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TUNGSTEN-RHENIUM THERMOCOUPLE PERFORMANCE

IN GTR-13 TEST

Report No. 7461:0094

6 July 1964

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TUNGSTEN-RHENIUM THERMOCOUPLE PERFORMANCE
IN GTR-13 TEST

Prepared by
G. L. Fluke

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ABSTRACT

Two tungsten-rhenium thermocouples, a W-W/26% Re model manufactured by Auto-Control Lab and a W/5% Re - W/26% Re Aerojet model manufactured by Aero-Research, were irradiated in GTR Test No. 13. The test was conducted for one-hundred hours.

The approximate neutron fluxes were 8×10^{11} and 2×10^{12} n/cm²-sec for fast and thermal neutrons, respectively. The gamma field was about 10^9 ergs/gm(C)-hr.

The W/5% Re - W/26% Re thermocouple malfunctioned (severe rise in millivolt output) 18.8 hours after the beginning of the test. Subsequent readings (the thermocouple completed the test) were erratic in that they fluctuated over a range of millivolt outputs. The W-W/26% Re thermocouple withstood the test although it showed a gradual decline in output throughout the test which exceeded the computed neutron effects.

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I OBJECTIVE

The objective of the test was to measure radiation effects on tungsten-rhenium thermocouples.

II CONCLUSIONS

The W/5% Re - W/26% Re thermocouple malfunctioned 18.8 hours after the beginning of the test. It was possible to take readings; however, the data showed that the thermocouple was a failure. The failure cannot necessarily be construed to be the result of nuclear radiation.

The W-W-26% Re thermocouple remained operative throughout the test. The data showed a gradual decrease in output during the test and the temperature was sensitive to the reactor power level. It is not possible to estimate the variation in helium purge flow rates; however, it is an excellent coolant and variations in the flow rate could have affected the results. The change of coolant temperature from day-to-night ambient values could not be detected in thermocouple readings. No explanation for the decrease in output can be offered. The test objective was not satisfied because it is impossible to attribute the primary degradation of the thermocouple to radiation effects.

III TECHNICAL DISCUSSION

A. TEST DESCRIPTION

Two tungsten-rhenium thermocouples were irradiated in GTR-13 beginning 8 June 1964. One thermocouple was a W-W/26% Re model manufactured by Auto-Controls Lab and one was a W/5% Re - W/26% Re Aerojet model (manufactured by Aero-Research).

The construction of the thermocouples is given in Auto-Controls Drawing No. 4737-1 and Aerojet-General Corporation Specification Control Drawing No's. 701515 through 701524. Calibrations of each thermocouple were made in Aerojet-General Experimental Laboratories prior to shipment to the reactor site. The calibration table of each is given in the appendix.

The thermocouples were mounted in separate heaters which were purged with helium from a constant supply at five psi. The drawings and schematic wiring diagrams of the thermocouple and heater were presented in AGC Report No. RS-S-0102, "Final Test Specifications for GTR Test No. 13." They are reproduced in this report as Figures 1 through 5. At intervals throughout the test the heaters were brought to power, the thermocouples were stabilized, and readings were made. Except for slight variations

the heaters were operated at constant power for each data point. Data was recorded continuously on a Sanborn recorder and, only during the heating cycles, on a Dymec digital voltmeter data system.

The test fixture was positioned at the north reactor face, approximately three inches from the reactor closet. The full-power flux levels were approximately 8×10^{11} and 2×10^{12} n/cm²-sec fast and thermal neutrons, respectively. The gamma field was approximately 10^9 ergs/gm(C)-hr.

The cold junction of the W/5% Re - W/26% Re thermocouple was maintained at the ice point. The W-W/26% Re output is insensitive to cold junction temperature if it is below 77°F. The cold junction of this thermocouple was monitored throughout the test. It showed 98°F for the first 1.6 hours of the test. After that it ranged from 59 to 88°F during each data-taking period.

