Submitted by the expert from the United States of America

Informal document GRSP-61-25
(61st GRSP, 08-12 May 2017
agenda item 6)

Electric Vehicles Safety Global Technical Regulation

Phase 1

EVS GTR Informal Working Group

Background

- In 2012, under the United Nations World Forum for Harmonization of Vehicle Regulations (WP.29) and the 1998 Agreement, China, Japan European Union and the United States are co-sponsoring to establish 2 working groups to address environmental and safety issues associated with electric vehicles (EVs)

- EV and Environment (EVE): focusing on the information exchange and joint research concerning the related impacts of the development of EVs to the environment such as CO_2 emissions, energy consumption and efficiency, energy storage (batteries, capacitors, etc.) and infrastructure.

- EV Safety (EVS): establishing a Global Technical Regulation (GTR) for EVs ensuring high voltage electrical safety, safety of electrical components, and rechargeable electric energy storage systems (REESS)

EVS-IWG

- EVS-informal working group (IWG): comprised of over 50 members from government regulators, industry standard organizations and vehicle and battery manufacturers.

- IWG has conducted 13 meetings. The meetings and process are transparent. Documents and reports are posted on the UN website:
  https://www2.unece.org/wiki/pages/viewpage.action?pageId=3178628

- Goal: WP.29 vote to establish the GTR is November 2017

EVS-GTR

- Terms of Reference:
  - To the extent possible, GTR will be science-based, data driven and performance based - avoiding design-specific requirements
  - IWG will investigate, conduct research and establish provisions at vehicle and system levels to address vehicle safety issues for EVs:

    In-use:
    - Occupant protection: protection against electric shock
    - Performance and safety requirements for Li-Ion based rechargeable energy storage system (REESS) including battery management system for conditions of low and high temperature, over-charge, over current, over discharge, external short circuit, and environment conditions such as extreme temperature, vibration, mechanical shock and fire resistance

    Post crash:
    - Electrical isolation; protection against electric shock
    - Battery integrity: battery management system, robustness and survivability
    - Battery discharge procedure

    End-of-life:
    - Disposal of battery

2-Phase Approach

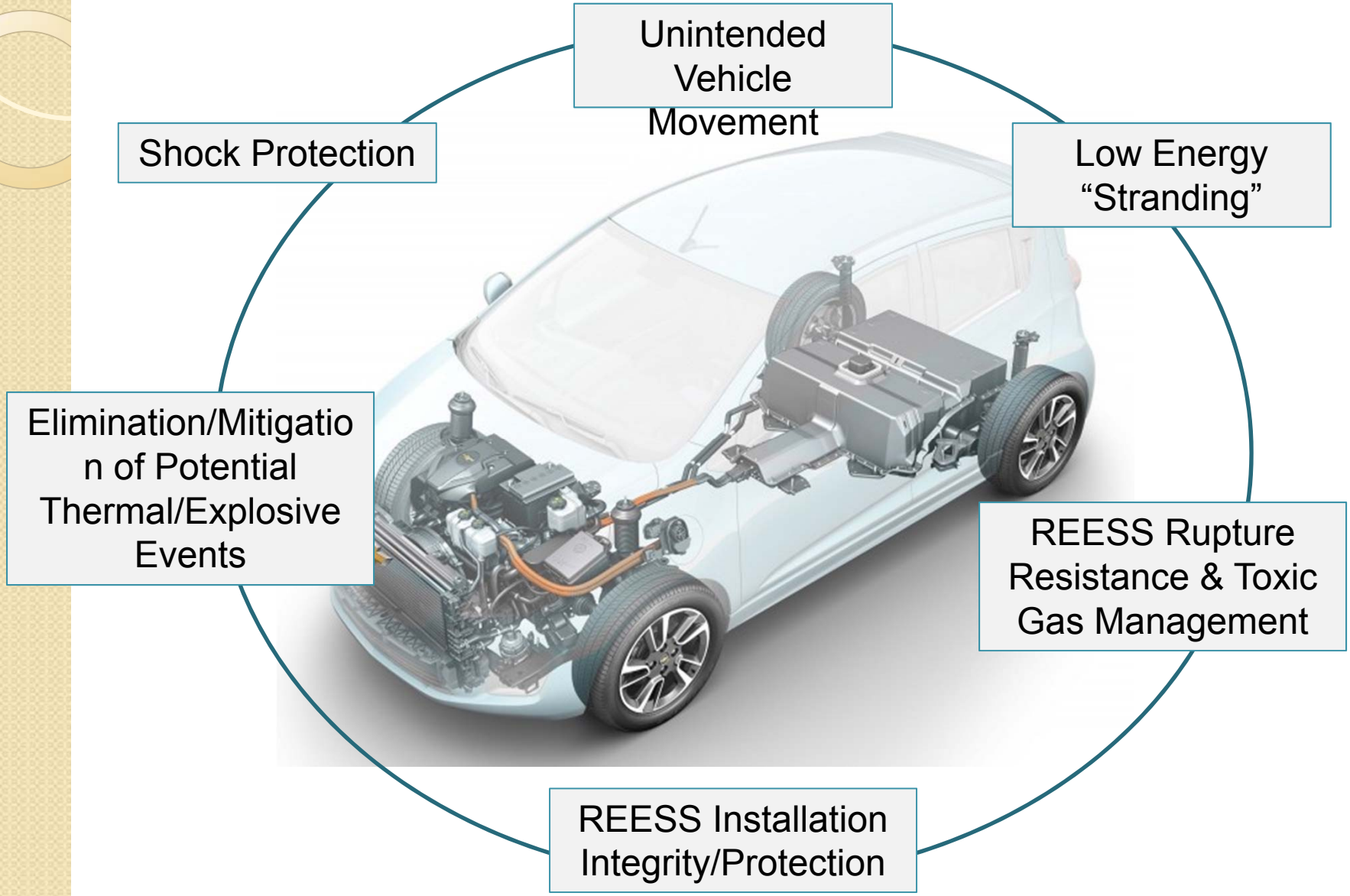
- Phase 1: near-term critical safety requirements
- Phase 2: safety requirements that require long-term research as well as further improvement of the GTR

