# Overstress Safety Evaluations of Consumer/Automotive Li-Ion Batteries Near "End-Of-Life"

The Battery Show

November 2012, Novi MI

Tom O'Hara, Håken Carlberg

# Global Presence – Energy Storage

**USA**

**Detroit, MI**

**Grand Rapids, MI**

**San Antonio, TX**

**EMEA**

**Kaufbeuren, Germany**

**Leatherhead, UK**

**Kista, Sweden**

**APAC**

**Shanghai**

**Taipei**

# Overstress Safety Evaluations of Consumer/Automotive Li-Ion Batteries Near "End-Of-Life"

# A Perspective on Battery Safety Standards

- **Intertek sits on many Battery Safety Standards Committees:**
  **ANSI, UL, UN/DOT, IEC, IEEE (CTIA), SAE**

# A Perspective on Battery Safety Standards

Intertek
Valued Quality. Delivered.

- Intertek sits on many Battery Safety Standards Committees
  ANSI, UL, UN/DOT, IEC, IEEE (CTIA), SAE
- **Each Organization and Standard has its own charter and focus**
  - **SAE – Automotive**
  - **UN/DOT – Transportation/Shipping**
  - **ANSI, UL, IEC, IEEE – Consumer Batteries/Cells**

# A Perspective on Battery Safety Standards

Intertek

Valued Quality. Delivered.

- Intertek sits on many Battery Safety Standards Committees

  ANSI, UL, UN/DOT, IEC, IEEE (CTIA), SAE

- Each Organization and Standard has its own charter and focus
- **On a test by test basis, there is much overlap across safety standards**
  - **Harmonization efforts abound, attempting to make similar tests identical**
  - **However, for some tests, differences will continue to exist**

# A Perspective on Battery Safety Standards

Intertek

Valued Quality. Delivered.

- Intertek sits on many Battery Safety Standards Committees

  ANSI, UL, UN/DOT, IEC, IEEE (CTIA), SAE
- Each Organization and Standard has its own charter and focus
- On a test by test basis, there is much overlap across safety standards
- **Real world Li-Ion battery "failure" rates are just 1 to 10 per million**
  - **Are test standards sufficient to identify "good" from "marginal" designs?**
  - **Do tests simulate real world overstress conditions?**
  - **Do tests evaluate actual failure mechanisms?**
  - **New cells and batteries generally pass industry safety tests – *but* only "fresh" cells/batteries are tested, while real world "failures" often occur late in life.**

# A Perspective on Battery Safety Standards

Intertek

Valued Quality. Delivered.

- Intertek sits on many Battery Safety Standards Committees

  ANSI, UL, UN/DOT, IEC, IEEE (CTIA), SAE
- Each Organization and Standard has its own charter and focus
- On a test by test basis, there is much overlap across standards
- Real world Li-Ion battery “failure” rates are just 1 to 10 per million
- **This presentation introduces Intertek’s program to evaluate the safety of Li-Ion batteries as they approach “End-Of-Life”**

# Program Overview

Intertek
Valued Quality. Delivered.

**On-going evaluation of "Near-End-Of-Life" Li-Ion Battery Safety**

<u>Purpose:</u>

Evaluate the safety performance of "Fresh" and "Near-End-Of-Life" Li-Ion batteries using both standard and overstress safety test metrics

- Are older batteries more susceptible to failure?
- If Fail Safe, does the failure mode or severity of failure differ?
- If distinctions exist in the safety performance of "Fresh" and "Near-End-Of-Life" batteries, what are the implications?

# Program Overview

Intertek

Valued Quality. Delivered.

**Phase I – Consumer**

- Aged (replaced) Li-Ion Notebook Computer Batteries
- Aged (replaced) Li-Ion Cell Phone Batteries

**Phase II – Automotive EV/HEV**

- Details TBD

# Technical Approach – Phase I (Consumer)

Intertek
Valued Quality. Delivered.

**Sampling:**

Our sampling procedure consists of replacing aged notebook computer battery packs from Intertek staff. We call these batteries "Near-End-Of-Life" as judged by the staff member requesting the replacement.

