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December, 1964

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**Westinghouse
Astronuclear Laboratory**

**Strain Gage Test, Experiment No. 23/W406
Irradiated At Plum Brook Reactor Facility
PBRF Cycle 20P (PB No. 7W)**

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STRAIN GAGE TEST, EXPERIMENT NO. 23/W406
IRRADIATED AT THE PLUM BROOK REACTOR FACILITY
PBRF CYCLE 20P (PB NO. 7W)

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Unclassified
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Authorized Classifier Date

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PREFACE

Strain gages are to be utilized in the NERVA reactor to diagnose strain in structural members. The primary purpose for irradiation experiments of various candidate strain gages is to study both their operational behavior and the manner of attachment to the reactor component in a high-radiation environment.

This report presents test information and test evaluation of thirteen (13) Microdot weldable strain gages irradiated at the Plum Brook Reactor on July 2-4, 1964 during PBRF Cycle 20P.

1.0 INTRODUCTION

1.1 GENERAL

When strain gages are exposed to a nuclear environment, several damage mechanisms may be actuated which can ultimately affect the applicability of the gage device. Some of the mechanisms which should be considered in the evaluation include:

1. Degradation of strain gage mounting material
2. Degradation of the bond between the gage and carrier
3. Resistance changes of the strain gage
4. Loss in insulation qualities of lead-in wires and the gage carrier
5. Structural distortion or warping

This report describes an irradiation experiment on strain gage elements conducted by the Westinghouse Astronuclear Laboratory (WANL) at the Plum Brook Reactor Facility (PBRF). This test, designated as Experiment No. 23/W406, was performed by WANL personnel during PBR Cycle 20P on July 2-4, 1964. The purpose of this experiment was to study the operational behavior of thirteen (13) Microdot weldable strain gages in a high radiation environment to determine their suitability for NRX-A service. The test system design is included in the literature⁽¹⁾. WANL-TME-753⁽²⁾ is the final test specification which describes the test experiments, test conditions, items to be tested, test circuitry, and test procedures. WANL-TME-914⁽³⁾ is the preliminary data report for this test and contains the experiment data.

1.2 DOSIMETRY

Four dosimeter packages were attached to the sample fixture as shown in Figure 1 and Figure 2. The dosimeters consisted of aluminum-cobalt wires, bare and cadmium covered for measurement of thermal and epi-thermal neutron flux, and sulfur for measurement of the fast neutron flux. The neutron flux experienced by each of the dosimeter positions indicated in Figure 2 is as follows:

<u>Dosimeter</u>	<u>ØThermal*</u>	<u>ØEpithermal**</u>	<u>Ø Fast***</u>
18	3.5×10^{14}	1.2×10^{13}	1.9×10^{13}
19	1.6×10^{14}	3.9×10^{12}	8.1×10^{12}
20	3.6×10^{13}	1.2×10^{12}	2.5×10^{12}
21	1.2×10^{14}	2.4×10^{12}	4.4×10^{12}

* $E < .48 \text{ Mev}$

** $.48 \text{ Mev} < E < 2.9 \text{ Mev}$

*** $E > 2.9 \text{ Mev}$

1.3 TEST SCHEDULE

Eight stainless steel deflection beams, onto which sixteen (16) Microdot strain gages**** were spot welded, were attached to a test fixture as shown in Figure 1. Since PBRF restricted the use of bare silver solder in the reactor primary coolant water, an approximately 2-mil thickness of nickel was plated on all soldered joints. Four thermocouples, located in the structural section to which the deflection beams were fixed, were positioned so that two of the thermocouples monitored fixture centerline coolant temperature, and the other two thermocouples monitored the fixture temperature.

