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BATTERY TESTING AT ARGONNE NATIONAL LABORATORY

Electric and Hybrid Propulsion Systems, No. 1

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ABSTRACT

Advanced battery technology evaluations are performed under simulated electric-vehicle operating conditions at the Analysis & Diagnostic Laboratory (ADL) of Argonne National Laboratory. The ADL results provide insight into those factors that limit battery performance and life. The ADL facilities include a test laboratory to conduct battery experimental evaluations under simulated application conditions and a post-test analysis laboratory to determine, in a protected atmosphere if needed, component compositional changes and failure mechanisms. This paper summarizes the performance characterizations and life evaluations conducted during FY 1992 on both single cells and multi-cell modules that encompass six battery technologies [Na/S, Li/FeS, Ni/Metal-Hydride, Ni/Zn, Ni/Cd, Ni/Fe]. These evaluations were performed for the Department of Energy, Office of Transportation Technologies, Electric and Hybrid Propulsion Division, and the Electric Power Research Institute. The ADL provides a common basis for battery performance characterization and life evaluations with unbiased application of tests and analyses. The results help identify the most-promising R&D approaches for overcoming battery limitations, and provide battery users, developers, and program managers with a measure of the progress being made in battery R&D programs, a comparison of battery technologies, and basic data for modeling.

INTRODUCTION

At the Argonne Analysis & Diagnostic Laboratory (ADL), advanced battery systems are evaluated with respect to both performance and life. Performance characterization includes the determination of capacity vs. discharge rate, peak power vs. depth-of-discharge (DOD), and capacity loss vs. standtime; life testing involves repeated cycling with simulated driving profile discharges until the capacity declines to <80% of its rated value. These evaluations, combined with post-test examinations of the advanced battery systems, provide insight into those factors that limit performance and life, and help identify the most-promising R&D approaches for overcoming these limitations.

TEST RESULTS

During FY 1992, electric-vehicle (EV) battery systems were evaluated in the ADL for the Department of Energy (DOE), Office of Transportation Technologies - Electric and Hybrid Propulsion Division (OTT/EHP), and the Electric Power Research Institute (EPRI) Transportation Program. Tests were conducted on single cells and 3- to 120-cell modules that encompass six technologies (Na/S, Li/FeS, Ni/Metal-Hydride, Ni/Zn, Ni/Cd, and Ni/Fe). Table 1 lists the general specifications and best performance (for the specified test conditions) of each EV battery technology evaluated at the ADL during FY 1992. Plots of specific energy and specific peak power for each technology are given in Figs. 1 and 2, respectively. The values of specific energies were measured using CP discharges to 100% DOD. The values of specific peak power were derived from driving profile discharge data and are plotted as a function of DOD based on available energy for the average power discharge rate. Results of the extended open-circuit stand test, plotted in Fig. 3, show the effects of self-discharge vs. time for each of the battery technologies examined. The data for the high-temperature systems (Na/S and Li/FeS) do not reflect enclosure thermal losses. Selected results for each technology are discussed below.

SODIUM/SULFUR - An 8-V Na/S module from Chloride Silent Power Ltd. (CSPL) in England was under test from June 1990 to March 1992. This module contained 120 cells (10-Ah each) configured into 30 parallel-connected strings of four series-connected cells. Life testing with SFUDS discharges to 100% DOD was started after completion of the performance tests (~120 cycles). There was a significant drop in module capacity between 450 and 550 cycles, Fig. 4, which reflected the loss of four 4-cell strings (~40-Ah loss). End-of-life (<80% of initial 2084-Wh SFUDS discharge energy) occurred at cycle >795, but testing was continued to acquire additional statistics for cell failure analyses. Testing was halted after 973 cycles, when the SFUDS discharge energy decreased to <75% of its initial level. At that time, module peak power had declined to 68 W/kg from an initial 94 W/kg (50% DOD), and capacity was ~79% of its initial 292 Ah. The module was returned to CSPL for post-test analyses.

