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SODIUM-SULFUR CELL TECHNOLOGY FLIGHT EXPERIMENT (SSCT)

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Introduction

The sodium-sulfur battery is emerging as a prime high-temperature energy storage technology for space flight applications. Useable specific energy of two to three times that of Ni-H_2 batteries is the key advantage of Na-S. This represents a significant launch cost savings and increased payload mass capability. Additionally, the Na-S battery offers high power capability attractive for some future military and science satellite applications. While ground testing has shown the Na-S cells to be versatile (capable of operation in any orientation and capable of handling severe vibration and shock loads), the basic cell has yet to be qualified for operation in the microgravity environment of space. There is buoyancy separation of the very viscous liquid sulfur and more fluid sodium polysulfides in the cell on the ground. Spatial control of the molten reactants is critical to proper cell operation. The present design of the cathode is based on capillarity and differential wettability for reactant transport within the cell. Thus the cell is believed to be suitable for operation in microgravity environments.

A Na-S cell demonstration is planned for a 1995-96 NASA Space Shuttle flight which focuses on the microgravity effects on individual cells. The experiment is not optimized for battery performance as such. Rather, it maximizes the variety of operating conditions which the Na-S cell is capable of in a relatively short 5-day flight. The demonstration is designed to reveal the effects of microgravity by comparison with ground test control cells experiencing identical test conditions but with gravity. Specifically, limitations of transport dynamics and associated cell performance characteristics should be revealed.

Experiment Description

The Na-S Cell Technology Flight Experiment consists of three separate experiments designed to determine cell operating characteristics, detailed electrode kinetics and reactant distributions. The experiments, summarized in Table 1, are controlled by an autonomous Experiment Control Unit (ECU). Subordinate controllers include a Power Conditioning Unit (PCU), Thermal Control Electronics (TCE) and a Data Conditioning Unit (DCU). A total of 6 Na-S cells enclosed within 2 thermal enclosures will be mounted to a HitchHiker-M structure top pallet within the Shuttle cargo bay, as indicated in Figure 1. The PCU, having high power dissipative loads, will also be mounted on a top pallet for improved heat rejection. The ECU, TCE and DCU will be

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integrated into a side mounting plate. Space Shuttle energy is supplemented with Ag-Zn batteries side mounted in a Gas canister. The batteries allow for high power charging of the Na-S cells and support an orderly-emergency shut down.

TABLE 1. FLIGHT EXPERIMENT MATRIX

TEST	TEST No.	NUMBER OF CELLS IN SPACE	GROUND	TEMP °C	DISCHARGE-CHARGE**** RATES
CELL CHARACTERIZATION	IA	2	2	350	DISCHARGE: C/2, C , 3C/2, 2C CHARGE: C/4, C/2, 3C/4, C
	IB	2	2	350 & 300	DISCHARGE: C/2, C CHARGE: C/4, C/2
CURRENT/TEMP DISTRIBUTION	II	2*	2*	350 & 300	DISCHARGE: C/2, C +Interrupts CHARGE: C/4, C/2 +Interrupts
REACTANT DISTRIBUTION (THERMAL QUENCH)	III-1	4**	4**	350	2 @ FULL CHARGE After C/2 CHG 2 @ HALF CHARGED After C/2 CHG
	III-2	2***	2***	350	1 @ HALF CHARGED After C/2 DIS 1 @ FULL DISCHG After C/2 DIS
	TOTAL	6	6		

* SPECIALLY INSTRUMENTED CELLS
** REUSE TEST #I CELLS
*** REUSE TEST #II CELLS
**** SECONDARY CHARGE (@C/8) INCLUDED IN ALL CHARGE CYCLES

Test Planning. Because sulfur molten salts are extremely sluggish and the cell cycle times are of long duration, it is not possible to maintain low-g conditions for an adequate duration to simulate the experiment on earth.

The criteria used for selecting these space experiments was that they could not be properly simulated with on-ground tests. The feature common to all of the selected tests pertains to the unknown spatial distribution of cathode reactants (molten S and Na_2S_x, x = 3 to 5) with respect to the Na^+-conducting solid electrolyte (Beta"-alumina). Together with the large volume shrinkage (>30%) of the reactants during charge, formation of insulating sulfur or void volume adjacent to the electrolyte could result in premature termination of the charge cycle and loss of capacity on the subsequent discharge cycle. Although differential surface tension is utilized in the cathode design to optimize gravity-assisted operation, it is unclear whether phase consolidation and segregation of immiscible components will occur without gravity assistance, so that capillarity can remain functional in space.

