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POWER TECHNOLOGY DIVISION
NASA Lewis Research Center

1992 NASA AEROSPACE BATTERY WORKSHOP

LEWIS RESEARCH CENTER BATTERY OVERVIEW

BY

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U.S. SPACE AND ROCKET CENTER
HUNTSVILLE, ALABAMA

NOVEMBER 17-19, 1992

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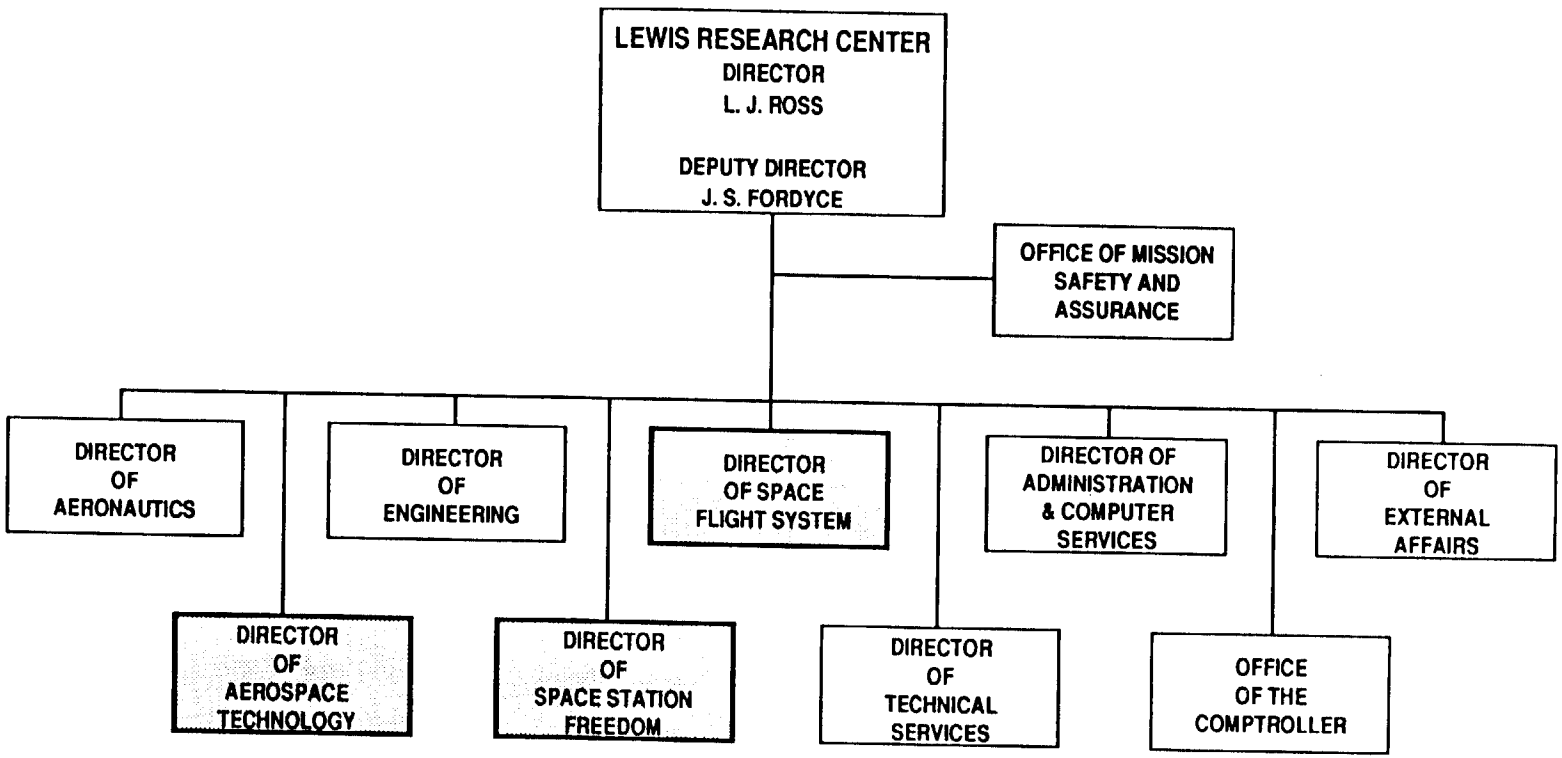

☐ BATTERY POWER SYSTEM PROGRAMS

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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

