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SACRAMENTO PLANT

REPORT NO. RN-S-0257
TO
AEC-NASA SPACE NUCLEAR PROPULSION OFFICE

FINAL TEST SPECIFICATION
FOR
PRESSURE TRANSDUCER EXPERIMENT 23/R510

OCTOBER 1965
CONTRACT SNP-1 NERVA PROGRAM

11/15/65

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FINAL TEST SPECIFICATION
FOR
PRESSURE TRANSDUCER EXPERIMENT 23/R510

ROCKET ENGINE OPERATIONS - NUCLEAR

CONTRACT SNP-1 OCTOBER 1965 NERVA PROGRAM

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FINAL TEST SPECIFICATION FOR
PRESSURE TRANSDUCER EXPERIMENT 23/R510

I. EXPERIMENT IDENTIFICATION

TEST PLAN REFERENCE NUMBER	23/R510
SPONSOR	REON
TESTING AGENCY	PLUM BROOK REACTOR FACILITY (PBRF)
TEST DATE	DECEMBER 1965

II. PURPOSE OF EXPERIMENT

The test described is a development irradiation test of a pressure transducer design which is a candidate for use in the NRX nozzle chamber control loop.

The primary purpose of this test is to study the effects of thermal gradients resulting from gamma heating rates comparable to those of NRX. Rate effects and cumulative damage, resulting from gamma and neutron radiations are also of interest.

The transducer stimulus will be varied in 80-psi increments from zero psig to 400 psig and back to zero at each reactor power level. Transducer output, coil resistance, insulation resistance, and transducer housing temperature will be measured and recorded at each power level.

When sufficient data have been gathered to satisfy the primary purpose of the test, the test items will be irradiated and data recorded until failure occurs. Failure is defined as greater than 25% degradation of output.

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III. DRAWINGS

A. TEST ITEMS

<u>Description</u>	Pressure Transducers
<u>Quantity</u>	Four transducers and three dummy cables
<u>Range</u>	75 psia
<u>Manufacturer</u>	Consolidated Controls Corporation
<u>AGC SCD</u>	706692-3
<u>Manufacturers Model Number</u>	412M117-250
<u>IDB Number</u>	P-111

B. TEST FIXTURE

Pneumatic System	Figure 1
Data Acquisition System	Figure 2
Resistance Measurement	Figure 3
Test Fixture Installation Drawing 1114773	Figure 4
Test Fixture Assembly Drawing 114020	Figure 5
Cable Assemblies	1115626-9

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IV. EQUIPMENT LIST

A. TO BE PROVIDED BY REON

Test fixture containing four transducers, three dummy cables, and sixteen thermocouples.

Translator, four channel, rack mounted.

Cable assemblies - transducers to translator.

Cable assemblies - dummy reference.

Pressure transducers - reference.

Function selector console.

B. TO BE PROVIDED BY TEST FACILITY AND/OR TEST AGENCY

One digital voltmeter with ohms converter.

One dual-trace oscilloscope, Tektronic Model 516 or equivalent, with Polaroid camera.

Temperature recorder (copper-constantan thermocouple)

One megohmmeter, General Radio Model 544B or equivalent.

One multi channel oscillograph.

One power supply, 28 vdc, 5-amp regulated.

One barometer to monitor containment vessel pressure,
± 1-inch water.

One still camera.

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V. TEST ENVIRONMENT

Temperature

Coolant 125°F (ambient water temperature)

Transducer (max.) 800°F at 1.63 watts/gm heating rate.

Pressure 130 psi (nominal water pressure).

Radiation Environment See Table 1.

Fluid Environment

Test Fixture Immersed in coolant water.

Test Items Gaseous helium.

Humidity As exists in helium supply.

Vibration Not applicable.

Duration 10 to 15 hours.

Power Level See Table 1.

