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Recommended Practice for General Fuel Cell Vehicle Safety

Foreword—Vehicles manufactured with liquid hydrocarbon as fuels have a long history of creating appropriate safety countermeasures. With the onset of new hydrogen fuel cell systems, new mechanical and electrical system safety design parameters will need to be provided to vehicle developers. These SAE reports are an initial attempt to formalize a list of important safety items for fuel cell vehicle and subsystem developers.

The purpose of this document is to identify the unique requirements and criteria for the integration of fuel cell systems into vehicles. This document relates to the overall design, construction, operation and maintenance of fuel cell vehicles including the integration of the Fuel Systems (and other fuel cell systems containing potentially hazardous fluids as defined in this document) into the vehicle.

TABLE OF CONTENTS

1. ***Scope*****—**This SAE Recommended Practice identifies and defines the preferred technical guidelines relating to the safe integration of fuel cell system, fuel storage, and electrical systems into the overall Fuel Cell Vehicle.

1.1 Purpose—The purpose of this document is to provide introductory mechanical and electrical system safety guidelines that should be considered when designing fuel cell vehicles for use on public roads.

1.2 Field of Application—This document covers fuel cell vehicles designed for use on public roads.

2. References—The following publications form a part of this information report to the extent specified. Unless otherwise indicated, the latest version of publications should apply.

2.1 Applicable Publications—The following publications form a part of this specification to the extent specified herein. Unless otherwise specified, the latest issue of SAE publications shall apply.

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

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

SAE J1142—Towability Design Criteria and Equipment Use—Passenger Cars, Vans, and Light-Duty Trucks
SAE J1645—Fuel System—Electrostatic Charge
SAE J1718—Measurement of Hydrogen Gas Emission from Battery-Powered Passenger Cars and Light Trucks during Battery Charging
SAE J1739—Potential Failure Mode and Effects Analysis in Design (Design FMEA), Potential Failure Mode and Effects Analysis in Manufacturing and Assembly Processes (Process FMEA), and Potential Failure Mode and Effects Analysis for Machinery (Machinery FMEA)
SAE J1742—Connections for High Voltage On-Board Road Vehicle Electrical Wiring Harnesses—Test Methods and General Performance Requirements
SAE J1766—Recommended Practice for Electric and Hybrid Electric Vehicle Battery Systems Crash Integrity Testing
SAE J1772—SAE Electric Vehicle Conductive Charge Coupler
SAE J1773—SAE Electric Vehicle Inductively Coupling Charging
SAE J2344—Guidelines for Electric Vehicle Safety
SAE J2574—Fuel Cell Vehicle Terminology

2.1.2 ANSI STANDARD—The following publication is provided for information purposes only and is not directly applicable to this document. The publication is available from ANSI, 25 West 43rd Street, New York, NY 10036-8002.

ANSI Z535.4—Product Safety Sign and Label

2.1.3 FEDERAL MOTOR VEHICLE SAFETY STANDARDS (FMVSS)—The publications are available from the U.S. Government Printing Office, 710 N. Capitol St. NW, Washington, DC 20401.

The following Federal Motor Vehicle Safety Standards are specifically applicable to this document for use in the U.S. See the Code of Federal Regulations (49 CFR 571) for other applicable FMVSS. In other countries, other regulations may apply.

FMVSS 301—Fuel system integrity
FMVSS 303—Fuel system integrity of compressed natural gas vehicles
FMVSS 305—Electric powered vehicles: electrolyte spillage and electrical shock protection

2.1.4 IEC PUBLICATIONS—The following publications are provided for guidance. The publications are available from International Electrotechnical Commission, 3, rue de Verambe, P.O. Box 131, 1211 Geneva 20 Switzerland.

IEC 60079 (Parts 0 through 20)—Electrical Apparatus for Explosive Gas Atmospheres
IEC 60417 (Parts 1 and 2)—Graphical Symbols for Use on Equipment
IEC 61508-1—1998 & Corrigendum: 05-1999, Functional Safety of Electrical/Electronic/Programmable Electronic Safety-Related Systems - Part 1: General Requirements
IEC 61508-3, 1998 & Corrigendum: 04-1999—Functional Safety of Electrical/Electronic/Programmable Electronic Safety-Related Systems - Part 3: Software Requirements

2.1.5 ISO PUBLICATION—Available from ANSI, 25 West 43rd Street, New York, NY 10036-8002.

ISO 6469-2—Electric road vehicles—Safety specifications—Part 2: Functional safety means and protection against failures

2.1.6 UL PUBLICATIONS—The following publications are provided for guidance. The publications are available from Underwriters Laboratories, 333 Pfingsten Road, Northbrook, IL 60062-2096.

UL 991—Standard for Tests for Safety-Related Controls Employing Solid-State Devices
UL 1998—Standard for Safety-Related Software
UL 2202—Standard for Electric Vehicle (EV) Charging System Equipment
UL 2231—Personnel Protection Systems for Electric Vehicle (EV) Supply Circuits
UL 2251—Plugs, Receptacles, and Couplers for Electric Vehicles
UL 2279—Standard for Electrical Equipment for Use in Class I, Zone 0, 1, and 2 Hazardous (Classified) Locations

2.1.7 OTHER PUBLICATIONS—The following documents should be consulted for additional information regarding Fuel Cell Vehicle safety control systems.

DGMK Research Report 508, 1996 "Avoiding the Ignition of Otto-type Fuel/Air Mixtures when Refueling Automobiles at Gas Stations"
EPRI TR-105939—Final Report Prepared Underwriters Laboratories, December 1995, "Personnel Protection Systems for Electric Vehicle Charging Circuits"
NFPA 496 Standard for Purged and Pressurized Enclosures for Electrical Equipment 1998 Edition

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 J551-1—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 Characteristics of Vehicles, Motorboats, and Spark-Ignited Engine-Driven Devices
SAE J551-4—Test Limits and Methods 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 J1113-2—Electromagnetic Compatibility Measurement Procedures and Limits for Vehicle Components (Except Aircraft)—Conducted Immunity, 30 Hz to 250 kHz—All Leads
SAE J1113-3—Conducted Immunity, 250 kHz to 5000 MHz, Direct Injection of Radio Frequency (RF) Power
SAE J1113-4—Immunity to Radiated Electromagnetic Fields—Bulk Current Injection (BCI) Method
SAE J1113-11—Immunity to Conducted Transients on Power Leads
SAE J1113-12—Electrical Interference by Conduction and Coupling—Coupling Clamp and Chattering Relay
SAE J1113-13—Electromagnetic Compatibility Measurement Procedure for Vehicle Components—Part 13—Immunity to Electrostatic Discharge
SAE J1113-21—Electromagnetic Compatibility Measurement Procedure for Vehicle Components—Part 21: Immunity to Electromagnetic Fields, 10 kHz to 18 GHz, Absorber-Lined Chamber
SAE J1113-24—Immunity to Radiated Electromagntic Fields; 10 kHz to 200 MHz—Crawford TEM Cell and 10 kHz to 5 GHz—Wideband TEM Cell
SAE J1113-25—Electromagnetic Compatibility Measurement Procedure for Vehicle Components—Immunity to Radiated Electromagnetic Fields, 10 KHz to 1000 MHz—Tri-Plate Line Method
SAE J1113-26—Electromagnetic Compatibility Measurement Procedure for Vehicle Components—Immunity to AC Power Line Electric Fields
SAE J1113-41—Limits and Methods of Measurement of Radio Disturbance Characteristics of Components and Modules for the Protection of Receivers Used on Board Vehicles
SAE J1113-42—Electromagnetic Compatibility—Component Test Procedure—Part 42 - Conducted Transient Emissions
SAE J1115—Guidelines for Developing and Revision SAE Nomenclature and Definitions
SAE J1654—High Voltage Primary Cable
SAE J1673—High Voltage Automotive Wiring Assembly Design
SAE J1715—Electric Vehicle Terminology
SAE J1752-1—Electromagnetic Compatibility Measurement Procedures for Integrated Circuits—Integrated Circuit EMC Measurement Procedures—General and Definitions
SAE J1752-2—Electromagnetic Compatibility Measurement Procedures for Integrated Circuits—Integrated Circuit Radiated Emissions Diagnostic Procedure 1 MHz to 1000 MHz, Magnetic Field—Loop Probe
SAE J1812—Function Performance Status Classification for EMC Immunity Testing

2.2.2 ANSI Standards—The following publications are provided for information purposes only and are not directly applicable to this document. The publications are available from ANSI, 25 West 43rd 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
ANSI Z21.83—Standard for Stationary Fuel Cell Power Plants

2.2.3 CISPR Publications—The following publications are provided for information purposes only and are not directly applicable to this document. The publications are available from IEC. See 2.2.5.

