JPL PUBLICATION 79-6

Primary Lithium Battery Technology and Its Application to NASA Missions

H. A. Frank

(NASA-CR-158229) PRIMARY LITHIUM BATTERY TECHNOLOGY AND ITS APPLICATION TO NASA MISSIONS (Jet Propulsion Lab.) 30 p
HC A03/MF A01 CSCL 10C
N79-19449
Unclas
G3/44 16382

February 15, 1979

National Aeronautics and
Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

PREFACE

The work described in this report was performed by the Control and Energy Conversion Division of the Jet Propulsion Laboratory, California Institute of Technology.

This report completes a portion of the work requirements under NASA RTOP 506-23-25 "Advanced Nickel-Cadmium and Probe Batteries".

ACKNOWLEDGMENT

The author wishes to acknowledge the helpful discussions held with R. Banes, P. Barnett, V. Clarke, G. Juvinall, M. Swerdling, and A. Uchiyama of JPL as well as J. Bene of NASA-LaRC, B. Bragg of NASA-JSC, E. Paschal of NASA-MSFC, D. Dugan, and J. Rubenzer of NASA-ARC, and F. Ford, and W. Nagle of NASA-GSFC.

ABSTRACT

A description is given of the components, overall cell reactions, and performance characteristics (where established) of promising new ambient-temperature lithium primary systems based on the Li-V_2O_5, Li-SO_2, Li-CF, and Li-$SOCl_2$ couples.

Developmental status of these systems is described in regard to availability and uncertainties in the areas of safety and selected performance characteristics.

The new lithium systems are shown to exhibit three unique characteristics which make them more attractive than existing primary systems. First, they are lightweight and compact, and deliver up to 600 W-hr/Kg and 1 W-hr/cm^3, respectively. Second, they have the potential of long active wet lives to periods of 10 years. Third, they can operate over a broad temperature range of -54°C to 74°C. By comparison, the best existing primary battery, the silver-zinc battery: a) delivers about 25% of the above gravimetric and volumetric energy densities, b) exhibits a maximum wet life of about 1 to 2 years, and c) operates effectively over a temperature range of 10°C to 70°C.

Studies have shown that use of lithium batteries would enhance a variety of missions and applications by decreasing power system weight and thereby increasing payload weight. In addition, the lithium batteries could enhance cost effectiveness of the missions. Among these missions are:

a) those dealing with planetary probes
b) those dealing with exploration of Mars
c) the Long Duration Exposure Facility
d) the Shuttle Launched Research Vehicle.

Among the applications are:

a) launch vehicles
b) scientific balloon flights
c) a variety of uses on the Shuttle.

CONTENTS

Figures

Tables

SECTION I

INTRODUCTION

Ambient-temperature primary lithium batteries are of interest for four reasons. First, the batteries are known to be extremely lightweight and compact, thereby saving appreciable mass and volume in a spacecraft power system. Second, the batteries have the potential of long storage life, which is essential for nearly all missions. Third, the batteries can operate effectively over a wide temperature range, which is highly desirable in several missions. Fourth, the batteries will help reduce spacecraft cost and contribute to cost effectiveness of future missions.

For the above reasons, JPL has been carrying out a program aimed at developing these batteries for future NASA missions. The overall program objective is to demonstrate a 330 W-hr/Kg primary lithium battery by the end of FY-82.

A subtask of this program involved a "Missions Application Study", with the objective to establish: a) which of the potential future missions could employ lithium batteries, b) how the batteries are to be employed on the missions, and c) the benefits that will accrue from use of these batteries.

Although this report is primarily concerned with the results of the Mission Application Study given in Section IV, Section II provides a description of these new lithium cells and their development status. Section III compares performance of these new cells with existing primary cells and also deals briefly with their cost aspects.

SECTION II

DESCRIPTION AND DEVELOPMENT STATUS OF LITHIUM CELLS

Interest in ambient-temperature primary lithium cells began in the 1960's and has continued to the present time. A great deal of progress has been made in the development of these cells, some of which are now available commercially. A brief description and developmental status of the more promising types are given below:

A. LITHIUM — VANADIUM PENTOXIDE (V_2O_5)(1,2)

This cell is comprised of a lithium anode, a carbon/V_2O_5 cathode, and an organic electrolyte. Overall cell reaction is given by the following:

$$2Li + V_2O_5 \rightarrow Li_2 V_2O_5$$

The cell exhibits three plateaus during discharge. The first of these occurs at a potential of 3.0 volts, the second at a potential of 2.4 volts, and the third at a potential of 2.0 volts. The cells are best suited for low rate applications, with discharge times greater than 20 hours. Under these conditions, the cells deliver up to 220 W-hr/Kg and 20 W/Kg. The cells have been shown to deliver 94 percent of original capacity after 2-year storage at 24°C. The cells are compact and deliver about 0.7 W-hr/cm^3. Cells are available "off the shelf" in sizes to 30 AH. Larger sizes can be specially ordered.

