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BATTERIES–FOR BIOTELEMETRY AND OTHER APPLICATIONS

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BATTERIES - FOR BIOTELEMETRY AND OTHER APPLICATIONS

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Larry B. Kuechle

DESCRIPTION OF ELECTRO-CHEMICAL CELLS AND THEIR APPLICATION TO RADIO TELEMETRY

INTRODUCTION

The improvement of design technique and component reliability during the last several years has made the power source the limiting factor in the design of biological radio-telemetry equipment. Of the many sources available the dry cell is most commonly used and is usually the most economical. This paper briefly describes the characteristics and limitations of the most commonly used primary and secondary dry cells. Familiarity with the operation and design philosophy of the various dry cells will enable the user to select the most suitable cell for a particular application. Also should the user want to discuss a particular application with the manufacturer, this familiarity will result in a better presentation of the problem.

This paper does not present complete information on all dry cells for two reasons: first, a complete presentation of the available information on all the variables involved would require several volumes, and second, complete information is not available. Since the discussion is of a general nature; the data sheets, and in many cases the manufacturer of the particular cell in question, should be consulted for more exact data. Also included is a section on thermoelectric cells powered by a radioactive source.

I. NON-RECHARGEABLE CELLS (PRIMARY CELLS)

MERCURY CELLS

(1) *General Characteristics of Mercury Cells*

(a) Electrical Characteristics: The mercury cell is the most commonly used cell in biological radio-telemetry today. There are many variations of the mercury cell, each designed for a specific purpose. All cells use zinc as the anode, mercuric oxide as the cathode, and an electrolyte of potassium hydroxide or sodium hydroxide saturated with the zincate ion. Since zinc is soluble in hydroxides, this saturation is necessary to prevent premature dissolution of the anode. The major advantages of mercury cells, which make them particularly well-suited to biological radio-telemetry are a high ratio of energy to volume and weight, relatively constant potential throughout their useful life, and long shelf life.

The mercury cell is capable of packaging 50 watt hours per pound or 6 watt hours per cubic inch. High vacuum or pressures of 5000 psi have no detectable effect on mercury batteries. Momentary short circuits usually cause no permanent damage and recovery to full voltage usually occurs within minutes (P. R. Mallory battery data sheets).

(b) Soldering: Soldering directly to the battery case should be avoided if at all possible. Some batteries are available off-the-shelf with tabs. All batteries are available on factory order with tabs; the manufacturer attaches the tabs by spot-welding before the battery is assembled or under closely controlled conditions after assembly. Mallory uses a "T" designation after the battery number to indicate tabs; a "T" would indicate one tab, a "T2" would indicate a tab on both the positive and negative terminals.

Should it be necessary to solder leads to mercury cells, it can be done successfully by observing the proper precautions. The location where the lead is to be soldered should be sanded or filed clean, a thin film of flux applied, and a hot soldering iron with a small point used to solder. Water or another cooling agent should be used to cool the joint immediately. Precooling would also help to localize the heating effects. Since the positive terminal has the double case on all but the smaller button cells, soldering to it is not nearly as critical as to the negative terminal which has a much smaller area and, on most cells, has only a single layer to dissipate the heat.

(c) Potting: Mercury cells may be completely potted. Potting compounds that may react with any electrolyte seepage should be avoided as should those that might cause corrosion on the terminals either by direct action or by electrolytic action between copper lead wires and the steel case. The epoxies and acrylics are probably the most suitable potting compounds. Water in itself is usually quite harmless; however, the combination of water and electrolyte or the salts that are contained in the water may cause corrosion or salt formation. These problems are more prevalent in cells using a potassium hydroxide electrolyte. Since cells having a neoprene seal have a smaller gap between the positive and negative terminal, they are more prone to salt bridging than are those with polyethylene seals.

