Nickel Cadmium Batteries
Application Manual

The nickel-cadmium battery is a remarkable device. More than fifty years of successful use has proved this point. Nickel-cadmium batteries may be recharged many times and have a relatively constant potential during discharge. They will stand more electrical and physical abuse than any other cell, have good low temperature performance characteristics, and are more than competitive with other systems in terms of cost per hour of use. They are true storage batteries using one of the very best electrochemical systems.

"Eveready" Sealed Nickel-cadmium Cells

The nickel-cadmium cell has been used in Europe for many years in its original form, as a vented or unsealed cell. Technological advances have made possible the extension of the nickel-cadmium system to small hermetically sealed batteries-rechargeable batteries that are free of the usual routine maintenance, such as the addition of water. These developments have brought the economic advantages of rechargeability to small batteries.

"Eveready" sealed nickel-cadmium cells can be recharged many times to give long useful life, and are not adversely affected by standing many months, either charged or discharged.

These high quality batteries, when used within their recommended ratings and in applications where the use of rechargeable cells is justified, will provide economical, trouble-free service. New portable devices requiring more energy than is economically available from ordinary primary batteries are practical with this complete line of rechargeable batteries.

Applications

"Eveready" sealed nickel-cadmium batteries are ideally suited for use in many types of battery-operated equipment. Some of the many applications are listed here:

- Calculators
- Cassette players and recorders
- Dictating machines
- Digital Cameras
- Instruments
- Personal Pagers
- Photoflash equipment

- Portable communications equipment
- Portable hand tools and appliances
- Portable computers
- Radios
- Radio control models
- Shavers
- Tape recorders
- Television sets
- Toothbrushes

Operation of the Sealed Nickel-Cadmium Battery

Any secondary cell is a combination of active materials which can be electrolytically oxidized and reduced repeatedly. The oxidation of the negative electrode occurring simultaneously with the reduction of the positive generates electric power. In a rechargeable battery both electrode reactions are reversible and the input of current in the proper direction from an outside source will drive the primary or discharge reaction backwards and in effect recharge the electrodes.

In the uncharged condition the positive electrode of a nickel-cadmium cell is nickelous hydroxide, the negative cadmium hydroxide. In the charged condition the positive electrode is nickelic hydroxide, the negative metallic cadmium. The electrolyte is potassium hydroxide. The average operating voltage of the cell under normal discharge conditions is about 1.2 volts. The over-all chemical reaction of the nickel-cadmium system can be considered as:

(Charged) KOH (Discharged)

$$Cd + 2NiOOH + 2H_2O \Leftrightarrow Cd(OH)_2 + 2Ni(OH)_2$$

During the latter part of a recommended charge cycle and during overcharge, nickel-cadmium batteries generate gas. Oxygen is generated at the positive (nickel) electrode after it becomes fully charged and hydrogen is formed at the negative (cadmium) electrode when it reaches full charge.

These gases must be vented from the conventional nickel-cadmium system. In order for the system to be overchargeable while sealed, the evolution of hydrogen must be prevented and provisions made for this reaction of oxygen within the cell container. These things are accomplished by the following:

- The battery is constructed with excess capacity in the cadmium electrode.
- Starting with both electrodes fully discharged, charging the battery causes the positive electrode to reach full charge first and it starts oxygen generation. Since the negative (cadmium) electrode has not reached full charge hydrogen will not be generated.

- The cell is designed so that the oxygen formed in the positive electrode can reach the metallic cadmium surface of the negative electrode which it oxidizes directly.
- Thus, in overcharge, the cadmium electrode is oxidized at a rate just sufficient to offset input energy, keeping the cell in equilibrium indefinitely. At this point of equilibrium the positive electrode is fully charged and the negative is somewhat less than fully charged.

Polarity Reversal:

When cells are connected in series and discharged completely, small cell capacity differences will cause one cell to reach complete discharge sooner than the remainder. The cell which reaches full discharge first will be driven into reverse by the others. When this happens in an ordinary nickel-cadmium sealed cell, oxygen will be evolved at the cadmium electrode and hydrogen at the nickel electrode. Gas pressure will increase as long as current is driven through the cell and eventually it will either vent or burst. This condition is prevented in some sealed nickel-cadmium cells by special construction features. These include the use of a reducible material in the positive in addition to the nickel hydroxide, to suppress hydrogen evolution when the positive expires. If cadmium oxide is used it is possible to prevent hydrogen formation and to react the oxygen formed at the negative by same basic process used to regulate pressure during overcharge.

