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BIMONTHLY REPORT NO. 2

ON THE

WATER-ACTIVATED BATTERY

Period: 22 August 1959 - 21 October 1959

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I. ABSTRACT

A detailed description of the construction and production of the large model battery is given. This includes some drastic changes in design, not included in the objectives for this contract. These changes permit a substantial reduction in the number of battery components, which in turn leads to a substantial simplification in operating procedures. The electrical performance of this large battery, operating at an environmental temperature of 25°C, exceeds the requirements by a substantial margin. Its thermal performance, on the other hand, requires the development of improved means for heat dissipation.

II. PURPOSE

Phase 1:

To demonstrate the feasibility of a large model, chemically rechargeable, magnesium-silver chloride battery, activated by a 3 per cent salt solution at room temperature and delivering an average current of 3 A at 12V for at least 60 minutes. The voltage regulation at a maximum load current of 5.3 A shall equal or surpass the stability obtained previously.

Phase 2:

To demonstrate reasonably satisfactory performance of this battery at environmental temperatures of -40°C and +40°C, using a variety of electrolytes such as 3 per cent salt solution, tap water and

others. It is recognized, however, that such performance cannot be expected to match that at room temperature.

Phase 3:

To fabricate and deliver six battery cases and thirty complete sets of chemical recharges for field testing purposes, including instructions on the proper handling, activation, deactivation, disposal and temperature control.

III. FACTUAL DATA

A. Large Battery Design

A comparison of the requirements, listed in Phase 1 of the previous section, with those of the previous model* reveals an increase in power level for the new model by almost a factor 11. At a current density of 0.25 A per inch² this would require an AgCl surface area of 21 inch². The rolled silver chloride, produced by the Rollief Corporation, is supplied by our Ordnance Department in Pittsfield, Massachusetts as 12" x 30" sheets. The electrical conductivity of these silver chloride sheets has been greatly enhanced by small perforations, 1/2" apart, and a very thin coating of porous silver covering the entire area. It has been found, that, for a given number of cells per sheet, the amount of wasted AgCl leftovers is minimized at a cell-size of 9" x 2.68" = 24 inch².

* Annual Report, pp. 55, 56

These are the AgCl dimensions adopted for this battery. The thickness of these sheets is about 0.015" as before. Since the cell-surface area is somewhat larger (24) than the extrapolated value (21), the ampere-minute capacity safety factor of this battery is slightly larger.

