NUCLEAR BATTERY-THERMOCOUPLE TYPE
FIFTH QUARTERLY PROGRESS REPORT
JANUARY 1, 1958 TO MARCH 31, 1958

B. C. Blanke

U. S. Army Signal Corps Contract No. R-65-8-99811-SC-01-91

U. S. Department of the Army Project No. 3-99-15-102

U. S. Army Signal Engineering Laboratories Ft. Monmouth, N.J.

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FIFTH QUARTERLY PROGRESS REPORT
JANUARY 1, 1958 TO MARCH 31, 1958

Bertram C. Blanke

Date: 31 March 1958

Issued:

The object of this contract is to conduct research on radioactive materials and thermocouples suitable for the direct conversion of heat to electrical energy.

U. S. Army Signal Corps Contract No. R-65-8-99811-SC-01-91

U. S. Army Signal Engineering Laboratories Technical Requirement
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TABLE OF CONTENTS

	Page
ABSTRACT	4
REPORTS AND CONFERENCES	5
FACTUAL DATA	6
CONCLUSIONS	28
PROGRAM FOR NEXT INTERVAL	28
KEY TECHNICAL PERSONNEL	28
ILLUSTRATIONS	
Fig. 1. Thermoelectric Generator No. 3	7
Fig. 2. Thermal Circuits, Generator No. 3, 4 Cards, 160 Junctions, Santocel Insulation, Atmos. Pressure	8
Fig. 3. Efficiency of Generator No. 3 <u>vs</u> Temp. Difference, Hot to Cold Junctions	10
Fig. 4. Efficiency of Generator No. 3 <u>vs</u> Electric Power Input	11
Fig. 5. Thermal Circuits, Generator No. 3, 11 Cards, 437 Junctions, 10^{-4} mm Pressure	12
Fig. 6. Thermal Circuits, Generator No. 3, 11 Cards, 437 Junctions, Santocel Insulation, Atmos. Pressure	14
Fig. 7. Thermal Circuits, Generator No. 3, 11 Cards, 437 Junctions, Santocel Insulation, 10^{-4} mm Pressure	15
Fig. 8. Calc. Power Output of Generator No. 3 <u>vs</u> Elapsed Time After Loading a Po-210 Power Source	19
Fig. 9. Experimental Circuits Representing the Voltage Drop and the Peltier, Thomson, and Joule EMF's	21

PURPOSE

Radioactive materials and thermocouples suitable for use in a system for the direct conversion of heat to electrical energy will be investigated. Isotopes having suitable characteristics will be determined, heat sources will be designed, and prototype batteries will be constructed.

ABSTRACT

A third thermoelectric generator has been constructed and tested. Specifications for batteries having out-puts of over six volts at power levels of 30, 50 and 1000 milliwatts at the end of six months have been made. An attempt was made to verify experimentally the theoretical equations of the Thomson and Peltier effects.

REPORTS AND CONFERENCES

On 31 January 1958 a conference was held at Fort Monmouth between Mr. Arthur Daniel, Mr. David Linden, Mr. W. L. Doxey, Mr. A. Metcalf, Mr. George Hunrath, Dr. Emil Kittl of U. S. Army Signal Engineering Laboratories and Dr. J. F. Eichelberger and Mr. B. C. Blanke of Mound Laboratory. It was decided that Mound Laboratory would construct a battery having a minimum independent output of 4.8 and 1.2 volts under a 30 milliwatt load after six months service. The thermoelectric generator of such a battery would undergo vibrational and gravitational testing at the Naval Ordnance Laboratory in Washington. If the tests were favorable, the radioactivity for this heat source would be prepared at Mound Laboratory and paid for from funds under the present contract. The price for the radioactivity was not fixed exactly, and additional funds would be transferred by amending the MIPR now in force. Consideration was to be given to a battery having a one watt output at the end of six months service, with attention being given to reactor space availability, time lag, and health hazards, as well as the usual design considerations.

