CECOM-TR-94-3

UNITED STATES ARMY ENVIRONMENTAL HYGIENE AGENCY

ABERDEEN PROVING GROUND, MD 21010

HAZARDOUS WASTE SPECIAL STUDY NO. 37-26-0310-84
EVALUATION OF MAGNESIUM BATTERIES
US ARMY COMMUNICATIONS-ELECTRONICS COMMAND
FORT MONMOUTH, NEW JERSEY
5 JANUARY - 6 JUNE 1983

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13. ABSTRACT (Maximum 200 words)

Magnesium batteries were analyzed to determine their hazardous waste characteristics under United States environmental regulations. The batteries were subjected to the hazardous waste criteria under 49 CFR 261 for ignitability, corrosivity, reactivity and toxicity. Extraction Procedure Toxicity (EP Tox) method was used to determine toxicity. Under these regulations and methods magnesium batteries are not listed as hazardous waste, nor were they found to have any characteristics identifying them as a hazardous waste.

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U. S. ARMY ENVIRONMENTAL HYGIENE AGENCY
ABERDEEN PROVING GROUND, MARYLAND 21010

Mr. Diem/jg/AUTOVON
584-2024

REPLY TO ATTENTION OF
HSHB-ES/WP

21 NOV 1983

SUBJECT: Hazardous Waste Special Study No. 37-26-0310-84, Evaluation of Magnesium Batteries, US Army Communications-Electronics Command, Fort Monmouth, New Jersey, 5 January - 6 June 1983

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and Readiness Command
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Alexandria, VA 22333

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2. Additional copies of this report are inclosed for mailing to HQDA (DAEN-ZCF-U), HQDA (DAEN-ZCE), and Commandant, Academy of Health Sciences (HSHA-IPM).

FOR THE COMMANDER:

NELSON H. LUND, P.E.
Colonel, MSC
Director, Environmental Quality

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as (20 cy)

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HQDA (DASG-PSP) wo incl
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DEPARTMENT OF THE ARMY
U. S. ARMY ENVIRONMENTAL HYGIENE AGENCY
ABERDEEN PROVING GROUND, MARYLAND 21010

REPLY TO ATTENTION OF
HSHB-ES/WP

EXECUTIVE SUMMARY
HAZARDOUS WASTE SPECIAL STUDY NO. 37-26-0310-84
EVALUATION OF MAGNESIUM BATTERIES
US ARMY COMMUNICATIONS-ELECTRONICS COMMAND
FORT MONMOUTH, NEW JERSEY
5 JANUARY - 6 JUNE 1983

1. PURPOSE. To evaluate the magnesium battery, BA 4386, for waste disposal characteristics under the requirements of the Resource Conservation and Recovery Act (RCRA), and to provide recommendations for disposal of these batteries based on analytical data.

2. ESSENTIAL FINDINGS. Magnesium batteries (BA 4386) are not RCRA hazardous wastes because:

a. They are not listed as hazardous waste.

b. They do not have characteristics of a hazardous waste.

3. MAJOR RECOMMENDATIONS.

a. Dispose of unused, unserviceable, or obsolete BA 4386 batteries in a permitted sanitary landfill at a rate not to exceed 1 percent by weight per day of the total quantity of refuse collected and buried, or seven batteries per ton of refuse. Ensure that batteries are disposed in the refuse at the working face of the landfill.

b. Incinerate batteries in a properly functioning municipal refuse incinerator after obtaining concurrence of the operating official for the incinerator. Burn at a rate not to exceed seven batteries per ton of refuse.

c. Contact state solid waste regulatory authorities to determine if special requirements apply for disposal of the BA 4386 batteries.

d. Avoid disposal with incompatible wastes such as might be found at a hazardous waste landfill.

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DEPARTMENT OF THE ARMY
U. S. ARMY ENVIRONMENTAL HYGIENE AGENCY
ABERDEEN PROVING GROUND, MARYLAND 21010

REPLY TO ATTENTION OF
HSHB-ES/WP

HAZARDOUS WASTE SPECIAL STUDY NO. 37-26-0310-83
EVALUATION OF MAGNESIUM BATTERIES
US ARMY COMMUNICATIONS-ELECTRONICS COMMAND
FORT MONMOUTH, NEW JERSEY
5 JANUARY - 6 JUNE 1983

1. AUTHORITY. Letter, DRSEL-SF-ME, US Army Communications-Electronics Command and Fort Monmouth, 29 September 1982, subject: Request Environmental Evaluation of Magnesium Battery, with indorsements thereto.

2. REFERENCES. See Appendix A for a listing of references.

3. PURPOSE. This special study was conducted to evaluate the magnesium battery, BA 4386, for waste disposal characteristics under the requirements of the Resource Conservation and Recovery Act (RCRA) and to provide recommendation for disposal of magnesium batteries based on analytical data.

4. GENERAL.

a. Personnel Contacted.

(1) Dr. Louis F. Soffer, Safety Office, US Army Communications-Electronics Command.

(2) Mr. Donald B. Wood, Power Sources Division, US Army Electronics Research and Development Command.

(3) Mr. David Friedman, Office of Solid Waste, United States Environmental Protection Agency (EPA), Washington, DC.

(4) Mr. Barrett Benson, National Enforcement Investigations Center, EPA, Denver, CO.

b. Protocol. See Appendix B for the background, study plan, and procedures.

5. FINDINGS AND DISCUSSION.

a. Background.

(1) The batteries studied were manufactured by the Marathon Battery Company of Waco, Texas, and the Ray-O-Vac Company of Madison, Wisconsin. Each battery contains 18 electrically connected cells. The study plan in the protocol implies that whole batteries were to be studied. The test matrix was used, but it was necessary to scale down the

size of samples because of the volume capacity of available equipment. The tests for characteristics of ignitability and Extraction Procedure (EP) toxicity were, therefore, performed on randomly selected cell pairs from randomly selected batteries. Single cells were used when testing for the characteristics of corrosivity and reactivity.

(2) A numbering sequence of cells was devised so that randomly selected cells could be paired for testing. Some of the numbered cells are shown in the data supporting this study. Figure 1 shows the sequence used.

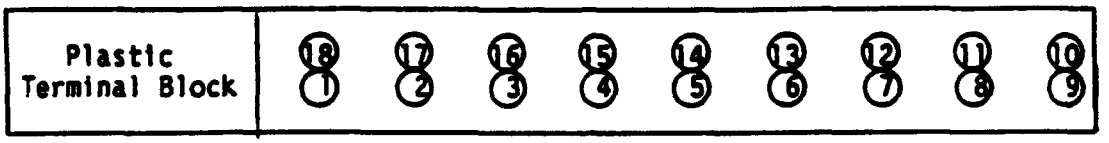

FIGURE 1. NUMBERING SEQUENCE OF BATTERY CELLS (TOP VIEW)

b. Characteristic of Ignitability.

(1) Hydrogen gas was generated, collected, and quantified. These data are shown on summary graphs in Figures 2 through 13.

(a) It was assumed that all the gas collected was hydrogen gas. No quantitative measurements on the purity of released hydrogen were made because appropriate analytical equipment was not available.

(b) Figures 2 through 13 show that some cell pairs were subjected to different temperature ranges during their reaction times. This was performed to simulate what might occur either in a cooling down landfill, or in one that was heating up through decomposition and decay or refuse. The figures illustrate the effects of heat in releasing more hydrogen than when the reaction occurs at room temperature. Not all landfills run hot. It takes weeks to months for a landfill to become hot. Technical literature (references 13 and 15, Appendix A) states that decomposition of waste can elevate a landfill temperature to approximately 40°C. The reaction temperature of 60°C was chosen for this study to simulate a very hot landfill, and parallels the temperature prescribed for the flashpoint test in 40 CFR 261.21(a)(1). The room temperature curves are considered valid for hydrogen release from cell decay in the early period of landfill burial. The generation rate shows that, within a few days, the curve has flattened out.

(c) Figure 7 is not considered valid or representative of hydrogen release. A procedural error caused the cell pairs to be initially exposed to 0.5 Normal acetic acid before the proper amount of water could be added to make the proper pH within the reaction flask. There was a very rapid and copious release of hydrogen. The reaction demonstrates the need to avoid disposal of batteries with incompatible wastes such as might be found at a hazardous waste landfill. The experiment was repeated, and results more consistent with other data are shown in curves A of Figures 5 and 6.

