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HF CELL DEVELOPMENT

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By

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ABSTRACT

The work described in this report has been presented in two phases. Phase 1 demonstrates the ability of the cathode material while Phase 2 characterizes the performance of the HF cell over a variety of operating conditions.

The shelf storage stability of the mercuric fluoride cathode was observed for stand periods of one month. Mercuric fluoride cathodes were prepared containing 5% electronically conductive filler. Electrodes were prepared with 3 different fillers namely, silver powder, graphite powder and dispersed liquid mercury. Electrodes were prepared, stored in glass bottles in a dry room and finally discharged at selected times during the one month interval. It was generally concluded that mercuric fluoride cathodes containing either silver powder or graphite powder do not deteriorate during this stand period. Electrodes containing mercury filler performed poorly during the first 2 weeks of the stand period. Tests made during the latter half of the stand period indicated performances approaching that observed for the silver and graphite filled electrodes. Least square equations are given in the text relating the electrode performance to its storage time. Since a large part of the background work had been performed with the silver filler in the cathode, it was decided to continue to use the silver filled cathodes for further work.

The second phase of the work began with a full factorial experiment involving 108 tests. These tests were all conducted at 25°C. Based on

the energy density calculated for each of these tests, several parameters were defined that would optimize the cell performance. These conclusions were that:

- (1) the tin anode should be made from 170 mesh tin particles.
- (2) the tin anode capacity should be 2500 ma/min. on a 0.75 inch diameter electrolyte.
- (3) the cathode capacity should be 2500 ma/min. on a 0.75 inch diameter electrode.

Six tests were conducted at 75°C using three quantities of electrolyte. Similarly, six tests were conducted at -54°C. The results of these twelve tests combined with the previous 108 tests show that the highest energy density over the whole temperature range could be obtained using 0.36 cc's of electrolyte per sq. centimeter of electrode area.

A variety of pulse currents were superimposed upon a continuous constant current. These tests demonstrate that the HF cell can withstand short pulses of 300 ma/cm². An additional 30 tests were performed at current drains ranging from 25 ma/cm² to 80 ma/cm². These tests have demonstrated that the HF cell can tolerate steady current drains of 80 ma/cm². As the current density is increased, there appears to be a general trend of energy density loss. It is particularly interesting to note that the energy density remains relatively constant over the complete military temperature range, i.e. -54°C to +75°C.

PHASE 1

INTRODUCTION

While performing the work of Contract 58-8484, it was observed that a chemical reaction was taking place in the cathode during storage. These cathodes were a compaction of 95% mercuric fluoride and 5% silver powder. These electrodes were routinely stored under dry room conditions where the relative humidity never exceeded 3% and the temperature was 33°C or less. This chemical reaction occurring on the stored cathodes resulted in diminished performance of an HF cell where this cathode was used. Since only a few electrodes have been stored for more than a single day, it became important to ascertain storage conditions under which the cathodes did not deteriorate and to determine their storage stability over a longer period of time.

The objective of this phase of the work was to determine the change in performance of an HF cell using cathodes that had been stored for a period ranging up to 27 days. Since it was conceivable that the addition of various types of electronic fillers might affect the stability of the electrode, cathodes were prepared and stored using silver powder, graphite powder and mercury. This report presents the data and results obtained from this study.

STORAGE STABILITY OF MERCURIC FLUORIDE CATHODES

The objective of this phase of the work was to identify the effect of cathode storage on the performance of an HF cell.

Three series of cathodes were prepared, each series being different only in the type of electronic filler used. In all cases 5% of the total cathode weight was filler not including the weight of the nickel screen. The three electronic fillers incorporated in the cathode were silver powder, graphite powder and liquid mercury. Accordingly, 10.48 grams of mercuric fluoride and 0.52 grams of electronic filler were accurately weighed and placed in a screw-capped glass bottle. The components were intimately mixed by a vigorous manual shaking for 15 minutes. Manual mixing was chosen over mechanical mixing since it was felt that a better dispersion of the mercury could be accomplished by this means. To provide uniformity in the three series, the mixtures containing silver powder and graphite powder were mixed by this same technique. The bulk mixture was then divided into portions from which cathodes could be fabricated. Each portion contained 0.55 grams of material. Each portion was weighed into a separate bottle from which the die cavity could be filled. The material from one container was spread evenly in the cavity of a 0.75 inch diameter die. A 60 mesh nickel screen, 1 inch square, was placed over the die cavity and the powdered material was pressed into the screen at 45 tons/sq. inch (20 tons force). Eighteen electrodes were prepared in this fashion for each of the three series of filler. Each series was placed in a screw-capped jar and stored in a desiccator containing silica gel. All of the above procedures

were carried out in a dry room having a relative humidity of 2% or less at 24°C. Generally, electrodes were removed from storage every 3 to 4 days and discharged in an HF cell. The anode of this cell was formed by pressing tin sheet into 60 mesh nickel screen. The capacity of the tin was in excess by 100% as compared to the cathode capacity to guarantee that the cell would be cathode limited. Three layers of 6 mil Kendall non-woven polypropylene separator was placed between the anode and cathode. Having placed the separator on top of the anode and the cathode on the separator, a piece of Teflon tape was wrapped around the cell to maintain component placement. The cell was then heat sealed into a plastic bag and the fabrication was placed in a screw-capped glass bottle. The cell construction was conducted in a dry room of the quality mentioned earlier. The cell was then transported to the HF hood enclosure in a wet laboratory. Leads were connected to the cell from the current generator and to the recording instruments. Using a hypodermic needle and syringe, 1.4 cc's of electrolyte was admitted to the cell. The electrolyte was 4m NH_4F in singly distilled anhydrous HF. All the tests were conducted at 25°C and at 25 milliamps per sq. centimeter. The electrode area was 2.85 cm² resulting in a total current of 71.25 mA. The resulting voltage vs. time data was recorded on a Varian G-14 Recorder.

A typical voltage vs. time graph is shown in Figure 1 for graphite, Figure 2 for silver and Figure 3 for mercury fillers. Tables 1, 2 and 3 indicate the results of the discharge tests. To determine the length of running time, a 0.4 volt cut-off was used.

