit components to supply regulated excitation to the transducer, demodulate the transducer signal, correct for the effects of transducer temperature, and provide linear output proportional to excitation pressures.

2. Cables and Connectors

The cables used in this experiment are the AeroResearch 125-4M-F (Cu) 24 type. The code indicates that they are sheathed in 347 stainless-steel tubing with an outside diameter of 0.125 in. In the sheathing are four, 24-gage copper conductors, which are insulated with magnesium oxide.

The transducer end of the cables is attached to PS08-10-6S-FI-H3-5405-1/8 - B2, Physical Science right-angle connectors. Two features of this type of connector are the special Inconel socket spring to provide positive contact and the ceramic insert for service up to 1200°F.

3. Dosimeters

Four neutron dosimeters (Figure 4) were mounted in the test fixture. The dosimeters included aluminum-cobalt wires, both bare and cadmium covered for thermal and epithermal flux measurement; sulphur pellets were used for fast flux measurements. As shown in Figure 3, the dosimeters (the small cylindrical metal tubes) were located near each of the test items.

4. Thermocouples

Copper-constantan thermocouples were used in the test fixture to measure temperature gradients along the height of the transducer and the mounting plate. The thermocouples were connected to the console with the same type of cable as was used with the transducers.

5. Test Fixture Assembly

Figure 5 shows the complete test fixture ready for installation in the test capsule. The test fixture and all associated tubing were fabricated of aluminum. The three 1/2-in. tubes extending to the rear contain the transducer and thermocouple cables. The two 1/4-in. tubes extending from the bottom of the fixture are for system pressurization and purging, respectively.

The 2-1/2-in. tube in the center of the test fixture carries water into and through the fixture for cooling. When the water has passed through the fixture it exits to the inside of the capsule and flows back over the top of the fixture for added cooling.

Figure 6 shows the physical connection of the fixture to the test capsules and the dimensions of the test capsule.

B. TEST PROCEDURES

The test specifications and a complete description of the test are contained in References 2 and 3.

Nonnuclear operational tests were performed as described below in the REON Research Laboratory. Upon operational acceptance, the fixture was sent to WANL/Large for integration with the W2-3 irradiation-capsule hardware. The system was then sent to the ATS building at the Plum Brook Reactor Facility (PBRF) in Sandusky, Ohio, where further operational acceptance checks were performed. On 28 March 1966, approximately 200 cc of water were discovered in the test fixture. The fixture was returned to WANL/Large and cut open. Small leaks were found at the welded corners of the internal box that formed the transducer cavity. The fixture was repaired and returned to PBRF. On 26 May 1966, the radiation portion of the test was performed. Part I of the test was concluded early when output-signal degradation exceeded 25% of base-line values.

Part II of the test was ended at the 0.25-w/gm position because "off-gases" were being accumulated faster than they could be vented, causing the storage container to become filled. The test capsule had to be withdrawn and the test ended.

The following procedure was used for both the nonnuclear and nuclear testing.

1. Preirradiation Testing

After all instrumentation had been heated for at least 30 min, the following steps were performed at each temperature level.

- a. Zero unbalance readings of the transducers were recorded.
- b. A 50-psig pressure was applied, and Step 1 was repeated.
- c. Step 1 was again repeated at pressures of 100, 150, 200, 300, and 400 psig. The pressure was then decreased and data were again taken at the same steps in reverse order.
- d. The coil resistance and insulation resistance of each transducer and dummy cable were recorded.
- e. Steps 1 through 4 were performed at each temperature.

2. Irradiation Testing

The parameters measured for each transducer during the test were pressure vs output voltage; insulation resistance between; pins A, B, C and capsule ground; pins A, B, C and equipment ground; and pins D, E, F and

equipment ground. Coil resistances from pin A to B, A to C, D to E and E to F were also recorded. Insulation resistance was measured with a 50-volt megohmmeter, output voltage with a digital volt meter, and resistance with a digital ohmmeter or Wheatstone bridge. A data cycle was made just prior to insertion of the test capsule in HT-1 as well as during insertion. A data cycle consisted of recording all of the preceding parameters, as well as the input voltage of the test transducers and the reference transducer, the test capsule temperatures, and reactor power level and time correlations.

a. Part I Test

The following time schedule was followed during the test. Steps 1 through 4 as already described were completed for each reactor power listed below. The power values shown are nominal and were corrected to the values shown in Figure 7.

<u>Date</u>	<u>Time</u>	<u>Event</u>
5/26/66	0530	Completed taking base-line data
	0815	Completed insertion of 23/R510 into capsule
	0910	Cooling flow and purge flow initiated
	0934	Capsule fully inserted
	1307	Reactor critical
	1319	Reactor at 100 Kw (157 Kw corrected)
	1330	Completed data cycle
	1424	Reactor at 1 Mw (1.6 Mw corrected)
	1440	Completed data cycle
	1617	Reactor at 10 Mw as reported by Plum Brook (15.6 Mw corrected)
	1705	Completed data cycle
	1720	Informed by Plum Brook that the previously stated 10 Mw was 15 Mw
	1730	Reactor at 10 Mw (9.6 Mw corrected)

<u>Date</u>	<u>Time</u>	<u>Event</u>
5/26/66	1838	Completed data cycle
	1845	Reactor at 20 Mw (21.0 Mw corrected)
	1908	Completed data cycle
	1915	Started retraction of capsule
	1928	Completed retraction of capsule

The values of corrected power shown in parentheses are the actual power levels attained. The mode of obtaining the low power values is such that full power (60 Mw) must be attained before low power correction factors can be obtained.

b. Part II Test

The following time schedule applied to Part II of the test.

<u>Date</u>	<u>Time</u>	<u>Event</u>
5/26/66	2000	Reactor at 40 Mw; completed data cycle with test capsule at seal position
	2130	Reactor at 60 Mw; obtained data cycle with the capsule at seal position
	2153	Inserted capsule to within approximately 27 in. of the fully inserted position (0.25 w/gm position)
	2225	Test was terminated because of Plum Brook inability to handle off-gas venting
	2226	Completed data cycle
	2237	Completed retraction of test article
5/27/66	1218	Aerojet terminated test
	1245	Test article removed from capsule

3. Posttest Operations

Posttest operations were performed in the hot cell at PBRF. Insulation-resistance measurements were obtained with the test fixture in three stages of disassembly: with the entire system intact, with the cables removed, and with the cables severed 2 ft from the irradiated end.

Insulation-resistance measurements were also obtained for the dummy cables.

C. TEST RESULTS

Test results are presented in Tables 1 through 6 and Figures 8 through 11.

The tables have been arranged so that the test data are presented in chronological order. Preirradiation data are shown for tests performed at the REON Laboratory in Sacramento and the ATS building at PBRF. The irradiation test data obtained in the reactor containment vessel are presented separately for Part I and Part II. Posttest measurements made in the hot cell at PBRF show insulation-resistance measurements made after the test.

