

THE LIAL/FES2 BATTERY  
POWER SOURCE FOR THE FUTURE

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NASA AEROSPACE BATTERY WORKSHOP  
OCTOBER 29 - 31, 1991  
MARSHALL SPACE FLIGHT CENTER  
HUNTSVILLE, ALABAMA

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**The LiAl/FeS<sub>2</sub> Battery**  
**Power Source for the Future**

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**Abstract:**

Advanced high power density rechargeable batteries are currently under development at SAFT. These batteries have the potential of greatly increasing the power and energy densities available for space applications. Depending on whether the system is optimized for high power or high energy, values up to 150 Wh/kg and 2,100 W/kg (including hardware) are projected. This is due to the fact that the system employs a high conductivity molten salt electrolyte. The electrolyte also serves as a separator layer with unlimited freeze thaw capabilities. Life of 1,000 cycles and ten calendar years is projected. The electrochemistry consists of a lithium aluminum alloy negative electrode, iron disulfide positive electrode, and magnesium oxide powder immobilized molten salt electrolyte. Processed powders are cold compacted into circular discs which are assembled into bipolar cell hardware with peripheral ceramic seals. The culmination of SAFT's development work will be a high energy battery of 40 kWh and a high power battery of 28 kWh.

**Introduction:**

Advanced rechargeable high energy batteries are desirable for a number of applications where the performance of present day lead acid batteries is

inadequate. Such applications as electric vehicle propulsion, utility load leveling, military and space demand high power and energy from reliable power sources. Rechargeable high temperature electrochemistries employing molten salt electrolytes and high energy electrodes offer promise for fulfilling present and future requirements in lower weight and volume packages.

Today, SAFT is developing LiAl/FeS<sub>2</sub> batteries in sealed bipolar configuration having superior energy and power densities. Such batteries promise to give improved performance with lower weight for future space applications.

#### Space Power Systems:

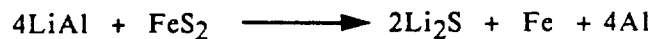
At the 1989 IECEC conference, a paper was presented entitled: "Advanced Electrochemical Concepts for NASA Applications"<sup>(1)</sup>. Presented in that paper were the results of a Jet Propulsion Laboratory survey of 23 electrochemical systems for space applications. The highest ranked advanced systems for operation in planetary inner-orbit spacecraft included Na/beta"alumina/z (where z = S, FeCl<sub>2</sub>, or NiCl<sub>2</sub>), upper plateau (U.P.) Li(Al)/FeS<sub>2</sub> and H<sub>2</sub>O<sub>2</sub> alkaline regenerative fuel cell (RFC). The achievable specific energy for these as operational batteries was estimated to be 130, 180, and 100 Wh/kg respectively. Energy storage requirements of six anticipated space missions are tabulated as shown in Figure 1. GEO, planetary rover, and lunar based applications were designated as shown to be good candidates for LiAl/FeS<sub>2</sub> primarily because of moderate cycles and large energy requirements.

As compared to present state-of-the-art nickel/cadmium and nickel/hydrogen batteries, the projected specific energy (Wh/kg) for bipolar constructed lithium

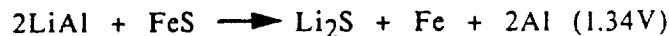
aluminum/iron disulfide batteries is three times that of nickel hydrogen with five times improvement in energy density (Wh/l) as shown in Figure 2.

**Lithium/Metal Sulfide System Description:**

During the 1970s, work was performed at Argonne National Laboratory (ANL) to develop batteries for electric vehicle propulsion and utility load leveling<sup>(2)</sup>. Both lithium aluminum/iron disulfide and iron sulfide couples were investigated. The complete discharge (two plateaus) of lithium aluminum/iron disulfide can be written as

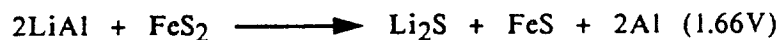


Failure to achieve good cycle life with this couple caused development emphasis to shift heavily in favor of the lower energy and less corrosive lithium aluminum/iron sulfide system. The discharge has a theoretical specific energy of 460 Wh/kg and can be written as



Full scale prismatic multiplate cells and small batteries were built at Eagle Pitcher, Gould, and ANL.

