Abuse Testing of High Power Batteries

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Overview

Timeline

- Start Date: Oct. 2007
- End date: Sept. 2014
- Percent complete: <10%

Budget

- Total project funding
  - $500K
- FY08 Funding: $500K
- FY09 Funding: $500K
- Funding for FY10: TBD

Barriers

- Abuse Tolerance of Energy Storage Device is identified as a barrier in USABC and DOE battery development programs.
- Immature technology for HEV/PHEV applications.

Partners

- USABC

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Objectives\Milestones

Objectives

- Sandia provides an independent test laboratory for DOE and USABC
- Abuse testing performed on cells and modules delivered by USABC contractors as part of their contract deliverables
- Test results generated are battery protected information and released only to the contractor and members of the USABC Tech Team

Milestones

- Perform abuse testing of cells and modules from contractors to USABC and report results to Tech Team

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Approach

Perform CHARACTERIZATION tests which evaluate the response to abuse environments

- **Usually results in failure of the test article.**
- **Documentation of conditions that cause failure.**
- **Evaluate failure modes and abuse conditions using destructive physical analysis (DPA)**
- **Provide quantitative measurements of cell/module response.**
- **Document improvements in abuse tolerance.**
- **Develop new abuse test procedures that more accurately determine cell performance under most likely abuse conditions**

Technical Accomplishments/ Progress/Results

USABC Cell Developer Contracts
All Test Data is Proprietary and Available
Only to the Developer and the USABC Tech Team

All HEV cell and module deliverables have completed abuse testing and final reports issued

- **Johnson Controls-Saft**
  - HEV Cell Level Tests Completed (2 groups of 6 cells)
- **Compact Power Inc.-LG Chem.**
  - HEV Cell and Module Level Tests Completed (6 cells, 6 modules)
  - PHEV Cells Delivered and Testing Completed (12 Cells)
- **A123**
  - HEV Cell Level Tests Completed (8 cells)
- **Enerdel**
  - Awaiting PHEV cell delivery

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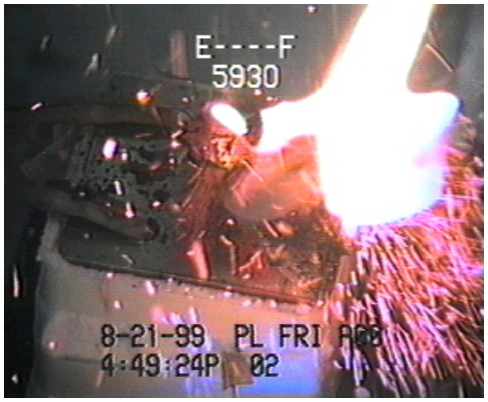
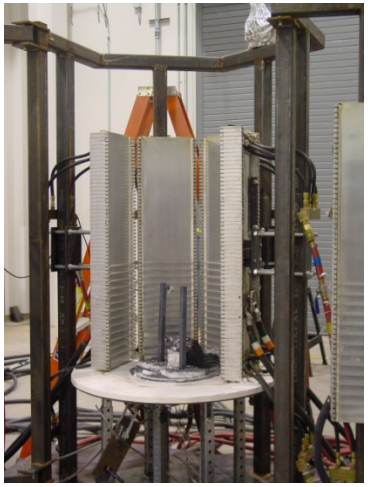
Examples of Sandia Abuse Laboratory Capabilities

Module Crush

Cell Crush

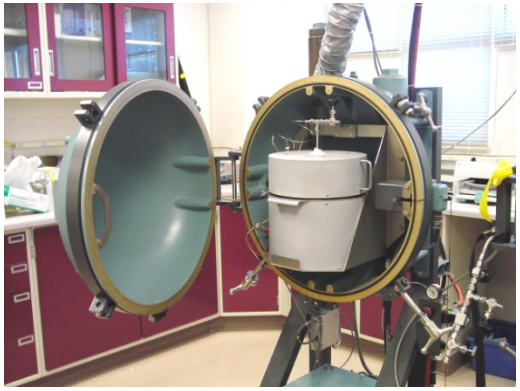


Thermal Ramp

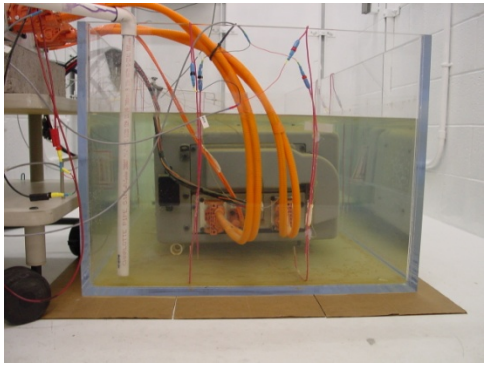


Simulated Fuel Fire

Overcharge



Accelerating Rate Calorimetry



Water Immersion

What are Abuse Test Conditions HEV\PHEV Batteries are Likely to Encounter?

