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MEASUREMENT OF THE HEAT PRODUCED INTERNALLY DURING DISCHARGE BY THE 6V EVEREADY ENERGIZER BATTERY, NO. 528

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ABSTRACT

When a 6V Eveready Energizer Battery, No.528, is discharged, heat is produced internally within the battery itself. Detailed measurements of this battery heat were made for a five day discharge period using a load resistance of 20 ohms and an ambient temperature of 10 Deg C. The battery heat produced per quarter day varied considerably, ranging from 1.08 watt-hrs to 2.63 watt-hrs. The total battery heat produced, using a 3.0 volt cutoff, is significant (37 watt-hrs) when compared to the total load heat produced (70 watt-hrs).

INTRODUCTION

In order to perform a thermal analysis of a payload, one needs to know all sources of heat. During the thermal analysis of our payload, the question was raised as to whether or not our batteries, the Eveready Energizer No. 528, should be considered a source of heat. To answer this question, we decided to measure the heat produced internally during discharge (Battery Heat) by a single No. 528, under load and temperature conditions similiar to those we expect during our actual flight. The basic approach that was chosen was to thermally insulate the battery, place it in a freezer and then heat it up to a fixed temperature. By comparing the heat that had to be supplied when the battery was not being discharged, to the heat that had to be supplied when the battery was being discharged, one could determine the Battery Heat. To make valid comparisons a fixed time interval was chosen.

APPARATUS

The apparatus used is shown in Fig. 1. There are two major systems, the discharge system and the thermal control system. The discharge system consists of the battery under test, a decade resistance box for the load, and one channel of a chart recorder to monitor the terminal voltage of the battery during the entire discharge. The decade resistance box was set to 20.0 ohms to simulate expected payload loads.

The remainder of the apparatus makes up the thermal control system designed to keep the battery under test at 10 Deg C. The desired temperature was achieved by using a freezer/heater combination. The freezer was set at its warmest setting, -15 Deg C, and its temperature was monitored through a thermocouple attached to one channel of a chart recorder. A heater and insulation were then placed around the battery and used to raise the battery temperature to +10 Deg C after being placed in the freezer. A second thermocouple attached to the other channel of the chart recorder monitored the battery temperature. The heater itself consisted of no. 30 insulated wire wrapped around the battery, and the insulation was of polyurethane foam. The heater was turned on and off automatically by a temperature control circuit which consisted of a thermistor, a controller and a power supply. Power for the heater came from a separate power supply. The heater voltage was monitored by a continuously connected voltmeter and a chart recorder. The heater current was monitored by a continuously connected ammeter. Actual heater on time was monitored by a clock turned on and off by a relay in the heater circuit.

PROCEDURE

Using the apparatus described above, data was taken in three steps:

1. Pre-Run calibration: Without the discharge circuit connected the thermal control circuit was activated and run for over a day. During this time the following variables were monitored and recorded: actual clock time, heater on time, heater voltage, heater current, battery temperature, freezer temperature and battery terminal voltage.
2. Discharge Run: Without changing anything the discharge circuit was connected. The same variables as listed above in step 1 were again monitored and recorded. This time readings were taken every quarter day (6 hours). The entire battery discharge was monitored for a total of 20 quarter days (5 full days).
3. Post-Run calibration: Same as pre-run calibration.

RESULTS AND DISCUSSION

Using the output from the chart recorder, which was several feet long, the battery terminal voltage was replotted using a compressed time scale (Fig. 2). As one typically finds with a 6V alkaline battery, the voltage quickly drops off after reaching around 3.0 volts.

During all three steps of the experiment, the following variables changed by less than 2%: heater voltage, heater current, battery temperature, and average freezer temperature. Thus, for all practical purposes they may be considered as constants. For all analysis a quarter day time interval was used.

Using the data obtained during the pre-run and post-run calibrations, we determined the average heat supplied per quarter day to keep the non-discharging battery at 10 Deg C. The pre-run calibration gave 4.58 watt-hrs and the post-run calibration gave 4.51 watt-hrs for an average of 4.54 watt-hrs. These values are indicated in Fig. 3 for later reference.