The test information tables include the following data:

1. Location or facility where data cycles were performed
2. Date that the data cycles were performed
3. Number of data cycles, if more than one cycle was recorded
4. Reactor power level during the irradiation portion of the test
5. Temperature of the transducer and its environment
6. Transducer output signal in millivolts versus the input pressure in lb/sq in. gage.
7. Coil resistances in ohms
8. Insulation resistances in megohms

During Part I of the irradiation portion of the test, due to symmetry of location, all transducers were assumed to have the same temperatures as those instrumented with thermocouples. In Part II, the temperatures shown apply only to the instrumented transducers.

The data shown in the tables were obtained with the temperature-compensation switches in the negative position. Time limitations precluded obtaining results with these switches in other positions.

Tables 1 through 4 present the data obtained from the four Consolidated Controls transducers. Transducer S/N 1186 failed before the radiation portion of the test, and no data are shown for it after shipment from the REON Laboratory. Data before the second REON checkout series are not included for S/N 1188. This transducer replaced a unit that was shown to be defective in early checkout testing.

Figures 8 through 11 show plots of zero shift and sensitivity values. These plots were made using data from the tables.

Figures 8 through 10 show zero-shift values as a function of gamma-heat-deposition rates for both phases of the experiment.

Figure 11 shows transducer sensitivity as a function of gamma-heating rates.

Sensitivity values during all phases of testing are shown in Table 5 for each transducer.

Insulation resistance data for the three dummy cables in the test fixture are presented in Table 6.

Due to transducer signal failure and temperature limitations, the planned test procedure was curtailed. Part I of the test was terminated at the 20 Mw (1 watt/gm) power level. Part II of the test was terminated early due to an "off-gas" venting problem. The capsule was exposed to only 0.25 watts per gram of radiation heat during Part II of the test.

Posttest operations consisted of insulation-resistance measurements. Due to high-activation dose rates, measurements had to be taken quickly and were limited in scope. Because of the water leak, subsequent insulation resistance information was erratic.

Dosimetry data from the four neutron dosimeters in the test fixture are shown in the Appendix.

The following material presents a discussion of zero shift, sensitivity, insulation resistance, and coil resistance trends indicated by the test data. The following definitions are used.

1. Zero unbalance: Transducer output signal at zero gage pressure and room temperature.

2. Zero shift: Transducer output signal at zero psig and appropriate temperatures. Use zero unbalance as base.

3. Sensitivity: The change in transducer output signal from zero to maximum pressure at any constant temperature.

4. Insulation resistance: The resistance measured between some portion of the transducer circuit and the housing or fixture chassis (pin to ground resistance, for example).

5. Coil resistance: The resistance of the coils of the transformer in the transducer.

6. Transducer failure criteria: (a) Signal degradation greater than 25 percent of baseline values at maximum pressure, (b) Insulation resistance of zero.

7. Maximum pressure: (a) 400 psig in the REON Laboratory, (b) 380 psig in the ATS building during the equipment check, and (c) 370 psig in the ATS building during the acceptance check and in the PBRF during Part I and II of the test. These changes were due to equipment limitations.

1. Transducer Data

The following discussion pertains to data contained in Tables 1 through 4 relative to the LVDT transducers used in this test. Absolute parameter values of the test articles vary, but the trends show enough similarity to be treated as a group. Anomalies are indicated.

a. Zero Shift and Zero Unbalance

After being heated from ambient temperature to 650°F in the REON Laboratory oven, the transducers had a 1 millivolt or less permanent change in zero unbalance. While the transducers were being heated zero-shift values varied. Transducers S/N 1186 and 1195 decreased 17.07 and 16.49 millivolts, respectively. S/N 1240 decreased 28.48 millivolts. S/N 1188 was not in the system during this portion of test.

On 19 January 1966 the transducers were again heated to 400°F and allowed to cool. The zero unbalance at ambient temperatures for S/N 1188 increased 4.03 millivolts from its initial baseline value. S/N 1195 and 1240 had an increase of 0.28 millivolts and a decrease of 0.13 millivolts, respectively. This was considered to represent no change. The 4-millivolt increase in S/N 1188 was not explained, since there was no change in coil or insulation-resistance values.

The values listed in the test information tables for 25 March 1966 reflect the water leak accident. Data obtained during the period 13 April to 29 April represent the pretest calibration after repair of the fixture and subsequent to the water leak. Assuming the values obtained on 29 April to be new baseline data, transducer changes in zero unbalance were less than 4 millivolts at the start of Part I of the test. S/N 1188, 1195 and 1240 had decreases of 0.44, 0.24, and 3.85 millivolts, respectively. S/N 1186 failed during pretest calibration and will not be discussed further.

On 26 May 1966 the radiation portion of the test was performed. Figures 8 through 10 show zero-shift values as a function of heat-deposition rate for both parts of the experiment. During Part I of the test the zero shifts for transducers 1195 and 1240 were similar. Transducer 1188 was also similar through 0.5 watts/gm. However, at heating rates above 0.5 watts/gm the slope of the curve decreased markedly. This was attributed to the individual characteristics of the transducer.

A major difference was noted in the seal position zero-unbalance value between Part I and Part II of the test for transducer 1240, indicating failure of the transducer or the signal cables.

During Part II, the zero-unbalance slope plotted for transducer 1195 was much greater than that of transducer 1188. This difference was due to the location of S/N 1188 in the rear of the capsule. Part II data for transducer 1240 were assumed to be invalid because of its apparent failure.

The transducers were not expected to fail in Part I of the test. However, when baseline output signal values for all three operational transducers exceeded a 25% change at maximum pressure and 15 Mw of power, failure criteria were met. The test was continued to obtain 10 Mw and 20 Mw readings. The 10 Mw values were obtained for intermediate information. The 20 Mw values were obtained to ascertain if going from 15 to 10 Mw and then back

again had any effect on the test data. There seemed to be no effect, indicating that rate effects are predominant over integrated effects if the fast neutron fluence is limited to less than 3.0×10^{16} nvt ($E > 1.0$ Mev).

Part II of the test was performed to correlate the effects of differential insertion in the HT-1 at 60 Mw and centerline positioning with varying power levels. The correlation was not completed due to the premature capsule withdrawal because of the accumulation of "off-gas."

b. Sensitivity

Table 5 presents sensitivity values for the four Consolidated Controls transducers. The values were obtained from the data cycles shown in the test information tables. The values were obtained by subtracting zero-pressure output signal values from maximum pressure-output signal values during the first half of each data cycle.

The chronological decreases in sensitivity values shown for each transducer are proportional to the decreases in maximum system pressure (See definition of maximum pressure).

As shown in Figure 11 deviations from normal sensitivity values occurred at the 10 Mw power level for transducer S/N 1188 after its exposure to 15 Mw of power, and the data point does not appear to be reliable. S/N 1195 and 1240 were relatively stable throughout all portions of the test. However, these stable sensitivity values were associated with unacceptable zero shift values.

During Part II of the test, all three transducers had baseline values of sensitivity at the seal position. In the 0.25 watt/gm position (approximately 27 in. from the core center) no changes occurred.

c. Insulation Resistance

Preirradiation insulation resistance measurements were made at the REON Research Laboratory in Sacramento and at the Plum Brook Reactor Facility.