Rather than disposing of these batteries, we are able to generate new, useful information regarding aged Li-Ion battery safety, while providing hands-on training opportunities for new hires.

# Technical Approach – Phase I (Consumer)

Intertek
Valued Quality. Delivered.

## State-Of-Health (SOH) Assessment:

Our SOH assessment consists of measuring battery and individual cell capacities, impedance, and conducting an elevated temperature soak while monitoring OCV for signs of low grade internal shorting.

This sorting by cell capacity quantifies the “Near-End-Of-Life” assessment made by the Intertek staff member requesting a battery replacement. Peoples’ tolerance for performance fade varies widely.

# Technical Approach – Phase I (Consumer)

Intertek
Valued Quality. Delivered.

**Safety Testing:**

Initially, Intertek will assess performance using industry standard safety tests as defined by ANSI, IEC, IEEE, UL, UN/DOT and SAE (for automotive). Overstress evaluations will follow.

Intertek plans to query industry leaders in order to generate an improved perspective on meaningful overstress tests.

# Technical Approach – Phase II (Automotive)

Details TBD

# Test Selection – Phase I (Consumer)

Intertek
Valued Quality. Delivered.

A Number of Industry Standards exist for evaluating Li-Ion safety. Those considered for this program include:

| | |
|---|---|
| ANSI C18 | IEEE 1625 & 1725 |
| IEC 62133 | UN/DOT 38.3 |
| UL 1642 & 2054 | SAE J2464 / J 2929 |

Although the various test standards listed above vary in scope and focus, they all involve some level of cell based safety evaluations and are worthy of consideration.

# Test Selection – Phase I (Consumer)

Intertek
Valued Quality. Delivered.

The following series of slides presents an overview of the various safety tests contained in the standards listed above.

Presentation is made from an SAE J 2464 perspective

# 4.3.1 Shock Tests

Intertek

Valued Quality. Delivered.

- Cells: follow UN/DOT 38.3
  - small cells/batteries (150g/6ms, 3 axis, +/-, 3X repeat)
  - large cells/batteries (50g/11ms, 3 axis, +/-, 3X repeat)
- Packs: 25g, 18 ms, 3 axis, +/- directions, 3X repeat

**SAE J2929 Criteria:**

**No rupture, fire, explosion, or loss of isolation**

-------------------------------

**Compare:**

UN 38.3 (75g/3ms, 125g to 175g peak, 3 axis, 3X; 50G/6ms for "Large Batteries")

UL 1642 (75g average through 3 ms, 125g to 175g peak, 3 axis, 3X)

IEC 62133 (same as UL 1642)

# 4.3.2 Drop Tests

- Pack level only
- 2 meter drop

**SAE J2929 Criteria:**

**No evidence of fire or explosion**

------------------------------

**Compare:**

UN/DOT 38.3 (n/a)

UL 1642 (n/a)

IEC 62133 (same as UL 2054)

# 4.3.3 Penetration Tests

Intertek
Valued Quality. Delivered.

- Cell
  - 3mm steel rod, sharp point, 8cm/s, through the cell
- Module/Pack
  - 20mm steel rod, sharp point, 8cm/s, through 3 cells / 100mm

**SAE J2929 Criteria:**

**No evidence of fire or explosion**

-------------------------------

**Compare:**

UN/DOT 38.3 (n/a)

UL 1642 (n/a)

IEC 62133 (n/a)

# 4.3.4 Roll-Over Tests

Intertek

Valued Quality. Delivered.

- Module and Pack level
- One full roll, 1 minute duration; repeat 90 degrees

**SAE J2929 Criteria:**

**No evidence of fire or explosion**

------------------------------

**Compare:**

UN/DOT 38.3 (n/a)

UL 1642 (n/a)

IEC 62133 (n/a)

# 4.3.5 Immersion Tests

Intertek

Valued Quality. Delivered.

