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SURFACE VEHICLE RECOMMENDED PRACTICE

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(R) Fuel Systems and Components—Electrostatic Charge Mitigation

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1. Scope

This SAE Surface Vehicle Recommended Practice deals with electrostatic charge phenomena that may occur in automotive fuel systems and applies to the following:

- Fuels that are in a liquid state at ambient temperatures and atmospheric pressures and are contained in vehicle fuel tanks that operate at or near atmospheric pressure.
- The group of components that comprise the fuel system (in contact and not in contact with fuels).
- Other components in proximity to the fuel system that may be affected by electrostatic fields caused by the fuel system.
- Electrostatic phenomena that arise from or are affected by the following aspects of vehicle or fuel system operation:
  a. Flowing fuel in the fuel delivery system
  b. Flowing fuel being dispensed to the vehicle while it is being fueled

1.1 Basic Approach

This recommended practice provides two approaches that may be used separately or collectively to ensure that there is no likelihood of adverse consequences resulting from electrostatic phenomena:

1. Recommendations for materials, components and subsystems to be used in conjunction with resistance and resistivity tests, noting that this is the conservative approach and may result in unnecessary use of these designs and materials for specific applications. See Section 4.1.
2. Recommendations for the limits on electrical charge accumulation and transfer – with an indication of the advanced tests and analyses that must be conducted, noting that these tests and analyses require specialist personnel with the appropriate knowledge, experience, test equipment and testing environment. See Section 4.2.

1.2 Rationale

This 2005 version of the SAE J1645 Recommended Practice is an update of the January, 1999, publication. The reasons for the update were a significant amount of new information about testing procedures, acceptance criteria, criteria that may be used to justifuy exceptions to the recommended practice, and possible sources of variability in analyzing the performance of a fuel system in an electrostatic charging situation. Incorporating all those areas of improved information caused changes so numerous that they cannot be individually noted. This version of the J1645 document replaces the previous version.

2. References

2.1 Applicable Publications

The following publications form a part of this specification to the extent specified herein. Unless otherwise indicated, the latest version of SAE publications shall apply.

2.1.1 SAE PUBLICATION

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

SAE J1681—Gasoline, Alcohol and Diesel Fuel Surrogates for Material Testing

2.1.2 ASTM PUBLICATIONS

Available from ASTM, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959, Tel: 610-832-9585, www.astm.org.

ASTM D 257—Standard Test Method for DC Resistance or Conductance of Insulating Materials
ASTM D 4496—Standard Test Method for DC Resistance or Conductance of Moderately Conductive Materials (October 30, 1987)
ASTM D 991—Standard Test Method for Rubber Property—Volume Resistance of Electrically Conductive and Antistatic Products
ASTM D 2624-02—Standard Test Method for Electric Conductivity of Aviation and Distillate Fuels

2.1.3 EUROPEAN COMMITTEE FOR ELECTROTECHNICAL STANDARDIZATION (CENELEC) PUBLICATIONS

Available from Cenelec Standards Inspections Ltd., Unit 22 Apex Business Village, Northumberland Business Park, Newcastle Upon Tyne NE23 7BF, United Kingdom, Tel: 44-0191-2502005, email: info@cenelec.com.

CLC/TR 50404 Electrostatics—Code of practice for the avoidance of hazards due to static electricity

2.1.4 INTERNATIONAL ELECTROTECHNICAL COMMISSION (IEC) PUBLICATIONS

Available from International Electrotechnical Commission, 3, rue de Verambe, P.O. Box 131, 1211 Geneva 20, Switzerland, Tel: +41-22-919-02-11, www.iec.ch.

IEC 60079-0—Electrical apparatus for explosive atmospheres
IEC 93—Methods of test for volume resistivity and surface resistivity of solid electrical insulating materials
IEC 61340-2-1—Electrostatics Part 2-1: Measurement methods—Ability of materials to dissipate static electric charge
IEC 61340-2-3—Electrostatics Part 2-3: Methods of test for determining the resistance and resistivity of solid planar materials to avoid electrostatic charge accumulation
IEC 60243-2—Electric strength of insulating materials—Test methods—Part 2: Additional requirements for tests using direct voltage

2.1.5 MILITARY SPECIFICATION

Available from DODSSP, Subscription Services Desk, Building 4D, 700 Robins Avenue, Philadelphia, PA 19111-5094.

MIL-STD-3010, Method 4046.1—Antistatic Properties of Materials

2.1.6 API PUBLICATIONS

Available from American Petroleum Institute, 1220 L Street NW, Washington, DC 20005-4070, Tel: 202-682-8000, www.api-ec.api.org.

88-1-461—Potential Fire Hazards of Lowering Gasoline Volatility
API 2003—Protection Against Ignitions Arising Out of Static, Lightning, and Stray Currents

2.1.7 NFPA PUBLICATION

Available from the National Fire Protection Agency, 1 Batterymarch Park, Quincy, MA 02169-7471, Tel: 617-770-3000, www.nfpa.org.

NFPA77—Recommended Practice on Static Electricity 2000 Edition

2.1.8 ELECTROSTATIC DISCHARGE ASSOCIATION (ESDA) PUBLICATIONS

Available from Electrostatic Discharge Association, 7900 Turin Road, Building 3, Rome, NY 13440-2069, Tel: 315-339-6937, www.esda.org.

ESDA Adv.1.0—Glossary of Terms (1994 publication)
ESD STM 11.11—Surface Resistance Measurement of Static Dissipative Planar Materials (2001 publication)
ESD STM11.12-2000—Volume Resistance Measurements of Static Dissipative Planar Materials (2000 publication)
ESD TR 02-99—High Resistance Ohmmeters—Voltage Measurements

2.2 Related Publications

The following publications are provided for information purposes only and are not a required part of this document; they mainly provide background information.

2.2.1 SAE PUBLICATIONS

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

SAE J2044—Quick Connector Specification for Liquid Fuel and Vapor/Emission Systems
SAE J2045—Tube/Hose Assemblies
SAE J2260—Non-Metallic Fuel System Tubing with One or More Layers

2.2.2 ASTM PUBLICATIONS

Available from ASTM, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959, Tel: 610-832-9585, www.astm.org.

ASTM D 150—Test Methods for A-C Loss Characteristics and Permittivity (Dielectric Constant) of Solid Electrical Insulating Materials
ASTM D 2679—Electrostatic Charge
ASTM D 3509—Electrostatic Field Strength Due to Surface Charges
ASTM D 4470—Standard Test Method for Static Electrification
ASTM D 4865—Standard Guide for Generation and Dissipation of Static Electricity in Petroleum Fuel Systems

2.2.3 MILITARY SPECIFICATION

Available from DODSSP, Subscription Services Desk, Building 4D, 700 Robins Avenue, Philadelphia, PA 19111-5094.

MIL-PRF-81705D—Barrier Materials, Flexible, Electrostatic, Free, Heat Sealable

2.2.4 UNDERWRITERS LABORATORY (UL) PUBLICATION

Available from Underwriters Laboratories Inc., 333 Pfingsten Road, Northbrook, IL 60062-2096, Tel: 847-272-8800, www.ul.com.

UL 330—Hose and Hose Assemblies for Dispensing Flammable Liquids

2.2.5 DIN PUBLICATION

Available from Deutsches Institut für Normung e.V., Burggrafenstrasse 6, 10787 Berlin, Germany, www.din.de.

DIN 53-486/VDE 030 Part 8/4 75 (April, 1975)—VDE Specifications for Electrical Tests on Insulating Materials: Evaluation of Electrostatic Behavior

2.2.6 OTHER PUBLICATIONS—DETAILED BACKGROUND

Journal of Research Article (Oct-Dec, 1965)—Electric Currents and Potentials Arising from the Flow of Charged Liquid Hydrocarbons through Short Pipes
ISO 3915-1981 (E)—Plastics—Measurement of Resistivity of Conductive Plastics
IEEE Transactions on Electrical Insulation Volume 23, No. 1 (ISSN 0018-9367) (February, 1988)—Electrical Insulation and Breakdown in Vacuum
IEEE Transactions on Electrical Insulation Volume 23, No. 1 (ISSN 0018-9367) (February, 1988)—Flow Electrification in Electrical Power Apparatus
Naval Research Laboratory Report 8021—Pro Static Agents in Jet Fuels (August 16, 1976)
Coordinating Research Council—Electrostatic Discharge in the Fuel Systems of Gasoline Powered Vehicles in North America (Paper by Ron Tharby, Nov., 1990)
ESSO Research and Engineering Company—Charging Tendency Test (April 9, 1959)

Naval Research Laboratory Report 8484—Generation of Electrostatic Charge in Fuel Handling Systems: A Literature Survey (September 24, 1981)

January, 1988 issue of Plant/Operations Progress Magazine—Collection of articles on aspects of electrostatic charge concerns arising in handling chemicals

Research Studies Press, Inc., John Wiley & Sons—Electrostatic Hazards in the Petroleum Industry by W. M. Bustin and W. G. Dukek

Analysis of "Flow Electrification in Fuel Distribution Systems" by J. C. Dean, G. H. Williams, and J. DeGiovann—IEEE Transactions on Industry Applications, vol 29, No 3, pp 132-138, 1993

DGMK Project 508—Avoidance of Ignition of Gasoline/Air Mixture During Refueling of Motor Vehicles at Filling Stations—DGMK German Society for Petroleum and Coal Science and Technology, Hamburg, Germany, February 1996

Report on the Risk of Static Ignition During Vehicle Refueling: A Study of Available Research—Institute of Petroleum, London, May 2001

SAE 1999-02-0797—Electrostatics of Fuel System for the Automobile; Hironori Ueda, Takashi Nagai, Genjiro Tada, Shoichi Yamamoto and Takayuki Kato

American Institute for Chemical Engineers—Center for Chemical Process Safety—Electrostatic Ignitions of Fires and Explosions; Thomas H. Pratt, PhD, PE

American Institute for Chemical Engineers—Center for Chemical Process Safety—Avoiding Static Ignition Hazards in Chemical Operations, Laurence G. Britton

Electrostatic Ignition Hazards in Motor Cars—Occurrence, Detection and Prevention—Proceedings ESA/IEEE Joint Meeting on Electrostatics, June 24-27, 2003, University of Arkansas, Little Rock, 78-89, U. von Pidoll

3. Definitions

In addition to this section, refer also to the Electrostatic Discharge Association publication: Glossary of Terms (ESDA Adv. 1.0).

