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(R) Recommended Practice for LNG Medium and Heavy-Duty Powered Vehicles

RATIONALE

The document has been updated to keep pace with field experience and technical advances.

FOREWORD

This SAE Recommended Practice is intended as a guide for standard practice and is subject to change in order to keep pace with experience and technical advances. Its purpose is to promote safety and efficiency by making available to sellers and buyers of commercial liquefied natural gas (LNG) powered medium and heavy-duty vehicles a recommended practice for construction, operation, and maintenance of such vehicles. Vehicles shall be defined as having a gross vehicle weight (GVW) rating of greater than 6350 kg (14 001 USA pounds), and all LNG vehicles used for public transit or commercial applications. The intent of this document is to cover these classes and application of vehicles only and specifically excludes automotive passenger vehicles.

The document was initially developed by the Manufacturer's LNG Technical Subcommittee of the ATA Foundation's Alternative Fuels Task Force, which was organized in 1994 to guide the trucking and cryogenic industries in their efforts associated with the use of LNG as an Alternate Fuel for use in heavy-duty trucks. Prior to the first Subcommittee meeting, some preliminary work had been performed by the LNG Onboard Fuel System Integration Committee (LOFSIC).

The first step in the SAE Subcommittee's work was to perform a Failure Modes and Effects Analysis (FMEA), facilitated by Failure Analysis Associates. This study identified Failure Scenarios and the Failure Mechanisms, which could potentially lead to the identified Failure Scenarios. It is the intent of these Recommended Practices to avoid the failure mechanisms identified by that study where possible, and to devise and recommend means of construction, operation, and maintenance, which would warn of an impending fault or failure, and/or mitigate the outcome, should a failure occur.

Concurrent with the FMEA, the SAE Subcommittee undertook an exhaustive review of existing codes, standards, recommended practices, and regulations pertinent to trucks and LNG in force or in preparation, so that the Recommended Practice would be consonant with such, whether in force or under preparation.

This SAE publication necessarily deals to some extent in generalities, since it is not possible to anticipate and address every individual set of conditions that might be found in constructing, operating, and maintaining LNG powered vehicles. It is intended to be a practical guide illustrating the application of recommended practices. The correct application of these practices in any actual field situation must rely on sound judgment and experience.

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1. SCOPE

This SAE Recommended Practice provides guidance for the construction, operation, and maintenance of LNG powered medium, heavy-duty vehicles and all LNG vehicles used for public transit or commercial applications.

1.1 Purpose

The purpose of this document is to establish a uniform practice for construction, operation, and maintenance of LNG powered vehicles and is subject to change to keep pace with experience and technical advances. The revised Failure Modes and Effects Analysis (FMEA) which influences this document is a separate document, available in part as an informative appendix (Appendix B).

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 issue of SAE publications shall apply.

2.1.1 API Publication

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

API 620 Design and Construction of Large, Welded, Low-Pressure Storage Tanks

2.1.2 ASME Publications

Available from the American Society of Mechanical Engineers, 22 Law Drive, P.O. Box 2900, Fairfield, NJ 07007-2900, Tel: 973-882-1170, www.asme.org.

ASME Boiler and Pressure Vessel Code Section VIII Pressure Vessels, Division 1

ASME B31.3 Process Piping

2.1.3 Compressed Gas Association Publication

Available from Compressed Gas Association, 4221 Walney Road, 5th Floor, Chantilly VA 20151-2923, Tel: 703-788-2700, www.cganet.com.

CGA G-4.1 Cleaning Equipment for Oxygen Service G4.1

2.1.4 Pipeline and Hazardous Materials Safety Administration Publication

Available from the Superintendent of Documents, U.S. Government Printing Office, Mail Stop: SSOP, Washington, DC 20402-9320, Tel: 202-512-0000, www.gpoaccess.gov/cfr/index.html.

49 CFR 178.57 Specification 4L Welded Insulated Cylinders

2.2 Related Publications

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

2.2.1 SAE 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 J703 Fuel Systems—Trucks and Truck Tractors

2.2.2 ANSI/FCI Publication

Available from IHS Global, 15 Inverness Way East, Englewood, CO 80112, Tel: 877-413-5184, www.global.ihs.com.

ANSI/FCI 70-2 Control Valve Seat Leakage

2.2.3 California Code of Regulations

California Department of Occupational Safety and Health – Pressure Vessel Unit (DOSH Title 8): Elihu Harris State Building, 1515 Clay Street, Suite 1302, Oakland, CA 94615, Tel: 510-622-4052, http://ccr.oal.ca.gov/, Donald Cook Principal Safety Engineer, dcook@hq.dir.ca.gov.

CCR Title 8 (Industrial Relations), Division 1 (Department of Industrial Relations), Chapter 4 (Division of Industrial Safety), Subchapter 1 (Unfired Pressure Vessel Safety Orders), Article 7 (Compressed and Liquefied Natural Gas System)

California Highway Patrol – Enforcement Division – Commercial Vehicle Section – 444 North 3rd Street, Suite 310, Sacramento, California 95614-0228, http://ccr.oal.ca.gov/, Cris Morgan, Tel: 916-445-1865, cmorgan@chp.ca.gov.

CCR Title 13 (Motor Vehicles), Division 2 (Department of California Highway Patrol), Chapter 4 (Special Equipment), Article 2 (Compressed and Liquefied Gas Fuel Systems), Section 935 (Liquefied Natural Gas) and Section 936 (Installation)

2.2.4 CCPS Publication

Available from the Center for Chemical Process Safety of the American Institute of Chemical Engineers, 3 Park Avenue, New York, NY 10016-5591, Tel: 212-591-7316, www.aiche.org/ccps/.

Guidelines for Evaluating the Characteristics of Vapor Cloud Explosions, Flash Fires and BLEVEs

2.2.5 Compressed Gas Association Publications

Available from the Compressed Gas Association, 4221 Walney Road, 5th Floor, Chantilly VA 20151-2923, Tel: 703-788-2700, www.cganet.com.

CGA S-1.2 Pressure Relief Device Standards—Part 2—Cargo and Portable Tanks for Compressed Gases

CGA S-1.3 Pressure Relief Device Standards—Part 3—Stationary Storage Containers for Compressed Gases

2.2.6 Federal Motor Carrier Safety Administration Publications

Available from the Superintendent of Documents, U.S. Government Printing Office, Mail Stop: SSOP, Washington, DC 20402-9320, Tel: 202-512-0000, www.gpoaccess.gov/cfr/index.html.

49CFR 393.65 All Fuel Systems

49CFR 393.67 Liquid Fuel Tanks

2.2.7 FEMA Publication

Available from Federal Emergency Management Agency, Publications Office, P.O. Box 2012, Jessup, MD 20794, Tel: 800-480-2520, www.fema.gov.

Handbook of Chemical Hazard Analysis Procedures

2.2.8 NFPA Publication

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

NFPA 52 2006 Vehicular Fuel Systems Code 2006 (new document includes old NFPA 57 and 52) NFPA 70—National Electrical Code

2.2.9 Texas Administrative Code Publication

Available from Railroad Commission of Texas, Capitol Station, P.O. Box 12967, Austin, TX 78711-2967, Tel: 512-463-7110, http://info.sos.state.tx.us/pls/pub/readtac$ext.ViewTAC.