In the 1980s, some work was continued at ANL on LiAl/FeS<sub>2</sub> by Kaun and others. Success was achieved in 1986 by cycling only the upper plateau



with a theoretical specific energy of 490 Wh/kg. Over 1,000 cycles was demonstrated in LiAl/FeS<sub>2</sub> prismatic bicell configuration<sup>(3)</sup>. Further developments in 1988 of an electrochemical overcharge tolerance<sup>(4)</sup> and in 1990 of a peripheral seal material<sup>(5)</sup> make bipolar stack construction both workable and practical.

At SAFT, primary reserve thermal batteries containing bipolar LiAl/FeS<sub>2</sub> have been manufactured since 1978, and research and development on rechargeable prismatic LiAl/FeS and bipolar LiAl/FeS<sub>2</sub> has been conducted since 1990.

The LiAl/FeS<sub>2</sub> electrochemistry consists of components fabricated from cold uniaxial pressed dry mixed powders. Three cell components are the negative electrode, electrolyte/separator, and positive electrode, all containing molten salt electrolyte. The negative electrode contains LiAl alloy and the positive electrode FeS<sub>2</sub>. The electrolyte/separator consists of molten salt immobilized by MgO ceramic powder which acts as a binder-separator at operating temperature.

Cell components are fabricated in prismatic or disc geometries for either prismatic multiplate cells (Figure 3) or cylindrical bipolar configurations (Figure 4). The bipolar battery is a triple seal construction. First, all cells are individually sealed around the periphery as shown in Figure 4. Second, arrays of series cells are sealed inside a steel case to form a module. And finally, the modules are contained inside a sealed thermally insulated enclosure (Figure 5). Integral cooling and heating systems maintain the modules at a constant temperature. The thermal enclosure is double walled construction with vacuum and multifoil insulation. Heaters are powered by the charging source during charge and the battery during discharge. Heat loss is limited to approximately 16% of battery capacity per day.

#### **System Advantages:**

As compared to other advanced battery chemistries, the LiAl/FeS<sub>2</sub> system offers some distinct advantages. In addition to high volumetric power and energy

densities, the system offers high reliability with intrinsic safety. Cells have performed for over 1,000 cycles with negligible performance degradation.

Single cell and battery tests have demonstrated that cells always fail short circuit. Configured as series arrays of bipolar cells, remaining series cells will continue to operate normally even with shorted cells included in the string. This is in contrast to the sodium/sulfur system where cells fail open circuit and the remaining series cells are inoperable.

The battery is intrinsically safe because it contains no liquids or gases. Unlike most lithium batteries, the negative electrode is not pure lithium but an alloy containing approximately 20 weight percent lithium which is less reactive and solid at the battery operating temperature. During operation the salt is molten in the electrodes and "wets" the active particles. If the container is punctured exposing the chemistry to the atmosphere, the salt freezes forming a protective coating over the lithium aluminum particles.

The electrochemistry in bipolar configuration is tolerant to dynamic environments as has been demonstrated for over 14 years in thermal batteries. These are primary reserve LiAl/FeS<sub>2</sub> batteries designed for military application. Installed in missiles, guided bombs, and projectiles, these batteries withstand severe environments of shock, vibration, and acceleration in both non-operating and operating conditions. The dense paste-like electrolyte/separator is not subject to cracking typical of solid ceramic separators. For secondary applications, this separator property provides unlimited freeze thaw capability.

An advantage over ambient temperature batteries is that the electrochemistry is always operating at optimum temperature independent of environmental changes.

### Development Goals:

Currently, SAFT is working on development of two batteries utilizing LiAl/FeS<sub>2</sub> electrochemistry in bipolar construction. One battery will be optimized for high energy utilizing thick electrodes at moderate current densities to achieve 150 Wh/kg with power of 340 W/kg. This battery is being developed for electric vehicle propulsion. The second battery will be optimized for high power utilizing thin electrodes at high current densities up to 5.0 amperes/cm<sup>2</sup> to achieve extremely high specific power of 2.9 kW/kg at a relatively low specific energy of 39 Wh/kg. This battery will provide high power for an electric weapon application. A comparison of development goals for these batteries is shown in Figure 6.

