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MODULE 6:

Fuel Cell Engine Safety

College of the Desert

Revision 0, December 2001

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The Fuel Cell Engine Company

BALLARD

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1958

ATT
Advanced Transportation Technology

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ac TRANSIT

VTA SANTA CLARA Valley Transportation Authority

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CONTENTS

OBJECTIVES

At the completion of this module, the technician will:

- Understand the hazards and safety provisions associated with hydrogen and fuel cell engine systems

MODULE 6: FUEL CELL ENGINE SAFETY

Key Points & Notes

6.1 Hydrogen

All fuels are dangerous because they are highly chemical reactive. It is this reactivity that makes fuels excellent sources of energy. Hydrogen is not inherently more dangerous than other fuels, such as natural gas or gasoline, but its properties are unique and must be handled with appropriate care. In many ways, hydrogen is safer than other fuels.

Hydrogen leaks form the basis of all gaseous hydrogen hazards, since without a leak there is no opportunity for hydrogen to mix with air, and therefore no basis for flammability or asphyxiation hazards. In addition to leaks, the low temperature of liquid hydrogen forms the basis for frostbite and oxygen condensation hazards.

6.1.1 Hydrogen Leaks

The properties of hydrogen that contribute to its leak hazard are:

- it has the lowest molecular weight, and the smallest molecule, of any element
- it has the lowest density and therefore highest buoyancy of any element
- it can cause embrittlement in some materials
- it is colorless, odorless and tasteless
- it acts as a simple asphyxiant when present in a sufficient concentration to reduce the level of oxygen

These properties are detailed in Section 1.

The small size of hydrogen molecules makes them more difficult to contain than the molecules of other gases. To a large extent, the potential for hydrogen leakage is minimized through design. Materials of construction are designed for hydrogen use and are resistant to metal embrittlement. Fuel lines never pass through the passenger compartment, eliminating the potential for hydrogen to leak into the vehicle.

In a transit bus application, hydrogen is stored on the roof in a series of high-pressure cylinders. Placing the fuel storage cylinders on the roof takes advantage of hydrogen's high buoyancy — any leaked gas dissipates quickly and vertically to the atmosphere with little impedance.

The storage cylinders contain the vast majority of hydrogen on the vehicle. The amount of hydrogen present in the fuel cell or internal combustion engine is very small when operat-

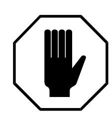
Key Points & Notes

ing, and none while shut down. Furthermore, the hydrogen in the storage cylinders and associated manifold is at high-pressure, whereas the hydrogen within the engine is at low-pressure. The higher the pressure, the more likely that a leak will occur. Fuel lines, unwelded connections, and non-metal seals such as gaskets, O-rings, pipe thread compounds and packings are potential leakage or permeation sites.

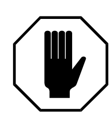
When hydrogen is used in a fuel cell engine, the hydrogen and air that pass through the fuel cell stacks are designed to not mix directly. This is accomplished using seals. A heavy-duty fuel cell engine may have thousands of seals. Over time, fuel cell stacks develop leaks either internally (between flow paths) or externally to the ambient environment. To deal with this potential leakage, fuel cell stacks are typically enclosed and the enclosure is vented with forced air in order to prevent hydrogen accumulation. Fuel cell stack leaks often manifest themselves in other ways, such as poor electrical performance of individual fuel cells.

A hydrogen leak in itself is not a hazard, but it poses a potential fire hazard when mixed with air at appropriate concentrations (Section 6.1.2), and poses an asphyxiation hazard when it displaces the oxygen in air.

Sufficient hydrogen to pose an asphyxiation hazard can only accumulate if hydrogen leaks into an enclosed area. Outdoors, the hydrogen diffusion is so rapid that the risk is negligible. **However, since hydrogen is colorless, odorless and tasteless, its presence cannot be detected by humans, and there are no warning symptoms before unconsciousness results.**



Leakage gases may be hot and pose a burn hazard as detailed in Section 6.3. Leakage gases may pose a high-pressure hazard as detailed in Section 6.4.



Detecting Hydrogen Leaks

Hydrogen leaks will occur. Undetected leaks are the cause of the greatest number of hydrogen accidents. To this end, transit bus applications include a leak detection system.

