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Use of Rechargeable Nickel-Cadmium Batteries for Portable Radiation Monitors

by

Mohammad Quamruz Zaman

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An effort was taken to assess the chargers available at the local market and the use of rechargeable batteries in the portable radiation monitors. This report is a very brief description of the study and observations. The details of the study can be seen in the attachment.

CONTENTS

Preface

The International Atomic Energy Agency is helping its member countries in various fields of the application of Atomic Energy for peaceful purpose by supplying instruments, training scientific and technical personnels etc.

It has supplied various types of portable radiation monitoring instruments to its member countries which uses ordinary throwaway primary batteries.

As Ni-Cd battery is being successfully used in an expanding range of new applications so it has aroused a question wheather it can be used in those portable radiation dosimeters and wheather it will be feasible both from the technical and economical point of views.

Effort was put to give a biref and clear picture of the probability of application of Ni-Cd battery specially in tropical countries and developing countries where the climate and other pre-requisite conditions required for proper application of Ni-Cd battery are yet to be considered.

In order to have a fair and justified conclusions regarding the use of Ni-Cd battery in portable instruments, many critereons have to be considered which takes very long time observations under some specified conditions.

This report is a combination of previous experimental results by scientists, data supplied by the manufacturers and short time observations in Seibersdorf Laboratory.

The report has three parts (a) comparison of the ordinary battery with the rechargeables (b) selection of a suitable charger and (c) probability of application of the Ni-Cd battery in portable dosimeters

Introduction:

The development of sealed rechargeable-system constitute a milestone in secondary battery technology. Areas of application previously reserved for primary battery are now open to a rechargeable system. The convenience of low cost throw away primary batteries are being offset by the lower overall cost (end life cost) for a rechargeable system. The rechargeable system extends the horizon of application of dry cell batteries.

The nickel-cadmium battery available in different sizes is the most widely used of all sealed, maintenance free rechargeable battery. It has many advantages which the other batteries don't have. The advantages and disadvantages are listed in Table I.

Rechargeable Ni-Cd batteries have two important electrical characteristics, these are (1) the battery charge and (2) discharge rates. These rates are expressed in multiples of the "C" rate. A cell discharging at the rate will expend its rated capacity in one-hour. There are four charge characteristics e.g. charge acceptance, charge voltage, cell pressure under charge and cell temperature under charge.

The effect of charge rate is shown in figure 1, which indicates that high the charging rate, high the cell voltage..
The effect of ambient temperature can be seen in figure 2, which shows that higher the ambient temperature lower the cell voltage.

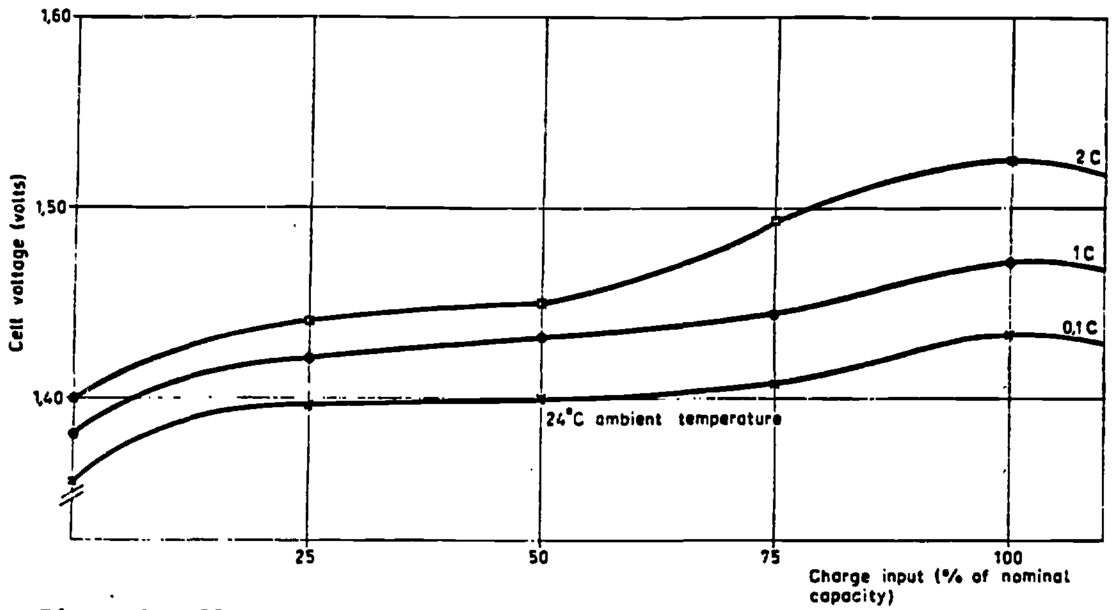


Figure 1. Effect of charge rate on voltage of a sealed NiCd cell. The current is expressed in C, where C is the nominal capacity of the cell.

