



SURFACE VEHICLE INFORMATION REPORT

J2990™/2

NOV2020

Issued 2015-01
Reaffirmed 2020-11

Superseding J2990/2 JAN2015

Hybrid and Electric Vehicle Safety Systems Information Report

RATIONALE

This report for first and second responders is intended to address concerns about electric vehicle propulsion technology. These topics include the possibility of human contact with high voltage, potential fire hazards, and protective features. Each of the Original Equipment Manufacturer (OEM) designs incorporate various safety features meant to address each of these concerns and this report provides general descriptions for some of the systems and practices. While many of these safety features are common throughout the industry, there are wide variations and this report is not all inclusive. This document continues to reflect the major methods used by vehicle OEMs to help ensure safety of emergency responders.

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https://www.sae.org/standards/content/J2990/2_202011

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1. SCOPE

This information report provides an overview of a typical high voltage electric propulsion vehicle (xEV) and the associated on-board safety systems typically employed by OEM's to protect these high voltage systems. The report aims to improve public confidence in xEV safety systems and dispel public misconceptions about the likelihood of being shocked by the high voltage system, even when the vehicle has been damaged. The report will document select high voltage systems used for xEV's and describe safety systems employed to prevent exposure to the high voltage systems.

2. REFERENCES

2.1 Applicable Documents

NOTE: Users should ensure that the latest revision and legislative updates of these documents is being referenced.

The following publications are provided for information purposes only and are not a required part of this document. Each was used by task force as a reference source during the development of this working document.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or 724-776-4970 (outside USA), www.sae.org.

SAE J1715	Hybrid Electric Vehicle (HEV) and Electric Vehicle (EV) Terminology
SAE J1766	Recommended Practice for Electric and Hybrid Electric Vehicle Battery Systems Crash Integrity Testing
SAE J2578	Recommended Practice for General Fuel Cell Vehicle Safety
SAE J2990	Hybrid and EV First and Second Responder Recommended Practice

2.2 Related Publications

The following publications are provided for information purposes only and are not a required part of this SAE Technical Report.

2.2.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or 724-776-4970 (outside USA), www.sae.org.

SAE J2344 Guidelines for Electric Vehicle Safety

2.2.2 U.S. GOVERNMENT

Available from the Document Automation and Production Service (DAPS), Building 4/D, 700 Robbins Avenue, Philadelphia, PA 19111-5094, Tel: 215-697-6257, <http://assist.daps.dla.mil/quicksearch/>.

FMVSS 305 Electric Powered Vehicles: Electrolyte Spillage and Electrical Shock Protection

FMVSS 208 Occupant Crash Protection

OSHA Construction eTool: https://www.osha.gov/SLTC/etools/construction/electrical_incidents/eleccurrent.html

2.2.3 United Nations Economic Commission for Europe

Available from United Nations Publications Customer Service, PO Box 960, Herndon, VA 20172, USA
Tel: 1-703-661-1571, Email: order@un.org

UN Regulation R94 Uniform provisions concerning the approval of vehicles with regard to the protection of the occupants in the event of a frontal collision.

UN Regulation R95 Uniform provisions concerning the approval of vehicles with regard to the protection of the occupants in the event of a lateral collision.

UN Regulation R100 Uniform provisions concerning the approval of vehicles with regard to specific requirements for the electric power train.

2.2.4 All About Circuits

Safe Circuit Design Website, "Shock current path", http://www.allaboutcircuits.com/vol_1/chpt_3/3.html

3. DEFINITIONS

Except as noted below, all definitions are in accordance with SAE J1715.

Additional definitions:

3.1 AUTOMATIC DISCONNECT

A device in any type of xEV which opens the primary high voltage circuit or circuits of the vehicle, and that is activated by automatic means such as a crash response or the operation of the vehicle ignition switch.

3.2 BADGING

Describes a durable emblem, insignia, or label securely affixed on the exterior surface of the xEV.

3.3 DIAGNOSTIC TROUBLE CODE

Information provided by an on-board diagnostic system for operators and repair technicians.

3.4 ELECTRICAL PPE

See Personal Protective Equipment.

3.5 FIRST RESPONDERS

Include but not limited to fire department, rescue squads, emergency medical, law enforcement, and in some instances military where the personnel are trained in assessing and treating injuries.

