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ADVANCED ENERGY STORAGE FOR SPACE APPLICATIONS A FOLLOW - UP

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AGENDA / OVERVIEW

- FUTURE SPACE MISSIONS
- OVERVIEW AND PERFORMANCE CHARACTERISTICS OF ADVANCED BATTERY TECHNOLOGIES
  - PRIMARY BATTERIES
  - RECHARGEABLE BATTERIES
- JPL EXPERIENCE WITH ADVANCED BATTERIES

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CATEGORIES OF SPACE MISSIONS USING BATTERIES

- **PRIMARY CELL APPLICATIONS**

  LAUNCH VEHICLES
  PROBES AND PENETRATORS
  SHUTTLE EXPERIMENTS
  PLANETARY STATIONS

- **RECHARGEABLE CELL APPLICATIONS**

  LOW EARTH MISSIONS
  GEOSYNCHRONOUS ORBIT MISSIONS
  ROVERS
  PLANETARY STATIONS

BATTERY CHALLENGES

- REDUCED WEIGHT
- REDUCED VOLUME
- INCREASED OPERATIONAL LIFE
- INCREASED SPECIFIC POWER AND POWER DENSITY
- INCREASE ACTIVE STORAGE AND CHARGE RETENTION
- EXTEND OPERATION TO EXTREME ENVIRONMENTS

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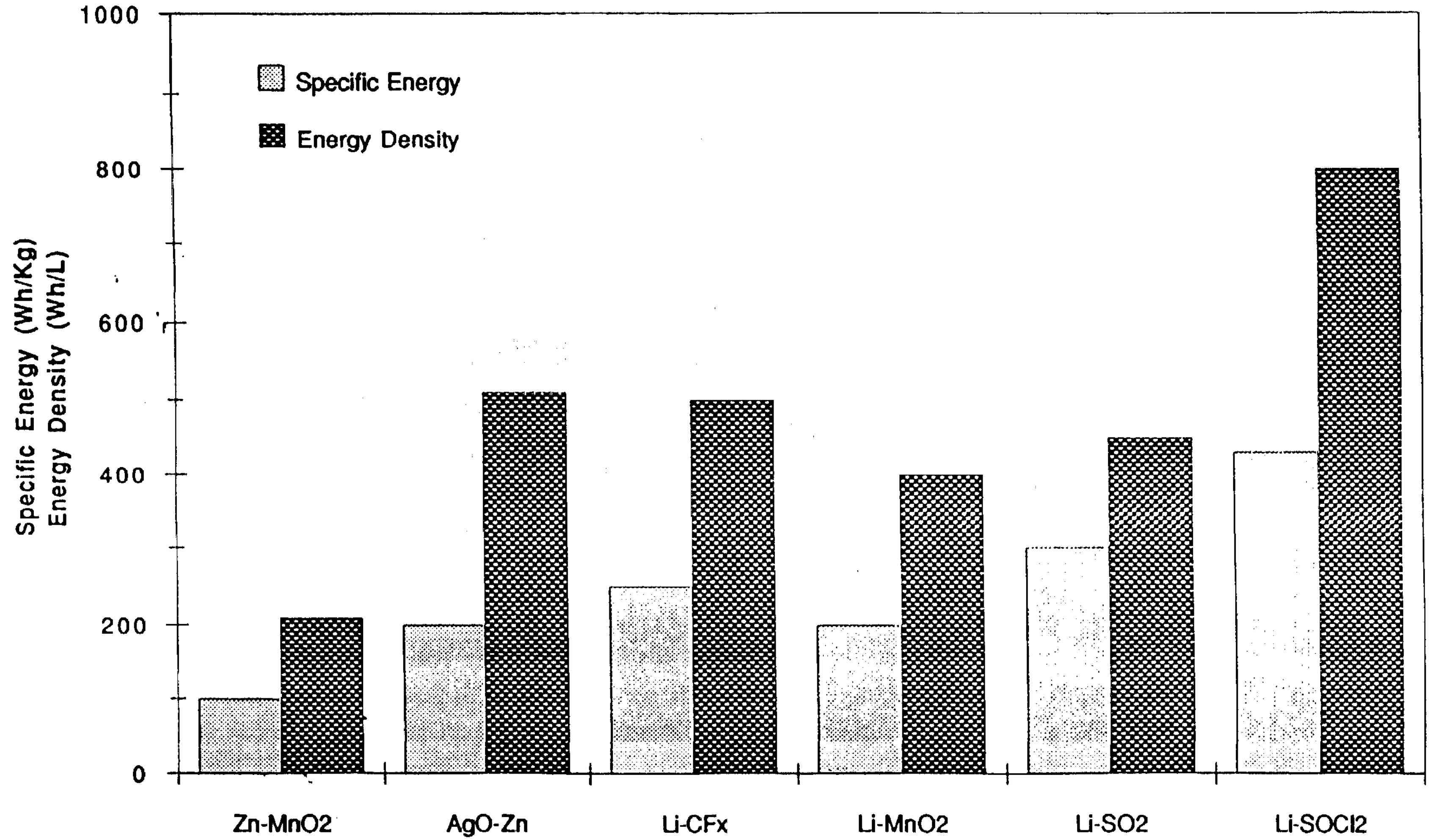
PROPERTIES OF SOA AND ADVANCED PRIMARY BATTERIES



