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BATTERY POWER SUPPLIES FOR POLICE ELECTRONICS

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Following a Congressional mandate* to develop new and improved techniques and equipment to strengthen law enforcement and criminal justice, the National Institute of Law Enforcement and Criminal Justice under the Law Enforcement Assistance Administration of the Department of Justice established the Equipment Systems Improvement Program. The objectives of the Program are to determine the priority needs of the criminal justice community to help in its fight against crime, and to mobilize industry to satisfy these needs. A close working relationship is maintained with operating agencies of the criminal justice community by assigning systems analysts to work directly within the operational departments of police, courts and corrections to conduct studies related to their operational objectives.

This document is a research report from this analytical effort. It is a product of studies performed by systems analysts of the MITRE Corporation, a not-for-profit Federal Contract Research Center retained by the National Institute to assist in the definition of equipment priorities. It is one of a continuing series of reports to support the program decisions of the Institute relative to equipment development, equipment standardization and application guidelines. Comments and recommendations for revision are invited. Suggestions should be addressed to the Director, Advanced Technology Division, National Institute of Law Enforcement and Criminal Justice, Law Enforcement Assistance Administration, U. S. Department of Justice, Washington, D. C. 20530.

Gerald M. Caplan, Director
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* Section 402(b) of the Omnibus Crime Control and Safe Streets Act of 1968, as amended.

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ABSTRACT

This report discusses the use of battery power supplies to power portable police radio transceivers. It reviews the battery types presently used in this service and those newly developed battery types which seem suitable for such use. It also discusses the requirements for adequate battery standards and system considerations of battery application. It concludes with a list of recommended studies.

NOTE: Cost figures given in this report reflect conditions obtaining in late 1972 and should be adjusted to the current market. Relative cost figures of battery types, however, have remained substantially the same.

INFORMATION INDEX RETRIEVAL TERMS: Batteries, Battery Chargers, Communications System Analysis, Connectors, Police Communications, Portable Radio Transceivers, Power Supplies, Standards.

EXECUTIVE SUMMARY

The widespread use of portable radio transceivers by police departments has identified several areas in which the improvement of the batteries used to power these radios is necessary and desirable. At present, nickel-cadmium storage batteries are commonly used for normal operations with zinc-mercuric oxide primary batteries held in reserve and used in emergency situations.

Recently developed types of batteries such as the gelled electrolyte lead-acid storage battery, the magnesium primary battery, and the organic electrolyte lithium primary battery are suitable for many police applications but are relatively unknown and unused.

The necessity for adequate battery standards, acceptable to both users and manufacturers, is pointed out and some of the considerations to be observed in establishing such specifications are discussed.

Many of the problems experienced with battery-powered radios are not caused by inherent limitations of the batteries but by improper matching of the battery with the electronics and the use requirements. The effect of equipment application is discussed, and some representative system cost trade-off analyses are provided to illustrate the advantages of proper system planning.

A list of areas wherein further study and analysis would be rewarding is provided. These areas include: a study of optimum power supply voltage, application of new battery types, redesigned battery chargers, development of state-of-charge measurement for batteries, study of battery connector problems, and a study of communications operations to optimize battery exchange cycles.

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1. INTRODUCTION

1.1 Background

In recent years, police command and control operations have been significantly aided by the widespread use of portable radio equipment. Lightweight portable receiver-transmitters carried by the patrolmen on duty have given them the same constant contact with a central control station that was formerly possible only with radio-equipped patrol cars. The patrolman is no longer isolated between reports at a call box, and the portable equipment can also supplement patrol car radios allowing an officer to call for assistance and receive instructions at the scene of an incident rather than necessitating a return to his vehicle. Portable radio communication has proven its value in crowd control for both peaceful assemblies and civil disturbances. With all these advantages, use of portable equipment has become widespread, and this use has identified areas in which improvement is necessary and desirable.

