(NASA-TM-110582) EXECUTIVE SUMMARY: REPORT TO CODES E AND Q ASSOCIATE ADMINISTRATORS. RESULTS OF A TECHNICAL ANALYSIS OF THE HUBBLE SPACE TELESCOPE NICKEL-CADMIUM AND NICKEL-HYDROGEN CELLS (NASA) 78 p

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EXECUTIVE SUMMARY

REPORT TO CODES E AND Q ASSOCIATE ADMINISTRATORS

RESULTS OF A TECHNICAL ANALYSIS OF THE HUBBLE SPACE TELESCOPE NICKEL-CADMIUM AND NICKEL-HYDROGEN CELLS

BY
HST BATTERY REVIEW SUBCOMMITTEE,
NASA AEROSPACE FLIGHT BATTERY SYSTEMS STEERING COMMITTTEE

NASA HEADQUARTERS
NOVEMBER 3, 1989
WASHINGTON, D. C.

DISCLAIMER

1. THE PRESENTATION REFLECTS THE OPINION OF THE SUBCOMMITTEE MEMBERS. RESULTS ARE BASED UPON DATA AND INFORMATION PROVIDED BY MSFC, LMSC, AND EPI AND THE SUBCOMMITTEE MEMBERS' EXPERIENCE.

2. THIS REPORT DOES NOT NECESSARILY REFLECT THE POSITION OF THE SUBCOMMITTEE MEMBERS' RESPECTIVE ORGANIZATIONS.

3. THE REPORT HAS BEEN REVIEWED WITH THE MSFC HST, GSFC, AND HQS PROGRAM OFFICES. IT DOES NOT NECESSARILY REFLECT THE POSITION OF THE HST PROGRAM OFFICE.

AGENDA

1. PURPOSE AND OBJECTIVES

2. SUBCOMMITTEE PROCESS

3. FINDINGS:
   - 3.1 NI-CD
   - 3.2 NI-H_2

4. HST CONSIDERATIONS

5. RELATIVE RISKS

6. SUMMARY

1.0 PURPOSE AND OBJECTIVES OF THIS ANALYSIS

PURPOSE

ASSIST NASA IN ARRIVING AT THE PROPER BATTERY SELECTION FOR THE HUBBLE SPACE TELESCOPE SPACE OBSERVATORY:

CONDUCT AN INDEPENDENT TECHNICAL ANALYSIS OF THE RELATIVE MERITS OF THE TWO BATTERY CHEMISTRY OPTIONS -- NI-CD AND NI-H_2 -- AS DESIGNED FOR AND MADE APPLICABLE TO THE HST MISSION.

OBJECTIVES

1. ASSIST CODE E IN ITS DECISION PROCESS FOR THE SELECTION OF EITHER NICKEL-CADMIUM OR NICKEL-HYDROGEN BATTERIES FOR THE HST LAUNCH BY PROVIDING FINDINGS FROM THE SUBCOMMITTEE'S ANALYSIS.

2. PROVIDE CODE Q WITH AN INDEPENDENT ANALYSIS OF THE HUBBLE SPACE TELESCOPE BATTERY OPTIONS FOR FIRST FLIGHT.

2.0 SUBCOMMITTEE PROCESS

SUBCOMMITTEE MEMBERS AND AFFILIATION

SCHULZE, NORMAN, CHAIRMAN	HQS.
CLARK, KARLA	JPL
GASTON, STEPHEN	GE, ASTRO DIVISION
HILL, CAROLE (ALTERNATE TO DR. HWANG)	AEROSPACE
HWANG, WARREN, PhD	AEROSPACE
MANZO, MICHELLE	LEWIS RESEARCH CENTER
MAURER, DEAN, PhD	AT&T
METHLIE, GEORGE	CIA
PICKETT, DAVID, PhD	HUGHES
EX OFFICIO: WANNEMAKER, HARRY	MDAC (GSFC CONTRACTOR)

THE BATTERY AND SYSTEM RELATED EXPERIENCE ABOVE TOTALS 167 YEARS.

KEY SUBCOMMITTEE ACTIVITIES

DATE	EVENT	OBJECTIVE
JUNE 14	NAFBSSC MEETING	ESTABLISH COMMITTEE POSITION
JUNE 27	PARTICIPATION LETTERS	ORGANIZE SUBCOMMITTEE
JULY 6	DATA REQUEST TO MSFC	OBTAIN PREVIEW DATA PRIOR TO SITE VISIT
JULY 14	MSFC RESPONSE	DATA TRANSMITTAL SENT TO MEMBERS
JULY 20	SUBCOMMITTEE TELECON	ORGANIZATIONAL MEETING
JULY 25-27	MSFC SITE VISIT	DATA GATHERING
AUG. 7	IECEC SUBCOMMITTEE CAUCUS	ESTABLISH: REPORT OUTLINE, ASSIGNMENTS, AND SCHEDULE
AUG. 8	NOTIFY MSFC ON EPI VISIT	PREPARATION FOR ESTABLISHING EPI REVIEW TOPICS
AUG 16	FLIGHT EXPERIENCE REVIEW	CONSIDER DATA BASE BEYOND NASA'S
AUG. 22-24	EPI SITE VISIT	REVIEW OF CELL DATA
SEPT. 14-15	SUBCOMMITTEE MEETING AT GE	REVIEW, ANALYSE DATA, DEVELOP POSITIONS
SEPT. 18	DPA TELECON, MSFC	ESTABLISH DPA PROCEDURE
SEPT. 19-22	EPI SITE VISIT	FURTHER DATA REVIEW - ONE MEMBER
SEPT. 27	DPA TELECON, MSFC	OPTIONS, ELABORATIONS ON DPA
SEPT. 27	BRIEF G. RODNEY	TUTORIAL AND STATUS UPDATE
OCT. 2	BRIEF MSFC ON FINDINGS	REVIEW FINDINGS WITH PROJECT STAFF
OCT. 5	SUBCOMMITTEE TELECON	REVIEW DRAFT PRESENTATION MATERIAL
OCT. 10-13	NAFBSSC MEETING	REVIEW SUBCOMMITTEE FINDINGS
OCT. 23	BRIEF PROGRAM STAFF	COORDINATE RESULTS WITH HQS. CODE EZ, MSFC, AND GSFC HST PROGRAM OFFICES
OCT. 30	SUBCOMMITTEE UPDATE	MSFC UPDATE GIVEN ON DPA, TV, LAUNCH STAND, CELL FAILURE, SHORT REVIEWS
NOV. 3	HQS. DECISION MEETING	PRESENT FINDINGS TO CODES E & Q

APPROACH

- EVALUATE SYSTEM "AS IS"
  - -EVALUATE HST'S EXISTING DESIGN FEATURES IN THE "ABSOLUTE" SENSE WITHOUT REGARD TO IMPACT
- IDENTIFY PROBLEMS AND CONCERNS REAL TIME TO THE HST STAFF
- EXPEDITE THE REVIEW PROCESS
  - -MINIMIZE FORMALITIES
- REQUEST INFORMATION ONLY

SCOPE OF ANALYSIS

THE FOLLOWING AREAS WERE CONSIDERATIONS OF THE ANALYSIS:

1. REQUIREMENTS: CELLS AND BATTERY SYSTEM
2. DESIGN
3. QUALITY
4. SAFETY
5. RELIABILITY
6. TESTING: REQUIREMENTS AND RESULTS TO DATE
   - -QUALIFICATION
   - -ACCEPTANCE TESTING
   - -OTHER (DEVELOPMENTAL)
7. DATA BASE (CELL HISTORY) - COVERED SEPARATELY
8. SYSTEM INTEGRATION
9. GROUND HANDLING
10. FLIGHT OPERATIONS

SUBCOMMITTEE AREAS OF EXPERTISE

NICKEL-CADMIUM CHEMISTRY

	ELECTROCHEMISTRY	SYSTEMS	MANUFACTURING	GROUND OPERATIONS	FLIGHT	TESTING
CLARK		X			X	X
GASTON	X	X	X	X	X	X
HILL						
HWANG	X	X	X		X	X
MANZO	X					
MAURER	X	X	X	X	X	X
METHLIE	X	X	X	X	X	X
PICKETT	X	X	X	X	X	X

NICKEL-HYDROGEN CHEMISTRY

	ELECTROCHEMISTRY	SYSTEMS	MANUFACTURING	GROUND OPERATIONS	FLIGHT	TESTING
CLARK		X				
GASTON	X	X	X	X	X	X
HILL			X			X
HWANG	X	X	X		X	X
MANZO	X					X
MAURER	X	X	X			X
METHLIE	X	X	X	X	X	X
PICKETT	X	X	X	X	X	X

HST MISSION DURATION OPTIONS CONSIDERED

THE FOLLOWING MISSION DURATIONS WERE CONSIDERED FOR BOTH CHEMISTRIES:

- 30 MONTHS -- CONTRACTURAL REQUIREMENT
- 60 MONTHS -- DESIRED
- GREATER THAN 60 MONTHS -- FOR CONSIDERATION

ASSUMPTIONS

THE FOLLOWING INTERFACES WERE NOT EXAMINED IN DETAIL BY THE SUBCOMMITTEE BUT WERE ACCEPTED AS REFERENCE INPUTS. ANY OF THESE PARAMETERS CAN HAVE A SIGNIFICANT IMPACT ON THE DECISION PROCESS FOR THE POWER SYSTEM.