The leak detection system consists of a series of sensors that are linked to the vehicle's control system. The sensors are located at strategic locations around the vehicle (such as the beneath the roof canopies and in the engine compartment) and are typically calibrated to trigger warnings at 5 and 15%, and an alarm at 25% of the LFL of hydrogen. Since the LFL of hydrogen is 4% hydrogen in air, these warning and

Key Points & Notes

alarm thresholds represent hydrogen concentrations of 0.2, 0.6 and 1% respectively. Thus, the leak detection system indicates an alarm before gas concentrations reach a dangerous level.

When a sensor trigger occurs, the control system alerts the driver by way of dashboard lights, a message display center, or other means and shuts down the engine if an alarm concentration occurs. Measured gas concentrations may be concurrently displayed on dedicated leak indicators. A typical leak detection system is described in detail in Section 5.12.

In most cases, the on-board leak detection system is only active whenever the vehicle is on. When the vehicle is off, it is probably unoccupied and so there is little benefit to dashboard annunciation. Accordingly, a supplementary leak detection system is an essential part of any parking or maintenance facility into which the vehicle is driven while fueled. Facility gas leak requirements are further described in Section 10.1.

Hydrogen leaks may be large or small. Leaks may manifest themselves through an audible gas rushing sound, a slow or sudden drop in fuel pressure, or a trigger of the leak detection system. Very slow leaks may not be noticeable through any of these means, and can only be detected through leak tests.

Leak tests are a routine part of fuel system maintenance, and fuel cell stack leak tests are an important part of fuel cell engine maintenance. Leak tests generally take three forms: pressure drop (or “leak-down”) observations over time, use of a hand-held leak detector (or “sniffer”), or application of a leak detection solution. These methods provide increasingly precise means of locating hydrogen leaks and are usually performed in sequence:

- Pressure drop tests indicate whether a leak exists in a large, generalized area.
- Hand-held leak detector tests indicate whether a leak exists within a localized area. Hand-held leak detectors only work on circuits pressurized with a flammable gas; they do not work on circuits pressurized with air or inert gases such as nitrogen.
- Leak detection solution tests indicate whether a leak exists at a precise location. These solutions work on any gas, flammable or not.

Hand-held Leak Detector

Stopping Hydrogen Leaks

Key Points & Notes

In principal, hydrogen leaks are stopped by tightening or replacing the leaking fitting or component.

Leaks must be remedied in a safe area where the hydrogen cannot accumulate and that is free of ignition sources. Ideally, this is outdoors away from overhead obstructions, or inside a hydrogen-safe maintenance facility. Personnel should be limited to those fixing the leak. Smoking is strictly forbidden.

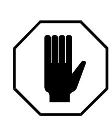
When a leak exists, the remaining hydrogen is safely stored on board the vehicle. The only reasons to vent the remaining fuel are to repair a component on the fuel storage circuit, or to move the bus into a facility that is not certified as hydrogen-safe.

Before a leak can be fixed, it must be located using leak tests and leak detection equipment as indicated above. If the leak occurs on a hydrogen powered vehicle, leak tests normally used during routine maintenance may be employed to help determine the leak location. A leak can only occur when the components are pressurized.

The fuel storage circuit remains pressurized even when the vehicle is off. Other circuits, such as the fuel delivery circuit (that is, downstream of the motive pressure regulator), are only pressurized when the vehicle is on. If the vehicle can be off, open (disconnect) the battery knife switches so that the vehicle is electrically dead while fixing the leak.

Once you locate a leak, tighten the connections, and if the leak persists despite tightening, replace the surrounding components. Tighten fittings only at low or ambient pressure: tightening a fitting while under high-pressure could cause it to shatter with serious personal injury. Thus, if a leak is detected in the high-pressure circuit, vent the circuit to near atmospheric conditions (using prescribed venting procedures and equipment) before tightening the fitting. Similarly, if a component must be replaced, vent the circuit to atmospheric pressure before opening the circuit: loosening a fitting while under pressure could cause it to be propelled with extreme force.

Never *tighten* any fitting while it is under pressure; doing so could cause the fitting to shatter with serious personal injury. Never *loosen* a fitting while under pressure; doing so may cause the fitting or component to be propelled with extreme force.