A cell is considered electrochemically protected against reversal of polarity if, after discharge at the 10 hour rate down to 1.1 volts, it may receive an additional 5 hour discharge with the same current without being damaged or otherwise affected. "Eveready" cylindrical cells are protected against cell rupture, caused by gassing generated during polarity reversal, by a pressure relief vent.

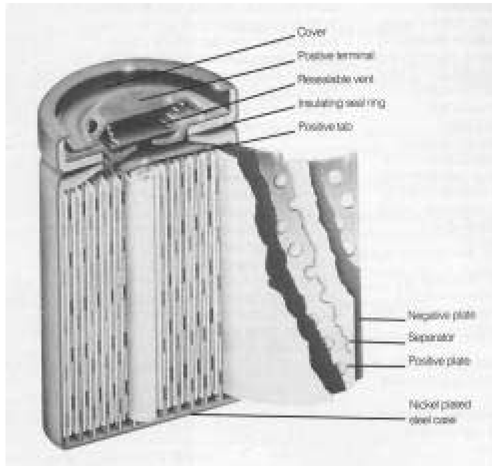
Energizer Sealed Nickel-Cadmium Rechargeable Batteries

Energizer nickel-cadmium cells are available in cylindrical configuration and range in capacity up to 5 Amp hours in sizes from AAA to D.

Cylindrical Cells

This cell type incorporates a different electrode arrangement than the button cell. Sintered plates are used in all cylindrical cells for the positive electrode. This electrode consists of thin, highly porous nickel plaques impregnated with active materials. The plaque is made by heating nickel powder in an inert atmosphere until the particles are welded together. The metallic phase serves as a highly conductive supporting structure for the electrode. The structure of the plate is such that a large surface is furnished for reaction of the active materials. With the sintered electrode it is possible to build cells of very low internal resistance.

The negative electrode of most Energizer cylindrical cells is a pasted electrode which consists of blended active materials pressed onto a metal carrier. It is this electrode that gives Energizer cylindrical nickel-cadmium cells outstanding cycle life, long term overcharge capability, with essentially no fade and with little or no memory effect.



Sealed nickel-cadmium cells under certain abuse conditions such as excessive charge or overcharge rate, deep discharge with subsequent polarity reversal, may develop high internal gas pressure. Usually the gas is oxygen, although hydrogen is also evolved in some cases. Either or both hydrogen and oxygen must be vented.

All Energizer high rate cylindrical cells have a resealing pressure vent. This vent permits the cell to release excess gas evolved if the cell, for example, is abused. When the internal pressure has dropped to an acceptable level, the vent will reseal, permitting the cell to be recycled in the normal manner with little or no further loss of electrolyte or capacity. Repeated venting will reduce capacity and cycle life.

Contact Material

External electrical connections can be made with any good conductor having adequate current handling capabilities.

Potting

Nickel-cadmium cells or batteries of any type should not be totally potted. Energizer cells have resealable vent mechanisms which wold be rendered inoperative by the potting compound.

Electrical Characteristics

Energizer sealed nickel-cadmium cells exhibit relatively constant discharge voltages. They can be recharged many times for long lasting economical power. They are small convenient packages of high energy output, hermetically sealed in steel cases, leak resistant and will operate in any position. The cells have very low internal resistance and impedance, are rugged and highly resistant to shock and vibration.

The temperature range under which these cells may be operated is wide. Use at high temperatures, however, or charging at higher than recommended rates, or repeated discharge beyond the normal cutoffs may be harmful.

Capacity

The capacity rating of Energizer nickel-cadmium cells and batteries is based upon output in discharge at the 1 hour rate to an endpoint of 1.0V/cell for all cylindrical cells. If current is withdrawn at faster rates than these standards, capacity is decreased.

