2007

Introduction:

360° Test Labs has been retained to measure the lifetime of four different types of battery packs when connected to a typical LCD Point-Of-Purchase display (e.g., 5.5" with cycling LED Lights).

Supplied to 360° Test Labs...

Battery packs as follows:

- 1 Brand #1 battery pack containing 16 Alkaline D-cells connected as two paralleled series strings of 8 D-cells, PN: SAMPLE-1
- 1 Brand #2 battery pack containing 16 Alkaline D-cells connected as two paralleled series strings of 8 D-cells, PN: SAMPLE-2
- 1 BRAND battery pack containing 8 D-cell sized Lithium batteries connected in series, PN: SAMPLE-3
- 4 Brand #2 lantern batteries type SAMPLE-4, connected as two paralleled series strings of 2 lantern batteries

Estimation of Battery Pack Service Lifetime

Previous testing of a sample 5.5" LCD based POP display showed that when not being operated (in stand-by), the electronics within the display draws a continuous quiescent (or "idling") current of about 4 milliamperes. When being operated, the display draws about 296 milliamperes at an input voltage of 12 volts. Previous measurements had also shown that when the input voltage to a 5.5" LCD based POP display drops to about 7.5 volts, the display then malfunctions; thus, 7.5 volts can be assumed to be where the Batteries To Be Tested (BTBT) are considered at End-Of-Life (EOL).

A custom test jig was designed and built so as to provide a load closely simulating a 5.5" LCD based POP display being operated in normal use. The test conditions assume that the 5.5" LCD based POP is continuously restarted five seconds after it finishes its nominal operating period of 40 seconds. The test jig also provides continuous voltage and battery temperature monitoring which is computer recorded for further analysis.

Preliminary calculations indicated that a 4-cell battery pack consisting of two paralleled sets of two series-connected Brand #2 type SAMPLE - 4 lantern cells (for a total of 12 volts at a rated 52 ampere-hours, based upon the type SAMPLE - 4 specifications) should operate at a continuous loading of 300 milliamperes for approximately 8.26 days before the battery voltage drops to the 7.5 volt EOL assumption point.

The specification for Brand #2 type SAMPLE-2 D-cells shows that at a continuous discharge loading of 250 milliamperes, the batteries should provide about 14 ampere-hours of capacity at an EOL voltage of 0.8 volts per cell, or a total, in this application where 8 cells are connected in series, of about 6.4 volts. Since the desired EOL voltage is about a volt higher, and the actual loading is 20% higher, the actual ampere-hour capacity of the D-cell pack will be between 20 and 25% lower than that specification, or about 10.5 ampere-hours. Thus, two paralleled D-cell battery packs should provide about 21 ampere-hours in this application, and provide a service life roughly 40% that of the paralleled lantern batteries or about 3-1/3rd days.

The Lithium cells provided to 360° Test Labs are claimed to have a capacity about 3 times that of alkaline cells. Since the Lithium pack consists of only a series-connected string of cells, it is expected that their ampere-hour capacity will prove to be about 30; thus, assuming that their discharge voltage curve will be similar to that of alkaline cells, the Lithium battery pack should last approximately 57% of the service life of the lantern batteries, or about 4-3/4 days.

Test Jig Setup

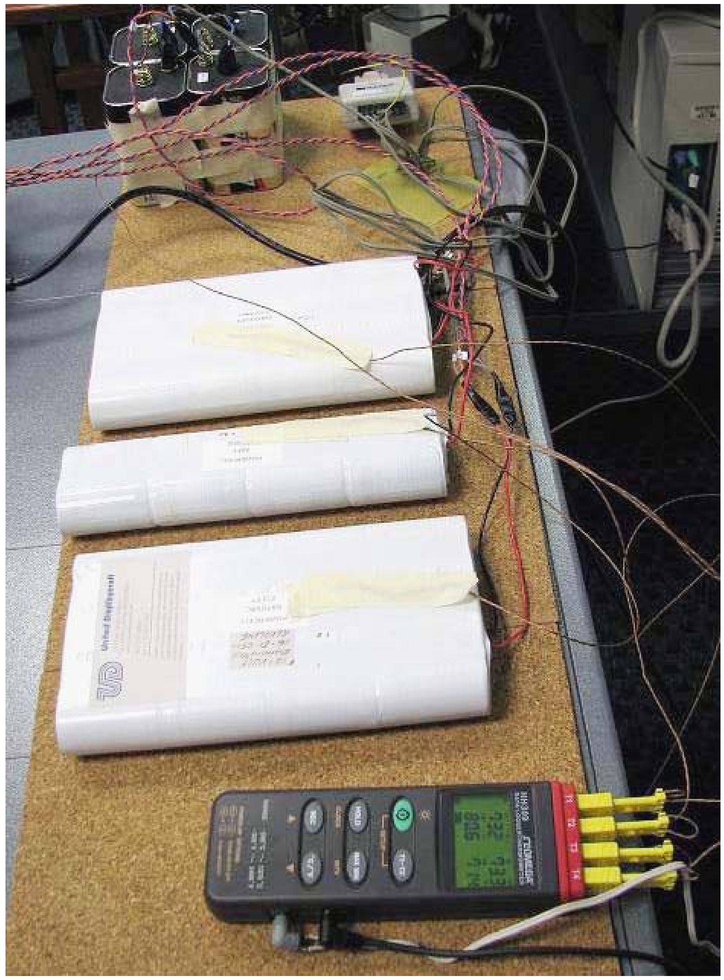
A test box was designed and built to provide an adjustable timed loading to four individual battery packs of about 296 milliamperes continuously with an adjustable off-time. The test box provides constant-current loading, which is assumed to be the same battery loading regimen that an actual 5.5” LCD based POP display provides.

360° Test Labs is assuming that the electronics within the display is operating from voltage regulators such that the voltage provided to the internal electronics is provided a constant voltage regardless of the actual battery voltage (until the battery voltage drops too low). This means that the actual current drawn from the battery pack power source will be constant until the point where the battery voltage drops below the minimum required input voltage at which the internal voltage regulator can provide a regulated output voltage to the electronics. Thus, the test jig was designed and built to provide a constant-current load of 296 milliamperes in one state, and a constant loading of 4 milliamperes in a second state. The time duration of each state is adjustable, and was set to 40 seconds of loading at 296 milliamperes and 5 seconds of loading at 4 milliamperes.

Monitoring of battery voltage is provided by a 4-channel analog-to-digital converter which output is provided to a computer, which stores the data. Thus, the data can be analyzed after the tests to observe the battery pack output voltage over time.

Temperature monitoring is performed by a 4-channel Data Logger Thermometer.