Once a fuel circuit has been vented to atmospheric pressure and exposed to air, it requires nitrogen and hydrogen purges before fueling. This normally applies to hydrogen storage cylinders only, but may include other components according to manufacturer's instructions. After a leak has been repaired, purge as required using facility equipment and procedures, re-pressurize the component, and repeat the leak test.

6.1.2 Hydrogen Fires

The properties of hydrogen that contribute to its flammability hazard are:

- it has the widest flammability range of any fuel
- it has the lowest ignition energy of any fuel
- it has the greatest energy per weight of any fuel
- it burns invisibly and without smoke
- it can potentially generate electrostatic charges that result in sparks through flow or agitation

These properties are detailed in Section 1.

Once leaked, hydrogen mixes with air and is flammable over a wide range of concentrations. This flammable mixture is very easy to ignite, and, once ignited, burns with great vigor. The flame is nearly invisible in daylight. If hydrogen leaks into an enclosed environment, the risk of combustion and explosion is increased. If hydrogen leaks into an open environment, it rises quickly and is rapidly diffused, reducing the risk of fire. Existing fires burn vertically and generally for short periods of time.

Most mixtures of hydrogen and air are potentially flammable and explosive, and can be easily ignited by a spark or hot surface. Hydrogen flames are almost invisible in daylight.

To some extent, the potential for fire is reduced through design. Materials of construction are fire-resistant and are thoroughly grounded to prevent static charge accumulation. High-pressure fuel storage cylinders include pressure relief devices that are designed to release the cylinder contents when immersed in fire, thus preventing explosive pressure buildup within the cylinders. The pressure relief device discharge is routed to vents that protrude to the top surface of the bus canopy, allowing unimpeded access to the atmosphere.

Key Points & Notes

Particular diligence must be applied by personnel when handling hydrogen directly, such as during venting or fueling. When venting or fueling, facility equipment and procedures must be followed exactly, and all sources of ignition must be eliminated.

The fueling and venting facility must be grounded together with the vehicle to prevent static electrical discharge. Suitable facility fire detection, fire extinguishing equipment and procedures must be in place.

Fueling facility requirements are further described in Section 10.2.

Detecting Hydrogen Fires

The near invisibility of hydrogen fires makes them hard to detect and a serious hazard to personnel.

Hydrogen fires may be large or small. The ferocity of a fire is directly related to the level of pressure behind the underlying leak. Fires may manifest themselves through the presence of flames, smoke from adjacent equipment engulfed in the flames, heat waves, a burning smell, explosion, component damage, or trigger of the fire suppression system. Very small fires may not be noticeable through any of these means.

Some transit bus applications include a fire suppression system in order to detect and extinguish fires. The fire suppression system consists of a series of sensors that are linked to the vehicle's control system. The sensors are located at strategic locations around the vehicle (such as the beneath the roof canopies and in the engine compartment) and are designed to trigger an alarm in the event of fire. Some types of sensors can also detect high heat. Fuel cell applications may include thermal wire wound around the fuel cell stacks that are designed to short when melted, thereby signaling the control system.

When a sensor trigger occurs, the control system alerts the driver by way of dashboard lights, a message display center, or other means and shuts down the engine. After the vehicle is shut off, single-shot fire retardants may be released into one or more zones associated with the triggered sensor. A fire suppression system is described in detail in Section 5-12. Fire retardants do not discharge into the vehicle passenger compartment.

When a retardant discharge occurs, expect a high noise level. A cloud of dry chemical retardant dust may exit

the vehicle from the discharge areas. Avoid breathing the dry chemical dust as it will irritate throat and lungs.

Key Points & Notes

In most cases, the fire suppression system is active at all times unless the vehicle battery knife switches are open (disconnected). Accordingly, a supplementary fire detection system is an essential part of any parking or maintenance facility into which the vehicle is driven. Facility requirements are further described in Section 10.1.

Extinguishing a Hydrogen Fire

The protocol for fighting a hydrogen fire is similar to fighting any fire fueled by a gas. The main thing to do is eliminate the fuel source. If this is not an option, allow the fuel to burn itself out under controlled conditions. The object is to minimize the risks of injury and danger to people, and risk of damage to equipment in the surrounding area. As with any fire, evacuate all personnel except those fighting the fire, contact local fire authorities if needed, and fight the fire from as great a distance as possible.

