“1.5 Volt” vs. “1.2 Volt” Batteries

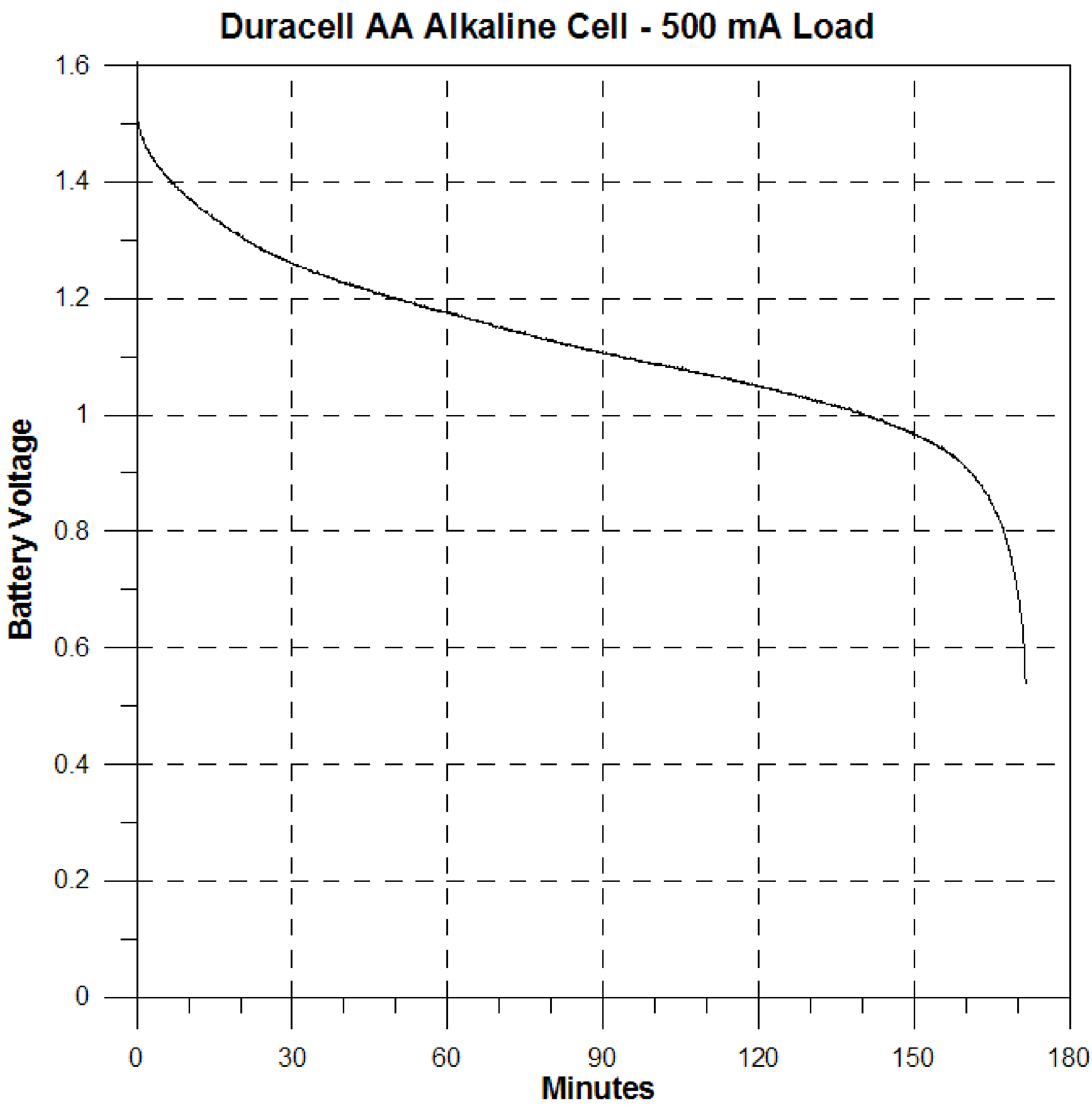
by Roy Lewallen

Very often I’ve read statements like **“1.2 volt NiMH cells can’t be used in some equipment designed for 1.5 volt alkaline cells because the voltage is too low.”**

This is a ***myth*** resulting from a number of misconceptions. I’ll explain why it isn’t true.