In the REON Laboratory, normal insulation resistance degradation occurred during heating of the test fixture to 650°F. After being cooled to ambient temperatures, all four transducers (cables, connectors, and transducers) recovered to normal values of 8,000 megohms of insulation resistance.

At Plum Brook, after water leaked into the test fixture, insulation resistance readings were erratic. Transducer 1188 recovered to 500 megohms. S/N 1195 measured 50 and 4 megohms from pins A and D to ground, respectively; S/N 1240 measured 1.0 and 0.4 megohms from pins A and D to ground, respectively; and S/N 1186 was completely inoperative.

Although two of the operative transducers indicated low insulation resistance, it was decided to perform the irradiation portion of the test. The transducer coil resistance values were much lower than the lowest insulation resistance and the system still operated efficiently. Moreover, a delay at this point would have caused a delay in the installation of the in-pile cryogenic loop.

The irradiation portion of the test was performed on 26 and 27 May 1966. During Part I of the test, insulation-resistance degradation increased as the power was increased and temperatures became higher. This was expected based on indications from the REON Laboratory testing. Maximum insulation resistance degradation occurred at the maximum power level attained (20 Mw). If insulation resistance had not been degraded before the test, there would have been increased radiation resistance.

During Part II of the test, data were taken rapidly due to the imminent removal of the test fixture. Limited insulation resistance values were obtained and no conclusions were drawn.

Posttest measurements of insulation resistance were limited because of the high induced radiation levels of the test fixture in the hot cell. Dose rates in excess of 14 R/Hr were encountered and work time was limited. Some values were obtained, but these were insufficient for a valid analysis of irradiation effects. Values obtained are shown on Tables 1 through 4.

During removal of the transducers from the mounting plate, water was detected in the boss wells. It was not determined if the water was present during the test or if it leaked in while the capsule was stored for posttest operations.

d. Coil Resistance

Coil-resistance measurements were made across the total secondary coil, one portion of the secondary coil, the temperature compensating coil, and the primary coil.

Three of the four transducers measured in the REON Laboratory had approximately the same baseline values of coil resistance. S/N 1186, 1195 and 1240 measured approximately 13, 8, and 12 ohms for pins AB, AC, and ED, respectively. S/N 1195 and 1240 measured approximately 102 ohms across pins EF; S/N 1186 measured only 89 ohms.

After water leaked into the test fixture, changes in coil resistance were not significant.

At the start of Part I of the irradiation portion of the test the three operative transducers had baseline coil resistance values that were almost identical to those obtained in the REON Laboratory. At 20 Mw of power, the coil resistances between pins A and B; A and C; and E and D were slightly less than the values obtained in the REON oven at 600°F. At 20 Mw, temperature readings of 270°F, 330°F, and 405°F were obtained for thermocouples 44, 63, and 106, respectively. These temperatures are far below 600°F, but the thermocouples were located on the surface of the transducers. Assuming that the increases in resistance of the interior coils are proportional with temperature, an indication of the large interior temperature gradients both radially and axially is obtained. Because of the temperature gradients, the coil resistance values appear reasonable.

For pins EF, the portion of the circuit that contains the temperature compensation coil, the following inconsistencies were noted. For temperature increases from ambient to 600°F in the REON Laboratory oven, increases of approximately 150 ohms were obtained across pins EF of transducers 1195 and 1240. At 20 Mw of power, when the surface temperatures of the transducers were greater than 600°F, increases of only 50 ohms were measured between pins E and F of the transducers. An increase of only 50 ohms corresponds to a rise from ambient to 200°F in the REON oven. Investigation revealed that the test transducers were mounted so that although the transformer coils were exposed to temperatures in excess of 600°F, the temperature compensation coils were heated to only 200°F. This explained the large difference in compensation coil resistance increases.

During Part II of the experiment, few coil resistance measurements were made because of the untimely withdrawal of the test fixture.

2. Dummy Cables

Table 6 shows insulation-resistance values obtained for three dummy cables and connectors included in the test.

While the cables were being heated in the REON Laboratory oven, typical insulation resistance degradation with heat increases was noted. However, upon cooling, normal values in the range of 4 to 8 thousand megohms were measured.

After being exposed to water damage during the test all three cables measured less than 1 megohm of insulation resistance before, during and after irradiation. The cables were not considered to have contributed valid data.

3. Temperature Data

The temperatures shown in the test information tables for the REON Laboratory tests were set on the laboratory oven control. Equilibrium conditions were attained for each reading; therefore, it is assumed that all components were at the temperatures shown.

During the irradiation portion of the test, copper constantan thermocouples were used to obtain the test article temperatures shown in the test information tables. The thermocouple temperatures indicate the surface temperatures of the transducer housing.

During Part I of the test, the fixture was positioned so that the temperature distribution from the center of the fixture to the outside edges was isotropic. Thermocouples 63, 64, 65, and 107 were mounted on transducer 1186. Thermocouples 66, 106, 162, 123, and 124 were mounted on transducer 1240.

The temperatures obtained with thermocouples 65 and 124, which measured the maximum temperatures on S/N 1186 and 1240, respectively, were in good agreement. The maximum temperature of 714°F measured during the 20 Mw power run is not the actual temperature, but was the upper limit that could be measured with the PBRF Data Logger as it was set up for this experiment. An extrapolated value of 800°F was obtained.

In Part II of the test, thermocouple number 65 measured a higher temperature than number 124. This was expected because 65 was located approximately 4 in. closer to the center of the core. In the 0.25 watt/gm position, thermocouple 65 measured a maximum temperature of 270°F.

Thermocouple 124 measured 220°F, showing a 50°F temperature gradient across a 4-in. length of the transducer mounting plate.

4. Gamma and Neutron Dose

Using the heating rates shown in the appendix, Figure 1, and a conversion factor of $3.6 \times 10^8 \frac{\text{Rads/hr}}{\text{watt/gm}}$, dose rates for each portion of the test were calculated. The total exposure time at each dose rate was obtained and a total gamma dose of 8.5×10^8 Rads (C) was obtained for the entire test. Data are presented in the Appendix.

The four neutron dosimeters described in Section III.A.3 were used to obtain four sets of average fast neutron fluxes ($E_n > 1.0 \text{ Mev}$) during the experiment. An arithmetic average of the four was calculated and a total neutron fluence of $3.0 \times 10^{16} \text{ n/cm}^2$ was obtained. Data are shown in the Appendix.

IV. CONCLUSIONS

Based on the preceding data, the general conclusions are as follows.

The water leak into the test fixture added an indeterminate variable to the test results. If this had not occurred, performance of the entire system would have been greatly improved. The test results show that the transducers will operate effectively with low values of insulation resistance only in reduced radiation fields. The insulating material would have held up better if moisture degradation had been prevented. Sensitivity values of the transducers were stable up to and through failure levels of radiation, but unacceptable zero shifts occurred. The magnitude of these zero shifts would have been reduced if the insulation resistance had been maintained.

The following specific conclusions are made for the Consolidated Controls Corporation transducers and for the AeroResearch cables with Physical Science connectors.