Using the data obtained during the discharge, we determined the heat supplied per quarter day to keep a discharging battery at 10 Deg C. The results are plotted in Fig. 3. It should be noted that the heat that had to be supplied varied considerably over the 20 quarter day period, reaching a low about half way through the discharge period when the battery terminal voltage was approximately 3.5 volts.

The difference in heat supplied per quarter day to the non-discharging and the discharging battery to keep it at 10 Deg C is the Battery Heat. More specifically, for any fixed time interval such as a quarter day, one can write:

BATTERY HEAT	=	HEAT SUPPLIED BY OUTSIDE HEATER DURING NON-DISCHARGE CALIBRATION RUNS	-	HEAT SUPPLIED BY OUTSIDE HEATER DURING DISCHARGE

Using the results plotted in Fig. 3 and the above formula the Battery Heat was determined. These results are plotted in Fig. 4. Consistent with the earlier observation that the heat supplied by the outside heater each quarter day varied considerably and reached a low at around 11 quarter days, the Battery Heat also varies considerably, ranging from a low of 1.08 watt-hrs during the 1st quarter day to a high of 2.63 watt-hrs during the 11th quarter day. To see how significant the Battery Heat was, we chose to compare it with the heat produced by the load (Load Heat).

The Load Heat for each quarter day was calculated by going back to the original chart recorder output of the terminal voltage and determining the average voltage for each quarter day. Using this average voltage, the known fixed value for the load resistance, and the common relationship $P = V^2/R$, the Load Heat for each quarter day was determined. These results are plotted in Fig. 5. As one would expect its shape is similiar to the plot of the terminal voltage seen earlier in Fig. 2.

The Battery Heat per quarter day and Load Heat per quarter day are compared in Figs. 6 and 7. In Fig. 6 we see that early in the discharge, for the first several quarter days, the Battery Heat per quarter day is quickly rising, while the Load Heat per quarter day is quickly dropping. Both variables then generally level off somewhat, finally intersecting after about 18 quarter days when the terminal voltage is between 2 and 3 volts. From Fig. 7 we can clearly see that for much of the discharge the Battery Heat per quarter day is over 50% of the Load Heat per quarter day.

Cumulative Battery Heat and cummulative Load Heat are compared in Figs. 8 and 9. In Fig. 8 we see that both totals grow almost linearly with time. By the time the terminal voltage has dropped to 3.0 volts during the 16th quarter day, the cummulative Battery Heat is about 37 watt-hrs and the cumulative Load Heat is about 70 watt-hrs (Fig. 8) for a ratio slightly over 50% (Fig. 9).

CONCLUSION

The heat produced internally during discharge by an Eveready Energizer No. 528, is significant when compared with the heat produced at the load by the same battery. Any thorough payload thermal analysis should incorporate this heat produced internally. For many payload designs it may even be a welcomed additional heat source used to keep the payload warm.

ACKNOWLEDGEMENTS

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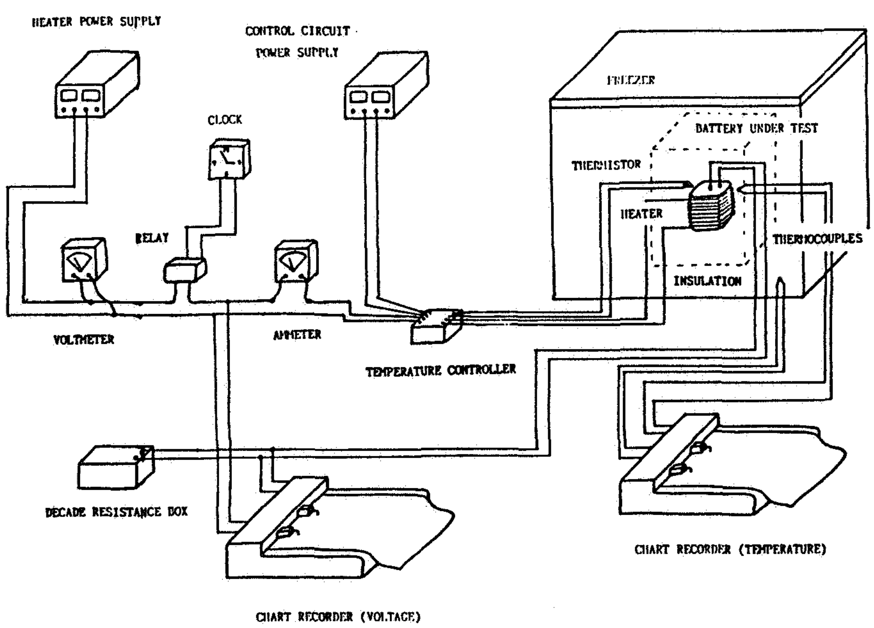