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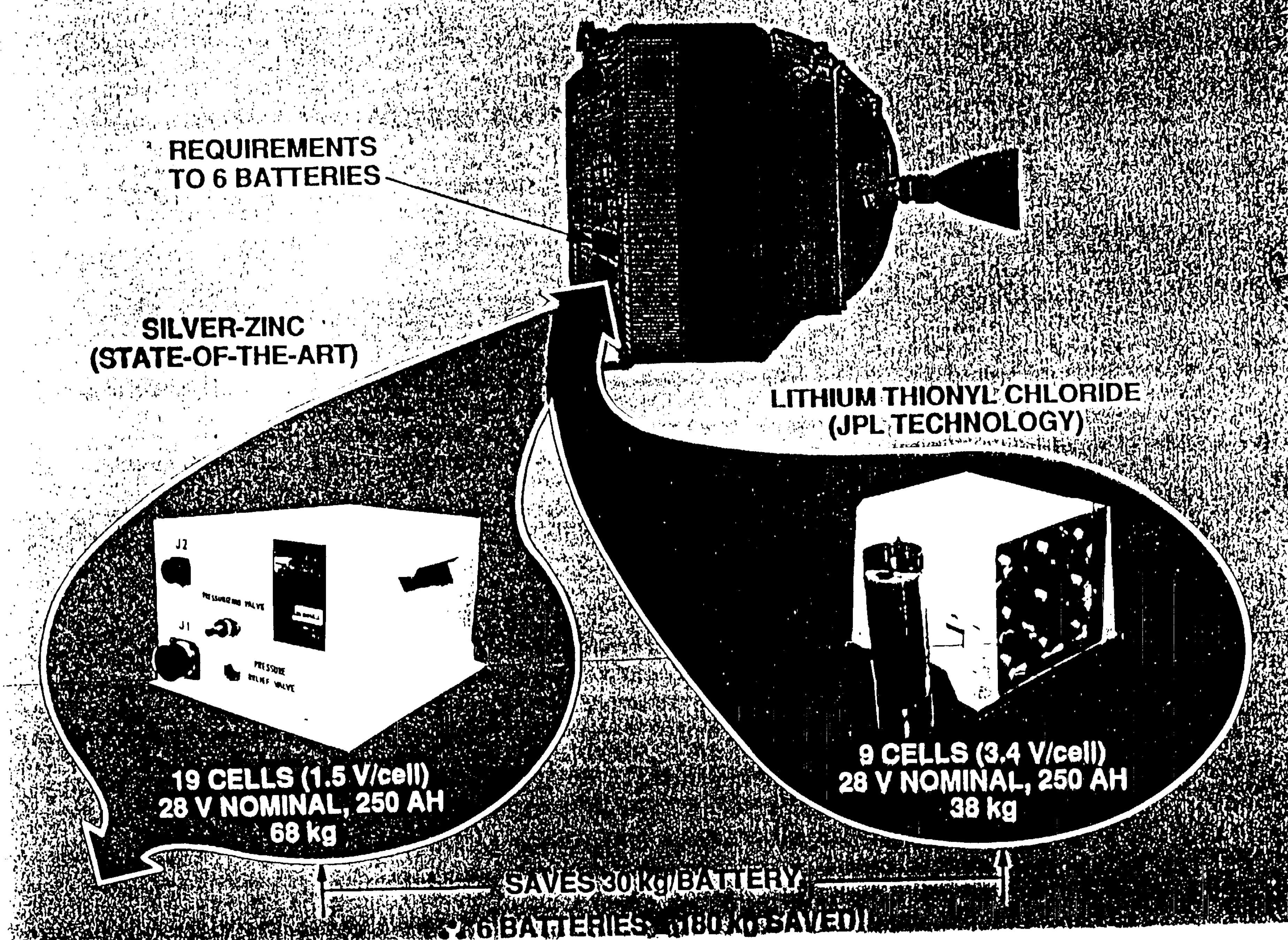
LITHIUM PRIMARY CELL APPLICATIONS

- CREW EQUIPMENT, TOOLS, EXPERIMENTS
  - EXTRAVEHICULAR MOBILITY LIGHT (1 Li - BCX)
  - EXTRAVEHICULAR MOBILITY TV (8 Li - BCX)
  - ACCELEROMETER RECORDING UNIT (2, 3 C Li - BCX)
  - CASSETTE DATA TAPE RECORDER (2 Li - BCX)
  - MINIOSCILLOSCOPE ((4 D Li - BCX)
  - ULTRASONIC LIMB PLETHYSMOGGRAPH (2 Li - BCX)
  - PRC - 112 MILITARY RADIO (3 C Li - BCX)
  - CAMCORDER, CAMERA, PRIMARY POWER, PAYLOADS (Li - X) WHERE X = $SOCl_2$, SO_2, CF_x, MnO_2, I, Ag_2CrO_4
- RANGE SAFETY (4, 28V Li - CF_x)
  -

ADVANCED LITHIUM BATTERIES FOR CENTAUR



ADVANCED RECHARGEABLE BATTERY APPLICATIONS

LEO	GEO	PLANETARY
Ni- MH ?	Ni-MH	Ni - MH
Na - S	Na - S	Li - ION
Na - $NiCl_2$	Na - $NiCl_2$	Li - TiS_2
	Li - ION	Li - POLYMER
	Li - TiS_2	
	Li - POLYMER	

