MASTER

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January 28, 1966

Westinghouse Astronuclear Laboratory

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WELDABLE AND BONDABLE STRAIN GAGES IRRADIATED AT PLUM BROOK REACTOR FACILITY (EXPERIMENT 23/W408 PBRF CYCLE 40) (NE 2460)

DISCLAIMER

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INFORMATION CATEGORY

UNCLASSIFIED

R L Ramp 1/27/66

Authorized Classifier Date

SUMMARY

This report presents the radiation test information and evaluation of foil gages bonded with inorganic cement and weldable gage in a nuclear radiation environment. Strain gages are to be utilized in the NERVA reactor to diagnose strain in structural members. The experiment presents test information and test evaluation of four pairs of Budd "C" series gages bonded with "H" ceramic cement and six active-dummy Microdot weldable gages. The experiment containing these test items was irradiated at the Plum Brook Reactor Facility on November 1965 during PBRF test 23/W408.

The test results indicate that the Budd foil gages and Microdot weldable gages can survive the radiation levels experienced in the PBRF Reactor. However, a detailed analysis of the strain gage performance has resulted in the following conclusions.

a. Budd series "C" foil gages bonded with "H" ceramic cement can be used for NRX application, such as the tie rods, lateral support springs, and titanium core band with an estimated overall accuracy of ± 100 microinches per inch for an one hour, full power NRX test duration.

b. Microdot weldable active-dummy gages can be used for NRX application, such as the tie rods, lateral support springs and titanium core band with an estimated overall accuracy of ± 500 microinches per inch for an one hour, full power NRX test duration. However, to achieve this accuracy a zero shift correction must be utilized.

TABLE OF CONTENTS

1.0 INTRODUCTION

1.1 GENERAL

This report describes the Westinghouse Astronuclear Laboratory (WANL) irradiation test conducted in the Plum Brook Reactor Facility (PBRF) in Sandusky, Ohio in November 1965. This test designated Experiment No. 23/W408 was conducted by WANL personnel curing reactor cycle 40P. The purpose of this experiment was to obtain operational data on Budd "C" series foil gages bonded with "H" ceramic cement and Microdot active-dummy weldable gages. The results of this test in conjunction with the non-nuclear test results will be used to predict the performance of these units on the NRX reactor.

Additional information related to this experiment is contained in the following WANL literature. WANL-TME-1116[1] is the Preliminary Test Specification and WANL-TME-1251[2] is the Final Test Specification, which describes the test experiment test conditions, items to be tested, test circuitry and test procedures. The Preliminary Data Report for this experiment which contains the raw data recorded during the test is contained in WANL-TME-1354[3].

1.2 DOSIMETRY

Six dosimeter packets were wired to the cage of the sample fixture in close proximity to the strain gages to measure the perturbed spacial neutron flux distribution. Bare and cadmium covered aluminum cobalt wires and sulfur pellets were located in each of the aluminum dosimeter tubes to determine the thermal, epi-thermal, and fast neutron fluxes. Upon completion of the experiment the dosimeter capsules were removed and prepared for analysis. The results of this analysis have not been received as of the date of this report.

The nuclear flux data which has been used in the preparation of this report is obtained from previous flux mapping of PBRF test hole HT-1 as described in WANL-TME-1085,[4] information received from PBRF,[5] and the PBRF information for Experiment Sponsors.[6]

1.3 TEST SCHEDULE

Six stainless steel deflection beams and one stainless steel stationary beam was utilized, onto which six active-dummy Microdot weldable gages and four pairs of Budd "C" series bondable gages were attached. Four of the Microdot weldable gages were spot welded to two constant strain deflection beams for dynamic testing while two gages were spot welded to a stationary beam for a static test. Four pairs of Budd "C" series gages were bonded with "H" ceramic cement on four constant strain deflection beams. To protect the ceramic cement from the quadrant water a tapered stainless steel bellows was welded on the deflection beams over the bonded gage area, thus hermetically sealing the bondable gages against moisture and contamination. In addition an approximately 2-mil thickness of nickel was plated on all silver soldered joints, because of a PBRF requirement restricting the use of bare silver solder in the reactor primary coollant water. The beams then were attached to a test fixture as shown in Figures 1 and 2.

Four thermocouples, located in the structural section to which the deflection beams were attached, were positioned such that the thermocouples will monitor fixture coolant water temperature and strain gage fixture temperature.

The strain gage test fixture with the strain gages attached was then tested for 30 hours in the WANL mock-up loop under the same condition that they would experience in the reactor except for the radiation.

After completion of the WANL mock-up loop test the strain gage fixture was shipped to Plum Brook where the irradiation test commenced on November 1965. The fixture was inserted in the HT-1 hole in predetermined steps (Table 1.3). During the insertion period the reactor was operating at a constant power of 60 megawatts. After completion of the irradiation, the test fixture was transferred from the water canal to the hot laboratory for postirradiation examination.

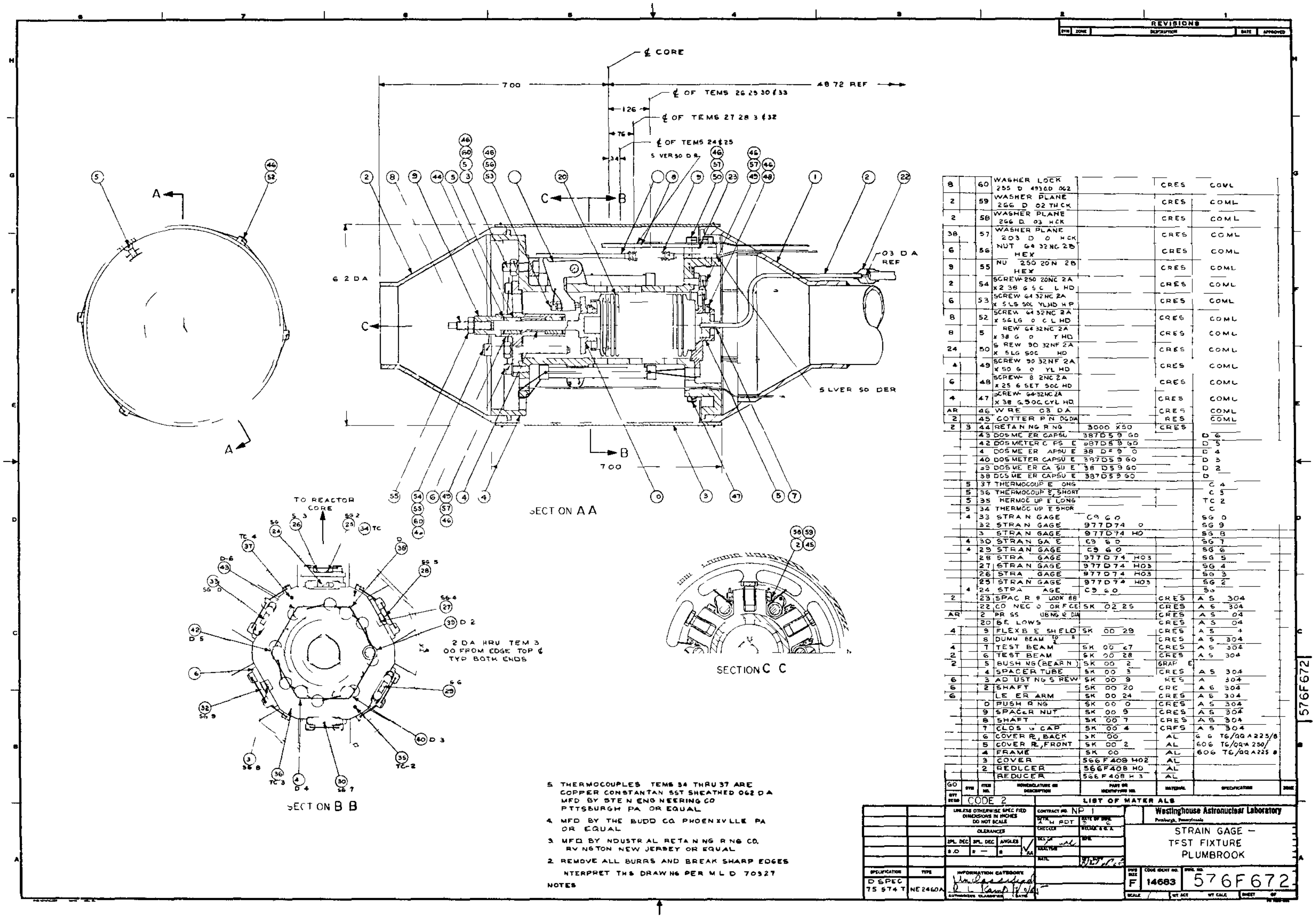

REVISIONS
℄ CORE
48 72 REF
SECTION A A
SECTION B B
SECTION C C
TO REACTOR CORE
SILVER SOLDER
5 THERMOCOUPLES ITEMS 34 THRU 37 ARE COPPER CONSTANTAN SST SHEATHED 062 DIA
4 MFD BY THE BUDD CO PHOENIXVILLE PA OR EQUAL
2 REMOVE ALL BURRS AND BREAK SHARP EDGES
NOTES
LIST OF MATERIALS
Westinghouse Astronuclear Laboratory
STRAIN GAGE –
TEST FIXTURE
PLUMBROOK
14683
576F672