- SOLAR ARRAY POWER OUTPUT (2 YEAR SPECIFICATION). {SUBCOMMITTEE DID NOT LOOK AT EXTENDED LIFE.}
- ELECTRICAL LOAD REQUIREMENTS {SUBCOMMITTEE DID NOT LOOK FOR TRANSIENT OR PEAK LOADS.}
- TEMPERATURE BALANCE REQUIREMENTS, HEAT LOAD ESTIMATES, AND THERMAL MAINTENANCE. {NO INDEPENDENT ANALYSIS DONE.}

3.0 FINDINGS: ANALYSIS RESULTS

3.1 NI-CD

FINDINGS: STRONG NI-CD POINTS SUMMARY

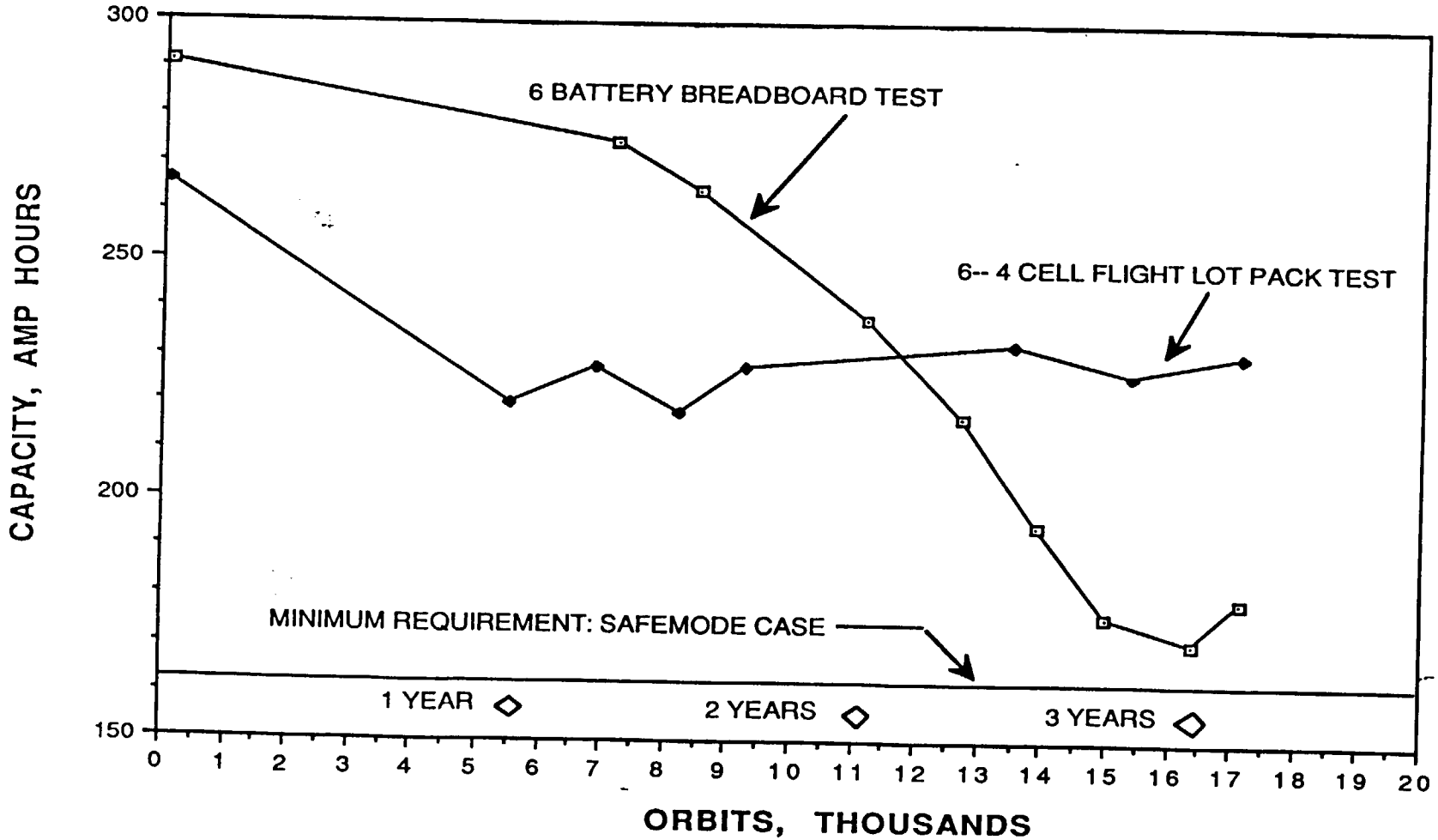
- EXTENSIVE TEST PROGRAM
  - 42 MONTH 6 BATTERY TEST SHOWS CAPABILITY OF THE SYSTEM -- WHEN NEW CELLS ARE USED -- TO MAINTAIN SUFFICIENT CHARGE CAPACITY TO MEET SAFE MODE REQUIREMENTS
  - 6 FOUR CELL PACK LIFE CYCLE TEST OF FLIGHT LOT CELLS -- PROVIDES ADDITIONAL CONFIDENCE IN THE FLIGHT LOT WHEN NEW CELLS ARE USED
- POWER SYSTEM BATTERY PROTECTION AND RECONDITIONING CAPABILITY
- APPROPRIATE CHARGING SYSTEM
- PROPER GROUND HANDLING: CELLS DISCHARGED, STORED COLD, AND SHORTED
- WELL ESTABLISHED FLIGHT OPERATIONAL EXPERIENCE: NI-CD'S (GATES) USED BY GSFC IN OTHER PROGRAMS

FINDINGS: WEAK NI-CD POINTS SUMMARY

- LIFE CYCLE PERFORMANCE OF CELLS SUBSEQUENT TO A FIVE YEAR SHELF LIFE NOT PROVEN BY 6 BATTERY TEST.
  - DEGRADATION COMMENCES FROM THE TIME OF ACTIVATION. FLIGHT CELLS, ACTIVATED FOR 5 YEARS. (DPA IN PROGRESS)
  - 45% LOSS IN CAPACITY IN 42 MONTHS BASED UPON NEW CELL PERFORMANCE AS DEMONSTRATED BY THE 6 BATTERY TEST.
  - 12% LOSS IN CAPACITY IN 42 MONTHS AS DEMONSTRATED BY THE 6 FOUR CELL PACK TEST
- WITH LONG TERM STORAGE, CELL LIFE WILL PROBABLY NOT EXCEED ~3 YEARS
  - FIRST CELL FAILURE -- SHORT AT 18,308 ORBITS (NEW CELLS--6 BATTERY TEST).
- CELL QUALITY UNCERTAINTIES: CELL PERFORMANCE VARIABILITY
- QUALIFICATION PROGRAM NOT CONDUCTED ON FLIGHT CELL OR BATTERY
  - BATTERY PROTOFLIGHT ACCEPTANCE USED INSTEAD. LACKS MARGIN AND DURATION OF A QUAL PROGRAM
- POSSIBLE LEAKAGE THRU VENT VALVE (A FAILURE MODE CONCERN -- NOT ACTUAL DATA)
- RELATIVELY LITTLE NASA FLIGHT EXPERIENCE WITH THIS MANUFACTURER'S CELL

NI-CD BATTERY CAPACITY LOSS

HST NICKEL-CADMIUM BATTERY CAPACITY DEGRADATION WITH CYCLE LIFE (5 LOW BATTERIES):
6 BATTERY BREADBOARD TEST AND FLIGHT LOT 4 CELL PACK TEST



3.2 NI-H_2

FINDINGS: STRONG NI-H_2 POINTS SUMMARY

- GOOD CELL DESIGN
- BETTER PLATE IMPREGNATION PROCESS
- BETTER SINTER PLATE PROCESS
- PASSED PLATE STRESS TEST
- EXTENSIVE TEST PROGRAM INITIATED
- HAS RECONDITIONING CAPABILITY BUT MAY NOT REQUIRE CELL RECONDITIONING
- GREATER CAPACITY (87 vs 55 AH)
- 2 REDUNDANT BATTERIES
- GOOD MANUFACTURING CONTROL DOCUMENT (MCD)
- HIGH CELL QUALITY
- PROPER GROUND HANDLING: CELLS DISCHARGED, STORED OPEN, AND STORED COLD (O TO 5 ^{o}C)
- EAGLE PICHER HAS MORE FLIGHT EXPERIENCE WITH NI-H_2 THAN ANY OTHER MANUFACTURER HAS.