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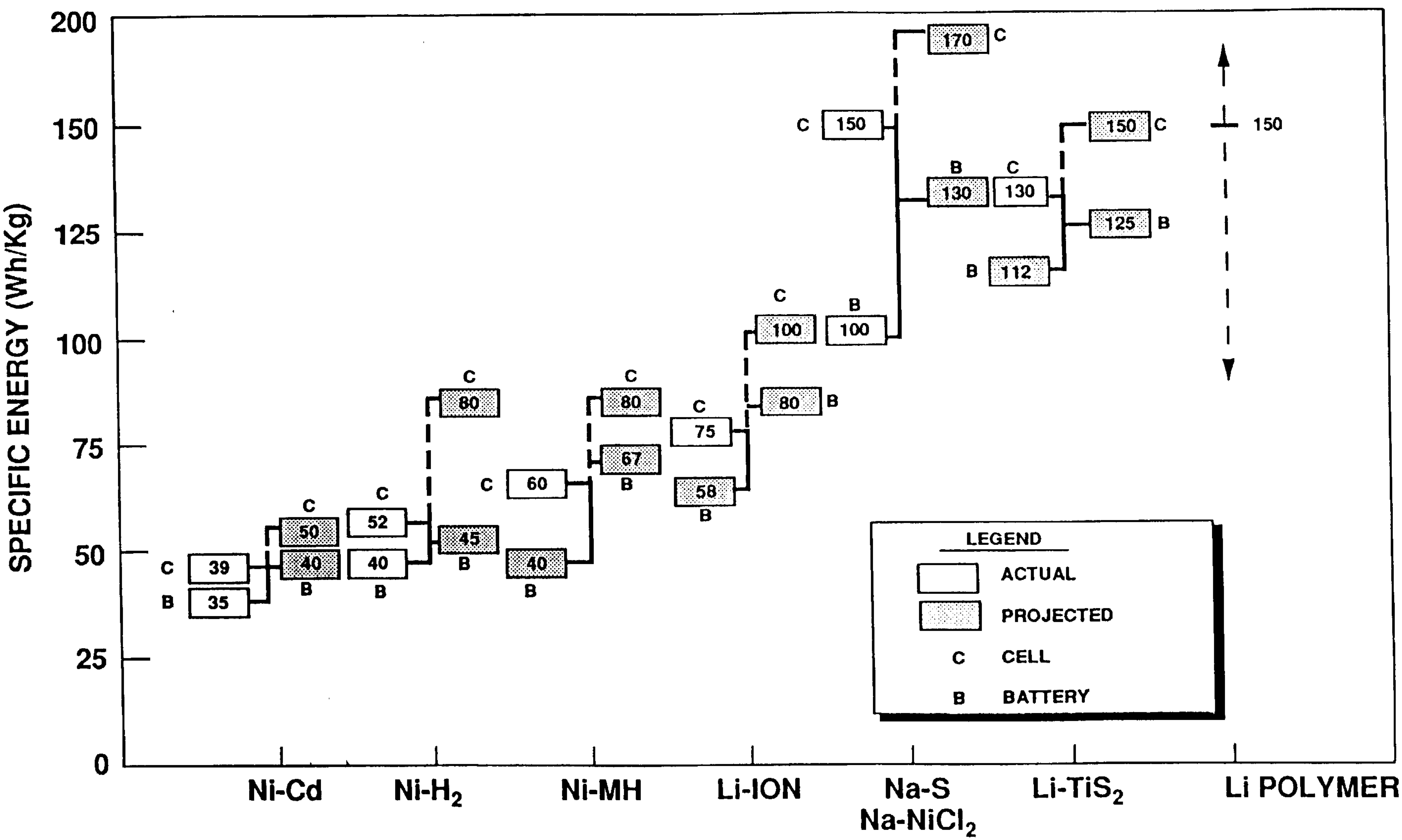
SPECIFIC ENERGY OF RECHARGEABLE CELLS AND BATTERIES



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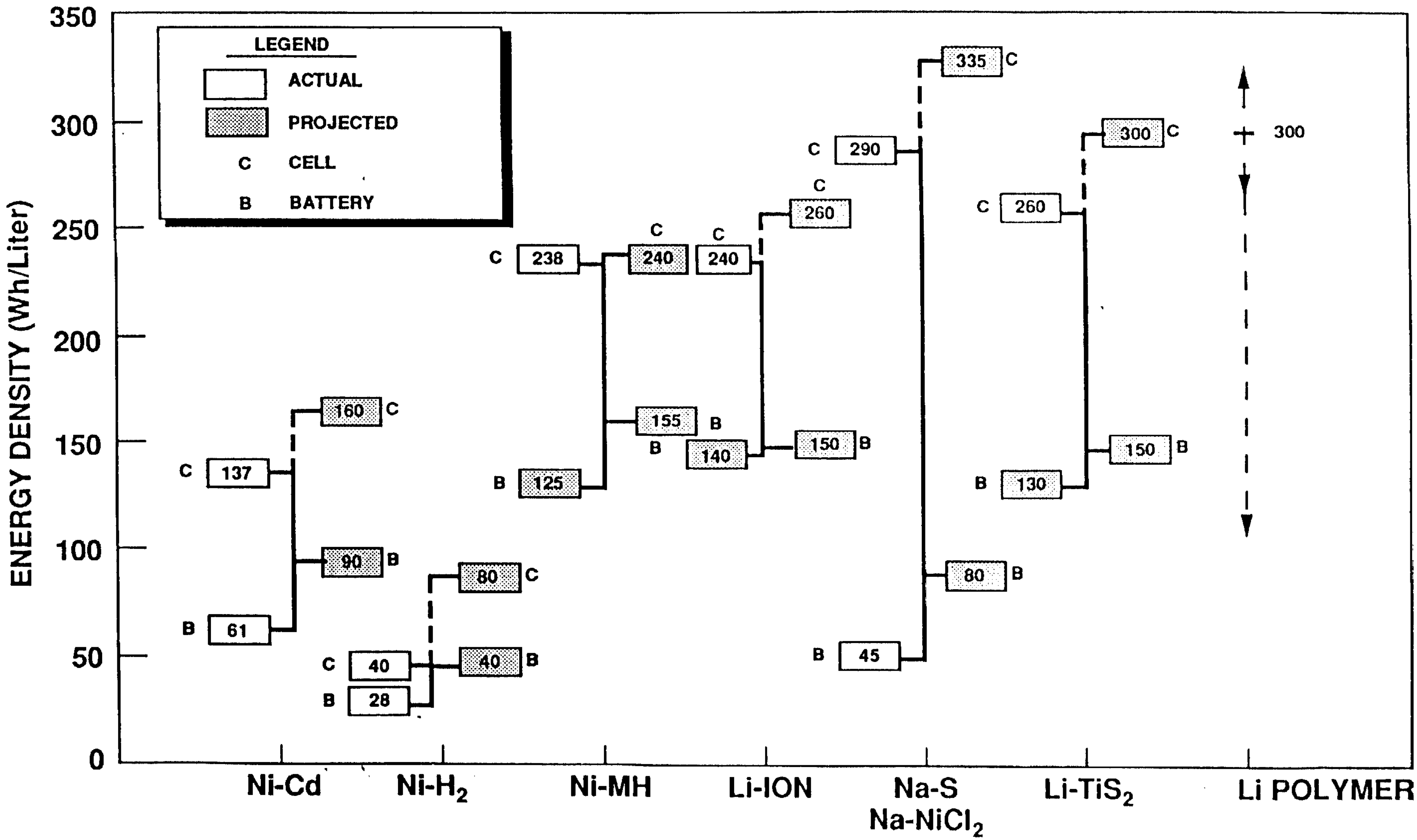
ENERGY DENSITY OF RECHARGEABLE CELLS AND BATTERIES