FIGURE 1

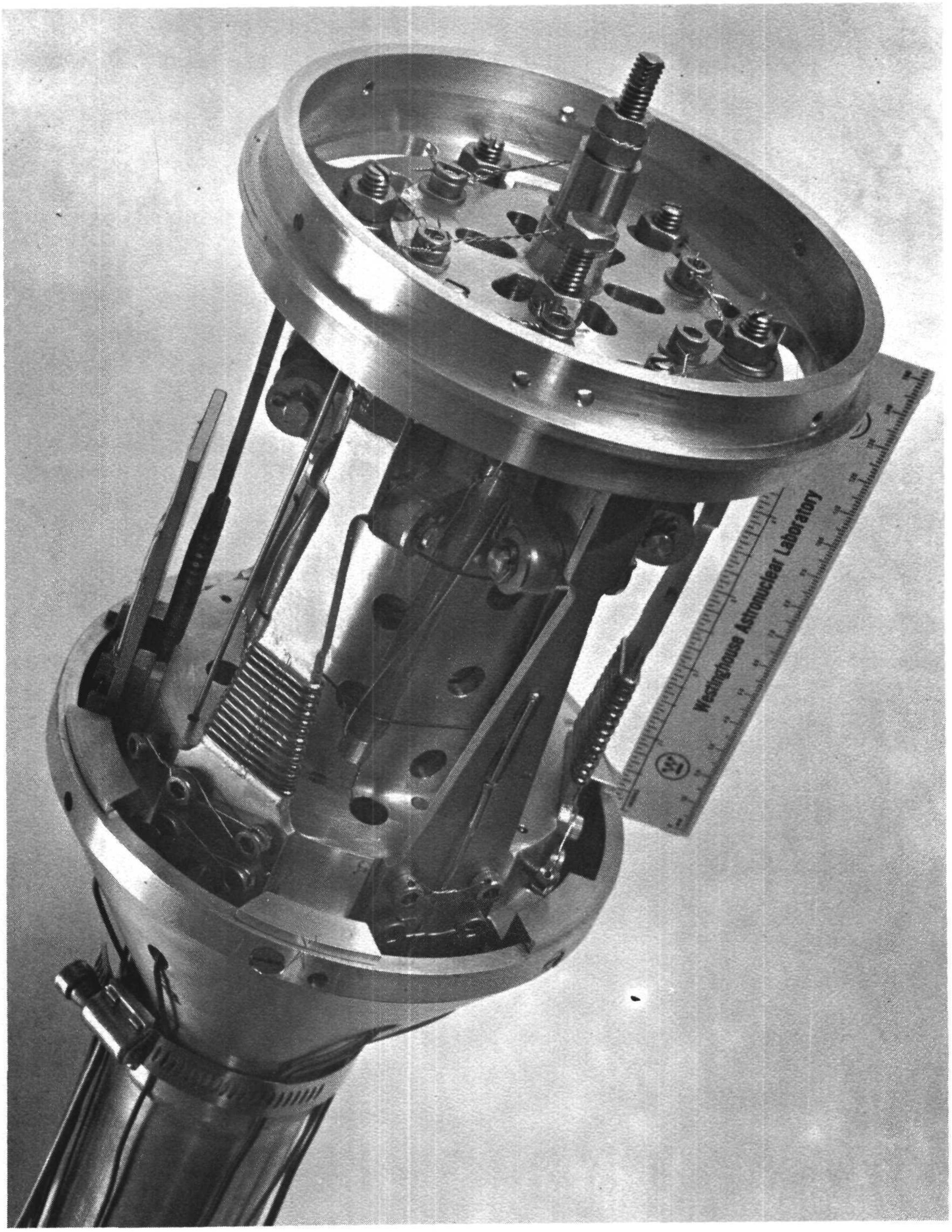


FIGURE 2

TABLE 1.3

Sequence of Strain Gage Fixture Position During Irradiation

	Time	
11/17/65	0055	Installed in WANL capsule
	0316	Started insertion
	0327	Capsule at 30" from fully inserted position
	0330	Completed data cycle
	0343	Inserted capsule to 20"
	0400	Inserted capsule to 12"
	0418	Inserted capsule to 5"
	0430	Capsule fully inserted
11/18/65	0848	Started removing capsule and stopped at 5"
	0914	Moved capsule from 5" to 12"
	0935	Moved capsule from 12" to 20"
	0955	Moved capsule from 20" to 30"
	1009	Started moving capsule from 30" to 120" (seal position)
	1018	Capsule in seal position
	1705	Removed strain gage test assembly from capsule

2.0 TEST DESCRIPTION

2.1 GENERAL

Strain gages are used in the NRX reactors on components such as tie rods, titanium core band and lateral support springs to measure vibration frequency, lateral support spring movement andstrains developed on reactor structural components during both cold flow and power tests of NRX reactors. The purpose of this experiment was to determine the performance of Budd bondable and Microdot weldable gages in a nuclear radiation environment. The experiment consisted of three parts. In the first part the effect of gamma dose rate on the insulation resistance of the gages and associated cabling was determined. During the second part, the test items were operated at the maximum gamma and neutron dose level for approximately 28 hours. This part provided performance data with respect to the integrated fast neutron flux that would be encountered in a one-hour full power NRX test. In the third part of the test, it was planned to determine the insulation resistance recovery as the gamma dose rate was decreased, and any other effects that might help to determine the zero shift encountered in previous irradiation tests.

2.2 SUMMARY OF TEST CONDITIONS

2.2.1 Items Tested

Eight unbacked foil gages manufactured by Budd. These were the C9-610 series gages and were bonded with "H" ceramic cement.

Six Microdot weldable gages. These were the Model SG-323/1 active-dummy gages, that is two types of sensing elements, an active and a dummy strain element into just one strain tube insulated with MgO powder and mounted on a flange assembly.

The arrangement used in the installation of the gages on the beams are tabulated in Table 2.1. The foil gages were connected in half bridge configuration. Each half bridge was encapsulated with tapered stainless steel bellows and provided with a 15-foot long, stainless steel sheathed, 3-conductor, MgO insulated cable, thus hermetically sealing the foil gage assembly against water and contamination.

2.2.2 Test Activities

During the irradiation of this experiment, the test fixture containing the strain gages was exposed to an average water pressure of 136 psig and a water temperature ranging from 90°F to 138°F. The strain gages experienced a total exposure of 1740 mw-hours. The temperature of the strain gage fixture and the water temperature was continually monitored throughout the irradiation. AC gage excitation was utilized for previous irradiation tests. However, for this test, in addition, DC excitation also was employed to simulate the data acquisition system at NRDS. The strain gage carrier output was recorded on a Baldwin-Lima-Hamilton strain indicator. The DC output was read from an EI type 883 digital multimeter, and at the same time it was recorded on a data logger. The insulation resistance was recorded by General Radio Megohmmeter type 1862-C. The gage continuity and gage resistance was also recorded by EI type 883 digital multimeter. The voltage output of each strain gage was measured at no load and full load.

The fixture was inserted into the reactor by means of the PBRF-WANL charging machine which provided the capability to adjust test fixture insertion depth at any time during the test.

