

National Highway Traffic Safety Administration



Lithium-ion based Rechargeable Energy Storage System Real-World Incident Review

GTR Status Update

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Brian Smith
Safety Compliance Engineer
Office of Vehicle Safety Compliance

Brian Park
Safety Engineer
New Car Assessment Program

Will Godfrey
Defects Assessment Engineer
Office of Defects Investigation

Medium/Heavy Duty Incident

- BAE systems equipped New Flyer and Orion transit bus
 - 47 buses recalled for potential electrical short in RESS
 - Air cooled batteries may accumulate moisture/debris
 - Loss of electrical isolation and conductive path (short)
 - Unintentional discharge produced smoke, melting, and fire
 - Fire damage did not pose a risk to passenger compartment



Chevrolet Volt Incidents

- Two vehicles involved in fires while parked
- Safety related concerns
 - First responders actions
 - Stranded Energy
 - Rekindle events
 - External fire exposure protection



Fisker Karma Incident

- Vehicle fire due to non-high voltage vehicle component
- Safety related concerns
 - Stranded Energy
 - First Responder Actions
 - External Fire Exposure



Tesla Model S Incidents

- Two vehicles strike objects on roadway
 - Objects penetrate HV battery enclosure
 - Mechanical abuse triggers thermal activity



Physical Battery Layout



Tesla Model S Incidents

- Safety related concerns
 - Multi-cell Abuse/Crush
 - Thermal Propagation
 - Containment
 - Operator Messaging
 - Monitoring/Fault Detection
 - Discharge
 - Passenger compartment isolation



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Real World Incidents Analysis and Conclusions

- Proper battery enclosure considerations
- HV fire containment and vent management
- HV vehicle identification
- First responder education and training
- Post incident handling
- Stranded energy management
- Rekindling of stored energy



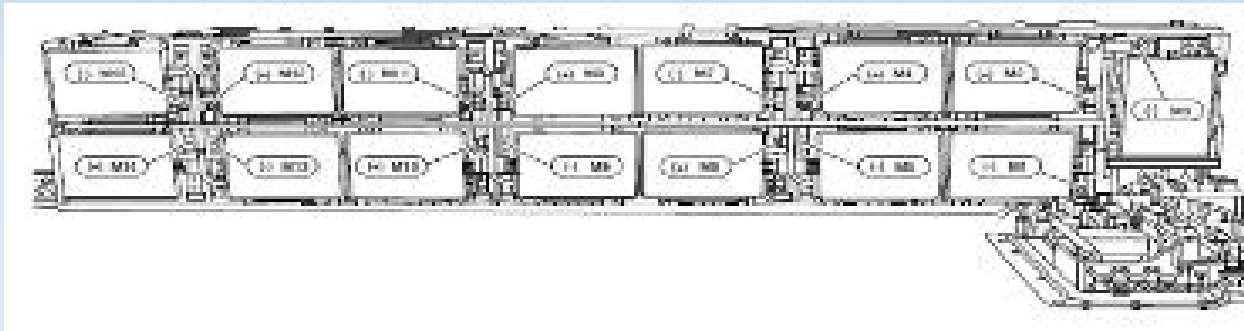
Hurricane Sandy Fisker Karma Inspections



338 Fisker Karmas were flooded in Newark, NJ



Fisker Battery





- Check for Thermal Activity
- Cut 12V power
- Remove MSD
- Check HV Battery Isolation and Voltages



HV Battery Removal

Inspection















Research Relevant Safety Observations

- Isolation (Many Batteries exhibited loss of isolation internal to the battery pack and to the vehicle chassis)
- Immersion in conductive liquids
- Battery health assessment (Not possible for damaged batteries)
- External Short Circuits (Internal to Battery Enclosure)
- Thermal Events (331 of 339 batteries had evidence of thermal activity)
- Mitigation (No thermal propagation or runaway)
- Containment (None of the battery thermal events breached the battery housing)
- Stranded Energy