FINDINGS: WEAK NI-H_2 POINTS SUMMARY

- LIMITED CELL DATA BASE IN GENERAL: FIRST USE -- CANNOT QUALIFY BY SIMILARITY.
- SPECIFICALLY, LACK OF LEO DATA BASE ON HST DESIGN: CELL DESIGN NOT PROVEN BEFORE FLIGHT.
  - CELLS OPERATED AT LOW DEPTH OF DISCHARGE, A NEW OPERATIONAL REGIME (SHOULD BE CONSERVATIVE)
  - CELLS OPERATED AT LESS THAN FULL STATE OF CHARGE
- "OPEN" CELL FAILURE MODE: ONE OPEN CELL FAILS THE BATTERY. (NO DIODE PROTECTION)
- LACK OF GSFC OPERATIONAL EXPERIENCE IN FLIGHT: NEW LEARNING CURVE.
- HIGH SELF DISCHARGE RATE: TESTS JUST COMPLETED IN MID OCTOBER SHOW ENOUGH CAPACITY FOR DEPLOYMENT ON ORBIT BUT NOT IF A LAUNCH DELAY MUCH GREATER THAN THE 2 DAY CONTINGENCY IS EXPERIENCED.
- CELL PERFORMANCE DEGRADES WITH HIGH TEMPERATURES: REQUIRES GREATER ATTENTION TO TEMPERATURE. THERMAL VACUUM TEST SHOWS MAINTENANCE OF ADEQUATE TEMPERATURES.

HST NI-H_2 TESTING AT MSFC

TEST ACTIVITY*	REQUIREMENTS		ACCUMULATED TEST TIME AS OF: NOVEMBER 1989			MARCH 1990	
	CYCLES	YEARS	CYCLES	YEARS	%	CYCLES	YEARS
• 4 CELL PACK	13,697/ 27,395	2.5/ 5.0					
TM-1 (4 CELLS)			4252	0.8	16	6457	1.2
TM-2 (4 CELLS)			3680	0.7	13	5885	1.1
• 6 BATTERY TEST							
TM-1 (66 CELLS)			2815	0.5	10	5020	0.9
TM-2 (66 CELLS)			2815	0.5	10	5020	0.9
• 4 CELL PACK (FSM LOT)			3000	0.5	11	5205	1.0
• 22 CELL FSM BATT. TEST			2133	0.4	8	4338	0.8
• 3 BATTERY FSM TV TEST			> 300			> 300	

* FSM = FLIGHT CELLS; TM HAS DIFFERENT ACTIVATION AND INITIAL BURN-IN PROCESS.

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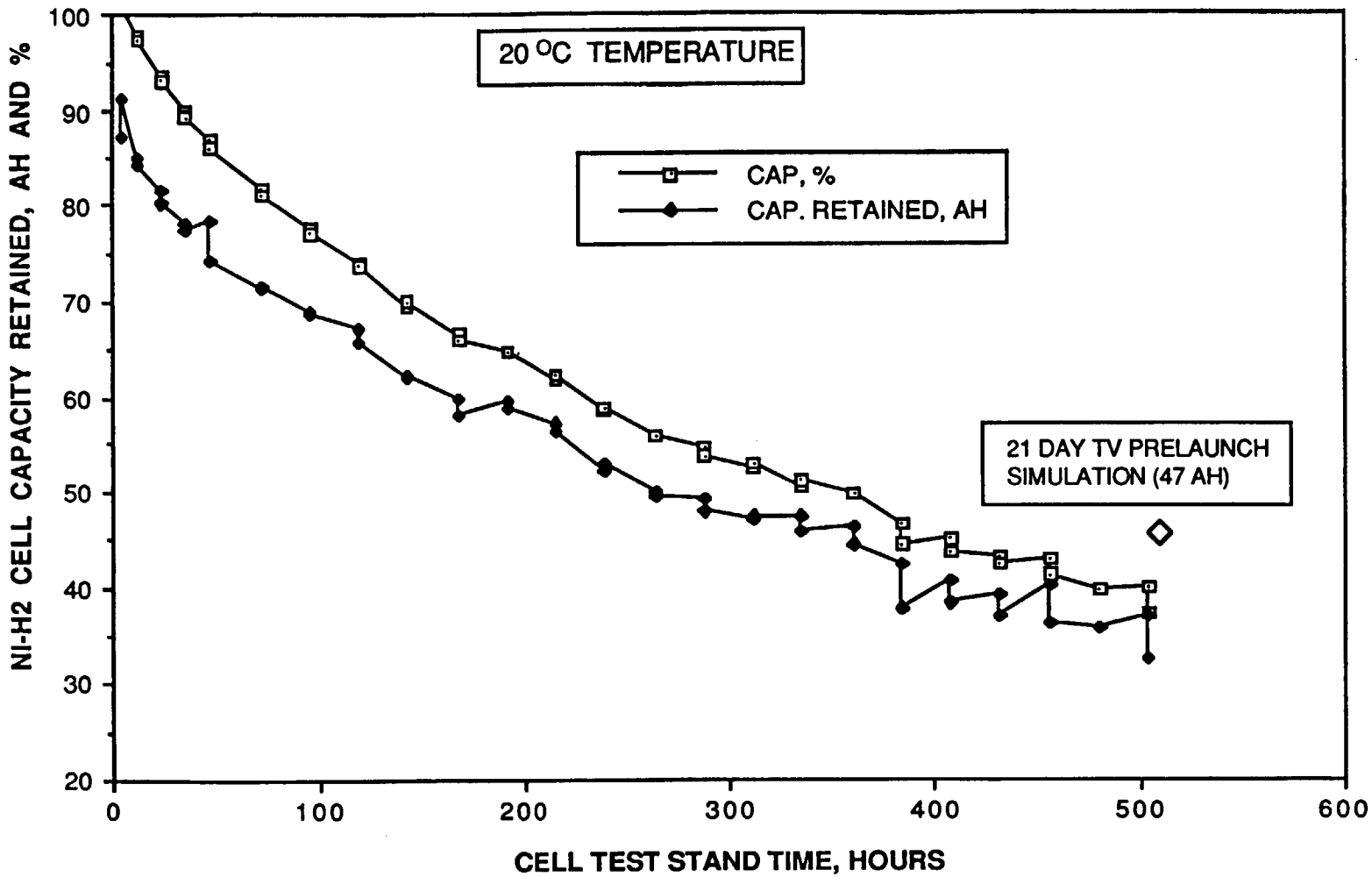
NI-H_2 STAND CAPACITY LOSS