3.6 GROUND ISOLATION

Electrical system where there is no direct connection between either pole of a high voltage battery and vehicle chassis ground.

3.7 HIGH VOLTAGE SYSTEM

A vehicle system inclusive of the battery system and high voltage components (e.g. inverter modules, high voltage cables, etc.) powered by the battery system.

3.8 INTERMEDIATE VOLTAGE

A system where the maximum voltage is greater than 15-V alternating current but not more than 30-V alternating current; or greater than 30-volts direct current but not more than 60-volts direct current.

3.9 LI-ION

Lithium ion battery / cell.

3.10 MANUAL DISCONNECT (MD)

A device in any type of electric vehicle which opens the primary high voltage circuit or circuits of the vehicle, and that is only activated by non-automatic means.

3.11 PERSONAL PROTECTIVE EQUIPMENT

Any of various safety equipment that workers wear or use to prevent injury when working around hazards, such as high voltage electrical energy, chemicals, and/or fire.

3.12 RESCUE SHEET

Provides necessary and useful information about a vehicle involved in an accident to support first responders in extricating occupants quickly and safely.

3.13 SECOND RESPONDERS

Include but not limited to tow/recovery personnel, vehicle storage operators, repair/ service technicians, dismantlers and auto salvage personnel.

3.14 SMARTPHONE

A cellular telephone with built-in applications and Internet access. In addition to digital voice service, modern smartphones provide text messaging, e-mail, Web browsing, still and video cameras, MP3 player and video playback and calling. In addition to their built-in functions, smartphones run myriad free and paid applications, turning the once single-minded cellphone into a mobile personal computer.

(From PC Magazine Encyclopedia, http://www.pcmag.com/encyclopedia_term/0,2542,t=Smartphone&i=51537,00.asp)

3.15 VENTING

The release of excessive internal pressure from a Battery System cell, module or pack in a manner intended by design to preclude rupture or explosion.

3.16 xEV

Any electrified propulsion vehicle with a high voltage system, including but not limited to HEV, PHEV, PEV, BEV, FCEV, and EV.

3.17 SYMBOLS

§ = Section

4. BACKGROUND

4.1 Electrical Safety

4.1.1 Electrical Voltage Classifications (High Voltage Exposure)

Twelve volt electrical systems used in passenger cars and other types of motor vehicles have a long history and present minimal risk of electric shock to humans. HV systems used in xEVs, on the other hand, usually contain enough electrical energy at sufficient voltage to cause serious harm. What about voltages in between? At what point does it become “high voltage” and, therefore, hazardous to humans? This section helps identify the difference by categorizing voltages into three different levels:

1. Low voltage
2. Intermediate voltage
3. High voltage

For AC, (alternating current):

A Low voltage AC system is one with a maximum voltage that is equal to or less than 15-V alternating current. This voltage range presents minimal risk of electric shock to humans.

An Intermediate voltage AC system is one with a maximum voltage that is greater than 15-V alternating current but not more than 30-V alternating current. Low risk of electric shock to humans.

A High voltage AC system is one with a maximum voltage that is greater than 30-V alternating current.

For DC, (direct current):

A Low voltage DC system is one with a maximum voltage that is equal to or less than 30-volts direct current. Minimal risk of electric shock to humans.

An Intermediate voltage DC system is one with a maximum voltage greater than 30-volts direct current but not more than 60-volts direct current. Low risk of electric shock to humans.

High voltage DC system is one with a maximum voltage greater than 60-volts direct current.

4.1.2 High Voltage Exposure

In addition to voltage levels, the current limit is also a key consideration in terms of exposure to risk of electric shock. This section identifies several factors that should be considered when establishing safe working levels for current and the effects on the human body. Examples for consideration are listed below:

- A.) Conditions surrounding the work area.
 - a. Wet surface, low resistance to current flow
 - b. Dry surface, high resistance to current flow
 - c. Levels of current and voltage.
 - d. AC
 - e. DC
- B.) Ground path
 - a. AC return path to mother earth.
 - b. DC chassis ground.

The following circumstance assumes a 350vdc rechargeable energy storage system. Body type is based on the 5th to 95th body percentile.