Figure 1

Typical voltage vs. time curve at
current of 25 ma/cm² for cell:
Sn/4m NH₄F, HF/HgF₂ (Graphite)

Figure 2

Typical voltage vs. time curve at
a current of 25 ma/cm² for cell:
Sn/4m NH₄F, HF/HgF₂ (Ag)

Figure 3

Typical voltage vs. time curve at
a current of 25 ma/cm^2 for the cell:
 $\text{Sn}/4\text{m NH}_4\text{F}, \text{HF}/\text{HgF}_2 (\text{Hg})$

Table 1Cell Discharge Tests with Cathodes ContainingGraphite Filler

<u>Storage Time</u> <u>(Days)</u>	<u>Initial Load</u> <u>Voltage (V)</u>	<u>Time - Mins.</u>			
		<u>1.0V</u>	<u>0.8V</u>	<u>0.6V</u>	<u>0.4V</u>
0	1.12	18.0	36.0	44.0	55.3
0	1.15	28.0	39.0	46.0	53.4
3	1.17	22.0	37.0	40.0	43.7
3	1.16	20.0	32.0	40.0	43.3
14	1.14	18.0	33.0	42.0	48.4
14	1.16	22.0	36.0	46.0	52.8
17	1.15	14.0	26.0	36.0	50.5
17	1.14	11.0	41.0	46.0	51.6
17	1.12	6.0	31.5	35.0	46.2
21	1.07	5.0	31.0	39.5	47.3
21	1.16	10.0	39.0	45.0	48.4
21	1.18	20.0	39.0	44.5	47.7
23	1.17	24.0	38.0	44.0	53.8
24	1.17	16.0	28.0	26.3	49.3
24	1.17	24.0	38.5	44.0	52.5
24	1.18	26.0	42.0	47.0	50.0

Table 2Cell Discharge Tests with Cathodes Containing Ag Filler

<u>Storage Time</u> <u>(Days)</u>	<u>Initial Load</u> <u>Voltage (V)</u>	<u>Time - Mins.</u>			
		<u>1.0V</u>	<u>0.8V</u>	<u>0.6V</u>	<u>0.4V</u>
0	1.03	8.0	33.0	44.0	50.5
0	1.09	12.0	36.0	43.0	48.2
3	1.12	16.0	33.0	39.5	45.8
3	1.10	14.0	27.0	35.0	42.8
6	1.11	16.0	33.0	42.0	48.0
6	1.05	8.0	25.0	41.0	50.0
17	1.11	13.0	28.0	35.0	42.8
17	1.08	14.0	29.0	40.0	48.3
24	1.11	16.0	36.0	44.0	50.2
24	1.11	16.0	33.0	38.3	42.3
27	1.09	16.0	36.0	44.0	48.3
27	1.04	8.0	34.0	42.0	50.0

Table 3

Cell Discharge Tests with Cathodes Containing Hg Filler

Storage Time (Days)	Initial Load Voltage (V)	Time - Mins.			
		1.0V	0.8V	0.6V	0.4V
0	1.02	2.5	19.0	28.5	37.7
0	1.01	2.0	19.3	26.0	35.2
2	1.05	10.0	26.3	34.5	41.5
2	1.03	7.0	25.0	34.0	40.3
14	1.03	8.0	22.0	29.0	36.4
14	1.03	8.0	28.3	36.8	43.2
14	0.98	--	19.5	23.8	31.9
19	1.02	8.0	30.5	38.0	44.2
19	0.88	--	24.0	34.5	41.0
19	0.86	--	23.0	33.8	42.5
20	1.02	8.0	32.0	40.0	47.1
21	1.03	8.0	24.0	32.0	39.1
21	1.01	8.0	30.0	38.5	43.5
21	1.03	6.0	29.0	37.0	42.5
21	1.02	6.0	32.0	40.0	45.9
26	1.04	8.0	36.0	44.5	49.5
26	1.03	8.0	36.8	45.5	50.5
26	1.04	12.0	30.8	37.3	43.0

A visual observation of the above results indicates two generalities:

- (1) The graphite containing cathodes showed the longest running time while the mercury containing cathodes showed the shortest running time.
- (2) Initial load voltages were highest with graphite containing cathodes while the mercury containing cathodes showed the lowest initial load voltage.

In addition, the cathodes containing mercury usually showed discharge results that contained 0.1-0.2V noise during the last 1/3 of its discharge time.

Figures 4, 5 and 6 show the data plotted as cathode storage time vs. the running time for that cathode in a cell. The data collected from experiment are shown on the graphs as points while the solid line represents the least square linear fit to these points. The least square equation for

Figure 4

Discharge time vs. storage time for
 HgF_2 cathodes containing graphite.

Figure 5

Discharge time vs. storage time for
 HgF_2 cathodes containing Ag

Figure 6
Discharge time vs. storage time
for HgF_2 cathodes containing Hg

the cathodes containing the various fillers are:

Graphite

$$Y = -0.0589X + 51.03$$

Silver

$$Y = -0.00219X + 47.29$$

Mercury

$$Y = 0.328X + 36.74$$

where Y is the cell discharge time in minutes to 0.4 volts and X is the cathode storage time in days. It is significant that the electrodes containing mercury filler increased in performance vs. storage time. This may be due to an insufficient dispersion of the mercury during the electrode fabrication. On the other hand, the mercury may be encapsulating particles of the mercuric fluoride which are isolated from the cell reaction on freshly prepared cathodes. On storage the mercury could coalesce into larger droplets thus exposing more of the reactive material. Considering the reproducibility of the running time in the discharge test for cathodes having the same storage time, levels of significance can be attached to the change in performance per day of storage slope. The region of slope insignificant for the three types of cathode fabrications are:

Graphite

$$-0.200 \text{ to } +0.083$$

Silver

$$-0.142 \text{ to } +0.138$$

Mercury

$$+0.187 \text{ to } +0.470$$

From this analysis it can be seen that the slope of the least square equation for graphite and silver is in the insignificant region. Within the limits of our test reproducibility, it must be concluded that no loss of cell performance has occurred due to the storage of cathodes containing graphite or silver. The significant slope limits for cathodes containing mercury show only positive limits and since the least square line of the data also showed a positive slope, it can be concluded with certainty that these electrodes do improve in performance during the 27 day storage time investigated.

Generally speaking, cells fabricated using cathodes containing a graphite filler result in the longest lived cell, higher initial load voltage and higher operating voltages throughout the test. Cells constructed with cathodes containing a silver filler appear slightly inferior to cells containing cathodes with a graphite filler. Cell discharge time is approximately 5% less and the initial load voltage is about 50 millivolts lower. Cathodes containing a mercury filler gave inferior cell performance throughout this period of study. However, it seems that longer storage time on these cathodes would result in a cell performance similar to those obtained with the cathodes containing the silver and graphite fillers.

OBSERVATIONS

One cathode was prepared containing 5% silver powder and another containing 5% graphite powder. These electrodes were relatively thick being 0.050 inches. Placing the electrodes in a horizontal position, a few drops of 4 molal ammonium fluoride electrolyte was placed on the center of the top face. On the electrode containing silver, approximately 15 minutes lapsed before the electrolyte completely penetrated or spread over the surface of the electrode. With the graphite containing electrode, the electrolyte entered the electrode as soon as it contacted its face. The surface of the silver containing electrode was observed to change from a pale yellow color to a silvery metallic nature. It is conceivable that the silver powder reacts with a small quantity of mercuric fluoride upon wetting to give silver fluoride and metallic mercury. The enhancement of the electrical conductivity of the cathode is most probably a result of the formation of the mercury and not directly to the silver particles.

For a high rate, high capacity cathode that must have a restricted surface area, the graphite filler would appear preferable. For a low discharge rate cathode of either high or low capacity, cathodes containing silver powder would probably give the better performance.

