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AEC-NASA SPACE NUCLEAR PROPULSION OFFICE

FINAL TEST REPORT RTT TEST 23/L101

NERVA PROGRAM DECEMBER 1964 CONTRACT SNP-1

RECEIVED

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ABSTRACT

Eleven Platinum wire resistance temperature transducers were irradiated for fifty hours in liquid hydrogen at the Ground Test Reactor (GD/FW) during April 1964 (Test 23/L101-GTR-12A). Five Rosemount Model 134EB, two Rosemount Model 110AA, and four Winsco Model 2448-5 RTT's were subjected to integrated fast neutron fluxes as high as 9.9×10^{15} nvt ($E > 2.9$ Mev) while being maintained at -423°F . The results of this test followed closely the predicted performance with respect to temperature measurement errors (2.0 to 6.0°F); however three transducer circuits (two Winsco Model 2448-5 and one Rosemount Model 110AA) experienced open circuits during irradiation.

for W. D. Stinnett
Program Manager
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I. INTRODUCTION

The NERVA Program requires several precise cryogenic temperature measurement systems. For example, a temperature difference of 0.054°F in the inlet temperature of hydrogen flowing into the NERVA pump represents five feet of vapor pressure head (net positive suction pressure). In addition cryogenic temperatures must be accurately measured in the thrust chamber and at other locations throughout the NERVA propellant feed-line system. Aerojet designed a cryogenic temperature measuring system to satisfy these requirements and this report summarizes the results of the first cryogenic irradiation test (test 23/L101) of three candidate resistance temperature-transducers.

II. SUMMARY AND RECOMMENDATIONS

A. RTT COMPONENT EVALUATION

The effects of radiation at cryogenic temperatures on the subject RTT's are summarized in Tables I and II. Estimated temperature measurement errors for each type of transducer are included in Table I for various NERVA RTT locations; whereas the fast neutron damage coefficients for resistance changes and temperature measurement errors are contained in Table II.

1. Rosemount Model 134EB

The test data indicate that the Rosemount Model 134EB RTT is the best transducer, both with respect to surviving in a radiation environment and for minimum temperature measurement error. Based on experimental data, temperature measurement errors of 2.9°F are anticipated for NERVA conditions. It is believed, however, that the temperature-measurement errors can be reduced for this unit by reducing the mandrel size (reduces gamma heating) and using the largest diameter wire compatible with sensitivity and manufacturing requirements. Test components modified as indicated above are scheduled for irradiation testing during the next few months.

2. Rosemount Model 110AA

Based on the experimental data presented herein, it is doubtful if this design can function reliably throughout a 30 minute NERVA test. If this unit is employed at locations THPFL, THNM, or THNMI, it should function for NERVA tests of approximately 20 minute duration; however, errors as large as 5°F will be observed. This unit would only function for 5 minute tests at the THNTO location. As this unit may be required for limited applications (shallow depth measurements) additional testing is scheduled for higher integrated fast neutron fluxes.

TABLE I

RTT TEST DATA SUMMARY

Error Analyses (Temperature Errors Anticipated)

Transducer Type	Units Tested	Units Failed	GTR - Test Environment*			NERVA Environment** THNMI, THPFL, & THNM Locations			NERVA Environment*** THNTO Location		
			Gamma Heating (°F)	Fast Neutron (°F)	Total Error (°F)	Gamma Heating (°F)	Fast Neutron (°F)	Total Error (°F)	Gamma Heating (°F)	Fast Neutron (°F)	Total Error (°F)
Rosemount- 134EB	5	0	0.65	2.1	2.8	0.9	2.0	2.9	1.7	5.2	6.9
Rosemount- 110AA	2	1	0.50 (Failure Anticipated)	8.0	8.5	0.45 (Failure Anticipated)	7.1	7.6	1.0 (Failure Anticipated)	14.0	15.0
Winsco- 2448-5	4	2	0.75	4.5	5.2	1.1	4.0	5.1	2.0 (Failure Anticipated)	8.0	10.0

* Gamma dose rate = 2.4×10^9 ergs/gm(C)-hr; Integrated fast neutron flux ($E > 1.0$ Mev) = 2.4×10^{16} neutrons/cm²

** RTT - Locations THNMI, THNM, & THPFL-Gamma dose rate = 7.2×10^9 ergs/gm(C)-hr; Integrated fast neutron flux ($E > 1.0$ Mev) = 2×10^{16} neutrons/cm² (assumes a 30 minute reactor test)