A. TRANSDUCERS

Zero unbalance and zero-shift values increased rapidly with increases in gamma heating rates. Only one of three transducers recovered fully to its baseline zero-unbalance values after exposure to 1.0 watt/gm (20 Mw of power).

Sensitivity values remained stable through exposure to 20 Mw. Baseline-sensitivity values were normal after irradiation, although zero unbalance values were significantly changed.

Changes in zero unbalance and zero shifts in the high-radiation environment may have been due to indirect causes. Signal shunts due to minimum threshold-insulation resistance values may have been the direct cause.

Transducer coil resistances were normal throughout the test.

B. CABLES/CONNECTOR ASSEMBLIES

Degradation of the insulation resistance of the dummy cable/connector assemblies was severe after the water leak, and no test conclusions can be made.

Insulation resistance measurements of the cable/connector assemblies attached to the transducers before the test and during posttest operations indicated that insulation degradation occurred after the water leak. Due to the high values of insulation resistance of the transducers after they were disconnected from the cable/connector assemblies, it must be assumed that the active cables had damage analogous to that suffered by the dummy cables.

V. RECOMMENDATIONS

Recommendations to improve component design for radiation environment performance and to ensure integrity during testing are as follows.

A. COMPONENT DESIGN

1. Incorporate integral swaged cables directly to the pressure sensing element. This change will decrease weight by eliminating right-angle connectors and transition portions of the transducer. An important side effect will be lower activation dose rate for posttest operations and study.

2. Ensure that integral cables are moisture-sealed by supplier.

3. Include a heat sink in the experiment to more closely simulate NERVA and XE nozzle conditions. Heat degradation of the system insulation was a major factor in the failure of the test articles and the termination of the test.

4. Increase the number of thermocouples on the test fixture and test articles.

5. Modify temperature-compensation coil design to operate in temperature gradient or omit the coil and associated weight.

6. Include gamma microdosimeters on the test articles to determine precise dose exposure. Compare these data with predicted NERVA and XE gamma doses and known NRX gamma doses.

B. TEST FIXTURE

1. Ensure that cables in the fixture are not exposed to moisture during nonradiation testing and during shipping.

2. Construct test fixture so that on-site replacement of the test item can be readily accomplished.

3. After moisture-resistant construction is complete perform pressure and temperature checks at the REON Laboratory. Pressure checks should be made to ensure the detection of slow leaks.

4. Increase the capability of the Data Logger at PBRF to ensure full-temperature range measurement and constant monitoring.

5. Modify the "off-gas" venting system at PBRF to enable longer testing cycles with proportional increases in irradiated "off-gas."

6. Provide test sponsor greater control of reactor conditions during test.

VI. REFERENCE LIST

1. WANL-TNR-173 Experiment Design Manual and Hazards Analysis, PBRF.
2. RN-S-0257 Final Test Specification for Pressure Transducer Experiment 23/R510.
3. WANL-TME-1450 AGC Pressure Transducer Experiment No. 23-R-510 Irradiated at the Plum Brook Reactor Facility, PBRF Cycle 47.

TABLE 1

CCC TRANSDUCER 1186 TEST INFORMATION

LOCATION	DATE	CYCLE	REACTOR		OUTPUT SIGNAL (MV) VS. INPUT PRESSURE (PSIG)														COIL RESISTANCE (OHMS)				INSULATION RESISTANCE (MEGOMHS)				
			POWER, MW	TEMP, °F	0	50	100	150	200	300	400/370	300	200	150	100	50	0	AB	AC	EF	ED	ABC TO CHASSIS	DEF TO CHASSIS	ABC TO FIXTURE	DEF TO FIXTURE		
REON LAB	1-6-66	1		AMB	4.33	16.03	26.99	37.60	48.01	67.95	87.08	68.17	47.60	37.81	26.93	15.89	4.37	13.47	8.76	88.97	12.63	5K	6K	9K	8K		
REON LAB	1-7-66	1		AMB	4.91	16.68	27.50	38.01	48.42	68.38	87.40	68.39	48.77	38.52	27.71	16.59	4.85	-	-	-	-	-	-	-	-		
REON LAB	1-8-66	1		200	1.33	12.50	23.99	34.46	44.76	64.26	83.15	64.42	44.43	34.41	23.63	12.77	1.11	-	-	-	-	-	-	-	-		
↓	↓	1		400	-5.14	6.49	17.09	27.63	37.55	57.03	75.65	57.18	37.87	27.72	17.25	6.24	-5.09	18.95	10.74	170.7	18.04	3K	3K	3K	3K		
		1		600	-10.95	0.04	10.28	20.57	30.57	49.43	68.50	49.88	30.93	20.83	10.92	0.48	-10.85	-	-	-	-	-	-	-	-		
		1		650	-12.74	-1.32	8.71	19.10	28.66	47.53	65.25	47.68	28.80	19.79	8.86	-1.51	-12.75	-	-	-	-	-	-	-	-		
		1		600	-11.17	0.3	10.53	21.01	30.87	49.73	68.60	49.63	30.46	21.01	10.65	0.22	-11.44	23.77	13.04	230.4	21.46	2K	2K	700	600		
		1		400	-5.71	5.55	16.54	27.31	36.96	56.33	74.60	56.17	37.07	27.28	16.43	5.69	-5.74	-	-	-	-	-	-	-	-		
		1		200	0.62	12.49	23.19	33.89	44.08	63.89	83.42	63.95	44.22	33.58	27.97	12.50	0.64	16.32	9.48	117.2	14.07	7K	7K	3K	5K		
		1		AMB	4.60	16.14	27.03	37.80	47.87	67.93	87.50	67.92	48.38	37.81	27.31	16.68	4.92	-	-	-	-	-	-	-	-		
		1	1-19-66	1		200	3.89	15.57	26.44	37.23	47.28	67.22	86.20	67.17	47.38	37.25	26.42	15.57	3.80	15.85	10.37	131.5	15.84	7K	7K	7K	7K
		1		300	-0.74	10.70	21.69	32.26	42.47	61.97	80.82	61.97	42.30	32.31	21.55	10.59	-0.76	-	-	-	-	-	-	-	-	-	
		1		400	-1.60	9.90	20.72	31.03	41.27	60.72	79.45	60.89	41.78	32.04	21.45	11.10	-0.58	-	-	-	-	-	-	-	-	-	
↓	↓	1		AMB	8.37	20.19	31.37	41.98	52.14	72.12	91.25	71.97	52.12	41.90	31.10	20.20	8.39	13.20	8.65	91.00	12.54	8K	8K	8K	8K		
ATS BLDG, PBRF	3-25-66	2		AMB	32.89	44.80	55.99	66.79	77.69	97.49	107.39	97.99	78.00	67.29	56.29	45.20	32.99	13.00	7.39	89.29	14.29	10K	15K	35K	50K		
↓	↓	3		AMB	30.70	42.19	53.69	64.29	74.79	95.19	110.69	95.29	74.89	64.59	54.00	42.49	31.00	12.29	7.19	96.49	11.49	40	68	35	70		
4-13-66	1		AMB	28.30	37.82	46.74	55.68	64.25	80.72	89.95	80.47	64.17	55.61	46.88	37.79	28.27	12.41	7.65	87.70	13.01	3K	3K	800	SHORT			
4-14-66	1		AMB	28.21	37.78	46.74	55.46	64.30	79.80	91.09	80.60	64.08	55.75	47.15	37.83	28.25	12.29	7.29	89.0	13.10	4K	3K	800	5			
4-29-66	1		AMB	-5.10	-	-	-5.12	-	-5.11	-	-	-	-5.11	-	-	-5.14	12.71	7.76	89.0	12.56	-	-	100.0	0.06			
↓	↓	2		AMB	-5.27	-5.29	-5.29	-5.32	-5.32	-5.33	-5.33	-5.33	-5.34	-5.35	-5.34	-5.35	-5.35	12.60	7.40	89.49	12.49	-	-	100.0	0.02		
TEST, PART 1, PBRF																											
A) SEAL POSITION	5-26-66	1	0.0	AMB	-5.20	-5.20	-5.20	-5.20	-5.20	-5.20	-5.20	-5.21	-5.20	-5.20	-5.20	-5.20	-5.20	13.01	7.29	88.19	12.39	-	-	1000.0	0.09		

