N92-22744

AIR FORCE PHILLIPS LABORATORY BATTERY PROGRAM OVERVIEW

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BATT-1

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PL BATTERY PROGRAM: OVERVIEW

- NICKEL HYDROGEN
  - LEO TESTING
  - EMBRITTLEMENT TESTING
- SODIUM SULFUR
  - FLIGHT EXPERIMENT
  - HOT LAUNCH EVALUATION
- SOLID STATE POLYMERS
  - GEO BATTERY DEVELOPMENT
  - PULSE POWER BATTERY SBIR
  - IN-HOUSE EVALUATION

BATT-2

Battery development and testing efforts at Phillips Laboratory fall into three main categories: nickel hydrogen, sodium sulfur, and solid state batteries. Nickel hydrogen work is broken down into a LEO Life Test Program, a LEO Pulse Test Program, and a Hydrogen Embrittlement Investigation. Sodium sulfur work is broken down into a GEO Battery Flight Test and a Hot Launch Evaluation. Solid state polymer battery work consists of a GEO Battery Development Program, a Pulse Power Battery SBIR, and an In-House Evaluation of current generation laboratory cells.

PL BATTERY PROGRAM:

- NICKEL HYDROGEN
  - LEO TESTING
  - EMBRITTLEMENT TESTING

The Phillips Laboratory Nickel Hydrogen testing effort consists of a LEO Life Test Program, a Pulse Test Program, and a Hydrogen Embrittlement Investigation.

NIH2 TEST PROGRAM: OBJECTIVES

- DEMONSTRATE NIH2 PERFORMANCE IN LEO
- DEVELOP A STATISTICALLY SIGNIFICANT BATTERY CELL DATABASE
- DEMONSTRATE THAT DATA BASE FOR 3.5 IN CELLS CAN BE APPLIED TO 4.5 IN CELLS
- DEMONSTRATE NIH2 CELL PERFORMANCE IN PULSE APPLICATIONS

NIH2-2

The objectives of the LEO Life Test Program are to: demonstrate NiH2 performance in low earth orbit, develop a statistically significant battery cell data-base, and demonstrate that the data base for 3.5 inch cells can be applied to 4.5 inch cells. The NiH2 Pulse Test, which is a subset of the larger LEO Life Test Program, has the objective of demonstrating NiH2 cell performance in pulse applications.

NIH2 TEST PROGRAM: GOALS

- DEMONSTRATION OF CYCLE LIFE

  30,000 CYCLES AT 40% DOD
  20,000 CYCLES AT 60% DOD

- ESTABLISH MINIMUM RELIABILITY OF 90% WITH CONFIDENCE LEVEL OF 80%

NIH2-3

Goals of the NiH_2 LEO Life Test Program are to demonstrate 20,000 cycles at 60% DOD and 30,000 at 40% DOD. An additional goal will be to establish a minimum reliability of 90% with a confidence level of 80%.

NIH2 TEST PROGRAM: OVERVIEW

- ACCEPTANCE TEST

  ALL CELLS

- CHARACTERIZATION TEST

  5 CELLS PER DESIGN PER MANUFACTURER

- RANDOM VIBRATION TEST

  20% OF CELLS PER DESIGN PER MANUFACTURER

- LIFE TESTS

  LEO - 25%, 10C
  40%, 10C & -5C
  60%,10C
  PULSE TEST
  STORAGE TEST
  CHARGE CONTROL TEST

The NiH_2 LEO Life Test Program consists of four main parts: acceptance testing, characterization testing, vibration testing, and life testing. The acceptance test consists of a visual inspection and leak test, a conditioning and stability check, standard capacity measurements, impedance measurements, overcharge test, and a charge stand loss measurement. The purpose of the acceptance test is to ensure that cells meet the requirements stated in our specification document. The purpose of the characterization test is to determine cell charge characteristics and efficiencies. Twenty percent of the cells in each lot are subjected to random vibration testing. The life test program consists of DOD's of 25%, 40%, & 60% at temperatures of -5C and 10C. In addition, ten cells are undergoing storage testing, while a charge control test is scheduled to begin in early FY93.