- A.) Size of the human body.
 - a. A body falling in to the 95th percentile range = 3,000Ω
Amperage = $\frac{350\text{vdc}}{3,000\Omega} = 116 \text{ mA}$
 - b. A body falling into the 50th percentile range = 1,750Ω
Amperage = $\frac{350\text{vdc}}{1,750\Omega} = 200 \text{ mA}$
 - c. A body falling into the 5th percentile range = 1,230Ω
Amperage = $\frac{350\text{vdc}}{1,230\Omega} = 284 \text{ mA}$

NOTE: Human body resistance is higher as touch voltage is lower. (Reference IEC60479-1:2005).

See Table 1 for examples of the effects current has on the human body.

Table 1 - Current effects on human body

(From https://www.osha.gov/SLTC/etools/construction/electrical_incidents/eleccurrent.html).

Current level (Milliamperes)	Probable Effect on Human Body
1 mA	Perception level. Slight tingling sensation. Still dangerous under certain conditions .
5 mA	Slight shock felt; not painful but disturbing. Average individual can let go. However, strong involuntary reactions to shocks in this range may lead to injuries.
6 mA – 16 mA	Painful shock, begin to lose muscular control. Commonly referred to as the freezing current or "let-go" range.
17 mA – 99 mA	Extreme pain, respiratory arrest, severe muscular contractions . Individual cannot let go. Death is possible .
100 mA – 2000 mA	Ventricular fibrillation (uneven, uncoordinated pumping of the heart.) Muscular contraction and nerve damage begins to occur. Death is likely .
> 2,000 mA	Cardiac arrest, internal organ damage, and severe burns. Death is probable.

4.1.3 High Voltage Circuit – Two Point Contact

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Without two contact points on the body for current to enter and exit, respectively, there is no hazard of shock. This is why birds can safely rest on high-voltage power lines without getting shocked: they make contact with the circuit at only one point.

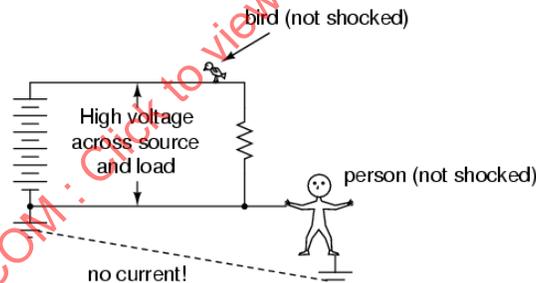


Figure 1 - Single point contact

Consider the situation of Figure 1. Such an accidental connection between a power system conductor and the earth (ground) is called a ground fault, modern vehicles have fault protection programmed into the operating system with Diagnostic Trouble Codes (DTC) to provide information. Ground faults may be caused by many things, including dirt buildup on high voltage insulators (creating a dirty-water path for current from the conductor to the technician, and to the ground), ground water infiltration in buried power line conductors, and birds landing on power lines, bridging the line to the pole with their wings. Given the many causes of ground faults, they tend to be unpredictable. In the case of trees, no one can guarantee which wire their branches might touch. If a tree were to brush up against the top wire in the circuit, it would make the top wire safe to touch and the bottom one dangerous - just the opposite of the previous scenario where the tree contacts the bottom wire (see Figure 2):

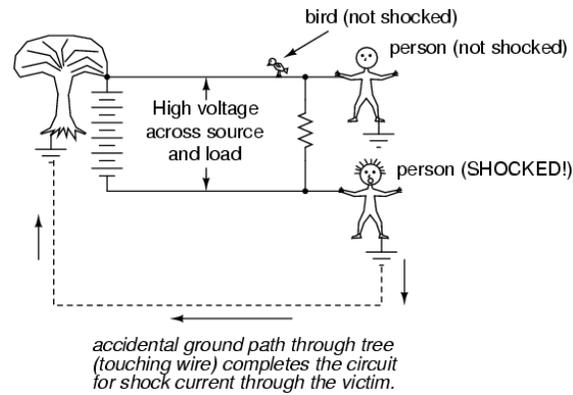


Figure 2 - Two point contact

With the tree branch theory in mind, the vehicle is similar to this scenario. One-hand work on high voltage is a must for technicians working on or around possible high voltage equipment. In most cases the high voltage has been isolated to a split power pack, meaning there is no path for the current to flow unless it is shorted. Since in a collision the technician does not know what wires are touching it is not always safe to assume the fault system has been activated. Caution and not becoming the ground path is essential.