Task Force Teams

- TF-1: Protection Against Water – China
- TF-2: Low Electrical Energy/Physical Barriers – OICA
- TF-3: Electrolyte Leakage – OICA
- TF-4: REESS Protocol BMS, environment exposure – OICA
- TF-5: Thermal Propagation – China
- TF-6: State of Charge (SOC) – Japan
- TF-7: Fire Resistance – Korea
- TF-8: Heavy Vehicles and Buses- China
- TF-9: Warning systems – U.S.

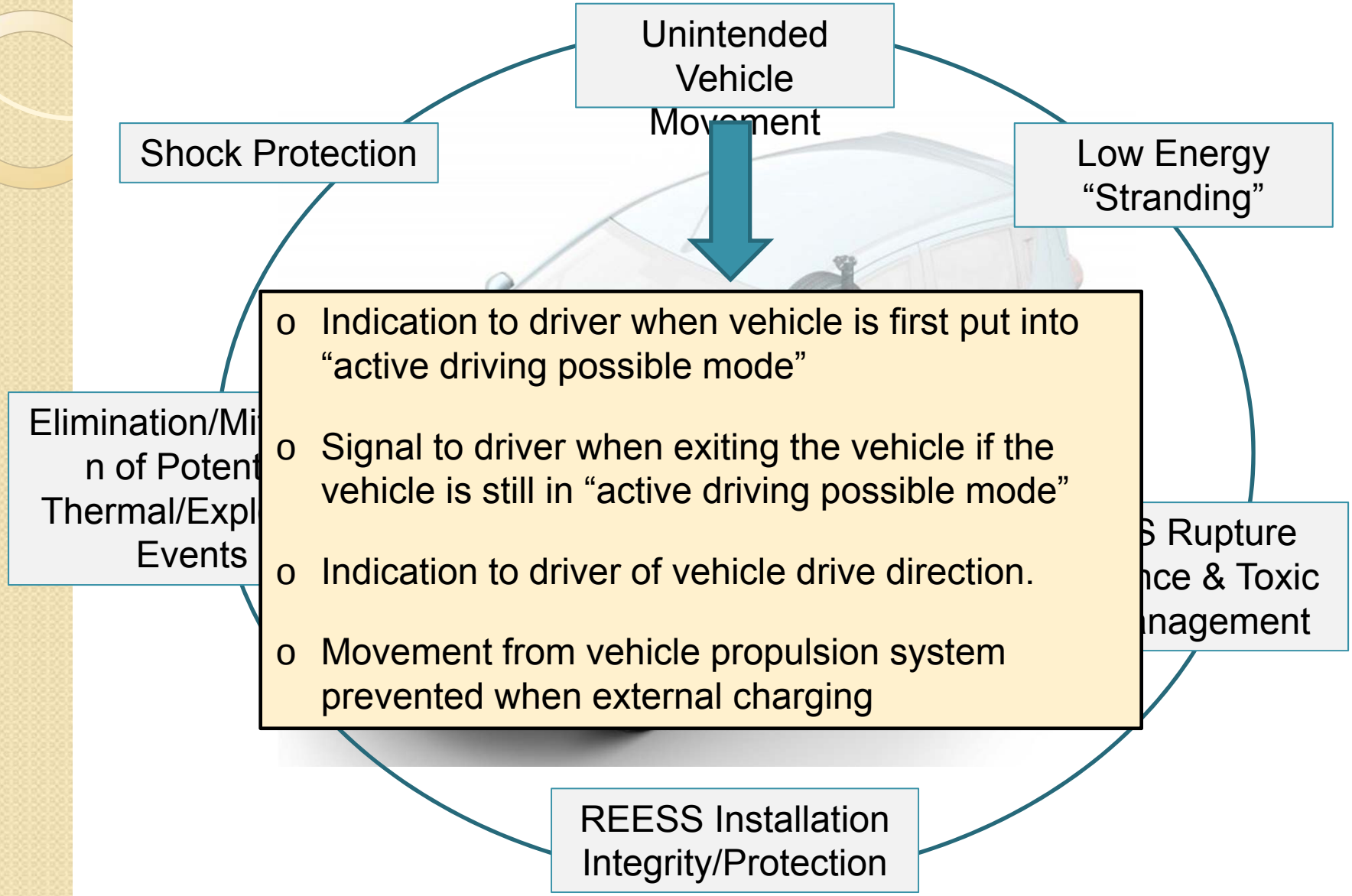
Draft GTR – Phase 1 Circle of Safety

Safety Hazards Addressed



Draft GTR – Phase 1 Circle of Safety

Safety Hazards Addressed

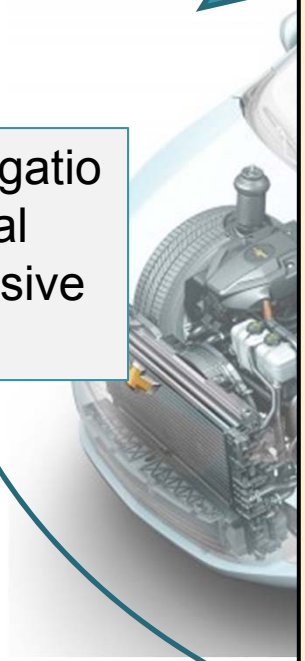


Draft GTR – Phase 1 Circle of Safety

Safety Hazards Addressed

Shock Protection

Elimination/Mitigation of Potential Thermal/Explosive Events



Integrity/Protection

In-Use

- Vehicle
  - Protection against direct contact
    - Physical barriers/access protection
    - Marking (enclosures/electrical protection barriers and color coding of high voltage wires/cables)
  - Protection against in-direct contact
    - Conductive physical barrier bonding (minimum resistance)
    - Grounding through conductive charge connectors
    - Minimum isolation resistance
    - Fuel cell isolation resistance monitoring
    - Isolation resistance for charging coupling system
    - Protection against water effects (contracting party options apply)
- REESS component testing (maintain greater than 100 ohm/volt isolation resistance)
  - Vibration
  - Thermal shock & cycling
  - External short circuit
  - Overcharge
  - Over-discharge
  - Over-temperature
  - Overcurrent

Post-Crash

- Vehicle (manufacturer must comply with one of the four options)
  - Absence of high voltage
  - Low electrical energy (contracting party option)
  - Physical barriers
  - Isolation resistance