### Development Status:

At SAFT, bipolar primary thermal batteries have been made since the 1950s. In 1978, SAFT introduced the LiAl/FeS<sub>2</sub> technology developed by ANL into thermal batteries. Since 1990, work on rechargeable lithium metal sulfide technology has been conducted at SAFT's Baltimore facility. This work included LiAl/FeS prismatic multiplate cells (200 Ah), LiAl/FeS<sub>2</sub> prismatic bicells (40 Ah), and LiAl/FeS<sub>2</sub> bipolar cells (0.3 to 3.2 Ah).

A number of recent accomplishments are noteworthy. Specific energy of 89 Wh/kg was achieved for LiAl/FeS prismatic multiplate cells tested at the C/3 rate.

Battery hardware was developed to accommodate 27 multiplate cells. Bipolar LiAl/FeS<sub>2</sub> cells and batteries have achieved 2,100 W/kg, and 6,700 W/l, at very high rates of charge (3C) and discharge (75C).

**Development Issues:**

A target of 1993 has been set to develop a 7 kW high power bipolar LiAl/FeS<sub>2</sub> scaleable module for test. A 5 kWh high energy module is targeted for development by 1994.

In order to achieve these development goals, work must progress towards improvement and scale up of peripheral seals, chemical equalization, and corrosion resistant materials at the cell and cell stack level. Engineering of stack pressure/restraint and current collection systems and methods for electrical isolation need development.

At the battery level, development of an optimized thermal management system that is reliable and producible at minimum cost is essential. The high battery volumes required for electric vehicles require development of a recycling program.



## References:

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2. P.A. Nelson, et al, "High Performance Batteries For Off-Peak Energy Storage and Electric Vehicle Propulsion," Argonne National Laboratory Report ANL-75-1.
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# ENERGY STORAGE REQUIREMENTS OF SIX ANTICIPATED SPACE MISSIONS

PRIORITY/ APPLICATIONS	CHARGE/ DISCHARGE DURATIONS	*QUAL		TYPICAL OPERATIONAL CYCLES REQUIRED	TYPICAL PEAK POWER AND ENERGY STORAGE REQUIRED (5 MINUTES)
		ACTUAL	DESIRED		
1 OUTER PLANETARY ORBIT	C - 2.0HR D - 0.7HR	500	1000	2000	0.50 C(1 KWH)
2 INNER PLANETARY ORBIT	C - 2.0HR D - 0.7HR	3000	6000	10000	1.50 C(2 KWH)
**3 GEO	C - 22.8HR D - 1.2HR	1500	2000	4000	1.50 C(5 KWH)
**4 PLANETARY ROVER	C - 12.0HR D - 3.0HR	300	600	800	1.30 C(3 KWH)
**5 LUNAR BASED	C - 11 DAYS D - 17 DAYS	80	160	350	0.02 C(5 MMH)
6 LEO	C - 1.0HR D - 0.6HR	30000	35000	50000	1.10 C(25 KWH)

GEO: GEOSYNCHRONOUS ORBIT      LEO: LOW EARTH ORBIT      \*\* CANDIDATES FOR LIAL/FES2  
 \*QUAL: MINIMUM NUMBER OF CYCLES NEEDED TO QUALIFY FOR APPLICATION.  
 SOURCE: G. HALPERT AND A. ATTIA, JPL

**TECHNOLOGY PERFORMANCE COMPARISON  
GEOSYNCHRONOUS ORBIT**

	<u>NI-Cd</u>	<u>NI-H<sub>2</sub></u>	<u>PROJECTED BIPOLAR LIAL/FES<sub>2</sub></u>
<b>SPECIFIC ENERGY, WH/KG</b>	25 -30	45 - 50	150
<b>ENERGY DENSITY, WH/L</b>	45	55	270
<b>CYCLE LIFE</b>	1000	1000	1000
<b>- DOD (%)</b>	70	70 - 80	80 - 100
<b>CALENDAR LIFE, YR</b>	15	15	10