- **Mechanical Abuse**
  - Controlled Crush
  - Penetration
  - Drop
  - Immersion
  - Roll-over Simulation
  - Mechanical Shock
- **Thermal Abuse**
  - Thermal Stability
  - Simulated Fuel Fire
  - Elevated Temperature Storage
  - Rapid Charge/Discharge
  - Thermal Shock Cycling
- **Electrical Abuse**
  - Overcharge/Overvoltage
  - Short Circuit
  - Overdischarge/Voltage Reversal
  - Partial Short Circuit

Ref.: Sandia Report SAND 2005-3123, "FreedomCAR Electrical Energy Storage System Abuse Test Manual for Electric and Hybrid Electric Vehicle Applications", Daniel H. Doughty and Chris C. Crafts, May 2005

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Abuse Testing is Performed to Characterize Response to "Off-normal Conditions" or Environments

Assign Hazard Severity Level Score using descriptions adapted from EUCAR and SAND2005-3123

Hazard Level	Description	Classification Criteria, Effect
0	No effect	No effect, no loss of functionality.
1	Passive Protection activated	No defect, no leakage, no venting, no fire or flame, no rupture, no explosion, no exothermic reaction or thermal runaway. Cell reversibly damaged. Repair of protection device needed.
2	Defect / Damage	No leakage, no venting, no fire or flame, no rupture, no explosion, no exothermic reaction or thermal runaway. Cell irreversibly damaged, repair needed
3	Leakage $\Delta m < 50\%$	No venting, no fire or flame**, no rupture, no explosion, Weight loss < 50% of electrolyte weight. (electrolyte = solvent + salt)
4	Venting $\Delta m \geq 50\%$	No fire or flame**, no rupture, no explosion, Weight loss ≥ 50% of electrolyte weight.
5	Fire or Flame	No rupture, no explosion, i.e., no flying parts.
6	Rupture	No explosion, but flying parts, ejection of parts of the active mass.
7	Explosion	Explosion, i.e., disintegration of the cell.

Core Abuse Test Performed

- Overcharge: (4 cells)
  - Rates: 1C and 3C
  - Flammability test: with and without external ignition source (spark)
  - Monitor heat generation rate and evolved gas species
- Short-Circuit: (2 cells)
  - Hard short (1 mohm)
  - Intermediate short (10 mohm or resistance comparable to cell internal resistance)
- Thermal Ramp: (4 cells)
  - Ramp to 250°C or failure (5 °C/min)
  - Two states of charge
    - 100%SOC
    - 50%SOC
  - Flammability test: with and without external ignition source (spark)
  - Monitor heat generation rate and evolved gas species
- Separator Shutdown Integrity: (2 cells)
  - Heat to slightly above separator shutdown temperature and hold
  - Apply external voltage (20V) and monitor for separator breakdown
  - Repeat at 10°C higher temperature
- Pressure Induced Internal Short Test (2 cells)
  - Room Temperature 100%SOC
  - Room Temperature 50%SOC