1.2 Improvement Needed

One of the most pressing needs identified is for improved portable power sources (batteries). For maximum utility, the weight of the equipment, including the battery, must be kept low and the transmitted power high. As a result, power drain is high relative to battery weight. In addition, the batteries are subjected to all the vicissitudes to be expected of a patrolman's equipment and are connected and disconnected at least twice daily to permit charging. Batteries which have improved capacity, longer operating life, wider environmental capability, better charge characteristics, and more reliable connectors would increase the effectiveness of existing portable police communications equipment and would facilitate the development of improved portable transceiver equipment having higher power-to-weight ratios, reduced maintenance requirements, and lower replacement costs.

1.3 Scope

This paper reviews the types of batteries presently used in portable radio communications and discusses the reasons for their use and acceptability. It surveys some of the alternate batteries presently available or in development which may be suitable for use in portable transceivers. It discusses the factors involved in developing and assuring compliance with suitable standards. It addresses the factors to be considered in matching batteries and equipment and describes the effect of equipment application on the design of a portable radio communications system. It concludes with recommendations for studies in areas where potential cost/benefit ratios will be high and where successful accomplishment of major improvement seems feasible within the existing technological state-of-the-art.

2. BATTERIES PRESENTLY USED

Portable radio transceivers are powered either with primary batteries[1] which can be used only once or with secondary (commonly called storage) batteries[2] which may be recharged and used repeatedly. The storage batteries are the most common because their initial cost can be prorated over many repeated operations. The primary batteries are generally reserved for emergency use when operational constraints preclude recharging or when extended operation is required. The following are descriptions of the more common types of both.

2.1 Nickel-Cadmium Storage Batteries

The great majority of portable radios used in police communications are powered with nickel-cadmium (ni-cad) storage batteries. These batteries may be either one of the two most commonly used types. The first or sintered plate type has plates made of porous material which provides a greater surface area of active material than for plates made of plain metallic sheets. This increased surface area provides higher currents and can, therefore, supply more power to the transmitter. The greater efficiency of sintered plates provides satisfactory operation at both high and low temperatures.

The second or pocket plate type has plates made of nickel sheet metal which are simpler to fabricate and lower in cost than the sintered plate. This type is also more rugged in construction but has the disadvantage that the maximum current which it will provide is less than that available from a sintered plate battery of equivalent capacity. As portable radio use expands, the requirements for higher transmitter power will be more urgent, and the higher capacity sintered plate ni-cad battery will dominate in spite of its somewhat higher cost.

Both types of ni-cad battery use an alkaline electrolyte and supply a nominal 1.2 volts[3] per cell when the cell is fully charged. This drops to about 1.0 volts per cell when 80% of the capacity of the

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[1] An assembly of cells designed to produce current through an electrochemical reaction which is not efficiently reversible.

[2] An assembly of identical cells in which the electrochemical action is reversible so that the battery may be recharged by passing a current through the cells in the opposite direction to that of discharge.

[3] Here, and later in the discussion, nominal battery voltages are discussed in terms of available voltage under light (stand-by) loads rather than the somewhat higher open circuit voltages commonly shown in battery manufacturers' catalogs.

cell has been discharged. For police patrol radios, the batteries most commonly used have twelve cells connected in series supplying a nominal 14.4 volts.

2.2 Other Storage Batteries

Lead-acid storage batteries, such as those used in automobiles, are also made in small sizes. They normally are not used in portable communications equipment because of the damage which could be caused by acid spillage and because of their relatively greater weight. Silver-zinc storage batteries, although excellent in terms of capacity, are seldom used because of their high cost and limited recycling life.

2.3 Carbon-Zinc Primary Batteries

Primary dry batteries are little used for portable police communications equipment because of the high cost of battery replacement and the relatively low capacity of such batteries. Carbon-zinc (zinc-manganese dioxide) dry batteries using either alkaline or ammonium chloride electrolytes are not suitable for supplying equipment subject to constant use; although in the past, they were used for lack of more suitable power sources.