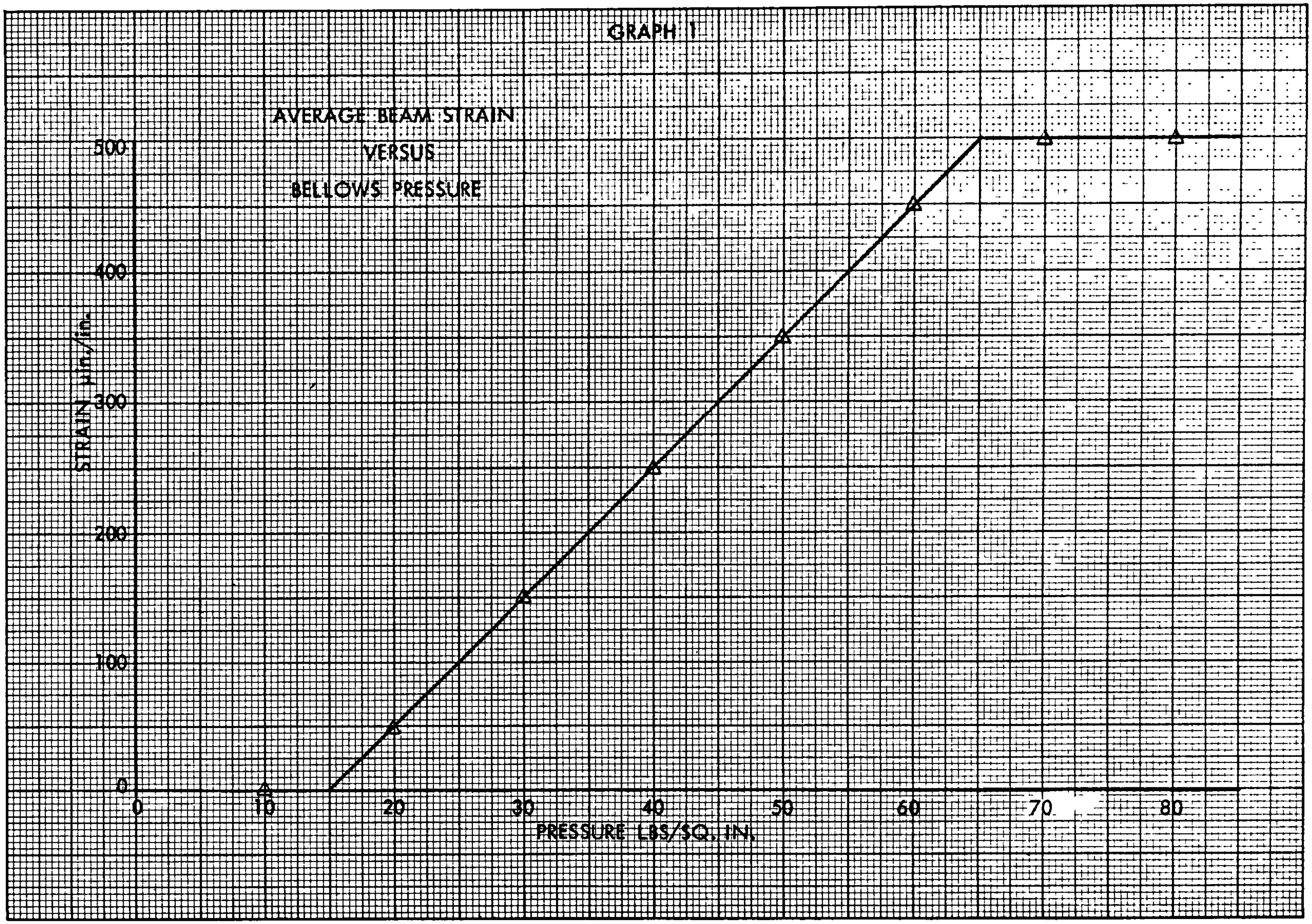
2.3 CALIBRATION OF THE GAGES

2.3.1 Strain Gage Output Calibration

Prior to irradiation of the strain gages a calibration test shown in Graph I was run to determine the strain gage output versus line pressure. As can be seen from this

TABLE 2.1

Gage Type	Strain Gage No.	Gage Location	Gage Installation
Budd C9-610	SG-1	Beam 1	Half bridge on opposite side of beam
Microdot SG-323/1	SG-2	Static part of fixture	Active-dummy static test
Microdot SG-323/1	SG-3	Static part of fixture	Active-dummy static test
Microdot SG-323/1	SG-4	Beam 2	Active-dummy tension test
Microdot SG-323/1	SG-5	Beam 2	Active-dummy compression test
Budd C9-610	SG-6	Beam 3	Half bridge on opposite sides of beam
Budd C9-610	SG-7	Beam 4	Half bridge 90° installation on the same side of beam
Microdot SG-323/1	SG-8	Beam 5	Active-dummy tension test
Microdot SG-323/1	SG-9	Beam 5	Active-dummy compression test
Budd C9-610	SG-10	Beam 6	Half bridge on opposite sides of beam


GRAPH 1
AVERAGE BEAM STRAIN
VERSUS
BELLOWS PRESSURE
STRAIN μin./in.
0
100
200
300
400
500
0
10
20
30
40
50
60
70
80
PRESSURE LBS/SQ. IN.

GRAPH 1

curve, the no-load position of the strain gage beam is established when the internal pressure of the bellows is 15 psig or less. The full load position on the other hand is accomplished when the internal pressure of the bellows is raised to 65 psig or more. These pressures were established with the ambient pressure at one atmosphere. When the fixture was inserted in the WANL mock-up loop where the ambient water pressure was raised to 150 psig, the no-load and full-load pressure points were 165 psig and 215 psig respectively.

2.3.2 Predicted Gamma Dose

The gamma dose rate expected in the HT-1 test location at a reactor power level of 60 mw is shown in Table 2.2 for the particular location of each transducer. These data were obtained by extrapolation of the curves in reference 5 and 6 which at this time represents the best available data. The data presented take into account the geometrical arrangements of the strain gages within the test capsule so that the gamma dose can be determined for any strain gage when capsule position (distance retracted from fully inserted) is known.

2.3.3 Predicted Fast Neutron Flux

Data obtained by the RE-2 dosimeter experiment described by reference 4 was used to estimate the neutron flux at the HT-1 location. From these data the predicted neutron flux rates are tabulated in Table 2.3 for the particular position of each strain gage at various test capsule positions. Six dosimeters were located on the fixture for this experiment. However, the analysis of these dosimeters are not available at the date of this report. The actual integrated neutron flux levels are determined by these dosimeters will be available later.

TABLE 2.2

Gamma Flux Levels at Strain Gage Locations

Gamma Flux ergs/gram (C)-hr

Capsule Position (Inches Retracted From Core Centerline)	Strain Gage Number									
	SG-1	SG-2	SG-3	SG-4	SG-5	SG-6	SG-7	SG-8	SG-9	SG-10
0	15.6×10^{10}	16.6×10^{10}	16.6×10^{10}	12.0×10^{10}	12.0×10^{10}	7.5×10^{10}	5.7×10^{10}	7.5×10^{10}	7.5×10^{10}	12.0×10^{10}
5	13.0×10^{10}	13.9×10^{10}	13.9×10^{10}	10.0×10^{10}	10.0×10^{10}	6.3×10^{10}	4.7×10^{10}	6.3×10^{10}	6.3×10^{10}	10.0×10^{10}
12	6.6×10^{10}	7.1×10^{10}	7.1×10^{10}	5.1×10^{10}	5.1×10^{10}	3.3×10^{10}	2.4×10^{10}	3.3×10^{10}	3.3×10^{10}	5.1×10^{10}
20	2.0×10^{10}	2.2×10^{10}	2.2×10^{10}	1.6×10^{10}	1.6×10^{10}	1.0×10^{10}	0.75×10^{10}	1.0×10^{10}	1.0×10^{10}	1.6×10^{10}
30	0.63×10^{10}	0.68×10^{10}	0.68×10^{10}	0.49×10^{10}	0.49×10^{10}	0.31×10^{10}	0.23×10^{10}	0.31×10^{10}	0.31×10^{10}	0.49×10^{10}
120	0	0	0	0	0	0	0	0	0	0

TABLE 2.3

Neutron Flux Levels at Strain Gage Locations

Neutron Flux (E> 1.0 Mev) n/cm^2-sec

Capsule Position (Inches Retracted From Core Centerline)	Strain Gage Number									
	SG-1	SG-2	SG-3	SG-4	SG-5	SG-6	SG-7	SG-8	SG-9	SG-10
0	20.4×10^{12}	20.4×10^{12}	20.4×10^{12}	16.2×10^{12}	16.2×10^{12}	12.0×10^{12}	9.4×10^{12}	12.0×10^{12}	12.0×10^{12}	16.2×10^{12}
5	16.2×10^{12}	16.2×10^{12}	16.2×10^{12}	13.8×10^{12}	13.8×10^{12}	9.0×10^{12}	7.5×10^{12}	9.0×10^{12}	9.0×10^{12}	13.8×10^{12}
12	8.0×10^{12}	8.0×10^{12}	8.0×10^{12}	6.3×10^{12}	6.3×10^{12}	3.9×10^{12}	3.0×10^{12}	3.9×10^{12}	3.9×10^{12}	6.3×10^{12}
20	3.0×10^{12}	3.0×10^{12}	3.0×10^{12}	1.8×10^{12}	1.8×10^{12}	0.6×10^{12}	0.45×10^{12}	0.6×10^{12}	0.6×10^{12}	1.8×10^{12}
30	0.75×10^{12}	0.75×10^{12}	0.75×10^{12}	0.21×10^{12}	0.21×10^{12}	0.03×10^{12}	0.03×10^{12}	0.03×10^{12}	0.03×10^{12}	0.21×10^{12}
120	0	0	0	0	0	0	0	0	0	0

3.0 WELDABLE AND BONDABLE STRAIN GAGE OPERATION IN RADIATION FIELD

3.1 TEST RESULTS AND ANALYSIS

The following strain gage parameters were measured during this test:

a. Insulation Resistance

b. Sensitivity Shift

c. Zero Shift

3.1.1 Insulation Resistance

An analysis of the insulation measurement data, tabulated on Table 3.1 and 3.2 for each gage, indicates that an average curve for the bondable gages and another one for the weldable gages will be reasonably sufficient to show the nuclear effect on the insulation resistance of these units. These two curves are shown in Graphs 2 and 3. As can be seen from the graphs the average insulation resistance for the Microdot gages at fully inserted position were 60 megohms while for the Budd gages bonded with "H" ceramic cement this was 120 megohms. The decrease in insulation resistance is predominantly a gamma rate effect as can be seen from the two plots. This is demonstrated in part 1 and 3 of the experiment. During part 2 very small change in insulation resistance was recorded. This indicates that the integrated neutron or gamma flux has very little effect on this property. The insulation resistance of No. 1 Budd bondable gage decreased from 440 megohms to 2 megohms when the fixture was fully inserted. Since this was not observed with the other bondable gages where the same technique of bonding was used, it is postulated that in the case of No. 1 gage the low insulation resistance may be attributed to contamination of the bonding agent. In general, the insulation resistance of these gages, in the fully inserted position, are high enough so that serious adverse effects on strain gage performance will not result during the NRX reactor test.