(d) Checking Battery Condition: Often it is desirable to check the capacity remaining in a battery. The constant potential throughout the life of the mercury cell makes detection of the life remaining difficult unless the cell has reached the knee in its voltage vs time curve. This voltage drop-off occurs when the cell has used more than 95% of the anode. Although the 1.4 volt mercury cells have a slight drop in voltage throughout their life, the characteristics of this drop are determined more by the past history of the cell than by the capacity remaining. This makes voltage an inaccurate measure of available capacity. Mercury cells are designed so that all of the zinc anode is used up at the end of the cell's life; this leaves at least two methods for determining the capacity remaining. Examination by x-ray has the advantage that in being nondestructive it allows the cell to be reused, should the capacity remaining warrant its reuse. This method has serious limitations, in that x-ray equipment is usually not readily available and an experienced observer is needed to obtain accurate results. The second method, a destructive test, is to remove the anode and weigh the remaining zinc. The anode weights are held to within better than 10% of nominal in the smaller cells and better than 5% in the larger cells. Life remaining is directly proportional to the amount of zinc remaining. If this method is used the zinc oxide can be removed by washing in watter. All precautions for handling corrosive and mercuric compounds should be observed.

Another method which will give a qualitative check on a cell's condition is its ability to provide surge currents into a low resistance load. The 10 ampere connection on a multitester can be used for this test.[1]

(2) *Characteristics of Specific Cells*

(a) Standard Mercury Cells: Standard mercury cells have an output voltage of 1.35 volts or 1.4 volts depending on cathode composition. Batteries may be made up of multiples of these voltages. The 1.35 volt cells use a pure mercuric oxide depolarizer (plus graphite). These cells are used where a constant voltage is desired such as in test and measurement equipment. Mallory uses an "R" designation after the cell number to designate it as a cell with pure mercuric oxide depolarizer. Over the normal life of the cell voltage regulation to within 0.5% of 1.35 volts should be maintained and for short periods (1 day) 0.1% should be maintained. The no-load voltage of the "R" suffix cells is guaranteed to be 1.35 ± 0.007 volts (P. R. Mallory data sheets). The 1.4 volt cells have a small quantity of manganese dioxide added to the mercuric oxide depolarizer which improves the low drain performance and reliability of the cell. The 1.4 volt cells should be used where the voltage regulation of the 1.35 volt cells is not required.

Most manufacturers specify the capacity of a cell at a particular current drain. This specification is at the 90% efficiency level (anode 90% used up) which occurs at about 0.2 ampere-hour per gram of depolarizer. A derating of at least 10% should be used when operating at drains other than the one at which the rating was made.

Sodium hydroxide is sometimes used in batteries for low drain applications; this increases the low drain capability and shelf life but decreases the low temperature capability of the cell. The change in electrolyte does not prevent the movement of mercury from the cathode to the anode (migration); a condition prevalent in many of the batteries used in our studies.

(b) Certified Cell Types: P. R. Mallory Company manufactures a series of cells known as certified cells. These cells were originally designed to meet the high reliability requirements of heart pacemakers. Certified cells are the same as standard cells except that they are manufactured to close tolerances and are inspected for defects at each stage of construction. The certified cells also have an added barrier between the anode and cathode which has prevented the migration of mercury in the cells we have used.

At the present time the sizes available off-the-shelf are the RM1 and the RM640. Other sizes could be special ordered; however, the quantities needed to make this economically feasible would not be practical in most cases. Off-the-shelf certified cells cost about ten times as much as regular types.

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[1]This method from personal communication. Howard A. Baldwin, Sensory Systems Laboratory.

In our studies the certified cells have been used on some snowshoe hare transmitters. Using the 401 (non-certified) type, 22 to 35% of the calculated life was obtained. Our test data on certified cells is not complete because we have not allowed the cells to use up their full capacity in the field. Examination of the cells on retrieval for replacement after 85% of normal capacity had been used, showed normal anode usage with no evidence of mercury migration. With the certified cells we feel that we can allow 80% of calculated capacity before replacement without danger of failure. A higher percentage could probably be used if we could reliably predict transmitter ageing and other effects which may cause changes in the current drain.