Before the reactor was brought to power, the heaters (with the thermocouples in place) were energized and four individual readings were taken. Two days elapsed between this calibration and the beginning of the irradiation.

B. TEST INCIDENTS

1. Failure of Thermocouple No. 2 (W/5% Re - W/26% Re)

During the heater cool down cycle on 9 June at 5:10 AM (18.8 hours after test initiation), the No. 2 thermocouple failed. According to Mr. J. S. Wachowski, who monitored the thermocouples, it acted like an open circuit since nothing but noise appeared on the Sanborn recorder. (Thermocouple No. 2 was always noisier when the heater came on.) At this time the data was erratic and went to 120% of full scale on the Sanborn recorder which is 25-30 millivolts. The reading went up when the power was decreasing. The noise went as high as 60⁺ millivolts on the Dymec system.

During this period resistances were checked and found to be:

White-to-shield - 4000 ohms

Black-to-shield - 100 ohms

White-to-black - 4000 ohms

The thermocouple behaved erratically from 5:10 AM until 1:00 PM, at which time readings could be obtained again. However, the plot of temperatures (Figure 6) shows that the thermocouple did not behave properly after its malfunction.

2. Helium Purge

As mentioned previously the helium purge was maintained by setting the pressure at five psi. This was done by a visual gage. During the heating cycle at 93.3 hours a helium bottle was emptied and the supply was momentarily interrupted. The thermocouples had higher temperature readings at this time. It was related that there was a 1.5 mv increase in thermocouple output which is equivalent to about 115° on thermocouple No. 1. The helium supply was stored outdoors; the daytime ambient temperature during the test was about 95°F.

3. Reactor Power

A decrease in the reactor power with the heaters energized was deliberately made on the second day. The purpose was to determine if the thermocouples followed the reactor power level.

C. ANALYSIS OF DATA

The output data, expressed in millivolts, was converted to temperatures from the calibration curves furnished. The difference in the temperatures recorded by the Sanborn recorder and Dymec system were, in some instances, pronounced. The Dymec system was considered to be more reliable by personnel directly associated with the test, and its values are used in this presentation.

The heater power varied slightly throughout the test; therefore all thermocouple values were normalized to the pre-irradiation power input of the respective heaters. Because the heat was radiant the temperatures were corrected by the expression

$$T = T_1 \left(\frac{P_1}{P} \right)^{1/4}$$

where T is in °R and P is the heater input in watts. P_1 is the pre-irradiation heater input and T_1 is the corresponding temperature. All temperatures were obtained by considering a straight-line relationship between temperature and millivolt output for each twenty-degree interval.

The calibration, which was run two days prior to the initiation of the test, consisted of taking four separate readings in a thirty-five minute period on each thermocouple. The heater output was constant. The range in values for thermocouple No. 1 was from 2558 to 2571°F or 0.5% spread. The range for thermocouple No. 2 was from 2552 to 2582°F or a 1.2% spread. A plot of the results of the irradiation test is shown in Figure 6;

a tabulation is given in Table I. Thermocouple No. 2 did not behave properly after its malfunction. The data of thermocouple No. 1 (Figure 6) shows that it was sensitive to the reactor power level in that the temperature decreased about 40° during power reduction. Two data points each were taken at power levels of 0.1 and 1.0 megawatts. The values, corrected for heater input, are as follows:

<u>Data Point Number</u>	<u>Reactor Power Level Megawatts</u>	<u>Temperature °F Thermocouple No. 1</u>
2	0.1	2539
9		2510
3	1.0	2542
10		2510
-	3.0 (Average)	2530

The thermocouple output gradually decreased during the run, therefore the sensitivity to power level variation is masked if the average of the three megawatt readings is considered.

An analysis of the output of thermocouple No. 1 was made when the reactor power was at three megawatts. The average temperature of the 18 measurements is 2530°F, with a standard deviation of 44°F. A random distribution is not present, however, because seven of the first eight points are above the average value and the last ten values fall below the average.