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PRESENT LIMITATIONS OF ADVANCED BATTERY TECHNOLOGIES

- SMALL - MEDIUM CAPACITY CELLS ARE AVAILABLE
- TO DATE ADVANCED BATTERIES ARE HANDMADE OR BATCH PROCESSED
- CYCLE LIFE GENERALLY LIMITED TO 1000 CYCLES
- ADVANCES IN CHARGE CONTROL NEEDED TO BALANCE CELLS IN BATTERY
- SAFETY AND ABUSE AFFECTS NOT WELL KNOWN

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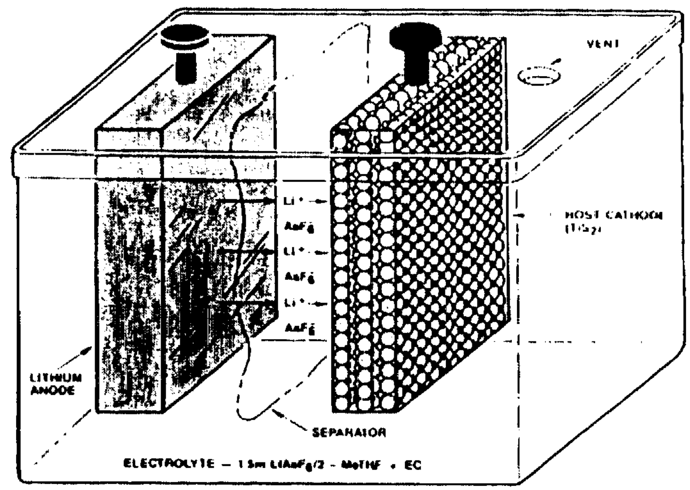
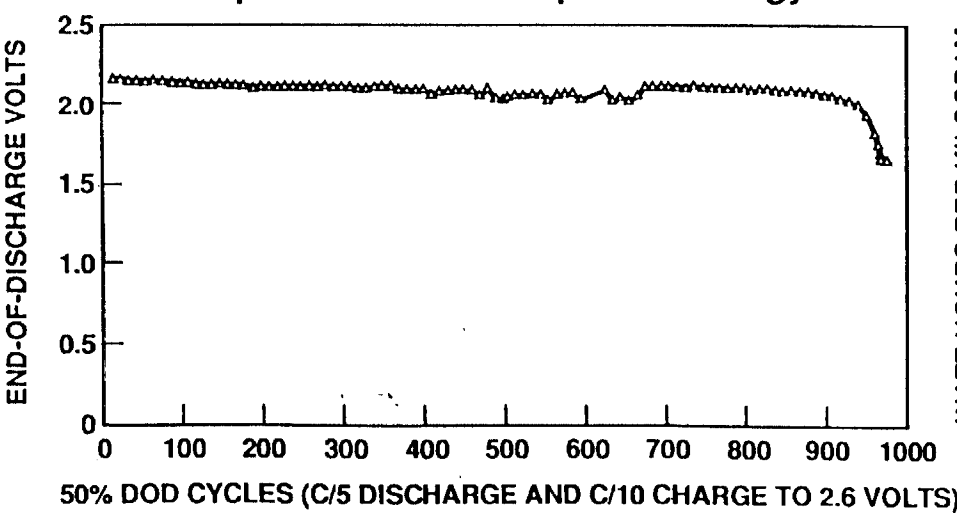
STATUS OF Li-TiS_2 CELL TECHNOLOGY