Untreated compressed graphite powder was observed to be hydrophobic. Graphite powder treated with carbon dioxide at 100°C resulted in a hydrophilic material.

PHASE 2

FACTORIAL CELL TESTING

The objective of this phase of the work was to conduct tests that would allow an optimum tin mesh size, tin anode weight and mercuric fluoride cathode weight to be chosen. Two tin mesh sizes, three mercuric fluoride cathode weights and three quantities of electrolyte provided the independent variables from which the full factorial tests were designed. The work program provided for the total of 108 tests in this series.

The cells were discharged at 25 ma/cm^2 using 2.85 square centimeter cells.

The electrodes were prepared by pressing the appropriate quantity of material onto a 60 mesh nickel screen. The diameter of the wire in the nickel screen was 3.5-4.0 mils. Individual component weights and thicknesses were measured for each cell. Where standard size components were reproducibly used for the cell fabrication, five samples were carefully measured and the average was used to represent that component in all the cells of that series. The physical measurements of the individual cell components for each cell are tabulated in Table 4.

In order to consolidate the parameter descriptions, a four number code has been established as defined on the following page. The cell configuration can then be identified in tables with this four number code. The following page contains a definition for each of the numbers in the code.

Parameter Code Definition

<u>Code Number</u>	<u>Parameter Definition</u>
1	20 mesh tin particles
2	170-200 mesh tin particles
3	0.197 grams tin
4	0.263 grams tin
5	0.394 grams tin
6	0.396 grams mercuric fluoride
7	0.524 grams mercuric fluoride
8	0.792 grams mercuric fluoride
9	0.36 cc's electrolyte
10	0.72 cc's electrolyte
11	1.44 cc's electrolyte

Table 4

Individual Cell Physical Properties

<u>Configuration</u>	<u>Anode Wt. (mg.)</u>	<u>Anode Screen Wt. (mg.)</u>	<u>Sn Wt. (mg.)</u>	<u>Cathode Wt. (mg.)</u>	<u>Cathode Screen Wt. (mg.)</u>	<u>HgF₂ Wt. (mg.)</u>	<u>Separator Wt. (mg.)</u>	<u>Cell Wt. (gm.)</u>	<u>Cell Thickness (ml.)</u>
1-3-6-9	269	78	191	459	93	366	34	0.754	--
"	276	79	196	442	95	347	35	0.751	--
2-3-6-9	251	82	167	445	89	356	36	0.718	--
"	233	82	151	466	93	373	35	0.732	--
1-3-6-10	287	80	207	437	91	346	35	0.744	21.0
"	282	87	195	448	91	357	35	0.702	--
2-3-6-10	277	82	195	439	93	346	36	0.788	--
"	250	82	168	446	90	356	36	0.734	--
1-3-6-11	287	89	198	421	98	323	35	0.742	21.0
"	283	84	199	428	89	339	36	0.742	22.0
2-3-6-11	250	82	169	454	92	362	35	0.726	21.0
"	254	88	166	449	90	360	36	0.721	19.5
1-4-6-9	343	84	259	497	94	403	36	0.874	--
"	352	87	265	490	89	401	36	0.878	--
2-4-6-9	281	85	196	476	88	388	36	0.790	--
"	293	83	210	499	92	407	37	0.822	--
1-4-6-10	304	78	226	497	96	401	39	0.839	25.0
"	348	85	263	491	92	399	38	0.866	--
2-4-6-10	311	87	224	479	90	389	38	0.820	--
"	288	81	207	495	92	403	37	0.815	--
1-4-6-11	350	85	264	459	91	368	33	0.832	24.5
"	346	83	263	497	87	410	33	0.879	25.5
2-4-6-11	310	82	228	481	94	389	35	0.841	23.5
"	311	85	226	680	90	369	37	0.825	23.0
1-5-6-9	480	86	394	487	93	395	38	1.010	--
"	477	89	388	502	93	410	36	1.012	--
2-5-6-9	439	87	352	486	93	393	41	0.983	--
"	431	88	343	498	91	407	39	0.963	--
1-5-6-10	465	79	386	511	94	417	38	1.031	26.5
"	472	85	387	508	96	412	39	1.007	--
1-5-6-11	474	85	389	480	93	387	38	0.995	27.5
"	472	87	385	489	92	398	37	0.995	27.5
2-5-6-11	418	81	336	495	90	405	39	0.946	28.5
"	430	83	347	467	91	375	39	0.938	27.0

Table 4 - Cont'd

Configuration	Anode Wt. (mg.)	Anode Screen Wt. (mg.)	Sn Wt. (mg.)	Cathode Wt. (mg.)	Cathode Screen Wt. (mg.)	HgF ₂ Wt. (mg.)	Separator Wt. (mg.)	Cell Wt. (gm.)	Cell Thickness (ml.)
1-3-7-9	274	82	192	544	86	458	60	0.878	40.0
"	277	84	193	602	84	518	56	0.935	32.5
2-3-7-9	253	83	170	636	90	547	67	0.956	--
"	258	86	172	643	89	554	57	0.931	--
1-3-7-10	273	76	194	592	88	504	55	0.920	40.5
"	279	82	197	651	88	563	56	0.986	42.5
2-3-7-10	260	84	176	629	87	542	58	0.947	39.5
"	251	82	169	627	87	540	54	0.922	42.5
1-3-7-11	276	79	196	590	87	503	60	0.917	42.5
"	279	80	198	584	80	504	56	0.918	41.5
2-3-7-11	260	84	176	583	87	497	50	0.884	37.5
"	260	84	176	663	90	573	56	0.945	42.5
1-4-7-9	353	92	263	630	92	538	60	1.035	--
"	344	87	257	610	92	518	52	0.997	--
2-4-7-9	336	83	253	595	93	502	58	0.976	--
"	316	81	235	621	91	530	53	0.981	--
1-4-7-10	361	89	272	596	89	507	54	1.004	43.0
"	355	87	269	616	93	523	55	1.004	--
2-4-7-10	296	81	215	602	88	514	60	0.941	--
"	311	79	232	614	88	526	59	0.984	--
1-4-7-11	346	80	266	582	90	492	58	0.979	44.0
"	351	82	269	606	91	515	56	0.967	43.0
2-4-7-11	340	88	258	607	92	515	54	1.010	43.0
"	333	83	251	636	93	543	56	1.010	42.0
1-5-7-9	474	77	397	621	94	527	59	1.140	--
"	484	89	396	622	93	530	53	1.150	--
2-5-7-9	427	82	344	645	91	554	53	1.113	--
"	454	85	369	632	92	540	54	1.132	--
1-5-7-10	479	85	394	599	89	509	58	1.129	43.5
"	480	86	394	573	89	484	60	1.103	--
2-5-7-10	437	80	357	607	93	514	59	1.093	--
"	444	87	357	584	95	489	57	1.081	--
1-5-7-11	478	84	394	566	96	470	55	1.094	47.5
"	474	82	392	621	92	530	55	1.142	44.0
2-5-7-11	435	83	352	619	90	529	60	1.112	45.0
"	454	82	372	578	89	489	51	1.180	43.0