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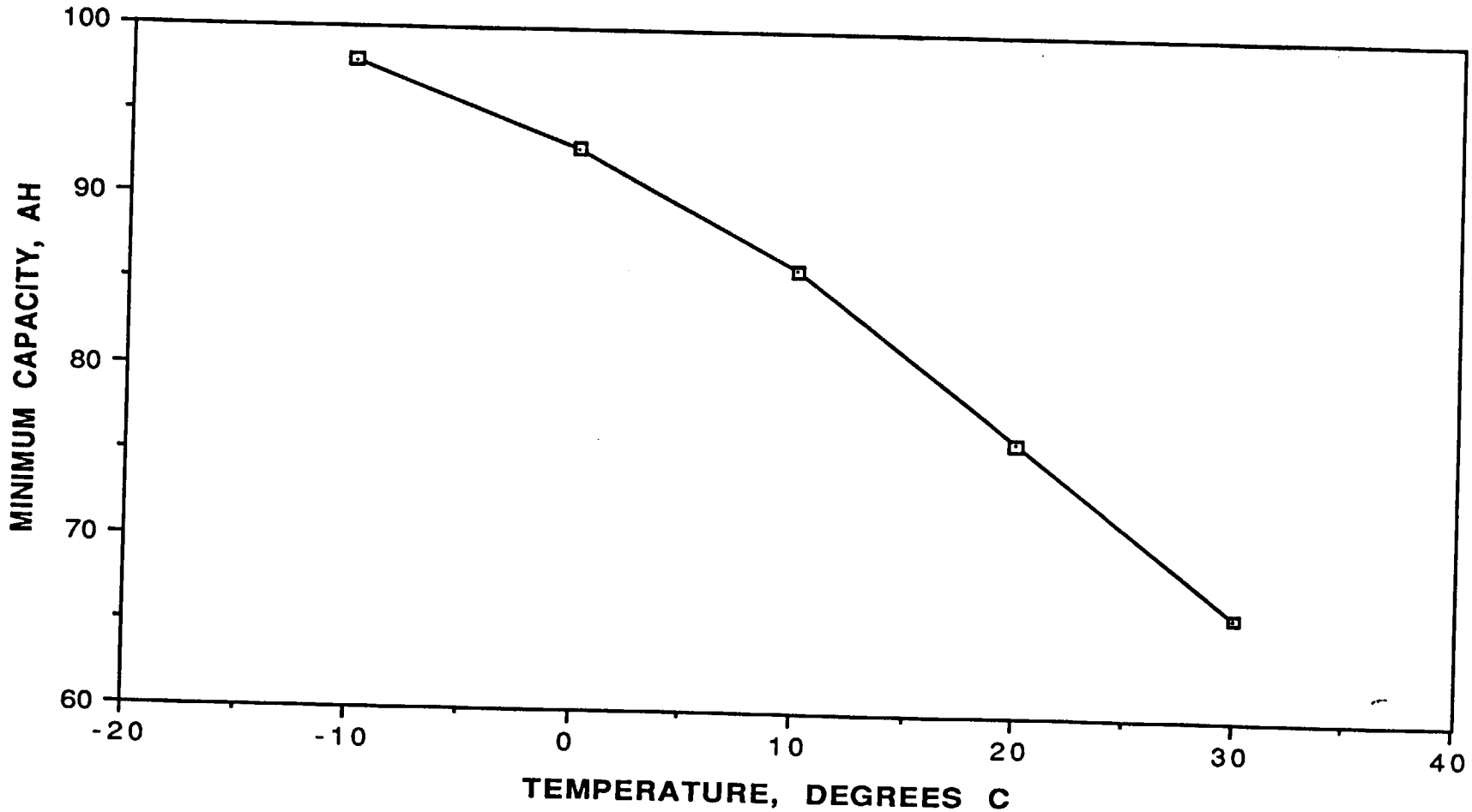
NI-H_2 CAPACITY LOSS WITH TEMPERATURE



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4.0 CONSIDERATIONS FOR THE HST PROGRAM

HST SAFEGUARD OPPORTUNITIES

- **MAINTAIN BOTH OPTIONS**

BOTH DESIGNS, IF KEPT FULLY ACTIVE IN THE LAUNCH PLANNING PROCESS AND IN THE GROUND TEST PROGRAM, PROVIDE THE HST WITH A QUICK, EMERGENCY OPTION USING ONLY A THREE WEEK TURNAROUND -- A PLEASANT, UNIQUE POSITION IN TODAY'S BATTERY SITUATION.

- **CONTINUE TESTING ON BOTH OPTIONS**

TESTING IS THE BEST INDICATOR OF THE DESIGN OF CHOICE. THE MORE DATA OBTAINED, THE BETTER THE CONFIDENCE LEVEL AND THE LOWER THE RISK. DEFERRING THE FINAL COMMITMENT AS LONG AS POSSIBLE (UP TO T-3 WEEKS) MINIMIZES THE PROGRAM IMPACT IN THE EVENT THAT ANY SUDDEN CHANGE IN PLANS ARE INDICATED. CONTINUE TESTING AFTER LAUNCH FOR FLIGHT SUPPORT AND ANALYSIS -- PROVIDES PREDICTIVE CAPABILITY AND REAL TIME TROUBLE SHOOTING SYSTEM.

- **CHECK FOR ELECTRICAL SHORT HAZARDS**

A CHECK OF ALL BATTERY MODULES FOR POTENTIAL AREAS FOR SHORTS BEFORE LAUNCH WOULD BE OF BENEFIT TO REDUCE THE SHORTING RISK. THE SUBCOMMITTEE NOTED ONE SUCH SITUATION BUT WAS UNABLE TO INSPECT MORE THAN THE NICKEL HYDROGEN FM-1 MODULE SINCE THEY WERE EITHER SEALED, NOT COMPLETED, OR LOCATED ELSEWHERE.* SHORT CONCERNS APPLY TO BOTH CHEMISTRIES. NI-CD ELECTROLYTE LEAKAGE AND PARTICULATE CLEANLINESS IS A CONCERN WHICH WARRANTS A PRELAUNCH INSPECTION .

* NOTE: CORRESPONDENCE FROM ROY LANIER SHOWS SUGGESTED "FIX" HAS BEEN APPLIED TO ALL HST FLIGHT HARDWARE.

HST SAFEGUARD OPPORTUNITIES

- **CERTIFY RSN 55-15 CELL FOR LIFE CYCLE PERFORMANCE AFTER STORAGE**

  PROPERLY PERFORM DPA ON CYCLED CELLS AND EVALUATE CELL DEGRADATION FROM STORAGE. IN WORK

- **PERFORM VIBRATION QUAL TESTING ON THE RSN 55-15 CELLS**

  QUAL WOULD VERIFY THE NEW CELL'S DESIGN TO WITHSTAND THE ANTICIPATED DYNAMIC FLIGHT LOADS FOR THE FLIGHT DURATION.

- **NI-H_2 CELL SHORT:**

  EVALUATE THE NI-H_2 HAZARD OF CELL SHORTS BY THE CONDUCT OF TESTS.

- **MAKE DETAILED CLOSE-OUT PHOTOS**

  THESE COULD BE OF VALUE IN CASE OF TROUBLE SHOOTING AND IN ANY POSSIBLE FUTURE INVESTIGATIONS.

PLANNED COMMITTEE ACTIVITIES

- FOLLOW-UP ITEMS:

OPEN ITEM UPDATE TELECON WITH MSFC - OCT. 30, 1989.

-NI-CD DPA: (OPEN)

- o MINIMAL DEGRADATION OF SEPARATOR.
- o CARBONATE CONCENTRATION IN PLATE -- UNBELIEVABLY LOW.

SUBCOMMITTEE TO EXAMINE CELLS AND REMAINDER OF DPA RESULTS.

-NI-H_2 PRELAUNCH SIMULATION TEST: (CLOSED)

- o ENERGY STORAGE REQUIREMENT DEMONSTRATED.
- o MEETS PLANNED LAUNCH FLOW FOR 2^+ DAY LAUNCH DELAY CONTINGENCY.

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PLANNED COMMITTEE ACTIVITIES

-<u>NI-H_2 TV TESTING</u>: (CLOSED)

- o 6.8 ^{o}C MAX. MEASURED CELL TEMPERATURE.
- o ADEQUATE THERMAL GRADIENT MEASURED ACROSS BATTERY.

- **COMPLETE WRITTEN TECHNICAL REPORT**

5.0 RELATIVE RISKS

RELATIVE RISK SUMMARY -- CATASTROPHE

THE HST IS LESS LIKELY TO EXPERIENCE A SUDDEN, CATASTROPHIC LOSS OF POWER USING NI-CD BATTERIES.

CATASTROPHIC[1] CONDITIONS LEADING TO SUDDEN LOSS OF BATTERY POWER

	NI-CD	NI-H_2
• CELL FAILURES		
-LEAK CONSEQUENCES	+	-
-EXTERNAL SHORTS	+	-
-INTERNAL SHORTS	-	+
-ELECTROLYTE REDISTRIBUTION	+	-
• SYSTEM FAILURES		
-BPRC FAILURE[2]	-	+
-SHORTS	-	-

+ = STRONG POINT
- = WEAK POINT

THE CHANCE OF A SUDDEN LOSS OF ENERGY STORAGE IS NOT CONSIDERED TO BE LARGE, BASED UPON EXPERIENCE TO DATE REGARDING EITHER CHEMISTRY.

1- CATASTROPHE = LOSS OF CAPACITY WITHIN ONE YEAR -- THE ASSUMED M & R TIME
2- FAILURE OF THE BPRC TO PROTECT AGAINST CELL VOLTAGE DEGRADATION.

RELATIVE RISK SUMMARY - MISSION LIFE

THE HST IS MORE LIKELY TO RECEIVE THE DESIRED 5 YEAR ENERGY STORAGE LIFE CYCLE CAPABILITY USING THE HST NI-H_2 BATTERIES.