3.1 Accumulation

An increase in the amount of electrostatic charge present on a fuel system component resulting from a rate of charge dissipation that is slower than the rate at which charge is delivered.

3.2 Assembly

A group of parts or components that form a self-contained unit designed to perform two or more specific functions. Examples are fuel pump/sender assembly, fuel tank assembly, fuel rail assembly, and fuel line assembly.

3.3 Bonding

An intentional electrical connection made between components for equalizing electrical potential between the components.

3.4 Breakdown Voltage

Potential difference which gives rise to an electric field of sufficient intensity to cause dielectric breakdown in a material.

3.5 Capacitance

A measure of the amount of electric charge stored for a given electric potential. The capacitance is defined as the total electric charge (measured in Coulombs) placed on an object divided by the potential of the object (measured in volts):

$$C = Q / V \qquad \text{(Eq. 1)}$$

The unit of measure is the Farad (F).

3.6 Charge

Quantity of unbalanced electricity on (or in) a body; i.e., an excess or deficiency of electrons, giving the body negative or positive electrification, respectively.

The unit of measure is the Coulomb (Q).

$$Q = CV \qquad \text{(Eq. 2)}$$

where:

C is the capacitance of the body (F)
V is the difference in electrical potential between the body and ground (V).
Q is the amount of charge (in coulomb C)

3.7 Chargeability

For the purpose of this Recommended Practice, the propensity of a liquid to generate charge separation during flow through a specified component or series of components. This is defined as streaming current (A) generated divided by liquid flow rate (measured in m^3/s).

The unit of measure is C/m^3 (as for charge density).

3.8 Charge Density

The net electric charge per unit volume (volume charge density) or electric charge per unit area (surface charge density).

The unit of measure is Coulombs per cubic meter (C/m^3) and Coulombs per square meter (C/m^2).

3.9 Charged Plate Monitor

Electrical measuring system. Employs high voltage source, isolated test surface, timing circuitry, and electrostatic field meter to provide quantitative measurements of a given material or a component's reaction to static charges.

3.10 Component

A part or product that performs a single function in its smallest assembled state. Examples are fuel pump, float rod, inline fuel filter, and fuel tank shell.

3.11 Conductance

A property of component or sub-system indicating how easily it allows the flow of electric current through it – as measured between two electrodes placed in specified positions. Reciprocal of resistance (1/Ω).

The unit of measure is the Siemen (S).

See also *conductivity*.

3.12 Conduction

Flow of electricity in a medium that does not involve movement of the medium itself. An example of this is the flow of electrons or ions in a material.

3.13 Conductive Materials

Materials exhibiting resistance low enough to prevent any meaningful electrostatic charge to accumulate by allowing those charges to be rapidly conducted to system or earth ground.

3.14 Conductivity

A property of a material indicating how easily the flow of electric current passes through it – denoted by σ. The reciprocal of volume resistivity.

The unit of measure is Siemens per meter (S/m).

See also *conductance*.

3.15 Corona Discharge

Luminous discharge due to ionization of the air surrounding a conductive material, around which exists a voltage gradient exceeding a certain critical value.

3.16 Coulomb

The unit of electric charge. The coulomb is the quantity of electric charge that passes a cross-section of a conductor in one second when the current is maintained at one ampere.

3.17 Dielectric

A material with very few free charges throughout its volume. Electrons are closely bound to atomic nuclei and cannot drift or diffuse about the material as in a conductor or semiconductor. A perfect dielectric (an insulator) has no free charge and therefore, zero conductivity.

3.18 Dielectric Breakdown

Condition arising when a dielectric material is subjected to an electric field of a critical strength (the dielectric breakdown field strength) such that electrons are pulled out of molecular bonds and accelerated until they collide with other parts of the molecular lattice, causing chemical changes or physical damage to the material. After breakdown occurs, a dielectric material may become irreversibly more conductive.

3.19 Discharge

The reduction of a charge accumulation at a given point by a flow of electric current.

3.20 Dissipation

The vanishing over time of the amount of a physical quantity such as electric charge or heat; also, the conversion of electric energy to heat in a resistive medium.

3.21 Dissipative Materials

Materials that prevent accumulation of electrostatic charges to values above a defined acceptable limit by allowing charge dissipation to either system or earth ground. In the context of this Recommended Practice this is characterized either by level of volume resistivity or rate of static decay.

3.22 Electrometer

A refined DC voltmeter exhibiting very high input resistance and negligible leakage current.

3.23 Electrostatic Charge

An accumulation of essentially stationary electric charges on the surface or in the volume of a material. Associated with the charge distribution is its surrounding electrostatic field.

3.24 Electrostatic (or electric) Field

The (vector) electric force exerted on a charge divided by the amount of charge. See also 3.31 Field Strength.

The unit of measure is Newtons per Coulomb (N/C).

3.25 Electrostatic Force

The force that electrically charged bodies exert upon one another.

The unit of measure is the Newton (N).

3.26 Electrostatic Potential

The electrostatic potential (volts) at a point is the energy required to move a charge from an agreed-upon reference point to that point, divided by the amount of charge moved. The reference point is usually called ground or zero potential.

The unit of measure is the Volt (V).

3.27 Energy of Discharge

The energy of a discharge (W) to ground is described by the following equations:

$$W = \tfrac{1}{2} CV^2, \quad W = \tfrac{1}{2} QV, \quad W = Q^2 / 2C \qquad \text{(Eq. 3)}$$

where:

C is the capacitance of the discharging body (F)
V is the difference in electrical potential between the discharging body and ground (V)
Q is the amount of charge (in coulomb C)
W is the energy (in joules J)

3.28 Erosion, Electrical

The progressive deterioration of a dielectric material by the action of electrical discharges through the material.

3.29 Faraday Cup or Cage

An apparatus for measuring electric charge that consists of two conducting enclosures: an inner conductor and an outer conductor, which are insulated from each other. The grounded outer enclosure shields the inner one from external electric fields; the charge object to be characterized is placed within the inner enclosure.

3.30 Field Strength Meter

A non-contact measuring instrument for detecting and quantifying the presence of static potentials on items and surfaces. Electrostatic field meters are calibrated to provide accurate measurements at a fixed distance. Key factors affecting the measurement are object size and the proximity of other objects or ground sufaces.

3.31 Field Strength

The magnitude of the local electric field.

The unit of measure is Volts per meter (V/m).

3.32 Fuel Containment Boundary

That portion of the fuel system that is in direct contact with liquid fuel or the vapor space directly above liquid fuel. Vapor management systems that are connected to the fuel tank interior via liquid/vapor discriminating valves are not considered part of the liquid containment boundary although the valves are.

3.33 Grounding

The intentional electrical connection of a component or vehicle to a ground plane, the earth, or a large conductor taken as the zero potential reference thus eliminating the electrical potential difference between the component and the ground plane, earth, or reference conductor.

3.34 Half Life

For the purposes of the Recommended Practice, it refers to the time required for the charge level on or in a body of material to decay to ½ of its original value (rather than 1/e, as in 3.40).

3.35 Insulative

Materials that allow accumulation of electrostatic charges to values above a defined acceptable limit by preventing adequate dissipation of those charges to either system or earth ground. (In the context of this Recommended Practice, this is characterized either by volume resistivity or rate of static decay).

3.36 Permittivity, Free Space (ε_0)

A scalar constant such that in a vacuum, the product of ε_0 and the electric field, E, is equal to the electric flux density. $D = \varepsilon_0 E$. The numerical value for ε_0 is 8.854×10^{-12} F/m.

3.37 Pro-static agent

A substance that increases the chargeability (of a fuel) without increasing its conductivity.

3.38 Relative Permittivity (ε_R)

The permittivity of a medium, ε, divided by the permittivity of free space, ε_0. See 3.36.

$$\varepsilon_R = \varepsilon / \varepsilon_0 \qquad \text{(Eq. 4)}$$

Relative permittivity is dimensionless.

3.39 Relaxation

The exponential return of a system to electrical charge equilibrium. It is characterized by a time constant “τ.“ For a system with a capacitance C and a resistance R the time constant is:

$$\tau = RC \qquad \text{(Eq. 5)}$$

The following equation holds for the case in which the discharge results from current flow within a “dielectric” material:

$$\tau = (\varepsilon_R \cdot \varepsilon_0)/\sigma \qquad \text{(Eq. 6)}$$

where:

ε_R = relative permittivity of the dielectric material
ε_0 = free space permittivity, and
σ = conductivity of the dielectric material

In Equation 5, τ is also called the material’s dielectric relaxation time.

The unit of measure is the second (s).

3.40 Relaxation Time

The time required for the charge in a system to drop to 1/e of its original value (e = base of the natural log system and is equal to 2.718…). For an exponential decay, this is τ, the relaxation time constant. See also *Half Life* and *Relaxation*.

3.41 Resistance

See "volume resistance".

3.42 Shear Rate

The flow velocity gradient in a gas or fluid perpendicular to the flow direction.

The unit of measure is s^{-1}.

3.43 Streaming Current

The flow of an electrically charged fluid constitutes an electrical current. Unit of measure is the ampere (A).

3.44 Surface Resistivity

A property of a material indicating how strongly it opposes the flow of electric current across its surface – defined as the ratio of DC voltage drop per unit length to the surface current per unit width. Denoted by ρ_s.

The unit of measure is the ohm (Ω).

NOTE—To differentiate from surface resistance, the unit ohms/square (Ω/sq) is often used. This arises from the units of length and width in the above definition. For every square surface area, i.e., an area in which the length equals the width, the surface resistance numerically equals the surface resistivity.

See also *volume resistivity*, *volume resistance* and *surface resistance*.

3.45 Surface Resistance

A property of component or sub-system indicating how strongly it opposes the flow of electric current across its surface – as measured between two electrodes placed in specified positions. For example, the resistance R of a component consisting of a flat, rectangular surface with width d and length l (d and l at right angles) and surface resistivity ρ_s is:

$$R = \rho_s\, l/d \qquad \text{(Eq. 7)}$$

In measuring this resistance it is assumed that current flows along the direction of length "l" in response to a voltage applied to the edge of width “d”. For a more arbitrarily-shaped component the current flow is more complicated, but the resultant total resistance between the two points of measurement is still the relevant quantity.

The unit of measure is the ohm (Ω). See also *volume resistivity*, *volume resistance* and *surface resistivity*.

3.46 System

A combination of components and assemblies that accomplishes the full function of the subject system, including interfacing with features outside of the system that may be required to accomplish a vehicle function level. (Examples are fuel [liquid] system and powertrain system.)