2.4 Zinc-Mercuric Oxide Primary Batteries

Zinc-mercuric oxide primary batteries (commonly called mercury batteries) have been successfully used to power emergency portable communications equipment and as supplementary power for regularly assigned equipment. Mercury batteries have a relatively high capacity, about three times that of a fully charged new nickel-cadmium sintered plate battery. They have the convenience of providing a nominal 1.25 volts per cell when new, which allows a cell-for-cell equivalency with ni-cad storage batteries. Mercury primary batteries operate well at normal and high temperatures but perform poorly at temperatures below freezing. These batteries are efficient and reliable but relatively expensive in terms of unit energy cost because they cannot be recharged.

3. TECHNOLOGY AVAILABLE BUT UNUSED

In recent years new developments in battery technology have made available improved types of batteries which are suitable for portable police communications but which have not yet been widely adopted by the manufacturers and users of such equipment. Some of these new battery developments are described below.

3.1 Gelled Electrolyte Lead-Acid Storage Battery

This battery type retains the relatively low cost of the standard lead-acid storage battery but, by means of improvements in the battery construction, it has avoided many of the disabilities that previously prevented the use of lead-acid batteries in communications equipment. This battery uses a gelling agent to lock the acid electrolyte into a solid gelled mass which cannot leak or spill. This gelled electrolyte has the further advantage of inhibiting free ion migration during storage so that the battery can remain fully charged for longer periods and at higher temperatures than can the regular lead-acid battery with liquid acid electrolyte. These batteries provide a nominal 2.2 volts per cell as do ordinary lead-acid batteries, which means that gelled electrolyte lead-acid batteries may be fabricated using half the number of cells required in ni-cad batteries of equivalent voltage rating.

This battery is in volume production and is in widespread successful use in consumer electronic equipment, such as portable television receivers. It has excellent charge cycle life[4] characteristics. It is low in cost compared to ni-cad batteries. The most logical applications for this battery are where cost is a primary factor or for reserve equipment where the batteries must remain fully charged for a long period of time between uses.

3.2 Magnesium Primary Dry Battery

The magnesium-manganese dioxide primary dry battery (commonly called the magnesium battery) is now manufactured in volume production and is being used successfully by the military in portable communications equipment. The individual magnesium dry cell is constructed similarly to the zinc-alkaline electrolyte dry cell but uses magnesium metal in place of zinc. As magnesium is a more active metal, the battery provides a higher voltage per cell (1.8 volts for magnesium compared to 1.5 volts for zinc and 1.25 volts for mercury) and higher energy capacity for each individual cell.

[4] The life of a storage battery is usually expressed in terms of the number of cycles of discharge and recharge it can withstand while still retaining 80% or more of its nominal capacity.

The battery produces slightly less energy than a mercury battery of equal volume, is lighter in weight, and is lower in cost. As an example, the U. S. Army presently uses a 14.4 volt magnesium battery weighing three pounds to power a transceiver which requires eleven watts during transmission for 60 hours of operation at normal temperatures. This is twice the operational life of an equivalent alkaline electrolyte zinc battery. This high capacity battery, built to meet military specification requirements, is comparable in cost to an ordinary carbon-zinc battery.

The magnesium battery has two disadvantages which have limited its use in civilian applications. These are both caused by the need for a passivating layer to protect the magnesium metal during storage. When the battery is first installed and used, there is an initial warm-up period, which can be as long as a few minutes, during which the passivating coating is being electrochemically removed and during which the battery will not provide its full rated current. After this initial warm-up, the battery operates normally. Once the battery is put into use and the passivating coating is removed, the battery may not be put back into storage as internal current leakage will sap the battery capacity even though the battery may not be used further. For these reasons, the magnesium battery is not suitable for intermittent use separated by periods of storage. It is quite suitable for relatively continuous use after an initial period of storage such as is required in both police and military applications.