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TABLE I

APPROXIMATE FLUXES

<u>POWER LEVEL</u>	<u>HEATING RATE (watts/gm)</u>	<u>DOSE RATE (ergs/gm(C)-hr)</u>	<u>N FLUX E > 1 mev (n/cm²-sec.)</u>
10 Kw	- - -	1.6×10^7	2.5×10^9
100 Kw	- - -	1.6×10^8	2.5×10^{10}
1 Mw	.044	1.6×10^9	2.5×10^{11}
10 Mw	.44	1.6×10^{10}	2.5×10^{12}
20 Mw	.88	3.2×10^{10}	5.0×10^{12}
22.8 Mw	1	3.6×10^{10}	5.7×10^{12}
25 Mw	1.1	4×10^{10}	6.3×10^{12}
27.3 Mw	1.2	4.3×10^{10}	6.8×10^{12}
30 Mw	1.3	4.7×10^{10}	7.5×10^{12}

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VI. ANALYTICAL**A. HEAT TRANSFER ANALYSIS**

The heat-transfer analysis, Appendix A, shows that the mass of the test items and test fixture will result in a rise of only 0.6°F in the coolant water temperature at a heat-generation rate of 1.63 watts/gram. The same heat-generation rate results in a maximum permissible temperature of 800°F in the area of the receptacle pins, which is the limiting transducer temperature.

B. ACTIVATION ANALYSIS

The activation analysis, Appendix B, shows that the neutron-induced activity of the test items and test fixture, at a distance of 2 feet, will be approximately 3 r/hr at 3 days after the test, and that this activity will be principally from the silver content of the coil windings in the transducer. The analysis also states that the only activity in the helium purge gas will come from impurities in the gas; therefore, activity of the gas discharged during the test will be minimal.

VII. FACILITY REQUIREMENTS

Electrical	115 V, 60 cps
Pneumatic	Helium, 400-psig transducer stimulus .03-ft ³ /min purge
Hydraulic	None
Special Fluids	None
Special Shielding	None
Instrumentation	See equipment list
"Hot" Lab	To be determined following data reduction and analysis.

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VIII. DATA HANDLING REQUIREMENTS

A. EXPERIMENT DATA LOGGER

Data will be gathered automatically by feeding into the Experiment Data Logging and Alarm System. The Data Logger will print three types of digital data from the experiment along with the operational and alarm system requirements for the reactor. The three types of data will be

pressure transducer output, in millivolts;

pressure transducer coil and dummy cable conductor resistances, in ohms; and

pressure transducer and dummy cable insulation resistance, in megohms.

In addition to the transducer data, the Data Logger will print both the temperature and pressure conditions of the experiment. The Data Logger will require 77 channels to collect the data for this experiment.

<u>NUMBER OF CHANNELS REQUIRED</u>	<u>DESCRIPTION</u>	<u>TYPE OF SIGNAL</u>
4	Test Item Output	dc millivolts
24	Test Item Coil Resistance	ohms
18	Dummy Cable Conductor Resistance	ohms
14	Test Item and Dummy Cable Insulation Resistance	megohms
16	Temperature (Cu-Con T/C)	dc millivolt
1	Reference Transducer Output	dc millivolt

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The Data Logger, the pressure transducer output (both test items and reference), the 16 copper-constantan thermocouple output, and the reactor power correlation will be constantly monitored on an oscillograph.

B. MANUAL DATA

A manual log shall be maintained during the irradiation test, including spot checks of each data point. Unusual occurrences will be noted.

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IX. TEST PROCEDURE

A. SYSTEM DESCRIPTION

For this test, 4 Consolidated Controls Corporation linear variable differential transformer (LVDT) pressure transducers will be mounted in a 6061T6 aluminum test capsule. The transducers consist of a diaphragm which is axially connected to a movable slug in the LVDT. As helium gas pressure is applied to the inlet port of the test capsule, it deflects the diaphragm thus causing the slug in the LVDT to move. This movement causes a change in the magnetic coupling between the primary and the two secondary windings. The voltage difference between the two secondary windings, resulting from the coupling change, is the output voltage of the transducer. A symmetry sensing module is used with the transducer. This module is an epoxy-resin-coated printed-circuit board containing all circuit components to supply regulated excitation to the transducer, demodulate the transducer signal, correct for the effects of transducer temperature, and provide a linear output representative of the pressure measured by the transducer.

These LVDT transducers are similar to the design employed on the NRX-A2 tests, except that the coolant case is absent and the air gaps between the outside of the coil and the inner surface of the LVDT housing have been eliminated by filling the voids with aluminum oxide. A diaphragm is used in place of the bellows and spring mechanism for the pressure sensing element. The external surfaces and body of the LVDT are made of type 410 stainless steel, and the pressure element of Inconel 718.