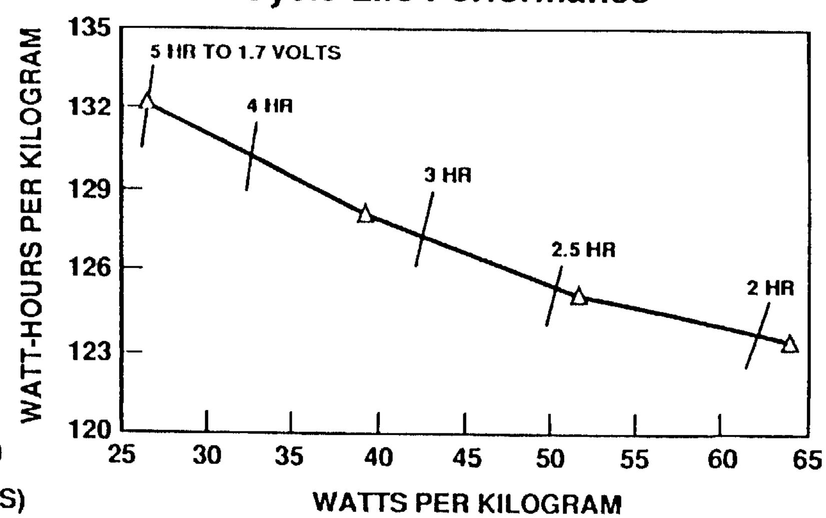
Schematic Diagram of a Li-TiS_2 Cell



Specific Power vs Specific Energy



Cycle Life Performance



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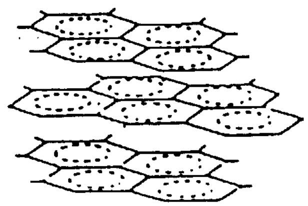
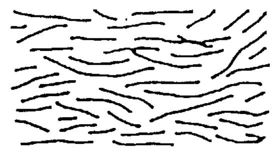
STATUS OF Li ION CELL TECHNOLOGY

CARBON MATERIALS UNDER STUDY



GRAPHITE



PETROLEUM COKE

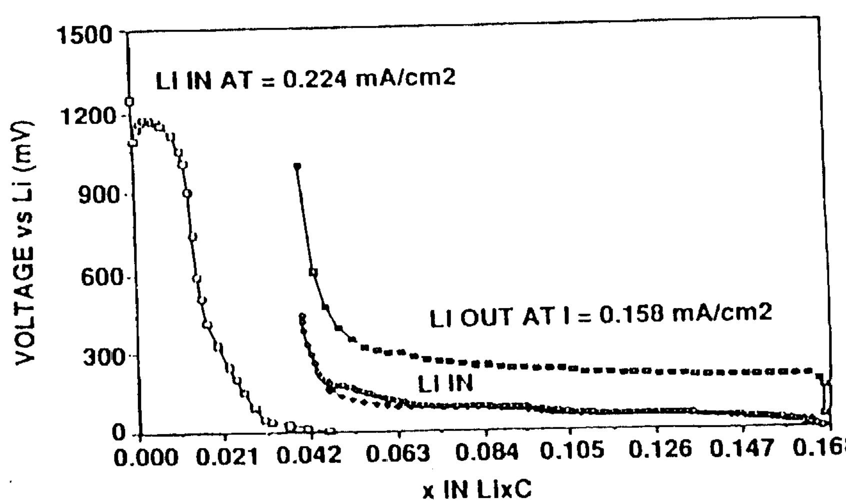
PITCH-BASED CARBON FIBER

REVERSIBLE Li CAPACITY OF SELECTED CARBONS

• PITCH COKE:	0.070 Li PER CARBON
• PETROLEUM COKE:	0.057 - 0.077 Li PER CARBON
• CARBON FIBER:	0.097 Li PER CARBON
• GRAPHITE:	0.124 Li PER CARBON

* PAN FIBER HAS VERY SLOW RATE CAPABILITY

INTERCALATION & DE-INTERCALATION OF Li IN GRAPHITE



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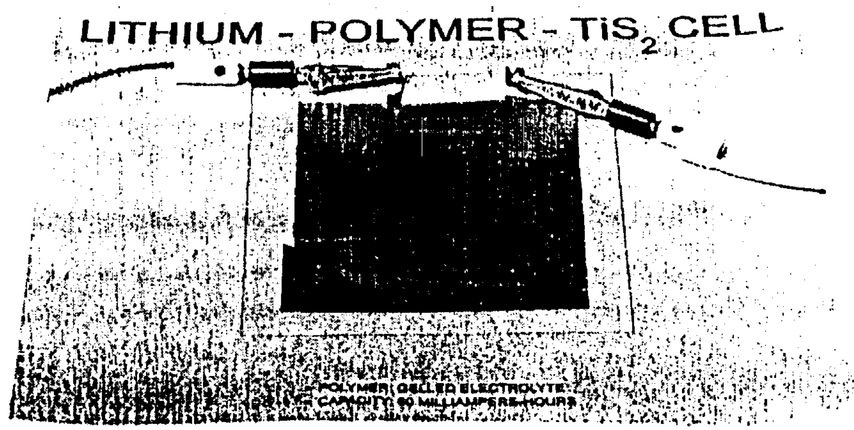
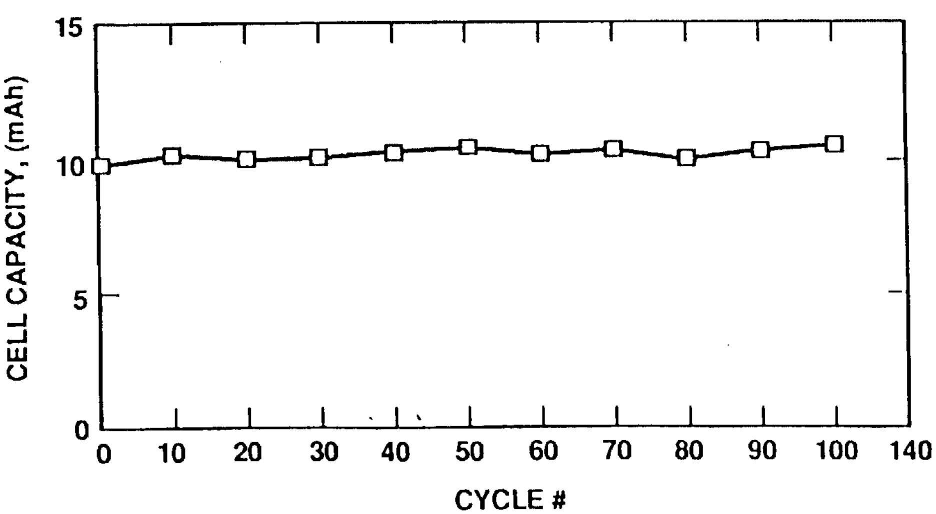
STATUS OF Li-TiS$_2$ CELL TECHNOLOGY