The photo at right shows the test setup. From left to right are the four Brand #2 alkaline lantern batteries; the Brand #2 D-cell pack; the Lithium D-cell pack; and the Brand #1 D-cell pack.



Preliminary Data

The unloaded voltage of each battery was measured before connection to the loading test jig:

Battery	Measured Voltage	Battery Type
A	12.841	Brand #1 Dual 8-D-cells
B	14.561	Lithium pack
C	12.986	Brand #2 Dual-8-D-cells
D	12.634	Brand #2 Dual-2 lantern batteries

The discharge test was begun; 29 minutes later, a “reality check” was performed and the following voltages measured:

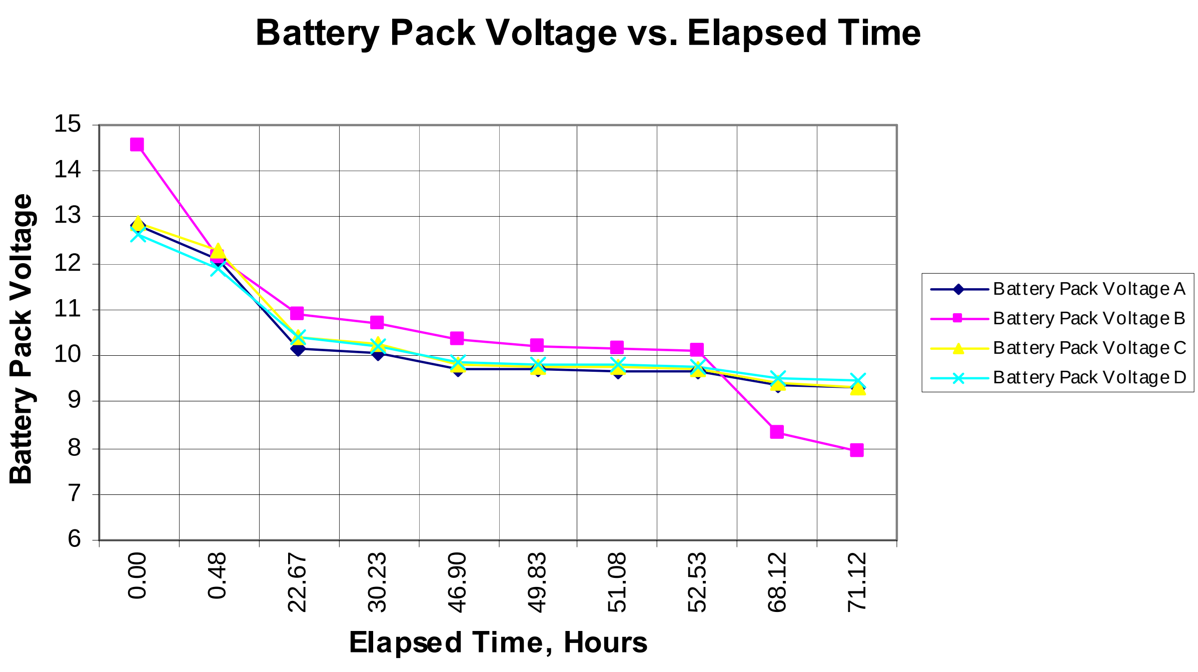
Battery	Measured Voltage After 30 Minutes	Battery Type
A	12.07	Brand #1 Dual 8-D-cells
B	12.117	Lithium pack
C	12.273	Brand #2 Dual-8-D-cells
D	11.905	Brand #2 Dual-2 lantern batteries

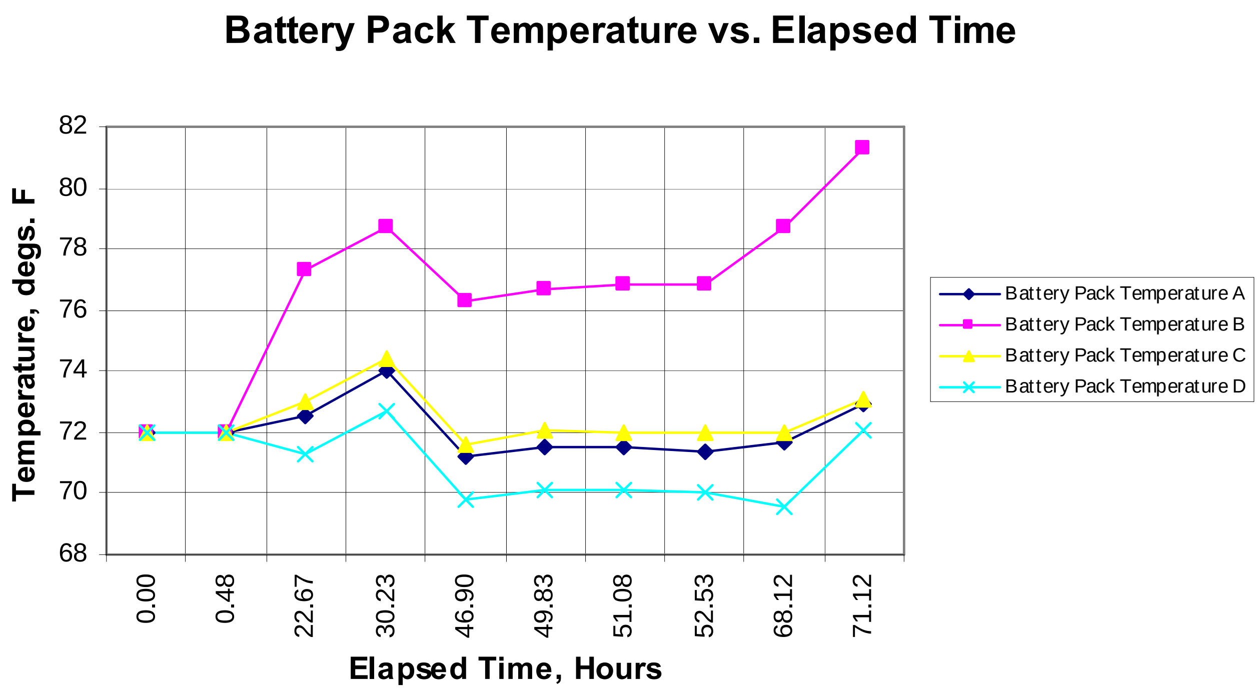
Note that the voltage of the Lithium battery pack has dropped significantly even after only a relatively short period of time of load testing, compared to the alkaline batteries.

The thermocouples of the Data Logging Thermometer were affixed to the middle cell of each D-cell pack and to the outside of one of the four lantern batteries. Initial ambient room temperature was 72° F and maintained between 70° and 73° F throughout the tests. The accuracy specification of the temperature recorder and thermocouples at 23° ±5°C is ±0.2% of the reading + 1°C.