CISPR 12—Vehicles, motorboats and spark-ignited engine-driven devices—Radio disturbance characteristics—Limits and methods of measurement
CISPR 22—Information technology equipment—Radio disturbance characteristics—Limits and methods of measurement
CISPR 25—Limits and methods of measurement of radio disturbance characteristics for the protection of receivers used on board vehicles

2.2.4 EU Directives—The following Directive is available for download from the European Union at http://www.europa.eu.int/eur-lex/en/index.html

Commission Directive 95/54/EC—Automotive Directive (amends 72/245/EEC)

2.2.5 IEC Publications—The following publications are provided for guidance. The publications are available from International Electrotechnical Commission, 3, rue de Verambe, P.O. Box 131, 1211 Geneva 20 Switzerland.

IEC 61508-2, 2000—Functional Safety of Electrical/Electronic/Programmable Electronic Safety-Related Systems - Part 2: Requirements for Electrical/Electronic/Programmable Electronic Safety-Related Systems
IEC 61508-4, 1998 & Corrigendum: 04-1999—Functional Safety of Electrical/Electronic/Programmable Electronic Safety-Related Systems - Part 4: Definitions and Abbreviations
IEC 61508-5, 1998 & Corrigendum: 04-1999—Functional Safety of Electrical/Electronic/Programmable Electronic Safety-Related Systems - Part 5: Examples of Methods for the Determination of Safety Integrity Levels
IEC 61508-6, 2000—Functional Safety of Electrical/Electronic/Programmable Electronic Safety-Related Systems - Part 6: Guidelines on the Application of IEC 61508-2 and IEC 61508-3
IEC 61508-7, 2000—Functional Safety of Electrical/Electronic/Programmable Electronic Safety-Related Systems - Part 7: Overview of Techniques and Measures

2.2.6 ISO Publications—Available from ANSI, 25 West 43rd Street, New York, NY 10036-8002.

ISO 6469-1—Electric road vehicles—Safety specifications—Part 1: On-board energy storage
ISO 6469-3—Electric road vehicles—Safety specifications—Part 3: Protection of users against electrical hazards
ISO 11451-1, 2001—Road vehicles—Vehicle test methods for electrical disturbances from narrowband radiated electromagnetic energy—Part 1: General and definitions
ISO 11451-2, 2001—Road vehicles—Vehicle test methods for electrical disturbances from narrowband radiated electromagnetic energy—Part 2: Off-Vehicle radiation sources
ISO 11451-3, 1994—Road vehicles—Electrical disturbances by narrowband radiated electromagnetic energy—Vehicle test methods—Part 3: On-Board transmitter simulation
ISO 11451-4, 1995—Road vehicles—Electrical disturbances by narrowband radiated electromagnetic energy—Vehicle test methods—Part 4: Bulk current injection (BCI)
ISO 11452-1, 2001—Road vehicles—Component test methods for electrical disturbances from narrowband radiated electromagnetic energy—Part 1: General and definitions
ISO 11452-2, 1995—Road vehicles—Electrical disturbances by narrowband radiated electromagnetic energy—Component test methods—Part 2: Absorber-Lined chamber
ISO 11452-3, 2001—Road vehicles—Component test methods for electrical disturbances from narrowband radiated electromagnetic energy—Part 3: Transverse electromagnetic (TEM) cell
ISO 11452-4, 2001—Road vehicles—Component test methods for electrical disturbances from narrowband radiated electromagnetic energy—Part 4: Bulk current injection (BCI)
ISO 11452-5, 1995—Road vehicles—Electrical disturbances by narrowband radiated electromagnetic energy—Component test methods—Part 5: Stripline
ISO 11452-6, 1997 & Technical Corrigendum 1: 02-01-1999—Road vehicles—Electrical disturbances by narrowband radiated electromagnetic energy—Component test methods—Part 6: Parallel plate antenna
ISO 11452-7, 1995—Road vehicles—Electrical disturbances by narrowband radiated electromagnetic energy—Component test methods—Part 7: Direct radio frequency (RF) power injection

2.2.7 OTHER PUBLICATIONS—The following documents should be consulted for additional information regarding Fuel Cell Vehicle safety control systems.

FCC Rules and Regulations Parts 15 and 18.
CAN/CSA-C108.4M-1992—Limits and Methods of Measurement of Radio Interference Characteristics of Vehicles, Motor Boats, and Spark-Ignited Engine-Driven Devices
CSA Component Acceptance Service No. 33
ICES-002—Spark Ignition Systems of Vehicles and Other Devices Equipped with Internal Combustion Engines
MIL SPEC-1472 B for Thermal Hazards Available from the U.S. Government, DOD SSP, Subscription Service Division, Building 4D, 700 Robbins Avenue, Philadelphia, PA 19111-5094
"Vehicle Hydrogen Storage Using Lightweight Tanks", Lawrence Livermore Nat. Laboratory, Proceedings of the 2000 DOE Hydrogen Program Review.

3. Definitions—Standard Fuel Cell Vehicle (FCV) terminology is provided in SAE J2574. Terminology specific to this document is contained in this section.

3.1 Auxiliary Circuit—Electrical circuit supplying low voltage vehicle functions other than for propulsion, such as lamps, windscreen (windshield) wiper motors, and radios.

3.2 Barrier—In the context of this document, a means for controlling leakage from spaces or compartments potentially containing hazardous fluids. Barriers may be passive or active.

3.3 Basic Insulation—The electrical insulation required for the proper functioning of a device, and for basic protection against electrical shock hazard.

3.4 Class I System—An electrical system having functional (basic) insulation throughout, whose conductive accessible parts are connected to the protective earthing conductor and provided with an earthing terminal or connection to the vehicle.

3.5 Class II System—An electrical system having double insulation and/or reinforced insulation throughout.

3.6 Compartment—A space that is enclosed (by barriers) except for openings necessary for interconnection, control, and ventilation.

3.7 Discharges—fluids leaving a system.

3.8 Double Insulation—A system of two independent insulations, each of which is capable of acting as the sole insulation between live and accessible parts in the event of failure of the other insulation. The insulation system resulting from a combination of basic and supplementary insulation.

3.9 Encapsulation—The process of applying a thermoplastic or thermosetting protective or insulating coating to enclose an article by suitable means, such as brushing, dipping, spraying, thermoforming, or molding.

3.10 Exhaust—discharges of spent or processed fluids.

3.11 Fuel Cell Module—Fuel cell modules are comprised of one or more fuel cell stacks; connections for conducting fuels, oxidants, and exhausts; electrical connections for the power delivered by the stacks; and means for monitoring and/or control. Additionally, fuel cell modules may incorporate means for conducting additional fluids (e.g., cooling media, inert gas), means for detecting normal and/or abnormal operating conditions, enclosures or pressure vessels, and ventilation systems.

3.12 Hazardous Area—An area or space in which an explosive gas atmosphere or other hazardous condition is or may be expected to be present in such quantities as to require special precautions for the construction, installation and use apparatus.

3.13 Hazardous Condition—A condition that is potentially dangerous. Among these are hazardous fluids (3.14) and hazardous electrical voltages (3.15).

3.14 Hazardous Fluids—Gases or liquids that pose potential dangers. Hazards present with fluids in fuel systems are as follows:

a. Flammability—Sufficient quantities of fuel/air mixtures at or above the lower flammability limit (LFL) are by definition dangerous. Fuel/air mixtures below 25% LFL are considered non-hazardous.
b. Toxicity—Point sources greater than the IDLH (Immediately Dangerous to Life and Health) and occupiable areas greater than OSHA TWA (Time Weighted Average) should be considered hazardous.
c. High Pressure—High-pressure fluids in fuel supply subsystems, fuel processors, fuel cells, and/or thermal management subsystems that can transfer kinetic energy causing personal injury.
d. Extreme Temperature—Very high or low temperature fluids or materials that are capable of causing personal injury such as burns or frostbite.

3.15 Hazardous Voltage—Intermediate or high voltage which can cause current through a human body. Hazardous voltage levels are defined in the Outline of Investigation for Personnel Protection Systems for Electric Vehicle (EV) Supply Circuits; General Requirements, UL 2231-1 July 1996 and in UL 2202.

3.16 Hazardous Voltage Interlock Loop (HVIL)—The HVIL is a system intended to protect people from exposure to hazardous voltage or other hazardous conditions. It typically detects unwanted access or faults by passing a small (non-hazardous) signal through a loop connecting a set of normally-closed conductors, connectors, sensors, and switches to check for electrical continuity.

3.17 High Voltage—Voltage levels greater than 30 VAC or 60 VDC can harm humans through electric shock.

3.18 Ignition Sources—Thermal or electric energy sources capable of igniting flammable gas mixtures. See 4.2.3.2 for discussion of avoiding thermal, electrical, and static discharges, respectively.