Title 16 (Economic Regulation), Part 1 (Railroad Commission of Texas), Chapter 13 (Regulations for Compressed Natural Gas [CNG] and Liquefied Natural Gas [LNG])

3. DEFINITIONS

The following definitions were derived in assembling this document.

3.1 Family of Tanks – Containers

A group of tanks related by the following common characteristics or properties: same manufacturer, same insulation system and materials, same inner support system, identical design, mounted in the same manner, with piping components in the same or similar orientation, constructed with the same material types of the same strength and a volume not greater than 100% of the test tank provided that the inner and outer vessels are of the same thickness as the test tank.

3.2 LOX

Liquefied oxygen.

3.3 LNG

Liquefied natural gas.

3.4 Maximum Allowable Working Pressure (MAWP)

The highest pressure which can occur within a system prior to operation of the protecting relief valve.

3.5 Pressure Regulator

Any device used to reduce pressure (independent of flow) exclusive of engine control regulators.

3.6 Ullage – Ullage Space

Ullage is another word for vapor space. Vapor space between the liquid cryogen and top of the tank.

4. REFUELING SITE CONSTRUCTION

Refueling Sites: The performance of the LNG onboard fuel system depends on the refueling station's engineering design and the equipment's ability to perform to the requirements of the onboard fuel system. Fuel flow, pressure, saturation, overfilling, under filling, hold times and safety shall be part of the coordinated functions of the LNG refueling station and onboard fuel system.

4.1 General Design Criteria

All materials used in fuel system devices, components, materials, devices or systems to protect the components from under hood temperatures which could be exposed to LNG or cold LNG vapors (during operating conditions) from the onboard fill receptacle forward to the engine interface shall be rated for a service temperature range of –162 °C (–260 °F) to +121 °C (+250°F). All fuel system components underneath the hood or where they would be exposed to higher temperatures must be rated for at least +121 °C (250 °F), or higher.

All metallic material shall be listed per ASME B31.3, *Process Piping*, and ASME *Boiler and Pressure Vessel Code*, or API 620, *Design and Construction of Large, Welded, Low-Pressure Storage Tanks*, Appendix Q. These materials shall not be used below the minimum design temperature established in these referenced standards.

All materials shall be selected or installed to minimize corrosion or to protect the material from corrosion. Stainless steels that do not resist chloride-induced pitting/corrosion cracking and sensitization-induced corrosion resistance reduction shall not be used. The use of all copper-zinc and copper-tin alloy families shall be restricted to those alloys that are metallurgically inhibited to prevent accelerated metallurgical deterioration from external environmental sources. The use of dissimilar metal junctions shall be minimized. Junctions shall provide good corrosion protection to reduce corrosion effects of such a materials combination on long-term corrosion.

All components of the fuel system shall be installed, supported, protected, and secured in order to minimize the possibility of damage, corrosion, or breakage due to expansion, contraction, vibration, strains, or wear and to preclude any loosening while in transit.

Piping or tubing passing through a panel or structural member shall be protected by devices that shall snugly fit the piping or tubing and the hole in order to prevent abrasion.

4.1.1 Device Mounting

All fuel system devices shall be installed so that their weight is not placed on, or supported by, the attached lines unless so designed by the system manufacturer.

4.1.2 Fuel System Cleanliness After Any Assembly or Repair

After assembly of the fuel system, the components between the tank and the engine shall be free of dust and debris before the system is put into service.

4.1.3 Pressure Tests

After the system has been completely assembled, it shall be tested for leaks while pressurized to the maximum operating pressure with nitrogen.

4.1.4 Pressure Relief Devices

Containers shall be equipped with pressure relief devices or pressure control devices required by DOT 4L as referenced in 49 CFR or ASME under which the containers were designed, fabricated and tested. The pressure relief device must be installed and located so that the cooling effect of the contents during venting will not prevent effective operation of the device. Primary and secondary relief device outlets shall be provided with a protective device to prevent the entrance and accumulation of dirt, debris, snow, ice, and/or water and must be designed to prevent the development of any dangerous excess pressure.

Automatic pressure regulating equipment shall be installed on fuel delivery systems that have operating pressures that exceed the engine operating pressure requirements between the vehicular fuel container and the engine to regulate the maximum allowable pressure of the fuel delivered to the engine.

Use of an equal method, design or choice of materials must be validated by engineering data. This data shall be available and considered within the Public Domain.

4.1.5 Design Ullage Space

The tank shall retain an appropriate ullage space according to vessel manufacturer's guidance during refueling such that the vessel shall not become overfilled when filled according to the manufacturer’s recommendations. Ullage space sizing considerations shall address the thermodynamic properties of the system, beginning and end points of fuel conditions, stratification, tank thermal design, insulation, hold time and other factors.

Adequate vapor space (ullage) shall be maintained to ensure vapor space communication of devices (pressure relief's, vent, etc.) and allowance for liquid expansion, when the tank content is allowed to warm from it’s initial 100% net full volume to the ending state defined by the primary pressure relief device, and when the initial fill condition is at the lowest point in the design filling temperature/pressure range. In no case shall the ullage be less than 10% of the gross water volume.

Tank System design that shall incorporate an ullage space or system capable of insuring adequate vapor space when filled properly to it's design "full" state, such that sufficient vapor space is provided to accommodate liquid expansion and maintaining the path to vapor communication for devices such as the vapor line, pressure relief devices or any components designed to operate in the vapor state and to provide specified "hold time". Note reference Appendix C for vapor space calculations and ullage space as a function of saturated pressure, temperature, relief valves, etc.

4.2 LNG Fuel Tanks

The inner and outer shells of fuel tanks shall be constructed of austenitic stainless steel, or equivalent. Tanks shall be equipped with a thermal insulation system that limits conduction, convection, and radiation. Insulation systems that use vacuum insulation may require maintenance as defined by the manufacturer. Insulation system design life shall be defined by the manufacturer. Insulation system shall be designed such that LNG product loss at static pressure shall be less than 1% per day at 34.5 KPa (5.0 psi)

Tanks shall be factory cleaned per CGA G-4.1 (1996), and in lieu of customer specification shall follow the numerical and written criteria of CGA 4.1

Vehicle LNG Tanks shall have a design hold time (build pressure without relieving) of 5 days after being filled net full and at the highest point in the design filling temperature/pressure range.

4.2.1 Design

Each tank shall be designed, fabricated, and tested in accordance with DOT 4L (Ref 49 CFR) or ASME Boiler Pressure Vessel Code requirements. The outer shell shall be provided with an overpressure safety device to vent the annular insulation space if pressure becomes excessive. Testing shall be performed at standard room temperature of not less than 18.3 °C (65 °F).

4.2.1.1 Container Gauges

All Containers shall be equipped with pressure gauges that are connected to the container at a point above the maximum liquid level.