Table 4 - Cont'd

Configuration	Anode Wt. (mg.)	Anode Screen Wt. (mg.)	Sn Wt. (mg.)	Cathode Wt. (mg.)	Cathode Screen Wt. (mg.)	HgF ₂ Wt. (mg.)	Separator Wt. (mg.)	Cell Wt. (mg.)	Cell Thickness (ml.)
1-3-8-9	279	79	200	915	94	821	36	1.220	
"	277	80	197	919	89	830	34	1.184	
2-3-8-9	252	82	170	883	93	790	38	1.164	
"	265	85	180	901	85	817	34	1.197	
1-3-8-10	280	80	200	885	90	796	35	1.196	31.0
"	287	84	204	902	89	813	37	1.221	
2-3-8-10	257	85	172	932	87	845	32	1.214	
"	266	82	184	891	87	804	34	1.171	
1-3-8-11	283	83	200	817	95	721	34	1.130	31.5
"	287	84	203	968	87	880	39	1.287	33.0
2-3-8-11	237	84	152	886	87	799	35	1.151	23.5
"	261	78	183	904	90	814	37	1.195	25.0
1-4-8-9	337	80	257	913	88	824	37	1.284	
"	342	80	262	917	90	827	37	1.294	
2-4-8-9	294	82	211	924	91	832	37	1.249	
"	300	81	219	919	90	822	38	1.243	
1-4-8-10	343	85	258	918	88	830	35	1.271	30.0
"	344	82	263	879	93	786	33	1.252	
2-4-8-10	301	79	228	840	97	844	39	1.271	
"	340	90	251	919	96	823	36	1.294	
1-4-8-11	348	91	258	865	90	776	40	1.235	30.0
"	343	86	258	909	94	815	37	1.269	31.5
2-4-8-11	318	87	231	915	97	818	40	1.251	29.0
"	333	90	243	907	86	820	37	1.269	30.5
1-5-8-9	468	79	389	892	86	806	36	1.387	
"	466	79	387	942	95	846	31	1.437	
2-5-8-9	454	86	367	940	92	848	37	1.425	
"	448	81	367	907	90	818	33	1.383	
1-5-8-10	466	78	388	869	86	783	34	1.365	33.5
"	467	80	387	920	93	827	37	1.419	
2-5-8-10	438	79	359	909	89	820	32	1.368	
"	457	83	374	867	88	784	38	1.356	
1-5-8-11	472	81	391	853	88	765	37	1.351	33.5
"	471	82	389	873	94	779	37	1.373	34.0
2-5-8-11	444	80	364	926	88	838	35	1.397	34.0
"	458	84	374	918	90	828	35	1.302	33.5

Table 5

Cell Electrical Performance

Configuration	O.C.V. (V)	Initial Load Voltage (V)	Time to 0.4V (min.)	Anode Efficiency (%)	Cathode Efficiency (%)	W-h/lb.	W-h/in. ³
1-3-6-9	1.235	1.062	24.96	34.1	35.8	15.9	2.26
"	1.245	1.076	23.03	30.8	34.9	14.4	2.58
2-3-6-9	1.241	1.097	22.26	35.0	33.0	14.7	2.56
"	1.232	1.057	21.77	37.8	30.7	14.0	2.44
1-3-6-10	1.242	1.082	27.39	34.7	41.8	17.3	3.07
"	1.244	1.077	25.68	34.4	37.7	17.6	2.95
2-3-6-10	1.230	1.084	25.66	34.4	38.9	15.5	2.91
"	1.246	1.024	22.81	35.6	33.8	13.8	2.38
1-3-6-11	1.252	1.074	25.84	34.2	40.6	16.4	2.92
"	1.245	1.073	18.64	24.5	29.0	12.1	2.15
2-3-6-11	1.243	1.080	20.90	32.4	30.5	13.6	2.35
"	1.247	1.079	24.57	38.9	36.1	16.3	2.80
1-4-6-9	1.258	1.091	25.70	25.9	33.4	13.4	2.40
"	1.261	1.087	24.28	23.9	31.8	12.9	2.32
2-4-6-9	1.239	1.080	26.07	34.9	35.4	15.5	2.51
"	1.267	1.112	33.02	41.2	42.9	19.2	3.23
1-4-6-10	1.261	1.101	27.31	31.5	35.8	15.5	2.67
"	1.257	1.101	24.41	24.3	32.3	13.3	2.37
2-4-6-10	1.257	1.10	27.97	32.7	37.8	16.1	2.71
"	1.259	1.084	24.59	31.2	32.2	14.2	2.38
1-4-6-11	1.243	1.090	24.63	27.8	35.2	14.0	2.39
"	1.253	1.114	28.58	28.6	36.7	15.4	2.77
2-4-6-11	1.258	1.106	31.45	36.3	42.8	18.8	3.14
"	1.264	1.109	34.09	39.4	48.7	18.1	3.07
1-5-6-9	1.272	1.091	27.64	18.4	37.0	12.9	2.37
"	1.276	1.093	30.47	20.6	39.2	13.6	2.50
2-5-6-9	1.264	1.095	36.64	27.3	49.2	17.0	3.04
"	1.267	1.094	38.06	29.0	49.2	18.1	3.17
1-5-6-10	1.266	1.106	31.16	21.2	39.3	13.8	2.58
"	1.248	1.051	30.44	20.7	39.0	14.0	2.55
1-5-6-11	1.260	1.077	32.37	21.8	44.1	15.4	2.78
"	1.260	1.080	32.46	22.0	42.9	13.8	2.50
2-5-6-11	1.264	1.10	33.66	26.0	43.6	17.0	2.92
"	1.270	1.108	29.49	22.3	41.6	15.1	2.57