PROPERTIES OF JPL Li/POLYMER ELECTROLYTES



CYCLE LIFE OF Li-TiS$_2$ CELL

ELECTROLYTE	CONDUCTIVITY (S/CM) RT 90°C	Li TRANSPORT #	ELECTROCHE WINDOW (V)	Li CYCLING EFFICIENCY (%)
PEO/12-CR4/LIBF$_4$	10^{-8} $8X10^{-4}$	0.2-0.4	1.4-4.6	88-93%
PEO/LII/Al_2O_3	--- $8X10^{-5}$	0.8-1.0	1.4-3.7	88-93%
ENVIBAR/EC-DEC/LIAsF$_6$	$2X10^{-3}$ ----	0.2-0.4	1.4-4.3	87-93%

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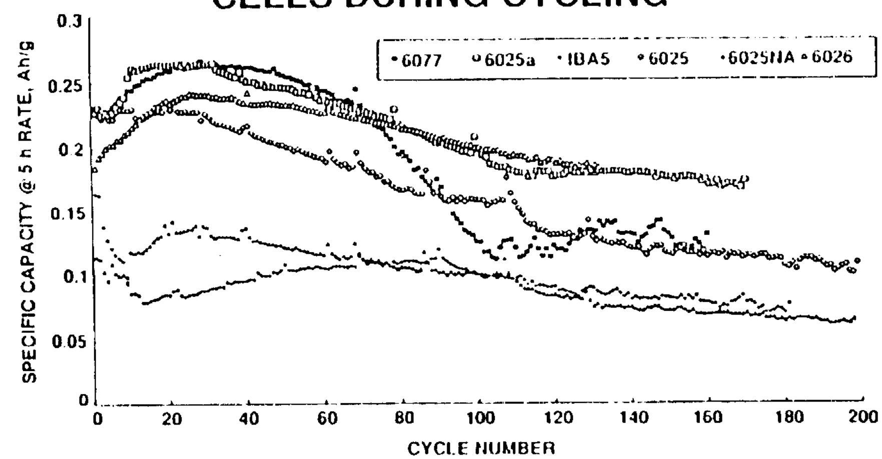
STATUS OF THE Ni-MH CELL TECHNOLOGY

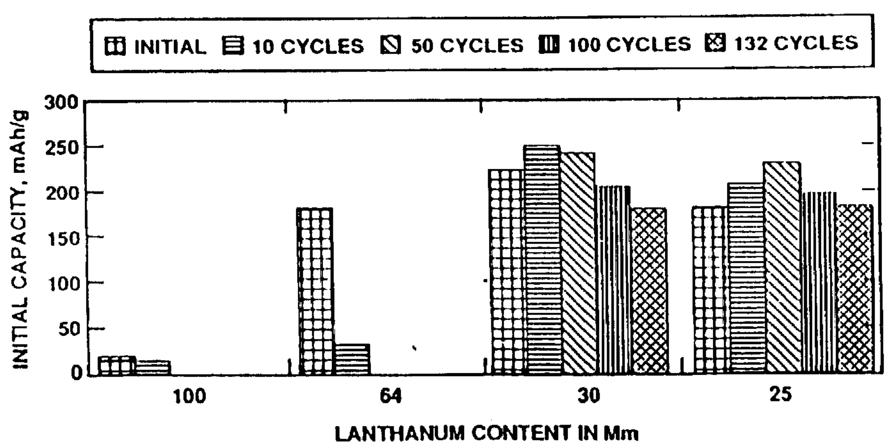
MH MATERIALS UNDER STUDY

- $LaNi_5$ (5978)
- $LA_{0.3}Ce_{0.51}Pr_{0.07}Nd_{0.13}Ni_{3.56}Co_{0.76}Mn_{0.4}Al_{0.3}$ (6025)
- $La_{0.25}Ce_{0.55}Pr_{0.07}Nd_{0.13}Ni_{3.68}Co_{0.75}Mn_{0.4}Al_{0.34}$ (6062)
- $La_{0.64}Ce_{0.25}Pr_{0.04}Nd_{0.08}Ni_{3.51}Co_{0.77}Mn_{0.4}Al_{0.31}$ (6039)
- $La_{0.49}Ce_{0.20}Pr_{0.09}Nd_{0.22}Ni_{3.05}Co_{1.50}Al_{0.53}$ (6077)
- $MmNi_{3.5}Co_{0.8}Mn_{0.4}Al_{0.3}$ (IBA MH NO 5)
- JPL/CALTECH/JPL MATERIAL