LITHIUM/IRON SULFIDE - In July 1991, a Li/FeS cell (200 Ah rating) was delivered to ANL by SAFT America, Inc. for performance testing. The clamping arrangement used in the test fixture for this cell was modified to provide additional compression on the electrode face. As a result, the cell was less sensitive to temperature variations and achieved high capacity (465°C). Performance tests were completed and life tests started in December 1991 after 120 cycles. After 158 cycles, the cell was cooled to ambient temperature for a two-week period in December 1991. In January 1992, the cell was heated to 465°C and testing resumed. The initial capacity (198 Ah) was greater than that exhibited before the shutdown, but on subsequent cycles, the capacity decreased. The cell exhibited a decline in voltage during the open-circuit-period after discharge and was unable to reach the required constant-voltage (CV) charge level (1.5 V with a 120% charge return). These factors indicate a high internal self-discharge rate. Testing was suspended at cycle 163.

NICKEL/METAL-HYDRIDE (MH) - Performance characterization tests were initiated on two Ni/MH cells (25-Ah rating) manufactured by Ovonics Battery Co. (Troy, MI) in June 1991. Performance tests were completed, and life evaluation started in November 1991. The peak power of the H-cells is the highest measured at the ADL to date (152 W/kg at 80% DOD and ~200 W/kg at 50% DOD). A high peak power provides full capacity and maximal vehicle range for all driving profile discharges. One H-cell was removed from life test after 380 cycles due to a sudden decline in capacity (to <70% of its initial 25-Ah capacity) caused by electrolyte loss. Water (13.6 g) was added to this valve-regulated cell, and full capacity (26.5 Ah) was achieved on a subsequent discharge. Thereafter, the capacity declined at a rate of ~0.5 Ah/cycle. Testing was halted when the capacity declined to 13.8 Ah on cycle 399. Cell weight was reduced again (by 6.3 g). This suggests problems with the integrity of the stainless steel case and/or the pressure release vent.

The second H-cell was removed from life test after 533 cycles due to capacity and power loss. End-of-life (EOL) with SFUDS discharges occurred on cycle 505. The weight of this cell did not change significantly with life. The charge return was increased from 120% to 150% after EOL, but no improvement in cell capacity resulted. The cell retained ~78% of its initial 28-Ah, 3-h rate capacity when testing was halted. Both H-cells were returned to Ovonics for further analyses.

NICKEL/ZINC - A Ni/Zn cell (60 Ah rating) manufacted by Electrochemica Corp. was tested from December 1991 to February 1992. Performance characterization indicated an initial 3-h rate capacity of 52.3 Ah with ~112% charge return. The cell was operated over the December holiday shutdown, during which its capacity increased slightly, and the charge return decreased from ~112 to 105% (for fixed 58.5-Ah return). In January 1992, when the charge return was increased from 105 to 110% (manufacturer recommended value), cell capacity increased from ~57 to 70 Ah. Because of this large increase in capacity, performance characterization was repeated. The cell then exhibited a specific energy of 66.7 Wh/kg (3-h rate) and a peak power of 185 W/kg (50% DOD). The highest constant-power discharge that could be applied without excessive cell heating was 35 W/kg. Life testing with 80% DOD SFUDS discharges (75 Wh) and CI/CV (12 A/1.95 V) charges to 110% return was started in February 1992 (95 cycles accrued). The cell completed only 20 cycles, when the 100% DOD termination condition (maximum power capability ≤50 W/kg) was reached before the 80% DOD energy (75 Wh) could be removed (end-of-life). At that time, a 3-h rate capacity of <50 Ah was obtained, and a thermal runaway condition began during the CV portion of the constant current/constant voltage (CI/CV) charges. The cell reached EOL on cycle 114 and was removed from test after 120 cycles. The cell was then returned to Electrochemica.

NICKEL/CADMIUM - Life tests were conducted on a 6-V Ni/Cd module (190-Ah rating) manufactured by SAFT (Industrial Storage Battery Division), France, from April 1990 to August 1992. The module was received from Idaho National Engineering Laboratory, where it had completed 35 performance characterization cycles. Life testing was started at the ADL in June 1990 after 78 cycles of performance testing. Life evaluation was conducted with discharges to 100% DOD using the J227aC driving profile for a Chrysler TEVan. The module had completed 1018 cycles and still retained ~99% of its initial 3-h rate capacity when it was voluntarily removed from test. At that time, the TEVan discharge energy had only declined to ~96% of its initial value. Variations in module resistance, IR-free voltage, and peak power vs. DOD during the life evaluation were examined. Analyses showed that module resistance had increased by ~23%, and IR-free voltage had remained constant to within 1.0%. As a result of the increased resistance, module peak power was decreasd from 190 to 154 W/kg at 50% DOD (~19% decrease) between cycles 46 and 1016. This module was sent to EPRI for other evaluations.

