Nickel Hydrogen Low Earth Orbit Test Program Update and Status

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C. C. Badcock and S. W. Donley
The Aerospace Corporation
P. O. Box 92957
Los Angeles, CA 90009

A. B. Felts and R. L. Haag
Naval Weapons Support Center
Crane, IN 47522

ABSTRACT

This document describes the current status of Nickel Hydrogen (NiH_2) testing ongoing at NWSC, Crane IN, and The Aerospace Corporation, El Segundo CA. The objective of this testing is to develop a database for NiH_2 battery use in Low Earth Orbit (LEO) and support applications in Medium Altitude Orbit (MAO). Individual pressure vessel-type cells are being tested. A minimum of 200 cells (3 1/2 in diameter and 4 1/2 in diameter cells) are included in the test, from four U.S. vendors. As of this date (Nov. 18, 1986) approximately 60 cells have completed preliminary testing (acceptance, characterization, and environmental testing) and have gone into life cycling.

INTRODUCTION

In the Spring of 1984 a survey of life testing status and results for NiH_2 cells was performed.[1]. Data were either available or would be available within the next two to three years to support the use of NiH_2 batteries in high orbits requiring up to 3000 cycles at maximum depths of discharge of up to 80% with a high level of demonstrated reliability and confidence. Calendar life on orbit in excess of ten years was anticipated. It was suggested that optimum performance would be achieved when the temperature of operation was at less than 15 deg. C and the amount of overcharge was minimized while maintaining an adequate state of charge.

On the other hand, the data available to support the use of NiH_2 batteries in low earth (LEO) and mid altitude orbits (MAO) are deficient. The extent of the data base consists of mixtures of technologies and several generations of LEO cell designs. Cells have been tested under extreme conditions with less regard for the limitations of these cells than is normally applied to space-type secondary cells. However, small samples of the most recently built cells when tested under severe conditions (90 m cycle, 80% DOD, 1.4 C discharge, 0.8 C charge, 105% charge return ratio, 23±4 deg. C) have consistently given 10,000 cycles before failure occurred. This suggests that the cells have the capability to surpass the performance of present state-of-the-art NiCd cells in LEO applications. Presently, design variations among NiH_2 cells are beginning to stabilize and future changes are expected to be incremental. Testing to establish reliability and performance appears to be practical at this time.

NiH_2 cells must significantly outperform NiCd cells or they would be disadvantageous to use because of their greater specific volume, higher present unit cost, and the risks inherent in any new design. This increase in performance can be in life and/or usable energy density. Present NiCd batteries used under near-optimum conditions offer 14 - 18,000 cycles at 20 - 25% DOD and 25 - 30,000 cycles at 7 - 14% DOD depending on specific conditions of load profile, power system requirements, and environment with high reliability and confidence. NiH_2 cells must demonstrate significant increases over these numbers if they are to be the next generation of LEO batteries. This life test will demonstrate the performance capabilities of state-of-the-art NiH_2 cells in low earth orbit, and in addition will support their use in mid altitude orbit; and, will provide a database, when combined with other relevant life test data and with program specific testing, that will permit an estimate of reliability at an appropriate confidence level.

Objectives and Goals

The NiH_2 cell life test has the following objectives[2]:

1. Demonstrate NiH_2 performance in LEO applications and support use in MAO at levels superior to current NiCd capabilities.
2. Develop a statistically significant NiH_2 battery cell database.
3. Disseminate the test data and results in a timely fashion.
4. Demonstrate NiH_2 cell performance in pulse applications.
5. Demonstrate that the Manufacturing Technology Program (MANTECH) cells are capable of performing in high orbit as well as LEO.

It is the intent to test cells from all viable vendors in sufficient numbers to provide a comparison and to establish a statistically significant database with a sufficiently high confidence level. A minimum of 155 3.5 in diameter and 45 4.5 in diameter cells are included in the test plan. Additional cells will be added as the need is demonstrated. Approximately equal numbers of cells from four U.S. vendors (GEBBD, Eagle Picher, Yardney, and HAC) are to be tested in so far as schedule and funding permit.