Draft GTR – Phase 1 Circle of Safety

Safety Hazards Addressed

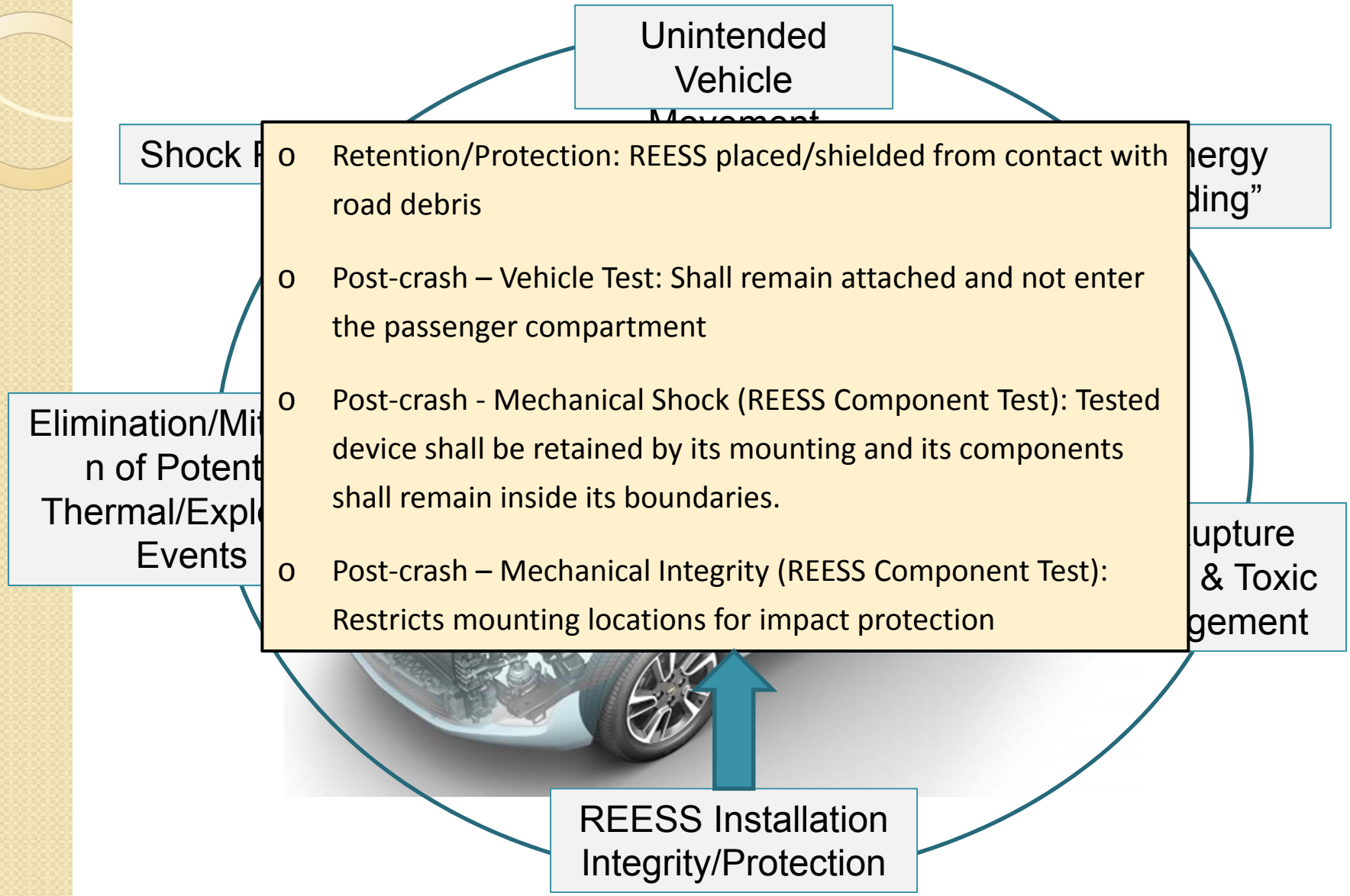
Shock Protectio

Elimination/Mitigation of Potential Thermal/Explosive Events

- Driver warnings for critical operational failures of REESS management systems
- Thermal propagation warning and/or functions of characteristics in the cell, REESS, or vehicle intended to protect vehicle occupants in case of single cell thermal runaway and propagation.
- In-Use: no fire or explosion
  - Vibration (component test)
  - Thermal shock & cycling (component test)
  - Fire resistance (vehicle based or component test (mfr option))
  - External short-circuit protection
  - Overcharge protection
  - Over-discharge protection
  - Over-temperature protection
  - Over-current protection
  - Low-temperature protection
- Post-Crash (vehicle test)
  - No evidence of fire or explosion
- Post-Crash (component test – mfrs alternative to vehicle test)
  - Mechanical shock – no fire or explosion
  - Mechanical integrity – no fire or explosion

Draft GTR – Phase 1 Circle of Safety

Safety Hazards Addressed



- Retention/Protection: REESS placed/shielded from contact with road debris
- Post-crash – Vehicle Test: Shall remain attached and not enter the passenger compartment
- Post-crash - Mechanical Shock (REESS Component Test): Tested device shall be retained by its mounting and its components shall remain inside its boundaries.
- Post-crash – Mechanical Integrity (REESS Component Test): Restricts mounting locations for impact protection