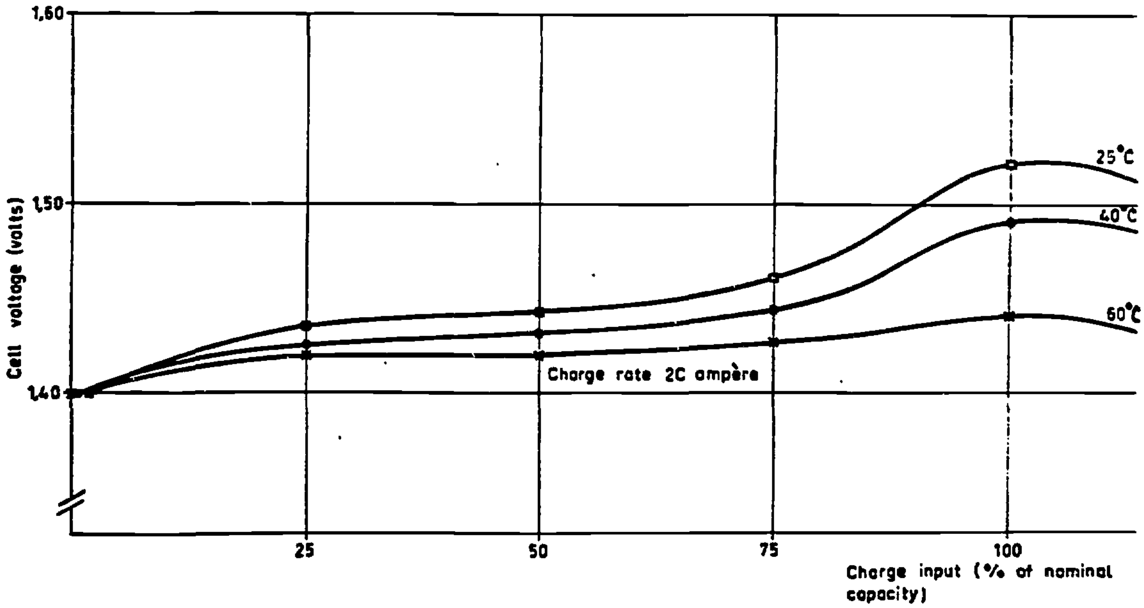


Figure 2. Effect of ambient temperature on charge voltage for a sealed NiCd cell.

Cell pressure and temperature are important factors during charging as they affect charge acceptance, voltage and battery life. These two characteristics are closely interrelated.

Figures 3 and 4 show the variation of voltage, pressure and temperature with charging time.

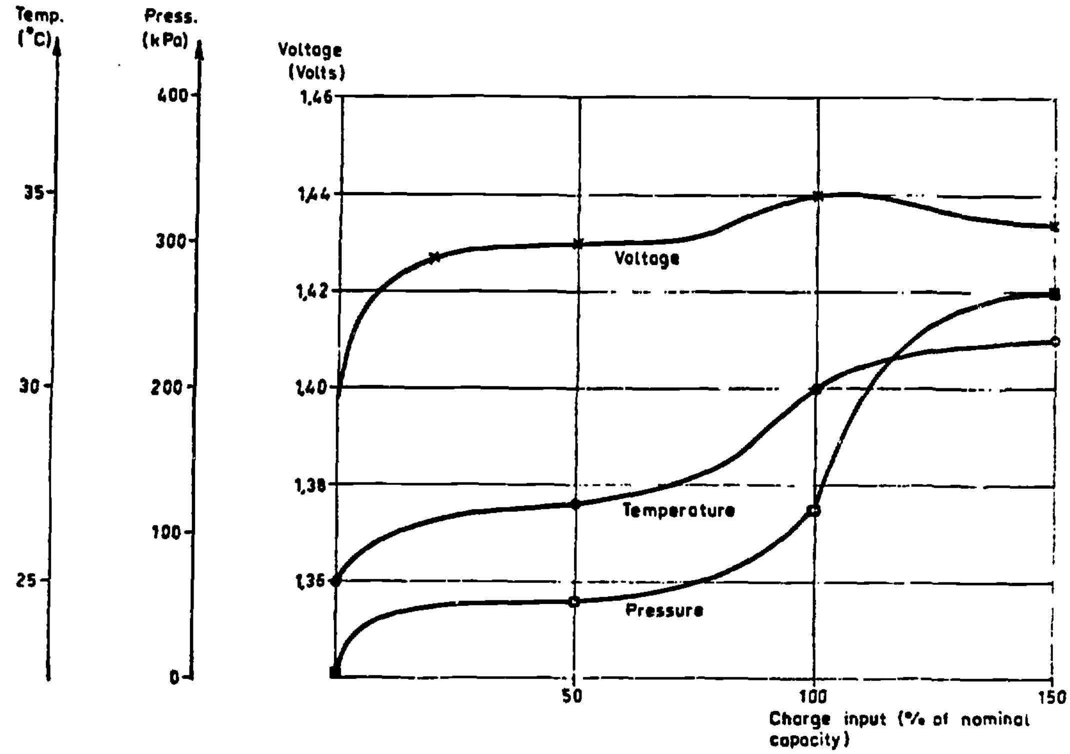


Figure 3. Variation of voltage, pressure and temperature during 16 hours charge of a sealed NiCd cell.