4.2.1.2 Container Design/Markings

Containers shall be designed, fabricated, tested in accordance with the Regulations of the U.S. Department of Transportation (DOT) Specification 4L, or the “Rules for the Construction of Unfired Pressure Vessels,” or ASME *Boiler and Pressure Vessel Code*, applicable at the date of manufacture. DOT 4L marking does not imply that the vessel is “certified” to DOT 4L, and these tanks cannot be used for the transport and sale of LNG or other fluids. Quality control systems at manufacturing sites must be approved by DOT and/or ASME. Tanks other than ASME shall be marked or stamped “SAE J2343”.

4.2.1.3 Container Mounting

No part of the container or its appurtenances shall protrude beyond the sides or top of any vehicle where the container can be struck or punctured. Non-roof-mounted containers shall not be mounted ahead of the front axle or beyond the rear bumper on motor vehicles. Fuel containers shall not be mounted above any driver or passenger compartment, unless a spill pan is installed between the fuel containers and the compartment, with a liquid capacity equal to at least the capacity of the largest single fuel container of a multiple container installation consisting of three or more fuel containers, but not less than one-quarter the fuel capacity of the containers located above the compartment and capable of preventing liquid from entering the interior or dripping into any window, door or emergency exit way. Spill pans shall be designed in such a manner that rain water is not retained. The spill pan drain shall not be directed into any confined space, the engine compartment, muffler area, battery box or other hazardous location.

4.2.1.4 The lowest part of any container, or fuel system component, including protective guards, shall not be lower than the lowest edge of the vehicle differential housing under maximum suspension deflection. In no event shall the container or any fuel system component have less clearance from the surface of a level roadway than the clearance between the roadway and the lowermost portion of any rim of any wheel in contact with the roadway.

4.2.1.5 Container Mounting/Exhaust

Tanks mounted within 20 cm (8.0 in) of exhaust or other heat sources shall be shielded from radiant heating.

4.2.1.6 Container Roof Mounting

Where a container is installed above the operator or passenger compartment of a vehicle the requirements of the following shall apply:

a. The container and its piping, fittings, and devices shall be protected from damage by the following:

   1. A guard rail or similar device that is designed to absorb the impact of a collision with a stationary object when the vehicle is moving either forward or backward at 8 km/hr (5 mph). The guard rail or similar device shall be free of projections that could damage the container or its devices and fittings.

2. A shield designed to absorb impacts that can occur during loading, unloading, or use of the vehicle. The shield shall be free of projections that could damage the container or its devices and fittings.

b. The top of the container and any LNG piping, fitting, valve, housing, guardrail, or shield shall not be more than 4.1 m (13.5 ft) above the road surface.

4.2.1.7 Container/Compartment Gas Sealing

Containers shall be installed and fitted so that no gas from fueling operations can be released inside the passenger or driver compartment by permanently installing the fueling receptacle outside the passenger compartment of the vehicle in a location protected from physical damage and dislodgment. Enclosures, structures, seals, and conduits used to vent enclosures shall be fabricated of materials designed to resist damage, blockage, or dislodgment caused by the movement of articles carried in the vehicle or by the closing of luggage compartment enclosures or vehicle doors and shall require the use of tools for removal.

4.2.1.8 Container Overfilling/Shutoff

LNG tanks shall be equipped with a device, or devices, that prevent overfilling.

The outer vessel shall be provided with an overpressure safety device to vent the annular insulation space In the event of a vacuum loss.

4.2.1.8.1 Container Shutoff Devices

Each container shall be equipped with accessible shutoff devices that allow for its complete isolation from the rest of the engine fuel supply system. Container shutoff devices shall be labeled as to their function (Decals or stencils shall be acceptable) and shall be appropriately labeled “LIQUID SHUTOFF” for liquid supply and “VAPOR SHUTOFF” for vapor supplies. Manual devices shall also be labeled with the direction of closure. (Decals or stencils shall be acceptable). Normally closed automatic shutoff devices that are held open by electric current, pneumatic or hydraulic pressure, or a combination thereof, or manually operated shutoff devices shall be permitted to be used to meet this requirement. An automatic shutoff valve used in lieu of a manual shutoff valve shall be marked with the words “AUTOMATIC SHUTOFF VALVE.”

4.2.1.8.2 Labels shall not be less than 1.27 cm (1/2 in) in height and shall contrast sharply with the background.

4.2.1.8.3 All parts of container shutoff devices, except gaskets, packing, and seats, shall be stainless steel, brass, copper or equivalent, suitable for LNG service.

4.2.1.9 Container Accident – Fire Damage Reinstall Criteria

When a vehicle is involved in an accident or fire causing damage to the LNG fuel system container, the system, container, or both shall be removed, inspected, repaired, and retested before being restored to service by the Original Tank Manufacturer, and the Final Stage Vehicle Manufacturer (FSVM).

4.2.2 Pressure Relief Devices

Containers shall be equipped with pressure relief devices or pressure control devices required by the code under which the containers were designed and fabricated. Rupture discs shall not be used except on the outer vessel. Each relief valve shall be labeled with the manufacturer’s name, part number, and set pressure. Each relief valve shall have separate inlet connections which communicate directly with the vapor space of the tank. Each relief device shall have a separate outlet. The primary pressure relief valve shall be piped to a vent stack which extends above the vehicle. The vent stack shall be suitable for LNG service. Primary and secondary relief valve outlets shall be protected from fouling by dirt, debris, snow, ice, and/or water. The vent stack shall be sized to prevent flow restriction due to pressure drop. Gas exiting the vent stack or secondary relief valve shall not impinge on enclosed areas, other vehicles, engine intakes, or engine exhausts. In the case of dual tanks, the primary relief valve outlet piping for each tank may be manifolded to a common outlet stack.

All safety relief devices on vehicular fuel containers that discharge to the atmosphere shall vent outside of the vehicle. All discharge lines and outlets shall be installed as follows:

1. Pressure relief discharge lines shall be suitable for the maximum pressure and temperature of the discharged fluid.

2. Discharge lines and adapters shall be sized, located, and secured so as to permit the required relief discharge capacity and to minimize the possibility of physical damage.

3. A means shall be provided (e.g., loose-fitting caps) to minimize the possibility of the entrance of water or dirt into either the relief device or its discharge line and to drain any water that accumulates in the discharge line. The means of protection shall remain in place except when the relief device operates. In this event, the means of protection shall permit the relief device to operate at required capacity.

4. The outlet of the discharge line shall be fitted with a device or configured to prevent the formation or accumulation of any ice that could prevent the relief device from operating at required capacity.

5. The relief valve discharge from fuel containers on vehicles shall be directed upward or shall not impinge directly on the vehicular fuel container(s), the exhaust system, or any other part of the vehicle, and shall not be directed into the interior of the vehicle.

6. The discharge line from pressure relief devices on all buses shall be located at the rear of the vehicle, directed upward, and extended to the top of the vehicle roof.

