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UNITED STATES ARMY ENVIRONMENTAL HYGIENE AGENCY

ABERDEEN PROVING GROUND, MD 21010-5422

HAZARDOUS WASTE STUDY NO. 37-26-0427-85
EVALUATION OF LITHIUM SULFUR DIOXIDE BATTERIES

US ARMY COMMUNICATIONS-ELECTRONICS COMMAND AND
US ARMY ELECTRONICS RESEARCH AND DEVELOPMENT COMMAND
FORT MONMOUTH, NEW JERSEY
1 MAY - 1 OCTOBER 1984

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Lithium sulfur dioxide 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, lithium sulfur dioxide batteries are not listed as hazardous waste; however, they were found to be reactive hazardous waste (D003), and components exhibit ignitable characteristics. Further, fully discharged batteries are not hazardous waste.

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DEPARTMENT OF THE ARMY
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ABERDEEN PROVING GROUND, MARYLAND 21010-5422

REPLY TO
ATTENTION OF

7 February 1985

HSHB-ES-H/WP

EXECUTIVE SUMMARY
HAZARDOUS WASTE STUDY NO. 37-26-0427-85
EVALUATION OF LITHIUM SULFUR DIOXIDE BATTERIES
US ARMY COMMUNICATIONS-ELECTRONICS COMMAND AND US ARMY ELECTRONICS RESEARCH AND DEVELOPMENT COMMAND
FORT MONMOUTH, NEW JERSEY
1 MAY - 1 OCTOBER 1984

1. PURPOSE. To evaluate the BA 5590 and BA 5567 lithium sulfur dioxide batteries 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.

a. Fully charged lithium sulfur dioxide batteries exhibit the RCRA hazardous waste characteristic of reactivity, and their lithium components exhibit the hazardous waste characteristic of ignitability.

b. Spent or duty-cycle discharged lithium sulfur dioxide batteries are considered hazardous waste because they exhibit the characteristic of reactivity.

c. Fully discharged lithium sulfur dioxide batteries are not hazardous wastes. However, it is highly unlikely that a battery will reach the fully discharged state because it is normally turned in for disposal once it reaches the duty-cycle discharged level.

d. Manually discharging lithium sulfur dioxide batteries by soaking them in aqueous solutions is not practical.

3. MAJOR RECOMMENDATIONS.

a. Dispose of used, unserviceable and spent lithium sulfur dioxide batteries as hazardous wastes through the servicing Defense Property Disposal Office.

b. Contact appropriate State solid waste regulatory authorities to determine if special requirements apply for disposal of these batteries.

c. Study other approaches for discharging lithium sulfur dioxide batteries to a fully discharged state.

d. Dispose of lithium sulfur dioxide batteries in a permitted sanitary landfill only if an appropriate procedure has been developed to fully discharge the batteries and assurances are given that the procedure has been accomplished.

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DEPARTMENT OF THE ARMY
U.S. ARMY ENVIRONMENTAL HYGIENE AGENCY
ABERDEEN PROVING GROUND, MARYLAND 21010-5422

REPLY TO
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US ARMY COMMUNICATIONS-ELECTRONICS COMMAND AND US ARMY ELECTRONICS RESEARCH AND DEVELOPMENT COMMAND
FORT MONMOUTH, NEW JERSEY
1 MAY - 1 OCTOBER 1984

1. AUTHORITY. 1st Ind, HQ DARCOM, DRCSG-S, 24 October 1983, to Ltr, this Agency, HSHB-E/WP, 16 August 1983, USAEHA, Mission Services, FY 84.

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

3. PURPOSE. To determine whether or not two types of lithium sulfur dioxide (Li/SO_2) batteries, BA 5590 and BA 5567, exhibit hazardous waste characteristics under the requirements of the Resource Conservation and Recovery Act (RCRA), and to provide results and recommendations for disposal of these batteries based on analytical data.

4. GENERAL.

a. Personnel Contacted. See Appendix B for a listing of personnel contacted.

b. Background.

(1) Battery Description. The BA 5590 and BA 5567 Li/SO_2 batteries, manufactured by Power Conversion Incorporated of Elmwood Park, New Jersey, and Duracell International Incorporated of Elmsford, New York, are two of the most commonly used Li/SO_2 types within the Army and are representative of other Li/SO_2 batteries being used. They are assigned the following National Stock Numbers and nomenclature, respectively: NSN 6135-01-036-3495 Battery, BA-5590/U and NSN 6135-01-090-5365 Battery, BA-5567/U. They have rated voltages of 30 and 3.0 volts corresponding to 7.1 and 0.8 ampere-hours of capacity, respectively. The BA 5590 battery contains 10 "D" cells, while the BA 5567 is a single-cell battery containing approximately one-tenth the quantity of the active components of one BA 5590 battery cell. The BA 5590 and BA 5567 represent the largest and the smallest (in capacity and physical size) of the family of Li/SO_2 batteries procured by the US Army. The makeup of the each battery cell is similar, consisting of a lithium metal anode, a carbon-type cathode on an aluminum support screen, and a polypropylene separator between the electrodes. The anode, cathode, and separator are wound together in a tight spiral configuration. Each cell contains an electrolyte composed of sulfur dioxide (SO_2), acetonitrile (CH_3CN), and a salt [usually lithium bromide (LiBr)] and is under pressure of 53 psi at 25°C. The entire contents are enclosed in a sealed nickel-plated steel container.

(2) Recent Historical Assessment. The Army position on the disposal of Li/SO_2 batteries, as developed by ERADCOM, has been that they are a potentially hazardous waste and that they must be collected for turn-in to the Defense Property Disposal Office (DPDO) (reference 20, Appendix A). As a precautionary measure, DPDO would process and dispose of the batteries as a hazardous waste, even though no detailed laboratory testing of Li/SO_2 batteries had previously been performed. This Agency began testing the batteries for reactivity, as requested by ERADCOM/CECOM, in February 1984, by using a bulldozer compaction procedure to simulate landfill conditions. However, this landfill testing was discontinued following several key events described below. In a letter to the Defense Logistics Agency (DLA-S), dated 7 March 1984 (reference 22, Appendix A), the US Environmental Protection Agency (EPA) stated that Li/SO_2 battery cells are reactive because the contained lithium metal will form potentially explosive hydrogen gas when mixed with water under [40 CFR 261.23(a)(3)] and because the cells are capable of violent rupture or reaction if subjected to a strong initiating source or if heated under confinement [40 CFR 261.23(a)(6)]. The EPA's primary concern, however, was the potential for components of the batteries to generate toxic gases, vapors, or fumes in a quantity sufficient to present a danger to human health or the environment when those components are mixed with water or exposed to pH conditions between 2 and 12.5 [40 CFR 261.23(a)(4) and (a)(5)]. On 19 March 1984, EPA issued a regulatory interpretive letter (RIL) (reference 24, Appendix A) concluding that spent or discarded Li/SO_2 batteries are reactive and must be managed as hazardous wastes; i.e., land disposal of regulated quantities is prohibited unless the waste is treated or otherwise rendered nonhazardous. Agency, along with CECOM and ERADCOM, personnel coordinated this project study plan with EPA for discussion and clarification based on their prior correspondences. The EPA agreed with this Agency's study plan to evaluate the Li/SO_2 batteries in the laboratory but not to any testing done outside the laboratory (reference 26, Appendix A). The EPA perceived that any bulldozer compaction testing constituted development of a waste management technique and would require a permit. As of 7 March 1984, the date of the EPA letter to DLA, no more bulldozer compaction testing has been conducted. Since that date, only controlled laboratory testing has been performed.

