ALKALINE SINGLE CELL BATTERIES AND RECHARGERS: RESULTS OF PRELIMINARY TESTS

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CONTENTS

INTRODUCTION

During 1994 there were significant advances in alkaline battery design and in recharging technology that now permits limited recharging of these cells. This development is important especially for people doing field work and using alkaline cells or nickel cadmium (NiCad) dry-cell batteries for torches and radios. Recharging these batteries will save funds and significantly reduce the number of dry-cells previously thrown away to rust and leak their chemical cocktail into the environment.

This report summarises tests done on a new alkaline single cell battery that can be reliably recharged, and a new commercially available recharger for regenerating any brand of standard alkaline cell. Other published recharger designs and test results are discussed.

Multi-cell high voltage packs such as lead-acid and nickel hydride batteries are mentioned, but not reviewed in this report.

ADVANTAGES OF ALKALINE CELLS AND RECHARGING

The main advantages of alkaline cells, and the ability of now being able to recharge them, can be summarised as:

- **REDUCED COSTS** - standard alkaline cells can be recharged rather than discarded, thus saving money. Also, there is less pollution of the environment from disposed cell electrolytes.

- **RELIABILITY** - alkaline cells are more reliable than NiCads as they don't suffer from ' memory' effect (shallow discharges causing loss of capacity) or cell failure (dendrites[1]) when trickle charged.

- **LONGER SHELF LIFE** - alkaline cells self discharge slowly and so have a longer shelf-life, typically 2-4 years, cf. NiCads (shelf-life 2-3 months). As such are ideal for applications where standby power is required by the equipment.

- **GREATER CAPACITY** - alkaline cells have a higher capacity (Ah) per cell than most other types of standard battery such as zinc-carbon and NiCads.

- **HIGHER VOLTAGE** - an alkaline cell has a higher voltage than a NiCad (1.5V instead cf 1.2) which makes them more reliable in equipment where decrease in voltage affect performance.

- **INDICATION OF FLATTENING** - an alkaline cell's voltage gradually tapers off when going flat, whereas NiCads flatten rapidly. Thus they are better for torches, or emergency equipment, where indication of battery flattening is needed.

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[1] Dendrites are crystals that can build up across the cell preventing uptake of charge, (Moxham, 1991).

- **LESS RISK OF OVER-CHARGING** - Alkaline batteries more reliably indicate full charge. The chargers detect the rise in cell voltage and switch off, so they are less likely to damage batteries by over charging. By comparison, good NiCad chargers need to have the battery fully discharged, then provide a timed constant current charge. Inexpensive NiCad chargers often don't have a timer so they rely on detecting the very small rise in cell voltage to switch off. This commonly fails, causing overcharging and cell damage.

REGENERATING PRINCIPLE

Clearly printed on the side of most dry-cell cases is the warning: "This battery may explode or leak if it is recharged... ". It is true that placing a dry-cell into an ordinary NiCad charger will create serious problems. Heat builds up and explosions can occur.

To overcome this problem, chargers have been designed to regenerate the charge without excessive heating. In fact, the charging technique has been around since 1955 (Yates, 1994) but not until the more recent widespread use of alkaline cells has it been worthwhile recharging cells. Two similar designs are described in recent electronics magazines (Yates, 1994 and Phillips, 1995a & b).

This regenerating method is very different from other conventional DC chargers, such as NiCad and lead-acid chargers. Regeneration produces a special kind of AC charging current. There is still some debate regarding the best frequency for this AC current but both 50Hz type chargers (Phillips, 1995a) and high frequency (HF) chargers (Phillips, 1995b) work. The alternating current is asymmetrical and positively biased, revitalising the cell to about 60-70% of its previous capacity. Any dry-cell such as alkaline and to a lesser extent heavy duty (but NOT lithium) can now be rejuvenated with varied success (Phillips, 1995b).

'Greencell' Regenerator

One brand of regenerator is the 'Greencell': Maxi (Appendix V), a HF type AC (300kHz) charger, suitable for all standard brands of alkaline cells. This unit charges up to four standard cells, alkaline, standard heavy duty or NiCad cells, of one size (either AAA, AA, C, D) at a time. It cannot charge the higher voltage packs where cells are connected in series. A multi-position switch is used for the manual selection of charge current depending on the size or type of battery. Switching off, upon reaching the fully 'charged' voltage, is automatic and separate for each cell. A 240V AC mains power-pack delivers 12 volts DC to the charger box.

A different design, using a 50Hz AC charger with timed switch off, is described by Phillips (1995a). This charger can recharge all cells including higher voltage series packs, such as 4.5V (Eveready 1703) and 9V (Radio Spares PP3) alkaline cells.