****Six of the strain gages operated as pairs, thus reducing the number to 13 for data purposes.

Figure 1. Strain Gage Fixture Assembly

NO.	DESCRIPTION	QTY	UNIT	REMARKS
1	Beam 1	1	PC	
2	Beam 2	1	PC	
3	Beam 3	1	PC	
4	Beam 4	1	PC	
5	Beam 5	1	PC	
6	Beam 6	1	PC	
7	Beam 7	1	PC	
8	Beam 8	1	PC	
9	Beam 9	1	PC	
10	Beam 10	1	PC	
11	Beam 11	1	PC	
12	Beam 12	1	PC	
13	Beam 13	1	PC	
14	Beam 14	1	PC	
15	Beam 15	1	PC	
16	Beam 16	1	PC	
17	Beam 17	1	PC	
18	Beam 18	1	PC	
19	Beam 19	1	PC	
20	Beam 20	1	PC	
21	Beam 21	1	PC	
22	Beam 22	1	PC	
23	Beam 23	1	PC	
24	Beam 24	1	PC	
25	Beam 25	1	PC	
26	Beam 26	1	PC	
27	Beam 27	1	PC	
28	Beam 28	1	PC	
29	Beam 29	1	PC	
30	Beam 30	1	PC	
31	Beam 31	1	PC	
32	Beam 32	1	PC	
33	Beam 33	1	PC	
34	Beam 34	1	PC	
35	Beam 35	1	PC	
36	Beam 36	1	PC	
37	Beam 37	1	PC	
38	Beam 38	1	PC	
39	Beam 39	1	PC	
40	Beam 40	1	PC	
41	Beam 41	1	PC	
42	Beam 42	1	PC	
43	Beam 43	1	PC	
44	Beam 44	1	PC	
45	Beam 45	1	PC	
46	Beam 46	1	PC	
47	Beam 47	1	PC	
48	Beam 48	1	PC	
49	Beam 49	1	PC	
50	Beam 50	1	PC	
51	Beam 51	1	PC	
52	Beam 52	1	PC	
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63	Beam 63	1	PC	
64	Beam 64	1	PC	
65	Beam 65	1	PC	
66	Beam 66	1	PC	
67	Beam 67	1	PC	
68	Beam 68	1	PC	
69	Beam 69	1	PC	
70	Beam 70	1	PC	
71	Beam 71	1	PC	
72	Beam 72	1	PC	
73	Beam 73	1	PC	
74	Beam 74	1	PC	
75	Beam 75	1	PC	
76	Beam 76	1	PC	
77	Beam 77	1	PC	
78	Beam 78	1	PC	
79	Beam 79	1	PC	
80	Beam 80	1	PC	
81	Beam 81	1	PC	
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89	Beam 89	1	PC	
90	Beam 90	1	PC	
91	Beam 91	1	PC	
92	Beam 92	1	PC	
93	Beam 93	1	PC	
94	Beam 94	1	PC	
95	Beam 95	1	PC	
96	Beam 96	1	PC	
97	Beam 97	1	PC	
98	Beam 98	1	PC	
99	Beam 99	1	PC	
100	Beam 100	1	PC

Figure 2. Strain Gage Fixture - Beam and Dosimeter Locations

Four dosimeter packages and the strain gage lead cables were incorporated in the fixture. Then the entire experiment was inserted into a plastic mock-up capsule and tested for one hour in a water flow of 50 gpm, a pressure of 50 psi, and temperatures ranging from 75-90°F. Further studies in the stainless steel mock-up capsule were conducted under test conditions of 75 gpm coolant flow, 150 psi water pressure, and approximately 135°F for a period of about 47 hours.

All operative systems were checked and pre-irradiation data for each strain gage were generated. The irradiation of Experiment 23/W406 was initiated at 2335 hours on July 1, 1964, and was completed at 0830 hours on July 4, 1964, for a total exposure of about 56 hours at an average reactor power of 48.9 Mw. A profile of the reactor power during this irradiation period, as obtained from the PBRF water power computer, is presented in Figure 3.

Pre-irradiation data for this experiment were recorded during check-out operations at both WANL and PBRF with the fixture in air and water. During irradiation, data were recorded at power levels of 100 Kw, 1 Mw, 10 Mw, 30 Mw, and 38 Mw, and then recorded hourly at the 50 Mw level. Post-irradiation data were recorded for about four hours immediately following irradiation and again in the hot laboratory during post-irradiation examinations. Transfer

Figure 3. Reactor Power Profile - Cycle 20 - Experiment 23/W406

of the test fixture from the reactor to the hot laboratory for the post-irradiation studies was performed eleven (11) days after termination of the irradiation. A chronological summary of the pertinent test activities is presented in Table 1.