TABLE 3.1

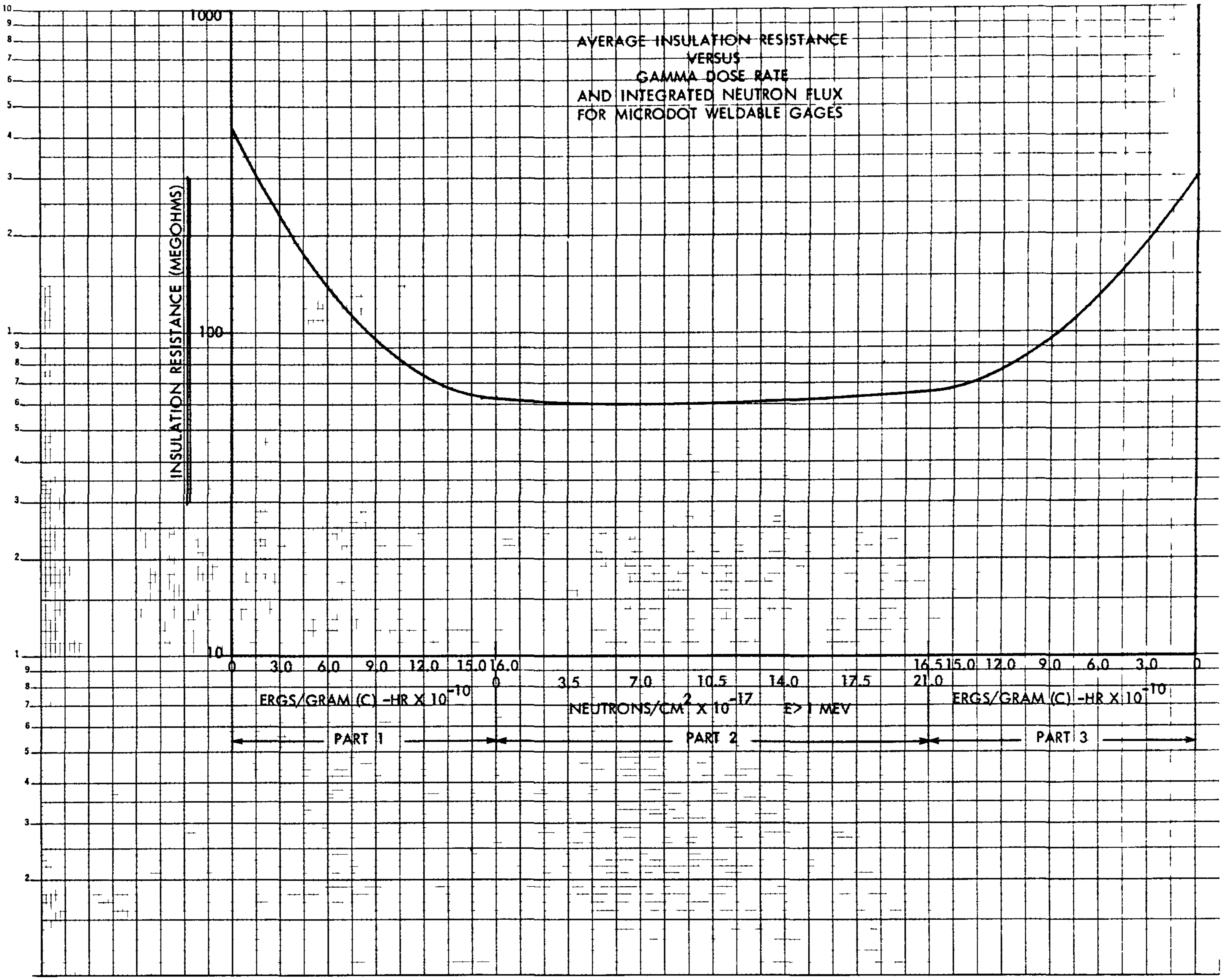
Insulation Resistance
Microdot Weldable Gages

Capsule Position (Inches Retracted From Core Centerline)	Run No.	SG-2	SG-3	SG-4	SG-5	SG-8	SG-9
120	2	600	490	580	500	450	540
30	3	500	250	400	400	400	450
20	4	300	120	220	350	300	400
12	5	130	35	64	160	150	250
5	6	80	20	35	90	100	180
0	7	50	20	30	68	74	120
0	8	63	20	30	68	74	125
0	9	66	23	33	70	74	130
0	10	66	20	35	70	72	130
0	11	69	23	35	73	76	135
0	12	69	23	33	71	74	130
0	13	69	22	33	70	74	135
0	14	70	20	35	70	73	130
0	15	70	20	35	70	74	130
0	16	72	22	35	70	70	130
0	17	72	20	35	68	70	140
0	18	74	24	35	63	70	140
0	19	74	24	35	64	60	140
0	20	75	23	35	62	66	140
0	21	72	25	35	60	65	140
5	22	95	20	40	70	70	190
12	23	150	45	75	120	85	300
20	24	400	170	250	250	120	450
30	25	500	400	500	400	130	500
120	26	700	450	500	400	120	500
120	27	680	430	600	400	120	580

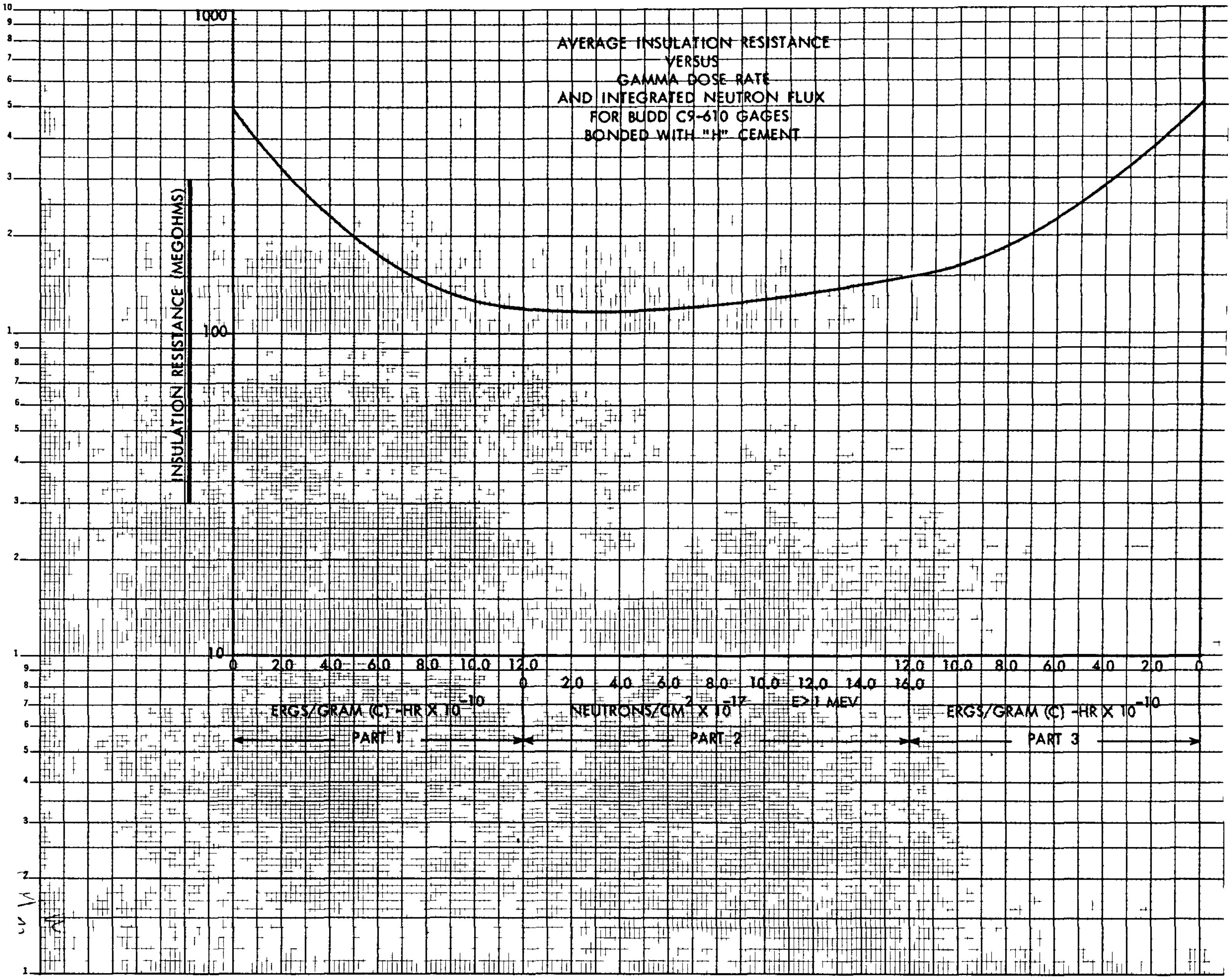
TABLE 3.2

Insulation Resistance
Budd Bondable Gage

Capsule Position (Inches Retracted From Core Centerline)	Run No.	SG-1	SG-6	SG-7	SG-10
120	2	440	560	620	480
30	3	420	450	500	400
20	4	250	400	500	300
12	5	110	300	300	150
5	6	2	200	200	90
0	7	1.5	140	150	70
0	8	12	150	160	80
0	9	10	160	170	85
0	10	2	150	170	85
0	11	2	165	185	91
0	12	5	160	175	92
0	13	3	160	180	92
0	14	2	160	170	95
0	15	3	150	180	100
0	16	2	160	180	95
0	17	3	170	190	100
0	18	4	170	190	100
0	19	5	170	190	100
0	20	5	170	195	100
0	21	5	170	190	100
5	22	2.5	200	250	130
12	23	35	350	400	200
20	24	130	500	500	350
30	25	190	500	500	500
120	26	200	550	600	500
120	27	200	600	700	560