The test items (transducers) in the test capsule include 3 dummy cables and 16 copper-constantan thermocouples. The dummy cables will provide a means of examining the effects of radiation on the cables, which in turn will influence the performance of the transducers. The thermocouples will be used for measuring capsule temperatures and surface temperatures on 2 of the test items.

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B. TEST PROCEDURE

1. General

Transducer-translator alignment and calibration will be performed in accordance with the manufacturer's procedures supplied with the translator. This operation must be performed prior to each check-out calibration and each test procedure, as described in paragraphs 3, 4, 5, 6, and 7 following. Transducer body temperatures will be recorded during all data runs taken in the water loop at WANL, in the test reactor, and in the Hot Lab Facility.

2. Data Cycle

A data cycle is defined as the following sequence of operations:

Apply pressure stimulus in 80-psi increments from zero to 400 psig and back to zero, recording the outputs of the four test transducers and the reference transducer at each step.

Measure transducer coil resistance.

Measure dummy cable conductor resistance.

Measure transducer and dummy cable insulation resistance.

During irradiation, repeat the pressure data cycle described above.

3. WANL Water Loop Test Procedure

Install the test fixture in the WANL water loop test capsule and establish a flow rate of 75 gpm for 10 hours. A minimum of two complete data cycles will be recorded.

4. Pre-Irradiation Checkout

With the system installed in the test capsule, a complete checkout will be performed according to the procedures described under paragraphs 1 and 2 above. A minimum of one complete data cycle will be recorded, both manually and with the automatic data acquisition equipment. All system thermocouple outputs will be recorded.

5. Pre-Irradiation Test in Test Position

With the system installed in HT-1 of the test reactor, transducer-translator alignment and calibration will be completed. Two complete data cycles, as described in paragraph 2 above, will be recorded. All test fixture temperatures will be recorded as a part of each data cycle.

6. Irradiation Test

During the irradiation test, the PBRF Data Logging and Alarm system will continuously record all system temperatures with reactor power level and time correlations. During power changes the reactor power level and time correlation, test transducer output and reference transducer output will also be recorded continuously.

After start-up, reactor power will be held at 10 Kw, 100Kw, 1 Mw, 10 Mw, 20 Mw, 22.8 Mw, 25 Mw, 27.3 Mw, and 30 Mw, while two complete data cycles, as described in paragraph 2 above, are taken. It is anticipated that each power level hold will be of 1/2 hour to 1 hour duration. Upon completion of the data cycles at the 30-Mw power level, the test fixture will be withdrawn from HT-1 to its extreme position where two data cycles will be taken.

With the test fixture withdrawn to its extreme position, the reactor power shall be increased from 30 Mw to its maximum power level. After reaching maximum power, the test fixture shall be repositioned such that the center of the transducer array is located on the HT-1 centerline at an average

heating rate of 1.5 watts/gm. The distance from the NS core vertical mid-plane will be determined by the reactor power level. With the fixture in this position one complete data cycle will be taken. Thereafter, the heating rate will be increased in steps of 0.25 watt/gm by moving the fixture toward the core North-South axis vertical mid-plane, and one data cycle will be recorded at each heating rate. The test will be terminated when all four transducers have failed. Failure is defined as more than 25% degradation of transducer output signal.

7. Post-Irradiation Test

At the termination of the test, the test fixture will be withdrawn from HT-1 and stored in the quadrant water. Final disposition of test fixture and recommendations regarding post-mortem examination will be established after reviewing the test data.

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X. HAZARDS

No hazards are anticipated with this irradiation. The hazards evaluation will be included in the Design Manual and Hazards Report, which will be issued prior to the test.

XI. DATA HANDLING REQUIREMENTS AND TEST REPORTS

Preliminary and final reports will be submitted.

One copy of the log and a full set of the raw data will be hand carried to REON by the REON representative.

XII. SHIPPING INSTRUCTIONS

Ship test fixture and support equipment to Mr. J. Coombe, WANL, Pittsburgh, Pennsylvania.

XIII. DISPOSITION OF HARDWARE

Hold test fixture at PBRF for post-mortem inspection.

Return support equipment to Aerojet-General Corporation, REON Laboratory, Building 2004, Attention T. C. Robb/W. M. Hart, Sacramento, California.