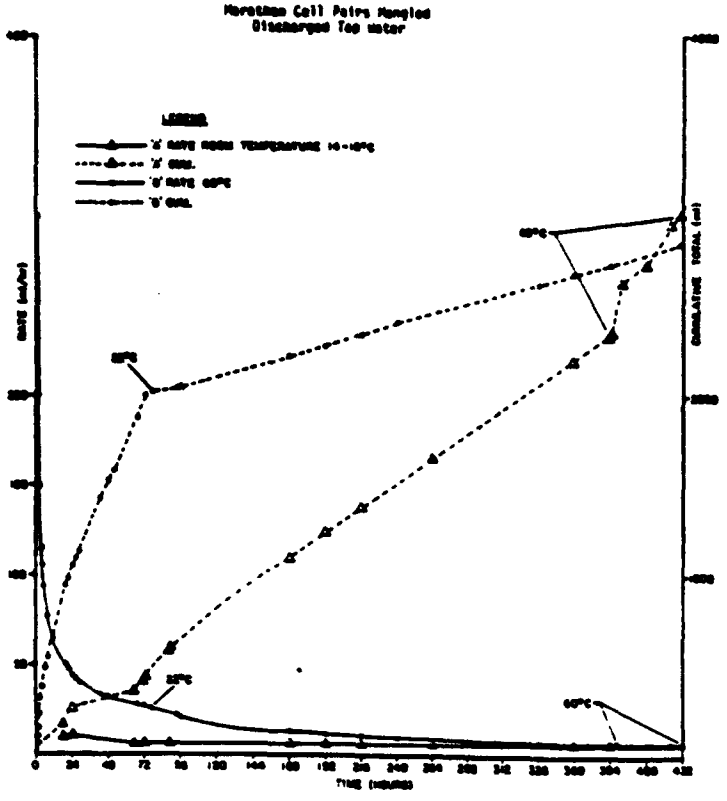

FIGURE 2. Summary of Hydrogen Release

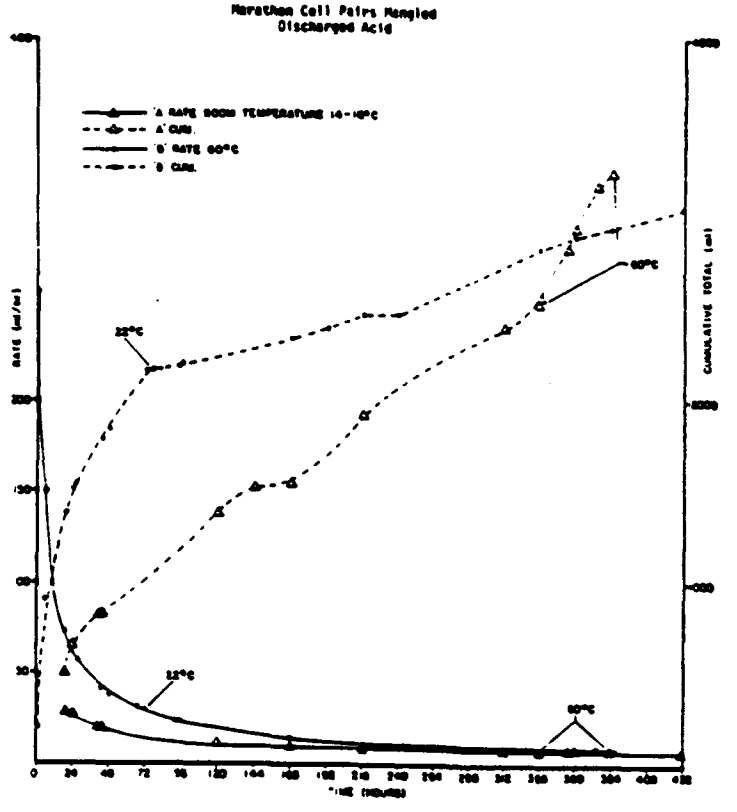

FIGURE 3. Summary of Hydrogen Release

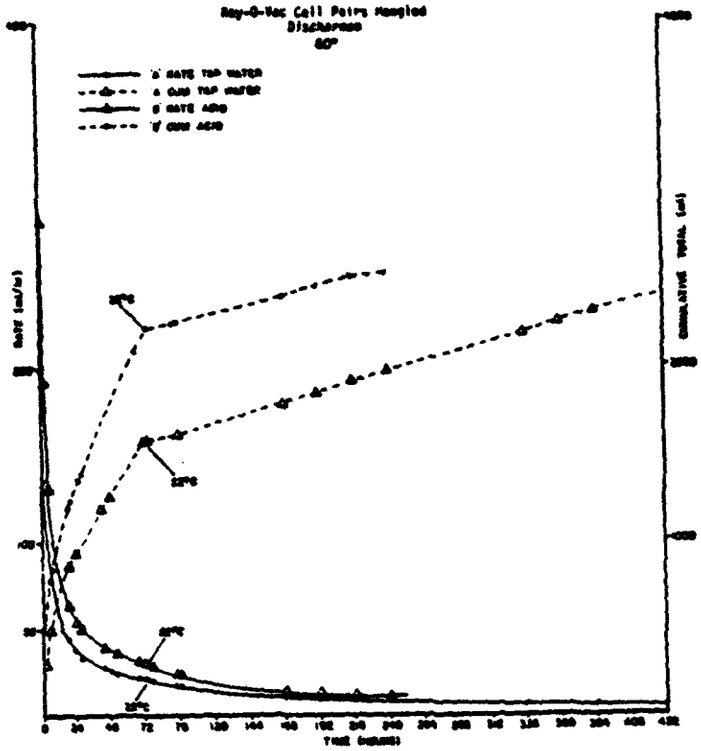

FIGURE 4. Summary of Hydrogen Release

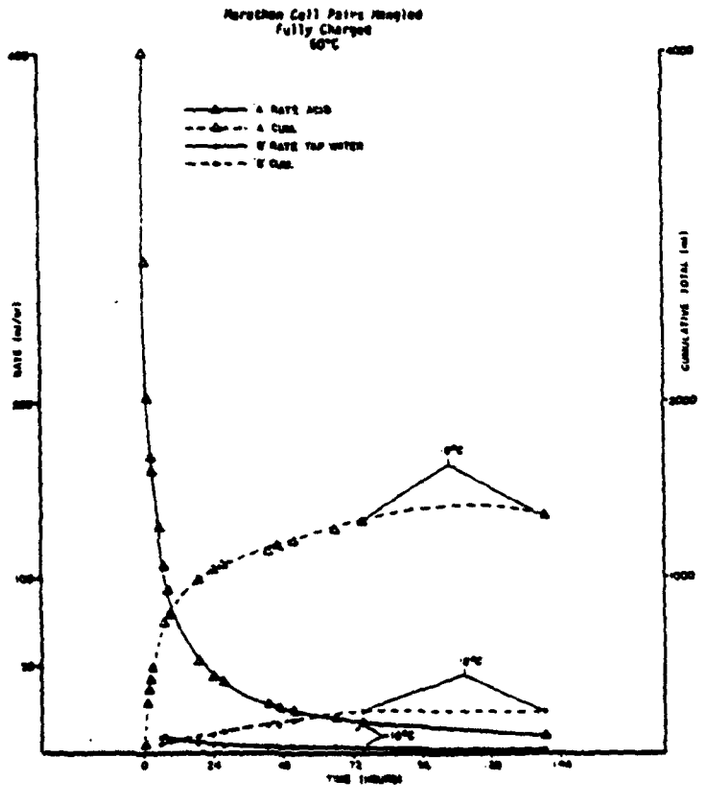

FIGURE 5. Summary of Hydrogen Release

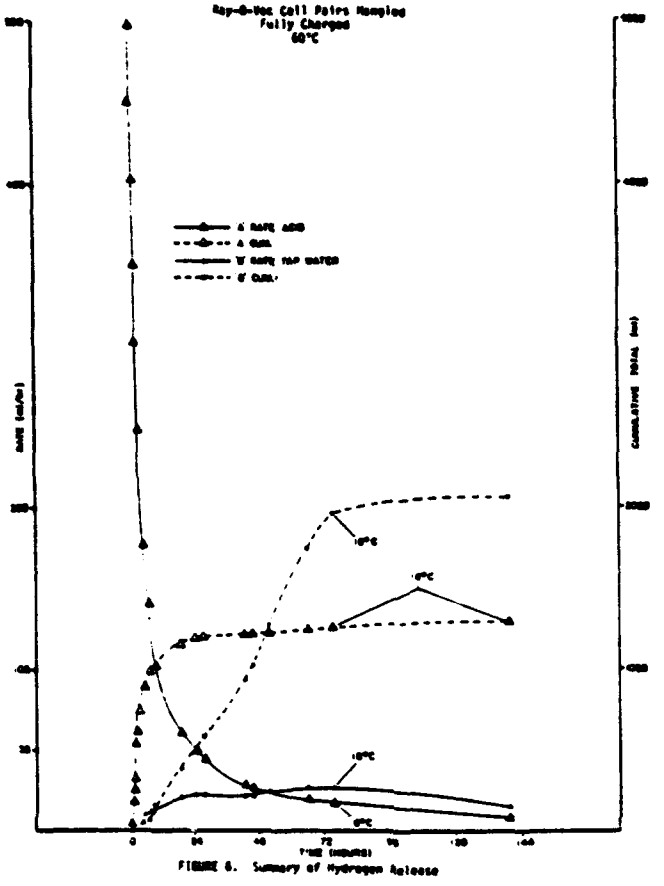

FIGURE 6. Summary of Hydrogen Release

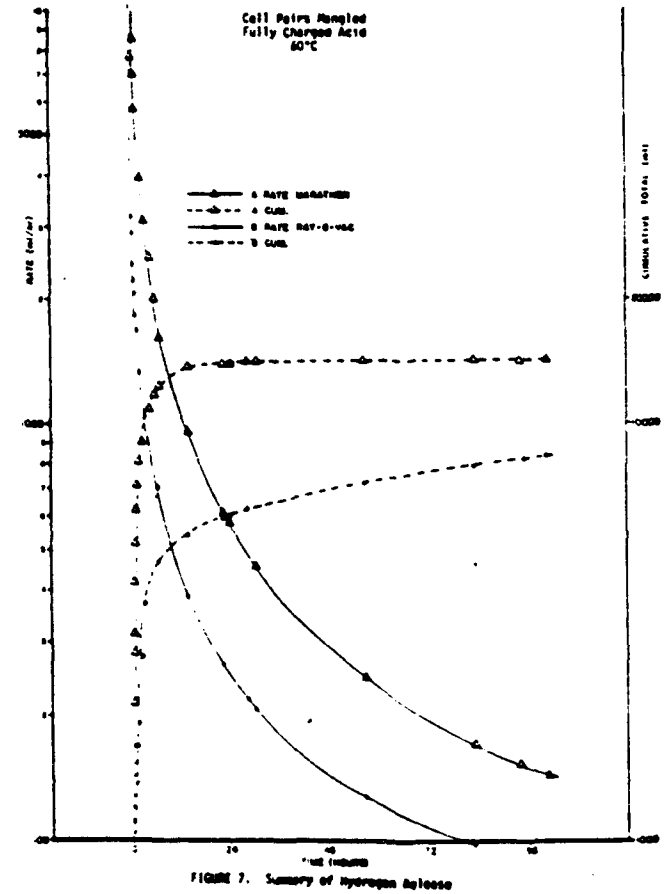

FIGURE 7. Summary of Hydrogen Release

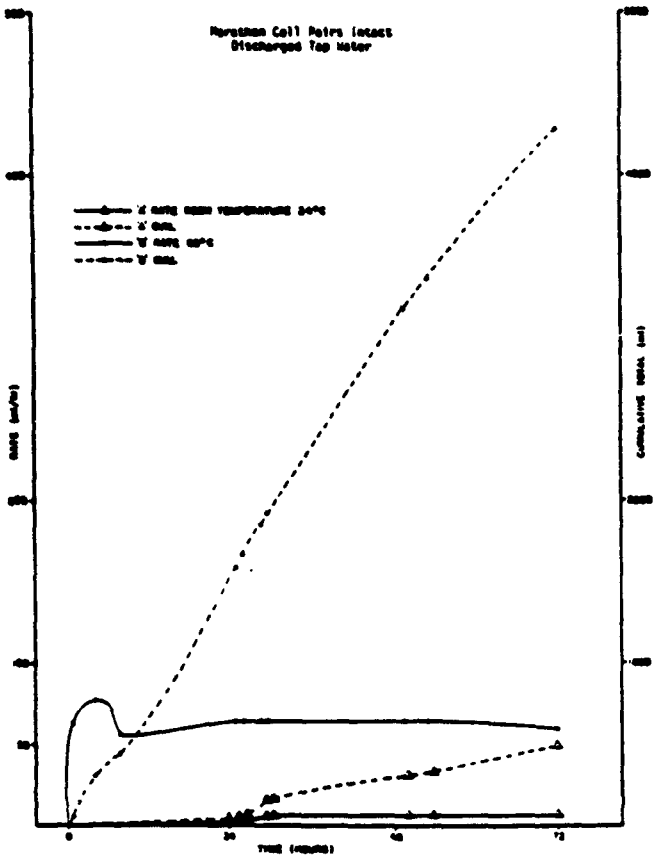

FIGURE 8. Summary of Hydrogen Release

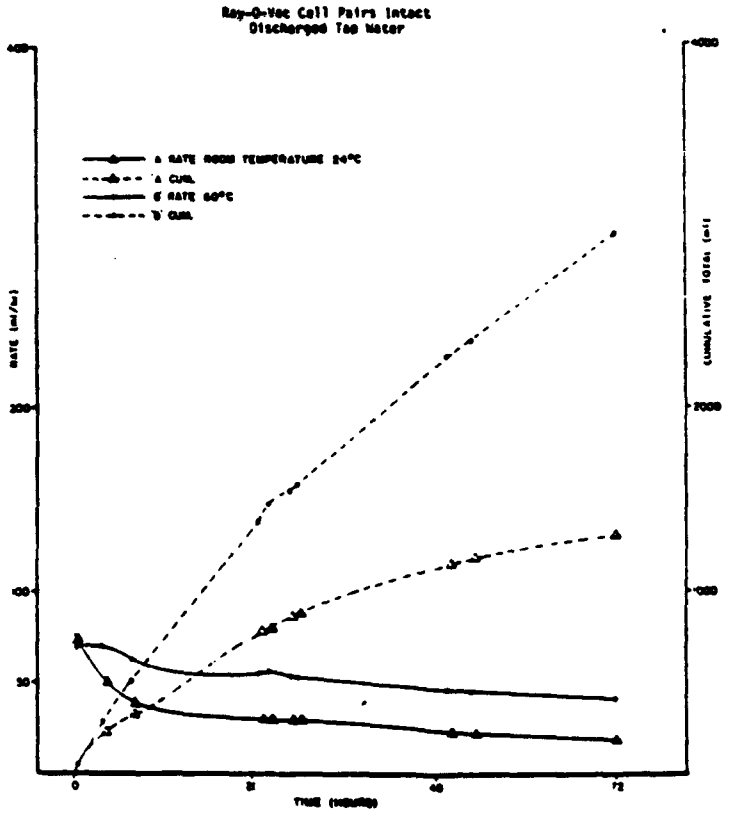

FIGURE 9. Summary of Hydrogen Release

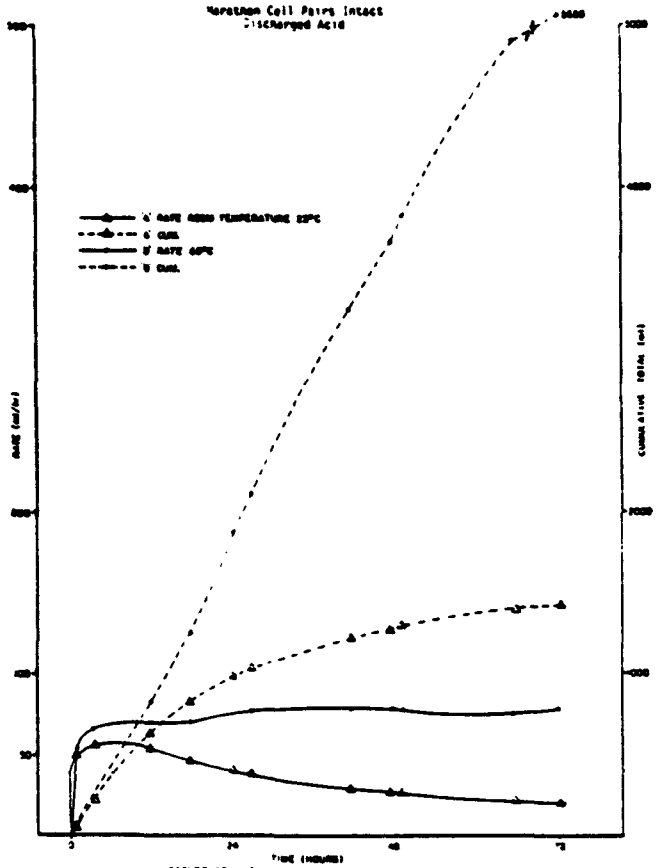

FIGURE 10. Summary of Hydrogen Release

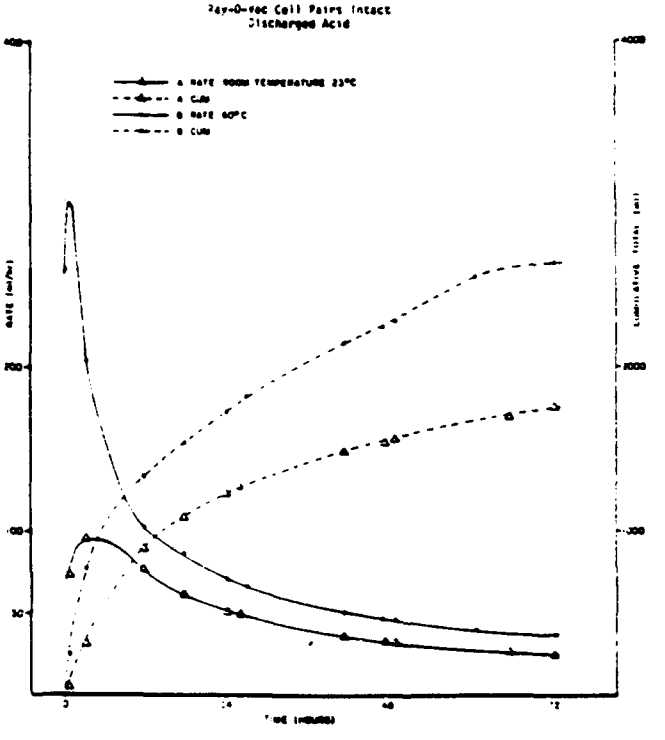

FIGURE 11. Summary of Hydrogen Release

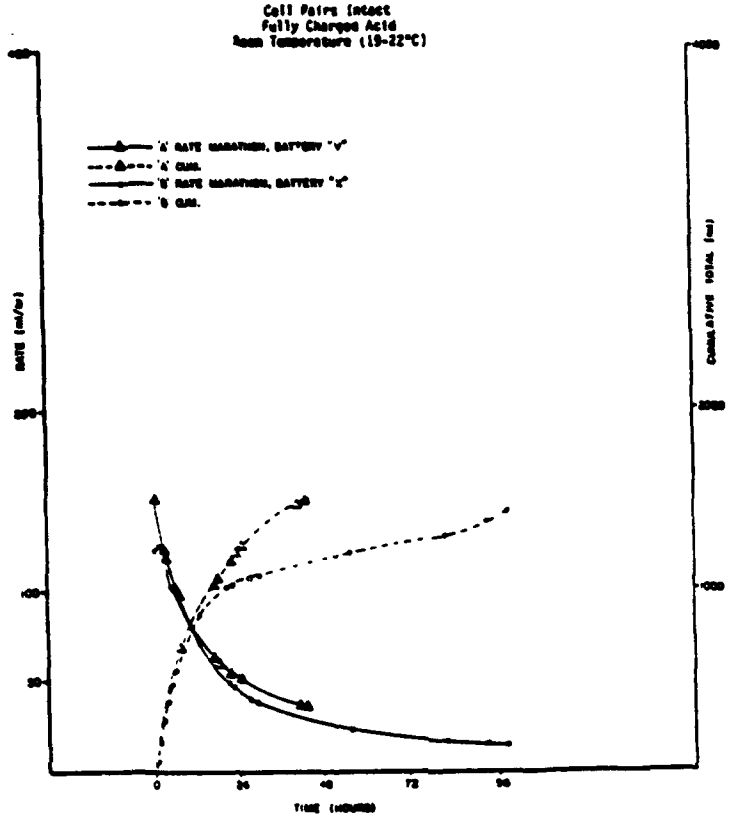

FIGURE 12. Summary of Hydrogen Release

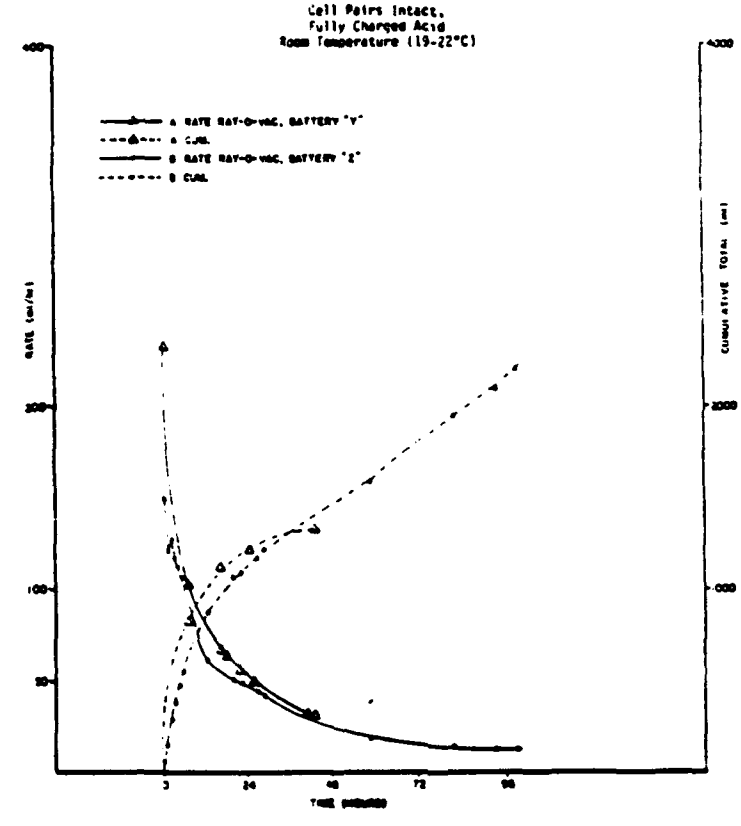

FIGURE 13. Summary of Hydrogen Release

(d) All hydrogen generation was conducted in an aquatic environment, either tap water or acidic water. This is a worst-case scenario. In a landfill, not all batteries will be wet to the extent that cells are constantly in contact with water or acid leachate. Therefore, in a real-world situation, the amount of hydrogen released is believed to be less than shown by the data from this study.