NIH2 TEST PROGRAM:
TEST MATRIX

TEST	MFR	3.5 IN DIAM 10C	3.5 IN DIAM -5C	4.5 IN DIAM 10C
LEO				
25%	(EPI-CS/GEP)			10*
	YARD	5		
40%	HUGHES	10	10	5
	YARD	10	10	
	EPI-J	7		8
	GATES	10	10	8
60%	HUGHES	10		
PULSE				
40%	EPI-J	10		
STORAGE	(EPI-CS/GEP)			10*
TOTAL CELLS		92 - 3.5 INCH		41 - 4.5 INCH

NIH2-8A

The LEO Life Test Program test matrix consists of 123 cells from four manufacturers: Eagle Picher, Hughes, Yardney, and Gates. Cells are of either the 3.5 inch diameter type or 4.5 inch diameter type. Once again, temperatures involved are -5C and 10C with DOD's of 25%, 40%, and 60%. The 25% DOD cells will be used in a comparison with nickel cadmium performance. Ten cells are undergoing storage testing.

NIH2 TEST PROGRAM: RESULTS

(AS OF 1 JUN 91)

MFR	ID#	# CELLS	DIAM	DOD	TEMP	CYCLES
YARDNEY*	5995A	10	3.5	40%	10C	23,877
YARDNEY*	5000Y	10	3.5	40%	-5C	21,401
YARDNEY*	5001Y	10	3.5	60%	10C	DIS 5,369
GEP*	5001G	10	3.5	60%	10C	DIS 5,206
HUGHES*	5002H	10	3.5	40%	10C	16,227
HUGHES*	5000H	10	3.5	40%	-5C	15,910
HUGHES*	5001H	10	3.5	60%	10C	16,043
GEP*	5002G	10	3.5	40%	10C	14,763
GEP*	5000G	10	3.5	40%	-5C	14,438
HUGHES	5402H	5	4.5	40%	10C	13,864
GEP	5402G	8	4.5	40%	10C	13,904
EP-CS	5402E	8	4.5	40%	10C	13,984
YARDNEY	5011Y	10	3.5	60%	10C	DIS 8,979
YARDNEY	5003Y	5	3.5	25%	10C	9,504
EPI-CS LT	5000C	5	4.5	25%	10C	6,464
GEP LT	5000A	5	4.5	25%	10C	6,464
EPI-J	5002E	7	3.5	40%	10C	2,937
EPI-J	BEL-PUL	10	3.5	40%	10C	4,300

NIH2-8

As of 1 June 1991, Phillips Lab's LEO Life Test Program has 123 cells undergoing cycling with 10 cells on storage test. Cycles range from a lcw of 2,937 to 23,877.

HYDROGEN EMBRITTLEMENT TEST: OBJECTIVES

PHASE I:

- TEST THE EMBRITTLEMENT SUSCEPTIBILITY OF NICKEL HYDROGEN BATTERY VESSEL MATERIAL IN 1,000 psig HYDROGEN ENVIRONMENT UNDER A SUSTAINED LOAD

PHASE II:

- INVESTIGATE FATIGUE CRACK PROPAGATION

BATT-8A

The Hydrogen Embrittlement Test consists of a two phase program. Phase I was just completed and was designed as a quick-look experiment to investigate the embrittlement susceptibility of NiH_2 vessel material in 1000 psi hydrogen environment under a sustained load. Phase II is still underway and will investigate fatigue crack propogation in Inconel 718.

HYDROGEN EMBRITTLEMENT TEST: APPROACH

PHASE I: EMBRITTLEMENT INVESTIGATION

- SAMPLES CUT FROM 3 SPENT CELLS FROM LEO LIFE TEST (EP-13,000 CYCLES, YARD-3,770 CYCLES, GATES-4,300 CYCLES). ALL 60% DOD. INCONEL 718 CASES.
- TENSILE SPECIMENS CUT PARALLEL TO LONG AXIS OF YARDNEY CELL
- 13 STRIPS CUT FROM OTHER TWO CELLS IN A CIRCUMFERENTIAL DIRECTION. WERE THEN BENT INTO U SHAPES AND PLACED IN A 1000 psig HYDROGEN ENVIRONMENT FOR 200 HOURS. 8 SAMPLES (6 OF WHICH WERE SCRIBED AT THE OUTER SURFACE OF THE U-BEND TO A DEPTH OF 0.0002-0.0005 IN) WERE THEN EXPOSED FOR AN ADDITIONAL 200-400 HOURS