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Figure 1
Pneumatic System

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Figure 2
Data Acquisition System

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Figure 3

Resistance Measurement

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Test Fixture Installation

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Figure 5

Test Fixture Assembly

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APPENDIX A

TEMPERATURE DISTRIBUTION IN CCC TRANSDUCERS MODELS 412 M102
AND R412 M117 IN PBRF TEST FIXTURE MOUNTING

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APPENDIX A

TEMPERATURE DISTRIBUTION IN CCC TRANSDUCERS MODELS 412 M102
AND R412 M117 in PBRF TEST FIXTURE MOUNTING

Steady-state temperature distributions for the CCC Pressure Transducer mounting arrangement illustrated in Figures 6, 7 and 8 have been determined as a function of heat generation rate.

A. COOLANT TEMPERATURE

Temperatures within the transducers are tabulated in Table 1. These temperatures represent the difference between the actual temperature of the transducer at a heat generation rate of 1 watt/gram and the heat sink temperature (135°F is the coolant temperature in the PBRF test facility). This coolant temperature is judged conservative since at a flow rate of 75 GPM and a heat generation rate of * 1.63 watt/gram the water temperature rises only 0.15°F per kilogram mass. The total test fixture containing the transducers weighs only 4Kg which results in a rise of only 0.6°F in the coolant temperature.

B. MODELS 102 AND 117 CONTRASTED

Comparison of the temperature distributions for the two models indicates the advantage of Model R412 M117 over Model 412 M102 in this mounting arrangement.

Coils - Since the coils in M117 have been placed effectively 0.25 inch closer to sink a considerable reduction in coil temperature occurs. The secondary coil (node 5) is reduced 123°F while the primary coil (node 11) is reduced 141°F.

* $T_{max} = 800^{\circ}F$ in receptacle

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Receptacle - Note, however, in Model 117 that the temperature difference between nodes 15 and 28 is larger than that in Model 102 (139° vs 41°). Comparing the geometry of the two models indicates that the heat-transfer area has been decreased and the distance between nodes increased resulting in this larger ΔT . By adapting M117 to conform more closely to the geometry of Model 102 a reduction of up to 98°F in receptacle temperatures may be effected. (When corrected for radiation and convection losses this figure is reduced to approximately 79°F). All of these figures are for a Q of 1.0 watt/gram. However, they may be extrapolated to 2 watt/gram since they are based upon over-all heat transfer coefficients calculated at an intermediate heat generation (1.6 watt/gram).

Diaphragm Assembly - Note that in Model 102 that the ΔT between node 2 (slug) and node 27 (diaphragm) is positive (336 to 233°) while in Model M117 this ΔT is negative (212 to 310°). The analysis of the M117 diaphragm assembly was more detailed since it considered air gaps in the path to sink, while the M102 analysis did not. The results of the analysis of the M117 diaphragm assembly are as follows:

M117 Diaphragm Assembly

		<u>ΔT (°F) at 1.0 watt/gram</u>	
	<u>Node</u>	<u>Air - °F</u>	<u>He - °F</u>
	21	137	133
Dia-	32	287	196
phragm			
Assy.	27	310	206
Slug	2	212	212

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TABLE 1

TEMPERATURE DISTRIBUTION 1.0 WATT/GRAM

 ΔT Relative to Water Coolant Temperature*

Node	Model	
	412 M102	R412 M117
1	365	236
2	336	212
3	382	250
4	367	237
5	330	207
6	251	161
7	212	134
8	211	133
9	382	249
10	359	222
11	299	158
12	204	122
13	195	119
14	196	121
15	385	253
16	358	220
17	294	144
18	186	109
19	176	105
20	184	111
21	188	137
22	126	109
23	162	129
24	137	96
25	78	78
26	64	82
27	233	310
28	426	392 (357)
29	61	61
30	435	401 (366)
31	441	407 (372)
32	---	287
33	---	109
34	476	442 (407)

Values in parentheses are corrected for radiation and convection losses.

*To convert to actual temperature ($^{\circ}\text{F}$), multiply these ΔT by the heat generation in watt/gram, and add to coolant temperature (135°F).

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The above table summarizes the temperature distribution obtained in two separate analyses of the M117 diaphragm assembly. These temperatures represent the ΔT above coolant temperature at a Q of 1.0 watt/gram.