Because of its relatively lower cost compared to mercury batteries and its lighter weight, the magnesium battery may be a logical replacement battery for use in emergency equipment and for emergency reserve stocks of primary batteries. It shares one disadvantage with the mercury battery in that it is not rechargeable.

3.3 Lithium-Organic Electrolyte Primary Battery

This battery is based on the use of lithium as the anode metal. Lithium is an extremely active metal and is as superior to magnesium as magnesium is to zinc. Lithium is so active that the metal is attacked by water and even by the moisture in the air. As a result, lithium batteries intended to withstand long storage are made using electrolytes based on organic solvents rather than on water solutions. Lithium primary batteries provide over twice the energy per unit weight compared to mercury batteries, and an individual lithium cell provides a nominal 2.5 to 3.0 volts compared to 1.25 volts for a mercury cell. This permits a 15 volt lithium battery to be built using only five cells compared to the 12 cells required for a ni-cad or mercury battery of equilvalent voltage. On a capacity-per-unit weight basis, large cells tend to be more efficient than small cells because a larger proportion of the cell can consist of active material. A

battery consisting of a few large cells is more efficient than one of many small cells, since fewer inter-cell connections, spacers, and packing materials are required.

The lithium battery is available in two configurations. The first, or reserve configuration, has the electrolyte stored separately from the active cell materials and may be stored indefinitely. When the battery is needed, the electrolyte is permitted to enter the cell spaces and the battery is activated. This type of battery is high in cost and is used primarily for emergency equipment which must be constantly available but which has a low probability of actual use. The second, or non-reserve configuration, uses appropriate inhibitors to prevent internal current leakage during storage. It may be stored for periods of up to two years or longer and is used as is any other primary battery.

Lithium batteries are presently in production but, because of their recent development, the price is high. However, major battery manufacturers are convinced that in mass production quantities, the non-reserve lithium batteries will be competitive in price with the alkaline-zinc dry battery. Lithium batteries have an additional advantage in that they continue to function effectively at temperatures as low as -20°F. As these batteries are not rechargeable, they are too costly for use in regular day-to-day service where their special qualities are not required.

3.4 Developmental Batteries

Other power sources are in development. The three battery types discussed above represent new batteries that have characteristics appropriate to portable police communications equipment, that have passed through the development stage and are now in production, and that have been proven by successful use in service similar to or more stringent than police communications.

Some other battery types, either new developments or new configurations of existing batteries, which may be appropriate candidates for police communications use in the near future include the following:

Primary Batteries

- Zinc-air batteries in new smaller cell configurations
- Mercury-cadmium batteries
- Solid electrolyte lithium batteries

Secondary Batteries

- Nickel-zinc batteries
- Rechargeable solid electrolyte batteries
- Lead chloride systems

With the competition generated by these new battery types in development, further improvements in the presently used battery types may also be anticipated. Such improvements are within the available state-of-the-art and can be incorporated by manufacturers in batteries suitable for portable communications equipment with only minimum additional development.

4. REQUIREMENT FOR ADEQUATE SPECIFICATIONS

To ensure satisfactory operation of any equipment, the design and construction of that equipment must be suitable to the environment in which it is to be used and for its intended purpose.

4.1 Environmental Requirements

Portable police communications equipment and the associated battery power sources are subject to a wide variety of environments. The United States has climates ranging from arctic to tropic, and many localities have temperatures covering nearly the entire range. Equipment may be carried on the person, transported in a variety of vehicles (with or without proper storage), left exposed to the weather and exposed to physical conflict. Without doubt, the batteries powering portable police radios must be rugged.

Unfortunately, the ability to withstand extreme environments may be costly, not only in terms of money but also in terms of the weight, convenience of use, and operational life of the batteries. As a result, most specifications for batteries are compromises which attempt to assure the full performance desired in those environments most commonly encountered while permitting reduced, but still acceptable, performance under extreme conditions.

