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REPORT NO. RN-S-0251
TO
AEC-NASA SPACE NUCLEAR PROPULSION OFFICE

SUMMARY REPORT
RESISTANCE TEMPERATURE TRANSDUCER
IRRADIATION PROGRAM

MASTER

DECEMBER 1965
NERVA PROGRAM CONTRACT SNP-1

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REPORT NO. RN-S-0251
SUMMARY REPORT
RESISTANCE TEMPERATURE TRANSDUCER
IRRADIATION PROGRAM
DECEMBER 1965

ROCKET ENGINE OPERATIONS - NUCLEAR

NERVA PROGRAM

CONTRACT SNP-1

CLASSIFICATION CATEGORY	
Unclassified	
<i>W. B. Guller</i>	<i>12/10/65</i>
CLASSIFYING OFFICER	DATE

AEROJET - GENERAL CORPORATION
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ABSTRACT

This report summarizes the results of three radiation effects tests on resistance temperature transducers: Test 23/L101, GTR-12A, April 1964; Test 23/L102, GTR-14, July 1964; and Test 23/R103, GTR-15, December 1964. A total of 18 RTT's of 6 different models (Rosemount 134EB250, Rosemount 134EB1X, Rosemount 134EB2X, Rosemount 134GT, Rosemount 110AA150, and Winsco 2448-5) were irradiated in LH₂; however, 2 units were irradiated in all tests and accumulated a fast neutron exposure of 2.2×10^{17} nvt ($E > 1.0$ Mev) while being maintained at -423°F. Since the units were irradiated under the same environment, the data are analyzed collectively. The results of these tests followed closely the predicted performance with respect to temperature measurement errors (2°F to 8°F). Although several transducer circuits experienced open circuits, none of the transducers themselves experienced mechanical or electrical failure from radiation.

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I. INTRODUCTION

The requirement for an accurate cryogenic temperature measurement system for the NERVA Program is evidenced by the fact that a temperature difference of 0.054°F in the inlet temperature of the liquid hydrogen flowing into the NERVA pump is equivalent to a vapor pressure head (net positive suction pressure) differential of five feet. Cryogenic temperatures must also be accurately measured in the thrust chamber and at other locations throughout the NERVA propellant feed system. To satisfy the temperature measurement requirements of the NERVA engine, Aerojet has designed a system which employs resistance temperature transducers as the sensing device. Resistance temperature transducers were chosen in preference to thermocouples because of their greater sensitivity and higher electrical output at cryogenic temperatures.

The temperature measurement system must function within the required accuracy limits in severe nuclear radiation environments. The temperature deviations will, therefore, depend upon the errors induced by gamma and neutron irradiation. To determine the magnitude of those errors on the measurements, a series of three irradiation tests designated GTR-12A (April, 1964), GTR-14 (July, 1964) and GTR-15 (December, 1964), were conducted on six different models of resistance temperature transducers at the Ground Test Reactor (General Dynamics/Fort Worth). The sensing elements of the resistance temperature transducers (high purity platinum wire) varied in diameter from 0.3 to 2.0 mils. The test dewar, which is an Aerojet design, used liquid hydrogen to maintain the cryogenic temperature.

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II. SUMMARY AND RECOMMENDATIONS

RTT's can be utilized to measure cryogenic temperatures at all required locations. All of the past NERVA NRX RTT measurements have used RTT's with 0.7 mil wire. Based upon results from the three tests, the optimum wire diameter with respect to sensitivity, accuracy, and manufacturing, is 1.0 mils, which results in a slight improvement over the 0.7 mil wire. Table I summarizes the predicted temperature measurement errors at each NERVA RTT location with 1.0 mil wire. However, it should be noted that the analyses presented herein indicate that the error caused by proton recoil damage can be reduced to zero by preventing the hydrogen from coming in intimate contact with the sensing element. Evaluation tests to confirm this theory are presently being designed.

TABLE I

PREDICTED TEMPERATURE MEASUREMENT ERRORS

<u>NERVA Locations</u>	<u>Gamma Heating Error</u>		<u>Error Caused by Proton Recoil Integrated Neutron</u>		<u>Total Error</u>
	<u>Gamma Dose Rate ergs/gm(C)hr</u>	<u>Estimated Error (°F)</u>	<u>Exposure for 30 min. Test (e > 1.0 mev)</u>	<u>Estimated Errors (°F)</u>	<u>°F</u>
THNMI, THPFL THMM	7.2×10^9	1.0	2×10^{16} nvt	0.7	1.7
THNTO	3.6×10^{10}	1.9	1.1×10^{17} nvt	2.2	4.1

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 measurements, the error caused by gamma heating and the error caused by fast neutron collisions. The error produced by gamma heating can be obtained by extrapolating the temperature deviation data to the zero flux intercept. The remaining portion of the temperature measurement deviation is caused by fast neutron defects as is evidenced by the annealing data obtained after irradiation termination. The temperature error caused by gamma heating is proportional to

the gamma dose rate and the resistance element diameter; however, the temperature error caused by neutron bombardment, while directly proportional to the integrated neutron flux, is inversely proportional to the resistance element diameter. The data emphasize the necessity of compensating the RTT output to minimize the effects of radiation; otherwise, the design requirements of the NERVA engine cannot be achieved.

The tests performed on the RTT's indicate that the units will saturate resulting in relatively constant temperature errors for neutron exposures greater than 2×10^{17} nvt ($E > 1.0$ mev). The experimental data revealed that the magnitude of this error is inversely proportional to the resistance element diameter.

At the completion of the test designated GTR-12A, the LH_2 boiled out of the dewar allowing the units to warm up to some unknown temperature. This resulted in partial annealing of the defects caused by fast neutron bombardment. When the dewar was refilled with LH_2 and several data cycles recorded for each unit, a recovery of 40 percent of the defects caused by fast neutron damage was noted. The units were then annealed at a maximum temperature of 385°F with a maximum recovery of 60 percent of the defects caused by fast neutron bombardment.

Annealing data for GTR-14 and GTR-15 were not taken; however, post-test calibration data after warm-up to room temperature for the RTT's irradiated in GTR-15 indicated that partial annealing had occurred. No attempt was made to anneal the units at higher temperatures.

The calculations and analyses performed indicate that the change in platinum element resistance might be due to interstitials resulting from recoil proton bombardment in the LH_2 which surrounds the platinum sensing elements. Since the recoil protons have a range of 10^{-4} cm in platinum, a surface defect results which has a greater influence on the resistance of the smaller diameter wire. Evaluation tests to verify this theory are presently being designed.

In addition to compensating for the gamma heating and neutron bombardment induced errors, additional compensation will be required for residual errors not annealed. This compensation need only be made in the event a reactor restart is required.

III. TEST DESCRIPTION

The subject resistance temperature transducers were irradiated in LH_2 at the General Dynamics/Fort Worth ground test reactor during three different reactor runs, designated GTR-12A (April 1964), GTR-14 (July 1964), and GTR-15 (December 1964).

A. COMPONENTS

Six different models of RTT's were tested with eight units being tested in two reactor irradiations and two of these being tested in all three reactor irradiations. Table II lists the transducers tested in each reactor run.

The Rosemount Model 134EB250 RTT shown in cross-section in Figure 1 is an immersion-type unit designed for temperature measurements between $+75^\circ$ and -425°F . The temperature-sensing element consists of approximately 8 feet of 0.7 mils, 99.99 percent platinum wire wound on a 90 percent platinum 10 percent rhodium mandrel which is supported by a stainless steel element mount. The element wire is encapsulated in ceramic to hold the wire in a strain-free configuration. This assembly is protected by a perforated stainless steel guard tube which permits intimate contact of the liquid hydrogen with the ceramic coated sensing element. The total resistance of the element is 1380 ohms at the ice point.

The Winsco Model 2448-5 RTT is similar to the Rosemount Model 134EB both electrically and mechanically. However, the diameter of the platinum sensing wire is only 0.5 mils for the Winsco units.

The Rosemount Model 110AA150 unit is specifically designed for making shallow immersion or limited space measurements. The sensing element of the Rosemount Model 110AA unit consists of 0.3 mils platinum wire. The element is similar to the 134EB except miniaturized and supported by struts to the inner shield. The total resistance of the element is 400 ohms at the ice point.

Figure 1
Cross Sectional Drawing of Rosemount Model 134EB RTT
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TABLE II

RTT TEST SUMMARY

<u>Transducer Make and Model</u>	<u>S/N</u>	<u>Element Diameter (mils)</u>	<u>GTR-12A</u>	<u>GTR-14</u>	<u>GTR-15</u>
Rosemount 110AA150	209	0.3	x		*
Rosemount 110AA150	211	0.3	x	x	x
Winsco 2448-5	156	0.5	x		
Winsco 2448-5	157	0.5	x		x
Winsco 2448-5	158	0.5	x		
Winsco 2448-5	159	0.5	x		
Winsco 2448-5	161	0.5			x
Rosemount 134EB 250	4081	0.7	x		*
Rosemount 134EB 250	4079	0.7	x		*
Rosemount 134EB 250	4080	0.7	x		*
Rosemount 134EB 250	4087	0.7	x		*
Rosemount 134EB 250	4107	0.7	x	x	x
Rosemount 134GT	9990	1.0			x
Rosemount 134GT	9991	1.0			x
Rosemount 134EB1X	9372	1.0		x	x
Rosemount 134EB1X	9373	1.0		x	x
Rosemount 134EB2X	9370	2.0		x	x
Rosemount 134EB2X	9371	2.0		x	x

*Units were irradiated in GTR-15; however, their performance was not monitored during irradiation. Only pre- and post data were obtained.

The Rosemount Model 134EB1X is identical to the Rosemount Model 134EB250 except that the sensing element wire diameter is 1.0 mils. This larger wire naturally reduces the length of wire and increases the cross-section of the wire which reduces the ice-point resistance accordingly. Both of these experimental units have an ice-point resistance of 635 ohms.

The Rosemount Model 134EB2X is identical to the Rosemount Model 134EB250 except that the sensing element wire diameter is 2.0 mils. Accordingly, the ice-point resistance is reduced to 131 ohms.