Note that the gradient between the slug and diaphragm assembly has been relieved by introducing helium in the gaps separating nodes 21 - 27, nodes 33 - 27 and nodes 32 - 26.

C. EFFECT OF AIR GAP TO SINK

The effect of a uniform air gap of 0.0005 inch was evaluated and led to an approximately constant increase in the temperature of every node of the transducer of 76°F at 1.0 watt/gram. This ΔT is proportional to both the air gap thickness and the heat generation rate. The importance of maintaining close tolerance between nodes 22, 24, 25, and 26 and the aluminum sink cannot, therefore, be underestimated.

Since the temperature and the coefficients of thermal expansion are different for the aluminum sink and the 304 S.S. body assembly, the air gap between the sink and transducer varies somewhat with heat generation rate.

Fortunately this effect is predictable and results in a favorable decrease in the air gap thickness with heat generation rate.

An interesting consequence of initial contact between the Al and 304 S.S. is that the contact is maintained independent of heat generation rate.

Criteria:

$$\frac{\Delta V_1}{V_1} = \frac{\Delta V_2}{V_2} = \beta_1 (T_1 - T_{oo}) = \beta_2 (T_2 - T_{oo})$$

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where

$$T_{oo} = \text{sink temp (135°F)}$$

$$\beta_1 = 13.0 \times 10^{-6}/\text{°F} \quad \text{coefficient of thermal expansion (Al)}$$

$$\beta_2 = 9.6 \times 10^{-6}/\text{°F} \quad \text{coefficient of thermal expansion (304 S.S.)}$$

$$T_1 - T_{oo} = (61.5\text{°F})Q \quad \text{Al temp. relative to sink temperature}$$

$$T_2 - T_{oo} = (85 + T_g)Q \quad \text{Average temperature of 304 S.S. relative to sink}$$

and where

$$T_g = \Delta T \text{ across air gap at } Q = 1 \text{ watt/gram}$$

$$Q = \text{heat generation watts/gram}$$

$$\frac{\Delta V_1}{V_1} = \text{fraction volume expansion (Al)}$$

$$\frac{\Delta V_2}{V_2} = \text{fraction volume expansion (304 S.S.)}$$

Solving, $T_g = 0\text{°F}$, which indicates thermal contact is exactly maintained.

It is also of interest to determine the actual rate at which the air gap thickness changes with heat generation rate.

Criteria:

$$\frac{\Delta V_2}{V_2} - \frac{\Delta V_1}{V_1} = \beta_2 (T_2 - T_{oo}) - \beta_1 (T_1 - T_{oo})$$

Also

$$\frac{\Delta V_2}{V_2} - \frac{\Delta V_1}{V_1} = 2 \frac{\Delta r}{r} + \frac{\Delta h}{h} = 3 \frac{\Delta r}{r}$$

where

Δr = change in thickness of air gap at a radius, r , of 0.5 inches

$\frac{\Delta h}{h}$ = fraction elongation assumed equal to $\frac{\Delta r}{r}$.

The following table indicates the rate at which an initial air gap of 0.5 mil (no heat generation) will vary with increasing Q .

<u>Q watt/gram</u>	<u>Gap (mil)</u>
0	.500
1.00	.400
1.37	.372
1.63	.355
4.86	.225

This general decrease in the air gap thickness is favorable in this test fixture design since it considerably diminishes the extrapolated temperature of the transducer. At 1.63 watt/gram, the calculated air gap ΔT is

$$1.63 \times \frac{.355}{.500} \times 76^\circ = 88^\circ$$

rather than the 124°F based upon an 0.5 mil gap.

D. CRITERIA FOR MAXIMUM HEAT GENERATION RATE

The hottest temperature in the M117 transducer is located in the gold-plated Inconel X pin of the transducer receptacle. At a heat generation rate of 1.63 watt/gram and with consideration of conduction as the only means of heat transfer a maximum temperature of 856°F resulted in the receptacle pin. A more detailed analysis corrected for convection and radiation losses in the region of nodes 15 and 28, and lowered the temperature in the pin to 799°F. Since 800°F is the thermal limit of the gold-plated Inconel X material 1.63 watt/gram is the limiting heat generation in this sink arrangement.

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The temperature distribution for the transducer at 1.63 watt/gram is listed in Table 2.