Specifications, to be reasonably economic, must be consistent with the inherent capabilities of the equipment specified. Batteries are electrochemical devices, and their activity is directly affected by the temperature. Most battery nominal voltage and energy ratings are specified for 70°F. As every automobile owner is reminded each winter, a battery's ability to provide power diminishes as the temperature falls. For communications equipment, this means that equipment or batteries left in exposed locations during the winter may not provide sufficient voltage and current for proper operation. In extremely cold conditions, the electrolyte may freeze and cause damage to the battery case or to the radio equipment. At the other extreme, batteries in containers or in vehicles exposed to direct sunlight in the summer may experience temperatures over 140°F, resulting in an overvoltage that may damage equipment and an internal current drain that may reduce operational life.

4.2 Comparable Military Specifications

The military has contended with these problems for years and has developed a series of battery specifications. These specifications most applicable to police portable equipment are MIL-B-18 Batteries, Dry; and MIL-B-23272 Batteries, Storage, Nickel Cadmium. These specifications include many requirements not applicable to police use, such as the ability to withstand long-term storage in the open, strict waterproof packaging, military camouflage color, etc. However, they provide very useful guides to the standards which may be specified and, more importantly, to the inspection and tests which are necessary to assure that standards are met. For law enforcement use, rather than each agency establishing its own standards and having to provide inspection and test, a set of generally applicable standards, which may be selected and used by any agency, would be desirable. Manufacturers could then certify that their batteries meet or exceed the requirements of certain of these standards.

5. MATCHING BATTERIES TO EQUIPMENT AND REQUIREMENTS

5.1 General Considerations

Unless the power source (battery) is properly chosen to match the equipment and the operational requirements, the most stringent specifications will not assure proper operation. In selecting batteries, the power demand of the equipment, the shift duration of the equipment, the necessity for emergency overtime extensions, the duty cycle of the equipment in its assigned application, the permissible weight and volume, and the cost (both initial and over the service life of the equipment) should all be analyzed; and the optimum values should be determined. This should be done in the initial design stages of the equipment itself. Unfortunately, the battery is too often the last item considered in equipment design.

5.2 Operating Voltage

Equipment operating voltage should be chosen not only with regard to available circuit elements and component cost trade-offs but also with consideration to the effect the designed operating voltage will have on battery construction and efficiency. For example, commonly used twelve cell ni-cad batteries nominally rated at 15 volts but actually operating at slightly over 12 volts for an eight hour shift are constructed of small individual cells equivalent in size to penlight batteries; and because of the inefficient use of available volume, they provide only 450 milliampere hours per charge. If the energy required could be obtained from fewer but more efficient, larger ni-cad cells, these batteries could provide two to four times the usable energy in the same weight and volume.

Radio equipment, batteries, and charging equipment should not be considered as separate entities requiring only connector compatibility but should be considered as components of a communications equipment system and so matched to optimize the utility and cost of the total system.

6. SYSTEMS EFFECT OF EQUIPMENT APPLICATION

The utility and operational effectiveness of a communications system incorporating portable transceivers are affected by the radio equipment used, the type and design of batteries used to supply power, the type of charging equipment used to replenish those batteries, and the operational procedures (both normal and emergency), which govern the use and duty cycles of the system elements.

6.1 Typical Systems

A typical portable communications system operating in a police department, manned on a three-shift basis, will have the portable transceivers powered by ni-cad batteries. These batteries are normally used for one eight-hour shift and then charged for 14 hours, leaving an hour at each end of the shift for battery exchange and placing depleted batteries on the charger.

Operational duty cycles and charging rates are both low, and in this service a battery life of over 500 charging cycles may be expected. Operation in this slow-charging mode requires three batteries and two charging positions for each transceiver, the latter because two of the batteries will often be on charge simultaneously. The batteries will require replacement about every 17 months.

