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SURFACE VEHICLE INFORMATION REPORT

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GUIDELINES FOR ELECTRIC VEHICLE SAFETY

Foreword—Vehicle safety is an important design element for all types of vehicles designed for use on public streets, roadways, and highways. Vehicles produced with liquid fuels have a long history of creating appropriate safety countermeasures. With the onset of new electric propulsion and charging systems, proposed for large scale production, new safety design parameters will need to be provided to vehicle developers. This SAE Information Report is a first attempt to formalize a list of important safety items for vehicle developers. Automotive manufacturers, insurance companies, the repair industry, and first responders groups will need to work together to update this document as more data becomes available.

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1. Scope—This SAE Information Report identifies and defines the preferred technical guidelines relating to safety for Electric Vehicles (EVs) during normal operation and charging. Guidelines in this document do not necessarily address maintenance, repair, or assembly safety issues.

1.1 Purpose—The purpose of this SAE Information Report is to provide introductory safety guideline information that should be considered when designing electric vehicles for use on public roadways.

1.2 Field of Application—This document covers electric vehicles having a gross vehicle weight rating of 4536 kg (10 000 lb) or less that are designed for use on public roads.

1.3 Product Classification—Not available.

1.4 Form—Not available.

2. *References*

2.1 Applicable Publications—The following publications form a part of this information report to the extent specified. Unless otherwise indicated, the latest version of SAE publications shall apply.

Applicable FMVSS standards and regulations shall supersede any SAE recommended practices as described in this document.

2.1.1 SAE PUBLICATIONS—Available from SAE, 400 Commonwealth Drive, Warrendale, PA. 15096-0001.

SAE 551-1—Performance Levels and Methods of Measurement of Electromagnetic Compatibility of Vehicles and Devices (60 Hz to 18 GHz)
SAE J551-2—Test Limits and Methods of Measurement of Radio Disturbance Charactersitics of Vehicles, Motorboats, and Spark-Ignited Engine-Driven Devices
SAE J551-4—Test Limits and Methoeds of Measurement of Radio Disturbance Characteristics of Vehicles and Devices, Broadband and Narrowband, 150 kHz to 1000 MHz
SAE J551-5—Performance Levels and Methods of Measurement of Magnetic and Electric Field Strength from Electric Vehicles, Broadband, 9 kHz to 30 MHz
SAE J551-11—Vehicle Electromagnetic Immunity—Off-Vehicle Source
SAE J551-12—Vehicle Electromagnetic Immunity—On-Board Transmitter Simulation
SAE J551-13—Vehicle Electromagnetic Immunity—Bulk Current Injection
SAE J1766—Electric and Hybrid Vehicle Battery Systems Crash Integrity Testing
SAE J1718—Hydrogen Gas Emissions
SAE J1772—Electric Vehicle Conductive Coupling
SAE J1773—Electric Vehicle Inductive Coupling
SAE J1654—High Voltage Primary Cable
SAE J1673—High Voltage Wiring

2.1.2 ANSI/IEEE—Available from ANSI, 11 West 42nd Street, New York, NY 10036-8002.

ANSI/IEEE—C62.41—Surge Voltages in Low-Voltage AC Power Circuits
ANSI/IEEE—C62.45—Equipment Connected to Low-Voltage AC Power Circuits, Guide on Surge Testing for

2.1.3 CISPR PUBLICATIONS—Available from ????

CISPR 12
CISPR 25

2.1.4 FMVSS PUBLICATION—Available from the Superintendent of Documents, U. S. Government Printing Office, Mail Stop: SSOP, Washington, DC 20402-9320.

FMVSS—(Federal Motor Vehicle Safety Standards)

2.1.5 IEC PUBLICATIONS—Available from International Electrotechnical Commission, 3, rue de Verambe, P.O. Box 131, 1211 Geneva 20, Switzerland.

IEC 801-4
IEC 555-2
IEC 555-3

2.1.6 ISO PUBLICATION—Available from ANSI, 11 West 42nd Street, New York, NY 10036-8002.

ISO 11451—Road vehicles—Electrical disturbances by narrowband radiated electromagnetic energy—Vehicle Test Methods

2.1.7 UL PUBLICATIONS—Available from Underwriters Laboratories, 333 Pfingsten Road, Northbrook, IL 60062-2096.

UL 2202—-Electric Vehicle Charging Equipment October 1996
UL 2231—Personnel Protection Systems for Electric Vehicle (EV) Supply Circuits: Part 1: General Requirements, July 1,1996

2.1.8 OTHER PUBLICATIONS—The following documents should be consulted for additional information regarding EV safety.

Applicable State and Local laws and regulations.
FCC Rules and Regulations Parts 15 and 18.
Canada's ICEs 002
European Union 72/245/EEC as amended by 95/54/EC

2.2 Related Publications—The following publications are provided for information purposes only and are not a required part of this document.