The goals of these tests are to demonstrate at least 30,000 cycles at 40% DOD and at least 20,000 cycles at 60% DOD in LEO and at least 5000 cycles at

80% DOD in MAO or high orbit. The 40% DOD cycle goal is greater than present NiCd cells can expect to achieve at three years of planned life. A small number of cells (5 from each vendor) will be tested at 25% DOD to provide correlation with present NiCd testing and life data bases. It must be emphasized that cells could fail to reach desired goals, e.g. 60% DOD and 5 years, and still perform significantly better than present state-of-the-art NiCd cells.

A second goal is to establish a minimum reliability of 90% with a confidence level of at least 80% for the goals stated above. This goal requires an additional year of testing beyond the goal periods, if one assumes the improbable condition that none of the groups of ten cells can be statistically combined.

Reports are issued when significant milestones are reached and at regular periods. Each major milestone, e.g. completion of acceptance testing, results in a brief report. The progress of the test shall be reported in an "Annual Report of Cycle Life Testing" from NWSC Crane and will, in addition, be summarized at least once a year and presented in an appropriate forum (of which this is the second). The detailed data will remain available after completion of the test for access by qualified organizations.

Test Plan

The test plan consists of acceptance and pre-life testing (including environmental testing), characterization testing, life testing, and failure and end-of-test analyses. Cell manufacturing specifications, testing procedures, and failure analysis procedure have been fully documented, except for end-of-test analysis which is in preparation.

All the packs in the test will be 10-cell packs except for those (LEO 25% DOD and some 4.5 in. packs) that are meant mainly to correlate with other data bases. The standard sample size of 10 was chosen by a method based on the two-parameter Weibull failure distribution function as a compromise between the high cost of a large sample size and the statistical uncertainties of a small sample size.

Acceptance Testing: Acceptance testing is conducted at NWSC. All cells of the same type and from the same vendor are tested in a single series string whenever practicable. The following tests are performed on all cells:

1. Visual inspection, weight, and dimensions (diameter and length).
2. Indicator leak test (at beginning and end of testing).
3. Conditioning capacity (10°C, repeat until two cycles agree within 2% in capacity).
4. Standard Capacities at -5°, 10°, and 20°C.
5. Impedance at 50% state of charge and 20°C.
6. Overcharge voltage and pressure stability (when available) at 0°C.
7. Capacity loss upon charged stand at 10°C for 72 hours.

The ampere-hour and watt-hour capacities of the cells are reported to 1.20, 1.15, 1.10, 1.05, 1.00, and 0.5 V. at the standard discharge rate (a C rate is used to correlate with the rates used in testing). All temperatures refer to the midpoint along the cell cylinder on the thermal flange.

A 20% sample of the cells of each type (at least two cells) and from each vendor are subjected to random vibration testing at levels 6 dB higher than the highest level anticipated in any application. The cells that are vibrated will be distributed throughout the test packs to determine any long-term effects of vibration.

Characterization Testing: These tests are performed to determine the required charge characteristics. A group of 5 are cells of each type and from each vendor are tested to determine charge efficiencies at selected rates and temperatures. These data along with acceptance data are used to initiate charge control for life testing.

Life Testing: Life testing will be performed using a nominal 90 minute orbit with a 30 min. eclipse period and a 60 min. sun period. Testing will be performed at -5° and 10°C with the latter temperature being baseline. In a corporate program-oriented test at Martin-Marietta Aerospace, 20°C is being used for a group of cells.[3] We choose not to duplicate this condition. The charge control method is ampere-hour integration (recharge fraction control). This method is flexible and particularly easy to integrate into a digital control system. In the LEO testing, control is accomplished by

changing the charge returned under a fixed depth of discharge until the following parameters are minimized:

1. The decrease in the end of discharge voltage.
2. The increase in the end of charge voltage (high rate and trickle).
3. The recharge fraction (both watt-hour and ampere-hour).