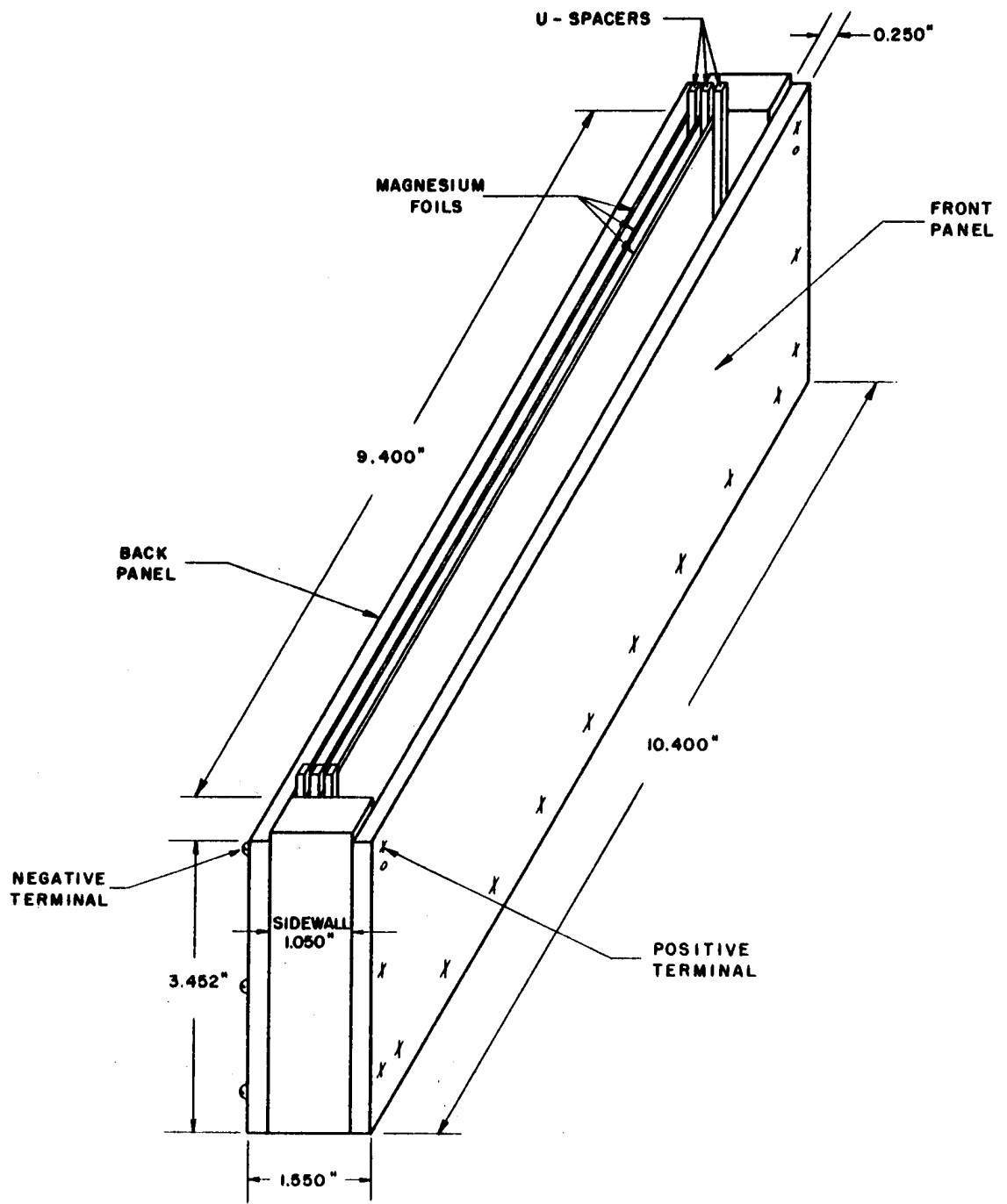
In order to minimize internal leakage processes*, the familiar U-shaped spacers are being used, which require slightly larger magnesium sheet dimensions (9.4" x 3.0"). These foils, 0.012" thick, are cut from 12" x 45" sheets, purchased from the Dow Chemical Company by our Ordnance Department. The composition of this magnesium alloy, type J1, is as follows:

Aluminum:	5.8 - 7.2% by weight
Manganese:	0.15% (min.) for corrosion resistance
Zinc:	0.4 - 1.5%
Impurities:	Approximately 0.5% (Si, Cu, Ni and Fe)
Magnesium:	Balance

The general outlay of the large battery design, including some of the pertinent dimensions, is given in Figure 1. Only two cells have been inserted in this illustration.

Provisions have to be made for the dissipation of heat, generated during discharge (Report No. 1, Section III). Consequently the two large front and back panels are made of aluminum. These panels serve also as battery terminals. Since aluminum is not a desirable electrode

* Annual Report, pp. 54, 61



LARGE BATTERY DESIGN

FIGURE 1

material, the panels are separated from the battery proper by thin layers of silver foil (not shown in Figure 1). The U-shaped bottom sidewall piece is made of black cloth textolite, an insulator. Its width (1.050") is the same as that used in the previous model. The amount of water necessary to activate the battery is about 320 cm³ or 11 fluid ounces. The other components, i.e. silver chloride and silver sheets, as well as the separators necessary to prevent internal short-circuiting, cannot be seen in Figure 1.

B. Drastic Reduction in the Number of Components

It has been found, that the type of technology developed during this project, in conjunction with a much larger size battery, can be used to reduce effectively the required number of battery components. This reduction, in turn, leads to a considerable simplification of the manipulations necessary for the storage, assembly, and disposal operations. In view of the great importance of simple operating procedures it was decided to explore such possibilities in spite of the fact that such a development is not included as a specific objective for this contract.