Figure 1. Battery Testing Apparatus

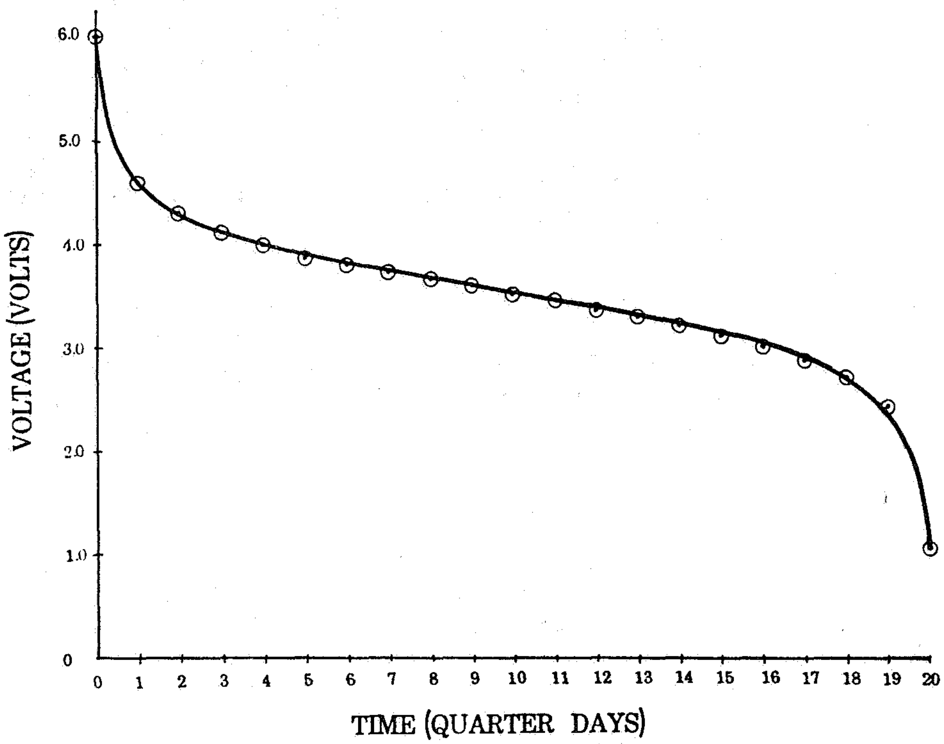

Figure 2. Battery Voltage vs. Elapsed Time

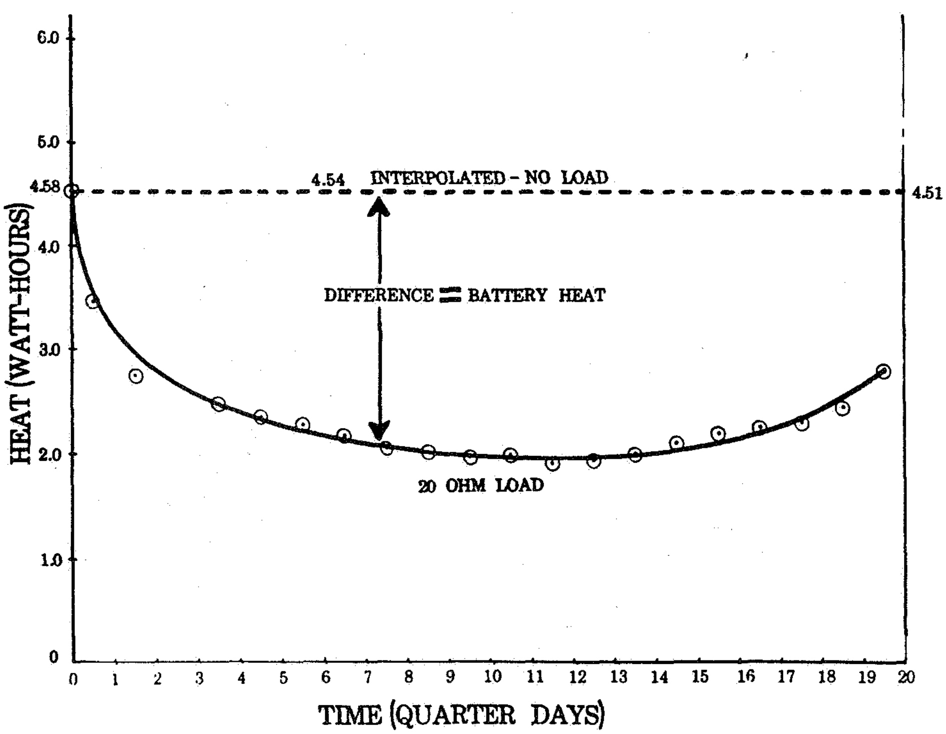