B. LITHIUM — SULFUR DIOXIDE (Li-SO_2) (1,2,3,4)

This cell is comprised of a lithium anode, a carbon/SO_2 cathode, and organic electrolyte. Overall cell reaction is given by the following:

$$2Li + 2SO_2 \rightarrow Li_2 S_2O_4$$

Open circuit voltage is 2.92 volts. The cell exhibits a "flat" discharge profile through 90 percent of its life. Operating voltages range from 2.5 to 2.8 volts, depending on discharge rate and temperature. The cells are best suited for moderate to low rate applications, with discharge items greater than 20 hours. Under these conditions, the cells deliver up to 264 W-hr/Kg and 7 to 11 W/Kg. The cells can deliver higher power densities of 26 W/Kg, but with a reduced energy density of 220 W-hr/Kg. The cells have been shown to exhibit zero percent loss in capacity after 1 year at 22°C, and a 20 percent loss in capacity after 1 year at 71°C. Project storage life at room temperature is 10 to 12 years, provided the cells are hermetically sealed. The cells are compact and deliver up to 0.4 W-hr/cm^3. The cells operate effectively at low temperatures and can deliver 50 percent of their room temperature capacity at -54°C. Cells are available "off the shelf" in sizes to 30 AH. Cells with larger capacity to 500 AH can be specially ordered.

C. LITHIUM — CARBON MONOFLUORIDE [Li - CF] (5,6)

This cell is comprised of a lithium anode, a $(CF)_n$ cathode, and organic electrolyte. Overall cell reaction is given by the following:

$$Li + CF \rightarrow C + LiF$$

Open circuit voltage is 2.8 volts. The cell exhibits a "flat" discharge profile throughout its life. It does, however, exhibit a sharper voltage slope than other lithium cells at the end of life. Operating voltages range from 2.3 to 2.6 volts, depending on discharge rate and temperature. The cells are best suited for moderate to low rate applications with discharge times of 10 hours or more. Under these conditions, the cells deliver 220 W-hr/Kg and 22 W/Kg. They can be operated at higher power densities of 44 W/Kg, but with reduced energy density of 176 W-hr/Kg. Limited storage life data has been obtained on this cell. At 71°C it is reported to exhibit a 20 percent loss in capacity after two months of storage. On this basis, the Li-CF cell would appear to have a shorter life than the Li-SO_2 cell. The cells are compact and deliver 0.3 to 0.4 W-hr/cm^3. The cells are made on special order to any given size specification.

D. LITHIUM — THIONYL CHLORIDE (Li-$SOCl_2$)(1,2,7,8,9,10,11,12)

This cell is comprised of a lithium anode and a $SOCl_2$/C cathode. (The $SOCl_2$ serves both as solvent and "active" cathode material.) Overall cell reaction is given by the following at temperatures from -20°C to 100°C.

$$4Li + 2SOCl_2 \rightarrow 4LiCl + SO_2 + S$$

Open circuit voltage is 3.63 volts. The cell exhibits a "flat" discharge profile like the Li-SO_2 cell over about 90 percent of its life. Operating voltages range from 3.2 to 3.5 volts, depending on rate and temperature. The cells can be designed either for low or high rate applications. The low rate versions deliver from 330 to 660 W-hr/Kg (for large cells) at power densities of about 5 W/Kg. The high rate versions deliver from 260 to 330 W-hr/Kg at power densities up to 150 W/Kg.

Very limited storage life data has been made available on this cell. In a 2-year storage test at room temperature, a cell was reported to have lost no capacity when discharged at low rates and a 20 percent capacity loss when discharged at a higher rate. More storage-life data will be made available during the latter part of 1978. The cells are extremely compact and deliver up to 1.1 W-hr/cm^3. Both active and reserve cells are made to special order in sizes up to 15,000 A.H. These large sizes are contemplated for use in missile silo applications by the U.S. Air Force.

E. UNCERTAINTIES

It is well to point out here that although a great deal is already known about the overall performance characteristics of lithium cells, there remains yet some degree of performance uncertainty with respect to:

(1) safety, especially in the case of the Li-$SOCl_2$ system, since these cells have, under certain conditions, been observed to vent, explode, or catch fire(15,16)

(2) thermal characteristics of these cells, i.e., internal heat generation rate as a function of load(17)

(3) passivation, i.e., voltage delay of the onset of discharge(18)

(4) ultimate life capability

(5) a realizeable high rate discharge capability.

Numerous programs are underway at both industrial and governmental organizations, including NASA, to study all of the above areas. Progress has been quite rapid, and it is anticipated that all of the uncertainties will be resolved within the next few years. At this point, all the previously described types of lithium cells may be confidently considered for use in the missions and applications described herein.

SECTION III

COMPARISON WITH EXISTING PRIMARY CELLS

This section compares performance of the new lithium systems with performance of existing primary systems, including silver-zinc, mercury-zinc, and zinc-manganese dioxide.

A. GRAVIMETRIC ENERGY DENSITY

Figure 1 provides a comparison of gravimetric energy densities of the lithium and existing systems. Inspection of this figure reveals that the Li-$SOCl_2$ system is far superior to any other system in gravimetric energy density. The Li-$SOCl_2$ system stores over twice the energy per unit mass of the other lithium systems and four times the energy per unit mass of the previously employed aerospace type silver-zinc system. Further the Li-$SOCl_2$ system stores six times the energy per unit mass of the mercury-zinc system and ten times the energy per unit mass of the manganese dioxide system (which is commonly referred to as the LeClanche Cell).

