ON-LINE DOCUMENTATION

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Chapter: 5

Pages: 7 (not including this page)

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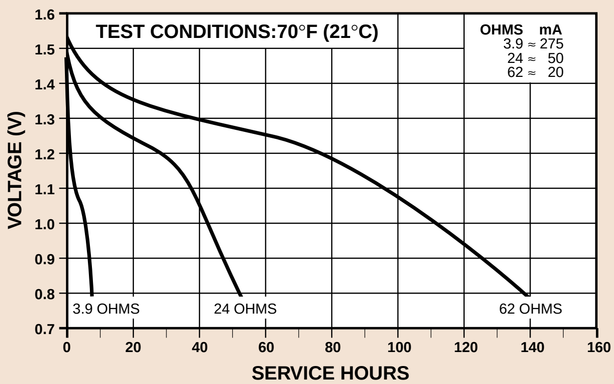
5 Performance Characteristics

The performance characteristics described in Sections 5.1 through 5.9 are those characteristics specific to the alkaline-manganese dioxide products manufactured and distributed by Duracell. The performance data shown is taken from actual test conditions. Conversions, shown in parentheses, are given for reference purposes only.

5.1 Voltage

Open circuit voltage ranges from 1.5 to 1.6 volts. Nominal voltage is 1.5 volts. Operating voltage is dictated by the state-of-discharge and the actual load imposed by the equipment. The voltage profile under discharge is a sloping curve as seen in **Figure 2**. In most instances, 0.8 volts is considered to be the end-voltage.

Figure 2



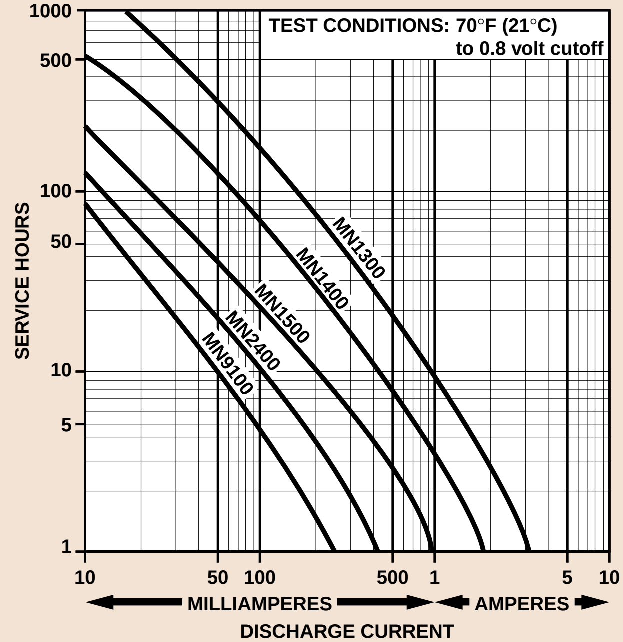
Typical discharge profile of the DURACELL® alkaline MN 1500 (“AA” size) cell.

5.2 Capacity

Capacity is usually expressed in ampere-hours or milliampere-hours. In any given continuous drain application, the average current flowing multiplied by the hours of service equals the rated capacity of the cell. Alkaline cells and batteries are available in button (45 mAh to 110 mAh) and in cylindrical (580 mAh to 15,000 mAh) configurations.

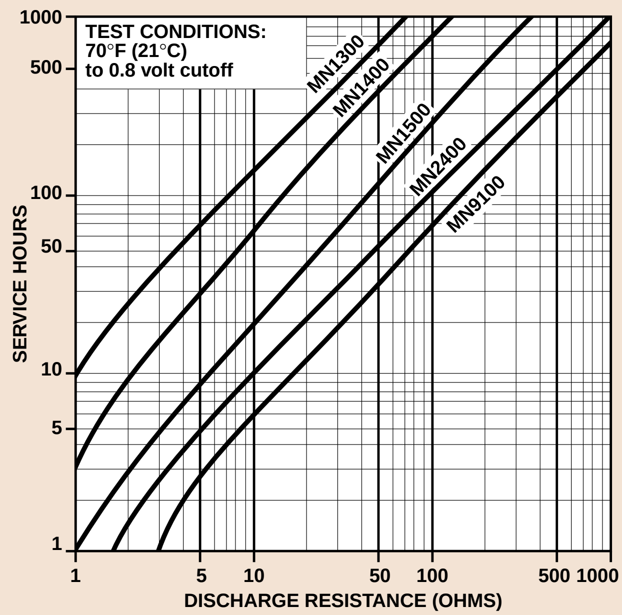
Figure 3 illustrates the typical discharge characteristics of the major cell types when discharged at a constant current at 70°F (21°C) to a voltage cutoff of 0.8 volts. **Figure 4** illustrates typical discharge characteristics when discharged at constant resistance at 70°F (21 ˚C) to a 0.8 volt cutoff.