The overall objective of the Na-S Cell Flight Experiment is to validate or refine the cell design codes for optimum performance and extended operation in space environments. The specific objective of Experiment I is to determine cell characteristics as a function of the operating temperature, charge rates and discharge rates for comparison with response on earth. These operating parameters will be varied from moderately slow cycles (C/2 Discharge, C/4 Charge) to very fast cycles (2C Dis, 1C Chg) at several temperatures to support conceptual engineering designs for diverse space applications.

The cell current time line for Experiment I, for example, is shown in Figure 2. Following one balanced conditioning cycle, the cells are operated for 3 cycles at 350°C at each test condition. Two of the charge/discharge rates are repeated at 300°C.

The objective of Experiment II is to determine variations in the distribution of reactants and reactions within the cathode volume as they develop in real time during operations in space. The objective of Experiment III is similar to Exp II - to document the spatial distribution of cathode reactants as a function of the cell's state-of-discharge and as a function of the dynamics of its previous electrical cycle as it is established without gravity. Experiment III involves a rapid thermal quench of the Exp I and II cells to immobilize the reactant distributions for analysis by DPA after re-entry.

Design Considerations

The two most demanding aspects of the Experiment design are thermal control and minimization of required STS energy. Because Na-S cells must be maintained at about 350°C for proper operation, and since each test requires separate conditions, two thermal enclosures are required. During most of the 5-day mission, heat generated within the Na-S cells is not adequate to offset thermal losses, hence substantial energy is required from the shuttle bus.

Cell Enclosure. The cell enclosure design is shown in Figure 3. Ceramic components provide mechanical support and electrical isolation for each cell, the interconnections, instrumentation leads, and the heater elements. Redundant heaters, positioned between cells for more uniform temperature, are sized for 150W for adequate heatup rates, but are derated to 60W during most of the mission to prevent excessive overtemperature. The inner container housing, a welded structure with hermetic electrical feedthroughs, provides absolute containment of any cell reactant leakage.

An outer module structure (Figure 4) with insulation is sealed by gaskets to form a third hermetic enclosure. Each experiment module is anchored to the HH-M top pallet with a NASA-LeRC designed support frame attachment that permits elongation of the enclosure as it periodically is heated and cooled, but which constrains transverse motion.

Thermal Design. To minimize heat loss from the enclosure, evacuated MLI (Multi-Layer Insulation) is utilized on the large area sidewall, and a high quality fibrous insulation (Min-K 1301) is used on the ends. Three or four large electrical conductors are required per enclosure to provide flexibility in control of test currents up to 80A. Power and instrumentation leads must be carefully sized to minimize heat loss across the thermal gradient. Steady thermal loss for the present design is projected at about 50W per enclosure, resulting in approximately 10 kWh of energy demand for thermal control.

Three aspects of thermal control are: (1) heaters for initial heatup and maintenance of test temperature, (2) limited cooling during occasional high-current cell tests (Exp I), and (3) massive cooling for reactant thermal quench (Exp III) as well as for any emergency situation to quickly secure the experiments for re-entry.

A Variable Conductance Insulation System (VCIS) is incorporated into the enclosure design. By injecting low pressure Helium gas into the MLI system, heat conductance dominates over the normally low radiation transfer rate. To re-establish good insulative properties, the helium is vented to space. When evacuated, the VCIS thermal loss is predicted to be less than 10 watts. In contrast, high effective cooling rates in excess of 400W are predicted for gas pressures of a few tens of Torr. A pressure regulated-helium gas supply is incorporated to adjust the cooling rate for the separate experiments.

Power Control Unit (PCU). It is an unfortunate paradox that to test high-power high-efficiency Na-S cells, a very high power/high energy source is required. Because of shuttle power limitations, we have selected large Ag-Zn primary batteries to provide the peak power and additional energy for recharge of the Na-S cells. The PCU circuit configuration is shown in Figure 5. Two independent PCU circuits are required to control the experiments since they are being performed simultaneously.