B. VOLUMETRIC ENERGY DENSITY

Figure 2 provides a comparison of volumetric energy densities of the lithium and existing systems. Inspection of this figure reveals that the Li-$SOCl_2$ system yields appreciably higher volumetric energy density than any of the lithium or existing systems. The Li-$SOCl_2$ system stores four times the energy per unit volume of the silver-zinc system and over twenty times the energy per unit volume of the manganese dioxide system.

C. POWER DENSITY

The lithium cells are best suited for low rate applications, with discharge times of 20 hours or more. At these rates, the lithium systems typically deliver from about 5 to 20 W/Kg, depending on the specific type. A high rate version of the Li-$SOCl_2$ system is available. This particular version can be discharged in 2 hours and deliver about 150 W/Kg, but with some sacrifice in energy density. The mercury-zinc

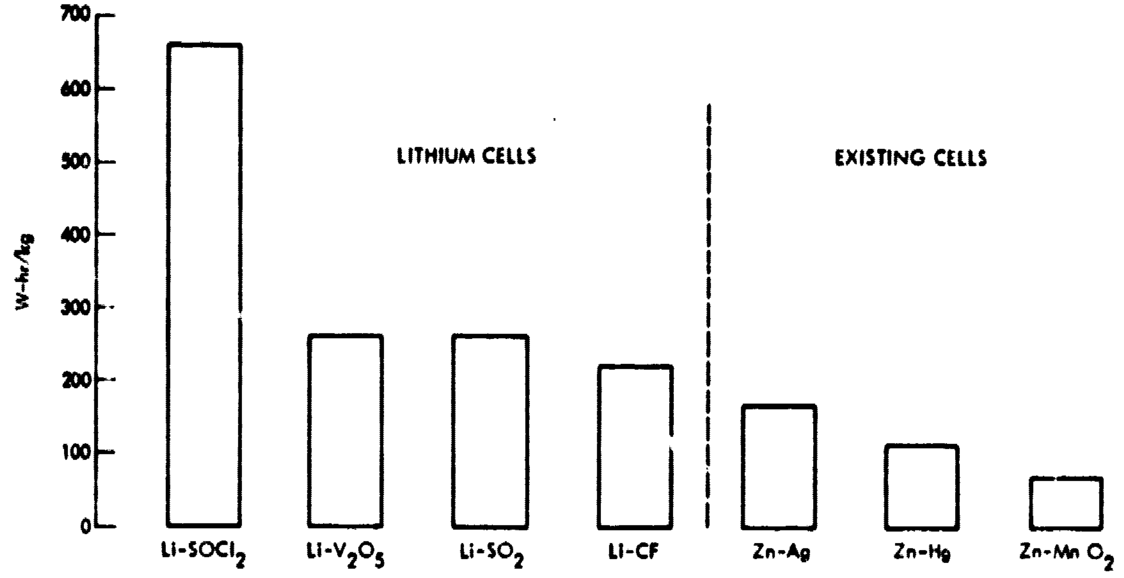

Figure 1. Gravimetric Energy Density

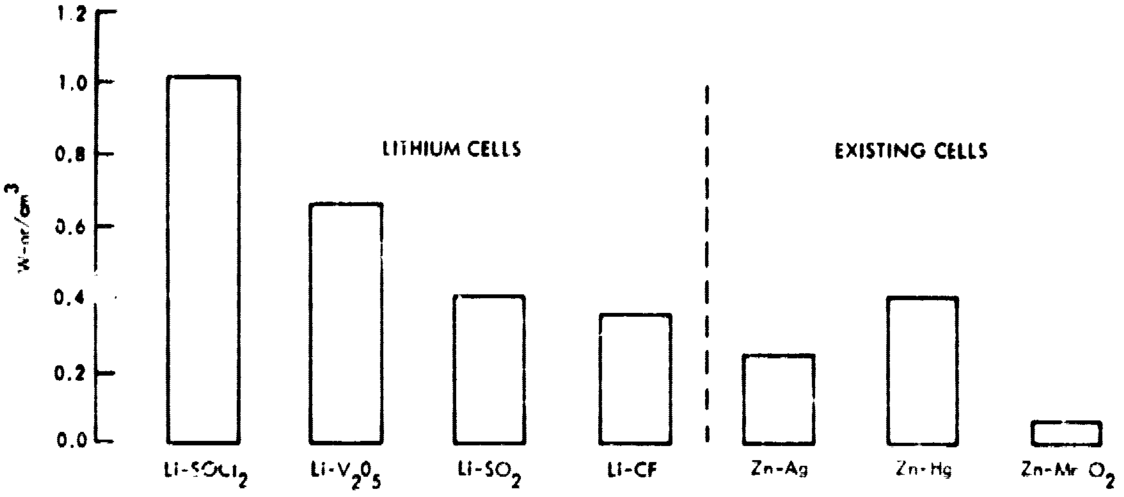

Figure 2. Volumetric Energy Density

and manganese dioxide systems are best suited for low rate applications and deliver from 1 to 10 W/Kg, depending on type and rate. The silver-zinc system, on the other hand, can be designed for very high rate applications, with discharge times of 1 hour or less. Under these conditions, the silver-zinc system is capable of delivering outputs in the range of 200 to 300 W/Kg.