A limit of a 112% charge return is established to permit the setting of charge rate capability (charge returns of this size are not anticipated during testing.) The charge sequence for LEO will be to return 100% of the charge at the required rate followed by C/5 charging for the remember of the charge period. The high charge rate is adjusted to set the charge control parameters. A similar approach will be used in MAO but the high charge rate and the final charge rates will be lower. Trickle charge, which is used only in emergencies, will be at C/80 or lower.

Reconditioning is not planned for the cells in LEO testing. MAO testing may require reconditioning to maintain adequate efficiency. No capacity discharges will be performed.

Failure is defined as a voltage of less than 0.50 V at the end of the prescribed discharge or a voltage greater than 1.75 V during any portion of the charge. Data for other end-of-useful-life criteria will be available. Upon being declared a failure, the affected cell will be removed from the test pack and subjected to a repeat of at least part of the acceptance test within 180 days of failure. The cell will then be dispositioned for further failure analysis.

The schedule given on Figure 1 shows the proposed plan. It is hoped that the test will continue until the majority of the cells in each pack have failed.

Special Testing: The general test will employ continuous constant discharges. However, the applications requiring pulsed high rate discharge within the envelope of the planned DODs are sufficiently prevalent to make the correlation of such results with the general life test important. A small group of cells will be placed on life test in a pulse discharge regime at maximum rates of approximately 5C. Cells will be acceptance tested at the

testing organization and sent to The Aerospace Corporation Battery Evaluation Laboratory for the special testing.

RESULTS AND STATUS

The full test matrix of cells expected to be tested is shown in Table 1. The total number of cells of all types and from all vendors is 275, of which 210 are 3.5 in diameter cells and 65 are 4.5 in diameter. Numbers and types of cells currently on hand or committed are shown in Table 2. Some cells manufactured in or prior to 1985 were found initially to have insufficient capacity. These have been subjected to a LEO cycling regime in order to increase their capacities to the minimum level required, namely 50 Ah for 3.5 in diameter cells. In all cases the capacities of affected cells have been recovered in this way, although requiring more than 400 LEO cycles in some cases. Newly manufactured cells have not exhibited this characteristic.

It is estimated that by the date of delivery of this paper 57 3.5 in diameter cells will be undergoing life cycling. The remainder of the 3.5 in cells on hand at this time, numbering 46 cells, will be undergoing pre-life testing for a total of 103 3.5 in diameter cells. Also, by this date 21 4.5 in diameter cells will have been received and will be in preparation for testing. Additionally, 45-3.5 in diameter cells, and 20-4.5 in diameter cells are on order and are to be received during FY 1987, so that by the end of FY 1987 189 cells should be undergoing testing in both LEO and MAO regimes.

We expect to have completed acceptance, characterization, and environmental testing on all 103 cells that are on hand at Crane by the end of January 1987. These cells will enter life testing as soon as pack assignments can be made but no later than the completion of all pre-life testing. Twenty-one high rate 4.5 inch diameter cells are expected in the last quarter of 1986. These will enter prelife testing as soon as the equipment is available (January 1987).

REFERENCES

1. C. C. Badcock and M. J. Milden, Nickel Hydrogen Battery Cell Testing Data Base: An Industry and Government Survey, Space Division/Air Force Systems Command, No. SD-TR-85-88, Dec. 31, 1985.

2. C. C. Badcock, Nickel-Hydrogen Low Earth Orbit Test Program, paper presented the 1985 NASA/GSFC Battery Workshop, Greenbelt, MD, Nov. 29, 1985.

3. J. K. McDermott, Low-Earth-Orbit Testing of Nickel-Hydrogen Cells, paper presented at the 21st Intersociety Energy Conversion Engineering Conference, Aug. 25-29,1986.