Linear regulators were selected for current control in order to minimize EMI interference with the extensive instrumentation required. Parallel MOSFETs are designed to control 40A charge and 80A discharge conditions. Details of the switching network for Experiment I are shown in Figure 6. Mechanical relays were selected for the switching network to minimize circuit losses because current must flow through at least four contacts in series to provide the desired interconnection of the test cells to the charger and the load. Recovery of energy from the discharge of the Na-S cells was not deemed practical because it occurs at low voltage and high amperage. In addition, the available energy is relatively small compared to the required primary energy.

The overall energy requirement for the 5-day Flight Experiment, shown in Table 2, is approximately 32 kWh which substantially exceeds the normal HH-M allocation to individual experiments. Energy required to power the control systems is about 12 kWh, and that for electrical heaters to overcome thermal losses from the two module housings is about 10 kWh. The subtotal of 22 kWh is within the HH-M energy budget, assuming the Na-S experiment is granted half the normal HH-M energy (in proportion to its area usage) plus a request for half the available supplemental HH-M energy. The maximum power level for these loads is well within allowable values.

TABLE 2. ESTIMATED ENERGY REQUIREMENTS

LOAD	AVG	PEAK	ENERGY	PURPOSE	SOURCE
Control					
ECU	30W	---	3.6kWh	Electronics	
TCE	15	---	1.6	Electronics	
PCU	30	---	2.0	Electronics	
DCU	10	---	1.1	Electronics	
RESERVE	30	---	3.3	Electronics	
Totals	115		11.6		
					STS-BUS
Heater Power					
TEST I	50W	150W	4.5kWh	Heatup & Maintain	
TEST II	50	150	4.9	Temperature	
TEST III	100	100	0.5		
Totals	140	340	9.9		
					STS-BUS
Cell Charging					
TEST I		320W	6.6kWh	Recharge	
TEST II		130	3.3	NA-S Cells	
TEST III		260	0.3		
Totals		440	10.2		
					AG-ZN BATT

One-third of the total energy is required to recharge the Na-S cells, and much of this occurs at high peak power levels. Such peak power demands if added to the other continuous loads would exceed HH-M maximum power levels and would constrain the timing of the individual experiments to avoid overlapping the power peaks. By incorporating the Ag-Zn primary battery source, the separate cell experiments can be performed independently, and the overall energy requirement falls within the budget for HH-M experiments.

Mission Planning

Payload integration and pre-launch testing are particularly simple because the Na-S cells are inactive at ambient temperature. Following orbit stabilization and cell heatup, a space conditioning cycle is included for all cells to disrupt the gravity-induced reactant distribution that was carried into space by the cells being frozen prior to launch.

Because of the short 5-day mission and the time to heat/cool the cells, careful planning of test sequences is necessary. Contingency plans will be developed for alternate tests and for maximizing information should a shuttle emergency or experiment malfunction develop and require premature shutdown by the autonomous controller. Cells will be secured with all reactants frozen prior to re-entry.

Acknowledgement

We gratefully acknowledge the program support of Olga Gonzalez-Sanabria and the technical suggestions of Harold Leibecki of NASA Lewis Research Center during the preparation for this critical space experiment.