D. STORAGE LIFE

Storage life of existing cells is in the range of 1 to 4 years, depending on specific type and ambient temperature.(1) Storage life of hermetically sealed lithium cells is projected to be 10 years.(1) **Both real-time and accelerated tests are in progress at Honeywell(2), PCI(4), GTE(8), Mallory(10), and Altus(12), to substantiate these claims on the lithium cells. Reserve-type versions of silver-zinc cells have been demonstrated to have life of at least 10 years.(13) Reserve-type versions of lithium cells should have comparable lives of at least 10 years depending on the type of electrolyte.(14)**

E. OPERATING VOLTAGES

Typical operating voltages of the lithium and existing cells are given in Table 1.

Table 1. Operating Voltages

Cell Type	Typical Operating Voltage
$Li-SOCl_2$	3.4V
$Li-V_2O_5$	3.0-2.0V
$Li-SO_2$	2.7V
Li-CF	2 5V
Zn-AgO	1.5V
Zn-HgO	1.2V
$Zn-MnO_2$	1.4V

Inspection of Table 1 reveals that the lithium cells exhibit markedly higher operating voltages than the existing cells. Based on cell voltages, a battery comprised of lithium cells would require about one-half the number of cells as a battery comprised of conventional cells.

F. COST CONSIDERATION

Lithium batteries appear attractive from a cost point of view for several reasons. First, the basic cell costs are significantly less than those of the currently employed silver-zinc cells. In large quantities of 100 or more, the costs of the Li-SO_2 and Li-$SOCl_2$ cells are about \$0.25/W-hr and \$0.50/W-hr, respectively. By comparison, the cost of a silver-zinc cell is \$2.50/W-hr, or 5 to 10 times that of the lithium cells. Next, the lithium batteries are maintenance-free and require no costly labor or equipment to keep them in operating condition. The Goddard Space Flight Center, for example, has found the cost of conditioning and testing silver-zinc cells to be an order of magnitude greater than readying lithium batteries for balloon flights.(27) The lithium batteries are simply installed in the Gondola-like flashlight batteries, whereas the silver-zinc batteries require lengthy discharge tests followed by recharges and top-off charges for each cell before flight. Long-duration planetary missions would require expensive and intricate remote-activation systems for silver-zinc batteries, while no such systems would be required for lithium batteries. Alternatively, costly cooling systems would be required for active silver-zinc cells for these long-duration missions, while no such systems would be required for lithium cells. The long-life features of lithium batteries should bring about additional cost savings by allowing NASA to purchase them in large quantities at reduced prices, store them, and use them as required. This approach is more cost effective than purchasing them as required in small quantities at higher prices. Further, the costs associated with qualifying the cells from a single large-production run are much less than the costs associated with qualifying the cells from numerous small-production runs. Finally, it is well to point out that the lightweight features of lithium batteries would permit increased payload weight. This, in turn, could enhance the effectiveness of the mission by permitting increased return of scientific information. Since a monetary reward may be ascribed to this additional information, it may be stated that the use of lithium batteries increases the cost effectiveness of the mission, i.e., more information per dollar spent on the mission.

SECTION IV

APPLICATIONS

This section describes a number of candidate missions that have been studied, and discusses how and where lithium batteries may be advantageously employed on these missions.

A. GALILEO (20,21,34)

The Galileo mission (scheduled for launch in 1982) is being designed to gather scientific data on the composition and structure of Jupiter's atmosphere and cloud cover and the radiative energy balance within the atmosphere. The mission will be carried out by launching (from the Shuttle) a spacecraft containing a highly instrumented atmospheric entry probe. After approximately three years of interplanetary cruise, the spacecraft will approach planetary encounter. At this point, the probe will separate from the spacecraft and be directed on a trajectory towards the planet, while the spacecraft will proceed to orbit the planet. About 50 days after separation from the spacecraft, the probe will enter the atmosphere and transmit data to the orbiting spacecraft for a period of about 1/2 to 1 hour. The spacecraft will relay a portion of the data to Earth and store some data for later transmission. The spacecraft will then continue orbiting and transmitting additional data for an additional two years.

The primary power supply for the spacecraft will be a Radioisotope Thermoelectric Generator (RTG). In the event of an undervoltage condition during a fault, (such as switching from main to standby inverter or a load fault), an auxiliary power source will be required for computer memory protection. Candidate power sources for this application are batteries or capacitors. If batteries are to be employed, a promising type is a long-life lithium battery. This is because existing active silver-zinc and mercury zinc batteries cannot meet the 7-year life requirement (2 years' shelf life prior to launch, plus 3 years' cruise, and 2 years in orbit). Rechargeable nickel-cadmium batteries could be employed, but require a charging system which adds complexity and diminishes reliability.

The power supply for the probe must be a lightweight battery that is capable of delivering several hundred watts after a 5-year shelf life. These requirements limit the choice to either a remotely activated silver-zinc or a lithium battery. The remotely activated silver-zinc battery showed promise of meeting these requirements during the study phase of a prior JPL program.(29) Further, the silver-zinc system was deemed most appropriate at the time because more was known about it than the relatively new lithium systems. The program was unfortunately canceled shortly after the study phase and it was not possible to demonstrate its capabilities. Since that time, more has become known about the lithium systems, and they now appear attractive for Galileo, especially because of their lightweight characteristics. Li-SO_2 batteries have tentatively been selected for this application.