- Total: 12 cells

* Duplicate runs can be performed depending of cell availability

Representative Overcharge Data

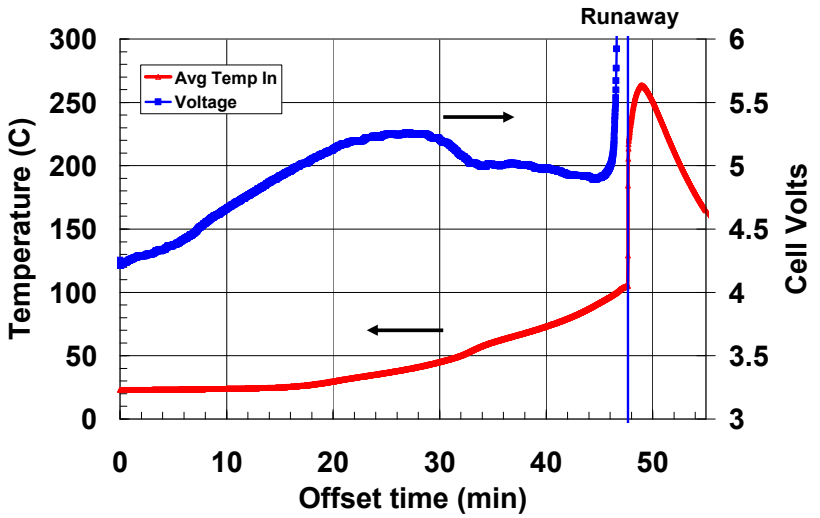
- **Overcharge Test Description:**

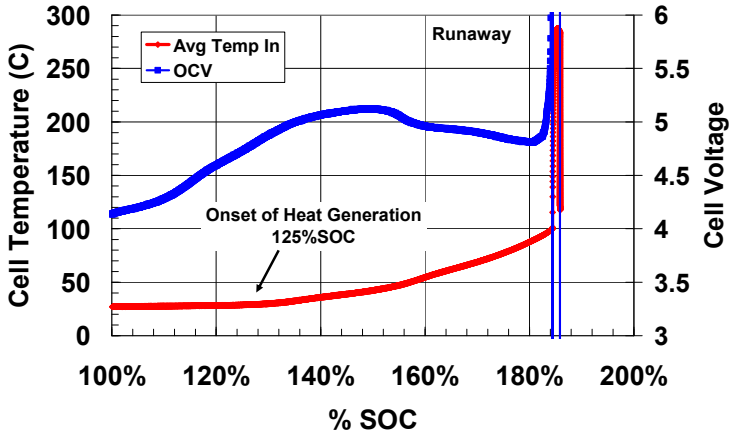
  Test for cell heat and gas generation, thermal runaway, separator integrity, flammability of vent gases

  - Starting Conditions: 100% State of Charge (SOC)
  - Charge Rate: 1C and 3C
  - Voltage Limit: Maximum voltage that can be delivered while in operation
  - Termination Conditions: 200% SOC or failure
  - Monitoring Parameters:
    - Voltage
    - Temperature
    - Current (SOC)
    - Gas Generation
    - Video