FACTUAL DATA

Construction and testing was completed on thermoelectric Generator No. 3 which was described in the last quarterly report. An exploded view of the generator is shown in Figure 1. The thermal and electrical circuit parameters are direct extrapolations of those of Generator No. 2 except for R_h , the thermal resistance between the source container and the hot junctions, and R_c , the thermal resistance from the cold junctions to ambient. These show an improvement over Generator No. 2 by a factor of four for R_c and two for R_h .

Four mica-card thermopiles with a total of 160 junctions were used in the initial test of the generator. The hot junctions were under slight pressure in the grooves on the heat source container but were not cemented in place. At atmospheric pressure and with Santocel insulation the thermal circuits shown in Figure 2 were obtained. R_h was much larger than would be expected from an extrapolation of the R_h of Generator No. 2, even though the thermocouples made better physical contact with the source container of Generator No. 3. The better thermal junction (across R_h) obtained on Generator No. 2 must have resulted from the use of Sauereisen cement to fix the position of the hot junctions. The R_h of Generator No. 3 increased from 30 to 75 °C/watt on evacuation, indicating that cementing the hot junctions to the source is imperative for operation in a vacuum.

The generator was then tested using eleven mica-card thermopiles totaling 437 junctions. Results indicated a large reduction in R_h and essentially no change in R_h on evacuating the generator. R_c , measured from the cold junctions to the water bath, increased greatly on evacuation, however. The portion of R_c from the cold junctions (which were sandwiched under pressure

between two 0.003-inch thick Teflon sheets) to the support bars, could not have changed greatly on evacuation, so that the increase in R_c must be attributed to the contact between the bars and the generator case, or between the generator case and the outer cylinder. The average space between the bars and the case was about 0.001 inch. The outer cylinder was machined to an I.D. 0.01-inch greater than the O.D. of the generator case. Apiezon grease smeared between the bars and the case decreased the temperature difference, $(T_2 - T_a)$, from 78°C to 52°C with 5.2 watts applied in the heater and the case evacuated. Apiezon was then smeared over the outside of the case, and the case was reinserted into the cylinder. $(T_2 - T_a)$ under the same heater input and same pressure dropped to only 2.0°C .

Figure 1. Thermoelectric Generator No. 3

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Figure 2. Thermal Circuits, Generator No. 3 with 4 Cards, 160 Junctions, Special Opacified Santocel Insulation, Atmospheric Pressure

Measurements were made after the application of the Apiezon grease; (1) with no insulating material and the generator evacuated to 10^{-4} millimeters of mercury; (2) with Santocel insulation under atmospheric pressure; and (3) with Santocel insulation and evacuated to 10^{-4} millimeters of mercury. A plot of the efficiency versus the temperature drop from the hot to the cold junctions is given in Figure 3. As a reference, the efficiency of Generator No. 2 is included as a dashed curve. Optimum efficiency occurs when the generator is filled with Santocel and evacuated. The efficiency is, in all cases, less than that obtained with Generator No. 2, but is not as much less as had been anticipated. The surface area of the source container and the surface area of the thermocouple leads were greater than in Generator No. 2 by 30 percent, and the thermal resistance of the leads (R_t) was 100 percent greater. Both of these factors would decrease the efficiency. No significant loss can be attributed to the mica-cards since the thermal resistance, R'_s , from the hot junctions to ambient for both generators are in the ratio of the surface areas of the thermocouple leads.

Figure 4 shows the efficiency of Generator No. 3 versus the power input to the heater. For the same power input, the optimum efficiency is larger for Generator No. 3 than for No. 2, primarily because R_t is twice as large for Generator No. 3.

Figure 5 shows the thermal circuit of Generator No. 3 at two power levels when insulated solely by vacuum. R_s , the thermal resistance from source container to ambient, was calculated by the black body radiation equation with $\epsilon = 0.85$. R_t was calculated from the dimensions and conductivities of

Figure 3. Efficiency of Generator No. 3 vs Temperature Difference, Hot to Cold Junctions

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Figure 4. Efficiency of Generator No. 3 vs Electric Power Input

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Figure 5. Thermal Circuits, Generator No. 3, 11 Cards, 437 Junctions,
 10^{-4}mm Pressure

the leads. R'_s , R_c , and R_h were then uniquely determined by R_s , R_t , and the temperature measurements. The temperature difference, hot to cold junctions ($T_1 - T_2$), was determined by the generator output. T_2 , the temperature of the source container, and the temperature of the inside of the heater were measured with individual thermocouples. The thermocouple used for the measurement of T_2 was one of the cold junctions in the generator circuit. The source container temperature was measured with a thermocouple lying in the unused twelfth groove, and pressed in position with a mica-card. It was found necessary to use an oil diffusion pump and cold trap to reduce the pressure to a point that further reduction in pressure was not accompanied by measurable temperature change. This pressure was about 10^{-4} millimeters of mercury.