(3) Sampling and Analysis. The battery sampling matrix consisted of the two battery types with three states of charge: fully charged, duty-cycle discharged, and fully-discharged. Each type and state-of-charge was tested on an intact and mangled cell basis. Title 40 CFR 260.22(h) requires that at least four samples be taken to represent the variability or uniformity of the waste. It was considered that four representative grab samples from the two manufactures, taken as a whole, would reflect a regulatory surveillance sampling program. The sampling matrix for the Li/SO_2 batteries is provided in Table 1. The analysis was broken down into a battery discharge study and an evaluation for the reactivity, ignitability, corrosivity, and Extraction Procedure (EP) toxicity characteristics under 40 CFR 261 as provided by methodologies in SW 846 (see Appendix C) or by the described empirical testing. The battery discharge study was undertaken in an attempt to manually discharge the batteries in a manner that would be environmentally safe for an Army field unit and hopefully produce a nonhazardous item. The evaluation for

reactivity included the partially completed bulldozer compaction testing. This testing was performed on intact, fully charged, BA 5590 batteries, with the results being empirical observations. With certain limitations, this testing may be applied to unserviceable charged and spent batteries.

TABLE 1. Li/SO_2 BATTERY SAMPLING MATRIX

Battery Type	Fully Charged	Duty-Cycle Discharged	Fully Discharged
Mangled BA 5567	4 cells	4 cells	4 cells
Mangled BA 5590	4 cells	4 cells	4 cells
Intact BA 5567	4 cells	4 cells	4 cells
Intact BA 5590	4 cells	4 cells	4 cells

5. FINDINGS AND DISCUSSION.

a. Battery Discharge Study. This study was performed to determine whether an Army field operation unit could easily and safely discharge Li/SO_2 batteries using an aqueous medium, so as to render them nonreactive, and then dispose of them as nonhazardous wastes. It is an accepted fact within the Department of Defense that routine duty-cycle discharged batteries contain trace amounts of lithium and/or other unreacted chemicals. It was hoped that this application could be extended to the duty-cycle discharged batteries. Both the BA 5567 and BA 5590 batteries were tested.

(1) Discharging BA 5567 Batteries.

(a) Six BA 5567 cells were immersed in a simulated ocean water matrix (3.5 percent sodium chloride solution). At first, a fairly vigorous reaction occurred, accompanied by a brown scum-like material. After 24 hours, the reaction slowed down considerably. It appeared that the salt corroded the outside positive plate of the battery, reducing the reaction rate and thereby decreasing the effective surface area. The voltages were measured periodically over a 30-day period, but no drop in voltages was detected. It was determined that the salt water discharging medium was too corrosive for the BA 5567 cells because of the diminished cell surface area, even though none of the cells developed leaks. Next, a weaker salt solution (1.5 percent) was used as the discharging medium. Again, no definitive discharging occurred after a 30-day soaking period. The reaction initially was vigorous but slowed down to nearly nothing at the end of the period. The corrosion was somewhat less than with those exposed to the 3.5-percent salt solution.

(b) Next, tap water was tested as the discharging medium. The tap water had a pH of 7.5 and a specific conductance of 150 micromhos per centimeter. Ten cells were immersed in the tap water. A little discoloration of the water occurred after 24 hours due to a slight corrosion of the cells. The water was replaced periodically, corresponding to when the voltages were measured. After 100 days, not much more corrosion developed, but only four cells lost most of their voltage charge. On the average, the voltages decreased by 25 percent from the original charge. Some of the cells that showed little or no remaining charge were used in other tests requiring discharged cells.

(2) Discharging BA 5590 Batteries.

(a) Four BA 5590 batteries were immersed in a 3.5-percent salt water solution. No strong reaction occurred, but some bubbling was observed. The batteries were removed after 24 hours because the pH of the solution dropped to 1, indicating the leaking of SO_2. Further investigation revealed that two of the four batteries developed leaking cells, yet all four batteries had greater than 10 volts for one of the two sets of five cells connected in series. The normal voltage of a fully charged set of five cells connected in series is 15 volts indicating that little discharging had occurred with those sets of the four batteries. The voltages of the other sets of 5 cells decreased to a level of 1-3 volts. As the salt solution became more acidic, more corrosion occurred, causing even more cell leaking of SO_2 and acetonitrile. Probably some electrodes became coated, and this interferred with the discharge rate. It was decided that 3.5-percent salt solutions were too corrosive and would not be used. Weaker salt solutions (1.5 percent) were used to discharge other BA 5590 batteries. This was done over a 16-hour period. However, again, not all the individual cells were discharged, and one vented SO_2. The weaker salt solution was also considered too corrosive. Some of the discharged cells were acceptable for use in other tests.

(b) Four fully charged BA 5590 and four duty-cycle discharged BA 5590 batteries were studied with respect to discharging, using a tap water medium. The duty-cycle discharged batteries were included, because it had been observed that approximately 25 percent of those batteries contained considerable voltage. A typical duty-cycle discharged battery is one that has a 90- to 95-percent voltage depletion. Each of the four randomly selected batteries initially had a voltage greater than a typical duty-cycle discharged battery (<2.0 volts per cell). It was hoped that all the batteries could be easily discharged ($\leq$ 1 volt per cell) in a minimal time frame. The tap water had a pH of 7.5 and a specific conductance of 150 micromhos per centimeter and was changed daily. The study was concluded after 120 hours.

(c) As with the batteries exposed to the salt water solutions, corrosion and cell leaking resulted. However, it was not as prevalent as with the salt solutions. The leaking was first noticed after a 48-hour exposure by the profound sulfurous acid smell and subsequent pH measurement of the resulting acid solution. The results were somewhat difficult to assess because not all the batteries did discharge, some developed leaks venting SO_2 and acetonitrile, and some individual cells maintained considerable, or their full, voltage even after the battery itself measured no voltage. This occurrence appeared to be a function of the high resistance interfering with the necessary current for discharging the individual cells. The cell voltages were measured by soaking extra batteries so that they could be opened up and the cells examined individually during the discharging time period. Some cells that exhibited high voltages also vented considerable SO_2 and acetonitrile. Even those that contained 1 to 2 volts, as opposed to 3 volts, had a vigorous release of SO_2 and acetonitrile when manually vented. Others have observed with the lithium-SO_2 chemical reaction, that once a battery reaches a low voltage charge, it can actually reverse reaction and increase in voltage. This did occur, although it should be noted that potentially dangerous lithium metal and/or SO_2 gas will not be formed during such a reaction (Appendix A, reference 29). The observed low battery voltages as opposed to the relatively high individual cell voltages with the corresponding increases in battery voltage were not fully understood and could not be explained. Table 2 provides the essential information with respect to corrosion, leaking batteries, and voltage change over time. It appeared that enough batteries will corrode and/or leak to make this discharging approach difficult for field use. In addition, one can never be sure that the individual cells are completely discharged, i.e., that the chemical ingredients have been fully reacted.

b. Characteristic of Reactivity.