(e) Upon occasion the generated hydrogen gas was ignited to test for flammability. In one instance a 1000 mL graduated cylinder with 635 mL of collected gas was turned upright to allow the gas to rise and pass through a burning stick held at the mouth of the cylinder. There was a sudden loud pop accompanied by a 5-inch yellow flame. When 1220 mL was ignited from a 2-liter cylinder, the yellow flame was about 8 inches long. The estimated burn time in both cases was well under 0.5 second. In a real-world landfill situation, hydrogen would be released more slowly and over a longer period of time than in this empirical popping experiment. Hydrogen dissipates very rapidly in air, and it is unlikely that dangerous or explosive accumulations would build up in a landfill. For comparative purposes, Table 1 shows the limits of inflammability of hydrogen and nine other compounds that are sometimes discarded.

TABLE 1. LIMITS OF INFLAMMABILITY (percent of gas or vapor in air)

COMPOUND	EMPIRICAL FORMULA	LIMITS OF INFLAMMABILITY LOWER	UPPER
Hydrogen	H_2	4.00	74.20
Methane	CH_4	5.00	15.00
Propane	C_3H_8	2.12	9.35
Butane	C_4H_{10}	1.86	8.41
Benzene	C_6H_6	1.40	7.10
Turpentine	$C_{10}H_{16}$	0.80	-----
Ethyl alcohol	C_2H_6O	3.28	18.95
Acetic acid	$C_2H_4O_2$	5.40	-----
Acetone	C_3H_6O	2.55	12.80
Ammonia	NH_3	15.50	27.00

Source - CRC Handbook of Chemistry and Physics, 62d ed, 1981 - 1982.