National Aeronautics and
Space Administration

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SPACE STATION FREEDOM

Photovoltaic Power Module Division

FREEDOM

Ni/H_2 BATTERY and CELL DESIGN

National Aeronautics and Space Administration

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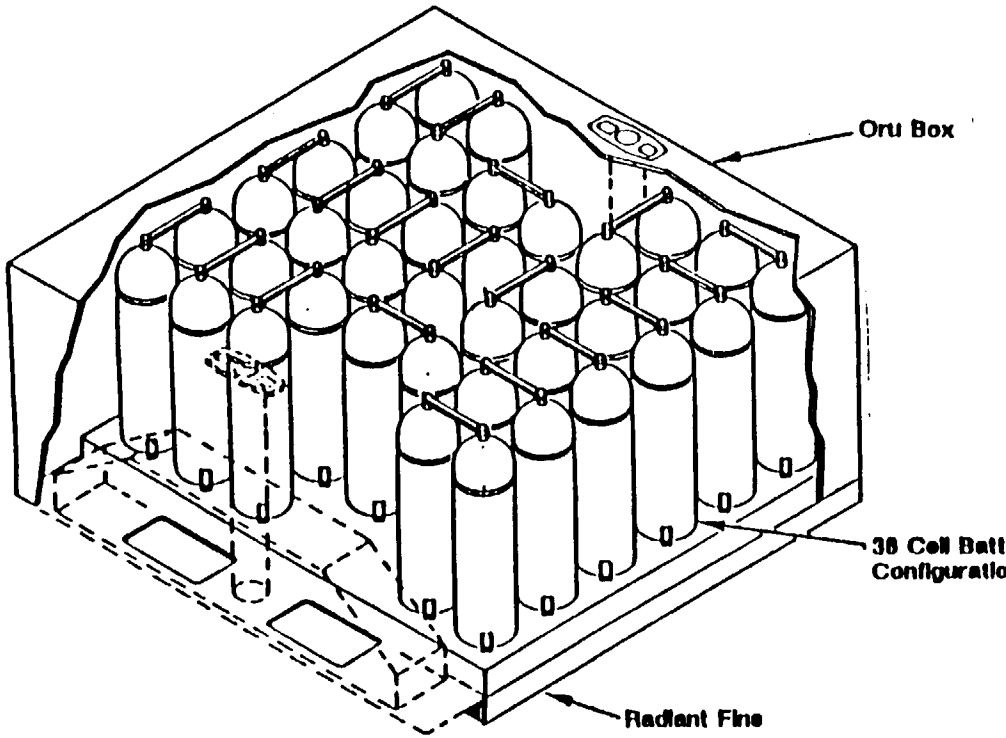
Photovoltaic Power Module Division

FREEDOM

ENERGY STORAGE SUBSYSTEM
Ni/H_2 BATTERY ORU



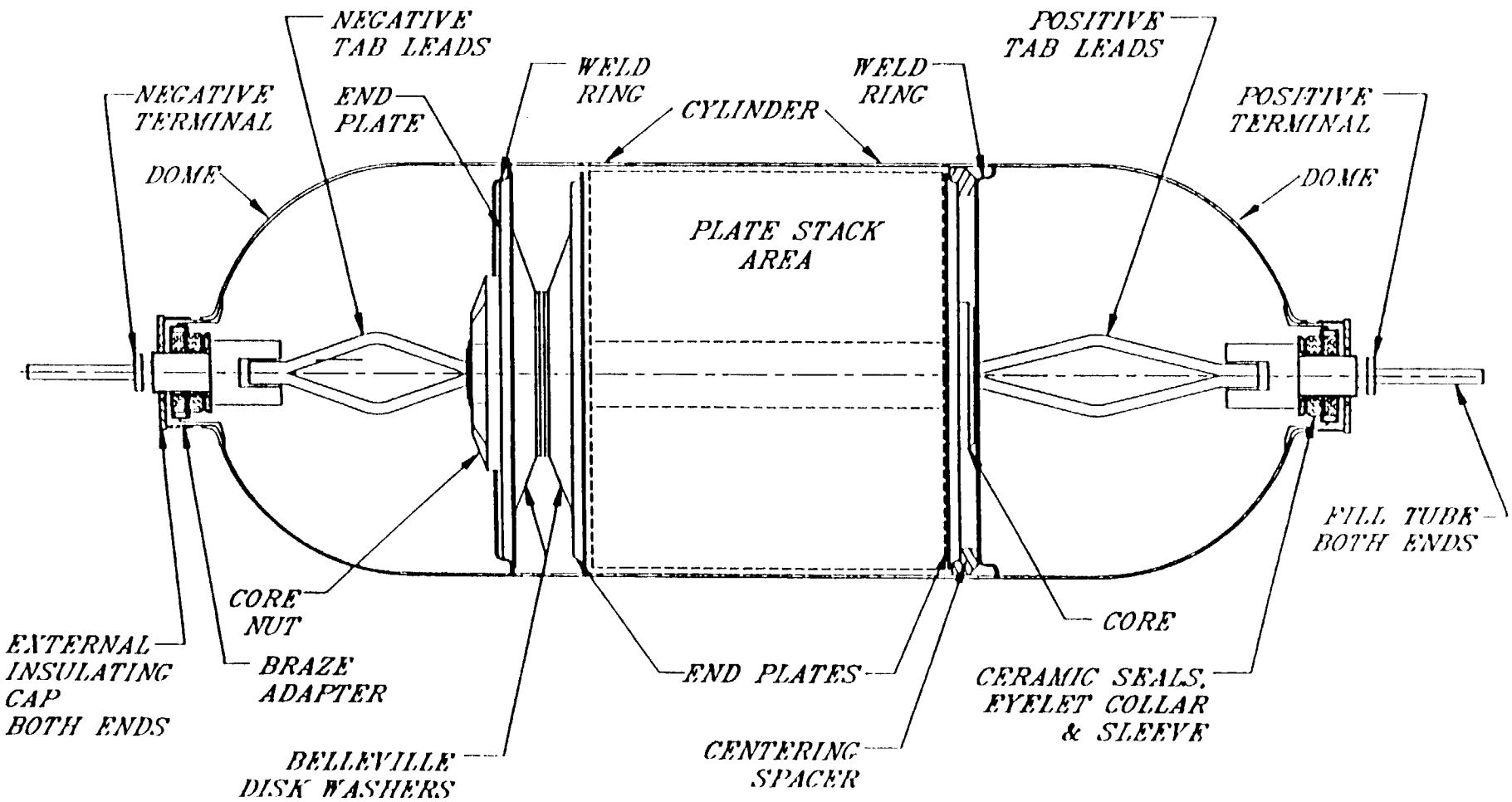
- Battery ORU provides station power during solar eclipse periods