(1) The criteria for reactivity under 40 CFR 261.23(a)(2), (3), and (4) are that the solid waste or a representative sample of the waste reacts violently with water, or forms potentially explosive mixtures with water, or when mixed with water generates toxic gases, vapors, or fumes in a quantity sufficient to present a danger to human health or the environment. Under these criteria, intact fully charged, duty-cycle discharged, and fully discharged BA 5590 and BA 5567 battery cells were exposed to water. As per the above RCRA characteristics, no violent reaction, nor potentially explosive mixtures, nor generation of toxic gases, vapors or fumes were evolved to present a danger to human health or the environment. However, it was noted that a small percentage (less than 5 percent) of the intact BA 5590 batteries, whether they were fully charged or duty-cycle discharged, developed SO_2 leaks after 24 hours. This was substantiated by the isolation of the battery and subsequent removal and examination of the leaking cells. These results tend to parallel the leaking battery percentages obtained in the battery discharge study (Table 2). The batteries were randomly selected and appeared to be in good condition prior to the water exposure.

(a) To measure the type of reaction between the Li/SO_2 cell components and water, the fully-charged BA 5567 and BA 5590 cells were first vented using a tapping valve assembly device provided by ERADCOM. For this procedure, only the lithium spiral roll anode and cathode were reacted with water. Approximately 3-inch strips of the spiral roll were reacted with water. The reactions were vigorous and somewhat deceptive because the polyproplene and carbon tended to shield the lithium from the water and actually slowed the reaction. However, once the mixture

TABLE 2. RESULTS FROM DISCHARGING BA 5590 BATTERIES

Initial Battery Charge and Results		Soaking Duration (hours) 0	24	48	72	96	120
Charged	Voltage for Both Sides*	15, 15	12, 6	7, 5	3.5, 5	3.2, 1	3.2, 1
	Description	-	NC	SC	SC	SC	SC
Charged	Voltage	15, 15	5, 1	3.5, 1	3.2, 1	2.8, 1.5	2.7, 1.5
	Description	-	SC	SC, leaking pH 2.5	SC, leaking SO_2 fumes pH 1.5	SC, leaking SO_2 fumes pH 1.5	SC, leaking SO_2 fumes pH 1.5
Charged	Voltage	15, 15	15, 10	7, 2	2.2, 2.5	3, 4.5	3, 4.5
	Description	-	SC	SC	SC	SC	SC
Charged	Voltage	15, 15	12, 10	6, 10	2.5, 15	1, 6.5	<1, <1
	Description	-	NC	SC	SC	SC	SC
Duty-Cycle Discharged	Voltage	7, 12	6, 9	5, 6	2.8, 1.8	1.5, 1.5	1.5, 1.3
	Description	-	NC	SC	SC	SC	SC
Duty-Cycle Discharged	Voltage	8, 1	5, 1	3.5, 1	1, <1	1, <1	<1, <1
	Description	-	NC	SC	SC, leaking SO_2 fumes, pH 2.0	SC, leaking SO_2 fumes, pH 1.5	SC, leaking SO_2 fumes, pH 1.5
Duty-Cycle Discharged	Voltage	12, 5	7, 4	1, 4	<1, 1.8	<1, 2.5	<1, 2.8
	Description	-	NC	SC	SC	SC	SC
Duty-Cycle Discharged	Voltage	6, 1	5, <1	5, <1	2.5, <1	2.5, 1.5	2, 1.8
	Description	-	NC	SC	SC	SC	SC

* Voltage of both sides (each five cells connected in series)

NC - No corrosion

SC - Some corrosion

containing portions of two or more unreacted lithium strips was stirred, a violent and potentially explosive reaction occurred. On two occasions, flames estimated at between 4 and 6 inches high resulted. Fortunately, the fires were contained, and no true explosions erupted. With the rest of the reactions, there was an evolution of hydrogen gas, but not of sufficient quantity to ignite.

(b) The reactions between lithium and water for quantifying hydrogen generation were performed on mangled cells using fully charged, duty-cycle discharged, and fully discharged BA 5590 and BA 5567 cells. The term "mangled" meant that the cells were first manually vented and then cut open. Although this experiment was conducted under controlled laboratory conditions, the generated hydrogen volumes may be correlated to gas evolved at a sanitary landfill. Hydrogen gas was generated, collected, and quantified, and these data are shown in Table 3. Small strips of lithium metal from the charged cells and reacted lithium dithionite from the duty-cycle discharged or fully discharged cells, each approximately 1/2 inch by 1 inch, were placed in an inverted, graduated cylinder that was completely filled with cold tap water (pH 7.5). The volume of hydrogen collected correlated to the volume of water displaced. This was continued until an entire lithium strip from one cell was used. 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.

TABLE 3. HYDROGEN GAS GENERATED FROM LITHIUM OF ONE CELL IN WATER (mL)

Cell Type	Fully Charged	Duty-cycle Discharged	Fully Discharged
BA 5567	550	50	50
BA 5567	570	70	<10
BA 5567	485	350	20
BA 5567	520	20	<10
BA 5590	3800	250	20
BA 5590	4000	200	40
BA 5590	4200	80	50
BA 5590	4000	20	10

(c) The small strips of lithium from the fully charged cells produced a vigorous reaction lasting approximately 5 seconds. If a strip of lithium was inserted in the water before the previous strip was allowed to react, or if the water solution was already hot and alkaline, the risk of a violent reaction was likely. Twice the reaction produced a flame 2 to 3 inches in height, and at times the hydrogen was lost. These particular experiments were repeated and demonstrated the need for exercising care when handling mangled cells. All the fully charged BA 5567 cells generated approximately 500 mL of gas, and the corresponding BA 5590 cells generated approximately 4000 mL of gas. This would be equivalent to 40 liters or 1.8 moles of hydrogen for a BA 5590 battery. However, it should be noted that an unwound lithium metal strip from an individual cell would not be easily encountered in a disposal situation. In fact, the lithium being so tightly wound in the cell ribbon makeup is relatively safe from water penetration. Although the reactions between lithium and water are considered hazardous by these criteria, it is a worst-case scenario for sample representation. Lithium represents less than 4 percent by weight of a battery cell. In addition, the BA 5590 cells, as with all the other Li/SO_2 battery types except the BA 5567, are encased in a relatively hard plastic box.

(d) The reaction between lithium and water will produce lithium hydroxide and hydrogen. Because of the intact nature of the lithium, the resulting lithium hydroxide product will be highly alkaline. In all cases the pH of the resulting solutions (approximately 1- to 2-gallon volumes) from the reaction of lithium from the fully charged cells and water was greater than 13.