3.47 Vehicle Ground

Basic metallic structure of the vehicle that includes such major elements as chassis, engine and body that are electrically bonded to each other and the negative terminal of the battery. (Sometimes, “chassis ground” is used; that is synonymous with vehicle ground.)

3.48 Virtual Charge (Also Called Mirror Charge, Induced Charge or Charge by Influence)

Conductive bodies near a charged object tend to acquire a charge of opposite sign (virtual charge) under the influence of the electric field created by the charged object. Under some circumstances discharges can occur from the object with the virtual charge. For example, a plastic fuel tank can contain a large charge during refueling with no adverse effects inside the tank. However, an ungrounded metal object near the tank exterior can acquire a virtual charge and discharge, possibly igniting vapors resulting from the refueling event.

3.49 Volume Resistivity

A property of a material indicating how strongly it opposes the flow of electric current through it – denoted by ρ_v, the reciprocal of conductivity.

$$\rho_v = R\ (A / L) \qquad \text{(Eq. 8)}$$

where:

R = resistance
A = minimum cross sectional area through which the current flows
L = mean length of part in the direction of current flow

The unit of measure is ohm-meters (Ω-m).

See also *volume resistance*, *surface resistivity* and *surface resistance*.

3.50 Volume Resistance

A property of component or sub-system indicating how strongly it opposes the flow of electric current through it – as measured between two electrodes placed in specified positions.

The unit of measure is ohms (Ω).

See also *volume resistivity*, *surface resistivity* and *surface resistance*.

4. Recommended Practices for Minimizing Electrostatic Charge Accumulation

Uncontrolled electrostatic charging in liquid fuel systems can have damaging effects on vehicle systems including:

i. EMI (electromagnetic interference) effects on electronic components and computers up to and including component damage.
ii. Electrical erosion of fuel system components resulting in pinhole leaks.
iii. Unintended ignition of combustible air-fuel mixtures that might occur under certain conditions

This document recommends the use of materials, components and fuel system designs that can help prevent the above-mentioned damaging effects as follows:

a. Reducing charge separation.
b. Reducing charge accumulation.
c. Recombining separated charges.
d. Preventing discharge.

4.1 Specifications for Materials, Components and Subsystems to be Used in Conjunction with Resistance and Resistivity Tests

NOTE—Each of the following recommendations apply unless they individually can be shown to be unnecessary as described in Section 4.2

4.1.1 RECOMMENDATIONS FOR FLOW CHANNELS

For all flow channels within the fuel system that are specifically designed to transport fuel from one component to another, the electrical resistance measured between points A and B and between points A and C should not exceed 1X10^8 Ω when measured by procedure 5.2.1 or 5.2.2. Definitions of point A, B and C are as follows:

Point A. Any point on any surface that is in contact with flowing liquid fuel and is part of a grounding strategy for the fuel system (refer to 3.33 of glossary).
Point B. Vehicle ground (refer to 3.47 of glossary).
Point C. Any metallic component with a capacitance greater than 3 pF located within 25 mm of any ungrounded or non-conductive component in the fuel system that could develop a virtual charge from within the fuel system. See Appendix A, Section A.1.2.1.3.

NOTE—The above should be verified as installed in a representative vehicle environment.

4.1.2 RECOMMENDATIONS FOR FILLER NOZZLE GROUNDING

4.1.2.1 The electrical resistance measured between a typical marketplace nozzle inserted into the filler pipe (point A above) and the vehicle ground (point B above) should not exceed 1×10^6 Ω when measured by procedure 5.2.1.

4.1.2.2 The electrical resistance measured between a typical marketplace nozzle inserted into the filler pipe (point A above) and a metallic plate on which each tire sits in succession should not exceed 5×10^8 Ω measured with up to 1000 V applied and with all other tires sitting on an insulating surface.

4.1.3 RECOMMENDATIONS FOR CONDUCTIVE COMPONENTS INSIDE THE FUEL CONTAINMENT BOUNDARY

The resistance between conductive components and vehicle ground should not exceed 1×10^8 Ω when measured by relevant procedure of Section 5.2.

4.1.4 DURABILITY RECOMMENDATIONS

The recommendations of Sections 4.1.1, 4.1.2 and 4.1.3 should be met for the vehicle life under expected conditions of vehicle usage, representative of the marketplaces in which the vehicle is intended for sale and at the time of initial retail sale. The fuels and exposure conditions to be considered to meet this recommendation should be agreed upon between the end user and the producer of a particular component or subsystem (refer to Section 5.4).

4.1.5 COMPONENT RECOMMENDATIONS

The off-vehicle (i.e. bench test) performance of individual components and sub-assemblies that contribute to compliance with Sections 4.1.1, 4.1.2 and 4.1.3 should be separately verified by means of a specified test procedure. Such specification should include details of simulated or actual mating component(s) where these form part of the required electrical path. Except where otherwise determined by expert testing and/or expert judgment, either of the following acceptance criteria should be applied:

a. The resistance of the complete electrical bonding or grounding path through the component in its system application (e.g., inlet to outlet of the flow path, flow path inlet to vehicle grounded mounting point, etc.) as measured by procedure 5.2.2, should not exceed $1 \times 10^6\ \Omega$.
b. The static dissipation time of the component as measured by the procedure specified in Section 5.3.1 (the decay time required for the charge level to reach 10% of an initial value of the applied voltage) should not exceed 0.5 seconds.

4.1.6 MATERIAL RECOMMENDATION

The relevant electrical properties (i.e. surface resistance and/or volume resistivity) for each individual material that contributes to compliance with Sections 4.1.1, 4.1.2 and 4.1.3 should be separately verified by means of a specified test procedure. Such specification should include details of the size and shape of test specimens, the electrodes to be used and the applied voltage. Except where otherwise determined by expert testing and/or judgment and except where susceptibility to prolonged fuel immersion is found, the following should be applied to virgin material that is representative of the intended production process:

a. Volume resistivity should not exceed $1 \times 10^4\ \Omega$-m. See Section 3 (Definitions).
b. Surface resistance should not exceed an empirically derived value consistent with the recommendations of Section 4.1.5. See Section 3 (Definitions).

Examples of appropriate test methods are given in Section 5.2.2.3.

The effect of prolonged immersion in fuels described in 5.4.1 should be evaluated by physical testing. Where it is found that such immersion adversely affects the material such that the recommendations of Sections 4.1.1, 4.1.2 or 4.1.3 cannot reliably be met, the recommendations of Section 4.2 should be invoked.

Materials and combinations of materials should be specified such that the recommendations of Section 5.1.4 can be met.

4.2 Specifications for the Limits on Electrical Charge Accumulation and Transfer

Designs that do not conform to the recommendations of 4.1 might be judged acceptable on the basis of the following criteria and testing. Verification testing to demonstrate compliance with this section and engineering judgements made on the basis of such testing require specialist personnel with the appropriate knowledge, experience, test equipment and testing environment. See Section A.2.4 and A.2.5 for test recommendations.

4.2.1 BASIC RECOMMENDATIONS

4.2.1.1 Conductive components which do not meet the recommendations of Section 4.1.

All of the following should be demonstrated by means of suitable testing involving expert practitioners:

a. Charge accumulation on such components cannot result in a spark discharge having an energy exceeding 0.2 mJ in a zone that could contain a combustible atmosphere.

b. Regardless of the presence of a combustible atmosphere adjacent or near to the component concerned, cumulative damage to materials over the intended operational life cannot occur, which could cause unspecified migration of fuel – unless such migration has no reasonable safety implication.
c. Regardless of the presence of a combustible atmosphere adjacent or near to the component concerned, damage to electronic systems over the intended operational life cannot occur.

4.2.1.2 Non-Conductive Components

Both of the following should be demonstrated by means of suitable testing:

a. Sudden transfer of charge cannot exceed 60 nC for any one event in a zone that could contain a combustible atmosphere.
b. Regardless of the presence of a combustible atmosphere adjacent to the component concerned, cumulative damage to materials over the intended operational life cannot occur, which could cause unspecified migration of fuel, unless such migration has no reasonable safety implication.

4.2.2 VERIFICATION TESTING

4.2.2.1 Basic Considerations

The tests required depend on the design solution involved and in particular on whether conductive or non-conductive components are used. It is not possible or appropriate to formulate standardised test procedures and these are not included in the recommendations portion of this document for that reason. Similarly, generalized pass/fail criteria cannot be given and must be left to expert judgement on a case-by-case basis.

Notwithstanding the above, some guidance can be given as follows and in Sections 4.2.2.2 and 4.2.2.3:

Tests should be conducted at low temperature and relative humidity representative of the worst case for the intended market – unless it can be shown that there is no sensitivity to these parameters. A maximum temperature of –40 °C and a maximum relative humidity of 30% are recommended where uncertainty exists.

Fuel or fuel substitute used for determination of charge accumulation by means of flow testing should be characterised for chargeability and conductivity. See definitions of these quantities given in Section 3 and the notes in Appendix, Sections A.1.4.1 and A.2.4.

4.2.2.2 Conductive Components

Recommendation (a) of Section 4.2.1.1 can be verified in any of the following ways:

a. Verify by measurements of capacitance and accumulated charge that 0.2 mJ cannot be achieved. The accumulated charge can be measured by flow testing as referenced in Section A.2.4 and A.2.5.
b. Verify that, even if such energy can be achieved, a spark discharge is not possible or a combustible atmosphere cannot occur.

4.2.2.3 Non-Conductive Components

Recommendation (a) of Section 4.2.1.2 can be verified by means of flow testing and direct measurement of local charge accumulation. Alternatively, it may be shown that the material concerned is incapable of holding and suddenly discharging greater than 60nC. An example of a test method that could be used is given by IEC 60079-0 Section 26.14 (see Section 2) or Appendix A.2.4 and A.2.5 of this document.

Compliance with recommendation (b) of Section 4.2.1.2 involves making an engineering judgement regarding the ability of a component and its constituent materials to safely withstand the measured (normally cyclic) electrostatic stress for the vehicle's expected working life. Such a judgement should involve comparison of this quantity with a measurement of the dielectric strength under representative temperature, humidity and ageing conditions. An example of a test method is given by IEC 60243-2 (see Section 2).

4.2.3 Examples of designs or circumstances that meet the criteria stated in 4.2 and therefore, do not have to meet the recommendations of 4.1 are presented in A.4.