Paralleling of Cells

"Eveready" sealed nickel-cadmium cells should not be charged in parallel unless each cell or series string of the parallel circuit has its own current limiting resistor. Minor differences in internal resistance of the cells may result, after cycling, in extreme variation in their states of charge. This may lead to overcharge at excessive currents in some cells and undercharge in other cells.

Voltage Characteristics

Except in the case of complete discharge, neither cell condition nor state of charge can be determined by open circuit voltage. Within a short while after charging it may be above 1.4 volts. It will fall shortly thereafter to 1.35V and continue to drop as the cell loses charge.

During discharge, the average voltage of a sealed nickel-cadmium battery is approximately 1.2 volts per cell. At normal discharge rates the characteristic is very nearly flat until the cell approaches complete discharge. The battery provides most of its energy above 1.0 volt per cell. If the cell is discharged with currents exceeding the rated value, however, the voltage characteristic will have more of a slope, a lower endpoint voltage will be necessary and the ampere hours per cycle will be reduced.

High Current Pulse Discharge

High rate nickel-cadmium cells will deliver exceedingly high currents. If they are discharge continuously under short circuit conditions, self-heating may do irreparable damage.

The heat problems vary somewhat from one cell type to another, but in most cases internal metal strip tab connectors overheat or the electrolyte boils. In some instances both events occur.

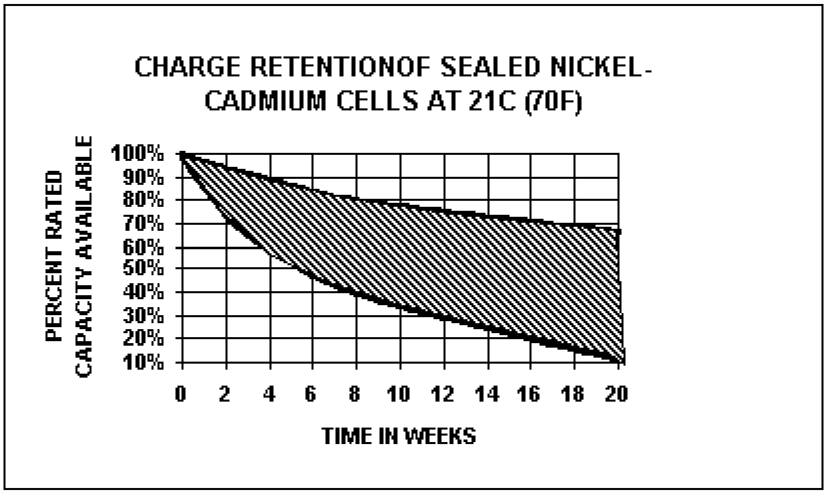
General overheating is normally easy to prevent because the outside temperature of the battery can be used to indicate when rest, for cooling, is required. In terms of cutoff temperature during discharge, it is acceptable practice to keep the battery always below 45^{o}C (113^{o}F).

The overheated internal connectors are difficult to detect. This form of overheating takes place in a few seconds or less, and overall cell temperature may hardly be affected. It is thus advisable to withdraw no more ampere seconds per pulse, and to withdraw it at no greater average current per complete discharge, than recommended on the data sheet for the "Eveready" cell in question. In special cases, where cooling of the cell or battery is likely to be poor, or unusually good, special tests should be run to check the important temperatures before any duty cycle adjustment is made.

Output capacity is any discharge composed of pulses is difficult to predict accurately because there are infinite combinations of current, "on" time, rest time, and end point voltage. Testing on a specific cycle is the simplest way to get a positive answer.