The following chart list and graphically compare the measured battery pack voltages and temperatures versus elapsed time as of 12:00 P.M., 14 December:

Elapsed Time, Hours	Battery Pack Voltage				Battery Pack Temperature			
	A	B	C	D	A	B	C	D
0.00	12.841	14.561	12.896	12.634	72	72	72	72
0.48	12.07	12.117	12.273	11.905	72	72	72	72
22.67	10.17	10.88	10.38	10.4	72.5	77.3	73	71.3
30.23	10.05	10.708	10.236	10.219	74	78.7	74.4	72.7
46.90	9.721	10.361	9.83	9.855	71.2	76.3	71.6	69.8
49.83	9.688	10.226	9.763	9.812	71.5	76.7	72.1	70.1
51.08	9.654	10.159	9.763	9.787	71.5	76.8	72	70.1
52.53	9.654	10.091	9.729	9.753	71.4	76.8	72	70
68.12	9.387	8.303	9.388	9.509	71.7	78.7	72	69.6
71.12	9.32	7.927	9.325	9.483	72.9	81.3	73.1	72.1





Note that the Lithium battery's voltage has continued to drop precipitously and that its temperature has continued to rise. It is apparent that it is rapidly approaching the EOL assumption point of 7.5 volts much sooner than the other three battery packs.[1]

Some temperature swings of several degrees are likely due to the test lab's ambient temperature dropping overnight.

Preliminary Summary

After 73 hours, it was the Lithium battery pack that was first to drop below 7.5 volts, where the 5.5" LCD based POP was previously determined to malfunction. The Brand #1 pack is providing a slightly lower output voltage than either of the Brand #2 battery packs. So far, the Brand #2 lantern batteries appear to be holding up the operating voltage the highest although the Brand #2 D-cells were, up to 52.5 hours of operation, providing nearly the same output voltage.

[1] As of 2.45p EST on 12/14, the Lithium B battery pack is below the 7.5-volt threshold and considered past EOL. They survived ~73-hours of operation and ~5,840 total activation simulations.

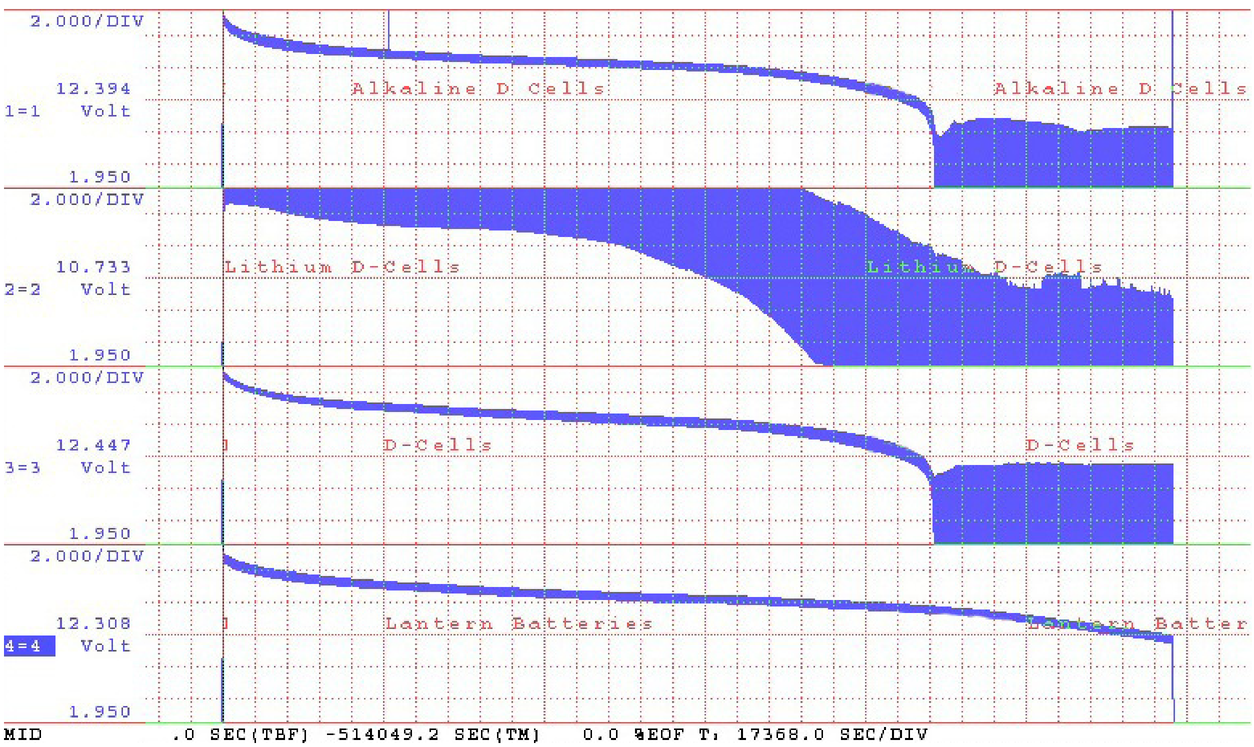
On The Graphs That Follow:
The exact test phase portrayed, along with differing battery characteristics, may result in a weak pack showing a voltage specification on the left margin that is significantly higher than the voltage that pack would have when fully loaded. Whereas, the plotted portions comprehensively indicate battery pack states.