SUBSEQUENT DATA WERE INVALID.

Table 1

TABLE 2 (cont.)

LOCATION	DATE	CYCLE	REACTOR		OUTPUT SIGNAL (mv) VS. INPUT PRESSURE (psig)														COIL RESISTANCE (ohms)				INSULATION RESISTANCE (megohms)			
			POWER, Mw	TEMP, °F	0	50	100	150	200	300	400/370	300	200	150	100	50	0	AB	AC	EF	ED	ABC TO CHASSIS	DEF TO CHASSIS	ABC TO FIXTURE	DEF TO FIXTURE	
B) HT-1 (CONTINUED)	5-26-66	1	9.6	477	17.62	27.53	37.41	47.40	57.17	76.64	89.62	76.67	57.24	47.84	37.95	27.84	17.94	16.19	10.00	114.69	14.29	-	-	7	0.9	
↓	↓	2	9.6	477	-	-	37.33	-	57.46	-	90.00	-	57.65	-	37.78	-	17.83	-	-	-	-	-	-	-	-	
		1	21.	714+	26.57	-	46.90	-	65.74	-	97.90	-	66.30	-	47.02	-	27.19	20.0	12.00	135.39	17.49	-	-	.8	.5	
C) SEAL POSITION	↓	1	0.0	~ 110	3.47	13.05	23.10	32.98	43.10	63.30	76.53	63.10	42.98	32.90	22.90	12.76	2.77	12.80	7.19	104.29	12.10	-	-	200	40	
↓		2	0.0	~ 110	2.66	-	22.43	-	42.60	-	76.20	-	42.65	-	22.57	-	2.56	-	-	-	-	-	-	-	-	
TEST, PART II, PBRF																										
SEAL POSITION	5-27-66	1	60.0	148	2.56	-	23.04	-	43.00	-	75.95	-	43.06	-	23.27	-	3.14									
.25 w/gm	↓	1	60.0	220	5.15	15.39	25.07	34.93	45.09	64.79	78.33	64.64	45.50	35.39	25.55	15.40	5.08							9.0	8.0	
		2	60.0	220	-	-	25.35	-	45.22	-	78.50	-	45.25													
.50 w/gm	6-9-66		NO DATA TAKEN, REACTOR SHUT DOWN																							
POST TEST OPS																										
WHOLE ASSEMBLY																										
73-Ft CABLE																										
2-Ft CABLE AND CONNECTOR																										
TRANSDUCER ALONE*																										

*MEASUREMENT MADE 90 DAYS AFTER TEST.

TABLE 3

CCC TRANSDUCER 1195 TEST INFORMATION

LOCATION	DATE	CYCLE	REACTOR POWER, MW	TEMP, °F	OUTPUT SIGNAL (mv) VS. INPUT PRESSURE (psia)													COIL RESISTANCE (ohms)				INSULATION RESISTANCE (megohms)			
					0	50	100	150	200	300	300/370	300	200	150	100	50	0	AB	AC	EF	ED	ABC TO CHASSIS	DEF TO CHASSIS	ABC TO FIXTURE	DEF TO FIXTURE
REON LAB	1-6-66	1		AMB	- 1.50	8.32	17.80	27.08	36.73	55.46	74.10	55.72	36.85	27.52	17.79	8.27	- 1.48	13.34	7.85	102.9	12.26	7K	8K	8K	9K
	1-7-66	1		200	- 1.91	7.46	17.26	26.76	36.16	54.54	73.00	54.68	35.95	26.58	16.96	7.59	- 2.26	--	--	--	--	--	--	--	--
	1-8-66	1		400	- 6.96	4.84	12.04	21.53	31.60	49.21	67.66	49.34	30.97	21.55	12.24	2.75	- 6.99	19.71	11.03	185.9	17.72	3K	3K	3K	4K
		1		600	-15.34	-6.42	2.42	11.65	20.89	38.95	57.28	39.34	21.17	11.71	2.83	-6.24	-15.89	--	--	--	--	--	--	--	--
		1		650	-17.99	-8.41	0.33	9.68	18.68	36.70	54.90	37.04	18.94	10.43	0.35	-8.62	-18.21	--	--	--	--	--	--	--	--
		1		600	-15.88	-6.36	2.82	12.19	21.30	38.83	57.50	39.36	21.09	12.39	2.94	-6.26	-15.81	24.51	13.22	251.1	21.20	2K	2K	800	800
		1		400	- 9.23	0.56	9.66	19.35	28.32	46.83	65.35	46.80	28.39	19.25	9.58	0.34	- 9.23	--	--	--	--	--	--	--	--
		1		200	- 4.45	5.45	14.62	24.22	33.68	52.52	71.16	52.40	33.87	24.24	14.62	6.54	- 4.49	16.11	9.63	127.3	13.78	7K	7K	3K	5K
		1		AMB	- 2.03	7.59	17.18	26.68	35.86	54.72	73.46	54.71	36.01	26.66	17.03	7.83	- 2.12	--	--	--	--	--	--	--	--
	1-19-66	1		200	- 1.85	7.99	17.30	26.92	36.16	55.80	73.53	54.92	36.26	26.97	17.34	7.94	- 2.01	15.99	10.70	140.4	15.34	7K	7K	7K	7K
ATS Bldg., BPRF		1		300	- 4.70	4.88	14.37	23.81	33.20	51.75	70.24	51.82	33.17	23.94	14.34	4.88	--	--	--	--	--	--	--	--	--
		1		400	- 7.97	1.67	11.11	24.46	29.72	48.17	66.50	48.11	29.89	20.72	11.15	2.07	- 7.93	--	--	--	--	--	--	--	--
		1		AMB	- 1.22	8.72	18.29	27.69	36.97	55.80	74.43	55.73	37.06	27.70	18.12	8.75	- 1.23	13.69	8.26	95.20	12.49	8K	8K	8K	8K
	3-25-66	2		AMB	13.79	23.39	32.49	41.69	51.29	70.19	80.0	70.19	50.99	41.29	31.59	21.79	12.00	14.00	7.99	98.69	15.59	15K	15K	67K	--
		3		AMB	24.69	35.19	43.99	53.89	63.79	82.69	97.49	82.29	63.99	53.89	43.99	34.99	24.79	12.79	7.29	94.49	11.80	SHORT	SHORT	SHORT	SHORT
	4-13-66	1		AMB	- 2.05	7.65	17.16	26.93	36.37	55.52	66.80	55.43	36.57	27.00	17.53	7.85	- 1.87	12.67	7.49	94.40	11.38	3K	3K	70	4
	4-14-66	1		AMB	- 1.89	7.35	16.06	26.26	36.23	55.11	67.56	54.17	33.46	26.45	17.14	7.45	- 2.33	12.79	7.41	95.89	11.51	4K	3K	60	3
	4-29-66	1		AMB	- 3.86	--	--	24.86	--	53.48	--	--	--	25.03	--	--	- 3.66	13.02	7.69	96.40	11.65	--	--	80	6
		2		AMB	- 3.71	5.80	15.43	25.25	34.75	53.54	66.92	53.70	34.98	25.48	16.05	6.32	- 3.46	12.79	7.89	96.89	11.49	--	--	50	4
TEST, PART 1, BPRF					T/C #65																				
A) SEAL POSITION	5-26-66	1	0.0	~ 95°	- 3.95	5.63	15.14	24.63	34.45	53.28	66.32	53.19	34.54	24.90	15.38	5.85	- 3.96	13.09	7.69	95.29	11.79	--	--	90	50
	5-26-66	2	0.0	~ 95°	- 3.40	6.31	16.0	25.5	35.0	53.9	67.10	54.0	35.1	25.6	16.1	6.53	- 3.23	12.89	7.79	96.99	11.49	--	--	90	50

