LEWIS RESEARCH CENTER BATTERY OVERVIEW

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HUNTSVILLE, ALABAMA

NOVEMBER 17-19, 1992
ADVANCED COMMUNICATIONS TECHNOLOGY SATELLITE

PROJECT: ACTS

LAUNCH DATE: 6/93

POWER SYSTEM: GE-ASTRO SPACE

RESOLUTION: GEO ORBIT MISSION OF APPROXIMATELY 4 YEARS USING 2 GATES 19 Ah Ni-Cd AT 50% DOD WITH RECONDITIONING AND INDIVIDUAL CELL VOLTAGE MONITORING AVAILABLE

# CYCLES REQUIRED: 400
SPACE STATION FREEDOM
Photovoltaic Power Module Division
Lewis Research Center
National Aeronautics and Space Administration

Ni/H₂ BATTERY and CELL DESIGN
ENERGY STORAGE SUBSYSTEM
Ni/H₂ BATTERY ORU

STATION
- 38 Cells per ORU
- Two ORUs per battery
- Nominal 95V
- Six Batteries per PV Module
- 24 Batteries total at Assembly Complete

REQUIREMENT
- ORU Interface Envelope 36"x40"x18.5"
- Battery ORU Assembly Mass 351 lb
- Nominal/Minimum Battery Cell Capacity 81/77 Ah
- Mean Time between Replacement 5.0 yr
- Design Life 6.5 yr
- Design Cycle Life 36,000 cycles
- Storage Life 4 yr
- Nominal Depth of Discharge 35%

- Battery ORU provides station power during solar eclipse periods
SPACE STATION FREEDOM GOALS AND PROGRAMS

- In March of 1986, Nickel–Hydrogen (Ni/H2) cells were chosen as the energy storage system for Space Station Freedom

- Goals
  - Obtain Experience in handling and testing Ni/H2 cells
  - Learn the effects on performance due to design differences
  - Prove 5-year life capability in a 90-minute Low-Earth-Orbit
  - Improve process control and optimize cell manufacturing parameters at cell vendor level

- Programs to Accomplish Goals
  - Non–Prime
    - LeRC in–house Ni/H2 Test Facility in Bldg 309
    - Ni/H2 cell testing at the Naval Weapons Support Center (NWSC) at Crane, IN
  - Prime
    - Cell development program with vendors
    - Engineering model life test at NASA LeRC/PSF
    - Two battery/BCDU integrated life tests at PSF
IPV NICKEL HYDROGEN CELL TESTING
SPACE STATION FREEDOM SUPPORT

- LEO life tests
- 39 Flightweight cells on test
- 50 Ah and 65 Ah capacity
- 3 Commercial vendors
- 10 °C and -5 °C temperatures
- 35% Depth-of-discharge
- 26% and 31% KOH comparison
- Cell design variations

Space Station Freedom Ni-H₂ Cells
ELECTROCHEMICAL TECHNOLOGY BRANCH

ROLES

RESEARCH & TECHNOLOGY DEVELOPMENT
DEVELOPING ELECTROCHEMICAL GENERATION AND STORAGE TECHNOLOGY TO A LEVEL OF READINESS SUFFICIENT TO ENABLE OR ENHANCE FUTURE MISSIONS

PROGRAM MANAGEMENT
DEVELOPING AND MANAGING THE FOCUSED R&T AND MISSION ORIENTED PROGRAMS WHICH WILL BRING THE ELECTROCHEMICAL TECHNOLOGY ADVANCEMENTS TO FRUITION
LeRC ELECTROCHEMICAL TECHNOLOGY BRANCH

RESEARCH & TECHNOLOGY DEVELOPMENT

I BATTERIES
- IPV Ni-H₂
- Bipolar Ni-H₂
- Nickel Electrode, Separators
- Modelling and Analysis

II FUEL CELL SYSTEMS
- Advanced Catalysts & Support (AFC)
- Bifunctional Catalyst (AFC & PEM FC)
- Modelling
- System Analysis
- Cell/Stack F.C. & Electrolyzer Expts.

III ADVANCED CONCEPTS
- Lithium/CO₂ Electrochemical System

PROGRAM MANAGEMENT

- NASA Aerospace Flight Battery Systems Program
- Space Exploration (Lunar/Mars) Regen. Fuel Cell Program
- Submarine Fuel Cell Aux. Power System Program
- Unmanned Undersea Vehicle Electrochemical Power Program

MISSION SUPPORTING

- Space Station Ni-H₂ Battery Program
- HST, EOS, & Advanced TDRSS Batteries
- DOE/GM Fuel Cell Auto Engine Project
MASS COST ADVANTAGE

DISTANCE FROM EARTH (1000'S N.M.)