3.19 Immediately Dangerous to Life or Health (IDLH)— An IDLH exposure condition is defined as one that poses a threat of exposure to airborne contaminants when that exposure is likely to cause death or immediate or delayed permanent adverse health effects or prevent escape from such an environment.

3.20 Intermediate Voltage—Voltage levels greater than 15 VAC or 30 VDC and less than high voltage levels.

3.21 Normal Discharges—Discharges expected during normal operation and not associated exclusively with failures.

3.22 Normal Operation—All transient and steady state operating conditions of the vehicle occurring during start, intended operation and shut down which do not involve a component or system failure.

3.23 Point of Release—Interface where ventilation exhaust or other discharge potentially containing hazardous fluids leaves the vehicle and is expelled to the surroundings, the passenger compartment, or other area that is assumed to be non-hazardous.

3.24 Purges—Discharges associated with the removal of fluids or types of fluids from systems.

3.25 Reinforced Insulation—A single insulation system with such mechanical and electrical qualities that it, in itself, provides the same degree of protection against the risk of electric shock as does double insulation. The term “single insulation system” does not necessitate that the insulation must be in one homogeneous piece. The insulation system may comprise two or more layers that cannot be tested as supplementary or basic insulation.

3.26 Releases—Discharges, which in the context of this report, are undesired or unwanted.

3.27 Safety Systems—A system that monitors for potentially hazardous conditions and can initiate actions to mitigate the situation.

3.28 Supplementary Insulation—An independent insulation provided in addition to the basic insulation to protect against electric shock hazard in the event that functional insulation fails.

3.29 Tubing—A metallic or non-metallic enclosed conduit for transferring gaseous or liquid fluids.

3.30 Vehicle Electrical Connector—A portable receptacle that by insertion into an vehicle inlet, establishes an electrical connection to the electric vehicle for the purpose of providing power and information exchange, with means for attachment of flexible cord or cable. This device is a part of the coupler.

3.31 Vehicle Electrical Coupler—A means of enabling the connection, at will, of a flexible supply cord to the equipment. It consists of a connector and a vehicle inlet.

3.32 Vents—Discharges of unspent, unprocessed, or partially processed gases or liquids.

4. Technical Systems Safety Guidelines

4.1 General Vehicle Safety—It is important to protect persons from hazardous conditions, where the fundamental hierarchy of vehicle system safety design is:

a. To protect vehicle occupants and the public from injuries that could result from the failures of components within the vehicle systems that support operation and/or as a result of damage caused by external events (e.g., collisions).
b. To protect vehicle occupants, general public, and service personnel from hazards associated with operation or servicing of the fuel cell vehicle (e.g., hazardous voltage, extreme temperatures, high pressure, and flammable or toxic fluids).
c. To minimize vehicle system damage caused by subsystem or component failures.

4.1.1 DESIGN FOR SAFETY—The vehicle and associated subsystems should be designed with the objective that a *single-point hardware or software failure should not result in an unreasonable safety risk to any person or uncontrolled vehicle behavior*.

4.1.1.1 Failure Modes and Effects Analysis (FMEA) as Best Practice—In meeting the requirements of 4.1.1, guidance can be found in SAE J1739 Reference Manual.

4.1.1.2 Isolation and Separation of Hazards—Isolation and separation of hazards are approaches used to prevent cascading of failures and preclude unwanted or unexpected interactions. Ignition sources should be isolated from hazardous fluid systems.

4.1.1.3 Critical Control Function—Safety-critical control systems should be designed such that a single hardware or software failure will not cascade into a hazardous condition. This may include isolation, separation, redundancy, supervision, and/or other means. Guidance for hardware design can be found in IEC 61508-1 and UL 991. Guidance for software design can be found in IEC 61508-3 and UL 1998.

4.1.1.4 *Fail-Safe Design*—The vehicle design should consider fail-safe design of electrical and hazardous fluid system controls. Automatic electrical disconnects should open and fuel shutoffs should close when deactivated. By so doing, any interruption of this control signal will cause isolation of electrical or fuel sources.

Vehicle operational safety should consider loss of vehicle power due to an automatic shutdown that may in itself lead to a hazardous operating condition. A staged warning and shutdown process or some other alternative means should be provided to mitigate the posed hazard, particularly, if the vehicle is moving. When faults that pose potential hazards are detected, specific actions to be taken are defined in 4.6.

Guidance can be found in ISO 6469-2—Electric road vehicles—Safety specifications. Part 2: Functional safety means and protection against failures.

4.1.2 ELECTROMAGNETIC COMPATIBILITY (EMC) AND ELECTRICAL TRANSIENTS—All electrical assemblies on an FCV, 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 may occur during normal operation of the vehicle during driving and fueling. Also, electrical transients resulting from normal operation of the vehicle should not cause false shutdowns of the vehicle.

The vehicle should meet the applicable government regulatory requirements for EMC. See industry standards and guidelines in 2.2.1, 2.2.3, 2.2.5, 2.2.6, and 2.2.7.

4.1.3 FUEL CELL VEHICLE CRASHWORTHINESS—Crashworthiness guidelines for FCVs should meet applicable government regulatory requirements. In the U.S., use the applicable FMVSS (see 2.1.3). See 4.6.2 for crash response.

4.1.3.1 *Fuel System Integrity*—Refer to FMVSS 301 and FMVSS 303 for fuel system integrity requirements of motor vehicles using liquid fuels with boiling points below 0 °C (32 °F) and compressed natural gas, respectively. For compressed hydrogen, the following modifications to FMVSS 303 are recommended based on the differences in chemical and physical properties between hydrogen and natural gas. See Appendix A for the derivation.[1]

a. In S5.2(a)(1), change 1062 kPa (154 psi) to 5.2% of service pressure.
b. In S5.2(a)(2), change 895 to 2640 for 24820 kPa (3600 psig), to 2800 for 34470 kPa (5000 psig), and to 3730 for 68950 kPa (10000 psig). For other service pressures, linear interpolation between these values to determine the appropriate value is allowed.
c. In S7.1.1 change nitrogen to helium within the on-board fuel storage system.

4.1.3.2 *Electrical Integrity*—FMVSS 305 is recommended for FCVs with the following modification. In S5.2, S7.6.6, and S7.6.7 of FMVSS 305, an electrical isolation criterion of 125 ohms per volt may be used in place of 500 ohms per volt for the fuel cell module.[2] An electrical isolation of 500 ohm per volt is recommended for other high voltage propulsion circuits that contain AC or are pulsed width modulated.

See also 4.6.2 and SAE J1766.

1. Appendix A is based on the amount of fuel leakage that is equivalent in combustion energy content to the amount of gasoline leakage permitted by FMVSS 301 but does not address the difference in flame speed (explosion effect) between hydrogen and hydrocarbon fuels, buoyancy effects, and gases trapped in confined spaces.
2. A disconnect may be used to separate the fuel cell module from other circuits but is not effective in isolating the fuel cell module from the vehicle conductive structure. The 125 ohms per volt criterion for the fuel cell module is a technically practical limit that does not present a shock hazard in DC systems by themselves or when connected to other circuits with 500 ohms per volt isolation. See EPRI TR-105939 and IEC 479 (parts 1 and 2) for guidance.

4.1.4 VEHICLE IMMERSION—Immersion of a FCV in water as specified by the vehicle manufacturer should not result in electric potential or current flow, gas or liquid emissions, flame or explosion that is hazardous to any person inside or outside the vehicle.

4.1.5 TOWABILITY DESIGN CRITERIA—Specific procedures for sling, wheel-lift, or car-carrier towing should be considered normal service information and included in the owner's manual/guide. Included in the procedures should be photographs or line drawings describing recommended attachment points. For further information on towing, refer to SAE J1142.

4.2 Fuel System Safety—Fuel systems that store, contain, process, and/or deliver fuel should be designed to standard engineering practices until relevant SAE documents are available. Integration of fuel systems into the vehicle should address the following items.

4.2.1 INSTALLATION—Integration of hazardous fluid systems into the vehicle should address normal operating requirements defined in 5.2. All components and interconnecting piping and wiring should be securely mounted or supported in the vehicle to minimize damage and prevent leakage and/or malfunction.

4.2.2 FAIL-SAFE SHUTOFF—A means should be provided to prevent the unwanted discharge of fuel arising from single-point failures to the shutoff function. The HVIL could also be used to isolate the fuel supply. See 4.1.1.