4.2 Electrical Isolation

Conventional vehicles generally use low voltage electrical systems, commonly a 12 volt system, to run lights, horn, power door locks and various other vehicle loads. A 12 volt electrical storage battery is used to supply energy to these devices even when the vehicle's engine is not running. Some smaller hybrid systems might use this low voltage battery as power for a hybrid motor, but many classes of hybrids require larger batteries with higher voltages to provide the necessary power. Hence, xEVs often have two nearly independent electrical systems.

One primary difference between the two electrical systems has to do with electrical isolation. Vehicle 12 volt systems are generally ground-referenced, meaning the negative terminal of the 12 volt battery is connected directly to the metal chassis of the vehicle and hence chassis ground can be used as the voltage reference point for all voltage measurements for devices on the 12 volt system. This allows many electrical devices to have only a single physical electrical terminal, since the return path for the current is through the device's mounting bolts to the vehicle frame.

In contrast, high voltage components on electrified vehicles are generally ground isolated – there is no direct connection between either pole of a high voltage battery and chassis ground. For a number of reasons (not the least of which is the fact that there is no such thing as a perfect insulator) the two systems are not completely isolated from one another -- the two are connected by some amount of resistance.

Isolation resistance is a common measure of how well the lower voltage electrical system including chassis ground and the high voltage electrical systems are decoupled or isolated from one another. Both the positive and negative rails of the high voltage bus are electrically separated from the vehicle's chassis ground by some amount of electrical resistance, and the lower of these two resistances is called the isolation resistance of the vehicle. SAE recommended practice J1766 provides more information about isolation resistance, including information about the minimum recommended isolation for some vehicle conditions.

There are a number of reasons manufactures keep the two electrical systems isolated from one another, the primary one being electrical safety. With sufficiently high isolation resistance there is some inherent protection against an electrical shock hazard if a person were to inadvertently contact any point on the high voltage bus and part of the 12 volt electrical system, such as chassis ground. While this condition could result in the person conducting some electrical current, this current would be greatly limited by the high isolation resistance. In many failure modes the isolation resistance would limit body current to nonhazardous levels.

Regardless of this inherent protection against electrical shock hazards afforded by isolated high voltage systems, however, such systems should only be accessed by properly trained individuals.