Table 1

Chronological Summary of Test Activities

<u>Date</u>	<u>Time</u>	
6/2-6/5	-	Pre-irradiation data were recorded with the sample fixture in the mock-up loop at WANL (wet).
6/6	-	Test fixture was shipped to Plum Brook by truck
6/9	-	Test fixture was uncrated and resistance checks of the thermocouples were taken. T/C #4 was found to be shorted and repairs were unsuccessfully attempted.
6/10	-	Continuity checks of the strain gage cables were conducted.
6/16	-	Read-out instrumentation was received at PBRF.
6/16-6/28	-	Pre-irradiation data were obtained with the sample fixture in the WANL set-up area (dry).
6/29	-	Sample fixture and read-out equipment were moved to the reactor containment vessel and were set up.
6/30	-	Sample fixture was inserted into HT-1 and data were recorded.
7/1	1600	An alarm and scram check were performed, and a complete set of experimental data was obtained.
7/1	1750	Last complete set of experimental data was obtained prior to reactor startup.
7/1	2335-0042	Reactor was taken critical to 100 Kw. Experimental data were taken.
7/2	0042-0115	Reactor power was at 1 Mw. Experimental data were recorded.
7/2	0115-0130	Reactor power was at 10 Mw. Experimental data were recorded.
7/2	0130-0210	Reactor power was at 19.8 Mw. Experimental data were recorded.
7/2	0210-0235	Reactor power was at 39 Mw. Experimental data were recorded.
7/2	0235-0430	Reactor power was at 40 Mw. Experimental data were recorded.
7/2	0430-2400	Reactor power varied between 49.4 Mw and 50.4 Mw. Experimental data were recorded at hourly intervals.
7/3	0000-2400	Reactor power varied between 50 Mw and 50.8 Mw. Experimental data were recorded at hourly intervals.
7/4	0000-0802	Reactor power varied between 50.4 Mw and 51.3 Mw. Experimental data were recorded at hourly intervals.
7/4	0802-0806	Slow power cutback to 1 Mw.
7/4	0806-0813	Reactor power was at 1 Mw. Experimental data were recorded.
7/4	0813	Reactor was shutdown.
7/4	0815	Experimental data were recorded.
7/4	1010	Experimental data were recorded.
7/4	1100	Experimental data were recorded.

2.0 STRAIN GAGES

2.1 GENERAL

Strain gages are used in the NRX reactors on components such as tie rods and lateral support springs. This test was designed to investigate the operability of strain gages in a radiation environment simulating that which these components will experience in NERVA and to determine the output reliability.

The gages tested were installed on tapered cantilevered beams that were deflected against a fixed stop when helium gas pressure was supplied to a single bellows. Ten of these gages were the active-dummy type and six were the single active element type, the latter operating in pairs. Each of the strain gages was provided with a 13-foot long, stainless steel sheathed, 3-conductor, MgO-insulated cable. The 13-foot length is sufficient to extend through the Conax fitting located on the back plate of the sample holder. The end of the sheathed cable was spliced to a shielded, 3-conductor, flexible extension cable insulated with irradiated polyolefin.

The single active element gages were connected in a half-bridge at the splice location; the gage on the outside of the beam was in compression while that on the inside surface was in tension when the bellows was energized. The active-dummy gages are internally wired in the gage itself in a half-bridge configuration⁽⁴⁾.

2.2 SUMMARY OF TEST CONDITIONS

2.2.1 Items Tested

Weldable strain gages as follows:

<u>Quantity</u>	<u>Mfg.</u>	<u>Model No.</u>	<u>Instrumentation Data Book No.</u>	<u>Flange Material</u>	<u>Sensing Elements</u>
6 (in pairs)	Microdot	SG 123/1	Sr-14	Stainless Steel	Single Active*
6	Microdot	SG 333/1	Sr-31	Gold	Active* and Dummy**
4	Microdot	SG 323/1	Sr-30	Stainless Steel	Active* and Dummy**

<u>Strain Gage No.</u>	<u>Model No.</u>	<u>Location***</u>	<u>Compression or Tension</u>
1	SG 333/1	Outboard Beam 1	C
2	SG 333/1	Inboard Beam 1	T
3	SG 333/1	Outboard Beam 2	C
4	SG 333/1	Inboard Beam 2	T
5	SG 333/1	Outboard Beam 3	C
6	SG 333/1	Inboard Beam 3	T
7	SG 123/1	Beam 4	-
8	SG 123/1	Beam 5	-
9	SG 123/1	Beam 6	-

* Simple Evanohm wire (MgO insulated)

** Evanohm wire coil-wrapped Evanohm wire (MgO insulated)

*** Refer to Figure 2 for locations

<u>Strain Gage No.</u>	<u>Model No.</u>	<u>Location</u>	<u>Compression or Tension</u>
10	SG 323/1	Outboard Beam 7	C
11	SG 323/1	Inboard Beam 7	T
12	SG 323/1	Outboard Beam 8	C
13	SG 323/1	Inboard Beam 8	T