Figure 3



Typical discharge characteristics with constant current of DURACELL® alkaline cells.

Figure 4



Typical discharge characteristics with constant resistance of DURACELL® alkaline cells.

Performance Characteristics (cont.)

5.3 Type of Discharge

A battery may be discharged under different modes depending on the equipment load. The type of discharge mode selected will have a significant impact on the service life delivered by a battery in a specified application.

Three typical modes under which a battery may be discharged are;

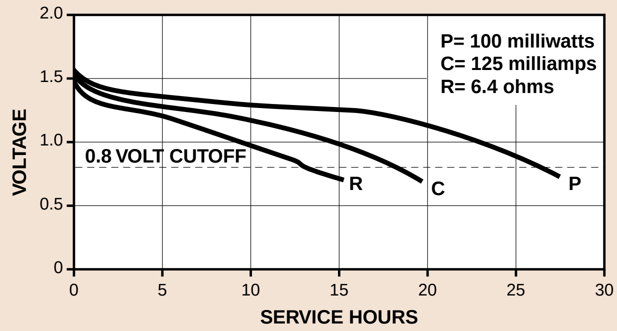
1. Constant Resistance ("R"): In this mode, the resistance of the equipment load remains constant throughout the discharge
2. Constant Current ("C"): In this mode, the current drawn by the device remains constant during the discharge
3. Constant Power ("P"): In this mode, the current during the discharge increases as the battery voltage decreases, thus discharging the battery at a constant power level. (Power = Current x Voltage)

The discharge profiles of a battery under the three different modes are plotted in **Figures 5, 6 and 7**. **Figure 5** shows the voltage profile; **Figure 6**, the current profile; and **Figure 7**, the power profile during the discharge of the battery.

Electrical devices require a minimum input power to operate at their specified performance level. The data in **Figures 5, 6 and 7** are based on the discharge of a "AA" size alkaline-manganese dioxide battery (MN1500). At the end of the discharge when the battery reaches its end-of-life, the power output is the same for all of the discharge modes and is at the level required for acceptable equipment performance. In the example shown, the minimum power level is 100 milliwatts and the battery end-of-life or cutoff voltage is 0.8 volts. During the discharge, the power output equals or exceeds the power required by the equipment until the battery reaches its end-of-life.

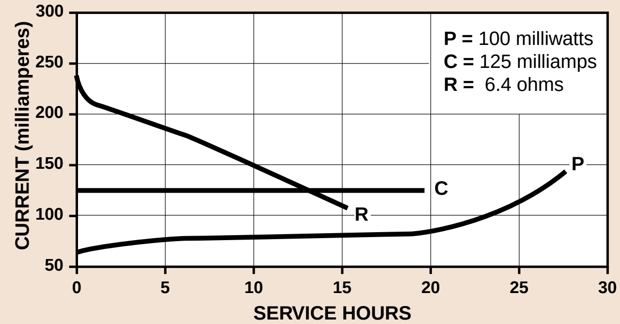
In the constant resistance discharge mode, the current during the discharge **(Figure 6)** follows the drop in the battery voltage **(Figure 5)**. The power, I x V or V^2/R, drops even more rapidly, following the square of the battery voltage **(Figure 7)**. Under this mode of discharge, to assure that the required power is available at the end-of-battery-life, the current at 0.8 volts is 125 milliamperes. As a result, the levels of current and power during the discharge are in excess of the minimum

Figure 5



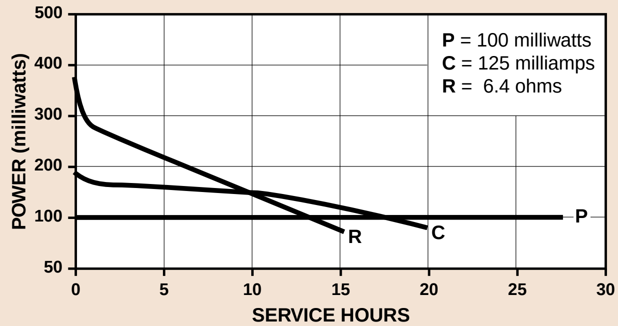
Voltage profile under different modes of discharge

Figure 6



Current profile under different modes of discharge

Figure 7



Power profile under different modes of discharge

Performance Characteristics (cont.)

required. The battery discharges at a high current, draining its ampere-hour capacity rapidly and excessively, resulting in a short service life.