Note: ***Older chargers for NiCads and lead-acid batteries are NOT suitable for recharging alkaline cells. With any charger, always read the instructions carefully and observe the approved battery sizes, types, polarity, number of cells and charge time.***

NEW RECHARGEABLE ALKALINE CELL, '555' BRAND

In late 1994, a new brand of rechargeable alkaline cell called "555" appeared on the market. According to manufacturers, it can be recharged up to 100 times. This type of cell has a different chemical composition from other common brands and can be recharged using a simple DC charger. At present, only one brand is available.

The '555' charger has several different models (and prices) for battery size (see Appendix VI-VIII) and for the number of cells to be charged at once.

TESTING METHODS

Since December 1994 I have been testing the two chargers described above. Batteries were purchased at a number of Wellington retail stores during early 1995 (see Appendix II for the retail prices). Only the more common brands were tested. The '555' brand was purchased from the only national distributor to date, PM Distributors Ltd, PO Box 27-557, Mt Roskill, Auckland.

All brands of alkaline cells in AA and D sizes were tested in the 'Greencell' Maxi charger (Dick Smith Electronics Ltd) and '555' cells in both the '555' charger and the 'Greencell' charger. Discharge curves for voltage against time, and change in capacity with recharges, were completed. Batteries were initially discharged (called charge "0") then recharged in the ' Greencell' and '555' charger (the latter is only for '555' batteries).

Each set of batteries were then discharged in groups of 2 cells in series (3V) at 0.52A to 1.2V (0.6V per cell), the voltage was automatically logged over time. A constant current sink of 0.52A was designed for the discharges so that the discharged capacity (Ah) could be easily calculated (Ah = 0.52 x hours) to any set voltage.

When reaching the minimum voltage, a voltage controlled relay disconnected the batteries from the load, preventing sustained discharge below the switching voltage. Voltage data was automatically logged, at 0.1 or 0.25 hourly intervals, using a Thurlby datalogger. For each battery, the capacity in Watts x hours per dollar (Wh/$) spent, throughout its estimated rechargeable life, was calculated.

Tests are still continuing so the results presented here are provisional and the number of replicates is low.

TEST RESULTS

Batteries

There is about 30 percent variation in initial battery capacity for the same-sized cell for different brands (Table 1 & Appendix II). These results should be viewed with some caution as sample sizes are small (n=4) and manufacturer's batch variation has not been assessed. Further tests at different times with different stock will better indicate manufacturer's production variations.

Table 1: **Alkaline battery brands mean capacity (Ah t 0.4) and recharge ability. (Number of samples = 4 per brand)**

BRAND	AA cell (Ah, 1 hr rate)	D cell (Ah, 10 hr rate)	Number of recharges, AA cells
Panasonic	1.6	8.6	*
Fuji	1.6	8.6	*
Eveready Energizer	1.4	8.2	7-10
Varta	1.2	7.8	*
Duracell	1.1	10.1	5-7[1]
Toshiba	0.7	-	-
555	0.7	6.8	30-100[2]

Key: "-" have not been tested yet. [1] from Phillips 1995b.
[2] higher value not yet confirmed.
* single recharge gave capacity drop similar to Energizer

On preliminary information, the recharge ability of Eveready Energiser AA cells appears to reduce to about 10% of their original capacity after about 7-10 recharges. All other brands were only tested for a single recharge and the initial capacity drop was similar to Energizers.

Nine repeat discharge and recharges for a set of Eveready Energizer AA cells can be compared, in Appendix IIIb & IVa, to the longer lasting '555' brand. Both battery types show a downward trend in capacity with number of recharges, however, Energizers charged in a '555' charger only lasted 2 charges. Energizers charged in a 'Greencell' charger lost capacity rapidly before levelling off and actually increased at the 8th charge (point ' A', Appendix IVa), before decreasing again. ' 555' cells start with lower capacities than Energizers but lose capacity more slowly. When charged with the 'Greencell' charger, they increased in capacity around 9-10 recharges (point 'B') before declining again.

Variable uptake of charge was recorded also by Phillips (1995b) who found that some cells had only ¼ of their original capacity but almost returned to their original value at the 6th and 9th recharge. He noted that this irregular recharging occurred 5 out of 9 times. As he used timed charges on cells that were soldered together, he was able to discount the possibility of charging stopping as a result of poor contacts or vibration. As found by my study, the rest times between recharges did not significantly increase the recharge ability of cells (Phillips, 1995b).

On one occasion, after recharging in the HF recharger, I found a Fuji D cell was leaking electrolyte from the end of the cell. Phillips (1995b) attributed leakage to the charge current being too high. Several three year old Eveready Energizer D cells gained very little capacity, or showed a red light for a 'dead' cell, when recharging was attempted.