A more conservative estimate of the limiting heat generation (corrected for an 0.5 mil air gap to sink) yields 1.37 watt/gram as the limiting heat generation. Node 34 $[1.37 (407 + 76) + 135 = 799]$

E. ALUMINUM HEAT SINK TEMPERATURE

The heat-transfer analysis performed on the transducers was based upon the assumption of a constant aluminum heat sink temperature of 61.5°F relative to coolant sink.

This assumption is valid since, at a Q of 1.0 watt/gram, a maximum of 5.4°F was calculated for the difference in temperature between the sink temperature at node 22 and that at node 26. An h of $693 \text{ Btu/hr ft}^2 \text{ }^{\circ}\text{F}$ resulted in a ΔT across the water film of 47°F . Breakdown of the 61.5° maximum sink temperature follows:

<u>$\Delta T(^{\circ}\text{F})$</u>	
7.2	Transducer through sink (radial + axial)
7.3	Inherent heat generation in sink
31.4	Across film due to sink mass
15.6	47.0 Across film due to 5 trans- ducers
<hr/>	
61.5	Total ΔT

F. ADDITIONAL ASSUMPTIONS

1. Coil Conductivity

An over-all coil conductivity of $4.9 \text{ Btu/hr ft } ^{\circ}\text{F}$ was assumed based upon the assumption of the closest packed circular cross-section pictured below.

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TABLE IITEMPERATURE DISTRIBUTION 1.63 WATT/GRAM ($T_{MAX} < 800^{\circ}F$)

Model R 412 M117

Actual Temperature $^{\circ}F$ (Sink Temperature of $135^{\circ}F$ has been added)

<u>Node</u>	<u>T $^{\circ}F$</u>	<u>Component</u>
1	520	Slug
2	481	
3	542	
4	521	
5	472	
6	398	Secondary Coil
7	353	
8	375	
9	541	
10	497	
11	393	Primary Coil
12	333	
13	329	
14	332	Temp Comp Coil
15	547	
16	493	Diaphragm Assembly
17	370	
18	313	
19	306	
20	316	
21	359	
22	313	
23	345	
24	291	
25	262	
26	269	
27	641	Aluminum Sink
28	(717)* 774	
29	235	
30	(731)* 788	Pin - Receptacle
31	(742)* 799	
32	603	Diaphragm Assembly
33	313	
34	(799)* 856	Pin - Extremity (Hot Spot)

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Criteria for calculating this conductivity is as follows:

In a closest packed coil each wire is surrounded by 6 wires and by 6 voids which may be filled by potting material or may be left void (air gaps).

Each of these voids are shared equally by 3 wires resulting in an average of 2 voids per wire.

CLOSEST PACKED COIL

SINGLE WIRE

The over-all conductivity of the coil is based upon radial series resistance through the silver ($K = 242$) alumina insulation ($K = 6.2$) and mica potting compound ($K = 0.15$). The over-all conductivity resulting is 4.9 Btu/hr ft °F.

Note that although the conductivity of the silver is large an over-all conductivity of one fiftieth its magnitude results.

The K of 0.15 assumed for the mica potting compound is admittedly conservative; however, justifiable since the assumption of closest packing is an ideal one. (If the voids are not filled with potting compound a conductivity of 0.73 Btu/hr ft °F results).

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2. Connectors and Cables

It was assumed in this analysis that no heat would be conducted from the connectors and from the cable into the receptacle. This would mean that all the heat generated in these fixtures would not result in a temperature much greater than the temperature in the receptacle, i.e., that the heat transfer by convection and radiation is sufficient to maintain these fittings at the receptacle temperature (800°F at 1.63 watt/gram).

The table below indicates the limiting mass (at 1.63 watt/gram) per inch length of fitting for two representative fitting diameters, 0.58 and 0.72 inch.

T	Fitting Diameter (In.)	Q_c $\frac{\text{Btu}}{\text{Hr In.}}$	Q_r $\frac{\text{Btu}}{\text{Hr In.}}$	Q_t $\frac{\text{Btu}}{\text{Hr In.}}$	Gram In.
830°F	.58	21.4	46.2	67.5	12.1
830°F	.72	25.4	56.6	82.0	14.7

Since the cable* mass is approximately 6.5 grams per inch length, little difficulty is experienced in maintaining it at an operable temperature. It is recommended, however, that the sample fixture side walls be manufactured of anodized aluminum ($\epsilon = .94$) so that the grey body shape factor for the radiating quartz surface may be substantially increased. A heat generation rate of 2.5 watt/gram results in only a 1000°F surface temperature.