In the constant current mode, the current is maintained at a level (125 milliamperes) such that the power output at the end of the discharge is 100 milliwatts, the level required for acceptable equipment performance. Thus, both the current and power throughout the discharge are lower than that for the constant resistance mode. The average current drain on the battery is lower and the discharge time, or service life, to the end-of-battery-life is longer.

In the constant power mode the current is lowest at the beginning of the discharge and increases as the battery voltage drops to maintain a constant power output at the level required by the equipment (100 milliwatts). This discharge mode requires the lowest average current drain and, hence, delivers the longest service time.

Under the constant power mode, the battery can also be discharged below its end voltage. With suitable power regulator circuitry, the current can be increased at these lower battery voltages, maintaining the required power output. The constant power mode provides the most uniform equipment performance throughout the life of the battery and makes for the most efficient use of the battery's energy.

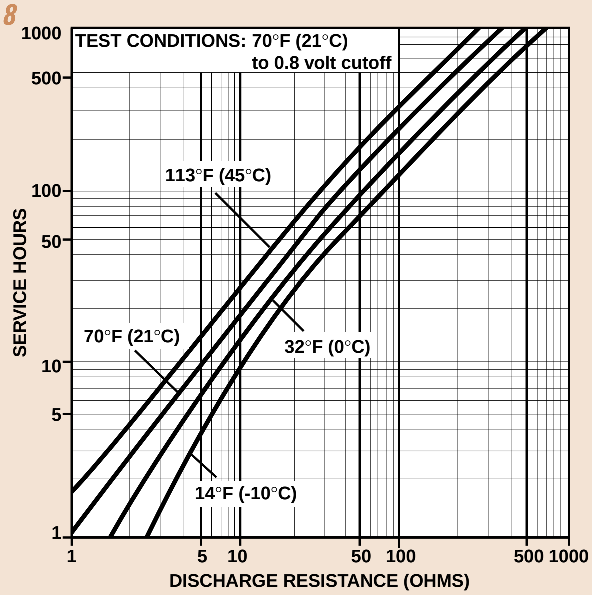
It should be noted that the advantage of the constant power discharge mode over the other modes of discharge is greatest with batteries that have a sloping discharge, such as the alkaline-manganese dioxide cell, as compared with those having a flat discharge characteristic.

5.4 Effect of Temperature

The alkaline-manganese dioxide system is best suited for use over a temperature range of -4°F to 130°F (-20°C to 54°C). At lighter loads, some output can be obtained at temperatures as low as -20°F(30°C). Actual service depends on cell size and current drain. For most cells, up to 75 percent of the rated capacity at room temperature can be delivered at 32°F(0°C).

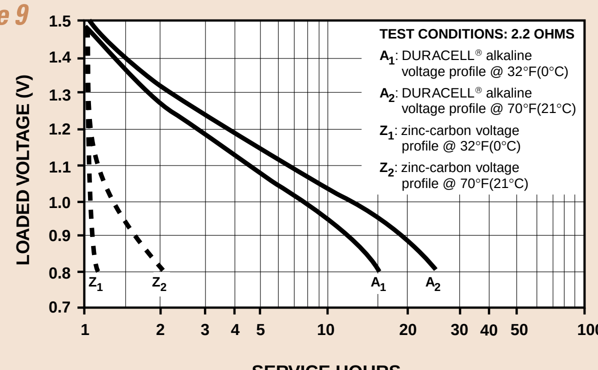
The graph in **Figure 8** illustrates how cell size and current drain affect performance over a range of temperatures. As current drain increases, temperature impact becomes more dramatic. Low temperature

Figure 8



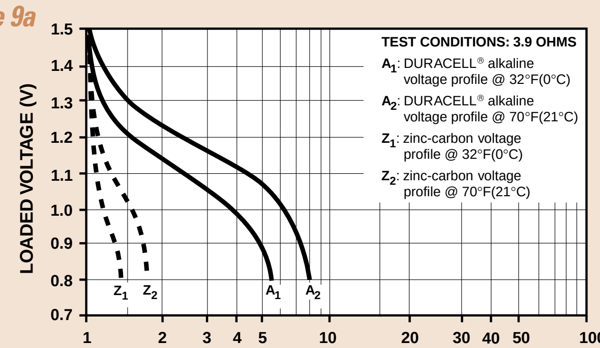
Effect of temperature and load on the performance of the DURACELL® alkaline MN1500 ("AA" size) cell.