Table 1. NiH_2 LOW EARTH ORBIT LIFE TEST

TEST MATRIX

ORBIT	DOD %	MFR	3.5" DIA. CELLS TEMPERATURE 10°C	3.5" DIA. CELLS TEMPERATURE -5°C	4.5" DIA. CELLS TEMPERATURE 10°C	TOTAL CELLS 3.5"	TOTAL CELLS 4.5"
LEO	25	YARD	5			5	
		EP	5			5	
		GEBBD	5			5	
		HAC	5			5	
	40	YARD	10	10		20	
		EP	10Z	10A	10	20	10
		GEBBD	10	10		20	
		HAC	10		10	10	10
	60	YARD	10	10	10	10	10
		EP	10Z, 10A	10Z		30	
		GEBBD	10		10	10	10
		HAC	10	10		20	
MAO	80	YARD	10			10	
		EP	10		10*	10	10
		GEBBD	10		10*	10	10
		HAC	10			10	
SPECIAL TESTS		2 or 3, 3.5" cells and 1+ 4.5" cell from each manufacturer				10	5
					TOTAL CELLS	210	65

Table 2.

NiH_2 LOW EARTH ORBIT LIFE TEST

CELLS COMMITTED TO THE TEST

MANUFACTURER	SIZE/CAPACITY	QUANTITY	DATE AVAILABLE
YARDNEY	3.5"/50	31 (ZA)	Now
EAGLE PICHER	3.5"/50	24 (A)	Now
		33 (Z)	Now
EAGLE PICHER (CS)	4.5"/100	8 (Z)	12/86
	4.5"/130	10 (Z)	4/87
GE BBD	3.5"/50	15 (Z)	Now
	3.5"/50	15 (Z)	8/87
	4.5"/100	8 (Z)	12/86
	4.5"/130	10 (Z)	4/87
HUGHES	3.5"/50	30 (Z)	8/87
	4.5"/100	5 (Z)	12/86

