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REPORT NO. RN-S-0291

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EVALUATION OF TEST RESULTS FOR
STRAIN GAGES AND PRESSURE TRANSDUCERS

GROUND TEST REACTOR (GTR) IRRADIATION
TEST NO. 15

JULY 1966

MASTER

AEROJET-GENERAL CORPORATION

SACRAMENTO, CALIFORNIA

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EVALUATION OF TEST RESULTS FOR
STRAIN GAGES AND PRESSURE TRANSDUCERS

GROUND TEST REACTOR (GTR) IRRADIATION
TEST NO. 15

ROCKET ENGINE OPERATIONS - NUCLEAR

NERVA PROGRAM

JULY 1966

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ABSTRACT

This document presents an analysis of the test results for weldable, full-bridge strain gages and vapor-deposited, strain gage pressure transducers that were irradiated at the Nuclear Aerospace Research Facility (NARF) of General-Dynamics/Fort Worth, Texas, during the month of December 1964.

This report is submitted in partial fulfillment of Subtask 2.4, Contract SNP-1.

Prepared by:

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I. SUMMARY

A. STRAIN GAGES

Eighteen, weldable, full-bridge strain gages manufactured by Microdot were tested in a combined radiation and cryogenic environment. Ten gages were mounted on aluminum beams and the remaining eight were mounted on Inconel beams.

Two test samples were inoperative prior to reactor startup, and one sample failed during post-irradiation warmup to ambient temperature. The remaining gages performed satisfactorily throughout the test. It was noted that temperature shock from the ambient to LN₂ temperature caused separation of part of the weldable flange from the beam on several gages mounted to the aluminum beams. Useful data were obtained from these gages in the neutral position.

The results of the tests show that these gages are suitable for use on NERVA engines. However, the radiation effects noted indicate a definite dependency upon weld flange material, beam material, and the adequacy of the bond (weld). Additional testing is required to define fully the significance and cause of the observed radiation effects.

B. PRESSURE TRANSDUCERS

Three, vapor-deposited, strain gage-pressure transducers manufactured by Statham Inc. were tested in a combined environment of radiation and cryogenic temperature.

The test results of the Statham vapor deposited strain gage concept indicate that continued development is warranted for eventual use on NERVA.

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II. INTRODUCTION

A. GENERAL

This report covers one of a series of tests to determine the effects of nuclear radiation on diagnostic instrumentation components being evaluated for use on NERVA engines. The test was conducted at the Nuclear Aerospace Research Facility (NARF) of General Dynamics/Fort Worth, Texas, December 1964 in the Ground Test Reactor (GTR) and was designated GTR Test No. 15.

The test items covered by this report, quantities tested, test identification, and location of the test fixture are listed in Table I.

TABLE I
REON TESTS, GTR NO. 15

<u>ITEM</u>	<u>QUANTITY</u>	REON <u>TEST NO.</u>	<u>LOCATION</u>
Strain Gages	18	23/R408	West Face of GTR
Pressure Transducers	3	23/R508	West Face of GTR

B. DOSIMETRY

Fast neutron and gamma dose measurements were made at representative positions so that the exposure of individual transducers could be compared. Eight dosimeter packets were placed adjacent to the front and back faces of the test fixture inside the LN_2 dewar and an additional ten packets were attached to the front and back faces of the LN_2 dewar. The location of these packets is shown in Figures 1 and 2, respectively.

Figure 1
Dosimetry Packets for Strain Gages and Pressure Transducers

Figure 2
 Dosimetry Packet Locations on Outside of Strain Gage LN₂ Dewar

Sulfur, phosphorus, and nitrous oxide dosimeters were used to measure fast neutron integrated flux ($E > 2.9$ Mev), thermal neutron integrated flux ($E < 0.48$ ev), and gamma dose, respectively. Gamma dosimeters were not used on packets located inside the LN_2 dewar. Fast neutron fluxes with $E > 2.9$ Mev are specified throughout this report. To convert these data to $E > 1.0$ Mev data, the following relation can be used.

$$(E > 1.0 \text{ Mev}) = 2.8 \phi (E > 2.9 \text{ Mev})$$

A summary for the limits of neutron and gamma exposure is presented in Table II.