4.2.3 MANAGEMENT OF POTENTIALLY HAZARDOUS CONDITIONS WITHIN VEHICLE COMPARTMENTS—All components containing or generating hazardous fluids should be located in spaces or compartments which have provisions to address the following:

a. External release of hazardous fluids (as defined in 3.14) from the vehicle per 5.2.1.
b. The entry of hazardous fluids (as defined in 3.14) into the passenger compartment per 5.2.2.
c. The passage of flammable fluids (as defined in 3.14) into compartments containing equipment not suitable for hazardous areas per 5.2.3.

Spaces or compartments should be formed using barriers defined in 4.2.3.1. Equipment installed within these compartments should be suitable for their environments based on control of the potentially flammable atmosphere per 4.2.3.2 and/or elimination of ignition sources per 4.2.3.3. Additional guidance can be found in IEC 60079-10.

4.2.3.1 Barriers—Barriers may be used to form spaces or compartments with hazardous materials and separate them from non-hazardous areas inside or surrounding the vehicle.

Barriers should control the passage of hazardous fluids by either passive or active means. All seams, gaps, and penetrations of passive barriers should be sealed sufficiently to meet 4.2.3. Active barriers should meet the criteria for pressurization in 4.2.3.2(c).

Barriers for containing fuel-bearing equipment as well as ventilation exhaust ducts and channels should be constructed of metallic or other materials that will not propagate flame and be designed to prevent static electrical discharges. Inlets and exhaust outlets should be protected such that functionality is not compromised due to flow restrictions.

4.2.3.2 *Potentially Flammable Atmospheres*—The following approaches may be used to manage potentially flammable atmospheres in compartments containing fuel bearing equipment by reducing the concentration of flammable gases to below 25% LFL:

a. Ventilation—Natural or forced ventilation is an effective method for reducing the potential for the existence of a flammable gas mixture by diluting the flammable gas to a level below its lower flammability limit. The ventilation flow should dilute normal releases of flammable gas mixtures to less than 25% LFL. If the ventilation flow is incapable of diluting all releases (including abnormal releases) of flammable gas mixtures to less than 50% LFL, then safeguards should be provided per 4.2.8.
When establishing a ventilation inlet location and flow requirement, possible contamination of the diluent should be considered. Ventilation equipment and sensors within ducts and channels carrying potentially flammable fluids should be suitable for their application. If there is a significant likelihood that flammable gas mixtures can exceed 25% of their lower flammability limit, this equipment should not provide an ignition source per 4.2.3.3. If forced ventilation is critical to safety, a method to confirm ventilation flow and shut down the fuel source as per 4.2.8 should be provided.
b. Encapsulation—Encapsulation may be used to isolate flammable atmospheres from potential ignition sources within equipment. See IEC 60079-18 for guidance.
c. Pressurization—Pressurization is a type of protection of electrical apparatus in which safety is achieved by means of a protective gas maintained at a pressure above that of the surrounding atmosphere. The pressure differential should be at least 25 Pa (0.1 inches of water column) or opposing ventilation flow should be at least 0.33 m/s (60 fpm) to prevent the leakage of hazardous fluids through openings into non-hazardous areas. See NFPA 496 for guidance.
d. Consumption—Catalytic reactors or other means to reduce flammable gas concentration may be used to reduce combustible mixtures. A means of flame suppression should be provided if catalytic reactors or other potential ignition sources are used.
e. Suppressants—Inert gases or other materials may be used to reduce the effective flammability of an atmosphere or prevent combustion. The asphyxiation risk or toxicity associated with suppressants should be considered.

4.2.3.3 *Potential Ignition Sources*—If a local area contains flammables exceeding 25% LFL on a frequent or continuous basis, then equipment installed in this area should not be an ignition source during either normal operation or a single failure of said equipment. If the discharge of flammables exceeds 25% LFL only on an abnormal or infrequent basis, then equipment should not be an ignition source during normal operation. The following ignition sources should be treated as follows:

a. External Surfaces—During normal operation, external surface temperatures of components within the areas or compartments containing fuel-bearing equipment should be less than the autoignition temperature of the flammable fluid. See IEC 60079-20 for guidance regarding auto ignition temperatures of flammable fluids.
b. Electrical Equipment—Electrical equipment installed within areas or compartments containing fuel-bearing equipment should be suitable for use within that area. Guidance for the determining the protection techniques can be found in IEC 60079-14 and UL 2279.
c. Static Discharge—The potential for static discharge in areas or compartments containing fuel-bearing equipment should be eliminated by proper bonding and grounding. See 4.4.8 for installation of equipment within areas containing fuel-bearing components.
d. Catalytic Materials—Equipment containing materials that are capable of catalyzing the reaction of flammable fluids with air should suppress the propagation of the reaction from the equipment to the surrounding flammable atmosphere.

4.2.3.4 *Potential Hydrogen Evolution from Traction Batteries*—The vehicle design should preclude the release of hazardous gases beyond the limits defined in 4.2.3 and follow safety measures defined in 4.2.3.1, 4.2.3.2, and 4.2.3.3.

4.2.4 NORMAL DISCHARGE SYSTEMS—The vehicle design for all fuel system exhausts, purges, vents, and other normal discharges should meet the physical and functional requirements set forth in 4.2.3 and 5.2.

4.2.5 DISCHARGES FROM PRESSURE RELIEF DEVICES—Fuel systems may need to vent fuel if malfunctions or accidents occur. It is often not practical to dilute these discharges to non-hazardous levels as done with normal discharges, in 5.2.1, making essential the placement and direction of flow away from people and potential ignition sources. Specifically, hydrogen discharges that exceed 25% LFL should be located high in the vehicle or otherwise directed to avoid exposure to humans or damage to safety-critical components on the vehicle.

All pressure relief devices (PRD) should be vented to the outside of the vehicle. Interconnecting tubing, ducting, channels, and outlets from PRDs should be constructed of materials capable of maintaining system integrity during venting. Interconnecting tubing made of metallic materials with melting points above 538 °C (1000 °F) are appropriate. Outlets should be protected such that functionality is not compromised due to flow restrictions.

4.2.6 FUELING—The fueling location on the vehicle should be designed to prevent the accumulation of flammable gases and the ingress of foreign material.

The vehicle system should contain automatic systems to ensure that the vehicle traction system is de-energized and the vehicle is ready for fueling.

4.2.7 DEFUELING—The design of the fuel system should provide a means for removing fuel from the FCV for maintenance or other special purposes. For compressed gas systems, this process includes depressurizing and purging the on-board fuel storage and fuel system. Removed fuel should be transferred to either an approved closed system or venting system.

4.2.8 FUEL SYSTEM MONITORING—The following faults are associated with the fuel system that may require monitoring to address potentially hazardous conditions.

a. Fuel Discharge Fault—A fuel discharge fault is a discharge of fuel that results in potentially flammable atmospheres in excess of the limits specified in 4.2.3. Fault detection methods may include odorants, direct measurements such as hydrogen concentration or combustibility, or indirect measurements such as flow or pressure measurements within the system.
b. Fuel Shutoff Fault—Detection of a fault in the fuel shutoff function as defined in 4.2.2.
c. Process Fault—A process fault is a pressure, temperature, or other process parameter exceeding its normal operating condition of the component or system.
d. Ventilation Fault—A ventilation fault is a loss or reduction of airflow intended to manage a potentially hazardous environment per 4.2.3.2.

Items exceeding limits for safe operation should be addressed using 4.1.1.4 for guidance and 4.6 for appropriate actions.

4.3 Fuel Cell System Safety—Fuel cell systems typically contain a gaseous-fueled electrochemical reactor (the fuel cell stack) and support subsystems, which if not monitored and controlled appropriately, can expose the vehicle occupants and/or the public to specific hazards (e.g., electrical shock, fuel leak).

4.3.1 FUEL CELL SYSTEM DESIGN—Standard engineering practice should be used for the design of subsystems or components containing hydrogen or other fuels and hazardous fluids until relevant SAE documents are available, and 4.2 should be used for integrating these subsystems into the vehicle. Correspondingly, subsystems using electrical components should comply with SAE J2344 and be designed to 4.4.

4.3.2 FUEL CELL STACK DESIGN—Fuel cell stacks should be designed to prevent hazardous operating conditions including hazardous fluid leakage, overpressure, fire, and shock hazard.

4.3.3 HIGH VOLTAGE ISOLATION—The fuel cell module should have adequate isolation resistance between its DC buss and other electrical circuits and the vehicle conductive structure as defined in 4.3.3.1 and 4.3.3.2.

4.3.3.1 *Design Validation*—The electrical resistance should be greater than or equal to 125 ohms per volt throughout a range of environmental conditions, including condensation, and should achieve a resistance of at least 500 ohm/volt by the end of test in a non-condensing environment. The isolation resistance should be measured at a voltage of at least 1.5 times the nominal voltage of the power system or 500 VDC, whichever is higher. See Appendix B for guidance in conducting this measurement.