TOTAL 3.5" CELLS.....	148
TOTAL 4.5" "LEO" CELLS.....	21
TOTAL 4.5" "HEO" CELLS.....	20

NiH2 LIFE TEST SCHEDULE

SCHEDULE

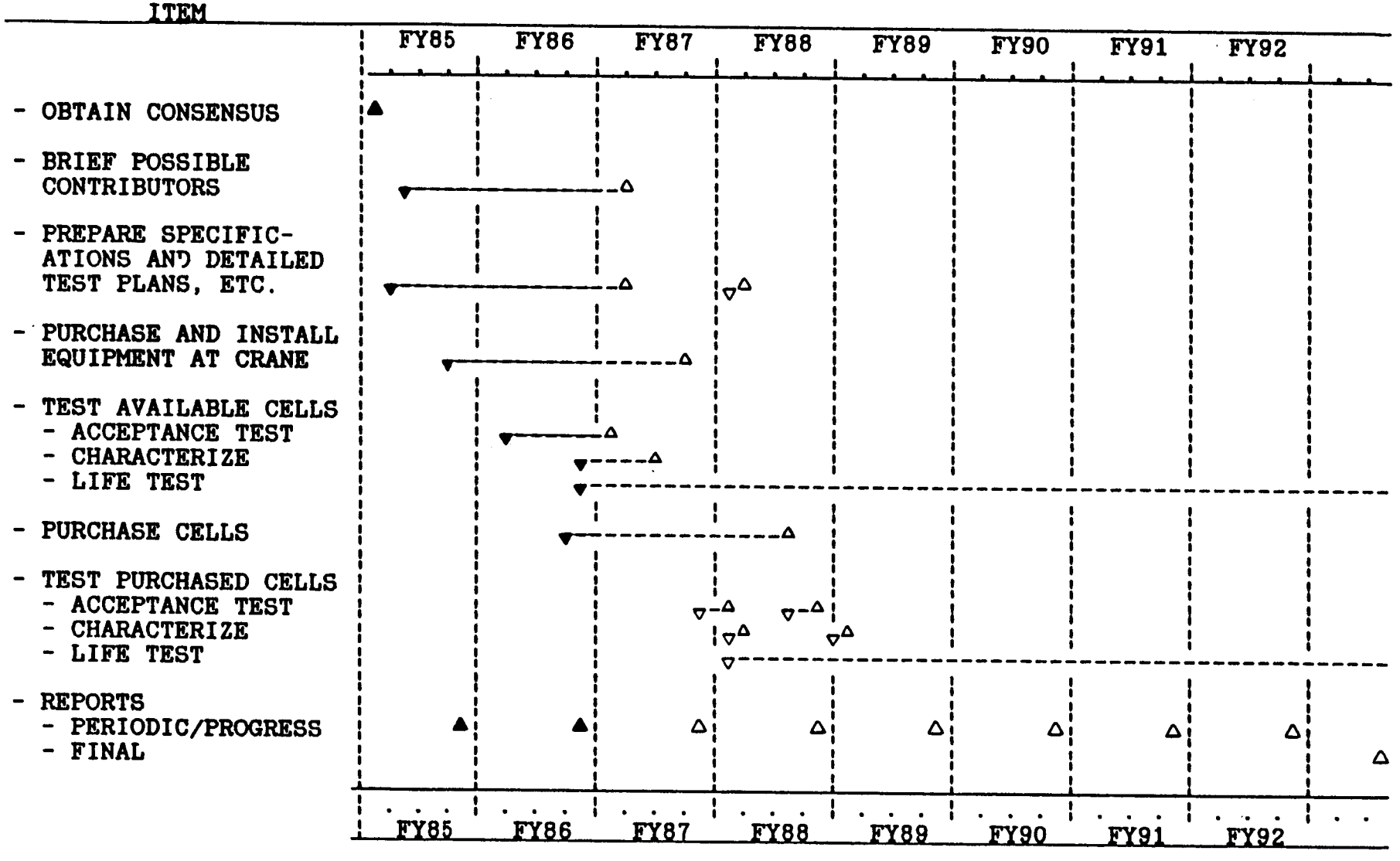

Figure 1.

Nickel Hydrogen Low Earth Orbit Test Program: Update and Status

C. C. BADCOCK AND S. W. DONLEY

THE AEROSPACE CORPORATION
LOS ANGELES, CA 90009

A. B. FELTS AND R. L. HAAG

NAVAL WEAPONS SUPPORT CENTER
CRANE, IN 47522

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NiH_2 Low Earth Orbit Life Test

- OBJECTIVES
  - DEMONSTRATE NiH_2 PERFORMANCE IN LEO
    - SUPPORT MID-ALTITUDE ORBIT OPERATION
    - RELATE LARGER DIAMETER CELLS TO DATA BASE
  - DEVELOP A STATISTICALLY SIGNIFICANT DATA BASE
    - PROJECT BATTERY RELIABILITIES
    - SUPPORT OTHER TESTING DATA
  - PROVIDE UNIFORM, COMPARABLE DATA
    - INCORPORATE OTHER DATA BASES
    - DIRECT COMPARISON OF MANUFACTURERS' CELLS
- GOALS
  - DEMONSTRATE A MINIMUM CYCLE LIFE
    - 30,000 CYCLES AT 40% DOD
    - 20,000 CYCLES AT 60% DOD
    - 5,000 CYCLES AT 80% DOD (MAO orbit)
  - ACHIEVE A MINIMUM RELIABILITY
    - 90% RELIABILITY AT AN 80% CONFIDENCE LIMIT

NiH_2 LEO Life Test

ORGANIZATION AND APPROACH

- ORGANIZATION
  - PROGRAM MANAGEMENT BY AFSTC
  - NWSC/CRANE TO PERFORM ACCEPTANCE, CHARACTERIZATION, AND LIFE TESTING
    - DOD NATIONAL TEST FACILITY FOR BATTERIES AND CELLS
  - AEROSPACE TO PROVIDE TECHNICAL SUPPORT
    - PREPARE DOCUMENTATION AND ASSIST IN REPORTING RESULTS
    - PERFORM SPECIALIZED TESTING
  - AFWAL/POOC TO SUPPORT PROGRAM
    - PROVIDE PREVIOUSLY PURCHASED CELLS AND PURCHASE SERVICES FOR FIRST CELLS PURCHASED (FY86)
- APPROACH
  - TEST CELLS UNDER LEO AND MAO REGIMES (majority in LEO)
    - LIMIT VARIABLES TO INCREASE STATISTICAL SIGNIFICANCE
    - TEST UNDER MOST BENIGN, ACHIEVABLE CONDITIONS
    - TEST CELLS FROM ALL VIABLE U.S. MANUFACTURERS
    - TEST 3.5 AND 4.5 INCH DIAMETER CELLS