The Rosemount Model 134GT is a prototype unit designed and fabricated after conducting GTR-14. This unit features the optimum size 1.0 mil wire however it differs in internal construction from the 134EB250 design. Mechanically, the model 134GT is interchangeable with the 134EB250. The 134GT has a double layer to provide a higher ice-point resistance (1128 ohms) than the 134EB1X units. To reduce the gamma heating, the mandrel wall thickness was reduced from 0.010 to 0.005 inches and is designed for tip mounting to reduce stem conduction errors. The ceramic used to encapsulate the element was changed to a flame-sprayed aluminum oxide to increase the heat transfer coefficient of the insulator. Four lead wires are carried to the element rather than the two on the 134EB250 to reduce potential leadwire errors. No protective guard was included on the prototype units.

B. TEST FIXTURE DESCRIPTION

Figure 2 shows a cut-away drawing of the Aerojet designed test dewar and its associated plumbing and electrical connections. The dewar is designed in two sections, the inner section fits concentrically within the outer section and is supported on the outer section by the lower flange. The inner section houses the resistance temperature transducers whose sensing elements are kept immersed in a liquid hydrogen bath. The liquid hydrogen is admitted to and vented from the inner section by means of the plumbing fixtures shown in the top flange. Electrical connections in the lower flange allow the outputs of the resistance temperature transducers to be measured.

Figure 2
Test Dewar Cross Section
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The lower flange also has plumbing fixtures to allow gases helium to flow into and around the inner section when the dewar is assembled. A jacket surrounds the outer section and has a plumbing fixture through which a high vacuum can be drawn. The purpose of this vacuum is to reduce the boil-off of the liquid hydrogen and prevent ice build-up around the outer dewar.

Prior to each test, the vacuum jacket region was evacuated to 50 microns and then sealed by a valve. The helium chamber was continuously purged with dry helium at approximately 0.1 psi at a flow rate of 0.1 cfm. Liquid hydrogen was supplied by a truck connected to a facility manifold. Delivery pressure from the truck was 9 psi throughout the test and usage was approximately 100 gallons per hour. The liquid hydrogen level was maintained above the RTT's by remote manual control of a facility pneumatic control valve based on liquid level indication as monitored by a resistor rake.

C. TEST PROCEDURES

The detailed test procedures which are summarized below are described in References (2) and (3). Prior to irradiation, each RTT was calibrated at the ice point, LN₂ point and at the LH₂ 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 full power (3 Mw) data were obtained hourly. Prior to each data cycle, the LH₂ was filled several inches above the RTT's and the LH₂ flow terminated while the data were being recorded, thus minimizing errors caused by pressure fluctuations. The pressure of the dewar was recorded approximately one second before each RTT measurement.

Upon reactor termination, three data cycles were obtained at LH₂ temperature. In GTR 12A, data at LH₂ temperatures were also obtained after heating the RTT's to temperatures up to 385°F. Upon completion of the post irradiation testing, the RTT's were removed from the fixture and sent to Aerojet, Sacramento for post calibration testing at the ice point, LN₂ point, LNe point and at the LHe point. The procedures for reducing the data and correcting the measurements for dewar pressure fluctuations are described in Appendix A.

D. REACTOR TESTS DESCRIPTION

1. GTR-12A (Test 23/L101) was performed in the space adjacent to the north face of the ground test reactor during April 1964. Eleven RTT's, five Rosemount Model 134EB250, two Rosemount Model 110AA150, and four Winsco Model 2448-5, were irradiated in LH_2 for fifty hours, accumulating an integrated fast neutron exposure of 9×10^{16} nvt ($E > 1.0$ Mev). The results of this test are described in Reference (4).

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 Section IV, indicate approximately a 40 percent recovery of the defects caused by fast neutrons.

Approximately 60 days after reactor irradiation, the dewar was 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 discussed in detail in Reference (4). Upon completion of these tests, the RTT's were returned to Aerojet-Sacramento for post-test calibration. These calibration data are discussed in Appendix C.

2. GTR-14 (Test 23/L102) was performed in the space adjacent to the east face of the ground test reactor during July 1964. Six RTT's, one Rosemount Model 134EB250 (previously irradiated in GTR-12A), one Rosemount Model 110AA150 (previously irradiated in GTR-12A), two Rosemount Model 134EB1X and two Rosemount Model 134EB2X units were irradiated for 100 hours, accumulating an integrated fast neutron exposure of 3×10^{16} nvt ($E > 1.0$ Mev). Because of technical difficulties and depletion of the LH_2 , test data were not obtained throughout the test. A brief summary of these events is shown in Table III.

TABLE III

CHRONOLOGICAL SUMMARY OF GTR-14 ACTIVITIES

		Accumulated Neutron Exposure nvt ($E > 1.0$ Mev)	Remarks
7/23	00:36	0	Reactor irradiation began.
	05:00	2.7×10^{14}	Reactor at 3 Mw.
7/24	08:44	7.3×10^{15}	Reactor power reduced to 2 Mw to conserve LH_2 .
	10:43	8.0×10^{15}	LH_2 depleted - reactor shutdown.
			LN_2 in test chamber to minimize annealing.
7/25	19:29	8.0×10^{15}	LH_2 replenished reactor operating.
7/26	13:35	1.3×10^{16}	Severe LH_2 leak caused termination of LH_2 . Reactor brought back to power using gaseous nitrogen (approximately 125°F) as coolant for remainder of test.
7/28	23:06	3.0×10^{16}	Irradiation test complete.

Upon completion of irradiation, the RTT's were returned to Aerojet-Sacramento for post-test calibration. Details are reported in Appendix C on the post GTR-14 calibration data.

3. GTR-15 (Test 23/R103) was performed in the space adjacent to the north face of the ground test reactor during December 1964. Ten RTT's, one Rosemount Model 110AA150 (previously irradiated in GTR-12A and GTR-14), two Winsco Model 2448-5 (one unit previously irradiated in GTR-12A), two Rosemount Model 134EB2X (previously irradiated in GTR-14), two Rosemount Model 134EB1X (previously irradiated in GTR-14), one Rosemount Model 134EB250 (previously irradiated in GTR-12A and GTR-14) and two Rosemount Model 134GT units were

irradiated for 100 hours in LH_2 , accumulating an integrated fast neutron exposure of 1.6×10^{17} nvt ($E > 1.0$ Mev).

Midway through the tests, the LH_2 trailers were switched. During this operation, the liquid level in the test chamber dropped below the lowest test item and a marked decrease in temperature deviation was evident for all RTT's.

Five additional RTT's were suspended on the outer surface of the LH_2 chamber and were irradiated at an average temperature of -200°F . These units were irradiated and then forwarded to Aerojet-Sacramento for post-test calibration. The average integrated flux for these units is 5×10^{16} nvt ($E > 1.0$ Mev). The calibration data are reported in Appendix C.

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IV. TEST RESULTS

The resistance of the RTT sensing element is the only component parameter that can be measured. The equivalent temperature can be determined by correlating the measured resistance with pre-irradiation calibration data. Since the temperature measurement errors are the most important from an engineering aspect, they are presented first and the resistance measurement data which are analyzed theoretically and correlated with the physical characteristics are presented second.

A. TEMPERATURE DEVIATION

Table II summarizes the tests performed on the eighteen resistance temperature transducers. Table II shows that eleven RTT's were irradiated in GTR-12A, 6 in GTR-14 and 15 in GTR-15; the units which were irradiated in more than one irradiation are also noted.

Figures 3 through 23 inclusive show the temperature deviations for each RTT as a function of integrated neutron flux ($E > 1$ Mev) and gamma dose. Only temperature deviation data from GTR-12A and GTR-15 are shown. Data from GTR-14 are not presented because of the difficulties noted in the preceding section.

Table IV lists the maximum temperature deviation for each of the resistance temperature transducers for each test. It is evident that the smaller diameter element wire gives larger temperature deviations. The temperature deviation ranges from a maximum of 9.0°F to a minimum of 2.5°F.

TABLE IV

MAXIMUM TEMPERATURE DEVIATION

Make and Model	Serial Number	GTR-12A		GTR-15	
		Integrated Neutron Flux $n/cm^2 \times 10^{16}$ (E > 1.0 Mev)	Max. Temp. (°F)	Integrated Neutron Flux $n/cm^2 \times 10^{16}$ (E > 1.0 Mev)	Max. Temp. (°F)
Rosemount 110AA150	209	3.1	6.1	*	
Rosemount 110AA150	211	3.1	6.2	15	9.0
Winsco 2448-5	156	3.4	6.2	*	-
Winsco 2448-5	157	7.1	5.4	11	5.0
Winsco 2448-5	158	3.1	3.9	-	-
Winsco 2448-5	159	6.5	5.1	-	-
Winsco 2448-5	161	-	-	15	7.7
Rosemount 134EB 250	4081	3.7	2.2	*	-
Rosemount 134EB 250	4079	3.4	2.4	*	-
Rosemount 134EB 250	4080	3.7	2.7	*	-
Rosemount 134EB 250	4087	7.1	2.9	*	-
Rosemount 134EB 250	4107	6.8	2.9	11	2.9
Rosemount 134GT	9990	-	-	11	2.5
Rosemount 134GT	9991	-	-	13	3.5
Rosemount 134EB1X	9372	-	-	15	3.1
Rosemount 134EB1X	9373	-	-	18	4.0
Rosemount 134EB2X	9370	-	-	11	3.0
Rosemount 134EB2X	9371	-	-	15	3.5

These RTT's were only exposed to irradiation during the test. No channels were available to measure the resistance during the actual test.