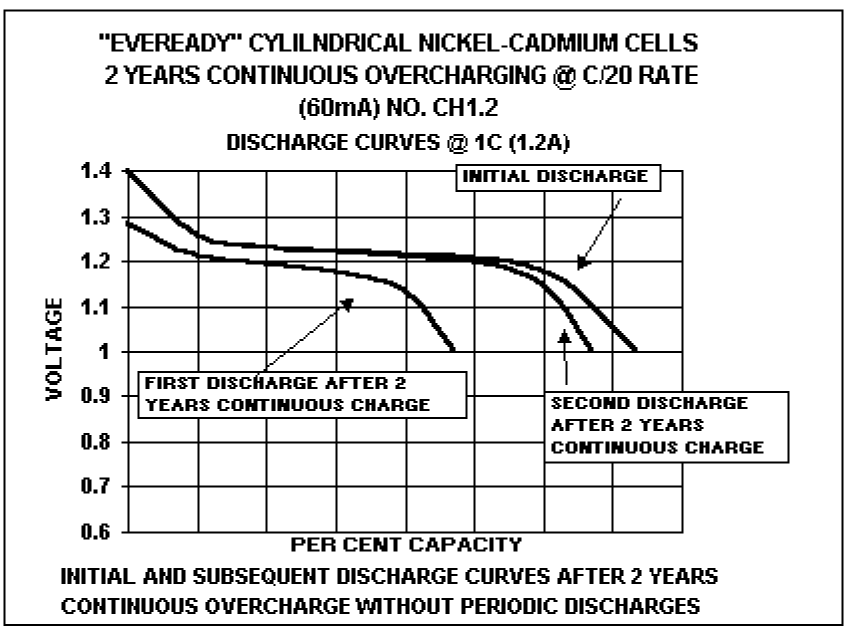
Self-Discharge

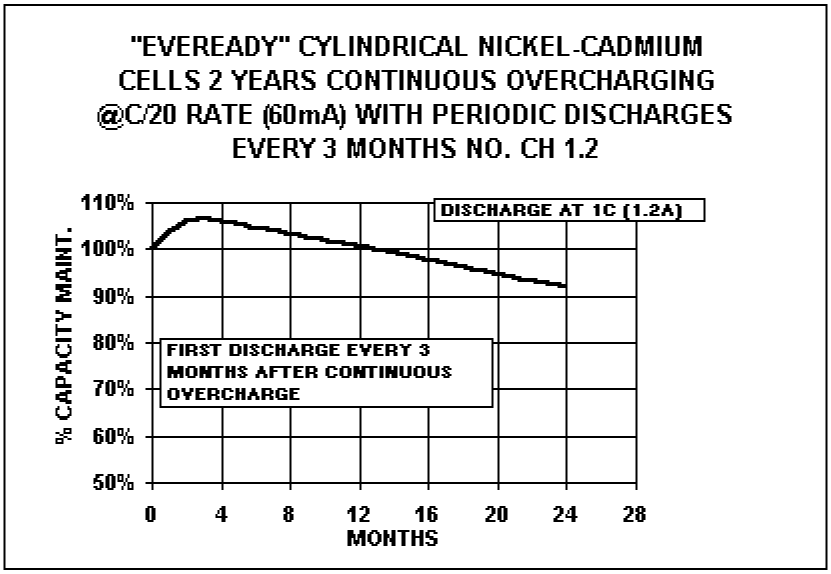
Self-discharge characteristics of Energizer nickel-cadmium cells are shown in the chart below. The characteristics are shown as a decline in percent of rated capacity available. Self-discharge is increased by elevated temperatures. Batteries are not harmed even if not used for long periods of time.



Continuous Overcharge

The overcharge capability of Energizer cylindrical nickel-cadmium cells is outstanding. The next chart illustrates initial and subsequent discharge curves after 2 years continuous overcharge without periodic discharges. The first discharge after the 2 year charge period yields a slightly reduced voltage curve and 65% capacity. The second cycle after 2 years continuous overcharge provides essentially the same discharge curve as the initial one.