INDICATORS WHICH PROVIDE CONFIDENCE IN THE ATTAINMENT OF THE REQUIRED POWER OUTPUT OVER A MISSION DUTY CYCLE

	NI-CD	NI-H_2
1. HST TESTING: CYCLE LIFE ELECTRICAL DATA	+[1]	-
2. CELL DESIGN	-	+
3. CELL QUALITY	-	+
4. QUAL ADEQUACY	-	+
5. CONSERVATIVE OPERATION IN FLIGHT	+	+
6. FLIGHT EXPERIENCE WITH EPI CELLS	-	-[2]
7. ON ORBIT MARGIN IN CAPACITY	-	+
8. NEWNESS OF FLIGHT CELLS	-	+

+ = STRONG POINT
- = WEAK POINT

1. THE POSITIVE POINT ASSUMES NEW CELLS.
2. THERE IS EXTENSIVE EXPERIENCE WITH NI-H2 CELLS IN GEO, NOT LEO. ONLY TWO OTHER NASA PROGRAMS USED EPI NI-CD CELLS.

6.0 SUMMARY OF FINDINGS

SUBCOMMITTEE'S MAJOR FINDINGS

NOTE:

THESE FINDINGS ADDRESS ONLY THE EPI NICKEL-CADMIUM AND NICKEL-HYDROGEN CELLS/BATTERIES AS READY FOR LAUNCH FOR THE HST PROGRAM IN CONSIDERATION OF THEIR ABILITY TO PERFORM 3 HST MISSION OPTIONS.

1. EPI NI-H_2 CELLS: BETTER SUITED FOR HST'S CYCLE LIFE REQUIREMENTS AS PRESENTLY ENVISIONED (60+ MONTHS DESIRED VS 30 MONTH SPECIFICATION VALUES).

2. NI-H_2 RISK: LACKS HST LIFE CYCLE QUALIFICATION DATA AND DATA BASE FOR LEO APPLICATION.

3. DEGREE OF NI-H_2 RISK: REASONABLE BUT NOT WITHOUT CONCERN.

4. NICKEL-CADMIUM CELLS: 6 BATTERY TEST PERFORMANCE USING NEW FLIGHT CELLS DEMONSTRATED 30 MONTH CAPABILITY. BUT FLIGHT CELLS DEGRADE OVER A 4.5 YEAR PERIOD OF ACTIVATED STORAGE. PERFORMANCE AFTER 4.5 YEARS IS A QUESTION BEING ADDRESSED.

5. NI-CD CELLS: FLIGHT CELLS NOT LIKELY TO BE DEPENDABLE MUCH BEYOND 30 MONTHS.

EXECUTIVE SUMMARY

BACK-UP MATERIAL

RESULTS OF A TECHNICAL ANALYSIS OF THE HUBBLE SPACE TELESCOPE NICKEL-CADMIUM AND NICKEL-HYDROGEN CELLS

REVIEW PROCESS

- DATA REQUEST & REVIEW
- MSFC SITE VISIT
- EAGLE PICHER SITE VISIT
- EVALUATE REQUIREMENTS, IMPLEMENTATION, PLANNING, AND STATUS
- COMPARE HST BATTERY/CELL DESIGN WITH AVAILABLE DATA BASES
- SUBCOMMITTEE CAUCUS AT GE ASTRO DIVISION
- TELECONS AS REQUIRED TO RESOLVE PROBLEMS, OBTAIN CLARIFICATIONS, DEBATE, OBTAIN CONSENSUS

3.0 SUMMARY OF ANALYTICAL FINDINGS

SUBCOMMITTEE'S MAJOR FINDINGS

NOTE:

THESE FINDINGS ADDRESS ONLY THE EPI NICKEL-CADMIUM AND NICKEL-HYDROGEN CELLS/BATTERIES AS READY FOR LAUNCH FOR THE HST PROGRAM IN CONSIDERATION OF THEIR ABILITY TO PERFORM 3 HST MISSION OPTIONS.

1. EPI NI-H_2 CELLS: BETTER SUITED FOR HST CYCLE LIFE REQUIREMENTS.

THE HST PROGRAM, WHETHER CONSIDERING A MISSION DURATION OF 30, 60, OR 60+ MONTHS, WILL MORE LIKELY MEET THE PROGRAM'S ENERGY STORAGE REQUIREMENTS USING THE NICKEL-HYDROGEN CHEMISTRY.

SUBCOMMITTEE'S MAJOR FINDINGS

NOTE:

THESE FINDINGS ADDRESS ONLY THE EPI NICKEL-CADMIUM AND NICKEL-HYDROGEN CELLS/BATTERIES AS READY FOR LAUNCH FOR THE HST PROGRAM IN CONSIDERATION OF THEIR ABILITY TO PERFORM 3 HST MISSION OPTIONS.

2. NI-H_2 RISK: LACK OF QUALIFICATION DATA

THERE IS RISK ASSOCIATED WITH RELIANCE UPON THE LIMITED NI-H_2 DATA BASE, PARTICULARLY SINCE THIS IS THE FIRST MAJOR LEO MISSION APPLICATION OF THIS NEW TECHNOLOGY AND ITS OPERATION IN A NEW, MORE DEMANDING OPERATIONAL REGIME THAN THAT CURRENTLY EXPERIENCED IN GEO.

SUBCOMMITTEE'S MAJOR FINDINGS

NOTE:

THESE FINDINGS ADDRESS ONLY THE EPI NICKEL-CADMIUM AND NICKEL-HYDROGEN CELLS/BATTERIES AS READY FOR LAUNCH FOR THE HST PROGRAM IN CONSIDERATION OF THEIR ABILITY TO PERFORM 3 HST MISSION OPTIONS.

3. DEGREE OF RISK: REASONABLE BUT NOT WITHOUT CONCERNS

WITH THE EXCEPTIONS (LACK OF DODE AND REDUNDANT WIRING PROTECTION) AS NOTED IN THE FINDINGS, THE PROGRAM HAS TAKEN PRUDENT MEASURES TO ASSURE THE SUCCESS OF THE ENERGY STORAGE PROGRAM. CONSEQUENTLY, THE RISK IDENTIFIED IN FINDING NUMBER 2 IS A REASONABLE ONE, BASED UPON THIS SUBCOMMITTEE'S ANALYSIS AND BATTERY EXPERIENCE.

SUBCOMMITTEE'S MAJOR FINDINGS

NOTE:

THESE FINDINGS ADDRESS ONLY THE EPI NICKEL-CADMIUM AND NICKEL-HYDROGEN CELLS/BATTERIES AS READY FOR LAUNCH FOR THE HST PROGRAM IN CONSIDERATION OF THEIR ABILITY TO PERFORM 3 HST MISSION OPTIONS.

4. NICKEL-CADMIUM CELLS: FLIGHT CELLS NOT DEMONSTRATED

THE NICKEL-CADMIUM BATTERIES CAN BE EXPECTED TO PERFORM FOR THE DURATION OF THE 30 MONTH MISSION ONLY IF THE 5 YEAR SHELF LIFE HAS NOT RESULTED IN UNACCEPTABLE CELL DEGRADATION. BASED UPON THE MEMBERS ELECTROCHEMICAL UNDERSTANDINGS, SOME CELL DEGRADATION HAS OCCURRED.

AT THE TIME OF THIS ANALYSIS, THAT HAS NOT BEEN DEMONSTRATED TO THE SATISFACTION OF THIS SUBCOMMITTEE.

STEPS ARE NOW (OCT) BEING TAKEN BY THE PROGRAM TO RESOLVE THE SUBCOMMITTEE'S CONCERNS.

SUBCOMMITTEE'S MAJOR FINDINGS

NOTE:

THESE FINDINGS ADDRESS ONLY THE EPI NICKEL-CADMIUM AND NICKEL-HYDROGEN CELLS/BATTERIES AS READY FOR LAUNCH FOR THE HST PROGRAM IN CONSIDERATION OF THEIR ABILITY TO PERFORM 3 HST MISSION OPTIONS.

5. **NI-CD CELLS: NOT LIKELY TO GO MUCH BEYOND 30 MONTHS**

FOR A MISSION DURATION BEYOND 30 MONTHS, THE SUBCOMMITTEE CONSIDERS THAT THERE IS A HIGH PROGRAM RISK IN RELYING UPON THESE PARTICULAR NICKEL-CADMIUM BATTERIES.

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REMAINDER OF REPORT

- RESULTS OF ANALYSIS THAT LED TO THOSE FINDINGS.
  - POSITIVE RESULTS
  - CONCERNS ASSOCIATED WITH EITHER OPTION.
- PLANNED SUBCOMMITTEE ACTIVITIES

4.0 BACKGROUND DISCUSSION ON BATTERIES

TASK OF SUBCOMMITTEE

BECAUSE THE PROGRAM HAS NOT CONDUCTED A FULL QUALIFICATION PROGRAM, INCLUDING THE LIFE CYCLES OVER THE EXPECTED ENVIRONMENTAL AND OPERATIONAL FLIGHT REGIME, A BROAD BASED SCOPE -- AS DEFINED EARLIER -- WAS CHOSEN AS ESSENTIAL TO PROVIDE AN EVALUATION OF THE RELATIVE MERITS OF THESE TWO CHEMISTRIES.