(e) The reaction between the already reacted lithium dithionite from the duty-cycle discharged cells and water was not as vigorous as with the corresponding lithium from the fully charged cells. However, there were sizeable but inconsistent hydrogen volumes generated from the lithium dithionite, accompanied by somewhat erratic reactions. The highest volume of gas generated from the BA 5567 cells was 350 mL with the average of the four volumes being 122 mL. There were two relatively high volumes of gas generated from the BA 5590 cells (250 and 200 mL), with the average from the four cells being 138 mL. Although the inconsistent hydrogen volumes generated by the duty-cycle discharged cells may be easily diffused in a disposal situation, they show that trace amounts of active lithium are present in these cells. Therefore, the duty-cycle discharged batteries may present a potential danger to human health or the environment because there is no guarantee that they can be uniformly and/or completely discharged.

(f) The reaction between the lithium dithionite from the fully discharged cells and water was considerably reduced. As with the duty-cycle discharged cell reactions, the lithium dithionite was quite friable and a little difficult to handle. However, this did not alter the experiment or affect the results. Low reproducible volumes of hydrogen gas were generated from both the BA 5590 and BA 5567 cells. The low volumes of hydrogen, averaging 18 and 30 mg/L for the BA 5567 and BA 5590 cells, respectively, were considered insignificant.

(g) On occasion, the generated hydrogen gas was ignited to test for flammability. In one instance, a 1000 mL graduated cylinder with 900 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 10-inch reddish yellow flame inside the cylinder. The estimated burn time was under 1.0 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 (Appendix A, references 13 and 14).

(2) The criterion under 40 CFR 261.23(a)(5) for the characteristic of reactivity is that a cyanide- or sulfide-bearing waste, when exposed to pH conditions between 2 and 12.5, can generate toxic gases, vapors or fumes in a quantity sufficient to present a danger to human health or the environment. The Li/SO_2 batteries contain SO_2 and acetonitrile which, under certain conditions, may produce free SO_2, sulfurous acid, lithium cyanide, and hydrogen cyanide. Results discussed in paragraph 5a(2)(b) demonstrated that, over time, approximately 25 percent of the intact BA 5590 fully charged or duty-cycle discharged batteries, when exposed to pH 7.5 tap water, will corrode and leak SO_2 gas. The amount of leaked SO_2 was not quantified, but enough of the batteries leaked to produce a strong sulfurous acid odor and lower the pH to less than 2. The BA 5590 cells that could be rendered fully discharged using the water matrix and had not displayed leaking during the discharging period appeared to be free of leaking afterward. Although there was corrosion with the BA 5567 cells, no SO_2 leaking occurred. In order to measure the potential for cyanide generation, both BA 5590 and BA 5567 fully charged, duty-cycle discharged, and fully discharged cells on an intact and on a mangled basis were tested. The intact cells were first subjected to the structural integrity procedure as outlined under the EP toxicity test. They all passed the test and then were extracted with pH 7.0 deionized water for 24 hours in accordance with the EP methodology. The mangled cells were manually vented using the tapping valve assembly device prior to cutting the top of the cell with a hacksaw and unraveling the rolled components of the cell. The contents were then carefully reacted with the deionized water, liberating hydrogen and residual SO_2. It was recognized that most of the acetonitrile was lost during the venting process, but residual amounts should have been present for possible breakdown to lithium cyanide. The entire cell contents, including the steel can, were extracted for 24 hours with the pH 7.0 deionized water. The pH of the resulting extract for the fully charged cells was greater than 13 but dropped off to the 7-9 range for the duty-cycle discharged and fully discharged extracts. The alkaline pH was due to the formation of lithium hydroxide. The extracts were analyzed for cyanide by EPA approved procedures outlined in SW-846 and EPA-600/4-79-020 and are listed in Appendix C. The cyanide results are summarized in Table 4. The entire data set is presented in Table D-3, Appendix D. The intact battery cells did not leach detectable concentrations of cyanide except in three isolated samples. However, these concentrations were low and are considered insignificant. The corresponding cyanide results of the mangled cells are somewhat inconsistent because high concentrations in the 30 to 40 mg/L range were leached from fully discharged BA 5567 samples. This may have been due to the nonuniform manner in which the cells were opened and the time required between cell venting and placement into extraction bottles or that the cells were not really discharged. It was hoped that the cells had been opened and vented in the same manner to provide a corresponding rate of acetonitrile residue. The most significant finding was not that the cyanide concentrations were different among the leachate samples, but that there were indeed detectable concentrations. These results indicated that some of the remaining acetonitrile residue, after cell venting, was broken down to cyanide during the extraction with deionizied water which was then detected in the 10 to 200 mg/L concentration range. Although EPA has not developed analytical methodologies for the evaluation of reactivity of

cyanide or sulfide-bearing waste [40 CFR 261.23(a)(5)], it has issued a regulatory interpretive letter (Appendix A, reference 28) on the concentration ranges of cyanide or sulfide. The letter states that for waste containing between 10 and 200 parts per million, no categorical statements can be made. Each waste must be evaluated against such factors as quantity and releasability of sulfide or cyanide and, in the case of complex cyanide-containing wastes, the potential for conversion of relatively stable complex cyanide species to more reactive species (Appendix A, reference 28).

TABLE 4. MEAN LEACHABLE CYANIDE RESULTS (mg/L)

Cell Type	BA 5567		BA 5590	
Charge	Intact	Mangled	Intact	Mangled
Fully Charged	<0.01	3.0	0.03*	0.01
Duty-Cycle Discharged	<0.01	0.07	<0.01	10.3
Fully Discharged	0.04*	37.5	5.5*	0.03

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* The values represent the only detectable results, as the other three values were <0.01 mg/L.

(3) Under 40 CFR 261.23(a)(6), a solid waste exhibits the characteristic of reactivity if a representative sample of the waste is capable of detonation or explosive reaction when subjected to a strong initiating source when heated under confinement. To test the Li/SO_2 batteries for this criterion, the intact fully charged, duty-cycle discharged, and fully discharged BA 5590 and BA 5567 cells were subjected to the structural integrity procedure. None of the cells were damaged by this testing; i.e., the integrity of the individual cells was not changed. The cells were not heated under confinement because the laboratory lacked adequate ovens.

(a) In order to better evaluate this reactivity criterion using real-world situations, the abbreviated outside compaction testing, as discussed in paragraph 4b(2), is addressed here. The testing was performed at a landfill to simulate landfill conditions and because the landfill site, equipment, and bulldozer operator were available to this Agency. It was also recognized that the landfill, being in an isolated area, would be the safest place for this experiment. As mentioned in paragraph 4b(3), the testing was halted before the experiment was finished. However, the early work with fully charged, intact BA 5590 batteries is worth discussing.