Most alkaline batteries have higher capacity than the '555' brand but although cheaper per cell they have limited recharging ability. From my preliminary tests, the new '555' brand was best value for money, confirming the ability of this battery to consistently accept a much higher number of recharges than other brands of alkaline batteries. My tests show the '555' AA cells will recharge greater than 30 times (Appendix IVb). The manufacturer's rating of 100 recharges was not reached in my tests but this higher figure may be possible in normal use; where there is a lower current drain or the discharge terminal voltage is set higher.

The dollar value improvement of '555' type over just discarding standard alkaline cells is greater than 15 times, and 60 times if 100 recharges is verified.

Chargers

The '555' battery requires a DC charger at a constant voltage (1.75V), with limited initial current. This is unlike the other types of alkaline batteries which will respond only to a special type of AC charging, such as used by the 'Greencell' charger. For the '555' charger, a charge LED would indicate by its brightness the state of each battery, extinguishing once the battery is fully charged. Its operation appeared reliable, although the charger did not detect a reversely inserted battery, which could then be damaged.

Warning lamps on the 'Greencell' charger indicate three battery states: a red lamp indicates a battery too flat to charge or a reversely inserted cell; an orange lamp indicates the charging state; green indicates fully charged. Sometimes it would switch to the green light earlier than expected. On three occasions this was found to be triggered by a physical vibration causing intermittent disconnection between the battery and the charger terminals. If the cell was near its charged voltage, the unit would not return to the charging (orange) state. The charger could be forced to return to charge mode by briefly disconnecting the DC supply lead. Cleanliness of battery contacts within chargers and equipment is very important for reliable operation. There were some erratic results recorded when cells appeared charged but were later found to have very little capacity or gained capacity on later recharges (Appendix IVa).

The charging time varies with the size of the batteries. For AA cells, the time to 'charged' voltage ranged from 12-16 hours. The D cell charge time was much longer,

(24-36 hours). The charge rate for D cells has probably been set lower to cater for low capacity model batteries.

Discharge rates for AA and D cells were set at ca 0.5A, similar to that of a torch bulb. For AA cells the complete discharge took only 1-2 hours, one tenth the time for D cells. Higher capacity would be obtained from the AA cells at lower rates of discharge. This rapid cycling is an atypical use of batteries so the results may show shorter life expectancies than that expected in equipment other than torches. In general practice it is not recommended to discharge the cells below 1.1V per cell (Phillips, 1995b).

My tests on one set of cells showed that the '555' batteries can be recharged in the 'Greencell' charger. This charger gave a good charge although more inconsistent (Appendix IVa). The rechargeable life of the '555' battery in the 'Greencell' charger appeared very similar to 555's in the '555' charger, even though both sets had different starting capacities. There may be some benefit in rejuvenating '555' cells in the 'Greencell' charger from time to time.

Standard alkaline cells (Eveready Energizer) were tested in the '555' charger and this caused excessive heating and failure to turn off, risking an explosion, leakage of electrolyte and permanent damage to the battery. The recorded regenerated capacity was reduced by half each time (Appendix IVa).

> ***It is therefore recommended not to attempt charging standard cells in any DC charger (such as the '555' charger) as they overheat and could explode.***

Both '555' & 'Greencell' chargers run off AC mains power packs that supply 12V DC. The '555' charger lead is wired in permanently, but this could be changed to a socket so an alternative external 12 battery connection (see Appendix 1) could be made for field users.

The 'Greencell' charger has a switch setting for NiCad cells. These cells were not tested here but Phillips (1995a) used a 50Hz regenerator and found it to be "most effective at recharging NiCads, and may even rehabilitate an otherwise 'dead' NiCad".

OTHER TYPES OF CELLS

NiCads still represent the highest Wh/$ over their life span than alkaline batteries (Appendix II). Although not specifically tested here, their characteristics are well known and widely reported (eg National Nickel Cadmium Battery Technical Handbook, 1983; Scott, 1985). Most problems arise with NiCads in their general use, or from poor charger design. Their lower shelf-life, and high cell failure in trickle chargers, (Moxham, 1991), makes them an unreliable choice for many standby applications. However, for high current demand applications, and where well designed chargers are used, they can be better value than '555' alkaline cells if used for more than 300 recharges.

Modern lead-acid sealed cells such as the Sonnenschein Dryfit Gel batteries, are economic, reliable and readily available, but not as low voltage single cells. They come in 6, 12, or 24V cells for applications requiring high capacity, voltage, current, and have a moderate shelf life (2 years).

Nickel metal hydride and vanadium pentoxide lithium rechargeable batteries, which don't exhibit many of the adverse characteristics of nickel cadmium, are slowly coming onto the market, but at the time of writing, are only available for specialised computer memory, portable computer power supplies and cellphones. These are still rather expensive batteries.