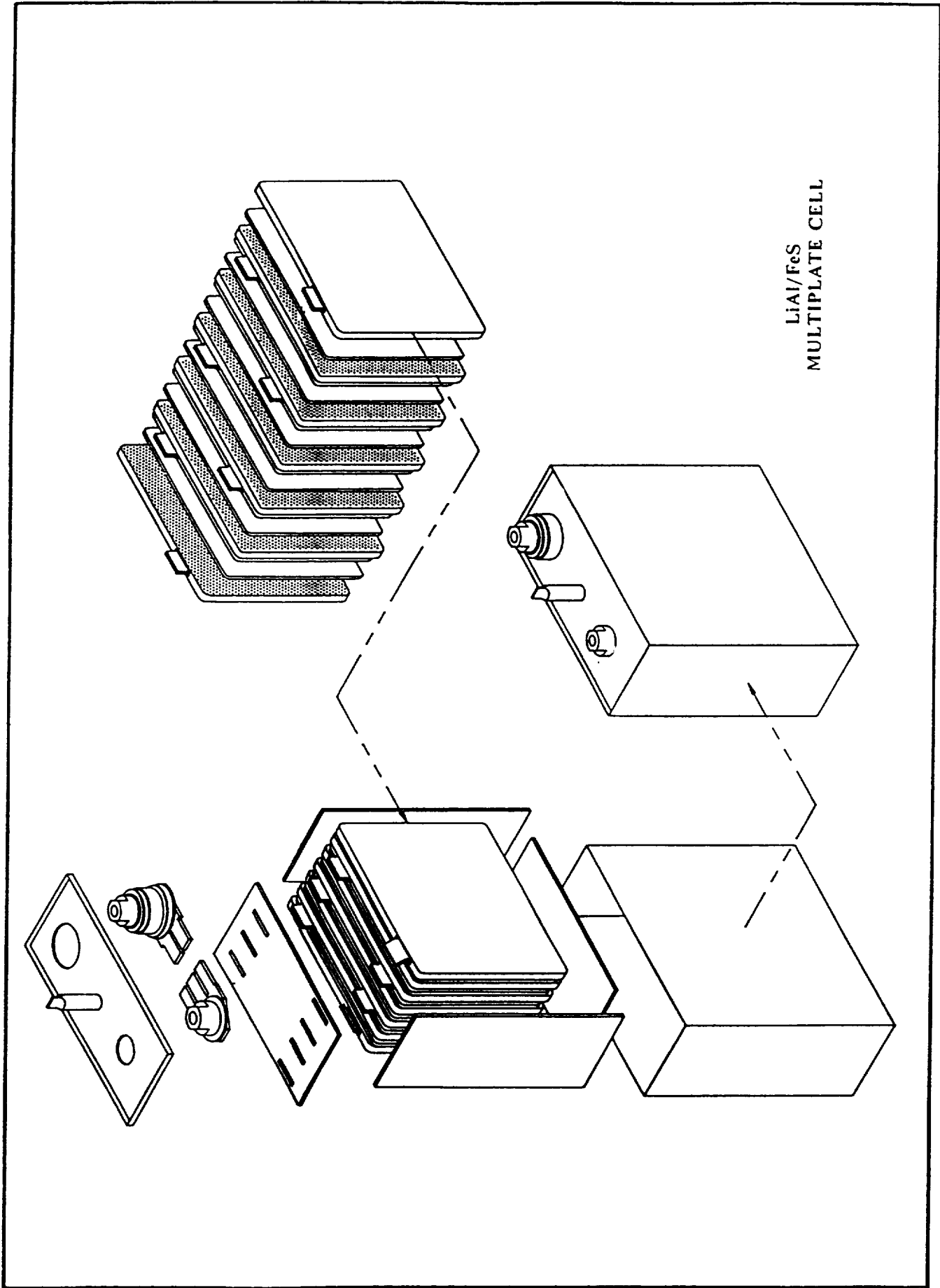