Large fires can only be extinguished by shutting off the fuel supply. Small fires can be fought with a dry powder retardant (recommended), carbon dioxide or halon extinguisher. Carbon dioxide extinguishers, modified by sawing off the fog nozzle, may be used to blow out the fire rather than smother it. A fire blanket may also be used. However, if a hydrogen fire is extinguished without shutting off its fuel supply, an explosive or flammable mixture may re-form and can reignite from surrounding hot surfaces or other ignition sources.

When the source of hydrogen cannot be shut off, the standard fire fighting practice is to prevent the fire from spreading while it burns out. Use copious amounts of water to cool surrounding equipment; and continue the water flow until well after the fire is out. Remove flammable materials from the surrounding area if it is safe to do so. When fighting a hydrogen fire, stay away from storage cylinder ends. Withdraw immediately in case of a rising sound from a venting safety device or any discoloration of a storage cylinder due to the fire.

For massive fires, use an unmanned hose holder or monitor nozzles, or withdraw from the area and let the fire burn. Keep upwind and avoid breathing the vapors. Evacuate to a radius of 1500 ft (450 m) for uncontrollable fires. Consider evacuation of the downwind area.

Key Points & Notes

If a fire occurs on board a hydrogen powered vehicle, shut it down as soon as it is safe to do so. This closes the solenoid valves associated with each cylinder and the high-pressure solenoid, effectively isolating the fuel in the fuel storage system. An alarm shutdown by the fire suppression system should automatically discharge retardants within the fire area. If the fire continues, use standard fire fighting techniques as described above. Once the fire is out, tow the vehicle back to the maintenance facility and notify the manufacturer.

6.1.3 Low Temperature Hazard

The property of hydrogen that causes a low temperature hazard is:

- it has second lowest boiling point of all substances, after helium.

This property is detailed in Section 1.

Low temperature hazards only exist when hydrogen is stored in liquid form. The extremely low temperature of liquid hydrogen results in severe frostbite danger and secondary fire danger.

Liquid hydrogen is stored below –423 °F (–253 °C; 20 K) in vacuum-lined vessels. Liquid hydrogen vessels must be completely insulated with specified materials to prevent any contact with the vessel.

A severe frostbite hazard danger occurs whenever skin comes into contact with liquid hydrogen, liquid hydrogen vapors or surfaces directly in contact with liquid hydrogen. Any skin contact can cause extensive tissue damage, burns, freezing or tearing.

Any surface in contact with liquid hydrogen poses a severe frostbite danger.

A secondary fire danger occurs whenever air comes directly into contact with cryogenic surfaces that contain liquid hydrogen. The temperature of liquid hydrogen is low enough to liquefy air and thereby concentrate the air's constituent components. Among these, liquid oxygen poses an explosion or flammability hazard if it drips onto combustible materials such as asphalt.

To minimize these low temperature hazards, all pipes, vessels and other equipment that contain liquid hydrogen must be completely insulated with appropriate materials. Liquid hydrogen must be removed from the vehicle or otherwise isolated during maintenance. Maintenance facility surfaces should be of concrete or be covered with suitable drip pans.

Air must not be allowed to liquefy on pipes, vessels or other components that contain liquid hydrogen.

Key Points & Notes

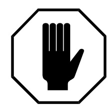
6.2 High Temperature

Key Points & Notes

Water, glycol solutions, oils and gases circulate through pipes and other vessels within a transit bus. The maximum temperature achieved by any of these streams is the turbocharger compressor outlet, which can exceed 400 °F (200 °C). Exposed surfaces can cause serious burns if touched.

During normal operation, engine compartment covers prevent exposure to hot surfaces; however, the engine may be operated with the engine covers open. If the covers are open, such as during maintenance procedures, contact with any internal surfaces containing circulating liquids or gases must be avoided. Internal components may remain hot for a long time after the engine has been shut down.

Avoid contact with internal surfaces that are in contact with liquids or gases. Heed all warning decals.