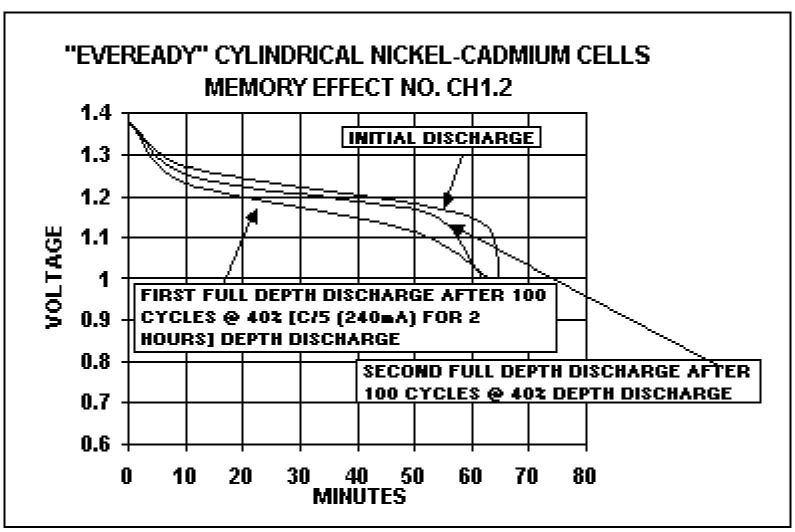




The chart above illustrates maintenance vs. months of continuous overcharge at the 20 hour rate with periodic discharges every 3 months at the 1 hour rate. The cells maintain 90% of their initial capacity after 2 years of this overcharge regimen. This pattern of use would occur if batteries are left on charge continuously and used one cycle only on an occasional basis.

Memory Effect

Memory effect is that characteristic attributed to nickel-cadmium cells wherein the cell retains the characteristics of the previous cycling. That is, after repeated shallow depth discharges the cell will fail to provide a satisfactory full depth discharge. Energizer cylindrical nickel-cadmium cells are particularly excellent with regard to lack of memory effect. The chart below depicts initial and subsequent cycles after repeated shallow discharges. The graphs show the initial discharge curve and the first and second discharge curves after 100 cycles @ 40% depth of discharge. You will note that the subsequent full depth discharges yield nearly equal capacity to the initial curve at slightly reduced voltage levels.



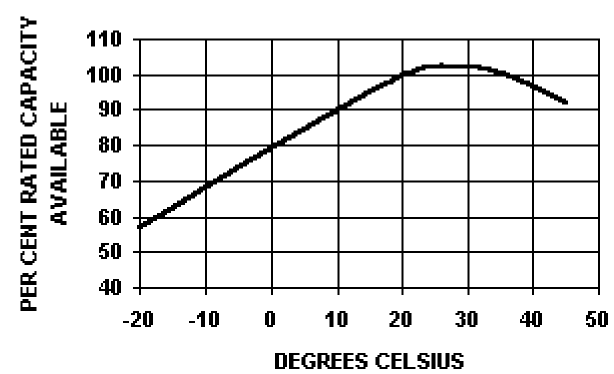
Storage

At elevated storage temperatures self-discharge will be considerably higher than at room temperature. It is recommended that batteries be stored at 21°C (70°F) or lower for this reason.

Temperature Characteristics

"Eveready" sealed nickel-cadmium cells experience a relatively small change of output capacity over a wide range of operating temperature. Charging, however, must be done in a much narrower range. Temperature limits applicable to operation of the cells are listed in the specification sheets for each battery.

The capacity vs. temperature curves which are on some individual specification sheets represent cells discharged at the temperatures shown after charging at room temperature for 14 hours at the 10 hour rate. This characteristic is also generalized on the following curve.



Charging nickel cadmium cells below the recommended temperature can cause oxygen pressure build up and activation of the resealable safety vent. Multiple vent activations will reduce cell capacity.

Effect of high and low temperatures on storage, discharging and charging of Energizer Nickel-Cadmium cells and batteries

	Low Temperature	**High Temperature**
Storage (All Types)	at - 40°C (-40°F) No detrimental effect. However, cells or batteries should be allowed to return to room temperature prior to charging.	at 60°C (140°F) No detrimental effect. However,, self-discharge is more rapid starting at 32°C (90°F) and increases as temperature is further elevated.

Discharge (All Types)	at - 20°C (-4°F) No detrimental effect but capacity will be reduced.	at 45°C (113°F) No detrimental effect.
Charge		
(7 -10 hour rate)	at 0°C (32°F) Cells or batteries should not be charged below 0°C (32°F) at the 7 - 10 hour rate.	at 45°C (113°F) Cells or batteries evidence charge acceptance of approximately 50%.
(1 to 3 hour rate)	at 15°C (60°F) Cells or batteries should not be charged below 15°C (60°F) at the 1 hour rate or below 10°C (50°F) at the 3 hour rate.	at 45°C (113°F) Cells or batteries evidence charge acceptance of approximately 90%.

Impedance and Internal Resistance

Sealed nickel-cadmium cells have a high effective capacitance. Their impedance is so low that cells which, in effect, are being continuously overcharged, make excellent ripple filters.