If the cables are separated rather than bound together the surface area is effectively doubled. At 4.0 watt/gram the surface temperature of the bound cable is 1260°F; while if separated a surface temperature of only 960°F results.

*Dwg 706509 - NERVA Cable - Special Purpose

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The maximum temperature in the bound cable is only 43°F greater than the cable surface for a Q of 1.0 watt/gram. Hot spot temperature at 2.5 watt/gram is therefore $1000 + 2.5(43) = 1108^{\circ}\text{F}$ within operable limits.

In order to protect the cable (outside the sample fixture) from the water coolant it was found necessary to enclose it in an aluminum tube.

The analysis indicated that the surface temperature of the cable was extremely dependent upon the emissivity of the aluminum as indicated in the following table. The table summarizes the limiting heat generation to maintain 1000°F maximum surface temperature.

Al Tube		ϵ	$Q_c \frac{\text{Btu}}{\text{Hr In.}}$	$Q_r \frac{\text{Btu}}{\text{Hr In.}}$	$Q_t \frac{\text{Btu}}{\text{Hr In.}}$	$Q_t \frac{\text{Watt}}{\text{Gram}}$
<u>O.D.</u>	<u>I.D.</u>		Conduction through Air Gap	Radiation	Total	Total
.875"	.805"					
Polished		.03	13.0	3.7	16.7	.76
Oxidized		.11	13.0	10.9	23.9	1.09
Anodized		.94	13.0	31.2	44.2	2.02
Filler		---	39.0	---	39.0	1.50
<u>O.D.</u>	<u>I.D.</u>					
.720"	.650"					
Polished		.03	26.0	3.0	29.0	1.32
Oxidized		.11	26.0	9.4	35.4	1.61
Anodized		.94	26.0	31.0	57.0	2.60
Filler		---	78.0	---	78.0	3.27

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Two aluminum tubes of different diameters are compared. The low density Al_2O_3 filler (.44 g/cm³, $K = .075 \text{ Btu/hr ft } ^\circ\text{F}$) compares favorably with radiation plus air conduction only for the smaller diameter tube. Perhaps the most reasonable solution to sustaining high heat-generation rates in this configuration is to use helium in the gap between the bound cable and the aluminum tube or to use a smaller diameter aluminum tube.

The use of helium ($K \text{ at } 600^\circ = .129$) increased the heat transferred by conduction by a factor of five ($K \text{ Air} = .025$), thus increasing the maximum allowable Q to 4.65 watt/gram for the larger diameter tube.

Although the use of high density alumina markedly increases the maximum allowable heat generation it is not recommended since it increases the total test mass.

G. PROPERTY VALUES

The thermal conductivities and densities of all solid material in the test assembly were evaluated at room temperature. Heat-transfer coefficients were calculated from the following relationships, which have been referenced in previous memos:

Free Convection	$N_u = 0.555 (\text{Gr Pr})^{1/4}$
Forced Convection (cross flow)	$N_u = C(\text{Rey})^n$
Forced Convection (annular flow)	$N_u = .023(\text{Rey})^{0.8} (\text{Pr})^{0.4}$

The emissivities used were quartz at 1000°F, 0.68, and stainless steel, 0.80.

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Grey body shade factors were calculated from the relationship

$$A_1 F_{1-2} = \frac{1}{\frac{1}{A_1 \epsilon_1} + \frac{1}{A_2 \epsilon_2} - \frac{1}{A_2}}$$

where

F_{1-2} = grey body shape factor based on area (A_1) of emitting surface of emissivity ϵ_1

A_2 = area of absorbing surface of emissivity ϵ_2 .