BATT-281

In Phase I, samples were cut from three spent cells that had undergone LEO cycling (varying from 3,770-13,000 cycles) at 60% DOD. All cases were Inconel 718. Several specimens were cut parallel to the long axis of one of the cells and subjected to tensile testing. Thirteen strips were cut from the other two cells in a circumferential direction, bent into U shapes and placed in 1000 psig hydrogen for 200 hours. Eight samples were then exposed for an additional 200-400 hours.

HYDROGEN EMBRITTLEMENT TEST: RESULTS

PHASE I:

- TENSILE DUCTILITY OF INCONEL 718 DECREASED AFTER LONG EXPOSURE TO NIH2 CELL ENVIRONMENT. FRACTURE MODE REMAINED DUCTILE.
- ONE FAILURE OBSERVED IN U-BEND SPECIMENS AFTER 200 HOURS. DETERMINED TO BE CAUSED BY APPLIED BENDING STRESS, HYDROGEN ENVIRONMENT, AND SURFACE DEFECT CAUSED BY IMPROPER MACHINING
- INCONEL 718 THAT HAS BEEN EXPOSED TO THE NIH2 CELL ENVIRONMENT APPEARS TO BE MORE SUSCEPTIBLE TO HYDROGEN EMBRITTLEMENT THAN VIRGIN INCONEL 718. THRESHOLD INTENSITY FACTOR COULD BE DECREASED FROM 22 ksi$\sqrt{\text{in}}$ FOR VIRGIN INCONEL TO BELOW 17 ksi$\sqrt{\text{in}}$ FOR MATERIAL EXPOSED TO HYDROGEN FOR LONG TIMEFRAMES

BATT-2C

Initial results indicate that the tensile ductility of Inconel 718 decreased after long exposure to the NiH2 cell environment. However, the fracture mode remained ductile. One failure was observed in the group of u-bend specimens after 200 hours exposure. However, the failure was determined to have been caused by a combination of the applied bending stress, the hydrogen environment, and a surface defect that was introduced as a result of improper machining during the process of cutting the sample from the cell. Inconel 718 that has been exposed to the NiH2 battery environment appears to be more susceptible to hydrogen embrittlement than virgin material.

HYDROGEN EMBRITTLEMENT TEST: RESULTS (CONT)

PHASE I:

- MAXIMUM APPLIED STRESS INTENSITY FACTOR FOR CELL SHELL IS APPROX 15 ksi$\sqrt{in}$, WHICH MAY BE VERY CLOSE TO THRESHOLD STRESS INTENSITY FACTOR OF THE INCONEL EXPOSED TO HYDROGEN OVER LONG PERIODS. ADDITIONAL TESTS NEEDED TO DETERMINE THRESHOLD STRESS INTENSITY FACTOR VALUE OF SHELL MATERIAL FOR SAFE OPERATION OF CELLS.

BATT-88

The maximum applied stress intensity factor fo. the cell shell has been calculated at approximately 15 ksi in, which may be very close to the threshold stress intensity factor of the Inconel material exposed to hydrogen over long periods of time. Therefore, it is recommended that additional tests be conducted to determine the threshold stress intensity factor value of shell material to warrant safe operation of the cells.

HYDROGEN EMBRITTLEMENT TEST: APPROACH

PHASE II: CRACK PROPOGATION RATES

- SAMPLES CUT FROM SPENT CELLS FROM LEO LIFE TEST. ALL INCONEL 718 CASES
- U-BEND SPECIMENS WITH PRECRACKS EMPLOYED TO ESTIMATE THE CRACK PROPOGATION RATE OF INCONEL 718 IN 1000 psig HYDROGEN. KOH ALSO PRESENT IN TEST ENVIRONMENT
- SOLENOID USED TO PLACE EACH SAMPLE UNDER A CYCLIC LOAD PROFILE

NOTE: PHASE II IS STILL IN PROGRESS

BATT-201

In Phase II, samples will be cut from spent cells from Phillips Lab's LEO Life Test (as in phase I). Specimens will be bent into u shapes and precracks will be employed. A solenoid will be used to place each sample under a cyclic load profile, roughly simulating the loading that cells would encounter under cycling. The test environment will consist of 1000 psig hydrogen as well as KOH solution.