Before reporting on these improvements it is desirable to summarize first the present status of required battery components. Such a listing can be found in Table I, under the column marked "Presently". A total of 37 components are almost equally divided among permanent ones (items 1-3) and those necessary for one chemical charge (items 4-7). Items 2 and 3 require rather careful handling.

TABLE I

Listing of Mg-AgCl Battery Components

(for 9 cells)

Item No.	Description	Number of Components		Remarks
		Presently	New	
1	Battery Case	1	1) Permanent) Parts
2	U-shaped spacers	9	0	
3	Separators	9	0	
4	Ag/Mg - Anode, Cell No. 1	1	1*) Expendable
5	AgCl - sheets, Cells 1-8	8) 8**	
6	Ag/Mg - sheets, Cells 2-9	8)) Refill
7	AgCl - Cathode, Cell No. 9	1	1***	
		37	11	TOTAL

* See Figure 2, part A

** See Figure 2, part B

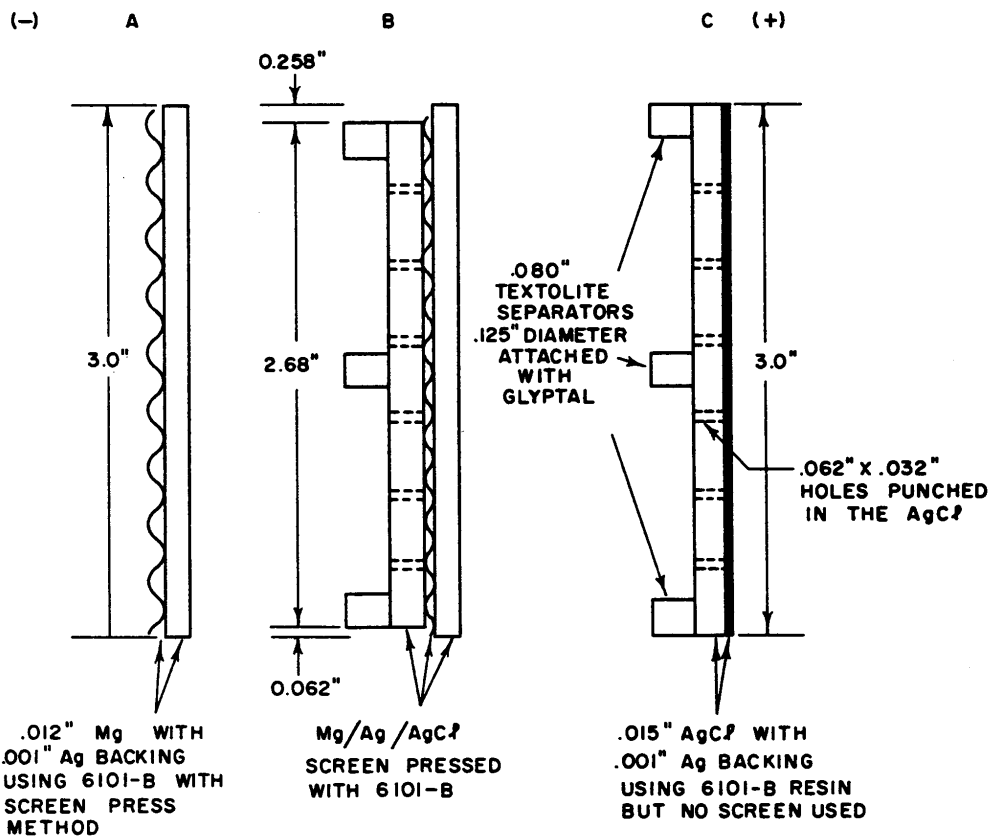
*** See Figure 2, part C

A first step towards a reduction of the required number of components can be taken, by extending the technique described in Section VA of Report No. 1 to include the silver chloride sheets. After applying a small amount of Hysol 6101 B to one side of these sheets, a satisfactory bond to the silver side of the Mg/Ag-package is obtained by applying about 300 lbs/inch² pressure at 150°C. The curing cycle is similar to the one described on pp. 13 and 14 of Report No. 1. This step eliminates item No. 5 as separate entities.