UPDATE

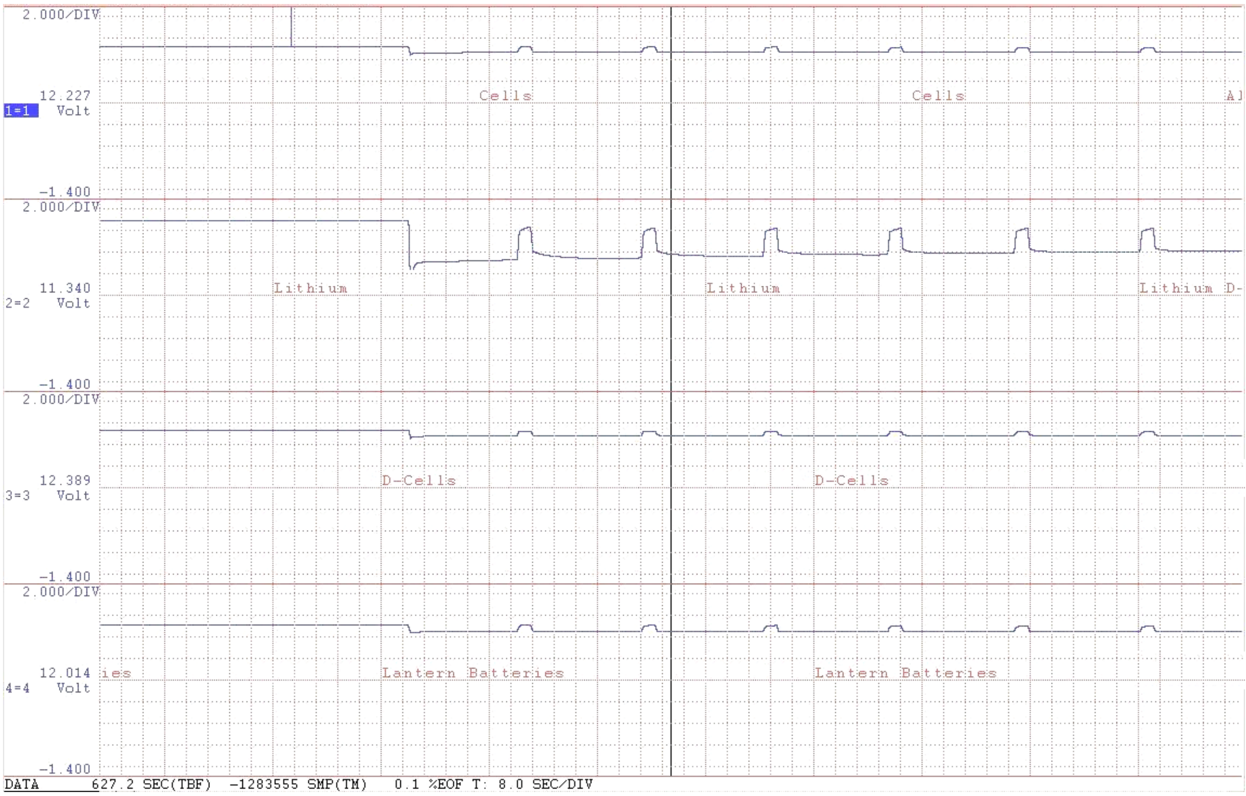
The following graph shows the entire discharge test from beginning to end. The graph consists of four plots, one for each battery pack.

The vertical axis is battery voltage while the horizontal axis is elapsed time. Battery pack A is the top trace, followed by B, C and D. The center line of each of the four plots, over which the battery type is written in text, is 7.5 volts. Each vertical division on each plot represents 2 volts.

The thickness of each of the traces is due to the battery voltage dropping when the 296 milliampere load is switched on, and then the voltage rises again as the load is switched off.

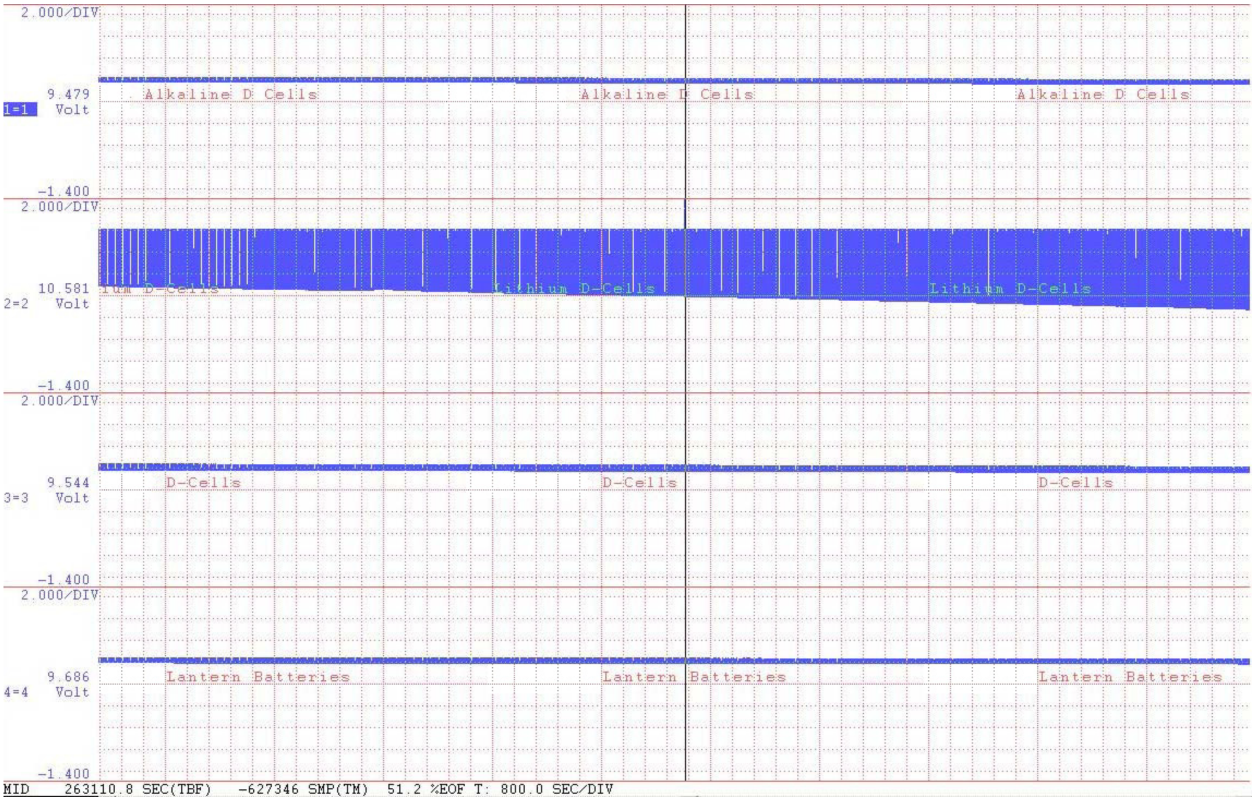


The below graph shows a much smaller period of time—the beginning of the discharge tests shortly after the load cycling test box was turned on. Note how the voltage from each battery dropped slightly as the 296 milliampere load was switched on, then rose after the heavy load was turned off, leaving the idling load of 4 milliamperes connected.



At the left side can be seen the voltage as measured where the center cursor intersects the battery voltage trace. The plot above is set to 2 volts per vertical division and 8 seconds per horizontal division. It can be seen that the voltage of the Lithium pack drops by more than 2 volts, even when fresh, shortly after the load cycling was begun, whereas the two D-cell packs show about ½ volt drop, and the lantern batteries show slightly more than ½ volt drop.

This next plot shows how the Lithium pack's output voltage was dropping as it approached and went through the EOL point of 7.5 volts. At this point, the total voltage swing of the Lithium pack was nearly 6 volts as the load cycled between 4 and 296 milliamperes.