(f) In the laboratory experiment some reaction flasks held intact cells and other flasks contained mangled cells. Mangling was performed in the laboratory using either a hammer or a hack saw to expose the cell case and its contents to the aquatic test environment. If buried in a landfill, mangling of a battery would be caused by compaction equipment. To better simulate landfill compaction conditions and illustrate the manual laboratory cell mangling, eight randomly selected batteries were compressed under the treads of a bulldozer.

- The bulldozer operator was experienced with landfill operations and drove over the batteries, using the same number of passes as would be used in a landfill. Some batteries were compacted against hard ground, others against soft soil. Batteries were promptly recovered and throughly examined for damage. Results are shown in Table 2. The percentage of cells remaining intact after simulated landfill compaction is 64 percent. Only 15 percent of the cells were broken. A cell with even a slight slit or visible crack was counted as being broken or mangled. The dented cells would equate to intact cells in the hydrogen generation reaction flasks.

- The notes in Table 2 state when warm spots developed. Some zones of the affected batteries were warm to the touch. Thermocouples were not available, but warm spots were not judged to exceed roughly 105 to 110°F. The warmth dissipated within 5 to 10 minutes. Temperatures were not considered warm enough to ignite dry paper refuse.

- Empirical results from this study suggest that compression of batteries during landfill compaction will not produce dead shorts sufficient to start or propogate a landfill fire. In a real-world scenario, dead shorts are not considered a serious problem to the environment.

(g) The method for calculating hydrogen release and relating it to methane production is shown in Appendix C. Similar calculations were made for various time intervals and for various physical battery conditions, states of charge, and manufacturers. These results are shown in Table 3. The rate of methane production reported in technical literature (reference 16, Appendix A) ranges from 1.38 to 2.2 cubic feet of methane per day per pound of ordinary refuse in a properly-operated landfill in current use. Values of hydrogen release (Table 3 and Figures 2 through 13) range from an average of 0.019 to 0.114 cubic foot per day per pound of battery, depending on the time interval calculated. The average of all tests was 0.07 cubic foot per day per pound of battery. Considering that the aqueous laboratory generation of hydrogen represents an across-the-board, worst-case scenario, the rate of hydrogen generation compares favorably (professional judgment of the authors) with the values reported for methane generation.

(h) A typical sanitary landfill that receives municipal or industrial refuse will contain many items that potentially can liberate various amounts of hydrogen gas. It is not realistic or prudent to assume that all worst-case actions will occur simultaneously. Hydrogen generation

TABLE 2. SIMULATED LANDFILL MANGLING TEST RESULTS

Contract Number	Manufacturer and Date	State of Charge	Substrate Density	Number of Cells Intact	Dented	Broken	Overall Condition	Notes
DAAB 07-810 6512	Ray-O-Vac 0981	Discharged	Hard	5	8	5	- Cells moderately corroded. - Battery twisted apart between cells 3-4 and 15-16.	- Terminal wires attached to tabs. - Terminal plastic block twisted and crushed.
DAAB 07-810 6511	Marathon 0981	Discharged	Soft	8	1	9	- Cells heavily. corroded. - Battery twisted apart lengthwise at midline.	- Terminal wires attached to tabs. - Terminal plastic block slightly bent and twisted.
DAAB 07-820 G029	Marathon 1182	Discharged	Soft	18	0	0	- Cells heavily corroded. - Battery intact; exterior cardboard scarred.	- Warm spot among 2-3 cells. - Terminal wires detached from plastic terminal. - Could dead short.
DAAB 07-810 6511	Marathon 0982	Discharged	Hard	9	9	0	- Cells not corroded. - Cells 1-9 dented; cells 10-18 intact.	- Terminal wires attached to tabs. Warm spot. - Terminal plastic block slightly bent and twisted.
DAAB 07 810 6511	Marathon 0882	Fully Charged	Hard	14	3	1	- Five cells slightly corroded. - Battery split in half between cells 5-6 and 13 14.	- Red terminal wire detached from plastic terminal. No short circuit. - Terminal plastic block bent.
DAAB 07 810 6512	Ray O Vac 0782	Fully Charged	Hard	Battery not recovered				
DAAB 07 820 G029	Marathon 1082	Fully Charged	Soft	17	1	0	- Two cells very slightly corroded. - Battery split in half between cells 5-6 and 13-14.	- Red terminal wire separated from terminal. - No dead short situation - Terminal plastic block not bent, broken, or twisted.
DAAB 07 820 G030	Ray O Vac 1082	Fully Charged	Soft	10	4	4	- Three cells slightly corroded. - Battery intact; exterior cardboard abraded and plastic wrap was ripped.	- Warm spot. - Terminal wires attached to tabs. - Terminal plastic block was cracked, broken and twisted.
Average				11.6	3.7	2.7		
Percentage				64	21	15		

TABLE 3. CALCULATION OF HYDROGEN RELEASE*

Battery Conditions†	24 Hours Cell Pair (mL)	24 Hours 7 Batteries (L)	24 Hours 7 Batteries (ft³)	48 Hours Cell Pair (mL)	48 Hours 7 Batteries (L)	48 Hours 7 Batteries (ft³)	72 Hours Cell Pair (mL)	72 Hours 7 Batteries (L)	72 Hours 7 Batteries (ft³)	96 Hours Cell Pair (mL)	96 Hours 7 Batteries (L)	96 Hours 7 Batteries (ft³)	144 Hours (6 days) Cell Pair (mL)	144 Hours (6 days) 7 Batteries (L)	144 Hours (6 days) 7 Batteries (ft³)	336 Hours (14 days) Cell Pair (mL)	336 Hours (14 days) 7 Batteries (L)	336 Hours (14 days) 7 Batteries (ft³)	Figure No.
M m d t r	260	16.4	0.58	320	20.2	0.71	400	25.2	0.89	640	40.3	1.42	960	60.5	2.13	2060	129.8	4.58	2A
M m d t b	1060	66.8	2.36	1530	96.4	3.40	2000	126.0	4.45	2060‡	129.8	4.50	2180‡	135.7	4.80	2630‡	165.7	5.85	2B
M m d a r	650	40.9	1.44	860	54.2	1.91	1000	63.0	2.22	1180	74.3	2.62	1520	95.8	3.38	2530	159.4	5.63	3A
M m d a b	1500	94.5	3.34	1840	115.9	4.09	2160	136.1	4.80	2200‡	138.6	4.80	2700‡	163.6	5.97	2840‡	178.9	6.32	3B
M m d t b	915	57.6	2.03	1250	78.8	2.78	1570	98.9	3.49	1620‡	102.1	3.60	1720‡	108.4	3.82	2100‡	132.3	4.60	4A
B m d a b	1300	81.9	2.89	1770	111.5	3.93	2200	138.6	4.89	2260‡	142.4	5.00	2360‡	148.7	5.25	NM§	--	--	4B
M m c a b	1040	65.5	2.31	1180	74.3	2.62	1300	81.9	2.89	1330	83.8	2.96	1360‡	85.7	3.02	NM	--	--	5A
M m c t b	110	6.9	0.24	165	10.4	0.37	230	14.5	0.51	235‡	14.8	0.52	235‡	14.8	0.52	NM	--	--	5B
M m c a b	1180	74.3	2.62	1220	76.9	2.71	1250	78.7	2.78	1260‡	79.4	2.80	1290‡	81.3	2.87	NM	--	--	6A
M m c t b	510	32.1	1.13	1100	69.3	2.45	1800	116.4	4.10	2025‡	127.6	4.50	2080‡	131.0	4.63	NM	--	--	6B
M m c a b	13930	877.6	31.00	14025	883.6	31.20	14250	897.8	31.70	14400	907.2	32.00	NM	--	--	NM	--	--	7A
M m c a b	6000	378.0	13.30	6950	437.9	15.50	7625	480.4	16.96	8300	522.9	18.50	NM	--	--	NM	--	--	7B
M i d t r	45	2.8	0.10	300	18.9	0.67	490	30.9	1.09	NM	--	-	NM	--	--	NM	--	--	8A
M i d t b	1500	94.5	3.34	3090	194.7	6.87	4280	269.6	9.52	NM	--	-	NM	--	--	NM	--	--	8B
M i d t r	740	46.6	1.64	1130	71.2	2.51	1310	82.5	2.91	NM	--		NM	--	--	NM	--	--	9A
M i d t b	1330	83.8	2.96	2225	140.2	4.95	2950	185.8	6.56	NM		-	NM	--	--	NM	--	-	9B
M i d a r	970	61.1	2.16	1280	80.6	2.85	1420	89.5	3.16	NM		-	NM	--	--	NM	-	--	10A
M i d a b	1825	115.0	4.06	3600	221.8	8.10	5650	355.9	12.56	NM			NM		--	NM		--	10B
M i d a r	1220	76.9	2.71	1550	97.6	3.45	1750	110.2	3.89	NM			NM		--	NM		-	11A
M i d a b	1610	101.3	3.60	2250	141.7	5.00	2635	166.0	5.86	NM			NM		--	NM		-	11B
M i c a r	1250	78.7	2.78	1520	95.8	3.38	NM			NM			NM		--	NM	--		12A
M i c a r	1050	66.1	2.33	1160	73.1	2.58	1260	79.4	2.80	1400	88.2	3.11	NM		--	NM	-		12B
M i c a r	1210	76.2	2.69	1300	81.9	2.89	NM		-	NM	--	-	NM		--	NM	--	-	13A
M i c a r	1110	69.9	2.47	1480	93.2	3.29	1760	110.9	3.91	2150	135.4	4.78	NM	--	--	NM		--	13B
Totals	[illegible]			32560			37495			38360			15965	1006	35.5	12250	771.7	27.2	
No. Cell Pairs	22			22			20			12			10			5			
Averages	1022	64.38	2.27	1480	93.24	3.29	1705	110.12	4.11	1530	96.39	3.4	1597	100.6	3.55	2450	154.35	5.45	
Average ft³ release/day/lb of Battery			0.114			0.082			0.069			0.042			0.025			0.019	

* Appendix C shows example of calculation method

† Legend for symbols used

M - Marathon	B - Bag-O-Vac	m - mangled	c - charged	d - discharged
b - heated (60°C)	r - room temperature (16-24°C)	t - tap water in reaction vessel	a - acid (acetic) in reaction vessel	i - intact

‡ Temperature after 72 hours was 18°-22°C.

§ NM - not measured

‖ Data do not include atypical results in Figures 7A and 7B, basic report

rates in the orders of magnitude reported in the data from this study would probably not be capable of measurement as gaseous emissions from a landfill, nor are they judged to pose a substantial hazard to human health or the environment.