TABLE II

SUMMARY OF COMPONENT EXPOSURE

<u>COMPONENT</u>	<u>INTEGRATED NEUTRON FLUX (N/cm²)</u>		<u>GAMMA DOSE</u> [<u>Ergs/gm(C)</u>]
	<u>E > 2.9 Mev</u>	<u>E < 0.48 ev</u>	
Strain Gages	1.78×10^{16}	9.09×10^{14}	*
	2.83×10^{15}	2.97×10^{14}	
Pressure Transducers	1.78×10^{16}	4.21×10^{14}	
	8.59×10^{15}	2.97×10^{14}	

The average total integrated neutron flux and gamma dose were:

Fast neutron flux (n/cm ²)	1.12×10^{16}
Gamma dose [ergs/gm(C)]	6.9×10^{10}

The dosimetry techniques and detailed dosimetry data for GTR-15 are presented in Appendix B of Reference 1.

*No gamma dosimeters were placed inside the dewar.

C. TEST SETUP

The test items and associated hardware were assembled and checked out in the Irradiation Materials Laboratory (IML) in accordance with the test specifications and procedures set forth in Reference 2.

The test items and associated hardware are illustrated in Figures 3 and 4 during checkout in the IML.

The irradiation test fixture was positioned with the front of the LN_2 dewar adjacent to, and approximately ten inches from, the west face of the GTR closet. An additional four inches of water, one inch of aluminum, and one-fourth inch of boral separated the face of the test fixture from the core of the reactor.

D. TEST SCHEDULE

The total irradiation time for the test was 100 hours. The reactor was inadvertently shut down for 44 minutes after approximately 17 hours of irradiation and after 39 hours for 16 minutes to permit an LH_2 trailer changeover. A GTR profile in MW-min and reactor power is shown in Figure 5.

Figure 3
Instrumentation for Strain Gages, Pressure
Transducers, Cables and Connectors

Figure 4
Strain Gage and Pressure Transducer Test Assembly

Figure 5
Reactor Power Profile

III. STRAIN GAGES

A. PURPOSE OF TEST

This test was conducted to evaluate the effects of nuclear radiation on strain gages as a part of the evaluation program to select transducers for use on NERVA engines.

The objective of the test was to determine the effects of temperature and radiation, under controlled conditions, on the sensitivity, zero shift, bridge resistance, and insulation resistance of weldable strain gages designed to measure surface strains on NERVA engines.

B. SUMMARY OF TEST CONDITIONS

1. Items Tested

Detailed information on the eighteen weldable, full-bridge strain gages tested is presented in Table III.

Table III

DESCRIPTION OF STRAIN GAGES

<u>AGC-SCD</u>	<u>MICRODOT P/N</u>	<u>FLANGE MATERIAL</u>	<u>BEAM MATERIAL</u>	<u>BEAM LOCATION</u>	<u>QUANTITY</u>
706720-1	33314SG cc/4	Gold Alloy	Aluminum 6061-T6	No. 1 Right	2*
				No. 2 Left	2
				No. 3 Right	2
				No. 4 Left	2
706720-1	33314SG cc/4	Gold Alloy	Aluminum 6061-T6	No. 5 Right	2**
706721-1	SG323/8	SS 321	Inconel X	No. 1 Left	2
				No. 2 Right	2
				No. 4 Right	2*
706721-1	SG323/8	SS 321	Inconel X	No. 5 Right	2

* No. 1 Right Upper failed during post irradiation warmup to ambient.

** No. 4 Right Lower and No. 5 Right Upper strain gages were inoperative prior to reactor start up.

2. GTR Test Conditions

Strain gages were resistance welded to both sides of the test beams and installed in the test fixture.