B. SATURN ORBITER DUAL PROBE (21,36,37)

The Saturn Orbiter Dual Probe Mission (a potential mission for launch in 1987) would gather scientific data on the composition and structure of the atmosphere of both the planet Saturn and one of its moons, Titan. The mission is similar to the Galileo mission, except that in this case the spacecraft will be launched from the Shuttle with two probes. After 6-1/2 to 7 years of interplanetary cruise, the spacecraft would approach planetary encounter. At this point, the two probes would separate from the spacecraft, and the spacecraft would proceed to orbit the planet. One of the probes would be directed on a trajectory towards Jupiter and the other on a trajectory towards Titan. After about 60 days from the time of separation from the spacecraft, the probes would enter their respective atmospheres and transmit data to the orbiting spacecraft for a period of 1/2 to 1 hour. The spacecraft would relay a portion of this data to Earth, and store some data for later transmission. The spacecraft would then continue orbiting and transmitting additional data for several more years. It is possible that the Titan exploration may be performed with a lander and would continue to transmit data for several hours, or perhaps even several days, from the Titan surface.

The primary power supply for the spacecraft would, again, be an RTG. In the event of an under voltage condition (as above), a small auxiliary battery may be selected for computer memory protection. Due to the extremely long lifetime of the spacecraft, this battery can be a long-life lithium system.

The power supply for the Saturn probe must be a lightweight battery that can withstand a 7-year life and be capable of delivering several hundred watts after this period of time. These requirements again limit the choice to either a remotely activated silver-zinc or a lithium battery. The lithium battery would be the lighter and simpler of the two, as above, and would therefore be the logical candidate for this application.

The power supply for the Titan probe or lander will depend upon its anticipated active life after entry. If this period of time is from a fraction of an hour to a few hours, the supply will logically be a long-life lithium battery for the reasons given above. If this period of time is several days or more, the power supply will logically be an RTG.

C. URANUS - NEPTUNE FLYBY WITH PROBES (21,35)

This potential mission (launch in 1987-1990) is to gather scientific data on the atmospheres of Uranus and Neptune. Cruise time for this mission would be 12 to 20 years, depending on the trajectory. The mission has not been studied in as much detail as those given above. By analogy, however, it should be similar to the Galileo and Saturn Orbiter Dual Probe Missions. On this basis, there would again be a need for long-life and lightweight batteries for computer memory protection on the bus and as the main probe power supply. As above, lithium batteries would be best suited for and would most likely be employed in this application.

D. MARS SAMPLE RETURN (22)

The Mars Sample Return Mission, as its name implies, is a potential mission designed to gather samples of the Martian soil and return them to Earth for scientific analysis (launch date in 1988). The mission would be carried out, using the Shuttle as a launch vehicle for the Sample Return Spacecraft. After approximately 1-1/2 years of cruise, the spacecraft would encounter and begin orbiting the planet. The spacecraft would then eject the lander capsule and its associated ascent vehicle. The lander capsule would gather the sample and transfer it to the ascent vehicle. The ascent vehicle would then rendezvous with and transfer the sample to the Earth-Return Capsule (ERC) attached to the orbiting spacecraft. The spacecraft would, in turn, return the ERC to Earth orbit and eject the ERC for eventual pickup by the Shuttle.

Minimum mass is an essential requirement for the spacecraft, especially for its lander capsule. The power supply for the lander must, therefore, be the lightest available. In all likelihood, this power supply may be a lithium battery; and, in particular, the high energy density Li-$SOCl_2$ type. This battery will be used to supply power during insertion and during surface operations. During insertion, the battery would be required to deliver about 120 watts for three hours from separation to descent for telecommunications and about 800 watts for the 1/2 hour during entry and landing for deorbit burn, engine valve drivers, and radar. During surface operations, the battery would be required to deliver about 50 watts for 48 hours for sample acquisition and processing. Estimated mass of a Li-$SOCl_2$ battery for this application is about 5 Kg. By comparison, the required mass of the best existing silver-zinc battery would be about 18 Kg for this application. Furthermore, the lithium battery would be better suited than the silver-zinc battery to the low temperatures to be encountered on the planetary surface.

E. MARS AIRPLANES (23,33)

The Mars Airplane Mission is a potential mission designed to gather a much broader range of information on Mars than the Mars Sample Return Mission. The Airplane Mission would be carried out, using the Shuttle as a launch vehicle for several spacecraft, each of which would contain four highly-instrumented airplanes with a wing-span of about 21 meters and an overall weight of about 300 Kg. After about 1-1/2 years of cruise, the spacecraft would encounter and begin orbiting the planet. The spacecraft would then eject a descent system containing the airplanes. The airplanes would then be deployed with parachutes in a manner proven in the Viking Mission. At a predetermined altitude, the airplanes would initiate a low-altitude, terrain-following cruise, possibly using technology developed on the Cruise Missile Program. Instrumentation on the airplanes would be employed for photography, sounding, altimetry, magnetic survey, meteorology, and site selection. The airplanes would also be used to deploy packages consisting of seismometers, magnetometers, instruments for meteorology and geochemical analysis, as well as penetrators and mini-rovers.

The power plants originally contemplated for these propeller-driven aircraft were mechanical hydrazine engines. Subsequent analyses, however, revealed that electrical power plants based on advanced batteries and dc motors would weigh less and perform much better than the mechanical power plants and should be much simpler than the mechanical power plants. Furthermore, the electrical power plants would give appreciably more range, cost less, have less vibration, and have fewer thermal problems than the mechanical power plant. Also, the electrical power plant would not exhaust products that could interfere with science instruments.