5. Testing Procedures

5.1 General Comments

5.1.1 Measured resistance values can be influenced by a number of factors in addition to the specific procedure itself. These factors primarily include:

a. Sample preparation
b. Relative humidity (see A.2.1.1.1, in particular)
c. Temperature
d. Test voltage
e. Electrode configuration

Consequently, the steps of a specific procedure should be followed carefully. Also, the considerations and guidelines of Section A.2. in the Appendix should be followed to assure the accuracy and repeatability of the measurements taken.

When results are obtained, the conditions of the test and other pertinent factors should be recorded as well (refer to Section 5.5).

5.1.2 INSTRUMENTATION

The instruments used in these test procedures are described in a general manner. More details are available in Section A.2.1.1.7 of the Appendix. Further details can be found by consulting the various test procedures referred to throughout the text. For whatever instrumentation is utilized, the user should refer to the manufacturer’s instructions for the equipment and follow them carefully.

5.1.3 SEQUENCE OF VOLTAGE LEVEL UTILIZED

Whenever a test procedure is followed that includes more than 1 level of voltage, the first one utilized should be the lowest one. Subsequent voltage levels should be stepwise, then, up to the highest indicated level.

5.1.4 SEQUENCE OF TESTING PERFORMED

Implied in Sections 5.2 and 5.3 and specifically mentioned in Section 5.4, the suggested sequence of testing to use for components is resistance measurement first. If an acceptable result for the resistance measurement is obtained, then no further testing is necessary. If the resistance measurement does not meet the acceptance criteria, then the static dissipation test is performed. If the requirements of that dissipation test are met, then the component or material is considered acceptable. If the OEM/end user and the supplier agree, then that sequence can be changed to include only the static dissipation test.

5.2 Resistance Test Procedures

5.2.1 RESISTANCE TEST FOR ASSEMBLIES/SYSTEMS

5.2.1.1 The procedure is the same as Section 5.2.2 with the following exceptions: Complete assemblies with several interfaces may require a higher test voltage to measure end-to-end resistance. To make this measurement test, voltages up to 1000 V may have to be used. The maximum current when measuring at 1000 V should not exceed 1 mA. Extreme care should be exercised when testing at these voltages. DO NOT touch the electrodes while the measurement is being taken.

5.2.1.2 Testing Setup

5.2.1.2.1 If the setup for testing the assembly/system utilizes some sort of fixturing or arrangement for testing, the ground path connections that would occur on a vehicle should be included as well.

5.2.1.2.2 Make sure all ground connections are secure during the test.

5.2.1.2.3 If servicable fluid couplings are part of the system/assembly being tested, then those couplings should be set up in a way that simulates how they would be configured during vehicle operation. For example, a pressured system will extend metal tubing slightly within a connector. For this reason, it would be acceptable to pull the metal tube so it “bottoms out” within the connector. It is also acceptable to apply up to a 2 N side load to the barbed end of a fitting to create the type of internal contact that would be present in the coupling as-installed on a vehicle.

5.2.1.2.4 Care must be taken for environmental conditions of testing to be controlled adequately. (Refer to Section A.2.1.1.1.)

5.2.2 RESISTANCE TESTS FOR COMPONENTS

The following test procedures shall be followed for measuring the resistance of components where they have not been exposed to fuel. When fuel exposure has occurred, follow the test sequence of Section 5.4. When testing parts that have been exposed to fuel, a maximum relative humidity should be specified by the OEM/end user because the effects of fuel exposure can significantly affect material properties. (Refer to Sections A.1.4.2 and A.2.1.1.1.).

5.2.2.1 Resistance Test Procedure

5.2.2.1.1 Reference Appendix A.2.2.1.2 for recommendations concerning clamps and contacts.

5.2.2.1.2 For the component being measured, place it on a surface having a resistance at least two orders of magnitude higher than the upper resistance limit (greater than 1×10^{10} Ohms).

5.2.2.1.3 Verify the test set up by clamping the electrodes to a 10 MΩ, 1% resistor and measuring its resistance at both 100 V and a lower level of voltage. 10 V is recommended, if available.

5.2.2.1.4 Connect the positive electrode to the designated point where a measurement is to be taken. The negative electrode should be connected to a point on the component where charges could flow to ground.

5.2.2.1.4.1 The electrodes should have a contact surface of 18 ± 0.5 square mm. Connect the meter lead to its banana jack.

5.2.2.1.4.2 In all cases, make sure that the contact electrodes sit as flat as possible and makes maximum surface contact with the part.

5.2.2.1.4.3 If the part has a metal ground strap, take measurements at the point on the plastic part where the ground strap is attached and at the point on the strap where the strap is connected to the vehicle.

5.2.2.1.5 If the resistance meter being used designates Source and Sense inputs, connect the Voltage Source to the “positive” electrode and the Sense input to the “negative” electrode.

5.2.2.1.5.1 If the resistance meter being used allows manual selection of the test voltage, select the lower level of voltage (identified in 5.2.2.1.3).

5.2.2.1.5.2 Apply the voltage for 5 seconds, then take and record the reading. If the reading is unstable, record the reading as “unstable”.

5.2.2.1.5.3 Select 100 V. Apply it for 5 seconds, then record the reading. If reading is unstable, then record reading as “unstable”.

5.2.2.1.5.4 The lower the measured resistance, the smaller will be the differential between the lower voltage level (identified in 5.2.2.1.3) and the 100 V readings.

5.2.2.1.6 For acceptance criteria, see Section 4.1.

NOTE—Parts that exhibit unstable resistance values during measurement are considered acceptable for use if any of the following are true:

a. A measured resistance may be unstable at lower voltage levels, but stable and within the specified limit at 100 V.

b. The resistance may be below the measurement capability of the instrument at 100 V (e.g., less than 10^3 Ω).. If so record this fact in the data.
c. The resistance is below the measurement capability of the instrument at the lower voltage level (e.g., less than 10^3 Ω). If so record this fact in the data.

5.2.2.2 Surface Resistance Test Procedure for Materials

To measure the surface resistance of the material, follow the procedure described in ESD STM 11.11.. The following modifications to the standard procedures should be used for conductive or dissipative materials:

5.2.2.2.1 Instrumentation: The instrumentation must be capable of making measurements from less than 1 × 10^3 to greater than 1 × 10^8 Ω. A humidity/temperature meter is recommended to record the test conditions.

5.2.2.2.2 System Verification Fixtures: This fixture need only conform to the Lower Resistance Range Fixture specified in Section 6.4.1 of ESD STM 11.11.

5.2.2.2.3 Testing specimens: Procedures are performed on flat plaques that are molded without use of mold release using recommended molding conditions for the material being tested. The dimension of the plaques are 70 to 80 mm wide, 120 to 130 mm long, and 3 mm thick.

5.2.2.2.4 Testing steps: Measure and record the resistance after 5 seconds using a voltage that is as low as practical (at no time should this voltage exceed 100 V). If the instrumentation cannot measure resistance below 1 × 10^6 Ω using 100 V, report only lower voltage measurement. If the resistance is very low and no resistance value can be measured then report the results as <(lowest meter reading) Ω.

5.2.2.2.5 If volume resistance is below 1 × 10^6, measurement should be taken at 10 V. If near or above 1 × 10^6, measurement should be taken at 100 V.

5.2.2.2.6 When making volume resistivity measurements, the measured value of volume resistance can be converted to volume resistivity (as described in Appendix A of ESD STM 11.12).

5.2.2.2.7 See Section 4.3.1.1 for guidelines of measured resistance values.

5.2.2.3 Resistivity Test Procedure for Materials

The test procedure to be followed is ASTM D 4496. The following modifications to the standard procedures should be used for conductive or dissipative materials.

5.2.2.3.1 Relating to Sample Preparation

a. Accepted methods for reading the volume resistivity of a material include breaking the surface, painting silver paint for contact, and/or puncturing surface electrodes such as are described in ASTM D 4496.

b. In order to account for surface effects caused by moisture, dirt, oil, and skinning effects caused by molding conditions, the volume resistivity should be measured through the volume by some means of breaking, or breaking the surface. Sample preparation is outlined in Annex A1 of ASTM D 4496; further suggestions are found in Section A.2.21.2.
c. ISO or ASTM tensile bars are molded on a standard injection-molding machine without mold release. A total of ten bars are molded for each resistivity test. The bars are then placed into a jig, cut with a razor knife, and the two ends are removed. This leaves the middle 60 mm of the tensile bars.
d. The broken ends are painted with conductive paint, along with 4 mm wide stripes across the face of the bar, 3 mm from each end. The paint is allowed to dry for a minimum of one hour.

5.2.2.3.2 Relating to the Test Procedure

a. With the test apparatus set at the lowest voltage range resulting in a measurable current, the current in milliamps (mA) through the volume of the part and across the surface of the part is determined.
b. Tester should specify voltage used when testing, which should not be less than 9 V, and not more than 510 V.

5.2.2.3.3 See Section 4.1.6 for guidelines of measured resistivity values.

5.3 Static Charge Dissipation Test Procedures

5.3.1 STATIC DISSIPATION TEST PROCEDURE FOR COMPONENTS

5.3.1.1 Prepare the samples to be tested in the same manner as described in Section 5.2.2.

5.3.1.2 Verify the test set up by measuring the dissipation time for a 10 MΩ, 1% resistor. Connect the positive electrode to the Charge Plate Monitor (CPM) detector plate and the resistor. Connect the negative electrode to ground such as the ground connection at the wall outlet. If a battery powered CPM is used, make sure it is also connected to ground. Leave the clamp unconnected.

5.3.1.2.1 Set the measurement parameters for voltage level up to 5000 V. Using that 5000 volts as an example, actual charging voltage is approximately 5100-5200 V or more, but the decay time measurement starts when the voltage on the part reaches 5000 V. Set the stops at the 10% cut off (500 V in our example). Apply the charging voltage for approximately 2 seconds. Release the "arm" button and quickly connect the grounded negative electrode to the resistor. Repeat the measurement 3 times. Record the dissipation times. Dissipation time must be less than 0.5 second. If a grounding module is used, charge the system as above then depress the “reset” pushbutton and record the reading.

NOTE—Do not use the grounding function of the CPM to perform this test. This function only grounds the detector plate.

5.3.1.3 Connect the electrodes to the assembly in the same manner as was done in Section 5.2.2.1. Place the assembly on a highly insulative surface having a surface resistivity greater than 10^{12} Ω. such as acrylic, Teflon™, polycarbonate etc. to ensure there is no secondary leakage path for the applied charge to bleed off.

5.3.1.4 Apply the charging voltage for approximately 2 seconds. Immediately ground the assembly by clamping the negative electrode to the desired point. Repeat the measurement 3 times and record the results.