Figure 3
Temperature Deviation vs Radiation Exposure
Rosemount 110AA S/N 211 GTR-12A

Figure 4
 Temperature Deviation vs Radiation Exposure
 Rosemount 110AA S/N 211 GTR-12A
 18

Figure 5
 Temperature Deviation vs Radiation Exposure
 Rosemount 110AA S/N 211 GTR-15

Figure 6
 Temperature Deviation vs Radiation Exposure
 Winsco 2448-5 S/N 156 GTR-12A
 20

Figure 7
 Temperature Deviation vs Radiation Exposure
 Winsco 2448-5 S/N 157 GTR-12A
 21

Figure 8
 Temperature Deviation vs Radiation Exposure
 Winsco 2448-5 S/N 157 GTR-15
 22

Figure 9
 Temperature Deviation vs Radiation Exposure
 Winsco 2448-5 S/N 158 GTR-12A

Figure 10
 Temperature Deviation vs Radiation Exposure
 Winsco 2448-5 S/N 159 GTR-12A
 24

Figure 11
 Temperature Deviation vs Radiation Exposure
 Winsco 2448-5 S/N 161 GTR-15
 25

Figure 12
 Temperature Deviation vs Radiation Exposure
 Rosemount ^{134}EB S/N 4079 GTR-12A
 26

Figure 13
Temperature Deviation vs Radiation Exposure
Rosemount 134EB S/N 4080 GTR-12A

Figure 14
 Temperature Deviation vs Radiation Exposure
 .Rosemount 134EB S/N 4081 GTR-12A
 28

Figure 15
 Temperature Deviation vs Radiation Exposure
 Rosemount 134EB S/N 4087 GTR-12A
 29

Figure 16
 Temperature Deviation vs Radiation Exposure
 Rosemount 134EB S/N 4107 GTR-12A
 30

Figure 17
 Temperature Deviation vs Radiation Exposure
 Rosemount 134EB S/N 4107 GTR-15
 31

Figure 18
 Temperature Deviation vs Radiation Exposure
 Rosemount 13⁴EB1X S/N 9372 GTR-15

Figure 19
 Temperature Deviation vs Radiation Exposure
 Rosemount 134EB1X S/N 9373 GTR-15

Figure 20
 Temperature Deviation vs Radiation Exposure
 Rosemount 134GT S/N 9990 GTR-15
 34

Figure 21
 Temperature Deviation vs Radiation Exposure
 Rosemount 134GT S/N 9991 GTR-15

Figure 22
 Temperature Deviation vs Radiation Exposure
 Rosemount 134EB2X S/N 9370 GTR-15
 36

Figure 23
 Temperature Deviation vs Radiation Exposure
 Rosemount 134EB2X S/N 9371 GTR-15
 37

Figure 24 shows the average slopes of Figures 3 through 23 inclusive plotted as a function of element diameter. The dashed line shows data extracted from GTR-12A, the solid line is from GTR-15 data. GTR-12A tested resistance temperature transducers whose element diameters were 0.3, 0.5 and 0.7 mil which had received no prior irradiation. The results indicate that the temperature deviations are much larger for the 0.3 and 0.5 mil diameter elements. Extrapolating the dashed curve to larger diameters indicates that an asymptote is rapidly approached whose value is approximately $0.246 \times 10^{-16} \text{ }^{\circ}\text{F} \text{ -sq.cm./n}$ ($E > 1.0 \text{ Mev}$) and that larger diameter elements will result in lower temperature measurement errors. Because of the asymptotic behavior of the dashed curve, however, no real advantage in temperature measurement accuracy will be obtained by increasing the element diameter beyond 1.0 mils.

Test data from GTR-15 verified the findings from the extrapolated data of GTR-12A, i.e., larger diameter elements will result in lower temperature errors. The solid line in Figure 24, which represents data from GTR-15, agrees quite well with the data from GTR-12A.

As noted in Figure 24, the temperature deviation coefficients are considerably smaller for those units which had been previously irradiated. For the 0.3 mil diameter element, the ratio of the temperature measurement coefficients from GTR-15 to those from GTR-12A is 0.357. A ratio of 0.705 is noted for the 0.5 mil units. No appreciable difference is noted for the 0.7 mil diameter elements. No comparison is available for those units whose element diameters are greater than 0.7 mil.

B. RESISTANCE RATIO

1. Test Results

The variation of electrical resistance with temperature provides an excellent means of determining temperatures, particularly in the cryogenic range. Units designed for this purpose are referred to as resistance temperature transducers. The sensing element is usually made from platinum and the cross-sectional area of the element is constant over its length. The electrical

Figure 24
Average Slope of Temperature Deviation Curves
vs Wire Diameter

resistance of the element is determined by causing a fixed current to flow in the circuit and measuring the resulting voltage drop across the element: the ratio of the voltage drop to current, Ohm's Law, is the resistance of the element. This resistance can then be converted to a temperature by referring to calibration charts supplied with the transducer.

To determine the effects of nuclear irradiation on the resistances of the transducers, eighteen resistance temperature transducers were irradiated as noted in Section III of this report. Throughout each of the tests continuous data were taken providing resistance information as a function of neutron flux. The normalized resistance ratio for each RTT, (which is defined as the ratio of the measured resistance to their pre-irradiation calibration resistance for the same temperature and dewar pressure) are shown in Figures 25 through 42 inclusive, as functions of integrated neutron flux. Data from GTR-14 are very limited for reasons noted in Section III-C, however, available results are shown where applicable.

The rate of radiation damage to the resistance temperature transducers may be obtained by taking the average slopes of the resistance ratio vs integrated flux curves. The data presented in Figures 25 through 42 show that the resistance ratio coefficients are dependent on irradiation history, i.e. the coefficients of previously irradiated units are less than the non-irradiated units. In order to present these data in a more meaningful form, the average slopes of the resistance ratio vs integrated flux curves are plotted as functions of element diameter in Figure 24 for units with no previous irradiation and units which have been irradiated. Figure 24 indicates that there is a minimum element diameter which will result in minimum radiation damage to the element. This minimum diameter ranges between 0.7 mil and 1.0 mil.

Figure 24 also indicates that previously irradiated units are less susceptible to radiation damage than units which have received no irradiation. Although not conclusive, this observation suggests that units may be irradiated to saturation, i.e. that point where an increase in the neutron flux produces a negligible change in the resistance ratio, to reduce the resistance measurement error. The effects of partial annealing of saturated units should be evaluated

as prior test results indicate that approximately 40 percent recovery occurs within 6 hours after termination of the irradiation, Reference (4). Since the units in Reference (4) were not irradiated to saturation, the amount of partial annealing cannot be predicted.

The resistance ratio data presented in Figures 25 through 42 inclusive were fitted to a curve described by the equation

$$\text{Resistance ratio} = A + B (1 - e^{-C\phi T}) \quad (1)$$

The physical significance of the constant A, B, and C are as follows:

A is the initial change in resistance ratio caused by gamma heating. It is a function of transducer design, wire diameter, and gamma heating rate.

B is the saturation value of the total resistance change, it is only influenced by wire diameter.

C is the rate of saturation. Its values are influenced only slightly by wire diameter. The flux is for $E > 1.0$ Mev.

The results of a computer (best fit) analysis of the data to Equation 1 are shown in Table V.

The coefficients A, B, and C were determined for individual test runs as well as the composite of the three tests and these values are also presented in Table V. Saturation values for the resistance temperature transducers may be obtained by inspections; in general, saturation will occur at approximately $\phi T = 10^{17}$.

Figure 25
Resistance Ratio vs Integrated Neutron Flux
Rosemount 110AA S/N 209
42

Figure 26
Resistance Ratio vs Integrated Neutron Flux
Rosemount 110AA S/N 211

Figure 27
Resistance Ratio vs Integrated Neutron Flux
Winsco 2448-5 S/N 156
44

Figure 28
Resistance Ratio vs Integrated Neutron Flux
Winsco 2448-5 S/N 157
45

Figure 29
Resistance Ratio vs Integrated Neutron Flux
Winsco 2448-5 S/N 158

Figure 30
Resistance Ratio vs Integrated Neutron Flux
Winsco 2448-5 S/N 159

Figure 31
Resistance Ratio vs Integrated Neutron Flux
Winsco 2448-5 S/N 161
47

Figure 32
Resistance Ratio vs Integrated Neutron Flux
Rosemount 134EB S/N 4079

Figure 33
Resistance Ratio vs Integrated Neutron Flux
Rosemount 134EB S/N 4080
48

Figure 34
Resistance Ratio vs Integrated Neutron Flux
Rosemount 134EB S/N 4081

Figure 35
Resistance Ratio vs Integrated Neutron Flux
Rosemount 134EB S/N 4087

Figure 36
Resistance Ratio vs Integrated Neutron Flux
Rosemount 134EB S/N 4107
50

Figure 37
Resistance Ratio vs Integrated Neutron Flux
Rosemount 134EB1X S/N 9372
51

Figure 38
Resistance Ratio vs Integrated Neutron Flux
Rosemount 134EB1X S/N 9373
52

Figure 39
Resistance Ratio vs Integrated Neutron Flux
Rosemount 134GT S/N 9990
53

Figure 40
Resistance Ratio vs Integrated Neutron Flux
Rosemount 134GT S/N 9991
54

Figure 41
Resistance Ratio vs Integrated Neutron Flux
Rosemount 134EB2X S/N 9370
55

Figure 42
Resistance Ratio vs Integrated Neutron Flux
Rosemount 13⁴EB2X S/N 9371
56

Make, Model and S/N	Element Diameter (mils)	Test GTR-12A			Test GTR-15			Composite of GTR-12A, GTR-14 and GTR-15		
		A	B	C ($\times 10^{-16}$)	A	B	C ($\times 10^{-16}$)	A	B	C ($\times 10^{-16}$)
Rosemount 110AA150, 209	0.3	1.04	0.95	-0.26						
Rosemount 110AA150, 211	0.3	1.03	0.72	-0.43	1.17	0.94	-0.10	1.04	0.74	-0.38
Winsco 2448-5, 156	0.5	1.08	1.09	-0.18						
Winsco 2448-5, 157	0.5	1.06	0.53	-0.24	1.14	0.48	-0.27	1.09	0.48	-0.29
Winsco 2448-5, 158	0.5	1.06	1.09	-0.12						
Winsco 2448-5, 159	0.5	1.07	0.97	-0.10						
Winsco 2448-5, 161	0.5				1.06	0.79	-0.16			
Rosemount 134EB250, 4079	0.7	1.05	0.030	-0.28						
Rosemount 134EB250, 4080	0.7	1.07	0.22	-0.57						
Rosemount 134EB250, 4081	0.7	1.05	0.31	-0.19						
Rosemount 134EB250, 4087	0.7	1.05	0.57	-0.08						
Rosemount 134EB250, 4107	0.7	1.05	0.41	-0.14	1.29	0.34	-0.24	1.06	0.98	-0.12
Rosemount 134GT, 9990	1.0				1.29	0.49	-0.17			
Rosemount 134GT, 9991	1.0				1.14	0.39	-0.21			
Rosemount 134EB1X, 9372	1.0				1.25	0.48	-0.08	1.01	0.57	-0.19
Rosemount 134EB1X, 9373	1.0				1.22	0.58	-0.10	1.02	0.068	-0.19
Rosemount 134EB2X, 9370	2.0				1.24	0.40	-0.25	1.01	0.67	-0.20
Rosemount 134EB2X, 9371	2.0				1.24	0.48	-0.16	1.01	0.82	-0.10