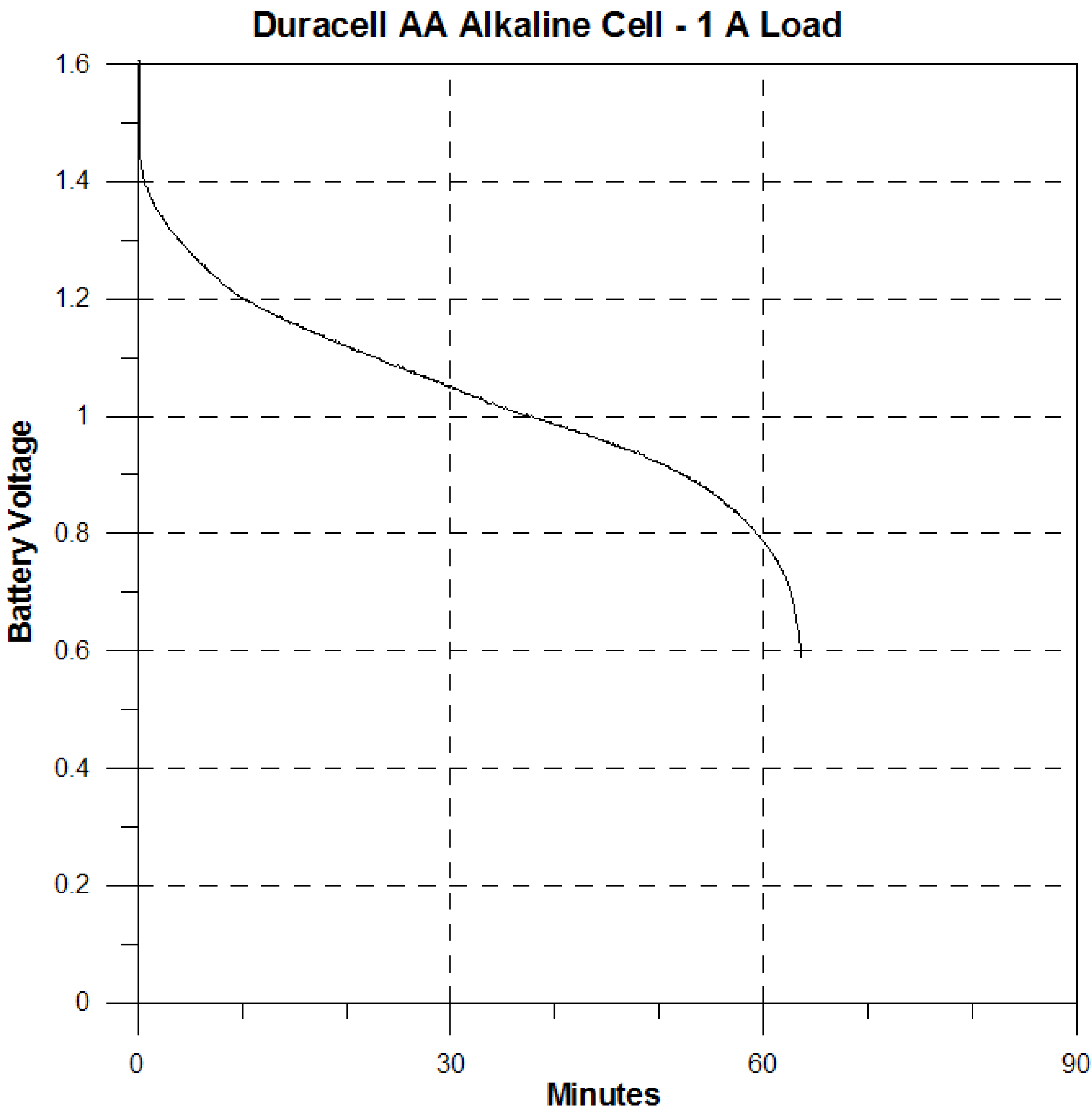
Misconception 1: Alkaline cells deliver 1.5 volts and NiMH cells deliver 1.2 volts.

