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 β" electrolyte production capability.
SODIUM-SULFUR GROUP

Advanced Systems Operation

Eagle Picher
Electronics Division
Joplin, MO

1992 NASA Aerospace Battery Workshop
-658-
Advanced Technologies Session
**SODIUM-SULFUR GROUP**

**CELL SIZES MANUFACTURED**

<table>
<thead>
<tr>
<th>Size</th>
<th>Description</th>
<th>Weight (gms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.4&quot; D X 12.3&quot; L</td>
<td>600 gms</td>
<td>1.31 lbs</td>
</tr>
<tr>
<td>1.4&quot; D X 9.0&quot; L</td>
<td>500 gms</td>
<td>1.10 lbs</td>
</tr>
</tbody>
</table>

50 AH

40 AH
SODIUM-SULFUR GROUP

AREAS OF IMPROVEMENT

- Resistance
- Cathode Performance
- Parts Count
- Weight
- Seals
<table>
<thead>
<tr>
<th></th>
<th>Baseline</th>
<th>Intermediate</th>
<th>Improved</th>
<th>State-of-the-Art</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spec. Energy (Whr/Kg)</td>
<td>266.9</td>
<td>127.3</td>
<td>139.8</td>
<td>158.5</td>
</tr>
<tr>
<td>Energy Dens. (Whr/L)</td>
<td>119.1</td>
<td>10.6</td>
<td>6.7</td>
<td>5.8</td>
</tr>
<tr>
<td>Resistance (mOhms)</td>
<td>17.6</td>
<td>1.74</td>
<td>1.89</td>
<td>1.95</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>Weight (grams)</td>
<td>509</td>
<td>506</td>
<td>500</td>
<td>455</td>
</tr>
</tbody>
</table>
SODIUM-SULFUR GROUP

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

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

VOLTS

AMPS

MINUTES
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

DISCHARGE (40 A) OPEN CIRCUIT CONSTANT CURRENT CHARGE (20 A)

F1(%) = 13.16
STATE-OF-THE-ART CELL

TYPICAL CELL PERFORMANCE (LEO 60% DOD)

- VOLTS
- AMPS
- MINUTES

DISCHARGE (40 A)  OPEN CIRCUIT  CONSTANT POTENTIAL CHARGE (25 A LIMIT)

F1(%) = 12.17
ENTRY LEVEL BATTERY

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

SODIUM-SULFUR GROUP

1992 NASA Aerospace Battery Workshop
Joplin, MO
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

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