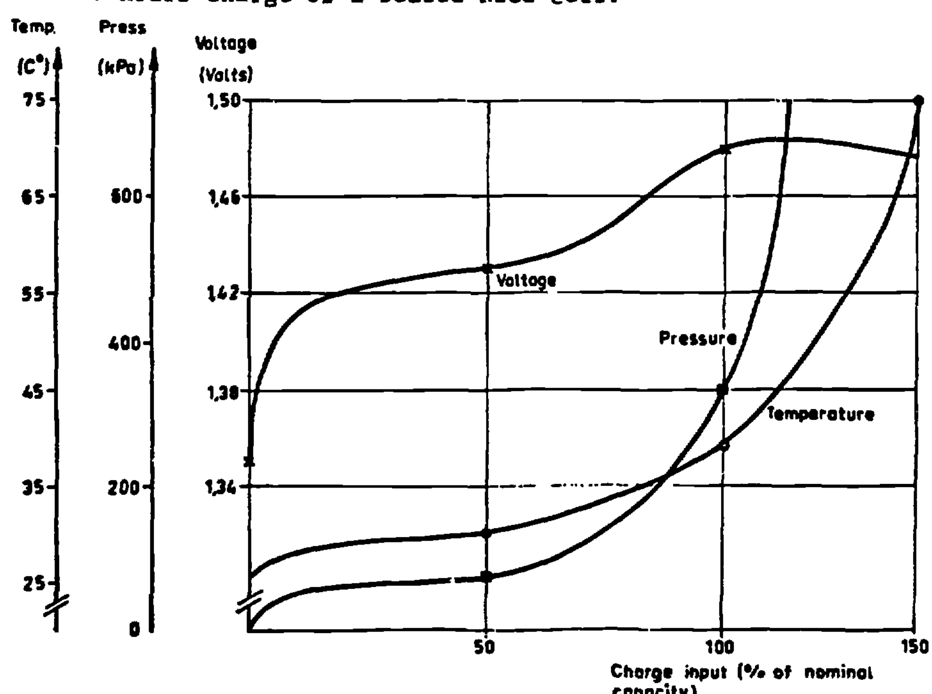


Figure 4 Voltage, pressure and temperature during one hour

There are two discharge characteristics namely discharge capacity and discharge voltage which in turn depends on effective internal resistance. The capacity of the cell indicates the amount of energy that the cell can deliver to the load and is usually defined in terms of ampere-hours/watt-hours.

The capacity available from a battery depends upon a number of items including (i) how fully the battery was charged; (ii) how long and what temperatures the batteries have been lying idle since the most recent charge and (iii) condition of the application. The effects of discharge rate and temperature can also be seen from figures 5 and 6.

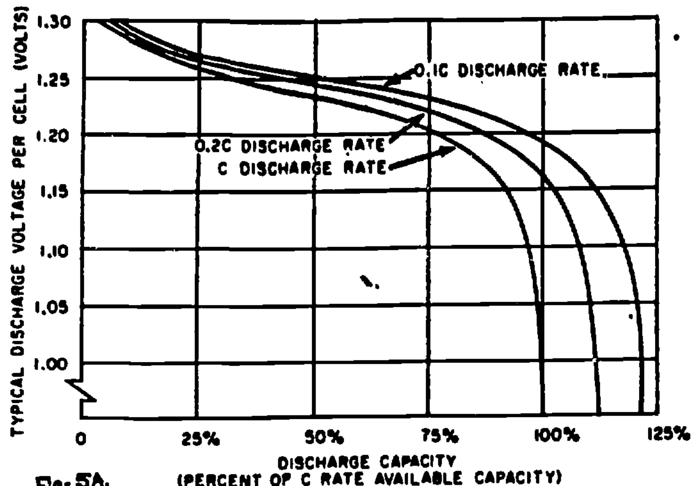


Fig-5A.

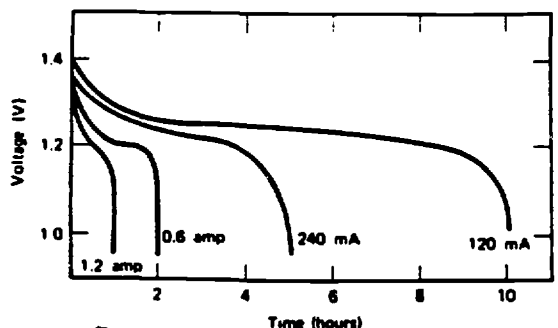


Fig-5B.

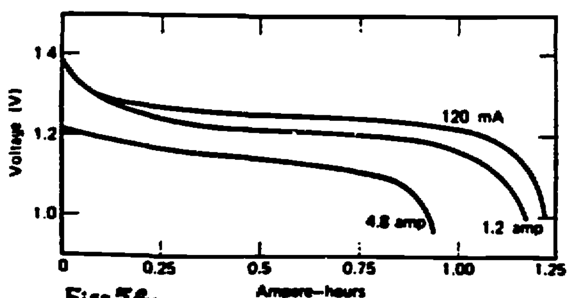
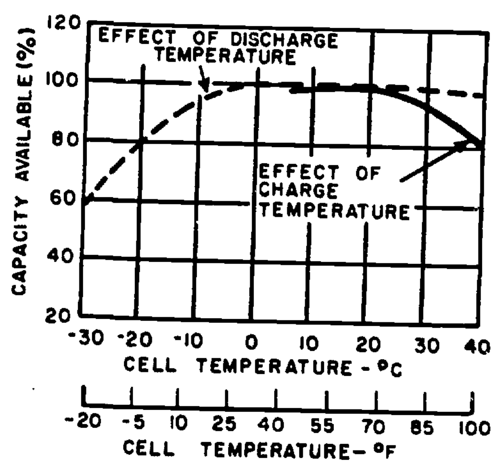


Fig-5C.



Temperature-capacity Relationships – Sealed Cells at C Rate Discharge
Figure-6

Charge Retention/Shelf Life is the ability of a battery to hold its charge under storage condition - the lower the shelf-discharge rate, the higher the charge retention. Nickel-cadmium cells can hold their charge for varying periods of time upto many months depending upon temperature, age of the cell. This can be seen in fig. 7. The shelf life is very much temperature dependent. At 45°C the rate of self-discharge is about seven times the rate of room temperature (20°C). The shelf life of an ordinary battery is also shown in fugure 8 to get a clear idea between the ordinary and the rechargeable batteries.