Since these cells use a sodium hydroxide electrolyte, an evaluation of their behavior at low temperatures is necessary. These tests have not yet been made; however, it is anticipated that at the low drains usually used no deterioration in cell performance will occur.

(c) Low Temperature Cells: Low temperature cells, compared to standard types, produce a greater percentage of their room temperature rated capacity at low temperatures. Their usefulness in biological radio-telemetry depends on the current drain and cell size. Since poor low temperature performance of standard mercury cells is at least partially due to an increase in anode impedance, and since the anode impedance is a function of current drain, the amount of capacity lost is also a function of drain. The lower the drain, the smaller the capacity loss due to low temperature. It is difficult to say at what current drains and at what temperatures low temperature cells should be used. In our studies on fox, raccoon, and owl at the Cedar Creek Natural History Area (Central Minnesota) we have found little difference in battery life from summer to winter. We do not have temperature measurements of the cells in these cases; however, they were probably somewhat higher than ambient because of their placement on the animals. We also ran a series of tests on Rm-12 cells at continuous low temperatures varying from -10°F to +20°F at drain levels of about 0.7 milliamperes. In the test we received about 100% of the room temperature capacity of these cells. These tests seem to indicate that low temperature cells would give no improved performance if the current drain is such that the expected life is 5000 hours or more.

(i) Wound Anode Types

Wound anode type cells have been developed to overcome the problem of high anode impedance at low temperatures. The anode is made up of a ribbon of zinc wound around an absorbent material saturated with electrolyte. This increases the anode surface area and reduces the overall anode impedance.

Behavior of the wound anode cells under vacuum or pressure is similar to that of standard mercury cells and their shelf life is also about the same. At present the wound anode types are made in five sizes varying from 360 to 13,000 milliampere-hour (mah). They are made only in the flat button cell types and their watt-hours to weight ratio is slightly less than the ratio of regular cells.

We have not tested these cells at high temperatures and low drains; however, we suspect some derating may be necessary under these conditions.

(ii) CMC Types

Another group of low temperature cells, the CMC types, has carboxy methyl cellulose added to the anode to decrease the cell's internal impedance at low temperatures. Since these cells, manufactured by P. R. Mallory Company, are relatively new, complete published data is not yet available. Cells presently available are RM-1CMC, RM-502CMC and RM-12CMC, with respective capacities of 1000, 2300, and 3600mah. Case sizes are the same as RM-1, RM-502, and RM-12. These cells also have an improved barrier to prevent the migration of mercury, a problem prevalent in low drain operation.

(d) Low Drain Types: Several sizes of mercury cells are built especially for low drain operation. They are different from standard types in that they may use sodium hydroxide instead of potassium hydroxide as the electrolyte and that they have an improved barrier between the cathode and anode. This improved barrier is designed to prevent the migration of particles from the cathode to the anode causing internal shorting. We feel that internal shorting is responsible for much of the poor battery performance in our biological radio-telemetry studies. All batteries examined without the improved barrier had some mercury migration, whereas none of those with the improved barrier exhibited mercury migration.

In our studies on raccoon using the RM-12 we had 41 transmitters that went dead after being on animals for 18 to 66% of their expected lives, 14 were removed from animals after 30 to 45% of their expected life was used. Using the Zm-12 cells we had five transmitters that had used more than 50% of their expected life when they were removed from the animal. These transmitters were then placed outdoors; all stopped functioning with 92 to 100% of their expected life used. Five batteries were replaced after 45 to 60% of expected life was used; three transmitters now on animals have more than 50% of their expected life used. Two transmitters failed while on animals, one at 53% of its expected life, the other at 59%. It is not known whether the battery or transmitter failed.