*** RTT location THNTO - Gamma dose rate = 3.6×10^{10} ergs/gm(C)-hr; Integrated fast neutron flux ($E > 1.0$ Mev) = 1.1×10^{17} neutrons/cm² (assumes a 30 minute reactor test)

TABLE II

FAST NEUTRON DAMAGE COEFFICIENTS

Transducer Type	Serial Number	Resistance Coefficient % R/n/cm ²	Temperature Coefficient °F/n/cm ²
Rosemount-134EB	4079	14 x 10 ⁻¹⁶	1.7 x 10 ⁻¹⁶
Rosemount-134EB	4080	18 x 10 ⁻¹⁶	2.1 x 10 ⁻¹⁶
Rosemount-134EB	5381	11 x 10 ⁻¹⁶	1.5 x 10 ⁻¹⁶
Rosemount-134EB	4107	12 x 10 ⁻¹⁶	1.3 x 10 ⁻¹⁶
Rosemount-134EB	4087	12 x 10 ⁻¹⁶	1.0 x 10 ⁻¹⁶
Rosemount-134EB (Average)		14 x 10 ⁻¹⁶	1.5 x 10 ⁻¹⁶
Rosemount-110 AA	209	63 x 10 ⁻¹⁶	8.0 x 10 ⁻¹⁶
Rosemount-110 AA	211	61 x 10 ⁻¹⁶	9.0 x 10 ⁻¹⁶
Rosemount-110 AA (Average)		62 x 10 ⁻¹⁶	8.5 x 10 ⁻¹⁶
Winsco-2448-5	156	43 x 10 ⁻¹⁶	6.1 x 10 ⁻¹⁶
Winsco-2448-5	158	30 x 10 ⁻¹⁶	3.6 x 10 ⁻¹⁶
Winsco-2448-5	159	21 x 10 ⁻¹⁶	2.7 x 10 ⁻¹⁶
Winsco-2448-5	157	17 x 10 ⁻¹⁶	2.5 x 10 ⁻¹⁶
Winsco-2448-5 (Average)		28 x 10 ⁻¹⁶	3.7 x 10 ⁻¹⁶

3. Winsco Model 2448-5

The Winsco unit is basically the same design as the Rosemount Model 134EB, the primary difference being in the wire diameter of the sensing element. Also, the purity and work condition of the platinum may have been different. Additional tests are scheduled for this unit.

B. EFFECT OF TEST DATA ON NERVA REQUIREMENTS

Accurate and reliable measurements of LH_2 temperatures are required for the turbopump and at other locations throughout all test phases of NERVA. The data presented in this report emphasizes the necessity of compensating the RTT output to nullify the effects of radiation, otherwise the design requirements cannot be achieved.

The experimental data verified the predictions contained in the pre-irradiation analysis (Reference 1) - i.e. there are two primary sources of error in temperature measurement error, (1) the error caused by gamma heating, and, (2) the error caused by fast neutron collisions. The portion caused by gamma heating can be obtained by extrapolating the data to the zero-flux intercept. The remaining portion of the temperature measurement error is caused by fast neutron defects as is evidenced by the annealing data obtained after irradiation termination. Basically there are three distinct compensations required for accurate RTT measurements at cryogenic temperatures in a neutron radiation environment; each is described below.

1. Temperature Rise Caused by Gamma Heating

The temperature measurement errors caused by gamma heating (approximately $0.9^{\circ}F$ for NERVA locations THPFL, THNMI and THNM; and $1.7^{\circ}F$ for THNT0) is a function of the gamma dose rate; however, several seconds are required for the RTT system to reach thermal equilibrium. Compensation for

temperature measurement errors caused by gamma heating requires accurate knowledge of both the gamma dose rate and the thermal response characteristics of the sensing device.

2. Temperature Measurement Error Caused by Fast Neutron Bombardment

The error caused by fast neutron bombardment initially varies linearly with integrated flux with a saturation effect becoming prominent at integrated fast neutron fluxes greater than 5×10^{15} neutrons/cm² ($E > 1.0$ Mev). The data presented indicate that the fast neutron damage coefficient is influenced by sensing element diameter. The optimum wire diameter with respect to sensitivity, accuracy and manufacturing is believed to be 1.0 mils, however, additional radiation tests are planned before finalizing this value. An extrapolation of these test results to a 1.0 mil diameter wire for the NERVA condition, would result in temperature measurement errors of 1.0°F for NERVA locations THPFL, THNMI, and THNM; and 2.2°F for NERVA location THNTO. The fast neutron damage coefficient is influenced strongly by LH₂ temperature and if the LH₂ storage chamber is pressurized to 30 atmospheres (which would result in an LH₂ boiling temperature of 32°K) the errors mentioned above can be decreased by 40%. Tests are scheduled during October 1964 to investigate this problem in more detail.