Cascading Cell Failure at Module Level

Typical Cell Response

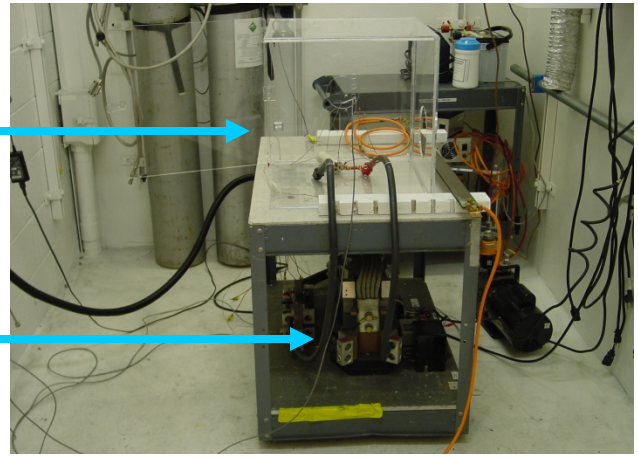




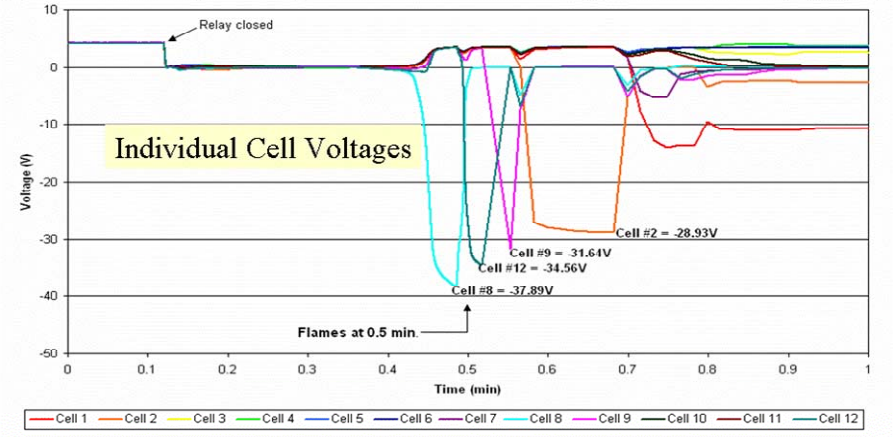
Representative Short Circuit Data

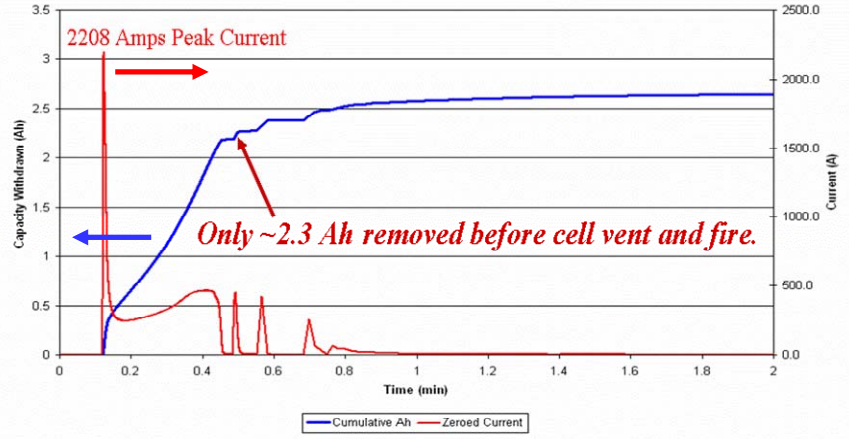
- **Short Circuit Test Description:**
  Test for internal cell shorting, thermal runaway and cell venting

  - Starting Conditions: 100% State of Charge (SOC)
  - Shorting Load: 1 mohm and 10 mohm
  - Time Limit: 1 hour
  - Termination Conditions: Stable temperature or failure
  - Monitoring Parameters:
    - Voltage
    - Temperature
    - Current (SOC)
    - Gas Generation
    - Video