Table V
Radiation Damage Coefficients

2. Theoretical Analysis of Damage Mechanisms

A brief analysis of the data in Table V indicates that the damage coefficients decrease with increasing wire diameter; thus suggesting that the defects are more prevalent near the surface of the wire. If the ceramic coating over the sensing element is permeable to hydrogen, (Laboratory tests have indicated that the ceramic glaze is not watertight and the wires fit loosely in the ceramic to eliminate any induced strains) there are two plausible causes for this surface phenomenon: (1) the impurities which result from recoil protons (hydrogen atoms) being imbedded in the surface, and (2) the interstitials which result from proton bombardment. The errors introduced by these processes were evaluated using the damage mechanisms model shown in Figure 43.

a. Impurity Content Resulting from Protons Being Imbedded in the Surface

The effective range of the protons can be approximated within 15% by the Bragg-Kleeman equation, i.e.

$$\lambda_1(E_x) = 3.2 \times 10^{-4} \frac{\sqrt{A_1}}{\xi_1} \lambda_{\text{air}}(E_x) \quad (2)$$

where $\lambda_1(E_x)$ is the range in material 1, at energy E_x

A_1 is the atomic weight of material 1

ξ_1 is the density of material 1

and $\lambda_{\text{air}}(E_x)$ is the range of the proton in air at energy E_x

For platinum: $A_1 = 195$, and $\xi_1 = 21.4 \text{ gms/cm}^3$,

for LH_2 $A_1 = 1$, and $\xi_1 = 0.071 \text{ gms/cm}^3$

Figure 43
Radiation Damage Mechanism
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The energy of the recoil proton can be calculated from the reaction kinetics of the n - p process; however, for the purpose of these calculations the average recoil energy of the proton is assumed to be 0.5 Mev. The range of a 0.5 Mev proton in air (λ_{air}) is 1.0 cm (Reference 5), therefore, for a 0.5 Mev proton:

$$\begin{aligned}\lambda_{\text{LH}_2} &= 4.5 \times 10^{-3} \text{ cm} \\ \lambda_{\text{pt}} &= 2.1 \times 10^{-4} \text{ cm}\end{aligned}$$

The reaction rate of n-p reactions occurring in LH₂ is given by the following expression

$$k = \phi(E) \sigma(E) N_H \quad (3)$$

where k is the reaction rate (protons recoiled/sec. cm³ of LH₂)

$\phi(E)$ is the neutron flux which is a function of energy (neutrons/cm²-sec)

$\sigma(E)$ is the cross section of the n-p process which is a function of energy (cm²/atom of H)

and

N_H is the hydrogen atom density (atoms/cm³)

$$N_H = \frac{6.02 \times 10^{23}}{A} \zeta_{\text{LH}_2} = 4.3 \times 10^{22} \text{ atom/cm}^3$$

The product $\phi(E) \sigma(E)$ can be determined by numerically integrating the neutron spectrum from Reference (6) and the cross section data from Reference (5) for the n-p process from thermal energy to 10 Mev using the following equation:

$$\bar{\phi(E) \sigma(E)} = \frac{\int_{\text{thermal}}^{10 \text{ Mev}} \phi(E) \sigma(E) dE}{\int_{\text{thermal}}^{10 \text{ Mev}} dE} \quad (4)$$

Numerically integrating the above expression from thermal energy to 10 Mev yields the following result.

$$\bar{\phi}(E) \sigma(E) = 4 \times 10^{-12} \text{ sec}^{-1}$$

Using the above values, the reaction rate is

$$k = 1.72 \times 10^{11} \text{ protons/cm}^3\text{-sec}$$

Since the range of protons is very small, a conservative estimate of the number of protons absorbed by the platinum wire is obtained by assuming the platinum wire to be immersed in LH_2 , thus reducing the problem to one dimension.

Only protons created within the range λ_{LH_2} of the wire can be absorbed by the wire, the probability being approximated by the following expression

$$P(R) = \frac{\pi}{16} \left[1 - \frac{R}{\lambda_{\text{LH}_2}} + \frac{r}{\lambda_{\text{LH}_2}} \right] \quad (5)$$

where $P(R)$ is absorption probability as a function of R

r is the radius of wire

and R is distance from center of wire to differential volume, dv

The rate at which protons are bombarding the surface, k_p , is

$$R = r + \lambda_{\text{LH}_2} \quad (6)$$

$$k_p = \int_{R=r} P(R) k dV$$

The differential volume dV is

$$dV = 2\pi RLdR$$

where L is the length of wire under consideration

$$k_p = \int_r^{r + \lambda_{LH}} \frac{\pi}{16} \left(1 - \frac{R}{\lambda_{LH}} + \frac{r}{\lambda_{LH}} \right) k \pi RL dR \quad (7)$$

which upon integration yields the following expression

$$k_p = \frac{\pi kL}{16} \lambda_{LH}^2 \left(r + \frac{\lambda_{LH}}{3} \right) \quad (8)$$

The impurity content of hydrogen (proton) atoms in the surface of the platinum can be estimated from the following expression

$$I = 100 \frac{\int_0^T k_p dt}{N_{pt} V_d} \quad (9)$$

where:

I is the impurity content (in percent)

T is the irradiation time (in seconds)

N_{pt} is the atom density of platinum (atom/cm³) and

V_d is volume of platinum in which the protons are being imbedded (cm³)

For purposes of calculation, the total accumulated irradiation time T is assumed to be 200 hrs (7.2×10^5 seconds) and k_p is assumed to be constant with no annealing. The atom density of platinum is

$$N_{pt} = 6.6 \times 10^{22} \text{ atoms/cm}^3$$

$$V_d = \pi L \lambda_{pt} \left[2r - \lambda_{pt} \right] \quad (10)$$

The impurity content is shown in Table VI for each wire diameter investigated.

TABLE VI

IMPURITY CONTENT SUMMARY

Wire Diameter (mils)	(Percent)
0.3	0.0028
0.5	0.0017
0.7	0.0012
1.0	0.00097
2.0	0.00067

It is obvious from the above calculations that the hydrogen impurity alone will not account for the resistance changes noted in the RTT irradiations. As these conservative calculations indicate, the hydrogen content in the surface is considerably less than 100 ppm. Although the hydrogen atoms which are imbedded in the surface do not themselves cause a drastic resistance change, they can create vacancy - interstitial pairs which can effect the resistance. Also, neutrons can cause vacancy - interstitial pairs.

b. Vacancy - Interstitial Pairs Resulting
From Neutron Bombardment:

The "range" of neutrons is considerably greater than the thickness of the platinum wire and will result in vacancy interstitial pairs being formed homogeneously throughout the wire. The basic mechanism of vacancy/interstitial formation is for the neutron to undergo a scattering reaction with a platinum atom which subsequently creates additional vacancy/interstitial pairs. The reaction rate, K_n for neutron-platinum atom first collisions is given by the following expression

$$K_n = \phi \sigma_s N_{pt} \quad (11)$$

where ϕ_n is the fast neutron flux = 2.0×10^{11} nv
 σ_s is the scattering cross section = 5 barns

$$K_n = (2.0 \times 10^{11}) (5 \times 10^{-24}) (6.6 \times 10^{22}) = 6.6 \times 10^{10} \frac{\text{interstitials}}{\text{cm}^3 \text{sec}} \quad (12)$$

The average energy imparted to platinum atoms, E_p , in a scattering process can be approximated by the following expression

$$E_p = (0.7) E_n \frac{1}{1 + A} \quad (13)$$

where E_n is the neutron energy = 1.0 Mev average
 A is the atomic weight of platinum = 195 and the factor
 0.7 weights the scattering process through all angles.

$$E_p = (0.7) (1.0 \times 10^6) \frac{1}{196} = 3.57 \times 10^3 \text{ ev}$$

The recoil platinum atom (interstitial) loses all of its kinetic energy in the wire and results in secondary interstitials which require approximately 50 ev per vacancy-interstitial pair. Thus, a 1.0 Mev neutron results in approximately M_n vacancy-interstitial pairs where $M_n = \frac{3570}{50} = 71$ pairs. In a platinum wire of Volume V , the number of vacancy pairs, n , created assuming no recombination occurs is

$$n = \int_0^T K V M_n dT \quad (13)$$

If the irradiation time T is assumed to be 200 hours, the reaction rate remains constant and no recombination occurs,

$$n = (6.6 \times 10^{10}) (71) (7.2 \times 10^5) = 3.4 \times 10^{18} \text{ v} \quad (14)$$

The atom percent of interstitials, due to neutrons, I_n , is

$$I_n = 100 \frac{n}{N_{pt} V} \quad (15)$$

$$I_n = \frac{3.4 \times 10^{18} \times 10^2}{6.6 \times 10^{22}} = 5.1 \times 10^{-3}\%$$

c. Vacancy - Interstitial Pairs Resulting From Proton Bombardment

The range of protons in platinum is very small compared to the wire diameter, therefore, all of the proton kinetic energy is transformed to excitation and kinetic energy of platinum atoms which in turn creates vacancy-interstitial pairs. If the average energy of protons bombarding the wire is 0.5 mev, the interstitials formed per proton, m_p , is:

$$m_p \cong \frac{1}{2} \ln \frac{5 \times 10^5}{50} \cong 5 \quad (16)$$

The interstitials resulting from proton bombardment are located within the range λ_{pt} of the surface with an exponential gradient from the surface. The atom percent of vacancy-interstitial pairs caused by proton bombardment, I_p is dependent on diameter and is given by the following expression:

$$I_p = I_{m_p} = 5 I \quad (17)$$

where I is obtained from Table VI. It is obvious that some recombination must take place as the vacancy-interstitial atom percent ranges from $3.4 \times 10^{-3}\%$ for the 2.0 mil wire up to $1.4 \times 10^{-2}\%$ for the 0.3 mil diameter wire. This effect which is only a surface phenomenon results in more interstitials than those which result from neutrons.