PL BATTERY PROGRAM:

- SODIUM SULFUR
  - FLIGHT EXPERIMENT
  - HOT LAUNCH EVALUATION

BATT-26

The Phillips Laboratory Sodium Sulfur development and testing effort consists of a flight test of a 16 cell GEO NaS battery and an evaluation of the hot launch capabilities of NaS cells.

NaS FLIGHT EXPERIMENT: OBJECTIVES

- VERIFY NaS TECHNOLOGY IN ZERO-G
- VERIFY NaS CELL DESIGN FOR GEO APPLICATIONS
- MONITOR THERMAL CONTROL PROCESSES
- ENABLE TRANSITION OF NaS TECHNOLOGY

BATT-8

The primary objective of the NaS Flight Experiment is to verify that the GEO cell design functions properly in zero-g. The end goal of the program is the transition of NaS technology to the user.

NaS FLIGHT EXPERIMENT: WHY NaS BATTERIES?

- ENABLING TECHNOLOGY FOR HIGH POWER SATELLITE MISSIONS
- ENHANCING TECHNOLOGY FOR MANY SATELLITE MISSIONS
- BENEFITS OF 100WHR/KG NaS BATTERY VS SOTA NIH2 BATTERY
  - 60% REDUCTION IN BATTERY MASS
  - 15% REDUCTION IN POWER SYSTEM MASS
  - 60% REDUCTION IN BATTERY VOLUME
  - 40% REDUCTION IN BATTERY COST

BATT-3A

Sodium sulfur batteries should provide a variety of advantages over SOTA batteries. NaS is expected to be an enabling technology for high power satellite missions and an enhancing technology for many other satellite missions. Benefits of NaS batteries over NiH_2 batteries include: 60% reduction in battery mass, 15% reduction in power system mass, 60% reduction in battery volume, and a 40% reduction in battery cost.

NaS FLIGHT EXPERIMENT: DESCRIPTION

- SCHEDULED TO FLY ABOARD P91-1 IN 1995
- FTU (FLIGHT TEST UNIT) WILL CONSIST OF:
  --16 CELL, 28 VOLT, 40 AMPERE-HOUR HEDRB MODULE (GFE)
  --EXPERIMENT SCIENCE PACKAGE
- GTU (GROUND TEST UNIT) WILL DUPLICATE THE FLIGHT EXPERIMENT

BATT-4

The flight experiment will utilize a 16 cell, 28 volt, 40 amp-hr GEO battery under development at Wright Patterson AFB. This battery will be delivered GFE to Phillips Lab for integration onto the Air Forces's P91-1 satellite which will fly in 1995. A separate ground test unit will duplicate the experiment concurrently on the ground.

NaS HOT LAUNCH EVALUATION: OBJECTIVES

- EVALUATE CELL PERFORMANCE UNDER HOT LAUNCH CONDITIONS. HOT LAUNCH IS A LAUNCH IN WHICH THE CELLS ARE AT OPERATING TEMPERATURE

- TO EVALUATE STRUCTURAL INTEGRITY OF CELLS UNDER HOT LAUNCH CONDITIONS

BATT-8

The purpose of the Sodium Sulfur Hot Launch Evaluation is to investigatte cell performance under hot launch conditions. For our purposes, a hot launch is defined as a launch in which the cells are at operating temperature.

