OVERVIEW OF RECHARGEABLE BATTERY TESTING IN THE UNITED STATES

P. C. BUTLER

Sandia National Laboratories, Division 2525, P.O. Box 5800, Albuquerque, NM 87185 (U.S.A.)

Introduction

Battery testing activities are a significant part of many battery development and engineering programs in the United States. Improved and advanced cells and batteries are being evaluated for electric vehicle, load-leveling, solar, aerospace, and military applications. These programs are being carried out by industrial, national, military, and other independent laboratories. Many testing laboratories are funded by the U.S. Department of Energy (DOE) for the evaluation of systems being developed by independent and government-funded programs. This paper will describe, in general terms, battery testing facilities, types of electrochemical systems on test, and testing methods for both DOE-funded and some independently-funded programs.

DOE-funded battery evaluation

Battery development and testing programs are funded by two organizations within DOE. The Office of Energy Storage and Distribution funds basic electrochemical research at Lawrence Berkeley Laboratory, advanced battery engineering at Sandia, and testing at Sandia and Argonne National Laboratories. Advanced battery concepts for electric vehicles (EV), load leveling, and solar applications are being developed and evaluated under this program. The Office of Vehicle and Engine Research and Development, Electric and Hybrid Propulsion Division, supports development, laboratory testing, and field testing of EV batteries. Development activities are managed by Argonne and Sandia National Laboratories, while laboratory testing is performed at Argonne National Laboratory, Idaho National Engineering Laboratory, and other laboratories. Figure 1 is a diagram of the relationships of these organizations.

Sandia National Laboratories

Sandia National Laboratories operates a computer-controlled cell and battery prototype testing laboratory. Electrochemical systems in the early stages of development are evaluated under parametric and solar application

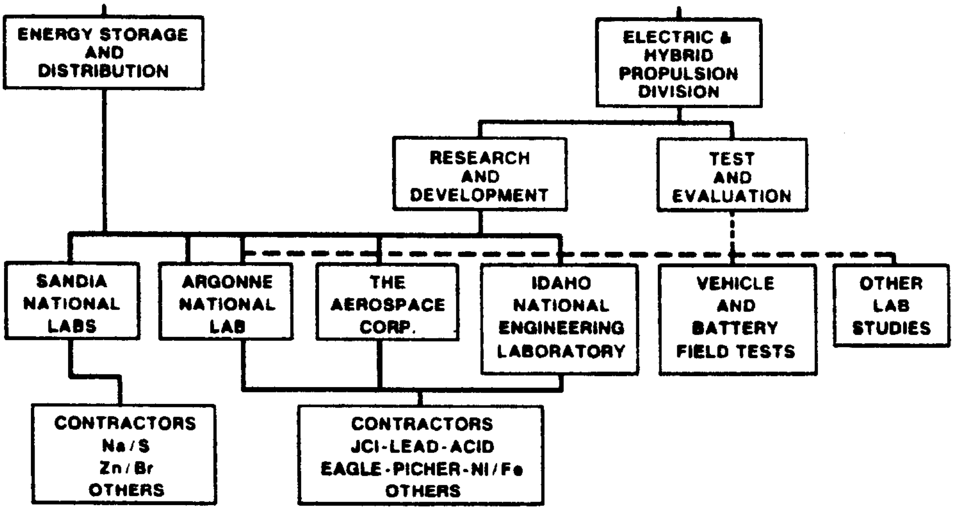

Fig. 1. U.S. Department of Energy sponsored battery testing.

TABLE 1

Cells and batteries presently on test at Sandia National Laboratories

Technology	Number of units on test	Type of test
GNB lead–acid discharge	1 battery	Life at $C/5$ CC*
COMSAT nickel/hydrogen	5 cells 1 battery	Parametric
Nickel/cadmium	10 batteries	Life and parametric
Exxon zinc/bromine	2 batteries	Life and parametric
GEL zinc/bromine	1 battery	Life and parametric
Ford Aerospace sodium/sulfur	3 cells	Parametric at $C/5$ CC* discharge
JCI Gel Cell lead–acid	4 batteries	Life and parametric

*CC = constant current.

test regimes. The goal of these tests is to identify key performance or life-limiting problems early in the engineering development of a system. These test results are reported to the respective developers for appropriate action. A further objective is to test improved batteries for solar applications to determine performance, life, and component sizing information. These results are used to support full scale field engineering testing of batteries with photovoltaic and wind turbine generator systems.

The Sandia cell and battery test laboratory has evaluated prototype, sealed lead–acid, nickel/cadmium, nickel/hydrogen, zinc/bromine, iron/chromium redox, zinc/ferricyanide, lithium/iron sulfide, and sodium/sulfur test units. Units presently on test are described in Table 1.

The Sandia solar application field tests have utilized conventional lead–acid batteries in order to collect baseline information. Systems under test include a stand-alone wind turbine/battery experiment at Rocky Flats, Colorado, a stand-alone photovoltaic array/battery residential experiment on a remote New Mexico, Indian Reservation, and a grid-connected photovoltaic array/battery experiment at Sandia. Recently, a sealed, lead–acid battery was installed and placed on test at Rocky Flats. A 20 kW h zinc/bromine battery was installed and is about to be tested at the Sandia photovoltaic array test facility. Data collected to date from these experiments have provided information on sizing the various system components, determining the amount of load satisfaction, and defining battery maintenance requirements.