STATION

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

REQUIREMENT

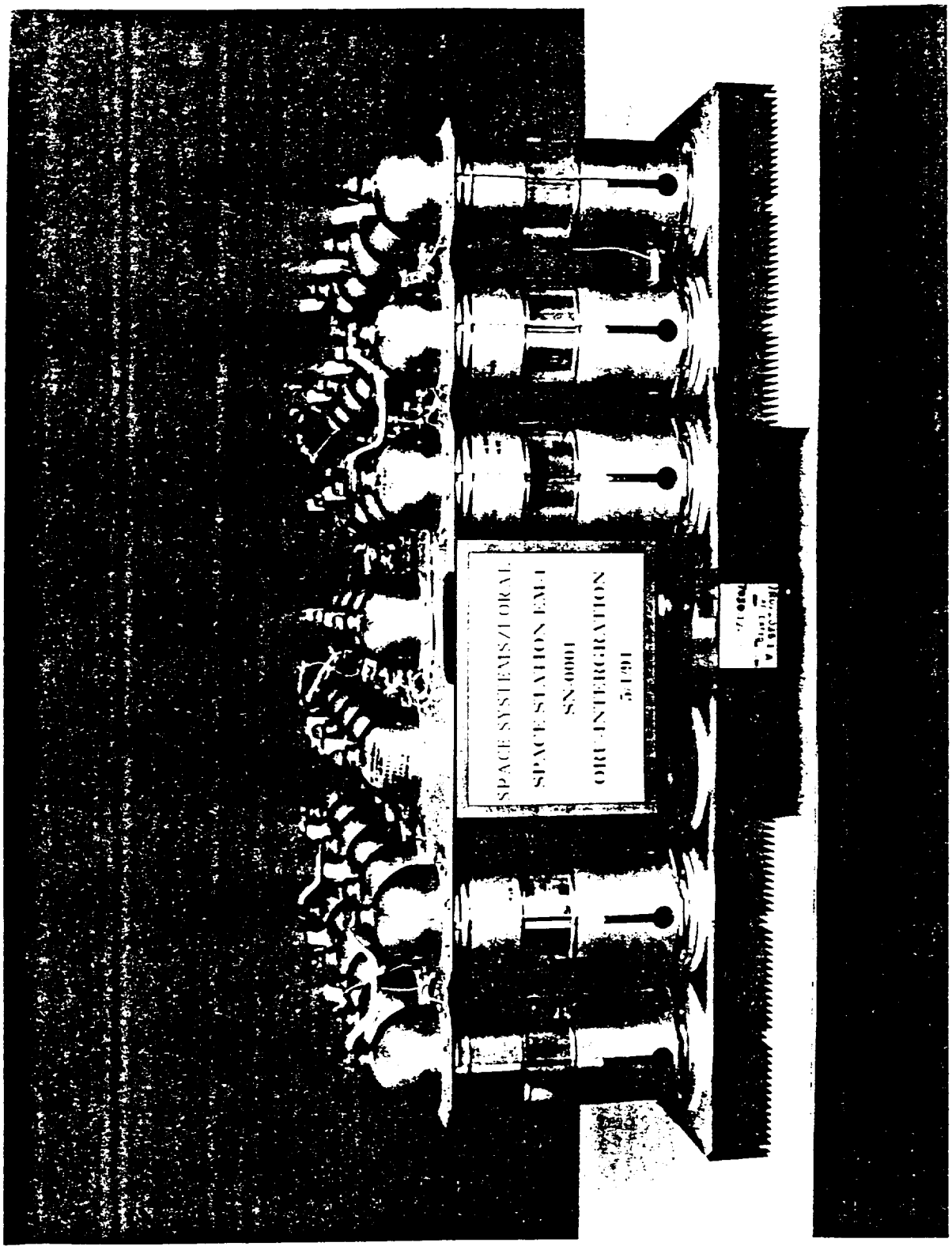
- ORU Interface Envelope 36"x40"x18.5"
- Battery ORU Assembly Mass 351 lb
- Nominal/Minimum Battery Cell Capacity 81/77 Ah
- Mean Time between Replacement 5.0 yr
- Design Life 6.5 yr
- Design Cycle Life 36,000 cycles
- Storage Life 4 yr
- Nominal Depth of Discharge 35%