3. Temperature Measurement Error-Recovery Caused by Annealing

The lattice defects produced by fast neutron bombardment are annealed as the temperature increases. Although this initially will not present a problem, reactor restart data will require compensation of the residual error remaining from prior radiations that has not been annealed. The data presented in Tables VI and VII indicate that approximately 40% recovery can be expected between reactor restarts.

III. TEST DESCRIPTION

A. COMPONENTS

Eleven, platinum wire, resistance-temperature transducers, which included five Rosemount Model 134EB, two Rosemount Model 110AA, and four Winsco Model 2448 units, were irradiated in test 23/L101. The cross sectional drawings and the materials lists of each RTT are contained in Reference (1).

The Rosemount Model 134EB RTT is an immersion-type unit designed for temperature measurements between +75°F and -425°F. The temperature-sensing element consists of approximately 8 feet of 0.0007 inch 99.9% platinum wire wound on a 90% platinum/10% rhodium mandrel which is supported by a BeO ceramic insulator and protected by a perforated stainless steel guard tube which permits intimate contact of the liquid hydrogen with the sensing element.

The Winsco Model 2448-5 RTT, shown in cross section in Figure 1, is similar to the Rosemount Model 134EB both electrically and mechanically. The diameter of the platinum sensing wire is only 0.0005 inches for the Winsco units.

The Rosemount Model 110AA unit is specifically designed for making shallow immersion or limited space measurements. The sensing element of the Rosemount Model 110AA unit consists of 0.0003 inch platinum wire, wound on a ceramic insulated platinum mandrel, and supported by struts to the inner shield.

Technical drawing of a probe assembly, showing a side view and a cross-sectional view. The drawing includes dimensions and callouts for various components.

Dimensions:

- Overall length: 2.090
- Top section length: .700
- Section 1 length: .400
- Section 2 length: .050
- Section 3 length: .189 DIA
- Section 4 length: .375
- Section 5 length: .930
- Section 6 length: 1.000
- Section 7 length: .125
- Section 8 length: .187
- Section 9 length: .75
- Section 10 length: .930
- Section 11 length: .10 I.D.
- Section 12 length: .116 O.D.

Callouts:

- 1: Top section
- 2: Section 2
- 3: Section 3
- 4: Section 4
- 5: Section 5
- 6: Section 6
- 7: Section 7

Other Labels:

- .516 DIA
- .628 DIA
- .300
- .450
- .788
- 7/16-20 UNF THD
- .250 DIA
- .083 I.D.
- .125 O.D.
- .125
- .10 I.D.
- .116 O.D.
- AL₂O₃ PACKED DRY

FIGURE 1
WINSO MODEL 2448-5 CROSS SECTION DRAWING
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B. TEST FIXTURE

The design drawings of the test fixture are presented in Reference (1). Figure 2 shows the dewar with its associated plumbing and electrical connections. It has three chambers. The inner chamber, shown in Figure 3, contains the LH_2 . The transducers which are inserted through the side walls of the test chamber, and the associated connectors and cables are shown in Figure 2. The inner chamber is surrounded by a helium chamber which in turn is vacuum jacketed.

The test chamber connections for filling and exhausting the hydrogen penetrate the top flange which is common to both the LH_2 and the gaseous helium chamber. Other plumbing into the test fixture included a safety disc assembly which employs a 50 psi rupture disc to alleviate excessive dewar pressures. The dewar pressure sensor line was connected into the line utilized by the rupture (safety) disc. The electrical leads, which can be seen in Figures 2 and 3 are routed through the helium chamber upward through the common flange. All penetrations to the flange of the hydrogen dewar were surrounded by a metal shroud. All lines into this shroud were welded to the upper surface plate of the shroud. Electrical leads through the shroud utilized a "Kovar"-type disconnect, soldered to the upper surface plate.

The vacuum jacket region was evacuated to 50 microns and then sealed by a valve. The helium chamber surrounding the hydrogen dewar was constantly purged with helium at approximately 0.1 psi at 0.1 cfm, also, dry helium gas at approximately 0.1 psi flowing at 0.4 cfm was constantly purging the shroud.

Liquid hydrogen, utilized to maintain the required test environment temperature, was supplied by a truck connected to a facility manifold. Delivery pressure from the truck was approximately 9 psi throughout the test and usage was approximately 100 gallons per hour.