TABLE 3 (cont.)

LOCATION	DATE	CYCLE	REACTOR		OUTPUT SIGNAL (mv) VS. INPUT PRESSURE (PSIG)														COIL RESISTANCE (OHMS)				INSULATION RESISTANCE (MEG OHMS)			
			POWER, Mw	TEMP, °F	0	50	100	150	200	300	400/370	300	200	150	100	50	0	AB	AC	EF	ED	ABC TO CHASSIS	DEF TO CHASSIS	ABC TO FIXTURE	DEF TO FIXTURE	
B) HT-1	5-26-66	1	0.16	114	1.88	11.70	21.33	74.0	40.58	59.33	72.50	59.4	40.71	31.13	21.53	11.93	2.08	12.69	7.59	96.39	11.90	-	-	70	45	
		2	0.16	114	-	-	21.38	-	40.51	-	72.30	-	40.57	-	21.65	-	2.10	-	-	-	-	-	-	-	-	
		1	1.6	180	5.59	14.79	24.63	34.04	43.70	62.33	75.55	62.62	43.70	34.65	24.56	15.09	5.26	13.49	7.99	99.99	12.32	-	-	8	7	
		2	1.6	180	-	-	24.50	-	43.44	-	75.65	-	43.79	-	24.74	-	5.44	-	-	-	-	-	-	-	-	
		1	15.7	625	27.55	37.20	47.00	56.48	65.95	84.80	97.69	84.75	65.95	56.36	46.90	37.41	27.90	19.59	11.70	128.98	17.19	-	-	0.1	0.1	
		2	15.7	625	27.42	-	46.75	-	65.55	-	97.31	-	65.45	-	46.60	-	-	-	-	-	-	-	-	-	-	
		1	9.6	482	17.68	23.71	36.65	46.16	55.45	73.85	86.20	73.69	55.40	46.48	37.04	27.35	17.35	16.89	10.59	115.29	15.19	-	-	0.8	.5	
		2	9.6	482	-	-	36.46	-	55.61	-	86.25	-	55.69	-	36.85	-	17.80	-	-	-	-	-	-	-	-	
		1	21.0	714+	33.23	-	53.17	-	71.37	-	102.45	-	71.96	-	53.83	-	34.45	21.49	12.39	136.79	17.89	-	-	0.09	0.1	
		C) SEAL POSITION		1	0.0	~ 110	1.98	11.09	20.60	29.92	39.38	57.94	71.06	58.03	39.30	29.80	20.40	10.65	1.07	13.19	7.39	99.39	12.07	-	-	1.0
		2	0.0	~ 110	1.05	-	19.95	-	39.21	-	71.00	-	39.30	-	20.10	-	1.04	-	-	-	-	-	-	-		
TEST, PART II, PBRF	5-27-66																									
SEAL POSITION		1	60.0	148	1.61	-	21.0	-	39.84	-	71.80	-	40.00	-	21.26	-	2.10	-	-	-	-	-	-	-		
.25 w/gm		1	60.0	270	6.17	15.97	25.24	34.40	44.04	62.54	75.35	62.42	44.50	34.98	25.68	16.11	6.32	-	-	-	-	-	5.0	5.0		
		2	60.0	270	-	-	25.23	-	44.07	-	76.07	-	44.11	-	-	-	-	-	-	-	-	-	-	-		
POST-TEST OPS	6-9-66																									
WHOLE ASSEMBLY																							100	300		
73 FT. SECTION																						-	-			
2 FT. SECTION & CONNECTOR																							100	600		
TRANSDUCER ALONE*																							40K	40K		