- Module or Pack
- Submerge in ambient temperature salt water (5% NaCl in water) for 2 hours

**SAE J2929 Criteria:**

**No evidence of fire or explosion**

------------------------------

**Compare:**

UN/DOT 38.3 (n/a)

UL 1642 (n/a)

IEC 62133 (n/a)

# 4.3.6 Crush (Impact) Tests

- Cell level or above
- Textured platen (radiused "cylinders")
- Crush to 15%, hold 5 minutes, crush to 50%, max force = 1000X DUT weight

**SAE J2929 Criteria:**

**No evidence of fire or explosion**

-------------------------------

**Compare:**

UN/DOT 38.3 (Impact Test: 15.8mm bar, 9.1kg weight dropped from 61cm)

UL 1642 (Impact Test: same as UN/DOT 38.3)

IEC 62133 (Crush Test: flat surfaces, 13kN crush)

# 4.4.1 High Temperature Hazard Tests

Intertek
Valued Quality. Delivered.

- **Pack Module and above**
- **890C (within 90s) for 10 minutes, indirect heat, fuel fire simulation**

**SAE J2929 Criteria:**

**No evidence of fire or explosion**

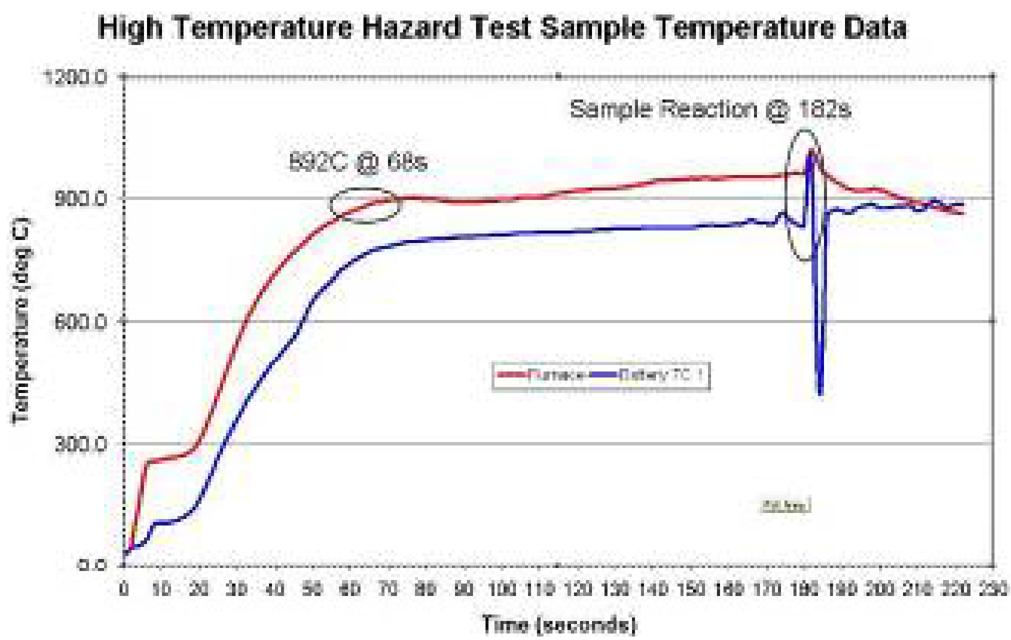
**------------------------------**

**Compare:**

UN/DOT 38.3 (n/a)

UL 1642 (Projectile Test: “Bunsen Burner” blue flame test)

IEC 62133 (n/a)



# 4.4.2 Thermal Stability Tests



- Cell level
- Thermal ramp 5C/min to 300C above max operating temp
- Repeat at 2C/minute and 1 hour hold to determine thermal stability limit
- Several additional repeat conditions (overcharge, cells at mid-life, etc.)

**SAE J2929 Criteria:**

**No evidence of fire or explosion**

------------------------------

**Compare:**

UN/DOT 38.3 (n/a)

UL 1642 (5C/min to 130C, hold 10 minutes)

IEC 62133 (same as UL 1642)

# 4.4.3 Cycling Without Thermal Management Tests

Intertek

Valued Quality. Delivered.