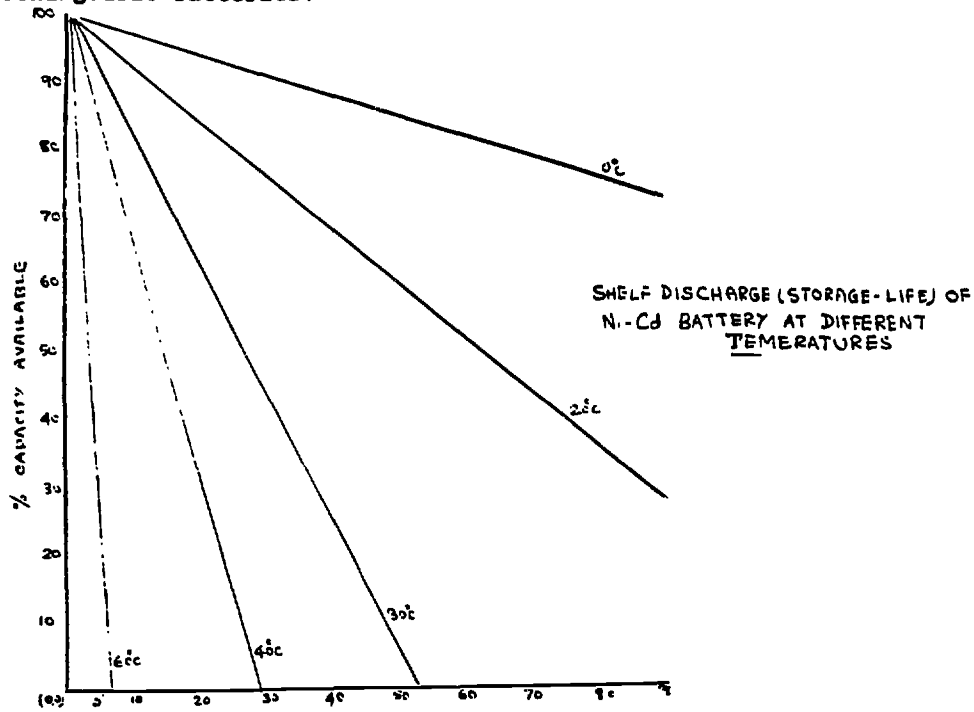


Figure-7.

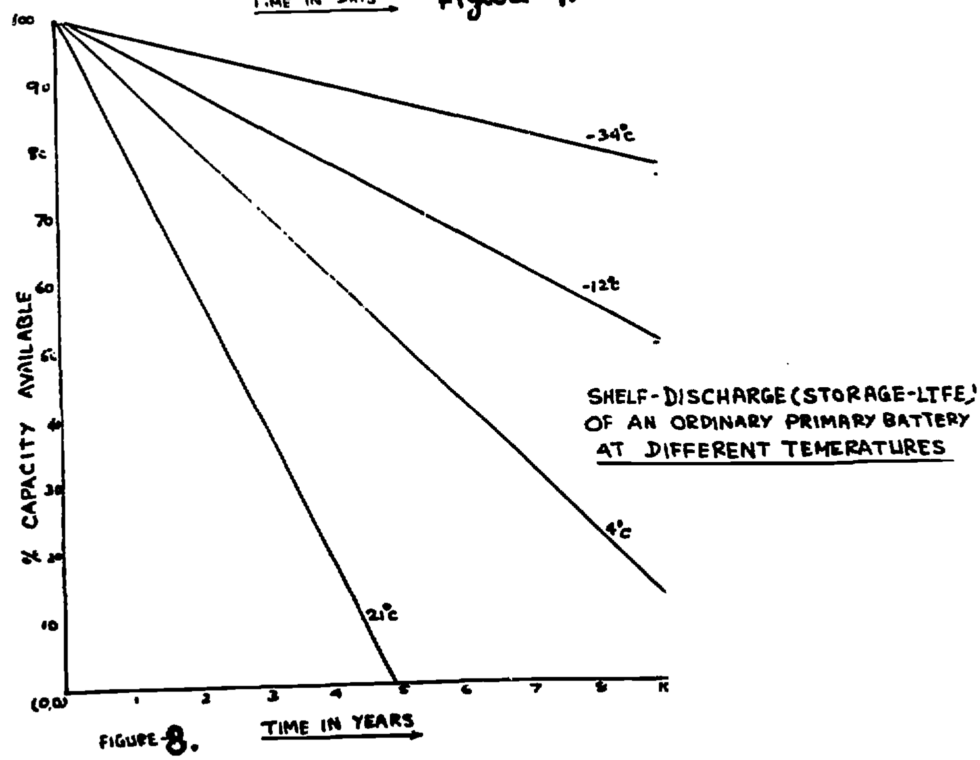


FIGURE 8.

Table I:

Comparison of Primary (ordinary) cells versus Nickel-Cadmium (rechcrgeable) cells/battery

Characteristics	Primary cell/battery	Rechargeable Ni-Cd cells/Battery
Initial costs	very low AS 12 per cell (D type) about 18 times less.	very high initial costs AS 184 per cell (D type) because the manufacturing technique is very complicated.
End life cost	high, when high power and long time operation considered; e.g. AS 12 per cell for D type	very low or neglegible depending on life cycle (200 - 1000 times) e.g. less than AS 1,42 for D type for 200 cycles. Highly economic.
Life cycle	can be used only once	good life cycle (200 to 1000 times) depending on various factors
Mechanical construction	corrosion takes place after long use or if left in the instrument for a long time, i.e. leakage takes place.	completely leak-proof, maintenance-free, very much rugged construction so can tolerate very high vibration and pressure variation and can be used in any position
Highrate discharge capability	long time discharge not possible	yes, good capability
Discharge curve	flat, indicating very good stability	also flat at a fixed temperature range
Open circuit voltage	1,5 V per cell	Low 1,2 V per cell
Charger used	no	yes and can be charged with simple inexpensive charger.
Temperature effect	good performance at higher temperature	poor performance at high temperature but better performance at low temperature (-10°C to -40°C). Can operate in the temperature range from -4o°C to + 45°C.
Overcharge	not applicable	can stand overcharge and deep discharge for short time but low charging rate decreases the capacity and charging is temperature sensitive