Table 2: Comparison of Three Battery Types

	STANDARD ALKALINE	'555' ALKALINE	NICADS	COMMENTS
Number of recharges	7-10	30-100*	700*	Approx * not confirmed
Shelf-life (mths)	48	24	3	Months decline to 10%
Cell memory	None	None	Yes, bad	Dendrites[1]
Standby trickle charging	Difficult	Easy	Easy*	* Can damage cell
Charging current	AC	DC	Constant DC	
Charger use	OK	Easy	Difficult	To use without damage
Capacity D size	8-10	6	4	Ah (20 hr rate)
Cost/cell D	$4	$7	$20	(Ret. Incl. GST)
Wh/$ value	x 1	x 3-8	x 15	cf. recharging Std Alkaline
Wh/$ value	x 1	x 15-60	x 100	cf. not recharg. Std Alkaline

Wh/$ = Watts (Volts x Amperes) x hours / dollars
[1] = dendrites are crystals that can build up in the cell, preventing uptake of charge.

RECOMMENDATIONS & CONCLUSIONS

1) Extend an alkaline battery's life, from 7-10 times, by using the 'Greencell' type recharger. A greater number of recharges may be possible by using lower current discharges, but this has not been tested. This charger will be useful for those that have already made a moderate investment in standard alkaline cells.

2) Do not overcharge or leave flat alkaline cells, as this reduces their life expectancy and often causes leakage of electrolyte.

3) For those who will be making even small investments in the future with single cells, the '555' brand of battery and its charger is the best to buy, achieving greater than 30 and possibly as many as 100 recharges. This represents a 3-8 times improvement in capacity delivered per dollar spent compared to recharging standard alkaline cells.

4) The '555' rechargeable are 15-60 times better value than discarding standard alkaline cells, as well as being far better for the environment.

5) Rechargeable '555' battery cells are better than standard nickel cadmium as they have 8-16 times greater shelf life, higher capacity, higher voltage per cell, fewer maintenance problems, indicate their state of charge more reliably, are easier to charge correctly and are cheaper per cell.

6) *DO NOT CHARGE STANDARD ALKALINE CELLS IN A DC CHARGER* (such as the '555' charger) as they overheat and could explode. Only use a special AC charger (eg the 'Greencell', model Maxi) for charging other brands of alkaline.

7) UNDER NO CIRCUMSTANCES SHOULD YOU TRY TO RECHARGE LITHIUM BATTERIES.

REFERENCES

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Nickel Cadmium Battery Technical Handbook. 1983. National, Matsushita Battery Industrial Co. Ltd., Osaka, Japan, pp. 10-18

Phillips, P., 1995a. Construction Project: Dry-Cell Charger. *Electronics Australia,* January 70-99.

Phillips, P., 1995b. Recharging Dry Cells. *Electronics Australia,* March 82-85.

Scott, J., 1985. Power to the people *Electronics International,* February 48-49.

Yates, D., 1994. Build a dry-cell battery rejuvenator. Silicon Chip November 14-19.

ACKNOWLEDGEMENTS

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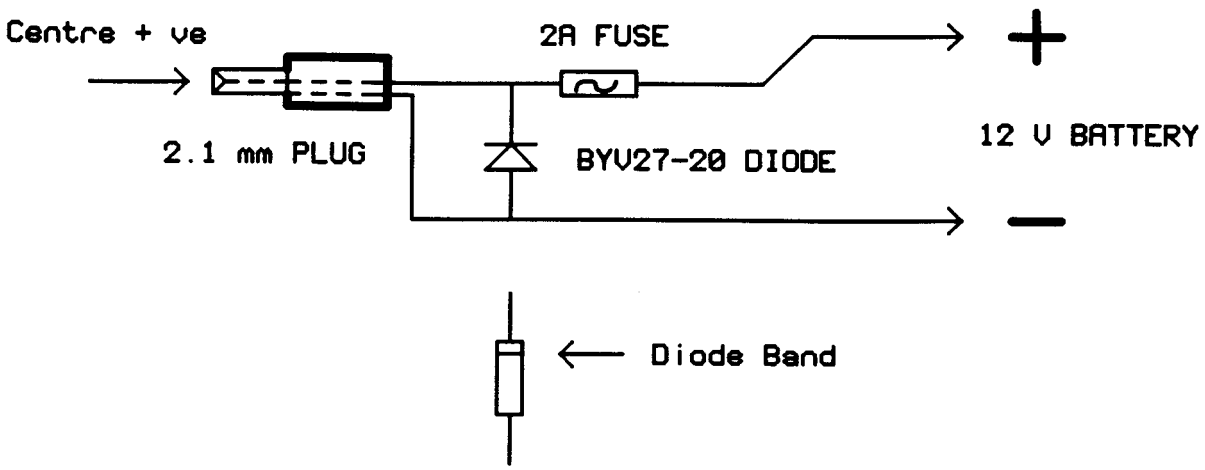
APPENDIX I

External 12V Charger Lead Adapter:

You can adapt the 'Greencell' charger, or the '555' charger, to run from a 12 volt car battery by making this adapter lead. Use a 2.1 mm plug (centre positive), a BYV27-20 (2A) diode connected across the lead, and a 2A fuse in series to a cigarette plug (centre positive) or alligator clips at the battery end. The diode conducts only if the leads are accidentally reversed, blowing the protection fuse and disconnecting the equipment. For the '555' charger, replace the permanently wired lead from the power pack with a plug and socket, so this alternative external adapter can be used.