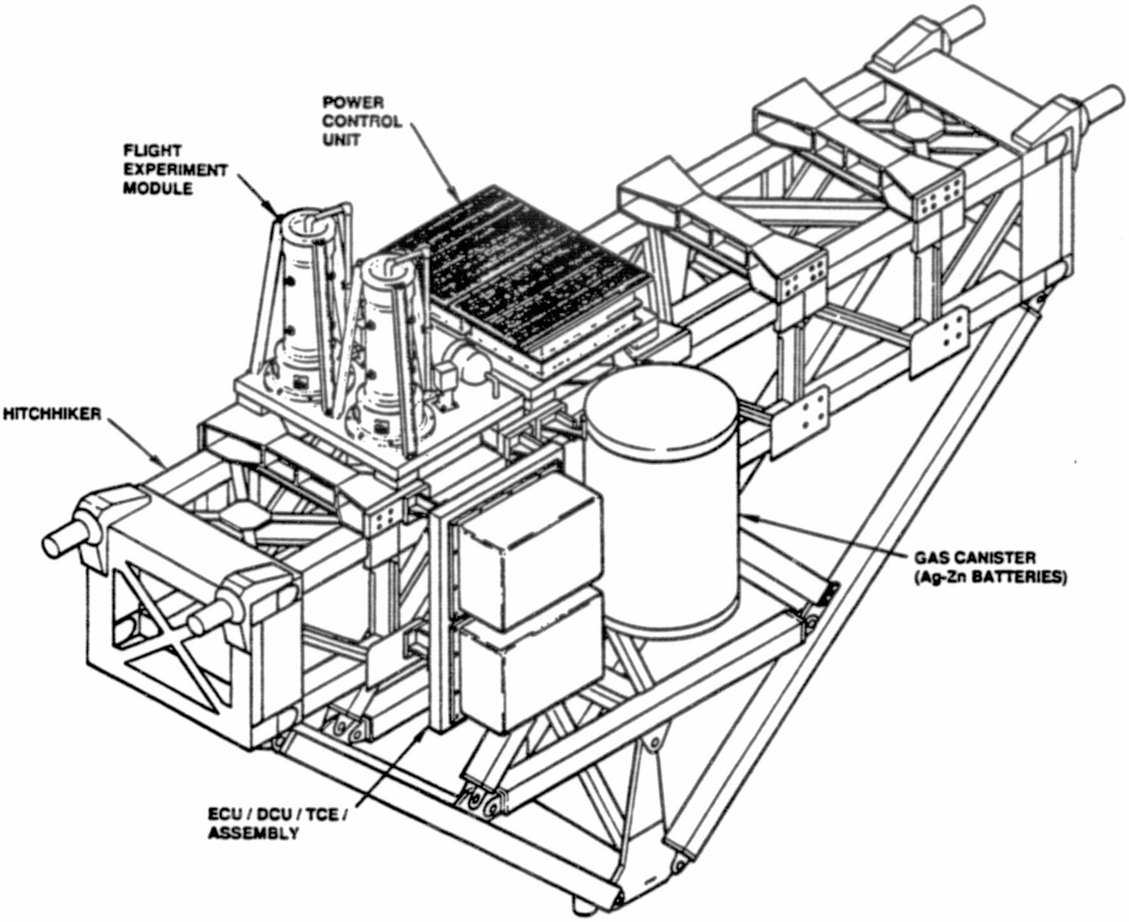

Figure 1. SSCT PAYLOAD CONFIGURATION

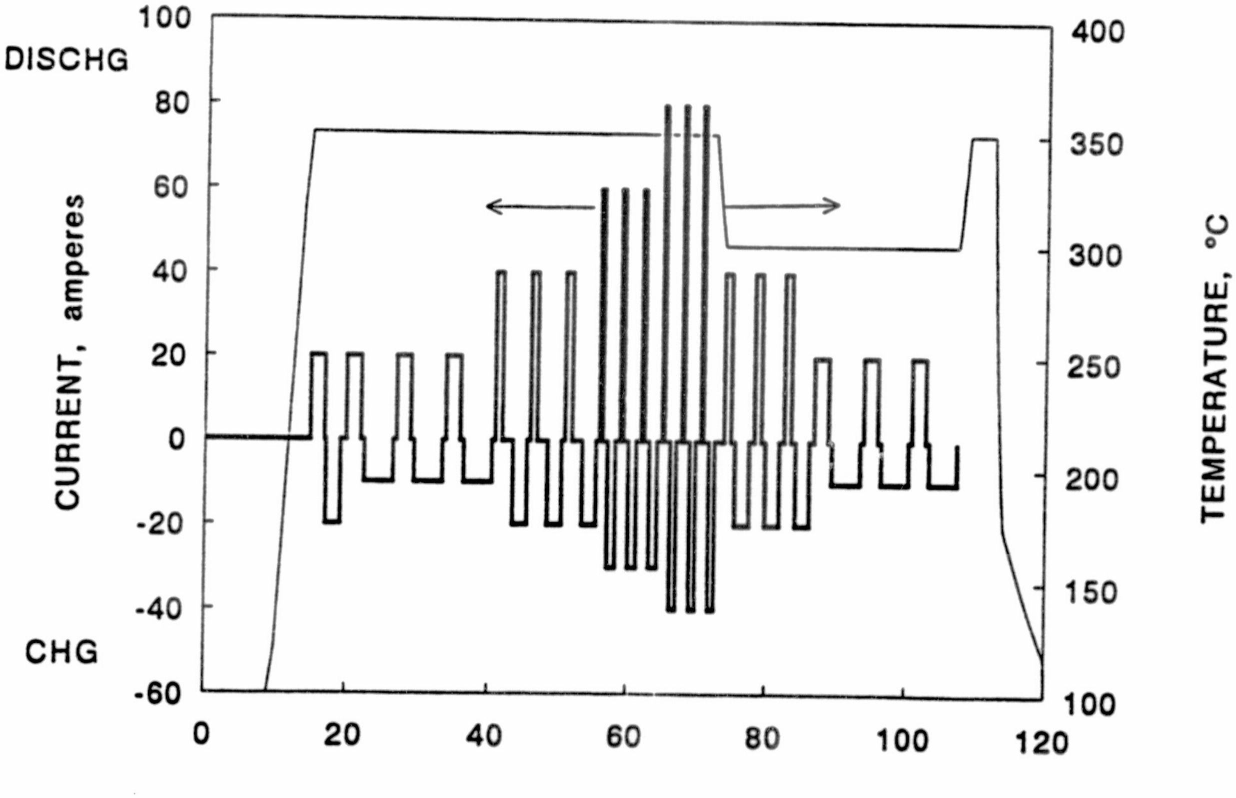