Cell impedance is dependent upon frequency and state of charge of the cell. It is lower for a charged cell than it is for a discharged cell. Values of impedance and resistance are shown on the individual specification sheets for each cell.

Internal resistance (R_e) is calculated using the voltage drop method as described in ANSI C18.2, which states that a fully charged cell rated at less than 5Ah shall be discharged at $10.0C_1A$(capacity rating at 1 hour rate in terms of amps) for 2 minutes then and switched to $1.0C_1A$. The voltage shall be recorded just prior to switching and again upon reaching its maximum value after switching. The effective internal resistance, R_e shall be calculated as indicated below:

$$R_e = \frac{DV}{D\,I} \text{ where } DV = V_L - V_H \text{ and } D\,I = I_H - I_L$$

Notations: R_e = Internal Resistance
DV = Voltage Change
D I = Current Change
V_L = Voltage recorded after switching
V_H = Voltage recorded prior to switching
I_L = Current recorded after switching
I_H = Current recorded prior to switching

For 50% discharged cells, multiply R_e by 1.2 factor.

Cycle Life

Cycle life of the nickel-cadmium sealed cell depends both upon cell design and the type of use in which it is subjected. Excepting violent abuse, the use factors which most seriously influence life expectancy are:

- Amount of overcharge (excessive overcharge is undesirable)
- Temperature of charge and overcharge (elevated or lowered temperature is undesirable)
- Endpoint requirements regarding rate and capacity (increased cycle life will ordinarily be the result of a shallow discharge regimen).

Any treatment which causes a cell to vent is harmful. Frequent or extended venting of even properly valved cells eventually destroys them.

In rating cycle life, end of life of the sealed nickel-cadmium cell is considered to be when it no longer provides 80% of its rated capacity. If a cell can be considered to be satisfactory while delivering less than the 80% endpoint figure, cycle life will be greater than that listed. The ratings are for 21°C (70°F) performance.

Charging

Constant current charging is recommended for sealed nickel-cadmium cells. The 10 hour rate should not be exceeded unless overcharge is specifically to be prevented. The recharge efficiency of sealed nickel-cadmium cell is dependent on a number of things, but it is most important to remember that charging becomes more difficult as temperature increases and charge rate decreases.

It is possible, under certain conditions, to charge at rates much higher than the 10 hour rate, but control devices which prevent high rate over-charge are sometimes required.

The nickel-cadmium battery can be trickle charged but floating and constant voltage charging are not recommended. For maximum performance in situations of long term trickle charge current required to keep the battery fully charged is approximately the 30-50 hour rate plus whatever is necessary to compensate for any major withdrawals.

Technical Background Information

This "Eveready" battery construction provides practical high rate charging with minimum cost and weight for control circuitry. Control concepts make use of the fact that, in the nickel-cadmium cell system, the cell will heat if charging continues after the electrodes reach full charge. The cell has been designed to exhibit sufficient temperature rise to effect charge control without a significant change in operating pressure. The "Eveready" Fast Charge cell series develops the desired temperature rise, and has the built-in ability to withstand short term overcharge at rates to one hour values without physical damage or loss in cell capacity. The cell construction is specifically designed to withstand overcharge at the three hour rate without special control circuitry. Considerable heat can be generated within the cell, however, if overcharge is extended beyond a reasonable period of time. To prevent this heat from causing gradual cell degradation, it is recommended that the cell temperature not exceed 46°C(115°F) during this extended overcharge and that the cells be removed from the charger within two or three days of reaching full charge.

Prior to this construction, any cell overcharged at the one hour rate would be permanently damaged. This "Eveready" Fast Charge cell can withstand overcharge at these high rates long enough for the temperature rise to be sensed by simple control elements. This temperature rise is very pronounced, and provides a positive signal for charge control. As a result, the control element can be small, lightweight and inexpensive.

Sealed secondary nickel-cadmium cells have been manufactured for many years based on the socalled "oxygen recombination" principle. The charge-accepting capacity of the negative electrode is made to exceed the charge-accepting capacity of the positive electrode. Upon charging, the positive electrode reaches a state of full charge before the negative electrode and oxygen is evolved at the positive electrode. The oxygen gas reacts or combines with the active cadmium metal on the surfaces of the negative electrode. Thus, recombination of oxygen prevents the buildup of an excessive internal gas pressure.