- Module and Pack level
- 20 full cycles, no rest

**SAE J2929 Criteria:**

**No evidence of fire or explosion**

**------------------------------**

**Compare:**

UN/DOT 38.3 (n/a, conditioning of samples requires 25 or 50 cycles)

UL 1642 (n/a, conditioning of samples requires continuous cycling for 90 days or to 25% of advertised cycle life)

IEC 62133 (n/a)

# 4.4.4 Thermal Shock Cycling Tests

- Cell level or above
- Cycle between +70C to -40C (<15 minute per transition)
- 5 thermal cycles, 1 hour hold at extremes for cells, 6 hours for packs
- 3X C/3 charge/discharge cycles before and after thermal cycling

**SAE J2929 Criteria:**

**No evidence of fire or explosion**

**-------------------------------**

**Compare:**

UN/DOT 38.3 (10 cycles, -40C to +75C, 30 min transition,
6h/12h hold for small/large)

UL 1642 (10 cycles, -40C to +70C, 30 min transition,
4h hold at -40C/+70C, 2h at +20C)

IEC 62133 (5 cycles, -20C to +75C, 30 min transition,
4h hold at -20C/+75C, 2h at +20C)

# 4.4.5 Passive Propagation Resistance Tests

Intertek

Valued Quality. Delivered.

- Module or Pack level
- Heat to +55C or max operating temperature
- Rapidly heat one cell to +400C to thermal runaway

**SAE J2929 Criteria:**

**No evidence of fire or explosion**

**------------------------------**

**Compare:**

UN/DOT 38.3 (n/a)

UL 1642 (n/a)

IEC 62133 (n/a)

# 4.5.1 Short Circuit Tests

Intertek
Valued Quality. Delivered.

- Cell and Module or Pack level, at Room Temp.
- Hard Short (Cell, Module, and Pack) – 5 mOhm or less, hold 1 hour
- Soft Short (Cell) – over 10 mOhm (DUT DC resistance), hold 1 hour

**SAE J2929 Criteria:**

**No evidence of fire or explosion**

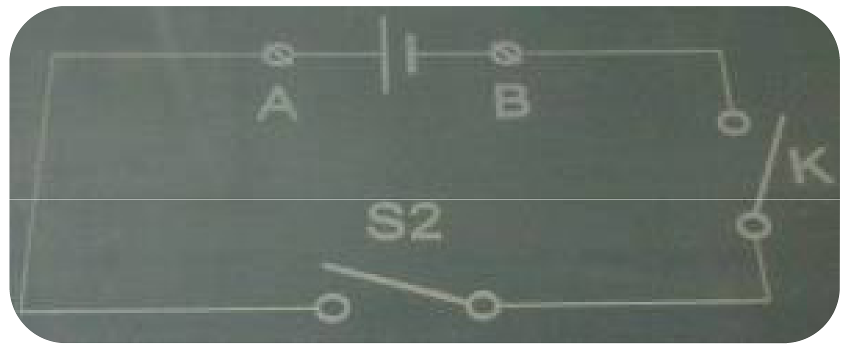
------------------------------

**Compare:**

UN/DOT 38.3 (<0.1 ohm at +55C, hold 1 hour)

UL 1642 (80 mOhm at both +20C and +55C,
hold to 0.2V or until temp is ambient)

IEC 62133 (<100 mOhm at both +20C and +55C,
hold for 24h or 20% of max temp rise)



# 4.5.2 Overcharge Tests

- Cell (both 1C continuous and max regen breaking / charging current, est. 3C)
- Module or Pack (1C continuous)
- Charge to 200% SOC or event

**SAE J2929 Criteria:**

**No evidence of fire or explosion**

------------------------------

**Compare:**

UN/DOT 38.3 (2X up to 22V for 18V system, 1.2X for >18V System, charge for 24 hours)

UL 1642 (constant max output voltage and 3X max charging current, 7 hours)

IEC 62133 (Cell charges at >10V at 2.5X C/5 rate)

# 4.5.3 Overdischarge (Forced Discharge) Tests

Intertek
Valued Quality. Delivered.