The values taken after the deliberate reactor excursion were more uniform. A consideration of the last thirteen values at three megawatts reactor power results in an average of 2507°F with a standard deviation of 25°F. The downward trend precludes a random distribution with these values also.

D. POSSIBLE SOURCES OF ERROR

Consideration of some of the causes of output variation included:

1. Neutron Absorption

The capture of neutrons by the rhenium would be expected to cause gradual degradation in the thermocouple output. Computations show, however, that the 100-hour radiation in GTR would produce about 1.5°F error during the irradiation period. It would be expected that some annealing of the neutron effects would occur as a result of the temperature cycling.

2. Gamma Heating

On the basis of the variation of temperature with reactor power level, the gamma heating may have contributed as much as 30°F to the

thermocouple temperature. This is a function of the heat balance between radiant heat received, gamma heating, and heat dissipation from the thermocouple and would be expected to vary with reactor power level. The temperature should remain constant for any given power level and gamma heating should not cause a gradual data shift.

3. Helium Purge

The helium purge was set at five psi by a visual gage. The writer was not able to ascertain an estimate of the variation of flow rate that might have occurred from the cognizant test personnel. The one instance where the helium flow was interrupted resulted in an increase of about 115°F in thermocouple temperatures. As far as could be determined, the effect of night and day ambient temperatures on the helium temperature were not reflected in thermocouple temperatures.

4. Thermocouple Junction Resistance

The tungsten-rhenium junction of thermocouple No. 1 was attached to copper lead wires by mechanical means. The wires were led into a small box which acted as a junction and were tightened by means of a screw block. The junction resistance would not have been expected to change as a result of radiation; humidity, conceivably, could have introduced some error.

5. Circuit Resistivity

As a result of radiation, the change of resistivity of the circuit could have caused some temperature error. Data on the effect of irradiation on tungsten and rhenium is scarce. The resistivity of tungsten was shown to increase when irradiated at 20°K. Another source showed that the resistivity of tungsten decreased 40% after irradiation with 10^{19} fast and 10^{19} thermal neutrons per square centimeter. The total exposure in GTR-13 was about three decades lower, therefore the effect would result in a second-order correction. A decrease in resistivity would be expected to increase the thermocouple output.

6. Radiation of Heaters

The radiation effect on the heaters is unknown and is a possible source of error.

E. FUTURE WORK

The resistances of the circuit and the insulation, obtained during the test, would be useful information and should be requested when future tests are planned. It would be desirable to repeat the tests in order to assess whether the degradation was peculiar to the particular thermocouple tested.

TABLE I
TABULATION OF THERMOCOUPLE TEMPERATURES

DATA POINT NUMBER	REACTOR POWER LEVEL	TIME (HOURS)	TEMPERATURE, °F (CORRECTED)	
			THERMOCOUPLE No. 1	THERMOCOUPLE No. 2
Pre	0	0	2550	2562
1	.01	.58	2539	2588
2	.1	1.18	2539	2565
3	1.0	1.60	2542	2569
4	3.0	2.02	2582	2587
5	3.0	2.52	2601	2646
6	3.0	10.77	2622	2573
7	3.0	18.77	2570	2538
8	3.0	26.77	2566	2803
9	.10	21.60	2510	2458
10	1.0	27.65	2510	2458
11	3.0	27.73	2519	2477
12	3.0	27.90	2541	2521
13	3.0	28.10	2554	2665
14	3.0	33.10	2523	2480
15	3.0	36.77	2525	2443
16	3.0	45.10	2509	2437
17	3.0	53.02	2494	2390
18	3.0	61.02	2499	2379
19	3.0	69.27	2485	2279
20	3.0	77.10	2486	2231
21	3.0	85.10	2498	2174
22	3.0	93.27	2495	>2000
23	3.0	101.57	2468	>2000
24	0	101.75	2461	>2000
25	0	101.92	2437	>2000
26	0	105.92	2382	>2000
27	0	119.69	2383	>2000