GATES NICKEL HYDROGEN AEROSPACE CELL

SPACE STATION FREEDOM

US PATENTS 4,904,551, 4,950,564, & 5,002,842


SPACE SYSTEMS/LORAL
SPACE STATION EM-1
SN 0001
ORU INTEGRATION
5/1991

National Aeronautics and Space Administration

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SPACE STATION FREEDOM

PHOTOVOLTAIC POWER MODULE DIVISION

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**

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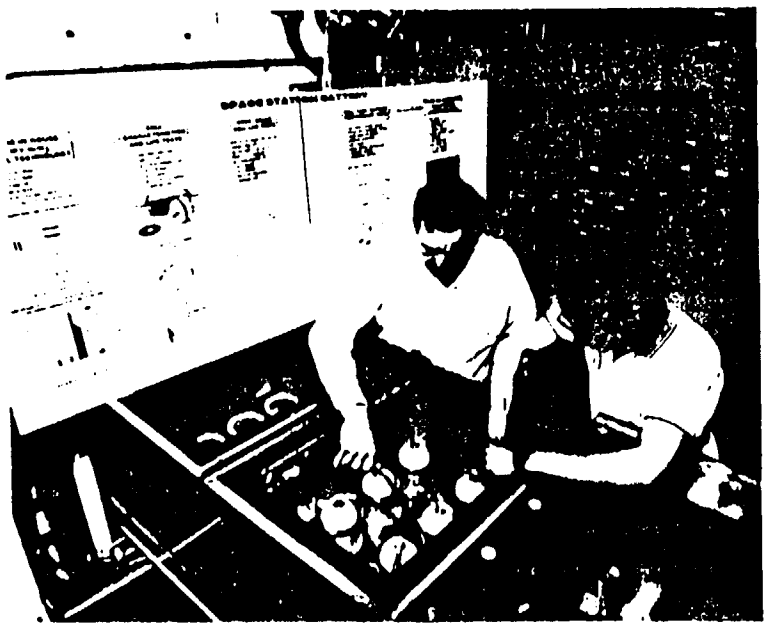
IPV NICKEL HYDROGEN CELL TESTING SPACE STATION FREEDOM SUPPORT



Space Station Freedom Ni-H_2 Cells

- 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

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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

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LeRC ELECTROCHEMICAL TECHNOLOGY BRANCH

RESEARCH & TECHNOLOGY DEVELOPMENT

I BATTERIES

- IPV Ni-H_2
- BIPOLAR Ni-H_2
- NICKEL ELECTRODE, SEPARATORS
- Na/S SPACE SYSTEM - FLIGHT EXPT.
- 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/CO_2 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-H_2 BATTERY PROGRAM
- HST, EOS, & ADVANCED TDRSS BATTERIES
- DOE/GM FUEL CELL AUTO ENGINE PROJECT

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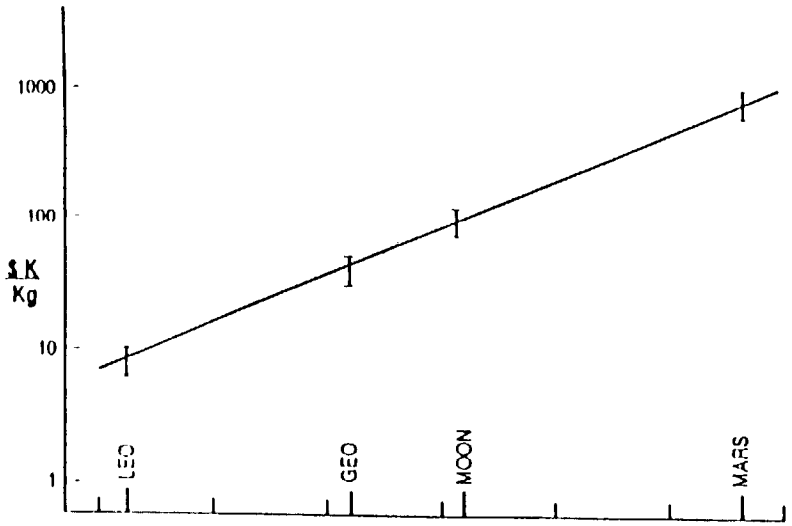
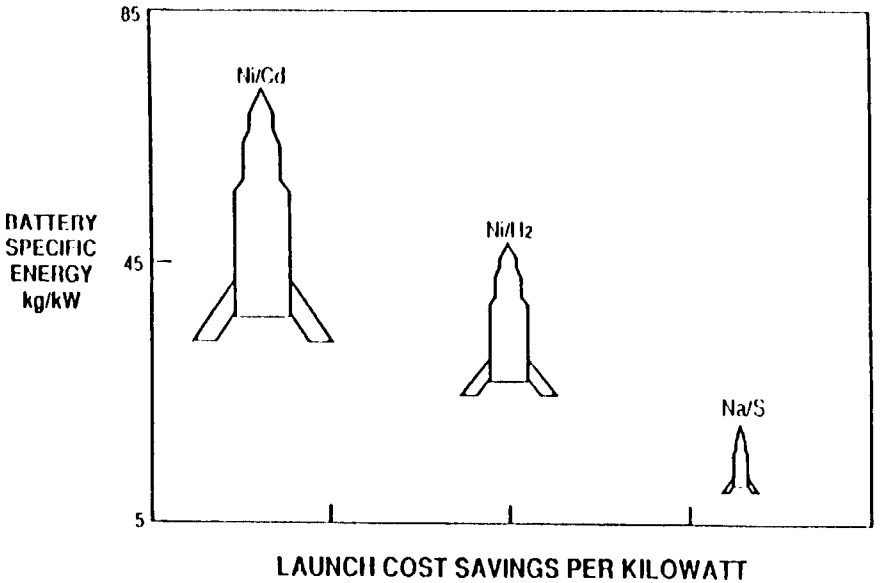
MASS COST ADVANTAGE





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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 (NiH_2) 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