AVERAGE INSULATION RESISTANCE
VERSUS
GAMMA DOSE RATE
AND INTEGRATED NEUTRON FLUX
FOR MICRODOT WELDABLE GAGES
INSULATION RESISTANCE (MEGOHMS)
1000
100
10
0 3.0 6.0 9.0 12.0 15.0 16.0
ERGS/GRAM (C) -HR X 10^{-10}
0 3.5 7.0 10.5 14.0 17.5 21.0
NEUTRONS/CM^2 X 10^{-17} E>1 MEV
16.5 15.0 12.0 9.0 6.0 3.0 0
ERGS/GRAM (C) -HR X 10^{-10}
PART 1
PART 2
PART 3

GRAPH 2


AVERAGE INSULATION RESISTANCE
VERSUS
GAMMA DOSE RATE
AND INTEGRATED NEUTRON FLUX
FOR BUDD C9-610 GAGES
BONDED WITH "H" CEMENT
INSULATION RESISTANCE (MEGOHMS)
1000
100
10
0 2.0 4.0 6.0 8.0 10.0 12.0
0 2.0 4.0 6.0 8.0 10.0 12.0 14.0 16.0
12.0 10.0 8.0 6.0 4.0 2.0 0
ERGS/GRAM (C) -HR X 10-10
NEUTRONS/CM2 X 10-17 E>1 MEV
ERGS/GRAM (C) -HR X 10-10
PART 1
PART 2
PART 3

GRAPH 3

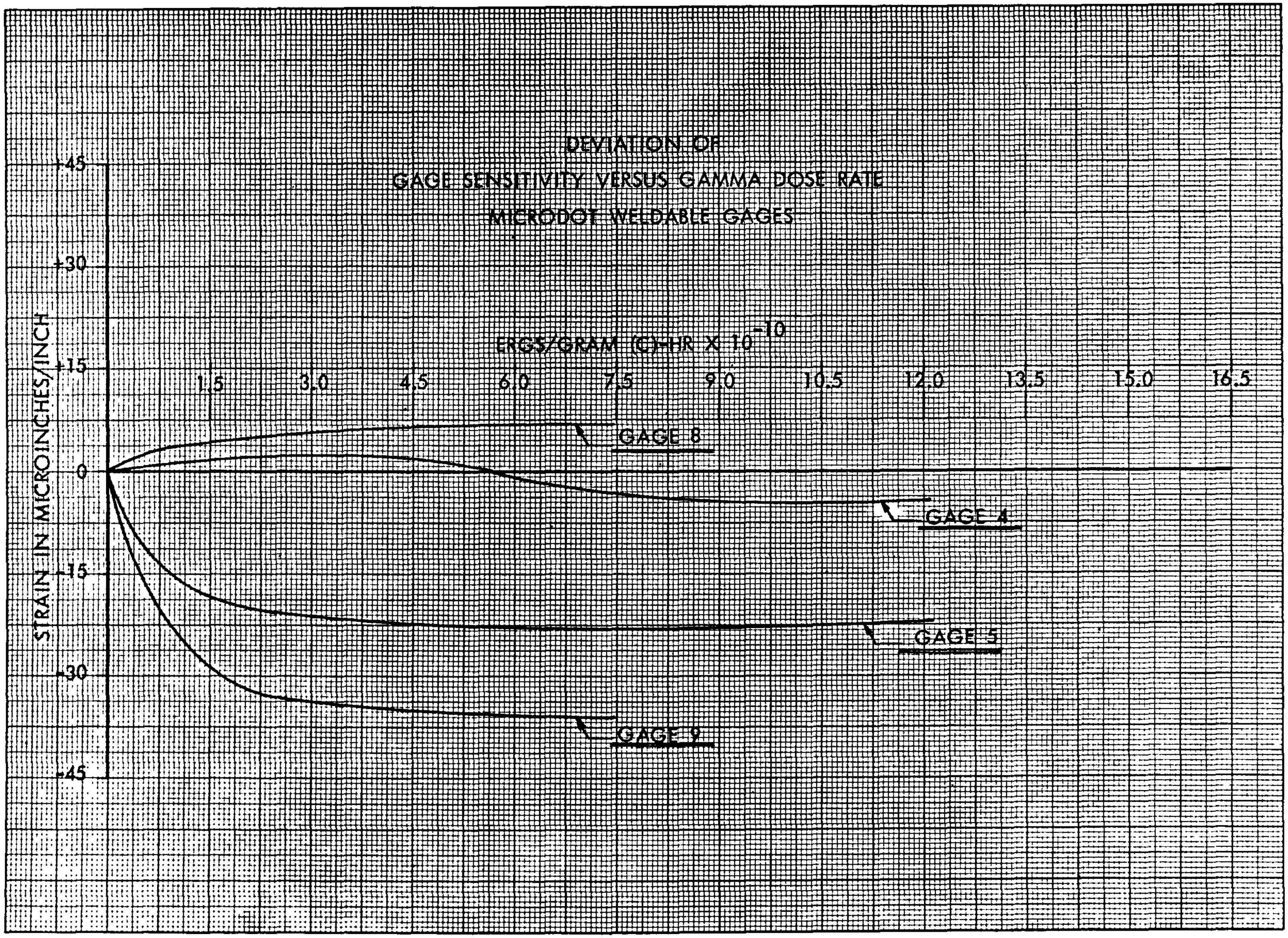
3.1.2 Deviation of Strain Gage Sensitivity

The graphs 4 through 7 show the average sensitivity change of the strain gages for a 500 microinches/inch strain level. Graphs 4 and 5 show sensitivity deviation versus gamma dose rate while graphs 6 and 7 show sensitivity deviation versus integrated neutron flux. While Tables 3.3 and 3.4 are individual strain gage output data points for the Microdot weldable and Budd bondable gages respectively. As can be seen from the plots, the sensitivity variation due to integrated neutron flux was less than $\pm$ 10 microinches per inch for the Budd bondable gages and $\pm$ 20 microinches per inch for the Microdot weldable gages. Since the data acquisition system accuracy is within $\pm$ 10 microinches per inch, the effects of integrated neutron flux to the strain gage sensitivity can be neglected. Sensitivity decrease due to gamma dose rate was not more than 40 microinches per inch. This decrease in sensitivity was caused by gamma ionization shunting effect on the strain gage bridge circuit and desensitization of the data acquisition system was attributed to noise level increases observed in the signal lines when the strain gage fixture was inserted closer to the reactor core centerline. Therefore, it can be concluded that radiation encountered in the NRX reactors will not change the sensitivity of these gages by more than 1 or 2 per cent.