*MEASUREMENT MADE 90 DAYS AFTER TEST

TABLE 4

CCC TRANSDUCER 1240 TEST INFORMATION

LOCATION	DATE	CYCLE	REACTOR POWER MW	TEMP, °F	OUTPUT SIGNAL (MV) VS. INPUT PRESSURE (PSIG)												COIL RESISTANCE (OHMS)				INSULATION RESISTANCE (MEG OHMS)				
					0	50	100	150	200	300	400/370	300	200	150	100	50	0	AB	AC	EF	ED	ABC TO CHASSIS	DEF TO CHASSIS	ABC TO FIXTURE	DEF TO FIXTURE
REON LAB	1-6-66	1	AMB	0.95	10.82	20.35	29.80	39.65	57.96	76.20	57.76	39.37	30.11	20.30	10.86	0.98	13.34	7.85	102.9	12.26	7K	8K	8K	9K	
	1-7-66	1	200	-3.43	6.10	15.85	25.39	34.68	52.93	71.27	53.23	34.81	25.34	15.81	6.41	-3.44	-	-	-	-	-	-	-	-	
	1-8-66	1	400	-14.07	-4.15	+5.11	14.51	23.56	42.06	60.35	42.21	23.81	14.65	5.36	-4.14	-13.97	19.33	10.70	183.8	17.92	3K	3K	3K	3K	
		1	600	-25.43	-16.26	-7.62	1.73	11.15	29.26	47.33	29.82	11.99	2.98	-5.97	-15.02	-24.58	-	-	-	-	-	-	-	-	
		1	650	-27.53	-17.78	-9.20	0.04	9.15	27.17	45.10	27.52	9.41	1.34	-8.81	-17.71	-27.34	-	-	-	-	-	-	-	-	
		1	600	-24.28	-14.68	-5.38	3.85	72.86	30.69	49.00	31.03	12.99	4.20	-5.08	-14.40	-24.01	24.20	13.03	248.3	21.71	1K	1K	500	200	
		1	400	-13.64	-3.64	5.37	15.01	23.91	42.23	60.50	42.32	24.04	14.91	5.35	-3.87	13.52	-	-	-	-	-	-	-	-	
		1	200	-3.56	6.41	15.65	25.19	34.49	53.22	71.73	53.00	34.65	25.26	15.66	6.55	-3.47	16.93	9.70	125.8	14.13	7K	7K	3K	5K	
		1	AMB	2.10	11.90	21.51	31.08	40.19	58.76	77.40	58.80	40.43	31.27	21.47	12.36	2.36	-	-	-	-	-	-	-	-	
	1-19-66	1	200	-6.30	3.52	12.99	22.49	31.73	50.38	68.86	50.50	31.90	22.66	13.07	3.62	-6.31	16.84	10.47	142.5	15.16	7K	8K	7K	7K	
		1	300	-12.54	-2.89	6.66	16.06	25.31	43.78	62.18	43.77	25.33	16.17	6.64	-2.94	-12.58	-	-	-	-	-	-	-	-	
		1	400	-19.15	-9.40	0.08	9.34	18.55	36.87	55.13	36.91	18.79	9.58	0.08	-8.96	-18.97	-	-	-	-	-	-	-	-	
		1	AMB	0.82	10.80	20.42	29.82	39.14	57.91	76.44	57.72	39.25	29.94	20.27	10.85	0.90	12.92	7.89	95.50	12.16	8K	8K	8K	8K	
ATS BLDG, PBRF	3-25-66	3	AMB	-1.70	8.40	17.4	35.5	45.7	66.0	80.0	65.0	48.5	39.6	29.6	19.8	10.4	12.39	7.60	93.39	11.89	SHORT	SHORT	SHORT	SHORT	
	4-13-66	1	AMB	-1.32	9.37	18.88	28.49	37.85	56.87	67.87	56.30	37.91	28.68	19.22	9.47	-0.29	12.03	7.24	93.50	11.56	3K	3K	2.0	0.6	
	4-14-66	1	AMB	0.70	8.49	17.91	27.30	37.69	55.91	68.59	55.29	36.40	27.59	18.30	8.74	-0.79	12.20	7.27	93.32	11.69	4K	3K	1.0	0.5	
	4-29-66	1	AMB	-0.31	-	-	28.31	-	56.40	-	-	-	28.56	-	-	-0.06	12.38	7.49	95.50	11.92	-	-	1.0	0.4	
TEST, PART 1, PBRF			T/C #124																						
A) O-O LEVEL	5-26-66	1	0.0	95	-4.16	5.48	15.04	24.37	33.88	52.28	65.64	52.58	34.01	24.54	15.06	5.59	-4.19	12.69	7.50	95.00	11.99	-	-	1	.05
B) SEAL POSITION	5-26-66	1	0.0	95	-2.34	7.2	16.9	26.3	35.6	54.20	67.30	54.20	35.70	26.3	16.80	7.20	-2.62	12.19	7.39	96.29	11.89	-	-	0.8	.1

Table 4, Page 1 of 2

Table 4, Page 2 of 2

*MEASUREMENT MADE 90 DAYS AFTER TEST.

TABLE 5

TRANSDUCER SENSITIVITY VS TEST ENVIRONMENT

LOCATION	DATE	CYCLE	REACTOR POWER Mw	TEMP, °F	SENSITIVITY (mv)			
					1186	1188	1195	1240
REON LABORATORY ↓	1-6-66	1		AMB	82.49	-	75.60	75.25
	1-7-66	1		200	81.82	-	74.91	74.70
	1-8-66	1		400	80.79	-	74.62	74.42
		1		600	79.45	-	72.62	72.76
		1		650	77.99	-	72.89	67.63
		1		600	79.77	-	73.38	73.28
		1		400	80.31	-	74.58	74.14
		1		200	82.82	-	75.61	75.29
		1		AMB	82.90	-	75.49	75.34
	1-19-66	1		200	82.31	78.66	75.38	75.16
		1		300	81.56	77.53	74.94	74.72
		1		400	81.05	77.01	74.47	74.28
		1		AMB	92.88	79.38	75.65	75.62
ATS BLDG. PBRF ↓	3-25-66	2		AMB	74.50	69.88	66.21	79.30
		3		AMB	80.00	75.58	72.80	68.19
	4-13-66	1		AMB	61.65	71.96	68.85	67.89
	4-14-66	1		AMB	62.88	73.76	69.45	-
	4-29-66	1		AMB	-	-	-	-
		2		AMB	0.06	73.86	71.63	
TEST, PART I, PBRF ↓	5-26-66	1	0.0		-	74.01	70.27	69.80
		2	0.0		-	73.93	70.50	69.64
		1	0.16		-	74.03	70.62	69.93
		2	0.16		-	-	-	-
		1	1.6		-	73.79	69.96	69.96
		2	1.6		-	-	-	-
		1	15.7		-	72.51	70.14	67.80
		2	15.7		-	72.29	69.89	66.48

TABLE 5 (cont.)

<u>LOCATION</u>	<u>DATE</u>	<u>CYCLE</u>	REACTOR POWER <u>Mw</u>	TEMP, <u>°F</u>	<u>SENSITIVITY (mv)</u>			
					<u>1186</u>	<u>1188</u>	<u>1195</u>	<u>1240</u>
TEST, PART I, PBRF								
↓	5-26-66	1	9.6		-	59.05	68.52	-
		2	9.6		-	-	-	-
		1	21.0		-	-	70.22	68.94
		1	0.0		-	59.63	69.08	-
		2	0.0		-	-	69.95	-
TEST, PART II, PBRF								
SEAL POSITION	5-27-66	1	60.0		-	73.39	70.19	70.04
A) .25 W/GM	↓	1	60.0		-	73.18	69.18	69.80

