SODIUM SULFUR BATTERIES
FOR
SPACE APPLICATIONS

James A. DeGruson

Eagle-Picher Industries, Inc.
C&Porter Streets
Joplin, MO

30 October 1991

1991 NASA AEROSPACE
BATTERY WORKSHOP
**PRESENTATION ABSTRACT**

<table>
<thead>
<tr>
<th>Name</th>
<th>James A. DeGruson</th>
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</thead>
<tbody>
<tr>
<td>Company</td>
<td>Eagle-Picher Industries, Inc.</td>
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<td>Address</td>
<td>P.O. Box 47, Joplin, MO 64802</td>
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<td>Telephone</td>
<td>417-623-8000, ex. 491</td>
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<tr>
<td>Preliminary Title</td>
<td>Sodium Sulfur Batteries for Space Applications</td>
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<tr>
<td>Brief Abstract</td>
<td>In 1986, Eagle-Picher Industries was selected by the Air Force to develop sodium sulfur cells for satellite applications. Specifically, the development program was geared toward low earth orbit goals requiring high charge/discharge rates. A number of improvements have been made on the cell level and a transition to a complete space battery has been initiated at Eagle Picher. The results of six months of testing a 250 watt-hour sodium sulfur space battery look very promising. With over 1,000 LEO cycles conducted on this first battery, the next generation battery is being designed. This next design will focus on achieving greater energy densities associated with the sodium sulfur chemistry.</td>
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Na-S BATTERIES

EAGLE EP PICHER

ELECTRONICS DIVISION
JOPLIN, MO

THERMAL-ORDNANCE OPERATION

SODIUM SULFUR 40AH CELL

SAFETY TUBE
COMPRESSION RINGS
SODIUM WICKS
# Thermal-Ordnance Operation

## Na-S Batteries

### Cell Design

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Discharge Rate</strong></td>
<td>75 AMPS</td>
<td>75 AMPS</td>
<td>75 AMPS</td>
<td>75 AMPS</td>
</tr>
<tr>
<td><strong>Discharge Time</strong></td>
<td>33 MIN</td>
<td>32 MIN</td>
<td>35 MIN</td>
<td>35 MIN</td>
</tr>
<tr>
<td><strong>Ave. Volts (DIS)</strong></td>
<td>1.20 VOLTS</td>
<td>1.24 VOLTS</td>
<td>1.39 VOLTS</td>
<td>1.56 VOLTS</td>
</tr>
<tr>
<td><strong>Whrs Discharge</strong></td>
<td>49.5 Whrs</td>
<td>49.9 Whrs</td>
<td>61.1 Whrs</td>
<td>67.7 Whrs</td>
</tr>
<tr>
<td><strong>Ave. Charge Rate</strong></td>
<td>33.5 AMPS</td>
<td>33.2 AMPS</td>
<td>34.81 AMPS</td>
<td>40.24 AMPS</td>
</tr>
<tr>
<td><strong>Charge Time</strong></td>
<td>73 MIN</td>
<td>73 MIN</td>
<td>73.9 MIN</td>
<td>65.2 MIN</td>
</tr>
<tr>
<td><strong>Ave. Volts (CHG)</strong></td>
<td>2.44 VOLTS</td>
<td>2.43 VOLTS</td>
<td>2.44 VOLTS</td>
<td>2.39 VOLTS</td>
</tr>
<tr>
<td><strong>Whrs Charge</strong></td>
<td>98.6 Whrs</td>
<td>98.3 Whrs</td>
<td>104.6 Whrs</td>
<td>104.6 Whrs</td>
</tr>
<tr>
<td><strong>Efficiency (Whrs DIS/Whrs CHG)</strong></td>
<td>50.20%</td>
<td>50.70%</td>
<td>58.40%</td>
<td>64.70%</td>
</tr>
<tr>
<td><strong>Specific Energy</strong></td>
<td>72.6 Whrs/Kg</td>
<td>73.1 Whrs/Kg</td>
<td>87.4 Whrs/Kg</td>
<td>98.6 Whrs/Kg</td>
</tr>
<tr>
<td><strong>Energy Density</strong></td>
<td>159.2 Whrs/l</td>
<td>160.5 Whrs/l</td>
<td>196.0 Whrs/l</td>
<td>217.4 Whrs/l</td>
</tr>
<tr>
<td><strong>End of Discharge</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Resistance (mOhms)</strong></td>
<td>8.8 mOhms</td>
<td>8.8 mOhms</td>
<td>6.4 mOhms</td>
<td>6.1 mOhms</td>
</tr>
<tr>
<td><strong>F1 (%)</strong></td>
<td>30.00</td>
<td>31.42</td>
<td>21.61</td>
<td>14.08</td>
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**Note:** F1 is a measure of the percent nonavailable theoretical cell capacity.
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THERMAL-ORDNANCE OPERATION

Na-S BATTERIES

TD-75 CYCLE 1828 (LEO 60% DOD)