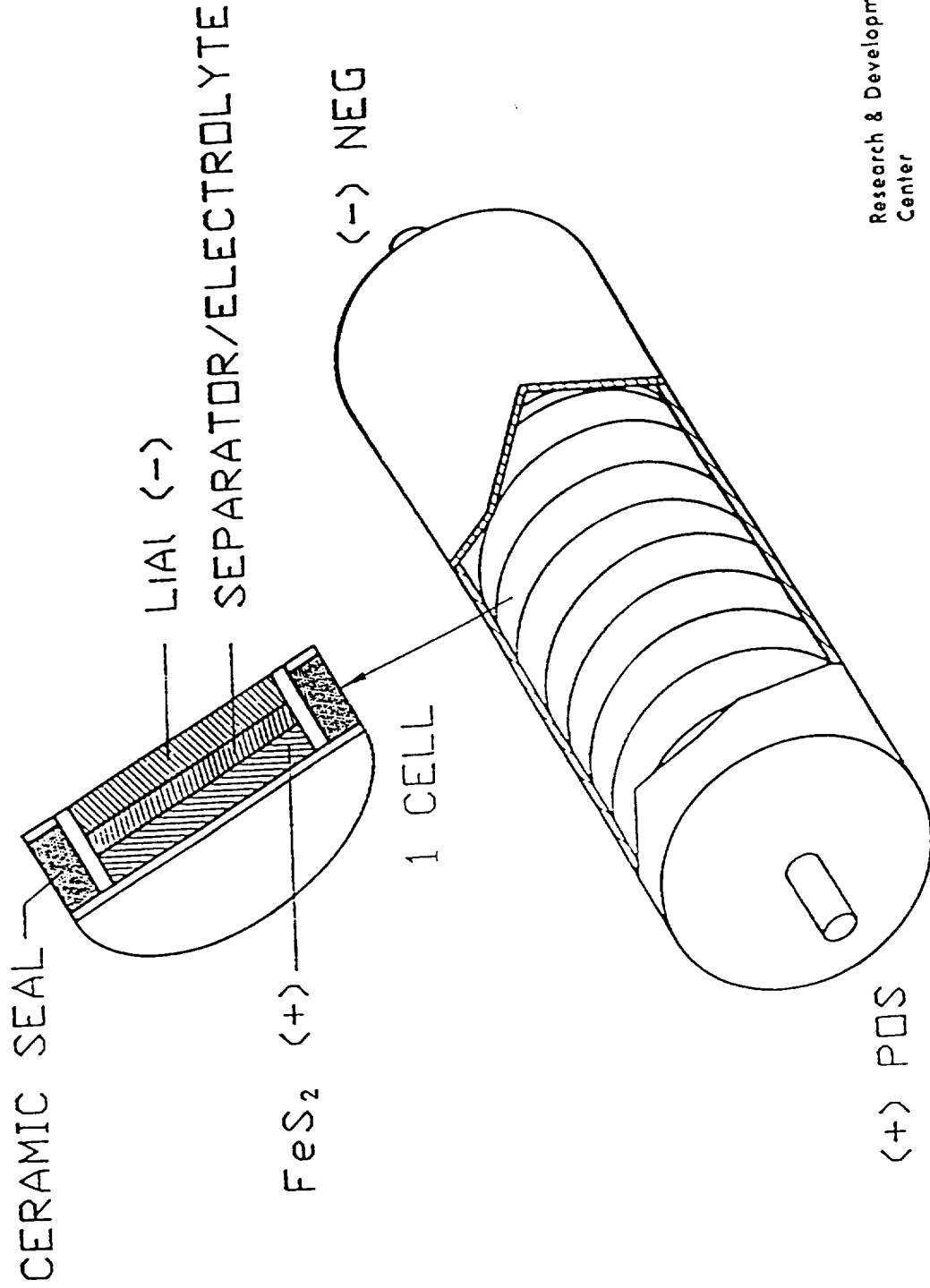