(2) Individual battery cells were tested to determine if they are oxidizers that display an oxidation-reduction reaction. Results are similar to the reaction of a cell and water and, therefore, are reported in paragraph 5d(2) under the topic of characteristic of reactivity.

c. Characteristic of Corrosivity. Cell cases along with their cathode mix were mixed with an equal weight of distilled water and then stirred. The pH readings ranged from 7.2 to 10.0, with pH 9.5 as the most common value. The pH of the cells is well within regulatory limits.

d. Characteristic of Reactivity.

(1) Mangled and intact individual cells were placed in beakers of tap water and distilled water. Observations included a few bubbles of gas (presumably hydrogen) collecting on the cells and rising to the water surface. There was no visible distinction between the reaction of cells in tap water or distilled water. The cells do not form potentially explosive mixture with water [40 CFR 261.23(a)(3)]. When mixed with water, the cells do not generate toxic gases, vapors, or fumes in a quantity sufficient to present a danger to human health or the environment [40 CFR 261.23(a)(4)].

(2) Cells representing all parameters of the test matrix were tested for oxidation-reduction reactions. Cells and cell contents were mixed with 10-percent sodium sulfite at room temperature (20 to 22°C). Most temperatures remained constant. Reaction tests were observed for approximately 4 hours before being terminated. One cell was minimally exothermic, causing a 5-degree temperature rise to 25°C. No off-gases or fumes could be detected by eye or nose; the few bubbles seen were assumed to be hydrogen gas. Excess sodium sulfite in the form of 10 grams of dry material was added to each beaker. No additional reaction was apparent.

e. Characteristic of EP Toxicity.

(1) Extractions were performed on 76 individual cells (38 cell pairs) randomly selected to represent the entire test matrix. The raw data are presented in Appendix D. Consolidated EP toxicity values are shown in Table 4.

(2) The regulatory threshold for lead is exceeded in two cell pairs from Marathon intact discharged batteries, two cells pairs from Ray-O-Vac intact discharged batteries, and one cell pair from Ray-O-Vac intact charged battery. Results for chromium represent hexavalent chromium. The regulatory threshold for chromium is exceeded in two cell pairs from Ray-O-Vac mangled discharged batteries and two cell pairs from Marathon mangled charged batteries. No regulatory thresholds for other heavy metals are exceeded.

TABLE 4. CONSOLIDATED EP TOXICITY VALUES (expressed as mg/L)

Parameter	Cell Condition	Marathon Range	Marathon Number of Cell Pairs*	Marathon Average	Ray-O-Vac Range	Ray-O-Vac Number of Cell Pairs*	Ray-O-Vac Average	Both Manufacturers Range	Both Manufacturers Number of Cell Pairs*	Both Manufacturers Average	Threshold Limits for EP Toxicity
Arsenic	Intact and mangled; fully charged and duty cycle discharged	<0.5 all values	11	<0.5	<0.5 all values	12	<0.5	<0.5	23	<0.5	5.0
Barium	do	<10-22	19	11.06	<10-12.2	19	10.18	<10-22	38	10.62	100.0
Cadmium	do	<0.1 all values	19	<0.1	<0.1 all values	19	<0.1	<0.1	38	<0.1	1.0
Chromium	do	<0.5-10.8	19	2.02	<0.5-8.24	19	2.55	<0.5-10.8	38	2.28	5.0
Lead	do	<0.5-17.8	19	2.64	1.0-9.95	19	1.77	<0.5-17.8	38	2.20	5.0
Mercury	do	<0.02 all values	8	<0.02	<0.02 all values	8	<0.02	<0.02	16	<0.02	0.2
Selenium	do	<0.1 all values	11	<0.1	<0.1 all values	12	<0.1	<0.1	23	<0.1	1.0
Silver	do	<0.5 all values	19	<0.5	<0.5 all values	19	<0.5	<0.5	38	<0.5	5.0

* A cell pair represents two cells randomly selected from an 18-cell battery.

(3) All cells of the tested cell pairs were subjected to the structural integrity procedure. All cells maintained their integrity. The magnesium alloy cell wall is strong enough to pass this test. It was not necessary, therefore, to mangle cells for extraction, but mangling was performed to provide a more complete set of data and to simulate a worst-case landfill situation. Under test conditions representing extraordinary disposal scenarios, it is possible for some cells to exceed the Federal regulatory threshold criteria.

(4) The over-threshold lead values may be explained either by the solder used to attach wires to the top of cells, or by the presence of terneplate. The Condensed Chemical Dictionary (10th ed) defines terneplate as a "lead-tin alloy used for coating iron or steel; its composition is approximately 75 percent lead and 25 percent tin." Military specification MIL-B-55252A(EL), Batteries, Magnesium, Dry, 12 April 1971, does not explain the reference made to terneplate. It is also not known why lead values of mangled cells fall below the regulatory threshold.

(5) The chromium values that exceed threshold limits could be explained by the presence of soluble lithium chromate as a component of the electrolyte. It is not known why chromium values of some mangled cell pairs fall within regulatory limits. Intact cells retain their structural integrity throughout the extraction process and thus prevent most contact between the electrolyte and extraction fluid. This is a likely explanation for finding chromium values within limits for intact cells.

(6) Table 4 shows that the averaged data fall easily within regulatory limits for lead and chromium. It is valid to look at the large picture in the discipline of waste disposal. The landfill should be viewed in the aggregate rather than only as separate or distinct disposal episodes, any one of which may occasionally exceed a threshold limit. An over-threshold value within a very few milligrams per liter are levels too low to be detected and attributed to batteries if leachate from a sanitary landfill were analyzed (reference 22, Appendix A).

f. Flame Test.

(1) Procedure. Cell remains from the hydrogen gas-generating experiments were placed in beakers and allowed to air dry. Then all components of cell pairs were placed in a stainless steel tray and subjected to direct flame from a propane torch. This procedure was repeated with approximately 17 different cell pairs. The experiment was conducted outdoors. The average composition of a new magnesium alloy cell wall (the anode) is shown in Table 5 (reference 17, Appendix A). The magnesium composition of cells subjected to the flame test is lower than shown in Table 5 because of corrosion and chemical reactions that released hydrogen.

TABLE 5. COMPOSITION OF MAGNESIUM ALLOY

Element	Percent
Magnesium	96.478
Aluminum	2.0
Zinc	1.2
Manganese	0.15
Calcium	0.17
Impurity: iron	0.001
Impurity: nickel	0.001

(2) Results. It was very difficult to ignite the cell carcasses. There were frequent magnesium flickers, glows, or pops that readily extinguished themselves. It often required between 20 and 180 seconds of continuous exposure to the torch to obtain a sustained burn. The duration of sustained, self-supporting magnesium fires ranged from 5 seconds to 8 minutes, with an average of about 1.5 minutes. Flame size ranged from a mere glow to 2 inches high, with the average at about one-fourth of an inch. Fire did not propogate to adjacent cells unless the latter had been preheated by the torch nearly to the same extent as was the burning carcass. Wind and manual turning aided the burning to completion of only a few cells. The powdery remains of electrolyte were not involved in the fires. Only one cell disintegrated with explosive force. It had been a fully charged, intact cell and had been in a reaction vessel with acidic water at room temperature for 4 days. Overall, this empirical testing suggested strongly that buried cells would not endanger a landfill, are not easily ignited, and would not sustain or advance the propogation of a potential landfill fire. Violent eruption of cells under some conditions is possible, and a properly functioning municipal refuse incinerator would be the only reasonable choice of disposal method if landfilling was not allowed.

6. CONCLUSIONS.

a. Magnesium batteries (BA 4386) (NSN 6135-00-926-8322) are not RCRA hazardous wastes because:

(1) They are not listed as hazardous waste.

(2) They do not have characteristics of a hazardous waste.

(a) These batteries are considered a special industrial type of solid waste that does not exhibit the RCRA characteristic of ignitability. The rate of gas generation under tested conditions averaged 0.07 cubic foot of hydrogen per day per pound of battery. This compares favorably with values reported in the technical literature of 1.38 to 2.2 cubic feet of methane per day per pound of ordinary refuse.

(b) Batteries do not exhibit the RCRA characteristic of corrosivity. The pH of the cells are within RCRA limits.

(c) Batteries do not exhibit the RCRA characteristic of reactivity. The cells show no oxidation-reduction reaction.

(d) Batteries do not exhibit the RCRA characteristic of EP toxicity. Average data from cells of randomly selected batteries are not toxic by EPA's criteria for EP toxicity testing. All other EP toxicity data were consistently near or below detection limits under all tested conditions.

(e) Cell carcasses will burn sporadically if subjected to high enough temperatures for sufficient time. They do not burn well enough to endanger a landfill or propogate a potential landfill fire.

b. Acceptable disposal methods are:

(1) Landfill. Because of the comparatively limited release of hydrogen gas, disposal of batteries must be limited to 1 percent by weight per day of the total quantity of refuse collected and buried. This rate equates to seven batteries per ton of refuse.

(a) The magnesium alloy casing of battery cells subjected to simulated long-term landfill conditions will not initiate, contribute to, or propogate a potential landfill fire.

(b) Battery cells will spontaneously generate heat when electrically or mechanically dead-shorted. This heating is not believed sufficient to ignite surrounding combustible materials, but may cause either skin burns or the rupture of cell contents.

(2) Incineration.

(a) Batteries may be mixed with refuse at the rate of 1 percent of the total waste load and burned in a properly functioning municipal refuse incinerator with the knowledge and concurrence of the operating official for the incinerator.

(b) Incineration in equipment other than a municipal refuse incinerator is potentially dangerous. Battery cells will violently break apart if subjected to intense heat or flame for several minutes.

c. Under Federal standards, the batteries require disposal as a non-hazardous solid waste. State disposal requirements may differ from or be more stringent than the Federal requirements used in this report. These batteries may be classified as a special or industrial type of solid waste by various state waste management regulations. Coordination with state waste disposal authorities is needed.

7. RECOMMENDATIONS. The following recommendations are based on good environmental practice.

a. In the absence of specific state or local requirements, dispose of used, unserviceable, or obsolete BA 4386 batteries as a nonhazardous solid waste.

(1) Dispose in a permitted sanitary landfill at a rate not to exceed 1 percent by weight per day of the total quantity of refuse collected and buried. This rate is equivalent to seven batteries per ton of refuse. Ensure that batteries are dispersed in the refuse at the working face of the landfill.

(2) Incinerate batteries in a properly functioning municipal refuse incinerator after obtaining concurrence of the operating official for the incinerator. Burn at a rate not to exceed seven batteries per ton of refuse.

(3) Contact state solid waste regulatory authorities to determine if special requirements apply for disposal of the BA 4386 batteries.

b. Return all used or unserviceable batteries from field training exercises to the home installation for disposal action. Do not dispose of the batteries in the field during field exercises.

c. Dispose of large accumulations of BA 4386 batteries (over approximately 200 batteries) by commercial contract if the recommended disposal rate (1 percent of the refuse rate per day) is impracticable. Obtain assistance from the servicing Defense Property Disposal Office or Defense Property Disposal Region if needed.

d. Avoid disposal with incompatible wastes such as might be found at a hazardous waste landfill.