In charging nickel-cadmium cells, an overcharge, i.e., ampere-hours input which is in excess of that previously removed upon discharge, must be provided to insure that the cells have reached full charge. If overcharge is continued at too high a rate of charge current, the evolved oxygen gas may not fully recombine, consequently a build up of excessive internal gas pressure may result. A safety resealable vent is provided to limit excessive build up of pressure. The proper selection of the electrolyte volume controls oxygen recombination pressure below the safety vent opening pressure.

The safe charge rate for sealed secondary nickel-cadmium cells for extended charge periods has been established at the ten hour, or the C/10 rate. Capacity (c) is the rated ampere-hour capacity of the cell and 10 is the number of hours required at perfect charge efficiency to bring a completely discharged cell to full charge. At the 10 hour rate and lower currents, an equilibrium condition is maintained in the cell and consequently there is no excessive build up of internal gas pressure.

Energizer sealed secondary nickel-cadmium cells and batteries are now widely used as a rechargeable power source in many different types of portable or cordless electric appliances. Charging at the safe recommended 7 to 10 hour rate has proven satisfactory for recharging the cells or batteries used in many of these appliances, such as tooth brushes, shavers, etc. where relatively long rest periods between uses are possible. However, there is now a demand for use of sealed nickel-cadmium cells and batteries in other appliances such as chain saws, electronic flash, portable drills, professional hair clippers, etc. where the rest periods between uses of the appliances are much shorter and consequently shorter recharging times, from about 3 hour to about 1 hour, i.e. C/3 to C/1 rate, are required.

To accomplish charge termination safely and reliably, temperature sensing has required fast-acting, precise and expensive equipment at the lower charge rates. Because of the size, cost and complexity of such a system, the thermal sensing approach to overcharge control heretofore has been impractical for the consumer oriented nickel-cadmium battery powered portable appliances and devices.

The Energizer Fast Charge cell has been specially designed to withstand high rate overcharge and thus to overcome the above mentioned drawbacks.

The Energizer Fast Charge cell exhibits a relatively sharp rise in temperature during high rate overcharge. The particular type of thermal sensor to be used in combination with the cell or battery and the charger system is not critical. Probably the least expensive overall cell or battery control unit is provided by use of a simple snap-action thermostatic switch. The snap-action thermostatic switch combines the temperature sensing and circuit switching functions in one small, inexpensive device which can be easily attached to the cell or battery.

A solid-state thermistor sensor may also be used. The thermistor is also relatively inexpensive and even more compact, although it performs only the function of a sensor. Auxiliary circuitry and switching means are required to cut off the charging current in response to the thermistor input. Among the commercially available types of thermistors, the positive temperature coefficient type is preferred because it changes resistance abruptly at a predetermined temperature. Auxiliary circuitry is thereby simplified without loss of reliability.

In constructing individual cell or battery units, it is not critical that the thermal sensor be placed or maintained in actual physical contact with the cell proper, although this is preferred. Individual cell units may be constructed with a small flat disc-type thermostatic switch welded in contact with the bottom of the cell. Similar battery units may be constructed with a small thermistor or bimetallic switch placed in the space between adjoining cells. Any arrangement is satisfactory providing the thermal sensor is well exposed to the heat generated by the individual cell or one or more cells of the battery. The use of extensive heat sinks, such as placing the entire battery in a water bath, is not recommended since this can prevent heat build up, impede oxygen recombination within the cell and lead to cell venting before sufficient heat rise occurs.

The terminal leads from the thermal sensor may be connected to additional external contacts or may be brought out from the cell or battery unit and connected directly into the circuit. Where a sensor-switch device is used in a series-connected battery, it may be preferred to wire the switch internally between two series cells so that no additional external contacts are required. The practicality of this connection depends upon discharge current value and sensor current rating. The advantage would be that the circuit would also open on discharge in case the battery becomes overheated for any reason.

The charger circuit required for charging the individual cell or battery is not unique. A constant current type charger is recommended with due regard for heat dissipation and wattage ratings of all components.