Figure 2

NOTES

1. REMOVE ALL BURRS AND SHARP EDGES.
2. INTERPRET DRAWING PER STANDARDS PRESCRIBED IN MIL-D-70327.
3. SURFACE ROUGHNESS TO BE R_a UNLESS OTHERWISE NOTED.
4. PRESERVE AND PACKAGE PER AGC-46387, CLASS I.
5. PROCESS AND INSPECT PER AGC-42136/11.
6. CLASSIFICATION OF CHARACTERISTICS PER MIL-N-9411, DENOTED BY: (CRITICAL), (MAJOR), AND (MINOR) SYMBOLS.
- SEE TABULATION BLOCK.
- STEM DIMENSIONS MAY BE REDUCED OVER THIS LENGTH TO A MINIMUM OF .100 OD.
- MULTI-USE PART. NEXT ASSEMBLIES TO OBTAIN EXTENSIVE LIST.
- NICKEL BRAZE PER MIL-B-7883.
- LEAD CABLE TO BE COILED IN A 3 FOOT DIAMETER COIL FOR SHIPMENT AND STORAGE.

12. UNSPECIFIED MATERIALS MUST BE CAPABLE OF WITHSTANDING THE FOLLOWING RADIATION EXPOSURE:
NEUTRON FLUX - 10^{18} NVT
GAMMA FLUX - 3×10^6 ERGS/GM (C)

13. A .005/0.010 DIA X .030/.060 DEEP HOLE IN EITHER A RADIAL OR AXIAL DIRECTION IS TO BE IN THE CLOSE VICINITY OF THE ACTIVE JUNCTION FOR OPTICAL CALIBRATION. THE HOLE SHOULD BE SO PLACED AS NOT TO JEOPARDIZE THE PERFORMANCE OF THERMOCOUPLE.

14. ACCEPTANCE INSPECTION TESTING AND CALIBRATION SHALL BE PERFORMED AT THE LOCATIONS LISTED BELOW:
A VISUAL & DIMENSIONAL CHECK RECEIVING INSPECTION

B CONTINUITY & RESISTANCE CHECK
TRANS-DUCER LAB, BLDG 3308 (EC-10)

C PRESSURE & OPERATING PRESSURE
HYDRO TEST LAB, BLDG 2009 (EC-4)

D TIME RESPONSE THERMOCOUPLE LAB,
BLDG 3308 (EC-10)

E LOW TEMP THERMOELECTRIC TEST
MEASUREMENTS & STDS LAB, BLDG 2002 (EC-19) OR AERO-PHYSICS LAB,
BLDG 0587

F CALIBRATION & TEMP CYCLING MEASUREMENTS & STDS LAB, BLDG 2001 (EC-19) OR AERO-PHYSICS LAB, BLDG 0587

15. REFERENCE DATA SUPPLIED BY THE ORIGINAL MANUFACTURER OF THE W-RE MATERIALS, SUCH AS BATCH & LOT NO, CALIBRATION DATA, ARE TO BE SUPPLIED WITH EACH ITEM FURNISHED.

16. OPERATIONAL ENVIRONMENTAL LIMITS SHALL BE AS FOLLOWS:

VIBRATION: 5-2000 CPS 20g LIMITED BY 0.4 DOUBLE AMPLITUDE SINE WAVE FORM
5-1000 CPS 32g EQUALIZED TO 346 WITH A 50 CPS OR LESS BAND WIDTH FILTER, RANDOM
MACHINE VIBRATION 30g, 6.5 MILLI SEC SAW TOOTH WAVE FORM
LOW TEMP -75°F
HIGH TEMP STEM +4200°F HOUSING & LEAD WIRE 500°F
TEMP SHOCK STEM 1000°F TO 4200°F
HUMIDITY 95 HES 30 TO 100% R.H. AT 160°F
TIME RESPONSE: AMBIENT TO 700°F LEAD 300 SEC
PRESSURE: 2000 PSIG
OPERATING PRESSURE: 1000 PSIG (NO LEAKAGE)
ACoustICAL: 150 ± 3 dB, 37 TO 9600 CPS
ELECTRICAL RESISTANCE AT 77 ± 3°F 10 ± 5 OHMS PLUS 1 ± 3 OHMS PER FT OF LEADWIRE.