Low drain cells are made in several sizes and with either sodium hydroxide or potassium hydroxide as the electrolyte. The ZM-12 and RM-1NW have potassium hydroxide as the electrolyte, the RM 1W has sodium hydroxide. The RM-42 is also available with either sodium hydroxide or potassium hydroxide as the electrolyte. The cells with potassium hydroxide electrolyte have better low temperature performance than do those with sodium hydroxide. There is some deterioration in the low drain cell's performance at high current drains. These cells can be used advantageously where the cell life exceeds 1000 hours. The cost of low drain cells is about the same as regular cells.

STANDARD TYPES

Battery type Mallory	Battery type Eveready	Suggested Max Drain (ma)	Service Cap Mah	Service Rated at (ma)	Dimensions Diameter (cm)	Length(cm)	Weight(gm)	Volume(cc)
RM-212	-	1	16	0.75	0.57	0.33	0.27	1.38×10^{-1}
RM-312	E312	3	36	2.	0.79	0.35	0.57	1.65×10^{-1}
RM-400	E400	5	70	2.	1.15	0.34	1.13	3.28×10^{-1}
RM-520	E520	10	130	5.	1.25	0.73	2.00	8.20×10^{-1}
RM-675	E675	10	160	5.	1.15	0.53	2.00	4.90×10^{-1}
RM-625	E625	20	350	5.	1.56	0.61	4.20	11.5×10^{-1}
RM-450	E450	30	350	5.	1.15	1.45	5.1	14.7×10^{-1}
RM-630	E630	20	350	5.	1.56	0.61	4.8	11.5×10^{-1}
RM-640	E640	50	500	15.	1.59	1.12	10.8	21.2×10^{-1}
RM-401	E401	75	600	25.	1.20	2.81	11.3	29.5×10^{-1}
RM-1	E1	75	1000	20.	1.59	1.65	12.2	32.8×10^{-1}
RM-601	E601	80	1800	30.	1.60	2.90	34.5	54.0×10^{-1}
RM-3	E3	60	2200	42.	2.50	1.68	26.4	82.0×10^{-1}
RM-502	E502	200	2400	50.	1.40	5.00	30.0	72.0×10^{-1}
ZM-9	E9	200	2400	25.	1.40	5.00	30.0	72.0×10^{-1}
RM-4	E4	80	3400	63.	3.04	1.68	45.0	121.0×10^{-1}
RM-12	E12	250	3600	62.	1.63	5.00	40.0	98.0×10^{-1}
RM-42	E42	500	14000	250.	3.30	6.10	167.0	480.0×10^{-1}

S P E C I A L   T Y P E S

Type No.	Description	Suggest Max Drain(ma)	Service Cap. Mah.	Service Rated at(ma)	Dimensions Diameter(cm)	Length(cm)	Weight(gm)	Volume cc
RM640WA	Wound anode, low temp.	50	360	15	1.6	0.97	10.2	19.5×10^{-1}
RM3WA	Wound anode, low temp.	75	1200	25	2.5	1.18	22.0	58.0×10^{-1}
RM1438R	Wound anode, low temp.	150	2700	100	3.7	1.00	41.0	100.8×10^{-1}
RM1450R	Wound anode, low temp.	200	4500	100	3.7	1.32	53.0	142.0×10^{-1}
RM2550R	Wound anode, low temp.	500	13000	405	6.5	1.39	168.0	460.0×10^{-1}
RM640CC	Certified cell	10	500	1	1.59	1.12	10.8	21.2×10^{-1}
RM1CC	Certified cell	20	1000	[illegible]	1.59	1.65	12.2	32.8×10^{-1}
RM1NW	Low drain, KOH elect.	20	1000	5	1.59	1.65	12.2	32.8×10^{-1}
RM1W	Low drain, NaOH elect.	20	1000	5	1.59	1.65	12.2	32.8×10^{-1}
ZM12	Low drain, KOH elect.	30	3600	10	1.63	5.00	40.0	98.0×10^{-1}
RM1CMC	Low temp. CMC	75	1000	30	1.59	1.65	12.2	32.8×10^{-1}
RM502CMC	Low temp. CMC	200	2400	50	1.40	5.00	30.0	72.0×10^{-1}
RM12CMC	Low temp. CMC	250	3600	62	1.63	5.00	40.0	98.0×10^{-1}
RM42W	Low drain	50		20	same as RM-42			