A cell doesn’t deliver a constant voltage. The voltage drops as the battery discharges, and it also drops due to internal resistance as the load increases. As an example, here’s a graph of the voltage of a “1.5 volt” alkaline cell – a fresh Duracell AA – with a constant 500 mA load:



It’s obvious from this graph that the “1.5 volt” cell delivers 1.5 volts for only the first few seconds of the discharge. And for the majority of the discharge period, its voltage is less than 1.2 volts.

The voltage, of course, drops more if the load current is greater, and less if it's less. 500 mA is a modest drain for something like a flashlight – many draw 1 amp or more. Some cameras draw many times this current when activating a flash. Radios and modern GPS receivers, on the other hand, draw much less. But as I mentioned, 1 amp isn't an unusually high drain for some battery powered devices including flashlights, so let's see what that same cell does at a 1 amp discharge rate:

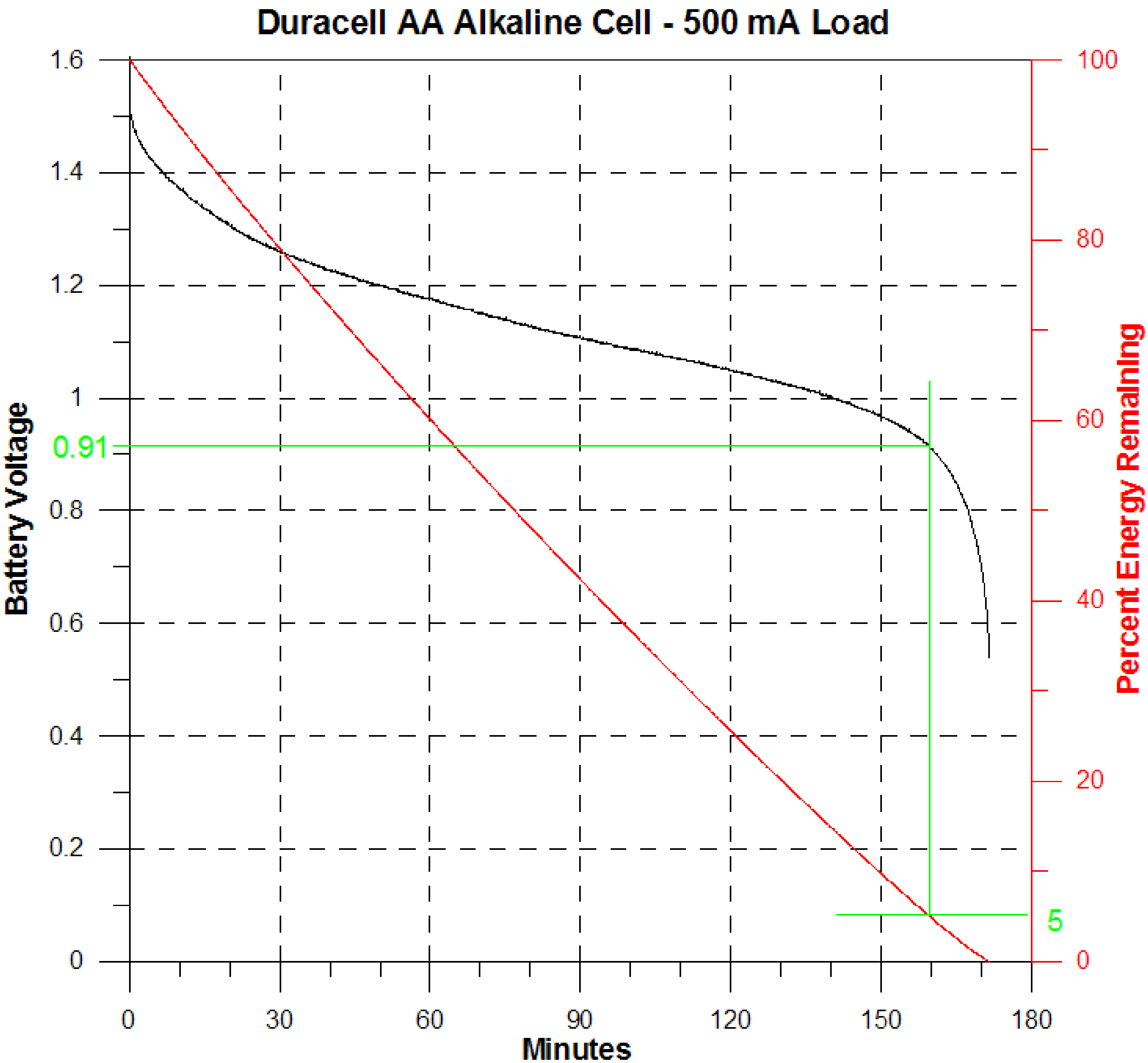


At this discharge rate, the cell voltage is less than 1.2 for all but about the first ten minutes of the hour-long discharge period. This brings us to. . .