MARK PER ASD5215C WITH APPLICABLE AGC SCD NO., VENDOR NAME, VENDOR PART NO & AGC ASSIGNED SERIAL NO

HOUSING
CRES TYPE 347
PER QQ 3763
CUTID CLASS
FORM FINISH OPT

FLUSH CUT AND
SEAL END
IF FOL OPTIONAL

TWO CONDUIT FOR LEAD ASSY
SHEATH TYPE 347
DIAMETER .125 OD
WALL THICKNESS .010-.020
MIRE .020 THERMOCOUPLE
WIRES OF W-26%RE
WITH MgO INSULATION

RIGID INSULATOR
50% / 50% BY VOLUME
COML PROD EPOCH 628, CODE IDENT NO 56361 & VERSAMIDE 140, CODE IDENT NO 24608.

TABULATION BLOCK		SOURCE OF SUPPLY			
AGC SCD NO	L DIM	M MIN DIM	VENDOR PART NO	CODE IDENT NO	VENDOR PART NO
701581	4.00	30 FT			
701582	4.00	10 FT			
701583	4.00	30 FT			
701584					
701585					
701586					
701587					
701588					
701589					
701590

SPECIFICATION CONTROL DRAWING

SEE FIELD OF DRAWING									
REV	DATE	DESCRIPTION	BY	CHKD	APP'D	DATE	DESCRIPTION	BY	CHKD
1	12/1/63	SEE AGC SCD							
<p>UNLESS OTHERWISE SPECIFIED, MATERIALS SHALL BE AS FOLLOWS:</p> <p>HOUSING: CRES TYPE 347, PER QQ 3763, CUTID CLASS, FORM FINISH OPT</p> <p>INSULATOR: 50% / 50% BY VOLUME, COML PROD EPOCH 628, CODE IDENT NO 56361 & VERSAMIDE 140, CODE IDENT NO 24608.</p> <p>W-RE: W-26% RE, .020 DIA MAX</p> <p>SEAL: SEAL TO CONTAIN BeO & WITHSTAND 3000°F & NOT REACT WITH W-RE ALLOYS</p> <p>LEAD: TWO CONDUIT FOR LEAD ASSY, SHEATH TYPE 347, DIAMETER .125 OD, WALL THICKNESS .010-.020, MIRE .020 THERMOCOUPLE WIRES OF W-26%RE WITH MgO INSULATION</p> <p>FINISH: FLUSH CUT AND SEAL END IF FOL OPTIONAL</p> <p>MARKING: MARK PER ASD5215C WITH APPLICABLE AGC SCD NO., VENDOR NAME, VENDOR PART NO & AGC ASSIGNED SERIAL NO</p>									
<p>AGC SCD NO: 701581 THRU 701590</p> <p>DATE: 12/1/63</p> <p>BY: [Signature]</p> <p>CHKD: [Signature]</p> <p>APP'D: [Signature]</p> <p>DATE: 12/1/63</p> <p>DESCRIPTION: THERMOCOUPLE, IMMERSION - TUNGSTEN VS TUNGSTEN WITH 26 PER CENT RHENIUM</p> <p>SCALE: NONE</p> <p>RELEASE DATE: 12/1/63</p>