Figure 3

# BIPOLAR LiAl/FeS<sub>2</sub> MODULE CONCEPT DESIGN



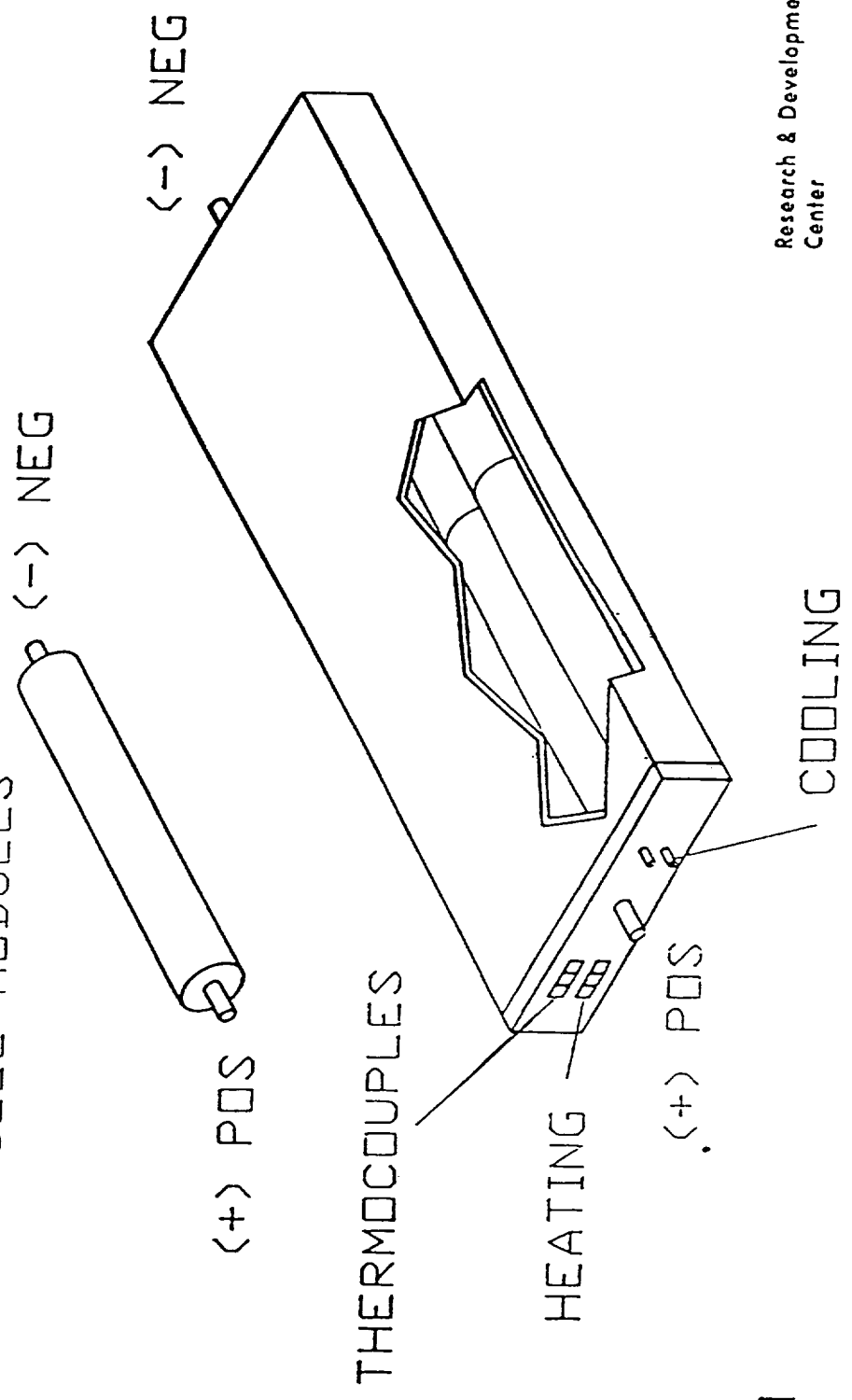
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Figure 4

BIFILAR LiAl/FeS<sub>2</sub> BATTERY CONCEPT DESIGN

1 OF 10 CELL MODULES



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Figure 5

# SAFT LIAL/FES<sub>2</sub> BIPOLAR BATTERY

## DEVELOPMENT GOALS

	OPTIMIZED FOR <u>HIGH ENERGY</u>	OPTIMIZED FOR <u>HIGH POWER</u>
ENERGY, kWh	40	28
VOLTAGE, VOLTS	210 - 350	450 - 550
SPECIFIC ENERGY, WH/KG	150 (C/3)	39 (75C)
ENERGY DENSITY WH/L	270 (C/3)	56 (75C)
PEAK, SPECIFIC POWER, W/KG	340	2900
PEAK, POWER DENSITY, W/L	610	4164
CYCLE LIFE	1000	1000
DOD (%)	80	40
CALENDAR LIFE, YR	10	4



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