2.2.1 SAE PUBLICATIONS—Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

SAE TSB 001—SAE Technical Standards Board Rules and Regulations
SAE TSB 002—SAE Preparation of SAE Technical Reports
SAE TSB 003—Rules for the SAE Use of SI (Metric) Units
SAE J1115—Guidelines for Developing and Revising SAE Nomenclature and Definitions
SAE J1142—Towability Design Criteria and Equipment Use-Passenger Cars, Vans, and Light-Duty Trucks
SAE J1715—Electric Vehicle Terminology
SAE Report—Format Guidelines for Electronic Capture of SAE Documents
SAE Committee Guidelines Manual

2.2.2 ISO PUBLICATIONS—Available from ANSI, 11 West 42nd Street, New York, NY 10036-8002.

ISO/WD 6469-1—Electric Road Vehicles—Safety Specifications—Part 1: On-board energy storage
ISO/WD 6469-2—Electric Road Vehicles—Safety specifications—Part 2: Functional safety means and protection against failures.
ISO/WD 6469-3—Electric road vehicles—Safety Specifications—Part 3: Protection of users against electrical hazards.

2.2.3 FEDERAL AND MILITARY PUBLICATION—Available from the U. S. Government, DOD SSP, Subscription Service Division, Building 4D, 700 Robbins Avenue, Philadelphia, PA 19111-5094

MIL SPEC -1472 B for Thermal Hazards

3. Definitions

3.1 Motor Vehicle—Means any vehicle driven or drawn by mechanical power manufactured primarily for use on the public streets, roads, and highways.

3.2 Motor Vehicle Safety Standard—Means a minimum standard for motor vehicle performance (written by the National Highway Traffic Safety Adminstration), or motor vehicle equipment performance, which is practicable, which meets the need for motor vehicle safety and which provides objective criteria.

3.3 Motoring—Defined as the Key (power-enabling device) in the “on” postion and that mode in which the transmission selector is in a forward or reverse drive position.

3.4 Potentially Hazardous Voltage—Means voltage levels that can harm humans through electric shock. Hazardous voltage levels are defined in the Outline of Investigation for Personnel Protection Systems for Electric Vehicle (EV) Supply Circuits; General Requirements, UL 2231 July 1996 in Section 5 and in UL 2202 Electric Vehicle Charging Equipment October 1996 in Section 6. Systems which are 60 VDC and above should be designed to protect against direct contact.

3.5 Potentially Hazardous Energy—Means the capability for damage to property or injury to persons, other than by electric shock. Potentially hazardous energy is considered to exist, if between a live part and an adjacent dead metal part or between live parts of different polarity, there exists a potential of 2 V or more and either an available continuous power level of 240 V-A or more, or a reactive energy level of 20 J or more. (reference - UL 2202)

3.6 Hazardous Voltage Interlock Loop (HVIL)—Means a continuous electrical circuit which begins and ends in an automatic disconnect device and sends a small (non-hazardous) electric current through a loop, where hazardous voltage is present, to check for electrical continuity.

3.7 Electrical Isolation—Means the electrical resistance between the vehicle traction battery high-voltage system and any vehicle conductive structure. A value greater than or equal to 500 Ω/V at the maximum battery pack working voltage, is defined as “isolated”. Isolation is measured from both the positive and negative battery terminals relative to the vehicle conductive structure.

3.8 Electrical isolation—Means a condition in which the traction battery is deliberately disconnected from external circuitry, as for example by an automatic disconnect device. Such isolation normally requires that both the positive and negative battery leads be disconnected.

4. Technical Safety Guidelines

4.1 EV Crashworthiness—Crashworthiness guidelines for EVs are contained in SAE J1766.

4.2 Single-Point Failure—A single-point hardware/software failure or single failure of trained personnel to follow documented procedures should not result in an unreasonable safety risk to any person.

4.3 Electrical Safety—EVs typically contain potentially hazardous levels of electrical voltage or current. It is important to protect persons from exposure to this hazard. Under normal operating conditions, adequate electrical isolation is achieved through physical separation means such as the use of insulated wire, enclosures, or other barriers to direct contact. There are conditions or events that can occur outside normal operation that can cause this protection to be degraded. Some means should be provided to detect degraded isolation or loss of separation, so that action can be taken to mitigate the degradation. In addition, processes and/or hardware should be provided to allow for controlled access to the high-voltage system for maintenance or repair. A number of alternative means may be used to achieve these electrical safety goals, including Automatic Hazardous Voltage Disconnects, Manual Disconnects, Interlock System(s), Special Tools, and Grounding. The intention of all these means is either to prevent inadvertant contact with hazardous voltages or to prevent damage or injury from the uncontrolled release of electrical energy.