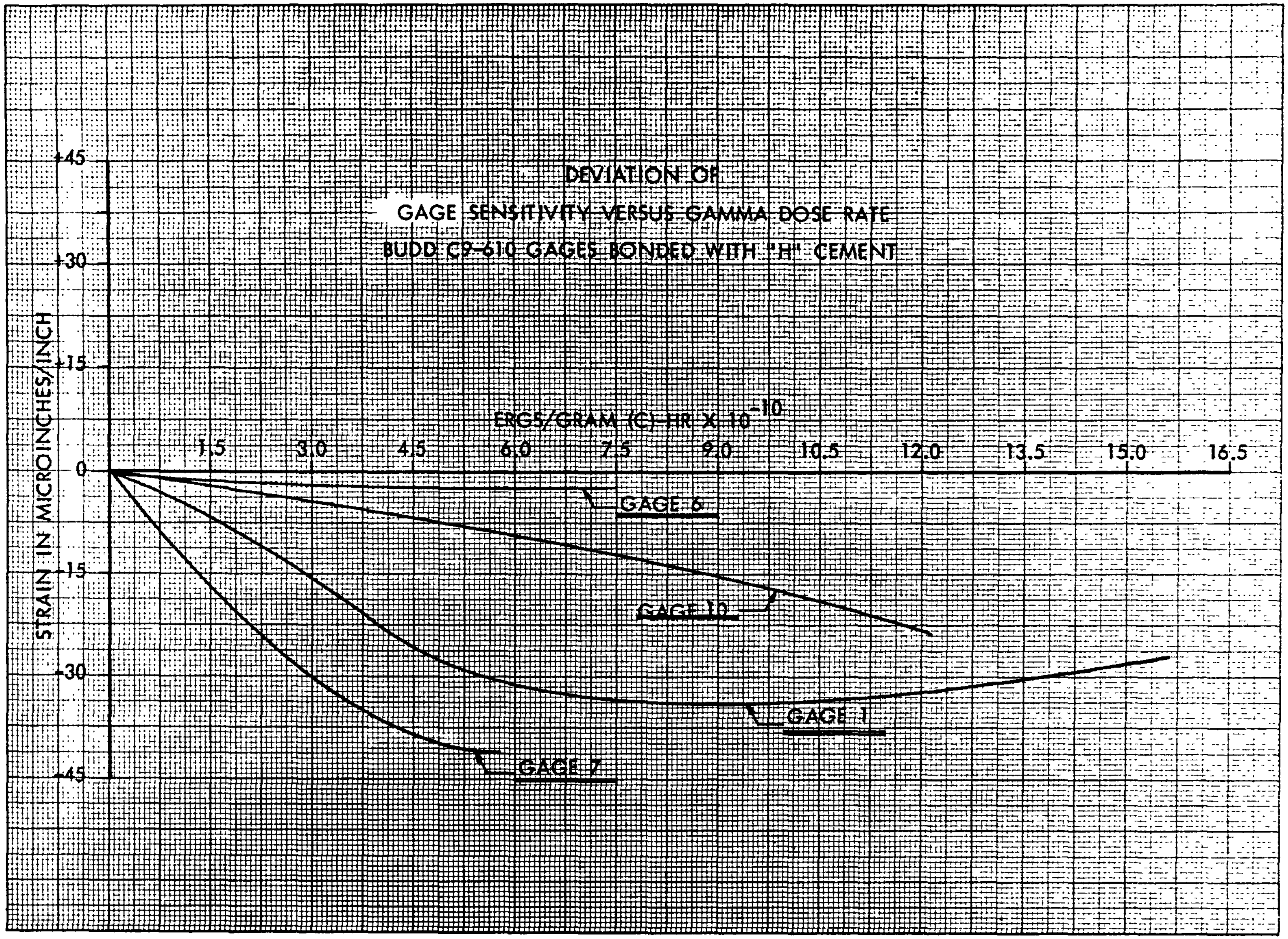
3.3.3 Zero Shift

Graphs 8 and 9 show the zero shift observed for Microdot weldable and Budd bondable gages respectively. Microdot weldable gages mounted on the same beams were exposed to the same integrated neutron flux. These gages indicated a zero shift that was of the same magnitude. Therefore, the gages were grouped in pairs for this plot and the average zero shift value was utilized for each pair of gages. The error expected due to the pairing of the Microdot gages is insignificant as compared to the total zero shift encountered during the irradiation test.

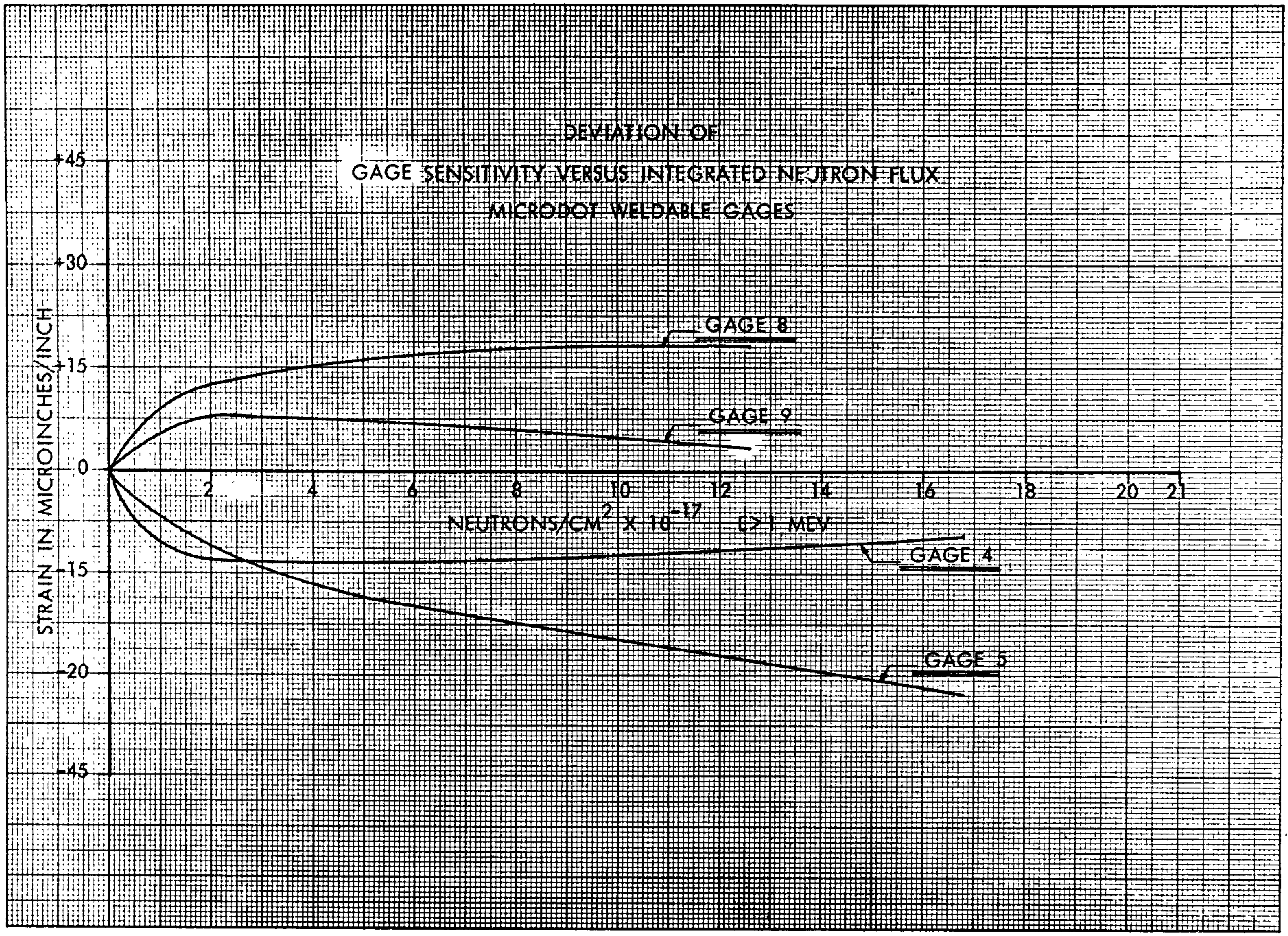
The four plots on graph 9 show the zero shift observed for the Budd bondable gages. Due to the position of the gages on the strain gage fixture, the total integrated neutron flux, for the duration of the test, was 1×10^{18} nvt for the gages furthest from the reactor core centerline as compared to 2.1×10^{18} nvt for those closest to the reactor core centerline.


DEVIATION OF
GAGE SENSITIVITY VERSUS GAMMA DOSE RATE
MICRODOT WELDABLE GAGES
ERGS/GRAM (C)-HR X 10^{-10}
1.5
3.0
4.5
6.0
7.5
9.0
10.5
12.0
13.5
15.0
16.5
STRAIN IN MICROINCHES/INCH
+45
+30
+15
0
-15
-30
-45
GAGE 8
GAGE 4
GAGE 5
GAGE 9