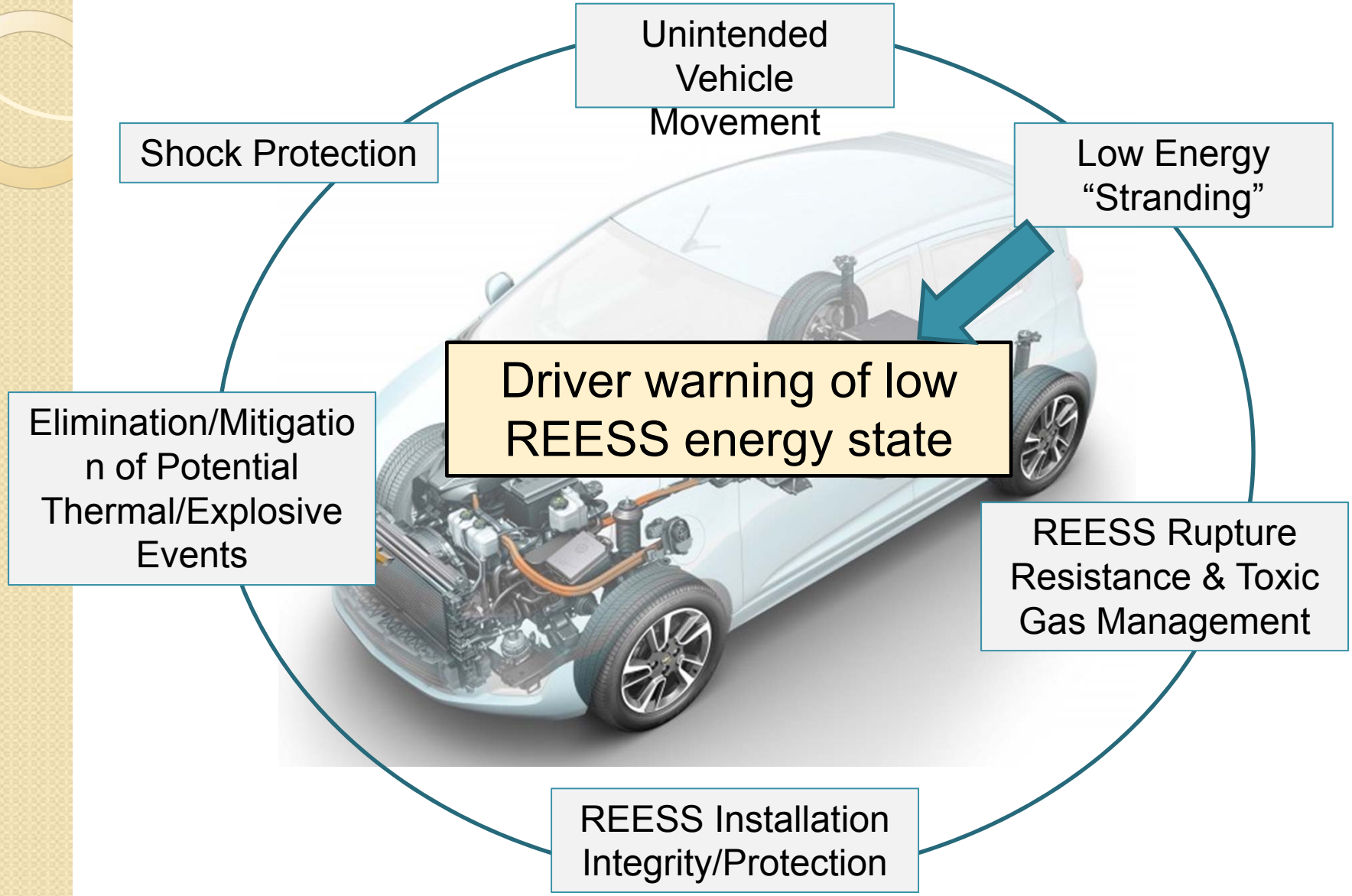
Draft GTR – Phase 1 Circle of Safety

Safety Hazards Addressed

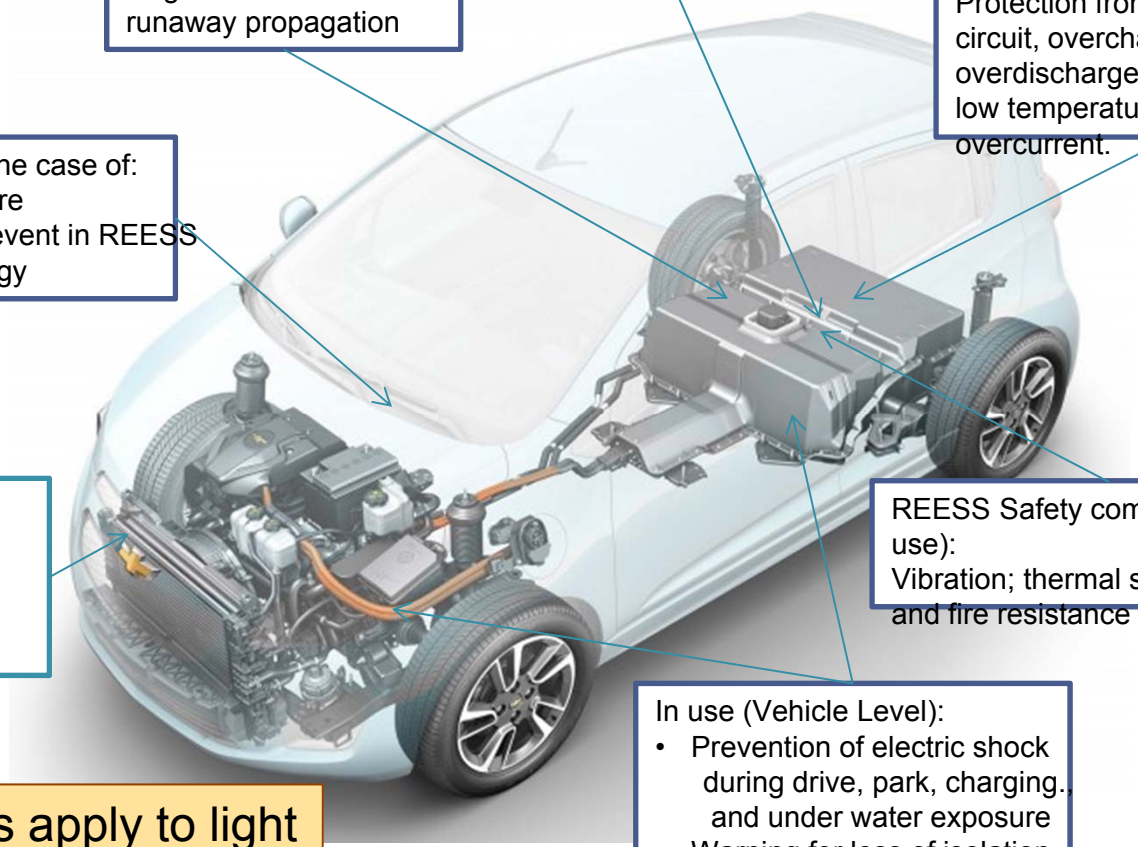
- Driver warnings for critical operational failures of REESS management systems and/or developing thermal events within the REESS
- Under vehicle operation, including operation with a failure, vehicle occupants shall not be exposed to any hazardous emissions from the REESS
- In-Use: no rupture, leakage, venting, fire or explosion
  - Vibration (component test)
  - Thermal Shock & Cycling (component test)
  - External Short-Circuit Protection
  - Overcharge Protection
  - Over-discharge Protection
  - Over-temperature Protection
  - Over-current Protection
  - Low-temperature Protection
- Post-Crash (vehicle test)
  - Electrolyte Leakage
- Post-Crash (component test - mfrs alternative to vehicle test)
  - Mechanical Shock
  - Mechanical integrity

Draft GTR – Phase 1 Circle of Safety

Safety Hazards Addressed



Draft GTR – Phase 1



Protection/Warning from single cell thermal runaway propagation

Management of gases emitted from battery

BMS functionality (in-use) at vehicle and pack levels:
Protection from external short circuit, overcharge, overdischarge, overtemperature, low temperature, and overcurrent.