TABLE 2

Major testing activities by Sandia National Laboratories contractors

Contractor	Technology	Number of units on test	Type of test
Ford Aerospace and Communications Corp.	Sodium/sulfur	116 cells 2 - 96 cell modules	*C*/3 CC* dischg.** *C*/5 CC dischg.
Exxon Research and Engineering Company	Zinc/bromine	>10 8-cell stacks 1 10-kW h system 5 20-kW h systems	Parametric *C*/3 CC dischg. *C*/3 CC and EV profile
Exide Management and Technology Company	Lead–acid Load-levelling	8 - 3100 A h cells	*C*/5 CC dischg. at elevated temperature

*CC = constant current.
**dischg. = discharge.

Testing conducted as part of Sandia-funded contractor development work for three major programs is summarized in Table 2. Development work by each contractor has been completed, and contracts for testing are active at Ford Aerospace and Exide. In addition, development and testing of nickel/hydrogen cells is in progress at Comsat Laboratories. The goals of these tests are to evaluate battery design, performance, life, and auxiliary systems' reliability and design. The Exide tests are accelerated tests using temperature as the acceleration factor. Typically, contractor tests have identified battery design or assembly problems. The Exide tests have demonstrated that very long lives (>4000 equivalent 25 °C cycles) are possible for improved lead–acid, load-leveling batteries.

Argonne National Laboratory

Argonne National Laboratory receives funding from DOE for operation of the National Battery Test Laboratory (NBTL) and for the development of

TABLE 3

Cells and batteries presently on test at Argonne's National Battery Test Laboratory

Technology	Number of units on test	Type of test
Johnson Controls lead–acid	1 cell 7 modules 2 batteries	Characterization Life & Characterization
Tubular lead–acid	4 modules	Characterization
Exide load-leveling lead–acid	3 modules	Life at high temperature
Eagle-Picher nickel/iron	4 modules	Life & Characterization
Electrochimica nickel/zinc	4 cells	Characterization
Ford Aerospace sodium/sulfur	4 cells	Life & Characterization
Energy Development Associates zinc/chlorine	1 battery	Characterization

EV batteries. The NBTL consists of a computer-controlled laboratory with 70 cell or module test stations and six battery stations. Most stations are capable of charge and discharge currents of 500 A and are able to apply power profile discharge tests. Typically, a standard series of tests is performed on state-of-the-art or pre-production cells and batteries. These tests include the evaluation of capacity at the $C/3$ discharge rate, charged stand tests, determination of capacity at constant power (Ragone plot), simulated driving power profile tests, determination of sustained power capability, and life cycle tests. Also, advanced batteries not suitable for EV applications have been tested at NBTL under test regimes which utilize discharge rates and other tests typical of stationary battery applications.

Technologies currently on test at NBTL are described in Table 3. These tests have resulted in performance characterization and cycle life determination of near-term EV batteries using standardized test procedures and have permitted the normalization of results. This has made possible meaningful technology comparisons which allowed development resources to be focused on the most promising technologies. Also, NBTL has performed independent detailed performance and life tests on zinc/chlorine and sodium/sulfur technologies.

Key accomplishments by NBTL personnel include the demonstration of good correlation between EV battery range projections based on NBTL laboratory results and the range obtained on dynamometer tests at the Jet Propulsion Laboratory. Furthermore, a methodology was developed and verified that allowed discharge times to be predicted for power discharge profiles based on the peak and average power demands of the profile. The predicted values closely matched the measured values obtained from running the profile test.

As part of the DOE-sponsored EV battery development program managed by Argonne, two contractors are developing and evaluating test units. Johnson Controls, Inc. is developing advanced lead–acid batteries, emphasizing flow-through electrode designs. Eagle-Picher Industries is developing and testing improved nickel/iron batteries.

Electric and Hybrid Vehicle Division testing

The DOE Electric and Hybrid Vehicle Division (EHV) supports a wide variety of vehicle, propulsion system, and battery testing programs. A major part of this activity is performed by Idaho National Engineering Laboratory. Much of this work was formerly done by the Jet Propulsion Laboratory. The present activity at Idaho is divided into vehicle testing, battery testing, data acquisition system development, and component development tasks.

Vehicle testing is performed on a dynamometer capable of imposing driving profiles on test units. Vehicles under test, or planned for testing, include two Bedford Motor Company vans, two Eaton Corporation vehicles (one a.c. and one d.c.), and two Soleq Corporation vehicles.

Battery testing consists of characterization tests of batteries in vehicles under simulated driving or dynamometer test conditions. Batteries on test, or to be tested in the near future, include nickel/cadmium and tubular lead–acid. Furthermore, a battery test facility is being built to perform capacity tests and other routine characterization evaluations.