7. Secondary relief devices designed to prevent rupture of the container upon failure of the primary relief device shall not be required to be piped away from the tank

Pressure relief devices shall be so designed that the possibility of tampering is minimized. Externally set or adjusted devices shall be provided with a means of sealing the adjustment

A pressure relief valve shall be installed in each section of piping or tubing in which LNG can be isolated between shutoff devices so as to relieve the pressure that can develop from trapped fuel to a safe atmosphere. The pressure relief valve shall not have a setting greater than the maximum allowable working pressure of the line or devices it protects.

4.2.3 Level Gauging

Each tank system shall to be provided with liquid level gauging which can be read from a suitable location in the driver's compartment or near the fueling connection. Accuracy shall be at least ± 12.5% capacity by volume.

4.2.4 Pressure Gauging

Each tank system shall be provided with a pressure gauge which can be read locally. Range shall be at least 1.2 times the MAWP (maximum allowable working pressure). Gauge opening shall be no larger than 1.4 mm (.055 in) and shall connect above the maximum liquid level, or provisions to prevent liquid from reaching the valve need to be made.

A pressure gauge, if provided within a driver or passenger compartment, shall be installed in such a manner that no gas flows through the gauge in the event of gauge failure. Gauging devices shall be designed for the most severe pressure and temperature conditions to which the devices may be subjected with a pressure safety factor of not less than four.

4.2.5 Fueling Connections

Each tank shall be provided with a fueling connection with a dust cap to preclude the introduction of dirt into system. A secondary check valve independent of the fueling connector shall be fitted between the fueling connector and the fuel tank. The fueling connector shall be rated for the MAWP of the fuel tank. The fueling connector shall be installed in accordance with the manufacturer’s recommendations. The fueling connector and its mounting system shall withstand the break-away forces generated by the fueling station breakaway device (Reference NFPA 52, 2006). Recessed or flush-mounted refueling connections shall be provided with a spill path which directs liquid to a safe location. Fueling connections shall be labeled “LNG only.”

4.2.6 Manual Vent Valve

Each tank shall be provided with a manual vent valve which can be used for controlled release of vapor from the tank ullage space. The vent valve shall be connected to the vent stack, a vapor recovery connector, or other safe location. The valve shall be labeled “Manual Vent Valve” and shall indicate the closed direction. Closing the manual vent valve shall not disable the pressure relief devices.

4.2.7 Extended Bonnet Devices

If equipped, extended bonnet devices shall be installed with their stem packing seals in such a position as to prevent leakage or malfunction due to freezing. If the extended bonnet in a cryogenic liquid line is installed at an angle greater than 45 degrees from the upright vertical position, evidence of satisfactory service in the installed position shall be demonstrated through validation by the component OEM.

4.2.8 Excess Flow Devices

Excess flow devices shall be provided for each line which supplies fuel to the engine. Excess flow devices shall trip on a fuel line failure. Excess flow devices shall be oriented so as to minimize the effect of road vibration on the valve actuation.

4.2.8.1 Container Back Flow Valve

The vehicle fueling system shall be equipped with a backflow check valve to prevent the return flow of LNG from the container(s) to the filling connection. Such a check valve shall be permitted to be integral to another component in the system, such as the vehicle fueling connector.

4.2.9 Connection and Manifold Enclosures

All non-electrical connections and manifolds for the fuel tank shall be protected from mechanical damage by means of a suitable connection enclosure. Enclosure shall be adequately vented and designed to prevent pooling of any liquids. Each non-electrical component within the connection enclosure shall be adequately labeled as to its function.

4.2.10 Vehicle Tank Supports

Tank mount supports shall be designed and tested in accordance with industry requirements. Testing shall be consonant with and in conformance with applicable federal, state and local requirements. Fuel tanks shall be oriented and mounted in accordance with the final stage vehicle manufacturer’s and the tank manufacturer’s recommendations.

4.2.11 Labeling

Each fuel storage tank shall be labeled with the following minimum data: Design Code, Service Pressure, Serial Number, Gross Capacity in Water Liters (Gallons), Manufacturer’s Name or Trademark, Date of Manufacture (MM/YY), LNG Symbol (Blue and White Diamond), and shall contain the statement: “This container meets or exceeds the drop test requirements of SAE J2343 in effect on the date of manufacture.”

Container markings shall be visible after the container is permanently installed on a vehicle. A portable lamp and mirror shall be permitted to be used when reading markings. Markings shall be visible either directly or by use of a mirror after installation.

All tank connections shall be adequately labeled as to its function per the latest NFPA document: Current NFPA 52-2006 label is 120 mm wide x 83 mm high (4.75 in wide x 3.25 in high).

A vehicle equipped with an LNG fuel system shall bear a durable label located at the fueling connection receptacle that shall include:

a. Identification as an LNG-fueled vehicle,

b. The maximum allowable working pressure of the vehicular fuel container.

c. The high and low allowable filling Pressure and Temperature

4.2.12 Drop Tests

Each family of fuel tanks shall be drop tested to verify tank integrity. Drop tests shall include a 9.1 m (30 ft) drop test of the fuel tank on the most critical area of the tank (other than the piping end) and a 3.1 m (10 ft) drop test on the piping end. Tank shall contain an equivalent full weight of liquid nitrogen saturated at one half the MAWP. There shall be no loss of product for a period of one hour subsequent to the drop test other than relief valve operation and vapor between the filler neck and the secondary check valve in the case of a drop test involving the filler neck. Loss of vacuum, denting of the vessel, piping and piping protection, and damage to the support structure system are acceptable. Acceptable drop test procedures can be found in Appendix A.

Pumps and other tank attachments shall also meet the drop test requirements for the tank and be attached as part of the tests.

4.2.12.1 Fuel Container Certification

LNG tank manufacturers shall certify compliance with the drop test requirements of individual fuel container models based upon tests witnessed and validated by a DOT or ASME recognized inspection agency. The results of the test shall be made available to the owner of the container.

4.2.13 Flame Test

Each family of fuel tanks shall be flame tested to verify tank integrity. Tank shall contain an equivalent full level of liquid nitrogen saturated at one half the MAWP. Tank shall be subject to an external temperature of 538 °C (1000 °F) for 20 min without reaching relief pressure.

4.3 Vaporizer

The vaporizer shall have the capacity to vaporize LNG completely at maximum engine fuel flow rates, within the engine manufacturer's specified fuel temperature range, with minimum differential design temperature. The fuel side of the vaporizer shall be rated at the MAWP at least equal to the maximum discharge pressure of the pump or pressurized system that supplies them, whichever is greater. Provision shall be made for bleeding air from the coolant side of the vaporizer or elsewhere in the cooling system. The vaporizer shall be mounted as close to the fuel tank manifold as possible. The vaporizer shall be protected from damage by road debris and from other mechanical damage by reasonable means.

4.3.1 Vaporizer Marking

Vaporizer shall be marked permanently at a readily visible point to indicate: the manufacturer's name, intended service, and the MAWP of the fuel-containing portion of the vaporizer.

4.3.2 Vaporizer Heat Source

Engine exhaust gases shall not be used as a direct source of heat to vaporize fuel. If the engine exhaust is used, it shall be used via an indirect heating system.