LAUNCH COST SAVINGS PER KILOWATT

BATTERY SPECIFIC ENERGY kg/kW

Ni/Cd

Ni/He

Na/S
IMPROVED DESIGN IPV NICKEL HYDROGEN CELLS
MAJOR PROGRAM OBJECTIVES/GOALS

- DEVELOP TECHNOLOGY BASIS FOR ADVANCED POWER SYSTEMS FOR LEO, GEO, AND ADVANCED PLANETARY MISSIONS FOR TRANSITION TO FOCUSED PROGRAMS

- GEO NICKEL HYDROGEN (NiH2) BATTERIES WITH INCREASED SPECIFIC ENERGY (2X SOA) AND RELIABILITY

- ESTABLISH HIGH SPECIFIC ENERGY SODIUM SULFUR (NaS) BATTERY AS A Viable FLIGHT SYSTEM

- ESTABLISH REGENERATIVE FUEL CELL (RFC) TEST BED

- ADVANCED FUEL CELL AND ELECTROLYZER COMPONENT DEVELOPMENT

- DEMONSTRATE FEASIBILITY OF NOVEL ELECTROCHEMICAL SYSTEMS SUCH AS THE LITHIUM CARBON DIOXIDE SYSTEM
ADVANCED TECHNOLOGY FOR IPV NICKEL-HYDROGEN FLIGHT CELLS

GOAL

IMPROVE CYCLE LIFE AND PERFORMANCE OF NICKEL-HYDROGEN BATTERY

OBJECTIVES

- VALIDATE SUPERIOR LEO CYCLE LIFE OF CELLS USING 26% KOH
- VALIDATE NASA LEWIS 125 Ah ADVANCED DESIGN IPV NICKEL-HYDROGEN CELL
NASA ADVANCED DESIGN IPV NICKEL-HYDROGEN

CELL FEATURES

- USE OF 26% KOH - IMPROVES CYCLE LIFE 10 X SOA
- SERRATED EDGE SEPARATOR - FACILITATES GAS MOVEMENT
- FLOATING STACK - ACCOMMODATES NICKEL ELECTRODE EXPANSION
- CATALYZED WALL WICK IMPROVES THERMAL AND OXYGEN MANAGEMENT
- ELECTROLYTE VOLUME TOLERANCE - MAINTAINS PROPER STACK ELECTROLYTE
- BACK-TO-RACK ELECTRODES - DIRECT OXYGEN TO CATALYZED WALL WICK
- COMPATIBLE WITH SOA AIR FORCE/HUGHES DESIGN - MINIMIZES DEVELOPMENT COST AND TIME

1. BELLEVILLE SPRING
2. NICKEL ELECTRODE
3. SEPARATOR
4. HYDROGEN ELECTRODE
5. GAS SCREEN
6. WALL WICK
7. OXYGEN SEAL
8. END PLATE
9. CATALYZED STRIP
10. ZIRCONIUM OXIDE STRIP
BREAKTHROUGH IN NiH₂ LEO CYCLE LIFE - EMERGING FROM KOH ELECTROLYTE CONCENTRATION EXPERIMENTS

SCREEN COMPLETED → VALIDATION IN PROGRESS → IMPROVED NiH₂ BATTERY

- Will enhance NASA missions (e.g., SSF, HST, EOS, etc.)

**31% KOH**

**26% KOH**

- Flight cells
- Real cycle times

KOH Concentration, %

- Boiler plate cells
- Accelerated cycles

Cycle life in thousands

Cell voltage end of discharge
LIGHTWEIGHT NICKEL-HYDROGEN CELL

- APPROACH:
  - ELECTRODE FABRICATION AND CHARACTERIZATION
  - HALF-CELL ELECTRODE TESTING
  - BOILERPLATE CELL TESTING
  - FLIGHTWEIGHT CELL TESTING
  - TECHNOLOGY TRANSFER

- FACILITIES:
  - ELECTRODE PREPARATION, SCREENING, AND CHARACTERIZATION LABORATORY
  - 12 TEST STANDS WITH AUTOMATED DATA ACQUISITION
LIGHTWEIGHT NICKEL-HYDROGEN CELL

• OBJECTIVE:
  - DEVELOP AND DEMONSTRATE A NICKEL ELECTRODE FOR A NICKEL-HYDROGEN CELL WITH IMPROVED SPECIFIC ENERGY AND LIFE

• GOAL:
  - 100 W-hr/kg (2X SOA), 10 YEAR LIFE IN GEO

• SCOPE:
  - LIGHTWEIGHT, LONG-LIVED GEO
    • DEVELOPMENTAL DESIGN EFFORTS
  - MOVE INTO FOCUSED PROGRAM IN '94
    • PLATFORM POWER AND THERMAL MANAGEMENT
BIPOLAR NICKEL-HYDROGEN BATTERY DEVELOPMENT

OBJECTIVE: DESIGN, BUILD, AND TEST BIPOLAR NICKEL-HYDROGEN BATTERY SYSTEM WITH HIGH SPECIFIC ENERGY AND ENERGY DENSITY. BATTERY DESIGN ADDRESSES OXYGEN, ELECTROLYTE, AND THERMAL MANAGEMENT CONCERNS.