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ADVANCED TECHNOLOGY FOR IPV NICKEL-HYDROGEN FLIGHT CELLS

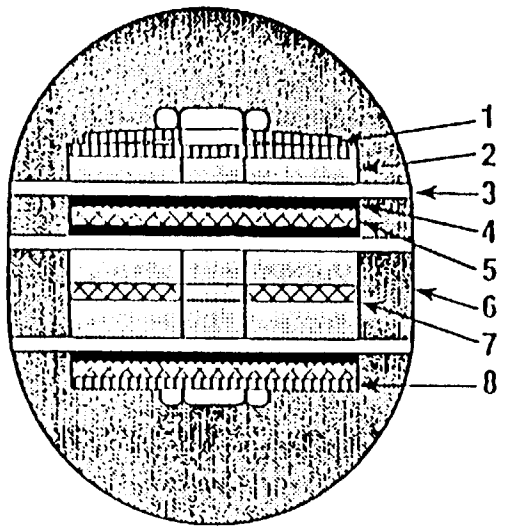
GOAL

IMPROVE CYCLE LIFE AND PERFORMANCE OF NICKEL-HYDROGEN BATTERY

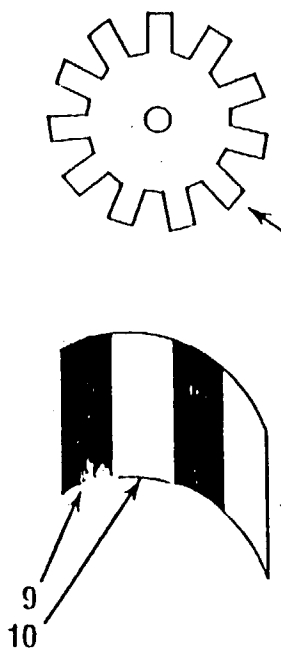
OBJECTIVES

- 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



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



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-BACK ELECTRODES - DIRECT OXYGEN TO CATALYZED WALL WICK
- COMPATIBLE WITH SOA AIR FORCE/HUGHES DESIGN - MINIMIZES DEVELOPMENT COST AND TIME

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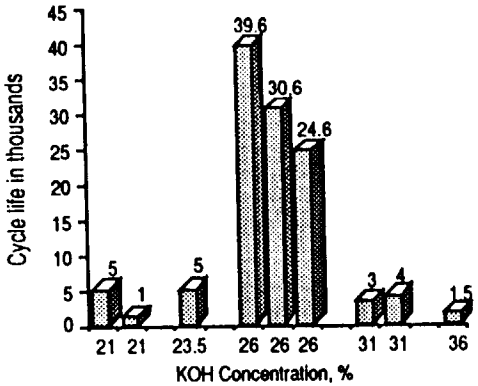
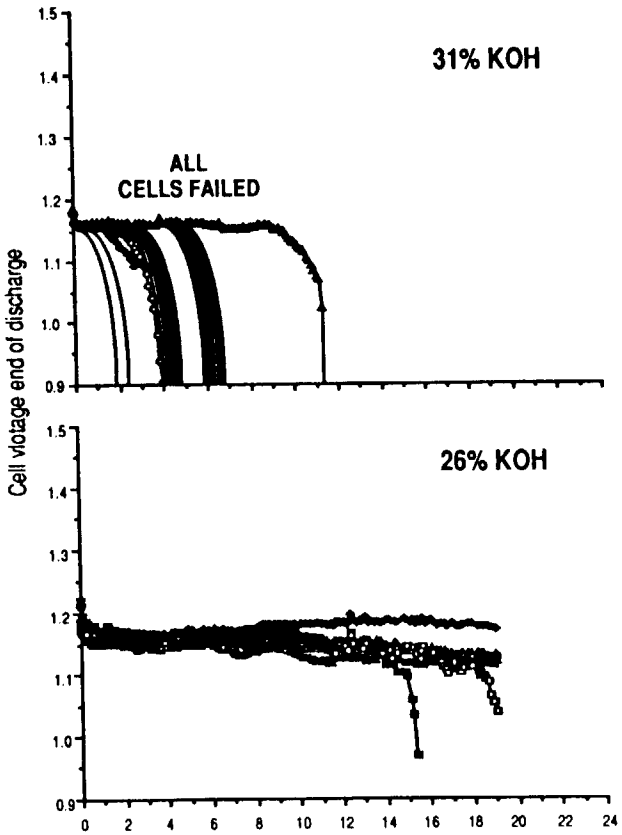
BREAKTHROUGH IN NiH_2 LEO CYCLE LIFE - EMERGING FROM KOH ELECTROLYTE CONCENTRATION EXPERIMENTS

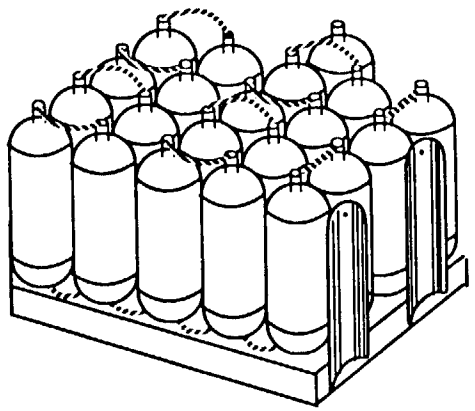
SCREEN COMPLETED ⟶ VALIDATION IN PROGRESS ⟶ IMPROVED NiH_2 BATTERY



- Boiler plate cells
- Accelerated cycles



- Flight cells
- Real cycle times



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

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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 FOCUSSED PROGRAM IN '94
    - PLATFORM POWER AND THERMAL MANAGEMENT

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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

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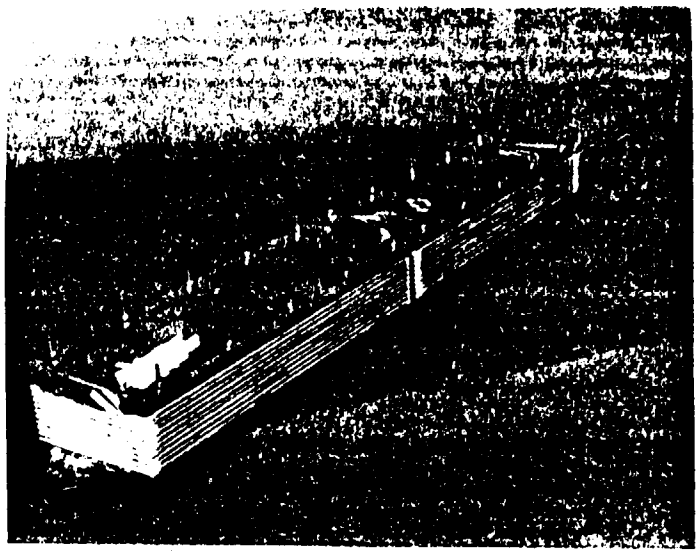
BIPOLAR NICKEL HYDROGEN BATTERY TECHNOLOGY OFFERS ADVANCES OVER IPV SYSTEM