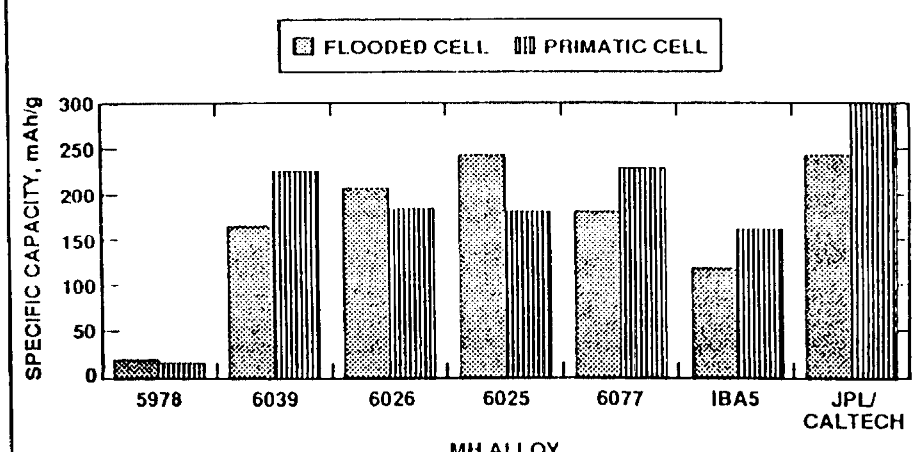
PERFORMANCE OF 250 mAh Ni-MH CELLS DURING CYCLING



VARIATION OF CAPACITY WITH Mn COMPOSITION AND CYCLING



SPECIFIC CAPACITIES OF MH ALLOYS



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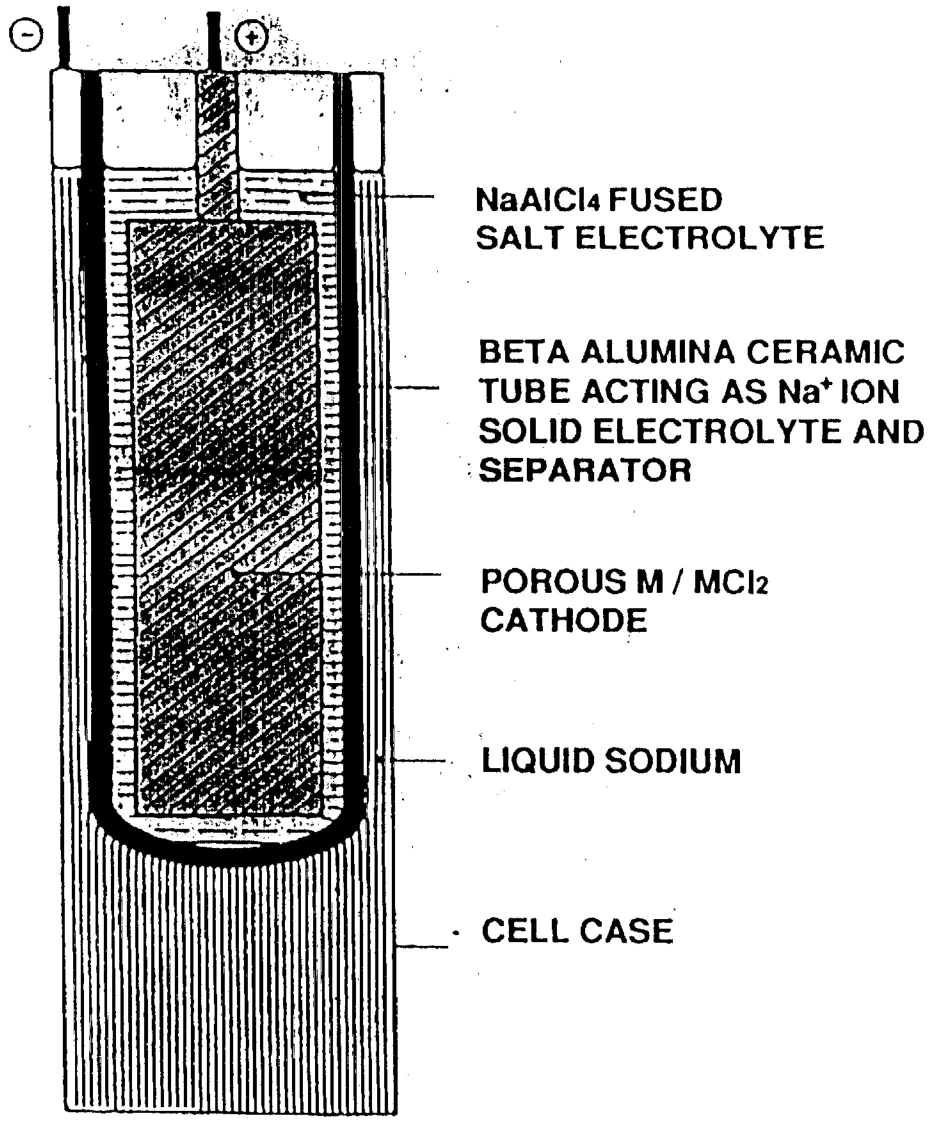
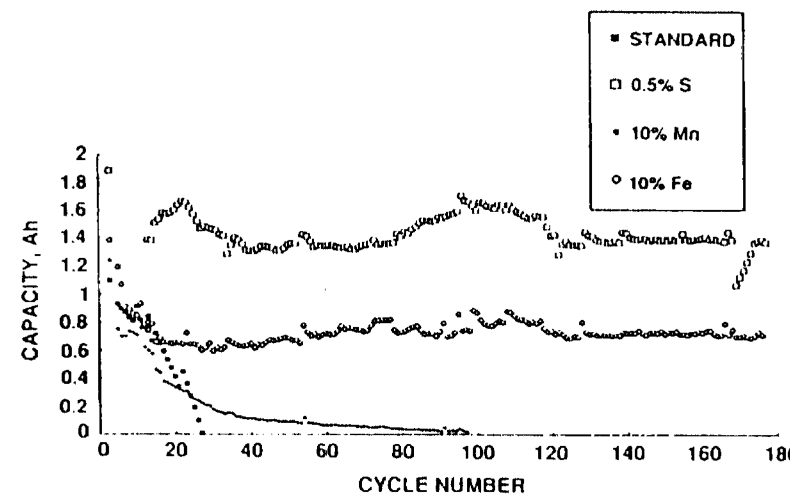
STATUS OF Na -$NiCl_2$ CELL TECHNOLOGY