Chevrolet Volt Post –Crash Test Incident

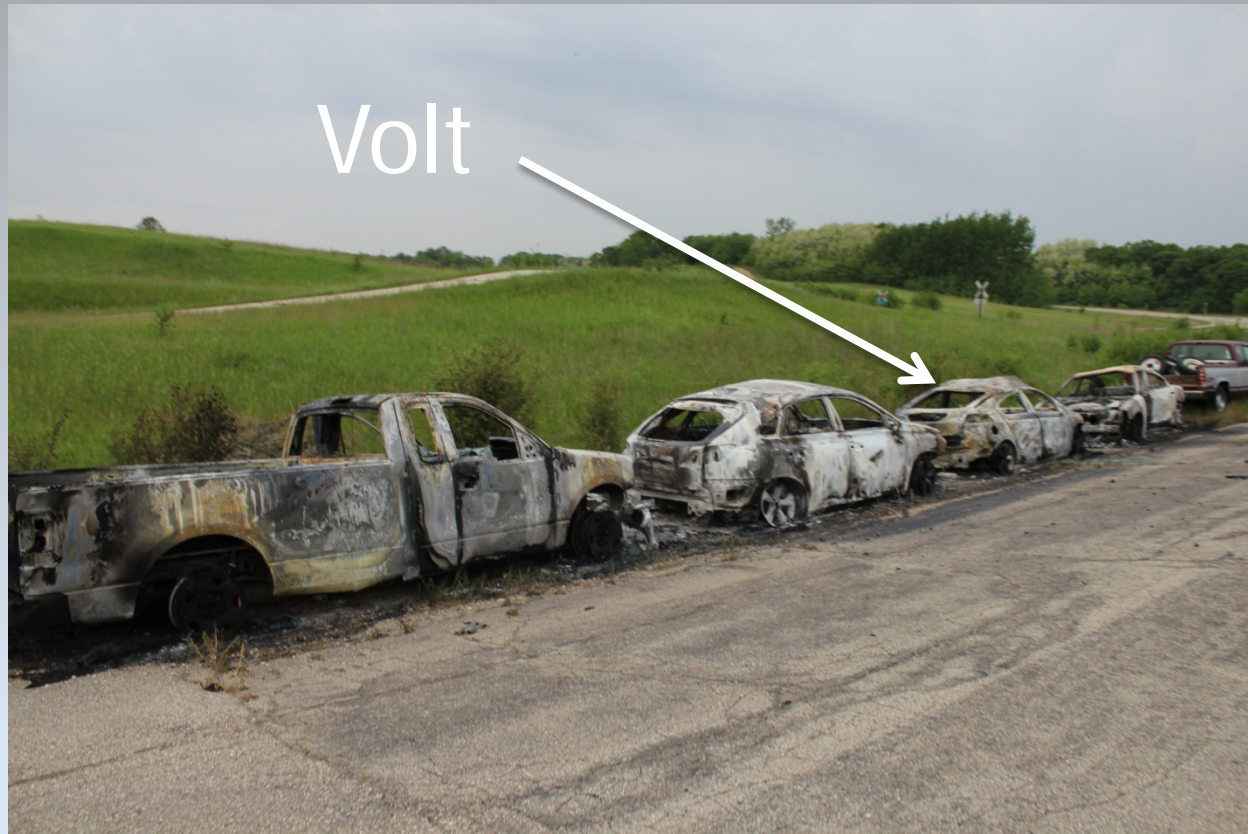


Volt Incident Recap

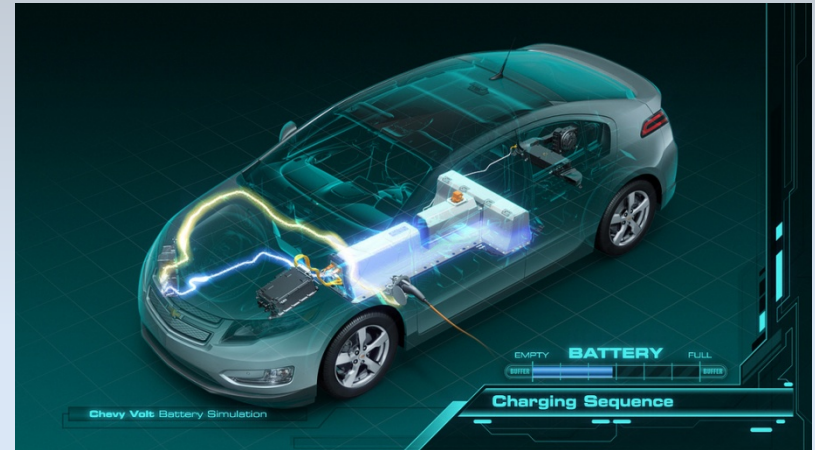
- NCAP Side Impact 20 mph Pole Test with 5th female driver dummy
- Tested 5/12/2011 including a post-test vehicle 360 degree roll
- Vehicle placed in storage area with battery at SOC used for test (approx. 58% SOC)
- Fire occurred 6/5/2011
- 4 vehicles consumed in fire