Misconception 2: Devices designed for alkaline cells require 1.5 volts.

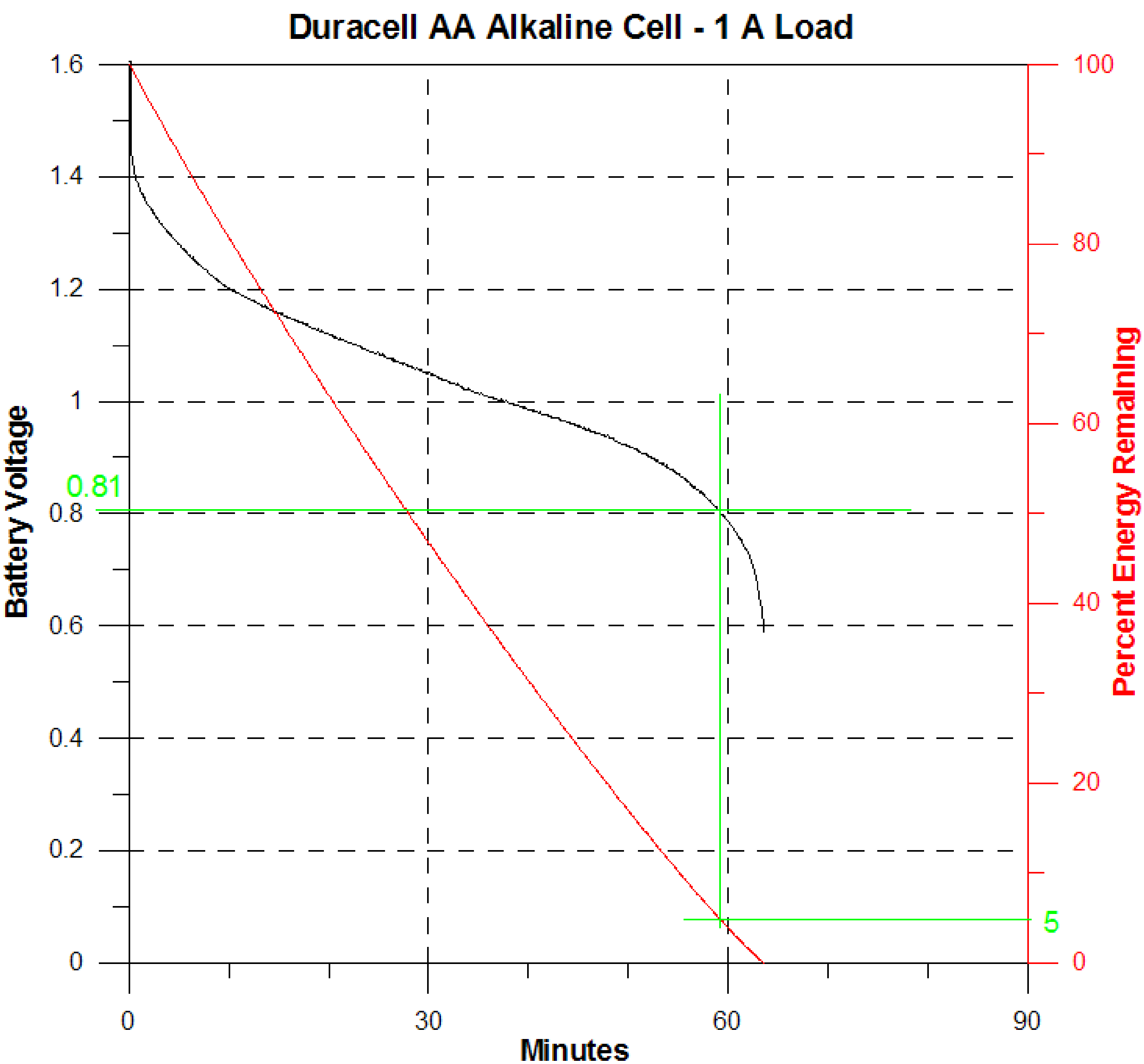
It's obvious from these graphs that even if a device having these current drains required 1.2 volts or more, it would quit a long time before the cell was fully discharged.