Having now developed a Mg/Ag, AgCl package we can proceed towards a second reduction in the number of battery components, by glueing small textolite punchings to the silver chloride layer, thereby eliminating the nine separators listed under Item No. 3. Figure 2 gives the cross sectional view of the new components for a 2-cell battery. Actually 8 parts B are used, instead of 1, to obtain a 9-cell battery.

The capacity reducing effects of internal leakage, mentioned already in Section IIIA, have been minimized by the use of U-shaped spacers. Measurements made on small batteries indicate a substantial improvement in battery capacity as a result of this. However, the relative importance of such leakage effects deminishes with increasing battery size. Since the power level has been increased by a factor 11, the use of spacers may no longer be required. Comparative tests with the large size battery show that standard load conditions can be maintained for 75 minutes without spacers, whereas a standard discharge can be maintained for 90 minutes with the spacers in position. Since this corresponds to a sacrifice in capacity of

8



NEW REFILL COMPONENTS FOR 2-CELL BATTERY

FIGURE 2

only 17% it is felt that simpler operation, resulting from the elimination of spacers, justifies this sacrifice. Consequently, item No. 2 in Table I can also be omitted. As indicated in the column marked "New", the three-step simplification project has resulted in a significant reduction of the total number of battery components from 37 down to 11.

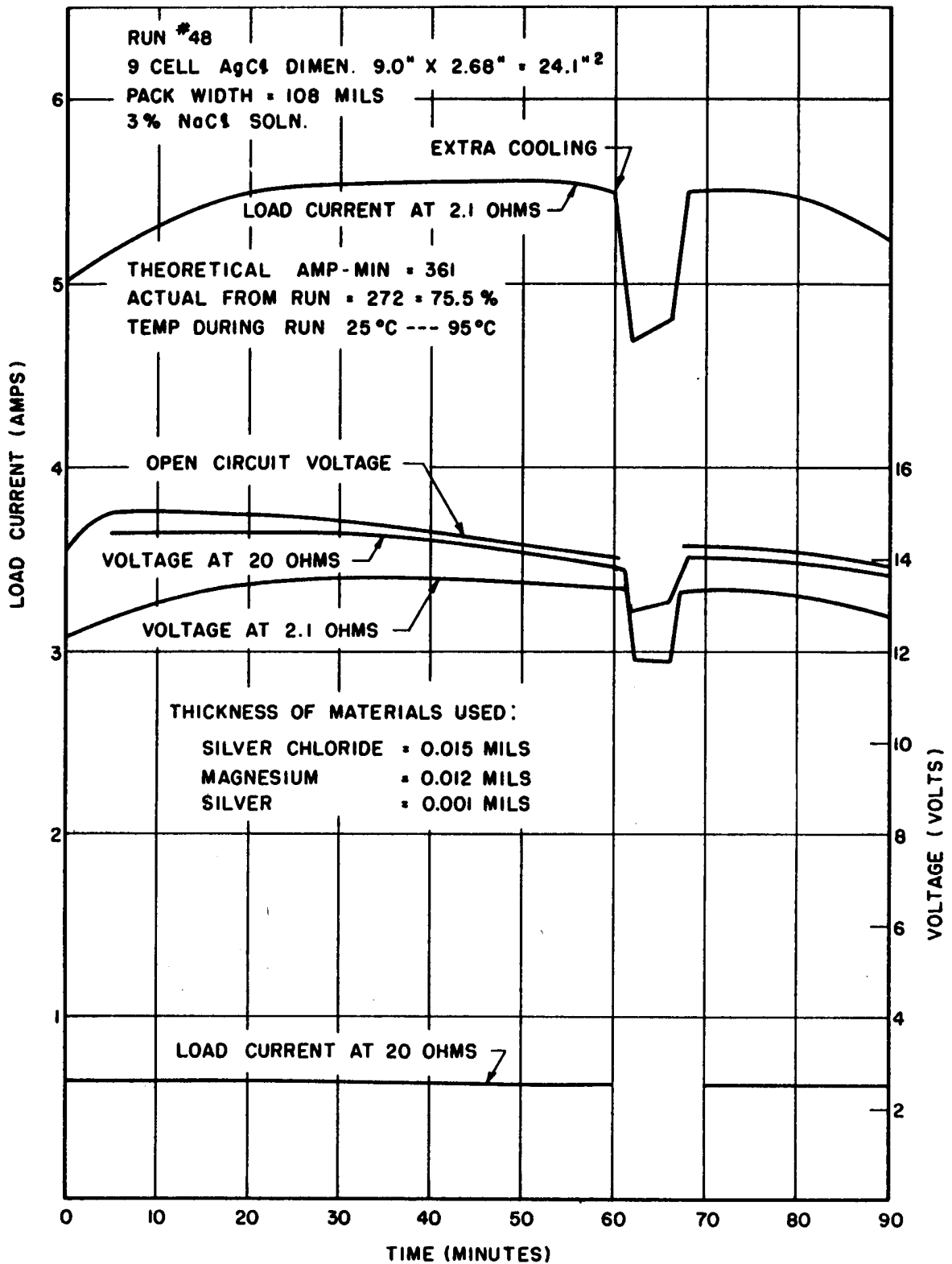
C. Load Tests

Exploratory small scale load tests have been made and reported on during all phases of this contract. In addition to this a certain number of large scale tests have been performed during this period. Some of these have already been discussed in the previous section in connection with the omission of spacers. Wherever possible we have conducted such tests, using only four cells instead of nine, to conserve our supply of silver chloride and to accelerate the preparation of components required. Except for the study of cooling problems it is felt that this is a permissible short-cut. In order to simulate the high temperature regime usually encountered in a 9-cell run, we often preheat the 4-cell test battery and its electrolyte to 70°C, prior to activation.

For direct comparison with No. 33*, which is representative of the previous smaller size, the load characteristics of a large size 9-cell run (No. 48) are shown in Figure 3. Except for the values of the load resistors R_1 and R_2 the same test circuit** has been used throughout. Spacers were used in this test. While the two sets of curves show a remarkable