5.3.1.4.1 If the grounding module is utilized follow the same procedure described for system verification.

5.3.1.4.2 Acceptance Criteria: Refer to Section 4.1.5.

5.4 Test Procedures for Fuel Exposed Components

5.4.1 TYPES OF FUEL

The test fluid used in exposure testing should be non-alcohol containing fuels such as test fluid C, Howell EEE, or similar grades per SAE J1681. Alcohol fuels can be used in exposure testing, but care must be taken because results can be misleading. (Refer to Appendix Section A.1.4.1.1.b). If exposure to alcohol fuels is required by the end user, the specific sequence of testing described in Sections 5.4.4 and 5.4.5 should be followed. (Specific fuels to be used should be decided between the OEM/end user and the producer.) Whever handling fuel in any situation, the appropriate safety measures should be taken.

5.4.2 FUEL SOAK PRECONDITIONING

The time and temperature used to pre-condition in the fuel are to be decided between the OEM/end user and the producers. The time and temperature chosen should be sufficient to allow the fuel to fully equilibrate with the materials prior to testing (refer to Appendix Section A.2.1).

5.4.3 TIME AFTER FUEL EXPOSURE

The time between completion of fuel exposure and the start of the test procedures should be as short as practical and consistent with safe laboratory practice. Minimizing the time between removal from fuel soak and electrical testing will minimize the changes that can occur due to fuel evaporating out of the material. The time should not exceed 2 hours.

5.4.4 RECOMMENDED TEST SEQUENCE

When exposure to fuel is required, resistance can increase, for example, due to swelling of a material. If capacitance decreases at the same time, then the rate of electrostatic charge dissipation can improve even though resistance may have increased to a level that might be considered unacceptable when tested under unexposed conditions. For these reasons, the sequence of tests identified in 5.4.5 is recommended for fuel exposed components.

5.4.5 COMPONENTS/ASSEMBLIES TESTS (AFTER FUEL EXPOSURE)

5.4.5.1 Resistance Test

a. Measure resistance first as in Section 5.2. If acceptable values are obtained, then no further testing is needed (the component is acceptable).

b. If results of resistance tests do not meet acceptance criteria, then conduct the appropriate static decay test as in Section 5.3. If the results of static decay tests are acceptable, the component performance is considered acceptable.

5.5 Recording and Reporting Results

For any procedure that is done, the specific results should be recorded and retained for future consideration. In addition, there are a number of other factors that should be recorded so they could be included when results are reported to an interested party. The level of data required for processing is a function of end user requirements. The following list is recommended. (Refer also to Section A.2.1.)

a. The specific procedure performed
b. Date, time, and location
c. The specific instrumentation used
d. Electrode configuration or any other pertinent details about the nature of the contacts made
e. Environmental conditions of the test (temperature and relative humidity at a minimum). (Refer to Sections A.1.4.2 and A.2.1.1.1)
f. Specific test voltages and the sequence in which they were used
g. Specific resistance meter range if selected manually
h. Description of the test sample used and how it was prepared for the procedure. If components or assemblies were used, adequate description of those should be included.
i. For any procedures involving fuel, the type of fuel should be described, along with the nature of the exposure (time, temperature, etc.). Also, record the length of time between fuel exposure conducting the test procedure.

6. Notes

6.1 Marginal Indicia

The change bar (l) located in the left margin is for the convenience of the user in locating areas where technical revisions have been made to the previous issue of the report. An (R) symbol to the left of the document title indicates a complete revision of the report.

PREPARED BY THE SAE J1645 TASK FORCE
OF THE SAE FUEL SYSTEMS TECHNICAL STANDARDS COMMITTEE

APPENDIX A

A.1 Background Information

A.1.1 General Comments

A.1.1.1 LIQUID FUEL PHENOMENON

Electrostatic charge separation can be generated when sufficiently non-conductive materials move past each other in a shear mode. This includes both solid and liquids such as liquid hydrocarbon fuels. Charge generation does not occur to any significant degree in gases and therefore fuel vapor systems are not affected.

A.1.1.2 DEVELOPMENT OF ELECTROSTATIC CHARGE

There are two primary functional areas of the fuel system where developing an electrostatic charge might occur:

a. The liquid fuel delivery system in the vehicle
b. The refueling system.

During refueling, electrostatic charges can be produced by:

a. Charges introduced into the fuel as it is pumped through fuel dispensing equipment.
b. Charges introduced into the incoming fuel as it flows through the fuel filler neck into the fuel tank.

A.1.1.3 BACKGROUND INFORMATION

Five documents that offer extensive background information on the electrostatic charge phenomenon are:

a. NFPA 77—National Fire Protection Association—Recommended Practice on Static Electricity 2000 Edition.
b. American Petroleum Institute—Recommended Practice 2003—"Protection Against Ignitions Arising Out of Static, Lightning, and Stray Currents.
c. Electrostatic Ignitions of Fires and Explosions American Institute for Chemical Engineers—Center for Chemical Process Safety; Thomas H. Pratt, PhD, PE
d. Avoiding Ignition Hazards in Chemical Operations. American Institute for Chemical Engineers—Center for Chemical Process Safety, Laurence G. Britton
e. CENELEC CLC/TR 50404 Electrostatics—Code of practice for the avoidance of hazards due to static electricity

While these publications do not specifically address automotive applications, they contain thorough discussions of the physics of the electrostatic charge phenomenon as well as recommendations for preventing or mitigating the formation of significant electrostatic charge accumulation. For additional background, the references cited in Section 2 can be consulted.

A.1.2 How Fuel System Components Contribute to the Electrostatic Charge Phenomenon

A.1.2.1 THE FOUR PROCESSES

Electrostatic charges can be generated in a fuel system by fuel flowing against and through fuel system components. Due to subtle chemical, electrical, fluid, and thermal forces, a charge separation occurs between the liquid and the surfaces the liquid touches. Local velocity conditions can further enhance the separation of charges contributing to an electrically unbalanced condition. Each component of a fuel system can participate in these phenomena in one or more of the following four processes.

A.1.2.1.1 Charge Separation

The dynamics of fuel interaction with fuel system components can cause separation of charges at or near interfacing surfaces or between turbulence induced boundary layers within the liquid. Electrical charges can become separated "significantly," mainly by the action of flowing, non-conductive fuel.

A.1.2.1.2 Charge Transport

Separated charges move from one part of the system to another, within the flowing, non-conductive fuel, and conductive or semi-conductive system components.

A.1.2.1.3 Charge Accumulation

Separated charges accumulate in areas with no or a poorly conductive path to the common ground plane, possibly causing localized charge build-up. These accumulations grow until the rate of dissipation equals the rate of accumulation (determined by the resistance of the conductive path to the common ground) or until some limiting mechanism (such as an electrical discharge) causes a sudden reduction in the accumulated charge.

For example, a plastic fuel tank could become charged by fuel entering it during refueling and that charge could remain in place until it is dissipated through the fuel to the sender unit. The exterior surface of the tank will exhibit a virtual charge (due to dielectric polarization) that is of similar magnitude, and of the same polarity as the interior charge. Nearby ungrounded metal components in turn will form static charge of opposite polarity to the charge in the interior of the tank. Discharges can occur from this ungrounded metal component to the surface of the tank or to other nearby grounded metal components.

A.1.2.1.4 Charge Dissipation

Dissipation is the action of unbalanced charge being recombined with charges of the opposite sign through conduction to ground or by recombining with nearby charge of the opposite sign.

A.1.2.2 CONTRIBUTIONS OF VARIOUS COMPONENTS

Tables A1 and A2 present the relative contribution of fuel system components to the processes described in A1.2.1.

A.1.2.2.1 Table A1 shows the relative contribution of the various components of an operating fuel delivery system to electrostatic charge processes. The information in Table A1 is independent of the information in Table A2.

A.1.2.2.2 Table A2 shows the relative contribution of the various components of a vehicle's fuel system to electrostatic charging processes during refueling. The information in Table A2 is independent of the information contained in Table A1.

TABLE A1—RELATIVE CONTRIBUTION OF FUEL SYSTEM COMPONENTS TO ELECTROSTATIC CHARGE PROCESSES DURING OPERATION OF THE FUEL DELIVERY SYSTEM

DEGREE OF CONTRIBUTION OF VARIOUS FUEL SYSTEM COMPONENTS										
Charge Process	Tank (Containing Liquid Fuel)	Fuel Pump	Fuel Lines & Connectors Conductive (and Properly Bonded)	Fuel Lines & Connectors Dissipative (and Properly Bonded)	Fuel Lines & Connectors Insulative	Fuel Filter Conductive (and Properly Bonded)	Fuel Filter Dissipative (and Properly Bonded)	Fuel Filter Insulative	Fuel Rail(1)	Pressure Regulator
Separation	---	Large	Small To Medium(2)	Small To Medium(2)	Small To Medium	Very Large	Very Large	Very Large	---	Medium
Transport	---	Medium	Large	Large	Large	Medium	Medium	Medium	Small(2)	Medium
Accumulation	Medium	Small	---	Small	Medium	Small	Medium	Very Large	Small	Small
Decay Or Dissipation	Large	Small	Medium	Medium To Small	Small	Medium	Medium To Small	Small	Medium	---

1. Contribution depends on type of material.
2. Degree of grounding to the engine block depends on configuration.

TABLE A2—RELATIVE CONTRIBUTION OF FUEL SYSTEM COMPONENTS TO ELECTROSTATIC CHARGE PROCESSES DURING THE REFUELING PROCESS

DEGREE OF CONTRIBUTION OF VARIOUS FUEL SYSTEM COMPONENTS					
Charge Process	Filler Neck Conductive (and Properly Bonded)	Filler Neck Dissipative (and Properly Bonded)	Filler Neck Insulative	Fuel Tank (Containing Liquid Fuel)	Fuel SendingUnit
Separation	Small	Medium	Large	Small	---
Transport	Medium	Medium	Medium	---	---
Caccumulation	---	Small	Medium	Large	Small
Decay Or Dissipation	Large	Small	---	Medium	Large

A.1.2.2.3 Experience has shown that fuel system materials do not need to exhibit significant levels of conductivity (such as in metals) to avoid adverse effects of electrostatic charges. Tables A1 and A2 describe components as "insulative" "dissipative," or "conductive." These terms are defined in Section 3 for materials that have not been exposed to fuel.