Figure 3. Heat Supplied to Battery per Quarter Day vs. Elapsed Time

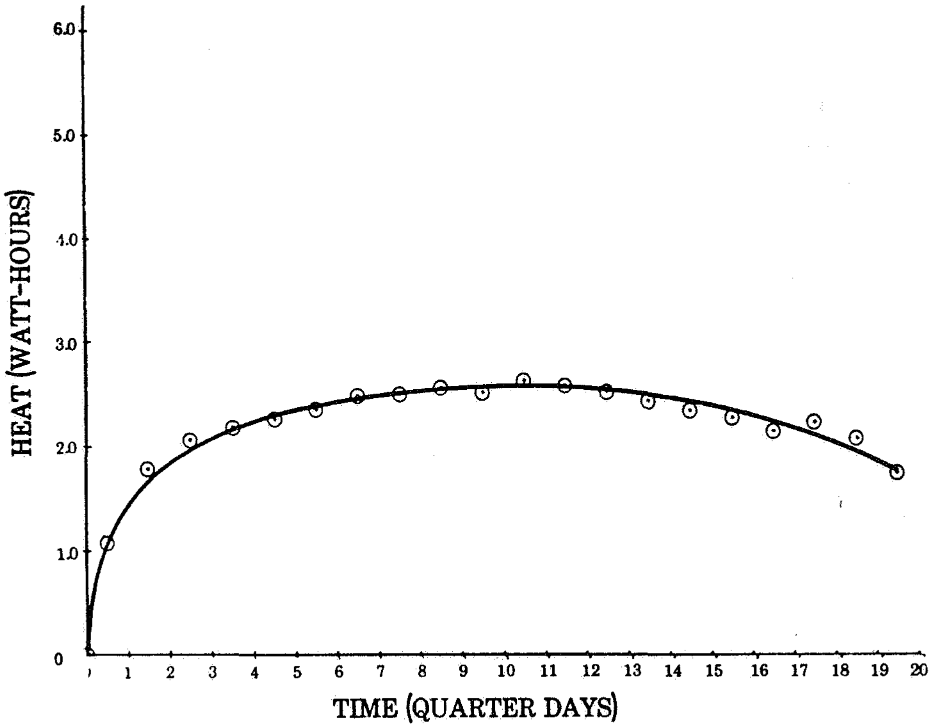

Figure 4. Battery Heat per Quarter Day vs. Elapsed Time