Ford Aerospace 75 Ah Bipolar Ni-H_2 battery

- 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

NASA
C-90-10338

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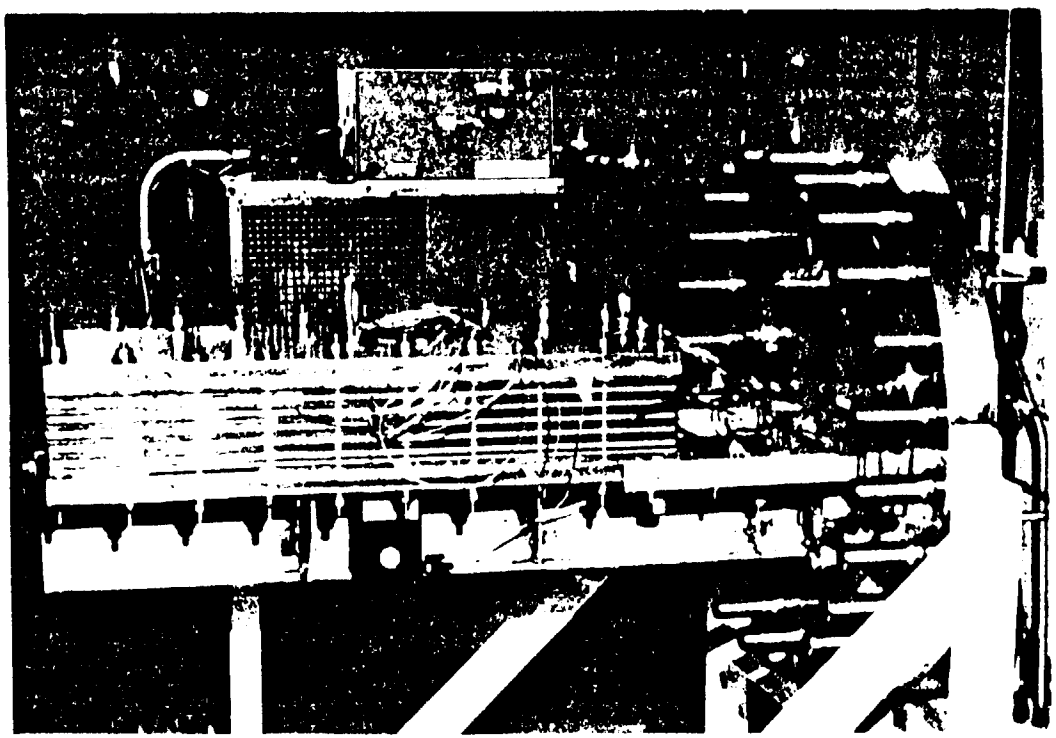
BIPOLAR NICKEL HYDROGEN BATTERY TECHNOLOGY

LeRC BIPOLAR Ni-H_2 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

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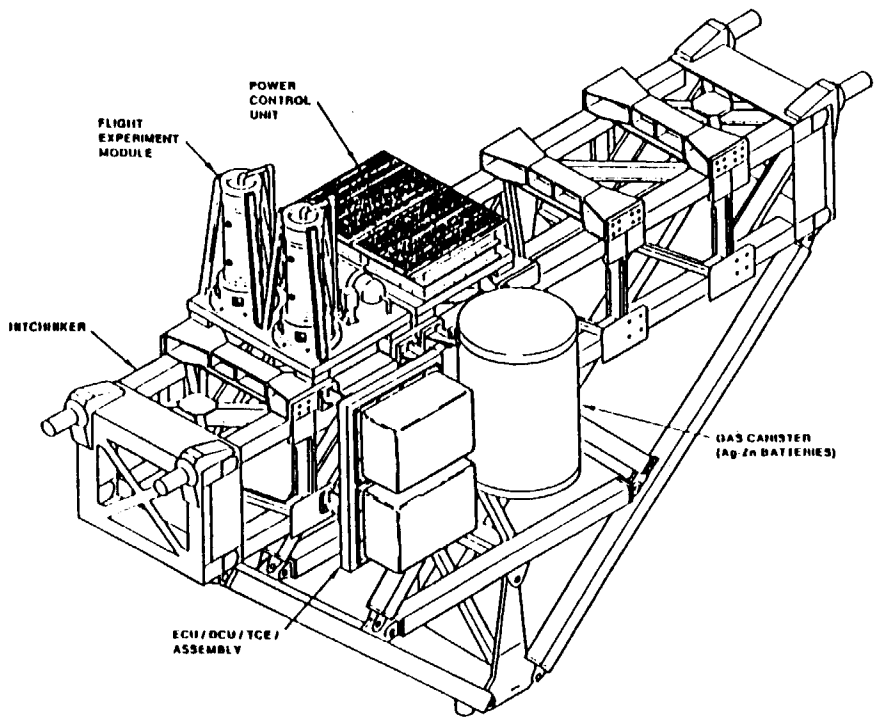
NASA SODIUM-SULFUR CELL TECHNOLOGY FLIGHT EXPERIMENT