* Annual Report, pp. 61, Figure 30

** Annual Report, pp. 56, Figure 26



LOAD CURVES OF LARGE BATTERY

FIGURE 3

similarity in their voltage regulation features, some striking differences are also noticeable. As expected, current levels are about eleven times higher in run No. 48. This is the direct result of the increase in battery size. However, in contrast to No. 33, these high current levels can be extended to a 90 minute period rather than the required 60 minutes, with load voltages remaining above 12 V. Thus the large size battery performance reveals the existence of a substantial reserve in capacity. The break in the curves at about 65 minutes is due to the accidental and temporary shorting of a single cell.

While the electrical characteristics of run 48 are very encouraging, its thermal behavior reveals somewhat inadequate cooling. With the battery case cooled by the surrounding air at 25°C and with the entire system at room temperature at the time of activation, the following approximate battery temperatures were recorded.

Minutes after activation	Battery Temperature
15	50°C
30	70°C
40	80°C
50	93°C

At this point "boiling" of the electrolyte became quite noticeable. Only by means of artificial cooling of the two side panels with small amounts of ice was it possible to stabilize the battery temperature between 80 and 93°C for the last part of the run. Other types of heat

removal such as partial submersion in a liquid bath or forced air cooling would have been equally effective. With an expected heat generation, equivalent to approximately 200 Watt (Section III, Report No. 1), such behavior is not too surprising. Since ice, liquid bath or forced air cooling cannot be considered to be desirable solutions to this cooling problem, the dissipation of excess heat will require further attention, particularly in connection with the $+40^{\circ}\text{C}$ temperature tests of Phase 2.

D. Heat Transfer Measurements

Since battery cooling is a problem determined essentially by "external" parameters, it can be studied independently of the actual heat generating processes. In the interest of efficiency and flexibility it was therefore decided to perform exploratory heat transfer measurements of this type by generating such heat by means of a resistance heater, submerged in the water filled battery case, in lieu of 9-cell battery runs. The resistance heater is placed inside a U-shaped quartzglass tube for protection, which fits inside the battery case. The amount of heat generated can be adjusted to the desired value with a Variac and it is measured directly by a wattmeter.