The liquid hydrogen level was maintained by remote manual control of a facility pneumatic control valve based on liquid level indication displayed in

FIGURE 2
TEST DEWAR WITH ASSOCIATED LINE
10

FIGURE 3
LH₂ TEST CHAMBER
11

the form of indicator lights. The actuation of the level indicating lights was controlled by individual resistors which allow current flow of increasing amounts as their temperature decreased, thus causing actuation of the lights when the desired temperature had been reached. Seven lights were utilized to indicate the liquid level position relative to the test RTT's. In addition to the level indicating display, two additional RTT's were installed above the uppermost test RTT. These were connected to micro-ammeters to indicate any change in their resistance, thus indicating the maximum and minimum desired liquid hydrogen levels. This means of level indication and control assured proper liquid level control throughout the test.

C. TEST PROCEDURES

The detailed test procedures which are summarized below for test 23/L101 are described in References (2) and (3). Prior to irradiation, each RTT was calibrated at the ice point, LN_2 point and at the LH_2 point. The resistance of the sensing element of each RTT was measured at reactor power levels of 10 kw, 100 kw, 1 Mw and at 3 Mw. Upon reaching power (3Mw) data were obtained hourly. The pressure of the dewar was recorded approximately one second before each RTT measurement. Data were obtained at LH_2 temperatures several hours after reactor termination and after heating the RTT's to temperatures up to 385°F. The procedures for reducing the data and correcting the measurements for dewar pressure fluctuations are described in Appendix A.

FIGURE 4
TEMPERATURE DEVIATION VS RADIATION EXPOSURE
(RTT-1 WINSO 2448-5 S/N 159)

FIGURE 5
TEMPERATURE DEVIATION VS RADIATION EXPOSURE
(RTT-3 WINSO 2448-5 S/N 157)

FIGURE 6
TEMPERATURE DEVIATION VS RADIATION EXPOSURE
(RTT-8 WINSKO 2448-5 S/N 156)

FIGURE 7
 TEMPERATURE DEVIATION VS RADIATION EXPOSURE
 (RTT-11 WINSO 2448-5 S/N 158)

FIGURE 8
TEMPERATURE DEVIATION VS RADIATION EXPOSURE
(RTT-2 ROSEMOUNT 134 EB S/N 4107)

FIGURE 9
TEMPERATURE DEVIATION VS RADIATION EXPOSURE
(RTT-4 ROSEMOUNT 134 EB S/N 4087)

FIGURE 10
TEMPERATURE DEVIATION VS RADIATION EXPOSURE
(RTT-7 ROSEMOUNT 134 EB S/N 4079)

FIGURE 11
TEMPERATURE DEVIATION VS RADIATION EXPOSURE
(RTT-14 ROSEMOUNT 134 EB S/N 4080)

FIGURE 12
TEMPERATURE DEVIATION VS RADIATION EXPOSURE
(RTT-15 ROSEMOUNT 134 EB S/N 4081)

FIGURE 13
TEMPERATURE DEVIATION VS RADIATION EXPOSURE
(RTT-12 ROSEMOUNT 110 AA S/N 211)

FIGURE 14
TEMPERATURE DEVIATION VS RADIATION EXPOSURE
(RTT-6 ROSEMOUNT 110 AA S/N 209)

IV. TEST RESULTS

A. PRE-IRRADIATION ANALYSES PREDICTIONS

Prior to performing this irradiation test, an analysis (Reference 1) was performed to predict possible sources of temperature measurement error and the magnitude of each. The predicted errors, which have been revised to reflect experimental flux data, are summarized in Table III. The experimental data are compared to the predicted performance and discussions concerning accuracy and reliability of predictions are contained in other sections of this report.

B. TEMPERATURE MEASUREMENT ERROR DATA ANALYSIS

The resistance of each RTT sensing element was measured hourly throughout the test as well as at each reactor power level. Each measurement consisted of an RTT resistance measurement with the dewar pressure recorded before each measurement.

The resistance of the sensing element was correlated to an equivalent temperature using the procedures and equations described in Appendix A. The calculated temperature measurement errors for each RTT are shown in Figures 4 through 14. It should be noted that the temperature deviation (after correcting for the error caused by gamma heating) varies linearly with integrated fast neutron flux. The coefficients, which are different for each type of RTT, are summarized in Table II.