SILVER OXIDE-ZINC CELLS

The silver oxide-zinc cell is similar to the mercury cell with the significant difference being the silver oxide depolarizer in the silver oxide-zinc cell vs. the mercuric oxide depolarizer in the mercury cell. Silver oxide-zinc cells were developed for use in watches and hearing aids and as such are made in very small sizes. Their milliampere hour to weight and volume ratio is about the same as the mercury cell; however, since silver cells have a voltage of 1.5 volts, their watt-hour to weight and volume ratio is better (approximately 10%).

Potassium hydroxide electrolyte is used in high current drain applications and sodium hydroxide is used to improve reliability where the current drain is low. As in mercury cells, manganese dioxide is added to the depolarizer to improve reliability in cells used in applications where a flat voltage discharge characteristic is not needed.

The shelf life of silver oxide-zinc cells is less than that of mercury cells, especially at higher storage temperatures. The low temperature characteristics are about the same, with the limiting factor again being anode surface area.

In general most of the characteristics such as checking for capacity remaining, stability, paralleling, etc., of mercury batteries apply to silver oxide-zinc cells.

Since these cells were designed for hearing aids and watches they are somewhat limited in capacity. The largest size manufactured by P. R. Mallory and also by Eveready is 165mah. Larger sizes are manufactured in dry-charge types; however, their bulk precludes use in most telemetry work.

II. RECHARGEABLE CELLS (SECONDARY CELLS)

NICKEL CADMIUM CELLS

(1) *General Description*

Nickel cadmium cells can be used advantageously where power consumption is relatively high and where a source of charging current is readily available. In biological radio-telemetry they could be used in portable receiving equipment, on transmitters where the animal can be readily recaptured or where solar cells can be used for recharging. Cell capability is about twelve watt-hours per pound and about 1.2 watt-hours per cubic inch.

Nickel cadmium cells are made up of a positive plate of nickelic hydroxide and a negative plate of metallic cadmium. The plates are of three types: a sintered type where the plates are sintered onto a fine mesh nickel screen, a pasted type where the materials are pressed onto a fine mesh screen, and the pocket type where the materials are held in finely perforated steel pockets. The sintered types are more expensive, have higher charge/discharge capability and have a longer cycle life than do the pressed or pocket types. In all cases the nickel screen is used for support. These plates are then cut to size, a separator placed between the positive and negative plates and the unit placed in a can. To obtain the needed surface area the units are usually made up of a roll of plates insulated from each other by the separator. In the smaller button-type size the plates consist of two pellets insulated from each other by the separator. The electrolyte in nickel cadmium cells is potassium hydroxide.

Both sealed cells and vented cells are available commercially. The vented types should be used where large peaks of power or high recharging rates are required. An example of high power drain would be engine starting; a high charging rate would be more than two amperes per pound of cell or a complete recharge in less than ten hours. Vented cells have the disadvantage of being non-pottable and of losing electrolyte through evaporation. Also, vented types must be kept in an upright position during operation. Vented types probably have little application in biological radio-telemetry.

Sealed cells are not truly sealed because, should the internal pressure become too high, the cell seal will be released and the excess gas vented. These seals may be of the resealing type where the seal is reformed once the excess pressure has been released or the non-resealing type where once the seal is broken the cell becomes essentially a vented type. Excess gas pressures are usually the result of the charging or discharging rates being too high, over-charging, or over-charging which may result in polarity reversal in series cell hookups. This generation of excess gas and the subsequent breaking of the seal should not occur during normal operation of the cell. The releasing seals are used as a safety measure to prevent distortion and possible rupture of the cell should a cell malfunction or improper operation generate excess gas pressure.