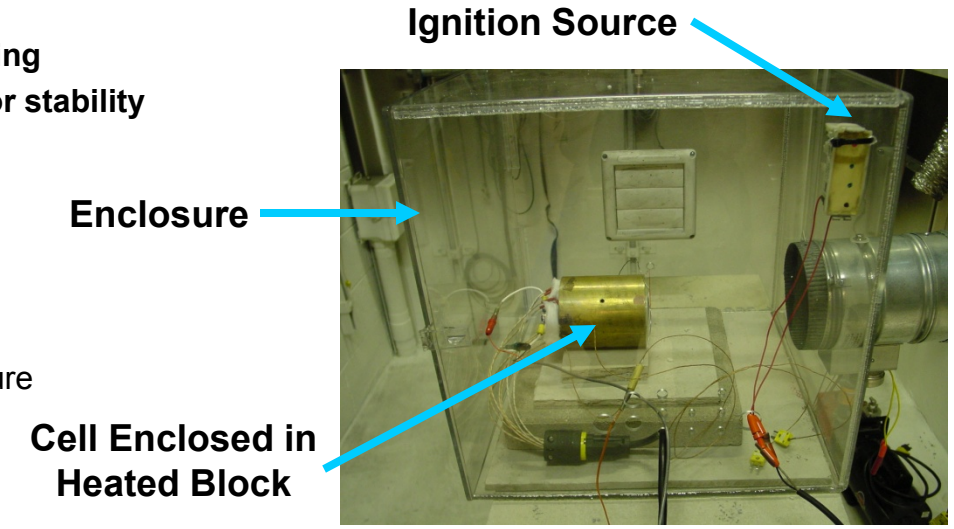
Cascade Cell Failure in Module

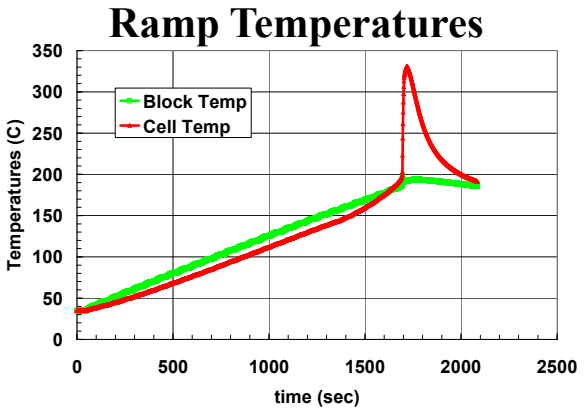


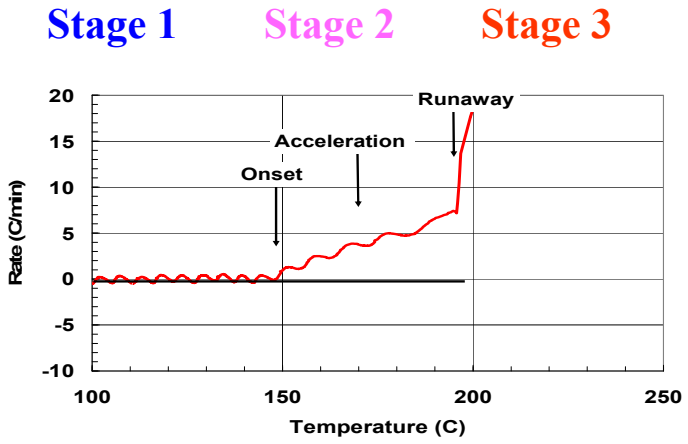


Representative Over-Temperature Data

- **Thermal Ramp Test Description:**
  - **Test for thermal stability, heat and gas generating reactions, flammability of vent gases, separator stability**
  - Starting Conditions: 100% State of Charge (SOC)
  - Ramp Rate: 5 °C/min
  - Ramp Temperature Limit: 250 °C
  - Ignition Source: Test for flammability
  - Termination Conditions: Stable temperature or failure
  - Monitoring Parameters:
    - Voltage
    - Temperature (Cell, Block, Air)
    - Cell Heating Rate
    - Gas Generation
    - Video







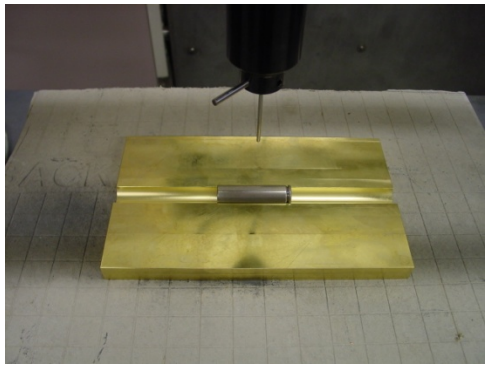
New Abuse Characterization Techniques Developed

- **Pressure Induced Internal Short Circuit Test**
  - Simulation of spontaneous internal short circuit by external pressure point
  - Test developed and adopted by USABC to measure cell response to internal short circuits over a range of temperatures and states of charge

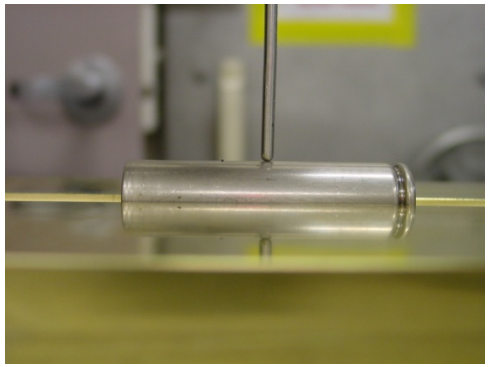
- **Separator Shutdown Integrity Test**
  - Measure of the separator integrity above shutdown with applied voltage source
  - Simulates common pack level failure mode

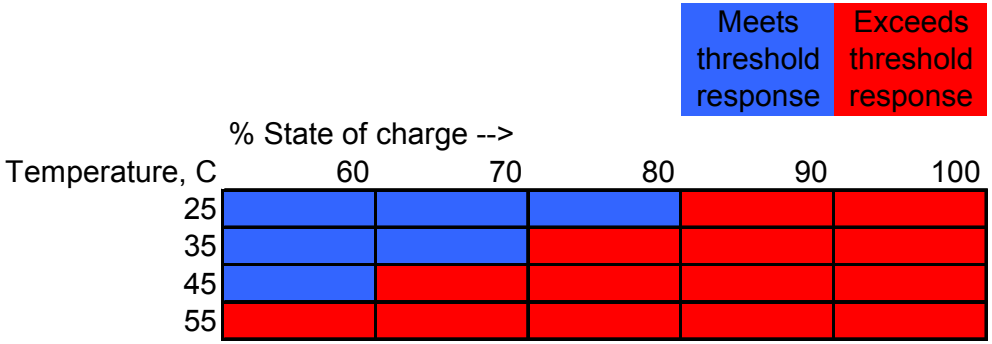
USABC Pressure Induced Internal Short Circuit Test