Warnings in the case of:
1. BMS failure
2. Thermal event in REESS
3. Low Energy

Post-crash (vehicle level):
Electric shock prevention
Battery retention
Electrolyte spillage
Battery integrity and fire safety

REESS Safety component level (In-use):
Vibration; thermal shock and cycling; and fire resistance

In use (Vehicle Level):
- Prevention of electric shock during drive, park, charging., and under water exposure
- Warning for loss of isolation.
- Functional safety at start-up exiting vehicle and charging

Notes: requirements apply to light duty vehicles.
Option to apply to heavy trucks and buses

Performance Requirements

5. Performance requirements (light duty/passenger vehicles)

5.1. Requirements of a vehicle with regard to its electrical safety - in-use

- 5.1.1. Protection against electric shock
- 5.1.2. Functional safety

5.2. Requirements of a vehicle with regard to its electrical safety - post-crash

- 5.2.1. General principle
- 5.2.2. Protection against electric shock

5.3. Requirements with regard to installation and functionality of REESS in a vehicle

- 5.3.1. Installation of rechargeable energy storage system (REESS) on a vehicle
- 5.3.2. Warning in the event of operational failure of vehicle controls that manage REESS safe operation (e.g. BMS)
- 5.3.3. Warning in the case of a thermal event within the REESS
- 5.3.4. Warning in the event of low energy content of REESS

Performance requirements (cont.)

5.4. Requirements with regard to the safety of REESS - in-use

- 5.4.1 General principle.
- 5.4.2. Vibration
- 5.4.3. Thermal shock and cycling
- 5.4.4. Fire resistance
- 5.4.5. External short circuit protection
- 5.4.6. Overcharge protection
- 5.4.7. Over-discharge protection
- 5.4.8. Over-temperature protection
- 5.4.9. Overcurrent protection
- 5.4.10. Low-temperature protection
- 5.4.11. Management of gases emitted from REESS
- 5.4.12. Thermal propagation

5.5. Requirements with regard to the safety of REESS - post-crash

- 5.5.1. Vehicle based test
- 5.5.2. REESS-component based test

Performance requirements (cont.)

5.4. Requirements with regard to the safety of REESS - in-use

- 5.4.1 General principle.
- 5.4.2. Vibration
- 5.4.3. Thermal shock and cycling
- 5.4.4. Fire resistance
- 5.4.5. External short circuit protection
- 5.4.6. Overcharge protection
- 5.4.7. Over-discharge protection
- 5.4.8. Over-temperature protection
- 5.4.9. Overcurrent protection
- 5.4.10. Low-temperature protection
- 5.4.11. Management of gases emitted from REESS
- 5.4.12. Thermal propagation

5.5. Requirements with regard to the safety of REESS - post-crash

- 5.5.1. Vehicle based test
- 5.5.2. REESS-component based test

Performance Requirements (cont.)

- *Based on the requirements of the light duty vehicles*

7. Heavy duty vehicles and buses

7.1. Requirements of a vehicle with regard to its electrical safety - in-use

7.1.1. Protection against electric shock

7.1.1.3 protection against water

7.1.2. Functional safety

7.2. Requirements with regard to installation and functionality of REESS in a vehicle

7.2.1. Installation of rechargeable energy storage system (REESS) on a vehicle

7.2.2. Warning in the event of operational failure of vehicle controls that manage REESS safe operation

7.2.3. Warning in the case of a thermal event within the REESS

7.2.4. Warning in the event of low energy content of REESS

Performance requirements (cont.)

7.3. Requirements with regard to the safety of REESS - in-use

- 7.3.1 General principle
- 7.3.2. Vibration
- 7.3.3. Thermal shock and cycling
- 7.3.4. Fire resistance
- 7.3.5. External short circuit protection
- 7.3.6. Overcharge protection
- 7.3.7. Over-discharge protection
- 7.3.8. Over-temperature protection
- 7.3.9. Overcurrent protection (phase 2)
- 7.3.10. Low-temperature protection
- 7.3.11. Management of gases emitted from REESS
- 7.3.12. Thermal propagation

7.4. Requirements with regard to the safety of REESS simulating inertial load

7.4.1. Mechanical shock

2.0 - Application

- Light Duty Vehicles (GVWR≤10,000 lb)
  - Contracting parties may apply to heavy vehicles as well
  - Contracting parties may exclude low mass vehicles (GVWR<770 lb with max speed 45 km/h, passenger vehicles with GVWR<1,000 lb, or cargo vehicles with GVWR<1,430 lb)

5.1 – In Use Electric Safety

- Similar to FMVSS No. 305 and UN R100
  - Markings/identification of high voltage sources
  - Direct and indirect contact protection
  - Electrical isolation
  - Isolation monitoring system for fuel cell vehicles
  - Shock protection during charging
  - Functional Safety- at startup, leaving vehicle, and charging.
- Protection from water effects
  - Documentation of IPX5 protection degree or electrical isolation protection after water trough test
    - Contracting parties may chose electrical isolation monitoring option

5.2 – Post-crash Electric Safety

- Each high voltage source must have at least one of the following safety measures
  - Electrical isolation
  - Direct and indirect contact protection
  - Low voltage
  - Low energy (only for capacitors)

5.3 – Warnings for REESS Operations

- Warning in the case of
  - BMS failure
  - Thermal event in REESS
  - Low energy content in REESS
- Documentation of how warning system operates and is activated.
- Specifications for warning in the form of tell-tale.