4.4 Pressure Regulators

If so equipped, pressure regulators shall be rated at the MAWP of the regulator inlet line. Pressure regulators shall be protected from damage by road debris and from other mechanical damage by reasonable means. The low-pressure side of pressure regulators used to reduce the MAWP shall be fitted with a relief device. This relief device shall be rated for 1.2 times the rated flow of the regulator when supplied with the upstream MAWP. The relief valve outlet shall be suitably piped above the vehicle per the requirements of the primary fuel tank relief valve.

4.5 Automatic Shutoff Devices

Automatic shutoff devices shall be rated at the MAWP of the supply (fuel tank or pressure regulator). Automatic shutoff devices shall not fail if mounted at any angle or available pressure differential. Automatic shutoff devices shall close on loss of ignition circuit or loss of engine operation.

4.6 Failure/Warning Devices

The fuel system shall activate a warning device in the driver area if abnormally low fuel temperatures are detected downstream of the vaporizer. The warning device (telltale) shall emit a red or yellow light when identifying the malfunction of the vaporizer. This function may be accomplished with the engine controls using a “check engine” light.

4.7 Fittings and Piping/Tubing

Piping shall be shielded from radiant heating which exceeds its temperature limitations. The number of fittings shall be kept to a minimum. Threaded pipe connections shall be kept to a minimum. Fittings shall be suitable for the intended service and shall be included in the vibration/durability and corrosion testing. All piping and tubing shall be protected from damage by road debris by reasonable means and from other mechanical damage. LNG piping shall be provided with insulation or shielding for personnel protection. All piping and tubing shall be adequately supported. Pipe sealant or tape shall be suitable for the intended cryogenic service. Vent stack connections shall allow sufficient flexibility to accommodate differential movement. The completed fuel system shall be leak tested with a suitable (nitrogen) medium at operating pressure prior to the introduction of product to the fuel system. All cryogenic piping shall be protected against blocking LNG between valved sections by relief device.

4.8 Corrosion/Vibration/Durability Integrity

The systems and subsystems unique to LNG operations shall be corrosion, vibration, and durability demonstrated as part of the overall vehicle testing process by the chassis OEM (or if it will not participate in a conversion of the vehicle to LNG, by the converter or other competent entity) to verify overall integrity.

4.9 Gas Detection

A gas detection system shall be installed per the system/device Original Equipment manufacturer's (OEM) recommendations and shall warn of the presence of methane in the following locations:

a. Within the drivers' compartment and any passenger compartment(s).

b. Within the engine compartment.

c. Within any enclosed fuel storage compartment, if so equipped.

The methane gas detection system shall provide a visual warning within the vehicle before the methane gas concentration reaches 20% of the lower flammability limit (LFL). The methane gas detection system shall sound an audible and visible warning alarm at 50% of the lower flammability limit (LFL). Such warning shall be plainly visible to the driver before entering the driver's compartment and while seated in the normal driving position. The methane gas detection system shall function continuously at all times. The methane gas detection system installation shall be certified by the system OEM to meet their published installation and performance standards.

The methane gas detection system shall be inspected/tested for calibration and verified, at the suggested intervals established by the system OEM and per latest NFPA document. Maintained in accordance with system OEM manufacturer instructions and maintenance manual. Inspection/testing and calibration shall be performed no less than yearly. Records of the inspection and maintenance conducted shall be retained for the life of the vehicle. The vehicle shall not be operated if the gas detection system is inoperable, has malfunctioned, or has been disconnected. The methane gas detection system shall be incapable of initiating ignition at any time or if the detection system is powered "on" at the lower flammability limit.

4.10 Electrical

All conductors shall be sized for the maximum anticipated load and shall be protected by over current protection devices.

Radio transmitters, radio receivers, electric motors, or other electrical equipment (except vehicle lamps and wiring) shall not be mounted in an enclosed compartment with fuel supply containers unless one of the following conditions is met:

1. All piping and all connectors and devices on the fuel supply containers are exterior to and sealed from the compartment containing electrical equipment, or

2. All piping, connectors, and devices within the compartment are contained in a vapor-tight enclosure and vented to the atmosphere exterior of the vehicle, or

3. The electrical equipment is contained in a vapor-tight enclosure that is vented to the atmosphere exterior of the vehicle, or

4. Intrinsically safe devices and circuits are used.

Wiring shall be installed, supported, and secured in a manner to prevent damage due to vibration, shock, strains, wear, or corrosion.

4.11 Gas Filtration

If a gas filter(s) is included by the engine, chassis or FSVM manufacturer in the vehicle fuel system, the filter(s) shall be shielded from excessive radiant heat and road debris by reasonable means. The filter(s) shall be rated at the MAWP of the supply fuel tank or pressure regulator.

5. OPERATION

5.1 General

Due to the large degree of variation possible in system configuration and component specifics, this section will outline the content, which shall be covered by each manufacturer/supplier's (i.e., chassis OEM, engine manufacturer, tank supplier, etc.) Operating Manual. It is the intent that the content described be presented in sufficient depth and clarity so as to provide basic understanding of systems unique to LNG powered medium to heavy-duty vehicles. Each manufacturer/supplier shall provide operations and maintenance manuals, as well as preventive maintenance requirements and intervals for their specific components. The Final Stage Vehicle Manufacturer (FSVM) shall have the overall responsibility for collection and consolidation of all LNG related operation and maintenance manuals.

5.1.1 The Final Stage Vehicle Manufacturer (FSVM)

FSVM shall have the responsibility for integration of the engine, fuel system and gaseous detection systems onto the vehicle chassis. Therefore, the FSVM shall be responsible for providing systems (fuel and gas detection) validation of: engineering, integration, installation, regulatory validation (NFPA, State, Federal), performance and durability. FSVM will provide documentation of the suitability of the fuel and detection systems components for each of following: Truck, Bus, Chassis, Engine, Gas Detection and Fuel System original equipment/component manufacturers. The final stage Vehicle Manufacturer by reference is the same as NFPA 52 Final Stage-Stage Vehicle Integrator/Manufacturer (FSVIM). Due to the large degree of variation possible in fuel and gaseous detection system configurations and component specifications, information regarding the content of these systems shall be documented by the FSVM in an operating manual.

5.1.2 Site Owner Operator Integration

The site owner-operator shall take measures to include the Final Stage Fueling Station Provider (FSFSP) in the full design of the system. The FSFSP shall have the responsibility for integration of refueling station to the vehicle onboard fuel system. Therefore, the FSFSP is responsible for providing validation of: engineering, integration, installation, regulatory validation, performance, safety and durability. FSFSP shall provide documentation of the validation and compatibility of refueling station components and systems for: fuel, truck, and bus, chassis, engine, and fuel system original equipment/component manufacturers.

5.2 LNG Safety

The following topics shall be covered in the vehicle operating manual:

5.2.1 Chemical and Physical Properties

The following properties of LNG shall be treated in the operating manual for LNG powered medium and heavy-duty vehicles: compositional characteristics, i.e., Material Safety Data Sheets (MSDS), general liquid properties, odor properties, cryogenic properties, general vapor properties, and spill/leak characteristics.