4.3.3.2 *Operation*—The electrical isolation of the fuel cell module should be at least 125 ohm/volt during normal operation with recommended maintenance throughout the operating life of the vehicle. See 4.3.5 for monitoring requirements.

4.3.4 HIGH VOLTAGE DIELECTRIC WITHSTAND CAPABILITY—For design validation, each high voltage system should demonstrate adequate dielectric strength such that there is no indication of a dielectric breakdown or flashover after the application of a voltage as per 4.4.4.

4.3.5 FUEL CELL SYSTEM AND STACK MONITORING—The following are faults associated with the fuel cell systems or the cell stack that may require monitoring to address potentially hazardous conditions.

a. Cell Stack or Process Fault—Out-of-limit thermal, pressure, flow, or composition conditions within cell stacks or other reactors in the fuel cell system could lead to internal or external component failures and subsequently expose personnel to hazards.
b. Ground Fault—Electrical isolation below the limit defined in 4.3.3.2 represents a hazard to service personnel.
c. Low Voltage Fault—The fuel cell stack or individual cells may experience low voltage that could lead to internal or external component failures and subsequently expose personnel to hazards.
d. Overcurrent Fault—Currents greater than the rated values could lead to internal or external component failures and subsequently expose personnel to hazards.

Items exceeding limits for safe operation should be addressed using 4.1.1.4 for guidance and 4.6 for appropriate actions.

4.4 Electrical System Safety—FCVs typically contain potentially hazardous levels of electrical voltage or current. The intention is either to prevent inadvertent contact with hazardous voltages or to prevent the development of an ignition source, or damage or injury from the uncontrolled release of electrical energy. Refer to SAE J2344 for guidance.

4.4.1 HIGH VOLTAGE WIRE—Refer to SAE J2344 for guidance on high-voltage wiring assemblies. It is recommended that harnesses containing high voltage be visually identified with a permanent orange covering material.

4.4.2 HIGH VOLTAGE CONNECTORS—Connectors for high voltage components for FCVs should comply with the test methods and general performance requirements established in SAE J1742.

4.4.3 HIGH VOLTAGE ISOLATION—High and intermediate voltage electrical circuits of the completed vehicle that were not addressed as part of 4.3.3 should have adequate isolation resistance between it and the electrical chassis and between it and other electrical circuits as defined in 4.4.3.1 and 4.4.3.2.

4.4.3.1 *Design Validation*—The electrical resistance should be greater than or equal to 500 ohms per volt throughout a range of environmental conditions, including condensation. The isolation resistance should be measured at a voltage of at least 1.5 times the nominal DC or peak AC voltage of the power system or 500 VDC, whichever is higher. See Appendix B for guidance in conducting this measurement.

4.4.3.2 *Operation*—Other than the fuel cell module in 4.3.3, the electrical isolation should be designed to be at least 500 ohms per volt during normal operation throughout the operating life of the vehicle. See 4.4.9 for monitoring requirements.

4.4.4 HIGH VOLTAGE DIELECTRIC WITHSTAND CAPABILITY—For design validation, each high voltage system should demonstrate adequate dielectric between the electrical circuits and the vehicle conductive structure such that there is no indication of a dielectric breakdown or flashover after the application of the appropriate voltage for one minute.

The voltage may be either a DC voltage or an AC voltage (with a frequency between 50 Hz and 60 Hz). When a direct-current potential is used for an AC circuit, a potential of 1.414 times the applicable rms value of alternating-current voltage specified is to be applied.

The voltage should be applied as follows for Class I equipment (with basic insulation) where U is the maximum working voltage of the equipment:

a. 2 U + 1000 VAC, but not less than 1500 V rms between all high voltage circuits and exposed conductive parts or chassis (common mode) and between each electrically independent circuit and all other exposed conductive parts (differential mode).
b. 500 VAC between all low and intermediate voltage auxiliary circuits and exposed conductive parts or chassis.

The voltage should be applied as follows for Class II equipment (with supplementary insulation):

a. 2 U + 2250 VAC, but not less than 2750 V rms between each electrically independent circuit and all other exposed conductive parts.

The voltage should be applied as follows for Class II AC supply equipment (with double or reinforced insulation):

a. 2 U + 3250 VAC, but not less than 3750 V rms between all high voltage circuits and exposed conductive parts or chassis.
b. 2 U + 3250 VAC, but not less than 3750 V rms between power circuits and auxiliary circuits.

See Appendix B for guidance.

4.4.5 ACCESS TO LIVE PARTS—An interlock, special fasteners, or other means should be provided on any cover whose removal provides access to live parts with hazardous voltage. If a Hazardous Voltage Interlock Loop is used for safety, such interlocks may be part of this monitoring loop. Refer to 4.2.2 and SAE J2344 for additional information on the HVIL.

4.4.6 LABELING—Hazardous voltage equipment or compartments containing hazardous voltage equipment should be identified using the high voltage symbol from IEC 60417 as shown in Figure 1.

4.4.7 FUSING/OVERCURRENT PROTECTION—Refer to SAE J2344 for guidance on fusing.

4.4.8 BONDING AND 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.

4.4.8.1 *Vehicle Bonding*—All body panels (e.g., doors, hood, fill door) and components that are a part of the fill process (e.g., nozzle receptacle) should have an electrical connection to the vehicle conductive structure.

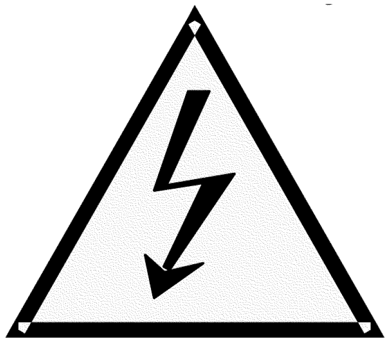

FIGURE 1—HAZARDOUS VOLTAGE SYMBOL

4.4.8.2 Vehicle Interior Bonding—Interior component materials should be selected that do not promote static discharges.

4.4.8.3 Electrical Components Bonding—Energy storage components (e.g., stack module, 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 connections. Case ground connectors routed from other components (as noted as follows) should be connected to this grounding means.

Other components, which are located in hazardous areas or receive hazardous voltages from sources outside their conductive enclosures, should have conductive 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.

4.4.8.4 Grounding to Fill Station During Refueling—A means needs to be provided to have the vehicle ground plane at the same potential as the fueling station prior to fill nozzle connection. A conductive path should exist from the vehicle chassis to ground. The total resistance through the tires should not exceed 25 megohms[3] and the fuel receptacle should be bonded to the chassis. See SAE J1645 for recommended practices for minimizing electrostatic charges and their effects. Special interdependencies with the filling station should be identified and addressed in 5.1.

4.4.9 ELECTRICAL SYSTEM FAULT MONITORING—The following are faults associated with the electrical system that may require monitoring to address potentially hazardous conditions.

a. Ground Fault —Electric isolation below the limit defined in 4.4.3.2 represents a hazard to service personnel. See also 4.4.10.1.
b. Overcurrent—Currents greater than the values could lead to electric component damage.

Items exceeding limits for safe operation should be addressed using 4.1.1.4 for guidance and 4.6 for appropriate actions.

3. National Institute for Science and Technology, “Refuelling Automobiles with Hydrogen,” September 2000 and DGMK Research Report 508 “Avoiding the Ignition of Otto-type Fuel/Air Mixtures when Refueling Automobiles at Gas Stations,” 1996, recommend individual tire resistance not exceeding 10^8 ohms. Four tires in parallel yield a total resistance of 25 megohms.

4.4.10 HYBRID FUEL CELL VEHICLES—Vehicles with fuel cells and batteries and/or capacitors should meet the following requirements.

4.4.10.1 Use of Electric Supply Equipment—Connections between premise wiring and the FCV including on-board and off-board chargers should conform to UL 2251 and SAE J1772 for conductive couplings or SAE J1773 for inductive couplings and be located on the vehicle in an area protected from moisture, debris, etc. Connectors complying with SAE J1742 may be used if the combination of the connector and the vehicle system comply with UL 2251.

A conductive connector mounted on the vehicle (inlet connector) should have safety features to prevent inadvertent contact with hazardous voltages such as recessed contacts or integration with the HVIL. If the HVIL is used, the inlet should include a mating connector "cap" that completes the HVIL circuit and remains on the vehicle when the portable charger is not connected to the vehicle. This HVIL will also be included in the portable charger connector to complete the path while the charger is connected. This inlet cap may also include drive-away protection such that the vehicle cannot be driven away with the portable charger attached to the vehicle.