Figure 6 shows the thermal circuit of Generator No. 3 at two power levels when insulated by specially opacified Santocel at atmospheric pressure.

R_s was calculated from Figure 6 of MLM-CF-58-1-40, "Nuclear Battery-Thermocouple Type. 4th Quarterly Report", R_t , R'_s , R_c , R_h , and the temperatures were determined or measured as in Figure 5.

Figure 7 shows the thermal circuit of Generator No. 3 at two power levels when insulated with specially opacified Santocel and evacuated to 10^{-4} millimeters of mercury. These two circuits are not as reliable as the others because R_s and R'_s were determined by trial and error. The results indicate that the thermal resistance of Santocel increases about 50 percent with evacuation, and that the Santocel reduces radiation losses by a factor of about two.

Figure 6. Thermal Circuits, Generator No. 3, 11 Cards, 437 Junctions, Special Opacified Santocel Insulation, Atmospheric Pressure

Figure 7. Thermal Circuits, Generator No. 3, 11 Cards, 437 Junctions, Special Opacified Santocel Insulation, 10^{-4}mm Pressure

In Figure 8 the calculated power output of Generator No. 3 for a matched load is plotted versus the elapsed time after the assumed loading of a polonium-210 heat source with sufficient power to produce an initial temperature of 565°C at the hot junctions (T_1) with T_2 at 27°C. Four curves are shown. Three curves are for various types of insulation. The fourth is a reference curve which applies if all thermal resistances are constant; it is independent of temperature and, consequently, is independent of the amount of polonium-210. With insulation by vacuum only, 850 curies of polonium-210 would produce a temperature of 565°C, and the power output would be 30 milliwatts after six months. With insulation by air and Santocel, the same initial temperature would be attained with 490 curies, and the output after six months would be 20 milliwatts. In the latter case, the efficiency is twice as great initially and is 33 per cent greater after six months. However, the battery life is about 30 days shorter. With Santocel and vacuum insulation the battery would require a 470-curie polonium-210 source, and would have a useful life of 149 days.

Three sets of calculations have been made using data from Thermoelectric Generators No. 2 and No. 3 to determine characteristics of batteries having an output of 30, 50, and 1000 milliwatts at six volts at the end of one-half year of service. The specifications are shown in Table 1.

During tests of Generator No. 3, two hot junctions separated, and in both cases they were the outer junctions of a card. These junctions are more subject to strain during the hook-up between cards. The junctions, made by spot welding, were much more fragile than the wire itself. A flame welding technique has been developed in which the junction obtained is stronger than the wire. This technique will be used in future generator construction.