(b) The landfill compaction testing matrix included 16 randomly selected, fully charged, intact BA 5590 batteries consisting of four sets of four. The first set of four batteries was left completely intact in their plastic wrappers and cardboard boxes. The cardboard boxes were removed, but the plastic wrappers were left in place for each of the batteries in the second set. The cardboard boxes and plastic wrappers were removed, but the fuses were left intact for the batteries in the third set. The cardboard boxes, plastic wrappers, and fuses were removed from the batteries in the fourth set. The batteries were laid one by one, each 3 feet apart, on a hard dirt road surface. The bulldozer operator who was experienced with landfill operations, drove over the batteries, using the same number of passes (four) as would be used in a real-world landfill operation. Observations were noted during and after each pass and are provided in Table 5. These empirical results include severity of battery eruptions, degree of battery and cell damage, duration and propogation of lithium fires, and the venting of toxic SO_2 fumes. Essentially no noteworthy distinctions were observed among the four battery sets. All four sets were heavily damaged, becoming reactive by producing explosive fire bombs, lithium sparks, and choking SO_2 clouds. The individual fires, lasting from 1 to 10 minutes, easily propogated fires to adjacent cell fragments. Only a few of the cells remained intact after four bulldozer passes. The remnants from the unreacted cells and cell fragments were individually positioned on a concrete pad, and then they were run over several more times by a flat road maintenance roller. Many fires resulted which, at times, led to propogation of other lithium/cell fragment fires. Again, the SO_2 smell was apparent but not choking. At the completion of the test, the cell fragments, which were extensively chewed up, measured less than 2 inches in area. They were placed in a 5-gallon, closable-type, metal can and filled with water. The pH of the mixture was 2 after 24 hours but gradually increased to greater than 13 after a 6-month storage. The initial pH was due to dissolution of residual SO_2; then the mixture became alkaline from the formation of lithium hydroxide. Examination showed that traces of lithium metal were still present after the 6 months of liquid storage. Table 5 represents subjective descriptions as observed and should not be interpreted as reproducible.

c. Characteristic of Ignitability.

(1) The criterion of concern with respect to Li/SO_2 batteries is 40 CFR 261.21(a)(2), which states that a solid waste sample which is not a liquid and is capable, under standard temperature and pressure, of causing fire through friction, absorption of moisture, or spontaneous chemical changes and, when ignited, burns so vigorously and persistently that it creates a hazard exhibits the characteristic of ignitability. With regard to absorption of moisture, this characteristic is related to reactivity [40 CFR 261.23(a)(2) and (3)] and was addressed earlier in paragraph 5b.

(a) Attempts to ignite opened, fully charged, duty-cycle discharged, and fully discharged BA 5590 and BA 5567 cells (having the spiral wound components left intact) with a propane torch produced a characteristic red flame of lithium. The flame was not vigorous and extinguished shortly after the torch was removed.

(b) When the contents of four BA 5590 and four BA 5567 fully charged cells were removed and the lithium ribbon ignited, a vigorous, persistent burning did result. The burning can be described as hazardous, because it would be difficult to control. One of the four BA 5590 duty-cycle discharged cells also produced a vigorous persistent burning when its spiral roll

TABLE 6. LANDFILL COMPACTION RESULTS

Bulldozer Pass No.	Set Number	No. of Battery Eruptions* and Severity		Set Number	No. of Cells/† Battery Damaged	Set Number	Individual Fires ‡ and Severity/Duration		Set Number	No. of Cells Venting SO_2§ and Severity	
1	1	1	slow, sparkling flames	1	2, 4, 3, 2	1	1	vigorous, 3-4 minutes	1	8	slight irritation
	2	1	violent, white smoke	2	2, 0, 4, 2	2	1	vigorous	2	6	pungent irritation
	3	1	violent, flames 1 foot	3	4, 2, 0, 2	3	2	vigorous, 1-2 minutes	3	7	pungent irritation
	4	2	cloud of smoke, flames 1 foot	4	5, 3, 6, 4	4	0		4	12	extreme choking irritation
2	1	1	slow, sparkling red flame	1	2, 2, 4, 4	1	1	moderate, 2-3 minutes	1	10	extreme choking irritation
	2	0	- - - - -	2	2, 2, 3, 2	2	0		2	9	do
	3	0	- - - - -	3	0, 4, 3, 4	3	1	slow continuous	3	10	do
	4	2	sizzling red flames, and white cloud of smoke	4	3, 4, 3, 2	4	2	3-4 minutes	4	10	do
3	1	1	sizzling red flames	1	1, 3, 3, 4	1	2	vigorous, propogation to other cells, 4-5 minutes	1	6	extreme choking irritation
	2	2	violent, white smoke, flames 1 foot	2	6, 4, 2, 1	2	2	do	2	9	do
	3	1	rapid, flames 0.5 foot	3	2, 3, 7, 3	3	1	do	3	10	do
	4	0	- - - - -	4	1, 2, 1, 1	4	0	- - - - -	4	5	do
4	1	1	violent, flames 1 foot	1	4, 1, 0, 0	1	1	vigorous, propogation to other cells, 5-10 minutes.	1	4	extreme choking irritation
	2	1	rapid, flames 0.3 foot	2	0, 4, 0, 2	2	2	do	2	4	do
	3	1	rapid, flames 0.3 foot	3	2, 0, 0, 2	3	2	do	3	4	do
	4	1	sizzling red flames 0.3 foot	4	1, 1, 0, 1	4	1	do	4	2	do

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* Characteristic of a loud popping noise and destruction of an exploding cherry bomb firecracker.

† A damaged cell is one that can be slightly vented, excessively vented, or severed in several places. The damaged cell column from top to bottom is a cumulative count for that particular battery.

‡ Many individual fires were observed; only those with a duration greater than 0.5 minutes are being reported.

§ Generally any cell that was venting SO_2 had an intolerable smell.

components were ignited. The other three BA 5590 duty-cycle discharged cells produced some sparks. The contents from the BA 5567 duty-cycle discharged cells, as with all the fully discharged cells, also produced some sparks when lit with the propane torch. The sparks were not considered hazardous. Although an intact lithium ribbon will burn in a vigorous, persistent manner, it is not likely to be encountered during conventional disposal of Li/SO_2 batteries.

(2) The Li/SO_2 cells were not evaluated for the other ignitability characteristics. A flash point property of less than 60°C as described in [40 CFR 261.21(a)(1)] does not appear to be applicable to the electrolyte in the fully charged cells because of the extinguishing property of SO_2. In addition, the Li/SO_2 cells do not meet the criteria of an ignitable compressed gas as described in 40 CFR 261.21(a)(3) and of an oxidizer as listed in 40 CFR 261.21(a)(4).

d. Characteristic of Corrosivity. The criteria under 40 CFR 261.22(a)(1) and (2) for the characteristic of corrosivity state that the solid waste sample is aqueous and has a pH less than or equal to 2 or greater than or equal to 12.5 or is a liquid and corrodes steel at a rate greater than 6.35 mm per year at a test temperature of 55°C. This Agency's laboratory does not have the capability to perform the corrosion to steel testing and, therefore, it was not undertaken. It is quite difficult to determine pH values of the liquid portion of the fully charged Li/SO_2 cells as it is not aqueous and readily evaporates. However, the pH test paper measurements performed on the liquid as it came in contact with moist air gave reproducible values of pH 1. As discussed in paragraph 5a(1)(b), leaking Li/SO_2 cells, when placed in water, did not lower the pH immediately but produced a corrosive pH solution over time.

e. Characteristic of EP Toxicity.

(1) Extractions were performed on 24 intact cells and 24 mangled cells representing the test matrix. As previously performed for the cyanide analysis, the mangled cells were first manually vented, removing the electrolyte so that the unraveled spiral components plus the cell casing could be extracted together. The pH of the fully charged cell extracts was greater than 13 for the BA 5590 mangled set and in the 7 to 9 range for the BA 5567 mangled set. The pH was also in the 7 to 9 range for one extract of the duty-cycle discharged BA 5590 mangled cells. This was probably due to an improperly created duty-cycle discharged cell allowing free lithium to remain for producing lithium hydroxide. The complete data are presented in Tables D-1 and D-2, Appendix D. Averaged EP toxicity values are provided in Table 6.