2.2.2 Test Item Conditions vs. Specifications

<u>Parameter</u>	<u>Actual Test Conditions</u>	<u>Test Specifications</u>
Temperature (°F)	130 - 144	125
Pressure (psi)	129	130
Fast Neutron Exposure (n/cm ² sec)	2.5 x 10 ¹² to 1.9 x 10 ¹³ (E > 2.9 Mev)	2.3 x 10 ¹³ (E > 1.0 Mev)*
	7.5 x 10 ¹² to 5.7 x 10 ¹³ (E > 1.0 Mev) *	
Thermal Neutron Exposure (n/cm ² sec)	3.6 x 10 ¹³ to 3.5 x 10 ¹⁴ (E < 0.48 ev)	1.4 x 10 ¹⁴ (E < 0.48 ev)
Gamma Exposure (ergs/g(C)hr)	-**	9.7 x 10 ¹⁰
Integrated Exposures		
Neutron (fast) (n/cm ²)	1.5 x 10 ¹⁸ to 1.2 x 10 ¹⁹ (E > 1.0 Mev) *	4.1 x 10 ¹⁸ (E > 1.0 Mev)*
Neutron (thermal) (n/cm ²)	7.3 x 10 ¹⁸ to 7.1 x 10 ¹⁹ (E < 0.48 ev)	2.5 x 10 ¹⁹ (E < 0.48 ev)
Gamma (ergs/g(C))	-**	4.9 x 10 ¹²
Fluid Environment	Water	Water
Duration (hrs)	56.5	50.0

* 3 (Ø (E > 2.9 Mev) = Ø (E > 1.0 Mev)

** The test specification value, obtained by calculation, may be applied here.

2.3 TEST RESULTS

2.3.1 Sensitivity Change

The graph in Figure 4 shows the average sensitivity change in the strain gages for a 1000 microstrain (1000 microinches/inch) strain level. As can be seen on this plot, the average sensitivity showed a maximum variation of less than 20 microstrains which corresponds to less than 2 per cent of the actual strain level.

2.3.2 Insulation Resistance

Figure 5 is a plot of insulation resistance change during the test run. The cross-hatched area indicates the range of insulation resistance variation for these gages during irradiation.

2.3.3 Zero-Shift

Figures 6 and 7 show the zero-shift observed in these strain gages. The cross-hatched area of Figure 6 indicates the range of zero-shift variation during irradiation. Figure 7 presents the zero-shift of the individual strain gages as a function of the integrated fast neutron flux above 1 Mev over the range of interest for NRX-A (10^{17} - 10^{19} n/cm² to include operating times between 5 minutes and 1 hour). All strain gages zero-shifted in the same direction. The zero-shift was permanent for all strain gages, i.e., the gages remained at their final zero positions upon termination of irradiation. A permissible zero-shift of 100 microstrains is indicated in Figure 7; zero-shifts as large as 200 microstrains are tolerable but not desirable; zero-shifts over 200 microstrains become intolerable.

Figure 4. Strain Output Deviation
(Microdot Weldable Strain Gages)

Figure 5. Insulation Resistance
(Microdot Weldable Strain Gages)

Figure 6. Zero Shift (Microdot Weldable Strain Gages)

Figure 7. Strain Gage Zero-Shift Variation With Integrated Flux

2.4 TEST ANALYSIS

2.4.1 Sensitivity Change

The sensitivity variations in Figure 4 indicate that the variations will be less than 1 per cent and 0.5 per cent for the NRX-A3 tie rod and lateral support spring applications, respectively. This curve also indicates that the deviation is a very slowly varying function of integrated exposure for high exposures and that the effect is a permanent one.

2.4.2 Insulation Resistance

The range of insulation resistance was between 35 and 40 megohms for the 50 Mw power level. This decrease in insulation resistance is predominantly a rate effect since the insulation resistance approached its initial value at the termination of radiation. These values of insulation resistance are high enough so that serious adverse effects on strain gage performance will not result.

2.4.3 Zero Shift

Possible causes of the observed zero-shifts include (1) degradation of the MgO insulation* due to irradiation**, resulting in local shifting of the sensing element, (2) a differential resistance between the active and dummy elements in a given strain gage due to differential dimensional changes under irradiation between a simple wire and a coil-wrapped wire, and

* MgO expands as a result of radiation exposure. The literature⁽⁵⁾ indicates however, that this does not take place until $\sim 10^{19}$ nvt.