Test Profile:
The test should be performed at a constant, slow rate (less than 1 mm/sec) so that the cell skin temperature can respond to any internally induced shorts. The deformation of the cell by the rod should continue until complete penetration of the cell is obtained. The response of the cell during this test should be considered as two separate regimes: response prior to penetration and response (thermal, gas, fire) after penetration.



Threshold acceptance criteria:
Cell response prior to penetration: Maximum skin temperature below 150°C and no venting. Cell response after penetration: Less than or equal to hazard severity response level 3 (No fire or flame; no rupture; no explosion. Electrolyte leakage <50%)





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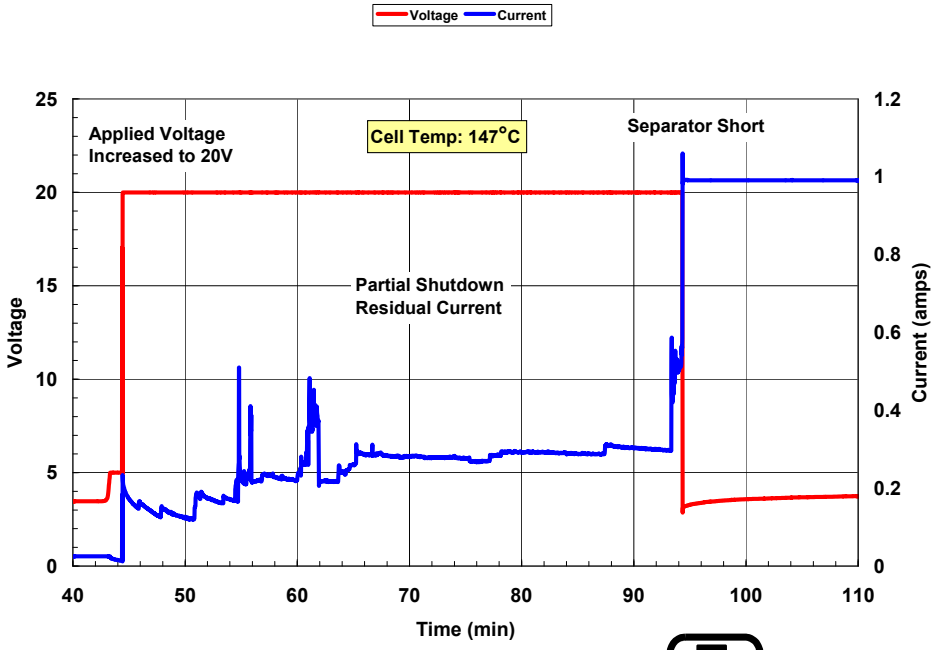
Separator Shutdown Integrity Test

- **Procedure**
  - Cell ramped to above shutdown temperature
  - Potential (20V) applied with 1C current limit
  - Cell temperature, current and voltage monitored for a minimum of 30 minutes
- **Pass Criteria**
  - No thermal runaway
  - No venting
  - No current flow from separator breakdown



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Revision of SAE J2464 Abuse Manual Prepared

- SAE J2464 is a common reference manual for abuse testing which is essentially the same as the Sandia document adopted by USABC
- A review committee of OEMs, developers and Sandia has worked over the last year to update this manual.
- Abuse testing procedures have been modified, dropped and new tests added to
  - Expand the scope of tests to include new storage devices and vehicular designs
  - Harmonize wording with other test standards
  - Make results more quantitative
  - Provide guidance to automotive community on how and what tests to perform
- New manual in final stages of approval

Future Work

- **PHEV – New high-energy density cells from USABC contractors will be tested as part of their deliverable requirements FY09**

- **New testing procedures will be refined based on USABC testing results**

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Summary

- Cell and Module abuse tests have been completed at Sandia in support of USABC contracts
  - Results have been used to develop improved abuse tolerant cells
- Improved testing procedures has lead to greater efficiency in performance of abuse testing
- New abuse test techniques will more clearly identify real-life abuse response of cells and modules

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