(2) The eight listed EP toxic metals plus copper, lithium, and nickel were analyzed on the extracts in accordance with approved EPA procedures. Of the listed metals, none was detected in the intact cell extracts, and only lead was detected in the mangled cell extracts. The detectable lead values, being well below the 5.0 mg/L regulatory threshold, were detected in most of the fully charged and duty-cycle discharged cell extracts. As expected, lithium was detected in high concentrations in the mangled cell extracts ranging from 700 to 1800 mg/L and in concentrations of approximately 1.0 mg/L

TABLE 6. AVERAGED* EP TOXICITY VALUES (mg/L)

Parameter	Cell Type Charge	BA 5567 Intact	BA 5567 Mangled	BA 5590 Intact	BA 5590 Mangled	Threshold Limits for EP Toxicity
Lithium	FC	<0.10	868	1.14	1515	-
Lithium	DD	1.72	973	0.32	1758	-
Lithium	FD	0.25	862	1.05	1755	-
Copper	FC	0.071	1.39	0.044	1.25	-
Copper	DD	0.034	<0.025	0.038	4.27	-
Copper	FD	0.05	0.035	<0.025	8.26	-
Nickel	FC	<0.10	0.78	5.20	<0.10	-
Nickel	DD	1.67	0.64	6.57	3.53	-
Nickel	FD	0.86	1.6	4.18	2.47	-
Lead	FC	<0.50	<0.50	<0.50	0.75	5.0
Lead	DD	<0.50	0.57	<0.50	0.96	5.0
Lead	FD	<0.50	<0.50	<0.50	<0.50	5.0
Arsenic		all values	<0.5			5.0
Silver		all values	<0.5			5.0
Barium		all values	<10.0			100.0
Cadmium		all values	<0.1			1.0
Chromium		all values	<0.5			5.0
Mercury		all values	<0.02			0.2
Selenium		all values	<0.1			1.0

* Averages were calculated only on detectable quantities.
FC - Fully charged
DD - Duty-cycle discharged
FD - Fully discharged

in the intact cell extracts. The leachable copper concentrations varied from not detectable to 10.1 mg/L. The leachable nickel concentrations varied from less than 0.10 to 7.8 mg/L. At present, there are no EP toxicity criteria for copper, lithium, and nickel. However, EPA has tentatively proposed adopting a regulatory threshold of 10.0 mg/L for nickel.

6. SUMMARY.

a. Discharging Li/SO_2 batteries by soaking them in aqueous solutions was not feasible because:

(1) A salt water matrix was too corrosive. It produced numerous leaks in the BA 5590 batteries and caused a reduced cell surface area on the BA 5567 batteries.

(2) A tap water matrix required at least 48 hours; by that time, leaks had occurred in 10 to 20 percent of the batteries.

(3) When discharging the BA 5590 batteries, the measured battery voltage was not always indicative of the individual cell voltages. This could present a potential danger in which the discharged batteries may contain individual cells with unreacted chemicals.

b. Over time, a small but certain percentage of fully charged Li/SO_2 batteries leaked SO_2 when mixed with water. The SO_2 quantities were sufficient to be irritating to human health and/or corrosive by the production of sulfurous acid.

c. Definitive concentrations of cyanide from acetonitrile breakdown were leachable from mangled Li/SO_2 batteries. Some of the concentrations were above 1.0 mg/L.

d. The fully charged Li/SO_2 batteries were easily erupted and produced explosive-type, propogating fires when subjected to a landfill disposal situation.

e. The lithium component of fully charged Li/SO_2 batteries reacted violently with water and at times produced explosive quantities of hydrogen.

f. The lithium component of fully charged Li/SO_2 batteries burned vigorously and persistently when ignited.

g. Duty-cycle discharged Li/SO_2 batteries contained low but sufficient concentrations of SO_2, acetonitrile, and lithium to present a danger to human health or the environment.

(1) Twenty-five percent of the BA 5590 batteries vented SO_2 after 48 hours when subjected to a tap water soaking. A definite amount, but less than 5 percent, leaked SO_2 after a 24-hour exposure.

(2) Cyanide in concentrations slightly above 10 mg/L was leachable from the BA 5590 batteries.

(3) The lithium portion reacted violently with water and burned vigorously when ignited.

h. Fully discharged Li/SO_2 batteries did not contain sufficient quantities of SO_2, acetonitrile, and lithium to present a potential danger. Although cyanide concentrations, in the 30 to 40 mg/L range were leached from the mangled discharged BA 5567 cells, the results cannot be explained. However, EPA has tentatively proposed the 10 to 200 parts per million total cyanide range as being of sufficient quantity that each waste must be evaluated against such factors as quantity and releasability of hydrogen cyanide (Appendix A, reference 28). Although the units are not directly correlated, the leachable cyanide values resulted from only a fraction of the acetonitrile present in the cells.

i. The importance of handling Li/SO_2 batteries in a proper manner was documented throughout the study.

7. CONCLUSIONS.

a. Lithium sulfur dioxide batteries cannot be discharged by soaking them in aqueous solutions.

b. Fully charged Li/SO_2 batteries (BA 5567 and BA 5590) are RCRA hazardous wastes because:

(1) They exhibit the RCRA hazardous waste characteristic of reactivity [40 CFR 261.23(a)(4), (5) and (6)].

(2) The lithium component exhibits the RCRA hazardous waste characteristics of reactivity [40 CFR 261.23(a)(3)] and ignitability [40 CFR 261.21(a)(2)].

c. Duty-cycle discharged Li/SO_2 batteries (BA 5567 and BA 5590) are RCRA hazardous wastes because they tend to exhibit the characteristic of reactivity.

d. Fully discharged Li/SO_2 batteries (BA 5567 and BA 5590) are not RCRA hazardous wastes. However, it is highly unlikely that a battery will reach the fully discharged state because it is normally turned in for disposal once it reaches the duty-cycle discharged level.

e. The acceptable disposal method for unserviceable and spent Li/SO_2 batteries, whether in the fully charged or duty-cycle discharged state, is through the servicing Defense Property Disposal Office.

f. At present, a safe procedure to fully discharge Li/SO_2 batteries is not available. The batteries could be disposed of in a permitted landfill only if an appropriate procedure had been developed to fully discharge the batteries and assurances are given that the procedure has been accomplished.

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

a. Study other approaches for discharging Li/SO_2 batteries to a fully discharged state.

b. Exercise proper handling, storage, and accountability for all types of Li/SO_2 batteries during use and disposal.

c. Dispose of unserviceable, used, and spent Li/SO_2 batteries through the servicing Defense Property Disposal Office as reactive hazardous wastes.

d. Contact appropriate State solid waste regulatory authorities to determine if special requirements apply for disposal of the Li/SO_2 batteries.

e. Dispose of Li/SO_2 batteries in a permitted sanitary landfill only if an appropriate procedure has been developed to fully discharge the batteries and assurances are given that the procedure has been accomplished.