Figure 9



Comparison of the effects of temperature on a regular zinc-carbon "D" size cell versus a DURACELL® alkaline MN1300 ("D" size) cell.

Figure 9a



Comparison of the effects of temperature on a regular zinc-carbon "AA" size cell versus a DURACELL® alkaline MN1500 ("AA" size) cell.

Performance Characteristics (cont.)

performance of alkaline and regular zinc-carbon cells is compared in **Figure 9**, showing the "D" size cell at 70°F (21°C) and 32°F (0°C). **Figure 9a** shows "AA" cell performance under the same conditions. The alkaline cell will maintain a higher voltage for considerably longer than the regular zinc-carbon cell, resulting in a service life at lower temperatures which is up to ten times that of the regular zinc-carbon cell.

5.5 Internal Resistance

Alkaline cells, because of their compact construction and highly conductive electrolyte, have low internal resistance, usually less than 1 ohm. The low internal resistance characteristic is a benefit in applications involving high current pulses. Unlike regular zinc-carbon cells, alkaline cells do not require rest periods between pulses and maintain their low internal resistance, increasing only at the very end of useful life.

5.6 Energy Density

Energy density is a measure of available energy in terms of weight and volume. It is the ratio of a cell's capacity to either its volume or weight and can be used to evaluate a cell's performance.

Table 1 is a summary of the major alkaline product types comparing both volumetric energy density and gravimetric energy density. Volumetric energy density is an important factor where battery size is the primary design consideration. Gravimetric energy density becomes important where weight of the battery is critical, such as in portable computers and cellular phones. The values shown in this table are typical for each cell size. Actual energy output will vary, dependent mostly on drain rates applied.

PRODUCT NUMBER	SIZE	NOMINAL VOLTAGE	RATED CAPACITY*	LOAD	WEIGHT		VOLUME		TYPICAL GRAVIMETRIC ENERGY DENSITY**		TYPICAL VOLUMETRIC ENERGY DENSITY	
		volts	ampere-hours	ohms	pounds	kilograms	cubic inches	liters	watt-hours per pound	watt-hours per kilogram	watt hours per cubic inch	watt hours per liter
MN1300	D	1.5	15.000	10	0.304	0.138	3.440	0.056	59.2	130	5.2	322
MN1400	C	1.5	7.800	20	0.143	0.065	1.640	0.027	65.5	144	5.7	347
MN1500	AA	1.5	2.850	43	0.052	0.024	0.510	0.008	65.8	143	6.7	428
MN2400	AAA	1.5	1.150	75	0.024	0.011	0.230	0.004	57.5	126	6.0	345
MN9100	N	1.5	0.800	100	0.021	0.010	0.210	0.003	45.7	96	4.6	320
7K67	J	6.0	0.580	340	0.075	0.034	0.960	0.016	37.2	82	2.9	174
MN908	Lantern	6.0	11.500	15	1.349	0.612	30.620	0.502	40.9	90	1.8	110
MN918	Lantern	6.0	24.000	9	2.800	1.270	75.880	1.243	41.1	91	1.5	93
MN1604	9V	9.0	0.580	620	0.101	0.046	1.390	0.023	41.4	91	3.0	182

* TO 0.8V per cell at 21°C (70°F).

** Based on 1.2 volt average operating voltage per cell at 21°C (70°F).

Table 1. Comparison of typical energy densities of major DURACELL® alkaline cells/batteries.

To determine the practical energy density of a cell under specific conditions of load and temperature, multiply the ampere-hour capacity that the cell delivers under those conditions by the average discharge voltage, and divide by cell volume or weight.