d. Change in Resistance Ratio

Since both neutrons and protons cause vacancy - interstitials pairs in the surface region in contrast to only neutrons causing vacancy - interstitial pairs in the central region of the wire, the equivalent resistance of the element may be obtained by employing the relationship for two resistors in parallel, namely

$$R_{eq} = \frac{R_1 R_2}{R_1 + R_2} \quad (18)$$

where

$$R_1 = (\zeta_o + \alpha (I_p + I_n)) \frac{L}{A_1} \quad (18a)$$

$$R_2 = (\zeta_o + \alpha I_n) \frac{L}{A_2} \quad (18b)$$

α is the resistivity change per atom percent vacancy - interstitials density, A_1 is the surface area where protons and neutrons are effective in forming V-I pairs, A_2 is the central region where only neutrons produce V-I pairs, and ζ_o is the unirradiated resistivity of the wire. Although α is not known, the shape of the normalized resistance ratio curve (i.e., the ratio of the resistance during irradiation to the unirradiated resistance) as a function of wire diameter can be estimated by expressing it as follows

$$\frac{R}{R_o} = 1 + \frac{\Delta R}{R_o} \quad (19)$$

$$\frac{R}{R_o} = 1 + \frac{\left[\frac{\alpha (I_p + I_n)}{A_1} \right] \left[\frac{\alpha I_n}{A_2} \right]}{\frac{\zeta_o}{A_o} \left[\frac{\alpha (I_p + I_n)}{A_1} + \frac{\alpha I_n}{A_2} \right]} \quad (19a)$$

or

$$\frac{R}{R_o} = 1 + \frac{\alpha}{\zeta_o} [\beta] \quad (19b)$$

Equation 19b was used to calculate $\frac{R}{R_o}$ and these results are shown in Table VII.

Figure 44
 Resistance Ratio Comparison
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TABLE VII
THEORETICAL RESISTANCE RATIO

D_w mils	β	Normalized
0.3	0.0105	1.86
0.5	0.0077	1.63
0.7	0.0066	1.54
1.0	0.0060	1.49
2.0	0.0056	1.45 (normalized point)

$$= 1 + \frac{x}{o} \beta$$

By normalizing this expression to the experimental data at 2.0 mils, and plotting it on Figure 44, one notes that the shape of the curve is in agreement with the experimental data.

C. ERRORS CAUSED BY GAMMA HEATING

Temperature derivations caused by gamma heating, which are summarized in Table VIII, were obtained by extrapolating the curves presented in Figures 3 through 23 inclusive to the zero flux intercepts. Figure 45 shows a comparison between the calculated temperature derivation Reference (1), the experimental data and the predicted temperature derivation at various NERVA locations assuming a Rosemount 134EB is used. Figure 45 shows that the experimentally determined temperatures are approximately 0.2°F higher than the predicted values from Reference (1).

The temperature deviation resulting from gamma heating is a function of both the physical size of the resistance element and the temperature difference between the element wire and the liquid hydrogen. Reducing the element diameter

TABLE VIII
GAMMA HEATING SUMMARY

Make & Model	Serial Number	GTR-12A		GTR-15	
		Gamma Dose Rate ergs/gm(C)-hr	ΔT_{β} °F	Gamma Dose Rate ergs/gm(C)-hr	ΔT_{β} °F
Rosemount 110AA	209	3.6×10^9	0.44	-	-
Rosemount 110AA	211	3.6×10^9	0.44	3.7×10^9	0.54
Winsco 2448-5	156	$3. \times 10^9$	0.56	-	-
Winsco 2448-5	157	3.2×10^9	0.63	2.8×10^9	0.5
Winsco 2448-5	158	3.38×10^9	0.6	-	-
Winsco 2448-5	159	$4. \times 10^9$	0.63	-	-
Winsco 2448-5	161	-	-	3.7×10^9	0.54
Rosemount 134EB	4079	3.2×10^9	0.56	-	-
Rosemount 134EB	4080	2.8×10^9	0.56	-	-
Rosemount 134EB	5381	2.8×10^9	0.5	-	-
Rosemount 134EB	4087	3.2×10^9	0.56	-	-
Rosemount 134EB	4107	3.6×10^9	0.69	2.8×10^9	0.5
Rosemount 134EB1X	9372	-	-	3.7×10^9	0.65
Rosemount 134EB1X	9373	-	-	3.78×10^9	0.62
Rosemount 134GT	9990	-	-	2.8×10^9	0.39
Rosemount 134GT	9991	-	-	3.66×10^9	0.54
Rosemount 134EB2X	9370	-	-	2.8×10^9	0.58
Rosemount 134EB2X	9371	-	-	3.7×10^9	0.73

Figure 45
Gamma Heating Errors
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would reduce the temperature deviation caused by gamma heating; however, a reduction in the element diameter would result in an increase in the temperature deviation caused by neutron bombardment. The temperature deviation caused by gamma heating will be lower than is indicated by the test data. Forced convective cooling because of the liquid hydrogen flowing at an average velocity of 75 fps in the engines' pump supply lines will produce some cooling for the resistance temperature transducer thereby reducing the temperature error caused by gamma heating. The tests conducted did not duplicate the flow conditions that will be experienced by the resistance temperature transducer installed on the engine. As the temperature deviation caused by gamma heating can be more accurately predicted than temperature deviation resulting from neutron bombardment it is suggested that neutron damage be selected as the criterion governing the selection of resistance temperature transducers.

D. POST CALIBRATION AND RADIATION ANNEALING SUMMARY

Upon completion of irradiation, all transducers were returned to Aerojet-Sacramento and post calibration measurements were made at the ice point, at LN_2 temperature and at LHe temperature. The following paragraphs summarize the results of post-calibration testing on the subject transducers, which are discussed in detail in Appendix C.

The post-calibration resistance ratios shown in Table IX were obtained for LH_2 temperatures by extrapolating the data obtained from LN_2 and LHe measurements. In all cases, the transducers were annealed to approximately 100°F prior to post-testing calibration. Figure 46 depicts the post calibration LH_2 resistance ratio as a function of integrated flux for each transducer sensing element wire diameter. It should be noted that the resistance ratio increases with integrated flux; however a saturation effect is evident. Also, the smaller wire diameter showed the largest resistance changes.

The recovery in resistance of the sensing element because of thermal annealing to approximately 100°F is listed in Table IX and plotted as a function of integrated flux in Figure 47. The room temperature anneal resulted in approximately 55% recovery of the radiation effects damage. All of the transducers which

were irradiated in GTR-12A were annealed at temperatures up to 385°F prior to measuring the resistance ratio in LH_2 . This annealing at higher temperatures (385°F) results in a recovery of approximately 60%.

Figure 46
Post Calibration Error Measurement Summary

Figure 47
Radiation Annealing vs Integrated Flux
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Transducer Make and Model No.	Serial No.	Element Diameter Mils.	GTR-12A				GTR-14				GTR-15			
			Integrated Neutron Flux nvt	Final Test Resistance Ratio	Post Test Resistance Ratio	% Recovery	Integrated Neutron Flux nut (GTR-12A+GTR-14)	Final Test Resistance Ratio	Post Test Resistance Ratio	% Recovery	Integrated Neutron Flux nut GTR-12A+GTR-14 +GTR-15	Final Test Resistance Ratio	Post Test Resistance Ratio	% Recovery
Rosemount 110AA150	209	0.3	3.1×10^{16}	1.59	1.1	31	-	-	-	-	-	-	-	-
Rosemount 110AA150	211	0.3	3.1×10^{16}	1.48	*	-	6.7×10^{16}	*	-	-	2.2×10^{17}	2.25	1.66	26.2
Winsco 244B-5	156	0.5	3.4×10^{16}	1.58	**	-	-	-	-	-	-	-	-	-
Winsco 244B-5	157	0.5	7.1×10^{16}	1.76	1.1	38	-	-	-	-	1.81×10^{17}	1.92	1.37	3.
Winsco 244B-5	158	0.5	3.1×10^{16}	1.32	**	-	-	-	-	-	-	-	-	-
Winsco 244B-5	159	0.5	6.5×10^{16}	1.55	**	-	-	-	-	-	-	-	-	-
Winsco 244B-5	161	0.5	-	-	-	-	-	-	-	-	1.53×10^{17}	1.79	1.78	1.
Rosemount 134EB	4079	0.7	3.1×10^{16}	1.22	1.05	14	-	-	-	-	-	-	-	-
Rosemount 134EB	4080	0.7	3.7×10^{16}	1.27	1.05	17	-	-	-	-	-	-	-	-
Rosemount 134EB	4081	0.7	3.7×10^{16}	1.21	1.03	15	-	-	-	-	-	-	-	-
Rosemount 134EB	4087	0.7	7.1×10^{16}	1.3	1.05	19	-	-	-	-	-	-	-	-
Rosemount 134EB	4107	0.7	6.8×10^{16}	1.3	1.06	18	1.02×10^{17}	*	-	-	2.1×10^{17}	1.6	1.6	0
Rosemount 134GT	9990	1.0	-	-	-	-	-	-	-	-	1.1×10^{17}	1.65	1.6	3.
Rosemount 134GT	9991	1.0	-	-	-	-	-	-	-	-	1.27×10^{17}	1.5	1.4	6.6
Rosemount 134EB1X	9372	1.0	-	-	-	-	2.26×10^{17}	*	-	-	3.8×10^{17}	1.55	1.48	4.5
Rosemount 134EB1X	9373	1.0	-	-	-	-	2.26×10^{17}	*	-	-	4.1×10^{17}	1.72	1.53	11.
Rosemount 134EB2X	9370	2.0	-	-	-	-	2.26×10^{17}	*	-	-	3.4×10^{17}	1.61	1.55	3.1
Rosemount 134EB2X	9371	2.0	-	-	-	-	3.4×10^{16}	*	-	-	1.9×10^{17}	1.7	1.6	6.