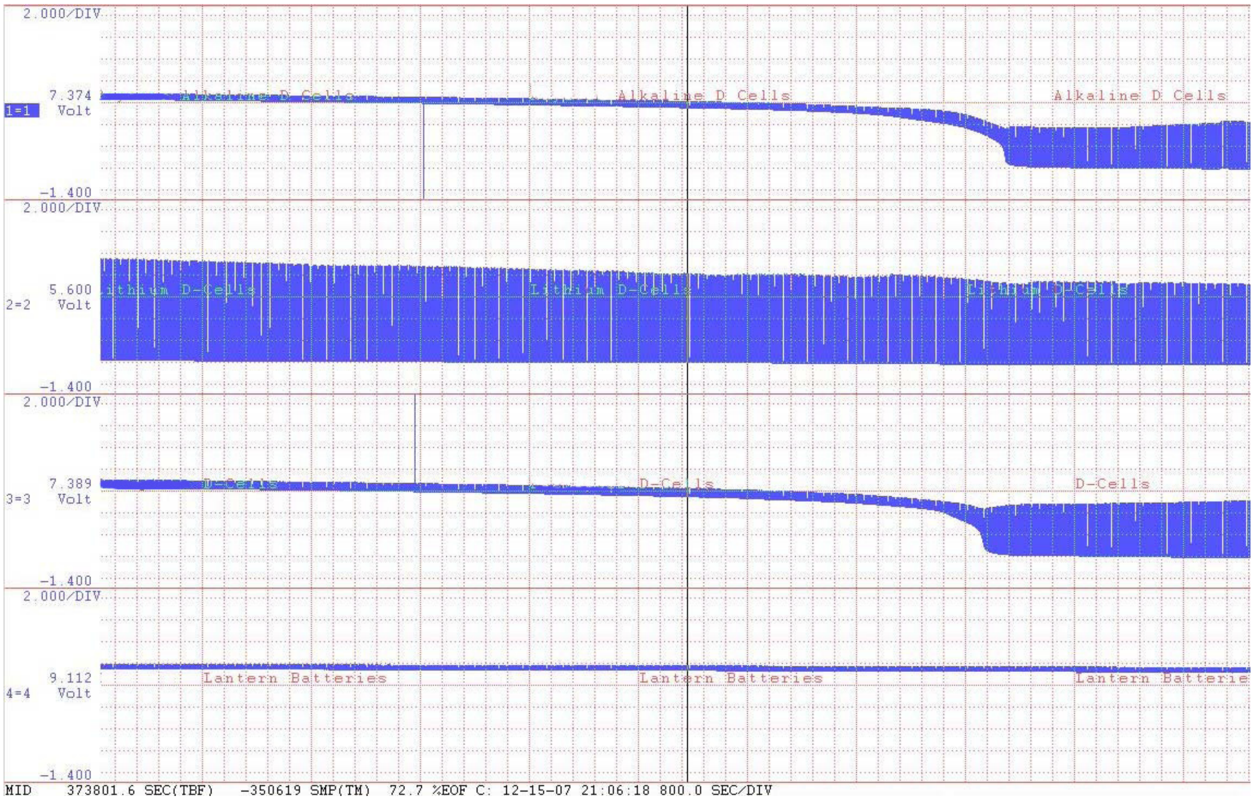


Each battery's output voltage first dropped below 7.50 volts (EOL) after the number of hours shown below:

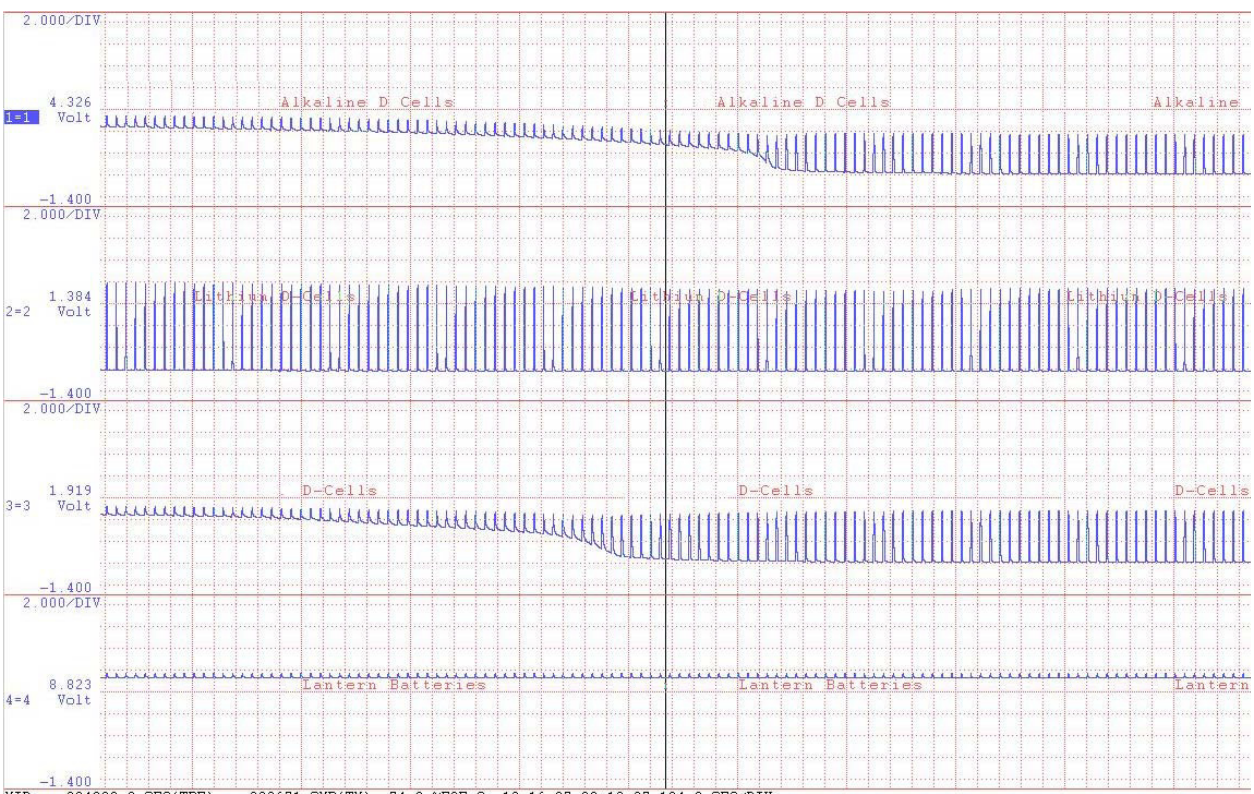
Battery Pack	Elapsed Time	Battery Type
A	101.00 hrs	Brand #1 Dual 8-D-cells
B	72.93 hrs	Lithium pack
C	100.92 hrs	Brand #2 Dual-8-D-cells
D	133.76 hrs	Brand #2 Dual-2 lantern batteries

Note that the Brand #1 pack was able to outlast the Brand #2 D-cell pack by only a matter of about 5 minutes.