5.2.2 Safety Hazards

The following safety hazards shall be explained in the operating manual: cold metal contact hazards, cryogenic burn hazards, asphyxiation hazards, over pressurization hazards, and fire hazards associated with the use of LNG as a vehicle fuel. Liquid spills and vapor releases into the atmosphere shall be discussed. Effects of liquid spills and vapor containment shall be discussed, e.g., LNG flowing down storm sewer or equipment garage vapor containment.

5.2.3 Protective Equipment

The use of appropriate protective equipment during fueling shall be discussed in the operating manual.

5.2.4 First Aid and Emergency Services

The First Aid issues to be discussed in the operating manual shall include cryogenic burn first aid; reminders to alert operators reporting incidents to alert response personnel that LNG fuel is involved shall be included.

5.3 Fuel System Overview

The following fuel system topics shall be covered in the vehicle operating manual.

5.3.1 Fuel Tank System

The basic construction, operation, and safety features (i.e., relief devices, manual shutoff devices, excess flow devices, etc.) shall be discussed in sufficient detail as to provide basic understanding of systems unique to LNG powered heavy-duty vehicles.

5.3.2 Vaporizer

The basic construction, operation, and safety features (i.e., low-temperature warning system, etc.) shall be discussed in sufficient detail to provide basic understanding of vaporizer system operation.

5.3.3 Pressure Relief Devices

The basic construction, operation and aspects shall be discussed in sufficient detail to provide basic understanding of relief valve operations.

5.3.4 Automatic and Manual Shutoff Devices

The basic construction, operation, and aspects shall be discussed in sufficient detail to provide basic understanding of shutoff valve operation.

5.3.5 Vent Stack

The basic construction, operation, and characteristics shall be discussed in sufficient detail to provide basic understanding of vent stack operations. Manual venting shall be clearly explained.

5.4 Operational Safety

At a minimum, the following topics shall be covered in the operating manual when addressing Operational Safety:

5.4.1 Pre- and Post-Operational Safety

For pre- and post-operational safety, the operating manual shall explain how to detect obvious leaks (vapor cloud or hissing from fuel line) and what to do about them.

5.4.2 Low-Temperature Warning

The function and remedial action necessary for the low-temperature warning system shall be adequately explained in the operating manual.

5.4.3 Methane Detection

The function, remedial action and maintenance necessary for the methane detection system shall be adequately explained in the operating manual.

5.5 Fueling Safety

The following topics shall be covered in the vehicle operating manual when addressing LNG safety:

5.5.1 Fueling Procedure

The fueling procedure shall be included in the operating manual and shall cover the following topics: shutting off the vehicle, grounding the vehicle, ensuring that the vehicle is not moved with the fuel hose connected to the vehicle, fuel connector operation, fuel connector spillage, cold metal contact, and required personnel protection.

Methods and safety considerations for defueling and purging a vehicle tank shall be addressed.

5.5.2 Grounding

The elimination of electrostatic discharge during fuel hose connection by adequately grounding the vehicle during fueling shall be covered in the operating manual.

5.5.3 Dust Caps

The importance of the use of all dust caps in eliminating moisture and dirt contamination shall be covered in the operating manual.

5.5.4 Tank Fueling with Venting Required

A fueling procedure when tank pressure relief is necessary shall be included in the operating manual, and shall address the hazards involved when venting vapor from the fuel tanks. Initial fueling or refueling of a tank, which has been emptied, may involve a special procedure, which shall be addressed.

5.5.4.1 Tank Venting

Circumstances when manual venting of the tank is required and procedures for carrying out such venting shall be included, and shall address the hazards involved when venting vapor from the fuel tank. Initial tank fueling or refueling of a tank, which has been emptied, involves special procedures which shall be addressed, including the fact that manual venting will cause fuel weathering.

5.6 Fuel Quality

This topic shall be covered in the vehicle operating manual when addressing Fuel Quality and shall also be specific to the engine manufacturers' requirements for the year and type of engine.

5.6.1 Fuel Specification

The minimum methane concentration and maximum inert, heavy hydrocarbon, and contaminant concentrations for the fuel delivered to the engine shall be specified in the operating manual. An adequate description of LNG weathering and nitrogen concentration shall be contained in the operating manual.

5.6.2 Fuel Contamination

The operating manual shall contain a discussion of contamination risks and methods to mitigate contamination sources and operating practices.

5.6.3 Use of CNG

The operating manual shall explain the use of properly regulated compressed natural gas (CNG) to move the vehicle when necessitated by circumstances.

5.6.4 Weathering of LNG Fuel

Fuel venting caused by either long-term parking of LNG vehicles or manual venting can lead to weathering of LNG fuel. Fuel composition may be altered and may violate engine manufacturer's specifications resulting in drivability problems or possible engine damage.

5.7 Indoor Parking Safety

The following topics must be covered in the vehicle operating manual when addressing indoor parking safety:

5.7.1 Short-Term Parking

The following topics shall be covered in the operating manual concerning short- term parking: suggested duration, preference to outdoor parking due to potential for leaks, relief valve leakage or operation, the potential need in local codes for structure methane detection with indoor parking, and the necessity for piping of the relief stack outside the building structure.

5.7.2 Long-Term Parking

The Operating Manual shall define the duration of long-term parking, and the special considerations with regard to the LNG fuel system and defueling to prevent potential hazards associated with long-term parking shall be addressed.

6. MAINTENANCE

6.1 General

Due to the large degree of variation possible in system configuration and component specifics, this section will outline the content, which shall be covered by the manufacturer/supplier's Maintenance Manual. The document shall provide technicians sufficient understanding to work on LNG powered vehicles safely, and contain a CAUTION against substitution of components or materials other than those supplied or recommended by the manufacturers.

6.2 LNG Safety

The following topics shall be covered in the maintenance manual when addressing LNG Safety:

6.2.1 Chemical and Physical Properties

The following properties of LNG shall be treated in the maintenance manual for LNG powered heavy-duty vehicles: compositional characteristics MSDS, general liquid properties, odor properties, cryogenic properties, general vapor properties, and spill/leak characteristics.

6.2.2 Safety Hazards

The following safety hazards shall be explained in the maintenance manual: cold metal contact hazards, cryogenic burn hazards, asphyxiation hazards, over pressurization hazards, and fire hazards associated with the use of LNG as a vehicle fuel. Liquid spills and vapor releases into the atmosphere shall be discussed. Effects of liquid spills and vapor containment shall be discussed: e.g., LNG flowing down sewer or equipment garage vapor containment.

6.2.3 Protective Equipment

The use of appropriate protective equipment during fueling, fuel system maintenance, and defueling shall be discussed in the maintenance manual.

6.2.4 Methane Detection

The use and maintenance necessary for the methane detection system shall be adequately explained in the vehicle owner’s manual.

6.3 Facility Safety

The following topics shall be covered in the maintenance manual when addressing maintenance facility safety along with a discussion of risks associated with each:

6.3.1 Fuel Supply Isolation

The maintenance manual shall explain the circumstances where it is necessary for isolation of the fuel system by closing the manual shutoff devices at the fuel tank any time that an LNG powered vehicle is brought into the maintenance facility for any reason.