5.4 – REESS In Use

- During and after tests of 5.4.2 and 5.4.3, there is no evidence of rupture, electrolyte leak, venting, fire, or explosion.
- **5.4.2. Vibration** – Component level test, sinusoidal wave from 2 to 10 gs in 7-50 Hz in vertical direction of mounting orientation for 3 hours. Then Normal charge/discharge cycle performed.
- **5.4.3. Thermal Shock and Cycling** – REESS stored for 6 hours at 60^{o}C then 6 hours at -40^{o}C and this process is repeated 5 times. The REESS undergoes normal charge/discharge cycle after storing in ambient conditions for 24 hours.

5.4.4 Fire Resistance

- Ensures occupants have sufficient time to evacuate the vehicle in case of fire exposure.
- Test is equivalent to UN34 for plastic fuel tanks. (60 sec preheat, 60 sec direct exposure, and 60 sec indirect exposure to gas pool flame.)
- Bottom of REESS is exposed directly to 60 cm LPG pool flame at 800-1100^{o}C for 2 min.
  - Manufacturer may choose optional gasoline pool test (ECE standard for plastic tanks) at component level or vehicle level.
- Requirement: During and after 5.4.4, there is no explosion.

BMS Functionality Tests

- Evaluates the ability of BMS in protecting in the event of
  - 5.4.5 - External short circuit
  - 5.4.6 – Overvoltage
  - 5.4.7 - Overdischarge
  - 5.4.8 - Overtemperature
  - 5.4.9 - Overcurrent
  - 5.4.10 - Low temperature
- Tests can be conducted at the vehicle level or component level. In some tests, vehicle level tests are conducted by operating the vehicle on a dynamometer or by connecting a breakout harness.
- Each test ends with a standard charge/discharge cycle, if not inhibited, which is followed by a 1 hour observation period.
- Requirement – During the test, there is no evidence of electrolyte leakage, rupture, venting, fire, explosion, or loss in electrical isolation,

5.4.5 - External Short Circuit Protection

- Only hard short (resistance ≤ 5 ohm)
- Test may be done at component level or at vehicle level using breakout harness.
- Additional requirement: Short circuit current is terminated or the temperature of REESS shall not vary more than 4^{o}C through 2 hours after introducing the short circuit.

5.4.6 Overcharge Protection

- Three options for conducting vehicle level overcharging
  - Driving on a chassis dynamometer (for vehicles that can be charged with onboard energy sources) simulating continuous down-hill driving that delivers highest possible charge current.
  - Charge by external electricity supply for externally chargeable vehicles
  - Charge by connecting breakout harness.
- Component level test is conducted by external charge equipment connected to REESS
- Continue charging until vehicle controls terminate charge current, or if REESS temperature is greater than 10^{o}C above max. operating temperature, or 12 hours after start of charging.

5.4.7 - Over-discharge Protection

- Two options for vehicle-level tests
- Option 1 Vehicle Level Test
  - Discharge by vehicle driving: Vehicle is driven on a chassis dynamometer simulating continuous driving at steady speed that will deliver as constant discharging power as reasonably possible, and
  - Discharge by auxiliary electrical equipment: Vehicle is in stationary operation mode and all auxiliary electrical equipment (air conditioning, heating, lighting, audio-visual equip. are in operation to discharge the REESS.
  - Operation is terminated when discharge current is terminated or when the REESS temperature varies by a gradient less than 4^{o}C through 2 hours or when REESS reaches 25 percent of its nominal voltage level.

5.4.7 - Over-discharge Protection

- Option 2 Vehicle Level Test
  - Discharge using discharge resistor and breakout harness: Connect breakout harness to REESS and discharge with a 1 kW power discharge resistor.
  - Discharge is terminated when discharge current is terminated or when the REESS temperature varies by a gradient less than 4^{o}C through 2 hours or when REESS reaches 25 percent of its nominal voltage level.
- Component Level Test
  - Discharge REESS using discharge equipment and REESS is discharged within normal operating range.
  - Discharge is terminated when discharge current is terminated or when the REESS temperature varies by a gradient less than 4^{o}C through 2 hours or when REESS reaches 25 percent of its nominal voltage level.