A.1.3 Mechanisms of Charge Reduction

If charge builds up in a fuel system there are at least six separate mechanisms that can reduce the charge:

a. Recombining of charges in the liquid.
b. Bulk conduction through bonded components to ground.
c. Dissipation through the fuel to bonded components to ground.
d. Surface dissipation along bonded components or along the interface between the liquid and components to ground.

e. Ionization of air (corona discharge and/or brush discharge). This is usually an external effect. It is not a direct dissipation route for charged fuel, except for inside the fuel tank.
f. Spark discharge (dielectric breakdown of a material, usually air).

A.1.3.1 SPARK DISCHARGE

This mechanism of charge recombination should be avoided because it can generate the highest discharge energy, which could result in some of the following:

a. Ignition of combustible air/fuel mixtures.
b. Microscopic holes through erosion of fuel system components.
c. Interference with the operation of electrical or electronic devices on the vehicle that are outside of the fuel system. (NOTE: Refer to NFPA 77) (Refer to Section 2.1.7)

A.1.3.1.1 Spark Discharge Mechanism

Spark discharge occurs when the electric field generated by an electrostatic charge exceeds the dielectric or breakdown strength of the material where the charge is located. Spark discharges with potentially destructive energy usually occur from metallic or highly conductive materials. Discharges generally occur through a dielectric:

a. Directly to ground or to another object at a sufficiently different potential
b. From one part of a component to another if there is sufficient potential difference between the two parts

A.1.3.1.1.1 Reductions in Dielectric Strength

Spark discharge becomes more likely if the dielectric strength of the material is reduced by mechanisms such as:

a. Extended periods of exposure to electric fields or high but sub-critical levels of electrostatic charge
b. Environmental factors (such as lower temperatures and lower relative humidity)
c. Aging: Degradation of the dielectric strength due to chemical (fuel) exposure, thermal exposure, thermal cycling, mechanical fatigue, etc.

A.1.3.1.2 Ignition of Fuel/Air Mixtures

Spark discharges can result in the ignition of fuel/air mixtures if the proper fuel/air ratio exists in the discharge gap and:

a. The electric field in the gap exceeds the breakdown strength of air
b. The discharge has sufficient energy
c. The discharge gap exceeds twice the quench distance for that fuel and air/fuel ratio

A.1.3.1.2.1 Combustible Air/Fuel Mixtures

Such mixtures may exist at the following locations of a vehicle:

a. Around the filler neck during refueling
b. Near atmospheric vent outlets for the vapor management system
c. Near redundant overpressure relief valves
d. In the vapor space inside the fuel system (under certain circumstances)

These circumstances include:

1.	Diesel fuel	(above its flash point; approx. 40 degrees C)
2.	M100 (methanol);	below 36 degrees C
3.	E100 (ethanol);	below 35 degrees C
4.	M85 (methanol/gasoline);	below -5 degrees C
5.	E85 (ethanol/gasoline);	below -7 degrees C
6.	15 RVP gasoline;	below -32 degrees C
7.	13 RVP gasoline;	below -20 degrees C
8.	10 RVP gasoline;	below -5 degrees C
9.	7 RVP gasoline;	below 13 degrees C

A.1.3.1.2.2 Breakdown Strength of Air

Under standard conditions, dry air breaks down when the local electric field exceeds a value of 3 kV/mm.

A.1.3.1.2.3 Ignition Energy

Ignition of combustible air fuel mixtures can occur if a discharge has sufficient energy. The energy of a discharge (W) to ground is described by the following equations:

$$W = \tfrac{1}{2} CV^2, \quad W = \tfrac{1}{2} QV, \quad W = Q^2/2C \quad \text{where} \quad Q = CV \qquad \text{(Eq. A1)}$$

where:
C is the capacitance of the discharging body (in farads, F)
V is the difference in electrical potential between the discharging body and ground (in volts, V)
Q is the amount of charge (in coulombs, C)
W is the energy (in joules, J)

For most automotive fuels the minimum ignition energy for a combustible mixture of air and saturated hydrocarbon vapor is greater than 0.20 mJ.

A.1.3.1.2.4 Corona Discharge

This type of charge dissipation is less rapid than a spark discharge and typically has few destructive results (non-incendive to ordinary automotive fuel vapors in air). It still proceeds on the basis of breaking down the dielectric properties of the local gas (air or air-fuel mixture).

A.1.3.1.3 Pinhole from Inside

Localized dielectric breakdown can occur through polymeric materials. The energy released in the discharge can melt, degrade, or burn the material in the discharge path and over time can produce a pinhole through the wall of an insulator. Residue from burned polymeric material has a high carbon content and the path produced by such discharges is sometimes referred to as a carbon track. Once dielectric breakdown occurs, the insulating properties of materials are weakened and subsequent breakdowns will generally occur at a lower electrical field strength. Any subsequent discharge or current flow will tend to occur along the more conductive path of the carbon track (enlarging the hole). In fuel systems where the charge is generated in flowing fuel, the hole in the non-conductive component grows from the inside out.

A.1.3.1.4 Pinhole from Outside

Discharge can also occur in the air between the surface of a non-conductive component to some other nearby conductive object that is at a different electric potential. This can cause the surface to decompose. This kind of discharge will occur between components having potential differences such that the electric field intensity in the air space between the components exceeds the dielectric breakdown strength of air (≈30 000 volts/cm). Many successive discharges from the outside to the same location of the non-conductive component can lead to erosion of the surface material. Eventually a pinhole could result from the outside in.

A.1.3.1.5 Charge Dissipation

This process of comparatively slow charge reduction is preferred for fuel system design because it generally occurs with no destructive effects.

A.1.4 Uncontrollable Factors

A.1.4.1 FUEL

Fuel has the largest single effect on the formation of electrostatic charges because its conductivity varies from less than 10^{-12} to over 10^{-9} Siemens per meter and it contains a widely varying range of components, additives and impurities. There are many sources and refining techniques for automotive fuels and an extremely wide array of compositions encountered. Very small amounts (parts per billion) of impurities, additives and even moisture can have a large effect on chargeability (see Section 3 for definition). No controls on automotive fuel for reducing its propensity for generating electrostatic charges are considered practical.

A.1.4.1.1 The following fuel characteristics and circumstances can significantly influence the ability of an electrostatic charge to develop:

a. Temperature of the fuel (electrostatic charging tendency increases as temperature decreases),
b. Composition, including the presence or absence of alcohol,

NOTE—Alcohols are pro-static agents (i.e., materials which increase fuel chargeability more rapidly than conductivity). This effect of pro-static agents is most pronounced at extremely low concentrations. As the concentration increases a point is reached where the conductivity effect takes over and the fuel ceases to develop electrostatic charge. This can occur with an alcohol concentration of as little as 0.1%.

c. Conductivity. For pure gasoline, this can vary from less that 1 to over 1000 pS/m. For E10 fuel it can range from 3000 to 5000 pS/m and occasionally as high as 20 000 pS/m. Note that chargeability is not a predictable function of conductivity, although it is generally accepted that the most critical conditions occur when the conductivity is in the region of 10 to 50 pS/m. At higher conductivity levels the rate of charge generation is overtaken by the rate of charge recombination in the fuel. Relaxation time (see Section 3 for definition) is a characteristic of materials, including fuel, that indicates how quickly charges recombine after they have separated. Highly conductive fuels have very low relaxation times (charges recombine very quickly).
d. Viscosity (electrostatic charging tendency increases as viscosity decreases),
e. Additives which are pro-static,
f. Impurities and contaminants can act as pro-static agents (see Section 3 - Definitions). Some trace materials in fuel are ionic and these affect both chargeability and relaxation time.
g. Moisture content, especially if the level is high enough to form a second phase. Emulsions can form in 2-phase flow. The surfaces on very small droplets in emulsions tend to be places where charges could form or accumulate.

A.1.4.1.2 Anti-static additives are available to improve a fuel's ability to allow separated charges to recombine by raising the conductivity of the fuel. Use of these anti-static additives have proven unreliable as a "solution" for preventing electrostatic charge concerns in automotive fuel systems because:

a. There are so many fuel producers and fuel outlets that it would be virtually impossible to guarantee the addition of a specific ingredient in every case
b. These additives tend to plate out on surfaces of pipes, tanks and tubing so their effect changes over time.
c. Moisture content of the fuel can affect the performance of the additives.
d. Trace quantities of anti-static agents are pro-static and can actually cause fuel to develop more charge separation.

A.1.4.2 ENVIRONMENT

The environmental factors that have the most significant effects on the electrostatic situation of a vehicle's fuel system are temperature and humidity. As a fuel system is exposed to moisture, environmental conditions, and dirt that can accumulate on a vehicle, the fuel system will tend to perform better from the standpoint of electrostatic charging (less likely to accumulate charge; what charging does occur is to a lower level, and dissipates faster).

A.1.4.2.1 High humidity can create a conductive path that permits charge recombination on fuel system surfaces, thus preventing charge accumulation and discharge. A low absolute humidity environment such as experienced at temperatures below freezing, is more likely to permit dielectric breakdowns by allowing a higher degree of charge accumulation. While environmental humidity primarily affects the exterior of the fuel system, it can also affect the moisture content of the fuel. A change in moisture content can cause fuel to change its conductivity. (Refer also to Section A.2.1.1.1.)

A.1.4.2.2 As temperature goes down, fuel conductivity decreases, fuel chemistry can change, and fuel viscosity increases. For each fuel the combination of changes of these factors can contribute to a greater amount of charge separation. Usually charge separation reaches a peak at a certain temperature.

A.1.4.3 FACTORS EXTERNAL TO THE VEHICLE

A.1.4.3.1 Fuel Dispensing Equipment

Local regulations and codes usually require that fuel dispensing equipment be conductive (or sufficiently conductive) and requires a connection from the dispenser nozzle to earth ground (per NFPA 77, see Section 2.1.7). If the electrical connection to earth is interrupted or if a nonconductive component is used in the fuel dispensing fluid circuit, a net charge can develop on the vehicle during refueling. Also, the use of pump mechanisms that greatly agitate fuel or cause air bubbles to form in the fuel can generate high charge levels.

A.1.4.3.2 People-Induced Charges

The actions of vehicle operators can cause them to develop a charge (e.g., sliding across a vehicle's seat). In addition, artificial materials used in some modern shoe bottoms tend to keep charges on a person rather than allowing them to pass to earth ground. As a result, a discharge is possible to whatever part of the vehicle or fuel dispensing equipment that a person touches. No fuel system or fuel dispenser equipment design practice can adequately deal with this circumstance. However, the following points/recommendation should be noted:

a. Vehicle and fuel dispenser operators might be advised to either remain in contact with the dispenser throughout the refueling operation or to ground themselves to the vehicle at a point away from combustible air/fuel vapor mixtures before contacting the fuel dispenser nozzle.
b. Vehicle designs that include a filler door that covers the fuel filler inlet can provide a charge dissipation point if the filler door is not completely opened by a remote release mechanism.