NICKEL/IRON - Life tests were conducted on four advanced Ni/Fe modules (NIF200) from Eagle-Picher Industries, Inc. The NIF200 design provides a capacity of 200 Ah in the same module package as the 170-Ah module developed for the dual-shaft electric propulsion (DSEP) vehicle developed by Eaton Corp. One module completed performance characterization tests in early 1990, and was then placed on life test. Since that time, another three NIF200 modules were tested. The longest operating module completed 918 cycles with (J227aC driving profile for G-Van) discharges to 80% DOD before reaching EOL. Another module was cycled using an ANL-recommended charge regime from November 1991 to October 1992. This module completed 394 cycles to 100% DOD using a J227aC profile for a Chrysler TEVan before reaching EOL. It retained ~79% of its initial 1.03 kWh energy with TEVan discharges to 100% DOD and 162 Ah charges (112% return). Module life was less than expected based on that exhibited by early NIF200 modules. All remaining NIF200 were voluntarily removed from testing to prepare for future deliverables.

FUTURE EVALUATIONS

In FY1993, performance and life evaluations will be continued for DOE/OTT and EPRI. It is anticipated that new battery systems will be tested at the ADL for the USABC.

ACKNOWLEDGEMENTS

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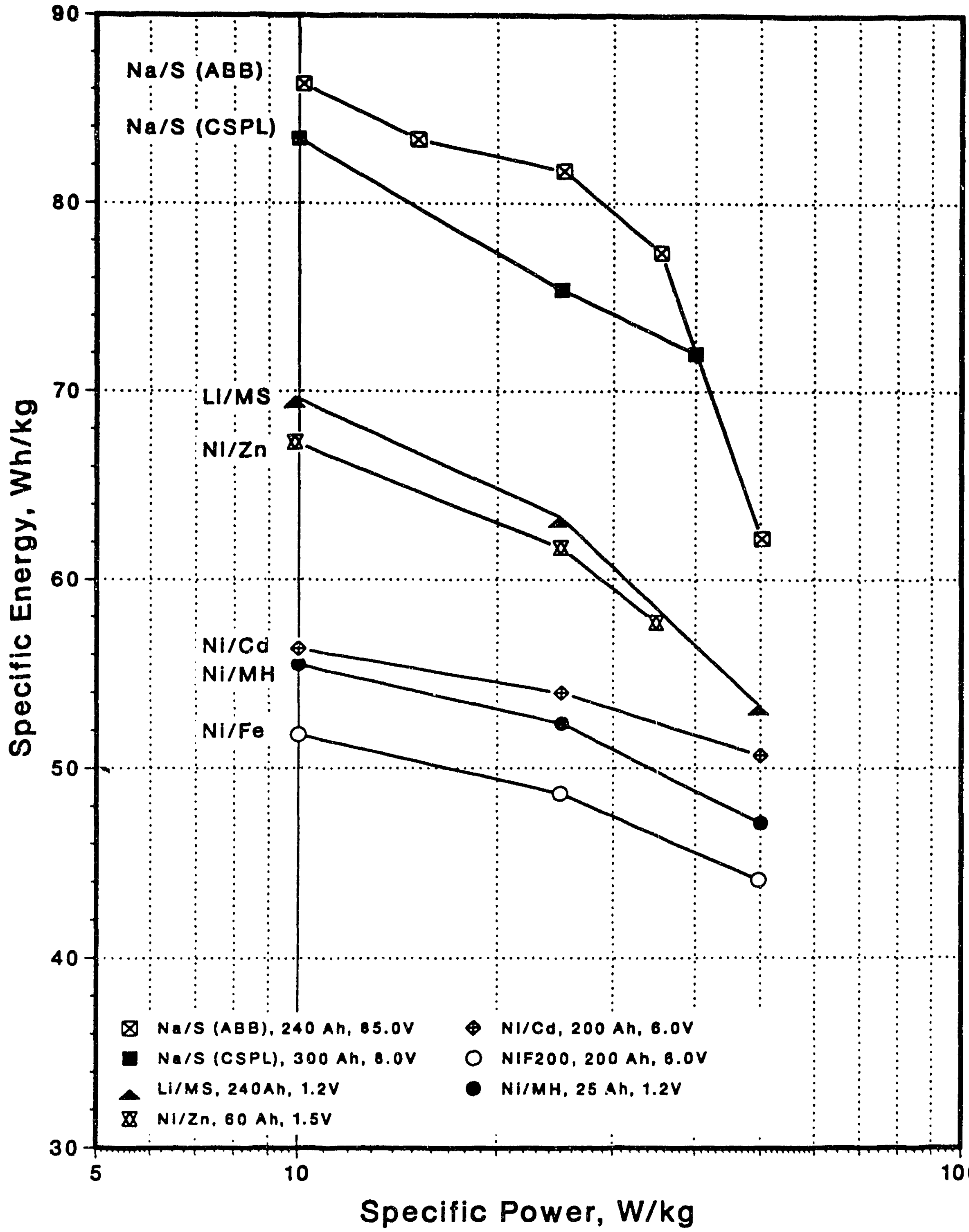