APPROACH: PARALLEL IN-HOUSE AND CONTRACT EFFORTS
COMPONENT DEVELOPMENT AND OPTIMIZATION
INVESTIGATE ACTIVE COOLING AND PASSIVE COOLING APPROACHES
DEVELOP HIGH VOLTAGE DESIGN
DESIGN FLIGHT WEIGHT BATTERY
 DEMONSTRATE PERFORMANCE OF FLIGHT BATTERY

STATUS: TESTING AND ANALYSIS OF PRELIMINARY VERSIONS OF BATTERIES ARE COMPLETE
BATTERIES REDESIGNED BASED ON DESTRUCTIVE PHYSICAL ANALYSIS RESULTS
IMPROVED BATTERIES BUILT AND ON TEST

RESULTS: IN-HOUSE 40 Ah, 10 CELL, BATTERY HAS ACCUMULATED >10,000 40% DOD LEO CYCLES
SPACE SYSTEMS/LORAL 75 Ah, 10 CELL, BATTERY HAS ACCUMULATED >10,500 , 40% DOD LEO CYCLES
BIPOLAR NICKEL HYDROGEN BATTERY TECHNOLOGY OFFERS ADVANCES OVER IPV SYSTEM

- Managed at the system level
- Higher energy density
- Reduced internal resistance yields higher efficiency
- High voltage and high current give higher DC and pulse power capability
- Improved specific volume

Ford Aerospace 75 Ah Bipolar Ni-H₂ battery
BIPOLAR NICKEL HYDROGEN BATTERY TECHNOLOGY
LeRC BIPOLAR Ni-H₂ BATTERY

40 Ampere hour, 12 volts, active cooling
AEROSPACE NICKEL-METAL HYDRIDE CELLS

GOAL
• EVALUATE SOA NICKEL-METAL HYDRIDE CELL TECHNOLOGY

OBJECTIVE
• CONDUCT CHARACTERIZATION AND CYCLE LIFE TEST ON SOA AEROSPACE NICKEL-METAL HYDRIDE CELLS

APPROACH
• PURCHASE PRISMATIC AEROSPACE CELLS
  • EAGLE-PICHER
  • GATES AEROSPACE BATTERIES
• TEST AT NWSC-CRANE, INDIANA
  • CHARACTERIZATION AND CYCLE LIFE TEST
• CONDUCT DPA-AT CELL MANUFACTURER DUE TO PROPRIETARY RESTRICTION
• MAINTAIN COGNIZANCE OF METAL HYDRIDE TECHNOLOGY ADVANCES
NASA SODIUM-SULFUR CELL TECHNOLOGY FLIGHT EXPERIMENT

OBJECTIVE: INVESTIGATE THE CRITICAL ISSUES OF SODIUM-SULFUR CELL OPERATION IN THE MICROGRAVITY ENVIRONMENT AND VALIDATE DESIGN METHODOLOGIES FOR SPACECRAFT SYSTEM CONTROLS AND SAFETY

LEAD CENTER: NASA LeRC

PRIME CONTRACTOR: SPACE SYSTEMS/LORAL
ADVANTAGE OF Na-S SYSTEM FOR SPACE USE

HIGH ENERGY DENSITY

HIGH EFFICIENCY
   ROUND TRIP (82%)
   FARADAY (100%)

NO SELF DISCHARGE

MEDIUM TEMPERATURE (350°C)

PASSIVE OPERATING SYSTEM

LESS MASS AND VOLUME NEEDED

LESS WASTE HEAT AND LIGHTER
SOLAR CELL ARRAY

INFINITE STORAGE LIFE BOTH HOT & COLD

LIGHTER RADIATOR REQUIRED

HIGHER RELIABILITY
TECHNICAL APPROACH:
- Establish effects of μg on cell performance
- Develop a performance database
- Determine reactant spatial distributions
- Determine cell current and temperature distributions
- Document performance of subsystems to relate to battery operations

ACCOMPLISHMENTS/STATUS:
- Conceptual design review completed 6/92
  - No major technical or development issues identified
- Ready to proceed to phase C/D
  - Review for approval to proceed planned for 11/92
SODIUM SULFUR CELL TECHNOLOGY ROAD MAP