TABLE 1

NUCLEAR BATTERY CHARACTERISTICS INITIALLY AND AFTER ONE-HALF YEAR

Characteristics*	One Watt Output		30 Milliwatt Output		50 Milliwatt Output	
	Initially	One-Half Year	Initially	One-Half Year	Initially	One-Half Year
H	5	5	2 1/2	2 1/2	2 1/2	2 1/2
D	5	5	2 1/2	2 1/2	2 1/2	2 1/2
h	2	2	3/4	3/4	3/4	3/4
d	1	1	3/8	3/8	3/8	3/8
n	657	657	720	720	720	720
a ₁	8.05×10^{-3}	8.05×10^{-3}	1.27×10^{-4}	1.27×10^{-4}	3.198×10^{-4}	3.198×10^{-4}
a ₂	7.06×10^{-3}	7.06×10^{-3}	1.27×10^{-4}	1.27×10^{-4}	3.198×10^{-4}	3.198×10^{-4}
k ₁	0.194	0.230	0.194	0.230	0.194	0.230
k ₂	0.289	0.358	0.289	0.358	0.289	0.358
ρ_1	48×10^{-8}	48×10^{-8}			48×10^{-8}	48×10^{-8}
ρ_2	63×10^{-8}	63×10^{-8}			63×10^{-8}	63×10^{-8}
r ₁	0.1055	0.1055	0.0127	0.0127	0.02019	0.02019
r ₂	0.098	0.098	0.0127	0.0127	0.02019	0.02019
	2	2	1/4	1/4	1/4	1/4
W _O	4.17	1.0	0.0583	0.0307	0.1207	0.0494
R	36	36	1226	1226	541	541
V _L	12.25	6.0	11.66	6.0	11.62	6.0
I _L	0.34	0.167		0.005	0.01023	0.00823
W _s	503	212	26.34	10.57	40.65	16.84
	15,700	6625	823	330	1269	506
	-	9700	-	309	-	538
	-	4850	-	1235	-	2152
Eff	0.84	0.47	0.51	0.29	0.508	0.297
R _t	1.25	1.545	44.2	58.9	23.39	28.91
f	0.25	0.20		1.017		1.774
β	74×10^{-8}	69×10^{-8}	74×10^{-8}	69×10^{-8}	74×10^{-8}	69×10^{-8}
T	30	30	30	30	30	30
T ₁	565	304	565	304	565	307
T ₂	61	39	64	40	65	40
E _O	24.5	12.0	26.67	12.97	26.67	13.16
R _g	36	36	1368	1368	541	541
L _g	3.8	3.8	2.6	2.6	2.6	2.6

* See the following page for definition and units of Characteristics.

Table 1 (Annex)

DEFINITIONS AND UNITS OF BATTERY
CHARACTERISTICS LISTED IN TABLE 1

<u>Symbol</u>	<u>Definition</u>	<u>Unit</u>
H	Length of generator case	inch
D	O. D. of generator case	inch
h	Length of source container	inch
d	O. D. of source container	inch
n	Number of junctions	—
a_1	Cross sectional area, a single lead of Chromel P wire	cm^2
a_2	Cross sectional area, a single lead of Constantan wire	cm^2
k_1	Thermal conductivity of Chromel P wire	$\text{watt-cm}^{-1} \text{ } ^\circ\text{C}^{-1}$
k_2	Thermal conductivity of Constantan wire	$\text{watt-cm}^{-1} \text{ } ^\circ\text{C}^{-1}$
ρ_1	Resistivity of Chromel P	ohm-cm
ρ_2	Resistivity of Constantan	ohm-cm
r_1	Diameter of Chromel P wire	cm
r_2	Diameter of Constantan wire	cm
	Weight of battery (estimated)	lb
W_O	Load power (E_L^2/R_L)	watts
R_L	Load resistance	ohms
V_L	Voltage across load	volts
I_L	Current through load	amperes
W_S	Source power Input	watts
	" " "	curies Po-210
	Watt-hours for first 182.5 days	watt-hour
	Watt-hours per pound	watt-hour-lb^{-1}
Eff	Efficiency of generator, W_O/W_S	percent
R_t	Thermal resistance hot to cold junctions of thermocouple materials, adiabatic surface conditions	C-watt^{-1}
f	—	—
β	Thermoelectric power of a junction	$\text{volt-}^\circ\text{C}$
T	Temperature, ambient	$^\circ\text{C}$
T_1^a	Hot junction temperature	$^\circ\text{C}$
T_2	Cold junction temperature	$^\circ\text{C}$
E_O	Open circuit EMF of generator	volts
R_g	Internal resistance of generator	ohms
L	Avg. length of wire, hot to cold junctions	cm

8676

Figure 8. Calculated Power Output of Generator No. 3 vs Elapsed Time After Loading a Po-210 Power Source

An attempt has been made to verify experimentally the theoretical equations for Peltier and Thomson EMF's and the Joule heating distribution. Previously, the loading effect caused by current flow in the generator was investigated by a transient analysis; a current, I_g , was maintained until all temperatures were constant. Then the current was cut and the generator voltage versus time was observed. A plot of the difference between the open circuit voltage, E_o , and the observed voltage across the generator output terminals, $E_g(t)$, versus time was made on semilog paper. Extrapolation of this curve to $t=0$ then gave the voltage drop of the generator caused by I_g . This method works, but is laborious to perform.