Figure 2. CELL CURRENT TIME LINE - TEST I

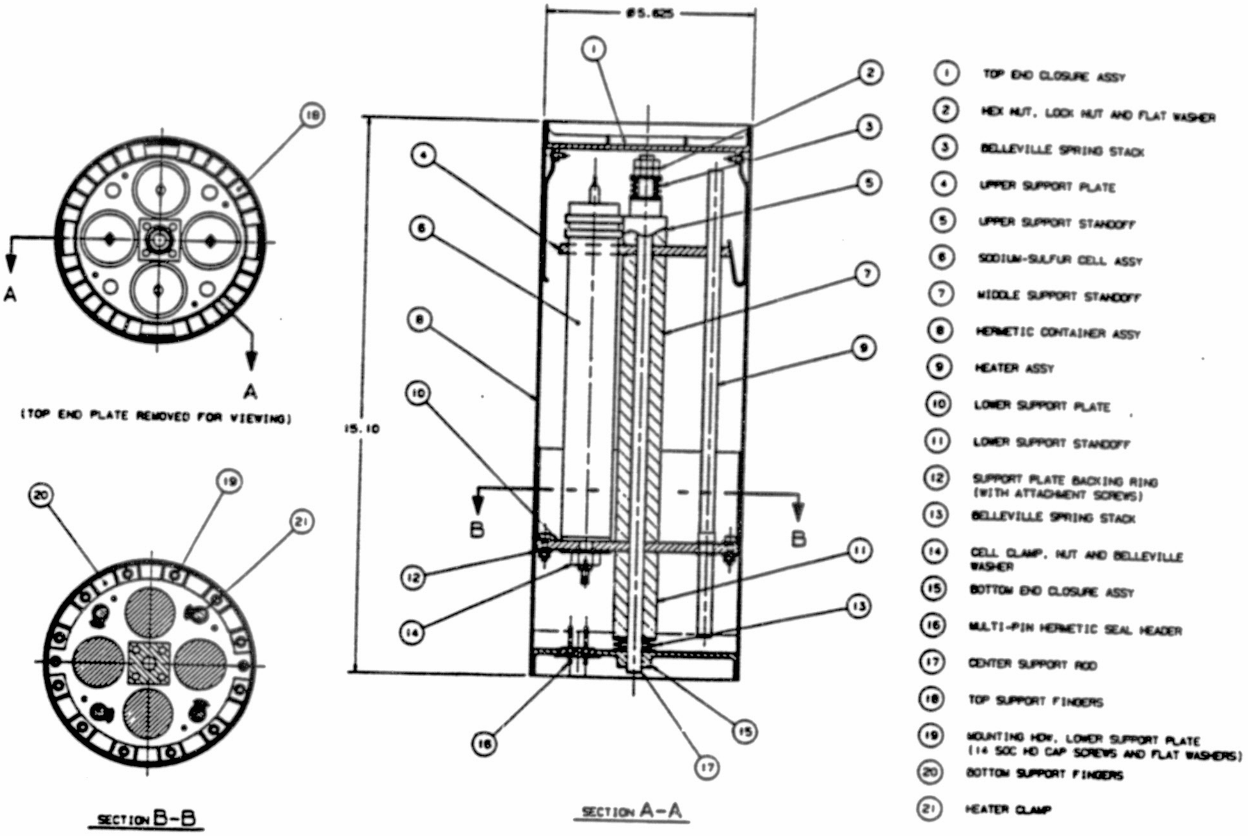

Figure 3. INNER CONTAINER ASSEMBLY