8. TECHNICAL ASSISTANCE. Informal technical advice and/or consultation regarding this report may be obtained by contacting the Chief, Waste Disposal Engineering Division, this Agency (AUTOVON 584-3651, Commerical 301-671-3651). Requests for services should be directed through appropriate command channels of the requesting activity to Commander, US Army Environmental Hygiene Agency, ATTN: HSHB-ES, Aberdeen Proving Ground, MD 21010, with an information copy furnished to the Commander, US Army Health Services Command, ATTN: HSPA-P, Fort Sam Houston, TX 78234.

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APPENDIX A

REFERENCES

1. AR 200-1, Environmental Protection and Enhancement, 15 June 1982.

2. Public Law (PL) 94-580, Resource Conservation and Recovery Act of 1976, 21 October 19876, as amended by PL 96-482, Solid Waste Disposal Act Amendments of 1980, 21 October 1980.

3. Title 40, Code of Federal Regulations (CFR), Part 122, EPA Administered Permit Programs: the National Pollutant Discharge Elimination System; the Hazardous Waste Permit Program; and the Underground Injection Control Program, as amended by 48 Federal Register (FR) 14228, 1 April 1983.

4. Title 40, CFR, 1982 rev, Part 241, Guidelines for the Land Disposal of Solid Wastes.

5. Title 40, CFR, 1982 rev, Part 257, Criteria for Classification of Solid Waste Disposal Facilities and Practices.

6. Title 40, CFR, 1982 rev, Part 260, Hazardous Waste Management System: General.

7. Title 40, CFR, 1982 rev, Part 261, Identification and Listing of Hazardous Waste.

8. Title 40, CFR, 1982 rev, Part 262, Standards Applicable to Generators of Hazardous Waste.

9. Title 40, CFR, 1982 rev, Part 264, Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities.

10. Title 40, CFR, 1982 rev, Part 265, Interim Status Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities.

11. EPA publication number EPA-600/2-80-018, Samplers and Sampling Procedures for Hazardous Waste Streams, January 1980.

12. EPA publication number SW-846, Test Methods for the Evaluation of Solid Waste, Physical/Chemical Methods, May 1980, with Technical Updates.

13. EPA publication number EPA-600/9-76-004, Gas and Leachate from Landfills: Formation, Collection and Treatment, March 1976.

14. EPA publication number EPA-625/6-82-006, Handbook for Remedial Action at Waste Disposal Sites, June 1982.

15. Hazardous Materials Control Research Institute, Papers from the National Conference on Management of Uncontrolled Hazardous Waste Sites, 29 November - 1 December 1982.

16. Principles of Land Waste Disposal, a paper by Dennis G. Fenn, undated.

17. Wood, Donald., Chapter 4: Magnesium Batteries. From Batteries, Volume 1, Karl Kordesch (editor), Marcel Dekker (publisher), 1974.

18. Letter, Ray-O-Vac Division, ESB Corp., 24 August 1982, subject: Magnesium Battery BA 4386 Disposal.

19. Letter, Marathon Battery Co., 3 September 1982, subject: Magnesium Battery BA-4386 Disposal.

20. FONECON, between Mr. Jim Poppity, EPA, Washington, DC, and Mr. David Rosak, this Agency, 7 October 1982, subject: RCRA Status of a Hydrogen-Producing Waste.

21. FONECON, between Mr. David Friedman, EPA, Washington, DC, and Mr. Michael Diem, this Agency, 31 May 83, subject: Magnesium Batteries - Technical Discussion.

22. FONECON, between Mr. Barrett Benson, EPA, Denver, CO, and Mr. Michael Diem, this Agency, 1 June 1983, subject: Magnesium Batteries - EPA Enforcement Views on Disposal.

APPENDIX B

PROTOCOL

DEPARTMENT OF THE ARMY
U. S. ARMY ENVIRONMENTAL HYGIENE AGENCY
ABERDEEN PROVING GROUND, MARYLAND 21010

REPLY TO ATTENTION OF

HSHB-ES-T

5 Jan 83

PROTOCOL
HAZARDOUS WASTE SPECIAL STUDY NO. 39-26-0310-83
US ARMY COMMUNICATIONS - ELECTRONICS COMMAND
FORT MONMOUTH, NEW JERSEY

1. AUTHORITY.

a. AR 40-5, Health and Environment,25 September 1974.

b. Letter, DRSEL-SF-ME, US Army Communications-Electronics Command and Fort Monmouth, 29 September 1982, with indorsement thereto.

2. REFERENCES. See Appendix A.

3. PURPOSE.

a. To evaluate the Magnesium Battery, BA 4386, for waste disposal characteristics under 40 CFR 261.

b. To provide recommendations for disposal of Magnesium Batteries based on analytical data.

4. BACKGROUND.

a. The BA 4368 magnesium battery is assigned the following National Stock Number and nomemclature: NSN 6135-00-926-8322 Battery, Dry BA 4386/PRC-25. It is used to power the PRC-25 radio and PRC-77 transceiver. The Army purchases approximately 60,000 of these batteries per month. They are produced by two different manufacturers: Marathon Battery Company, (Waco, TX) and Ray-O-Vac Div of ESB Inc. (Madison, WI). Each producer uses identical power-producing components, but the manufacturing process is not governed by a military standard or military specification. The batteries have been in the military services for several years and have a world-wide distribution.

b. The batteries are classified as hazardous in the Defense Hazardous Materials Information System (HMIS). The HMIS states that batteries should not be incinerated, but should be disposed of according to local, state, and Federal regulations in an approved site for toxic materials. To date, no physical testing on production batteries is known. Therefore, CECOM has prepared a message directing that magnesium batteries be reported to the Defense Property Disposal Office for disposal, and recommends use of either a secure chemical landfill or a hazardous waste landfill.

c. Conflicting opinions regarding the hazardous nature of waste batteries are held by the two manufacturers and by EPA. Ray-O-Vac hired a laboratory to analyze waste magnesium battery dry cell batteries (ref m, App A). The laboratory concluded, in their April 1981 tests, that the release of some hydrogen gas from cells in an

acid environment may favor considering the waste as reactive under the EPA hazardous waste criteria. The laboratory found that the leachable heavy metals were below the EPA regulatory threshold. Their tests showed that the wastes are not corrosive and they further concluded, based on statements rather than measurement, that the wastes are not ignitable. Analyses were made on production line wastes rather than on batteries for Army use. Ray-O-Vac's 1979 Material Safety Data Sheet (MSDS) recommends disposal in a toxic materials landfill site.

d. Marathon Battery Company determined by stoichiometry that the BA 4386 battery is nonhazardous (ref n, App A). The calculations were made in August 1982 and are concerned only with barium and chromium (40 CFR 261.24). That company uses a Texas-approved landfill to dispose of magnesium cells that are rejected during the manufacturing process. Marathon's undated MSDS says a normal landfill may be used for disposal.

e. This Agency sought clarification from EPA on how to classify wastes that potentially release hydrogen gas. Specifically, hydrogen-releasing wastes do not easily fit the regulatory criteria [40 CFR 261.23(a)] of a Reactive waste, as Ray-O-Vac contends it might be; or of an Ignitable waste [40 CFR 261.21(a)]. EPA said (ref o, App A) that such wastes possess the characteristic of Ignitability under 40 CFR 261.21(a)(2). The wastes would therefore have the EPA Hazardous Waste Number of D001.

f. CECOM is seeking, through this study, an independent evaluation of the BA 4386 and an interpretation of the best way to manage unserviceable batteries that are available for use by the Army.

(1) Unserviceable batteries can be fully charged, fully discharged, or have various amounts of charge remaining in them, such as when they have operated radios/transceivers. Expired shelf life, withdrawal from use, obsolescence, or impairment of the connectors are ways by which a fully charged battery would require disposal. Quantities of fully charged batteries may potentially vary from Depot stocks (considered a rare possibility) to sporadic individual batteries located at scattered military installations (the more likely situation). Spent or depleted batteries from normal use will likely be the source of most waste batteries for disposal. It is assumed that at least 90 percent of the waste batteries (between 45,000 and 54,000 batteries per month for another year or two) will be generated by many military installations throughout the world. Generation rates will vary depending on the number of soldiers at the installations and their training or operational missions. No precise or maximum generation rate from any particular installation can be quantified at this time.

(2) Present disposal instructions advise reporting items to the Defense Property Disposal Office for disposal. Discarding into trasn is not recommended.

(3) This Agency does not know if there are large accumulations of batteries in any given place waiting for ultimate disposal action. This study will attempt to demonstrate potential dangers and possible environmental harm from a worst-case scenario, such as loss of physical integrity from handling or compaction. The study will also attempt to provide background data to serve as a basis for loading rates to a sanitary landfill, if that disposal method is defensible.

5. PERSONNEL.

a. Mr. Michael H. Diem, Waste Disposal Engineering Division, Environmental Scientist, GS-12, Project Officer.

b. Mr. David A. Rosak, Waste Disposal Engr Div, Environmental Scientist, GS-13.

6. STUDY PLAN.

a. Sampling. There is a need to collect and test an adequately sized, representative sample of issued batteries. Two sampling choices are available. One is regular surveillance sampling where one or two samples are taken. The other choice, and the one this Agency has selected to use, is sampling for regulatory purposes. This method [40 CFR 260.22(h)] requires that at least four samples be taken over a period of time sufficient to represent the variability or uniformity of the waste. This condition is met by virtue of the manufacturers' sending to CECOM representative samples of each lot for quality control testing and CECOM's providing randomly selected batteries to USAEHA for evaluation. This Agency has received from CECOM 32 fully charged batteries randomly chosen from manufacturing runs during two distinct months in 1982. Half were made by Ray-O-Vac and half by Marathon. Similarly, this Agency has received 32 depleted batteries some of which were made in 1981 and others in 1982, by both manufacturers. CECOM believes this selection adequately represents the variability or uniformity of the waste batteries.

b. Generator Responsibility. Hazardous waste regulations published by EPA (40 CFR 261.3 and 262.11) and by most States require generators to determine whether or not their wastes require management and disposal as hazardous wastes. A waste might be a hazardous waste if it is listed in Subpart D of 40 CFR 261. Regardless of the state of charge, magnesium batteries are not listed in Subpart D. Therefore Subpart D does not pertain and will not be further considered in this study. A hazardous waste determination is required if the waste exhibits any characteristic in Subpart C of 40 CFR 261. Determination of which characteristic is exhibited can be made by knowledge, testing, or both [40 CFR 262.11(c)]. Interpretations have been made that the batteries exhibit one or more hazardous waste characteristics, as discussed in paragraphs 4c and 4e above.