The vehicle manufacturer should provide the capability to monitor any circuits energized from premise wiring during charging, and, if the electrical isolation falls below operating limit in 4.4.3.2, the circuit should be de-energized.

4.4.10.2 Back-Feed to Fuel Cell—The fuel cell stack module should be protected from unintended back-feed of power from energy sources such as the traction battery pack and/or the regenerative braking system.

4.4.10.3 Traction Battery Pack—If the vehicle is equipped with a traction battery pack or other high voltage batteries, the isolation of the battery from the vehicle conductive structure should comply with SAE J1766, Appendix A.

4.4.11 AUTOMATIC DISCONNECTS—An automatic disconnect function, should provide a means of electrically isolating both poles of a fuel cell stack module, a traction battery, and other high voltage sources (if equipped) from external circuitry or components. This function would be activated by either the main switch per 4.5.1 or as an automatic triggering protection per 4.1.1.4 or 4.6. Refer to SAE J2344 for additional information on automatic disconnects.

4.4.12 MANUAL DISCONNECTS—A means should be provided to disconnect both poles or de-energize the fuel cell module, a traction battery, and other high voltage sources (if equipped) from external circuitry or components. This function would be used for vehicle assembly, service, and maintenance operations. Refer to SAE J2344 for additional information on manual disconnects.

4.4.13 HIGH VOLTAGE BUSS DISCHARGE— Refer to SAE J2344 for guidance on high voltage buss discharge.

4.5 Mechanical Safety—Mechanical safety functionality should be provided but need not be implemented mechanically.

4.5.1 MAIN SWITCH—A single main switch function should be provided so that the operator can disconnect traction power sources per 4.4.11, shutdown the fuel cell system, and shutoff the fuel supply. The main switch should be activated by and accessible to the operator, similar to a conventional ignition switch.

4.5.2 SHIFT MECHANISMS—Refer to SAE J2344 for guidance on preventing unintended motion of electric vehicles when they are parked. This guidance is also relevant to fuel cell vehicles.

4.6 Fail-Safe Procedures—The FCV should include the ability to perform staged warnings and/or safety shutdowns when faults that could lead to hazardous conditions are detected. As discussed in 4.1.1.4, the sequence of actions depends on the operating state of the vehicle. The vehicle control system should be capable of isolating the fuel and electrical energy supplies whether the operator has deactivated the vehicle systems or not. Required provisions for automatic electrical disconnect are defined in 4.4.11.

A number of alternative means may be used to achieve a staged response to faults. For example, a limited operating strategy such as actively reducing power output and/or running on battery power to mitigate the hazard posed by the failure or other manufacturer-specific means for recovering and/or preserving power output after failure of a component or subsystem may be employed.

Specific actions are defined in 4.6.1 through 4.6.5 for when hazardous faults are detected.

4.6.1 MAIN SWITCH DEACTIVATED—Deactivation of the main switch function as defined in 4.5 should shutoff the fuel and disconnect the fuel cell Stack Module, Traction Battery, or other high voltage electrical power sources.

4.6.2 RESPONSE TO CRASH—If detected by crash sensors, the automatic fuel shutoff(s) and electrical disconnect(s) should be actuated. The electrical disconnect may also be used for assuring that the electrical isolation required by SAE J1766 is maintained after a crash. The fuel shutoff and electrical disconnect functions may be manually restorable.

4.6.3 VEHICLE START-UP—If the vehicle is in the process of start up when a potentially hazardous fault is detected, it may be appropriate to immediately shutdown and isolate the electrical and fuel sources.

4.6.4 VEHICLE NOT MOVING—If the vehicle has started up but is not moving when a potentially hazardous fault is detected, a warning should be provided to the operator. If the vehicle has not moved after a predetermined time then it may be appropriate to execute an automatic shutdown even if the main switch is not deactivated (per 4.5.1).

4.6.5 VEHICLE MOVING—If the vehicle is moving when a potentially hazardous fault is detected, a warning should be immediately provided to the operator. The fail-safe design (per 4.1.1.4) may delay the shut down cycle, limit power, or follow another appropriate strategy in response to this fault. Certain faults may require immediate removal of high voltage or traction power and/or fuel.

If the fuel cell is the sole source of power, a shutdown should be executed after the vehicle comes to rest (per 4.6.4) or the main switch is deactivated (per 4.5.1).

4.7 Safety Labeling—Safety labels, marking, or other means of identification should be employed to warn of potential hazards associated with the operation and service of the vehicle. High voltage lines should be identified per 4.4.1. Electrical equipment or compartments containing hazardous voltage should be labeled per 4.4.6. If there are any hazards identified with fuel bearing components or temperature extremes, guidance for labeling can be found in ANSI Z535.4

Additionally, a label like those provided in Figure 2 should be applied to the exterior of the vehicle to warn emergency responders of the unique fuel hazards associated with fuel cell vehicles. The symbol should indicate the type of fuel stored in the fuel tank. The diamond should be blue, and the lettering within the diamond should be white. “Compressed Hydrogen” should be used to indicate sources of gaseous hydrogen including compressed gas tanks and hydrogen generation systems, “Liquid Hydrogen” should indicate liquefied hydrogen storage systems, and “CNG” should indicate the use of compressed natural gas.

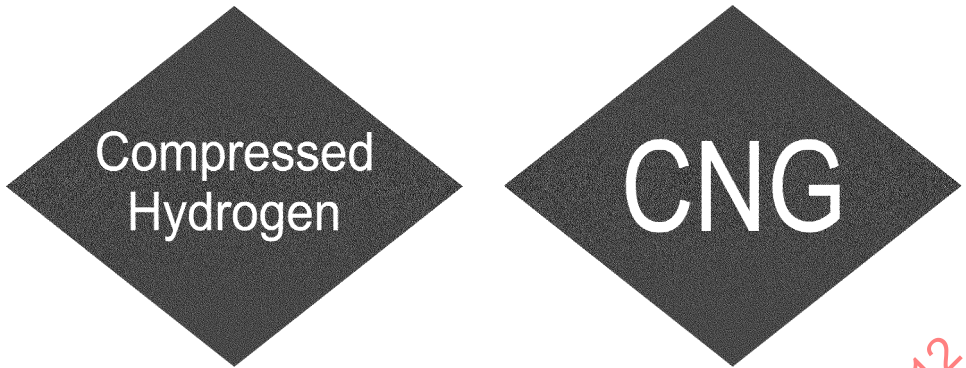

FIGURE 2—EXTERIOR FUEL TYPE LABELS

5. Operation

5.1 Owner Guide or Manual—Due to large degree of variation possible in fuel cell vehicle systems, the vehicle manufacturer should provide an Owners Guide or Manual that addresses the unique operating, fueling, and safety characteristics of the vehicle. It is recommended that the following items be addressed.

a. Procedures for safe vehicle operation, including operating environments.
b. Precautions related to the fluids and materials stored, used, or processed in the vehicle.
c. Possible safety hazards posed by vehicle or system operation and appropriate action(s) if a problem is detected. Any restrictions or building requirements related to operation or parking in residential garages, commercial structures, or tunnels should be noted.
d. Fueling procedures and safety precautions.
e. Precautions related to operator replacement of parts or fluids.
f. Information for roadside emergencies.

5.2 Fuel Releases During Normal Operation—The following operating requirements should be met during normal operation. The vehicle design should account for the effects of operating variations, component wear, and ageing effects on discharges. If any failure may result in discharges with concentrations above the limits set forth in this section, then the design of the components or systems subject to this failure mode should be suitably improved to minimize the probability of any such failures. Additionally, any cautions should be addressed in 5.1.

5.2.1 NORMAL GASEOUS DISCHARGES OUTSIDE THE VEHICLE—Fuel constituents in purges, vents, and exhausts, which occur during normal operation including startup and shutdown, should be non-hazardous. See 4.2.3.2.

The vehicle discharges should result in the surroundings being less than 25% LFL and below the OSHA TWA (Time Weighted Average). Guidance on conducting tests that simulate outdoor operation can be found in Appendix C. See also 5.2.4 and 5.2.5 for indoor requirements.

Discharges should nominally be less than 50% LFL at the point of release from the vehicle and at no time exceed the lower flammability limit or the IDLH. As part of design validation, measurements should be taken in the area of maximum concentration of the discharge stream. Data should be recorded to confirm that these criteria are met when the vehicle is at rest.

5.2.2 NORMAL GASEOUS DISCHARGES TO THE PASSENGER COMPARTMENT—Flammable gas and toxic gas levels inside the passenger compartment should be limited to 25% LFL and OSHA TWA (Time Weighted Average). This can be accomplished using barriers, natural or forced convection, catalytic reactors (recombiners) or other means.

5.2.3 NORMAL GAS DISCHARGES TO OTHER COMPARTMENTS—Fluids exceeding 25% LFL should not discharge into compartments containing equipment not suitable for hazardous locations.