The test fixture, shown in Figure 4, consisted of a rectangular array containing nine cantilever beams, four attached to the left side and five to the right. A vertical driver located in the center of the array was capable of deflecting the beams up or down and returning them to a central reference position. The driver was actuated by an opposing bellows system provided with a pneumatically operated neutral reference stop. All gages were immersed in liquid nitrogen throughout the irradiation test by installing the test fixture in a LN₂ dewar.

Figure 6 depicts the electrical schematic for the strain gage test. An excitation voltage of 10.00 vdc was applied continuously to all bridges. The output voltages and excitation voltage were fed into a Dymec 2010-D Digital Data Acquisition System. The system sequentially provided a guard circuit to each bridge as its output was sampled. The Dymec was capable of resolving the data to six decimal places and provided a digitized tape as well as a punched tape. Insulation current and guard current measurements were made with RCA Ultra-sensitive Model WV-84C Microammeters.

A data run consisted of recording the output of each instrument for three complete cycles (neutral-position, up-position, down-position) of the fixture, measuring output resistance in the neutral position, and measuring insulation current. Data runs were taken prior to irradiation at ambient temperature and again with the fixture immersed in liquid nitrogen. During the power ramp, a data run was made at reactor power levels of 10 KW, 100 KW, and 1 MW. When the 3 MW power level was reached, data runs were taken at one hour intervals for 9 hours and every four hours thereafter. After shutdown, data runs were again taken at one hour intervals for 5 hours. One data run was taken after return to ambient temperature.

Figure 6
Electrical Schematic For Strain Gage Test

The integrated radiation exposure for the strain gages is presented in Table IV.

Table IV

RADIATION ENVIRONMENT FOR STRAIN GAGES

LOCATION	GAMMA DOSE	INTEGRATED NEUTRON FLUX (N/cm ²)	
	[Ergs/gm(C)]	E > 2.9 Mev	E < 0.48 ev
INSIDE DEWAR			
Upper Right Front	*	1.78 x 10 ¹⁶	- - - -
Upper Right Back		8.97 x 10 ¹⁵	4.21 x 10 ¹⁴
Upper Left Front		1.43 x 10 ¹⁶	2.97 x 10 ¹⁴
Upper Left Back		8.59 x 10 ¹⁵	3.46 x 10 ¹⁴
Lower Right Front		7.28 x 10 ¹⁵	9.09 x 10 ¹⁴
Lower Right Back		2.83 x 10 ¹⁵	5.08 x 10 ¹⁴
Lower Left Front		1.19 x 10 ¹⁶	- - - -
Lower Left Back		7.04 x 10 ¹⁵	4.72 x 10 ¹⁴
OUTSIDE DEWAR			
Upper Right Front	2.80 x 10 ¹¹	4.22 x 10 ¹⁶	4.62 x 10 ¹⁴
Upper Right Back	1.44 x 10 ¹⁰	2.88 x 10 ¹⁵	9.24 x 10 ¹⁴
Upper Left Front	2.37 x 10 ¹¹	3.75 x 10 ¹⁶	- - - -
Upper Left Back	3.67 x 10 ¹⁰	2.93 x 10 ¹⁵	8.09 x 10 ¹⁴
Center Front	- - - -	- - - -	- - - -
Center Back	- - - -	1.26 x 10 ¹⁶	9.89 x 10 ¹⁴
Lower Right Front	> 3.78 x 10 ¹¹	2.81 x 10 ¹⁶	9.14 x 10 ¹³
Lower Right Back	1.44 x 10 ¹⁰	1.06 x 10 ¹⁵	8.55 x 10 ¹⁴
Lower Left Front	2.36 x 10 ¹¹	2.55 x 10 ¹⁶	3.23 x 10 ¹³
Lower Left Back	1.59 x 10 ¹⁰	2.42 x 10 ¹⁵	1.11 x 10 ¹⁵

* No nitrous oxide dosimeters were mounted inside the dewar.