An alternative technique is to use fast charge ni-cad batteries and rapid chargers. These batteries may be recharged in one to four hours but have a life of only 300 cycles. This fast-charge mode of operation requires two batteries and one charging position for each transceiver, and the batteries will require replacement every ten months.

In practice, not all transceivers nor all batteries are used every day, so the fast-charge batteries will be replaced yearly and the slow-charge batteries every 18 months to two years. The savings to be made from buying fewer batteries and chargers are usually considered to be offset by the higher unit cost and shorter battery cyclic life, so that operational rather than economic considerations usually determine the choice of battery and charger.

6.2 Premature Battery Failure

The equipment use and battery charging procedures, described above, function well in normal circumstances of routine patrol but may break down in emergency situations. When portable radio equipment is used more or less continuously, the batteries may tend to lose power and fail well before the end of an operational shift. This may be caused by use of the equipment in excess of its designed duty cycle but, more

frequently, the failures occur well within the designed energy provisions of the battery. The reason for this is a phenomenon known as "memory" or "patterning." When a rechargeable storage battery is repeatedly discharged of only a part of its energy (say 50%) and is then regularly recharged, it develops a resistance to supplying the remaining, normally unused, energy. This is because the active plate metal most easily reached by the electrolyte is used constantly, and the remainder is not used at all. When a demand for power is made on this unused reserve material, the energy is supplied slowly and through a relatively high resistance. When this occurs during an operational emergency, battery failure and loss of communications are the results.

The traditional remedy for "patterning" is complete discharge and recharge of the battery at regular intervals to prevent the "memory" from developing. Unfortunately, in a battery made up of several cells, not all cells age at the same rate and, after a battery has been in use for some time, complete discharge of the stronger cells may result i· cell reversal and damage to the weaker cells.

6.3 Reserve Battery Supply

From the above, we may conclude that it is desirable to have a store of reserve batteries for use in emergency situations. These may be supplied in various ways.

A stock of primary batteries (usually zinc-mercuric oxide with a 40-hour service life) may be maintained and issued to units operating in emergency situations. This method is effective but relatively expensive, as there is no practical way of measuring the energy remaining in the primary batteries after use, and they are then discarded.

An alternate method is to shorten the battery shift length by removing reserve batteries from charge prior to the usual shift change time and exchanging them in the field. This method is more effective with fast-charge batteries which will be fully charged after a few hours. However, exchanging batteries in the field is inconvenient at best and particularly difficult in an emergency situation.

A really satisfactory battery and charger system - one which is economical for normal application but which provides sufficient reserve capacity for emergency situations - remains to be developed. If a battery could be developed within the desirable size and weight limitations to support normal operations for two shifts, it would be dependable for at least one full shift even in the more strenuous, emergency service. At present, it is difficult to determine the true amount of energy available in a battery after it has been charged or remaining after it has been partially discharged in operation. Presently used test methods, based on voltage measurement under load, are least effective on the better batteries such as ni-cad or mercury batteries, because they have a flat discharge characteristic in which the battery voltage does not vary appreciably with the state of charge.

7. SYSTEM COST TRADE-OFF ANALYSES

The cost of individual batteries is low compared to the cost of a portable radio transceiver; but, in the long run, the cost of providing power for the transceiver may be appreciable over its service life.

7.1 Representative Cost Factors

For system cost analyses, the following costs are assumed as representative. It is recognized that costs of individual items of equipment may vary appreciably, but the cost of the items relative to each other will maintain roughly the same ratios.

