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>1.4&quot; D x 12.3&quot; L</th>
<th>1.4&quot; D x 9.0&quot; L</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 AH</td>
<td>600 gms (1.31 lbs)</td>
<td>500 gms (1.10 lbs)</td>
</tr>
<tr>
<td>40 AH</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
AREAS OF IMPROVEMENT

- Resistance
- Cathode Performance
- Parts Count
- Weight
- Seals
<table>
<thead>
<tr>
<th></th>
<th>Weight (grams)</th>
<th>Avg. Volts (Discharge)</th>
<th>Resistance (mOhms)</th>
<th>Spec. Energy (Whr/Kg)</th>
<th>Energy Dens. (Whr/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>509</td>
<td>1.64</td>
<td>17.6</td>
<td>119.1</td>
<td>266.9</td>
</tr>
<tr>
<td>Intermediate</td>
<td>506</td>
<td>1.74</td>
<td>10.6</td>
<td>127.3</td>
<td>283.6</td>
</tr>
<tr>
<td>Improved</td>
<td>500</td>
<td>1.89</td>
<td>6.7</td>
<td>139.8</td>
<td>307.8</td>
</tr>
<tr>
<td>State-of-the-Art</td>
<td>455</td>
<td>1.95</td>
<td>5.8</td>
<td>158.5</td>
<td>334.0</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 (LEO 60% DOD)

- VOLTS
  - Cycle 8148
  - Discharge (54 A)
  - Open Circuit
  - Charge (45/30/25/22.5/20/17.5/15 A)

- AMPS

- MINUTES

F1(%) = 19.01
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

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

MINUTES

0 2 4 6

VOLTS

0 10 20 30 40 50 60

AMPS

0 2 4 6

AMPS
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 (CAP 90% DOD)

VOLTS

AMPS

DISCHARGE (20 A) OPEN CIRCUIT CONSTANT CURRENT CHARGE (10 A/4 A)

MINUTES

F1(%) = 11.62
STATE-OF-THE-ART CELL

TYPICAL CELL PERFORMANCE (LEO 60% DOD)

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

MINUTES
STATE-OF-THE-ART CELL

TYPICAL CELL PERFORMANCE (LEO 60% DOD)

- VOLTS
  - 3
  - 2.8
  - 2.6
  - 2.4
  - 2.2
  - 2.0
  - 1.8
  - 1.6
  - 1.4
  - 1.2
  - 1.0
  - 0.8
  - 0.6
  - 0.4
  - 0.2
  - 0

- AMPS
  - 1
  - 0.8
  - 0.6
  - 0.4
  - 0.2
  - 0

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

- MINUTES
  - 0
  - 10
  - 20
  - 30
  - 40
  - 50
  - 60
  - 70
  - 80
  - 90
  - 100
  - 110
  - 120
  - 130
  - 140
  - 150

- 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

Eagle Picher Electronics Division

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
**SUMMARY**

Sodium Sulfur cell and battery designs continue to evolve with significant improvement demonstrated in:
- Resistance
- Rechargeability
- Cycle Life
- Energy Density
- Electrolyte Characterization