C. TEST RESULTS

1. General

Data obtained from the irradiated test items were reduced and plotted as a function of the integrated flux (Figures 7 through 22). The plots show data obtained before, during, and after irradiation.

The data acquisition system used to accumulate the test data had an inherent uncertainty of $\pm 0.005\%$ of Dymec full-scale plus 0.01% of measured value. The strain gage average resistance value was 125 ohms and the Dymec range was 1000 ohms. The resulting data uncertainty, in ohms, is ± 0.073 .

The strain gage insulation resistances are shown in Table V for the periods before, during, and after irradiation.

2. Resistance

The measured resistance of the bridge on the top of beam 1, right, was erratic from the beginning of pre-irradiation testing and the connection was finally broken on return to ambient conditions. The strain data from this channel, however, was not erratic. These facts indicate that a poor connection existed in the bridge-completion wiring between the bridge and the output terminal. Since negligible current is drawn through this connection, the resistance can change appreciably before the strain indication is effected.

The resistances of other instruments indicate a decreasing trend during irradiation which ranged from 0.05 to 0.096 ohm. The average decrease during 3 MW operation was 0.085 ohm for gages on aluminum beams and 0.062 ohm for gages on Inconel beams. These changes are not significant since the measurement included lead resistance and the greatest change in measured effect is only 1.3 times the uncertainty of the data system and less than 0.08% of the measurand.

Figure 7
 Strain Gage Output VS Irradiation
 Inconel Beam No. 1-Top-Left Side

Figure 8
Strain Gage Output VS Irradiation
Inconel Beam No. 1-Bottom-Left Side

Figure 9
Strain Gage Output VS Irradiation
Inconel Beam No. 2-Top-Right Side

Figure 10
Strain Gage Output VS Irradiation
Inconel Beam No. 2-Bottom-Right Side

Figure 11
Strain Gage Output VS Irradiation
Inconel Beam No. 4-Bottom-Right Side

Figure 12
Strain Gage Output VS Irradiation
Inconel Beam No. 5-Left-Top Side

Figure 13
Strain Gage Output VS Irradiation
Inconel Beam No. 5-Bottom-Left Side

Figure 14
Strain Gage Output VS Irradiation
Aluminum Beam No. 1-Top-Right Side

Figure 15
Strain Gage Output VS Irradiation
Aluminum Beam No. 1-Bottom-Right Side

Figure 16
Strain Gage Output VS Irradiation
Aluminum Beam No. 2-Top-Left Side

Figure 17
Strain Gage Output VS Irradiation
Aluminum Beam No. 2-Bottom-Left Side

Figure 18
Strain Gage Output VS Irradiation
Aluminum Beam No. 3-Top-Right Side

Figure 19
 Strain Gage Output VS Irradiation
 Aluminum Beam No.3-Bottom-Right Side

Figure 20
 Strain Gage Output VS Irradiation
 Aluminum Beam No. 4-Top-Left Side

Figure 21
Strain Gage Output VS Irradiation
Aluminum Beam No. 4-Bottom-Left Side

Figure 22
Strain Gage Output VS Irradiation
Aluminum Beam No. 5-Top-Right Side

Table V

INSTRUMENT STRAIN GAGES: INSULATION RESISTANCE
(megohms except where designated ohms)