Fire Scene at MGA



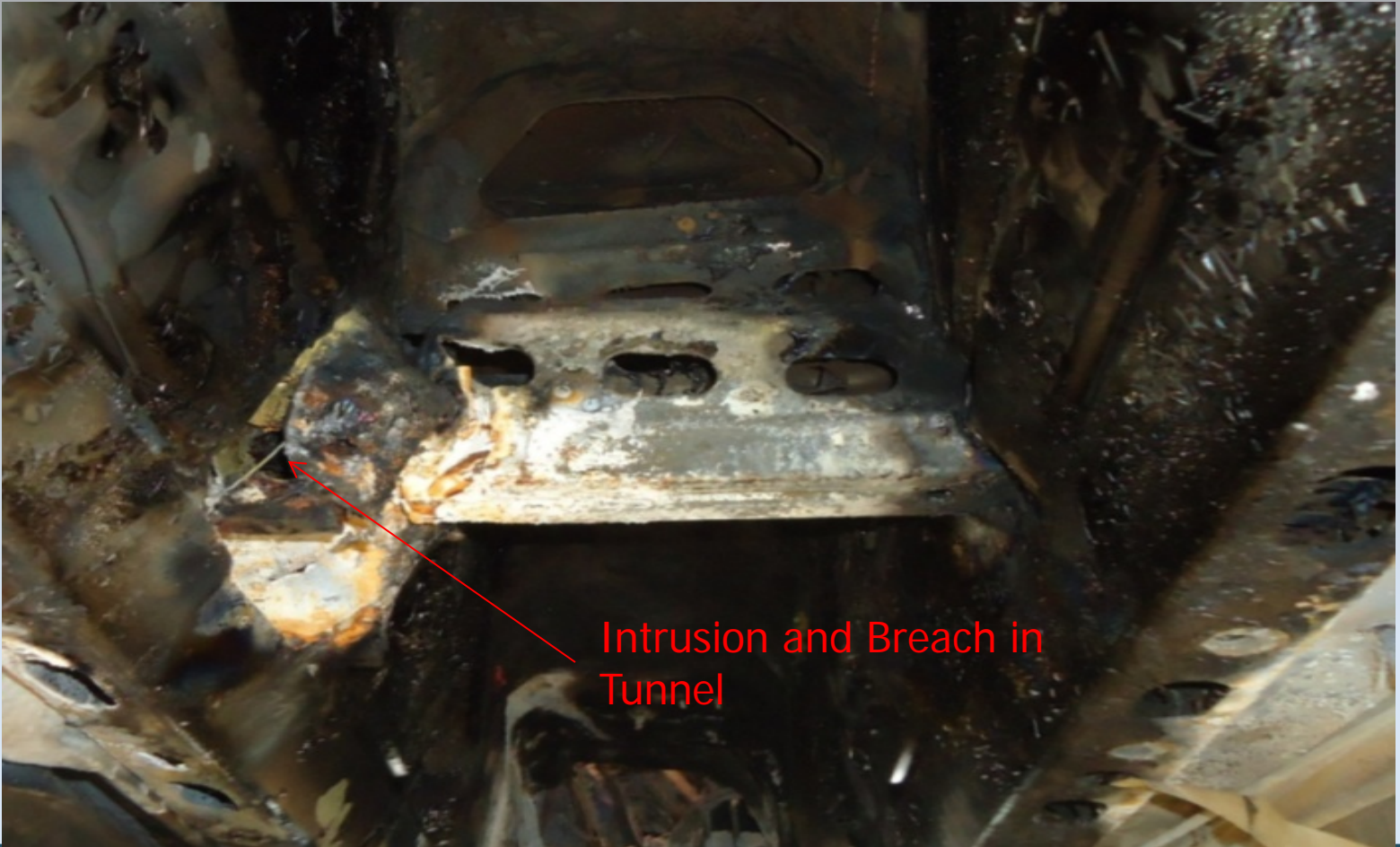
Volt Battery Pack



Cross-member Intrusion Into Battery Compartment



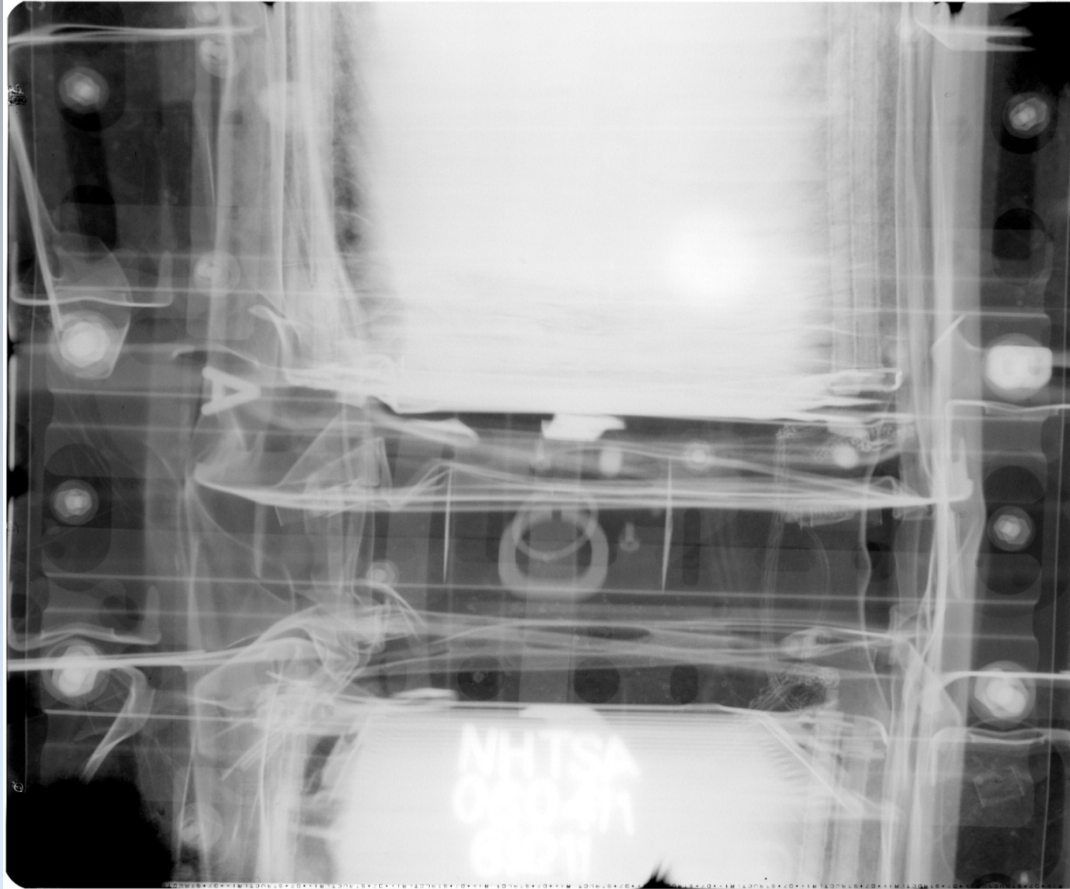
NCAP Pole Test Volt Crash Damage



Intrusion and Breach in Tunnel



NCAP Pole Test Volt Crash Damage



Volt Incident Analysis and Conclusions

- The battery and cooling system were damaged during the crash test
- Conductive liquid coolant leaked inside the battery compartment
- The monitoring electronics for the battery were exposed to the conductive coolant (rollover test)
- Fire initiated in the Volt 23 days after testing as a result of the damage and exposure.
- The fire was initiated and sustained by the stored energy in the battery.