cont'd

Characteristics	Primary cell/battery	Rechargeable Ni-Cd cells/Battery
Shelf-life	very long (4-6 years) at normal temperature	short, cell capacity decreases at higher rate depending on temperature
Memory effect	not at all	very bad effect due to recrystallization. Proper cell balance is critical for long life
Subject to damage	only due to short circuit	The following various factors shorten the life cycle: 1. Depth of discharge places a stress on the stability 2. Overcharge increases internal heat which leads to rapid deterioration of cell components 3. Overtime charging increases cell's temperature and pressure which may lead to short circuit 4. High temperature increases chemical reaction rate and decreases electrode polarization. If the battery is damaged or partly damaged it cannot be recharged anymore or the life cycle is shortened, therefore, it becomes very expensive.

Battery chargers:

There are three types of battery chargers available to charge Ni-Cd cells/batteries:

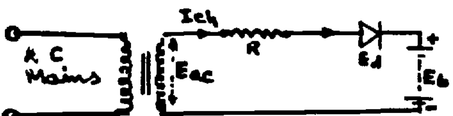
1. Constant current chargers
2. Constant voltage chargers
3. Voltage limited Taper charger (VLTC)

The constant current chargers are very simple and inexpensive.

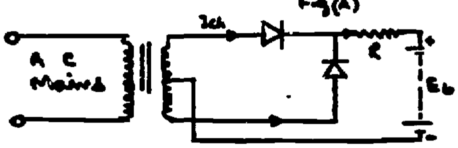
The constant voltage charger needs no cut-off time but is more complex and expensive.

The voltage limited taper charge combines the good features of both constant current and constant voltage type. Some more systems are also available with coulometer, pressure or temperature sensors or auxiliary electrode, but all of these add to the complexity and cost of the charger.

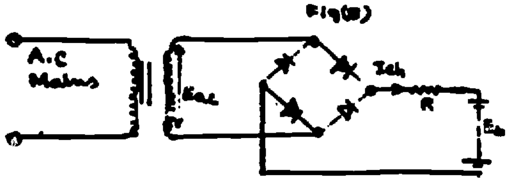
The commercial chargers available at the market are constant current chargers. They can be either half wave or full wave rectifier type using a very simple circuitry and consists of a transformer, rectifier and limiting resistors. Following are the examples of circuits being used (Figs. A, B and C):



Fig(A)



Fig(B)



Fig(C)

A. Half wave charger

B. Full wave charger with centre tap

C. Full wave bridge charger

The optimum charging temperature range is +5°C to +20°C. It should not be charged at temperatures lower than -10°C and higher than +45°C.

Ni-Cd batteries should be always charged in series. Parallel charging is not recommended.

There are three charging systems:-

(i) Slow charging also called "overnight" charge is a charge rate of 0.1C and is high enough to charge a fully discharged battery in 14 and 16 hours.

(ii) Quick charging is the charging in 3-5 hours at the rate of 0.3C.

(iii) Fast charging means charging by one hour at the rate of 1C but this requires some control systems to terminate the fast current before undesirable pressure or temperature conditions are reached. So very accurate sensing and tight tolerances are required for fast charging systems. This has raised the cost of the system.

Care should be taken while charging. If charged at the lower rate there will be a reduction in capacity as shown in figure 9. If it is overcharged for a long time, it will also cause a reduction in capacity resulting the recrystallization phenomenon leading to memory effect.

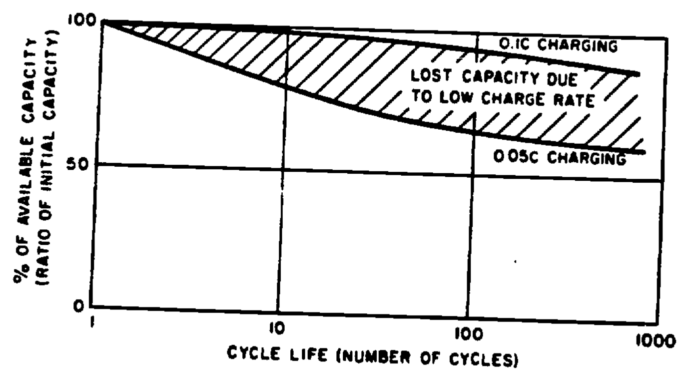


Figure 9 Typical Reduction in Capability Due to Low Charging Rate at 25°C

It was found that there are various types of chargers available in the local market, ranging from AS 89 to 1290. The prices vary from shop to shop. Three chargers were purchased and studied in details, e.g. circuit diagram, constructions and functions. The details of the study can be seen in Table II. The circuit diagrams are shown in figures D and E.