Strain Gage	Preirr. LN ₂	Reactor Power			70 Mw-min	4,430 Mw-min	9,340 Mw-min	13,610 Mw-min	17,930 Mw-min	Postirr.	
		10 kw	100 kw	1 Mw						LN ₂	Amb.
1-LU	500+	500+	500+	500+	500+	500+	385	500	416	500+	500+
1-LL	250	*	*	*	*	14.8K	4.17K	12.0K	12.4K	12.4K	4.7K
2-LU	500+	500+	500+	500+	500+	500+	500+	500+	500+	500+	500+
2-LL	500+	500+	500+	500+	500+	500+	500+	500+	500+	500+	500+
--LU	500+	500+	500+	500+	500+	500+	500+	500+	500+	500+	98
--LL	500+	500+	500+	500+	500+	500+	500+	455	500+	500+	500+
5-LU	500+	500+	455	427	427	**	143	59	77	31	57
5-LL	500+	500+	500+	500+	500+	500+	500+	500+	500+	161	500+
1-RU	500+	500+	500+	500+	500+	100	96	119	100	500+	500+
1-RL	500+	500+	500+	427	500	25	25	143	67	500+	310
2-RU	500+	500+	500+	294	111	66	77	83	113	500+	500+
2-RL	500+	500+	500+	500+	500+	500+	500+	500+	500+	500+	500+
3-RU	500+	500+	500+	500+	455	385	500+	500+	416	500+	500+
3-RL	500+	500+	500+	500+	500+	455	500+	500+	455	500+	500+
--RU	500+	500+	500+	500+	500+	500+	500+	500+	500+	500+	500+
--RL	500+	500+	500+	500+	333	278	250	200	208	500+	500+
5-RU	500+	500+	500+	500+	500+	500+	500+	500+	500+	500+	500+
5-RL	500+	500+	500+	500+	427	333	333	333	294	500+	500+
Ceramic Bonded:											
Front	500+	500+	500+	500+	500+	500+	500+	500+	500+	500+	500+
Rear	500+	500+	500+	500+	500+	500+	500+	500+	500+	500+	417

*Less than 50K

**Erratic meter reading

3. Insulation Resistance

The insulation resistance of the gage attached to the bottom of beam 1 on the left side decreased to less than 50K ohms between the pre-irradiation data run and the 10 KW power level hold.

Just prior to shutdown, insulation resistances of the other gages ranged from 55.5 to 877 megohms with a mean of 431 megohms. The minimum insulation resistance for these gages at any time during the test was 12.5 megohms. This value did not adversely affect the instruments.

4. Sensitivity

Changes in the sensitivity of the gages attached to the Inconel beams were within the limitations of the fixture, the data system, and the specification of linearity, hysteresis, and repeatability for the instruments. Sensitivity changes of gages attached to aluminum beams could not be investigated because of degradation of the welds caused by thermal cycling prior to irradiation.

5. Zero Shift

Table VI depicts the ranges of observed zero shift for each strain gage.

a. Inconel Beams

The instruments attached to the Inconel beams indicated zero shifts into compression. The average shift was 129 microinch/inch with a range from 92 to 168 microinch/inch. The shifts are gradual, beginning shortly after the 3 MW power level was reached. The shifts are not an indication of a change in the bending of the beam, since this would be indicated by a positive shift on one side of a beam accompanied by a negative shift on the other side. In no case do two beams show the same shift. However, in each of the three

Table VI

CHANGES IN STRAIN GAGE OUTPUT DURING 3 MW OPERATION

	Data Run #6 Up to Down (in./in.)	Data Run #98 Up to Down (in./in.)	Change During 3 Mw Operation (in./in.)	Zero Shift (in./in.)	System Uncertainty (in./in.)
Gages Attached To Inconel					
1-Left-Top	3261	3301	+40	+158	+ 18.1
-Bottom	3426	3442	+16	+168	+ 21.9
2-Right-Top	3135	3166	+31	+ 92	+ 15.2
-Bottom	3382	3426	+44	+106	+ 6.1
4-Right-Bottom	3312	3352	+40	+144	+ 15.8
5-Left-Top	3312	3358	+46	+119	+ 17.9
-Bottom	3165	3155	-10	+117	+ 11.2
Gages Attached to Aluminum					
1-Right-Top	2369	2338		- 3.6	+ 6.2
-Bottom	1403	1395		-12	+ 15.2
2-Left-Top	611	614		- 8.8	+ 8.7
-Bottom	2415	2443		0.0	+ 16.7
3-Right-Top	897	935		-24.2	+ 11.1
-Bottom	697	702		-17.8	+ 11.8
4-Left-Top	1946	1903		- 4.5	+ 9.2
-Bottom	1020	932		- 1.3	+ 10.9
5-Right-Top	2302	2283		- 7.7	+ 2.4

cases where there were functioning gages on both sides of an Inconel beam, the magnitude of the shift in the output of the top gage was substantiated by that in the output of the bottom gage.