TABLE 6

DUMMY CABLE INSULATION RESISTANCE VS TEST ENVIRONMENT

LOCATION	DATE	CYCLE	REACTOR POWER Mw	TEMP °F	DUMMY CABLE INSULATION RESISTANCE (MEGOHMS)											
					CABLE 1				CABLE 2				CABLE 3			
					ABC TO CHASSIS	DEF TO CHASSIS	ABC TO FIXTURE	DEF TO FIXTURE	ABC TO CHASSIS	DEF TO CHASSIS	ABC TO FIXTURE	DEF TO FIXTURE	ABC TO CHASSIS	DEF TO CHASSIS	ABC TO FIXTURE	DEF TO FIXTURE
REON LABORATORY	1-6-66	1		AMB	8K	8K	6K	8K	8K	8K	6K	7K	8K	9K	8K	9K
	1-7-66	2		AMB												
	1-8-66	1		200												
		1		400	2K	4K	800	4K	800	4K	300	4K	3K	4K	3K	5K
		1		600												
		1		650												
		1		600	800	3K	10	700	2K	3K	600	2K	3K	3K	1K	2K
		1		400												
		1		200	7K	7K	4K	7K	7K	7K	4K	7K	7K	7K	6K	7K
		1		AMB												
ATS BLDG, PBRF	3-25-66	2		AMB	15K	15K	40K	-	10K	15K	170K	-	15K	15K	7K	-
		3		AMB	SHORT	SHORT	SHORT	SHORT	SHORT	SHORT	SHORT	SHORT	SHORT	SHORT	SHORT	SHORT
	4-13-66	1		AMB	3K	3K	0.7	0.5	3K	3K	SHORT	SHORT	3K	3K	SHORT	0.50
	4-14-66	1		AMB	4K	3K	0.5	0.5	4K	3K	SHORT	SHORT	4K	3K	SHORT	0.50
	4-29-66	1		AMB	0.2	0.3	-	-	SHORT	SHORT	-	-	0.10	0.05	-	-
		2		AMB	0.2	0.2	-	-	SHORT	SHORT	-	-	0.09	0.05	-	-
TEST, PART I, PBRF																
A) SEAL POSITION	5-26-66	1	0.0		0.1	0.4			SHORT	SHORT			0.4	0.6		
		2	0.0		0.09	0.5			SHORT	SHORT			0.3	0.6		
B) HT-1		1	0.1		0.08	0.4			SHORT	SHORT			0.3	4.0		
		2	0.1		-	-			-	-			-	-		
		1	1.0		SHORT	SHORT			SHORT	SHORT			0.1	0.1		
		2	1.0		-	-			-	-			-	-		
		1	15.0		-	0.1			-	-			0.08	0.07		
		2	15.0		-	-			-	-			-	-		
		1	10.0		SHORT	0.9			SHORT	SHORT			0.8	1.0		

TABLE 6 (cont.)

LOCATION	DATE	CYCLE	REACTOR POWER MW	DUMMY CABLE INSULATION RESISTANCE (MEGOHMS)												
				TEMP. OF	CABLE 1		CABLE 2		CABLE 3							
					ABC TO CHASSIS	DEF TO CHASSIS	ABC TO FIXTURE	DEF TO FIXTURE	ABC TO CHASSIS	DEF TO CHASSIS	ABC TO FIXTURE	DEF TO FIXTURE	ABC TO CHASSIS	DEF TO CHASSIS	ABC TO FIXTURE	DEF TO FIXTURE
B) HT-1 (CONTINUED)	5-26-66	2	10.0													
↓		1	20.0	-	0.1			-	0.08			0.05	0.05			
		2	20.0	-	-			-	-			-	-			
C) SEAL POSITION		1	0.0	SHORT	1.0			SHORT	0.02			0.9	4.0			
↓		2	0.0													
TEST, PART II, PBRF																
SEAL POSITION		1	60.0													
0.25 WATT/GM		1	60.0	SHORT	1.0			SHORT	SHORT			1.0	1.0			
		2	60.0	-	-			-	-			-	-			
POST TEST OPS	6-9-66															
WHOLE ASSEMBLY				SHORT	SHORT			100.0	100.0			0.8	100.0			
73 FEET OF CABLE												5.0	80.0			
2 FEET AND CONNECTOR				7K	100.0

Figure 1

Consolidated Controls Corporation Pressure Transducer Cross Section

Figure 2

Top View of Fixture Mounting Plate

Figure 3

Fixture Mounting Plate with Instrumentation Locations

Figure 4

WANL Drawing No. 387D519,
Capsule Dosimeter Arrangement for PBRF and NSEC (WANL)

Figure 5

AGC Drawing No. 7497-66-0089

Pressure Transducer Test Capsule Assembly - Plumbrook Reactor
(PBRF 23/R510)

WNL Drawing No. 710J372,
W2-3 Water-Cooled In-pile Capsule Assembly General Arrangement

Figure 7

Power Profile During Test 23/R510

Figure 8

Transducer Zero Shift vs Gamma Heating Rate, S/N 1188

Figure 9

Transducer Zero Shift vs Gamma Heating Rate, S/N 1195

Figure 10

Transducer Zero Shift vs Gamma Heating Rate, S/N 1240

Figure 11

Transducer Sensitivity vs Gamma Heating Rate

APPENDIX

RESULTS OF DOSIMETRY CALCULATIONS
AND MEASUREMENTS FOR TEST 25/R510

I. GAMMA DOSE

Calorimetry measurements reported in Figure 1 show that at 60 Mw of power, the gamma heating rate at the centerline of HT-1 (flooded) with the control rods at a bank height of 18 in., is approximately 3 watts/gm. For the calculations presented herein, a direct ratio was assumed and values of 1 watt/gm at 20 Mw; 0.5 watt/gm at 10 Mw; and .05 watt/gm at 1 Mw, were used.

Figure 7 (in main text) shows the power profile during the test. The corrected power values on the graph were used in these calculations. Table I shows the time each power was attained, the time at that power, the heating rate at that power, and the associated gamma dose. The total calculated gamma dose was 8.45×10^8 rads (C).

II. NEUTRON DOSE

Using the dosimeters described in Section III.A.3, average fast flux ($E_n > 2.9$ Mev) values of 1.8×10^{11} , 4.6×10^{11} , 6.0×10^{11} , and 5.9×10^{11} neut/cm²-sec were obtained for both parts of the test. The arithmetic average of these was $4.63 \times 10^{11} \frac{\text{neuts}}{\text{cm}^2 - \text{sec}}$ ($E_n > 2.9$ Mev). The total period of irradiation was approximately 6 hours or 2.16×10^4 seconds. The integrated neutron dose (nvt = fluence) was $1.0 \times 10^{16} \frac{\text{neuts}}{\text{cm}^2}$ ($E_n > 2.9$ Mev). Using a conversion factor of 3 (based on a watt fission spectrum) the integrated neutron dose was 3.0×10^{16} neut/cm² ($E_n > 1.0$ Mev).

23/R510 GAMMA DOSE

<u>Time</u>	<u>ΔT, hrs</u>	<u>Gamma Heating Rate, (watts/gram)</u>	<u>Total γ Heat, (watt/hr/gm)</u>	<u>Gamma* Dose x 10⁻⁸, (RADS (C))</u>
13:19 @ 0.16 Mw	1.08	0.008	0.008	0.029
14:24 @ 1.6 Mw	1.90	0.080	0.152	0.548
16:17 @ 15.6 Mw	1.20	0.780	0.936	3.370
17:30 @ 9.6 Mw	1.25	0.480	0.600	2.160
18:45 @ 21.0 Mw	0.50	1.050	0.525	<u>1.890</u>
19:15 End Part I				
Dose Part I				7.997
Part II	0.50	0.250	0.125	0.450
<u>Total Dose</u>				8.447

* $3.6 \times 10^8 \frac{\text{R/Hr}}{\text{watt/gram}}$ was used as a conversion factor.

Table A-1

Figure A-1

Gamma Heating on Axis of HT-1
 HT-1 Flooded, Cylindrical Capsule 0.5 in. Aluminum
 Wall Thickness in Place