Another project funded by the DOE Electric and Hybrid Vehicle Division is managed by The Aerospace Corporation and consists of battery characterization tests and support for vehicle field tests. The University of Alabama at Huntsville is performing battery charging tests and developing optimized charge-control algorithms for Alco and Phase III Gel Cell (Johnson Controls) lead–acid batteries. Tests of KW Batteries Company tubular plate, lead–acid batteries at temperature extremes are in progress. Twenty-first Century Electric Vehicles, Mellon Institute and Soleq Corporation are also involved in tests of various lead–acid batteries. Several organizations are involved with evaluation of Phase II Gel Cell batteries in vehicle tests under driving conditions.

Field tests of electric vehicles and batteries are in progress at approximately 24 test and evaluation sites across the country. A wide variety of vehicle use patterns, weather conditions, and vehicle types is being evaluated in these tests. Part of the evaluation process for these site tests has been the development of the Versatile Data Acquisition System. This system provides standard data from the various sites, and permits comparison of vehicle and battery operating characteristics. The development of the software for these devices is a continuing activity managed by the Idaho National Engineering Laboratory.

In order to coordinate the many electric vehicle battery test activities, the EHV Battery Test Working Task Force was established in 1983. The Task Force is composed of technical representatives of many of the above-described organizations. Issues such as developing a simple power profile battery test regime, coordinating testing information exchange, and the specification of standard battery test methods have been addressed by the Task Force. The development of standard test methods and reporting formats has special significance to this Workshop because of the need to facilitate meaningful comparisons of differing technologies tested in different laboratories.

Non-DOE testing organizations

Many other research, industrial, and military laboratories have significant battery testing programs. The types of test regimes utilized are dependent upon the battery application under consideration.

The Battery Energy Storage Test (BEST) facility is operated by Public Service Electric and Gas Company in New Jersey and provides system testing of load-leveling batteries. Testing to date has involved a 1.8 MW h conventional lead–acid battery, a 500 kW h improved lead–acid battery, and a 500 kW h zinc/chlorine battery. These tests have proven the viability of batteries for this application. Plans are being made to test other advanced batteries in this facility in the future.

The Tennessee Valley Authority has established an electric vehicle and battery test facility in Chattanooga, Tennessee. The goal of this work is to evaluate commercially available electric vehicles and batteries and to investigate the impact of large scale electric vehicle usage on electric utility operations. A wide variety of vans, buses, and fleet utility vehicles has been evaluated on a test track and in dynamometer-simulated road tests. Data have been collected relative to vehicle and battery performance under a variety of duty cycles. Battery maintenance requirements have been measured, and data acquisition systems have been developed.

EPRI also funds battery development and testing at Energy Research Corporation (zinc/bromine), Energy Development Associates (zinc/chlorine), and Chloride Silent Power (sodium/sulfur).

Other organizations have evaluated batteries for various defense-related applications. Extensive, accelerated tests of nickel/cadmium cells have been conducted at the Naval Weapons Support Center in Crane, Indiana. A statistical test matrix was performed and results of accelerated and non-accelerated tests were compared.

Tests of many types of electrochemical systems for aerospace applications have been conducted at Wright-Patterson Aeronautical Laboratories. Sealed nickel systems have been tested and, during the last year, sodium/sulfur cells have been evaluated.

During the last year, abusive tests of sealed lead–acid batteries have been conducted at Boeing Aerospace Corporation. The ability of this technology to recover from very deep discharge has been investigated.

Conclusion

In conclusion, there is a diversity of battery evaluation programs for different applications in progress in the United States. Commercially available units, near-term technologies, and advanced, development prototypes are all being evaluated. Testing is being conducted by industry, government, and independent research organizations. A wide variety of testing methods, reporting procedures, and facilities is in use by these organizations. For comparison purposes, Table 4 presents capacity and life rating values for certain applications as generally used in the United States. Some groups advocate using constant power or a power profile for electric vehicle battery life testing. Values for load-leveling applications are variable depending on specific use, *i.e.*, short peak shaving discharge ($C/1$) as opposed to a several hour discharge.

TABLE 4

Battery capacity and cycle life rating parameters for various applications (U.S.A.)

Item	Application		
	Electric vehicle	Load leveling	Solar
Battery capacity rating			
Discharge rate at which capacity of battery is rated. (C_x/X) X = ___ h:	3	1 - 5	5
Life cycle rating			
Type of discharge, Constant current = CI Constant power = CP Pattern = P:	CI	CI	CI
Discharge rate, (C_x/X) X = ___ h:	3	5	5
Depth of discharge, (%)	80	80	80
End of life criteria:	less than 75% of $C/3$ rated capacity	less than 80% of $C/5$ rated capacity	less than 80% of $C/5$ rated capacity

Values for load-leveling application are variable depending on specific use, *i.e.*, short-peak shaving discharge as opposed to several-hour discharge. Life ratings for this application could be stated in years or equivalent cycles.

Some of the United States testing organizations have been described in this paper, although certainly not all could be mentioned. Papers included in this Workshop will describe many of these activities in more detail. Hopefully, this information exchange can result in improved communication between all testing organizations and lead to the development of meaningful test results comparisons and more reliable battery evaluation methodologies.

Acknowledgement

This work is supported by the U.S. Department of Energy under contract DE-AC04-DP00789.