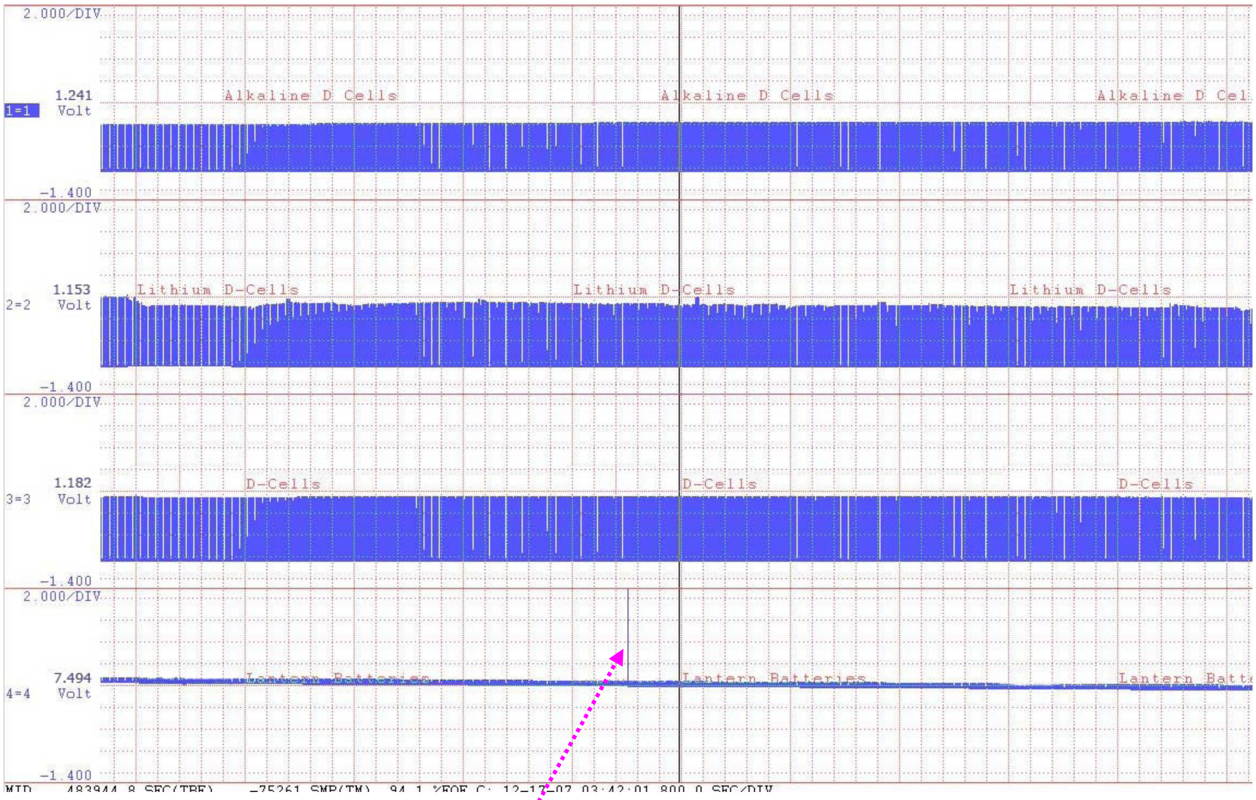
The plot below shows how each battery pack's output voltage was dropping at the time that batteries A and C were discharging through 7.5 volts.



Note that End-Of-Life is quite obvious for battery packs A and C, as their loaded versus unloaded voltages deviated very noticeably and widely after about 106.8 hours. The chart below shows greater detail of this true EOL time period.



Note that on the above graph, according to the left side readout of each trace, although the Brand #2 D-cells have dropped to about 1.92 volts, the Brand #1 D-cells are continuing to hold up a bit better at 4.33 volts. The Lithium cells have dropped to a total of less than 1.4 volts, while the lantern batteries are still holding up well at 8.8+ volts.



The plot above shows what was happening as the lantern batteries dropped below 7.5 volts, as denoted by the short blue marker line extending upward from the bottom plot. At this point, the Brand #1 cells measured 1.24 volts, the Lithium yielded 1.15 volts, and the Brand #2 D-cells were down to 1.18 volts.

In the table that follows, we estimate the number of days to EOL based on a range of activation levels for a 5.5" LCD based POP type display. The table shows the elapsed time for each battery to drop to 7.5 volts; the calculated number of cycles that each battery provided over that time; the calculated ampere-hour capacity of each battery based upon the elapsed time and number of cycles; and an estimate of how many days of full operation each battery should provide at 50, 30 and 15 cycles per day (based upon the ampere-hour capacity calculated as a result of the discharge test).

Estimates are based upon the discharge test provided. Our discharge cycling test represents a worst-case discharge condition since the "activation" duty cycle was not only very high but also continuous. In reality, the number of daily display activations are more likely to be in the modeled 15 - 50 / day, as opposed to the tested 1920 daily activations.