9. 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, Commercial 301-671-3651). Requests for services should be directed through appropriate command channels of the requesting activity to the Commander, US Army Environmental Hygiene Agency, ATTN: HSHB-ES, Aberdeen Proving Ground, MD 21010-5422, with an information copy furnished the Commander, US Army Health Services Command, ATTN: HSCL-P, Fort Sam Houston, TX 78234-6000.

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APPENDIX A

REFERENCES

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

2. Public Law 94-580, 21 October 1976, Resource Conservation and Recovery Act of 1976.

3. Title 40, Code of Federal Regulations (CFR), 1984 rev, Part 241, Guidelines for the Land Disposal of Solid Wastes.

4. Title 40, CFR, 1984 rev, Part 257, Criteria for Classification of Solid Waste Disposal Facilities and Practices.

5. Title 40, CFR, 1984 rev, Part 260, Hazardous Waste Management System: General.

6. Title 40, CFR, 1984 rev, Part 261, Identification and Listing of Hazardous Waste.

7. Title 40, CFR, 1984 rev, Part 262, Standards Applicable to Generators of Hazardous Waste.

8. Title 40, CFR, 1984 rev, Part 264, Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities.

9. Title 40, CFR, 1984 rev, Part 265, Interim Status Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities.

10. Title 40, CFR, 1984 rev, Part 270, EPA Administered Programs: The Hazardous Waste Permit Program.

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

12. EPA publication number SW-846, 2nd edition, July 1982, Test Methods for the Evaluation of Solid Waste, Physical/Chemical Methods.

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

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15. Di Masi, Gabriel, "Behavior of Li/SO_2 Cells under Forced Discharged," Lithium Battery Session, 27th Annual Proceedings, Power Sources Conference, June 1976.

16. Kilroy, William P., "The Chemistry of the Li/SO_2 Battery - A Review," 28th Annual Proceedings, Power Sources Conference, June 1978.

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18. Di Masi, Gabriel, "Performance, Storage, Safety, and Disposal of Li/SO_2 Cells," presented at the 1980 NASA Conference, November 1980.

19. Environmental Assessment for the Disposal of Lithium-Sulfur Dioxide Batteries," Defense Property Disposal Service (DPDS-H), Battle Creek, Michigan, 1982.

20. Letter, HQDA, DAPE-HRS, 11 January 1982, subject: Army Position on the Disposal of Lithium Sulfur Dioxide Batteries.

21. ERADCOM Technical Report, DELET-TR-79-0285, Testing of Lithium Sulfur Dioxide Cells for Waste Disposal Hazards, performed by Wapora, Inc., Chevy Chase, Maryland, October 1980.

22. Letter, Office of Solid Waste and Engineering Response, 7 March 1984, regarding response to DOD requests for guidance on the regulatory status of spent and/or discarded lithium-sulfur dioxide (Li/SO_2) batteries.

23. Report, Hazard Assessment of Management of Waste Lithium Batteries, performed by Factory Mutual Research Corporation, under EPA Contract No. 68-01-6698, June 1983.

24. Notice of availability of regulatory interpretive letter (RIL), Clarification of Regulatory Status of Spent or Discarded Lithium-Sulfur Dioxide Batteries; 49 Federal Register (FR) 10155, 19 March 1984.

25. Draft Protocol, this Agency, HSHB-ES-H, 23 February 1984, Hazardous Waste Special Study No. 37-26-0427-84, US Army Communications-Electronics Command, US Army Electronics Research and Development Command, Fort Monmouth, New Jersey.

26. Meeting, 1 May 1984, at the Office of Solid Waste, EPA, between the Army (CECOM, ERADCOM and USAEHA) and EPA, subject: Discussion of Li/SO_2 Battery Study Plan.

27. FONECON between Mr. Robert Axelrad, EPA, Washington, DC, and Mr. David Rosak, this Agency, 16 April 1984, subject: Regulatory Status of Li/SO_2 Batteries.

28. FONECON between RCRA Superfund Hotline, Washington, DC, and Mr. David Rosak, this Agency, 24 October 1984, subject: Regulatory Threshold Status of Generated Cyanide.

29. FONECON between Mr. Gabriel Di Masi, ERADCOM, and Mr. David Rosak, this Agency, 17 October 1984, subject: Discharging Li/SO_2 Batteries.

APPENDIX B

PERSONNEL CONTACTED

1. Dr. Louis F. Soffer, Safety Office, USACECOM.

2. Mr. Edward Reiss, Power Sources Division ERADCOM.

3. Mr. John Christopulos, Power Sources Division, ERADCOM.

4. Mr. Gabriel Di Masi, Power Sources Division, ERADCOM.

5. Mr. Robert Axelrad, Office of Solid Waste and Emergency Response, EPA.

6. Ms. Francine Jacoff, Office of Solid Waste and Emergency Response, EPA.

7. Ms. Florence Richardson, Office of Solid Waste and Emergency Response, EPA.

8. Mr. Ronald Ney, Land Disposal Branch, EPA.

9. Mr. Matt Strauss, Waste Management and Economics Division, EPA.

10. Mr. Randy Chrismon, Permits Branch, Headquarters EPA.

11. Dr. Samuel Rotenberg, Permits Division, Region III, EPA.

12. Ms. Paula McCLain, Property Disposal Division, Defense Logistics Agency.

13. Mr. Joseph Hoenscheid, Environment Research and Analysis Division, Defense Property Disposal Service.

AP' X C

CHEMICAL LABORATORY PROCEDURES

Parameter	Method	Identification
EP Toxicity Metals (eight) plus copper, nickel, and cadmium	SW-846, 2d ed., Section 2.1.4, 1310, "Test Methods for Evaluating Solid Waste, Physical/Chemical Methods," US Environmental Protection Agency, July 1982.	Extraction performed at pH 5 using acetic acid. Individual metals analyzed by appropriate SW-846 Atomic Absorption Spectrometry Methodology.
Cyanide	Modified EP Method, SW-846, 2d ed. Section 2.1.4, 1310, July 1982.	Extraction performed at pH 7.0. Manually distilled and analyzed by automated UV Method.
	Colorimetric, EPA-600/4-79-020, Method 335.3 "Methods for Chemical Analysis of Water and Wastes," EPA, March 1983.	