CELL TECHNOLOGY
- nondestructive tests
- vibration analysis

SYSTEM ANALYSIS
- studies
- missions

VERIFICATION
- state-of-art
- advanced

DESIGN
- preliminary
- advanced

NASA SPACE EXPERIMENT

COORDINATION
- WRDC
- DOE
LITHIUM-CARBON DIOXIDE BATTERY
Thermodynamic Model

Discharge

\[ 2\text{Li} = 2\text{Li}^+ + 2\text{e} \]
\[ 2\text{CO}_2 + 2\text{e} = \text{CO} + \text{CO}_3^{\cdot-} \]
\[ 2\text{Li} + 2\text{CO}_2 = \text{Li}_2\text{CO}_3 + \text{CO} \]

Charge

Chemically
- Replenish Li Supply
  - 6400 wh/kg

Electrochemically
- Regenerate Li Supply
- Central Station
  \[ 2\text{Li}^+ + 2\text{e} = 2\text{Li} \]
  \[ \text{CO}_3^{\cdot-} = \text{CO}_2 + 1/2\text{O}_2 + 2\text{e} \]
  \[ \text{Li}_2\text{CO}_3 = 2\text{Li} + \text{CO}_2 + 1/2\text{O}_2 \]
BENEFITS OF TECHNOLOGY DEVELOPMENT
- QUANTIFIABLE -

- MISSION COST SAVINGS
  - $100 - 400 M SAVINGS FOR SSF USING ADVANCED NiH₂ TECHNOLOGY

- INCREASED MISSION LIFE
  - 10 X LEO CYCLE LIFE USING ADVANCED NiH₂ TECHNOLOGY

- RFC STORAGE SYSTEM IS ENABLING TECHNOLOGY FOR EXPLORATION SOLAR SURFACE POWER SYSTEM
  - 20,000 hr LIFE RFC SYSTEM
  - 800 - 1000 Wh/kg FOR LUNAR MISSION

- IN-SITU UTILIZATION FOR MARS AND VENUS USING THE LITHIUM CARBON DIOXIDE SYSTEM
  - CO₂ CONVERSION
  - 850ºC OPERATION
NASA AEROSPACE FLIGHT BATTERY SYSTEMS PROGRAM

OBJECTIVE: PROVIDE NASA WITH THE POLICY AND POSTURE TO INCREASE AND INSURE THE SAFETY, PERFORMANCE AND RELIABILITY OF BATTERIES FOR SPACE POWER SYSTEMS
PROGRAM STRUCTURE

- BATTERY SYSTEMS TECHNOLOGY
- SECONDARY BATTERY TECHNOLOGY
- PRIMARY BATTERY TECHNOLOGY
NASA AEROSPACE FLIGHT BATTERY SYSTEMS PROGRAM

NASA HEADQUARTERS
S&MQ OFFICE
CODE QE
S. HABIB

BATTERY STEERING COMMITTEE

NASA LeRC
PROGRAM MANAGER
PATRICIA O'DONNELL
DEPUTY - MICHELLE MANZO

NASA KSC
- TRAINING
- BATTERY SYSTEMS GUIDELINES & TRAINING
- EVALUATION & RESOLUTION OF Ni-Cd PROBLEMS
- VERIFICATION OF QUALITY & RELIABILITY OF SECONDARY CELLS

NASA GSFC

NASA JSC
- PRIMARY BATTERIES GUIDELINES & QUALIFICATIONS
- BATTERY SAFETY & HANDLING
- Zn-O₂ DEVELOPMENT
- LI CELL DEVELOPMENT

JPL
- Ni-Cd MODEL
- CRANE DATA EVALUATION

NASA LeRC
- PROGRAM SUPPORT
- NI-H₂ TECHNOLOGY
- Ni-Cd TECHNOLOGY
- SEPARATOR DEV.
- IMPEDANCE
- DATA BASE

NASA MSFC
- BATTERY WORKSHOP
- DPA PROCEDURE/FACILITY

NASA LaRC
- ADVANCED NDE FOR Ni-H₂
APPROACH

• PROVIDE FOR IMPROVED CELL/BATTERY MANUFACTURING CONTROL PROCESSES

• ESTABLISH SPECIFICATIONS, DESIGN AND OPERATIONAL GUIDELINES FOR CELLS & BATTERIES

• COORDINATE BATTERY TECHNOLOGY ACTIVITIES BETWEEN CODE R PROGRAM AND CODE Q NEEDS

• OPEN COMMUNICATION LINES WITHIN NASA AND THE AEROSPACE COMMUNITY

• INCREASE THE FUNDAMENTAL UNDERSTANDING OF PRIMARY AND SECONDARY CELLS