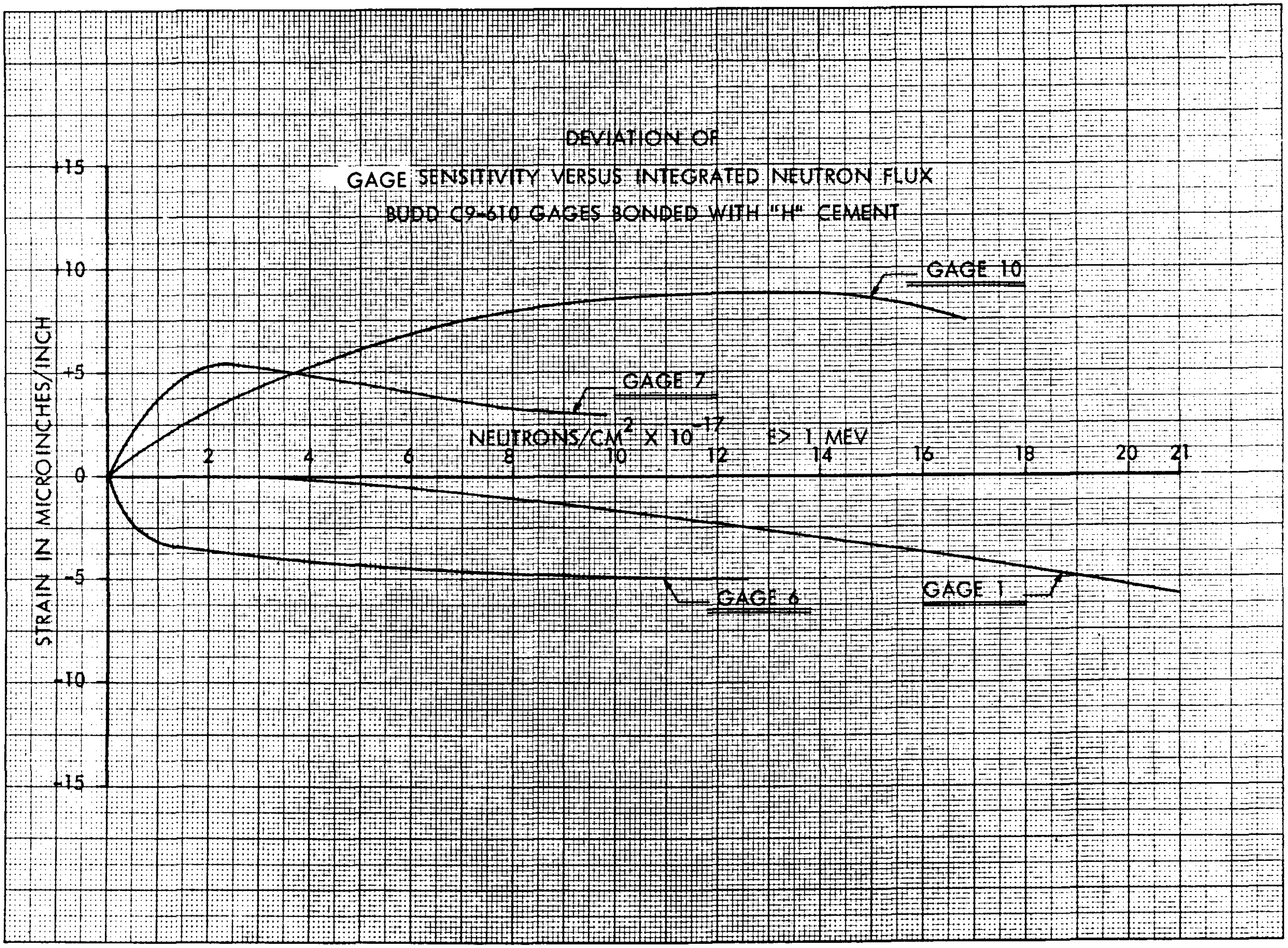
GRAPH 4


DEVIATION OF
GAGE SENSITIVITY VERSUS GAMMA DOSE RATE
BUDD C9-610 GAGES BONDED WITH "H" CEMENT
STRAIN IN MICROINCHES/INCH
+45
+30
+15
0
-15
-30
-45
ERGS/GRAM (C)-HR X 10^-10
1.5
3.0
4.5
6.0
7.5
9.0
10.5
12.0
13.5
15.0
16.5
GAGE 6
GAGE 10
GAGE 1
GAGE 7

GRAPH 5


DEVIATION OF
GAGE SENSITIVITY VERSUS INTEGRATED NEUTRON FLUX
MICRODOT WELDABLE GAGES
STRAIN IN MICROINCHES/INCH
+45
+30
+15
0
-15
-20
-45
2
4
6
8
10
12
14
16
18
20
21
NEUTRONS/CM² X 10⁻¹⁷ E>1 MEV
GAGE 8
GAGE 9
GAGE 4
GAGE 5

GRAPH 6


DEVIATION OF
GAGE SENSITIVITY VERSUS INTEGRATED NEUTRON FLUX
BUDD C9-610 GAGES BONDED WITH "H" CEMENT
STRAIN IN MICROINCHES/INCH
+15
+10
+5
0
-5
-10
-15
NEUTRONS/CM^2 X 10^{-17} E> 1 MEV
2
4
6
8
10
12
14
16
18
20
21
GAGE 10
GAGE 7
GAGE 6
GAGE 1

GRAPH 7

TABLE 3.3

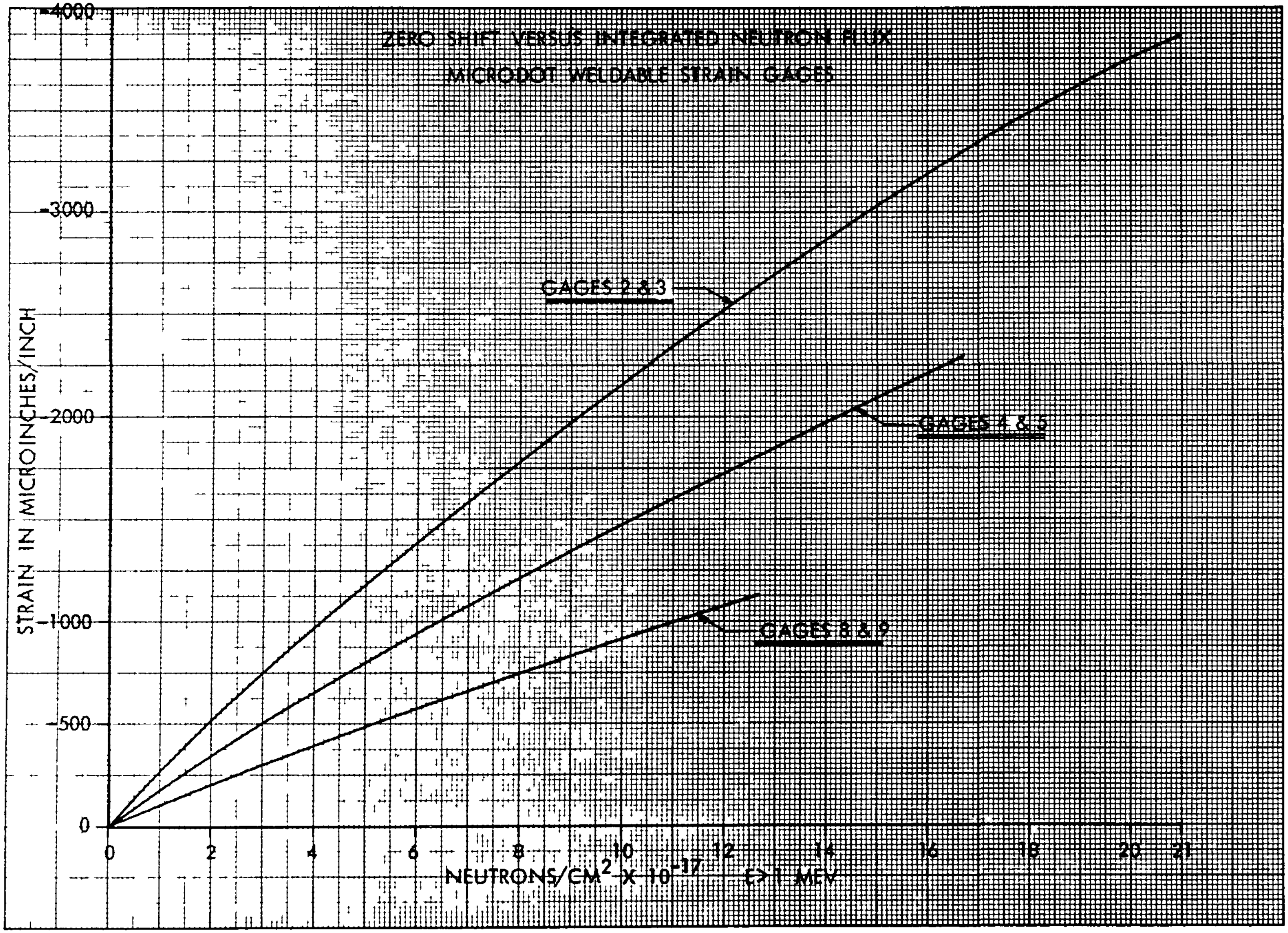
Strain Gage Output (Microinches) Under Full Load
Microdot Weldable Gages

Capsule Position (Inches Retracted From Core Centerline)	Run No.	SG-4	SG-5	SG-8	SG-9
120	2	+570	-528	+644	-524
30	3	+596	-518	+646	-500
20	4	+594	-510	+648	-494
12	5	+598	-506	+644	-490
5	6	+590	-506	+652	-488
0	7	+594	-508	+644	-488
0	8	+580	-500	+656	-492
0	9	+582	-498	+656	-498
0	10	+584	-490	+660	-490
0	11	+582	-478	+662	-496
0	12	+584	-490	+660	-494
0	13	+580	-488	+660	-492
0	14	+596	-484	+654	-494
0	15	+582	-486	+652	-492
0	16	+586	-490	+658	-496
0	17	+586	-484	+658	-490
0	18	+580	-478	+666	-490
0	19	+588	-470	+664	-488
0	20	+590	-474	+664	-492
0	21	+580	-476	+662	-488
5	22	+588	-474	+666	-494
12	23	+584	-468	+662	-488
20	24	+588	-462	+664	-490
30	25	+594	-464	+666	-490
120	26	+588	-466	+664	-492
120	27	+586	-468	+664	-488