Fig. 1. Effect of discharge specific power on available energy of nine advanced battery technologies.

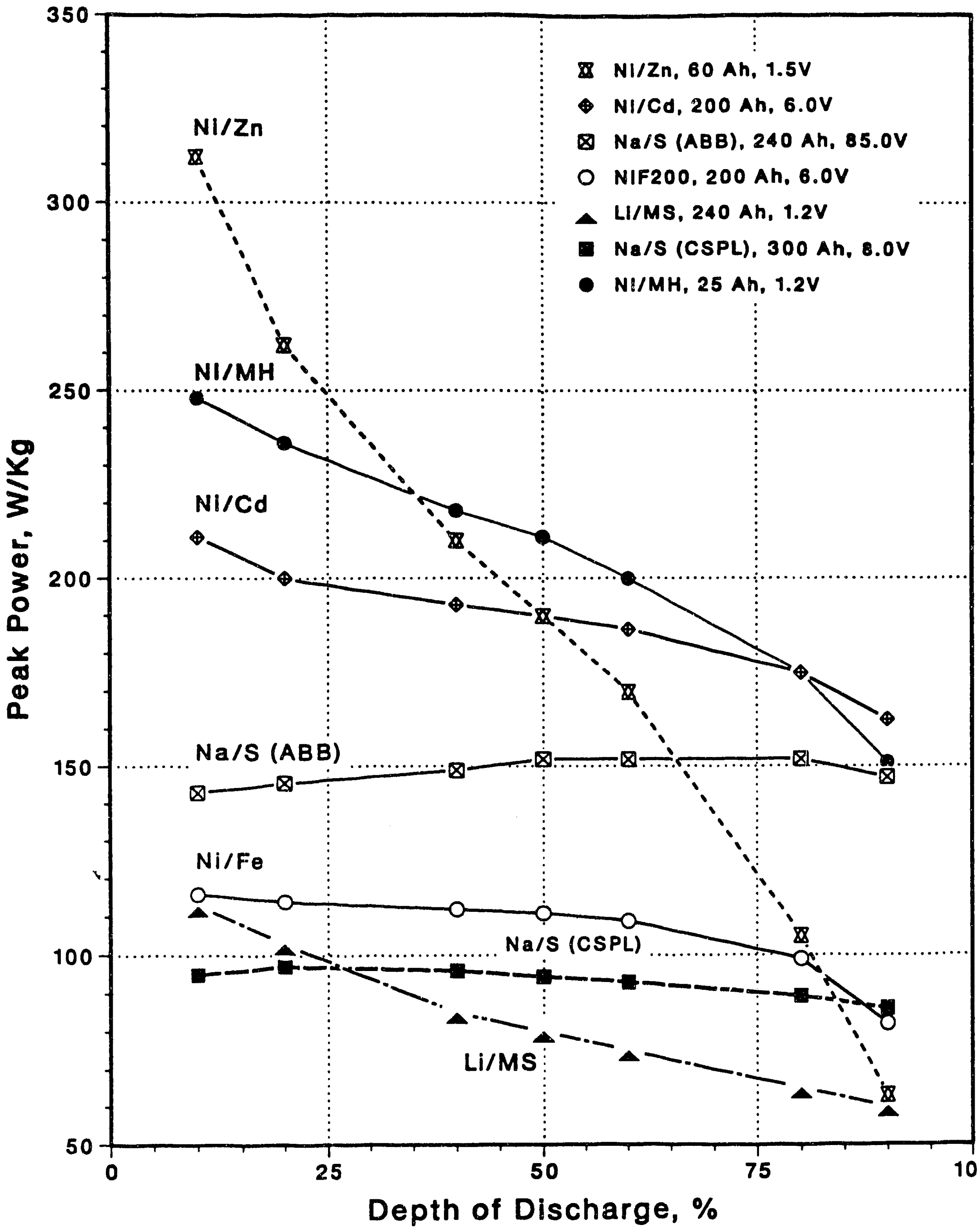

Fig. 2. Derived peak power vs. DOD of nine advanced battery technologies