c. Waste Characteristics. In Subpart C to 40 CFR 261, EPA describes four characteristics of a potentially hazardous waste. They are the characteristics of Ignitability, Corrosivity, Reactivity, and EP Toxicity. Testing shall be performed by USAEHA for each characteristic, and shall follow methodology described in SW-846 (ref 1, App A) to the maximum possible extent. Preparing the sample for testing may require some modification based on the physical make-up of the battery and its cells. However, a randomly selected number of cells within each battery will be used to assure a representative sample and to meet minimum weight or size requirements for particular tests. Cells will be cut, crushed, mangled, or an appropriate combination of these to simulate a worst case handling/disposal condition (see para 4f(3) above). Some cells will be subjected to the structural integrity test and other cells will be tested intact to provide a comparison of data between various handling/disposal conditions. Selection of cells from

batteries will be based on the table of random numbers shown in reference k, Appendix A, a copy of which is attached to this protocol as Appendix B. It should be noted, however, that this Agency will not be able to identify, by chemical analysis, classes of exotic compounds that may or may not be produced. Where appropriate, known chemistry reactions will be used academically to show that certain classes of compounds cannot or do not exist.

d. Test Matrix. Parameters will include all contractors, physical battery conditions, and states of charge. The following chart depicts the Matrix:

Ray-O-Vac		Mallory	
Charged (off the shelf, fully charged)		Charged	
intact	: 4 batteries	intact	: 4
mangled	: "	mangled	: 4
dead short	:+4 "	dead short	:+ 4
	12 charged batteries		12 charged batteries
Discharged (by CECOM, using standard protocol for depletion thru simulated duty cycle)		Discharged	
intact	: 4	intact	: 4
mangled	: 4	mangled	: 4
dead short	: +8	dead short	: +8
	16 batteries		16 batteries

e. Storage. Prior to testing, fully charged batteries will be stored on the shelf in ambient room temperatures. These batteries are designed to have a long shelf life. Depleted batteries were stored in a freezer from the time they were removed from the duty-cycle discharge regime (Oct-Nov 1982) until they are subjected to testing procedures. Frozen storage prevents further deterioration from a non-functional inhibition system within the battery. The frozen state was maintained during transportation by placing batteries in a well-insulated cooler chest in an unheated automobile trunk.

f. Ignitability Characteristic. Methodology in SW-846 is descriptive prose and reads as shown in 40 CFR 261.21. Testing by USAEHA (see Appendix C) shall attempt to generate and quantify the collection of hydrogen gas to verify 40 CFR 261.21(a)(2), as interpreted by EPA (see para 4e above). In addition, we shall subject a battery cross section to strong reducing agents (e.g., sodium sulfite, sodium thiosulfate, oxalic acid) to test the possibility of the battery being an oxidizer, as described in 40 CFR 261.21(a)(4). The generation of heat would be a product of a strong oxidation-reduction reaction; this heat production is not anticipated. Other tests for ignitability do not apply as the batteries are not liquid [40 CFR 261.21(a)(1)] and not compressed gas [40 CFR 261.21(a)(3)].

g. Corrosivity Characteristic. The pH of the cathode mix in various cells will be measured using standard methodology described in SW-846 (Electrometric Method).

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See Appendix D. Results will be compared to criteria in 40 CFR 261.22(a)(1). Corrosivity against steel is not a pertinent procedure and will not be tested because the batteries are not a liquid waste.

h. Reactivity Characteristic. Methodology in SW-846 is descriptive prose and reads as shown in 40 CFR 261.23. USAEHA will empirically test and record observations on reactions between a mangled battery and water [40 CFR 261.23(a)(3) and 261.23(a)(4)]. Results may be related to those obtained when testing for Ignitability. Knowledge of the magnesium battery chemical composition and of field experience precludes reactivity characteristics as listed in 40 CFR 261.23(a)(1),(2),(5),(6),(7), and (8); therefore, these properties of reactivity will not be further considered in this study. See Appendix E for text of 40 CFR 261.23.

i. EP Toxicity Characteristic. Methodology in both SW-846 and Appendix II to 40 CFR 261 will be used. See Appendix F. The Structural Integrity Procedure is part of the test. The extracts will be prepared in the Waste Disposal Engineering Division laboratory. Analysis of the extracts will be performed for the 8 hazardous metals by atomic absorbtion and/or inductively coupled plasma emission spectrometry equipment in the Chemistry Divisions at USAEHA, using normal quality control procedures commonly employed in testing for hazardous waste streams. Data on the eight heavy metals in 40 CFR 261.24 will be recorded. EP toxicity testing for the four insecticides and two herbicides will not be performed because they are not ingredients in the batteries.

j. Reaction vessels. Clean glassware shall be used to the maximum possible extent.

k. General considerations. For several of the test procedures described in this study plan, there are no recognized, standard, EPA-adopted analytical methods. The tests described are based on knowledge of chemistry, experience in RCRA hazardous waste practices, available literature, and familiarity with the batteries. The tests for Ignitability and Reactivity represent state-of-the-art best judgments for testing whether or not the wastes truly exhibit the characteristics. Experience with performing these procedures, some of which are empirical, may warrant modifying the procedure described in this protocol. Modifications will be made as needed to obtain defensible results, and the final methodology will be described in the Agency's final report.

7. AREAS OF RESPONSIBILITY.

a. CECOM.

(1) Select batteries using random sampling methods.

(2) Provide batteries for testing by USAEHA.

(3) Discharge batteries using standard protocol for simulated duty cycle. Freeze discharged batteries.

b. USAEHA.

(1) Provide equipment for sampling and testing batteries and cells.

(2) Perform analysis and record data.

(3) Establish liaison with and maintain communication with regulatory agencies.

(4) Provide written report to CECOM Safety Office.

8. RESOURCES REQUIRED.

a. Personnel. Two civilians 14 days - 28 man days.

b. Transportation. Local travel, as needed, to Ft Monmouth.

c. Financial.

(1) Per Diem - none.

(2) POV mileage - estimated $100.00.

9. MILESTONS.

a. Draft Protocol Completion: 15 December 1982.

b. USAEHA - CECOM meeting: 20 December 1982.

c. Final protocol completion: 7 January 1983.

d. Results: 29 April 1983.

e. Report: 31 May 1983.

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Appendix A

REFERENCES.

a. AR 200-1, Environmental Protection and Enhancement, 15 June 1982

b. Public Law (PL) 94-580, Resource Conservation and Recovery Act of 1976, 21 October 1976, as amended by PL 96-482, Solid Waste Disposal Act Amendments of 1980, 21 October 1980.

c. Title 40, Code of Federal Regulations (CFR), 1981 rev., Part 122, EPA Administered Permit Programs: The National Pollutant Discharge Elimination System; the Hazardous Waste Permit Program; and the Underground Injection Control Program.

d. Title 40, CFR, 1981 rev., Part 241, Guidelines for the Land Disposal of Solid Wastes.

e. Title 40, CFR, 1981 rev., Part 257, Criteria for Classification of Solid Waste Disposal Facilities and Practices.

f. Title 40, CFR, 1981 rev., Part 260, Hazardous Waste Management System: General.

g. Title 40, CFR, 1981 rev., Part 261, Identification and Listing of Hazardous Waste, as amended by 46 Federal Register (FR) 47429, 25 September 1981.

h. Title 40, CFR, 1981 rev., Part 262, Standards Applicable to Generators of Hazardous Waste.

i. Title 40, CFR, 1981 rev., Part 264, Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities.

j. Title 40, CFR, 1981 rev., Part 265, Interim Status Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities.

k. USEPA publication number EPA-600/2-80-018, Samplers and Sampling Proceedures for Hazardous Waste Streams, January 1980.

l. USEPA publication number SW-846, Test Methods for the Evaluation of Solid Waste, Physical/Chemical Methods, May 1980, with Technical Updates.

m. Letter, Ray-O-Vac Division, ESB Corp., 24 August 1982, subject: Magnesium Battery BA 4386 Disposal.

n. Letter, Marathon Battery Co., 3 September 1982, subject: Magnesium Battery BA-4368 Disposal.

o. FONECON, between Mr. Jim Poppity, Headquarters USEPA, and Mr. David Rosak, this Agency, 7 October 1982, subject: RCRA Status of a Hydrogen-Producing Waste.

APPENDIX B

RANDOM SAMPLING*

Random Numbers

03	47	43	73	86	36	96	47	36	61	46	98	63	71	62
97	74	24	67	62	42	81	14	57	20	42	53	32	37	32
16	76	62	27	66	56	50	26	71	07	32	90	79	78	53
12	56	85	99	26	96	96	68	27	31	05	03	72	93	15
55	59	56	35	64	38	54	82	46	22	31	62	43	09	90
16	22	77	94	39	49	54	43	54	82	17	37	93	23	78
84	42	17	53	31	57	24	55	06	88	77	04	74	47	67
63	01	63	78	59	16	95	55	67	19	98	10	50	71	75
33	21	12	34	29	78	64	56	07	82	52	42	07	44	38
57	60	86	32	44	09	47	27	96	54	49	17	46	09	62
18	18	07	92	46	44	17	16	58	09	79	83	86	19	62
26	62	38	97	75	84	16	07	44	99	83	11	46	32	24
23	42	40	64	74	82	97	77	77	81	07	45	32	14	08
52	36	28	19	95	50	92	26	11	97	00	56	76	31	38
37	85	94	35	12	83	39	50	08	30	42	34	07	96	88
70	29	17	12	13	40	33	20	38	26	13	89	51	03	74
56	62	18	37	35	96	83	50	87	75	97	12	25	93	47
99	49	57	22	77	88	42	95	45	72	16	64	36	16	00
16	08	15	04	72	33	27	14	34	09	45	59	34	68	49
31	16	93	32	43	50	27	89	87	19	20	15	37	00	49

HOW TO USE THE TABLE OF RANDOM NUMBERS:

1. Based on available information, segregate the containers (i.e., drums, sacks, etc.) according to waste types.
2. Number the containers containing the same waste types consecutively, starting from 01.
3. Decide on how many samples you wish to take. This number is usually determined by the objective of the sampling. For regular surveillance sampling, the collection of one or two samples is usually adequate. In this case, random sampling is not necessary. But for regulatory or research purposes, more samples (such as one sample for every group of five containers) taken at random will generate more statistically valid data. Hence if there were 20 drums containing the same type of waste, 5 drums have to be sampled.
4. Using the set of random numbers above, choose any number as a starting point.
5. From this number, go down the column, then to the next column to the right, or go in any predetermined direction until you have selected five numbers between 01 and 20, with no repetitions. Larger numbers are ineligible.

   Example: If you were to choose 19 as the starting point on column four, the next eligible numbers as you go down this column are 12 and 04. So far you have chosen only three

* Source: EPA publication number EPA-600/2-80-018, Samplers and Sampling Procedures for Hazardous Waste Streams, January 1980.

eligible numbers. Proceed to the next column to the right. Going down and starting from the top of this column, the next eligible numbers are 12 and 13. But 12 is already chosen. Proceeding to the sixth column, the next eligible number is 16. Your five random numbers, therefore, are 19, 12, 04, 13 and 16. Thus the drums with corresponding numbers have to be sampled.

APPENDIX C

GUIDELINE FOR GENERATION AND MEASUREMENT OF HYDROGEN GAS FROM MAGNESIUM BATTERIES

1. PURPOSE. This guideline will be used for generating and measuring hydrogen gas from BA 4368 magnesium batteries to determine their hazardous characteristics.