ALKALINE BATTERY 1.5V CELL Wn/$ ANALYSIS

SOURCE	MANUF	MODEL	RETAIL COST	AHr	No. REGEN	$/Charg	Wh/$	Rel. Value
		AA cells	(Incl. GST)		(See Foot Note)			Factor
DEKA	EVEREADY	ALK. Energizer	$1.59	1.4	7	$0.23	6.82	2.2
DICK SMITH	PANASONIC	Alkaline	$1.95	1.6	7	$0.28	6.27	2.0
DICK SMITH	FUJI	Novel Alkaline	$1.75	1.6	7	$0.25	6.99	2.2
PHOTO&CAM	TOSHIBA	Alkaline	$1.74	0.7	7	$0.25	3.11	1.0
WISEMAN	VARTA	Alkaline	$2.03	1.2	7	$0.29	4.67	1.5
PHOTO&CAM	TOSHIBA	Alkaline	$1.74	0.7	7	$0.25	3.11	1.0
BOND & BON	DURACELL	Alkaline	$1.74	1.1	7	$0.25	5.10	1.6
PM DIST	555	Alkaline	$3.00	0.7	100	$0.03	25.76	8.3

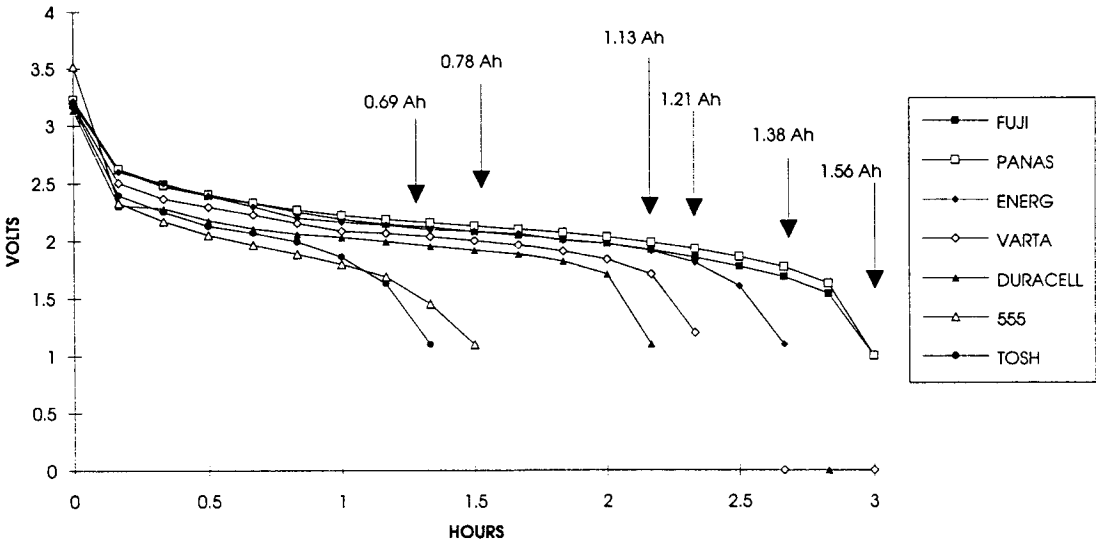
SOURCE	MANUF	MODEL	RETAIL COST	AHr	No. REGEN	$/Charg	Wh/$	Rel. Value
		D Cells			(See Foot Note)			Factor
DEKA	EVEREADY	ALK. Energizer	$2.90	8.2	7	$0.41	22.21	1.5
DICK SMITH	PANASONIC	Alkaline	$4.00	8.6	7	$0.57	16.82	1.1
DICK SMITH	FUJI	Novel Alkaline	$3.75	8.6	7	$0.54	17.98	1.2
WISEMAN	VARTA	Alkaline	$4.05	7.8	7	$0.58	15.10	1.0
BLUE STAR	DURACELL	Alkaline	$3.20	10.0	7	$0.46	24.50	1.6
PM DIST	555	Alkaline	$7.00	6.8	100	$0.07	108.16	7.2

SOURCE	MANUF	MODEL	RETAIL COST	AHr	No. REGEN	$/Charg	Wh/$	Rel. Value
		D cell			(See Foot Note)			Factor
DICK SMITH	FUJI	NICAD	$20.00	6.8	700	$0.03	236.60	15.7