IT IS IMPORTANT TO UNDERSTAND THE DESIGN FEATURES WHICH THE SUBCOMMITTEE CONSIDERS IMPORTANT TO THE SUCCESSFUL USE OF THESE CELLS.

NICKEL-HYDROGEN DEVELOPMENTAL INCENTIVES

- PRODUCE LARGE GAIN IN CYCLE LIFE AND REDUCE WEIGHT. REPLACE LIFE LIMITING COMPONENTS:
  - REPLACE THE LIFE LIMITING NEGATIVE ELECTRODE WITH PROVEN FUEL CELL PLATINUM ELECTRODE
  - ELIMINATED CADMIUM SOLUBILITY, MOBILITY AND NEGATIVE STATE OF CHARGE INCREASE, DENDRITE FORMATION
  - ELIMINATE/REDUCE SEPARATOR HYDROLYSIS EFFECTS: REPLACE NYLON SEPARATOR WITH INERT SEPARATOR.
- HIGHER EFFECTIVE ENERGY DENSITY

(NOTE: A SIDE BENEFIT IS THAT CELL PRESSURE PROVIDES A DIRECT MEANS FOR KNOWING STATE OF CHARGE.)

REFERENCE DESIGNS

- NI-CD
  - GATES (FORMERLY GE) CELL DESIGNS --
    - o CELL SUPPLIER FOR NEARLY ALL OF THE AEROSPACE INDUSTRY
    - o NASA STANDARD - GATES
  - EAGLE PICHER:
    - o HST. NASA'S ONLY CURRENT APPLICATION.
    - o SOME DOD USE
- NI-H_2
  - COMSAT
  - HUGHES MANTECH (AIR FORCE)
    - o HST (MILSTAR + AF FEATURES)

THEORETICAL DESCRIPTION

NI-CD

POSITIVE ELECTRODE-

$$Ni(OH)_2 + OH^- \underset{\text{DISCHARGE}}{\overset{\text{CHARGE}}{\rightleftharpoons}} NiOOH + H_2O + e$$

NEGATIVE ELECTRODE-

$$1/2Cd(OH)_2 + e \rightleftharpoons 1/2Cd + OH^-$$

Ni-H_2

POSITIVE ELECTRODE-

$$Ni(OH)_2 + OH^- \rightleftharpoons NiOOH + H_2O + e$$

NEGATIVE ELECTRODE-

$$H_2O + e \rightleftharpoons 1/2H_2 + OH^-$$

5.0 FINDINGS: ANALYSIS RESULTS

5.1 NI-CD

5.1.1. SHELF LIFE EFFECTS: FLIGHT CELLS NOT PROVEN.

THE 6 BATTERY TEST PROGRAM HAS COMPLETED 42 MONTHS (OCT) OF TESTING -- MEETS REQUIREMENTS FOR NEWLY BUILT CELLS. LOSS OF CAPACITY IS BEING EXPERIENCED. THE DEGREE TO WHICH THAT TESTING VALIDATES THE FLIGHT CELLS IS QUESTIONED SINCE THE TEST ARTICLES USE CELLS WHICH WERE ONLY ~4 MONTHS OLD AT TEST COMMENCEMENT. THE HST FLIGHT ARTICLE WILL USE CELLS THAT HAVE EXPERIENCED DEGRADATIVE EFFECTS OVER A 5 YEAR DURATION.

DISCUSSION:

- NI-CD CELLS ARE KNOWN TO DEGRADE WITH TIME FROM ACTIVATION INCLUDING INACTIVE STORAGE
- DPA PERFORMED:
  - -ON 2 CYCLED CELLS WITH NON FLIGHT SEPARATOR (T-41; SHORT STORAGE, 2506, 28K CYCLES). SEVERE SEPARATOR DETEORIATION, O/C NORMAL
  - -ON 3 UNCYCLED CELLS WITH 3.5 YEARS STORAGE (FLT. SEP.). SEP. LOOKS GOOD
  - -ON 3 UNCYCLED CELLS (T-41; NON FLT. SEP.) AT 54, 63, AND 66 MONTHS. SOME = PLATE GROWTH, SEP. OK.
- DPA NOT ACCOMPLISHED ON CYCLED FLIGHT CELLS
  - -AGREEMENT REACHED TO TEST FOUR FLIGHT CELLS: 2 CELLS AFTER 100 CYCLES TO THE HST DUTY CYCLE; 2 UNCYCLED CELLS AS CONTROL CELLS.
- SPECIFIC PROCEDURES REQUESTED BY THE SUBCOMMITTEE

5.1.1. SHELF LIFE EFFECTS CON'T.

IMPACT:

- POTENTIAL FOR REDUCED CYCLE LIFE OF STORED FLIGHT CELLS. NEW CELLS TESTED FOR 42 MONTHS HAVE DEGRADED BY 45 % IN CAPACITY AND HENCE DO NOT EXHIBIT MUCH CYCLE LIFE MARGIN.

5.1.3 CELL DESIGN/MANUFACTURING PROCESS.

THE CELL DESIGN, AS A DELIVERED PRODUCT, IS NOT OPTIMIZED FOR LONG LEO CYCLE LIFE.

DISCUSSION:

- AMOUNT OF OVERCHARGE PROTECTION LOW
- HIGH AMOUNT OF PRECHARGE
- VENTED CELL
- PLATE SWELLING NOT MINIMIZED
- CARBONATE LEVEL NOT CONTROLLED TO SUFFICIENTLY LOW LEVEL

IMPACT:

- SHORTER CELL CYCLE LIFE RESULTS FROM THE PERFORMANCE POTENTIAL THAT IS POSSIBLE FROM NI-CD TECHNOLOGY

5.1.3 QUALITY CONTROL.

THE QUALITY DOCUMENTATION ON THIS CELL AND ITS PROCESS CONTROLS IS WEAK.

DISCUSSION:

- LACKS TRACEABILITY
- PLATE POROSITY DISTRIBUTION DATA
- PLAQUE BENDING DATA
- MCD LACKS DETAIL

IMPACT:

- RESULTS IN POTENTIALLY GREATER VARIABILITY OF CELL PERFORMANCE

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5.1.4 QUALIFICATION TESTING.

NEITHER THE TYPE 44 BATTERY NOR ITS RSN 55-15 CELL RECEIVED A FORMAL QUALIFICATION TEST PROGRAM.

DISCUSSION:

- PROTOFLIGHT (FLT. LEVEL/SHORT DURATION) VIBRATION TEST PERFORMED ON TYPE 44 BATTERY IN LIEU OF QUAL. FULL QUAL PERFORMED ON TYPE 40 CELL. THE DESIGNS ARE DIFFERENT. LOAD MARGINS AND FLT. DUR. TIME ARE NOT DEMONSTRATED.

- 17 CHANGES MADE TO THE TYPE 41 CELL. TYPE 40 RECEIVED CELL VIBRATION. SOME CHANGES COULD AFFECT CELL SUSCEPTIBILITY TO DAMAGE.

- THE PROGRAM IS IN THE PROCESS OF DEVELOPING CONTINGENCY PROCEDURES. CARE MUST BE TAKEN TO KEEP CELL TEMPERATURES ABOVE THE -7 ^{o}C LIMIT.

5.1.4 QUALIFICATION TESTING (CON'T.).

IMPACT:

- CELLS WILL BE FLOWN UNQUALIFIED
- POTENTIAL FOR PREMATURE CELL FAILURE DUE TO DYNAMIC LOADS

5.1.5 RELIEF VALVE LEAKAGE.

CELL DESIGN USES OF THE BUNSEN CELL PRESSURE RELIEF VALVE WHICH PROVIDES A POTENTIAL LEAK PATH FOR THE ELECTROLYTE AND CELL GAS.

DISCUSSION:

- MAIN CONCERN IS A VENT WHICH MAY RESULT IN LOSS OF SEAL INTEGRITY.
- OVERCHARGING IS THE ACT THAT MAY RESULT IN VENTING OF O_2 & H_2 AND POSSIBLE PERMANENT LEAK CAUSING LOSS OF ELECTROLYTE & GAS AND ULTIMATELY LEADING TO CELL FAILURE.
- SYSTEM DESIGNED CAREFULLY TO AVOID OVERCHARGING
- BUT CELL PERFORMANCE DISPERSIONS AT END OF CHARGE COULD RESULT IN SOME OVERCHARGING.
- LEAKAGE STATUS OF HST FLIGHT CELLS IS CURRENTLY UNKNOWN BUT SHOULD BE VERIFIED STABLE BEFORE FLIGHT. LAST NSPECTED 1 YEAR AGO.