6.3.2 Relief/Vent Stack Piping

The maintenance manual shall explain the circumstances where it is necessary for piping the relief/vent stack to a safe outdoor location any time that an LNG powered vehicle is brought into the maintenance facility for any reason.

6.3.3 Methane Detection

The maintenance manual shall explain the circumstances where it is necessary for methane detection for checking for fuel leakage any time that an LNG powered vehicle is brought into the maintenance facility for any reason.

6.3.4 Fuel System Cleanliness After Reassembly

The maintenance manual shall explain the need to assure that the fuel system between the tank and engine is free of all dust and debris before being returned to service after reassembly.

6.3.5 Fuel Tank Maintenance

The maintenance manual shall explain the procedure for defueling the fuel tank prior to removing or performing maintenance on it. Disposal of removed fuel shall be in conformance with local regulations.

6.3.6 Fuel System Leaks

The maintenance manual shall explain the necessity for repairing fuel system leaks prior to bringing an LNG powered vehicle into the maintenance facility.

6.3.7 Firefighting Techniques

Because of differences in firefighting characteristics of LNG compared to conventional fuels, the maintenance manual shall address basic reference materials and officials to be consulted for further guidance.

6.4 Pressure Relief Valve Maintenance

The maintenance manual shall discuss the appropriate service interval for relief devices and other components unique to the LNG fuel system.

6.5 Fuel System Modification and Maintenance

The maintenance manual shall contain a CAUTION against modifying the LNG Fuel System from its original (OEM) configuration. The following topics shall be covered in the maintenance manual when addressing fuel system maintenance:

6.5.1 Fuel System Overview

The basic construction, operation, maintenance, and safety features (i.e., relief devices, manual shutoff devices, excess flow devices, etc.) shall be discussed in sufficient detail to familiarize the service technician with the LNG fuel system and the component and service replacement intervals.

6.5.1.1 Fuel System Bleed Down

Appropriate CAUTIONS regarding pressurized fuel lines and components and appropriate methods for de-pressurizing fuel lines and components for maintenance work shall be included.

6.5.2 Fuel Tank

The basic construction, operation, maintenance, and safety features (i.e., relief devices, manual shutoff devices, excess flow devices, etc.) shall be discussed in sufficient detail to familiarize the service technician with proper maintenance procedures for servicing the fuel tank and its related components.

6.5.2.1 Tank Venting

Circumstances when manual venting of the tank is required and procedures for carrying out such venting shall be included, and shall address the hazards involved when venting vapor from the fuel tank. Initial tank fueling or refueling of a tank, which has been emptied, involves special procedures which shall be addressed, including the fact that manual venting will cause fuel weathering.

6.5.3 Vaporizer

The basic construction, operation, maintenance, and safety features (i.e., low-temperature warning system, etc.) shall be discussed in sufficient detail to familiarize the service technician with proper maintenance procedures for servicing the vaporizer and its related components.

6.5.4 Pressure Relief Devices

The basic construction, operation, maintenance, and aspects shall be discussed in sufficient detail to familiarize the service technician with proper maintenance procedures and intervals for servicing the pressure relief devices and their related components.

6.5.5 Shutoff Devices

The basic construction, operation, maintenance, and aspects shall be discussed in sufficient detail to familiarize the service technician with proper maintenance procedures for servicing the shutoff devices and their related components.

6.5.6 Leak Testing

The maintenance manual shall explain the procedure for leak testing the fuel system if any maintenance is done on the fuel system.

6.5.7 Protection from Ignition Sources

The maintenance manual shall explain the proper procedure for protecting the fuel system from ignition sources such as welding, flame cutting, etc., which may be performed on the vehicle. The potential hazards which could arise from weld spatter, arc strikes, cutting a live fuel line, etc., shall be clearly explained.

6.5.8 Other System Components

The maintenance manual shall discuss all fuel system replacement parts giving replacement part specifications, appropriate installation and servicing procedures, and other unique elements relating to the LNG fuel system.

7. NOTES

7.1 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 TRUCK AND BUS ALTERNATIVE FUELS SUBCOMMITTEE
OF THE SAE TRUCK AND BUS CHASSIS AND POWERTRAIN COMMITTEE

APPENDIX A - DROP TEST PROCEDURES

A.1 TEST PROCEDURE FOR LNG VEHICLE FUEL TANKS—9.1 m (30 ft) CRITICAL AREA DROP

A.1.1 Scope

The drop test will subject a full-size vehicle fuel tank to a free-fall impact onto an unyielding surface (metal or concrete) from a height of 9.1 m (30 ft). Fuel tank will be released by firing one or more explosive cable cutters simultaneously or an equivalent means of simultaneously releasing the fuel tank. The fuel tank will impact the outer shell on the critical area as determined by the manufacturer. The fuel tank will be filled with an equivalent full weight of liquid nitrogen saturated to at least 1/2 the maximum allowable working pressure (MAWP) of the fuel tank. There shall be no loss of product other than relief valve operation and loss of vapor between the filler neck and the secondary relief valve in the case of a test involving the filler neck. Loss of vacuum, denting of the vessel, piping and piping protection, and damage to the support system are acceptable. The drop test will be documented using two standard speed video cameras and still photographs.

A.1.1.1 Purpose

This procedure defines the sequence of events to be followed in execution of the 9.1 m (30 ft) critical area drop test of LNG vehicle fuel tanks. This procedure describes the orientation, execution, documentation, and pass/fail criteria for the test.

A.1.2 Pre-Drop Preparations

Prior to drop testing a vehicle fuel tank the manufacturer will provide an orientation, which results in impact of the most critical area for the tank to be tested. Lifting lugs will then be attached using epoxy adhesive or equal means of attachment such that the fuel tank can be suspended from the lifting lugs at the orientation specified by the manufacturer. Once the lifting lugs have cured, the vessel will be moved to the cryogenic test area where it will be filled with liquid nitrogen to simulate a full load of LNG (liquefied natural gas). The liquid nitrogen will be saturated to at least 1/2 the MAWP of the fuel tank. The tank is then transported to the drop pad for drop testing.

A.1.3 Drop Test

Once the fuel tank to be drop tested has been filled and has reached the drop pad, it will be connected to the drop pad hoist and a preliminary check of vessel orientation and tank pressure will be performed. Adjustments as necessary will be made until orientation and pressure are satisfactory. Pressure will be checked via the remote pressure monitoring transducer which is connected via quick disconnect to the ullage space of the fuel tank. Pressure readout will be set up for monitoring from outside the drop pad fence. Once the vessel pressure has been recorded on the drop test data sheet (Figure A1), the fuel tank vent manual shutoff valve will be closed and the transducer will be disconnected.

The vessel is then weighed by means of a 907 kg (2000 lb) load cell in the main lifting line. Combined load cell and readout repeatability shall be better than 1%. Load cell readout will be set up for remote monitoring from outside the drop pad fence. Weight is recorded on the drop test data sheet (Figure A1).