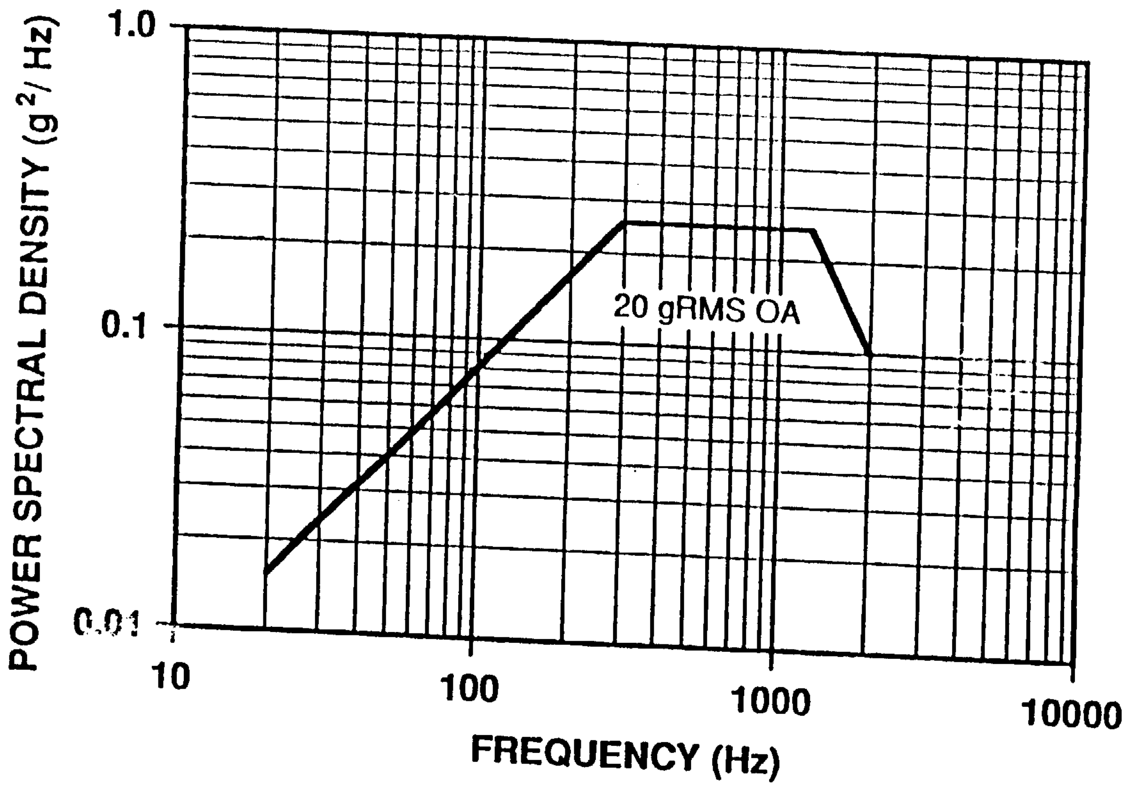
NaS HOT LAUNCH EVALUATION: TEST PLAN

- TWO APPROACHES
  - 2 CELLS MOUNTED ORTHOGONALLY
  - EACH CELL TESTED INDEPENDENTLY IN TWO AXES
- CELL PREPARATION
  - PHYSICAL EXAMINATION
  - COLD OPEN CIRCUIT VOLTAGE
  - MOUNTING AND PROBE CONNECTION
  - CELL THAW
    - AMBIENT TO 90 C AT 25 C PER HOUR MAX
    - 90 C TO 140 C AT 10 C PER HOUR MAX
    - 140 C TO 350 C AT 25 C PER HOUR MAX
  - FUNCTIONAL TESTING

BATT-6A

Two cells will be mounted orthogonally to each other and subjected to vibration testing designed to simulate the worst launch environment that the cells are likely to see. Preparation for th etest consists of a physical examination, cold open circuit voltage measurement, the mounting and connection of instrumentation, a controlled thaw procedure, and functional testing to determine initial state-of-health of the cells.

NaS HOT LAUNCH EVALUATION: VIBRATION ENVIRONMENT



C-2

The cells will be subjected to the vibration environment shown. This environment corresponds to the worst environment that an operational NaS battery is likely to see on launch.