Table 5 - Cont'd

Configuration	O.C.V. (V)	Initial Load Voltage (V)	Time to 0.4V (min.)	Anode Efficiency (%)	Cathode Efficiency (%)	W-h/lb.	W-h/in. ³
1-3-7-9	1.28	1.11	33.43	45.4	38.3	17.7	1.89 (2.90)
"	1.28	1.10	29.28	39.8	29.8	15.4	1.66 (2.55)
2-3-7-9	1.27	1.25	33.86	52.2	32.5	17.6	2.08 (3.19)
"	1.11	1.12	36.18	55.0	34.4	19.2	2.21 (3.39)
1-3-7-10	1.27	1.12	35.80	48.4	37.5	19.1	2.17 (3.33)
"	1.27	1.10	31.65	42.2	29.7	15.3	1.86 (2.85)
2-3-7-10	1.24	1.10	22.35	33.2	21.7	11.5	1.35 (2.07)
"	1.22	1.10	28.28	43.6	27.5	15.7	1.80 (2.76)
1-3-7-11	1.27	1.10	36.26	48.4	37.8	18.7	2.13 (3.27)
"	1.27	1.10	29.14	38.5	30.5	15.4	1.75 (2.68)
2-3-7-11	1.27	1.13	26.64	39.4	28.2	15.2	1.66 (2.55)
"	1.27	1.10	32.25	47.7	29.6	16.4	1.92 (2.95)
1-4-7-9	1.26	1.07	30.28	30.2	29.7	14.1	1.69 (2.51)
"	1.26	1.10	33.50	34.2	33.3	16.6	1.91 (2.83)
2-4-7-9	1.27	1.10	41.85	43.3	43.8	20.6	2.32 (3.44)
"	1.27	1.12	29.68	33.0	29.4	14.9	1.70 (2.52)
1-4-7-10	1.27	1.10	39.73	38.1	41.2	18.6	2.12 (3.20)
"	1.27	1.10	46.04	44.9	46.3	21.8	2.54 (3.77)
2-4-7-10	1.27	1.08	46.85	57.3	48.1	23.0	2.51 (3.72)
"	1.27	1.11	30.25	33.3	30.3	15.5	1.76 (2.61)
1-4-7-11	1.27	1.10	39.54	38.9	42.2	19.4	2.20 (3.26)
"	1.27	1.11	43.90	42.8	44.8	21.9	2.45 (3.63)
2-4-7-11	1.27	1.12	43.17	43.8	44.1	20.6	2.41 (3.57)
"	1.27	1.11	40.42	42.2	39.2	19.8	2.32 (3.44)
1-5-7-9	1.28	1.09	39.32	25.9	39.1	15.8	2.01 (2.94)
"	1.28	1.11	41.75	27.6	41.6	18.2	2.32 (3.39)
2-5-7-9	1.28	1.08	30.85	23.4	29.3	13.5	1.67 (2.44)
"	1.28	1.11	33.50	23.8	32.7	15.0	1.89 (2.76)
1-5-7-10	1.28	1.12	42.73	28.4	44.2	18.9	2.38 (3.48)
"	1.29	1.12	45.77	30.4	49.7	20.7	2.55 (3.73)
2-5-7-10	1.28	1.08	45.16	33.0	44.9	20.0	2.44 (3.57)
"	1.28	1.11	39.66	28.9	41.2	18.6	2.24 (3.27)
1-5-7-11	1.27	1.10	42.55	28.2	47.6	18.6	2.27 (3.32)
"	1.24	1.09	42.50	27.4	42.3	17.4	2.22 (3.25)
2-5-7-11	1.28	1.12	41.50	30.9	41.5	19.1	2.38 (3.48)
"	1.24	1.06	36.37	25.6	39.1	14.7	1.93 (2.82)

Table 5 - Cont'd

Configuration	O.C.V. (V)	Initial Load Voltage (V)	Time to 0.4V (min.)	Anode Efficiency (%)	Cathode Efficiency (%)	W-h/lb.	W-h/in. ³
1-3-8-9	1.234	1.033	21.73	28.5	13.9	8.2	1.74
"	1.241	1.113	22.18	29.5	14.1	8.3	1.70
2-3-8-9	1.246	1.082	31.03	47.8	20.7	9.6	1.93
"	1.238	1.070	26.70	38.9	17.2	10.3	2.13
1-3-8-10	1.239	1.081	34.17	44.9	22.7	13.4	2.77
"	1.239	1.063	37.80	48.5	24.5	14.6	3.09
2-3-8-10	1.236	1.047	27.00	41.1	16.8	10.6	2.22
"	1.229	1.024	26.37	37.5	17.2	10.2	2.07
1-3-8-11	1.228	1.097	31.43	41.2	23.0	12.5	2.44
"	1.221	1.049	30.87	40.0	18.5	10.1	2.25
2-3-8-11	1.279	1.057	32.19	55.5	21.2	12.4	2.62
"	1.238	1.082	35.66	51.0	23.1	14.1	2.90
1-4-8-9	1.245	1.071	29.37	29.9	18.7	11.3	2.40
"	1.256	1.095	34.65	34.7	22.1	12.9	2.75
2-4-8-9	1.225	1.120	26.00	32.4	16.5	10.4	2.14
"	1.253	1.096	23.80	28.4	15.2	9.3	1.90
1-4-8-10	1.237	1.076	28.90	29.4	18.3	10.6	2.23
"	1.235	1.058	29.42	29.3	19.7	10.8	2.23
2-4-8-10	1.252	1.078	31.25	35.8	19.3	11.3	2.36
"	1.266	1.082	28.89	30.1	18.5	10.9	2.32
1-4-8-11	1.232	1.092	42.13	42.7	28.5	15.7	3.20
"	1.236	1.089	33.27	33.9	21.5	12.1	2.53
2-4-8-11	1.235	1.083	30.73	34.8	19.8	15.5	2.38
"	1.238	1.064	24.99	27.0	16.1	9.3	1.94
1-5-8-9	1.250	1.080	33.80	22.9	21.8	10.0	2.04
"	1.258	1.063	29.81	20.2	18.6	9.8	2.09
2-5-8-9	1.261	1.088	23.10	16.5	14.3	7.9	1.66
"	1.243	1.066	19.25	13.7	12.4	6.9	1.40
1-5-8-10	1.241	1.091	42.32	28.5	28.4	15.2	3.07
"	1.256	1.069	33.78	22.9	21.5	11.7	2.44
2-5-8-10	1.250	1.070	29.84	21.7	19.2	10.7	2.17
"	1.250	1.080	35.43	24.8	23.8	12.6	2.53
1-5-8-11	1.239	1.092	51.60	34.6	35.6	17.9	3.57
"	1.232	1.075	48.18	32.4	32.5	16.3	3.30
2-5-8-11	1.240	1.095	51.90	37.3	32.6	18.0	3.72
"	1.279	1.085	43.12	30.3	27.3	14.1	2.74

According to the program design, the results of these 108 tests are to provide the basis for obtaining three conclusions. The three areas where decisions are required are:

- (1) The selection of either 20 mesh or 170 mesh tin particles to be used in the anode fabrication.
- (2) The selection of an anode capacity that results in an optimum energy density for the cell.
- (3) The selection of a cathode capacity that results in an optimum energy density for the cell.

A total of 54 cells were constructed and tested in which the anode was prepared from the 20 mesh tin particles. These 54 tests were duplicated in all respects except that the anodes were prepared with 170 mesh tin particles. The energy density for each of these cells was calculated and is shown in Table 2. The average energy density found for cells using 20 mesh tin was 14.9 w-hr./lb. The similar average for cells containing 170 mesh tin anodes gave an energy density of 14.8 w-hr./lb. Since this difference is well within the range of experimental error, the results indicate that the cell performance is independent of the tin particle size used in the fabrication of the anodes. It will be shown in the succeeding paragraphs that 253 milligrams of tin and 550 milligrams of mercuric fluoride produce cells with the greatest energy density. The average energy density for cells with a configuration 1-4-7 is 18.7 w-hr./lb. and 3.20 w-hrs./in.³. For cells with a configuration 2-4-7, the average energy density is 19.1 w-hrs./lb. and 3.22 w-hrs./in.³. Since the remaining part of the program provides for the use of only tin mesh size, the

170 mesh tin was selected for future use. This selection is based on the marginally better performance observed in the cell configuration 1-4-7 and 2-4-7.