NiH_2 Low Earth Orbit Life Test

TEST PARAMETERS

- TEST ~80% OF THE CELLS UNDER LEO CONDITIONS
  - 16 CYCLES/DAY: 30m DISCHARGE/60m CHARGE
  - MAO TESTING AT 6 HOURS/CYCLE
- DEPTH OF DISCHARGE BASED ON ACTUAL MINIMUM/PACK
  - LEO
    - 25% (correlation with NiCd only)
    - 40% IS THE CONSERVATIVE GOAL
    - 60% IS THE DESIRED GOAL
  - MAO
    - 80% WILL PERMIT BOL DESIGNS AT 70+%
- TEMPERATURE
  - LEO TESTING AT 10°C AND −5°C (±4°C)
  - MAO TESTING AT 10°C ONLY
- CHARGE CONTROL MINIMIZES RECHARGE FRACTION
  - MINIMIZE PARAMETERS
    - DECREASE IN EODV
    - INCREASE IN EOCV
    - WH AND AH RECHARGE FRACTION

NiH_2 Low Earth Orbit Life Test

STATISTICAL CONSIDERATIONS

- DEMONSTRATE STATISTICAL SIGNIFICANCE IN TESTING
  - TRADE-OFF TEST TIME AND NUMBER OF CELLS AGAINST OTHER GOALS
- MINIMUM CREDIBLE TEST MATRIX CHOSEN AS BEST COMPROMISE
  - LONGER TEST TIME WITHOUT FAILURE CAN INCREASE SIGNIFICANCE
  - COMBINING TEST PACKS FROM DIFFERENT CONDITIONS AND/OR MANUFACTURERS CAN INCREASE SIGNIFICANCE
- LONGER TEST TIME IS MOST EFFECTIVE DIRECTION FOR RELIABILITY
  - 5 YEAR APPLICATION, TESTING WITH NO FAILURES
    - 10 CELLS: TEST TIME = 5 YEARS, CL = 0.8, R = 86.3%
    - 20 CELLS: TEST TIME = 5 YEARS, CL = 0.8, R = 92.6%
    - 10 CELLS: TEST TIME = 8 YEARS, CL = 0.8, R = 97.8%

NiH_2 Low Earth Orbit Life Test

TEST MATRIX

ORBIT	DOD %	MFR	3.5 in. dia CELLS TEMPERATURE		4.5 in. dia CELLS TEMPERATURE	TOTAL CELLS	
			10°C	−5°C	10°C	3.5 in.	4.5 in.
LEO	25	YARD	5			5	
		EP	5			5	
		GEBBD	5			5	
		HAC	5			5	
	40	YARD	10	10		20	
		EP	10Z	10A	10	20	10
		GEBBD	10	10		20	
		HAC	20		10	10	10
	60	YARD	10	10	10	10	10
		EP	10Z, 10A	10Z		30	
		GEBBD	10		10	10	10
		HAC	10	10		20	
MAO	80	YARD	10			10	
		EP	10		10*	10	10
		GEBBD	10		10*	10	10
		HAC	10			10	
SPECIAL TESTS 2 OR 3, 3.5 in. CELLS AND 1 + 4.5 in. CELL FROM EACH MANUFACTURER						10	5
					TOTAL CELLS	210	65