from driving profile discharge (J227aD/IETV1) data.

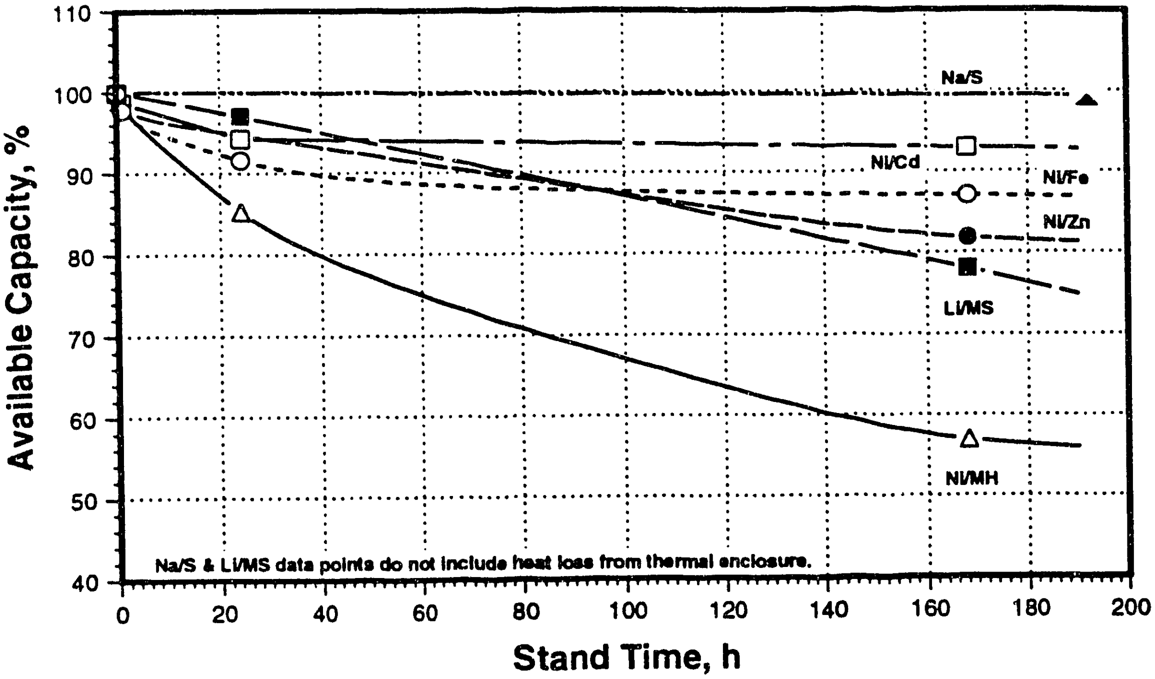

Fig. 3. Available discharge capacity vs. open-circuit stand time after charge for each advanced battery technology evaluated.