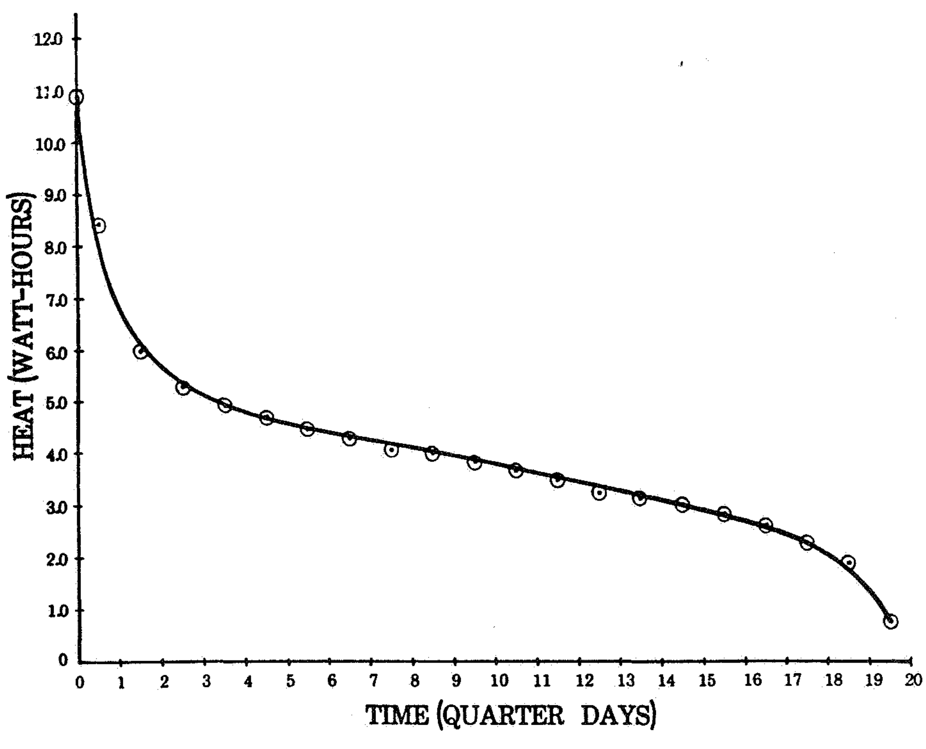

Figure 5. Load Heat per Quarter Day vs. Elapsed Time

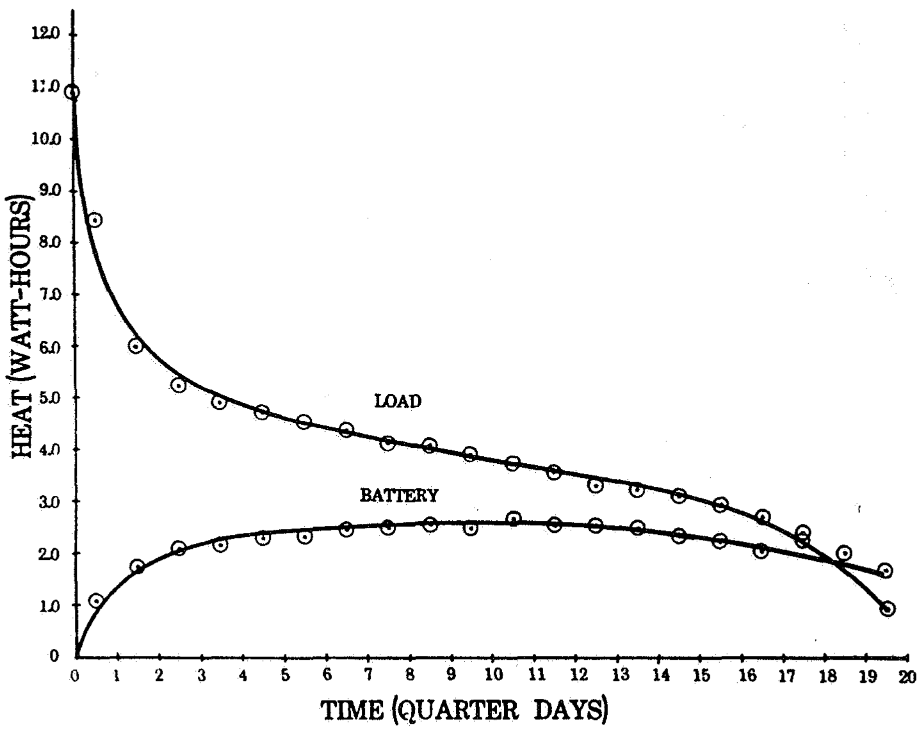

Figure 6. Battery and Load Heat per