6.3 High Pressure

Key Points & Notes

Hydrogen to fuel a transit bus is typically stored in roof-mounted cylinders at an operating pressure of up to 3600 psig (250 barg), and potentially as high as 5000 psig (345 barg). Personnel handle hydrogen at high-pressure when fueling these cylinders. This high-pressure is extremely dangerous and could result in an explosive force if a leak or component rupture occurred. Even when depleted, the hydrogen cylinders are often at a residual pressure of 300–500 psig (21–35 barg).

Never crack open or loosen the fitting of any high-pressure component; doing so may cause the fitting or component to be propelled with extreme force. Never tighten a high-pressure fitting while under pressure; doing so could cause the fitting to shatter with serious personal injury. Follow fueling and venting procedures exactly.

All high-pressure components are certified pressure vessels and must be inspected regularly and replaced if any damage or fault occurs. Hydrogen storage cylinders must survive a battery of tests to obtain certification as described in Section 2.2.1.

Hydrogen storage cylinders have multiple safety features. Each cylinder contains a solenoid valve that automatically closes whenever the engine is shut down or when a collision sensor trips as the result of bus impact. Each cylinder also includes an internal excess flow valve that closes whenever the gas flow leaving the cylinder is too great (such as if a pipe bursts). An additional excess flow valve, on the common cylinder manifold, serves the same function. Pressure relief devices mounted at each end of each cylinder release the cylinder contents when exposed to fire.

Refer to warning and cautions in Section 7.1.1 whenever accessing rooftop components.

All high-pressure components reside on the roof and within the filling box. Hydrogen leaving the cylinders is regulated to the intermediate (or “motive”) pressure of approximately 178 psig (12 barg); this is further regulated to pressures up to 30 psig (2 barg) within the fuel delivery circuit.

Additional components protect the motive- and low-pressure circuits against fuel overpressure. A pressure relief valve is mounted downstream of the motive pressure regulator and vents to atmosphere if the pressure exceeds 200 psig (14 barg). A burst disk vents hydrogen from the fuel delivery

Key Points & Notes

circuit to the atmosphere if the pressure within the circuit exceeds 46 psig (3 barg).

Hydrogen, air, water and coolant operate at a maximum pressure of approximately 35 psig (2.4 barg) within the fuel cell engine. The lubrication oil and hydraulic fluid operate at a maximum pressure of approximately 90 psig (6.2 barg). The bus chassis air system (air brakes) operates at up 125 psig (9 barg). These pressures are potentially dangerous and caution must be exercised when dealing with any pressurized component.

When a fuel cell engine shuts down, the following circuits vent or depressurize:

- motive pressure fuel circuit
- fuel delivery circuit
- air delivery circuits
- humidification water circuits
- hydraulic circuits
- lubrication circuits

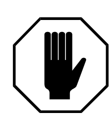
When a fuel cell engine shuts down, the following circuits remain pressurized for some time, but depressurize slowly:

- stack coolant circuit
- bus coolant circuit

When the a fuel cell engine shuts down, the following circuits do not depressurize:

- fuel storage cylinders
- high-pressure fuel circuit
- bus chassis air system

The hydrogen cylinders and high-pressure circuit are pressurized even when the engine is shut down.



In addition, fuel cell vehicles that include a fire suppression system contain fire retardant tanks that remain pressurized at all times.

6.4 Electrical Shock

Key Points & Notes

A fuel cell powered transit bus contains a variety of high and low voltage components.

Fuel cell stacks produce voltage in proportion to the number of fuel cells, and overall levels can exceed 1000 VDC (open circuit voltage) for a heavy-duty engine such as for a transit bus. This is converted to AC power within an inverter to operate the drive motor. The inverter adjusts the AC output frequency and current to achieve a prescribed torque setpoint and the output voltage floats as required, but can reach levels as high as 460 VAC.

At times, some of this AC power is diverted into one or more water- or coolant-cooled bleed resistors (or "dump choppers") where it is converted to heat. These high voltage components pose a severe shock or electrocution danger and can remain charged for up to five minutes even after the engine has shut down.

Fuel cell engines contain high DC and AC voltages. Exercise caution when accessing electrical components to prevent shock or electrocution.

The fuel cell stacks, inverter and other high voltage components are individually enclosed and located within the engine compartment. During normal operation, these barriers offer protection against shock and electrocution, and must be in place.

Do not operate a fuel cell engine unless all high voltage barriers are in place.