Wind speed is then checked to ensure that wind is below 16 km/hr (10 mph) with gusts less than 24 km/hr (15 mph). Wind conditions and ambient temperature are recorded on the drop test data sheet (Figure A1).

The armor plate or equal surface is measured using a hand-held surface thermometer. The armor plate must be above –17.8 °C (0 °F) in order to proceed. The armor plate temperature is recorded on the drop test data sheet (Figure A1).

The stadia boards are then moved into position and clamped in place. The boards will be positioned such that the reference grid matches at the inside corner of the boards.

The impact area will be cleared of all unauthorized personnel. The fuel tank is then lowered and the explosive cable cutter or equal is installed and wired to the zip cord, which will extend to the firing mechanism located outside the drop pad fence. The explosive circuit is then checked for continuity.

Tag lines and a 9.1 m (30 ft) drop height indicator string are then attached to the fuel tank. The fuel tank is raised to the drop height, the height is verified, and the tension on the hoist hold-down cables is checked. The tank orientation will be corrected with the tag lines and the height verification tag line will be removed.

The impact area will then be washed down with water or antifreeze-based solution if the surface has frost on it. This will aid in visualizing the impact.

The blasting machine or equal will be wired to the explosive cutter zip cord or equal and a status check made by the test manager. The video cameras will then be started. Upon confirmation that video cameras are operational, all personnel will be evacuated from the fenced drop pad area. The blasting machine will be charged. Shortly after the blasting machine has been charged (1 to 2 seconds) the explosive cutter will be fired.

A.1.4 Post-Drop Measurements

After impact, the fuel tank will be approached by two technicians who have had training in cryogenic safety. The technicians will use self-contained breathing apparatus, cotton shirt and pants, loose-fitting work gloves, and work boots. No other personnel will be permitted within the drop pad area fence.

The final location of the fuel tank, orientation to the drop test pad, and fuel tank position will be documented on video and with 35 mm or equal size photographs.

The fuel tank will then be reconnected to the drop pad hoist and weighed by means of the lifting line load cell. Weight is recorded on the drop test data sheet (Figure A1) at this time and every 10 min thereafter.

The remote fuel tank pressure monitor system will be reconnected at this point. The technicians will again evacuate the drop pad area.

Fuel tank pressure will be checked at this point and every 10 min thereafter for 1 hour. Fuel tank pressure will be recorded on the drop test data sheet (Figure A1).

If the relief valve operates during the 1 hour interval after the drop, tank pressure and weight will be recorded immediately upon relief valve reseat.

One hour after the fuel tank has been dropped and the final data has been recorded the fuel tank will again be approached by the two technicians who have had training in cryogenic safety. The technicians will once again use self-contained breathing apparatus; cotton shirt and pants, loose-fitting work gloves, and work boots. No other personnel will be permitted within the drop pad area fence. The liquid nitrogen will be removed from the fuel tank and vented to the atmosphere in a safe manner. Venting will continue until all liquid has been removed and the tank has been completely depressurized. Once this has been completed other personnel may enter the drop pad area.

A.1.5 Pass/Fail Criteria

There shall be no loss of product for a period of 1 hour after the drop other than relief valve operation and loss of vapor between the filler neck and the secondary relief valve in the case of a test involving the filler neck. Loss of vacuum, denting of the vessel, piping and piping protection, and damage to the support system are acceptable.

A.1.6 Documentation

A letter report will be prepared supported by the data sheets. Two copies of the test videotape will also be provided. Documentation will be made available to SAE and other agencies. The documentation will be considered in the public domain.

A.2 TEST PROCEDURE FOR LNG VEHICLE FUEL TANKS—3.1 m (10 ft) PIPING AREA DROP

A.2.1 Scope

The drop test will subject a full-size vehicle fuel tank to a free-fall impact onto an unyielding surface (metal or concrete) from a height of 3.1 m (10 ft). The fuel tank will be released by firing one or more explosive cable cutters simultaneously. The fuel tank will impact the outer shell on the critical area as determined by the manufacturer. The fuel tank will be filled with an equivalent full weight of liquid nitrogen saturated to at least 1/2 the maximum allowable working (MAWP) pressure of the fuel tank. There shall be no loss of product other than relief valve operation and loss of vapor between the filler neck and the secondary relief valve in the case of a test involving the filler neck. Loss of vacuum, denting of the vessel, piping and piping protection, and damage to the support system are acceptable. The drop test will be documented using two standard speed video cameras and still photographs.

A.2.1.1 Purpose

This procedure defines the sequence of events to be followed in execution of the 3.1 m (10 ft) piping area drop test of LNG vehicle fuel tanks. This procedure describes the orientation, execution, documentation, and pass/fail criteria for the test.

A.2.2 Pre-Drop Preparations

Prior to drop testing a vehicle fuel tank, the orientation will be selected which results in impact of the piping area for the tank to be tested. Lifting lugs will then be attached using epoxy adhesive such that the fuel tank can be suspended from the lifting lugs at the orientation selected. Once the lifting lugs have cured, the vessel will be moved to the cryogenic test area where it will be filled liquid nitrogen to simulate a full load of LNG (liquefied natural gas). The liquid nitrogen will be saturated to at least 1/2 the MAWP of the fuel tank. The tank is then transported to the drop pad for drop testing.

A.2.3 Drop Test

Once the fuel tank to be drop tested has been filled and has reached the drop pad, it will be connected to the drop pad hoist and a preliminary check of vessel orientation and tank pressure will be performed. Adjustments as necessary will be made until orientation and pressure are satisfactory. Pressure will be checked via the remote pressure monitoring transducer which is connected via quick disconnect to the ullage space of the fuel tank. Pressure readout will be setup for monitoring from outside the drop pad fence. Once the vessel pressure has been recorded on the drop test data sheet (Figure A2), the fuel tank vent manual shutoff valve will be closed and the transducer will be disconnected.

The vessel is then weighed by means of a 907 kg (2000 lb) load cell in the main lifting line. Combined load cell and readout repeatability shall be better than 1%. Load cell readout will be setup for remote monitoring from outside the drop pad fence. Weight is recorded on the drop test data sheet (Figure A2).

Wind speed is then checked to ensure that wind is below 16 km/hr (10 mph) with gusts less than 24 km/hr (15 mph). Wind conditions and ambient temperature are recorded on the drop test data sheet (Figure A2).

The armor plate surface is measured using a hand held surface thermometer. The armor plate must be above –17.8 °C (0 °F) in order to proceed. The armor plate temperature is recorded on the drop test data sheet.

The stadia boards are then moved into position and clamped in place. The boards will be positioned such that the reference grid matches at the inside corner of the boards.

The impact area will be cleared of all unauthorized personnel. The fuel tank is then lowered and the explosive cable cutter is installed and wired to the zip cord, which will extend to the firing mechanism located outside the drop pad fence. The explosive circuit is then checked for continuity.

Tag lines and a 3.1 m (10 ft) drop height indicator string are then attached to the fuel tank. The fuel tank is raised to the drop height, the height is verified, and the tension on the hoist hold-down cables is checked. The tank orientation will be corrected with the tag lines and the height verification tag line will be removed.