APPENDIX D

RESULTS OF EP TOXICITY AND CYANIDE ANALYSES

TABLE D-1. EP TOXICITY RESULTS ON INTACT CELLS (mg/L)

Cell Type	Cell Charge	Arsenic	Barium	Cadmium	Chromium	Lead	Mercury	Selenium	Silver	Nickel	Copper	Lithium
BA 5567	FC	<0.5	<10	<0.1	<0.5	<0.50	<0.02	<0.1	<0.5	<0.10	0.068	<0.10
	FC	<0.5	<10	<0.1	<0.5	<0.50	<0.02	<0.1	<0.5	<0.10	0.072	<0.10
	FC	<0.5	<10	<0.1	<0.5	<0.50	<0.02	<0.1	<0.5	<0.10	0.075	<0.10
	FC	<0.5	<10	<0.1	<0.5	<0.50	<0.02	<0.1	<0.5	0.10	0.071	<0.10
	DD	<0.5	<10	<0.1	<0.5	<0.50	<0.02	<0.1	<0.5	6.26	0.025	<1.72
	DD	<0.5	<10	<0.1	<0.5	<0.50	<0.02	<0.1	<0.5	0.15	0.040	<0.10
	DD	<0.5	<10	<0.1	<0.5	<0.50	<0.02	<0.1	<0.5	0.12	0.034	<0.10
	DD	<0.5	<10	<0.1	<0.5	<0.50	<0.02	<0.1	<0.5	0.14	0.036	<0.10
	FD	<0.5	<10	<0.1	<0.5	<0.50	<0.02	<0.1	<0.5	0.86	0.038	0.24
	FD	<0.5	<10	<0.1	<0.5	<0.50	<0.02	<0.1	<0.5	0.93	0.038	0.25
	FD	<0.5	<10	<0.1	<0.5	<0.50	<0.02	<0.1	<0.5	0.83	<0.025	0.26
	FD	<0.5	<10	<0.1	<0.5	<0.50	<0.02	<0.1	<0.5	0.84	0.030	0.26
BA 5590	FC	<0.5	<10	<0.1	<0.5	<0.50	<0.02	<0.1	<0.5	6.63	<0.025	1.77
	FC	<0.5	<10	<0.1	<0.5	<0.50	<0.02	<0.1	<0.5	6.69	<0.025	1.65
	FC	<0.5	<10	<0.1	<0.5	<0.50	<0.02	<0.1	<0.5	0.26	0.044	0.13
	FC	<0.5	<10	<0.1	<0.5	<0.50	<0.02	<0.1	<0.5	7.23	<0.025	1.02
	DD	<0.5	<10	<0.1	<0.5	<0.50	<0.02	<0.1	<0.5	6.44	0.039	<1.10
	DD	<0.5	<10	<0.1	<0.5	<0.50	<0.02	<0.1	<0.5	6.04	0.046	<0.10
	DD	<0.5	<10	<0.1	<0.5	<0.50	<0.02	<0.1	<0.5	6.80	0.044	1.15
	DD	<0.5	<10	<0.1	<0.5	<0.50	<0.02	<0.1	<0.5	7.80	0.025	0.16
	FD	<0.5	<10	<0.1	<0.5	<0.50	<0.02	<0.1	<0.5	3.86	<0.025	1.27
	FD	<0.5	<10	<0.1	<0.5	<0.50	<0.02	<0.1	<0.5	4.39	<0.025	2.82
	FD	<0.5	<10	<0.1	<0.5	<0.50	<0.02	<0.1	<0.5	4.82	<0.025	0.12
	FD	<0.5	<10	<0.1	<0.5	<0.50	<0.02	<0.1	<0.5	3.67	<0.025	0.31

FC - fully charged
DD - duty-cycle discharged
FD - fully discharged

TABLE D-2. EP TOXICITY RESULTS ON MANGLED CELLS (mg/L)

Cell Type	Cell Charge	Arsenic	Barium	Cadmium	Chromium	Lead	Mercury	Selenium	Silver	Nickel	Copper	Lithium
BA 5567	FC	<0.5	<10	<0.1	<0.5	<0.50	<0.02	<0.1	<0.5	0.81	1.36	804
	FC	<0.5	<10	<0.1	<0.5	<0.50	<0.02	<0.1	<0.5	0.61	0.43	875
	FC	<0.5	<10	<0.1	<0.5	<0.50	<0.02	<0.1	<0.5	0.90	1.57	896
	FC	<0.5	<10	<0.1	<0.5	<0.50	<0.02	<0.1	<0.5	0.79	2.21	896
	DD	<0.5	<10	<0.1	<0.5	0.54	<0.02	<0.1	<0.5	0.11	<0.025	1053
	DD	<0.5	<10	<0.1	<0.5	0.50	<0.02	<0.1	<0.5	0.17	<0.025	1059
	DD	<0.5	<10	<0.1	<0.5	0.69	<0.02	<0.1	<0.5	1.20	<0.025	1021
	DD	<0.5	<10	<0.1	<0.5	<0.50	<0.02	<0.1	<0.5	1.10	<0.025	759
	FD	<0.5	<10	<0.1	<0.5	<0.50	<0.02	<0.1	<0.5	1.90	0.062	702
	FD	<0.5	<10	<0.1	<0.5	<0.50	<0.02	<0.1	<0.5	2.50	0.038	882
	FD	<0.5	<10	<0.1	<0.5	<0.50	<0.02	<0.1	<0.5	0.28	<0.025	944
	FD	<0.5	<10	<0.1	<0.5	<0.50	<0.02	<0.1	<0.5	1.70	<0.025	921
BA 5590	FC	<0.5	<10	<0.1	<0.5	0.82	<0.02	<0.1	<0.5	<1.10	0.695	1540
	FC	<0.5	<10	<0.1	<0.5	0.73	<0.02	<0.1	<0.5	<1.10	0.778	1526
	FC	<0.5	<10	<0.1	<0.5	0.73	<0.02	<0.1	<0.5	<1.10	2.19	1510
	FC	<0.5	<10	<0.1	<0.5	0.73	<0.02	<0.1	<0.5	<1.10	1.37	1487
	DD	<0.5	<10	<0.1	<0.5	0.92	<0.02	<0.1	<0.5	6.80	1.64	1643
	DD	<0.5	<10	<0.1	<0.5	1.00	<0.02	<0.1	<0.5	0.72	1.11	1823
	DD	<0.5	<10	<0.1	<0.5	<0.50	<0.02	<0.1	<0.5	5.10	4.84	1740
	DD	<0.5	<10	<0.1	<0.5	<0.50	<0.02	<0.1	<0.5	1.60	9.52	1830
	FD	<0.5	<10	<0.1	<0.5	<0.50	<0.02	<0.1	<0.5	1.30	8.11	1540
	FD	<0.5	<10	<0.1	<0.5	<0.50	<0.02	<0.1	<0.5	2.30	9.43	1970
	FD	<0.5	<10	<0.1	<0.5	<0.50	<0.02	<0.1	<0.5	4.80	5.40	1710
	FD	<0.5	<10	<0.1	<0.5	<0.50	<0.02	<0.1	<0.5	1.50	10.10	1800

FC - fully charged
DD - duty-cycle discharged
FD - fully discharged

TABLE D-3. LEACHABLE CYANIDE RESULTS (mg/L)

	BA 5567		BA 5590	
Cell Type Charge	Intact	Mangled	Intact	Mangled
Fully Charged	<0.01	3.4	0.03	0.01
	<0.01	2.6	<0.01	0.01
	<0.01	3.1	<0.01	0.02
	<0.01	2.8	<0.01	0.02
Duty-Cycle Discharged	<0.01	0.01	<0.01	10
	<0.01	0.02	<0.01	11
	<0.01	0.23	<0.01	10
	<0.01	0.02	<0.01	10
Fully Discharged	<0.01	45	<0.01	0.05
	0.04	38	<0.01	0.02
	<0.01	34	<0.01	0.02
	<0.01	33	5.5	0.01