The electric motor to be employed here is of the permanent magnet-type and is based on a new samarium-cobalt material. The motor is extremely lightweight and delivers about 1.5 kW/Kg (1 hp/lb). Size of the motor for this application is about 15 kW. The battery to be employed here is the Li-$SOCl_2$ system. Twenty-seven cells, each with a capacity of 1000 AH, would be required per battery. Total battery mass would be about 123 Kg (270 lbs). It is well to point out that the technology for this application may be transferred directly from a current Navy program for development of 1000 AH Li-$SOCl_2$ cells.$^{(30)}$

F. LONG-DURATION EXPOSURE FACILITY (LDEF) (24)

The LDEF is designed to serve as a facility for carrying out a number of experiments in space. The first LDEF will contain 72 experiments in such fields as fibre optics, thermal coatings, solar plasma, solar cells, heat pipes, materials, etc. The LDEF will be placed in Earth orbit for periods up to 11 months and will then be retrieved and returned to Earth by the shuttle.

Power will not be available on the LDEF so that each of the experimental packages must, if necessary, contain its own power supply. Altogether, a total of 16 such experiments will require battery power supplies. In addition, a battery power supply will be required to operate a data acquisition system.

The batteries must be as compact as possible. They will be subjected to a wide temperature range, from -34°C to +65°C while on board the LDEF. In addition, the batteries will be required to have a life of about 1-1/2 years, including six months on the Earth and eleven months in orbit. These constraints ruled out use of existing batteries consisting of silver-zinc, mercury-zinc, and LeClanche cells. On this basis, NASA-Langley decided some time ago to employ $Li-SO_2$ batteries, which were then available and were known to be capable of meeting the temperature and life requirements. Electrical requirements call for voltages from 7.5 to 20 volts and capacities from 1 to 45 AH. These requirements are met by packaging the appropriate number of "D" size cells. The Langley Research Center is currently in the process of qualifying these $Li-SO_2$ batteries for the 16 experimental packages.

The Marshall Space Flight Center has designed and is fabricating two additional packages for the LDEF Mission. Both of these are powered by Li-CF rather than $Li-SO_2$ batteries. The first, located aboard the LDEF, is an experimental package designed to study thermal control. This is designated as the Thermal Control Surfaces Experiement (TCSE). The second, located aboard the orbiter, is a device designed to monitor chemical and radiation contaminants aboard the orbiter. This is designated as the Induced Environmental Contamination Monitor (IECM).

Plans have not been formulated as yet for the second LDEF. It is possible, although unlikely, that this spacecraft will have central power for all experiments. In all likelihood, the second LDEF will again require individual battery power supplies. These may again be the $Li-SO_2$ cells, or perhaps the more advanced $Li-SOCl_2$ cells, which should be qualified by launch time of the second LDEF.

G. SHUTTLE LAUNCHED RESEARCH VEHICLE (SLRV) (25)

The SLRV is a miniature orbiter that would be launched from the Shuttle. It is designed for research purposes only. One such purpose is to gather data on performance of new engines. Another is to gather aerodynamic data upon re-entry. Yet another is to study materials for re-entry purposes.

Duration of the SLRV missions is quite short, in the range of three to six hours from Shuttle launch through re-entry.

The power supply for the SLRV must operate at 28 volts and deliver from 12 to 20 kWH. Present plans call for use of silver-zinc batteries to supply this power. Appreciable weight savings and increased payload weight could result from use of lithium batteries, especially Li-$SOCl_2$ batteries to supply this power. Second generation SLRVs may very well employ such lithium batteries.

H. SHUTTLE APPLICATIONS (25,28)

There are a variety of applications of lithium batteries for the Shuttle. A number of these are described below.

One of these is to supply power for the Integrated Upper Stage (IUS) which will be used to launch a number of planetary spacecraft in the 1980s and 1990s. From liftoff through orbit insertion of the Shuttle, battery power is required on the IUS to operate gyros, avionics, and thermal control systems. During deployment of the IUS, battery power is required for guidance, control, telemetry, thermal control, and firing of solid propellant motors. Present plans call for use of silver-zinc batteries aboard the IUS to supply this power.

The mass of the IUS vehicle is extremely important, since it directly influences payload mass of the spacecraft. A significant increase in payload mass could be achieved if the silver-zinc batteries were replaced by Li-$SOCl_2$ batteries. In the case of the Galileo Mission, the payload mass could be increased by 16 Kg with Li-$SOCl_2$ batteries in the IUS.(38) In the case of the Venus Orbiter Imaging Radar Mission, the payload mass could be increased by 46 Kg with Li-$SOCl_2$ batteries in the IUS.(38)

In addition to the above, the Shuttle will be used to launch a number of Earth-orbiting satellites into a higher orbit than that planned for the Shuttle. The device that will be used to launch these spacecraft is designated as the Payload Assist Module (PAM). The PAM is similar to the IUS, but somewhat smaller in that the spacecraft that it launches are somewhat smaller. Like the IUS, the PAM must contain its own power supplies for telemetry, firing a motor, and an active nutation control system. Present plans call for use of primary silver-zinc batteries for this application.