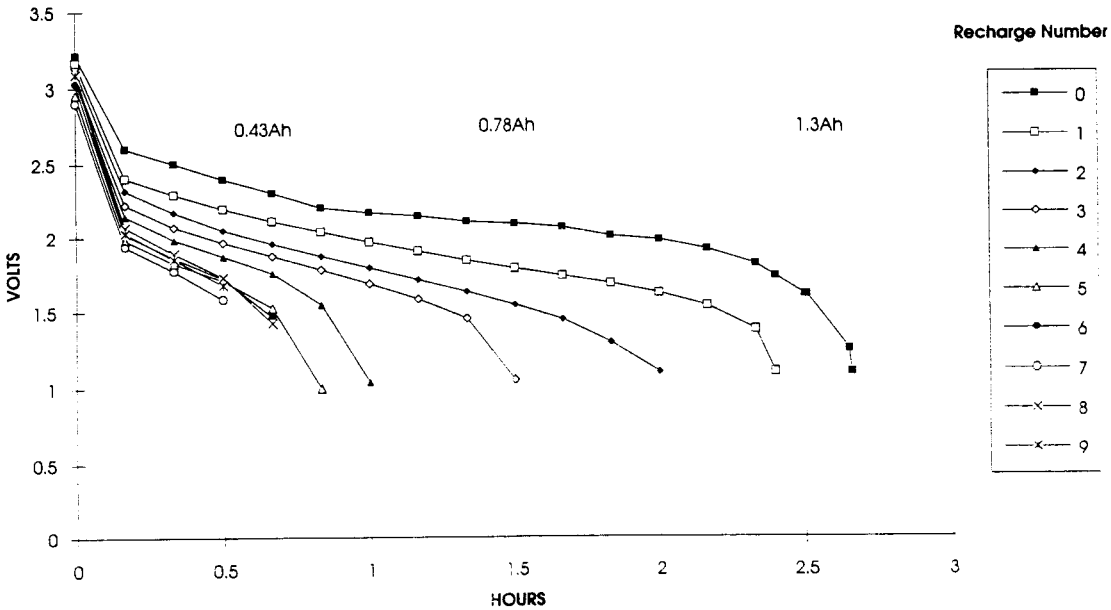
FOOT NOTE: 'No. REGEN': tested for Energizer, estimated others

APPENDIX III: RATE OF VOLTAGE AT CONSTANT DISCHARGE RATE

(a) 2 x AA ALKALINE BATTERIES IN SERIES (All Brands)