Quarter Day vs. Elapsed Time

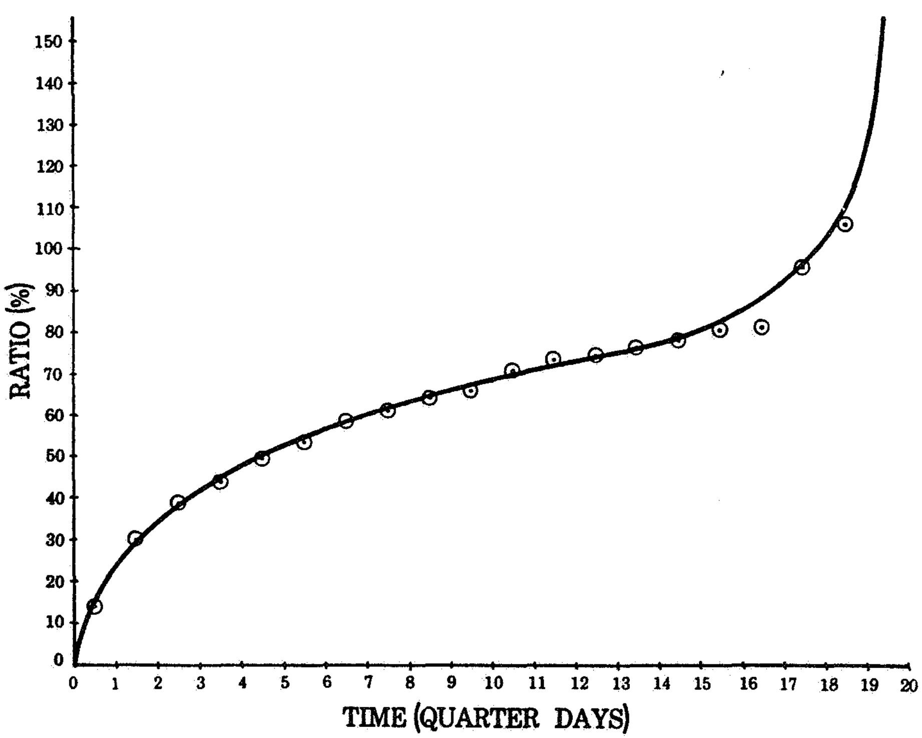

Figure 7. Heat Ratio (Battery to Load) vs. Elapsed Time

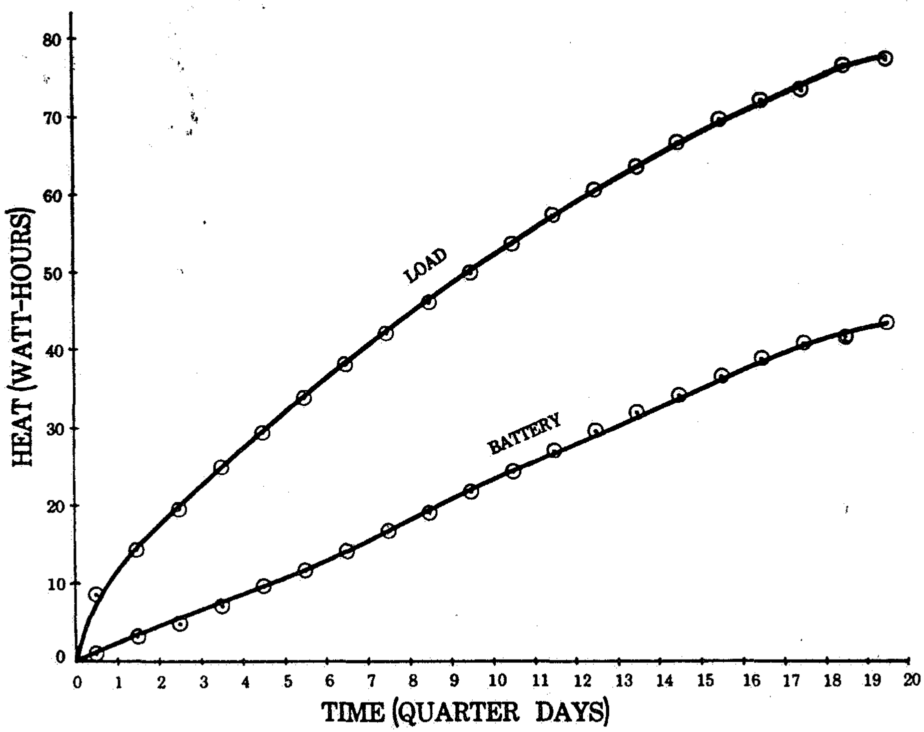