NOTES: * Data not available
 ** No calibration data, open element

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LIST OF REFERENCES

1. RN-S-0063 - "Pre-Irradiation Analysis of Test 23/1101 - Resistance Temperature Transducers", March, 1964
2. RN-S-0086 - "Final Test Specification for Ground Test Reactor (GTR) Irradiation Test No. 12A", February 1964
3. RN-S-0167 - "Final Test Specification for Ground Test Reactor (GTR) Irradiation Test No. 15", September 1964
4. RN-S-0157 - "Final Test Report RTT Test 23/1101". December 1964
5. Evans, R. D. The Atomic Nucleus, McGraw Hill Book Company, New York, New York, 1955
6. NARF Facilities Handbook General Dynamics Report FZK-185, March 1964

APPENDIX A

I. 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.

A. CALIBRATION CONSTANT

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

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

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.

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

$$\text{Let } T_i = T_r$$

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

$$B_o = A_o + A_1 P + A_2 P^2 + \dots \dots + A_4 P^4 - B_1 R - B_2 R^2 - \dots \dots - B_o R^9$$

B_o 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.

B. 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 A-1

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:

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 Section A, above, "Calibration Constant."

$$\begin{aligned} B_1 &= + 0.33114091E-01 \\ B_2 &= - 0.46452311E-01 \\ B_3 &= - 0.79330482E-02 \\ B_4 &= - 0.17037884E-02 \\ B_5 &= + 0.25143277E-03 \\ B_6 &= + 0.56537078E-05 \\ B_7 &= - 0.18473031E-05 \\ B_8 &= + 0.58453272E-07 \\ B_9 &= + 0.38042806E-09 \end{aligned}$$

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 Section A, above.

$$C_1 = + 0.14095685E-02$$

$$C_2 = - 0.25752804E-01$$

$$C_3 = + 0.21676446E-00$$

C. 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:

$$\text{Tr} = A_0 + A_1 P + A_2 P^2 + A_3 P^3 + A_4 P^4$$

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

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

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

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

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

APPENDIX B

I. CURVE FITTING PROBLEM

The purpose of the computer program is to fit experimental data for resistance ratio vs integrated neutron flux to a curve of the form:

$$\frac{R}{R_{\text{standard}}} = A + B (1 - e^{-C\phi T})$$

The minimum number of data points which can be fitted to the curve is 3, the maximum 50.

The program employs the method of least squares in fitting the data to the curve. To obtain the best possible fit, an iterative process is used in determining the exponent C. The best curve fit is obtained when the sum of the squares of the residuals (residuals are the difference between the experimental data and the calculated values) is minimum.

Data for the resistance ratios with the corresponding neutron flux values are input to the computer together with a selected value for the "C" term and a "C" increment or ΔC . The value of $(1 - e^{-C\phi T})$ is computed and the data is then fitted to the curve described by the equation. The differences between the data input and calculated values are obtained, squared and then are added. The "C" term is then incremented by the amount ΔC and the process is repeated. The sums of the squares of the residuals are compared to determine if the residuals are converging or diverging. Should the residuals continue to converge for each increment of C another initial value of C may have to be selected, depending on the rate of convergence. If the rate of convergence is low the last incremented value for C may be selected, the maximum number of iterations is determined by the computer input.

Should the residuals diverge after 4 successive iterations the sign of the ΔC is reversed and the process starts again. When the residuals converge and then diverge, the last convergent point is selected and the value of C at that point is

incremented by $\frac{\Delta C}{2}$ and iteration continues. After successive iterations, C should converge to the desired value.

In the event convergence is not obtained after 4 successive iterations for positive and negative values of ΔC that case will be terminated and an error statement written indicating that an incorrect initial value for C was selected.

ISSUE DATE: 2 July 1965

ENGINEERING REPORT NO. 0700:0350

GTR IRRADIATED RESISTANCE TEMPERATURE
TRANSDUCERS

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GTR IRRADIATED RESISTANCE TEMPERATURE
TRANSDUCERSI. INTRODUCTION

The purpose of this report is to document the pre and post calibration data for all resistance temperature transducers (RTT's) irradiated on either GTR-12A, GTR-14, or GTR-15 reactor tests. Photographs of all RTT's tested, with amplifying remarks, are also included. It is intended that this data and the photographs be used for inclusion in the final GTR-14 and GTR-15 test report. The reason for failure of three RTT's tested on GTR-12A has been determined and is documented in this report.

II. DISCUSSION

A. TEST ITEMS

In conducting the three RTT tests at General Dynamics, Fort Worth, a total of 18 RTT's have been irradiated. Of this total, 14 RTT's have been included in two or more of the tests to increase the integrated neutron exposure and evaluate the possibility of using RTT's on more than one NRX test series. Table I is a list of all RTT's with the integrated neutron flux for each.

All RTT's are constructed with a high purity platinum element. There are 5 wire sizes used in the construction of the RTT's 0.0003, 0.0005, 0.0007, 0.001, and 0.002 inches for groups 1 thru 5. Group 1 thru 3 RTT's are fully described in REON report no. RN-S-0157, Reference 1. The model 134EB1X of group 4 are identical to the 134EB250 except for wire substitution. As a result of the larger OD wire, the resistance of the element at any temperature is reduced about 50 percent. Similar, the 134EB2X of group 5 are identical in construction and materials except the element is wound with 0.002 inch OD wire. The resistance at any temperature is reduced to about 15 percent of the 134EB250 values.

The model 134 GT is an experimental unit with several new design changes. This RTT has a theoretically optimum wire diameter of 0.001 inches. The element is designed for tip mount and has a double layer of wire for a higher resistance vs temperature curve. The element also has four leadwires carried to the tip which is an improvement over the 2 lead wire method of the 134EB250 design.

B. ACCEPTANCE TEST DATA

Calibration data measured by Aerojet during the acceptance testing was recorded and evaluated for the items of group 2 and 3. This data appears on the calibration curves to be discussed later in this report.

All RTT's were calibrated at temperatures of +32°F (ice/water bath), -320°F (LN₂ bath) and -423°F (GHe Cryostat in the Measurement Standards Laboratory). The techniques and equipment are described in detail in Report 9271-9, reference 2, Section III-B.

MFR	GROUP	MODEL	SN	INTEGRATED NEUTRON FLUX (n/cm ²)x10 ¹⁶			
				GTR-12A	GTR-14	GTR-15	TOTAL
Rosemount	I	110AA150	209	1.1	---	5.5	6.6
			211	1.1	1.2	5.4	7.7
Winsco	II	2448-5	156	1.2	---	---	1.2
			157	2.5	---	3.5	5.0
			158	1.1	---	---	1.1
			160	2.3	---	---	2.3
			161	---	---	5.4	5.4
Rosemount	III	134EB250	4079	1.2	---	5.5	6.7
			4080	1.3	---	5.5	6.8
			4087	2.5	---	5.5	8.0
			4107	2.4	1.2	3.5	7.1
			5381	1.3	---	5.5	6.8
	IV	134EB1X	9372	---	0.8	5.4	6.2
			9373	---	0.8	6.5	7.3
		134GT	9990	---	---	3.5	3.5
			9991	---	---	4.5	4.5
	V	134EB2X	9370	---	0.8	3.5	4.3
			9371	---	1.2	5.4	6.6

TABLE I
NEUTRON IRRADIATION HISTORY

C. Pre GTR-15 Test Data

All of the RTT's except Winsco Model 2448-5 (SN 156, 158, and 160) and Rosemount Model 134GT (SN 9990 and 9991) were tested prior to conducting GTR-15 test at Fort Worth. This calibration included measurements for insulation resistance, thermal EMF, and calibration. Each RTT was calibrated at temperatures of 32°, -320° and -411°F in fixed point baths of ice/water, LN₂ and LHe. The test settings are identical to those described in reference 2.

The Dymec system from the Engineering laboratory was used to measure the element resistance of each RTT. Calibration results are graphically illustrated in Figures 1 thru 15 and tabulated in Tables II thru IV. All of the data is normalized for ease of direct comparison of the various models.

The three model 2448-5 (SN 156, 158 and 160) RTT's have open elements, thus could not be calibrated. The 134GT RTT's were delivered directly to General Dynamics, thus were not calibrated at Aerojet prior to conducting the GTR-15 test.

All three of the Winsco RTT's (156, 158 and 160) were tested on GTR-12A and presently have open elements. The cause for the open elements is attributed to bending of the stem and mandrel. This condition was found during the visual inspection when the RTT's were returned after GTR-12A from General Dynamics and must have occurred during removal from the GTR-12A test fixture.

D. Post GTR-15 CALIBRATION DATA

All RTT's tested in GTR-15 were calibrated after completion of the test to measure accurately the resistance shift at four discreet temperatures, as a result of the neutron exposure. Each RTT was calibrated in baths of ice/water, LN₂, LHe, and LHe. The element resistance was measured with a Leeds and Northrup bridge. All values between 0 and 111.1 ohms were measured with a type G-2 Bridge and for the values greater than 111.1 a precision wheatstone bridge was used.

All test setups except LHe remain the same as the pre GTR-15 calibration. For the LHe setup a LN₂ cooled copper dewar was used.

The data is also graphically illustrated in figures 1 thru 15 and is tabulated in tables V thru VIII. Again the data was normalized for direct comparison of the different models.

E. VISUAL INSPECTION AND PHOTOGRAPHS

Photographs of each RTT were taken in the "as received" condition from General Dynamics. They are included in this report along with the accompanying remarks.