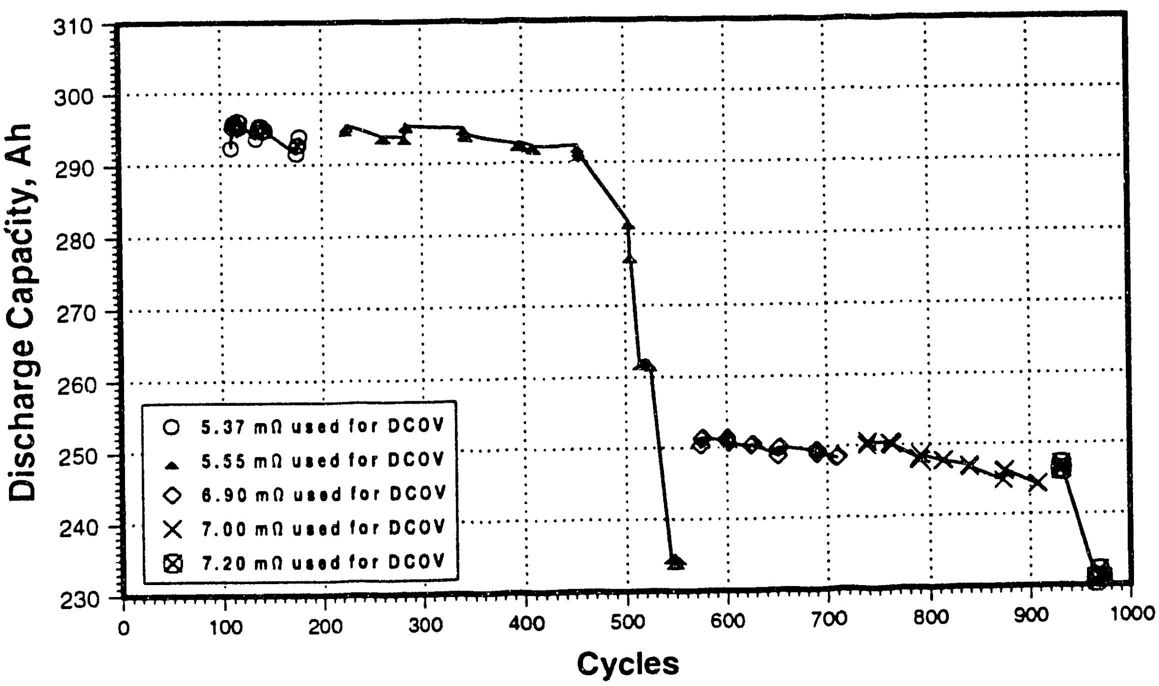

Fig. 4. Capacity History of 120-Cell NaS 8-V, 300Ah Module.

Table 1. Performance Summary of EV Battery Technologies Evaluated in the ANL/ADL during FY1992

Battery Description			Initial Module		Specific	Volumetric	Peak	Efficiency[a]			Van
			Weight,	Capacity,[a]	Energy,[a]	Density,[a]	Power,[b]	Coulombic,	Energy,	Life,[c]	Range,[d]
Technology	Manufacturer	Model	kg	Ah	Wh/kg	Wh/L	W/kg	%	%	cycles	mi (km)
Sodium/Sulfur	ABB	B-11	253	238	81	83	152	100	91	592[f]	154 (246)
	CSPL	PB-MK3	29.2[e]	292	79	123	90	100	88	795[f]	150 (240)
Lithium/ Monosulfide	SAFT America	Prismatic	2.94[e]	203	66	133	64	95	81	158	93 (149)
Nickel/Zinc	Electrochemica	R&D Cell	1.69	69	67	142	115	91	77	114	108 (173)
Nickel/Metal-Hydride	Ovonics	H-cell	0.628	28.0	55	152	175	90	80	505	97 (155)
Nickel/Cadmium	SAFT	STM5-200	24.5	217	55	104	175	90	78	>1000[f,g]	102 (163)
Nickel/Iron	Eagle-Picher	NIF200	25	203	51	118	99	74	58	918[g]	87 (139)

a Determined for 3-h rate CI discharges.
b Determined from driving profile discharge data at 80% DOD.
c Determined with SFUDS discharges to 80% DOD unless otherwise indicated.
d Determined for the IDSEP Van with a 695 kg battery on an SFUDS driving schedule.
e Performance based on manufacturer projections of future battery weight and case volume.
f Determined with 100% DOD discharges.
g Detemined with J227aC discharges.

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