The 108 tests were designed factorially so that a significant number of tests would be limited by the anode capacity and others would be limited by the cathode capacity. Surveying the data given in Table 5, it is seen that the average anode and cathode efficiency are about 40%. Hence, one would expect the maximum energy density to be observed for cells having equal electrode capacities. Three conditions were tested in which equal anode and cathode capacities existed. Six tests were run for each of the three capacities and their average performance is shown in Table 6.

Table 6

Comparison of Cells Having Equal

Electrode Capacities

<u>Configuration</u>	<u>Energy Density (w-hrs./lb.)</u>
2-3-6	14.8
2-4-7	19.1
2-5-8	11.7

The combination of conditions 4-7 was selected to be used in further work since this combination yielded the highest cell energy density.

For cells having a 1.905 cm. diameter with an area 2.85 cm.² and operating at 25 ma/cm² at 25°C, the following combinations of parameters results in the highest energy densities.

- (1) Use of 170 mesh tin particles for the anode fabrication.
- (2) Use of 263 mg Sn at the anode.

(3) Use of 550 mg. HgF_2 containing 5% Ag powder at the cathode.

A typical cell will have an open circuit voltage of 1.2V and an initial load voltage of 1.05V. The cell will typically deliver power for 40 minutes to a cut-off voltage of 0.4V.

Throughout this program the tests have been equally divided to provide performance data at three electrolyte volumes, namely, 0.36, 0.72, and 1.44 cc's. These electrolyte volumes have been given the code numbers 9, 10, and 11 respectively. Six discharge tests were conducted at 74°C and an additional 6 cells were discharged at -54°C . Based on these tests the electrolyte volume that produces a cell with the highest energy density will be selected.

The cells were prepared and placed in the proper temperature environment along with a separate container of electrolyte from which the cell is activated. The temperature variation in all the tests was controlled to within $\pm 1^\circ\text{C}$. The cells to be discharged at the high temperature were allowed to heat soak for 30 minutes before activation. The cells used for the low temperature tests were allowed to soak for 1 hour before activation. A constant current of 25 ma/cm^2 was maintained on the cells throughout the tests. The physical and electrical data obtained from these cells are shown in Tables 7 and 8.

Table 7

Physical Data for Cells Discharged at 74°C and -54°C

T = 74°C

<u>Configuration</u>	<u>Anode Wt. (mg.)</u>	<u>Anode Screen Wt. (mg.)</u>	<u>Sn Wt. (mg.)</u>	<u>Cathode Wt. (mg.)</u>	<u>Cathode Screen Wt. (mg.)</u>	<u>HgF₂ Wt. (mg.)</u>	<u>Separator Wt. (mg.)</u>	<u>Cell Wt. (gm.)</u>	<u>Cell Thickness (ml.)</u>
2-4-7-11	330	83	247	626	97	539	42	0.989	28.0
"	333	82	251	627	99	528	42	0.999	22.5
2-4-7-10	331	84	247	629	95	534	42	0.995	29.5
"	342	83	260	634	92	542	39	1.014	28.0
2-4-7-9	341	85	256	625	92	533	41	1.000	29.0
"	331	86	245	626	101	526	41	0.999	26.0

T = -54°C

2-4-7-11	345	80	265	652	93	560	41	1.032	28.0
"	337	80	257	646	94	552	39	1.010	28.0
2-4-7-10	337	84	254	612	98	523	41	0.984	27.0
"	349	82	267	643	94	548	41	1.022	28.0
2-4-7-9	349	84	265	656	97	559	38	1.038	28.5
"	347	83	264	650	97	553	42	1.028	28.0

Table 8

Electrical Data for Cells Discharged at 74°C and -54°C

T = 74°C

<u>Configuration</u>	<u>O.C.V.</u> (V)	<u>Initial Load</u> <u>Voltage</u> (V)	<u>Time to</u> <u>0.4V</u> (min.)	<u>Anode</u> <u>Efficiency</u> (%)	<u>Cathode</u> <u>Efficiency</u> (%)	<u>W-h/lb.</u>	<u>W-h/in.³</u>
2-4-7-11	1.261	1.083	35.91	38.1	35.1	17.3	3.14
"	1.318	1.112	38.22	40.0	38.2	19.4	3.54
2-4-7-10	1.296	1.099	28.63	30.3	28.2	14.5	2.63
"	1.314	1.141	28.50	28.7	27.7	13.6	2.51
2-4-7-9	1.325	1.112	28.71	28.8	28.3	14.1	2.57
"	1.369	1.085	26.29	28.2	26.4	12.7	2.31

T = -54°C

2-4-7-11	1.211	1.004	28.00	27.6	27.7	12.9	2.37
"	1.212	1.010	22.39	22.8	22.5	10.0	1.79
2-4-7-10	1.203	1.029	24.15	24.9	25.6	10.5	1.83
"	1.222	1.026	27.87	27.4	28.2	13.0	2.36
2-4-7-9	1.221	1.016	21.91	24.9	25.0	9.6	1.78
"	1.230	1.028	18.75	18.6	18.8	6.2	1.66

The energy density values given in Table 8 does not consider the weight of the electrolyte. These numbers have been presented in this table in this fashion so as to maintain consistency with the previous data. However, since the goal of this part of the work is to select an electrolyte volume that yields the highest energy density cell, the energy densities have been calculated including the weight of the electrolyte. To make these calculations, the density of the electrolyte has been assumed to be 1 gm/cc.

Table 9
Cell Energy Density as a Function
of Electrolyte Volume

Cell Configuration 2-4-7

<u>Electrolyte Volume (cc)</u>	<u>Temp. (°C)</u>	<u>Energy Density (W-Hr/lb.)</u>	<u>Average Energy Density (W-Hr/lb.)</u>
1.44	75	7.2	7.0
		8.1	
	25	8.6	
		8.3	
	-54	5.5	
0.72	75	4.2	8.8
	25	8.5	
		8.1	
	-54	13.2	
0.36	75	9.1	9.9
		6.2	
	25	7.7	
		10.2	
	-54	9.3	
		15.1	
		10.9	
		7.1	
		6.7	

Even though somewhat shorter running times are observed for cells with the least electrolyte, the effect of the lower weight produces the highest energy density cells with the least electrolyte. Consequently, since the goal was to achieve the highest possible energy density, the 0.36 cc electrolyte volume has been selected for use in the remaining tests.