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	LESS MASS AND VOLUME NEEDED
HIGH EFFICIENCY ROUND TRIP (82%) FARADAY (100%)	LESS WASTE HEAT AND LIGHTER SOLAR CELL ARRAY
NO SELF DISCHARGE	INFINITE STORAGE LIFE BOTH HOT & COLD
MODERATE TEMPERATURE (350°C)	LIGHTER RADIATOR REQUIRED
PASSIVE OPERATING SYSTEM	HIGHER RELIABILITY

NASA SODIUM-SULFUR CELL TECHNOLOGY FLIGHT EXPERIMENT

TECHNICAL APPROACH:

- ESTABLISH EFFECTS OF uG ON CELL PERFORMANCE
- DEVELOP A PERFORMANCE DATABASE
- DETERMINE REACTANT SPATIAL DISTRIBUTIONS
- DETERMINE CELL CURRENT AND TEMPERATURE DISTRIBUTIONS
- DOCUMENT PERFORMANCE OF SUB-SYSTEMS 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

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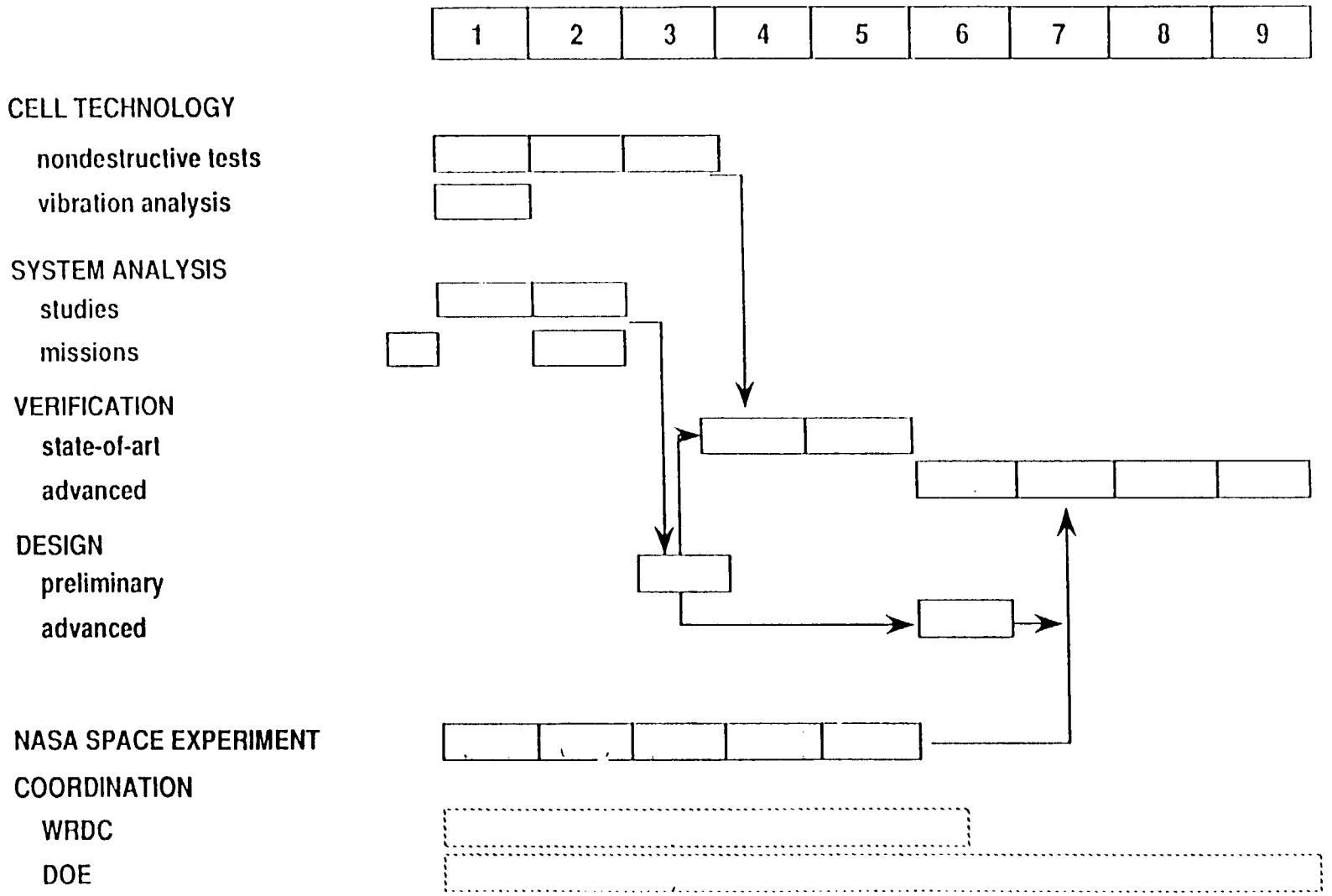
SODIUM SULFUR CELL TECHNOLOGY ROAD MAP