** Located around the sensing element, the behavior of the insulation was not directly observable under the conditions of this test.

(3) irradiation effects on the flange material. Note that Item (2) may not apply to SG 123/1 because compensation for radiation effects, temperature*, etc., is presumably achieved by two separate strain gages in a half-bridge network, each having a simple wire sensing element. It is doubtful that radiation bending of the supporting stainless steel beams occurred to cause the zero-shifts because sensitivities of all the strain gages remained essentially at their pre-irradiation levels; beam bending exhibiting zero-shifts of more than about 50 microstrains would have also exhibited marked changes in total deflection readings. Pre-irradiation tests of these strain gages showed no permanent zero-shift.

2.5 CONCLUSIONS AND RECOMMENDATIONS

The Microdot weldable strain gages tested under 23/W406 are significantly adversely affected by integrated neutron fluxes in the investigated range of $10^{17} - 10^{19}$ n/cm² (above 1 Mev) only insofar as the permanent zero-shift reported above.

From Figure 7 and Table 2, one can tentatively conclude that except for short runs the single active strain gages (SG 123/1) are inadequate for any NRX-A applications, while the active-dummy strain gages in tension are reasonably adequate for all NRX-A applications presently under consideration. Definite conclusions about these strain gages may be reached after additional testing.

*A maximum temperature rise of 0.5°F has been calculated.

Table 2

Strain Gage Ordering According to the Degree of Zero-Shifts

<u>Observed Ordering of Strain Gages</u>	<u>State</u>	<u>Flange</u>	<u>Element Type</u>
(Large zero shift) 8	-	Stainless Steel	Single Active
3	Compression	Gold	Active - Dummy
7	-	Stainless Steel	Single Active
9	-	Stainless Steel	Single Active
1	Compression	Gold	Active - Dummy
5	Compression	Gold	Active - Dummy
11	Tension	Stainless Steel	Active - Dummy
12	Compression	Stainless Steel	Active - Dummy
6	Tension	Gold	Active - Dummy
2	Tension	Gold	Active - Dummy
13	Tension	Stainless Steel	Active - Dummy
10	Compression	Stainless Steel	Active - Dummy
(Small zero shift) 4	Tension	Gold	Active - Dummy

Observed Ordering of Strain Gage Groups

<u>State</u>	<u>Flange</u>	<u>Element Type</u>	
-	Stainless Steel	Single Active	(Large zero shift)
Compression	Gold	Active - Dummy	
Tension	Stainless Steel	Active - Dummy	
Compression	Stainless Steel	Active - Dummy	
Tension	Gold	Active - Dummy	(Small zero shift)

Owing to a 15 per cent uncertainty in the measured neutron flux and a 10 per cent uncertainty in the Plum Brook Reactor power level, the integrated flux values along the abscissa of Figure 7 are correct to within ± 20 per cent. This error cannot be reduced, but confidence in the results can be gained by additional testing.

It is not possible from the data in Figure 7 to explain the mechanism responsible for the observed zero-shifts with certainty. Neither is the role played by random differences among the strain gages ascertainable from these data. Since these curves are monotonic, always positive, and do not appreciably cross over one another, one expects that a general mechanism is responsible for the zero-shift. More data from additional testing may establish this mechanism. As a result, the zero-shift for any Microdot weldable strain gage may be predicted and the gage appropriately rezeroed.

In the recent literature⁽⁶⁾, it has been reported that the stress condition of a material influences its behavior in a radiation environment. It is possible that the Microdot weldable strain gage design is a sensitive method of investigating this phenomenon. Only additional testing can determine this. If additional testing is scheduled the utility of other current developments, such as recently designed and fabricated strain gage DC instrumentation as used at NRDS as opposed to the AC system used on previous tests and described herein will be used.

The conclusions are summarized as follows:

1. All strain gages with the exception of single active gages for some applications were determined to be within operational requirements for NRX-A2.
2. The extreme zero-shift may preclude the use of the active-dummy test strain gages in compression for higher NVT than NRX-A2 for certain applications.
3. The zero shift was of a higher magnitude for gages in compression than it was for those in tension.
4. The extreme zero shift may have been the result of the following:
 - a. Basic material changes resulting from a combination of radiation and stress.
 - b. Non-similarity of active and dummy elements' radiation behavior.
 - c. Expansion of MgO insulation resulting in a mechanical shifting and a slight buckling in compression causing local shunting.

Additional strain gage irradiation tests at the Plum Brook Reactor Facility are suggested.

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