(2) *Pertinent Characteristics of Nickel Cadmium Cells*

(a) Voltage regulation: Nickel-cadmium cells have a peak open circuit voltage of 1.45V, with a voltage of about 1.2 when operating with a rated load. Voltage regulation of cylindrical cells is usually better than that of button cells. Somewhat better regulation will occur when operating at less than rated loads with poorer regulation at higher than rated loads.

(b) Temperature: Maximum operating range of nickel cadmium cells is -20°C to +40°C. Available capacity decreases to about 20% of the 20°C capacity when operating at -20°C or +40°C and at rated load. Capacity will be somewhat less temperature dependent at less than rated loads and somewhat more dependent at greater than rated loads. They should not be charged at temperatures below 0°C or above 45°C.

(c) Charging: The usual method of recharging is with a constant current at a rate of 1/10 (C/10) the ampere hour capacity of the cell for 14-16 hours. The 14-16 hours recharging is necessary since the recharging process is not 100% efficient making it necessary to replace more charge than had been removed. Depending on the manufacturer, cylindrical cells may be left at the C/10 charging rate for several weeks or longer without cell damage. Charging of button cells is more critical and charging at the C/10 rate for much longer than the 14-16 hours may result in cell damage. A charging rate of 1/15 the ampere-hour capacity is a more suitable rate for button cells and should be used if possible.

A continuous trickle charge of 1/100 the ampere hour capacity may be used on both button and cylindrical cells without damage. In all cases manufacturer's data sheets should be consulted for information on recharging a particular cell.

(d) Charge Retention: The self discharging characteristic of nickel cadmium cells is one of its most serious drawbacks in biological radio-telemetry. This self discharge is temperature dependent; at 50°C a typical cell will have lost 75% after 90days, at 0°C it will retain close to 90% of its original charge after 120 days (G. E. data sheets). This figure will vary somewhat with cell type and with manufacturer. Although a cell may become completely discharged while on the shelf it need merely be recharged before use with no loss in cell life. It may, however, take several charge-discharge cycles before the cell reaches full capacity.

(e) Parallel Operation: Nickel-cadmium cells should not be connected in parallel. Differences in internal resistance may result in one cell not discharging while other cells over-discharge resulting in polarity reversal and cell damage. In recharging parallel arrangements it is very difficult not to over-charge some cells and under-charge others. If cells must be connected in parallel either during the charging or discharging cycle a swamping resistor of 100 times the internal resistance of the cell should be used to negate the internal resistance variation.

(f) Series Operation: Nickel-cadmium cells may be connected in series to get multiples of 1.2 volts. It is necessary to avoid completely discharging the series connected cells. If one cell of the group is completely discharged before the others, the charged cells will continue to force current through the discharged cell. When this occurs the polarity of the cell reverses, hydrogen is generated at the nickel electrode and oxygen, at the cadmium, resulting in the buildup of high gas pressure and cell damage. This should be prevented by specifying capacities at least 10% greater than needed or using a relay or other protective device to disconnect the load should the voltage fall below the 1.0 volt per cell level.

(g) Cycle Life: With intermittent use the cycle life of the cell(s) should be several years. Under normal charge-discharge cycles a cell life of 300 cycles can be expected from the sintered types and about 100 cycles from pressed or pocket types. This cycle life can be increased by 10 times or more if the cell is discharged to no more than 25% of its capacity and not over-charged.

SILVER OXIDE-ZINC SECONDARY CELLS

Silver oxide-zinc secondary cells are superior to most other secondary cells in watt-hours to weight and volume ratio and in low temperature characteristics. They also have a higher and more constant voltage than do most of the other secondary cells.

Silver oxide-zinc cells are used where their superior watt-hours to weight ratio or their behavior at low temperatures is needed. At low temperatures these cells can be temporarily shorted with the resulting internal heat generated warming the cell sufficiently to yield about 30% of its room temperature capacity.