The method described below has some inherent difficulties, but is much easier to apply. The circuit diagram, Figure 9, shows the experimental set-up. Circuit (a) gives the open circuit voltage, E_o , resulting from a power input, W_s , to the heater. In the second circuit (b) a current, I_g , is caused to flow in the generator in the same sense as the self-generated current. The same W_s is maintained in the heater. By virtue of I_g , heat is absorbed by Peltier cooling, the temperature of the hot junctions decreases, and E_p is the resulting decrease in voltage at equilibrium and is shown as subtracting from E_o . The Thomson voltage, E_T , occurs in the opposite sense when the temperature is from the hot to the cold junctions. The Joule voltage, E_J , results from the heating of the hot junctions caused by the power dissipated in the leads.

From inspection of the circuit, we can write

$$E_g(1) = E_o - E_p + E_T + E_J - I_g R_g \quad (1)$$

In circuit (c), the same current (I_g) is caused to flow in the reverse direction. The Peltier effect causes heating of the hot junctions, the

Figure 9. Experimental Circuits Representing the Voltage Drop and the Peltier, Thomson, and Joule EMF's Resulting from Natural or Forced Current Flow in a Thermoelectric Generator

Thomson effect, cooling, and the Joule effect is unchanged. Then

$$E_g(2) = E_o + E_p - E_t + E_j + I R_{gg} \quad (2)$$

If I is relatively small, E_g , E_p , E_t , and E_j will have the same magnitude in both Equations 1 and 2. Adding Equations 1 and 2

$$E_g(1) + E_g(2) = 2E_o + 2E_j \quad (3)$$

or

$$E_j = \frac{E_g(1) + E_g(2) - 2E_o}{2} \quad \text{volts} \quad (4)$$

and subtracting Equations 1 and 2

$$E_g(1) - E_g(2) = 2(E_p - E_t) + 2I R_{gg} \quad (5)$$

or

$$E_p - E_t = \frac{E_g(2) - E_g(1) - 2I R_{gg}}{2} \quad \text{volts} \quad (6)$$

This experimental technique has effectively separated the reversible Peltier and Thomson effects from the non-reversible Joule heating. Equations 4 and 6 can be converted to equivalent temperature changes by dividing by the thermoelectric power of the junctions, de/dT , at the operating temperature, T_1 , and by the number of junctions, n .

$$\Delta T_J = \frac{E_j}{n \, de/dT} \quad ^\circ\text{C} \quad (7)$$

$$\Delta(T_p - T_t) = \frac{E_p - E_t}{n \, de/dT} \quad ^\circ\text{C} \quad (8)$$

Equations 7 and 8 can be converted to the equivalent power in watts by the use of Equation 19, MLM-CF-58-1-40, the parameters of which are determined under open circuit conditions with W watts in the heater.

s

$$W_J = \frac{E_J(1 + f_1)(1 + f_2)(1 + f_3)}{n R_t \text{ de/dT}} \text{ watts} \quad (9)$$

and

$$W_P - W_T = \frac{(E_P - E_T)(1 + f_1)(1 + f_2)(1 + f_3)}{n R_t \text{ de/dT}} \text{ watts} \quad (10)$$

Substituting Equations 4 and 6 in Equations 9 and 10, the final result is obtained

$$W_J = \frac{(E_g(1) + E_g(2) - 2E_o)(1 + f_1)(1 + f_2)(1 + f_3)}{2n R_t \text{ de/dT}} \text{ watts} \quad (11)$$

and

$$W_P - W_T = \frac{(E_g(2) - E_g(1) - 2I R_g)(1 + f_1)(1 + f_2)(1 + f_3)}{2n R_t \text{ de/dT}} \text{ watts} \quad (12)$$

The Joule and Thomson heat can be assumed to be divided 50:50 between hot and cold junctions since the heat is generated uniformly along the leads (MLM-CF-58-1-40).