Research Relevant Safety Observations

- Mechanical crush/structural integrity of the battery pack (multiple cells crushed)
- Isolation (isolation internal to pack unknown)
- Immersion in conductive liquids
- Battery health assessment (not available at time of test)
- External Short Circuits (Internal to Battery Enclosure with slow development)
- Containment
- Toxic Gas Vented



Boeing 787 Dreamliner Li-Ion Battery Incident



Incident Overview

- APU battery pack suffered a thermal event with release of smoke and gasses on a JAL 787 while on the ground at Logan Airport in Boston, MA



Incident Overview

- Failure deemed the result of a single cell failure

“After an exhaustive examination of the JAL lithium-ion battery, which was comprised of eight individual cells, investigators determined that the majority of evidence from the flight data recorder and both thermal and mechanical damage pointed to an initiating event in a single cell. That cell showed multiple signs of short circuiting, leading to a thermal runaway condition, which then cascaded to other cells. Charred battery components indicated that the temperature inside the battery case exceeded 500 degrees Fahrenheit.”

NTSB press release dated 2/7/2013



Changes to Battery System Design

- Improved thermal materials and better isolation of individual battery cells
- Improved battery container to contain thermal events
- Improved vents to pass cell venting product to the outside



Research Relevant Safety Observations

- Propagation (single cell event that spread to all cells)
- Containment
- Exposure to toxic gases



NHTSA EV Crash Test Programs



NHTSA's Testing Protocol for EV/HEVs

	Enforcement	NCAP
Frontal Impact	FMVSS No. 208 (35 mph crash test into a flat barrier)	35 mph crash test into a flat barrier
Side Barrier Impact (MDB)	FMVSS No. 214 (MDB) (33.5 mph crash test with a MDB)	38.5 crash test mph with a MDB
Side Pole Impact	FMVSS No. 214 (Pole) (20 mph crash test into a pole)	20 mph crash test into a pole
Post Test Fuel, electrolyte observation, and isolation tests	FMVSS Nos. 301 & 305	Same procedure
Post Test Inspection	Battery pack evaluation	Same procedure

Li-Ion Battery-Powered EV/HEV Evaluated for Safety

<i>MY</i>	<i>Manufacturers</i>	<i>Models</i>	<i>MY</i>	<i>Manufacturers</i>	<i>Models</i>
2011	Buick	LaCrosse eAssist	2013	Malibu	Malibu Eco eAssist FWD
2011	Hyundai	Sonata Hybrid	2013	Honda	Civic Hybrid 4dr
2011	<i>Chevrolet</i>	<i>Volt</i>	2013	Ford	C-MAX Energi
2011	<i>Nissan</i>	<i>Leaf</i>	2013	Ford	C-MAX Hybrid
2012	Honda	Civic IMA (Hybrid)	2013	Ford	Fusion HEV FWD
2012	Buick	Regal eAssist	2013	Ford	Fusion Energi FWD
2012	Kia	Optima Hybrid (TF HEV)	2013	Lincoln	MKZ HEV FWD
2012	<i>Mitsubishi</i>	<i>iMiEV</i>	2013	<i>Nissan</i>	<i>Leaf</i>
2012	<i>Coda</i>	<i>Coda</i>	2013	Toyota	Prius C 5HB FWD
2012	Scion	iQ EV	2013	Toyota	Prius v SW FWD
2013	<i>Ford</i>	<i>Focus BEV</i>	2013	Honda	Civic 4DR Hybrid FWD
2013	Mercedes	Smart Coupe	2013	Infiniti	M35 HEV RWD
2013	Toyota	PRIUS Plug-In	2014	Chevrolet	Malibu eAssist FWD
2013	Acura	ILX Hybrid	2014	Infiniti	Q50 HEV AWD
2013	<i>Tesla</i>	<i>Model S</i>	2014	Toyota	Highlander Hybrid AWD
2013	<i>Toyota</i>	<i>RAV4</i>	2014	Toyota	Prius 5HB FWD

Vehicles highlighted with bold and italicized are battery electric vehicle.