A cell can deliver some total amount of ***energy***. Energy, when dealing with batteries, is the product of power and time. There are many common units of energy, including joule (the fundamental MKS unit which equals a watt-second), the dieter's calorie, the heater and air conditioner's BTU, our power company's kilowatt-hour, and many others. Any of these can readily be converted to any other. For this analysis I'll use the watt-hour (Wh), which equals 3600 joules. The energy in a cell can be delivered slowly (low current load), rapidly (high current load), or at any rate between. The total amount of energy a cell can deliver depends on the discharge rate and conditions. In general, a cell will deliver less total energy if discharged at a high rate than it does if discharged at a low rate. The next graph shows the percentage of remaining deliverable energy as a function of time for the alkaline cell at a 500 mA discharge rate.



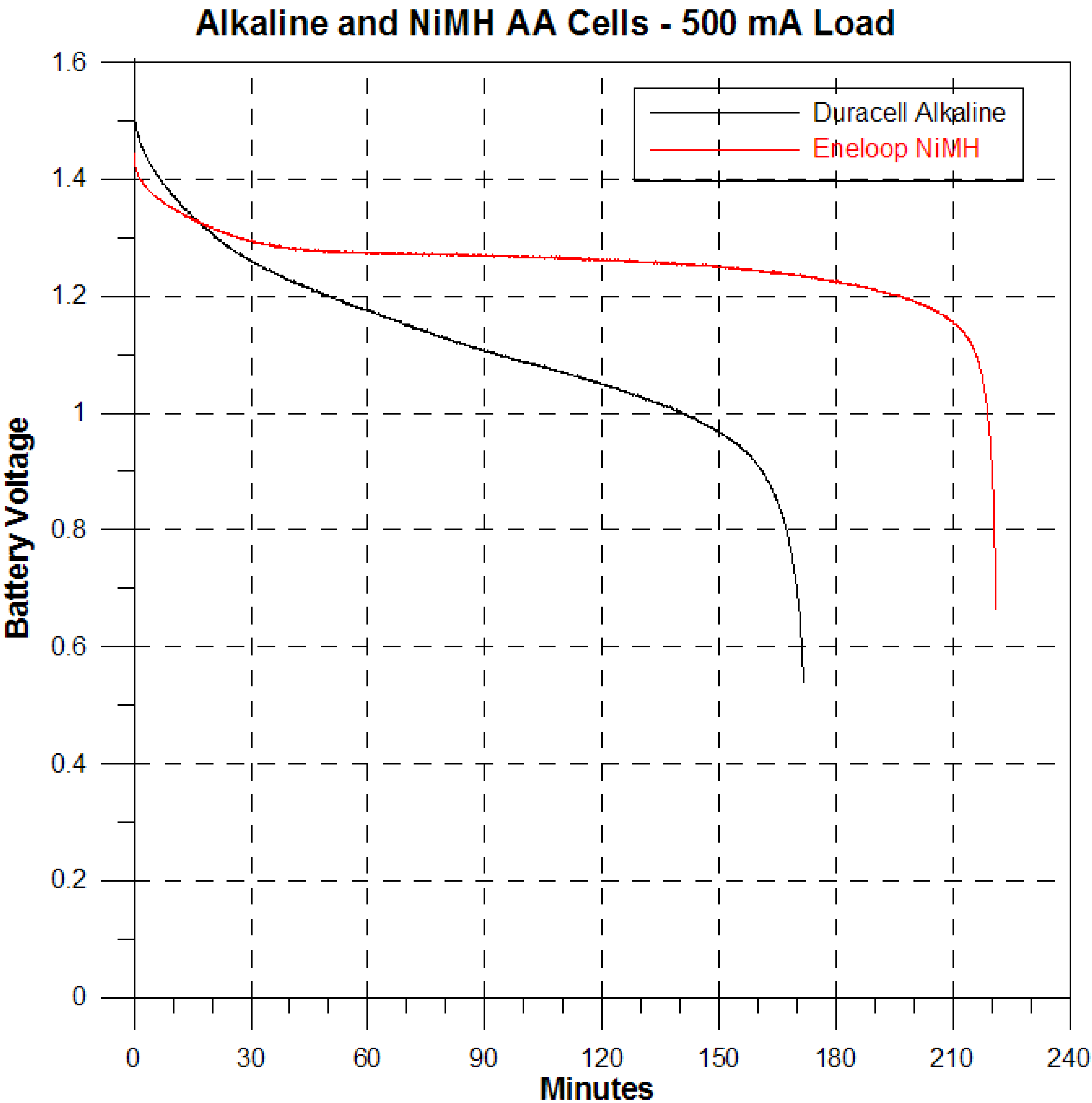
This graph shows two important facts. The first is that when the cell voltage is 1.2 volts, about 65% of the available energy is still remaining in the cell. So any device which would fail to work when the cell reached 1.2 volts would extract only about 35% of the available energy from the cell. The other is that in order to extract 95% of the available energy, the device must function until the cell voltage drops to 0.91 volt. ***Any properly designed device intended to operate from alkaline cells must function until the cell voltage drops to about 0.9 volt or lower (at this current drain).***