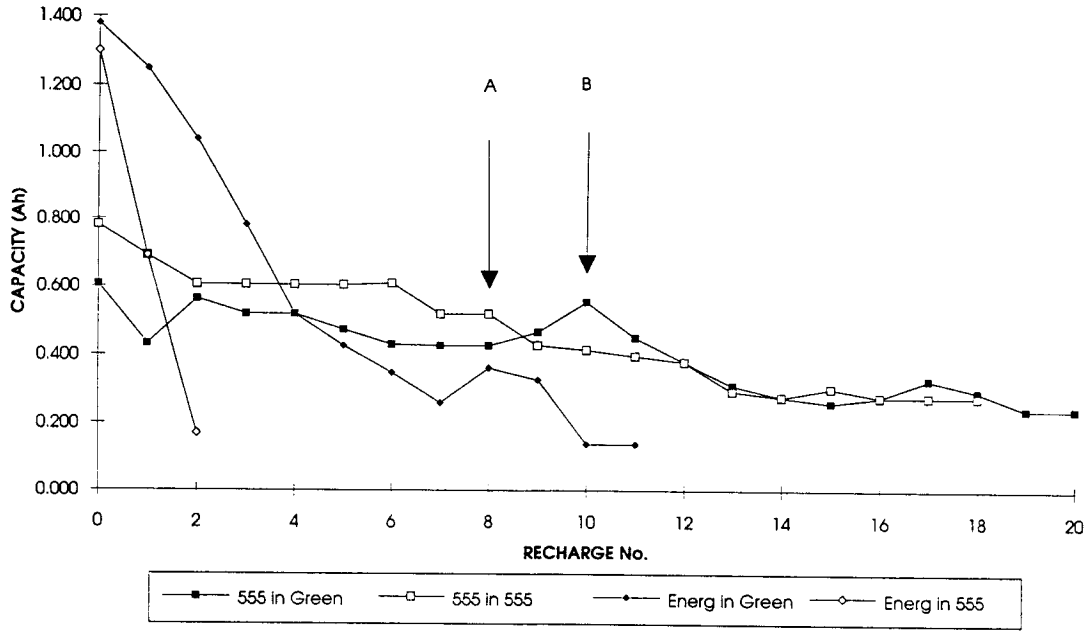


(b) 2 x AA EVEREADY ENERGIZERS IN SERIES 0-9 recharges

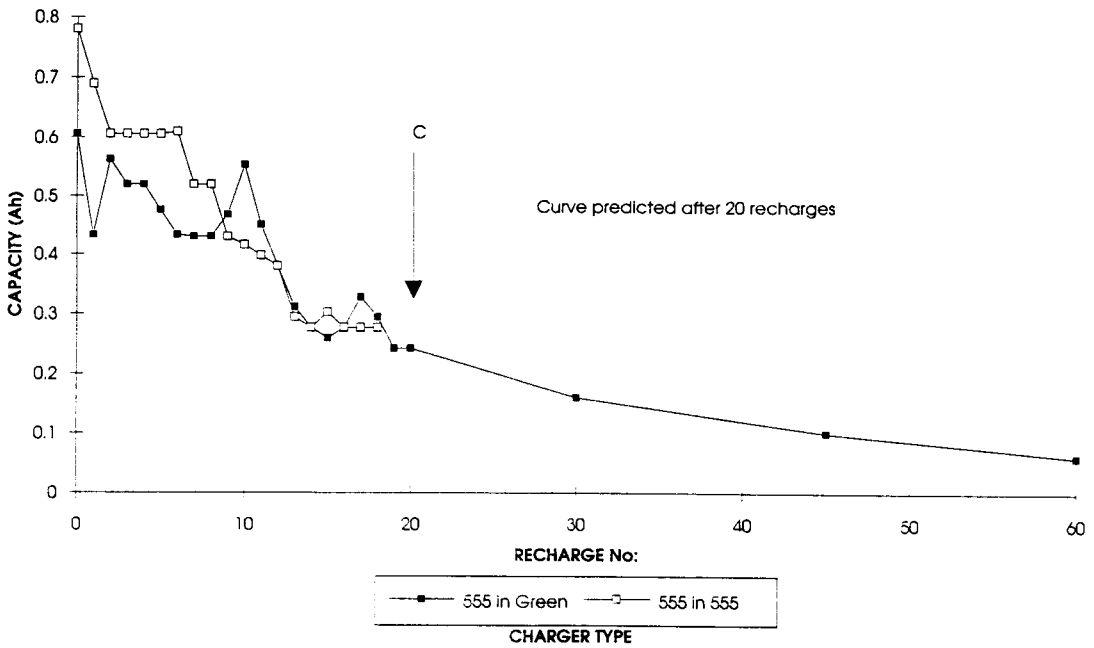


APPENDIX IV: CAPACITY OF BATTERIES AFTER MULTIPLE RECHARGING

(a) 2 x AA ALKALINE IN SERIES: Capacity / Recharge Number

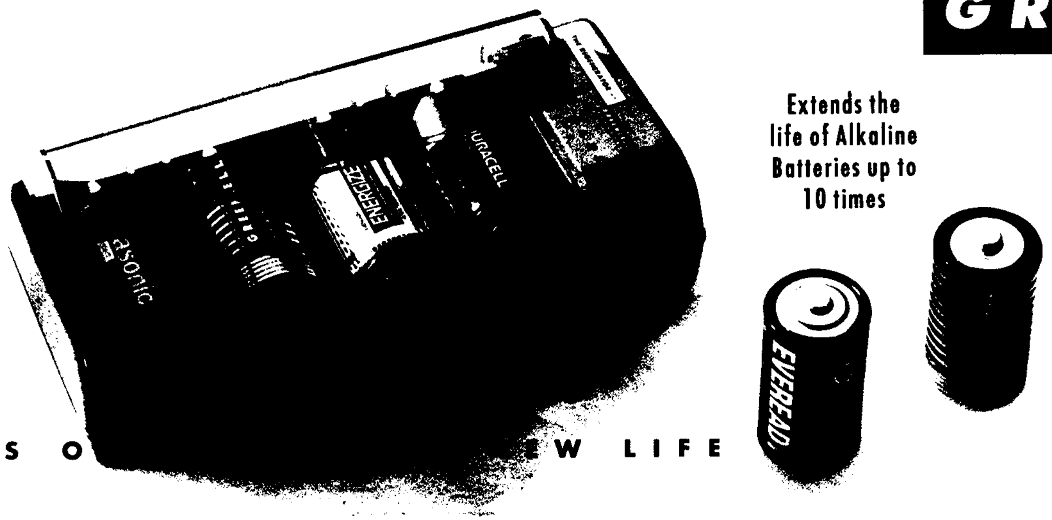


(b) 2 x '555' CELLS - Life Prediction



GREENCELL

MAXI



Extends the life of Alkaline Batteries up to 10 times

- Recharges Alkaline batteries up to 10 times.
- Recharges Heavy Duty and Super Heavy Duty batteries up to 3 times.
- Also recharges NiCad batteries.
- Recharges AAA, AA, C and D battery sizes.
- Pays for itself many times over.
- Helps save the environment.