Gravimetric Energy Density:

$$\frac{\text{(Drain in Amperes x Service Hours) x Average Discharge Voltage}}{\text{Weight of cell in Pounds or Kilograms}} = \frac{\text{Watt-Hours}}{\text{Pound or Kilogram}}$$

Volumetric Energy Density:

$$\frac{\text{(Drain in Amperes x Service Hours) x Average Discharge Voltage}}{\text{Volume of cell in Cubic Inches or Liters}} = \frac{\text{Watt-Hours}}{\text{cubic Inch or Liter}}$$

Performance Characteristics (cont.)

Using the MN1300 data from **Table 1** the previous equations can be used to determine energy density for this cell.

Gravimetric Energy Density:

$$\frac{\text{15.00 Ampere-Hours x 1.2 Volts}}{\text{0.304 Pounds (0.138 Kilograms)}} = \frac{59.2 \text{ Watt-Hours}}{\text{Pound}} \text{ or } \frac{130.4 \text{ Watt-Hours}}{\text{Kilogram}}$$

Volumetric Energy Density:

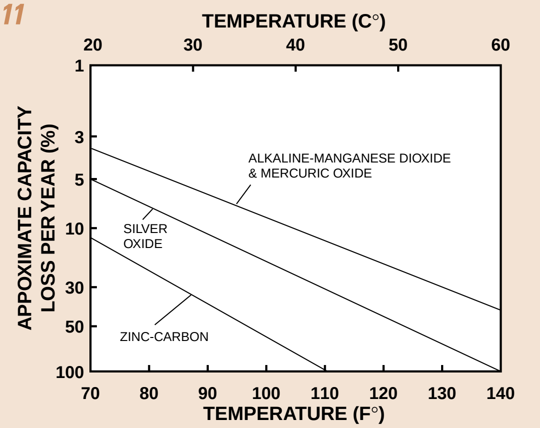
$$\frac{\text{15.00 Ampere-Hours x 1.2 Volts}}{\text{3.44 Cubic Inches (0.563 Liters)}} = \frac{5.23 \text{ Watt-Hours}}{\text{Cubic Inch}} \text{ or } \frac{320 \text{ Watt-Hours}}{\text{Liter}}$$

5.7 Shelf Life

Alkaline cells have long shelf storage life. After one year of storage at room temperature, cells will provide 93 to 96 percent of initial capacity. When stored for four years at 70°F (21°C), service of about 85 percent is still attainable. Storage at high temperatures and high humidity will accelerate degradation of chemical cells. At low temperature storage, the chemical activity is retarded and capacity is not greatly affected. Recommended storage conditions are 50°F (10°C) to 77°F (25°C) with no more than 65 percent relative humidity.

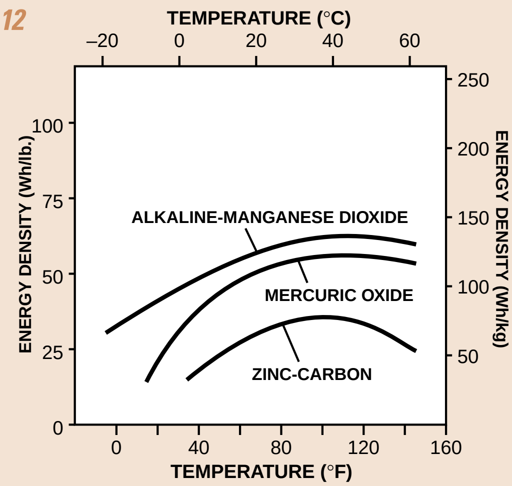
Figure 11 compares various DURACELL® zinc anode systems and the effect of temperature on capacity retention. At room temperature, the alkaline system loses approximately 5 percent capacity after one year of storage. Subsequent capacity loss is approximately 2 percent per year. By comparison, zinc-carbon cells lose nearly 15 percent capacity per year at room temperature. As the temperature elevates, capacity losses increase. At temperatures above 113°F (45°C), the regular zinc-carbon cells will be completely discharged within one year, whereas the alkaline system will still retain approximately 80 percent of its original capacity.

Figure 11



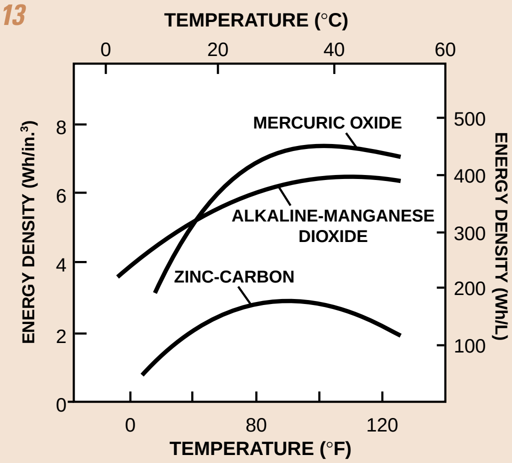
Effect of temperature on capacity retention for various DURACELL® zinc anode systems

Figure 12



Gravimetric energy density comparison of zinc anode systems.