A.2 Testing and Measurements—Basic Guidelines and Considerations

A.2.1 General Comments

The test procedures in Sections 5.2 and 5.3 are for evaluating the electrostatic dissipative properties of materials, components and assemblies used in automotive fuel systems. These procedures do not evaluate the antistatic (charging) properties of materials, components or assemblies.

A.2.1.1 MEASUREMENT PARAMETERS

The evaluation of the electrostatic characteristics of materials, components and assemblies should be accomplished in three separate steps.

- First, the basic material used to make the components should have the correct electrostatic characteristics. Guidelines are provided as a starting point.
- Second, the components should be tested to confirm that the manufacturing process did not significantly alter the basic material electrostatic properties.

- Finally, the complete assembly should be tested to ensure that satisfactory bonding occurs between all components and between components and ground.

To ensure repeatable measurement results between different test laboratories of the same material or parts, it is necessary to specify all parameters that may have an effect on the measurement. ASTM D-4496 and ESD STM 11.11 and 11.12 are excellent references for defining these parameters and are listed below: (Refer also to Section 5.4).

A.2.1.1.1 Sample Preparation (refer also to Section A.1.4.2)

A.2.1.1.1.1 When measuring resitance or resistivity, it is best to do it under controlled environmental conditions. Since lower humidity can affect the material resistance properties all certification tests should be prepared and performed at 12 ± 3% RH and 23 °C as specified in ESD STM 11.11 and 11.12.

A.2.1.1.1.2 Testing can be conducted at 50% relative humidity if data collected is considered “useful”. (The 50% level of RH conforms to generally accepted test conditions for testing material properties). This additional information will allow comparison to existing data. It must be kept in mind, however, that level recommended for compliance to the requirements of Section 4.3 is 12 ± 3% RH.

A.2.1.1.1.3 Testing components and assemblies in a controlled environment may not be practical. Under these conditions the humidity and temperature should be recorded at the time of testing. It is recommended that relative humidity should be between 12% and 65%. Humidity levels outside of that range will cause measurement results that are less accurate and consistent. Tests should not be conducted outside of that range of humidity.

A.2.1.1.2 Test Instrumentation Including Setup and System Verification Tests

For loaded material, the test instrumentation, electrodes and system verification are all critical in obtaining multi-lab correlation and must be specified.

A.2.1.1.3 A Defined Electrification Period (Measuring Time)

A.2.1.1.3.1 When measuring very high resistance, the RC time constant of the sample and the instrumentation may require a significant amount of time for the test voltage to completely develop across the sample. The electrification time may be different for different instruments. Hence, measuring a known resistor at the upper limit will enable the user to determine the time it takes to measure the correct value.

A.2.1.1.3.2 Since the upper resistance limits in fuel systems are not extremely high, a measurement taken at a fixed time, or at the actual time it takes the instrumentation to make the measurement, whichever is less, should be used.

A.2.1.1.3.3 Some materials exhibit a change in resistance during the measurement. Taking measurements within a fixed time frame minimizes this problem.

A.2.1.1.4 Test Procedure

The steps of the test procedure are extremely important. How the sample is prepared, test electrode requirements, how the instrumentation is connected, test voltages used and how the measurement is taken all affect the accuracy of the data.

A.2.1.1.4.1 Components and Assemblies

The test methods for certifying material are not practical for measuring components and assemblies. Therefore, different test procedures are required.

A.2.1.1.4.1.1 The most important ESD characteristic of a fuel system component is its ability to dissipate a static charge in a controlled manner to prevent static charge accumulation or a spark discharge. First, the individual components should be conductive as defined. Second, these components when assembled should be bonded to form a resistance less than the limit specified. Third, the complete assembly should be bonded to the vehicle ground (chassis) so that the resistance to ground from any point on the assembly is within the specified upper limit.

A.2.1.1.4.1.2 The relevant dissipation path is generally along the inside surface of the assembly where flowing fuel contacts the part. Hence, all resistance measurements should be made between specified points on this inside surface and specified points to ground or the groundable point.

A.2.1.1.4.1.3 In addition, the ability of the assembly to dissipate a static charge should be measured. This measurement takes into account the resistance of the system. A system may test as if it exceeds the specified resistance limit, but the complete assembly may be able to bleed off a static charge in a timely manner.

A.2.1.1.5 Instrumentation

A.2.1.1.5.1 Resistance

The materials being measured are generally nonlinear and voltage dependent. When using test voltages of 100 V or more, the maximum current allowed is 5 mA. However, many instruments limit the maximum current to 2-3 mA, especially when testing at 500 V. If testing is performed using 1000 V the maximum current should be limited to 1 mA or the level designed into the measuring instrument. When testing at 500 V or 1000 V extreme care must be taken to avoid electrical shock. The minimum resistance that can be measured at different test voltages with current limited to 5 mA and 1 mA for 1000 V are as shown in the following list:

Applied Test Voltage (V)	Minimum Measurable Resistance (Ω)
1000	1×10^6 @ 1 mA
100	2×10^4 @ 5 mA
10	2×10^3 @ 5 mA

A.2.1.1.5.2 Resistance values for materials used in fuel systems are typically in the less than 10^3 to less than 10^6 Ω range. ESD STM 11.11, 11.12 and 11.13 utilize 10 and 100 V to measure over the range of less than 10^3 to 10^{11} Ω. These test voltages have been found to be satisfactory for measuring ESD materials over the above range. A number of manufacturers now offer resistance meters that utilize these test voltages. In addition, some meters automatically switch from 10 Volts to 100 Volts when the measured resistance is greater than or equal to 1×10^6 Ω. ESD TR 02-99 details the voltage characteristics of these instruments.

A.2.1.1.5.3 Contact Probes

The measurement of resistance both for certifying material and for verifying components and assemblies will require specific electrode configurations and resistance meters. These measurements cannot be made with standard DMMs, clips or probes.

A.2.1.1.5.3.1 Using STM 11.11 and/or 11.12 will meet the requirements of certifying the thermoplastic material used in fuel systems. These standards can be adapted in whole or modified to meet the specific requirements for fuel systems.

A.2.1.1.5.3.2 Prior to use, the system performance should be checked by measuring the resistance of both 1000 Ω and 10 MΩ, 1% resistors using 10 V or other lower test voltage, and 100 V.

A.2.1.1.6 Static Dissipation

When measuring static dissipation (static decay) the test method must be specified since several different test methods are available. Unfortunately, there is no direct correlation between methods. For fuel system analysis it will be necessary to use two different test methods.

A.2.1.1.6.1 The first, based on Mil Std 3010, Method 4046.1 and following the proposed test procedure, would be used for certifying material plaques.

A.2.1.1.6.2 The second, using a charged plate monitor, and following the proposed test procedure would be used for testing assemblies. The same sample preparation used for resistance measurements would also be used for dissipation testing.

A.2.1.1.6.3 The electrostatic decay/dissipation time measuring equipment needs to meet the following requirements:

a. The time resolution of the equipment shall not exceed 0.1 sec.
b. The equipment would preferably display a 1 volt resolution.
c. All probes used along with this equipment shall comply with SAE J1645 document.
d. The equipment shall meet ESD STM 3.1-2000 and other relevant specifications.

A.2.2 Cautions

A.2.2.1 MISINTERPRETATION OF MEASUREMENT

It may appear comparatively simple to make a measurement of parameters related to electrostatic charge. However, it can be very difficult to accurately measure the specific parameter of interest or completely understand the effect of that individual parameter on the situation because other contributing factors are interrelated, including specific component or system design. Also, there are many sources of variability that can cause errors in obtaining or interpreting test results.

A.2.2.2 SMALL VARIATIONS

Small, seemingly inconsequential variations in test methods as well as component condition and testing circumstances can cause wide differences in results. This can be especially important when attempting to compare the performance of different designs. Therefore, all aspects of such measurements should be controlled, or at least noted. These include:

a. Temperature
b. Humidity
c. Surface conditions (paint, roughness, etc.)
d. Aging due to such factors as fuel and chemical exposure, thermal exposure, mechanical fatigue, etc.
e. Corrosion/wear
f. Manufacturing variations
g. Accumulation of dirt and foreign substances
h. Characteristics of fuel (conductivity, viscosity, additives, etc.)
i. Velocity of fuel flow

A.2.2.3 EFFECTS OF MEASUREMENT PROCEDURES

The procedure used to make measurements of electrostatic related parameters can affect the results. (Standardizing factors such as these will reduce variations in the measurement taken).

A.2.2.3.1 Field Strength Measurements

a. Distance to Point or Component Being Tested—Field strength varies as a function of the distance from the charge that is causing the field. Therefore, the distance from the charge to the measurement device should be carefully controlled to obtain an accurate measurement from test to test.
b. The Measurement Itself—Placing a measurement device into an electrostatic field to measure this field strength disturbs the field and changes the result.

A.2.2.3.2 Resistance Measurements

a. Type of Contact Made—When measuring resistance, a point contact can give a different result compared to surface contact.
    i. Point contact could break through corroded, contaminated or coated surfaces of a component.
    ii. Thermoplastic resins containing conductive fillers/reinforcements may be heterogeneous mixtures that could create inconsistent contact with point probes. For this reason, contacts such as needle point probe or alligator clips are not recommended.

iii. Resistance measurements should be made using methods that do not disturb the surface and average the effects of surface variability; these include:
   1. Use of compliant contacts made of a conductive elastomer (with a surface resistance lower than the material being measured) with a hardness not to exceed 65D and an applied force of 2 to 4 Newtons. A clamp having .25 × .25" (6 × 6 mm) outer and .25 × .125" (6 × 3 mm) inner electrodes are recommended.
   2. Use highly conductive materials for contact or connections.

NOTE—ASTM D257-99 is a test procedure for insulative materials. It is not a procedure to be used as part of this document; however, it does provide important support to the measurement procedures of Section 5.2. It identifies fixtures that can be used in the resistance measurement process and recommends that measurements be taken using a contact method that mimics the way a particular component or subsystem is attached to the larger system.

b. Motion During Measurement—Movement of the probe, sensor or contact device can affect the measured value obtained. There should be either no movement or the movement should be identical during each measurement.
c. Surface Condition at Point of Contact—If surface conditions vary from measurement to measurement (humidity, dirt, roughness, etc.) the results obtained can vary widely. Differences should be minimized.