Mass of the PAM is important since it directly influences payload weight of the spacecraft. Any reduction in mass of the PAM is therefore beneficial. Li-$SOCl_2$ batteries could be substituted for the silver-zinc batteries to reduce mass of the PAM and increase payload capability.

Another application is to provide power for the Extravehicular Mobility Unit (EMU). Two such units will be located within each Shuttle. These are personal back-pack-type life support systems for the astronauts when they emerge from the Shuttle. Power is required to drive vent fans, operate valves for oxygen, operate sensors, etc. The units are designed to operate for periods up to three hours. Electrical requirements call for currents up to 8 amps at 16.8 volts and a capacity of 18 AH. Current plans call for use of silver-zinc batteries to supply this power. Appreciable savings in mass and, perhaps more importantly, in volume on the EMU would result from use of Li-$SOCl_2$ batteries in this application.

Another application is to provide power for the Manned Maneuvering Unit (MMU). These are small personal propulsion devices that enable the astronauts to maneuver outside the Shuttle. Power is required for the opening and closing of gas valves and other control functions. Present plans call for use of silver-zinc batteries to supply this power. As above, appreciable savings in mass and volume on the MMU would be realized if power were supplied by Li-$SOCl_2$ batteries.

In addition, the compact and lightweight features of lithium batteries make them very attractive for use in a variety of equipment items for the crew aboard the Shuttle. Among these items are flashlights, tape recorders, hand-held radios, survival radios, wireless microphones, calculators, portable saws, and portable drills. It is well to point out that lithium batteries were already used for a camera drive on the Skylab and a light on the Apollo-Soyuz Test Projects.

I. LAUNCH VEHICLE APPLICATIONS (26,31,32)

Compact batteries are required for launch vehicles for two reasons. The first is for range-safety purposes. In this case, the battery is used to trigger an arming device to destroy the Solid Rocket Booster (SRB) in the event of a mulfunction. The second is for location-aid purposes. In this case, the battery is used to deploy an antenna and transmit signals from the SRB and also power flashing lights on the SRB. Four range-safety batteries and two location-aid, or "frustrum," batteries are required per flight. Altogether, eight such batteries are required per Shuttle launch. Electrical requirements for both types of batteries are identical. These must operate at 28 ±4 volts and have a capacity of 18 AH.

The Li-CF type battery has been selected by Marshall Space Flight Center for these applications. MSFC has conducted extensive electrical and mechanical tests on these batteries and has qualified them for flight. In the unlikely event that MSFC deems it necessary to upgrade, performance, they might consider use of the Li-$SOCl_2$ type battery which, as noted previously, would offer more volume saving than the Li-CF type battery.

J. BALLOON APPLICATIONS (27,39)

Goddard Space Flight Center (GSFC) designs and builds a variety of scientific balloon systems. These are used to conduct several types of experiments in the upper atmosphere. Typical experimental packages installed on the balloons consist of ultra-violet spectrometers and gamma ray detectors for stratospheric research, high energy physics, and cosmic ray studies. The Jet Propulsion Laboratory also conducts a variety of balloon flights to gather data on solar cells and to study composition of the atmosphere. The balloons are launched by the National Scientific Balloon Facility in Palestine, Texas. Altitudes attained in the flights are in the vicinity of 40,000 meters, and typical flight times are 8 to 40 hours.

Power is required aboard the balloons to operate the science equipment and telemetry. Requirements for the power system are that it be light weight, low cost, and capable of operating over a temperature range of -45°C to +50°C. For these reasons, GSFC has recently selected the Li-SO_2 system to replace the silver-zinc system as a power source for these balloons. 30 AH hermetically sealed Li-SO_2 cells are arranged in series to provide a 28-volt battery which delivers required currents to 8 amps. Mass and cost of the Li-SO_2 battery are about one-third that of comparable silver-zinc batteries.

SECTION V

CONCLUSIONS

Lithium batteries appear very attractive for space applications because they are exceptionally lightweight, compact, and have projected long storage life. The batteries are, however, relatively new and uncertainties exist about their safety, thermal, passivation, and rate capability characteristics. Work is in progress to resolve these uncertainties and then qualify them for flight.

Lithium batteries would enhance a number of candidate future NASA missions and applications by increasing payload mass and size by extending life and by decreasing cost. The missions identified include: a) planetary probes and landers, b) exploration of Mars, c) the LDEF, and d) the SLRV. Applications aboard the Shuttle have been identified as: a) for crew equipment, b) for the EMUs and the MMUs, and, c) for the IUS, and PAM. Additional applications have been identified for launch vehicles and for scientific balloon flights.

REFERENCES

1) Lithium Battery Product Brochure from Honeywell Power Sources Center, 104 Rock Road, Horsham, PA., 19044.

2) Personal communication with Dr. R. Walk of Honeywell Power Sources Center, Horsham, PA., (215)-674-3800, April, 1978.

3) Lithium Battery Product Brochure from Power Conversion, Inc., 70 MacQuesten Parkway South, Mount Vernon, NY., 10550.

4) Personal communication with Mr. J. Sullivan of Power Conversion, Inc., Mount Vernon, NY., (914)-699-7333, April 1978.

5) Lithium Battery Product Brochure from Eagle Picher Industries, Inc., P.O. Box 47, Joplin, MO., 64801.