GIVES O W LIFE

RMK 2

MAXI

GREENCELL

● Recharges AAA, AA, C and D Alkaline batteries up to 10 times and Heavy Duty and Super Heavy Duty batteries up to 3 times ● Also recharges NiCad batteries ● The more high drain battery operated devices you use, the more money you'll save ● Charging is monitored automatically so it's perfectly safe

Greencell Battery Co. is not related to any other battery manufacturer or distributor in Australia

APPENDIX VI: ' 555' DC Charger Models & Prices

COMMERCIAL CHARGERS

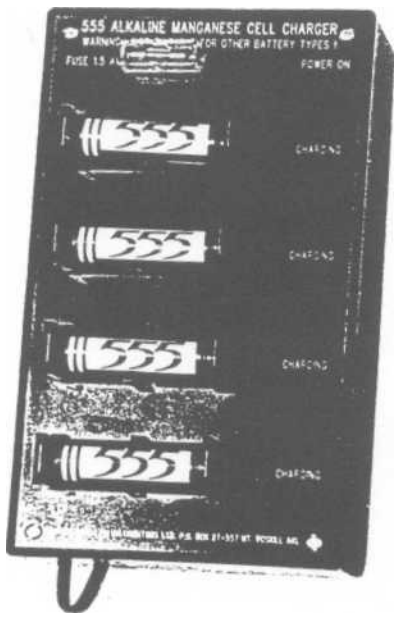
These chargers are specifically designed for charging **only 555 Rechargeable Alkaline Cells** at the required **constant voltage and taper current.** Each cell is individually electronically monitored and overcharging is not possible. An LED charging indicator for each cell indicates when charging is complete.

The charger comes in a 4 cell modular form to allow for individual requirements.

Each 4 cell module will only charge **one size of cell.** However, 2, 3 or 4 modules for different size cells can be linked to form the 8, 12, or 16 cell charger.

With 2.5Amp Power supply	Pre GST	Incl GST
4 cell unit	$57.00	$64.13
8 cell unit	$97.00	$109.13
12 cell unit (except D size)	$135.00	$151.88
16 cell unit (AA size only)	$175.00	$196.88

With 5Amp Power supply		
12 cell (D size)	$155.00	$174.38
16 cell (C & D size)	$190.00	$213.75



APPENDIX VII: '555' Rechargeable Alkaline Battery Prices

555 RECHARGEABLE ALKALINE BATTERIES

QUANTITY PRICE BREAKS *NOVEMBER 1994*

CELL	PRICE EXCL. GST					RECOM. RET. INCL. GST
		10%	15%	20%	25%	
QUANTITY (120 per box)	**0-59**	**60-119**	**120-239**	**240+**	**960+**	
LR6 AA	$2.67	$2.40	$2.27	$2.13	$2.00	$3.00
QUANTITY (48 per box)	**0-23**	**24-47**	**48-95**	**96+**	**384+**	
LR14 C	$5.33	$4.80	$4.53	$4.27	$4.00	$6.00
QUANTITY (24 per box)	**0-23**	**24-47**	**48-95**	**96+**	**192+**	
LR20 D	$6.22	$5.60	$5.29	$4.98	$4.67	$7.00

APPENDIX VIII: PM Distributors Ltd, Order Sheet

PM DISTRIBUTORS LTD

PO BOX 27-557, MT ROSKILL, AUCKLAND FAX 09 625 0040

555 RECHARGEABLE ALKALINE BATTERIES

ORDER FORM

ITEM	DESCRIPTION	UNIT PRICE (incl GST)	NUMBER REQUIRED	AMOUNT
LR6	AA battery	$3.00		$
LR14	C battery	$6.00		$
LR20	D battery	$7.00		$
ACH4	4 cell AA Charger	$64.13		$
CCH4	4 cell C Charger	$64.13		$
DCH4	4 cell D Charger	$64.13		$
ACH8	8 cell AA Charger	$109.13		$
CCH8	8 cell C Charger	$109.13		$
DCH8	8 cell D Charger	$109.13		$
ACH12	12 cell AA Charger	$151.88		$
CCH12	12 cell C Charger	$151.88		$
DCH12	12 cell D Charger	$174.38		$
ACH16	16 cell AA Charger	$196.88		$
CCH16	16 cell C Charger	$213.75		$
DCH16	16 cell D Charger	$213.75		$
Special Charger (specify- see Note)				$
		FREIGHT		$
		TOTAL INCL. GST		**$**

Please add freight charge North Island $3.50
South Island $7.00

PLEASE NOTE
Each charger module (4 cell) is capable of charging one size of battery only.
Charger modules for different sized batteries can be linked if required up to 3 modules.
Prices as for standard linked units - ie 8 cell, 12 cell

NAME _____

COURIER DELIVERY ADDRESS _____

_____

Please check if Tax Invoice is required