It was initially believed that some of the RTT's appeared to have opened during the course of the test. A post-mortem examination after the post irradiation test showed that the open circuits occurred in the test fixture cables rather than the RTT's. The actual "opens" were located at the connector in the lid of the dewar. It appears that the expansion and contraction of the potting compound around the cable to connector terminations had either broken the wires or pulled the weld cups off of the connector pins. The epon-versamide potting material has a very high coefficient of expansion when exposed to gamma radiation. A 10% expansion of the potting material was anticipated for this test.

TABLE III

PRE-IRRADIATION ERROR ANALYSIS PREDICTIONS

<u>SOURCE OF ERROR</u>	<u>PREDICTED ERROR (°F)</u>
Thermal Neutron Absorption	+ 0.01
Fast Neutron Collision	+ 0.80
Gamma Heating	+ 0.29 (Rosemount 134EB)
	+ 0.21 (Rosemount 110AA)
	+ 0.29 (Winsco 2448-5)
Self Heating	+ 0.01
Induced Strains	+ 0.05
LH ₂ Pressure Variation	<u>±</u> 0.04/0.1 psia
Insulation Degradation	- 0.02

If one of the excitation leads opens, it is quite apparent on the RTT output. However, if one of the signal leads opens, the effect is not so obvious. If the open signal lead has a resistance of about one megohm, the effect on the output signal would be to reduce the signal by an amount proportional to the signal impedance over the data system input impedance. An open signal lead would account for the data excursions noted in Figures 4, 5, 6 and 14 either an open excitation lead or both excitation and signal leads are noted in Figures 7 and 13.

C. RTT RESISTANCE MEASUREMENT ERROR ANALYSIS

The resistance of the sensing element of each RTT is the basic parameter measured in these investigations. Figures 15, 16 and 17 depict the resistance ratio, i.e. resistance observed to the calibrated resistance of the sensing element prior to irradiation at the measured dewar pressure (see Appendix A), versus integrated fast neutron flux for each model RTT. It should be noted that the resistance ratio, when corrected for gamma heating, i.e. zero flux intercept varies linearly with integrated fast neutron flux. The resistance measurement error caused by fast neutron bombardment shows a saturation effect that can be observed at the higher integrated fluxes. Table II summarizes the resistance ratio coefficients. These data indicate a definite correlation with the diameter of the sensing element wire and this variation is shown in Figure 18. Also shown in Figure 18 is a $1/D^2$ "Best Fit" curve. These data indicate that the temperature error from fast neutron defects can be minimized by going to larger diameter wire for the sensing element. This, however, may be modified by manufacturing and component sensitivity considerations. The larger the diameter wire the lower the resistance and a corresponding decrease in sensitivity. Based on the above considerations it is believed that a 1.0 mil diameter wire will result in the optimum design; however several RTT units have been manufactured with sensing wire diameters up to 2.0 mils and these will be tested under irradiation within the next few months. The resistance ratio coefficients shown in Table II compare favorably with the results obtained by T. Blewitt (Reference 4). Blewitt's data indicated 20×10^{-16} percent change in resistance per fast neutron ($E > 1.0$ Mev) whereas the data presented in this report varies between 10 and 62×10^{-16} percent per neutron.

FIGURE 15
RESISTANCE RATIO VS INTEGRATED NEUTRON FLUX
(ROSEMOUNT MODEL 134EB)

FIGURE 16
RESISTANCE RATIO VS INTEGRATED NEUTRON FLUX
(ROSEMOUNT MODEL 110AA)

FIGURE 17
 RESISTANCE RATIO VS INTEGRATED FAST NEUTRON FLUX
 (WINSO MODEL 2448-5)

FIGURE 18
RESISTANCE COEFFICIENT VS SENSING ELEMENT DIAMETER

D. GAMMA HEATING DATA ANALYSIS

The temperature deviation caused by gamma heating, i.e. the extrapolated zero flux intercepts of Figures 4 through 14 are summarized in Table IV. The experimental data are shown in Figures 19 which presents the calculated gamma heating error-vs-gamma dose rate. It should be noted that the experimentally determined temperature deviations caused by gamma heating are approximately 0.2°F higher than the calculated errors of Reference 1. Based upon the best fit of the experimental data the predicted temperature deviation because of gamma heating for RTT's located at specific NERVA locations are summarized in Table V, assuming that a Rosemount 134EB is used as the sensing device.