5.1.5 RELIEF VALVE LEAKAGE CON'T.

- NO KNOWN GENERIC PROBLEM IN SPACE, BASED ON LIMITED PAST SKYLAB FLIGHT EXPERIENCE BUT A DEFINITE PROBLEM OCCURS IN COMMERCIAL CELLS USING A SIMILAR RELIEF VALVE DESIGN.

- MSFC CONSIDERS THAT LEAKAGE PROBABILITY IS LOW BECAUSE SYSTEM IS DESIGNED TO AVOID OVERCHARGING. THE MAXIMUM CELL PRESSURE IS MEASURED AT ~20 PSI. THE RELIEF VALVE IS SET AT 150 PSI.

IMPACT:

- PREMATURE LOSS OF CELLS
- CORROSION OF BATTERY MODULE DUE TO KOH ON AL
- GAS CONTAMINATION OF ENVIRONMENT -- CONSIDERED BY PROJECT TO HAVE NO IMPACT ON HST SCIENCE. CELL MUST CRACK DUE TO PRESSURE OR LEAK BY FAILURE MODE, PLUS THE BATTERY CASE RELIEF VALVE MUST MUST CRACK/LEAK.

5.1.6 SEPARATOR QUALITY.

SOME RISK IS ASSOCIATED WITH THE USE OF PELLON 2505 SEPARATOR AS A RESULT OF AN INADEQUATE UNDERSTANDING OF THE CAUSE OF THE PROBLEM. A CONCERN EXISTS INDUSTRY WIDE.

DISCUSSION:

- THIS ITEM IS BASED UPON THE NOT WELL DEFINED PROBLEM RESOLUTION OF THE GATES BAD BATCH OF 2505 IDENTIFIED BY GATES.
- SOME SPECIFIC BATCHES HAVE BEEN IDENTIFIED AS SUSPECT. NOT ALL CELLS IDENTIFIED AS HAVING BEEN MADE FROM THAT BATCH EXHIBIT ANOMOLOUS PERFORMANCE.
- SOME BATCHES HAVE BEEN IDENTIFIED AS NOT AFFECTED, BUT CELLS USING IT HAVE EXHIBITED ANOMALOUS PERFORMANCE.
- THE PROBLEM IS NOT UNDERSTOOD AND THE CELL COMPONENTS FOR NI-CD DESIGNS ARE SUFFICIENTLY SIMILAR THAT ANY NI-CD USING THE MATERIAL MUST BE CONSIDERED AS POSING SOME RISK.

5.1.2 SEPARATOR QUALITY (CON'T).

- NOT MUCH CAN BE ACCOMPLISHED AT THIS POINT EXCEPT TO RECOGNIZE THAT RISK EXISTS.
- ON THE POSITIVE SIDE, 162 HST CELLS HAVE BEEN TESTED, 3 OF WHICH WERE DPA TESTED WITHOUT EXPERIENCING THE PROBLEM.

IMPACT:

- PREMATURE LOSS OF CYCLE LIFE CAPABILITY HAS BEEN EXPERIENCED WITH GATES CELLS AND COULD OCCUR ON HST.

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5.1.6 PROCESS CONTROL.

QA DATA SHOWS THAT THE PROCESS IS NOT UNDER GOOD ENOUGH CONTROL TO BE REPRODUCABLE.

DISCUSSION:

- THIS IS A CONCERN OF THE SUBCOMMITTEE. HOWEVER, IT IS NOTED THAT ALTHOUGH THOSE CELLS WHEN TESTED NEW, I.E., WITHOUT SHELF LIFE STORAGE, HAVE ALL PASSED THE 30 MONTH TEST PROGRAM, CELL DISPERSIONS HAVE BEEN NOTED. THE SYSTEM RELIES HEAVILY ON THE BPRC FOR CELL RECONDITIONING.

- CELL DISPERSIONS HAVE BEEN EXHIBITED BY:
  - PLATE THICKNESS VARIATIONS
  - PLATE CAPACITY VARIATIONS
  - STATE OF CHARGE
  - END OF CHARGE VOLTAGE

IMPACT:

- PROVIDES CYCLE LIFE THREAT
- LOSS OF CAPACITY

5.2 NI-H_2

5.2.1 LIFE CYCLING QUALIFICATION.

LIFE CYCLING NOT TO BE COMPLETED BEFORE LAUNCH - NOT A QUAL REQUIREMENT.

DISCUSSION:

- CYCLE LIFE QUALIFICATION IS NOT A REQUIREMENT BY THE PROGRAM. THIS DEFICIENCY CONSTITUTES ONE MAJOR WEAKNESS IN THE USE OF NI-H_2.
- IF REQUIRED, THE NI-H_2 CELLS COULD NOT BE QUALIFIED IN TIME FOR THE MARCH 1990 LAUNCH.
- OTHER PROGRAMS WHICH HAVE BEEN USING NI-CD CELLS MAY NOT LIFE CYCLE TEST QUALIFY FOR EACH FLIGHT, BUT THE CELL DESIGN HAS A VERY WIDE DATA BASE IN A FAMILIAR ENVIRONMENTAL AND OPERATIONAL REGIME. IT IS IN A SENSE QUALIFIED BY SIMILARITY TO THE PREVIOUS PROGAM OR A SIMILAR APPLICATION IN A DIFFERENT PROGRAM. QUALIFICATION IN THOSE CASES IS BASED UPON AN EXTENSIVE DATA BASE IN REPEATED ENVIRONMENTS.

NI-H_2 CRITICAL ITEMS

IMPACT:

- INCREASED RISK SINCE THE CELL DESIGN CANNOT BE LAUNCHED QUALIFIED TO A LIFE CYCLE VERIFICATION.

- THE CONCERN IS APPROPRIATELY ILLUSTRATED BY AN ANALOGY WITH THE QUALIFICATION THE SPACE SHUTTLE MAIN ENGINE. THE SSME WAS NOT CONSIDERED TO BE CERTIFIED UNTIL A 300% LIFE MARGIN DEMONSTRATION HAD BEEN ACHIEVED FOR ITS 600 SECOND MISSION DURATION. TO LAUNCH THE HST POWER SYSTEM WITH ONLY 3830 CYCLES AT THE TIME OF LAUNCH (22 CELL FSM) WOULD HAVE BEEN EQUIVALENT TO LAUNCHING THE SHUTTLE SSME WITH ONLY 168 SECONDS OF DEMONSTRATED TEST TIME WITH RESPECT TO A 2.5 YEAR HST MISSION. OR FOR A FIVE YEAR HST MISSION, IT IS ANALOGOUS TO LAUNCHING THE SSME WITH ONLY 84 SECONDS OF TEST TIME.

GENERIC NI-H_2 TESTING AT MSFC

THE TEST RESULTS PRESENTED BELOW ARE NOT HST DESIGN NI-H2 CELLS, BUT THE DATA COMPRISE AN IMPORTANT ELEMENT OF THE RATIONALE FOR THE PROGRAM TO BE ENCOURAGED THAT NICKEL-HYDROGEN CELLS ARE A VIABLE SOURCE FOR LEO HST ENERGY STORAGE. THE DUTY CYCLES ARE REPRESENTATIVE OF THE HST MISSION.

TEST ACTIVITY*	HST REQUIREMENTS		ACCUMULATED TEST TIME AS OF: NOVEMBER 1989		MARCH 1990	
	CYCLES	YEARS	CYCLES	YEARS	CYCLES	YEARS
• RNH 30-1: 14 CELLS COMSAT DESIGN	13,697/ 27,395	2.5/ 5.0	15,600	2.8	18,080	3.3
• RNH 35-3 12 CELLS AF DESIGN			7,550	1.4	10,030	1.8

5.2.2 CAPACITY LOSS

CHARGED STAND CAPACITY -- CELL CAPACITY LOSS DURING SHUTTLE LAUNCH TO HST DEPLOYMENT MISSION PHASE.