6) Personal communication with Mr. Robert Higgins of Eagle Picher, Joplin, MO., (417)-623-8000, May 1978.

7) Lithium Battery Specification Sheet from G.T.E. Laboratories, 40 Sylvan Road, Waltham, MA., 02154.

8) Personal communication with Mr. Robert Keegan, G.T.E. Laboratories, Waltham, MA., (617)-890-8460, April 1978.

9) Personal communication with Dr. Carl Schlaikjer, G.T.E. Laboratories, Waltham, MA., (617)-890-8460, May, 1978.

10) Personal communication with Dr. A.N. Dey and Dr. P. Bro, P.R. Mallory & Co., Burlington, MA., (617)-272-4100, May 1978.

11) Lithium Battery Specification Sheet from Altus Co., 440 Page Mill Road, Palo Alto, CA., 94306.

12) Personal communication with Mr. Douglas Gladder, Altus Co., Palo Alto, CA., (415)-328-1300, May 1978.

13) Bogner, S., "Sergeant Battery Tests at Eagle Picher Co., Joplin, Missouri," Internal JPL Memorandum, 11 December 1967.

14) Frank, H.A., "Thermal Decomposition Rate of Thionyl Chloride," Extended Abstracts, Abstract No. 58, Fall Meeting of the Electrochemical Society, Pittsburgh, PA., October 15-20, 1978.

15) Chua, D.L., "Lithium-Thionyl Chloride System - Studies On Safety Aspects," <u>Extended Abstracts</u>, Abstract No. 59, Fall Meeting of the Electrochemical Soceity, Pittsburgh, PA., October 15-20, 1978.

16) Blagdon, L.J., "Analysis of Li-SO_2 System Safety", 28th Power Sources Symposium, Atlantic City, NJ., 12-15 June 1978.

17) Bro, P., "On the Thermal Analysis of Li/$SOCl_2$ Batteries," <u>Journal of the Electrochemical Society</u>, Vol. 125, No. 4, pp. 674-675, April 1978.

18) Chua, D.L., and Merz, W.C., "Lithium Passivation in the Thionyl Chloride System," Proceedings of the 27th Annual Power Sources Conference, Atlantic City, NJ, June 1976.

19) Taylor, H., <u>The Storability of Li/SO_2 Cells</u>, P.R. Mallory & Co., Inc., Burlington, MA., 01803, June 1978.

20) Personal communications with Mr. D. Dugan and J. Rubenzer of NASA Ames Research Center, Moffett Field, CA., 94035, August 1978.

21) Personal communications with Mr. R. Banes and G. Juvinall, Jet Propulsion Laboratory, Pasadena, CA., 91103, July 1978.

22) Personal communication with Mr. J. French, Jet Propulsion Laboratory, Pasadena, CA., 91103, June 1978.

23) Personal communication with Mr. V. Clarke, Jet Propulsion Laboratory, Pasadena, CA., 91103, June 1978.

24) Personal communication with Mr. J. Bene, NASA-Langley Research Center, Hampton, VA., 23665, August 1978.

25) Personal communication with Mr. R. Bragg, Johnson Space Center, Houston, Texas, 77058, August 1978.

26) Personal communication with Mr. A. Paschal, NASA Marshall Space Flight Center, Alabama, 35812, August 1978.

27) Personal communications with Mr. F. Ford and W. Nagel, NASA Goddard Space Flight Center, Greenbelt, MD., 20771, August 1978.

28) Personal communication with Mr. P. Barnett, Jet Propulsion Laboratory, Pasadena, CA., 91103, July 1978.

29) Wheat, C.G., "Preliminary Investigation of a Sealed, Remotely Activated Silver-Zinc Battery," Eagle Picher Industries, Inc., Report No. 1026-77-1, Final Report JPL Contract 954768, 7 September 1977.

30) Personal communication with Mr. J. McCartney, Naval Oceans System Center, San Diego, CA., concerning the Navy's High Energy Density Battery Program, May 1978.

31) Specification for Range Safety Battery (No. 16A10496), Marshall Space Flight Center, Georgia, 1978.

32) Specification for Frustum Battery (No. 16A10498), Marshall Space Flight Center, Georgia, 1978.

33) "A Concept Study of a Remotely Piloted Vehicle for Mars Exploration," Developmental Sciences, Inc., City of Industry, Calif., Final Technical Report SOW Task 4, JPL Contract 955012, August 1, 1978.

34) Blomeyer, L.S., Project Plan for Galileo 1982 Mission, Document 625-1, Jet Propulsion Laboratory, Pasadena, Calif., July 1978 (JPL Internal Document).

35) Personal communication with Mr. C. Uphoff, Jet Propulsion Laboratory, Pasadena, CA., 91103, October 1978.

36) Personal communication with Mr. J. Wright, Jet Propulsion Laboratory, Pasadena, CA., 91103, October 1978.

37) Wright, J., Saturn Orbiter Dual Probe Mission Concept, JPL Publication 710-20, Jet Propulsion Laboratory, Pasadena, Calif., July, 1978 (JPL Internal Document).

38) Personal communication with Mr. B. Mann, Jet Propulsion Laboratory, Pasadena, CA., 91103, November 1978.

39) Personal communication with Mr. J. Riccio, Jet Propulsion Laboratory, Pasadena, CA., 91103, October 1978.

NASA–JPL–Coml., L.A., Calif.