By means of this calibrated heat supply to the battery it was found that at the calculated rate of 180 Watt equivalent (Report No. 1, page 3) and normal air cooling, the battery never reached the boiling stage. Only at a heating level of 250 W could the thermal behavior of run No. 48 be reproduced. This corresponds to a H/W ratio of about 7, instead of the value 5 calculated in Report No. 1. This experimental

result is consistent with the known occurrence of an internal leakage process, the existence of which has been neglected in our calculations. The effect of heating on the equilibrium temperature of the water filled battery case is given in Figure 4. The boiling point of 100°C is reached at a heating level somewhere between 200 W and 250 W.

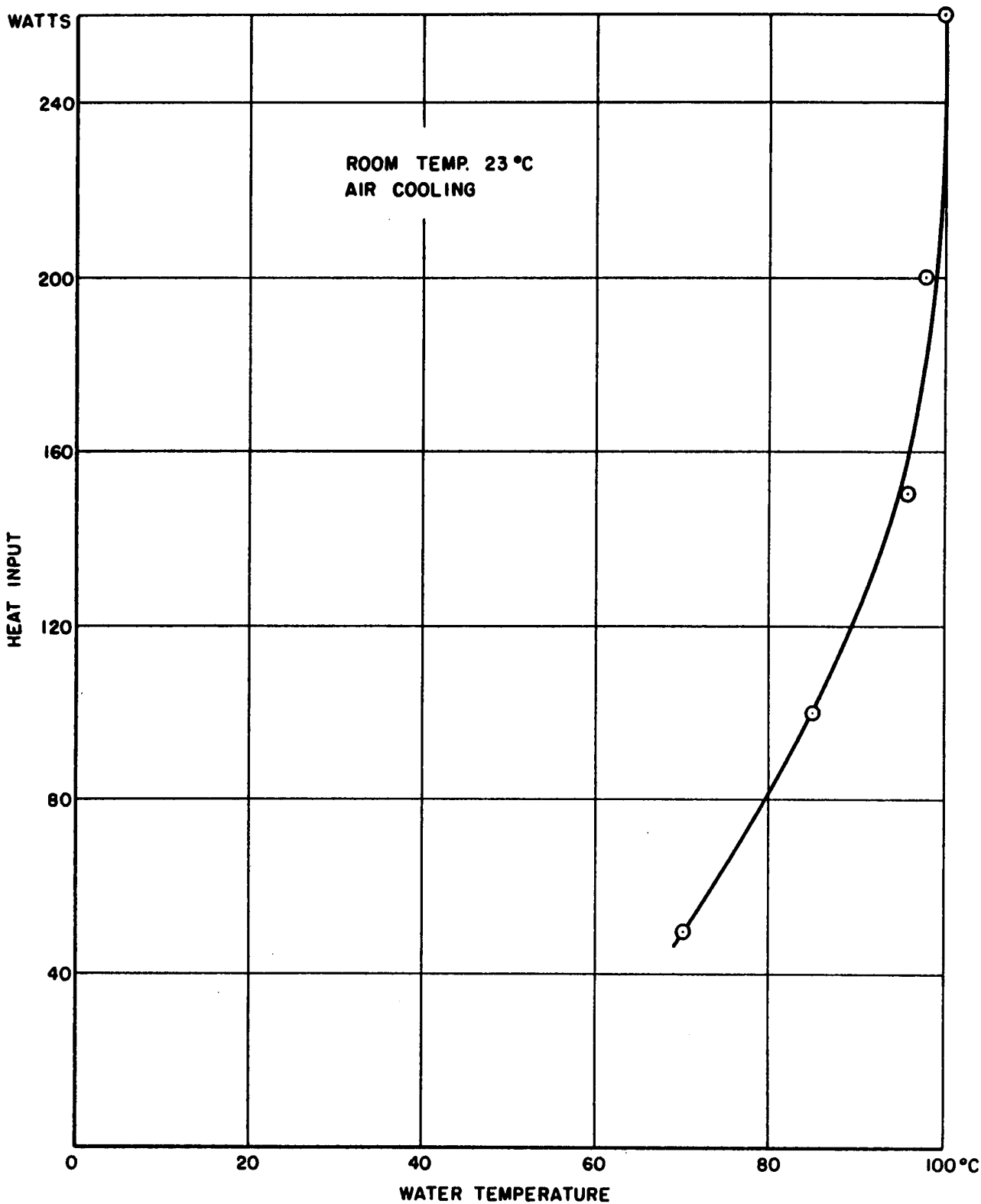
Other types of battery cooling have been investigated at a heating level of 250 W. Placing the hot battery case in 1 1/2" of cold water, provides excellent cooling. For our particular geometry and starting at the boiling point, the battery temperature dropped rapidly to 72°C, rising slowly thereafter up to 82°C. Cooling by means of wet sand in contact with the side-panels is also suitable, although it is not as effective as water. The cooling effect of dry sand, on the other hand, is very disappointing.