The major limitations of these cells are low cycle life, poor charge retention, and poor wet life. Their cycle life varies from 15-200 cycles depending on the rate of discharge and amount of overcharge (Gould-National data). The charge retention of silver oxide-zinc cells also varies with use and design; 20% loss/month is typical for high drain rates, 5 to 10% loss per month is typical for low drain types. The wet life of the cell is the life after it has been activated from its dry-charged state. Wet life varies from 30 days to 18 months depending on cell design and use (Gould-National data). Some improvement in these characteristics can be expected as better positive-negative plate separators are developed.

SILVER OXIDE-CADMIUM CELLS

Silver oxide-cadmium and silver oxide-zinc cells are very similar in general construction and characteristics. The major difference is the substitution of cadmium for zinc as the anode material. The ampere-hour per pound yield of the silver oxide-cadmium cell approaches that of the silver oxide-zinc cell, however, the 1.1 volt operating voltage results in a watt-hour per pound ratio of a little more than half that of silver oxide-zinc cells. They have about twice the watt-hour per pound capacity of nickel-cadmium cells.

The lower activity of cadmium results in a lower output voltage but also results in a much higher charge retention; shelf losses of 1 to 2% per month are typical. The insolubility of cadmium and cadmium oxide in alkalines is the most significant factor in the improvement of the reliability of silver oxide-cadmium cells over silver oxide-zinc. The cycle life of silver oxide-cadmium cells is 10-25 times greater than that of silver oxide-zinc cells.

III. SPECIAL AND DEVELOPMENTAL CELLS

SPECIAL CELLS

There are two low voltage cells, both manufactured by P. R. Mallory Battery Company, which may have some application in biological radiotelemetry where a voltage lower than the 1.35 to 1.5 volts usually available is needed. The first of these, the XA-10B lead oxide-silver system, has a nominal output voltage of 0.9 volts with about half the milliampere-hour capacity of the mercury cell. One of the features of this cell is that it is manufactured in the inactive state allowing storage for long periods without cell deterioration. The cell is activated before use by charging (electrically). Another feature is its ability to deliver full capacity at drain rates utilizing the cells capacity in two days or two years.

Another cell has been designed for use as a bias cell or with tunnel diodes. It has a normal voltage of 0.5 volts, is made in 160, 500, and 1000 mah sizes, and has a milliampere-hour capacity similar to that of mercury cells. Due to its lower voltage it has about one-third the watt-hour per pound capacity of the mercury cell.

Another system which may have some application is the water activated magnesium-silver chloride system. It has a capability of 50 to 70 watt-hours per pound (dry weight) and can be activated by immersion in either fresh water or sea water. Its wet life is usually quite short, several days at most.

DEVELOPMENTAL CELLS

Probably the most recent development in power sources with direct applicability to biological radio-telemetry is the radio isotope thermoelectric generator. At least two groups are currently working on devices of this type. Nuclear Materials and Equipment Corporation, under contract from AEC, is developing a unit specifically for the heart pacemaker. It is to be about 2/3 the size of a cigarette pack, have power output of 162 microwatts and a life of 10 years or more. (Electronics, 13 June 1966). The fuel is plutonium -238.

General Atomic, a division of General Dynamics Corporation, is working on a more general power source designated SNAP - 15A. This device has a power output of 1.55 milliwatts, weighs 0.85 lbs., has a volume of about 25 cubic inches, a minimum life of 5 years, and its efficiency is 0.106%. It also uses plutonium -238 as fuel. The efficiency of these devices is greatly increased as they are designed for higher power output. With further development the volume should also be greatly reduced with little loss in efficiency. (Electronic Industries, May 1966).

The primary difficulty in building radio isotope generators for biological radio-telemetry is reducing weight and volume to a feasible range and yet having sufficient shielding to eliminate any radiation danger.