Whenever the engine is shut down, the reactant gases are automatically vented and one or more dump choppers are engaged. These dump choppers continuously absorb any power generated by residual reactant gases within the stacks. If groups of fuel cell stacks or individual stacks have been removed from the vehicle, the dump chopper is no longer connected and a residual voltage may build up in as little as several minutes. Furthermore, a reading of zero volts (0 V) across an entire fuel cell stack does not guarantee that all cells are uncharged.

Always assume that the fuel cell stacks are electrically charged. Do not touch the fuel cell stack, its graphite cells, or the cell voltage monitoring wires until you confirm that no voltage exists.

The bleed resistor is located on the bus chassis. When the stacks are removed from the chassis or electrically disconnected, the bleed resistor is no longer connected.

Jewelry (such as rings, necklaces, bracelets and watches) may concentrate an electric current when it comes into contact with charged components, or when a shock passes through the human body. These concentrations can cause serious heat burns.

Do not wear jewelry near the fuel cell engine. To minimize conductivity, your hands and clothes should be dry.

The vehicle control system and other components operate on 12 and/or 24 VDC. This power derives from one or more batteries while the engine is off, and from an alternator when the engine is on. These low voltage components are located in many places throughout the vehicle and do not pose a shock hazard. Some of these components may remain charged even when the engine is shut down.

Vehicle Ground Fault Monitor

High voltage components are electrically isolated from the vehicle chassis. In order to guard against inadvertent charge leakage onto the vehicle chassis, a ground fault monitor is incorporated into the inverter that constantly monitors the approximate electrical resistance between the two planes. A high resistance indicates that there is little or no current leakage onto the chassis (as it should be), and a low resistance indicates that a leakage current exists.

A leakage current, or ground fault, occurs wherever an electrical short-circuit occurs and usually derives from ion accumulation in the humidification water or stack coolant. If the resistance is too low, the ground fault monitor generates a warning or alarm.

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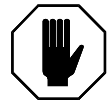
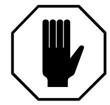




6.5 Chemical

A fuel cell powered transit bus does not pose any serious chemical hazards although caution should be exercised when handling the following substances.

6.5.1 De-Ionizing Resin

De-ionizing filters contain a mixed-bed de-ionizing resin used to remove anions and cations from the humidification water or stack coolant. De-ionizing resin is inert and considered safe, but can cause mechanical eye irritation. **As a preventative measure, wear safety glasses when handling the filters or resin.** Respirators and ventilation are not required under normal conditions.

Store new de-ionizing resin above freezing and below 120 °F (49 °C). Keep containers sealed to prevent drying. Dispose of used resin by incineration or landfilling according to local regulations.

Refer to the manufacturer's Material Safety Data Sheet for comprehensive safety information.

6.5.2 Ethylene Glycol

The stack and bus coolant circuits contain solutions that include ethylene glycol. (*Ethylene glycol* is different from *propylene glycol*, which is essentially non-toxic. Propylene glycol is not used as it is incapable of sufficient heat absorption.)

Ethylene glycol is toxic. Ingestion can lead to central nervous system, cardiovascular and kidney effects, including kidney failure and death. Symptoms of ethylene glycol ingestion are numerous and include slight inebriation, eye problems, depressed reflexes, convulsions, mild hypertension, rapid heartbeat and increased respiration among others.

Ethylene glycol is toxic if ingested, or if its vapors are inhaled.

Ethylene glycol vapors pose little hazard due to low vapor pressure, however, when heated or misted they present a significant health hazard. Irritation, cough and headache may occur from repeated exposure to vapors, and more severe symptoms including coma can occur from inhalation of heated or misted vapors.

Heated or misted ethylene glycol is a significant health hazard.

Key Points & Notes

Process fluids and cleaning solutions can also pose chemical hazards if ingested, inhaled or absorbed. Always refer to manufacturer's instructions and Materials Safety Data Sheet prior to use.

Key Points & Notes

Skin absorption occurs, although toxic amounts have not been reached in human cases.