4.3 xEV High Voltage System Description

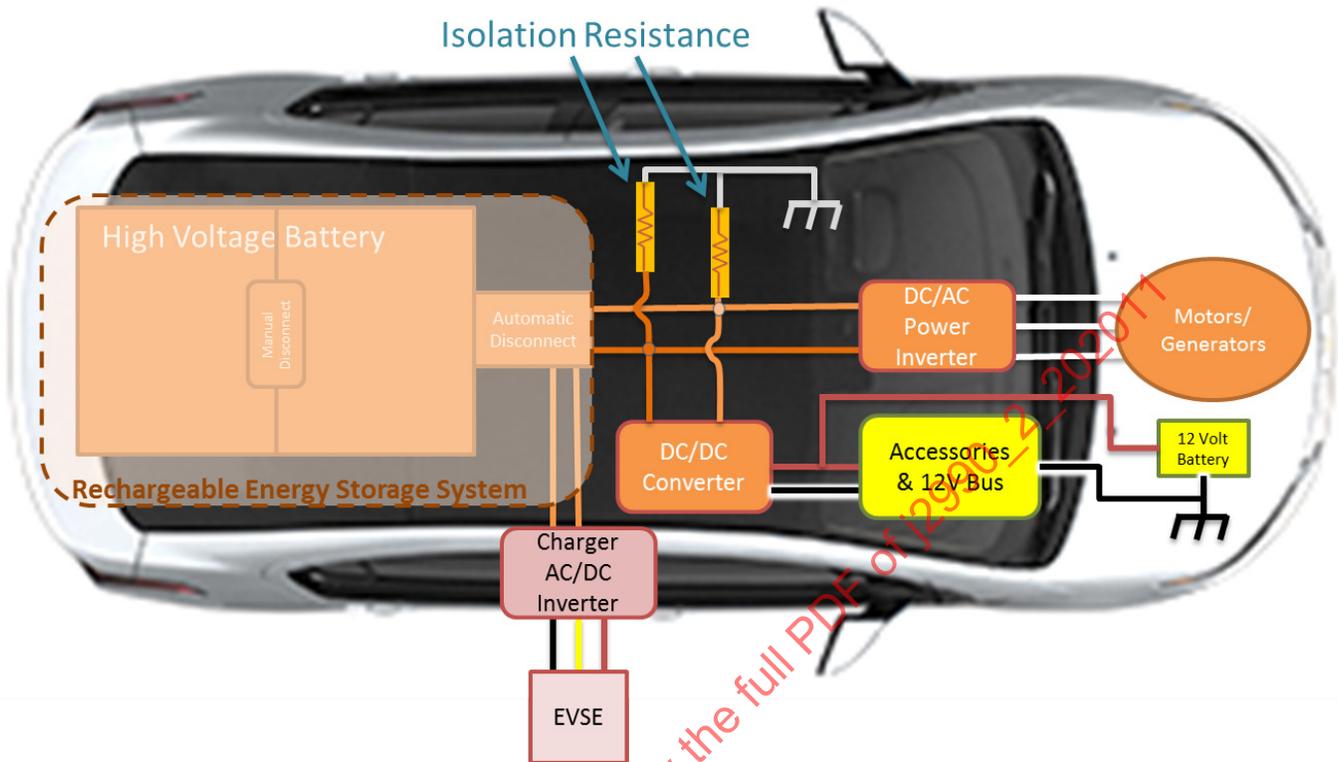


Figure 3 - Typical xEV high voltage system

The components of a typical xEV High Voltage System is shown in Figure 3. The system is comprised of a high voltage battery, referred to as a Rechargeable Energy Storage System (RESS), which provides and stores the energy to and from the vehicle. The RESS often incorporates a manual disconnect which breaks a series connection somewhere within the battery. When removed, this prevents significant energy flow from the energy storage system. The energy in the high voltage battery remains, but the energy is isolated within the battery so exposure to the energy outside the battery is minimized.

The main interface between the battery and the rest of the high voltage system is controlled via an automatic disconnect which opens and closes, allowing voltage and current flow to and from the vehicle and battery. Sometimes the automatic disconnect is referred to as contactors. For plug-in EV's there is sometimes an automatic disconnect which allows the flow of current and a voltage from a charger and the battery. The equipment and wiring off board the xEV used to connect the vehicle to the grid are termed Electric Vehicle Supply Equipment (EVSE). EVSE are installed specifically for the purpose of delivering energy to xEVs.

Electric motors are used to propel the vehicle electrically, and typically are powered by AC Voltage. This requires the battery which is a DC Voltage source, to be converted to AC. This is done through power conversion devices. Power conversion can convert DC to AC, and also boost or lower the voltage. For the 12V auxiliary power, a DC to DC power converter is used to reduce the high voltage battery down to 12V DC to supply accessory power to the vehicle.

The high voltage system components are connected to each other through cables. These cables are usually orange in color when they are connecting high voltage components. However, the high voltage cables may not be orange in color if covered or behind a shield, cover, jacketing or enclosure. Typically when high voltage cables are covered, the covering object will be orange or marked to indicate high voltage. The high voltage system is designed to be electrically isolated from the rest of the vehicle.

4.4 Regulatory Requirements

All xEVs are required to comply with governmental regulations in the individual countries in which the vehicles are offered for sale. xEVs are also required to comply with an increasing body of regulations aimed specifically at protecting against the unique potential hazards of electrified propulsion systems. Furthermore, many vehicle manufactures also voluntarily comply with industry standard practices, such as those published by SAE International in the United States. The reference section of this document provides a listing of the most notable regulations and industry practices unique to xEVs that are in place at the time of this document's publication. It is emphasized, however, that this listing is only intended to be an introduction to applicable design requirements and guidelines - it is not a comprehensive catalog of requirements.

Many of the current xEV requirement documents define a vehicle's expected performance after an impact has occurred, although some do give either direct or indirect requirements on the performance of the electrification system during normal vehicle operation. One representative document is *SAE J1766 - Recommended Practice for Electric and Hybrid Electric Vehicle Battery Systems Crash Integrity Testing*. SAE J1766 is a good example of an industry standard, especially since it served as the original technical basis for the *National Highway Traffic Safety Administration's* FMVSS305 federal regulation. The SAE J1766 recommended practice defines a number of methods vehicle manufactures can utilize to help ensure the safety of vehicle occupants and responders post-impact. These methods are mainly focused on the following areas:

1. Electrolyte spillage
2. Retention of high voltage components
3. Component voltage levels (excluding high voltage sources)
4. Electrical isolation levels between high voltage buses and the electrical chassis
5. Usage of physical barriers to prevent high voltage contact

Fuel cell electric vehicles (FCEVs) also pose some additional unique potential hazards, primarily around the onboard storage of hydrogen used to power the fuel cell. Again to promote safety of occupants and responders, the automotive industry and regulatory agencies are working to standardize requirements for FCEVs. A representative document in this area would be *SAE J2578 - Recommended Practice for General Fuel Cell Vehicle Safety*.