- Fully discharged cell, discharge at max current to 2X Ah capacity, hold 30 min
- Module – fully discharged cell in series with charged module cells, discharge configuration at maximum current to 0.2V

**SAE J2929 Criteria:**

**No evidence of fire or explosion**

-------------------------------

**Compare:**

UN/DOT 38.3 (cells – discharge rated Ah at max current using a 12 V DC Power Supply)

UL 1642 (discharged cell in series w/ charged cells, 80 mOhm discharge to 0.2V)

IEC 62133 (discharged cell reverse charged at ItA for 90 minutes)

# 4.5.4 Separator Shutdown Integrity Tests

Intertek
Valued Quality. Delivered.

- Cells which have a shutdown separator
- Heat cell to shutdown temperature plus 5 C
- Apply 20V over voltage potential (current limited to <1C), 30 minutes

**SAE J2929 Criteria:**

**No evidence of fire or explosion**

------------------------------

**Compare:**

UN/DOT 38.3 (n/a)

UL 1642 (n/a)

IEC 62133 (n/a)

# Miscellaneous Additional Evaluations

- SAE: 4.2 Hazardous Substance Monitoring
- Battery Enclosure Tests (UL & IEC)
- Altitude Simulation (UN/DOT, UL, IEC)
- Vibration (UN/DOT, UL, IEC)
- Forced Internal Short Circuit, Nickel Particle (IEC)
- Cell Safety Vent (IEEE)

# Initial Test Results

Intertek

Valued Quality. Delivered.

Two 6 cell Notebook Computer packs were evaluated:

- Packs are approximately 30 months old
  - Pack A: Code Date April 2010
  - Pack B: Code Date February 2010
- Both packs were in service approximately 2 years
- Packs are rated at 4910 mAh
  - Pack A measured 4700 mAh
  - Pack B measured 1000 mAh

**Clearly, we have a distinction!**

Note:

- It is interesting that the owners of both Pack A and Pack B requested a battery replacement. This Speaks to differences in tolerance and perceptions regarding performance expectations

# Initial Test Results

Intertek
Valued Quality. Delivered.

**First tests conducted were IEC 62133's Overcharge and Thermal Abuse:**

| Overcharge | Thermal Abuse |
|---|---|
| 2 Cells per Pack | 2 Cells per Pack |
| All Cells Passed | All Cells Passed |

***It is obvious that more aggressive overstress tests are needed!***

# Conclusions and Recommendations

Planning and initial testing for Intertek's ongoing overstress safety evaluation of aged Li-Ion batteries was presented.

Much more will follow. Stay tuned…

# Global Automotive Depth

Intertek
Valued Quality. Delivered.

| | | | |
|---|---|---|---|
| Airbag Deployment | Brake Hose Testing | EMC Certification (Type Approval) | Engine Dynamometer Development & Durability Testing |
| Exhaust & Evaporative Emissions Analysis | Failure Analysis | Fuel Certification - including biofuels | Fuel handling & Hazardous Area Classification |
| Fuel System Testing | Import Inspection | Lighting | Lubricant development |
|  | Vehicle Component Validation and Durability Testing | Transmission Fluid Testing | Upholstery, Trim, Paint & Surface Analysis |
|   |  | Metallurgy & Corrosion | Materials Performance Testing |

# Why Intertek?

Intertek
Valued Quality. Delivered.

**Experienced Team**

200+ years of collective experience and academic advanced degrees in the field of battery technology and applied electrochemistry

**Combination of advisory and testing experience**

**World-Class Test Facilities**

Unique scope and breadth of testing capabilities

We assess over 20,000 batteries each year, covering all chemistries and sizes

Independently accredited laboratories

**Global reputation recognized for uncompromised independence and well-founded advice– the "Sagentia Catella" brand**

**Global Network contacts in the battery industry and among leading research institutions**

Intertek

Valued Quality. Delivered.

# Valued Quality. Delivered.