4.3.1 AUTOMATIC HAZARDOUS VOLTAGE DISCONNECTS—An automatic hazardous voltage disconnect function provides a means of electrically isolating hazardous voltage within a battery pack from external circuitry or components without user intervention, based on some input triggering event. An automatic disconnect device should also provide a reset capability for restoring the traction voltage after the initiating condition has been cleared. Several types of events are commonly used as inputs to an automatic disconnect function.

4.3.1.1 Typical Automatic Disconnect Function Inputs

4.3.1.1.1 Vehicle Crash Sensor—Actuating an automatic disconnect in the event of a crash may be an appropriate means for assuring that the electrical isolation required by SAE J1766 is maintained after a crash, provided that the automatic disconnect function is qualified to operate in the crash tests described in SAE J1766 .

4.3.1.1.2 Detected Loss Of Battery Isolation (Ground Fault)—It is desirable to monitor the degree of electrical isolation between traction battery voltage and vehicle conducting structures. Loss of such isolation is not in and of itself an unsafe condition; however, detection of a loss of isolation may be used to activate an automatic disconnect. If the vehicle is in operation when the loss of isolation is detected, the disconnect action should occur only in the non-motoring mode (e.g., Examples: Key (power-enabling device) off, key removed, or in Park).

4.3.1.1.3 Hazardous Voltage Interlock Loop (HVIL)—The general intent of a HVIL is to monitor the integrity of a loop where hazardous voltage is present which could expose persons to potentially hazardous voltage if opened or disconnected. In general, the response to loss of continuity in a HVIL should be to actuate an automatic hazardous voltage disconnect.

4.3.1.1.4 Overcurrent—In addition to other functions as described in the preceding sections, an automatic disconnect device may be used to perform either a primary or secondary/redundant overcurrent protection function. If some other device acts as the primary overcurrent protection means, it may also be desirable to actuate the automatic disconnect device in the event of an overcurrent condition, either to perform its disconnect function or to provide more accurate overcurrent protection.

4.3.1.2 Other Automatic Disconnect Function Guidelines

a. It is desirable for the automatic disconnect device to be located as close to the battery output terminals as possible to minimize the external circuitry which is not de-energized when it actuates.
b. Reset of an automatic disconnect device should require a deliberate action of the operator. Reset should not expose the operator to hazardous voltages.
c. An automatic disconnect should,where practical, detect failures of its function (e.g.,welded contacts) and provide an indication of such condition to a manufacturer-specified interface such that the driver or service personnel may be alerted to the existence of this condition.
d. An automatic disconnect should not require power to actuate, i.e., it should be normally open ("fail-safe") when in the unpowered state.
e. An automatic disconnect should actuate when any associated supply voltage(s) falls to a level below which the disconnect may not function properly.
f. An output signal may be needed from the automatic disconnect to permit de-energizing other power sources on the load side of the automatic disconnect.

4.3.2 MANUAL DISCONNECTS—A Manual Disconnect can provide manually operated hazardous voltage electrical isolation for vehicle assembly, service, and maintenance operations. The following guidelines are provided for manual disconnects:

4.3.2.1 Suggested Disconnect Location and Type—A single-pole manual disconnect, if used, should be located as close as possible to the electrical center of the battery pack. Alternatively, a single two-pole manual disconnect can be used to disconnect both the positive and negative terminals of the battery. The use of multiple manual disconnects is not recommended.

4.3.2.2 Disconnect Function—Opening a manual disconnect should remove any voltage between positive and negative battery pack output terminals.

4.3.2.3 *Disconnect Operation*—Removal of or opening the manual disconnect should not require tools and should require a force that a person can easily provide. Manual disconnect devices should be electrically insulated to prevent personnel from inadvertently completing a conductive path.

4.3.3 INTERLOCKS

4.3.3.1 *Hazardous Voltage Bus Discharge*—When high-voltage circuitry is disconnected from the battery pack (e.g., when the hazardous voltage automatic disconnect or manual disconnect is opened), it may be necessary to discharge the capacitance of the hazardous voltage bus to a non-hazardous level. This is a manufacturer-specific choice depending on the voltage and energy present and the time required for voltage to decay. (See UL 2202 for guidance.)

4.3.3.2 *Access Cover Interlocks*—An interlock, or other means, may be provided on any cover whose removal provides direct access to exposed conductors with hazardous voltage. If a Hazardous Voltage Interlock Loop is used (see next section), such interlocks should be a part of this monitoring loop.

4.3.3.3 *Hazardous Voltage Interlock Loop*—A Hazardous Voltage Interlock Loop (HVIL) is a type of interlock system which typically uses a small (non-hazardous) signal through a loop connecting a set of conductors and connectors where hazardous voltage is present to check for electrical continuity. In the event of a loss of electrical continuity through the loop, for example due to opening a connector, the automatic disconnect device is opened to remove hazardous voltage from potentially exposed points. Methods other than a HVIL may be used to detect the loss of electrical continuity. The HVIL may also be routed through other vehicular devices at the vehicle manufacturer's option, e.g., a power-enabling switch or a "manual disconnect" which could be used as a lock out device for system maintenance operations.