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WATER FLOW 75 GPM 135°F (MAXIMUM)

Figure 6

Pressure Transducer R412 M 102

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Figure 7
Temperature Distribution (M 102)

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Pressure Transducer Model R412 ML17

APPENDIX B

ACTIVATION ANALYSIS FOR PRESSURE TRANSDUCER TEST 23/R510

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APPENDIX B

ACTIVATION ANALYSIS FOR PRESSURE TRANSDUCER TEST 23/R510

A. MEMO 7425:0159, 12 MARCH 1965

An activation analysis of pressure transducer 412M117-750 (described in Reference A*) was performed. This transducer is to undergo a test at the Plum Brook Facility with the irradiation history shown in the following table:

TABLE I

<u>Power</u>	<u>Time at Power</u>	<u>Grouping of Test for Analysis</u>
10 KW	1 hr	Group I (4 hours at 2.8 MW)
100 KW	1 hr	
1 MW	1 hr	
10 MW	1 hr	
20 MW	1 hr	Group II (5 hours at 25 MW)
22.8 MW	1 hr	
25 MW	1 hr	
27.3 MW	1 hr	
30 MW	1 hr	

The analysis was performed with the ACT-II computer program using the 2 time periods of 4 group irradiation fluxes shown in Table II which were extracted from HT-1 (PBRF) data and extended with a typical NERVA neutron spectrum.

*Ref A - Preliminary Test Specification for Pressure Transducer
Test 23/R510 (PBRF/65-R2)

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TABLE II

Time Period	Neutron Flux (n/cm ² -sec)			
	10 Mev-0.9 Mev	0.9 Mev-3 Kev	3 Kev-.41 ev	Thermal
I	6.713 x 10 ¹¹	2.347 x 10 ¹²	3.300 x 10 ¹²	5.555 x 10 ¹²
II	5.039 x 10 ¹²	1.748 x 10 ¹³	2.475 x 10 ¹³	4.170 x 10 ¹³

The results of this activation analysis are depicted in Figure 9 which gives the resulting dose rate in r/hr at 2 feet from the transducer vs time after shutdown of the test. At 36 hours, the radiation activity level of the transducer is 0.461 curies.

The main contributor after 1.5 days of decay is the silver in a ceramic covered wire. If this wire could be removed at some time after the test, then the radioactive decay of the remaining materials should result in relatively low levels of radiation in approximately eight days.

B. MEMO 7425:0188, 6 APRIL 1965

To further define the neutron induced activity of the pressure transducer irradiation test as described in paragraph A, the scope of the analysis was enlarged to include the test fixture and its grouping of seven transducers. Additional questions were asked concerning the test with these conclusions:

Consolidated Controls Corporation has used some mica phosphate with the Al₂O₃ in the coil void of the pressure transducer, CCC P/M 412M117. This material should not increase the neutron induced activity of the transducer. The level of activity of the transducer even with the silver wire removed is sufficient to mask the small contribution of either the phosphorus or the silicon (mica).

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MATERIALS LIST

	Inconel 718	AISI 347 SS	AISI 410 SS	AISI 416 SS	AISI 300 SERIES	SILVER*	NICKEL- IRON*	ALUMINUM OXIDE & MICA
CORE				.177				
STEM	.018							
PRESSURE ELEMENT	5.253							
PRESSURE SLEEVE		.195						
CAP AND CAPILLARY		.023						
BODY			78.063					
INNER SLEEVE		.222						
UPPER DISC			7.911					
CENTER DISC		.263						
LOWER DISC			2.091					
BOTTOM DISC			2.903					
WIRE, CERAMIC COVERED						8.890	.113	
INSULATING MAT'L								9.752
COVER			15.422					
CONNECTOR					7.121			

All masses in grams

* Mass given for wire includes ceramic insulating material

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Helium will be used to purge the system. This element has no activation cross section and any activity in the purge gas will be due to impurities and this will be negligible.

The test fixture will be fabricated of 6061 T6 aluminum alloy with a weight of 8.8 pounds. Assuming this fixture, with seven transducers attached, to be subjected to an irradiation history as shown in Table II, the activation of the assembly was computed using the ACT-II program. The results of this study are depicted in the attached figure which gives the resulting dose rate in r/hr at 2 feet from the assembly.

As in paragraph A, it can be readily seen that the main contribution after 1.5 days of decay is the silver in a ceramic covered wire.

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ACTIVATION ANALYSIS FOR PLUMBROOK REACTOR TEST 23/R510
DOSE RATE AT TWO FEET VS TIME AFTER SHUTDOWN

Figure 9

Activation Analysis for Plumbrook
Reactor Test 23/R510

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Figure 10

Pressure Transducer Cross-Section

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