NiH_2 LEO Life Test

CELL ACQUISITION STATUS

MANUFACTURER	SIZE/CAPACITY	QUANTITY	DATE AVAILABLE
YARDNEY	3.0 in./50	31 (ZA)	NOW
EAGLE-PICHER (JOP)	3.5 in./50	24 (A)	NOW
		33 (Z)	NOW
EAGLE-PICHER (CS)	4.5 in./100	8 (Z)	12/86
	4.5 in./130	10 (Z)	04/87
GENERAL ELECTRIC BBD	3.5 in./50	15 (Z)	NOW
	3.5 in./50	15 (Z)	08/87
	4.5 in./100	8 (Z)	12/86
	4.5 in./130	10 (Z)	04/87
HUGHES AIRCRAFT	3.5 in./50	30 (Z)	08/87
	4.5 in./100	5 (Z)	12/86

	TOTAL CELLS ACQUIRED	TOTAL CELLS TO BE PURCHASED
3.5 in. LEO	148	62
4.5 in. LEO	21	24
4.5 in. GEO	20	

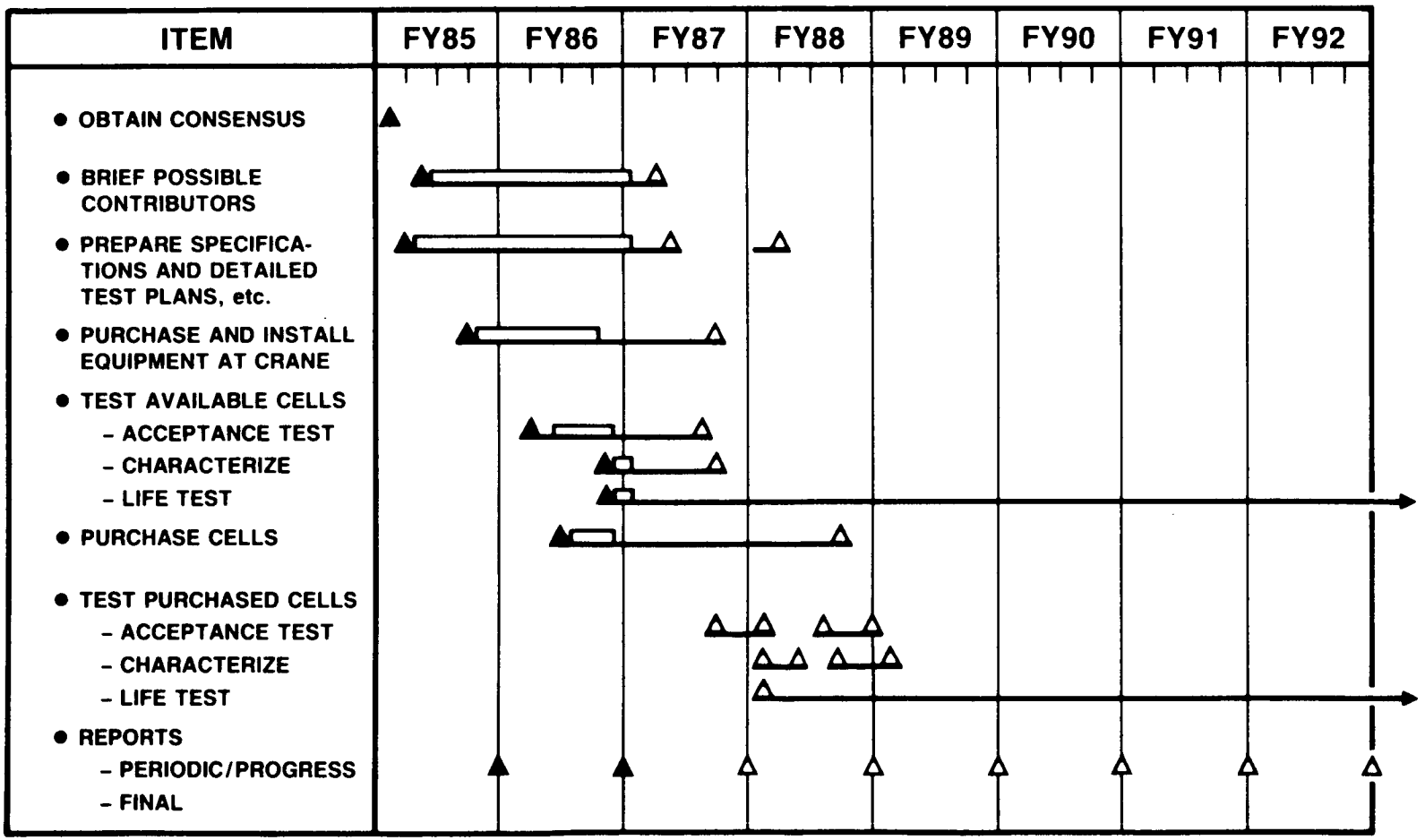
NiH_2 LEO Life Test

PROGRAM PLAN

- DOCUMENTATION
  - TEST PLAN (revision 5 in preparation)
    - STATISTICAL SUPPLEMENT (complete)
    - SPECIFICATION, INCLUDES ACCEPTANCE TEST (50 Ah complete)
    - CHARACTERIZATION PROCEDURE AND PLAN (complete)
    - SPECIAL TEST PROCEDURE (complete, not issued)
    - LIFE TEST PROCEDURE (in review)
    - FAILURE ANALYSIS PROCEDURE
    - ANNUAL STATUS AND MILESTONE REPORTS (FY85 and FY86 issued)
- TESTING
  - EQUIPMENT (most purchased in FY85)
  - RECEIVE AND ACCEPTANCE TEST CELLS (20% environmentally tested)
  - CHARACTERIZE 5 CELLS OF EACH DESIGN/VENDOR (non-destructive)
  - LIFE CYCLE TEST CELL PACKS
    - CYCLE UNTIL ~50% OF CELLS FAIL IN EACH PACK TO ESTABLISH FAILURE DISTRIBUTION