TABLE IV
Temperature Rise Due to Gamma Heating

Transducer Type	Serial Number	Gamma Dose Rate (ergs/gm(C)-hr)	ΔT Temperature Rise (°F)
Rosemount 134EB	4107	2.4×10^9	0.62
Rosemount 134EB	4087	2.4×10^9	0.67
Rosemount 134EB	4079	1.36×10^9	0.70
Rosemount 134EB	4080	1.36×10^9	0.62
Rosemount 134EB	4081	1.36×10^9	0.60
Rosemount 110AA	209	1.36×10^9	0.40
Rosemount 110AA	211	1.36×10^9	0.40
Winsco 2448-5	159	2.4×10^9	0.71
Winsco 2448-5	156	1.36×10^9	0.60
Winsco 2448-5	158	1.36×10^9	0.60
Winsco 2448-5	157	2.4×10^9	0.80

FIGURE 19
TEMPERATURE RISE DUE TO GAMMA HEATING
32

TABLE V

PREDICTED GAMMA HEATING ERRORS FOR
VARIOUS NERVA LOCATIONS*

NERVA LOCATION	Gamma Dose Rate (ergs/gm(C)-hr)	Predicted Temperature Deviation (°F)
THPFL	7.2×10^9	0.9
THNMI	7.2×10^9	0.9
THNM	7.2×10^9	0.9
THNTO	3.6×10^{10}	1.7

* Assumes sensing device is Rosemount Model 134EB RTT

E. ANNEALING AND POST CALIBRATION DATA ANALYSIS

Upon termination of the irradiation, the LH_2 boiled out of the dewar and the RTT's warmed up to an unknown temperature with a resultant partial annealing of the defects caused by fast neutron bombardment. Approximately three hours after irradiation, the dewar was refilled with LH_2 and several data cycles were recorded for each RTT. These data, shown in Table VI, indicate approximately a 40% recovery of the defects caused by fast neutron.

Approximately 60 days after reactor irradiation, the dewars were filled with LH_2 and additional data cycles were obtained. The dewar was then purged with hot nitrogen gas of a specified temperature for approximately 15 minutes; then the dewar was refilled with LH_2 and three data cycles were completed. This procedure was repeated for temperatures of 100°F, 200°F, 300°F and 385°F. These data are shown in Table VII. Only a small amount of annealing was achieved by going from 100°F to 385°F, (from 40% to 50%) hence it is surmised that a restart of NERVA will require compensation of temperature measurements to account for the annealing effect.

T. Blewitt of ORNL (Reference 4) investigated the annealing characteristics of platinum and his data are shown in Figure 20. It should be noted that approximately 30% recovery is obtained at a temperature of 32°K. This means that if the system is pressurized to 30 atmospheres (LH_2 boiling Temp = 32°F), the observed resistance change would be reduced by 30%.

Upon completion of the above annealing studies, the RTT's were recalibrated at LN_2 boiling point and at the ice point. Then data are shown in Table VIII and are compared with the pre-irradiation calibration data. The pre- and post-calibration data for each RTT compare quite closely at the LN_2 and ice point; however it should be noted that in many instances the post-irradiation resistance is lower than the pre-irradiation value. This can not be explained as the experimental set-up including cables and instrumentation were identical.

FIGURE 20
RECOVERY OF PLATINUM VS ANNEALING TEMPERATURE
(REFERENCE 4)

TABLE VI
Recovery Data*

Transducer Type	Serial Number	Gamma Heating ΔT_g (°F)	Final Temp Error ΔT_f (°F)	T Elapsed Time After Irradiation (Hours)	ΔT_x (°F)	% Recovery
Rosemount-134EB	4107	0.62	2.80	3.4	1.52	35
				3.5	1.48	32
				3.6	1.40	36
				5.9	1.37	37
				6.0	1.28	41
Winsco-2448-5	159	0.71	4.78	3.4	2.40	41
				3.5	2.42	40
				3.7	2.30	43
				3.8	2.38	41
				5.7	2.23	45
Rosemount-134EB	4087	0.67	2.80	5.8	2.18	47
				3.4	1.50	30
				3.6	1.43	33
				5.7	1.33	38
				5.8	1.28	40
Rosemount-134EB	4079	0.70	2.32	3.4	1.27	22
				3.5	1.19	27
				3.6	1.16	29
				3.7	1.22	25
				5.7	0.99	39
Rosemount-134EB	4080	0.62	2.59	5.8	1.02	37
				5.9	1.08	34
				3.4	1.38	30
				3.5	1.48	25
				3.6	1.33	32
				5.8	1.13	42

*Test components warmed up to approximately -200°F after irradiation.