Figure 3

Fixture - Thermocouple Test

Figure 4

Schematic - Thermocouple Wiring Diagram

Figure 5

He Gas Flow Schematic

OUTPUT OF TUNGSTEN-RHENIUM THERMOCOUPLES IN GTR-13

NORMALIZED TO PRE-IRRADIATION HEATER OUTPUT

Figure 6

APPENDIX

THERMOCOUPLE CALIBRATION TEMPERATURE TABLE

W-W/26% Re, P/N 4737-1, S/N 003, Mfgr. Auto-Control Lab

24 April 1964

TEMPERATURE (DEG F)	0	20	40	60	80
	EMF (MILLIVOLTS)				
2000.0	13.477	13.759	14.040	14.320	14.599
2100.0	14.877	15.155	15.431	15.707	15.982
2200.0	16.256	16.530	16.802	17.074	17.344
2300.0	17.614	17.883	18.151	18.418	18.684
2400.0	18.949	19.213	19.477	19.739	20.001
2500.0	20.261	20.520	20.779	21.037	21.293
2600.0	21.549	21.803	22.057	22.309	22.561
2700.0	22.811	23.060	23.309	23.556	23.802
2800.0	24.047	24.291	24.534	24.776	25.017
2900.0	25.257	25.495	25.733	25.969	26.204
3000.0	26.438	26.671	26.903	27.134	27.363
3100.0	27.591	27.818	28.044	28.269	28.492
3200.0	28.715	28.936	29.156	29.374	29.591
3300.0	29.808	30.022	30.236	30.448	30.659
3400.0	30.869	31.078	31.285	31.491	31.695
3500.0	31.898	32.100	32.301	32.500	32.698
3600.0	32.894	33.089	33.283	33.476	33.667
3700.0	33.856	34.045	34.231	34.417	34.601
3800.0	34.783	34.965	35.144	35.323	35.499
3900.0	35.675	35.849	36.021	36.192	36.361
4000.0	36.529	36.696	36.861	37.024	37.186
4100.0	37.346	37.505	37.662	37.818	37.972
4200.0	38.125	38.276	38.425	38.573	38.719
3400.0	38.864	39.007	39.148	39.288	39.426
4400.0	39.562	39.697	39.830	39.962	40.092
4500.0	40.220	40.347	40.471	40.594	40.716

APPENDIX

THERMOCOUPLE CALIBRATION TEMPERATURE TABLE

W/5% Re - W/26% Re, P/N 701518, S/N 0016, Aerojet-General Corp.

6 May 1964

TEMPERATURE (DEG F)	0	20	40	60	80
	EMF (MILLIVOLTS)				
2000.0	18.012	18.232	18.451	18.669	18.887
2100.0	19.103	19.318	19.532	19.745	19.957
2200.0	20.168	20.379	20.588	20.796	21.003
2300.0	21.209	21.414	21.618	21.821	22.023
2400.0	22.224	22.424	22.623	22.820	23.017
2500.0	23.213	23.408	23.602	23.794	23.986
2600.0	24.177	24.366	24.555	24.742	24.929
2700.0	25.114	25.298	25.482	25.664	25.845
2800.0	26.025	26.204	26.382	26.559	26.735
2900.0	26.910	27.084	27.257	27.428	27.599
3000.0	27.768	27.937	28.104	28.271	28.436
3100.0	28.600	28.763	28.925	29.086	29.246
3200.0	29.405	29.562	29.719	29.874	30.029
3300.0	30.182	30.334	30.485	30.636	30.784
3400.0	30.932	31.079	31.225	31.369	31.513
3500.0	31.655	31.796	31.936	32.076	32.213
3600.0	32.350	32.486	32.620	32.754	32.886
3700.0	33.018	33.148	33.277	33.404	33.531
3800.0	33.657	33.781	33.905	34.027	34.148
3900.0	34.268	34.387	34.504	34.621	34.736
4000.0	34.850	34.964	35.076	35.186	35.296
4100.0	35.405	35.512	35.618	35.723	35.827
4200.0	35.930	36.032	36.132	36.231	36.329
4300.0	36.426	36.522	36.617	36.710	36.803
4400.0	36.894	36.984	37.072	37.160	37.247
4500.0	37.332	37.416	37.499	37.580	37.661