TABLE 3.4

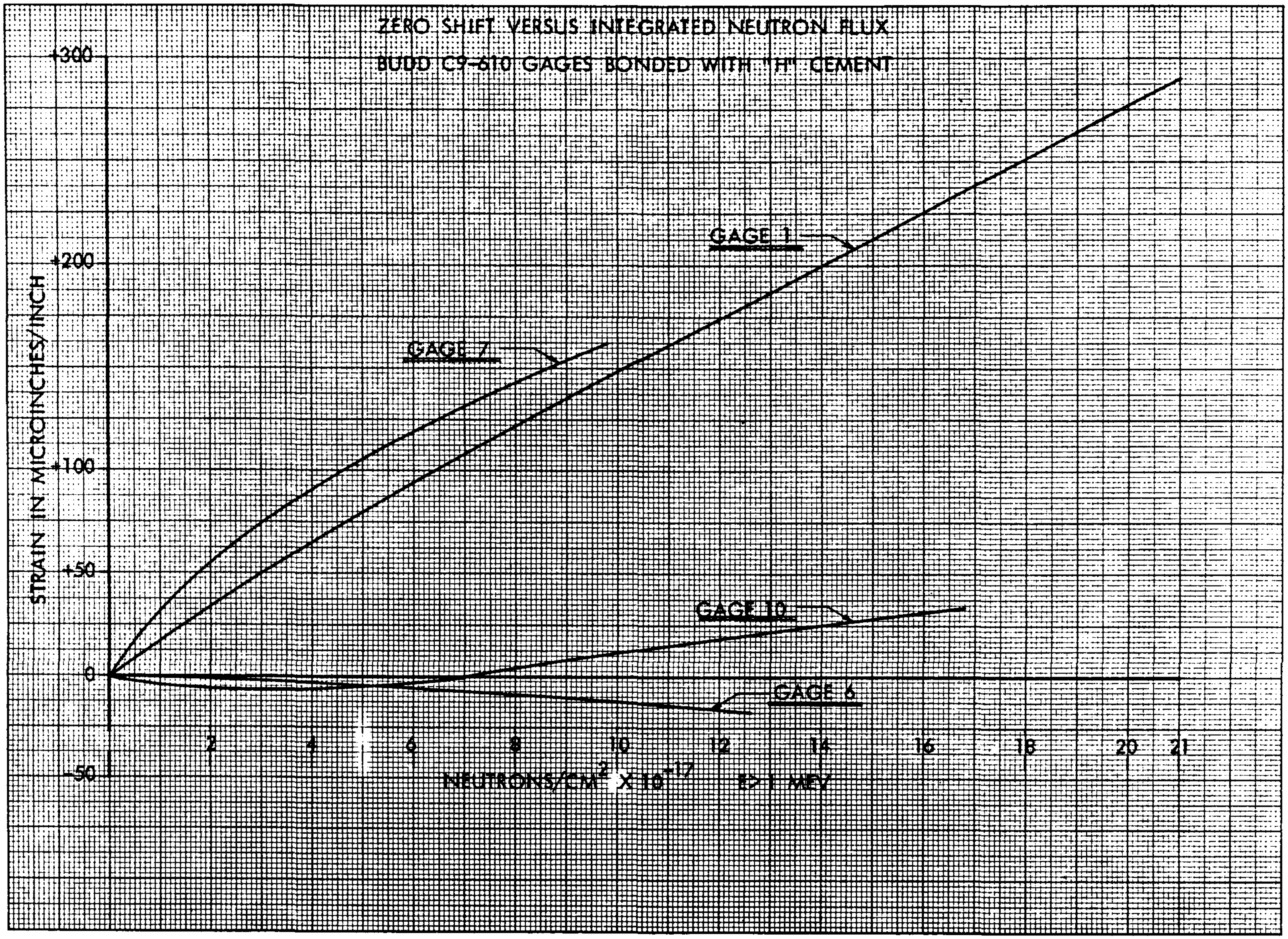
Strain Gage Output (Microinches) Under Full Load
Budd Bondable Gages

Capsule Position (Inches Retracted From Core Centerline)	Run No.	SG-1	SG-6	SG-7	SG-10
120	2	518	495	494	514
30	3	513	467	494	517
20	4	509	496	486	514
12	5	485	493	466	505
5	6	488	494	456	496
0	7	491	494	454	489
0	8	492	489	456	492
0	9	489	490	454	493
0	10	491	491	460	493
0	11	488	492	462	495
0	12	494	489	458	497
0	13	493	490	456	497
0	14	488	489	458	495
0	15	488	492	458	499
0	16	487	490	456	495
0	17	475	490	456	498
0	18	488	492	456	499
0	19	487	486	458	500
0	20	488	490	458	497
0	21	482	492	456	495
5	22	491	494	456	500
12	23	498	498	468	506
20	24	505	500	486	519
30	25	508	505	492	524
120	26	509	503	494	524
120	27	508	500	494	522



ZERO SHIFT VERSUS INTEGRATED NEUTRON FLUX
MICRODOT WELDABLE STRAIN GAGES
GAGES 2 & 3
GAGES 4 & 5
GAGES 8 & 9
STRAIN IN MICROINCHES/INCH
-4000
-3000
-2000
-1000
-500
0
0 2 4 6 8 10 12 14 16 18 20 21
NEUTRONS/CM^2 X 10^{-17} E>1 MEV

GRAPH 8


ZERO SHIFT VERSUS INTEGRATED NEUTRON FLUX
BUDD C9-610 GAGES BONDED WITH "H" CEMENT
GAGE 1
GAGE 7
GAGE 10
GAGE 6
STRAIN IN MICROINCHES/INCH
+300
+200
+100
+50
0
-50
2
4
6
8
10
12
14
16
18
20
21
NEUTRONS/CM^2 X 10^{-17} E>1 MEV

GRAPH 9

3.1.3.1 Budd Gages

Budd foil gages bonded with "H" ceramic cement indicates a zero shift of less than ± 25 microinches per inch. This zero shift may be caused due to the following effects:

a. Oxidation of the foil gage surface.
b. Differential expansion of the ceramic cement.
c. Interaction effects of expansion coefficient of wire, cement and specimen.
d. Leakage resistance from gage to ground.

The high zero shift for the SG-1 Budd gage was attributed to the low insulation resistance observed during the irradiation test run, this may be caused due to improper curing or contamination of the ceramic cement. A zero shift of 165 microinches per inch was recorded for the SG-7 Budd gage at a total integrated neutron flux of 1×10^{18} nvt. It is postulated that the higher zero shift in this gage may be attributed to the 90^{o} installation of the compensating gage.

3.1.3.2 Microdot Weldable Gages

Six Microdot weldable gages were attached to three beams by resistance welding methods. Gages SG-2 and SG-3 were attached to a beam and evaluated under static test conditions, in this mode of operation the beam did not deflect during the entire test cycle. Gages SG-4 and SG-5 were attached to beam 2 with the gage SG-4 attached to the inner surface of the beam while SG-5 gage was attached to the outer surface of the beam. In this arrangement SG-4 was in tension and SG-5 was in compression when the beam was deflected by the bellows. In the same manner gages SG-8 and SG-9 were attached to beam 5 with SG-8 gage being in tension and SG-9 gage being in compression when the beam was deflected by the bellows.

As can be seen from graph 8 the zero shift for the active-dummy weldable gages did not depend on the mode of loading (tension or compression) as was suspected from the results obtained during the previous irradiation test runs. But analysis of the results indicate that the zero shift is a function of neutron dose rate and integrated effect. Possible causes of the observed zero shift may be due to the following effects.

a. Degradation of the MgO insulation due to irradiation.

b. A differential resistance change between the active and dummy element in a given strain gage due to differential dimensional change under irradiation between a simple wire and a wire wound in a tight helix of the proper pitch angle.

c. Degradation of spot weld due to irradiation.

3.2 HOT CELL EXAMINATION

After completion of the irradiation the test capsule was removed from the reactor and the test fixture was transferred to the hot cell for examination. The test fixture was disassembled in the hot cell and the strain gages were examined and photographed. Preliminary evaluation of hot cell examination does not indicate any deterioration of the spot welds or the ceramic cement. More detailed investigations will be performed when the photographs are received showing close-up views of the flange welds and surface of the ceramic cement.

4.0 CONCLUSIONS AND RECOMMENDATIONS

The test results indicate that the Budd foil gages bonded with "H" ceramic cement and Microdot weldable gages can survive the radiation levels experienced in the Plum Brook Reactor Facility. However, a detailed analysis of the strain gage performance has resulted in the following conclusions.

4.1 BUDD GAGES BONDED WITH "H" CEMENT

a. The average insulation resistance of these gages decreases from 500 megohms at room temperature to 120 megohms at a gamma dose rate of 1.2×10^{11} ergs/gram (c)-hr.

b. An average sensitivity decrease of 30 microinches per inch can be expected for gamma dose rate of 1.2×10^{11} ergs/gram (c)-hr.

c. No sensitivity change due to integrated neutron flux of 2.1×10^{18} neutrons/cm^2 is expected.

d. An average zero shift of $\pm$ 50 microinches per inch is expected for an integrated neutron flux of 2.1×10^{18} neutrons/cm.^{2} The above zero shift holds true for a half bridge configuration with the gages bonded at 180° rather than at 90°.

e. A postirradiation test revealed that the strain gage insulation resistance recovered and that no visible cracks were observed on the surface of the ceramic cement.

f. Based upon the Plum Brook test results, it is concluded that the Budd series "C" foil gages can be used for NRX application, such as the tie rods, lateral support springs, and titanium core band with an estimated overall accuracy of $\pm$ 100 microinches per inch for an one hour, full power NRX test duration.

4.2 MICRODOT WELDABLE GAGES

a. The average insulation resistance of these gages decreased from 400 megohms at room temperature to 60 megohms at a gamma dose rate of 1.6×10^{11} ergs/gram (c)-hr.

b. An average sensitivity decrease of 30 microinches per inch can be expected for a gamma dose rate of 1.6×10^{11} ergs/gram (c)-hr.

c. No sensitivity change due to integrated neutron flux of 2.1×10^{18} neutrons/cm^2, is expected.

d. The Microdot weldable gages experienced a wide zero shift during this test. Since the curves of zero shift for the individual gages are monotonic and do not cross each other, therefore, they can be represented by an approximate straight line function

$Z = (0.9 \times 10^{-28})$ (R) (N)

where Z = Zero shift in microinches per inch

R = Neutron rate (neutrons/cm^2-sec)

N = Total neutron flux (neutrons/cm^2).

e. Based upon the Plum Brook test results, it is concluded that the Microdot weldable active-dummy gages can be used for NRX application, such as the tie rods, lateral support springs and titanium core band with an estimated overall accuracy of $\pm$ 500 microinches per inch for an one hour, full power NRX test duration. However, to achieve this accuracy a zero shift correction must be added utilizing the above straight line function.

For vibrational measurements where the strain gage output is capacitively coupled to the data acquisition system an overall accuracy of $\pm$ 100 microinches per inch can be achieved.

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