MFR	Group	MODEL	SN	A	B	C	D	E
				Original MFR R_o (ohm)	AGC Meas.* R_o (ohm)	ΔR_o (ohm)	Normalized ΔR_o (%)	ΔT_o (°F)
Rosemount	I	110AA150	209	399.456	400.093	0.637	0.159	0.80
			211	399.694	400.643	0.949	0.238	1.19
Winsco	II	2448-5	157	1380.450	1380.827	2.037	0.147	0.74
Rosemount	III	134EB250	4079	1380.817	1381.332	0.635	0.046	0.23
			4080	1380.417	1381.509	0.719	0.052	0.26
			4087	1380.313	1381.527	0.214	0.016	0.08
			4107	1380.618	1381.113	0.494	0.037	0.18
			5381	1380.817	1381.407	0.310	0.022	0.11
	IV	134EB1X	9372	641.733	641.652	- 0.081	-0.013	-0.06
			9373	629.043	629.082	0.038	0.006	0.03
	V	134EB2X	9370	133.214	Invalid date	-----	-----	-----
			9371	129.086	Invalid date	-----	-----	-----

* Bath temperature remained constant at 32.00°F

$$\Delta R_o = B - A$$

$$\text{Normalized } \Delta R_o = \frac{100C}{B}$$

$$\Delta T_o = 5D$$

TABLE II

RTT SUMMARY SHEET

PRE GTR-15 ICE BATH CALIBRATION DATA

MFR	MODEL	SN	BATH TEMPERATURE	A	B	C	D	E
				Original MFR R_{LN_2} (ohm)	AGC Meas. R_{LN_2} (ohm)	ΔR_{LN_2} (ohm)	Normalized ΔR_{LN_2} (%)	ΔT_{LN_2} (°F)
Rosemount	110AA150	209	-320.38°F	75.762	76.263	0.501	0.125	0.52
		211		76.084	Invalid Data	-----	-----	-----
Winsco	2448-5	157	-320.49°F	261.219	263.656	2.437	0.176	0.74
Rosemount	134EB250	4079	-320.36°F	260.056	260.897	0.841	0.061	0.35
		4080		260.267	261.460	1.193	0.086	0.36
		4087		260.224	Invalid Date	-----	-----	-----
		4107		260.321	260.888	0.567	0.041	0.17
		5381		260.398	260.639	0.241	0.017	0.07
	134EB1X	9372	-320.43°F	120.893	120.874	-0.019	-0.003	-0.01
		9373		118.474	118.480	0.006	0.001	0
	134EB2X	9370	-320.43°F	25.082	25.087	0.005	0.004	0.02
		9371		24.302	24.302	0.001	0.001	0

$$\Delta R_{LN_2} = B - A$$

$$\text{Normalized } \Delta R_{LN_2} = \frac{100C}{R_0}$$

$$\Delta T_{LN_2} = 4.16 D$$

TABLE III

RTT SUMMARY SHEET

PRE-TR-1, _QUL _TRC CAL _FIO _PA

MFR	MODEL	SN	BATH TEMPERATURE	A	B	C	D	E
				Original MFR R_{LNe} (ohm)	AGC Meas. R_{LNe} (ohm)	ΔR_{LNe} (ohm)	Normalized ΔR_{LNe} (%)	ΔT_{LNe} (F)
Rosemount	110AA150	209	-410.93°F	5.327	5.911	0.584	0.146	1.67
		211		5.305	Invalid Data	-----	-----	-----
Winsco	2448-5	157	-410.86°F	17.804	19.074	1.270	0.092	1.03
Rosemount	134EB250	4079	-410.90°F	17.171	17.774	0.603	0.044	0.50
		4080		17.286	17.913	0.627	0.045	0.52
		4087		17.242	17.850	0.608	0.044	0.51
		4107		17.321	18.033	0.712	0.052	0.60
		5381		17.269	17.592	0.323	0.023	0.27
	134EB1X	9372	-410.92°F	7.970	7.992	0.022	0.003	0.04
		9373		7.791	7.905	0.114	0.018	0.20
	134EB2X	9370	-410.92°F	1.643	1.638	-0.005	-0.004	-0.04
		9371		1.588	1.610	0.022	0.017	0.10

$$\Delta R_{LNe} = 4.16 \text{ D}$$

$$\text{Normalized } \Delta R_{LNe} = \frac{100C}{R_o}$$

$$\Delta T_{LNe} = 11.5 \text{ D}$$

TABLE IV

RTT SUMMARY SHEET

PRE GTR-15 LIQUID NEON CALIBRATION DATA

MFR	MODEL	SN	A	B	C	D	E
			Original MFR R_o (ohm)	AGC Meas.* R_o (ohm)	ΔR_o (ohm)	Normalized ΔR_o (%)	ΔT_o (°F)
Rosemount	110AA150	209	399.456	400.677	1.221	0.305	1.52
		211	399.694	401.793	2.099	0.523	2.62
Winsco	2448-5	157	1380.450	1384.93	4.48	0.323	1.62
		161	1380.350	1386.48	6.13	0.442	2.21
Rosemount	134EB250	4079	1380.817	1382.44	1.62	0.117	0.58
		4080	1380.417	1381.83	1.41	0.102	0.51
		4087	1380.313	1381.75	1.44	0.104	0.52
		4107	1380.618	1382.10	1.48	0.107	0.54
		5381	1380.817	1382.77	1.95	0.141	0.70
	134EB1X	9372	641.733	642.906	1.173	0.183	0.92
		9373	629.043	629.989	0.946	0.150	0.75
	134GT	9990	1153.033	1154.04	1.01	0.082	0.42
		9991	1103.415	1104.42	1.00	0.096	0.48
	134EB2X	9370	133.214	133.395	0.181	0.136	0.68
		9371	129.086	129.379	0.293	0.226	1.13

* Bath Temperature remained constant at 32.00°F

$$\Delta R_o = B - A$$

$$\text{Normalized } \Delta R_o = \frac{100C}{B}$$

$$\Delta T_o = 5D$$

TABLE V

RTT SUMMARY SHEET

POST GTR-15 ICE BATH CALIBRATION DATA

MFR	MODEL	SN	A	B	C	D	E
			Original MFR R_{LN_2} (ohm)	AGC Meas.* R_{LN_2} (ohm)	ΔR_{LN_2} (ohm)	Normalized ΔR_{LN_2} (%)	ΔT_{LN_2} (°F)
Rosemount	110AA150	209	75.8385	76.5143	0.6758	0.169	0.70
		211	75.8325	77.9699	2.1374	0.532	2.22
Winsco	2448-5	157	262.005	266.435	4.430	0.320	1.33
		161	261.934	267.550	5.616	0.373	1.55
Rosemount	134EB250	4079	260.2540	261.880	1.626	0.118	0.49
		4080	260.4637	261.510	1.046	0.076	0.31
		4087	260.4215	261.650	1.228	0.089	0.37
		4107	260.520	261.975	1.455	0.105	0.44
		5381	260.5974	261.135	1.538	0.111	0.46
	134EB1X	9372	121.0931	121.470	0.377	0.059	0.25
		9373	118.6710	119.315	0.644	0.102	0.42
	134GT	9990	217.891	218.545	0.654	0.057	0.24
		9991	208.307	208.845	0.538	0.049	0.20
	134EB2X	9370	25.1241	25.2050	0.0809	0.061	0.25
		9371	24.3427	24.4392	0.0965	0.075	0.31

* Bath Temperature remained constant at -320.30°F

$$\Delta R_{LN_2} = B - A$$

$$\text{Normalized } \Delta R_{LN_2} = \frac{100C}{R_0}$$

$$\Delta T_{LN_2} = 4.16D$$

TABLE VI

RTT SUMMARY SHEET

POST GTR-15 LIQUID NITROGEN CALIBRATION DATA

MFR	MODEL	SN	A	B	C	D	E
			Original MFR R_{LN_e} (ohm)	AGC Meas.* R_{LN_e} (ohm)	ΔR_{LN_e} (ohm)	Normalized ΔR_{LN_e} (%)	ΔT_{LN_e} (°F)
Rosemount	110AA150	209	5.3429	6.0239	0.6810	0.170	1.95
		211	5.3211	7.0051	1.6840	0.419	4.82
Winsco	2448-5	157	17.770	20.5482	2.778	0.200	2.30
		161	17.846	21.1772	3.331	0.239	2.75
Rosemount	134EB250	4079	17.1920	18.9347	1.7427	0.126	1.45
		4080	17.3052	18.4481	1.1429	0.083	0.95
		4087	17.2607	18.7368	1.4761	0.107	1.23
		4107	17.3418	18.7157	1.3939	0.099	1.14
		5381	17.2872	18.9680	1.6808	0.122	1.40
	134EB1X	9372	7.9923	8.5280	0.5357	0.083	0.95
		9373	7.8131	9.0329	1.2198	0.194	2.23
	134GT	9990	14.2995	15.0338	0.7343	0.064	0.56
		9991	13.6634	14.4210	0.7576	0.069	0.79
	134EB2X	9370	1.7529	1.6473	0.1056	0.079	0.91
		9371	1.5928	1.7108	0.1180	0.091	1.05

* Bath Temperature remained constant at -410.88°F

$$\Delta R_{LN_e} = B - A$$

$$\text{Normalized } R_{LN_e} = \frac{1000}{R_0}$$

$$\Delta T_{LN_e} = 11.5D$$

TABLE VII

RTT SUMMARY SHEET

POST GTR-15 LIQUID NEON CALIBRATION DATA

MFR	MODEL	SN	A	B	C	D
			Original MFR R_{LHe} (ohm)	AGC Meas.* R_{LHe} (ohm)	ΔR_{LHe} (ohm)	Normalized ΔR_{LHe} (%)
Rosemount	110AA150	209	0.623	1.05347	0.4305	0.105
		211	0.6061	1.5959	0.9898	0.247
Winsco	2448-5	157	no data	2.7981	----	----
		161	1.405	2.9906	1.5856	0.114
Rosemount	134EB250	4079	1.0835	2.49073	1.4072	0.102
		4080	1.1533	2.1215	0.9782	0.071
		4087	1.1051	2.32726	1.2222	0.088
		4107	1.1884	2.30601	1.1176	0.081
		5381	1.1059	2.51308	1.4072	0.102
	134EB1X	9372	0.47100	0.90537	0.4344	0.068
		9373	0.4431	1.03406	0.5910	0.094
	134GT	9990	0.68300	1.34367	0.6607	0.057
		9991	0.6868	1.34577	0.6590	0.060
	134EB2X	9370	0.0866	0.17217	0.0856	0.064
		9371	0.0806	0.17792	0.0973	0.075

* Bath Temperature remained constant at -452.1°F

$$\Delta R_{LHe} = B - A$$

$$\text{Normalized } R_{LHe} = \frac{100C}{R_o}$$

TABLE VIII

RTT SUMMARY SHEET

POST GTR-15 LIQUID HELIUM CALIBRATION DATA

Figure 1

Rosemount Model 110AA150, S/N 209

Normalized Deviation vs. Calibration Temperature

Figure 2

Rosemount Model 110AA150, S/N 211

Normalized Deviation vs. Calibration Temperature

Figure 3

Winsco Model 2448-5, S/N 157

Normalized Deviation vs. Calibration Temperature

Figure 4
 Winsco Model 2448-5, S/N 161
 Normalized Deviation vs. Calibration Temperature