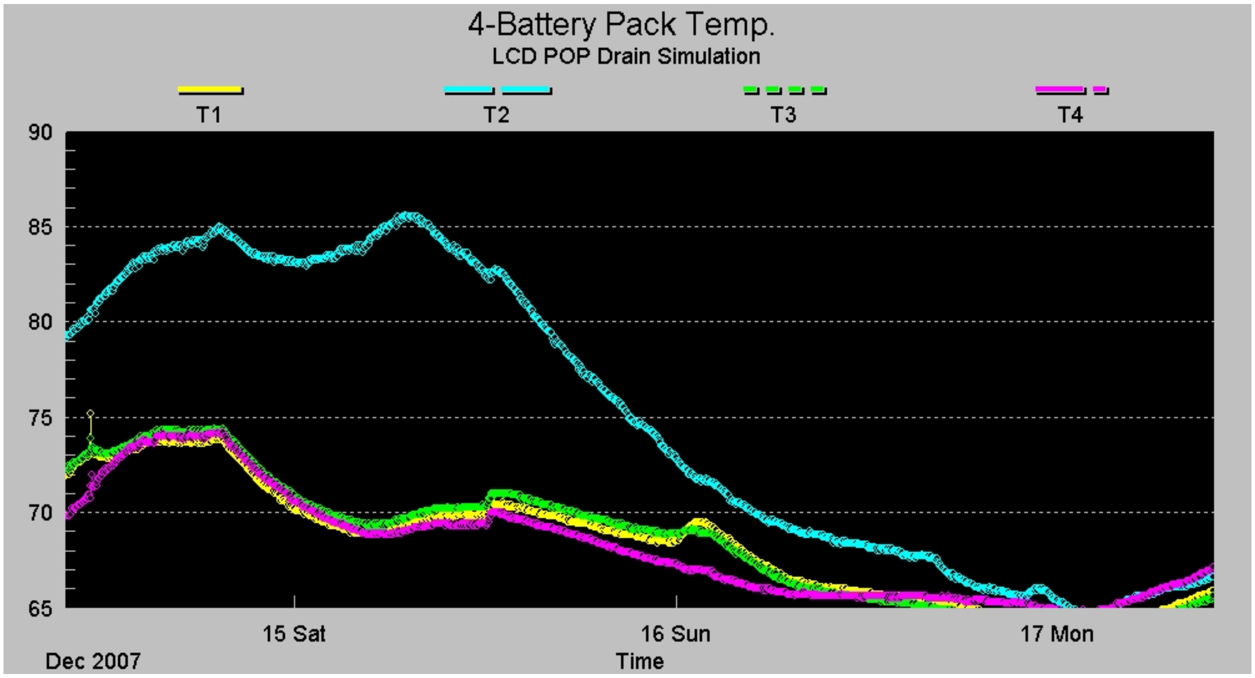
Since the discharge test had a very high activation-time duty cycle (88.9% on, 11.1% off [2]), the below battery life estimates for 50, 30 and 15 daily activations, based on this test data, are very conservative -- even without factoring in all the variables associated with long-term battery use and storage.

Battery Pack	**Elapsed Time, Hours**	**Number of Cycles that Each Battery Lasted**	**Apparent Ampere-Hours**	**Days Operational [3] at 'x' Activations Per**		
				x = **50**	**30**	**15**
A	101	8080	26	**48.5**	**107.7**	**287.7**
B	72.9	5834	19	**23.5**	**78.7**	**210.2**
C	100.9	8074	26	**48.5**	**107.6**	**287.4**
D	133.8	10701	35	**65.3**	**144.9**	**387.2**

Further, since testing determined when the various battery packs would reach EOL in relation to a 5.5" LCD based POP like display, we were able to compute when the batteries no longer will properly operate the display, as opposed to past calculations that estimated battery life until complete draining.

[2] Off refers to the nominal 4-milliamp load used to simulate a continuous marquee LED operation

[3] Operational is defined as normal video display functioning (i.e., > 7.5-volts available)

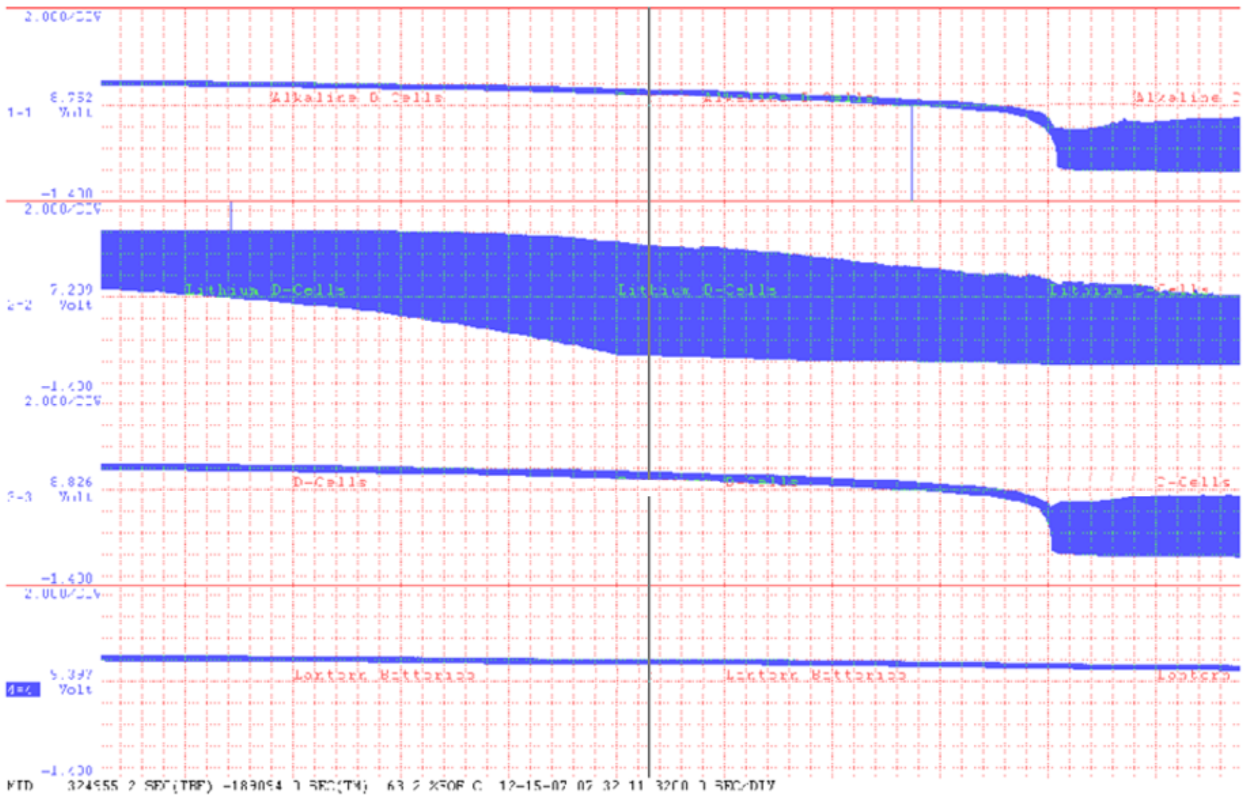


T1, the yellow trace, is battery A, or the Brand #1; T2 is the Lithium pack, T3 the Brand #2 D-cell pack, and T4 is the lantern battery pack. Although all of the Alkaline cells also showed evidence of temperature rise, the rise was only several degrees.

The drop of all temperatures to about 65 degrees early Monday morning indicates that the lab ambient temperature had dropped substantially lower than anticipated. A peak can be seen occurring late Friday night with the temperature then dropping overnight until between 6 and 8 am Saturday morning, when all temperatures then began rising slightly once more before falling off for good after midday Saturday.

The first temperature peak of the Lithium cells was 85.0°F and occurred at 7:17 P.M., 12/14/07, 78.5 hours after discharge testing began. At this time, the Lithium pack's voltage was recorded as 6.345 volts and was merely decreasing slowly with no noticeable "artifacts" on the voltage discharge curve.