NiH_2 LEO Life Test

SCHEDULE



Special Testing at Aerospace

- SCOPE OF TEST
  - 10 – 3-1/2 INCH DIAMETER CELLS
  - 5 – 4-1/2 INCH DIAMETER CELLS
- PURPOSE OF TEST
  - VERIFY LIFE CAPABILITY OF NiH_2 CELLS IN A LEO ORBIT. REGIME CONTAINING HIGH RATE (5C) PULSES
- TEST SCENARIO
  - ACCEPTANCE AND CHARACTERIZATION TESTING AT CRANE
  - LIFE TESTING AT AEROSPACE — DURATION 3–5 YEARS FROM START
- TEST STATUS
  - SPECIAL HARDWARE AND SOFTWARE DESIGNED AND IN CONSTRUCTION
  - PRELIMINARY SYSTEM CHECK-OUT END OF NOVEMBER, 1986
  - LIFE TEST START DATE — ON RECEIPT OF CELLS

NiH_2 LEO Life Test

SUMMARY

- NiH_2 BATTERIES HAVE THE CAPABILITY TO OPERATE AT MUCH HIGHER ENERGY DENSITIES THAN NiCd BATTERIES
  - GREATEST ADVANTAGE IS IN LEO APPLICATIONS
  - CELL CAN BE SCALED TO LARGE CAPACITIES
- PROGRAM NEEDED TO ESTABLISH BASELINE DATA FOR ORBITAL USE OF NiH_2 CELLS IN LEO AND MAO
  - CORRELATE DESIGNS AND SIZES IN DATA BASE
- LIFE TEST PROGRAM ESTABLISHED TO PROVIDE REQUIRED DATA
  - LONG TERM TEST TO ESTABLISH LIFE
  - COORDINATE WITH OTHER LIFE TEST PROGRAMS
    - USE ALL DATA TO COMPLETE DATA BASE
  - NEED ADDITIONAL FUNDING TO COMPLETE PROGRAM AS PRESENTLY CONFIGURED
    - MODIFY PLAN TO CONFORM TO FUNDING BY MID-1987
- LIFE EVALUATION AND LONG TERM PERFORMANCE DATA WILL BEGIN TO BE AVAILABLE BY 1990