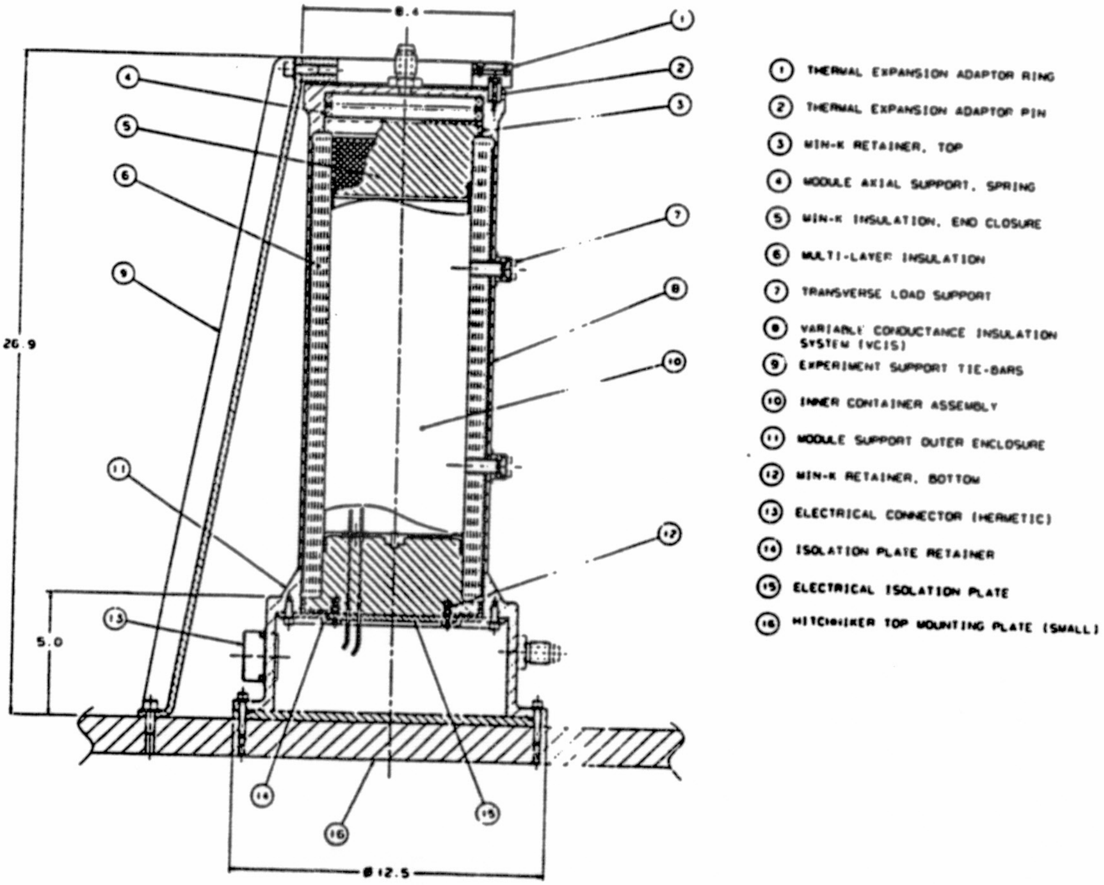

Figure 4. EXPERIMENT MODULE

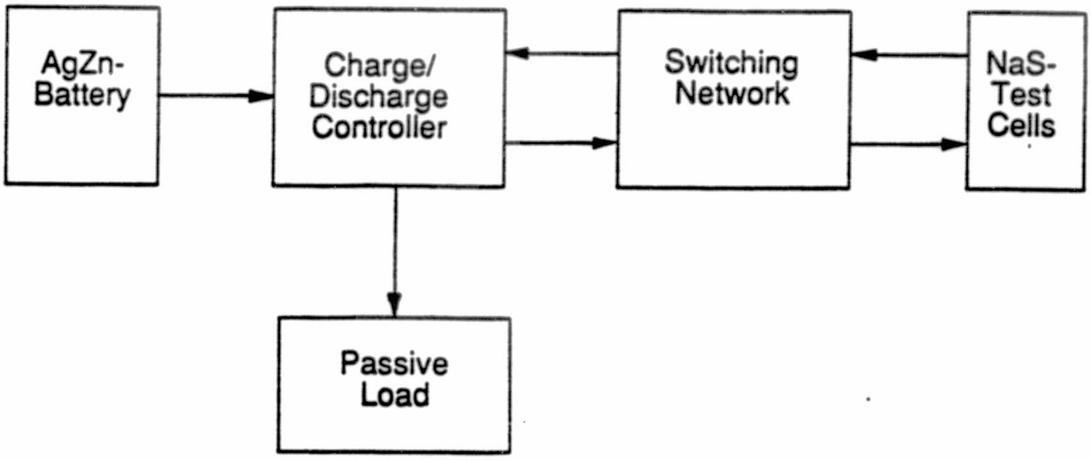