5. GENERAL PROTECTION METHODS

5.1 Enclosures

High voltage components are generally contained within cases or enclosures which may provide one or more of the following functions:

1. Environmental Protection
2. Impact Protection
3. Electrical Shock Protection
4. Mechanical Functions

Enclosures for high voltage components typically have a pollution degree assigned to them based on the environmental characteristics of the enclosure's mounting location within the vehicle. This pollution degree specifies the expected amount of dry contaminants (e.g. dust) or condensation expected and is used by engineers as a shorthand notation for defining what the enclosure must seal against so the parts inside the enclosure can perform without degradation particularly for isolation resistance. For example, a high voltage battery pack mounted under a vehicle or in the engine compartment would require better sealing to prevent moisture and road salt from encroaching on the interior of the pack, while a battery mounted in the trunk might require minimal sealing because the vehicle itself affords the majority of the environmental protection.

In the event of a vehicle impact, the enclosure can help protect the high voltage components from physical damage. Enclosures can also protect devices from occupant induced impacts such as from shifting luggage/cargo loads and from inadvertent knee loads. Preventing physical damage helps ensure the component can maintain its electrical isolation between the high voltage inside the enclosure and the chassis of the vehicle. The enclosure may also provide some protection against direct contact with high voltage post-impact, however only appropriately trained individuals should work on or near high voltage components that might have impact damage.

Enclosures can also provide several miscellaneous mechanical functions. For example, many enclosures have integrated cooling systems (either liquid or air) to help keep the component's temperature within its designed operational band. Enclosures also provide mounting features to secure the high voltage component in the vehicle. For batteries, the enclosures may provide venting of gases away from the passenger compartment if the vehicle itself does not prevent the gases from entering the passenger compartment.

5.2 Labels and Identification

Labels and badging are frequently used on xEVs to communicate important information and instructions to both vehicle occupants and first and second responders. First responders rely on vehicle badging to help identify the vehicle when approaching to assess the hazards present. SAE J2990 provides recommendations to OEM's for badging vehicles to effectively identify xEVs. Beyond vehicle badging, labels are placed throughout the vehicle on high voltage components to warn of the high voltage hazard. An example high voltage label is shown in Figure 4.



Figure 4 - Example high voltage label

On the battery itself, many OEM's include additional hazard information with the high voltage warning. The additional hazards typically cover flammability, chemical exposure, etc. Figure 5 provides an example of a multiple hazard label.

To assist first responders, several OEM's have included labels to identify where the 12V and high voltage batteries are located in the vehicle (Figure 6) and to identify the cut points for the first responders to cut the 12 V battery cables to disable the vehicle (Figure 7). While a standard does not exist yet, many OEM's are including a red fire hat symbol on the labels intended for first responders.



Figure 5 - Example multi hazard battery label

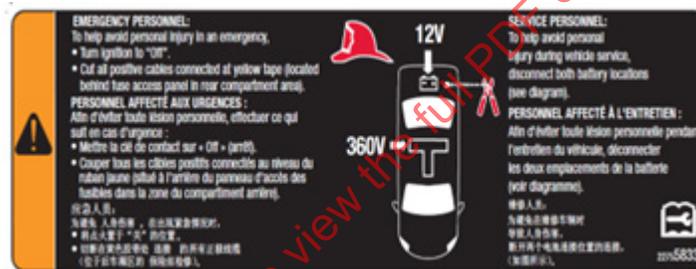


Figure 6 - Vehicle label showing location of batteries



Figure 7 - First responder cut label

A new label concept recently employed utilizes a QR Code (see Figure 8), which allows responders to scan with a smartphone or device and bring up rescue sheet information on the vehicle in the native language of the device scanning the label.