Here's the equivalent plot with 1A current drain:



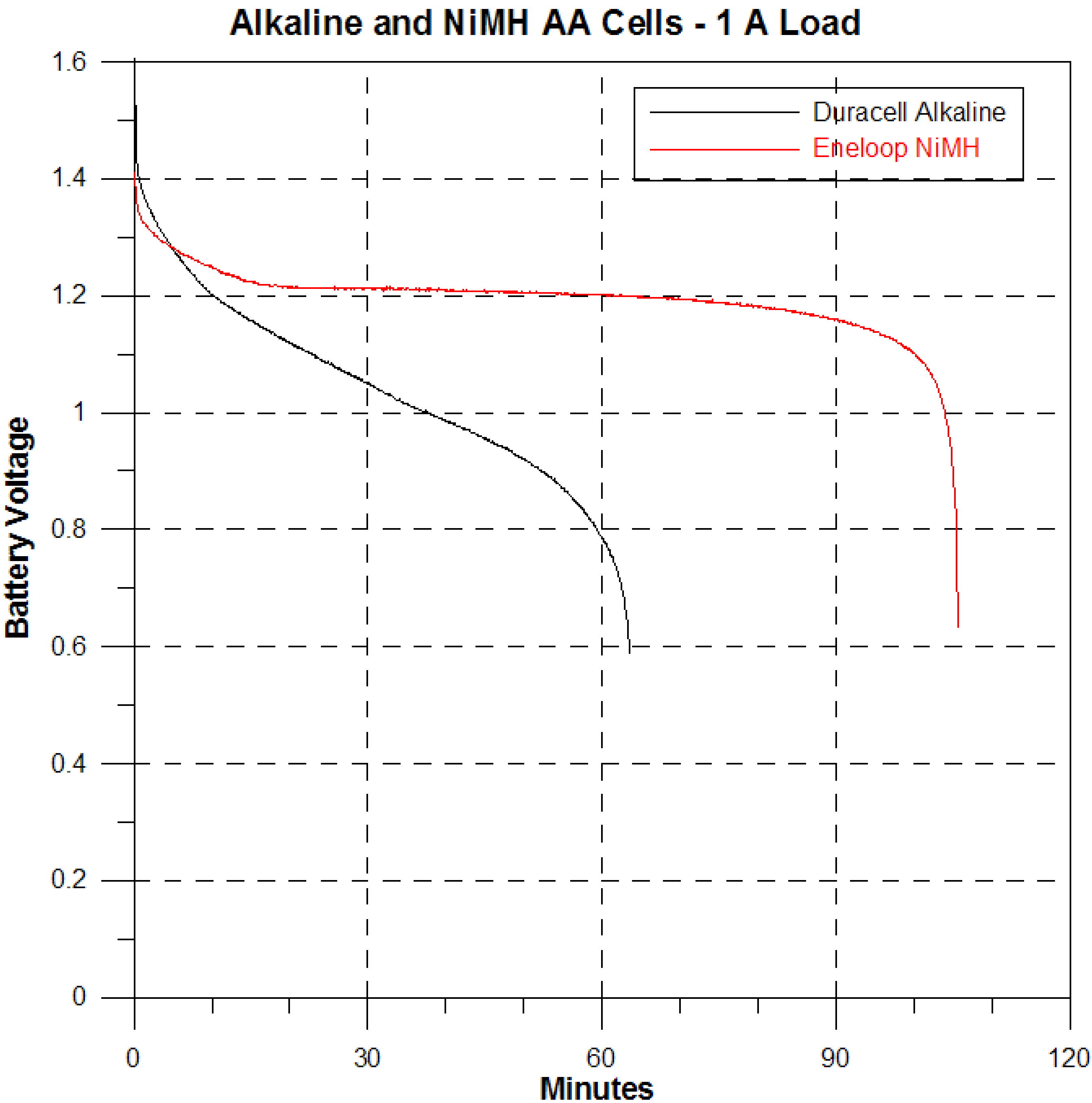
With the higher current drain, only about 25% of the available energy has been extracted when the cell voltage reaches 1.2, and the cell has to be discharged to about 0.8 volt in order to extract 95% of the available energy. Incidentally, the available energy at 500 mA is 1.60 Wh, and at 1 A, 1.10 Wh.