Axial loading of the beam because of temperature contraction of the fixture was investigated as a possible cause of the beam oriented zero shifts. Measurements of the fixture clearances at ambient temperature have been made and dimensions at -320°F have been calculated. Based upon these measurements and calculations, it is not possible for the beam to be loaded axially at all, much less for the axial load to increase. The relative magnitudes of the measured zero shifts do not correlate with the relative magnitudes of measured neutron exposure.

b. Gages on Aluminum Beams

Prior to irradiation, the nine gages attached to the aluminum beams partially lifted from the beams as a result of thermal shocks. The result was a reduction of output for a given deflection of the beams from their reference (neutral) position. Three, retaining more than 70% strain sensitivity, experienced zero shifts of 7.7-, 3.6-, and zero microinch/inch. Four, with less than 40% strain sensitivity, shifted 1.3-, 8.8-, 17.8-, and 24.2-microinch/inch with a mean of 8-microinch/inch.

The gages attached to aluminum were identical to those attached to Inconel except for the weld flanges. At the neutral position, all gages were subjected to the same test conditions (environment, excitation, physical stimulus). However, the average zero shift of gages on aluminum was 8-microinch/inch into tension while that of gages on Inconel was 130-microinch/inch into compression.

D. CONCLUSIONS

In general, the data accumulated during this test was of exceptionally good quality and permitted evaluation in greater detail than has been possible on previous strain gage irradiation tests. As a result, several separate effects of

small magnitude were noted that were previously obscured by the data system errors. These effects are:

1. The zero shift of the gages on Inconel X are in compression while the gages mounted on aluminum are in tension.
2. The average zero shift of the Inconel mounted-strain gages is 16 times greater than the zero shift of the aluminum mounted gages.
3. The observed zero shift of the aluminum mounted-gages is negligible and is less than the data system uncertainty limits.
4. Gages mounted on both sides of a given beam have nearly identical zero shifts that differ in magnitude from beam to beam.
5. The magnitude of the beam oriented zero shifts do not relate to the magnitude of the radiation levels at the respective locations within the test fixture.

These effects are radiation caused but there is a definite dependency upon the weld flange material, beam material, and the bond (weld). Additional testing would be required to define fully the significance and cause of the observed effects.

The gages tested are recommended for use on NERVA engines with the following reservation. The nozzle on NERVA is AISI 347 stainless steel and not Inconel X. The results of this test indicate a dependency on the type of material used. The magnitude of the zero shift on AISI 347 stainless steel cannot be defined without tests on that material.

IV. PRESSURE TRANSDUCERS

A. PURPOSE OF TEST

This test was conducted to evaluate the effects of nuclear radiation on pressure transducers as a part of the evaluation program to select pressure transducers for use on the NERVA engine.

The objective of the test was to determine the effects of temperature and radiation, under controlled conditions, on the electrical characteristics of a vapor-deposited, strain-gage, pressure transducer.

B. SUMMARY OF TEST CONDITIONS

1. Items Tested

Three Statham pressure transducers were tested; two Model Number PA810TC-2M, Serial Numbers 1 and 2, and one Model Number PA810TC-30, Serial Number 13.

2. GTR Test Conditions

Two Model PA810TC-2M pressure transducers were mounted on a pressure manifold and fastened to the side of the strain gage fixture as shown in Figure 4. Helium gas was used to pressurize the transducers to 1000 psia during the test. The Model PA810TC-30 pressure transducer was mounted on the side of the pressure manifold, but did not receive a pressure stimulus. The three transducers were immersed in LN₂ throughout the test.