RECOMMENDATIONS

Primary Cells: The mercury cell is the most widely used and the most suitable cell in most cases. In low drain applications the ZM-12 is the most readily available low drain cell and is well suited for both low temperature and low drain. If more capacity is needed the RM-42 can be special ordered with potassium hydroxide electrolyte and with the improved low drain barrier. If a smaller cell is needed and cost is not a factor the certified cell in the RM-1 size is the best choice. If operating temperatures are low or if cost is a factor, the RM1NW is suitable. A still smaller certified cell suitable for low drain operation is available in the RM640 size. In applications requiring a cell smaller than 500 mah capacity the standard cell types can be used.

If the cell drain is such that the cell will be drained in 1000 hours or less the standard types are suitable. If high regulation is not required use the types with the manganese dioxide added to the depolarizer.

If the current drain-cell size combination is such that a drop of 0.05 volts or more occurs, a low temperature type will probably give better performance. The CMC types should give better performance than the wound anode types if the drain is low, and if part of it is to be at higher temperatures.

Secondary cells: The sintered nickel-cadmium cells are probably the best choice in most cases. The silver oxide-cadmium cells cost more but give better shelf life and a better watt-hours-to-weight ratio. The silver oxide-zinc cell should not be used unless the superior watt-hours-to-weight ratio or low temperature performance is absolutely needed. Significant improvement in the reliability of the silver-oxide zinc will probably come in the next year or so.

Domestic sources of batteries compiled from Electronic Buyers Guide, a McGraw-Hill publication.

		Mercury	Nickel-Cadmium	Silver Cadmium	Silver Zinc
Mallory Battery Co.	S. Broadway & Sunnyside Tarrytown N.Y.				X
Ray-O-Vac	212 E. Washington Ave. Madison, Wis.	X	X	X	X
Brightstar Industries	600 Getty Ave. Clitton N.J.	X	X		
Burgess Battery Co.	Freeport, Ill.	X	X		
Electro Chimica Corp.	1140 O'Brien Dr. Menlo Park, Calif.	X		X	X
Power Inc.	Electronics Div. Box 138 Mpls, Minn.	X	X		X
RCA	415 S. Fifth St. Harrison, N.J.	X			
Eveready	270 Park Ave. New York, N.Y.	X	X		X
Eagle-Picher Co.	Electronics Div. Box 47 Joplin, Mo.		X	X	X
General Electric	ECSO 1 River Rd. Schenectady, N.Y.		X		
Sonotone Corp.	Battery Div. Elmsford N.Y.		X		
Alkaline Batteries Corp.	2271 Mora Dr. Mountain View, Calif.		X		
Amphenol Cadre Div.	20 Valley St. Endicott, N.Y.		X		
Excelsior Elect.	19541 Hatteras St. Tarzana, Calif.		X		
Gould National	E1201 1st Natl. Bank Bldg. St. Paul, Minn		X	X	X
Gulton Indústries	212 Durham Ave. Metuchen, N.J.		X	X	
LaPine Scientific Inc.	6001 Knox Ave. Chicago, Ill.		X		
Ramsey Eng. Co.	707 N. Anaheim Blvd. Anaheim, Calif.		X		
TRW Systems	1 Space Park Redondo Beach, Calif.		X	X	X
Whittaker Corp.	Tech. Prod. Div. 9601 CanogoAve. Chatsworth Calif.		X	X	X
Yardney	40-52 Leonard St. New York, N.Y.			X	X
Carbone Corp.	400 Myrtle Ave. Boonton, N.J.			X	X
Electric Storage Battery Co.	2510 Louisburg Rd. Raleigh, N.C.			X	X

		Mercury	Nickel-Cadmium	Silver Cadmium	Silver Zinc
Catalyst Research Corp.	6101 Falls Rd. Baltimore, Md.				X
Epic Inc.	150 Nassau St. New York, N.Y.				X
Espy Mfg. & Electronics	Box 422 Saratoga Springs, N.Y.				X