5.2.4 PARKING IN NON-MECHANICALLY VENTILATED ENCLOSURES—For vehicles designed to be parked in garages or enclosures without forced ventilation, a test based on SAE J1718 should be conducted in an enclosure with a natural air exchange rate not exceeding 0.18 air changes per hour. See Appendix C for guidance.

The following conditions should be met:

a. Vehicle emissions for one startup and one shutdown cycle should not result in concentrations above 25% LFL or above the OSHA TWA for toxic gases within the enclosure.
b. Fuel permeation, leakage, and any other discharges from a vehicle when tested in the enclosure should not result in concentrations above 25% LFL or above OSHA TWA for toxic gases.

If any single-point failure may result in concentrations above 25% LFL or above OSHA TWA, then the design of the components or systems subject to this failure mode should be suitably improved to minimize the probability of any such failures. Additionally, any cautions should be addressed in 5.1.

5.2.5 OPERATION IN VENTILATED STRUCTURES—For vehicles designed to be operated in ventilated structures (such as tunnels, parking structures and garages), a test should be conducted to demonstrate that discharges are non-hazardous. This test should be conducted in an enclosure that is ventilated to no more than 0.152 m^3 per minute per square meter (0.5 ft^3 per minute per square foot) based on the vehicle footprint. Guidance on conducting the test is provided in Appendix C. The concentration of hazardous fluids should be maintained below 25% LFL and the OSHA TWA while the vehicle idles for at least three (3) hours.

5.3 Byproducts—Discharges of product water or other substances should be non-toxic and limited such that they do not pose a hazardous condition nor affect vehicle traction.

6. Emergency Response—The manufacturer of the FCV should have available information for safety personnel and/or emergency responders with regard to dealing with accidents involving a FCV.

The following information may be requested:

a. Explanation of hazards associated with the fluids, hazardous voltage systems, and any materials or components in the fuel cell system or vehicle in general.
b. Identification of vehicle by safety labels (based on 4.7).
c. Procedure for verifying that automatic fuel shut-off and electrical disconnection functions have occurred.
d. Location and procedures for manual shut-off of fuels and disconnection of electrical bus, if applicable.

7. *Maintenance*

7.1 Service Manual—Due to large degree of variation possible in fuel cell vehicle systems, the vehicle manufacturer should be responsible for the compilation of information related to vehicle service and maintenance. It is recommended that the following items be addressed:

a. Chemical and physical properties of hazardous materials stored or processed in the vehicle.
b. Possible safety hazards posed by the vehicle or its systems during maintenance and appropriate action(s) if a fault is detected.
c. First aid procedures specific to the unique hazards of the vehicle.
d. Maintenance tools, equipment, and personal protective equipment (PPE).
e. Methods and procedures for specific maintenance work.
f. Suggested and required maintenance items and their schedules.

7.2 Defueling Procedures—The vehicle manufacturer should provide procedures for removing fuel from FCVs. For compressed gas fuel systems, defueling normally requires the on-board fuel storage and/or fuel system to be depressurized to a recommended level followed by a purge with an inert gas, which reduces the atmosphere to a non-hazardous level.

7.3 Facility Safety—Vehicle repairs should be conducted in a garage facility equipped with adequate safety measures and in compliance with local and state building codes. Additionally, the manufacturer of the FCV should have information about the vehicle available for building code committees or local authorities and businesses at their request.

PREPARED BY THE SAE SAFETY SUBCOMMITTEE OF THE
SAE FUEL CELL STANDARDS TECHNICAL COMMITTEE

APPENDIX A

CALCULATIONS FOR FUEL SYSTEM INTEGRITY COEFFICIENTS

A.1 FMVSS 303 contains the following requirement for fuel system integrity of compressed natural gas (CNG) fueled vehicles. These values are based upon the physical properties of CNG (and nitrogen as a test gas) and measurement errors associa ted with CNG storage systems ranging from 0 to 20685 kPa (0 to 3000 psig). These values have been adjusted in this appendix to represent the physical properties of hydrogen with helium as a test gas, and compressed hydrogen storage systems ranging from 0 to 68950 kPa (0 to 10000 psig).

FMVSS 303

S5.2 Fuel system pressure drop: barrier crash

a. *For all vehicles, the pressure drop in the high pressure portion of the fuel system, expressed in kilopascals (kPa), in any fixed or moving barrier crash from vehicle impact through the 60 minute period following cessation of motion should not exceed:*

   1. *1062 kPa (154 psi), or*
   2. *895 (T/V_{FS}); whichever is higher*

where T is the average temperature of the test gas in degrees Kelvin, stabilized to ambient temperature before testing, where average temperature (T) is calculated by measuring ambient temperature at the start of the test time and then every 15 minutes until the test time of 60 minutes is completed; the sum of the ambient temperatures is then divided by five to yield the average temperature (T); and where V_{FS} is the internal volume in liters of the fuel container and the fuel lines up to the first pressure regulator.

The first criteria stated in FMVSS 303 S5.2(a)(1) is based upon measurement error associated with a state-of-the-art capacitance type pressure transducer that would be required for the test. The American Automobile Manufacturers Association (AAMA) provided measurement errors of 0.11% for the pressure transducer, 0.2% for thermal zero shift associated with 5.6 °C (10 °F), 0.15% for thermal coefficient sensitivity associated with 5.6 °C (10 °F) and 0.056% for conversion of analog data to digital form. For a pressure range of 0 to 20685 kPa (0 to 3000 psi), the individual measurement error was aggregated to a total measurement error of ±106.1 kPa (±15.4 psi). Since the total measurement error should not exceed 10% of the value being measured, the minimum pressure drop that can be accurately measured was determined to be 1062 kPa (154 psi) for the 0 to 20685 kPa (0 to 3000 psi) system.

For compressed hydrogen, current technology for vehicle systems utilizes standard tank system pressures of 24820 kPa (3600 psi) and 34470 kPa (5000 psi), with the intent to progress to 68950 kPa (10000 psi) systems. The rationale for the 0 to 20685 kPa (0 to 3000 psi) systems described above yields the following for a 0 to 68950 kPa (0 to 10000 psi) compressed hydrogen system:

a. Pressure transducer error (0.11%) = ±75.8 kPa (±11 psi)
b. Thermal zero shift error (0.2%) = ±137.9 kPa (±20 psi)
c. Thermal coefficient sensitivity error (0.15%) = ±103.4 kPa (±15 psi)
d. Analog to digital conversion error (0.056%) = ±38.6 kPa (±5.6 psi)

Total measurement error equals ± 355.7 kPa (± 51.6 psi) for 0 to 68950 kPa (0 to 10000 psi) system and total measurement error should not exceed 10% of the value measured, resulting in a minimum pressure drop value of ±3557 kPa (±516 psi).

The second criterion stated in FMVSS 303 S5.2(a)(2) is based on the amount of CNG leakage that is equivalent in combustion energy content to the amount of gasoline leakage permitted by FMVSS 301. The total amount of combustion energy released is based upon the following for CNG.

The fuel leakage in any fixed or moving barrier crash test should not exceed:

- *a. 1336 kilojoules (kJ) (1266.25 Btu), in energy content from impact until motion of the vehicle has ceased;*
- *b. 6680 kJ (6331.25 Btu) during the five-minute period following cessation of motion; and*
- *c. 1336 kJ 9 (1266.25 Btu) in any one-minute interval during the 55 minutes following the five-minute period specified previously.*

The resulting allowed leakage is 81496 kJ from impact through the 60-minute interval after motion has ceased. For hydrogen, the mass can be calculated using the equivalent energy (81496 kJ) and the lower heating value of hydrogen (119863 kJ/kg or 51532 Btu/lb).

$$m_H = \frac{81496\,kJ}{119863\frac{kJ}{kg}} = 0.68\,kg \qquad \text{(Eq. A1)}$$

This represents the mass of hydrogen that is equivalent in combustion energy to the CNG release allowed in FMVSS 303 but does not address the difference in flame speed (explosion effect) between hydrogen and hydrocarbon fuels, buoyancy effects, and gases trapped in confined spaces.

For a particular storage volume, initial pressure, and average gas temperature, the allowable mass release (leakage) can be expressed as an orifice (hole) size in the fuel system. Once the orifice size is determined, the test gas (helium) can be substituted and the constant, K, in the relationship to determine the allowable pressure drop over time, $\Delta P = K \times (T/V_{FS})$, can be determined.