TABLE VI (continued)

Recovery Data

Transducer Type	Serial Number	Gamma Heating ΔT_g (°F)	Final Temp Error ΔT_f (°F)	T Elapsed Time After Irradiation (Hours)	ΔT_x (°F)	% Recovery
Rosemount-134EB	5381	0.60	2.00	3.4	1.08	
				3.5	1.03	
				3.6	0.96	
Winsco-2448-5	157	0.80	6.35	3.4	2.65	52
				3.5	2.60	53
				5.6	2.30	58
				5.7	2.25	60
Rosemount-110AA	209	0.40	5.80	3.4	3.16	40
				3.6	3.12	41
				5.6	2.85	47
				5.7	2.78	48
				5.8	2.74	49

TABLE VII
Annealing Recovery Data*

Transducer Type	Serial Number	Annealing Temperature (°F)	Temperature Deviation	Percent Recovery
Rosemount-134 EB	4107	100	0.97	55
		200	0.92	57
		300	0.95	57
		385	0.86	61
Winsco-2448-5	159	100	1.76	57
		200	1.74	57
		300	1.67	59
		385	1.45	63
Rosemount-134 EB	4087	100	0.98	54
		200	0.98	54
		300	0.96	55
		385	0.91	57
Rosemount-134 EB	4079	100	0.71	56
		200	0.73	55
		300	0.73	55
		385	0.67	59
Rosemount-134 EB	4080	100	0.88	55
		200	0.85	57
		300	0.85	57
		385	0.80	59
Rosemount-134 EB	5381	100	0.60	57
		200	0.63	55
		300	0.65	54
		385	0.60	57
Winsco-2448-5	157	100	1.80	67
		200	1.83	67
		300	1.80	67
		385	1.65	70

*Data obtained 60 days after irradiation.

TABLE VII (Continued)
Annealing Recovery Data

Transducer Type	Serial Number	Annealing Temperature (°F)	Temperature Deviation	Percent Recovery
Rosemount-110 AA	209	100	2.30	57
		200	2.30	57
		300	2.20	59
		385	1.95	64

TABLE VIII
RTT CALIBRATION DATA*

Transducer Type	Serial Number	Ice Water Calibration		LN ₂ Calibration	
		Pre- Irradiation (ohms)	Post- Irradiation (ohms)	Pre- Irradiation (ohms)	Post- Irradiation (ohms)
Rosemount-135EB	4079	1380.1	1388.7	261.47	260.73
Rosemount-134EB	4080	1380.4	1378.4	261.47	262.01
Rosemount-134EB	4102	1380.6	1381.6	261.34	260.56
Rosemount-134EB	4087	1380.2	1378.7	261.64	261.18
Rosemount-134EB	5381	1380.8	1375.8	261.30	260.96
Rosemount-110AA	209	399.5	396.5	(Calibrated in NEON)	
Winsco-2448-5	159	1378.4	1387.5	261.42	263.72
Winsco-2448-5	157	1380.8	1385.5	262.52	264.68

*Data obtained 60 days following irradiation after components had warmed up to 100°F

LIST OF REFERENCES

1. RN-S-0063 - "Pre-Irradiation Analysis of Test 23/L101 - Resistance Temperature Transducers" - March 1964
2. RN-S-0086 - "Final Test Specification for Ground Test Reactor (GTR) Irradiation Test No. 12A
3. REM No. 1334 (GD/FW) - "GTR-12A Irradiation Test Planning Document" dated April 1964
4. T. H. Blewitt - "Low Temperature Irradiation Studies" - Proceedings of the International School of Physics - XVIII Course - Radiation Damage in Solids; Academic Press - (1962)

APPENDIX A

DATA REDUCTION PROCEDURES

The purpose of this appendix is to describe the data reduction procedures for radiation effects tests on platinum resistance temperature transducers (RTT's) at liquid hydrogen temperatures. The RTT's are inserted into a dewar of liquid hydrogen and their resistances measured by recording voltage drop across the sensing element for a known current. The temperature of the liquid hydrogen in the dewar is determined by precise measurements of the dewar pressure and assuming that the hydrogen is at the boiling point.

The data reduction procedure consists of three basic calculations:

1. A calibration constant for each transducer
2. An indicated temperature based upon the measured RTT resistance
3. The liquid hydrogen temperature, or reference temperature.

Calibration Constant

The equations of temperature as a function of resistance are of the form:

$$T = K_0 + K_1 R^1 + K_2 R^2 + \dots \dots K_n R^n$$

All of the RTT's of the same model number have the same temperature vs resistance curve except that the curve may be shifted slightly up or down. Therefore, each RTT curve can be represented by an equation that is identical to the others except for a different constant term (K_0). The constant term in the equations has been designated the calibration constant.