SPLIT CHARGE RATE
50/40/30/25/20/15/10/0
7.90 mOhms

DISCHARGE RATE
54 AMPS

DISCHARGE CAPACITY
RESISTANCE (EOD) VS. CYCLE LIFE

- TD-75
- TD-87
- TD-89
LIFE CYCLE TESTS

55AH CELLS DISCHARGED TO 60% DOD AT "C" RATE

CYCLES ACCOMPLISHED TO DATE: 7,200

AVERAGE VOLTS WHILE DISCHARGING: 1.50

AVERAGE VOLTS DURING CHARGE: 2.40

SPECIFIC ENERGY: 63.3 WH/KG

ENERGY DENSITY: 145 WH/L

E.O.D. RESISTANCE: .0088 ohms
LATEST CELL DESIGN

55AH CELLS DISCHARGED TO 60% DOD AT "C" RATE

CYCLES ACCOMPLISHED TO DATE: 5,000

AVERAGE VOLTS WHILE DISCHARGING: 1.63

AVERAGE VOLTS DURING CHARGE: 2.40

SPECIFIC ENERGY: 73 WH / KG

ENERGY DENSITY: 165 WH / I

E.O.D. RESISTANCE: .0075 ohms
IMPROVED CELL TECHNOLOGY AVAILABLE NOW

55AH CELLS DISCHARGED TO 60% DOD AT "C" RATE

AVERAGE VOLTS WHILE DISCHARGING: 1.75

AVERAGE VOLTS DURING CHARGE: 2.40

SPECIFIC ENERGY: 100 WH/KG

ENERGY DENSITY: 225 WH/L

E.O.D. RESISTANCE: .005 ohms
1. CELL OPTIMIZATION AND DEVELOPMENT

A. IMPROVED LOW-RESISTANCE CATHODE
B. POROUS ANODE STRUCTURE
   LIGHT WEIGHT
   REGULATES / LIMITS AVAILABLE SODIUM FOR SAFETY
C. FABRICATION OF LIGHT-WEIGHT MOLYBDENUM COMPONENTS
D. DEFINE OPTIMUM ELECTROLYTE PARAMETERS
   BALANCE OF PHYSICAL / ELECTRICAL PROPERTIES
   TAILOR TO CELL REQUIREMENTS AND GEOMETRY
   PROCESS DEFINITION / FORMULATION
   INSPECTION CRITERIA
2. CELL TESTING - BUILD STATISTICAL BODY OF DATA

   A. MONITOR TEMPERATURE AND ELECTRICAL DATA
   B. VARYING LENGTHS OF ORBITS
   C. OPTIMUM RECHARGE PARAMETERS VS. DOD
   D. ESTABLISH PERFORMANCE TRENDS DURING LIFE CYCLE
   E. DETERMINE VARIABILITY / CONSISTENCY WITHIN CELL POPULATION

3. INCORPORATION INTO BATTERY CONFIGURATION

   A. AIDED BY HISTORY OF NUMEROUS SECONDARY BATTERY CHEMISTRIES
   B. USE CELL-LEVEL RESULTS TO ACHIEVE BATTERY REQUIREMENTS
   C. FIX MEANS OF MONITORING AND ELECTRICAL CONTROLS
   D. PACKAGE FOR EFFICIENCY, RUGGEDNESS, AND SAFETY
EAGLE PICHÉR

ELECTRONICS DIVISION
JOPLIN, MO

THERMAL-ORDNANCE OPERATION

Na-S BATTERIES

CELL TEST LABORATORY
THE NEXT GENERATION SPACE BATTERIES

EAGLE-PICHER INVOLVEMENT IN SODIUM SULFUR SPACE BATTERIES BEGAN IN 1986.

U.S. AIR FORCE SELECTED EAGLE-PICHER AS THE SOLE DEVELOPER FOR SODIUM SULFUR LEO CELLS.

EAGLE-PICHER'S EXPERIENCE IN NICKEL HYDROGEN SPACE BATTERIES PROVIDES A VALUABLE BASE FOR TRANSITIONING TO SODIUM SULFUR SPACE BATTERIES.
BATTERY STATUS

ENTRY LEVEL BATTERY EFFORTS FUNDED INTERNALLY

UNIT APPROACHING 1000 CYCLES
CONSTANT CURRENT CHARGE / DISCHARGE
NOMINAL 60% DOD (= 30 A.H.)

CYCLE CONTROLLED BY FIRST CELL TO ACHIEVE PRE-SET VALUES
(OTHERWISE BY CYCLE DEFINITION ONLY)

CALENDAR LIFE NOW FIVE MONTHS
Battery Test Set-up
IRD BATTERY (CYCLE 32)

SPLIT CHARGE RATE

F1 (IRD 7) = 15.48
F1 (IRD 9) = 16.05
F1 (IRD 9) = 15.39

DISCHARGE RATE

31.5 AMPS

1991 NASA Aerospace Battery Workshop

Advanced Technologies Session
IRD BATTERY (CYCLE 918)

SPLIT CHARGE RATE
35/25/20/15/10/8 AMPS

DISCHARGE RATE
37.5 AMPS

FI(IRD 7) = 24.59
FI(IRD 8) = 26.59
FI(IRD 9) = 26.46

DISCHARGE CAPACITY
BATTERY DESCRIPTION

1. NUMBER OF CELLS DEPENDENT UPON USER SPECIFICATION
   (ENERGY, POWER, CAPACITY, VOLUME CONSTRAINT, CYCLE LIFE)

2. CELLS ORIENTED VERTICALLY
   INTERCONNECTS DEPEND UPON REQUIREMENT

3. EFFICIENT THERMAL ENCLOSURE TAILORED TO APPLICATION
   "MONOLITHIC WALL"
   MULTILAYER - EVACUATED WALL
   PROVISIONS FOR ELECTRICAL HEATING
   ACTIVE OR PASSIVE COOLING

4. MONITOR / CONTROLS
   CELL / BATTERY VOLTAGE
   TEMPERATURE (SAMPLED OR INDIVIDUAL)
   ASSURANCE AGAINST EXCESSIVE CHARGE / DISCHARGE
   PROTECTS MAY BE ELECTRICAL (SWITCHING)
   OR PHYSICAL (FUSIBLE)