CYCLE LIFE OF 2 Ah Na -NiCl2 CELLS WITH DIFFERENT ADDITIVES



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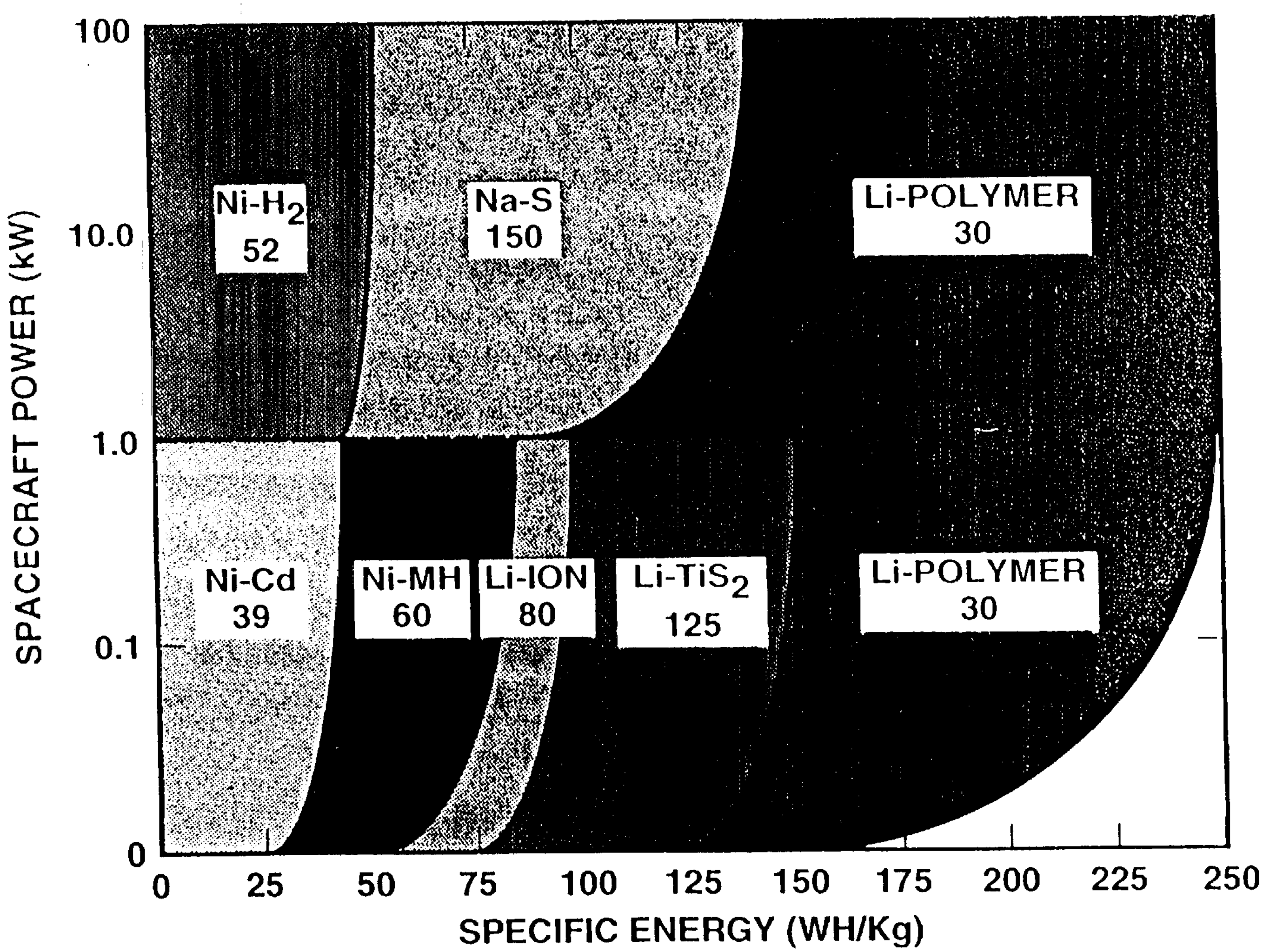
PROJECTED PERFORMANCE ENEVELOPE STATE OF ART AND ADVANCED CELLS



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SUMMARY

- FUTURE SPACE MISSIONS REQUIRE LIGHTER WEIGHT, SMALLER VOLUME, HIGHER ENERGY BATTERIES ("SMALLER, CHEAPER ,BETTER")
- SEVERAL ADVANCED BATTERY SYSTEMS ARE UNDER DEVELOPMENT
- SEVERAL, PRIMARY LITHIUM BATTERY SYSTEMS ARE IN USE
- SELECTION OF THE NEW RECHARGEABLE SYSTEMS REQUIRES ADDED CYCLE LIFE AND BATTERY PERFORMANCE DEMONSTRATION

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ACKNOWLEDGEMENT

- THE AUTHORS ARE APPRECIATIVE OF THE SUPPORT OF NASA HEADQUARTERS CODE C AND CODE Q FOR THIS EFFORT

- THE BATTERY SYSTEM COMPARATIVE DATA WAS DERIVED FROM REPORTS IN:
  - THE 1991-3 NASA BATTERY WORKSHOP PROCEEDINGS
  - THE 1991 AND 1993 SPACE ELECTROCHEMICAL RESEARCH AND TECHNOLOGY PROCEEDINGS

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