DISCUSSION:

- OCCURS DUE TO HYDROGEN RECOMBINATION ON THE POSITIVE PLATE
- DATA SHOW A 50% LOSS IN CAPACITY OVER A 13 DAY STAND AT 68 ^{o}F -- A TEMPERATURE DEPENDENT FUNCTION
- BATTERY RECEIVES NO CHARGING POWER FROM T- 2 DAYS UNTIL DEPLOYMENT -- APPROX. 6 DAYS WORSE CASE ASSUMED. CELL CAPACITY REQUIREMENT IS 43 AH, INCL. 15% CINTINGENCY. AVAILABLE AMOUNT IS APPROXIMATELY THAT QUANTITY OR SLIGHTLY LESS B IF INSTALLED AT VPF BASED UPON TRICKLE CHARGE CAPABILITY. IF INSTALLED AT PAD, 52 TO 54 AH AVAILABLE.
- MSFC IS WORKING THE PROBLEM. PLAN TO HANDLE THE WORSE CASE CONDITION IS MISSING.

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5.2.2 CAPACITY LOSS CON'T.

IMPACT:

- WORSE CASE IS LOSS OF HST. CONCERN IS LOSS OF CAPACITY IF LAUNCH OR ORBITAL DELAYS OCCUR THAT PREVENT SUCCESSFUL DEPLOYMENT OF HST. RETURN TO EARTH IS A POTENTIAL SALVAGE OPTION. PLANS FOR ACCOMPLISHING THE RETURN OF THE HST TO EARTH COULD NOT BE ESTABLISHED BY THE SUBCOMMITTEE.

5.2.3 BY-PASS DIODES

THE HST NI-H_2 BATTERY SYSTEM HAS BEEN DESIGNED WITHOUT THE BENEFIT OF BY-PASS CIRCUITRY TO PROTECT AGAINST A FAILED OPEN CELL.

DISCUSSION:

- RISK TO SYSTEM WITHOUT DIODES CONSIDERED TOO GREAT BY OTHER PROGRAMS TO NOT USE
- PROTECTS AGAINST OPEN CELL FAILURE MODE
- TOO LATE TO INCORPORATE FOR INITIAL LAUNCH
- REDUNDANCY IN THE 6 BATTERIES REDUCES THE RISK
- MSFC CONSIDERS CELL RELIABILITY TO BE GREATER THAN DIODES. THAT IS UNPROVEN.

5.2.3 BY-PASS DIODES

IMPACT:

- LOSS OF ONE CELL CAUSES LOSS OF ONE BATTERY. IMPACT FOR TWO BATTERIES FAILING IS TOTAL LOSS OF REDUNDANCY.
- LOSS OF ADDITIONAL CELLS CAN RESULT IN LOSS OF MISSION IF LOSS OCCURS IN ANOTHER BATTERY.

5.2.5 CELL LEAKAGE

CELL DESIGN OPERATES AT 900 TO 1200 PSI AND CONTANS 2 PENETRATIONS FOR ELECTRODE TERMINALS (2 PER CELL), 164 SEALS ON THE SPACECRAFT.

DISCUSSION:

- RESULTS IN OPEN CIRCUIT = LOSS OF BATTERY
- FAULT IN PRESSURE VESSEL (GOOD FRACTURE MECHANICS REPORT)
- CELLS UNPROTECTED BY DIODES
- POTENTIAL SEAL LEAK BUT -- NEVER OBSERVED IN INTELSAT V, G STAR, SPCC, ASC, AND SATCOM K1 AND K2 WITH ACCUMULATIVE 30 MILLION CELL HOURS OF FLIGHT TIME. DIFFERENT DESIGNS ARE USED. FLEET LEADER TIME = 5.5 YEARS (SPACENET)
- CASE SHORT TO GROUND COULD CAUSE LEAK IF HOLE IS BURNED THROUGH.

NI-H_2 CRITICAL ITEMS

IMPACT:

- LESS TOLERANT TO CELL FAILURE THAN NI-CD. ONE OPEN CELL CAN RESULT IN LOSS OF A BATTERY.

5.2.4 ELECTRICAL SHORTS

THE HST'S NI-H_2 POWER SYSTEM IS PARTICULARLY SENSITIVE TO SHORTS.

DISCUSSION:

A. NEED FOR ELECTRICAL INSULATION REDUNDANCY

- HST INSULATION DESIGNED DIFFERENTLY FROM COMMERCIAL SPACECRAFT. BAD EXPERIENCE WHERE NOT DONE PROPERLY. PROPER DESIGN HAS REDUNDANT INSULATION.
- ONLY ONE LAYER OF INSULATION BETWEEN CASE AND GROUND - THE THERMAL SLEEVE + 5 MIL KAPTON
- CHOTHERM (15 MILS) + RTV TAPE (AROUND WELD) COMPRISE THE ELECTRICAL INSULATION FOR THE CASE.

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5.2.4 ELECTRICAL SHORTS CON'T.

- THERE IS THE POSSIBILITY THAT PARTICLES CAN CAUSE SHORT.

B. WIRING SHORTS

- ONE EXAMPLE NOTED BY THE SUBCOMMITTEE OF A SITUATION LEADING TO A POTENTIAL SHORT -- CORRECTED BY EP.
- NEED FOR INSPECTION OF OTHER NI-H_2 BATTERY MODULES BEFORE LAUNCH .

IMPACT:

- SHORT HAS BATTERY LOSS AND FIRE POTENTIAL (FUSED)
- SYSTEM CAN ACCEPT 2 BATTERY FAILURES.

7.0 RISKS

RELATIVE RISK SUMMARY -- CATASTROPHE

CATASTROPHIC CONDITIONS LEADING TO SUDDEN LOSS OF POWER

1. LOSS OF CAPACITY WITHIN ONE YEAR -- THE ASSUMED M & R TIME (INCLUDES LAUNCH TO DEPLOY TIME)
2. SINGLE CELL FAILURE
3. MULTIPLE CELL FAILURES
4. SHORTS

CONSEQUENCE OF FAILURE MODE OCCURRENCE

CELL OPTION	SUDDEN CAPACITY LOSS	SUDDEN SINGLE CELL LOSS	MULTIPLE OPEN	SHORTS
NI-CD	CATASTROPHIC	NON CATASTROPHIC	REQUIRES MANY	POSSIBLE LOSS OF REDUNDANCY
NI-H2	CATASTROPHIC	NON CATASTROPHIC	CATASTROPHIC	POSSIBLE LOSS OF REDUNDANCY

POSSIBILITY OF OCCURRENCE

CELL OPTION	SUDDEN CAPACITY LOSS	SUDDEN SINGLE CELL LOSS	MULTIPLE OPEN	SHORTS
NI-CD	REMOTE	REMOTE	REMOTE	UNCERTAIN
NI-H2	MORE PROBABLE	HIGHER THAN NI-CD	REMOTE	UNCERTAIN

THE HST IS LESS LIKELY TO EXPERIENCE A SUDDEN, CATASTROPHIC LOSS OF POWER USING NI-CD THAN NI-H_2 CELLS.

RELATIVE RISK SUMMARY - MISSION LIFE

INDICATORS WHICH PROVIDE CONFIDENCE IN THE ATTAINMENT OF THE REQUIRED POWER OUTPUT OVER A MISSION DUTY CYCLE

1. HST TESTING: CYCLE LIFE ELECTRICAL DATA
2. CELL DESIGN
3. CELL QUALITY
4. TEST DURATION
5. QUAL ADEQUACY
6. CONSERVATIVE OPERATION IN FLIGHT

STATUS OF PARAMETERS INDICATING LIKELIHOOD OF MEETING FIVE YEARS LIFE CYCLE

CELL OPTION	ALL TESTING (HST + OTHER)	HST CELL TEST DURATION	DESIGN	QUALITY	ENV.QUALIFICATION
NI-CD	NOT LIKELY	NOT DEMONSTRATED	UNDESIRED FEATURES	LESS QUALITY	LESS
NI-H2	ANTICIPATED LONGER THAN NI-CD	NOT DEMONSTRATED	DESIRABLE	MORE ATTENTION	BETTER

THE HST IS MORE LIKELY TO RECEIVE THE LIFE CYCLE CAPABILITY FOR FIVE YEARS USING NI-H_2 THAN NI-CD CELLS.

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13. ABSTRACT (Maximum 200 words)

The results of an independent technical analysis on the relative merits of nickel-cadmium and nickel-hydrogen cell chemistry for meeting the Hubble Space Telescope (HST) mission are presented. The work was conducted by an ad hoc subcommittee of the NASA/DoD Battery Systems Steering Committee. The results were to assist in the decision process for cell selection and for independent oversight purposes. Design and test results are factored into a relative risk summary which are summarized into subcommittee findings that compares the likelihood that either may meet the 3-year mission objective, and beyond as an option. The analysis showed that the nickel-hydrogen cells are more likely to meet mission requirements although there is inadequate life cycle engineering data as applied to that chemistry for the low earth orbit (LEO) mission. The use of the nickel-hydrogen cell design is believed to have the potential to save a HST refurbishment mission, saving NASA 10's of millions of dollars.

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