Figure 13



Volumetric energy density comparison of zinc anode systems.

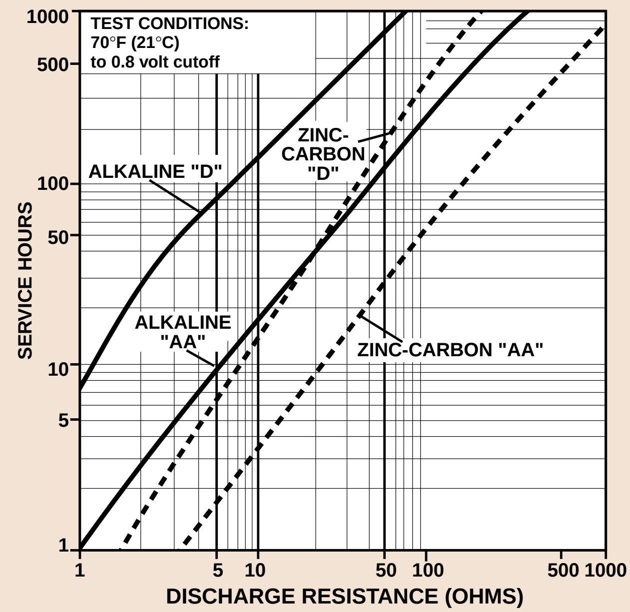
Performance Characteristics (cont.)

5.8 Comparison of Zinc-Carbon and Zinc-Alkaline

In **Figures 12 and 13**, comparisons are made between the DURACELL® alkaline-manganese dioxide system and several other zinc anode systems, showing the effect of temperature on both gravimetric energy density and volumetric energy density.

Another comparison, showing the effect of discharge load on the cell's capacity and how this can influence the selection of a battery for an application, is illustrated in **Figure 14**. The regular zinc-carbon cell performs efficiently under light discharge loads, but its performance falls off sharply with increasing discharge rates. The alkaline system has a higher energy density at light loads and does not drop off as rapidly with increasing discharge loads. For low-power applications, the service ratio of alkaline compared to regular zinc-carbon is in the order of 2:1. At heavier loads, such as those required for toys, motor-driven applications, and pulse discharges, the ratio can widen to 8:1 or greater. At these heavy loads, alkaline batteries are preferred on both a performance and cost basis.

Figure 14



Comparison of the typical discharge characteristics of regular zinc-carbon "D" and "AA" size cells versus DURACELL® alkaline "D" (MN1300) and "AA" (MN1500) size cells.

5.9 Cost Effectiveness

The impact of the discharge rate and duty cycle on the cost of battery operation is shown in **Table 2** which compares the service life and cost-per-hour of service of regular zinc-carbon cylindrical cells with alkaline-manganese dioxide cells under various loads. The relative cost-per-service-hour column shows the cost savings resulting from the use of alkaline-manganese dioxide batteries versus zinc-carbon batteries in each application.

BATTERY TYPE	TEST*	ACTUAL SERVICE HOURS ZINC-CARBON	ALKALINE	RELATIVE COST PER SERVICE HOUR ZINC-CARBON	ALKALINE
D	Flashlight: 2.2 ohms	3.7	20.5	1	.56
C	Toy: 3.9 ohms	2.2	20.8	1	.33
AA	Flashlight: 3.9 ohms	1.1	6.2	1	.41
AA	Tape Player: 10 ohms	3.5	17.4	1	.47
	Relative Cost Ratios	0.35	1.0		

* Test conditions: D - Flashlight - 2.2 ohms, 4 minutes/hour to 0.9 volts. C - Toy - 3.9 ohms, 1 hour/day to 0.8 volts.
AA - Flashlight - 3.9 ohms, 4 minutes/hour to 0.9 volts. AA - Tape Player - 10 ohms, 1 hour/day to 0.9 volts.

Table 2. Impact of discharge rate and duty cycle on the cost of battery operation.