Now let's see how a NiMH cell stacks up against the alkaline cell at these current drains. First, a comparison at 500 mA. The NiMH cell is a 2000 mAh Sanyo Eneloop, which rested for several hours after charging.



Here we can see that after the first 15 minutes, the "1.2 volt" NiMH cell voltage is higher than the "1.5 volt" alkaline cell voltage! The total energy delivered by the alkaline cell, as noted above, is 1.60 Wh. The NiMH cell is delivering 2.31 Wh.

The final graph is a comparison of the same cell types at 1 A:



At this current drain, the NiMH cell voltage is higher than the alkaline cell voltage for all but less than the first five minutes. It's interesting to note that the alkaline cell is delivering 1.10 Wh at 1 A, or 69% of the energy it did at 500 mA, but the NiMH cell is delivering 2.10 Wh, or 91% of the energy it did at 500 mA. So while both deliver less total energy with the higher discharge current, the alkaline cell's energy capacity drops much more than the NiMH cell's.

Misconception 3: Multiple cell devices are more of a problem because the total voltage difference is greater.

The observations and analysis above applies exactly the same to multiple cell devices as it does single cell devices. All that's needed is a slight modification of a statement made earlier: ***Any***

properly designed device intended to operate from alkaline cells must function until the voltage <u>per cell</u> drops to about 0.9 volt or lower (at 500 mA for AA cells) or about 0.8 volt or lower (at 1 A for AA cells). If it doesn't, then the device will quit functioning before the battery is drained. To see what happens with a multiple cell device, simply multiply the voltage at the left of each of the graphs by the number of cells. The relationship between the alkaline and NiMH cells remains exactly the same.

For example, a six-cell device that quits working when the battery voltage reaches 7.0 volts is quitting when the cells are each at 1.17 volts (assuming they're equal). From the graphs above, you can see that an alkaline cell draining at 500 mA still has over 60% of its energy remaining at 1.17 volts, and about 75% remaining if the drain is 1 A. So this would be a very poorly designed device for alkaline cell use, and would eat batteries much faster than it should.

The analysis above also applies generally for other cell sizes, but with the currents scaled according to the relative cell capacity. For example, an AAA cell has about 1/3 the capacity of an AA cell. So the 500 mA graphs would apply to AAA cells being drained at 500/3 = 167 mA, and the 1 A graphs to AAA cells being drained at 333 mA. There might be some additional factors involved because of the different cell construction, however, so the voltage crossover might occur at a somewhat greater or lesser discharge point. I'll run some tests of other cell sizes as time permits.

The conclusions are that:

1. You can use "1.2 volt" NiMH cells in devices which are *<u>properly</u>* designed to use "1.5 volt" alkaline cells.
2. At moderate to high current drains, NiMH cells will work much better in these devices than alkaline cells, delivering both a higher voltage during discharge and greater total energy.
3. The above conclusions apply exactly the same to multiple cell devices as to single cell devices.

I hope this has been helpful in gaining a better understanding of basic battery use. Comments, suggestions, and corrections are welcome. Please send them to w7el@eznec.com.

Roy Lewallen
August 30, 2007