Table II

Comparative Study of Battery Chargers

Model No.	Price	Characteristics
1. MONACOR BC-900 Made in Taiwan	AS 499 - 1600	1. Operates on 220/240 V a.c 2. Charge up to 23 cells ranging from 1.2 V to 12 V D.C. 3. Extra charging socket with universal type plug to charge TV set, radio, calculator, car toys 4. Has test meter and indicator lamps and fully automatic 5. Outputs 2.5 - 3 V and 150 mA d.c 1.2 - 1.5 V and 80 mA d.c 1.2 - 1.5 V and 25 mA d.c 6 - 9 V and 14 mA d.c 12 V and 50 mA d.c 6. All types of rechargeable batteries can be charged. 7. Constant current charger type 8. Charging time 14 - 18 hours 9. Select current and voltage

Model No.	Price	Characteristics
2. Audio Ton V-668 Made in Hong Kong	AS 200 - 300	1. Operates on 220/240 Volts a.c 50 Hz 2. Sizes AA, C, D and 9 Volt types can be charged. No button or special sizes can be charged. 3. 2 - 4 cells of AA, A, C or D can be charged 4. only one 9 V battery can be charged 5. Difficult to put all the 4 batteries and 9 V battery at a time i.e. bad construction. 6. No test meter available 7. Charging time: I. AA - A type 4 - 6 hours II. 9V square type 12 - 14 hours III. C or D type 14 - 18 hours 8. Output: I. 2.9 V and 100 mA d.c II. 9 V and 14 mA d.c 9. Constant current charger
3. Universal Battery charger MW 398 Made in Hong Kong	AS 95 - 219	1. Operates on only 220V a.c 50Hz or 220/110V a.c 2. Test meter and indicator lamps available (only 1,5 V battery can be tested) 3. AA, C, D and 9 V type can be charged and all the 5 batteries can be put at a time. 4. Charging time: I. 1,5 V D type 12-25 hours II. 1,5 V C type 10-20 hours III. AA Type 5-8 hours IV. 9 V Type 5-10 hours 5. Output I. 1,5 Volts and 100 mA d.c II. 9 V and 11,7 mA d.c

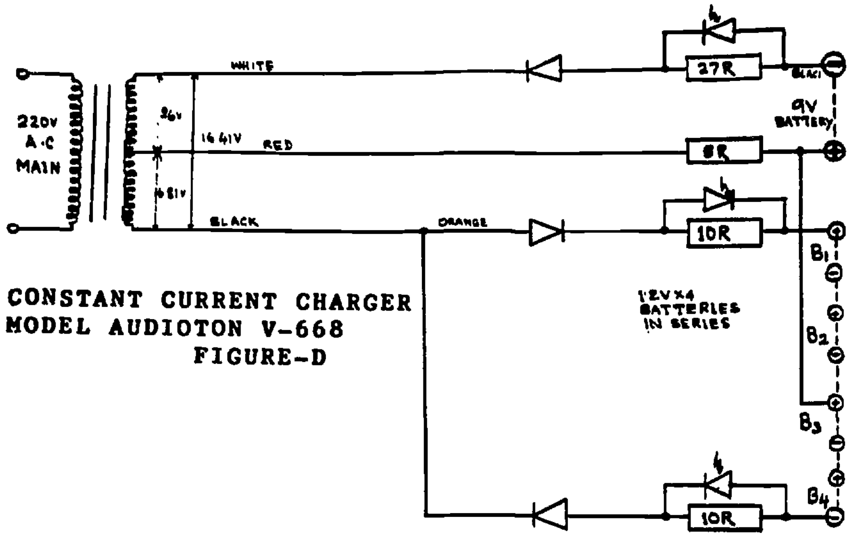
Applications of Ni-Cd batteries in portable dosimeters.

Three varieties of dry cell batteries (ordinary, alkaline and rechargeable) of different sizes and different voltage (1.2, 1.5 and 9 V) were purchased.

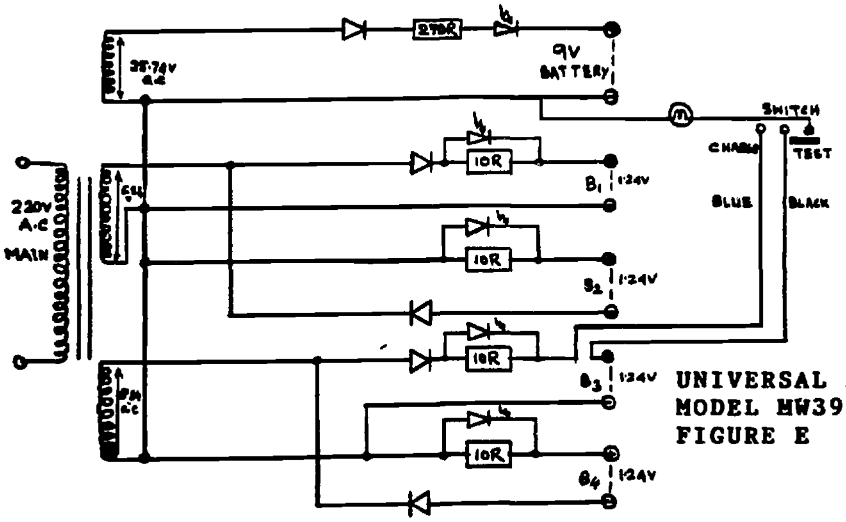
The rechargeable Ni-Cd (three different varieties) batteries were charged, discharged and used in the portable radiation monitors of 1.5 V, 6 V and 9 V operating types to see whether they can be used instead of ordinary primary batteries. The shelf discharge, deep discharge and shallow discharge characteristics were also observed by putting with loads at different discharge rates.

It was found that at shallow discharge rate of C/34 (117 mA) across a load of 47 ohms, the discharge curve was flat after long 2 hours of discharge. At deep discharge at the rate of C/4 (950 mA) across a load of 5.7 ohms, it was found that after 2 hours 15 minutes, the batteries were completely discharged. It was also observed that both the new (2 weeks) and the old (4 years) stock had the same discharge time indicating that rechargeable batteries can be used with full capacity even after long time if maintained properly. The second variety (SHAFT) did not work as they were not maintained properly and one of the batteries (out of 4) was completely damaged, which could not be even recharged. The observations can be seen in figure 10.