NHTSA's Battery Evaluation Test Protocol

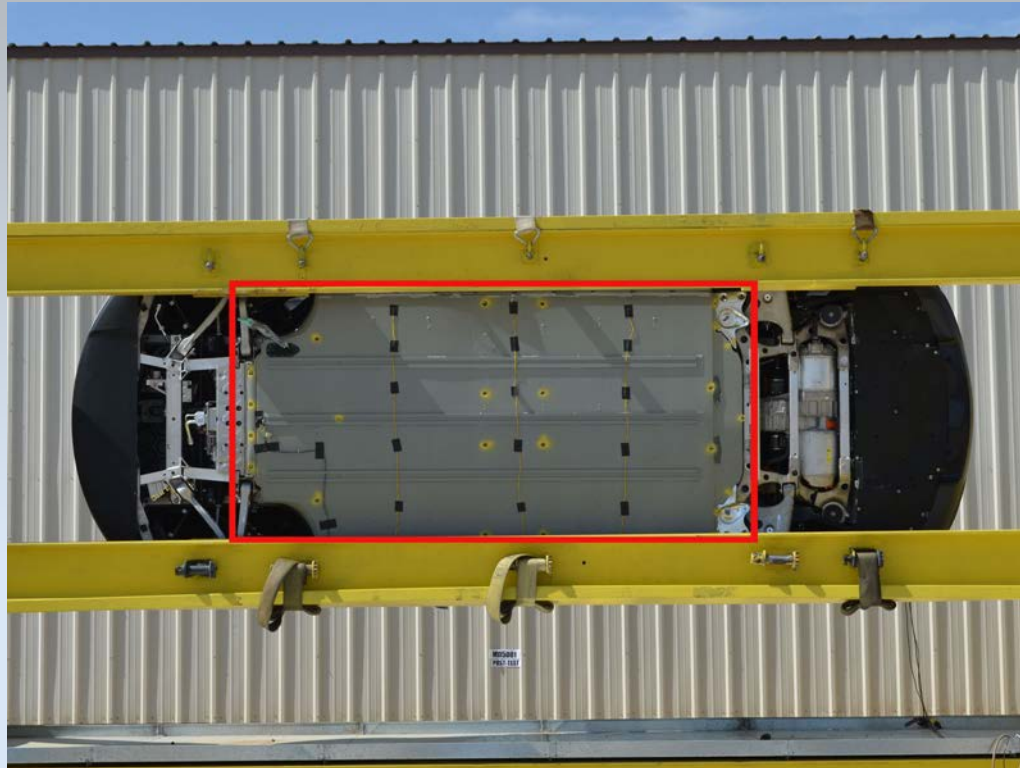
- **Pre-Crash Procedures**
 - Obtain battery cell MSDS from the manufacturer.
 - Install high speed video camera(s) and lighting.
 - Using the manufacturer's supplied test hardware, read and record battery cell voltages and temperatures. (Additional data may be recorded if it is available)
 - Perform FMVSS No. 305 measurements for electrical isolation.
- **Post-Crash Procedures**
 - Perform FMVSS No. 305 measurements for isolation.
 - Inspect visually for damage to the battery. For liquid cooled batteries also inspect for battery coolant leakage.
 - Using the manufacturer's supplied test hardware, read and record battery cell voltages and temperatures. (Additional data may be recorded if it is available)
 - Using an infrared thermometer or imager, inspect the battery for signs of thermal activity.
 - Perform FMVSS Nos. 301 and/or 305 rollover tests. Cell voltage and temperature data may also be collected if possible.
- **Post-Test Procedures**
 - If post-crash inspection indicates damage to the battery, have x rays taken of the damaged area.
 - Following the manufacturer's instructions, remove the battery from the vehicle.
 - Open the battery pack and inspect for any movement or separation of components or wiring.
 - Inspect the battery for leakage on liquid cooled batteries.
 - Reinstall the battery pack into the vehicle.
 - Place the vehicle in an outdoor monitoring location for a minimum of 3 weeks .