A 500 ($\pm$ 0.01%) ohm precision resistor was sequentially connected in series, by means of a stepping switch, to six different combinations of the bridge elements in each transducer (Figure 23). A 1 vdc excitation was applied across the system for each stepper-switch position and the voltage drop across the 500 ohm resistor was recorded, along with the input voltage, by a Dymec 2010-D Digital Data Acquisition System.

Figure 23

Electrical Schematic for Measuring Pressure Transducer Bridge Resistance

An RCA Ultrasensitive Model WV-84C Microammeter was used for the insulation resistance measurements (Figure 24).

The average integrated radiation exposure for the pressure transducers was

Fast Neutron Flux (n/cm^2)	1.12×10^{16}
Thermal Neutron Flux (n/cm^2)	5.08×10^{14}
Gamma Dose [ergs/gm (C)]	6.9×10^{10}

C. TEST RESULTS

1. General

Data obtained from the irradiated transducers were reduced and plotted. The plots show data obtained before, during, and after irradiation.

The data acquisition system used to accumulate the test data had an inherent uncertainty of 0.005% of Dymec full-scale, plus 0.01% of measured value, plus 1 digit. The uncertainties expressed in ohms for the various nominal resistance values measured are shown in Table VII.

Table VII

UNCERTAINTIES FOR VARIOUS
NOMINAL RESISTANCE VALUES

<u>Nominal Resistance (ohms)</u>	<u>Uncertainty (ohms)</u>
750	± 0.3
1000	± 0.4
1250	± 0.5
1600	± 0.7
2500	± 1.4
3800	± 2.6

Figure 24
Electrical Schematic For Measuring Pressure
Transducer Insulation Resistance

Insulation resistance measurements for the periods before, during, and after irradiation are shown in Table VIII.

2. Insulation Resistance

The insulation resistance values depict the typical dose sensitivity common to insulation materials. S/N 1 and 14 both show approximately 80% decrease in resistance with recovery to pre-irradiation values during the post-irradiation data cycles. S/N 2 shows little if any degradation, and it is questionable whether the data show the transducer insulation resistance or an open circuit.

3. Bridge Resistance

A large variation in the bridge resistance measurements on all channels was observed during the test. The cyclic nature of the data variations occurs in 12 hour intervals and indicates the possibility that external factors were influencing the data. However, a gradual increase in all resistance channels can be seen in Figures 25 through 41.

A statistical analysis of the data obtained was performed in an attempt to gain information as to the damage effects caused by radiation. Two computer programs were used; the first attempted a simple linear regression analysis and the second attempted a statistical polynomial curve-fit-analysis of from 1 to 7 degrees.

The results of the statistical analysis for Position 3 are shown in Figure 42 for both the 0 psig and 1000 psig as an example of all the data. The simple linear regression analysis shows that the best fit to the data is a straight line of the form:

$$Y = MX + B$$

where: $M = 0.0250$

$B = -0.1524$

Std Dev = 0.33%

Table VIII

PRESSURE TRANSDUCERS: INSULATION RESISTANCE
(megohms)

Pressure Transducers	Pre- LN ₂	Reactor Power			70 Mw-min	4,430 Mw-min	9,340 Mw-min	13,610 Mw-min	17,930 Mw-min	Post- LN ₂
		10kw	100 kw	1Mw						
S/N 1	100+	100+	100+	100+	100+	18	25	40	38	100+
	100+	100+	100+	100+	100+	20	27	42	45	100+
S/N 2	100+	100+	100+	100+	100+	100+	83	100+	100+	100+
	100+	100+	100+	100+	100+	100+	91	100+	100+	100+
S/N 14	100+	100+	100+	50	30	19	19	24	25	100+
	100+	100+	100+	50	29	20	20	25	27	100+

Figure 25
 Bridge Resistance vs Radiation Exposure: Pressure Transducer
 PA810TC-2M, S/N 1, Stepper Switch Position 3