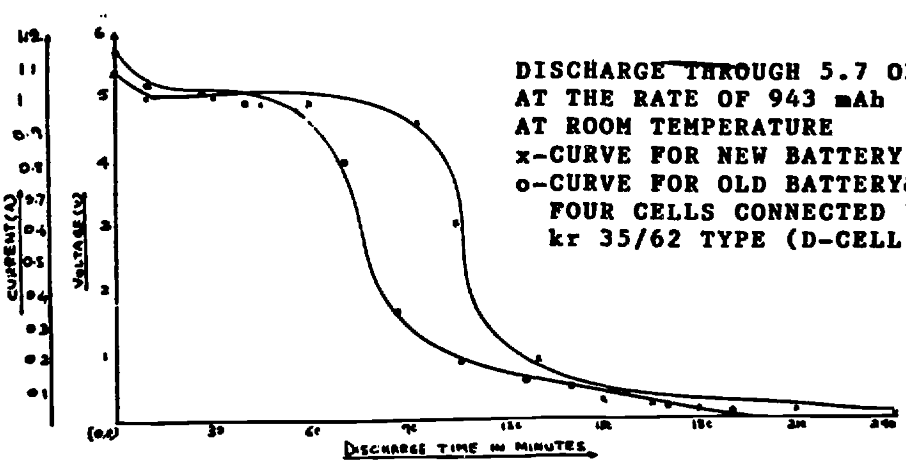
The shelf-life or the self-discharge rate of ordinary primary batteries were more stable than rechargeables. There was almost very negligible change in open circuit voltage for ordinary batteries (12 days period) from 1.5589 to 1.5584 and (9.998 to 9.988) but in case of rechargeable batteries there were significant changes within the same (12 days) period as "D" type from 1.385 to 1.2941 Volts, "AA" type 1.363 to 1.285 Volts, "C" type 1.39 to 1.32 Volts and 9 Volt type 9.91 to 9.157 Volts.



CONSTANT CURRENT CHARGER
MODEL AUDIOTON V-668
FIGURE-D



UNIVERSAL BATTERY CHARGER
MODEL MW398
FIGURE E



DISCHARGE THROUGH 5.7 OHM LOAD.
AT THE RATE OF 943 mAh (AT C/4 RATE)
AT ROOM TEMPERATURE
x-CURVE FOR NEW BATTERY
o-CURVE FOR OLD BATTERY&
FOUR CELLS CONNECTED IN SERIES
kr 35/62 TYPE (D-CELL)

Figure-10

The shelf-discharge characteristics of both the batteries can be seen in figure 11, which indicates that the self-discharge of rechargeables are faster than the ordinary batteries.

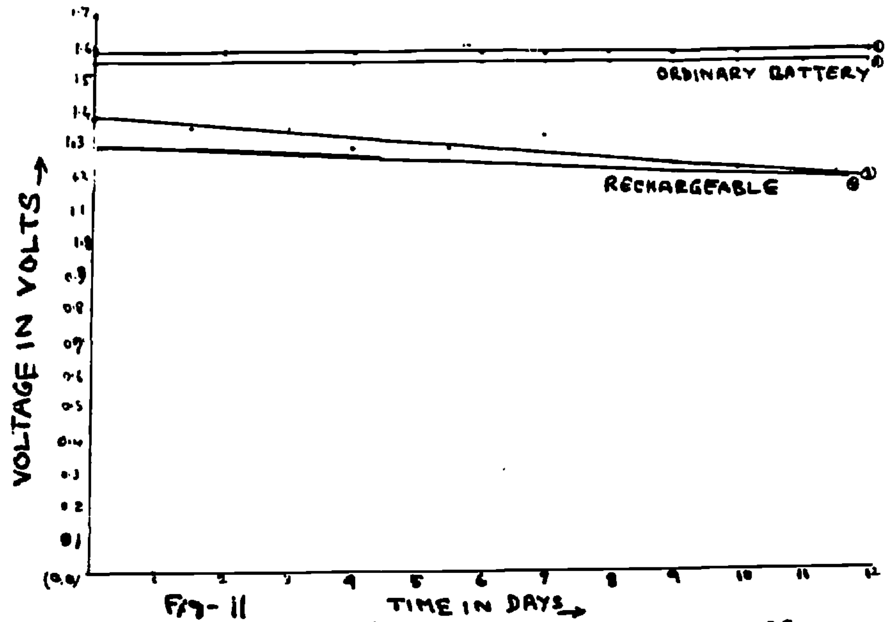


Fig- 11

SELF- DISCHARGE CHARACTERISTICS.

It was also observed that the rechargeable batteries were working satisfactorily in Portable Radiation Monitors in 1.5 V, 6 V and 9 V operating voltages.

In case of 1.5 Volt operating voltage, rechargeable batteries worked satisfactorily since the minimum working voltage of the instrument was 1.085 Volts, in 6 Volts type the working voltage was 4.4 Volt and for 9 Volt type the minimum response was at 6.5 Volts.

The end life cost for D type was calculated for 200 cycles as AS 184 per cell and AS 95 for the charger.

$$\text{cost per cycle} = \frac{184 + 95}{200}$$

= AS 1.395, which is very low in comparison with AS 12 per cell for ordinary batteries.

Conclusions

The primary concern of this study was to evaluate a good working battery charger at a reasonable cost and to observe the effect of application of Ni-Cd batteries in portable radiation monitors.

(i) Choice of Charger:

Regarding the selection of the charger, the Model 398 Universal Battery charger could be used as it is fairly low priced, better constructed, easy to use and has better facilities than others of the same type, e.g. has the battery tester, charging indicator lamp, charges batteries in single or in groups, different sized batteries may be charged together, the charging time can be selected by looking at the indicator lamps.