$$\text{Then } W_J = I^2 R_g / 2 \text{ watts} \quad (13)$$

and by Equation (4a), MLM-CF-58-1-40, the Thomson heat at the hot junctions is

$$W_T = \frac{n I g}{2} \int_{T_1}^{T_2} T \text{ d}^2 e / \text{dT}^2 \text{ dT} \text{ watts} \quad (14)$$

By equation (1a), MLM-CF-58-1-40, the Peltier heat is given by

$$W_P = n I g T_1 \text{ de/dT} \Big|_{T_1} \text{ watts} \quad (15)$$

Values of W_J and $W_P - W_T$ were experimentally determined to see whether Equations 11 and 12 agree with theoretical values as determined by Equations 13, 14, and 15. Verification of Equation 11 offers no experimental difficulty as all parameters are easily measured. To solve Equation 12, the internal resistance of the generator, R_g , must be known. It cannot be measured by Ohms Law unless there is no change in temperature, i.e. $E_P - E_T - E_J = 0$. This condition can be accomplished in two ways. (1) The insulation could be replaced by a good heat-conducting medium making $E_P = E_T = E_J = 0$, or (2) I_g can be adjusted to give $E_P - E_J - E_T = 0$. The latter method was used, and the condition of $E_P - E_T - E_J = 0$ was assumed when I_g was such that no change of temperature from source container (T_s) to the cold junctions (T_2) was observed.

The experimental data are listed in Table 2. A run consisted of measuring E_g , T_s , T_2 , and W_s first with I_g in a positive direction and then with I_g reversed. Runs 1 through 6 are with $W_s = 0$. Run 7 is for $W_s = 1.65842$ watts and $I_g = 0$, so that $E_g = E_o$. Run 7 was also used to determine the thermal circuit with T_1 obtained from $E_o/n\beta$. Runs 8 through 12 were made with the same current through the heater as in Run 7. The small variations in W_s are caused by changes of heater resistance with temperature.

Table 3 gives calculated results. In column 8 is the ratio, the theoretical $(W_P - W_T)$ to the experimental $(W_P - W_T)$. The theoretical value is about nine per cent greater than the experimental value, both for no gradient and for a gradient of about 80°C . Or the theoretical Thomson effect of about 5 per cent, as a result of the gradient, is necessary for consistency. This,

TABLE 2

EXPERIMENTAL DATA TO DETERMINE PELTIER, THOMSON, AND
 JOULEAN EMF'S, GEN. NO. 3, INSULATION-AIR, SANTOCEL
 (See Figure 9)

Run	W_s (Watts)	I_g (ma)	E_g (Volts)	T_s (°C)	T_2 (°C)
1	0	0	0	26.050	26.050
2	0	+1.0000	-0.836015	25.724	26.050
	0	-1.0000	+0.837104	26.417	26.050
3	0	+5.0000	-4.1709	24.699	26.050
	0	-5.0000	+4.1963	28.296	26.067
4	0	+10.0000	-8.31835	24.305	26.018
	0	-10.0000	+8.4211	31.513	26.002
5	0	+15.0000	-12.4453	24.794	26.034
	0	-15.0000	+12.6752	35.705	26.034
6	0	+25.0000	-20.639	28.398	26.226
	0	-25.0000	+21.275	47.204	26.246
7	1.65842	0	+2.1536	107.29	27.000
8	1.65835	+2.0000	+0.4654	106.37	27.000
	1.65852	-2.0000	+3.8462	108.18	27.000
9	1.65822	+5.0000	-2.0594	105.31	26.763
	1.65872	-5.0000	+6.3928	109.96	26.837
10	1.65812	+10.0000	-6.2471	104.34	26.763
	1.65903	-10.0000	+10.6616	113.62	26.650
11	1.65968	+17.0000	-12.0720	104.31	26.600
	1.65968	-17.0000	+16.6797	120.44	26.690
12	1.65832	+25.0000	-18.6782	106.43	26.666