Cost Allocations

1. Portable Radio Transceiver: five watts, two frequencies, each $900, five-year expected life.

2. Standard, Eight-Hour, Ni-Cad Storage Battery: each $38, 18-month expected life.

3. Rapid-Charge, Eight-Hour, Ni-Cad Storage Battery: each $42, 12-month expected life.

4. Slow Battery Charger, 12 Unit: each $300, five-year expected life.

5. Fast Battery Charger, 12 Unit: each $650, five-year expected life.

6. Mercury Primary Battery: 40-hour operational life, each $7, storage life of two years.

7. Gelled Electrolyte, 12-Hour, Lead Acid Storage Battery: each $20, 18-month expected life.

8. Magnesium Primary Battery: 40-hour operational life, each $5, storage life of two years.

Using the above cost allocations, some typical systems may be developed, each based on the use of 100 portable transceivers.

7.2 Typical System Costs

Typical Power Source Systems for Portable Radios

System A - Standard Nickel-Cadmium

Unit	Cost	Initial Cost	Annual Cost
300 Ni-cad Batteries	$ 38	$ 11,400	$ 7,600
17 Battery Chargers	300	5,100	1,020
200 Mercury Batteries	7	1,400	1,400
TOTAL		$ 17,900	$ 10,020

System B - Rapid Charge Nickel-Cadmium

Unit	Cost	Initial Cost	Annual Cost
200 Rapid Ni-cad Batteries	$ 42	$ 8,400	$ 8,400
9 Rapid Chargers	650	5,850	1,170
100 Mercury Batteries	7	700	700
TOTAL		$ 14,950	$ 10,270

System C - Lead-Acid Gelled Electrolyte

Unit	Cost	Initial Cost	Annual Cost
300 Gelled Electrolyte Batteries	$ 20	$ 6,000	$ 4,000
17 Battery Chargers	300	5,100	1,020
200 Magnesium Batteries	5	1,000	1,000
TOTAL		$ 12,100	$ 6,020

To each of these systems must be added the cost of 100 transceivers plus the cost of maintenance and service, which is assumed to be about the same for all systems. With some transceivers, it is possible to plug the whole radio (battery and all) into the charger. This is usually not desirable, as it requires the provision of two to three times the number of radios that would otherwise be required.

7.3 Cost Comparison of Alternate Systems

From these simple examples, it is apparent that the higher individual cost of rapid-charge batteries and their chargers is more than compensated by the lower system cost. It is assumed that the rapid recharge capability will reduce the need for emergency primary batteries. Therefore, in this system, a reserve of only one battery per transceiver is provided. The total acquisition cost of the power supply system for the rapid vs. standard recharge battery is reduced by about 17%, and the annual cost of material replacement remains about the same. The operational advantages of a rapid-charge system, thus, come as a no-cost bonus.

Use of the recently developed gelled electrolyte lead-acid storage batteries and magnesium primary batteries would provide even further cost reductions and could be introduced in those departments already committed to use of slow-charge batteries.

Similar, but more complex, system cost analyses considering all factors, actual costs, and local considerations should be performed before a decision on equipment choice is made.

8. RECOMMENDED STUDIES

The foregoing broad review of power supplies for portable police communications indicates areas wherein further study, data acquisition, and analysis would be rewarding. Some of these are:

1. A study of optimum battery voltage and energy for transceivers, making best use of available volume and weight. This study should consider electronic componetry, radiated power requirements, transceiver design, and battery design.

2. A study of the application of new types of batteries to portable radio equipment. This should investigate electrical characteristics, costs, and the influence of their use on transceiver design, battery-charger design and operation.

3. A study for redesign of battery connections and battery chargers. This study would investigate the potential for charging individual cells with series cell operation to permit efficient charging as batteries age.

4. A study of alternate methods to reliably measure the state of charge of batteries during and after charging and after operational use.

5. A study of battery connector problems. The power source contacts on a typical transceiver are made and broken three times daily, and those on the battery and the charger at least twice daily. This constitutes severe service for low-voltage connectors. Sturdy, reliable connectors are urgently required.

6. A study of portable communications operations to provide for more efficient power utilization. This study should investigate the traditional use of a battery to supply power for one eight-hour shift and attempt to discover the most effective battery exchange cycle compatible with efficient police operation.

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