(ii) Temperature sensitivity:

There are some limitations which may hamper the use of rechargeable batteries especially in tropical countries. Since the discharge rate, charging rate, shelf-life and performance all are very much temperature sensitive, so the use of these batteries may create problems.

For proper and long time performance, the batteries must be kept at an optimal temperature (20°C) which may not be possible while working outside the laboratory in tropical countries.

The shelf life (storage life) will also be affected by higher temperature, it may be self-discharged (25 % loss per month at 20°C) and looses its useful capacity in more than one month whereas the shelf life of ordinary batteries is very long, about 4 - 5 years (17 % loss per year at 21°C) at the same temperature. So the high temperature causes a serious limitation on the use of rechargeable batteries. Moreover, with the development of technology, the newly developed digital instruments with negligible power consumption the use of Ni-Cd may not be economical because though theoretically it appears that at low discharge rate it will last for a long period but practically it will not be so as the shelf-discharge rate is high and even higher at high temperature. Using the charger may also be a problem for the tropical countries and developing countries since it requires main supply which may not be available at the working area, e.g. desert, deep forest, remote areas from the city.

(iii) Use instead of ordinary battery:

Regarding the use of Ni-Cd battery in lieu of ordinary primary battery, it can be used with portable radiation monitor working at 1.5 V, 6 V and 9 V systems without any problems since voltages supplied by Ni-Cd are high enough than the minimum required operating voltages of the instruments and also discharging curve is very flat until by the end of complete discharge stage.

The use of rechargeable batteries is more economic in older analogue types of instruments (i.e. high power/current consumption > 20 mA) but for new advanced digital types it may not be that much economical (very low power consumption < 5 mA) as the ordinary batteries last long with these new types of digital instruments.

(iv) Charging:

While charging, care should be taken not to overcharge the battery for a longer period which causes increases internal heat generation leading to rapid deterioration of cell components, e.g. additional stress on the mechanical and chemical stability and ultimately leads to shorten battery life cycle or seals may develop leaks or lead to short circuit as a result of the stress of excessive internal pressure.

The long charging time or overnight charging can be overcome by fast charging method but it is more complicated and needs special attention while charging.

(v) Life Cycle:

The cycle life is determined primarily by its chemical and mechanical stability. Factors such as depth of discharge, overcharge and temperature places a stress on the stability and decreases life cycle. Batteries that only receive shallow discharge have a much larger life cycle than those which are completely discharged in each cycle.

(vi) Charge time:

Charge time is also a very important factor while being charged imposing a limitation. A higher charge rate for long time is very bad. A slow charge favours more uniform current distribution, recrystallization and diffusion which results in good cycle life. The important factors for charging are the exchange current, reactant availability, internal resistance and charging current. Cell reversal may occur when a cell is completely discharged yet current continues to flow in the discharging direction which is very bad. The battery can operate normally in vacuum or high pressure environment, high or low relative humidity, corrossive atmosphere and capable of withstanding high shock and vibration.

(vii) Proper applications:

In applications where power, rather than just total energy, is required, Ni-Cd can be the most economical battery. The first cost (replacement cost/initial cost) of a battery is frequently evaluated in terms of cost per watt-hour. When battery cost is determined in this term only, the Ni-Cd battery is more costly, but, however, if evaluated over the operating life of the product, the Ni-Cd may be the most economic choice. Typically, the battery will yield at least 80 % of rated capacity from 200 to 500 cycles.

So, for countries/laboratories where well-trained people are available who can take care of all the limitations of the Ni-Cd batteries, i.e. can take proper care against the causes of damage, the Ni-Cd battery is a very good and highly economic substitute for the throwaway ordinary primary batteries. But if this is not the case, then it is better not to use Ni-Cd batteries in all instruments in general, except in special cases.

(viii) Limitations:

Some limitations of the Ni-Cd batteries should be emphasized:

1. The average environmental temperature should be below 25°C because of the temperature effects on charging, self-discharging, etc.

2. The rechargeable batteries are specially suitable for high power consumption portable instruments. For the new portable dosimeters with advanced and low-power consumption circuitry, e.g. FET, CMOS, LCD, etc., it would not be recommended to use rechargeable batteries. This is because Ni-Cd batteries lose 50% of their capacity within two months, by self-discharge, even if no use is made of them, while conventional batteries may last a year or more in a low-current application only if conventional batteries are unobtainable should Ni-Cd batteries be preferred.

3. To get satisfactory usage/service from Ni-Cd batteries, it is essential to take care to avoid too deep discharge, overcharge, overtime charge and use in high temperature. The charging reaction is very temperature sensitive. Proper cell balance is critical for long life of cells. Electrode uniformity is necessary to achieve the proper cell balance and cell capacity. Overcharge may cause recrystallization of the surface layers of the active materials, thus causing a temporary decrease in cell capacity. The so-called "memory-effect" appears to be related to the recrystallization phenomenon.

References

1. Dry Cell Batteries, Chemistry and Design
By Louis F. Martin
NOYES DATA CORPORATION

2. The Primary Battery Volume II
By N. Corey Cahoon
and
George W. Heise
John Wiley & Sons

3. Ni-Cd Rechargeable Batteries
Application Engineering Handbook
General Electric Company
Publication No.GET-3148A
2nd Edition, 1975

4. Guide for Designers
DURACEL - Europa Ltd. 1983

5. Ni-Cd Rechargeable Batteries
Engineering Applications
EVERADY Limited, 1976

6. Fast charging and a new charging method
Per-Edward Samsioe
FAO report A 30013-G5
December 1977.