A.2.3 Measurement Theory and General Case

A.2.3.1 JUSTIFICATION OF RESISTANCE LEVELS

This section of the appendix is included to provide a justification for the limits on resistance stated in Section 4. These limits are based on two assumptions:

1. "Sufficiently" conducting paths from each component in contact with the fuel should be provided to some common point in the system, which is taken as the vehicle or chassis ground.
2. Components in contact with flowing fuel should have an electrical conductivity that equals or exceeds some minimum level.

These two assumptions are related, and are designed to insure that charges carried by the fuel cannot accumulate on the components to the degree that they are excessive. The conduction drains the charges away to ground at a sufficient rate such that the resultant voltage levels throughout the system are limited to what are considered safe levels. Section 4 accomplishes this by establishing a maximum value for the resistance to ground and a maximum value of volume resistivity of a given component.

To illustrate the need for the total resistance limit consider the illustration in Figure A1, which shows a vehicle being refueled. The steaming current carried by the flowing fuel, here called I_{in}, passes into the fuel tank. This current flow must be continuous so it flows back to the pump by a number of different electrically conducting paths such as the tires and pavement, the fuel hose, and through the electrical conductivity of the fuel itself. Within the vehicle some of these paths include hoses connecting the fuel filler tube to the fuel tank and the inlet housing, etc.

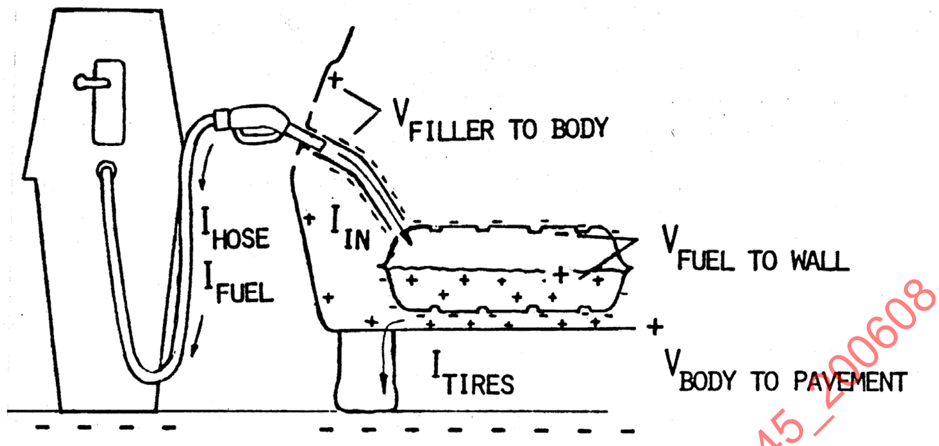

FIGURE A1—REPRESENTATION OF CHARGING CONDITIONS AS VEHICLE IS REFUELED

To some degree of approximation, the equivalent electric circuit that represents this electrostatic flow of charge in Figure A1 is shown in Figure A2.

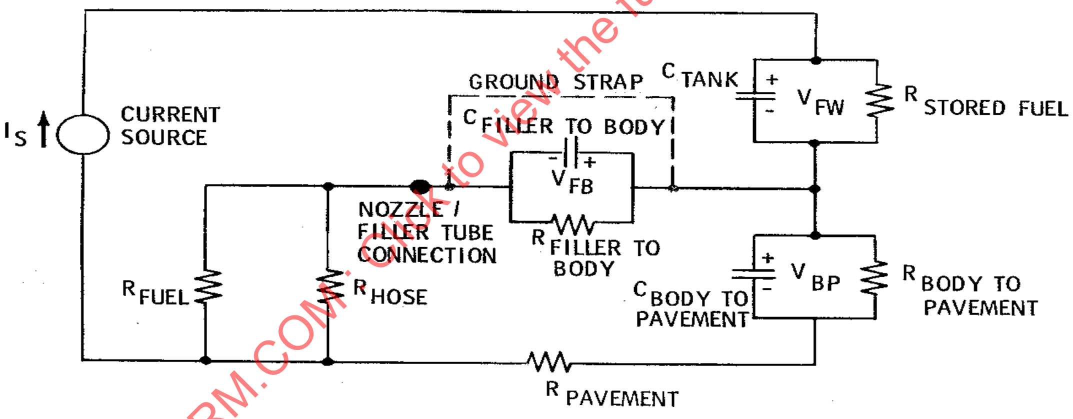

FIGURE A2—EQUIVALENT CIRCUIT FOR FIGURE A1

The system is seen to be a number of capacitors, upon which charges can be stored, and resistors that provide conducting paths in parallel and series with these capacitors. The total steaming current, here called I_S, divides according to the magnitudes of the various resistive paths. The voltages that develop across the various capacitances depend upon the value of the resistance in parallel with them and the current flowing through that resistance. Details depend upon geometry and material properties. What the resistance limit in Section 4 accomplishes is to avoid all of these details by assuming the situation where the worst case steaming current passes through that resistance and limits that resistance so that the resulting voltage is a safe value. In the given example consider the filler tube to body resistance. From experience the worst case steaming current is known to be on the order of 10^{-6} A. Because it is probable that a combustible fuel-air mixture will exist at the fuel door opening during the fueling operation, the maximum voltage at this specific location is chosen to be no greater than 1 V.

Thus, the maximum resistance from the filler tube to ground is set at $1/10^{-6} = 10^{+6}\ \Omega$. More generally, experience has shown voltages on the order of kilovolts are questionable so the maximum safe voltage at other locations is taken to be 100 V. Thus, the maximum resistance across a given resistor is limited to $100/10^{-6} = 10^{+8}\ \Omega$. The limit of Section 4.1 generalizes this to be the maximum allowable potential drop from any point in the system to chassis ground. A similar circuit could be developed for the situation where the current/fuel flows arise from the vehicle's fuel pump. Thus, the limit is independent of the specific current source.

The second limit is a material specification that sets its maximum volume resistivity (ρ) at $10^{+4}\ \Omega$ - m. This is chosen in anticipation of that material ultimately being used to form a component that satisfies the first limit on total resistance. That resistance is geometry dependent, but an order of magnitude rule of thumb estimate is:

$$R = \rho\, L / A \qquad \text{(Eq. A3)}$$

where ρ is the volume resistivity, L is the mean length of the part in the direction of current flow, and A is the minimum cross-sectional area across which the current flows. A component that has a large resistance is one that is long and thin. Consider a 0.61 m (two-foot) length of 0.01 m (3/8 inch) diameter fuel line with a wall thickness of 1.59×10^{-3} m (/16 inch) and resistivity of $10^{4}\ \Omega$ - m. Substitution into the formula estimates the resistance to be $3 \times 10^{+8}\ \Omega$, which is on the order of magnitude of the $10^{+8}\ \Omega$ limit.

A.2.3.2 JUSTIFICATION OF STATIC DECAY TIME

Finally, Section 4 requires that fuel-exposed material and parts satisfy the static decay test detailed in Section 5.3.5.2. Specifically, the test exposes the material to up to 5000 V charge and expects it to decay to to 10% of its initial value in 0.5 s or less. To put this on a theoretical basis, again refer to the equivalent circuit in Figure 2. Each of the capacitances have resistances in parallel and/or in series with them that will dissipate their stored charge (voltage) once the source of the charge (in this case the streaming current) is removed. To a first order approximation, assuming the conduction in the resistors is ohmic, the decay will be exponential:

$$V(t) = V_0 \exp(-t/\tau) \qquad \text{(Eq. A4)}$$

where V_0 is the initial voltage at time t = 0 and $\tau = R \bullet C$ is the decay time constant for a resistance R and a capacitance C. If at time t_0, $V(t_0) = 0.1\, V_0$, then this equation requires

$$\exp[-t_0 / (R \bullet C)] = 0.1 \quad \text{or} \quad -t_0 / (R \bullet C) = \ln(0.1) = -2.3 \qquad \text{(Eq. A5)}$$

Taking $R = 10^{+8}\ \Omega$ and assuming the largest capacitance seen in an automotive system, $C \cong 1000$ pF, $t_0 =$ 0.23 s. The proposed recommended standard rounds this estimated value up to 0.5 since the 0.23 sec was calculated only as a first order approximation.

A.2.4 Tests Using Flowing Fuel or Fuel Substitute

A.2.4.1 GENERAL

In Section 5 of this document and in the previous sections of this Appendix, test methods have been described that are capable of being conducted on a routine basis by many testing sources with standard tools and by technicians with normal training. When exceptions to the general rules stated in Sections 4.1 of this document are taken the requirements of Section 4.2 must be applied on the basis of expert knowledge of the field of electrostatics. The validity of the exceptions may require verification by non-routine tests that must be designed and conducted by experts. These generally involve flowing fuel or test fluid in a fuel system or portion of a fuel system in the manner simulating worst case conditions in the actual vehicle and measuring the electrostatic effects created by flow in that specific design condition. This section establishes the minimum conditions that must be observed if these tests are to be adequate for assessing the potential for harmful electrostatic charge effects.

A.2.4.2 ENVIRONMENT

A.2.4.2.1 Tests should be conducted over the temperature range from 23 °C down to the lowest temperature anticipated for the product in its intended marketplaces.

A.2.4.2.2 Relative humidity to be 30% maximum.

A.2.4.3 TEST FLUID

Test fuel or test fluid shall have a demonstrated capability of generating significant electrostatic charges during the test. It has been found that certain common industrial solvents can exhibit chargeability representative of worst case fuels. This avoids the safety issues associated with gasoline and makes it easier to obtain consistent and reproducible results. These types of relatively safe fluids have the following characteristics:

A.2.4.3.1 Known commercially as de-aromatized white spirits they are mixtures of paraffinic and naphthenic hydrocarbons and very low aromatic content. They should have a boiling range of 145 °C/200 °C so that the flash point temperature is above 35 °C.

A.2.4.3.2 Maximum static electric conductivity, at 23 °C should be 30 pS/m per ASTM D 2624-02, Standard Test Method for Electric Conductivity of Aviation and Distillate Fuels.

An example of such a product is as follows:

Hydrolsol P 150
DHC Solvent Chemie GmbH
Timmerhellstraße 28
D-45478 Mülheim an der Ruhr
Phone: +49 (0) 2 08 / 99 40 - 0
Fax: +49 (0) 2 08 / 99 40 - 1 50
E-Mail: info@dhc-solvent.de