The second (and largest) temperature peak of the Lithium pack occurred at about 7 A.M., 12/15/07, approximately 90 hours after the inception of testing; the pack's voltage had dropped to about 2.16 volts. This time, there is an interesting incident occurring; see the voltage plot below.



The black center cursor is placed within a few seconds of when the Lithium battery pack's temperature peaked the second time, and it can be seen that the voltage under load had suddenly changed slope.

Another interesting observation is that both the D-cell battery packs maintained a higher voltage under load until they reached their EOL; note the sudden downturn in the curves above for battery packs A and C. This occurred when pack A's voltage was down to 5.88 volts while pack C's voltage was 5.927; the lantern batteries, had not reached the 7.5 volts EOL point yet, measuring 8.84 volts. The elapsed time was just under 107 hours. The discharge test was stopped before the lantern batteries had discharged to this point of a sudden drop in output voltage.

Comparison of Actual Life vs. Estimated Life

Before the discharge tests began, ez-Lab engineers roughly estimated the lifetime to be expected for each battery pack, in the case of the Brand #2 D-cells, based upon published manufacturer's data. The table below shows our original estimates and the actual, observed lifetime.

Battery Pack	Est. Lifetime, Hrs.	Actual Lifetime, Hrs.
A	80	101
B	114	73
C	80	101
D	198	134

The estimate for the Lithium pack was made based upon customer information that this battery pack was claimed by the manufacturer to be able to last three times as long as alkaline D-cells.

The lifetime estimate for the Brand #2 lantern batteries was based upon a curve in the data sheet labeled "LIGHTING: 33 ohm 30/min/hour 8 hrs/day", the closest application shown to the loading factor that was actually applied to simulate a 5.5" LCD based POP like display. However, in addition, there is another chart showing how the milliampere-Hours capacity is decreased with a heavier load.

For example, the lantern batteries are rated at 26 ampere-hours with a constant 25 milliampere load (discharged to an EOL of 3.2 volts, or 6.4 volts in our application), but if the load is increased to 100 milliamperes, the rating decreases to about 20 ampere-hours.

It is apparent that the loading that this discharge test simulated closely approximates a constant load of slightly under 300 milliamperes. The duty cycle was 5 seconds off, 40 seconds on, or about 89%. This would be an average loading of about 263 milliamperes. This can be divided by two since for this application, two sets of two series-connected lantern batteries were connected in parallel, effectively doubling the total ampere-hour capacity. Thus, for comparison against the published graph, the actual continuous load current can be assumed to be about 132 milliamperes, about 33% larger than the graph's data.

If the actual battery capacity is assumed to be about 18000 millimapere-hours at our load of 132 milliamperes, then dividing the milliampere-hour capacity by the load current yields 136 hours, very close to the actual lifetime obtained to discharge to 7.5 volts.

The discharge test was terminated before the lantern battery was discharged to 6.5 volts; so direct comparison is not possible. The lantern battery's voltage had dropped to about 7.0 volts by test termination, which occurred about 5 hours after the lantern battery's voltage had dropped through 7.5 volts.

Based upon the discharge curves of the D-cells from 7.5 volts to 6.5 volts, it seems reasonable to expect that the lantern battery's voltage would have dropped from the test-termination-point of 7.0 volts to 6.5 volts after no more than another 5 hours, and more likely 4. Adding the 5 hours for dropping from 7.5 to 7.0 volts, to 5 hours to drop further to 6.5 volts, to the actual lifetime measured of 134 hours, would exceed the Brand #2's published capacity by several percent.

On the other hand, the lifetime of the D-cells was under-estimated by approximately 20%, which can be accounted for by noting that the estimation was based upon the full load of 296 milliamperes which was not reduced by the operational duty cycle of 40 seconds on, 5 seconds off. Thus, the actual measured capacity of the D-cells indicates they actually exceeded the typical ampere-hour capacity by about 10%, just as the lantern batteries did.

The manufacturer and model of the Lithium battery cells was unknown before the batteries were received by 360° Test Labs; however, examination of the received batteries shows that these cells are type Model#, made by BRAND. A search of the BRAND website brings up a data sheet for these cells, showing the following characteristics:

Nominal capacity *(at 5 mA + 20°C 2.0 V cut off. The capacity restored by the cell varies according to current drain, temperature and cut off)*	17.0 Ah
Open circuit voltage (at + 20°C)	3.67 V
Nominal voltage (at 0.7 mA + 20°C)	3.6 V
Pulse capability: *(400 mA/0.1 second pulses, drained every 2 mn at + 20°C from undischarged cells with 10 µA base current, yield voltage readings above 3.0 V. The readings may vary according to the pulse characteristics, the temperature, and the cell's previous history. Fitting the cell with a capacitor may be recommended in severe conditions. Consult BRAND)*	Typically up to 400 mA
Continuous current permitting 50% of the nominal capacity to be achieved at + 20°C with 2.0 V cut off. *(to maintain cell heating within safe limits. Battery packs may imply lower level of maximum current and may request specific thermal protection. Consult BRAND)*	250 mA

Several specifications shown above are of interest:

- Nominal capacity is stated as 17 ampere-hours at 5 milliamperes load
- “Continuous current permitting 50% of the nominal capacity to be achieved at +20°C with 2.0 V cut off: 250 mA”

Thus, at a continuous current load of 250 milliamperes, the actual capacity is stated to be half of nominal, or just 8.5 ampere-hours. Since there were two paralleled strings of cells, the actual capacity should have been twice that or 17 ampere-hours, for a cutoff voltage of 8.0 volts. Examining the discharge curve for the Lithium batteries, the elapsed time to 8.0 volts was found to be 70.6 hours. Dividing the total ampere-hour capacity of the battery pack, 17, by 70.6 hours, yields a constant current of 241 milliamperes, slightly less than the actual average current draw of the test setup.

The ... data sheet also contains several graphs, one showing loading of a Model# cell at 100 and 200 milliamperes. Extrapolating that graph to about 132 milliamperes (since there are two paralleled cells) and an EOL cell voltage of 1.875 (since four cells are in series) gives an estimated lifetime of 70 to 80 hours, within the range of what the battery pack actually provided.

Summary

The least-capable battery pack, both in terms of ability to support a 296 milliampere load and in terms of ampere-hour capacity at that load current, was the set of BRAND Lithium-ion cells; this pack dropped below 7.5 volts after only 73 hours. In contrast, the two sets of alkaline D-cells both dropped below 7.5 volts after 101 hours, within minutes of one another, even though they were made by different manufacturers and clearly, according to the observed voltage discharge curves, were made either of slightly different materials or internal construction. The alkaline lantern batteries lasted 33% longer than the D-cell packs.