The determination of the orifice size is done through a step-wise calculation of leakage through the orifice, changing the orifice size until the maximum allowable hydrogen mass release is reached. The orifice flow equation is as follows for choked flow (for most gases, a pressure ratio greater than 2):

$$W = CC_dA\frac{P_s}{\sqrt{T_s}} \qquad \text{(Eq. A2)}$$

where C_d is the orifice discharge coefficient, A is the orifice area, P_s and T_s are the upstream (higher) pressure and temperature, respectively. C is given by:

$$C = \sqrt{\frac{k}{R\left(\frac{k+1}{2}\right)^{\left(\frac{k+1}{k-1}\right)}}} \qquad \text{(Eq. A3)}$$

where k is ratio of specific heats, and R is the gas constant.

The scope of FMVSS 303 is as follows:

S3. Application. This document applies to passenger cars, multipurpose passenger vehicles, trucks and buses that have a gross vehicle weight rating (GVWR) of 10,000 pounds or less and use CNG as a motor fuel. This standard also applies to school buses regardless of weight that use CNG as a motor fuel.

It is not expected that on-board fuel storage capacity for these classes of vehicles will greatly exceed 200 liters. In addition, the changes in K at a given service pressure diminish as fuel storage capacity increases (Figure A1). Finally, there is a floor in the maximum allowable pressure drop due to measurement accuracy. Therefore, the values for a 200-liter fuel storage system will be used in this document. These values are more restrictive when used for smaller volume systems (i.e., yield a smaller allowable pressure drop).

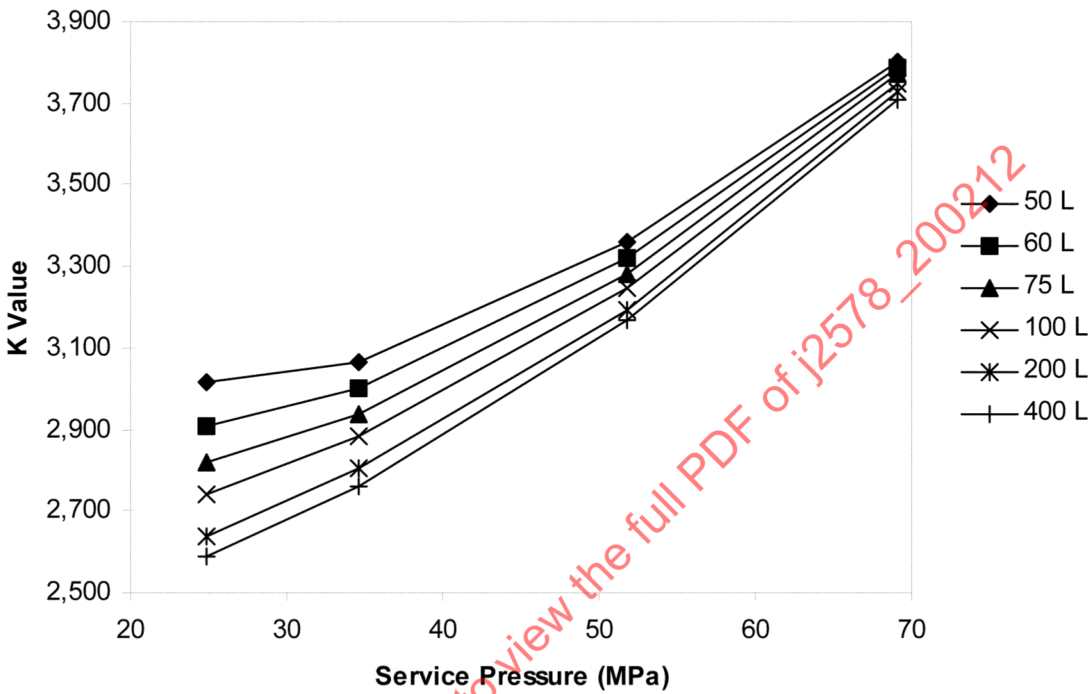

FIGURE A1—CRASH PRESSURE DROP K VALUES

Between service pressure levels, the changes in K values are fairly linear; therefore three K values are provided with an allowance for interpolation between these values if other service pressures are employed. The K values appear in Table A1.

TABLE A1—K VALUES FOR HELIUM TEST GAS CRASH TESTS

Service Pressure kPa (psig)	K kPa(°K/L)
24820 (3600)	2640
34470 (5000)	2800
68950 (10000)	3730

APPENDIX B

GUIDANCE FOR CONDUCTING HIGH VOLTAGE TESTS

***B.1 High Voltage Isolation Test*—**The high voltage isolation test should be conducted on high and intermediate voltage systems. The test may be performed on the entire system at one time or on individual assemblies and then calculating the overall system resistance. The test generally follows the following procedure for the purpose of design validation:

a. Any on-board energy storage device (e.g., traction battery, auxiliary battery) complying with 4.4.10.3 can be disconnected for this test.
b. Prior to conducting the test, the fuel cell system or other equipment may be preconditioned such that normal operating conditions are established. The fuel cell system should be shut down and its high voltage poles should be electrically connected for this test.
c. Both sides of electrical circuits not under test (such as low voltage circuits) should be connected to the vehicle conductive structure at a common point. If some electronic components connected between the vehicle conductive structure and the live part cannot withstand the test voltage, they should be disconnected from the test electrical circuit. Printed-wiring assemblies and other electronic-circuit components that may be damaged by application of the test potential or that short-circuit the test potential should be removed, disconnected, or otherwise rendered inoperative before the tests are made. Semiconductor devices in the unit can be individually shunted before the test is made to avoid destroying them in the case of a malfunction elsewhere in the circuits.
d. The equipment should be subjected to a preconditioning period of at least 8 hours at 5 °C ± 2 °C, followed by a conditioning period of 8 hours at a temperature of 23 °C ± 5 °C with a humidity of 90 +10/ –5% at atmospheric pressure. Alternative preconditioning and conditioning parameters may be selected provided transition across the dew point occurs shortly after the beginning of the conditioning period.
e. A test voltage of at least 1.5 times the nominal voltage of the power system or 500 VDC, whichever is higher, should be applied for a time long enough to obtain stable reading.
f. The isolation resistance should be measured at the beginning of and periodically throughout the conditioning period. The measurements should be performed using suitable instruments (e.g. MΩ meter) between the live parts of each power system and the vehicle conductive structure.

If a high voltage isolation test is used as part of production testing, the use of conditioning atmospheres in item d) may be deleted and the test time may be shortened.

***B.2 High Voltage Withstand Test*—**The high voltage withstand test should be conducted on high voltage systems. The test may be performed on the entire system at one time or on individual assemblies. The test generally follows the following procedure for the purpose of design validation:

a. Any on-board energy storage device (e.g., traction battery, auxiliary battery) can be disconnected for this test.
b. Prior to conducting the test, the fuel cell system or other equipment may be preconditioned such that normal operating conditions are established. The fuel cell system should be shut down and its high voltage poles should be electrically connected for this test.
c. Both sides of electrical circuits not under test (such as low voltage circuits) should be connected to the vehicle conductive structure at a common point. If some electronic components connected between the vehicle conductive structure and the live part cannot withstand the test voltage, they should be disconnected from the test electrical circuit. Printed-wiring assemblies and other electronic-circuit components that may be damaged by application of the test potential or that short-circuit the test potential should be removed, disconnected, or otherwise rendered inoperative before the tests are made. Semiconductor devices in the unit can be individually shunted before the test is made to avoid destroying them in the case of a malfunction elsewhere in the circuits.

d. The test should be performed by applying a DC voltage or an AC voltage (with a frequency between 50 Hz and 60 Hz), for one minute between the electrical circuits and the vehicle conductive structure. When a direct-current potential is used for an AC circuit, a test potential of 1.414 times the applicable rms value of alternating-current voltage specified is to be applied.

e. The dielectric withstand voltage should be applied as follows for Class I equipment (with basic insulation) where U is the maximum working voltage of the equipment:

   1. 2 U + 1000 VAC, but not less than 1500 V rms between all high voltage circuits and exposed conductive parts or chassis (common mode) and between each electrically independent circuit and all other exposed conductive parts (differential mode).
   2. 500 VAC between all low and intermediate voltage auxiliary circuits and exposed conductive parts or chassis.

f. The dielectric withstand voltage should be applied as follows for Class II equipment (with supplementary insulation):

   1. 2 U + 2250 VAC, but not less than 2750 V rms between each electrically independent circuit and all other exposed conductive parts.

g. The dielectric withstand voltage should be applied as follows for Class II AC supply equipment (with double or reinforced insulation):

   1. 2 U + 3250 VAC, but not less than 3750 V rms between all high voltage circuits and exposed conductive parts or chassis.
   2. 2 U + 3250 VAC, but not less than 3750 V rms between power circuits and auxiliary circuits.

If a high voltage withstand test is used as part of production testing, the test time may be shortened.