2. SCOPE. This guideline applies to BA 4368 magnesium battery, NSN 6135-00-926-8322 being produced by Marathon Company (Waco, TX) and Ray-O-Vac Division of ESB, Inc. (Madison, WI). It is not intended to apply to other Army batteries, although the general principles involved may pertain.

3. GENERAL PROCEDURE.

a. Landfill Simulation Test

(1) Intact and mangled batteries on a charged and uncharged basis will be exposed to cold tap water in a closed flask connected by appropriate tubing to an inverted graduated cylinder partially or completely filled with tap water.

(2) As the hydrogen is being generated, it will be carried over into the graduated cylinder and displace the water. The volume of hydrogen collected will correlate to the volume of water displaced.

(3) The reaction will be conducted over a 24 hour time interval.

(4) A more quantitative measurement on the purity of generated hydrogen gas may be instituted using either hydrogen detector tubes or a hydrogen meter, if appropriate tubes and/or meter can be successfully calibrated.

(5) Applying basic laboratory safety practices, attempts to ignite the generated hydrogen gas will be made and results recorded.

b. Worst Case Simulation Test

(1) Steps 3a(1) through 3a(5) will be repeated using a pH 5 acetic acid solution.

(2) If deemed necessary, other matrix modifications will be incorporated, such as warm water and/or the use of catalysts.

4. VARIATIONS TO PROCEDURE. This guideline is the projected procedure based on the chemical makeup of the batteries. Other variations may be incorporated, if necessary, after experimenting with the batteries. This statement is based on this Agency having no prior experience with the batteries plus not knowing the possible internal reactions of the chemicals once they are intimately crushed and mixed.

APPENDIX C

CALCULATIONS FOR HYDROGEN GENERATION
(Using a Tested Sample)

2 cells (mangled discharged)(Marathon) (acid)(room temp 16°C) — 14 days

2538 mL $H_2\uparrow$ measured
X 9 cell pairs
22,840 mL/battery in 14 days
X 7 batteries
159,880 mL = 159.8 liters of $H_2\uparrow$ gas

Conversion: liters X 0.0353 = cubic feet
Calculation 159.8 L X 0.0353 = 5.64 ft^3 $H_2\uparrow$ in 14 days from 7 batteries

2 cells (mangled discharged)(Marathon) (tap water)(room temp 16°C) — 14 days

2347 mL
X 9
21,123 mL/battery
X 7
147,861 = 147.8 liters $H_2\uparrow$

Landfill gas: Methane (CH_4) = 55% CO_2 45% (Source: pg 10, reference 16, Appendix A)
Actual (research and tests) = 2.5 - 4.0 ft^3 gas per pound of waste X 55%

= 1.375 - 2.2 ft^3 CH_4 per pound of waste

Comparative calculation:
5.64 ft^3 $H_2\uparrow$ in 14 days from 7 batteries
5.64 ft^3 ÷ 14 days = 0.40 ft^3 H_2 released per day from 7 batteries
0.40 ft^3 ÷ 20 lb per 7 batteries* = 0.02 ft^3 $H_2\uparrow$ released per day per pound of battery

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* Battery weights:
unused fully charged batteries average 1255.46 grams (= 2.7 lb)
used duty cycle discharged batteries average 1185.26 grams (= 2.6 lb)
1% of a ton = 20 lb = 7 batteries

NOTE: $H_2\uparrow$ = hydrogen gas

APPENDIX D

EP TOXICITY TEST _TS

Contract Number	Battery Maker & Date	Cell No.*	Condition†	Weight 2 Cells (grams)	pH filtered extract	Pb	Cr	Corrosion Observed at Cell Surface Before Extraction	As	Ba	Cd	Hg	Se	Ag
Not Recorded	M0881	5/6	In-Dis	110	6.9	<0.50	0.853	heavy	<0.5	22.0	<0.1	NT	<0.1	<0.5
DAAB07-81-D-6512	R0881	13/1	In-Dis	101	7.0	<0.50	3.03	heavy	<0.5	<10	<0.1	<0.02	<0.1	<0.5
DAAB07-81-D-6512‡	R0981	16/2	In-Dis	102	7.0	<0.50	1.70	heavy	<0.5	<10	<0.1	<0.02	<0.1	<0.5
DAAB07-81-D-6511§	M0982	9/12	In-Dis	112	5.6	17.80	0.511	none	NT	<10	<0.1	<0.02	NT	<0.5
DAAB07-81-D-6512‡	R0981	2/13	In-Dis	105	7.0	<0.50	1.02	heavy	<0.5	12.2	<0.1	NT	<0.1	<0.5
DAAB07-81-D-6511§	M0982	15/18	In-Dis	112	5.5	15.20	<0.50	none	<0.5	<10	<0.1	NT	<0.1	<0.5
N/A	Pitch	#	N/A	100	5.0	<0.50	<0.50	N/A	<0.5	<10	<0.1	<0.02	<0.1	<0.5
N/A	Blank		N/A	100	5.0	<0.50	<0.50	N/A	<0.5	<10	<0.1	<0.02	<0.1	<0.5
DAAB07-81-D-6511	M0982	1/6	In-Dis	111	4.8	1.46	<0.50	none	<0.5	<10	<0.1	NT	<0.1	<0.5
DAAB07-81-D-6511	M0981	13/18	In-Dis	113	5.3	3.84	0.689	slight	<0.5	<10	<0.1	NT	<0.1	<0.5
DAAB07-81-D-6511	M0981	15/4	In-Dis	110	4.8	1.26	0.521	slight	<0.5	<10	<0.1	NT	<0.1	<0.5
DAAB07-81-D-6512	R0981	1/10	In-Dis	104	7.0	<0.50	<0.50	heavy	<0.5	<10	<0.1	<0.02	<0.1	<0.5
DAAB07-81-D-6512	R0981	11/3	In-Dis	101	7.0	5.92	<0.50	heavy	<0.5	<10	<0.1	NT	<0.1	<0.5
DAAB07-81-D-6512	R0981	12/3	In-Dis	107	7.0	6.71	<0.50	slight	<0.5	<10	<0.1	NT	<0.1	<0.5
DAAB07-82-D-G029	M1082	6/8	In-FC	109	5.5	1.51	<0.50	none	<0.5	<10	<0.1	<0.02	<0.1	<0.5
DAAB07-82-D-G029	M1082	17/2	In-FC	112	5.5	<0.50	1.82	slight	<0.5	15.4	<0.1	NT	<0.1	<0.5
DAAB07-81-D-6511	M0882	14/11	In-FC	112	5.0	0.90	0.690	slight	<0.5	<10	<0.1	NT	<0.1	<0.5
DAAB07-81-D-6511	M0182	5/9	In-FC	113	5.5	2.75	<0.50	none	<0.5	<10	<0.1	<0.02	<0.1	<0.5
DAAB07-81-D-6512	R0782	5/14	In-FC	107	5.5	1.11	<0.50	none	<0.5	<10	<0.1	0.02	<0.1	<0.5
DAAB07-81-D-6512	R0782	14/12	In-FC	111	6.0	9.95	<0.50	none	<0.5	<10	<0.1	NT	<0.1	<0.5
DAAB07-81-D-6512	R0782	11/6	In-FC	109	5.5	1.59	<0.50	none	<0.5	<10	<0.1	NT	<0.1	<0.5
DAAB07-82-D-G030	R1082	2/7	In-FC	108	5.5	1.84	<0.50	none	<0.5	<10	<0.1	NT	<0.1	<0.5
Not Recorded	M0881	13/14	Ma-Dis	110	7.6	<0.50	2.43	slight	<0.5	<10	<0.1	<0.02	<0.1	<0.5
DAAB07-81-D-6512	R0881	12/9	Ma-Dis	106	7.7	<0.50	0.591	slight	<0.5	11.2	<0.1	<0.02	<0.1	<0.5
DAAB07-81-D-6512	R0981	1/18	Ma-Dis	110	7.6	<0.50	7.09	slight	<0.5	<10	<0.1	NT	<0.1	<0.5
DAAB07-81-D-6511	M0982	8/3	Ma-Dis	110	7.7	<0.50	1.11	slight	<0.5	<10	<0.1	<0.02	<0.1	<0.5
DAAB07-81-D-6511	M0982	14/9	Ma-Dis	112	7.6	<0.50	1.72	slight	NT	<10	<0.1	NT	NT	<0.5
DAAB07-81-D-6511	M0981	5/6	Ma-Dis	113	7.7	<0.50	0.785	slight	NT	12.7	<0.1	<0.02	NT	<0.5
DAAB07-81-D-6511	M0981	11/7	Ma-Dis	112	7.7	<0.50	1.74	slight	NT	<10	<0.1	NT	NT	<0.5
DAAB07-81-D-6512	R0981	15/3	Ma-Dis	109	7.7	<0.50	1.00	heavy	NT	10.2	<0.1	<0.02	NT	<0.5
DAAB07-81-D-6512	R0981	2/4	Ma-Dis	111	7.7	<0.50	3.94	heavy	NT	<10	<0.1	NT	NT	<0.5
DAAB07-81-D-6512	R0981	17/7	Ma-Dis	116	7.7	<0.50	8.24	heavy	NT	<10	<0.1	NT	NT	<0.5
DAAB07-82-D-G029	M1082	9/16	Ma-FC	108	7.1	<0.50	5.56	slight	NT	<10	<0.1	<0.02	NT	<0.5
DAAB07-82-D-G029	M1082	1/7	Ma-FC	110	7.2	<0.50	4.69	none	NT	<10	<0.1	NT	NT	<0.5
DAAB07-81-D-6511	M0882	10/7	Ma-FC	110	7.3	<0.50	10.8	slight	NT	<10	<0.1	NT	NT	<0.5
DAAB07-81-D-6511	M0182	16/8	Ma-FC	111	7.4	<0.50	2.54	none	NT	<10	<0.1	<0.02	NT	<0.5
DAAB07-81-D-6512	R0782	6/9	Ma-FC	107	7.2	<0.50	4.84	none	NT	<10	<0.1	NT	NT	<0.5
DAAB07-81-D-6512	R0782	9/10	Ma-FC	112	7.3	<0.50	4.47	none	NT	<10	<0.1	<0.02	NT	<0.5
DAAB07-81-D-6512	R0782	14/4	Ma-FC	109	7.3	<0.50	4.02	none	NT	<10	<0.1	NT	NT	<0.5
DAAB07-82-D-G030	R1082	9/15	Ma-FC	104	7.3	<0.50	4.22	none	NT	<10	<0.1	<0.02	NT	<0.5

* Refer to sequence shown in Figure 1

† Explanation of Symbols:
In - Intact Ma - Mangled FC - Fully Charged Dis - Discharged by duty cycle
N/A - Not applicable NT - Not Tested

‡ Same battery

§ Same battery

Pitch from three batteries

for [signature]
PETER J. PANU
Chief, Metals Analysis Branch
Radiological and Inorganic Chemistry Division