The calibration constant was calculated by setting the indicated temperature equations equal to the reference temperature, substituting in measured values of pressure and resistance, and solving for the constant.

$$T_i = B_0 + B_1 R + B_2 R^2 + \dots \dots + B_9 R^9$$

Let $T_i = T_r$

$$T_r = A_0 + A_1 P + A_2 P^2 + \dots \dots + A_4 P^4$$

$$B_0 = A_0 + A_1 P + A_2 P^2 + \dots \dots + A_4 P^4 - B_1 R - B_2 R^2 - \dots \dots - B_9 R^9$$

B_0 Calibration Constant

P Absolute dewar pressure

R RTT resistance

This procedure was repeated ten times and the results averaged for each RTT. The average calibration constant was then used in the RTT equation to calculate indicated temperature for the remainder of the data reduction process.

Indicated Temperature

The indicated temperature is the temperature derived from the temperature-resistance relationship for each individual transducer. To calculate the indicated temperature from the measured values of resistance, an equation had to be calculated that would fit the temperature-resistance calibration values. Since there were two basically different types of RTT's in the test, two equations were calculated, one for the Rosemount 110AA's, and another for the Rosemount 134EB and Winsco 2448-5's. The equation for the Rosemount 110AA's was based upon seven temperature-resistance points and that for the Rosemount 134EB's and Winsco's was based upon ten temperature-resistance points. The points used were:

TABLE IX

RESISTANCE OF STAGING ELEMENTS

RTT		Temperature (Degrees Rankine)	Resistance (Ohms)
Rosemount 134EB & Winsco 2448-5	1	44	11.933
	2	43	11.040
	3	42	10.195
	4	41	9.400
	5	40	8.652
	6	39	7.951
	7	38	7.295
	8	37	6.683
	9	36	6.112
	10	35	5.584
Rosemount 110AA	1	41	3.043
	2	40	2.825
	3	39	2.621
	4	38	2.430
	5	37	2.251
	6	36	2.084
	7	35	1.928

The "best fit" equations resulting from the computer run are:

1. For the Rosemount 134EB and Winsco 2448-5

$$T_1 = B_0 + B_1 R + B_2 R^2 + \dots + B_9 R^9$$

B_0 is a constant that is peculiar to each individual RTT - see the paragraph on "Calibration Constant."

$$B_1 = + 0.33114091E-01$$

$$B_2 = - 0.46452311E-01$$

$$B_3 = - 0.79330482E-02$$

$$B_4 = - 0.17037884E-02$$

$$B_5 = + 0.25143277E-03$$

$$B_6 = + 0.56537078E-05$$

$$B_7 = - 0.18473031E-05$$

$$B_8 = + 0.58453272E-07$$

$$B_9 = + 0.38042806E-09$$

2. For the Rosemount 110AA

$$T_i = C_0 + C_1 R + C_2 R^2 + C_3 R^3$$

C_0 is a constant that is peculiar to each individual RTT - See paragraph on "Calibration Constant."

$$C_1 = + 0.14095685E-02$$

$$C_2 = - 0.25752804E-01$$

$$C_3 = + 0.21676446E-00$$

Reference Temperature

The reference temperature is the temperature of the liquid hydrogen surrounding the test transducers. If the assumptions are made that the hydrogen is at the boiling point and that there are no thermal gradients in the hydrogen, the reference temperature can be determined from measurements of the dewar pressure.

Allen Schmidt at the National Bureau of Standards recommended a paper, The Vapour Pressure of 20°K Equilibrium Hydrogen, by A. L. Weber, D. E. Diller, H. M. Roder, and R. D. Goodwin, Cryogenics, June 1962, as the best vapor pressure vs. temperature data available for hydrogen at pressures near atmospheric. Since the absolute pressure in the dewar used for these tasks is about 18 psi, the following points were extracted from the paper to be used in the reference temperature equation calculation:

Vapor Pressure

Temperature (Degrees Rankine)	Pressure (p.s.i.)
36.4824	14.696
37.8000	18.126
39.6000	23.700

The "best fit" as determined by a program based upon the method of least squares was:

$$Tr = A_0 + A_1 P + A_2 P^2 + A_3 P^3 + A_4 P^4$$

$$A_0 = +0.64289892 \text{ E } 02$$

$$A_1 = -0.40590461 \text{ E } 01$$

$$A_2 = +0.11594372 \text{ E } 00$$

$$A_3 = +0.48593985 \text{ E } -02$$

$$A_4 = -0.18479969 \text{ E } -03$$