Figure 5

Rosemount Model 134EB250, S/N 4079
Normalized Deviation vs. Calibration Temperature

Figure 6

Rosemount Model 134EB250, S/N 4080

Normalized Deviation vs. Calibration Temperature

Figure 7

Rosemount Model 134EB250, S/N 4087
Normalized Deviation vs. Calibration Temperature

Figure 8
Rosemount Model 134EB250, S/N 4107
Normalized Deviation vs. Calibration Temperature

Figure 9

Rosemount Model 134EB250, S/N 5381

Normalized Deviation vs. Calibration Temperature

C-20

Figure 10

Rosemount Model 134EB1X, S/N 9372

Normalized Deviation vs. Calibration Temperature

Figure 11
 Rosemount Model 134EB1X, S/N 9373
 Normalized Deviation vs. Calibration Temperature

Figure 12

Rosemount Model 134 GT, S/N 9990

Normalized Deviation vs. Calibration Temperature

Figure 13
Rosemount Model 134 GT, S/N 9991
Normalized Deviation vs. Calibration Temperature

Figure 14

Rosemount Model 134EB2X, S/N 9370

Normalized Deviation vs. Calibration Temperature

Figure 15

Rosemount Model 134EB2X, S/N 9371

Normalized Deviation vs. Calibration Temperature

The surface oxidation on all of the Winsco RTT's was greater than on the Rosemount RTT's. This could be due to the two methods of surface finish on the RTT's. Winsco RTT's have a bright polish and the Rosemount's are hydrohoned finished. Most of the oxidation occurred at the location of identification which is electrolytically etched on the RTT housing.

Six of the RTT's - Rosemount model 134EB1X, 134GT, and 134EB2X - were provided with engraved identification on the housing. It was observed that little or no oxidation occurred on these RTT's.

RTT #209, "Rosemount Model 110AA150, SN 209"

- a) Photograph No. 6-65SP-242
- b) Element and shield nicked at the tip
- c) Housing is slightly oxidized

RTT #211, "Rosemount Model 110AA150, SN 211"

- a) Photograph No. 6-65SP-244
- b) Housing is oxidized

RTT #156, "Winsco Model 2448-5, SN 156"

- a) Photograph No. 6-65SP-238
- b) Element and shield bent approximately 20°
- c) Housing is slightly oxidized
- d) Open circuit in element

RTT #157, "Winsco Model 2448-5, SN 157"

- a) Photograph No. 6-65SP-260
- b) Housing is oxidized

RTT #158, "Winsco Model 2448-5, SN 158"

- a) Photograph No. 6-65SP-240
- b) Element and shield bent approximately 10°
- c) Housing slightly oxidized
- d) Open circuit in element

RTT #160, "Winsco Model 2448-5, SN 160"

- a) Photograph No. 6-65SP-241
- b) Shield over element partially flattened
- c) Housing is oxidized
- d) Open circuit in element

RTT #161, "Winsco Model 2448-5, SN 161"

- a) Photograph No. 6-65SP-259

RTT #4080, "Rosemount Model 134EB250, SN 4080"

- a) Photograph No. 6-65SP-263
- b) Housing slightly oxidized

RTT #4087, "Rosemount Model 134EB250, SN 4087"

- a) Photograph No. 6-65SP-243

RTT #4107, "Rosemount Model 134EB250, SN 4107"

- a) Photograph No. 6-65SP-245

RTT #4107, Connector View
a) Photograph No. 6-65SP-252

RTT #5381, "Rosemount Model 134EB250, SN 5381"
a) Photograph No. 6-65SP-261

RTT #9373, "Rosemount Model 134EB1X, SN 9373"
a) Photograph No. 6-65SP-269

RTT #9990, "Rosemount Model 134GT, SN 9990"
a) Photograph No. 6-65SP-234

RTT #9991, "Rosemount Model 134GT, SN 9991"
a) Photograph No. 6-65SP-231

RTT #9990 and 9991 (Right), End View
a) Photograph No. 6-65SP-265

RTT #9990 and 9991 (Right), Side View
a) Photograph No. 6-65SP-225

RTT #9990 and 9991 (Right), Connector View
a) Photograph No. 6-65SP-254

RTT #9370, "Rosemount Model 134EB2X, SN 9370"
a) Photograph No. 6-65SP-268

RTT #9371, "Rosemount Model 134EB2X, SN 9371"
a) Photograph No. 6-65SP-266

F. RTT RADIOACTIVITY LEVELS

Measurements were taken to determine the RTT's radioactive levels. The results are listed in Table IX.

III. CONCLUSIONS

Analysis of the acceptance test, pre GTR-15 and post GTR-15 calibration data establishes that the entire resistance curve increases with integrated neutron flux. This effect was measured over the -452°F to +32°F range. The shift in resistance is essentially constant at all temperatures. Since the slope in resistance of an RTT element is not a constant, the equivalent temperature change of the element is not constant over the temperature range.

Calibration data for all GTR tests conducted are summarized in Table X. From this data and the calibration curves, it can be concluded that, for a given integrated neutron flux, the smaller the platinum wire size, the greater the resistance shift. The 0.001 and 0.002 inch OD wire damage is the same, thus, it may be concluded that the 0.001 is more desirable than the 0.002 because of the shorter wire length required for a given element resistance.

MFR	GROUP	MODEL	SN	m R/Hour*
Rosemount	I	110AA150	209	80
			211	205
Winsco	II	2448-5	157	140
			161	180
Rosemount	III	134EB250	4079	160
			4080	90
			4087	130
			4107	200
			5381	140
	IV	134EB1X	9372	190
			9373	200
		134GT	9990	120
			9991	150
	V	134EB2X	9370	120
			9371	190

* Measured on June 3, 1965

TABLE IX
RTT BETA/ GAMMA RADIOACTIVITY

SUMMARY OF RTI RESISTANCE SHEET

TABLE X

GROUP	MPR	MODEL	SN	GTR-12A			GTR-14			Combined GTR-12A and 14			GTR-15			Combined GTR-12A, 14 and/or 15		
				Integrated Neutron Flux (n/cm ²)x10 ¹⁶	Average Normal. R* (ohm)	Average Stan. R (ohm-cm ²) 10 ¹⁶ n	Integrated Neutron Flux (n/cm ²)x10 ¹⁶	Average Normal. R* (ohm)	Average Stan. R (ohm-cm ²) 10 ¹⁶ n	Integrated Neutron Flux (n/cm ²)x10 ¹⁶	Average Normal. R* (ohm)	Average Stan. R (ohm-cm ²) 10 ¹⁶ n	Integrated Neutron Flux (n/cm ²)x10 ¹⁶	Average Normal. R** (ohm)	Average Stan. R (ohm-cm ²) 10 ¹⁶ n	Integrated Neutron Flux (n/cm ²)x10 ¹⁶	Average Normal. R** (ohm)	Average Stan. R (ohm-cm ²) 10 ¹⁶ n
I 0.0003 in. OD Wire	Rosemount	110AA150	209	1.1	0.143	0.130	---	---	---	---	---	---	5.5	0.057	0.010	6.6	0.187	0.028
			211	1.1	no data	---	1.2	no data	---	2.3	0.193	0.084	5.4	0.298	0.055	7.7	0.491	0.064
II 0.0005 in. OD Wire	Winsco	2448-5	156	1.2	no calibration data, open element // // // //					// // // // // // // //			// // // // // // // //			// // // // // // // //		
			157	2.5	0.124	0.050	---	---	---	---	---	---	3.5	0.157	0.045	6.0	0.281	0.047
			158	1.1	no calibration data, open element // // // //					// // // // // // // //			// // // // // // // //			// // // // // // // //		
			160	2.3	no calibration data, open element // // // //					// // // // // // // //			// // // // // // // //			// // // // // // // //		
			161	---	---	---	---	---	---	---	---	---	5.4	0.306	0.057	---	---	---
III 0.0007 in. OD Wire	Rosemount	134EB250	4079	1.2	0.050	0.042	---	---	---	---	---	---	5.5	0.074	0.013	6.7	0.116	0.017
			4080	1.3	0.058	0.045	---	---	---	---	---	---	5.5	0.038	0.007	6.8	0.083	0.012
			4087	2.5	0.030	0.012	---	---	---	---	---	---	5.5	0.085	0.015	8.0	0.097	0.012
			4107	2.4	no data	---	1.2	no data	---	3.6	0.043	0.012	3.5	0.055	0.016	7.1	0.098	0.014
			5381	1.3	0.031	0.024	---	---	---	---	---	---	5.5	0.095	0.017	6.8	0.119	0.018
IV 0.001 in. OD Wire	134EB1X	9372	---	---	---	---	0.8	0.000	0	---	---	---	5.4	0.070	0.013	6.2	0.070	0.011
			9373	---	---	---	0.8	0.008	0.010	---	---	---	6.5	0.125	0.019	7.3	0.135	0.018
	134GT	9990	---	---	---	---	---	---	---	---	---	---	3.5	0.059	0.017	---	---	---
			9991	---	---	---	---	---	---	---	---	---	4.5	0.059	0.013	---	---	---
V 0.002 in. O.D. Wire	134EB2X	9370	---	---	---	---	0.8	0.000	0	---	---	---	3.5	0.068	0.019	4.3	0.068	0.016
			9371	---	---	---	1.2	0.009	0.008	---	---	---	5.4	0.071	0.013	6.6	0.080	0.012

* Based upon Ice/Water, LN₂ and LHe Calibration Data** Based upon Ice/Water, LN₂ and LHe and LHe Calibration Data

Calibration of irradiated RTT's was conducted at Aerojet with very little difficulty. It is suggested that NRX-A RTT's be recalibrated and reused on later tests. This would result in a considerable savings as the recalibration cost would be less than 25% of the replacement cost.

IV. LIST OF REFERENCES

1. REON Report RN-S-0157, "Final Test Report RTT Test 23/L 101", Aerojet General Corp., December 1964.
2. Engineering Report 9271-9, "A Standardized Temperature Measurement System with Constant Current Excitation and Platinum Element Transducers, Aerojet General Corp., February 1965.