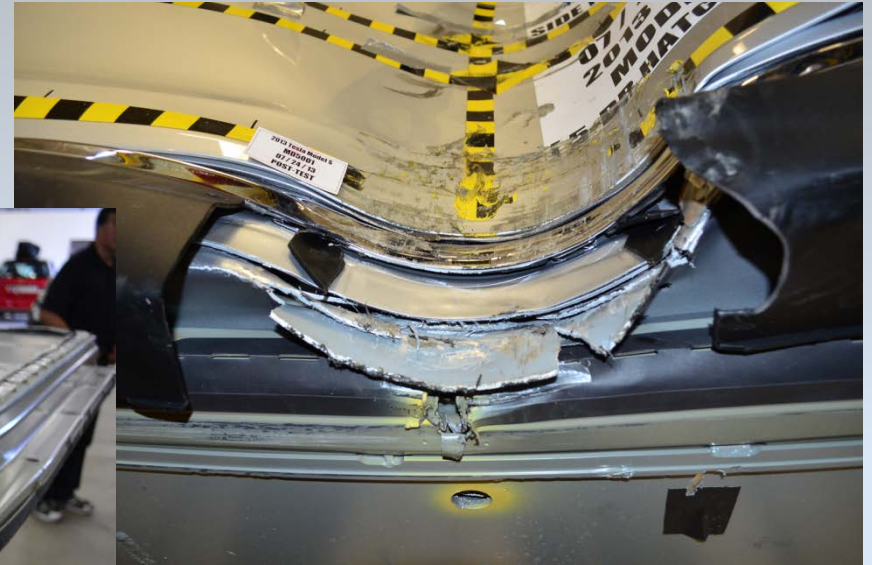
20 MPH Side Impact Pole Test



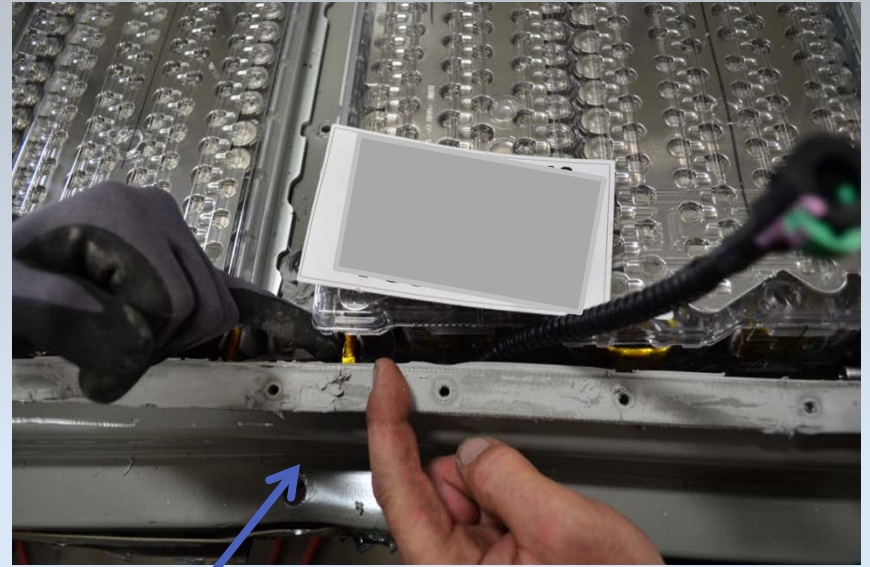
Example of Static Rollover



Example of a Post Test Crashworthiness Inspection



Example of a Post-Crash Battery Pack Inspection



Impact Point



Summary of Safety Related Observations

- Mechanical crush/structural integrity of the battery pack
 - No battery cell damage was observed
- Electrical Isolation
 - Isolation was maintained
- Battery monitoring
 - Utilizes manufacturer support to monitor battery
 - No standard measurement solution available currently
- Battery health assessment
 - Based on physical (visual) inspection and prolonged post-test observation
 - Research would identify performance metrics that could be measured using better tools to evaluate the battery post-crash