Figure 8. Cumulative Battery and Load Heat vs. Elapsed Time

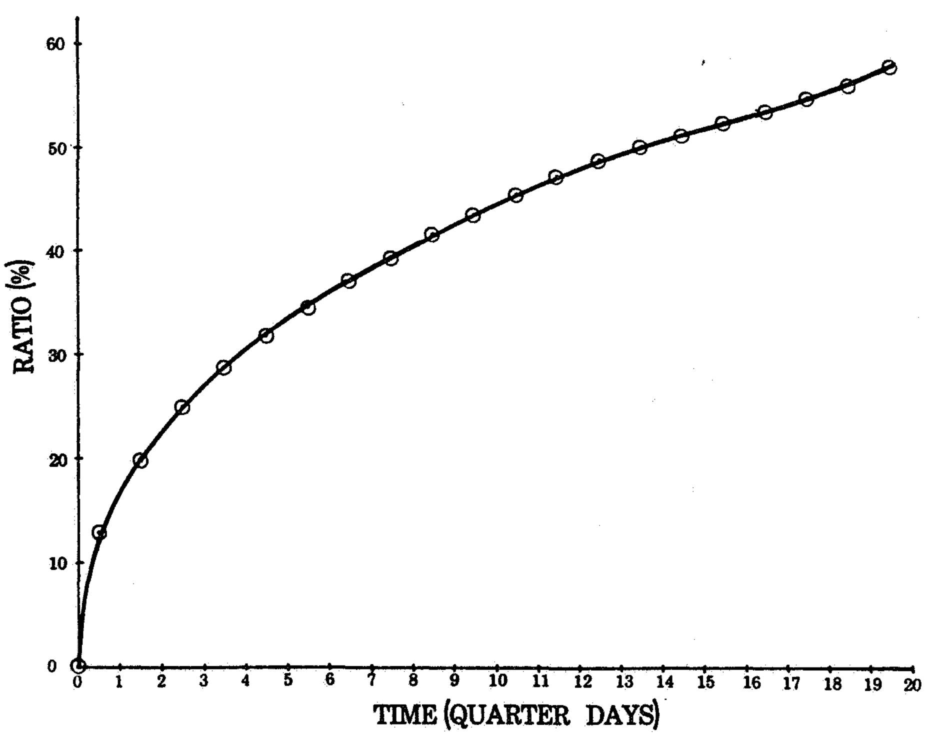

Figure 9. Cumulative Heat Ratio (Battery to Load) vs. Elapsed Time