Figure 26

Bridge Resistance vs Radiation Exposure: Pressure Transducer
PA810TC-2M, S/N 1, Stepper Switch Position 4

Figure 27

Bridge Resistance vs Radiation Exposure: Pressure Transducer
PA810TC-2M, S/N 1, Stepper Switch Position 5

Figure 28

Bridge Resistance vs Radiation Exposure: Pressure Transducer
PA810TC-2M, S/N 1, Stepper Switch Position 6

Figure 29

Bridge Resistance vs Radiation Exposure: Pressure Transducer
PA810TC-2M, S/N 1, Stepper Switch Position 7

Figure 30

Bridge Resistance vs Radiation Exposure: Pressure Transducer
PA810TC-2M, S/N 1, Stepper Switch Position 8

Figure 31

Bridge Resistance vs Radiation Exposure: Pressure Transducer
PA810TC-2M, S/N 2 Stepper Switch Position 9

Figure 32
 Bridge Resistance vs Radiation Exposure: Pressure Transducer
 PA810TC-2M, S/N 2, Stepper Switch Position 10

Figure 33

Bridge Resistance vs Radiation Exposure: Pressure Transducer
PA810TC-2M, S/N 2, Stepper Switch Position 11

○ - ZERO PSIG
 △ - 1000 PSIG

Figure 34

Bridge Resistance vs Radiation Exposure: Pressure Transducer
 PA810TC-2M, S/N 2, Stepper Switch Position 12

Figure 35

Bridge Resistance vs Radiation Exposure: Pressure Transducer
PA810TC-2M, S/N 2, Stepper Switch Position 13

45

○ - ZERO PSIG

Figure 36

Bridge Resistance vs Radiation Exposure: Pressure Transducer
PA810TC-30, S/N 14, Stepper Switch Position 14

⊙ - ZERO PSIG

Figure 37

Bridge Resistance vs Radiation Exposure: Pressure Transducer
PA810TC-30, S/N 14, Stepper Switch Position 15

Figure 38

Bridge Resistance vs Radiation Exposure: Pressure Transducer
PA810TC-30, S/N 14, Stepper Switch Position 16

Figure 39

Bridge Resistance vs Radiation Exposure: Pressure Transducer
PA810TC-30, S/N 14, Stepper Switch Position 17

Figure 40

Bridge Resistance vs Radiation Exposure: Pressure Transducer
PA810TC-30, S/N 14, Stepper Switch Position 18

Figure 41

Bridge Resistance vs Radiation Exposure: Pressure Transducer
PA810TC-30, S/N 14, Stepper Switch Position 19

Figure 42
Statistical Analysis of Position 3 Data
60

The results of the best polynomial fit for the data also indicated that the best possible fit for every position was a straight line:

$$Y = MX + B$$

where: $M = 0.0246$

$B = 0.1517$

D. CONCLUSIONS

The conclusions derived from the analysis of the data are that, although there is a great amount of deviation, the test produced more good data points than bad and that the change in resistance of the transducers as a function of irradiation time approximates a straight line. The change in resistance is less than 0.3% of the total resistance. Since this test was conducted at LN_2 temperature, where self annealing of radiation defects is minimized, it is expected that radiation damage will be less than 0.3% when irradiated at ambient temperatures or higher.

The decrease in insulation resistance during the test was not significant enough to affect the operation of the transducers.

The results of the test indicate that the Statham vapor-deposited bridge concept performs adequately in a radiation environment and that continued development is warranted for eventual use on NERVA. However, since both gamma and neutron rates are considerably less than the NERVA rates, additional testing is recommended at higher rates to determine fully the radiation effects on the Statham transducer.

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2. RN-S-0167, Final Test Specifications for Ground Test Reactor (GTR) Irradiation Test Number 17*, Aerojet-General Corporation, Sacramento, Calif.

* Changed to GTR 15.

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