4.3.3.4 *Charge Interlocks*—There should be no accessible contacts carrying hazardous voltage during or in connection with charging operations. The vehicle should be equipped with an interlock that will prevent application of drive power while the vehicle is still mechanically connected to the charging power source. (Refer to SAE J1772 and SAE J1773)

4.3.4 SPECIAL TOOLS—In general, special tools should not be used as a substitute for fail-safe design features. However, they may be appropriate in some cases as a substitute for interlocks or automatic disconnects for restricting access to non-user-serviceable functions. Use of such tools should be coupled with appropriate safety handling procedures and/or labeling practices.

4.3.5 GROUNDING—If hazardous voltages are contained within a conductive exterior case or enclosure that may be exposed to human contact as installed in the vehicle, this case should be provided with a conductive connection to the vehicle chassis.

Energy storage components (i.e., batteries) and major power electronics components should have their external conductive cases connected directly to the vehicle conductive structure (chassis) by a ground strap, wire, welded connection or other suitable low-resistance mechanical connection. Case ground connectors routed from other components (as noted as follows) should be connected to this grounding means.

Other components which receive hazardous voltages from sources outside their conductive enclosures may have their cases grounded either directly as previously stated or indirectly through the wiring harness which carries the voltage(s) from the external source. The intent of this guideline is that disconnecting a wiring harness used to provide indirect case grounding should also disconnect the source of hazardous voltages.

4.3.6 HIGH-VOLTAGE WIRING ASSEMBLIES—It is recommended that high-voltage wiring assemblies for EVs should follow the guidelines established in both SAE J1654 and SAE J1673.

4.3.7 FUSING—Fuses are protective devices designed to interrupt the electrical circuit when subjected to excessive current. They are nonreversible and must be replaced after the circuit malfunction is corrected. They should not be used as personnel protection devices, since they do not respond sensitively enough to protect persons from injury due to contact with hazardous high voltage.

4.4 Fault Monitoring—The vehicle operator should be alerted to the existence of a propulsion system fault or condition that could lead to further damage to propulsion system hardware and should not be allowed to persist uncorrected. The following are instances of faults which might need to be indicated (as applicable to a particular design):

Loss of Battery System Isolation
Low State-of-Charge
Low Oil Pressure (analogous to Engine Oil Pressure)
Over Temperature, Temperature Fault, or Temperature Out-of-Range
Hazardous Voltage Fault
Failure of Contactor to Open When Commanded (Welded Contacts)

4.5 Hazardous Liquid Leakage—The propulsion system shall not leak any hazardous liquids in any position during normal storage, shipment, assembly, driving, or charging. Post-crash leakage guidelines are provided in SAE J1766.

4.6 Hazardous Gas Leakage—Hydrogen gas accumulation, in EV battery packs should be limited to less than 2% of the total free volume of the battery pack as described in SAE J2289. For other vehicle compartments, outside the battery pack, it is recommended that the vehicle design preclude accumulation of hazardous gas beyond the same limit stated previously. Specific atttention to placement of vent tube exhausts is required in order to assure the limits are met. Vehicle level testing for hydrogen gas emissions during charging are described in SAE J1718.

4.7 Vehicle Immersion—Total or partial immersion of an EV in water should not result in electric potential or current flow, gas or liquid emissions, or explosion that is hazardous to any person inside or outside the vehicle.

4.8 Electromagnetic Compatibility (EMC) and Electrical Transient—All electrical assemblies on an EV which could affect safe operation of the vehicle should be functionally tolerant of the electromagnetic environment to which the vehicle will be exposed. This includes fluctuating voltage and load conditions which will occur during normal operation of the vehicle during driving and charging. Also, electrical transients resulting from normal operation of the vehicle should not cause false shutdowns of the vehicle.

Several industry standards and guidelines exist including:

Complete Vehicle Documents—SAE J551-1, SAE J551-2, SAE J551-4, SAE J551-5,SAE J551-11, SAE J551-12, SAE J551-13, SAE J1812, CISPR 12, CISPR 25, ISO 11451 series.
Component/Electrical Assemblies—SAE J1113 series, SAE J1752 series, CISPR 25, ISO 11452 series.
Other Industry Documents—ANSI/IEEE C62.41, ANSI/IEEE C62.45, IEC 801-4, IEC 555-2, IEC 555-3

The foregoing guidelines on EMC safety are in addition to applicable government regulatory requirements for EMC, such as:

FCC Rules and Regulations Parts 15 and 18.
Canada's ICEs 002
European Union 72/245/EEC as amended by 95/54/EC