EPI Sodium Sulfur Program

- NaS program initiated in 1986.
- EPI selected by USAF as sole developer for NaS LEO cells.
- Over 200 cells constructed for a variety of applications.
- Developed a $\beta''$ electrolyte production capability.
<table>
<thead>
<tr>
<th>Cell Sizes Manufactured</th>
<th>50 AH</th>
<th>40 AH</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.4&quot; D x 12.3&quot; L</td>
<td>600 gms (1.31 lbs)</td>
<td>500 gms (1.10 lbs)</td>
</tr>
</tbody>
</table>
SODIUM-SULFUR GROUP

AREAS OF IMPROVEMENT

- Resistance
- Cathode Performance
- Parts Count
- Weight
- Seals
<table>
<thead>
<tr>
<th>Performance Improvement Demonstrated (16 Amp Discharge)</th>
<th>Baseline</th>
<th>Intermediate</th>
<th>Improved</th>
<th>State-of-the-Art</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight (grams)</td>
<td>509</td>
<td>506</td>
<td>500</td>
<td>455</td>
</tr>
<tr>
<td>Avg. Volts (Discharge)</td>
<td>1.64</td>
<td>1.74</td>
<td>1.89</td>
<td>1.95</td>
</tr>
<tr>
<td>Spec. Energy (Whr/Kg)</td>
<td>119.1</td>
<td>127.3</td>
<td>139.8</td>
<td>158.5</td>
</tr>
<tr>
<td>Energy Dens. (Whr/L)</td>
<td>266.9</td>
<td>283.6</td>
<td>307.8</td>
<td>334.0</td>
</tr>
<tr>
<td>Resistance (mOhms)</td>
<td>17.6</td>
<td>10.6</td>
<td>6.7</td>
<td>5.8</td>
</tr>
</tbody>
</table>
50 AHR Cell — "Improved" Design

- 8,400 Cycles (>95% LEO, 60% DOD)
- On test 33 months
- Discharge resistance 8.3 milliohms (7.3 milliohms BOL)
- F1% 16.1 (14.0 BOL)
- Capacity 53.3 Ahr (52.1 BOL)
IMPROVED CELL PERFORMANCE (CAP 95% DOD)

- CYCLE 8338 F1(%) = 16.12
- CYCLE 1119 F1(%) = 13.26

DISCHARGE (25 A/2 A/25 A)
OPEN
CONSTANT CURRENT CHARGE (15 A/5 A)
CIRCUIT

VOLTS
AMPS

MINUTES

0 30 60 90 120 150 180 210 240 270 300 330 360 390 420 450

0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46 48 50 52 54 56 58 60

-605-
**SODIUM-SULFUR GROUP**

**SINGLE CELL TEST MILESTONES**

- Over 11,000 cycles to date
- 43 month calendar life
- 3,130 AHR/cm² in cell testing
- 5,900 AHR/cm² in sodium-sodium testing
- Discharge resistance < 5 milliohms
- F1 of less than 5 (low rate charge)
ENVIRONMENTAL TESTING ACCOMPLISHED

- Shock ........................................ 30g's, 11ms
- Acceleration .............................. 15g's, 5 min.
- Random Vibration .............. 0.25g²/Hz, 300-1200Hz
  (0A=19.5g RMS)
- Sine Vibration ....................... 7.5g peak, 5-2000Hz
- Humidity ................................. MIL-STD-810B, Method 507
- Freeze/Thaw ............................. 20 Cycles
STATE-OF-THE-ART CELL

TYPICAL CELL PERFORMANCE (LEO 60% DOD)

VOLTS

AMPS

MINUTES

F1(x2) = 13.16

CONSTANT CURRENT CHARGE (20A)

OPEN CIRCUIT

DISCHARGE (40 H)

1992 NASA Aerospace Battery Workshop

Advanced Technologies Session
STATE-OF-THE-ART CELL

TYPICAL CELL PERFORMANCE (LEO 60% DOD)

- Discharge (40 A)
- Open Circuit
- Constant Potential Charge (25 A Limit)

Volts

Amperes

Minutes
ENTRY LEVEL BATTERY

- Effort funded internally 1990-1991
- Three cell module
- 1,000 cycles achieved
  Constant current charge/discharge
  Nominal 60% DOD (=30Ah)
- 30 Whr/Kg
- Calendar life: 6 months
Advanced Systems Operation

Sodium-Sulfur Group

1992 NASA Aerospace Battery Workshop

Eagle Picher Electronics Division
Joplin, MO

Advanced Technologies Session
Next Generation Battery Performance Projections

- 35 Amp-Hour cells
- 20 cell series string
- Battery OCV: 42 Volts
- Battery working volts: 38 Volts
- Weight: 13.5 Kg
- Volume: 30 L
- Energy Density: 100 Whr/Kg, 45 Whr/L
STATE-OF-THE-ART CELL

TYPICAL THREE CELL GROUP

DISCHARGE (20 A)          OPEN CIRCUIT          CONSTANT CURRENT CHARGE (20 A)

VOLTS

AMPS
STATE-OF-THE-ART CELL

TYPICAL THREE CELL GROUP

VOLTS

AMPS

DISCHARGE (20 A)  OPEN CIRCUIT  CONSTANT CURRENT CHARGE (20 A)

MINUTES
SUMMARY

Sodium Sulfur cell and battery designs continue to evolve with significant improvement demonstrated in:

• Resistance
• Rechargeability
• Cycle Life
• Energy Density
• Electrolyte Characterization