As preventative measures: wear safety glasses or chemical safety goggles, wear chemically protective gloves, boots, aprons and gauntlets made of natural or nitrile rubber or of Neoprene to prevent skin contact. Do not eat, drink or smoke in the work area. Follow OSHA respirator regulations and if necessary, wear a MSHA/NIOSH approved respirator. Provide general and local ventilation or local exhaust ventilation to minimize ethylene glycol vapors.

Wash hands after contact with ethylene glycol, and before eating, drinking, smoking, using the toilet or applying cosmetics. Separate contaminated clothing from street clothes and launder before re-use. Clean contaminated boots.

Heated or misted ethylene glycol is a moderate fire and explosion hazard. The auto-ignition temperature of ethylene glycol is approximately 748 °F (398 °C).

Avoid exposing ethylene glycol to heat and ignition sources.

Ethylene glycol fires can be extinguished with carbon dioxide, dry chemical, water spray or alcohol-resistant foam fire extinguishers. To fight ethylene glycol fires, wear self-contained breathing apparatus (pressure-demand MSHA/NIOSH approved or equivalent) with a full facepiece operated in pressure-demand or positive-pressure mode. Apply cooling water to sides of containers until well after the fire is out.

Ethylene glycol is chemically incompatible with many chemicals and causes ignition at 212 °F (100 °C) with others. Refer to the MSDS for the complete list of incompatibles. **Avoid exposing ethylene glycol to incompatible chemicals.**

Ethylene glycol can absorb twice its weight in water at 100% relative humidity. Avoid exposing new ethylene glycol to water or high humidity.

Used ethylene glycol may be contaminated with trace amounts of lead or other metals and should be disposed of in accordance with local regulations.

Refer to the manufacturer's Material Safety Data Sheet for comprehensive safety information.

6.5.3 Purple K Dry Chemical Fire Retardant

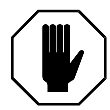
Key Points & Notes

Fire suppression system retardant tanks contain Purple K dry chemical fire retardant. Purple K dry chemical is a powder consisting of a mixture of chemicals and is generally non-hazardous, except when present in sufficient concentration to cause asphyxiation by oxygen displacement.

During normal operation, Purple K dry chemical is contained under pressure within the fire suppression system retardant tanks. In the event of a fire sensor trigger, the dry chemical mixture is discharged through nozzles into each of the affected zones.

When a retardant discharge occurs, expect a high noise level. A cloud of dry chemical retardant dust may exit the vehicle from the discharge areas. Avoid inhalation of Purple K dry chemical. Skin does not absorb Purple K dry chemical. It is slightly irritating to skin or eyes. Prolonged or repeated skin contact may cause irritation, drying and cracking.

Avoid inhalation and contact with Purple K powder.



If ingestion of Purple K dry chemical occurs, do not induce vomiting, rinse mouth with water and contact a physician or poison control center. Purple K dry chemical reacts violently with lithium.

As preventative measures: wear safety glasses (or goggles) and gloves when handling the Purple K dry chemical; wash hands with soap and water and flush for 15 minutes after contact. Do not eat, drink or smoke during handling.

Dispose of used Purple K dry chemical or its containers according to local regulations. Purple K dry chemical is known to contribute to ozone depletion in the upper atmosphere — recycling is either required or encouraged by local authorities.

Refer to the manufacturer’s Material Safety Data Sheet for comprehensive safety information.

6.6 Physical

Key Points & Notes

Physical hazards include rotating equipment and weight hazards.

Rotating Equipment

The fuel cell engine contains fans and belt-driven rotating equipment that may be partially exposed, or could become exposed if protective guards are removed.

During normal operation, engine and radiator compartment covers prevent exposure to these rotating components; however, the engine may be operated with these covers open. If the covers are open, such as during maintenance procedures, contact with rotating equipment is possible and must be avoided. **Loose clothing may become entrained in rotating equipment and should not be worn.**

Weight

A fuel cell powered transit bus is very heavy and weighs approximately 2200 lb (1000 kg) more than a CNG bus. **Hoisting equipment capable of safely lifting this weight is required during some maintenance procedures.**

Individual fuel cell engine components, such as the power train, stack modules and other components can weigh as much as 2200 lb (1000 kg) and require either a crane or hoist to lift, and special cradles to handle. To prevent slippage, properly secure the components to the lifting equipment.

Wear appropriate safety equipment, such as steel-toed boots when handling heavy components.