A telephone consultation was held with Dr. R. P. Clark, Contract Manager, at which time these results were discussed. The conclusions, as presented in this report, were accepted. These conclusions provide the basis for fabricating a cell with an optimum energy density. The remaining tests in this program will be conducted using 170 mesh tin, 263 milligrams of tin on the anode, 550 milligrams of mercuric fluoride on the cathode and 0.36 cc's of electrolyte.

PULSE CURRENT DISCHARGE TEST

A series of 30 cells were subjected to pulse discharge testing. The objective of this part of the study was to ascertain the ability for the HF cells to withstand various levels of pulse and current. Cells were constructed based on the results of the previous testing. The tests were conducted at 3 temperatures, i.e., -54°C , 25°C and 75°C . All the tests were performed in duplicate. Each of the 30 cells was discharged under a constant current of 25 ma/cm^2 . At the end of each 2 minute period, a current pulse of a proper intensity was applied to the cell for a period of 5 seconds. A record of the voltage vs. time was kept for each test. The construction parameters of each of these cells are given in Table 10 and their electrical performance is shown in Table 11.

Table 10

Construction Properties for the Pulse Test CellsCell Construction 2-4-7-9

<u>Cell Number</u>	<u>Anode Wt. (mg.)</u>	<u>Anode Screen Wt. (mg.)</u>	<u>Sn Wt. (mg.)</u>	<u>Cathode Wt. (mg.)</u>	<u>Cathode Screen Wt. (mg.)</u>	<u>HgF₂ Wt. (mg.)</u>	<u>Separator Wt. (mg.)</u>	<u>Cell Wt. (gm.)</u>	<u>Cell Thickness (ml.)</u>
1	337	87	250	658	96	561	44	1.038	29.0
2	340	84	258	632	92	540	32	1.007	26.5
3	349	81	268	633	93	540	38	1.016	28.0
4	321	82	239	637	98	539	33	0.993	28.5
5	342	86	256	658	102	556	40	1.036	29.0
6	335	87	248	640	98	542	40	1.011	28.5
7	356	85	267	657	98	559	38	1.046	29.0
8	354	87	267	631	96	535	43	1.022	29.0
9	333	84	249	655	99	556	39	1.024	27.5
10	358	89	270	642	102	540	37	1.031	28.5
11	340	87	253	659	98	561	39	1.038	28.0
12	315	82	232	648	98	550	38	1.000	28.0
13	329	89	240	634	98	536	43	0.963	29.5
14	339	84	255	645	98	547	39	1.022	28.5
15	345	74	270	636	88	548	33	1.013	28.0
16	341	87	254	638	97	541	40	1.011	28.0
17	326	84	242	658	96	562	41	1.021	30.5
18	314	84	230	622	96	526	41	0.994	27.5
19	357	84	273	658	102	556	43	1.043	30.5
20	340	86	254	632	93	539	41	1.008	28.0
21	325	86	240	651	95	556	42	1.015	28.0
22	348	85	263	658	97	561	41	1.040	28.0
23	330	81	249	649	104	545	41	1.013	28.5
24	338	83	256	642	95	547	41	1.017	26.0
25	331	80	251	614	94	520	42	0.983	29.5
26	357	87	272	663	101	562	40	1.055	29.5
27	361	88	273	643	100	543	45	1.034	30.0
28	351	85	265	650	96	554	43	1.039	28.5
29	350	88	262	651	96	555	41	1.040	29.0
30	340	84	256	657	99	558	44	1.034	28.5

Table 11

Electrical Properties of the Pulse Cells

Cell Number	Pulse Current (ma/cm ²)	Temp. (°C)	O.C.V. (V)	Initial Load Voltage (V)	Time to 0.4V (min.)	Anode Efficiency (%)	Cathode Efficiency (%)	W-h/lb.	W-h/in. ³
1	50	75	1.282	1.116	23.25	25.3	23.9	10.6	1.86
2	50	75	1.275	1.107	30.08	31.6	32.2	15.2	2.88
3	50	25	1.264	1.129	26.77	27.2	28.6	12.8	2.31
4	50	25	1.254	1.128	25.73	29.3	27.5	12.4	2.15
5	50	-54	1.212	1.073	30.87	32.9	32.1	13.6	2.42
6	50	-54	1.253	1.102	27.52	30.2	29.2	12.4	2.19
7	75	75	1.314	1.082	18.50	19.6	18.8	8.1	1.45
8	75	75	1.294	1.065	17.64	18.4	19.4	9.0	1.58
9	75	25	1.276	1.118	40.35	46.0	41.4	18.0	3.33
10	75	25	1.254	1.111	25.39	26.6	28.1	10.1	1.82
11	75	-54	1.253	1.073	31.47	35.2	31.9	12.2	2.26
12	75	-54	1.232	1.069	22.08	27.1	22.9	9.3	1.65
13	100	75	1.303	1.105	23.34	29.1	25.8	12.7	2.06
14	100	75	1.326	1.101	27.51	31.6	29.7	12.7	2.27
15	100	25	1.295	1.179	39.82	43.3	42.9	18.6	3.36
16	100	25	1.288	.992	34.58	40.7	37.8	14.1	2.51
17	100	-54	1.211	1.050	20.00	23.2	20.1	9.3	1.55
18	100	-54	1.231	1.083	19.33	24.6	21.6	9.6	1.74
19	200	75	1.365	1.033	20.88	26.7	26.3	8.5	1.45
20	200	75	1.278	1.084	20.08	26.8	27.3	10.2	1.82
21	200	25	1.273	1.110	30.00	41.7	36.2	13.5	2.43
22	200	25	1.286	1.072	29.55	37.6	35.4	12.6	2.33
23	200	-54	1.227	1.077	18.45	25.0	22.9	8.5	1.51
24	200	-54	1.222	1.085	16.30	21.5	20.2	8.2	1.60
25	300	75	1.353	1.103	12.50	18.8	18.2	6.5	1.08
26	300	75	1.354	1.089	16.08	22.6	23.1	8.1	1.45
27	300	25	1.285	1.129	26.59	37.0	37.4	13.1	2.26
28	300	25	1.288	1.114	33.44	47.6	45.8	14.1	2.56
29	300	-54	1.212	1.050	18.54	26.8	25.5	8.3	1.49
30	300	-54	1.244	1.084	20.58	30.5	28.1	9.3	1.69

The energy derived from cells experiencing pulsing is somewhat less than that obtained from cells that have not been pulsed. The general trend seems to exist relating the energy output to the pulsing current. At 300 ma/cm² pulse and 75°C, a significant performance decline is observed. Generally it appears that rather uniform performance can be obtained over a wide range of pulsing currents and a wide range of temperature.

DISCHARGE TEST AT SEVERAL CURRENTS

A series of cells were evaluated to determine the effect of current density on the cell energy density. 24 cells were constructed for this section of the study. The cells were discharged at 4 current densities and at 3 temperatures. Each test was conducted in duplicate. Tables 12 and 13 give the physical and electrical data obtained from each of the cells.