TABLE 3

EXPERIMENTAL AND THEORETICAL PELTIER, THOMSON, AND JOULE
HEATING AT HOT JUNCTIONS, GEN. NO. 3. INSULATION-AIR SANTOCEL

(1) Run	(2)* R g (Ohms)	(3)** nde/dT (n=436) (Volts-°C ⁻¹)	(4)*** $\frac{R_t(1+f_4)}{1+f}$ (°C-Watt ⁻¹)	(5) W _P -W _T (Eqn.12) (Watts)	(6) W _P (Eqn.15) (Watts)	(7)**** W _T (Eqn.14)	(8) $\frac{(W_P-W_T)_{calc}}{(W_P-W_T)_{meas}}$	(9) W _J (Eqn.11) (Watts)	(10) W _J (Eqn.13) (Watts)	(11) $\frac{W_{Jcalc}}{W_{Jmeas}}$
2	827.29	0.0268	49.2	0.00703	0.0080	0.0000	1.138	0.000415	0.000414	1.00
3	827.29	0.0268	49.2	0.0358	0.0400	0.0000	1.117	0.00964	0.01035	1.074
4	827.29	0.0269	49.2	0.0732	0.0810	0.0000	1.107	0.03882	0.04138	1.066
5	827.52	0.0269	49.2	0.1114	0.1223	0.0008	1.090	0.08685	0.09311	1.072
6	828.05	0.0272	49.2	0.1911	0.2112	0.0025	1.092	0.2379	0.2586	1.087
						Average	(1.088)		Average	(1.074)
8	831.83	0.0292	47.6	0.0192	0.0221	0.0010	1.099	0.00159	0.001665	1.047
9	831.83	0.0292	47.6	0.0482	0.0554	0.0025	1.098	0.00947	0.01040	1.098
10	831.83	0.0292	47.6	0.0979	0.1113	0.0050	1.085	0.03884	0.04161	1.071
11	831.83	0.0295	47.6	0.1672	0.1927	0.0100	1.092	0.10693	0.12026	1.125
							(1.094)		Average	(1.085)

* Determined Primarily by T_s and T₂, Table 2

** Determined by Figure 4 MLM-CF-57-10-31

*** Determined by Run 7 (Table 2) and Extrapolation Using Thermal Circuit of Figure 6

**** Determined by Figure 2, MLM-CF-57-10-31

however, does not prove the validity of the Thomson effect. The nine per cent difference is outside of the expected experimental error. $R_t(1 + f_4)/(1 + f)$ and de/dT are believed to be correct to 1.5 percent. The generator voltages were measured and the generator currents adjusted to 0.005 per cent or better. Other values of R_g were tried with the result that in decreasing the nine per cent difference, the inconsistency increased.

If, instead of assuming a 50:50 distribution of the Joule heat between hot and cold junctions, column 9 of Table 3 is used to calculate the percentage of the total Joule heat ($I_g^2 R_g$) to be assigned to the hot junctions, the result is that for $W_s = 0$, the average is 46.6 per cent, and for $W_s = 1.658$ watts and $T_1 = 107.3^\circ\text{C}$, the average is 46.1 per cent.

A method for the calculation of the upper bound to the intensity of Bremsstrahlung from self absorption of the beta emission has been worked out. Results have been calculated for a cerium-144 source, as cerium trifluoride, in equilibrium with its daughter, praseodymium-144. The estimated upper bound is 0.86 roentgen/curie/day/cm² at one meter distance. This value is in reasonable agreement with the estimate of Cohen [S.T. Cohen, "Estimate of Bremsstrahlung Radiation from a Ce-144 Power Plant", 10 June 1949, RM-766 (classified)].

CONCLUSIONS

Batteries with the characteristics described can be constructed, and construction has started on battery having independent output voltages of 4.8 and 1.2 volts under a 50 milliwatt load after six months service. An attempt to verify experimentally the theoretical equations of Peltier and Thomson EMF's as well as the Joule heat distribution showed that within the reliability of the measurements, these equations are approximately, but not exactly correct.

PROGRAM FOR THE NEXT INTERVAL

Construction of the 50 milliwatt battery will be completed and the battery will be tested.

IDENTIFICATION OF KEY PERSONNEL

Bertram C. Blanke	(296 hours)
Kenneth C. Jordan	(478 hours)
John H. Birden	(520 hours)
Elton L. Murphy	(240 hours)
John McKinney	(224 hours)