NaS HOT LAUNCH EVALUATION: PAYOFF

BENEFITS DERIVED FROM LAUNCHING HOT

- ABLE TO HAVE SATELLITE ON-LINE IMMEDIATELY UPON REACHING ORBIT

- ELIMINATE THE NEED FOR AN ALTERNATE POWER SOURCE FOR CELL THAW ONCE ON ORBIT

BATT-8C

There are several reasons for wishing to launch a sodium sulfur battery in a hot condition as opposed to launching in the frozen state. For one thing, launching hot would allow the satellite to be on-line immediately upon reaching orbit. If launched in a frozen state, the battery would require approximately eighteen hours to complete its thaw cycle. A second advantage is gained due to the fact that the need for an alternate power source is eliminated. This alternate power source (such as a backup battery) would usually be needed to provide power to the satellite during the thaw period of the NaS battery and would also be used to provide power to the heaters used to thaw the NaS battery.

PL BATTERY PROGRAM:

- SOLID STATE POLYMERS
  GEO BATTERY DEVELOPMENT
  PULSE POWER BATTERY SBIR
  IN–HOUSE EVALUATION

The Phillips Laboratory Solid State Polymer Battery development and testing effort consists of a GEO Battery Development Program, a Pulse Power Battery SBIR, and an in-house evaluation of current-design laboratory polymer battery cells.

SOLID STATE BATTERIES: GEO BATTERY DEVELOPMENT

GOALS:

- DEVELOPMENT OF HIGH ENERGY DENSITY POLYMER BATTERIES FOR GEO SATELLITE SYSTEMS
  - >200 WHR/KG
  - 10 YR LIFE, 1000 CYCLES, 80% DOD
  - CELL SIZE – 50 AH

APPROACH:

- DESIGN AND FABRICATION
- SCALBILITY AND PRODUCIBILITY ANALYSIS
- CELL PERFORMANCE TESTING AND ANALYSIS

STATUS:

- FY92 NEW START
- 2 YR BAA EFFORT FOLLOWED BY EXPANDED PROGRAM

BATT-7

An FY92 new start program will begin the process of developing a solid state battery for use in GEO orbits. Goals of the program will be the development of cells with energy densities of greater than 200 WHR/KG having at least a ten year life, with the capability of at least 1000 cycles at 80% DOD. Cell capacities will be on the order of 40-50 amp-hr. As stated previously, the program will start in early FY92 with several concepts being funded during the first two years under a BAA contract. In the third year, one concept will be chosen for an expanded program.

SOLID STATE BATTERIES: PULSE POWER BATTERY DEVEL

GOAL:

DEVELOPMENT OF SOLID-STATE, PULSE POWER BIPOLAR BATTERY WITH MAX SPECIFIC POWER OF 50 kW/kg AND MAX SPECIFIC ENERGY OF >50 Wh/kg

APPROACH:

- POLYACRYLONITRILE (PAN) POLYMER ELECTROLYTE (2x10-3/OHM CM AT 25C)
- LINIO2 HIGH VOLTAGE (3.5 V) INTERCALATION CATHODE
- CARBON INTERCALATION ANODE

STATUS:

- PHASE I SBIR NEARING COMPLETION

BATT-6

Phillips Lab is currently managing a phase I SBIR for SDIO with the goal of developing a pulse power battery with a specific power of approximately 50kW/kg and an energy density of greater than 50 Wh/kg. The battery will utilize a poly-acrylonitrile electrolyte, a high voltage cathode, and a carbon-based anode. Phase I is currently nearing completion.

SOLID STATE BATTERIES: IN-HOUSE EVALUATION

GOALS:

- ASSESS CAPABILITIES OF CURRENT-GENERATION SOLID STATE CELLS
- GAIN INSIGHTS INTO AREAS REQUIRING FUTURE DEVELOPMENT EFFORTS

APPROACH:

- PROCURE SAMPLE CELLS FROM SEVERAL MANUFACTURERS
- CYCLE UNTIL FAILURE
- PERFORM ANALYSIS TO DETERMINE FAILURE MODES/MECHANISMS

STATUS:

- PROCURING EQUIPMENT AND CELLS
- TESTING SHOULD BEGIN IN EARLY JANUARY

BATT-8

An in-house program at Phillips Lab will also assess the capabilities and limitations of current solid state cells, thus providing valuable information for use on our GEO battery development program. The approach will be to procure cells from several manufacturers, cycle them until failure, and perform a series of tests to determine the failure modes/mechanisms.