Table 12

Physical Characteristics of the Cells Discharged at Constant CurrentCell Configuration -- 2-4-7-9

<u>Cell Number</u>	<u>Anode Wt. (mg.)</u>	<u>Anode Screen Wt. (mg.)</u>	<u>Sn Wt. (mg.)</u>	<u>Cathode Wt. (mg.)</u>	<u>Cathode Screen Wt. (mg.)</u>	<u>HgF₂ Wt. (mg.)</u>	<u>Separator Wt. (mg.)</u>	<u>Cell Wt. (gm.)</u>	<u>Cell Thickness (ml.)</u>
1	329	81	248	640	95	545	34	1.007	28.0
2	339	84	255	653	98	555	32	1.023	28.5
3	338	80	258	631	95	536	33	1.001	28.5
4	348	83	265	644	100	545	34	1.026	26.5
5	323	82	241	648	93	551	35	1.002	27.0
6	335	81	255	641	93	547	32	1.008	26.5
7	350	84	266	650	97	553	36	1.036	27.5
8	349	83	266	645	91	554	32	1.046	27.0
9	351	85	266	653	97	556	34	1.038	28.0
10	342	84	258	654	91	563	39	1.035	28.0
11	350	83	276	657	99	558	34	1.051	28.5
12	341	84	257	636	95	541	38	1.015	28.5
13	336	88	248	658	98	560	41	1.035	28.5
14	356	85	271	642	92	550	39	1.037	28.0
15	330	82	248	644	90	554	40	1.014	28.5
16	337	84	252	654	96	558	41	1.032	28.5
17	350	83	266	652	97	555	36	1.038	29.0
18	349	83	267	644	92	551	40	1.030	28.5
19	326	80	247	637	89	548	39	1.002	27.5
20	345	84	261	641	92	549	34	1.021	28.5
21	342	80	262	656	94	562	39	1.038	28.5
22	346	87	259	667	96	560	41	1.052	28.5
23	352	82	270	647	98	549	36	1.035	27.5
24	337	81	256	650	97	553	36	1.023	28.0

Table 13

Electrical Performance for Cells at Various Constant Currents

Cell Number	Pulse Current (ma/cm ²)	Temp. (°C)	O.C.V. (V)	Initial Load Voltage (V)	Time to 0.4V (min.)	Anode Efficiency (%)	Cathode Efficiency (%)	W-h/lb.	W-h/in. ³
1	35	75	1.308	1.057	18.31	27.3	26.2	12.3	2.20
2	35	75	1.303	1.122	14.33	20.7	20.2	8.9	1.60
3	35	25	1.263	1.098	24.00	34.4	34.7	15.1	2.65
4	35	25	1.274	1.097	27.31	28.0	29.1	16.9	3.26
5	35	-54	1.158	1.050	18.93	29.0	26.9	12.1	2.24
6	35	-54	1.154	1.061	19.33	27.9	27.8	12.1	2.30
7	50	75	1.246	1.045	16.32	32.1	32.8	15.6	2.94
8	50	75	1.262	1.033	16.75	33.0	33.6	16.6	3.21
9	50	25	1.250	1.060	11.96	23.4	23.7	9.8	1.22
10	50	25	1.265	1.059	15.06	30.6	29.6	12.7	2.35
11	50	-54	1.214	1.008	9.72	18.4	19.3	8.5	1.56
12	50	-54	1.221	1.032	9.12	18.6	18.7	8.8	1.57
13	65	75	1.234	.983	8.20	22.6	21.2	9.1	1.65
14	65	75	1.308	1.031	9.79	24.6	25.8	10.9	2.01
15	65	25	1.250	1.013	7.17	19.8	18.7	8.4	1.49
16	65	25	1.231	1.036	6.78	18.1	17.3	7.8	1.41
17	65	-54	1.143	1.006	5.45	14.0	14.2	6.2	1.12
18	65	-54	1.222	1.019	8.43	21.6	22.1	10.0	1.81
19	80	75	1.245	.995	7.05	24.0	22.8	10.0	1.82
20	80	75	1.271	.962	9.76	31.5	31.8	12.9	2.30
21	80	25	1.223	1.012	5.50	17.2	17.4	7.5	1.36
22	80	25	1.254	.997	4.41	14.3	14.0	5.7	1.05
23	80	-54	1.124	.974	3.66	11.4	11.9	4.8	0.91
24	80	-54	1.182	.999	6.16	20.3	19.8	8.5	1.56

The average values from the above table have been calculated and are shown in Table 14. Table 14 shows how the energy density varies at different temperatures as the current density is changed.

Table 14

Energy Density as a Function of
Current Density & Temperature

Temp. (°C)	Energy Density - W/hrs/lb			
	35 ma/cm ²	50 ma/cm ²	65 ma/cm ²	80 ma/cm ²
75	10.6	16.1	10.0	11.5
25	16.0	11.3	8.1	6.6
-54	12.1	8.7	8.1	6.7

Scanning this table horizontally, the increased current densities does not seem to influence the energy output at 75°C. At 25°C and -54°C, there is a trend of decreasing energy output as the current density is increased. If the table is considered vertically, there is not a significant variation in output between 75°C and -54°C at the 35 ma/cm² current density. At the higher current densities the energy output tends to decrease as the temperature is decreased. The greatest difference in performance is observed between the high temperature and room temperature. The energy output between room temperature and -54°C appears relatively constant.

Appendix 1 graphically shows a number of typical discharge curves. These discharge curves have been selected to exemplify the data collected from the different aspects of the testing.

APPENDIX I
TYPICAL FIGURES

Figure 1 - HF Cell Discharge

100 min. capacity
0.36 cc electrolyte
25 mA/cm²
Temperature, 75°C

Figure 2 - HF Cell Discharge

100 min. capacity
0.36 cc electrolyte
25 mA/cm²
Temperature, 25°C

Figure 3 - HF Cell Discharge

100 min. capacity

0.36 cc electrolyte

25 mA/cm²

Temperature, -54°C

Figure 4 - HF Cell Discharge
at Various Current Densities

100 min. capacity
0.36 cc electrolyte
Temperature, 75°C

Figure 5 - HF Cell Discharge
at Various Current Densities

100 min. capacity
0.36 cc electrolyte
Temperature, 25°C

Figure 6 - HF Cell Discharge
at Various Current Densities

100 min. capacity
0.36 cc electrolyte
Temperature, -54°C

Temperature, -54°C
Pulse Current, 50 mA/cm^2 for
5 sec. every 2 min.
Constant Current, 25 mA/cm^2
2.5A min. cell capacity
0.36 cc electrolyte

Figure 9 - HF Cell Discharge
with Pulse

Figure 12 - HF Cell Discharge
with Pulse

Figure 13 - HF Cell Discharge
with Pulse

Figure 14 - HF Cell Discharge
with Pulse

Figure 15 - HF Cell Discharge
with Pulse

Figure 19 - HF Cell Discharge
with Pulse

Figure 20 - HF Cell Discharge
with Pulse