All our tests indicate very good heat transfer from the center of the battery to the outer surfaces of the two panels. On the other hand the transport processes, carrying the heat away from these surfaces, are the ones requiring improvement. The search for a more suitable cooling method continues.

IV. CONCLUSIONS

During this reporting period the design and fabrication of the large battery, including all the components for chemical recharge, have been completed. Its electrical performance at room temperature exceeds the requirements by a substantial margin.

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EFFECT OF HEATING ON BATTERY TEMPERATURE

FIGURE 4
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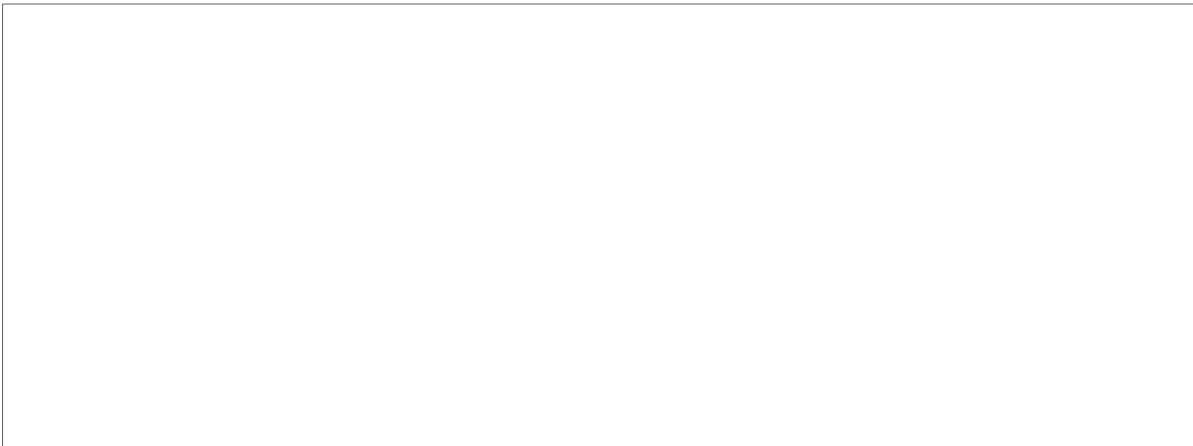
Further application of the bonding technology, developed during the previous period, combined with some sacrifice in excess capacity, has led to a reduction in the number of battery components from 37 down to 11. This leads to a substantial simplification in operating procedures, an achievement not included in the objectives called for in the contract.

The heat dissipated by the battery under load is larger than expected ($H/W \approx 7$ instead of 5) and the means for dissipating this heat, developed so far, are not entirely satisfactory.

V. FUTURE PLANS

During the next period our efforts will be devoted mainly to Phase 2, with special emphasis on the development of a new cooling method, permitting satisfactory operation at $+40^{\circ}\text{C}$ without the need for additional accessories and/or increases in size or weight.

VI. PERSONNEL



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