Figure 5. POWER CONTROL UNIT CONCEPT

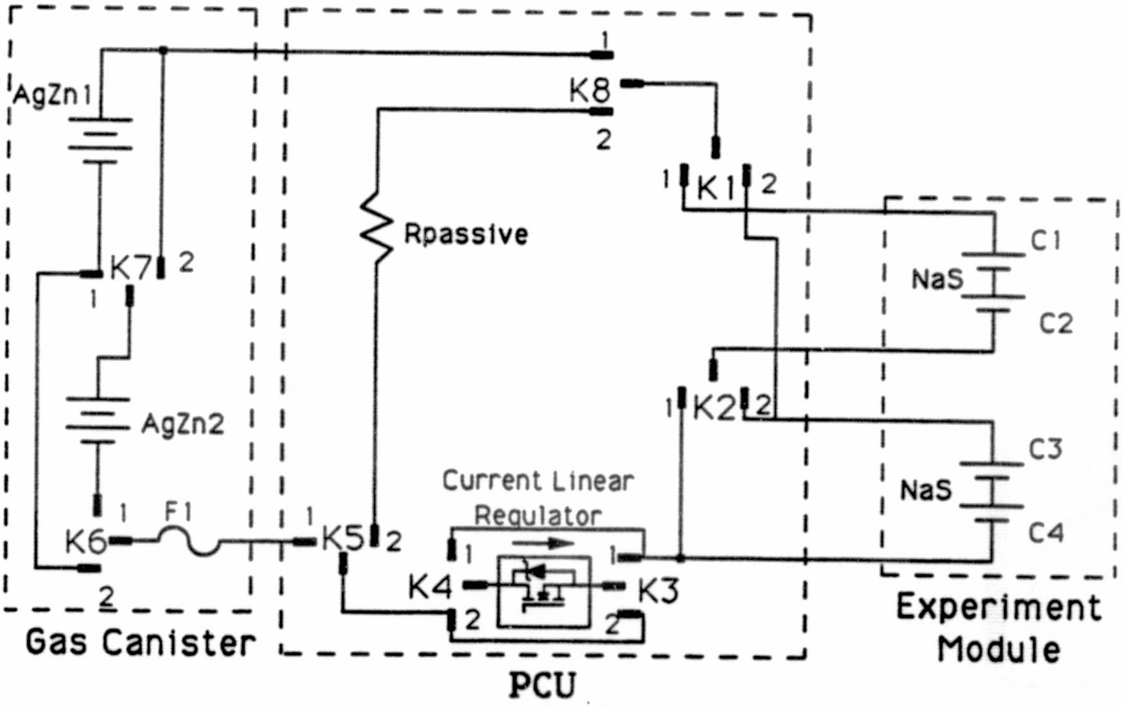

Figure 6. SWITCHING NETWORK CIRCUIT