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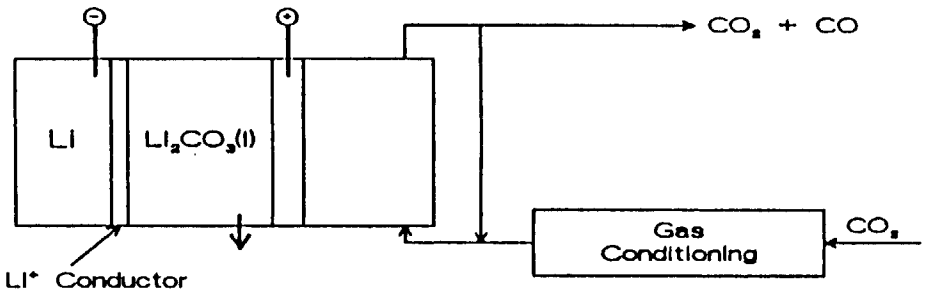
LITHIUM–CARBON DIOXIDE BATTERY

Thermodynamic Model



Discharge

$$2Li = 2Li^+ + 2e$$

$$2CO_2 + 2e = CO + CO_3^=$$

$$2Li + 2CO_2 = Li_2CO_3 + CO$$

Charge

Chemically

- Replenish Li Supply
  - 6400 wh/kg

Electrochemically

- Regenerate Li Supply
- Central Station

$$2Li^+ + 2e = 2Li$$

$$CO_3^= = CO_2 + 1/2O_2 + 2e$$

$$Li_2CO_3 = 2Li + CO_2 + 1/2O_2$$

BENEFITS OF TECHNOLOGY DEVELOPMENT

- QUANTIFIABLE -

- MISSION COST SAVINGS
  - $100 - 400 M SAVINGS FOR SSF USING ADVANCED NiH_2 TECHNOLOGY
- INCREASED MISSION LIFE
  - 10 X LEO CYCLE LIFE USING ADVANCED NiH_2 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
  - CO_2 CONVERSION
  - 850°C OPERATION

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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

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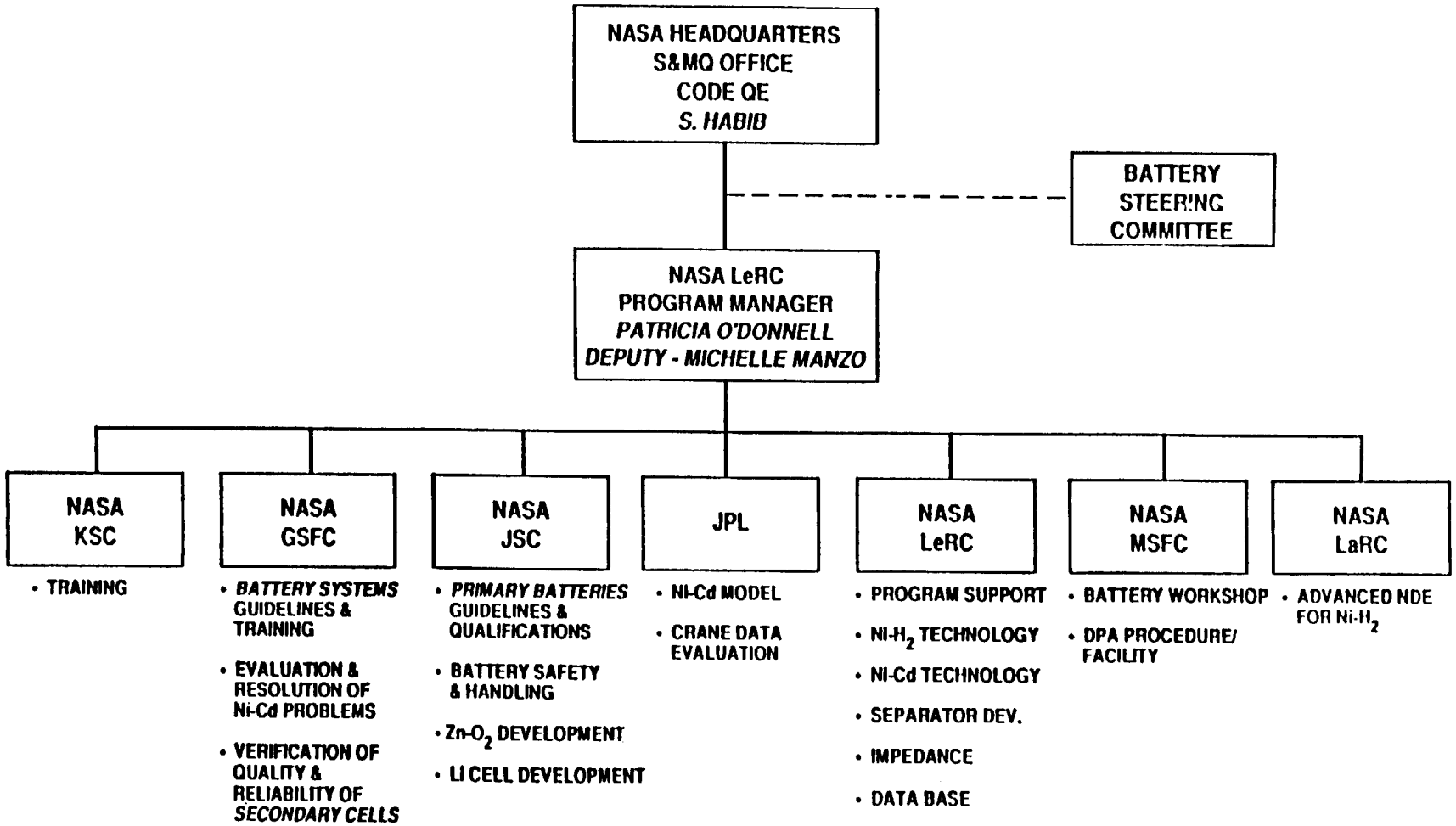
NASA AEROSPACE FLIGHT BATTERY SYSTEMS PROGRAM



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