5.4.8- Over-temperature Protection

- Component level test
  - Cooling function disabled or at reduced operation
  - REESS is placed in climatic chamber and REESS is connected to the vehicle control system.
  - Continuously charge/discharge to increase REESS temperature by charge/discharge equipment or by vehicle driving operation or chassis dynamometer.
  - The temperature of the chamber is gradually increased until it reaches manufacturer specified max. temperature.
  - Test is terminated when charge/discharge current, is terminated or temperature of REESS is stabilized to vary by a gradient less than 4^{o}C through 2 hours, or fire/venting/explosion occurs, or 3 hour elapse from staring the charge/discharge cycles

5.4.8- Over-temperature Protection

- Component level test
  - Cooling function disabled or at reduced operation
  - Put vehicle in climate control chamber at temp. 40^{o}C-45^{o}C for at least 6 hours
  - Continuously charge/discharge to increase REESS temperature by driving on a chassis dynamometer. For vehicles that can be externally charged, charging can be done by external power supply.
  - Test is terminated when the vehicle terminates charge/discharge current, or temperature of REESS is stabilized to vary by a gradient less than 4^{o}C through 2 hours, or fire/venting/explosion occurs, or 3 hour elapse from staring the charge/discharge cycles

5.4.9 – Overcurrent Protection

- Only applies to DC external charging.
- Two options for vehicle level tests
  - Charging using external DC electricity supply by connecting the DC supply equipment to the DC charging vehicle inlet. Charge control communication of supply equipment is altered or disabled to permit overcurrent level.
  - Charging using breakout harness connected to REESS.
- Normal charging is initiated at highest normal charge current. Then charge current is increased over 5 seconds from highest normal charge current to overcurrent level. Charging is then continued at the overcurrent level.
- Test is terminated when charging is terminated or REESS temperature is stabilized (less than 4°C through 2 hours).

5.4.10 – Low Temperature Protection

- Vehicle manufacturers shall make available documentation demonstrating that vehicle controls REESS operations at low temperature at the safety boundary limits of the REESS
  - System diagram
  - Written explanation on safe operation of REESS at low temperature
  - Method of detecting REESS temperature
  - Action taken when REESS temperature is at its lower boundary for safe operation.

5.4.11. Management of gases emitted from REESS

- No venting during vibration, thermal shock and cycling, external short circuit, overcharge, over-discharge, over-temperature, and overcurrent tests).
- Venting requirements for open-type traction batteries
  - During normal charge procedure, hydrogen emissions less than 125 g in 5 hours.
  - During charging with failed charger, hydrogen emissions less than 42 grams. The charger will limit possible failure to not more than 30 minutes.

5.4.12 - Thermal Propagation

- Vehicle manufacturers shall make available documentation demonstrating the vehicle's ability to minimize the risk associated with single cell thermal runaway caused by an internal short circuit.
- The vehicle shall provide an advance warning indication to allow occupant egress or 5 minutes prior to hazardous conditions inside the passenger compartment. The following documentation shall be made available to regulatory entities:
  - The parameters of the single cell thermal runaway (for example, temperature, voltage or electrical current) which trigger the warning indication.
  - Description of the warning system
  - A risk reduction analysis using appropriate industry standard methodology (for example, IEC 61508, ISO 26262, DFMEA, fault analysis as in SAE J2929, or similar) which documents the risk to vehicle occupants caused by thermal propagation triggered by an internal short circuit and the risk reduction from identified risk mitigation functions or characteristics.

5.4.12 – Thermal Propagation (contd.)

- A system diagram of all relevant physical systems and components that contribute to protection of vehicle occupants from single cell thermal runaway thermal propagation.
- A diagram showing the functional operation of the relevant systems and components, identifying all risk mitigation functions or characteristics.
- For each identified risk mitigation function or characteristic:
  - A description of its operation strategy.
  - Identification of the physical system or component which implements the function;
  - One or more of the following engineering documents relevant to the manufacturers design which demonstrates the effectiveness of the risk mitigation function:
    - tests performed including procedure used and conditions and resulting data.
    - analysis or validated simulation methodology and resulting data.

5.5 Requirements with regard to the safety of REESS – Post-Crash

- 5.5.1 - Vehicle-based tests: (crash tests per FMVSS)
  - Electrolyte leakage
    - Aqueous Electrolyte: No leakage in passenger compartment and less than 7% by volume outside of the vehicle.
    - Non-aqueous Electrolyte: No leakage permitted. Verified by visual inspection
  - REESS Retention: REESS shall remain attached to the vehicle by at least one component and REESS outside passenger compartment shall not enter passenger compartment (same language as in FMVSS 305)
  - Fire hazard: No fire/explosion through 1 hour after crash

5.5 Requirements with regard to the safety of REESS – Post-Crash

- 5.5.2 - REESS Component Based Tests (Option for Type Approval systems)
  - Mechanical Shock – REESS is subject to acceleration:
    - Vehicles with GVWR<7,700 lb: 20-28 G acceleration pulse with 100-120 msec duration
    - Vehicles with GVWR>7,700 lb: 10-17 G acceleration pulse with 100-120 msec duration
  - Mechanical Integrity – REESS subject to 100 kN crush force
    - Force is applied horizontally and perpendicular to the direction of travel of REESS in a vehicle. Manufacturer may choose alternative force levels based on vehicle crash tests.
  - During both tests, there shall be no evidence of electrolyte leakage, fire, explosion, loss in isolation, or direct contact protection

Thank you